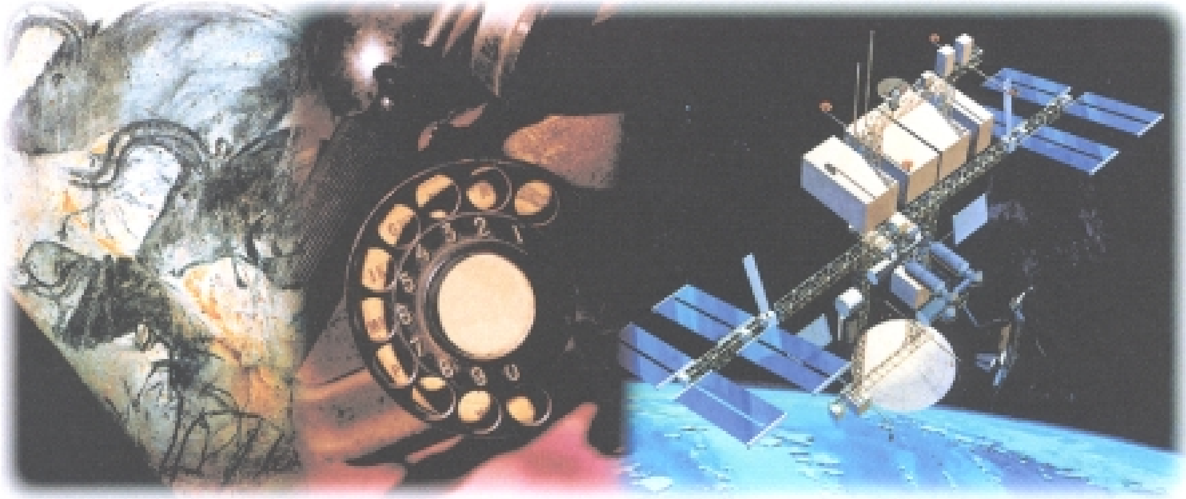

Introduction to T1

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T-1 BASICS

WHAT IS T-1

T-1 is a term that has evolved form early telephone company voice multiplexing and transmission facilities. T-1 is currently used to describe almost any communications link operating at 1,544,000 bits per second. The main purpose of a T-1 is to provide up to 24 channels of voice and data over a 4-wire circuit or fiber optic pair.

WHY T-1

The use of private T-1 networks has grown rapidly during the past decade. Several factors have contributed to this growth:

- Increase in voice and data traffic
- communications cost reduction
- quality and reliability of service
- Increased flexibility and control
- Simplification

As we enter the information age, the demand for fast and accurate transmission of large volumes of information has forced the development and implementation of higher speed communications facilities. It can be argued that usage grew to fill the capacity created by the technology, nevertheless, information has become a critical resource to the operation of any industry today.

COST/RELIABILITY

One of the benefits of using private T-1 networks is the reduction of leased telephone service costs. The initial cost of T-1 equipment and the high installation cost of fiber optic cable or the monthly cost of leased T-1 lines is off-set by reducing the number of dedicated telephone lines and monthly service charges. T-1 systems can pay for themselves over time. The emphasis however in power utility and industry applications is primarily reliability and quality of service.

T-1 links utilized digital transmission facilities which offer significantly better quality of transmission than analog lines. The reliability of T-1 networks is much better due to the reduced number of lines and equipment to be installed, managed, and maintained.

FLEXIBILITY

In today's rapidly changing environment, T-1 networks provide the ability to assign capacity as required to meet the needs of the installation. Bandwidth can be re-assigned by the user without any involvement with a common carrier.

SIMPLIFICATION

T-1 simplifies the task of networking different types of communication functions. To illustrate, Figure 1 shows what a typical utilities communications network might look like without T-1. As you can see various types of communication mediums were used to satisfy the applications.

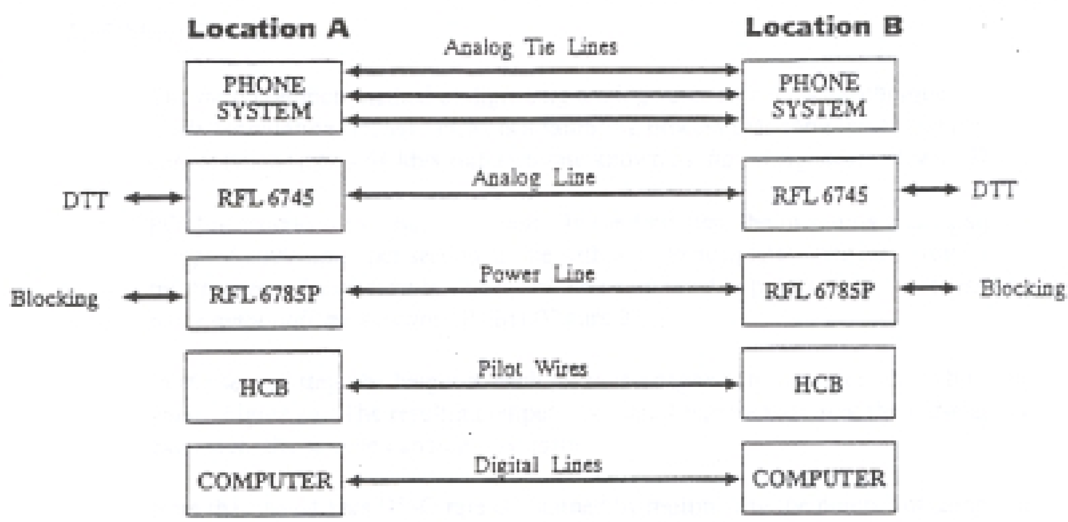


Figure 1. A Communications Network Without T1

Figure 2 depicts the same network with a T-1 link installed Substation hardened multiplexes such as the Model 9001 have different interfaces to support the utility needs for T-1 to become a viable solution for their applications.

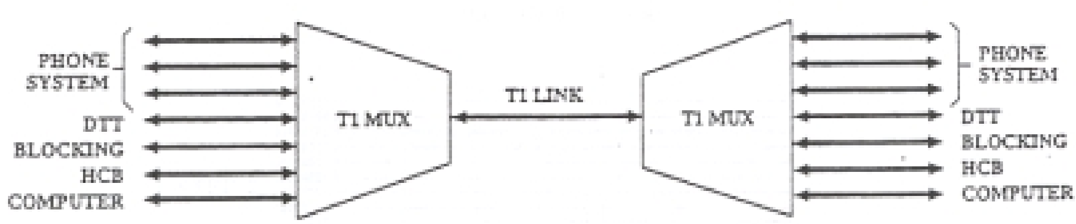


Figure 2. A Communications Network With T1

HOW T-1 WORKS - MAKING VOICE AND DATA COMPATIBLE

Many benefits of T-1 are attributable to the fact that voice and data are transmitted over a single digital communications link. Since digital data consist of 1's and 0's (the symbols of the binary system), it is already compatible with T-1's digital format. However, because voice signals are actually complex analog waveforms, they must be digitized to achieve compatibility with T-1.

PULSE CODE MODULATION

The most common method of digitizing analog voice signals is a technique called *Pulse Code Modulation* (PCM). PCM is a sampling process that compresses a voice conversation into a 64 kb/s standard rate known as *digital signal-level zero* (DS-0)

PCM is actually a two-step technique. In the first step, the incoming analog signal is sampled 8000 times per second, a rate sufficient to adequately represent voice information. These sample values are then converted to pulses using a process known as *pulse amplitude modulation* (PAM) (Figure 3).

In the second step, the height of each pulse is assigned an equivalent eight-bit binary value (Figure 4). The resulting output is a digital representation of the pulse and, by extension, the sampled analog waveform.

Note that the 64 kb/s DS-O rate is obtained by multiplying the number of samplings per second (8000) by the number of bits in each sample (8).

Pulse Code Modulation

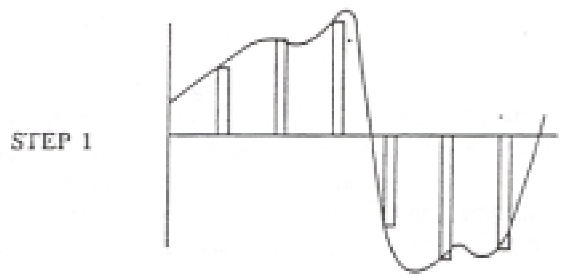
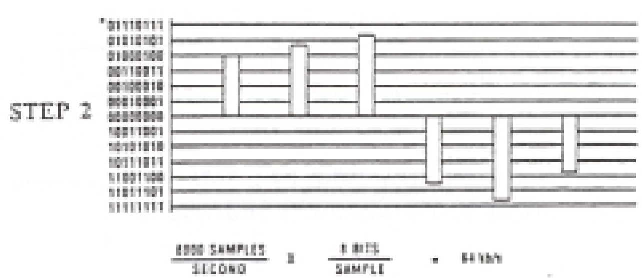


Figure 3
Pulse Amplitude Modulation



* For example only. Not actual bit values.

Figure 4
Assigning Binary Values To Pulses

TIME DIVISION MULTIPLEXING

Once digitized , voice and/or data signals from many sources can be combined (i.e., multiplexed) and transmitted over a single T-1 link. This process is made possible by a technique called *Time Division Multiplexing* (TDM).

TDM divides the T-1 link into 24 discrete 64 kb/s time slots. An identical number of DS-0 signals (representing 24 separate voice and/or data channels) is assigned to each time slot for transmission within the link (Figure 5).

In addition to being critical operational techniques, PCM and TDM are also key to understating the basic T-1 rate of 1.544 Mb/s.

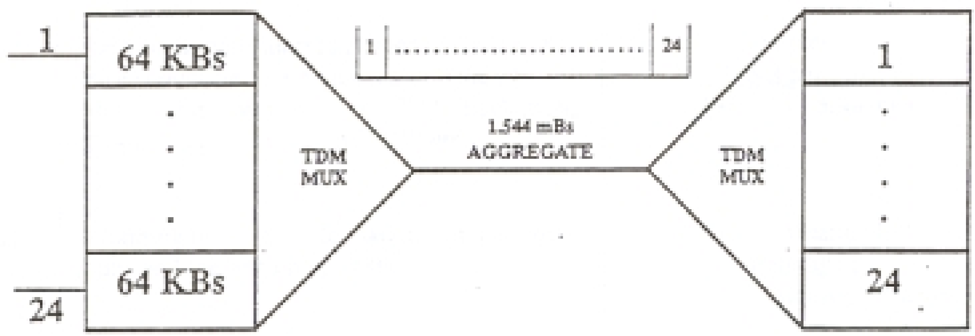


Figure 5. Time Division Multiplexing

UNDERSTANDING 1.544 Mb/s

In T-1, the 8-bit digital samples created in the PCM step (for voice traffic only) are grouped into the 24 discrete DS-0 time slots created by TDM. Each group of 24 time slots is called a T-1 *frame* (Figure 6.). Since each time slot contains eight bits, the number of information bits within each frame totals 192 (24 X 8). Additionally, a 193rd bit is added to mark the end of one frame and the beginning of the next. Appropriately enough, this added bit is called the *framing bit.*

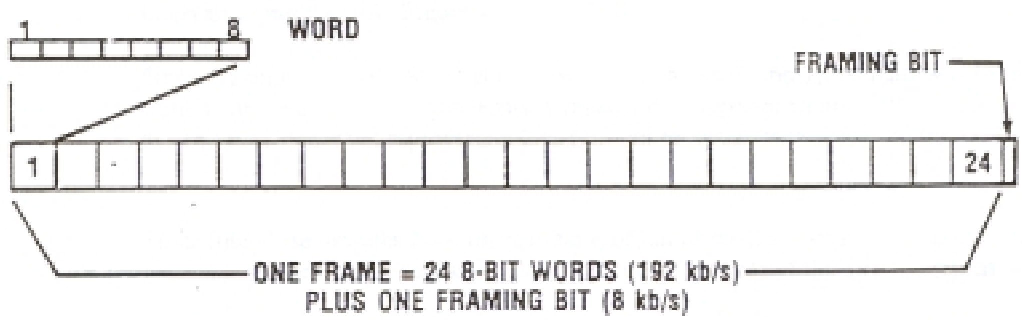


Figure 6. A T1 Frame

Since the DS-0 signals are sampled 8000 times per second, it means that 8000 192-bit information frames are created during that period. Total: 1.536 Mb/s. At 8000 samples per second, framing bits are created at the rate of 8 kb/s. Result: A single 1.544 Mb/s signal known as *digital signal-level one* (DS-1).

CALCULATING THE 1.544 MB/S T-1 RATE

STEP:	WHAT HAPPENS:	CALCULATION:
1.	The 8-bit digital samples created by PCM (for voice signals only) are grouped into the 24 discrete time slots created by TDM. Each group of 24 time slots is called a T-1 *frame*.	24 samples X 8 bits per sample 192 information bits per frame.
2.	A framing bit is added to mark the end of one frame and the beginning of the next.	192 information bits + 1 framing bit 193 total bits per frame.
3.	T-1 frames are transmitted at the rate of 8000 per second.	8000 samples X 193 total bits 1,544,000 bits per second (1.544 MB/s).

SIGNAL REGENERATION

Any newly created DS-1 signal begins strongly, but degrades (i.e., attenuates) as it progresses along the T-1 link. Such attenuation is usually the result of line noise caused by interference from other electrical sources. To compensate for these negative effect, devices called *regenerative repeaters* sample and recreate the original signal at periodic intervals along the link (Figure 7).

Since the digital signal consist of only two basic values (0 and 1), recreating it is not a complicated matter. In simple terms, a regenerative repeater samples the signal input, determines if the input represents a 0 or a 1, and recreates each value accordingly.

Since line noise deviates from the standard format of the DS-1 signal, it is discarded. In this way, a regenerative repeater produces a "clean" replica of the original signal.

The number of regenerative repeaters that may be required along the path of the T-1 link varies with the type of transmission media used. For example, cooper wire (a common short-haul metallic medium) is highly prone to signal attenuation; thus, repeaters are normally required at 6000-foot intervals. By contrast, fiber optic cable is a long-haul medium with low potential for attenuation; as such, repeaters are spaced at 30-mile intervals.

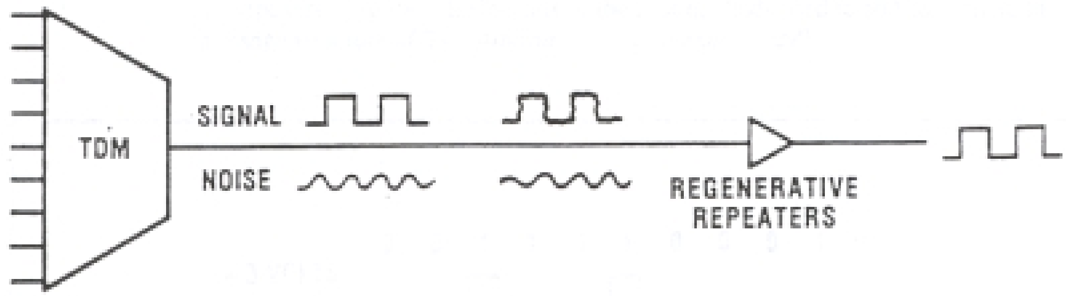


Figure 7. Signal Regeneration

T-1 OPTICAL SPAN

The T-1 digital stream can be transmitted greater distances when applied over a fiber optic system. To prepare a T-1 signal for transmission over an optical system, it must first be converted to a bipolar signal. An optical transmitter is most efficient when the light source is modulated on and off. Depending on the type of light source used (LED or LASER) span distances of up to 50 miles can be achieved without the use of repeaters.

HOW T-1 WORKS

PROCESS:	WHAT HAPPENS:
Pulse Code Modulation (PCM)	1. Samples the incoming analog signals 8000 times per second and converts to pulses. 2. Assigns the height of each pulse an equivalent 8-bit digital value. 3. Creates a 64 kb/s DS-0 signal (8000 samples per second multiplied by eight bits.
Time Division Multiplexing (TDM)	Combines 24 DS-0 signals to create a single 1.544 Mb/s signal (DS-1) .
Signal Regeneration	Recreates the 1.544 Mb/s signal at prescribed intervals along the transmission path.

THE DS-1 SIGNAL FORMAT

The DS-1 signal is transmitted on the T-1 link in a binary format (1's and 0's). The ability to recognize the proper format of the DS-1 signal is crucial to the reliability of multipexers. Figure 8 depicts one of the first methods used to add security to the message structure of T-1: *Alternate Mark Inversion* (AMI).

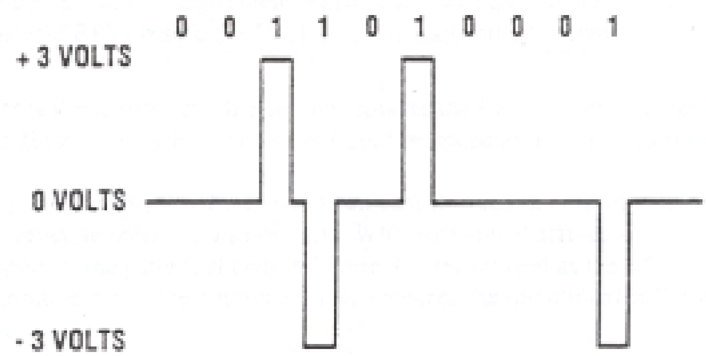


Figure 8. Alternate Mark Inversion

ALTERNATE MARK INVERSION

In the AMI signaling format, the binary value of 1 is represented by a square wave (i.e., pulse); the binary value of 0 is represented by a straight line (i.e., the absence of a pulse). Note that each pulse alternates between positive and negative polarity, making the signal *bipolar* in format.

The primary advantage of the bipolar format is that it allows the DS-1 signal to travel twice as far on a pair of copper wires. Another advantage of the bipolar format is its ability to offer a built-in method of error detection. When consecutive pulses of the same polarity are detected, it constitutes a *bipolar violation* (BPV). BPVs indicate that signal input has been disrupted and is no longer valid.

B8ZS, SIGNAL TIMING, AND ONES DENSITY

To correctly identify DS-1 input, the multiplexer must know when to sample the bipolar signal to determine whether a 0 or a 1 is being transmitted at any given time. To ensure proper sampling, the multiplexer relies on a timing method that uses the binary pulses (i.e., ones) to maintain synchronization with the network equipment that is transmitting the DS-1 signal.

Since pulses are critical to maintain power signal timing, all DS-1 signals are required to meet specific ones density standards. These standards require that at least one pulse be transmitted within any eight-bit sequence (i.e., 12.5% ones density). Further, since long strings of consecutive zeros between digital values can also hinder signal timing, ones density standards prohibit the transmission of more than 15 zeros in succession.

Success in meeting ones density requirements can vary based on application. For example. Since the size and content of the bit patterns that represent human speech are consistent, acceptable ones density in voice applications is a virtual certainty. But since digital data is highly variable in size and content, conformance to ones density standards cannot always be guaranteed. This technical problem is why a coding technique know as *bipolar with 8-zero substitution* (B8ZS) has gained in popularity.

B8ZS uses intentional BPVs to break up long strings of zeros, allowing their transmission through the T-1 link without violating the ones density standard. Figure 9 shows how B8ZS works.

With B8ZS, network equipment replaces any string of eight consecutive zeros with two intentional BPVs before the DS-1 signal is transmitted over the T-1 link: the first BPV

replaces the fourth zero; the second replaces the fifth and seventh zeros. Additionally, the eight zero bit, which normally would be coded as a zero, is assigned a pulse value.

Using this format, the DS-1 signal can pass through the multiplexer on the T-1 link with an acceptable level of pulse density. When the signal arrives at the receiving network equipment, the pattern shown in Figure 9 is recognized as the B8ZS substitute for eight consecutive zeros; the equipment then replaces the intentional BPVs with their zero values.

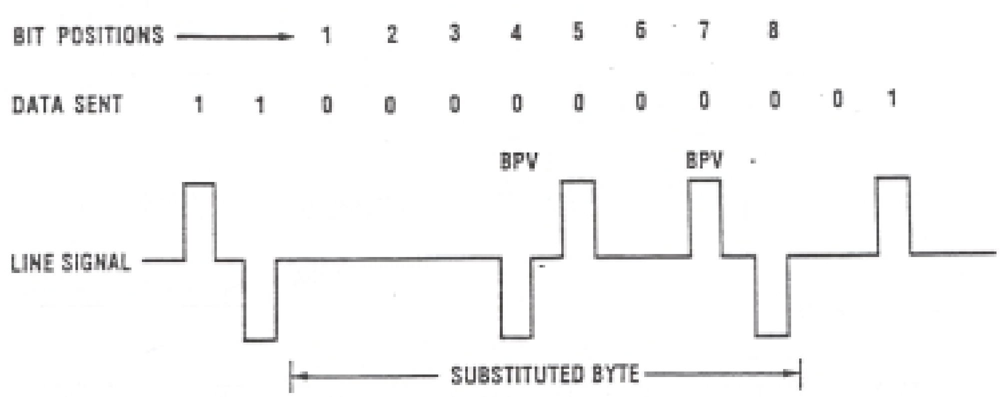


Figure 9. Bipolar With 8-Zero Substitution (B8ZS)

DS-1 FRAMING

The bits in the 1.544 Mb/s DS-1 signal are meaningless unless they are organized in an orderly, understandable way. *Framing* provides this organization.

A frame contains one sample (byte) from each of the DS-1's 24 time slots. Framing bits separate the frames an indicate the order of information arriving at the receiving equipment.

Although most standard T-1 networks use framing, the pattern of the frame can vary depending on the sophistication of the equipment that is sending and receiving the DS-1 signal. The sections that follow describe typical DS-1 framing patterns starting with the most simple: The D1 frame.

THE D1 FRAME

Shown in Figure 10, D1 was the first framing pattern to be used in T-1 transmission.

A D1 frame contains 24 time slots, each carrying an 8-bit word, with one bit serving as a framing boundary (24 X 8 = 1 = 193). In the D1 framing pattern, bits 1-7 of each eight -bit word are reserved for customer information (i.e., digitized voice), bit eight of each word is reserved for signaling information (i.e., call set-up and routing), and bit 193 serves as the boundary between the end of one frame and the beginning of the next.

The D1 framing format can certainly simplify framing and signaling management for T-1 networks with older, unsophisticated equipment. Unfortunately, D1 is also very inefficient: Reserving one bit in every 8-bit word for signaling can degrade a voice signal to levels below toll quality.

Fortunately, the sophistication level of the equipment in T-1 networks has increased dramatically. As such, it is not possible for many frames to share the same framing and signaling information. Thus, the chance to free more bits for customer information (thereby improving signal quality) inspired the development of the *superframe*.

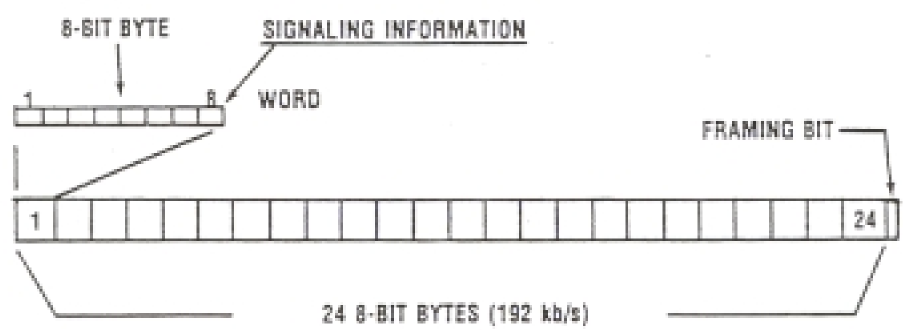


Figure 10. The D1 Framing pattern

D4 FRAMING/SUPERFRAME (SF)

In today's multiplexer networks the pattern commonly used to organize the superframe is the D4 *framing pattern*.

The DS1 (1.544 Mbps) D4 format is used to transmit 24 separate channels of PCM voice or digital data. Each channel is transmitted 8 bits at a time. All 24 channels are grouped together to form a group of 192 bits. For synchronization of both end span equipment, every group of 192 bits is proceeded by a framing bit (F-bit). Together, all 193 bits make up a frame, and 12 frames (in the D4 format) are grouped to form a superframe (Figure 11)

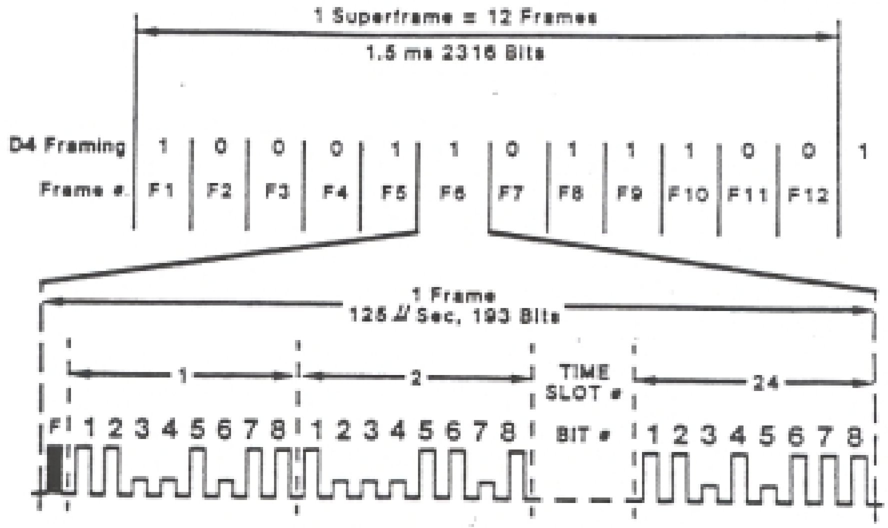


Figure 11. D4 Super Frame

Table 1 outlines the superframe format as stated in ANSI standard T-1.403-1989. As previously stated a superframe is made up of 12 individuals frames, with the 193rd bit in each frame used as a control bit. When combined, these control bits form a 12-digit word (100011011100) that provides frame and signal management.

In D4 framing the odd bits in the control word (called *terminal frame or* f_t bits: 1X0X1X0X1X0X) mark frame and superframe boundaries so that the receiving equipment can correctly process the customer's voice or data information.

The even bits in the control word (called *signaling frame* or f_s bits: X0X0X1X1X1X0)identify the frames which carry signaling information. Note that frames with signaling information are marked by changes in the bit pattern. For example, control bits 2 and 4 contain zeros; since control bit 6 is coded as a one, it means that the 6th frame contains signaling information. Further, control bits 8 and 10 contain ones; since control bit 12 is coded as a zero, it means that the 12th frame also contains signaling information.

To enable the sharing of signaling bits by all 12 frames in the superframe, D4 framing uses a process called *robbed bit signaling* (Figure 12).

Table 1
Superframe Format

Frame Number	F Bits			Bit Use In Each Time Slot		Signaling Bit Use Options	
	Bit Number	Term Frame (F_t)	Signal Frame (F_s)	Traffic	Signal	T	Signaling Channel
1	0	1	—	1-8	—	—	—
2	193	—	0	1-8	—	—	—
3	386	0	—	1-8	—	—	—
4	579	—	0	1-8	—	—	—
5	772	1	—	1-8	—	—	—
6	965	—	1	1-7	8	—	A
7	1158	0	—	1-8	—	—	—
8	1351	—	1	1-8	—	—	—
9	1544	1	—	1-8	—	—	—
10	1737	—	1	1-8	—	—	—
11	1930	0	—	1-8	—	—	—
12	2123	—	0	1-7	8	—	B

NOTES
(1) Frame 1 transmitted first.
(2) Frames 6 and 12 are denoted signaling frames.
(3) Option T- Traffic (bit 8 not used for Robbed-Bit signaling).

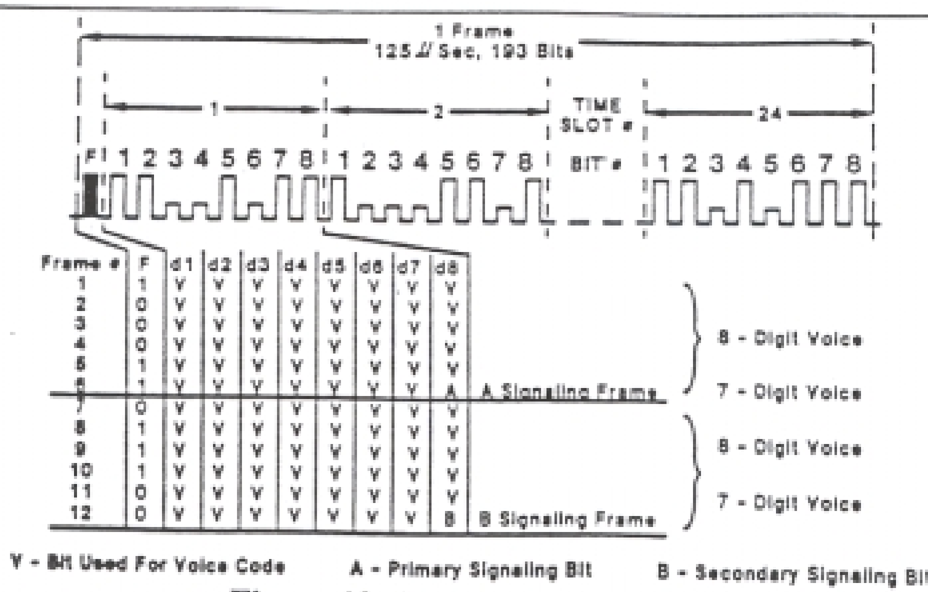


Figure 12. Robbed Bit Signaling

Using robbed bit signaling, the least significant (8th) bit of the DS-0's in the 6th and 12th frames is reserved for signaling information. The steady state of the bit, 0 or 1, indicates whether the called device is on-hook, off-hook, disconnected, busy, etc.

In summary, D4 framing improved signal quality by freeing more bits for customer information. But the continued emphasis on quality and the evolution of integrated circuit technology have yet enhanced the superframe.

EXTENDED SUPERFRAME (ESF)

Extended Superframe (ESF) expands the superframe from 12 to 24 193-bit frames (Figure 13). Like the D4 format, the 193rd bit in each frame is always a control bit. Extended superframe was developed in order to be able to evaluate system performance without disrupting service by testing the T-1 link with test equipment. With that in mind, three-fourths of the 24 control bits are reserved for evaluation of circuit performance.

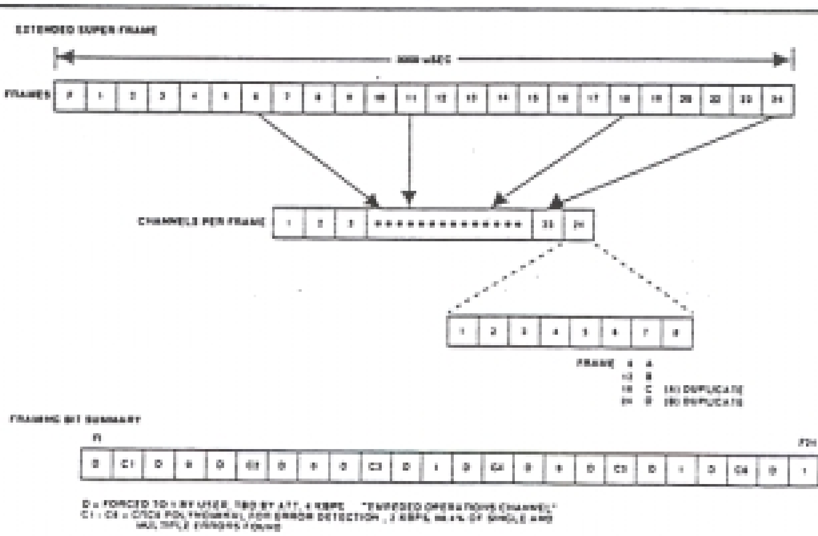


Figure 13. Extended Super Frame

Table 2 outlines the extended superframe format as stated in ANSI Standard T-1.403-1989.

In ESF, 6 control bits are reserved for a Cyclic Redundancy Check (CRC), a method of detecting errors as information is transmitted along the T-1 link (2 kb/s); 12 bits are reserved as a data link for communication between transmitting and receiving equipment at either side of the T-1 link (4 kb/s); and 6 bits are used to manage signaling and framing (2 kb/s).

The sections that follow briefly describe the ESF's CRC and data link capabilities.

CRC-6

CRC-6 is a six-bit word that detects, with 98.4% accuracy, bit errors (i.e., zeros that should be ones and vice versa) in any block of live data. Table 3 depicts how CRC-6 works in very simple terms.

TABLE 3
HOW CRC-6 WORKS

Step:	Activity:
1.	The network equipment building the ESF performs a mathematical calculation on the signal to be transmitted across the T-1 link. (Control bits are excluded from the calculation.)
2.	The signal is transmitted across the T-1 link to the receiving equipment. The result of the mathematical calculation is a six-bit word which is sent to the receiving equipment in the six CRC bit positions of the *next* ESF.
3.	The receiving network equipment performs the same mathematical calculation on the customer information, and compares the result with the six-bit word which arrives in the next ESF. If the results match, it is likely that no bit errors have occurred; if the results do not match, it indicates that one or more logic errors have occurred, either in the customer information or in the CRC bits.

THE ESF DATA LINK

ESF reserves 12 bits (transmitted at 4 kb/s) as a data link for communication between the transmitting and receiving equipment on each side of the T-1 link. Although it can be used for any purpose, one typical use is the transmission of trouble flags such as the *yellow alarm signal*.

The yellow alarm signal is sent by the receiving equipment when synchronization to a transmitted DS-1 signal cannot be achieved. The yellow alarm is a continuous 16-bit pattern of eight consecutive ones followed by eight consecutive zeros.

Note that the yellow alarm signal is only one example of how a data link can be used. Table 4 depicts the assigned bit-orientated ESF data-link messages as outlined in ANSI Standard T-1.403-1989.

Table 2
Extended Superframe Format

Frame Number	F Bits				Bit Use In Each Time Slot		Signaling Bit Use Options			
	Bit Number	FPS	DL	CRC	Traffic	Signal	T	2	4	16
1	0	—	m	—	1-8	—	—	—	—	—
2	193	—	—	C1	1-8	—	—	—	—	—
3	386	—	m	—	1-8	—	—	—	—	—
4	579	0	—	—	1-8	—	—	—	—	—
5	772	—	m	—	1-8	—	—	—	—	—
6	965	—	—	C2	1-7	8	—	A	A	A
7	1158	—	m	—	1-8	—	—	—	—	—
8	1351	0	—	—	1-8	—	—	—	—	—
9	1544	—	m	—	1-8	—	—	—	—	—
10	1737	—	—	C3	1-8	—	—	—	—	—
11	1930	—	m	—	1-8	—	—	—	—	—
12	2123	1	—	—	1-7	8	—	A	B	B
13	2316	—	m	—	1-8	—	—	—	—	—
14	2509	—	—	C4	1-8	—	—	—	—	—
15	2702	—	m	—	1-8	—	—	—	—	—
16	2895	0	—	—	1-8	—	—	—	—	—
17	3088	—	m	—	1-8	—	—	—	—	—
18	3281	—	—	C5	1-7	8	—	A	A	C
19	3474	—	m	—	1-8	—	—	—	—	—
20	3667	1	—	—	1-8	—	—	—	—	—
21	3860	—	m	—	1-8	—	—	—	—	—
22	4053	—	—	C6	1-8	—	—	—	—	—
23	4246	—	m	—	1-8	—	—	—	—	—
24	4439	1	—	—	1-7	8	—	A	B	D

NOTES:
(1) Frame 1 transmitted first.
(2) Frames 6, 12, 18, and 24 are denoted signaling frames.
(3) FPS = Framing Pattern Sequence (...001011...)
(4) DL = 4kbit/s Data Link (Message Bits m)
(5) CRC - CRC-6 Cyclic Redundancy Check (Bits C1-C6)
(6) Option T = Traffic (Bit 8 not used for Robbed-Bit signaling)
(7) Option 2 = 2-State Signaling (Channel A)
(8) Option 4 = 4-State Signaling (Channels A and B)
(9) Option 16 = 16-State Signaling (Channels A, B, C, and D)

Table 4
Assigned Bit-Oriented ESF Data-Link Messages

Function	Codeword
Priority Messages	
Yellow Alarm	0 000000 011111111
Reserved for network use	0 001110 011111111
Reserved for network use	0 010110 011111111
Reserved for network use	0 011010 011111111
Command and Response Messages	
Line Loopback Activate	0 000111 011111111
Line Loopback Deactivate	0 011100 011111111
Payload Loopback Activate	0 001010 011111111
Payload Loopback Deactivate	0 011001 011111111
Reserved for Network Use (Loopback Activate)	0 001001 011111111
Reserved for Network Use (Loopback Deactivate)	0 010010 011111111
Reserved for Protection Switch Line 1	0 100001 011111111
Reserved for Protection Switch Line 2	0 100010 011111111
Reserved for Protection Switch Line 3	0 100011 011111111
Reserved for Protection Switch Line 4	0 100100 011111111
Reserved for Protection Switch Line 5	0 100101 011111111
Reserved for Protection Switch Line 6	0 100110 011111111
Reserved for Protection Switch Line 7	0 100111 011111111
Reserved for Protection Switch Line 8	0 101000 011111111
Reserved for Protection Switch Line 9	0 101001 011111111
Reserved for Protection Switch Line 10	0 101010 011111111
Reserved for Protection Switch Line 11	0 101011 011111111
Reserved for Protection Switch Line 12	0 101100 011111111
Reserved for Protection Switch Line 13	0 101101 011111111
Reserved for Protection Switch Line 14	0 101110 011111111
Reserved for Protection Switch Line 15	0 101111 011111111
Reserved for Protection Switch Line 16	0 110000 011111111
Reserved for Protection Switch Line 17	0 110001 011111111
Reserved for Protection Switch Line 18	0 110010 011111111
Reserved for Protection Switch Line 19	0 110011 011111111
Reserved for Protection Switch Line 20	0 110100 011111111
Reserved for Protection Switch Line 21	0 110101 011111111
Reserved for Protection Switch Line 22	0 110110 011111111
Reserved for Protection Switch Line 23	0 110111 011111111
Reserved for Protection Switch Line 24	0 111000 011111111
Reserved for Protection Switch Line 25	0 111001 011111111
Reserved for Protection Switch Line 26	0 111010 011111111
Reserved for Protection Switch Line 27	0 111011 011111111
Reserved for Protection Switch Acknowledge	0 001100 011111111
Reserved for Protection Switch Release	0 010011 011111111
Under Study for Synchronization	0 011000 011111111
Under Study for Synchronization	0 000110 011111111
Under Study for Synchronization	0 010001 011111111
Under Study for Synchronization	0 010100 011111111
Reserved for network use	0 001011 011111111
Reserved for network use	0 001101 011111111
Reserved for network use	0 001111 011111111
Reserved for network use	0 011101 011111111
Reserved for network use	0 010101 011111111

NOTES:

(1) Rightmost bit transmitted first.

(2) The "Protection Switch Line" codes of the form 01XXXXX0 11111111 use the five X-bits to indicate the number of the line, 1 through 27, to be switched to a protection line.

ESF's ENHANCED SIGNALING CAPABILITY

In addition to circuit management, ESF also provides enhanced signaling capability. By robbing the eight bit from the 6th, 12th, 18th, and 24th frames (signaling bits A, B, C, and D, respectively) in the superframe, more than 16 signaling states can be represented. Enhanced signaling capability is essential for merging services such as video, where signaling states beyond the few used in voice service may be required.

MULTIPLEXER FEATURES

Modern T-1 multiplexers incorporate many features and options to enhance T-1 network implementation and operation. The various manufacturers may call their features by different names, and the features may differ somewhat in functionality. The following sections provide a brief description of some of the major features of T-1 multiplexers.

SYNCHRONOUS DATA

The ability to intermix voice and data, and preserve the transmission characteristics of each, is a primary requirement of T-1 multiplexers. Voice transmission, for example, can tolerate a few bit errors and not affect the quality of the voice at the receiving end. Speed of delivery is important as any delay is noticeable in voice conversations. In Telco style multiplexers data transmission is treated just the opposite. Error free transmission is a higher priority than speed of delivery. It is this practice that makes most Telco grade T-1 systems unusable for critical real time applications such as current differential and phase comparison relaying.

Synchronous data transmission is characterized by the use of clocking signals to synchronize bit times. (Figure 14). The multiplexer utilizes synchronous channel cards to terminate the data links which provide and accept the clock signals to and from the synchronous device. The channels are protocol transparent and pass exactly what is received through the system. Error control is the responsibility of the protocol and the devices.

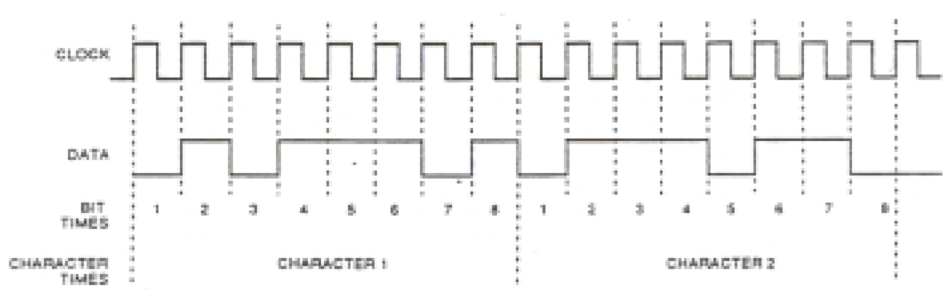


Figure 14. Synchronous Data

T-1 multiplexers divide the 1.544 Mbps stream into 24 channels of 64 Kbps each. Since very few end devices operate at 64-Kbps, multiplexers have the capability of reducing the speed of the channel to more useful rates (rate adaptation). Operating a 64 Kbps channel at 9,600 bps is obviously wasteful. The multiplexers can divide a 64 Kbps time slot in the D4 frame into several lower speed channels called subrate channels. Subrate time division multiplexing provides channels from 75 bps to 64 Kbps.

The channels are sometimes connected to analog modems or digital circuits to reach remote locations that do not have enough traffic to warrant a T-1 multiplexer. These connections are called tail circuits. The connections to synchronous devices or tail circuits are made using standard connectors and cables. For links operating at less than 20 Kbps, EIA RS-232 interfaces are used. Higher speed links can use either EIA RS-449 or CCITT V.35 interface connections.

ASYNCHRONOUS DATA

Asynchronous data does not use clock signals to maintain data word synchronism. Instead, each word is preceded by a start bit and needed with a stop bit. (Figure 15). A typical eight-bit byte from an end device will be transmitted using ten bits when the start and stop bits are added. Asynchronous data normally operate at rates of 75 bps to 19.2 Kbps.

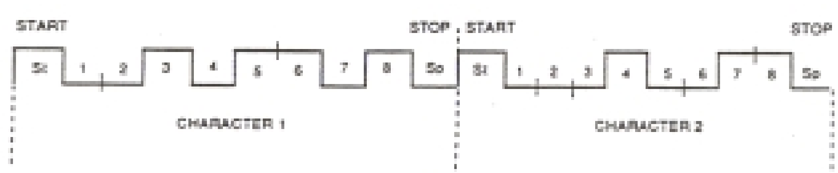


Figure 15. Asynchronous Data

CONTROL SIGNALS

Control Signals such as Request-to-Send (RTS) and Clear-to Send (CTS) must be passed through the T-1 network for both synchronous and asynchronous data channels. The control signals are coded by the channel card into unique data characters and sent with the data characters (in-band signaling) at the remote end the unique characters are recognized by the channel card, reconstructed as control signals, and passed to the attached equipment.

DROP AND INSERT

Multiple aggregate T-1 multiplexers must provide the ability to remove and insert traffic from a T-1 link while passing the remainder of the T-1 aggregate along to another site. (Figure 16). Drop and insert capabilities considerably improve network efficiency and reduce cost. Depending on the type of buffering applied to the received T-1 aggregate the drop and insert through times can vary greatly between multiplexers of different manufacturers. When Teleprotection schemes are to be applied to a T-1 network the addition of these times can prove prohibitive to real time protection applications. Typical D&I through times for protection applications are in the order of 25 μs.

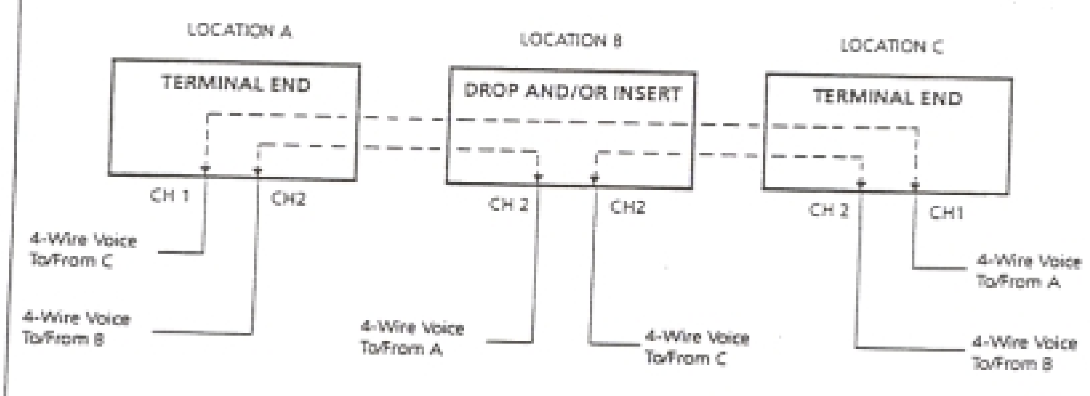


Figure 16. Typical Drop-And-Insert Application

NETWORK TIMING

T-1 networks are designed to be primarily synchronous networks. That is, data clocked in at one point in the network has a fixed timing relationship to the point in the network at which the data is clocked out. Technically, this means that the speeds at both points are the same, and there is a fixed frequency relationship between the clocks which strobe the data in and out. This condition is usually referred to as frequency locked.

The North American T-1 network is derived from a series of higher order network multiplexer unsynchronized clocks using a technique called pulse stuffing to overcome clock inaccuracies and fluctuations. The use of unsynchronized clocks for higher level TDM network does not, however, preclude network synchronization of the lower level T-1 or DS1 signals. Synchronization of the network at the DS1 level is achieved by framing (D4 or ESF in North America) the data streams and frequency locking the node and network clocks. Loss of synchronization or unlocked clocks result in frame slips. A frame slip is a condition in which framing is momentarily lost, as well as network timing information, typically resulting in data loss.

Some multiplexers, such as the Model 9001, provides four selections for primary node synchronization source plus fallback synchronization source. The reasons used and their application are described below.

1. INTERNAL
2. EXTERNAL
3. LOOP
4. THRU

In a T-1 network, the bipolar pulse transmission technique is used because the clocking information is embedded in the data. Any delays in the pulse stream result in equal delays of the clock and data. During transmission, clock and data are essentially locked together. Thus, distribution of the T-1 aggregate links provides a source of network timing transmission.

INTERNAL

This involves selecting one nôde as the master (clock) reference node. The master clock is distributed to the network nodes, enabling them to lock to the common master reference. This is a simple technique, with the outlying nodes operating in through and loop timed modes.

EXTERNAL

Multiple systems can be synchronized by deriving their timing form a common source. Multiple systems which are loop-timed to the same network are also synchronized, both to each other and the network. T-1 systems are synchronized to prevent buffer overflows or underflows, generally called "slips". In network switching systems such as digital central offices, PBXs, and digital cross connect systems (DACS).

LOOP

Just as there must be a clock source in a network there must also be a tail end. The tail of the network takes the received clock information and LOOPs it back towards the master clock terminal. In a point to point system the clock is generated at the master used by the remote terminal and is looped back to the master where it is terminated.

THRU

In drop and insert networks there may be many terminals between the master clock source and the last or LOOP timed terminal. It is possible and quite normal for differences in time to exist between when the transmitted and received clocks pass through a D&I terminal. THROUGH timing is used in this instance to eliminate the need to frame realign between terminals. It is this ability that helps the multiplexer to maintain very low drop and insert through times.

Some examples of the timing considerations are depicted in Figures 17 and 18.

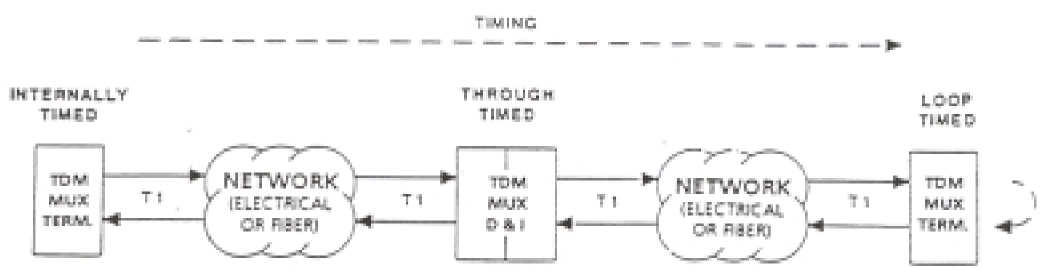


Figure 17. Drop/Insert System Internally Timed From One End

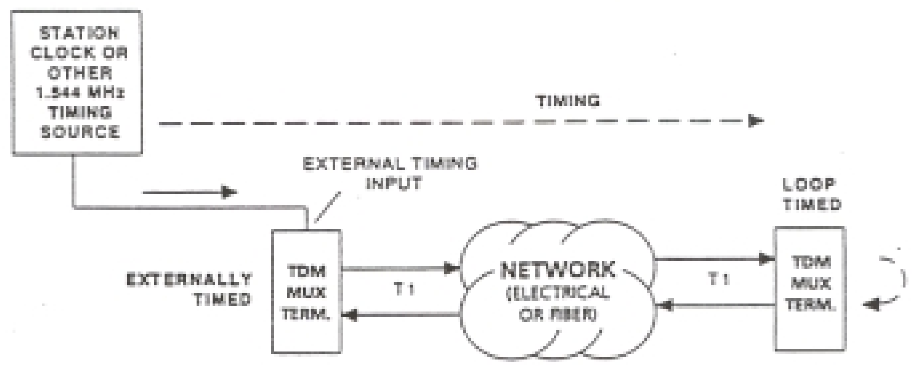


Figure 18. Point-To-Point System Externally Timed From One End

FALLBACK TIMING

Each multiplexer has its own internal clock. Upon loss of the incoming timing source the multiplexer has the option to revert to its "Fallback timing" mode which typically is set to its own internal clock. Whichever multiplexer first losses its incoming clock and reverts to its internal fallback timing mode, the multiplexers down the line will now synchronize to that new clock source.

MULTIPLEXER RELIABILITY CONCERNS

Several considerations must be taken into account when selecting a multiplexer for a utilities protection scheme. Some of those concerns are listed with an explanation of their importance.

REFRAME TIME

Reframe Time is defined as the amount of time it takes a multiplexer to re-synchronize to the network should there be an interruption in the incoming signal. This amount of time equates to an outage of system availability during that interruption. This is why this time should be kept to a minimum.

ROBUSTNESS

Robustness is defined as the mean time to lose frame at 10^{-3} Bit Error Rate. If a multiplexer loses frame it will then have to reframe. This time is considered outage time so the ability of a multiplexer not to lose frame in the first place becomes another consideration for the utility.

THROUGH - CHANNEL DELAY

Through-channel delay is defined as the amount of delay time incurred by a channel passing through a drop and insert location. Since many T-1 applications are multipoint, certain channels will typically pass through several locations before reaching their final destination. This amount of delay incurred may become prohibitive to certain relaying applications (current differential or blocking) should these delays not be kept to a minimum.

FALLBACK TIMING

Fallback timing is a necessity that guarantees system clock is available should there be a loss of the incoming clock source. This insures the remainder of the system will continue to operate from that new clock source.

Figure 19 addresses the Reliability Aspects of the Model 9001 T-1 Multiplexers.

Average Reframe Time	7.5 ms for ESF, 3.75 ms for SF.
Robustness	Mean time to lose frame at 10^{-3} Bit Error Rate: Greater than 10 hours for ESF. Greater than 2 hours for SF.
Through-Channel Delay	Less than 25 microseconds.
Fallback Timing	Automatically enabled in case of primary timing failure. Smooth phase transition to fallback timing minimizes down line perturbations.

Figure 19. RFL 9001 Reliability

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