Digital Terminals and Multiplexers

Contents

1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, and other
     interested parties with information and recommendations on digital
transmission systems. This section specifically covers digital terminal

equipment, or channel banks, in detail and briefly discusses digital
multiplexers, terminal maintenance systems, and alarms. TE&CM Sections 950
and 951 should be referenced for an overview and summary of digital
transmission and a glossary of digital transmission terminology,
respectively. Digital span lines, span line interrogation and automatic
protection switching (APS) are described in TE&CM Section 956.

1.2 In general, a digital channel bank consists of the necessary components
     to encode analog signals (voice and signaling) into digital words and
multiplex the digital words from a group of channels into a digital bit
stream. At the distant end of a span line another channel bank demultiplexes
the incoming bit stream into its component parts and decodes the digital words
into analog signals. Channel banks generally consist of 24 channels or
multiples of 24 channels. REA Specifications PE-60 and PE-64 outline the
interface requirements for trunk and subscriber carrier systems. This section
provides information on older types of channel banks for historical purposes.
Additionally, several types of encoding processes are briefly discussed. The
bulk of the description provided in this section refers to the D3- and D4-type
channel banks. For many years, the D3-type was the industry standard and
remains in extensive use, particularly for subscriber carrier systems. Today,
new digital trunk carrier systems are generally of the D4-type. Both of these
types are described in detail in later paragraphs. In recent years, a D5
channel bank has been introduced. This is an intelligent software-controlled
system which enhances the maintenance and administrative capabilities of the
digital channel bank function.

1.3 Historically, most digital information has been transmitted at the DS1
     rate of 1.544 Mb/s via T1 type span lines on paired telephone cables.
Basic DS1 signals are also combined (multiplexed) to form higher rate digital
signals for transmission over paired cables, radio, optical fibers and coaxial
cables. Digital multiplexers are briefly discussed in this section to
describe how separate, nonsynchronized DS1 signal inputs are multiplexed to
form a higher rate synchronized output. This discussion is limited in scope
and is not intended as an exhaustive description of specific multiplex
equipment.

2. DIGITAL TECHNIQUES AND CHARACTERISTICS

2.1 General: The following paragraphs summarize some of the techniques used
     for digital encoding, transmission, and multiplexing. Technical
characteristics of the digital signals and decoded analog signals of several
techniques are briefly reviewed and compared. Emphasis is placed on D3 voice
encoding as a telephone industry standard. It should be kept in mind that D3
encoding is used in D4 as well as D3-type channel banks.

2.1.1 The first digital transmission system was the Western Electric D1
       channel bank (and T1 span line) used for trunk service. From this
system evolved the D1A, D1B, D1C, D1D, D2, D3, and D4 channel banks for trunk
service and variations of D1, D3 and differential PCM for subscriber service.
The Independent telephone equipment manufacturers generally provided versatile
channel banks that were made compatible with several Western Electric channel
bank types via strapping options or special plug-in cards.

2.1.2 Digital systems for voice transmission use nonlinear encoding (unequal coding steps). Early systems used instantaneous compandors (compressors and expandors) and linear coders and decoders (equal coding steps) to provide the nonlinear encoding. Current systems use nonlinear encoders and decoders (codecs) to achieve the same (or improved) results. Nonlinear encoding provides improved voice quality with fewer coding steps. In nonlinear encoding, coding steps are small for low amplitude level voice samples and larger for high level samples. This is the case because statistically the greater amount of voice samples are of the low level variety. Smaller coding steps provide for a much better resolution (less quantizing noise). The nonlinear coding steps for digital systems are determined by a "companding law" of mu = 100 for D1 channel banks and mu = 255 for D2, D3, and D4 channel banks. European systems use an "A law" compandor. Today's digital systems in North America are standardized on the mu = 255 companding law.

2.2 <u>Trunk Systems</u>: The following paragraphs provide a brief summary of the characteristics of the various types of trunk channel banks.

2.2.1 <u>D1</u>: The D1 channel bank was the first digital channel bank used in telephony. The analog voice signal was fed into an instantaneous compandor before encoding. The voice signal was sampled and fed onto a bus containing the pulse amplitude modulated (PAM) signals from 12 of the 24 channels. The PAM signals were compressed utilizing the mu = 100 law and encoded into 7 bits per PAM sample representing 127 coding levels. A signaling bit was added for each voice encoded sample and a framing bit was added at the end of each 24 channel sequence. This resulted in 24 x 8 = 192 + 1 = 193 bits per frame x 8000 frames per second = 1.544 Mb/s. The D1 system used two compandors, channels 1 through 12 were fed into one and channels 13 through 24 into the other. The outputs from the two compandors were interleaved such that the outgoing channel sequence was 1, 13, 2, 14, 3, 15, etc. This interleaving reduced crosstalk in adjacent time slots.

2.2.2 <u>D1A</u>: The D1 channel bank was later designated as the D1A channel bank. As described in the previous paragraph the D1 channel bank used one of the eight bits assigned per channel for signaling. Some PCM channels require two signaling bits. To accomplish this with D1A channel banks, a bit normally assigned for voice encoding was used for the additional signaling bit. This left only six bits for voice encoding resulting in greater noise and distortion during this signaling condition.

2.2.3 <u>D1B</u>: The D1B channel bank is the same as the D1A except that the signaling bit was divided into four segments (a superframe of four frames) to provide two signaling channels. This allowed the seven remaining bits to be used for voice encoding at all times. The Independent manufacturers provided D1 channel banks that could be arranged for either D1A or D1B signaling.

2.2.4 <u>D1C</u>: The D1C was a special purpose D1 channel bank used in TSPS applications. The signaling bits for all 24 voice channels were combined into a separate high speed data channel (192 kb/s).

2.2.5 <u>D1D</u>: After D2 and D3 channel banks were already being used,
Western Electric developed a modified version of the D1 channel bank to
achieve D3 voice quality. This was designated the D1D and was developed to
utilize the large quantities of D1 racks and shelves already installed. The
Independent manufacturers utilized D3 channel banks to meet D1D application
requirements by changing the channel sequence from 1, 2, 3, 4,.....24 (for D3)
to 1, 13, 2, 14, etc. (for D1). This change was accomplished by a plug-in
card or by a change in channel bank backplane wiring, depending on the
specific type and age of the equipment.

2.2.6 <u>D2</u>: The D2 channel bank was developed to achieve a higher quality
voice circuit for intertoll applications. The D2 bank utilizes 8 bit
nonlinear encoding to derive 255 coding levels determined by the mu = 255
companding law. Two signaling channels are provided by "robbing" the least
significant voice bit from each channel every sixth frame. In the sixth
frame, signaling Channel A is transmitted and in the twelfth frame signaling
Channel B is transmitted. Twelve frames make up a superframe and the
sequence repeats. The Western Electric D2 was designed in 96 channel groups
for T1 applications (24 channels) and T2 applications (96 channels). The
Independent manufacturers designed D2 channel banks in 24 channel groups.
The D2 channel sequence is shown in Table 1. The Independent manufacturers'
channel banks can be arranged for D2, D3, or D1D applications by changing the
channel sequence via plug-in cards.

<div align="center">Table 1</div>

<div align="center">Channel Sequence</div>

Time Slot	D1	D2	D3
1	1	12	1
2	13	13	2
3	2	1	3
4	14	17	4
5	3	5	5
6	15	21	6
7	4	9	7
8	16	15	8
9	5	3	9
10	17	19	10
11	6	7	11
12	18	23	12
13	7	11	13
14	19	14	14
15	8	2	15
16	20	18	16
17	9	6	17
18	21	22	18
19	10	10	19
20	22	16	20
21	11	4	21
22	23	20	22
23	12	8	23
24	24	24	24

2.2.7 <u>D3</u>: The Western Electric D3 channel bank was designed in 24 channel
groups for Tl applications to provide the same voice quality as D2
channel banks. The channel sequence is 1, 2, 3, 4,...24. The Independent
manufacturers' D2 was redesigned to cover both D2 and D3 applications. (Field
modification of early D2 systems for D3 application was sometimes awkward to
accomplish.) The D3 format is considered the standard for most of the digital
channel banks in production today including high density applications such as
lightwave systems and direct digital interface to digital central office
equipment. D3 voice encoding is also used for digital subscriber carrier
equipment; however, the use of signaling and framing bits vary with equipment.
The channel sequences for D banks are shown in Table 1.

2.2.8 <u>D4</u>: The D4 channel bank is designed in 48 channel groups for Tl,
TlC and T2 span line applications. The D4 channel bank is essentially
a lower cost, smaller combined packaging of two D3 channel banks (24 channel
each) arranged for five modes of operation with Mode 3 being the same as two
D3 channel banks. D3 and D4 channel banks are discussed in more detail in
Paragraph 3.

2.2.9 <u>ADPCM</u>: Adaptive Differential Pulse Code Modulation (ADPCM) is an
encoding technique that provides PCM voice transmission quality and
doubles the Tl span line capacity. Since human speech follows regular
patterns, many portions of a speech waveform are redundant and predictable.
Therefore, using ADPCM, fewer bits can be used than required for D3 PCM to
transmit speech with only a small degradation. Using ADPCM, the normal 8-bit
sample of a 64 kb/s DS1 bit stream is reduced to a 4-bit sample in a 32 kb/s
bit stream. By combining two such bit streams, the Tl line capacity is
doubled, i.e., 48 voice channels can be transmitted over a single Tl span line
when robbed bit signaling is used (Unbundled mode). In the Bundled mode, 44
channels of voice information can be transmitted with 4 additional channels
dedicated to signaling. The ADPCM algorithm is specified in ANSI standard
T1.301-1987 "32 KB/S Adaptive Differential Pulse Code Modulation (ADPCM)
Algorithm and Line Format".

2.3 <u>Subscriber Systems</u>: The following paragraphs provide a brief summary
of the characteristics of carrier systems used for subscriber service.

2.3.1 <u>Dl Subscriber</u>: Early versions of PCM subscriber carrier and
integrated carrier-concentrators used Dl voice encoding. The
signaling bit was generally used on a per channel basis (8 kb/s per channel)
to encode and initiate dialing, ringing (including a variety of multiparty
ringing schemes), other signaling, supervision, and test functions. Alarms,
status reporting, and similar functions were usually handled on a system
basis. Integrated carrier-concentrators generally used the signaling bits
from all channels on a serial bit stream basis (192 kb/s) to instruct
microprocessors to initiate all signaling, switching, alarm, status, and test
functions. PCM subscriber carrier was generally packaged in 24 or 48 channel
groups for transmission over Tl span lines. One system provided 36 channels
using ternary encoding (three level pulse stream) utilizing a special span
line near the Tl rate.

2.3.2 <u>D3 Subscriber</u>: PCM subscriber carrier and digital loop carrier systems
(integrated carrier-concentrators) have standardized on the use of D3
voice encoding and most other D3 system characteristics. One exception is the

type of signaling used. Present day D3 subscriber carrier systems generally use the signaling bits on a per channel basis (8000/6 = 1333 b/s per channel). Digital loop carrier systems generally use the signaling bits for all channels on a serial bit stream basis (32 kb/s) to interface with microprocessors. Steadily decreasing costs have substantially increased the use of microprocessors in D3 subscriber carrier equipment. D3 subscriber carrier is described in more specific detail in paragraph 3.

2.3.3 DPCM Subscriber: Differential PCM (DPCM) is a technique for encoding and transmitting changes in amplitude of analog voice signals. The encoded signal represents a change in amplitude rather than an absolute level. Delta Modulation is an example of DPCM where a single bit is used to indicate if a sample has increased or decreased compared to the previous sample. Acceptable voice quality was attained with a per channel rate of 32 kb/s to 40 kb/s in subscriber service. This rate was more efficient than the 64 kb/s per channel rate (including signaling) required for D3 PCM. Several DPCM subscriber carrier and carrier-concentrator systems were developed and placed into service. Production of DPCM equipment for subscriber service has now been discontinued because of standardization on D3 voice encoding.

2.4 Multiplex Systems: The digital channel bank performs the first level of multiplexing by interleaving the individual 8 bit words from 24 voice channels into a digital pulse stream (DS1) which is suitable for universal interface and efficient transmission over paired cables. Digital multiplex equipment is available to combine two or more asynchronous inputs into higher rate synchronized outputs. Multiplexers interleave incoming bit streams on a bit-by-bit or byte (group of bits) basis. Multiplexers are generally designed to interface at standard Bell Communications Research (Bellcore) signal levels, e.g., DS1, DS2, DS3, etc. However, they may not all follow the specific signal format or bit rate outlined for standard Bellcore specified M-type multiplexers at both the input and output interfaces. Most multiplexers use similar techniques for scrambling, stuffing, and temporary storage of bits in the multiplexing process.

2.4.1 The following is a generalized description of a multiplexer using the M12 as a model. The multiplexer combines four asynchronous DS1 inputs into a DS2 output. Prior to multiplexing, the second and fourth input signals are inverted (ones become zeros and zeros become ones) as a first stage of randomizing (scrambling) the multiplexed output (See paragraph 2.5.3). Twelve bits are taken from each input and interleaved into a single bit stream and one control bit is added (12+12+12+12+1 = 49 bits). This sequence is repeated six times to form a subframe (49 x 6 = 294 bits). The subframe sequence is repeated four times to form a frame consisting of 1176 bits (294 x 4). Of these 1176 bits, 1152 are information bits from the four DS1 inputs and 24 are control bits.

2.4.2 Since the four DS1 inputs are not synchronized, each input is written into a buffer (elastic store) from which the bits can be extracted (read) at the exact time required. Since each input may be operating at a different speed, some of the input buffers may become empty before others. Extra bits (stuff bits) are added to the incoming bit streams as required to

prevent the stores from becoming empty and thus synchronizing the inputs. Stuff bits may be added only at specified locations (time slots) in the outgoing bit stream. Specific control bits identify when a stuff bit has been added.

2.4.3 The 24 control bits per frame are divided into four "M" bits, eight "F" bits and twelve "C" bits. The M bit pattern (011X) aligns the frame and the subframes and transmits alarm information (X=0 or 1) between multiplexers. The patterns of F and C bits further align each subframe and possible stuff bit time slots. The C bits also identify whether or not stuff bits have been transmitted. A maximum of about 0.3 percent of the output bit stream may be stuff bits. The clocks driving the individual DS1 inputs do not require high level precision but must remain within specified limits to ensure that excessive stuff bits are not required.

2.4.4 The multiplexer output bit rate is the sum of all DS1 inputs plus a fixed number of control and framing bits plus a variable number of stuff bits. The output is processed to ensure that no more than five consecutive zeros are transmitted (See paragraph 2.5.8). Table 2 provides examples of standard Bellcore M-type multiplexers. The characteristics of the DS line signals are discussed in paragraph 2.5.

Table 2

Standard Multiplexes

Multiplex	Input	Output	Channels
M1C	2 DS1	DS1C	48
M12	4 DS1	DS2	96
M13	28 DS1	DS3	672
M23	7 DS2	DS3	672
MX3 (See Note)	28 DS1 } 14 DS1C } 7 DS2 }	DS3	672
M34	6 DS3	DS4	4032

NOTE: The MX3 multiplexer provides inputs for 28 DS1, 14 DS1C or 7 DS2 streams or a mixture of rates equivalent to 28 DS1's.

2.5 Transmission and Multiplex Signals: The following paragraphs describe several encoding and format techniques. In addition, DS signal characteristics are outlined.

2.5.1 Unipolar Pulses: Unipolar pulses (one polarity) are used within equipment and local systems but are not generally transmitted over any distance. These pulses can be converted into other line signals, generally bipolar pulses, for transmission over the network.

2.5.2 Bipolar Pulses: Bipolar pulses (alternating between positive and negative) are generally used for transmission over exchange cable pairs. Bipolar pulse transmission, e.g., Alternate Mark Inversion (AMI), has

several advantages over unipolar pulse transmission. These advantages are illustrated in Figure 1 based on a T1 bit stream. The advantages include the following:

    a. Power is concentrated near 772 kHz.
    b. Low frequency power is reduced (no dc).
    c. High frequency power is reduced.
    d. Many errors can be easily recognized.

2.5.2.1 In the following discussion of bipolar pulse transmission, it is generally assumed that the pulses are random and contain no bipolar violations. (A bipolar violation consists of two consecutive pulses of the same polarity.) Most systems are designed to transmit alternate bipolar pulses with no violations except in the case of zero suppression as described in paragraph 2.5.8. Some systems use ternary encoding as described in paragraph 2.5.4. Additionally, quaternary (four level) coding is emerging for use with ISDN. These schemes contain a large quantity of bipolar violations which convey information. To transmit and recover signals containing bipolar violations, the system must pass low frequencies, possibly near dc.

2.5.2.2 In the DS1 bit stream certain repetitive patterns are generated either by design or otherwise. These patterns may be greater during no traffic or low traffic conditions. Framing pulses are by necessity repetitive and produce a low level 8000 hertz signal. In the idle, on-hook condition, D1A systems transmitted two pulses in 8 bits each frame excluding framing pulses. D1B systems transmitted one pulse in 8 bits in three out of four frames and two pulses in 8 bits in the fourth frame. In D3 and D4 systems the pulse density was increased to 8 pulses in 8 bits during the idle condition. This improves the system stability by providing more pulses for clock timing and concentrates the power near 772 kHz. Some random pulses may be generated by noise or equipment conditions. These random pulses tend to spread the power somewhat but the system can still transmit large discrete power components.

2.5.3 Scrambling: Various techniques are used to "scramble" or "condition" the digital bit stream for modulation or transmission. Scrambling is used to keep the signal in a dynamic state of random change. Long strings of consecutive zeros and repetitive patterns are therefore avoided in the transmitted signal. Scrambling may be required because of the modulation techniques or may be used to improve system performance. The scrambler rearranges the digital bit stream in a predetermined manner to produce a random-appearing sequence of bits. The descrambler at the receiver restores the digital bit stream to its original form. Scrambling is used in carrier systems to maximize performance. In higher order systems, such as radio, lightwave and coaxial cable systems, scrambling is used because of the modulation techniques and to reduce system loading. The error rate of a scrambled bit stream must be several times better than that of a nonscrambled bit stream since the descrambling process will increase the error rate of the received signal.

2.5.4 Ternary Encoding: Ternary encoding is used to increase the information rate with a smaller corresponding increase in the transmitted span line signal rate. Ternary refers to three states such as positive, negative, and zero. The signal is bipolar where the presence and

polarity of pulses convey information. One ternary encoded transmission system uses a four binary to three ternary code (4B3T) to transmit four information bits in three time slots. This converts a 48 channel 3.152 Mb/s binary signal into a 2.364 Mb/s ternary signal. The span line signal imposes a small increase in the facility requirements (compared to T1) for exchange cable applications. A large quantity of bipolar violations is normal in the ternary encoded bit stream.

2.5.5 **Duobinary Encoding:** The information rate of a bit stream can be doubled with a small increase in the facility requirements (compared to T1) for exchange cable applications through the use of duobinary encoding. A modified duobinary encoded system divides a TIC stream into two bit streams and then interleaves the two signals into a duobinary format. A TIC system transmits pulses of 158 nanoseconds duration in a 317 nanosecond time slot (50 percent duty cycle). The duobinary system takes advantage of the "dead time" between pulses. The two bit streams are interleaved every 317 nanoseconds and the resultant combined output pulses may be either 158 or 317 nanosecond wide. The duobinary signal transports the TIC information but with a power spectrum similar to T1.

2.5.6 **Bit Stuffing:** Bit stuffing (sometimes called pulse stuffing) is used to synchronize two or more bit stream inputs to a multiplexer. Extra noninformation bits are inserted (stuffed) as required at the multiplexing end and removed at the demultiplexing end.

2.5.7 **Buffer Stores:** A buffer store (elastic store) is a temporary storage unit for digital information (temporary memory for binary digits). Buffer stores are used in digital multiplexers to combine two or more asynchronous inputs into a synchronous output. The incoming bit streams are written into the buffer stores at their individual bit rates and read out at an internal clock rate (synchronized). The size of the buffer store (number of stored bits) is dependent upon how frequently stuffing bits may be inserted into the bit stream. The stores are never allowed to become "empty". Frequent stuffs allow for smaller stores.

2.5.8 **Zero Substitution Codes:** Pulses (ones) or transitions (changes of state) in the bit stream are used to synchronize the clocks at the transmitting and receiving ends of a digital connection. Since long strings of consecutive zeros can lead to a loss of synchronization, zero substitution codes are used to prevent such strings. The type of zero substitution code used is dependent upon the DS level of the bit stream. For example, a DS2 line signal is a 50 percent duty cycle bipolar pulse stream with controlled bipolar violations. The format is called "bipolar with six-zero substitution" or B6ZS. In this format no more than five consecutive zeros are transmitted. When six consecutive zeros are encountered, a six bit code consisting of zeros and a pattern of bipolar violations is substituted. At the receiving end of the connection, the code is recognized and the six zeros are reinserted into the bit stream. A similar code for a DS3 level signal is called "bipolar with three-zero substitution" or B3ZS. For the DS1 level, newer carrier and multiplex equipment can be optioned to provide a line code called "bipolar with eight-zero substitution" or B8ZS. This code not only provides for synchronization protection but also, together with common channel signaling, permits Clear Channel Capability, i.e., the entire 64 kb/s channel can be used for information transmission.

2.5.9 <u>Line Signal Characteristics</u>: Digital line signal characteristics
       have been standardized in specifications written by Bellcore and the
American National Standards Institute (ANSI). These specifications outline
bit rates, signal format (time slot assignment), signal waveshape and other
characteristics. Table 3 lists some of these design characteristics.

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Table 3

Digital Line Signal Characteristics

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Level	Rate Mb/s	Pulse/Duty	Zero Sub. Code
DS1	1.544	Bipolar/50%	B8ZS
DS1C	3.152	Bipolar/50%	B8ZS
DS2	6.312	Bipolar/50%	B6ZS
DS3	44.736	Bipolar/50%	B3ZS
DS4	274.176	Polar/100%	NRZ

2.5.9.1 The DS1, DS1C, DS2, and DS3 line signals are transmitted as bipolar
        pulses. When the Alternate Mark Inversion (AMI) line code is used,
the DS1 and DS1C signals may contain no more than 15 consecutive zeros and no
bipolar violations. DS2 and DS3 signals contain bipolar violations to
identify zero substitution codes (B6ZS and B3ZS) as do DS1 and DS1C signals
using the B8ZS line code. DS4 signals are transmitted as 100 percent duty
cycle, nonreturn-to-zero (NRZ) polar signals where positive represents a logic
one and negative a logic zero. The NRZ signal is kept in a dynamic condition
via scrambling.

2.5.9.2 With standard signal formats, each bit has a special identity or
        significance when processed with other bits. However, the bit stream
must be descrambled and stuffed pulses removed before the DS1 bit stream, for
instance, can be used as a unit or separated into 64 kb/s channels.

2.6 <u>Synchronous Transmission</u>: In today's environment of high capacity
       digital radio and lightwave systems, the DS3 rate is used extensively for
interoffice transmission. Since the DSO and DS1 levels which make up the DS3
rate are used to offer most network services, it is necessary to be able to
efficiently insert, extract and/or rearrange these levels without the
necessity for demultiplexing the DS3 bit stream.

2.6.1 The traditional DS3 signal is asynchronous since it is made up of DS1
       signals whose frequencies are not precisely the same. To bring the DS1
signals to a common frequency, stuff bits are added as described previously.
Thus, it is not possible to associate bits with particular DSO or DS1 signals
within the DS3 bit stream without first demultiplexing. For the exact
location of all the DS1 and corresponding DSO signals within the DS3 bit
stream to be known, it is necessary to synchronously multiplex the DS1 signals
to the DS3 level. Two such methods for providing this function have been
defined: Synchronous Transmission (SYNTRAN) and Synchronous Optical Network
(SONET).

2.6.2 SYNTRAN operates at the standard DS3 rate of 44.736 Mb/s and is
compatible with the existing asynchronous transmission network. SONET
is intended to operate in new or overlay systems and not through the existing
high speed network. The transmission rate for SONET is N x 51.84 Mb/s where N
can currently be 1, 3, 9, 12, 18, 24, 36, and 48.

3. PRESENT DAY EQUIPMENT

3.1 General: The D3 channel bank or an adaptation of D3 has been the
standard for digital terminal equipment and for integrated digital
transmission and switching systems. Although new trunk carrier installations
are almost exclusively of the D4 variety, the following D3 description is
presented since it is essential to the understanding of D4 operation.

3.2 D3 Channel Bank: A large number of existing digital trunk carrier
installations consist of D3 channel banks. This carrier equipment may
interface the central office on a per channel voice frequency basis or via a
direct digital DS1 bit stream. There are variations in manufacturers'
equipment but Figure 2 serves to illustrate the basic D3 functions.

3.2.1 Analog voice signals enter the voice frequency hybrid (on two-wire
channels) where transmit and receive directions are separated. In
order to provide a faithful reproduction of the analog signal, a time division
multiplex (TDM) system must sample the analog signal at a frequency of at
least twice the highest frequency to be transmitted. Since D3 samples at 8000
times per second, frequencies above 4000 hertz cannot be transmitted and must
be eliminated before sampling. To accomplish this, the voice signals are
passed through a low pass filter to attenuate frequencies above 3500 hertz.
Because of equipment design and noise considerations, frequencies below 200
hertz are also attenuated. Using a relatively precise clock, the voice
signals are sampled 8000 times per second and converted into discrete voltage
levels corresponding to the sampled analog signal. This is called pulse
amplitude modulation (PAM). The PAM signals are fed through a gate and onto a
PAM bus with each channel in sequence (1, 2, 3, 4,.... 24).

3.2.2 Each PAM signal is converted into "bits" of encoded information
(ones and zeros) by the encoder. Each group of bits represents a
specific PAM voltage. D3 channel banks use an eight bit code, allowing for
256 possible code levels, of which 127 positive, 127 negative, and zero are
used. The all zero code is not used; a zero level is transmitted as all
ones. This encoding process is called Pulse Code Modulation (PCM). D3
channel banks use nonlinear encoders and decoders (unequal coding steps) to
improve voice quality with fewer coding steps than would be required for a
linear encoder providing similar quality. The coding steps are small for low
amplitude level samples, e.g., 1 millivolt, and larger for high level samples,
e.g., 128 millivolts. From the encoder, the bits are transmitted on a PCM bus
in groups of 8 unipolar pulses in the proper channel sequence. The bits
corresponding to the sampling of 24 channels in sequence are called a frame.
An extra bit, called a framing bit, is added at the end of each frame. Since
there are 8 bits per channel and 24 channels, each frame consists of 193 bits
(8 x 24 + 1 framing bit).

Since there are 8000 frames transmitted per second, the overall transmission rate is 1.544 Mb/s (193 x 8000). This is the T1 or DS1 rate used as the basic building block for digital transmission in North America.

3.2.3 The framing bits are generated in the transmitter in a special sequence so that the receiver can be synchonized with the transmitter. The framing bits form a repeating pattern (100011011100) every twelve frames. These twelve frames are called a superframe. The odd numbered bits in the framing sequence form an alternating 1 and 0 pattern (101010) which is used for framing synchronization. The even framing bits beginning with bit 12 form a 000111 pattern. Considering only these even bits, it is seen that the bit changes during the sixth and twelfth frames. This change is used to indicate that signaling information is contained in these frames as described in the following paragraph.

3.2.4 Voice and signaling information for each channel is combined in the outgoing bit stream. The least significant bit of each channel is used from signaling every sixth frame. This implementation is commonly called "robbed bit signaling". In this implementation only 7 5/6 bits are used for voice encoding. Since the 6th and 12th frames are used for signaling, there are two signaling channels (A and B) available for each voice channel. The signaling bit transmitted in the 6th frame is called the A-bit and the signaling bit in the 12th frame is the B-bit. Each signaling channel contains 1333 bits per second (8000/6). All dialing, ringing, and supervisory information is transmitted from one terminal to another via the signaling channels. The 1.544 Mb/s bit stream consisting of unipolar pulses is fed into a bipolar converter for transmission on a paired telephone cable. The reasons from bipolar conversion are discussed in paragraphs 2.5.2 and illustrated in Figure 1.

3.2.5 The master clock can be driven from an internal 1.544 MHz $\pm$ 50 Hz generator or can be synchronized locally or on the received bit stream for synchronous operation such as a direct interface to a digital interface to a digital central office. The $\pm$ 50 Hz generator stability is established primarily to narrow the "pull-in" range of the transmitter for nonsynchronous operation but is not required for synchronous operation. Where channel banks provide the terminations at both ends of a system, the transmitter at each end independently generates its 1.544 Mb/s clock. The receivers clock on the incoming bit streams. No other synchronization of signals is necessary and a relatively wide frequency variation can be tolerated, e.g., $\pm$ 200 Hz.

3.2.6 The receiver functions much like the transmitter, only in reverse. The decoding process is outlined briefly below. The bipolar bit stream is received and converted into unipolar pulses. Timing and framing information is extracted from the received bit stream to synchronize the receiver. As noted previously, the received bit stream also controls the transmitter when the system is synchronized on a distant digital central office. The input separates the voice and signaling bits and the decoder converts the voice bits into a PAM signal. The PAM signal is gated into the proper channel through a low pass filter which attenuates frequencies above 3500 Hz and aids in reconstructing a voice signal much like the original analog signal. Some residual distortion remains because of the limited number of encoding levels

and the sampling rate. The analog voice signal is then amplified and passed through the voice frequency hybrid into the analog telephone network.

3.2.7 A typical D3 channel bank consists of 24 channel cards and common equipment consisting of a transmit card, a receive card, an alarm card, and a power supply card. A card slot is generally available to insert a specialized PCM test set for alignment and maintenance. On separate shelves serving several channel banks are span terminating equipment, patching jacks, and other specialized test and service units. The most common types of channel units offered are:

    4-wire E & M (600 ohms)
    2-wire E & M (600 or 900 ohms)
    2-wire Dial Pulse Originating (600 or 900 ohms)
    2-wire Dial Pulse Terminating (600 or 900 ohms)
    4-wire without Signaling (600 ohms)

3.3 D4 Channel Bank: The D4 type channel bank, used almost exclusively for new trunk carrier installations, is designed in 48 channel groups for T1, T1C, and T2 span line applications. Essentially a lower cost, smaller combined packaging of two D3 channel banks (24 channels each), the D4 channel bank is arranged for five possible modes of operation. Figure 3 illustrates a typical arrangement of a D4 channel bank and Figure 4 shows the D4 modes of operation. The general operation of the D4 channel bank (encoding, decoding, etc.) is basically the same as described previously for the D3 channel bank. Differences are described in later paragraphs.

3.3.1 D4, Mode 1: In Mode 1 operation, 48 channels are combined and operated at the DS1C level over a T1C span line (3.152 Mb/s). The transmit unit combines two synchronized DS1 signals (1.544 Mb/s each) and adds framing bits (64 kb/s).

3.3.2 D4, Mode 2: Mode 2 operation consists of 48 channels combined as if they were two D3 channel banks using the equivalent of an M1C multiplexer. The output of Mode 2 is at the DS1C level (3.152 Mb/s). The distant terminal can be another D4 terminal operating at Mode 2 or two colocated or separate D3 type channel banks and an M1C multiplexer. Mode 2 differs from Mode 1 in that it uses an M1C frame format and the 24 channel groups do not require synchronization.

3.3.3 D4, Mode 3: In Mode 3 operation, 48 channels are operated independently as two separate D3 channel banks over two T1 span lines.

3.3.4 D4, Mode 4: Mode 4 operation consists of two colocated 48 channel D4 groups combined and operated at the DS2 level over a T2 span line (6.312 Mb/s). The distant end can be another D4, Mode 4 terminal or one to four terminal locations of 24 channel groups operated over T1 span lines and combined with an M12 multiplexer at a common location.

3.3.5 D4, Mode 5: Mode 5 operation is the same as Mode 4 except the DS2 interface is optical rather than electrical.

3.3.6 D4 channel banks generally use a codec per channel rather than shared codecs used in D3 and earlier channel banks. This provides easy access to the bit stream for high speed data. The 1.544 Mb/s bit stream can be accessed in multiples of 64 kb/s for each voice channel when clear channel capability is used or in multiples of 56 kb/s when robbed bit signaling is used.

3.3.7 Modes 1, 2, and 4 require multiplexers to operate at DS1C and DS2 rates. These multiplexers are plug-in cards in the D4 channel bank. Few equipment changes are required to change from one operation mode to another. With the multiplexers designed as an integral part of the D4 channel bank, costs are reduced over the separate units used with D3 channel banks.

3.4 PCM Subscriber Carrier: The model for the majority of present day PCM subscriber carrier is the D3 trunk carrier channel bank. Some areas of the specification requirements may be relaxed slightly where D3 is used for subscriber service. The carrier system subscriber channel is, in effect, a central office line circuit located remotely from the central office. Though not an exact duplicate of the CO line circuit, it does extend some of the basic line circuit functions to the remote location. PCM subscriber carrier systems generally use D3 voice encoding. The signaling bits along with the framing bits and inband tones are used for various signaling, status reporting, testing, alarm, and other functions. These functions are not standardized among the systems of the various manufacturers.

3.4.1 Dialing is accomplished in PCM subscriber carrier much the same as in trunk carrier. The signaling bits simply denote on-hook and off-hook conditions. To avoid CO overload, subscriber systems generally go into an on-hook condition during failure rather than the disconnect and make-busy condition used with trunk systems. The on-hook and off-hook signaling can easily be handled by one signaling channel leaving the second signaling channel for other functions.

3.4.2 Single party ringing in a PCM subscriber carrier system is generally accomplished by switching a common ringing generator located at the remote terminal into the channel unit assigned to the subscriber to be rung. Normally a 20 hertz sine wave generator is used. Signaling channel A is used to control application and removal of the ringing voltage at the subscriber carrier terminal.

3.4.3 Multiparty ringing is normally accomplished using bridged frequency ringing (BFR). Signaling between the office and remote terminal is accomplished via signaling Channel A. In most systems, bursts of 1's and 0's are transmitted at the assigned ringing frequency from the office terminal to the remote terminal. The ringing voltage at the assigned frequency is then formed by the subscriber channel unit.

3.4.4 Other signaling functions can also be accomplished with subscriber carrier, e.g., foreign exchange service and paystation signaling. These special services are provided via specialized plug-in channel units.

3.4.5 <u>Distributed Subscriber Carrier</u> systems are available from several manufacturers. These systems enable subscriber channels to be placed at several locations along a single T1 span line. One such system allows up to 6 subscriber channels to be located in up to 4 remote terminals along a span line. The equivalent of channel bank common equipment is required at each remote terminal. In many cases, ac power is not required at the remote terminals. The terminals can be operated via dc power from the central office over an order wire or a spare wire pair. However, ac power may be required for long subscriber loops.

3.5 <u>Extended Superframe Format</u>: Newer D4 channel banks and subscriber carrier systems provide a frame format consisting of 24 DS1 frames rather than the 12 frame superframe discussed previously. This is called the Extended Superframe Format (ESF). Technological advances enable only six of the 24 framing bits to be used for actual framing synchronization. The remaining 18 framing bits can be used for other specialized purposes as described in the following paragraphs.

3.5.1 Twelve of the frame bits in the ESF are used as a Facility Data Link (FDL). This 4 kb/s channel can be used in various applications such as protection switching, alarms, loopback, supervisory signaling, network configuration and maintenance. The Exchange Carriers Standards Association T1E1/88-001 document "Carrier to Customer Installation-DS1 Metallic Interface" provides standards for the FDL. Enhanced uses for the FDL are under study.

3.5.2 The remaining 6 framing bits are used as a Cyclic Redundancy Check (CRC-6). The CRC-6 is used to determine that the bit stream received at the distant end is an exact duplicate of the transmitted bit stream. The CRC-6 can be used in various functions such as false framing protection, protection switching, terminal-to-terminal performance monitoring and automatic restoration after alarms.

3.5.3 As in the superframe format described previously, robbed bit signaling can be used in ESF. Since there are 24 DS1 frames in the ESF and signaling bits are transmitted every sixth frame, there are four signaling channels (A, B, C, and D) available rather than the two for the superframe format. This provides for 16 possible signaling states.

3.6 <u>Clear Channel Capability (CCC)</u>: Traditional DS1 terminal systems and multiplexers are able to use only 56 kbps of the 64 kbps DS1 channel bandwidth for information transfer because of constraints placed on the bit stream, i.e., the "ones density" requirements state that no more than 15 consecutive zeros may be transmitted and at least N "ones" must be transmitted in every series of 8(N+1) digit time slots where N is equal to 1 through 23. In other words, long strings of consecutive zeroes are not permitted. Most current equipment places a "1" bit in the next to least significant bit position of any channel word which contains all zeroes prior to transmission. This is commonly called B-7 Zero Code Suppression. In order to fully utilize the 64 kbps channel bandwidth it is necessary to provide a substitution code which can be uniquely identified by the receiving equipment.

3.6.1 Several methods have been proposed to provide Clear Channel Capability and currently two of these methods have been standardized. The more widely

adopted of these methods is called "Bipolar with 8 Zero Substitution" or B8ZS. B8ZS substitutes a string of "1" bits and "0" bits with a pair of bipolar violations for every string of 8 consecutive zeros in the DS1 bit stream. Because the bipolar violations convey information, and are not errors, the equipment used to process and test the bit stream must be designed to handle these violations appropriately. For example, traditional automatic protection switching (APS) systems are designed to operate based on a threshold of bipolar violations and remove these violations from the bit stream. Obviously, where B8ZS is used, the APS must be able to differentiate between the substitution code and bipolar errors.

3.6.2 A second method used to provide CCC is called "Zero Byte Time Slot Interchange" or ZBTSI. ZBTSI removes selected strings of 8 consecutive zeros and replaces the string with an address code to identify its location in the bit stream. ZBTSI can be used with existing equipment with minor modifications to the DS1 transport facility but as noted above B8ZS requires extensive equipment changeout. Certain manufacturers have also designed equipment which converts between B8ZS and ZBTSI.

3.7 Alarms and Maintenance: Alarm, maintenance and test functions are relatively easy to initiate, transmit, and register using digital techniques. There is a wide range of alarm and maintenance hardware available. Present capability ranges from simple alarm indications to large centralized maintenance systems. Some of the basic alarm and maintenance functions are standardized for trunk carrier systems. However, the majority are not, especially for subscriber carrier systems. The ability to provide elaborate alarm, test, or control functions from a remote location is limited primarily by economics rather than by technology. When digital subscriber carrier systems are installed in larger quantities in a single location, maintenance functions become more practical than for distributed systems. The following paragraphs provide a summary of alarm and maintenance techniques for digital terminal and multiplex equipment. Refer to TE&CM Section 956 for a discussion of span line interrogation and automatic protection switching.

3.7.1 In the digital trunk network, basic alarm indications are generated in terminal and multiplex equipment and this information is transmitted to distant locations as an integral part of the bit stream. For universal interface, Bellcore specifications identify certain alarm conditions and specify how the information is to be transmitted.

3.7.2 Channel banks in trunk service have standard red and yellow alarm indicators incorporated in the equipment. A red alarm indicates a loss of signal or framing at the receive terminal. A yellow alarm indicates a loss of signal or framing at the distant terminal. A local failure (red alarm) causes a yellow alarm to be transmitted by forcing bit 2 for each channel to zero in the transmitted DS1 bit stream. A terminal service failure initiates a carrier group alarm (CGA) which forces the trunk channels at both ends into a disconnect and make-busy (DMB) condition. The system is automatically restored when the alarm condition is cleared.

3.7.3 An MIC multiplexer failure indication is transmitted in the "M" bits used for framing in the DS1C bit stream. An M bit begins each of the four subframes. The M bit pattern is transmitted as 011X where X=0 when an alarm condition exists and X=1 during a normal condition. Other M-type multiplexers use a similar alarm bit sequence.

3.7.4 Digital subscriber carrier terminals generally use the same basic red and yellow alarms described above for trunk terminals. Subscriber channels are normally forced into a disconnect and make-idle condition during a service failure to avoid permanent central office seizures. Subscriber carrier systems generally provide a number of other simple alarm functions as a part of the basic equipment. Subscriber terminal alarm information is transmitted to the central office in the bit stream. Alarm conditions include subscriber terminal ac power failure, battery charger failure, housing door open and other abnormal conditions that may soon affect service. These alarm indications may be retransmitted to a central location as major and minor alarms or as specific alarms.

3.7.5 Some maintenance and test features are standard in D3 and D4 trunk channel banks. Basic transmission tests and alignment can be made at one end of a system with the channel bank in a "looped" mode. Test codes can be generated to digitally provide 1000 hertz or another frequency at zero dBm0 to align receivers. Transmitters can then be aligned using these precisely aligned receivers. To isolate noise between a transmitter and receiver, an all ones code (except framing) can be sent. All ones represents no voice signal (digital quiet condition).

3.7.6 Manufacturers enhanced these basic test features and extended them into subscriber service. Remote testing of equipment and facilities becomes more desirable as the distances between equipment locations and available personnel increase. Many equipment and facility faults can be determined from the CO terminal and from a centralized test location. Remote testing of subscriber carrier equipment and associated cable facilities between the carrier terminals and subscriber drops can be done in varying degrees depending on the carrier type. The test and control signals are transported as specified bits in the bit stream, in carrier-derived voice frequency circuits and/or over express cable pairs to the remote locations. If sufficient channels are installed at a single location, they may be economically treated as a central office or major wire center for remote testing purposes.

3.7.7 The introduction of new digital alarm and maintenance systems is expected to continue. The rapid development of digital hardware and software promotes competition but discourages standardization. The Extended Superframe Format discussed previously provides extra bits which can be used for maintenance purposes. The exact uses for all of these bits have not been defined and it is not expected that there will be a standardization of usage among the various manufacturers.

3.8 Digital Interface: The transmission of information in a digital format and the modular characteristics of digital system hardware make it possible to operate transmission and switching as separate or integrated

systems. An integrated digital network can be formed with currently available hardware. The basic building block for today's trunk network is the D4 channel bank. The DS1 trunk interface is universally accepted by manufacturers in the USA. Much of the current transmission equipment operating at rates higher than DS1 does not follow the standard DS hierarchy. This will gradually change as lightwave systems are designed to meet Synchronous Optical Network (SONET) standards. Standardization of subscriber carrier systems, however, does not appear to be forthcoming. It appears likely that transmission and switching equipment from different manufacturers will continue to interface only on an analog voice frequency basis. There are, of course, exceptions; the major one being the AT&T SLC96 which many digital switches interface with on a direct digital basis.

3.8.1 The following is a brief discussion on the use of D3 and D4 trunk carrier channel banks and PCM (D3) subscriber carrier systems interfaced to the network on a direct digital basis.

3.8.2 With the introduction of digital switching, bit streams may enter the digital network and be switched one or more times before being decoded at some distant location by a digital switch or D3 or D4 channel bank. Switching and loss insertion as required to meet the network loss plan can be accomplished digitally by the rearrangement or other alteration of the bit stream.

3.8.3 The economic and technical advantages of integrated transmission and switching are significant especially for subscriber services. On the technical side, the voice could be encoded at or near the calling subscriber's telephone set and decoded at or near the called subscriber. The transmission quality of the circuit would depend almost entirely on the characteristics of a single encoder and decoder. The signal is not significantly affected by the digital transmission and switching path. One exception is that the digital switch is synchronized on a frame rather than a superframe basis. As described previously, the least significant bit of each channel is used for signaling every sixth frame. The lack of superframe synchronization increases the probability of robbing this voice bit from other frames each time the bit stream is switched. Eventually the least significant bit will be lost completely. However, voice quality will remain good as long as there is only one (or few) analog to digital conversions in the transmission path. Data transmission is also enhanced through the use of integrated transmission and switching. The digital bit stream provides for wideband data (56 kb/s per voice channel plus signaling or 64 kb/s when Clear Channel Capability and Common Channel Signaling are available) and is more immune to interference than analog techniques. Where digital data is switched, digital attenuators should not be used. The digital attenuator would restructure the eight bit codes and change the data bit stream.

3.8.4 The economic advantages in using a direct digital interface are largely savings brought about by the elimination of trunk circuits and line circuits in the central office. This is somewhat offset by added complexity of the digital switch for things such as digital attenuation and special software.

3.8.5 Digital Loop Carrier Systems: Digital Loop Carrier (DLC) systems, often called concentrators, are available with interface to a digital switch on an analog or digital basis. As with trunk and subscriber carrier systems, the interface is largely analog for DLC systems and digital switches of different manufacturers with some exceptions. DLC systems which interface on a direct digital basis are often called Integrated Digital Loop Carrier (IDLC) systems while those interfacing on an analog basis are called Universal Digital Loop Carrier (UDLC) systems. The use of an IDLC system eliminates the need for a CO terminal and line circuits.

4. RECOMMENDATIONS

4.1 General: Generalized recommendations on the selection and application of digital transmission equipment are briefly summarized in the following paragraphs. There is a variety of hardware currently available and more under development. The application engineer has a variety of choices but few specifically defined guidelines in making these choices. Acceptable trunk and subscriber carrier equipment is shown in the REA List of Materials.

4.2 Minimizing Obsolescence: To minimize obsolescence, the following recommendations are made. Choose among the latest models of equipment that have a demonstrated reliability record. Select equipment that meets industry interface compatibility standards or meets the key areas of those standards. Where standardization does not exist, compare costs over the projected life of all hardware and software. The lack of standardization for digital hardware and software for subscriber services combined with the rapid introduction of new systems is expected to accelerate software and equipment obsolescence - especially for those systems interfacing switches on a digital basis. The discussions on digital transmission equipment and techniques in paragraphs 2 and 3 may be helpful in choosing the most appropriate equipment.

4.3 Trunk Terminal Equipment: Channel banks for trunk service should be chosen for economy, compatibility, flexibility, and ease of maintenance. There are several D3 and D4 types of channel banks in service in rural areas. In general, this equipment has a reliable service record. Later systems using more recent technology have improved transmission characteristics, lower power consumption and generally lower cost. Obsolescence of earlier channel banks have been a concern especially for smaller telcos. The impact of channel bank obsolescence is minimized by the relatively low cost and by standardization. Older systems can be removed from service one channel bank at a time and used as spares for other equipment still in service.

4.4 Subscriber Terminal Equipment: Each digital subscriber carrier system is generally unique. Few, if any, components are interchangeable with other trunk or subscriber equipment. The use of integrated switching and transmissions systems can result in significant initial savings. Careful planning, however, is needed to minimize the impact of obsolescence. Because of limited standardization in this area, there can be advantages in choosing smaller separate transmission systems for subscriber service. Separate systems can be relocated with minimal concern about central office hardware and software interface.

4.4.1 Remote subscriber terminals should be located for easy access.
Equipment enclosures range from very small housings to prefabricated or masonry buildings. The enclosure choice should be guided by installation size, frequency of site visits expected, climate, right-of-way availability, land costs, etc. Since enclosure costs can exceed equipment costs, options should be reviewed carefully. Dependent upon the equipment type and the application, ac power may be required at the remote terminal(s). Some systems are capable of powering remote terminals from the CO or other ac power location via an order wire or spare pair. This powering method is commonly called "express" powering.

4.5 Multiplex Equipment: In the past, multiplex equipment used in rural applications was generally designed for efficient use of the spectrum rather than complete standardization. With the increased use of optical fiber, today's multiplex equipment generally follows the M-type standards. With the rapidly growing usage of the D3 level for transport, a need for synchronous transmission has arisen so that the DS1 and DSO signals making up the DS3 bit stream can be efficiently manipulated. Synchronous transmission (SYNTRAN) specifications have been issued and there is multiplex equipment in compliance on the market today. For lightwave transmission, rates above the DS3 level are required. For standardization, a Synchronous Optical Network (SONET) standard is being finalized. Multiplex equipment conforming to the SONET standard should be on the market in the near future. Careful consideration of the particular application should be undertaken in the selection of multiplex equipment.
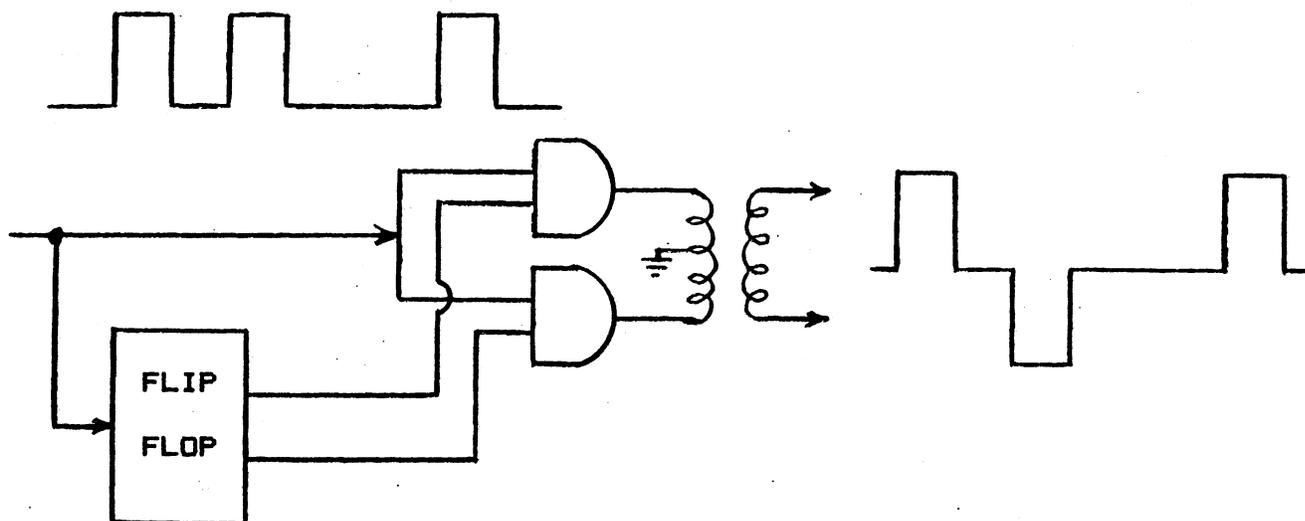
4.6 Alarms and Maintenance: Alarm and maintenance systems in terminal and multiplex equipment are varied. These integrated and separate systems provide many features, but standardization is limited to the basic features specified for D-type channel banks for trunk service and M-type multiplexers. It is recommended that all digital systems contain basic alarm and maintenance systems to minimize the period subscribers will be without service during failures. More elaborate alarm and maintenance systems should be compared primarily on an economic basis. Additional equipment costs should be offset by improved service and operating costs.

4.7 Software Compatibility: As digital systems have incorporated more microprocessors for various functions such as signaling, testing and automated alarms, the potential for incompatibility has increased for transmission systems and integrated transmission and switching systems. Microprocessor operations generally require acknowledgment of execution commands. The speed of operation is limited by the round trip delay of the transmitted and received signals. Equipment performance is optimized between operational speed and application limits. It is important that the application engineer consider maximum system length and other software compatibility factors as well as hardware and function compatibility. It is recommended that the engineer outline all present and future system requirements and obtain written assurances regarding compatibility from the Seller prior to equipment purchase.

FIGURE 1

Unipolar and Bipolar Pulses

   A.   Unipolar to Alternate Bipolar Conversion
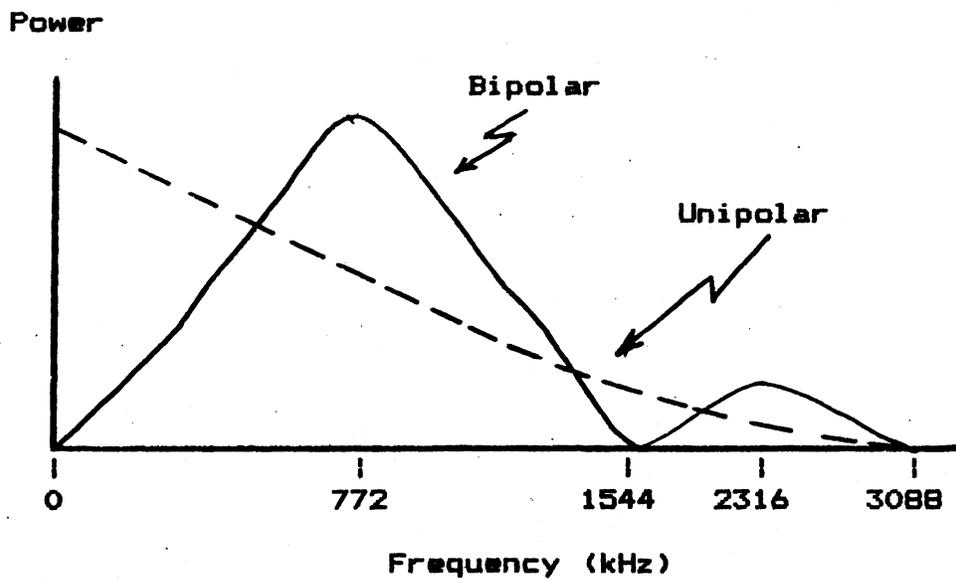

   B.   Power Spectrum (T1)
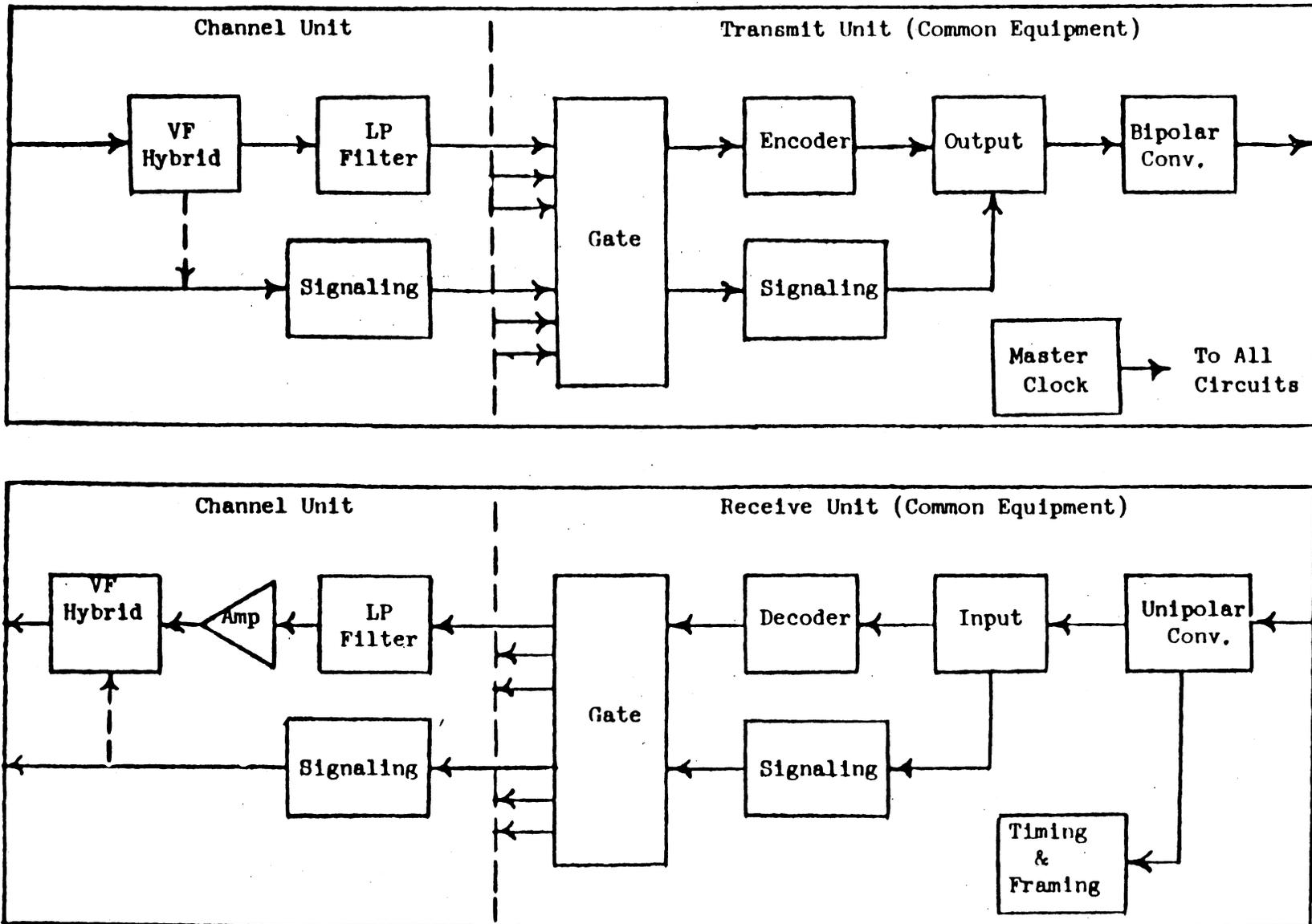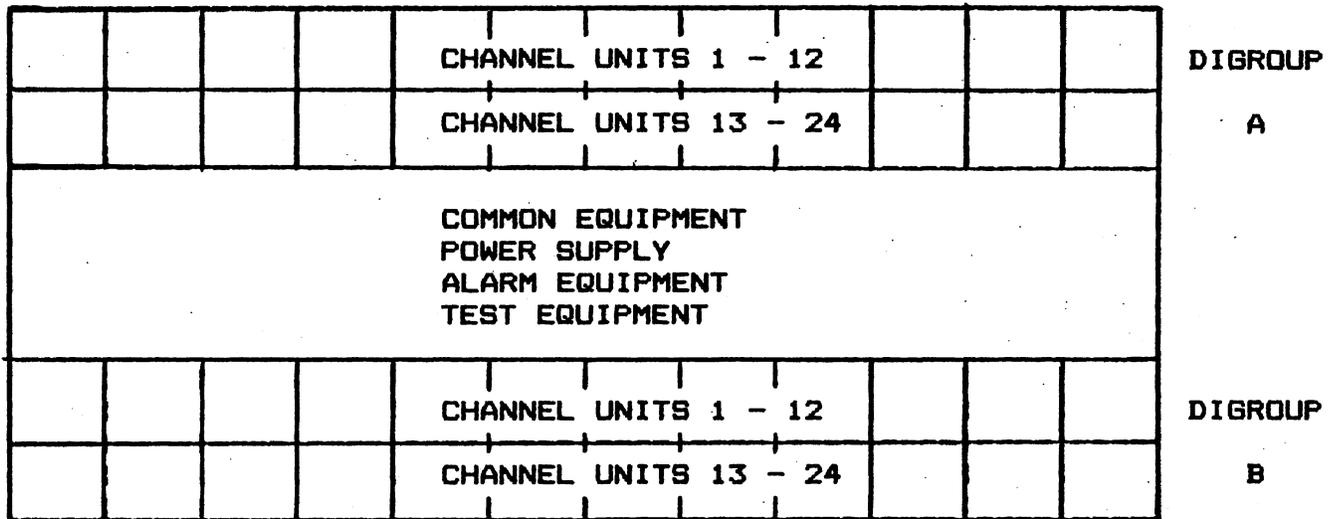
FIGURE 2

D3 CARRIER TRANSMITTER AND RECEIVER

Channel Unit — Transmit Unit (Common Equipment)

VF Hybrid → LP Filter → Gate → Encoder → Output → Bipolar Conv.

Signaling → Gate → Signaling → Output

Master Clock → To All Circuits

Channel Unit — Receive Unit (Common Equipment)

VF Hybrid ← Amp ← LP Filter ← Gate ← Decoder ← Input ← Unipolar Conv.

Signaling ← Gate ← Signaling ← Input

Timing & Framing

FIGURE 3

D4 Channel Bank

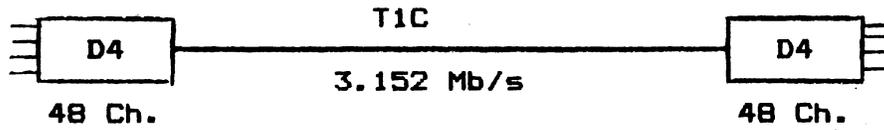| | | | | | CHANNEL UNITS 1 - 12 | | | | | DIGROUP |
					CHANNEL UNITS 13 - 24					A
COMMON EQUIPMENT POWER SUPPLY ALARM EQUIPMENT TEST EQUIPMENT										
					CHANNEL UNITS 1 - 12					DIGROUP
					CHANNEL UNITS 13 - 24					B

NOTE: This figure illustrates the general arrangement
       of the D4 Channel Bank. Equipment of different
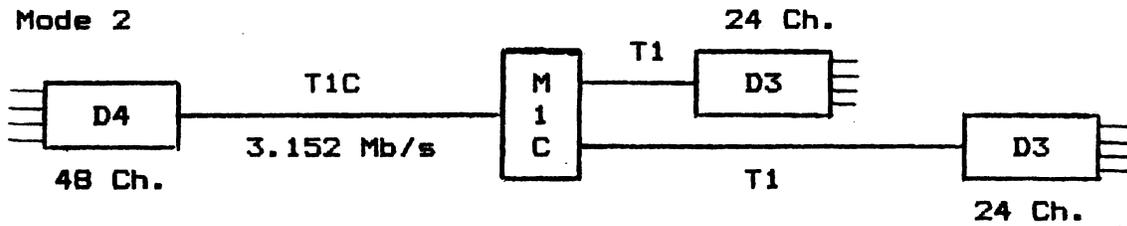   manufacturers is arranged in various configurations.
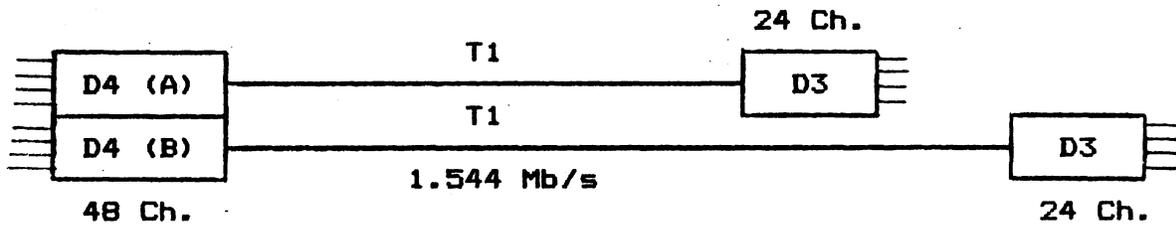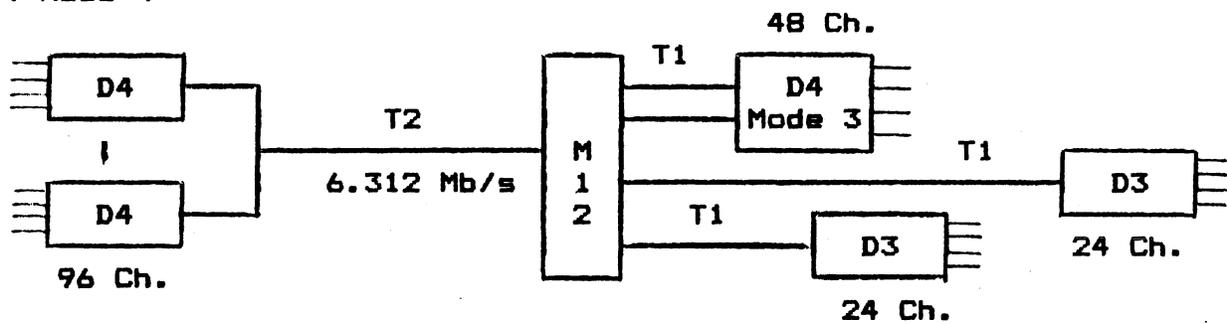
FIGURE 4

D4 CHANNEL BANK MODES 1-4

D4 Mode 1

D4 Mode 2

D4 Mode 3

D4 Mode 4

	A	B	C	D
1	TIME SLOT	D1	D2	D3
2	1	1	12	1
3	2	13	13	2
4	3	2	1	3
5	4	14	17	4
6	5	3	5	5
7	6	15	21	6
8	7	4	9	7
9	8	16	15	8
10	9	5	3	9
11	10	17	19	10
12	11	6	7	11
13	12	18	23	12
14	13	7	11	13
15	14	19	14	14
16	15	8	2	15
17	16	20	18	16
18	17	9	6	17
19	18	21	22	18
20	19	10	10	19
21	20	22	16	20
22	21	11	4	21
23	22	23	20	22
24	23	12	8	23
25	24	24	24	24