Table of Contents

Notes

5.0 Transmission Hierarchy

Objectives

This section will:

- Review frequency division multiplexing
- Survey North American and European time division multiplexing schemes
- Examine various transmission line codes
- Consider various methods of eliminating long strings of zeros

Minimum Reading

Digital Loop Tutorial by AFC

For Advanced Students

http://www.ece.wpi.edu/infoeng/textbook/main.html

5.1 Multiplexing

High speed or high bandwidth transmission facilities are often used for inter-office trunks or in the long haul network. Multiple end-user channels are multiplexed onto these trunk facilities.

With the advent of large private networks and computer facilities, some of these transmission facilities are moving into the end-user market as well.

The first multiplexing systems operated in the analog frequency domain using FDM[†]

5.1.1 Frequency Division Multiplexing

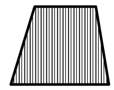
Traditional terrestrial microwave and satellite links employ FDM. Although FDM in telecommunications is being reduced, several systems will continue to use this technique, namely: broadcast & cable TV, and commercial & cellular radio.

Analog Carrier Systems

The standard telephony voice band [300 – 3400 Hz] is heterodyned and stacked on high frequency carriers by single sideband amplitude modulation. This is the most bandwidth efficient scheme possible.

† Frequency Division Multiplexing

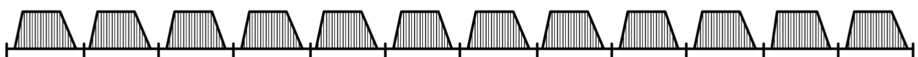
A Single Voice Channel [SSB]



The analog voice channels are pre-grouped into threes and heterodyned on carriers at 12, 16, and 20 KHz. The resulting upper sidebands of four such pre-groups are then heterodyned on carriers at 84, 96, 108, and 120 KHz to form a 12-channel group.

Since the lower sideband is selected in the second mixing stage, the channel sequence is reversed and a frequency inversion occurs within each channel.

A 12 Channel Group



This process can continue until the available bandwidth on the coaxial cable or microwave link is exhausted.

Analog Carrier Systems			
# Voice Channels	Bandwidth	Spectrum	Terminology
12	48 KHz	60 – 108 KHz	Group
60	240 KHz	312 – 552 KHz	Supergroup
300	1.232 MHz	812 – 2044 KHz	CCITT Mastergroup
600	2.520 MHz	564 – 3084 KHz	Mastergroup
900	3.872 MHz	8.516 – 12.388 MHz	CCITT Supermastergroup
3600	16.984 MHz	.564 – 17.548 MHz	Jumbogroup
10800	57.442 MHz	3.124 – 60.566 MHz	

In the North American system, there are:

- 12 channels per group
- 5 groups per supergroup
- 10 super groups per mastergroup
- 6 master groups per jumbogroup

In the European CCITT system, there are:

- 12 channels per group
- 5 groups per supergroup
- 5 super groups per mastergroup
- 3 master groups per supermastergroup

There are other FDM schemes including:

- L600 - 600 voice channels 60–2788 KHz
- U600 - 600 voice channels 564–2084 KHz
- L3 - 1860 voice channels 312–8284 KHz, comprised of 3 mastergroups and a supergroup
- L4 - 3600 voice channels, comprised of six U600s

5.1.2 Time Division Multiplexing

TDM is a convenient method for combining various digital signals. These signals may be interleaved at the bit, byte, or some other level. The resulting pattern may be transmitted directly, as in digital carrier systems, or passed through a modem to allow the data to pass over an analog network.

Digital data is generally organized into frames for transmission and individual users assigned a time slot, during which frames may be sent. If a user requires a higher data rate than that provided by a single channel, multiple time slots can be assigned.

Digital transmission schemes in North America and Europe have developed along two slightly different paths, leading to considerable incompatibility between the networks found on the two continents.[1]

BRA Comparison		
Characteristic	North America	Europe
Basic channel rate	64 Kbps	64 Kbps
CODEC format	µ-Law	A-Law
Binary format	Folded binary	Sign magnitude
Voice Channels per frame	24	30
Signaling	Bit robbing	Dedicated channel

[1] *The Evolution of the Digital Loop Carrier,* IEEE Communications Magazine, March 1991

Digital Transmission Systems[2]

Designation	User	Bit Rate [Mbps]	Line Code	Media	Repeater Spacing
T1	AT&T	1.544	AMI/B8ZS	Twisted pair	6 Kft
CEPT1	CCITT	2.048	HDB3 (B4ZS)	Twisted pair	2 Km
T1C	AT&T	3.152	Bipolar	Twisted pair	6 Kft
T148	ITT	2.37 ternary	4B3T	Twisted pair	6 Kft
9148A	GTE	3.152	$1\text{-}D^2$ duobinary	Twisted pair	6 Kft
T1D	AT&T	3.152	1+D duobinary	Twisted pair	6 Kft
T1G	AT&T	6.443	4-level	Twisted pair	6 Kft
T2	AT&T	6.312	B6ZS	Low cap twisted pair	14.8 Kft
LD-4	Canada	274.176	B3ZS	Coax	1.9 Km
T4M	AT&T	274.176	Polar	Coax binary NRZ	5.7 Kft

5.2 North American TDM

The various transmission rates are not integral numbers of the basic rate. This is because additional framing and synchronization bits are required at every multiplexing level.

DS Hierarchy			
Designation	# Voice Channels	Bit Rate [Mbps]	Comments
DS[†]–0	1	.064	100% duty cycle, unipolar
DS–1	24	1.544	Media: 22 AWG cable Repeater spacing: 6000 ft Signal: bipolar RZ
DS–1C	48	3.152	Media: 22 AWG cable Repeater spacing: 6000 ft Signal: bipolar RZ
DS–2	96	6.312	media: low capacitance 22 AWG Max repeater spacing: 14,800 ft Signal: bipolar RZ, B6ZS
DS–3	672	44.736	Media: microwave, fiber Signal: RZ, B3ZS
DS-3A	1344	91.04	
DS–4	4032	274.176	Media: coax, microwave Signal: bipolar NRZ

[2] *Digital Telephony* (2nd ed.), John Bellamy, Table 4.7

[†] Digital Signal type 0

For Advanced Students

Japanese TDM Carriers

Japanese systems are included here since they generally follow the North American lead.

Level	# Voice Channels	Bit Rate [Mbps]
1	24	1.544
2	96	6.312
3	480	32.064
4	1440	97.728
5	5760	400.352

Fixed rate TDM networks do not require the flow control mechanisms found in packet networks and error control is performed on a channel basis.

To aid in identifying the beginning of a frame, a framing pulse or a control channel is inserted into the data stream. In spite of this, it is possible for the transmitter and receiver to get out of sync. In such a case, all channels are lost as the receiver enters a search mode.

Loss of lock can occur if noise disrupts the sequence, or if the transmitter and receiver clocks run at slightly different rates. It may be necessary to stuff the occasional bit into the data stream to resynchronize both ends of the link.

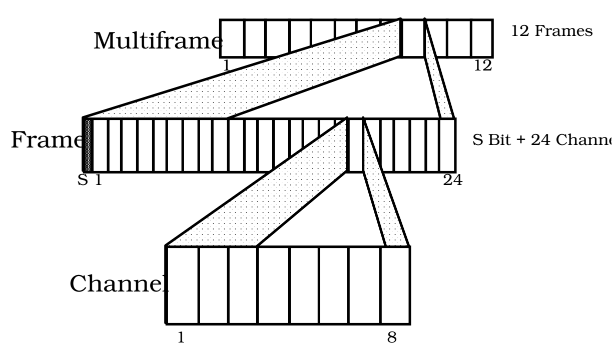
5.2.1 DS-1 24 Channel System

Minimum Reading

[T1 Application Brief by Coastcom]

In North America, the basic digital channel format is known as DS-0. These are grouped into frames of 24 channels each.

A concatenation of 24 channels and a start bit is called a frame. Groups of 12 frames are called multiframes or superframes. These vary the start bit to aid in synchronizing the link and add signaling bits to pass control messages.



5.2.1.1 S Bit Synchronization

The S bit is used to identify the start of a DS-1 frame. There are 8 thousand S bits per second. They have an encoded pattern, to aid in locating channel position within the frame.

Frame	1	2	3	4	5	6	7	8	9	10	11	12
S Bit	1	0	0	0	1	1	0	1	1	1	0	0

This forms a regular pattern of 1 0 1 0 1 0 for the odd frames and 0 0 1 1 1 0 for the even frames.

Additional synchronization information is encoded in the DS-1 frame when it is used for digital data applications, so lock is more readily acquired and maintained.

For data customers, channel 24 is reserved as a special sync byte, and bit 8 of the other channels is used to indicate if the remaining 7 bits are user data or system control information. Under such conditions, the customer has an effective channel capacity of 56 Kbps.

To meet the needs of low speed customers, an additional bit can is robbed to support sub-rate multiplexer synchronization, leaving 6 x 8 Kbps = 48 Kbps available. Each DS-0 can be utilized as:

- 5 x 9.6 Kbps channels or
- 10 x 4.8 Kbps channels or
- 20 x 2.48 Kbps channels.

In the DS-2 format, 4 DS-1 links are interleaved, 12 bits at a time. An additional 136 Kbps is added for framing and control functions resulting in a total bit rate of 6.312 Mbps.

5.2.1.2 Signaling

Signaling provides control and routing information. Two bits, called the A and B bits, are taken from each channel in frames 6 and 12 in the multiframe.

The A bit is the least significant bit in each channel in frame 6, and the B bit is the least significant bit in each channel in frame 12. This provides a signaling rate of 666 $^{2}/_{3}$ bps per channel.

The quality of voice transmission is not noticeably affected when 2% of the signal is robbed for signaling. For data, it may be a different story. If the data is encoded in an analog format such as FSK or PSK, then robbing bits is of no consequence, but if the data is already in digital form, then robbing bits results in unacceptable error rates. It is for this reason that in North America, a 64 Kbps clear channel cannot readily be switched through the PSTN. This means that data customers are limited to 56 Kbps clear channels. This simple condition has a profound effect on the development of new services such as ISDN.

In most facilities, the A and B bits represent the status of the telephone hook switch, and correspond to the M lead on the E&M interface of the calling party.

_____ Notes _____

A 1 or mark represents on-hook and 0 or a space represents off-hook. In a pulse dial phone system, the A and B bits follow the pulses. In this way, the system passes the routing information to the next office. When the called party answers, the returning A and B bits are set to 0 to signify that the call has been picked up. The system drops the connection when the bits in either direction are set to 1 for a prescribed length of time.

5.2.2 ESF†

CCITT has modified the North American digital hierarchy for the deployment of ISDN, by means of recommendation G.704. ESF consists of 24 DS-0 channels in a frame, but groups them into a 24-frame multiframe instead of the usual 12-frame multiframe.

The S bit is renamed the F bit, but only 1/4 of them are used for synchronization. This is possible because of improvements in frame search techniques and allows more signaling states to be defined.

Bit robbing is still used for signaling over an ESF link, but with the advent of ISDN, it will not be permitted. Instead, channel 24 is used to support a D channel.

F Bit Function	Frame Position	Comments
Sync pattern	4, 8, 12, 16, 20, 24	Pattern: 001011
CRC check	2, 6, 10, 14, 18, 22	Is the remainder from modulo-2 division of all the bits in the previous frame by the binary polynomial x^6+x+1
Maintenance	all odd frames	Currently not specified, but will convey: maintenance, diagnostic, and status information

For Advanced Students

5.2.3 DS-1C

This signal contains two DS-1s plus a 64 Kbps framing and synchronization channel.

The two bipolar DS-1 signals are converted to a unipolar format, but one of them is inverted. They are then brought into alignment by bit stuffing and bit interleaving. A control bit is introduced at the beginning of every 52-bit group. The 26-bit control pattern defines a 1272 bit block, which is subdivided into several components:

† Extended Super Frame

Control Bit Pattern

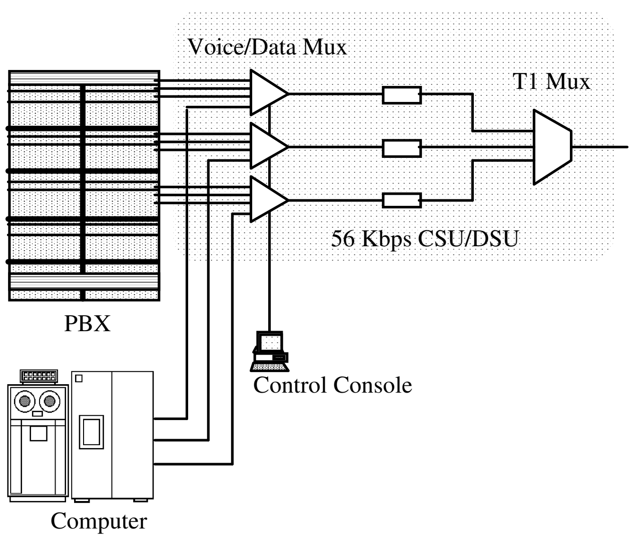
M1	C11	F0	C12	C13	F1
M2	C21	F0	C22	C23	F1
M3	C11	F0	C12	C13	F1
M4	C21	F0	C22	C23	F1

Bits	Function
M1, M2, M3	These bits are set to 011 and define the M frame
M4	This forms a signaling channel and is set to 0 if there is an alarm condition
F	This sequence has alternating 1s and 0s appearing at the beginning of every third 52 bit group
C	This bit identifies the presence of stuffed bits

5.2.4 Typical T1 CPE Application

The large telecom carriers are not the only ones who deploy high-speed TDM facilities. In many cases, heavy users of voice or data services can reduce their transmission costs by concentrating their numerous low speed lines on to a high-speed facility.

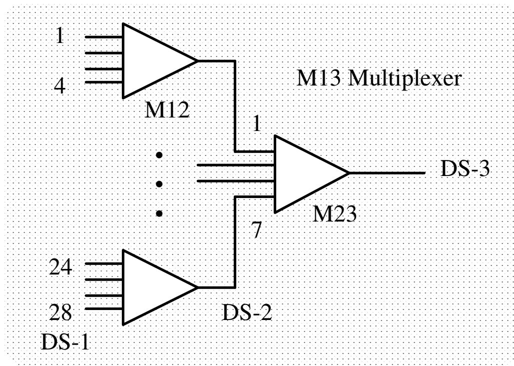
There are many types of T1 multiplexers available today. Some are relatively simple devices, while others allow for channel concatenation, thus supporting a wide range of data rates. The ability to support multiple DS-0s allows for easy facilitation of such protocols as the video teleconferencing standard, Px64.



Notes

Multiplexers

Multiplexing units are often designated by the generic term M*ab* where *a* is input DS level and *b* is the output DS level. Thus, an M13 multiplexer combines 28 DS–1s into a single DS–3 and an M23 multiplexer combines 7 DS–2s into a single DS–3.

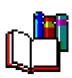


ZBTSI

ZBTSI[†] is used on DS–4 links. Four DS-1 frames are loaded into a register, and renumbered 1–96. If there are any empty slots [all zeros], the first framing bit is inverted and all blank slots are relocated to the front of the frame. Channel 1 is then loaded with a 7-bit number corresponding to the original position of the first empty slot. Bit 8 used to indicate whether the following channel contains user information or another address for an empty slot.

If there is a second vacancy, bit 8 in the previous channel is set, and the empty slot address is placed in channel 2. This process continues until all empty positions are filled.

The decoding process at the receiver is done in reverse. Borrowing 1 in 4 framing bits for this system is not enough to cause loss of synchronization and provides a 64 Kbps clear channel to the end-user.



For Advanced Students

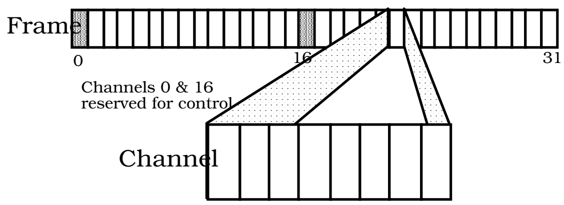
5.3 European TDM Carriers

European systems were developed along slightly different principles. The 64 Kbps channel is still the basic unit, but signaling is not included in each channel. Instead, common channel signaling is used. In a level 1 carrier, channels 0 and 16 are reserved for signaling and control.

† Zero Byte Time Slot Interchange

Notes

Level	# Voice Channels	Bit Rate [Mbps]	Line Code
0	1	.064	
1	30	2.048	HDB3
2	120	8.448	HDB3
3	480	34.368	HDB3
4	1920	139.264	CMI
5	7680	565.148	



In the ISDN application, the 2.048 Mbps primary access structure is organized into 16 consecutive frames where channel 0 is defined as follows:

European Multiframe Structure

	Channel 0 Bit Functions							
Frame	1	2	3	4	5	6	7	8
0	C1	0	0	1	1	0	1	1
1	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
2	C2	0	0	1	1	0	1	1
3	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
4	C3	0	0	1	1	0	1	1
5	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
6	C4	0	0	1	1	0	1	1
7	0	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
8	C1	0	0	1	1	0	1	1
9	1	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
10	C2	0	0	1	1	0	1	1
11	1	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
12	C3	0	0	1	1	0	1	1
13	E	1	A	Sa4	Sa5	Sa6	Sa7	Sa8
14	C4	0	0	1	1	0	1	1
15	E	1	A	Sa4	Sa5	Sa6	Sa7	Sa8

Nomenclature:

C1 - C4	CRC code generated by the polynomial: x^4+x+1
E	error bits indicating that the CRC procedure detected an error
A	RAI† bit indicating loss of layer 1 capability
Sa4 & Sa8	presently undefined but reserved for international use
Sa5 - Sa7	used for national purposes

† Remote Alarm Indication

______ Notes ______

5.4 ISDN TDM

ISDN Hierarchy			
Designation	# Voice Channels	Bit Rate [Mbps]	Comments
D	-	.016 or .064	Carries signaling information for the network or end-user
B	1	.064	Digital voice
H0	6	0.384	A submultiple of both 1.544 and 2.048 Mbps
H11	24	1.536	ISDN equivalent to DS-1
H12	30	1.920	ISDN equivalent to Level-1
H21	512	32.768	
H22	690	44.160	ISDN equivalent to DS-3
H4	2112	135.168	

Various administrations may organize these ISDN channels to meet their specific needs. Some possible primary rate structures include:

Primary Rate Channel Structures	
1.544 Mbps	2.048 Mbps
23B + D	30B + D
3H + 5B + D	5H0
24B	31B
4H0	5H0
H11	H12 + D

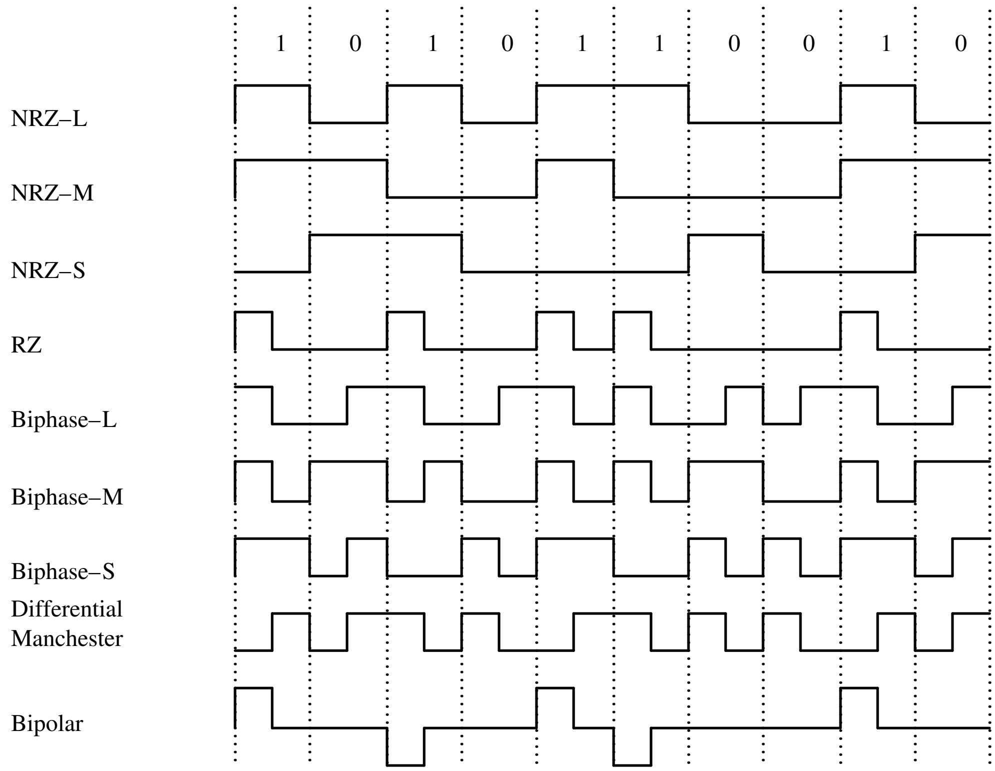
5.5 Codes

5.5.1 Line Codes

There are numerous ways digital information can be coded onto a transmission medium. Some of the more common include:

Signal	Comments
NRZ–L	Non-return to zero level. This is the standard positive logic signal format used in digital circuits. 1 forces a high level 0 forces a low level
NRZ–M	Non return to zero mark 1 forces a transition 0 does nothing
NRZ–S	Non return to zero space 1 does nothing 0 forces a transition
RZ	Return to zero 1 goes high for half the bit period 0 does nothing
Biphase–L	Manchester. Two consecutive bits of the same type force a transition at the beginning of a bit period. 1 forces a negative transition in the middle of the bit 0 forces a positive transition in the middle of the bit
Biphase–M	There is always a transition at the beginning of a bit period. 1 forces a transition in the middle of the bit 0 does nothing
Biphase–S	There is always a transition at the beginning of a bit period. 1 does nothing 0 forces a transition in the middle of the bit
Differential Manchester	There is always a transition in the middle of a bit period. 1 does nothing 0 forces a transition at the beginning of the bit
Bipolar	The positive and negative pulses alternate. 1 forces a positive or negative pulse for half the bit period 0 does nothing

_____ Notes _____

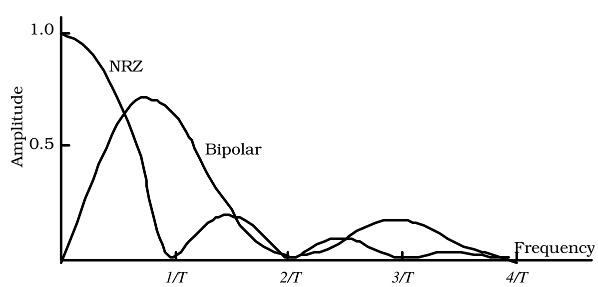


Each of the various line formats has a particular advantage and disadvantage. It is not possible to select one, which will meet all needs. The format may be selected to meet one or more of the following criteria:

- Minimize transmission hardware
- Facilitate synchronization
- Ease error detection and correction
- Minimize spectral content
- Eliminate a dc component

The Manchester code is quite popular. It is known as a self-clocking code because there is always a transition during the bit interval. Consequently, long strings of zeros or ones do not cause clocking problems.

NRZ and Bipolar Spectral Density[3]



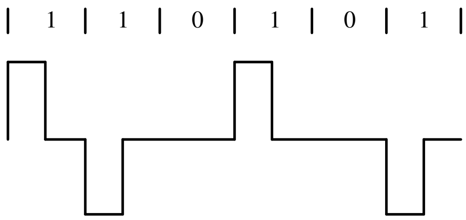
[3] Based on figure 4.13, *Digital Telephony* (2nd ed.), John Bellamy

_____ Notes _____

NRZ codes are more bandwidth efficient than bipolar ones. However, their spectral components go all the way down to 0 Hz. This prevents them from being used on transmission lines which are transformer coupled, or for some other reason cannot carry DC.

AMI

AMI[†] is an example of a bipolar line code. Each successive mark is inverted and the average or DC level of the line is therefor zero. This system cannot readily be used on fiber optic links.

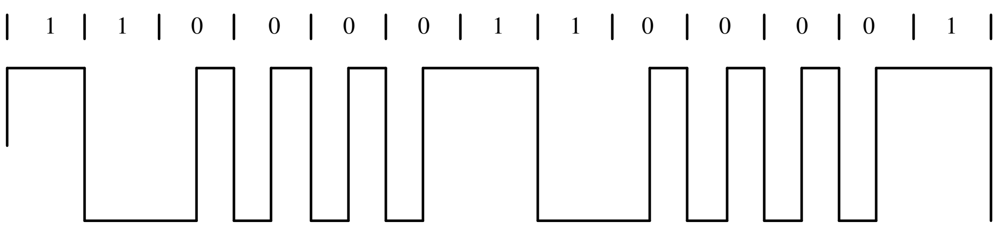


AMI is usually implemented as RZ pulses.

One of the weaknesses of this approach is that long strings of zeros cause the receivers to loose lock. It is therefor necessary to impose other rules on the signal to prevent this.

CMI

The CMI[†] bipolar line code is a subset of AMI. Marks are encoded as alternate polarity full period pulses. Spaces are encoded by half a period at the negative voltage and half period at the positive voltage. This coding scheme has the advantage that it uses only two voltage levels instead of 3, and requires less logic to implement than HDB3.



5.5.2 Zero Substitutions

In order to prevent transmission systems from loosing lock on the data stream, it is necessary to avoid long strings of zeros. One of the most effective ways of doing this is to replace the zeros with a predetermined code. This substitution must be done in such a way that the receiver can identify it and strip it off before passing the data stream to the client.

AMI provides a simple means of detecting substitutions. In the normal course of events, alternate marks are inverted. Therefor, deliberately inducing a bipolar

† Alternate Mark Inversion

† Coded Mark Inversion

variation at the transmitter can alert the receiver of a substitution. However, a single violation is indistinguishable from a transmission error. Consequently, some additional condition must also occur.

There are two common methods to create a second condition:

- Create a second bipolar violation in the opposite direction, within a specified time. This has the effect of keeping the average signal level at zero.
- Count the number of marks from the last substitution to predict the next type of violation

B6ZS

B6ZS[†] is used on T2 AMI transmission links.

Synchronization can be maintained by replacing strings of zeros with bipolar violations. Since alternate marks have alternate polarity, two consecutive pulses of the same polarity constitute a violation. Therefor, violations can be substituted for strings of zeros, and the receiver can determine where substitutions were made.

Since the last mark may have been either positive or negative, there are two types of substitutions:

Polarity of previous mark	Substitution					
-	0	-	+	0	+	-
+	0	+	-	0	-	+

These substitutions force two consecutive violations. A single bit error does not create this condition.

B6ZS Example:

Original data:	0	-	0	0	0	0	0	0	0	+	0	-	+
After substitution:	0	-	0	-	+	0	+	-	0	+	0	-	+
Original data:	0	+	0	0	0	0	0	0	0	-	0	+	-
After substitution:	0	+	0	+	-	0	-	+	0	-	0	+	-

B8ZS

This scheme uses the same substitution as B6ZS.

Polarity of previous mark	Substitution							
-	0	0	0	-	+	0	+	-
+	0	0	0	+	-	0	-	+

† Binary 6 Zero Substitution

B3ZS

B3ZS[†] is more involved than B6ZS, and is used on DS–3 carrier systems. The substitution is not only dependent on the polarity of the last mark, but also on the number of marks since the last substitution.

Previous Mark Polarity	Number of marks since the last substitution	
	Odd	Even
-	0 0 -	+ 0 +
+	0 0 +	- 0 -

B3ZS Example:

Let’s suppose that there were 27 marks since the last substitution:

Original data:

- 0 0 0 0 + 0 0 0 - + 0 0 0 0 -

After Substitution:

- 0 0 - 0 + 0 0 + - + - 0 - 0 -

HDB3

HDB3[†] introduces bipolar violations when four consecutive zeros occur. It can therefore also be called B4ZS. The second and thirds zeros are left unchanged, but the fourth zero is given the same polarity as the last mark. The first zero may be modified to a one to make sure that successive violations are of alternate polarity.[4]

Previous Mark Polarity	Number of marks since the last substitution	
	Odd	Even
-	0 0 0 -	+ 0 0 +
+	0 0 0 +	- 0 0 -

HDB3 is used in Europe. Violation, or V pulses are injected after three consecutive zeros. The fourth zero is given the same polarity as the last mark. In the event of long strings of zeros occurring, a succession of single polarity pulses would occur, and a dc offset would build-up.

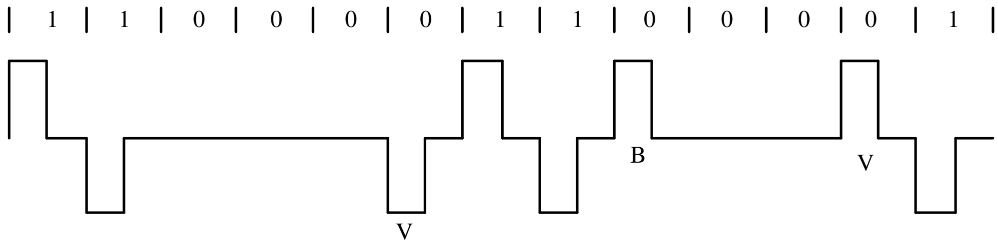
To prevent this, the first zero in a group of 4, may be modified to a 1. This B or balancing pulse assures that successive violations are of alternate polarity.[5]

[†] Binary 3 Zero Substitution

[†] High Density Binary 3

[4] Freeman, Telecommunication Handbook, & Stallings W., ISDN an Introduction

[5] Freeman, Telecommunication Handbook, & Stallings W., ISDN an Introduction



5.5.3 Block Codes

These schemes operate on bytes rather than a bit at a time. Some transmit the signal as binary levels, but most use multi-level pulses. Some authors categorize these as line codes.

A binary block code has the designation *n*B*m*B, where *n* input bits are encoded into *m* output bits. The most common of these is the 3B4B code.

3B4B Coding	
Input	Output
000	- - + - or + + - +
001	- - + +
010	- + - +
011	- + + -
100	+ - - +
101	+ - + -
110	+ + - -
111	- + - - or + - + +

In Europe 4B3T, which encodes 4 binary bits into 3 ternary levels, has been selected as the BRA for ISDN. In North America, 2B1Q which encodes 2 binary bits into 1 quaternary level has been selected for BRA.

2B1Q Coding	
Input	Output
00	-3
01	-1
10	+1
11	+3

Some block codes do not generate multilevel pulses. For example, 24B1P or 24B25B simply adds a P or parity bit to a 24 bit block.

5.6 Statistical TDM

This is also known as asynchronous TDM or intelligent TDM. A main weakness of a standard TDM facility is that resources are assigned even if the customer is transmitting nothing.

To overcome this, channels are assigned on a demand basis. If data is waiting for transmission it is organized into subframe packets and sent without regard as to which channel conveys it. Addressing information is added to the data to keep track of it. Since short-term overloads may occur, the transmitter must contain temporary storage buffers.

To minimize the system hardware complexity, one could reduce the buffer size or lower the maximum data rate. Unfortunately, reducing one increases the other.

This redistribution of resources allows the link utilization to increase significantly since the sum of the user bandwidths is greater than the required link bandwidth. Additional increases in throughput are possible if some form of data compression or variable length packet capsulation is used.

It is the successful deployment of statmuxes that has led to the recent interest in ATM.

5.6.1 Link Utilization

A queue is simply a line of customers or packets waiting to be served. Under most circumstances, the arrival rate is unpredictable and therefor follows a random or Poisson distribution pattern, whereas the service time is constant.

The utilization or fraction of time actually used by a packet multiplexing system to process packets is given by:

$$\rho = \lambda\tau = \frac{\alpha NR}{M} = \frac{\alpha}{K} = \frac{\lambda}{M}$$

where

$\lambda =$ average arrival rate in bps

$\tau =$ service time in seconds

$\alpha =$ fraction of time each source is transmitting

$N =$ number of inputs sources

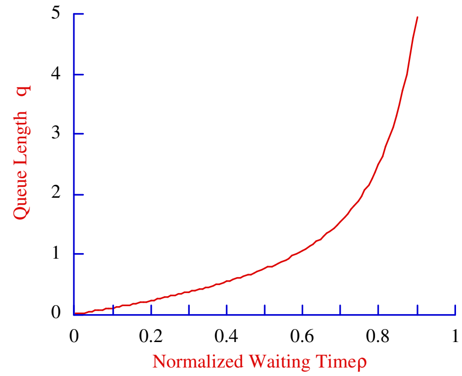
$R =$ source data rate in bps

$M =$ effective channel capacity in bps

$K =$ compression ratio

The queue length or average number of items waiting to be served is given by:

$$q = \frac{\rho^2}{2(1-\rho)} + \rho$$



The standard deviation of queue size is:

$$\sigma_q = \frac{1}{1-\rho}\sqrt{\rho - \frac{3\rho^2}{2} + \frac{5\rho^3}{6} - \frac{\rho^4}{12}}$$

The average time delay:

$$t_q = \frac{\tau(2-\rho)}{2(1-\rho)}$$

Example:

A T1 link has been divided into a number of 9.6 Kbps channels and has a combined user data rate of 1.152 Mbps. Access to this channel is offered to 100 customers, each requiring 9.6 Kbps data 20% of the time. If the user arrival time is strictly random find the T1 link utilization.

$$N = 100 \text{ customers}$$

$$R = 9.6 \times 10^3 \text{ bps}$$

$$\alpha = 0.2$$

$$M = 1.152 \times 10^6 \text{ bps}$$

Solution:

The utilization or fraction of time used by the system to process packets is given by:

$$\rho = \frac{\alpha NR}{M} = \frac{0.2 \times 100 \times 9.6 \times 10^3}{1.152 \times 10^6} = 0.167$$

The average number of items waiting to be served is:

$$q = \frac{\rho^2}{2(1-\rho)} + \rho = \frac{0.167^2}{2(1-0.167)} + 0.167 = 0.184$$

The standard deviation of the number of items in the system waiting and being served:

$$\sigma_q = \frac{1}{1-\rho}\sqrt{\rho - \frac{3\rho^2}{2} + \frac{5\rho^3}{6} - \frac{\rho^4}{12}} = 0.431$$

A 24 channel system dedicated to DATA, can place five 9.6 Kbps customers in 23 channels, for a total of 115 customers. In the above statistical link, 100 customers created a utilization of 0.167 and were easily fitted, with room to spare if they transmit on the average 20% of the time. If however, the customer usage were not randomly distributed, then the above analysis would have to be modified.

A utilization above 0.8 is undesirable in a statistical system, since the slightest variation in customer requests for service would lead to buffer overflow.

For Advanced Students

5.6.2 Hybrid Techniques

These combine voice circuit switching and data packet switching.

TASI

TASI[†] is usually employed on analog lines but has also been implemented on the TAT-8 fiber link. For the most part, during a conversation, one party is listening while the other is talking. This means that half a full duplex connection is idle. Therefor on long lines, such as the transatlantic cable, only half circuits are assigned to the active (loudest) talker. This allows the facility nearly to double its capacity.

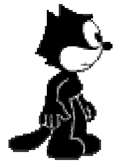
TADI

TADI[†] is used on digital lines. Activity on each channel is monitored, and data packets inserted during normal gaps in speech, occurring between words and sentences. With an effective per channel bit rate of 64 Kbps, a 1000 bit packet would take a little over 15 mSec.

[†] Time Assignment Speech Interpolation

[†] Time Assignment Data Interpolation

Assignment Questions



Quick Quiz

1. The DS-1 systems has [12, 24, 32] channels
2. A multiframe consists of [12, 24, 36] concatenated DS-1 frames.
3. The ESF adds a CRC check to the DS-1. [True, False]
4. The DS-1C consists of [1, 2, 4] DS-1s.
5. A DS-3 link is comprised of __________ DS-1 links.
6. The ESF presently [uses, does not use] bit robbing.
7. Biphase line codes [have, do not have] a dc component.
8. AMI codes are used in North America but not Europe. [True, False]
9. [Block, Line] codes are primarily used to reduce the baud rate.
10. Link utilization is [improved, reduced] with statistical TDM.
11. TASI and TADI are not compatible with fiber optic links. [True, False]
12. If the utilization of a transmission link is 0.9, the average delay is about 2 times the service time. [True, False]
13. Physical star networks [may, may not] be connected as rings.

Analytical Questions

1. Stating any and all assumptions, determine the B3ZS line code for the following sequence:

   1010001100000000010001

2. How many data customers who require 56 Kbps for any 1 hour in a business day could be served over a T1 link if the utilization is 50%?
3. For a statistical multiplexer with the following features:
   - A constant server time
   - Random user request rate
   - Number of users: N = 120
   - Average user transmission utilization $\alpha = .25$
   - Average user transmission rate: R = 9600 bps

Find:

a) The multiplexed line capacity necessary to obtain a utilization of .8

b) The average number of data terminals being served

c) The average number of data terminals waiting to be served

d) The standard deviation of buffer length

Notes

Composition Questions

1. Where are S, A, and B bits found, and what are they used for?
2. Describe the bipolar methods employed to remove long strings of zeros in binary transmissions.
3. In a DS-1 link, what is:
   a) the channel rate (channels per second)
   b) the channel bit rate (bps)
   c) the signaling rate (bps)
   d) the clock rate (bps)
4. What modifications are made to the DS-1 format, when it gets dedicated to handling data traffic only?
5. What is statistical TDM?
6. What is ZBTSI, and where is it used?

_____ Notes _____

For Further Research

Freeman, R L, Telecommunications Transmission Handbook

Giacoletto, Electronic Engineers Handbook

Helgert, Hermann J., *Integrated Services Digital Networks*, Addison-Wesley, New York, (1991)

Inglis, A F, *Electronic Communications Handbook*

Mazda, F, *Electronic Engineers Reference Book*

Miller, G M, *Handbook of Electronic Communication*

Reeve, *Subscriber Loop Signaling and Transmission Handbook*

General Telecom Site

http://telecom.tbi.net/

PCM

http://www.aydinvector.com/pcm_1.html

http://www.wiz-com.com/techno/WWWnet/Backbone/tdm.htm

http://www.cs.panam.edu/~meng/Course/CS6345/Notes/chpt-2/node2.html

Inverse multiplexing

http://www.larscom.com/whatnew/wp_e1imux.htm

T1 Multiplexers

http://www.coastcom.com/

http://www.alliancedatacom.com/adtran-t1-t3.htm

http://www.engagecom.com/html/primers.html

http://faraday.ukc.ac.uk/faraday/tdm.html

T3

http://www.ora.com/reference/dictionary/terms/D/Digital_Transmission_Rate_3.htm

_____ Notes _____

Bipolar Line Code

http://telecom.tbi.net/isdn-pu.htm