Department of Communications Engineering, College of Engineering, University of Diyala

Digital Communication I

Lecture # 6

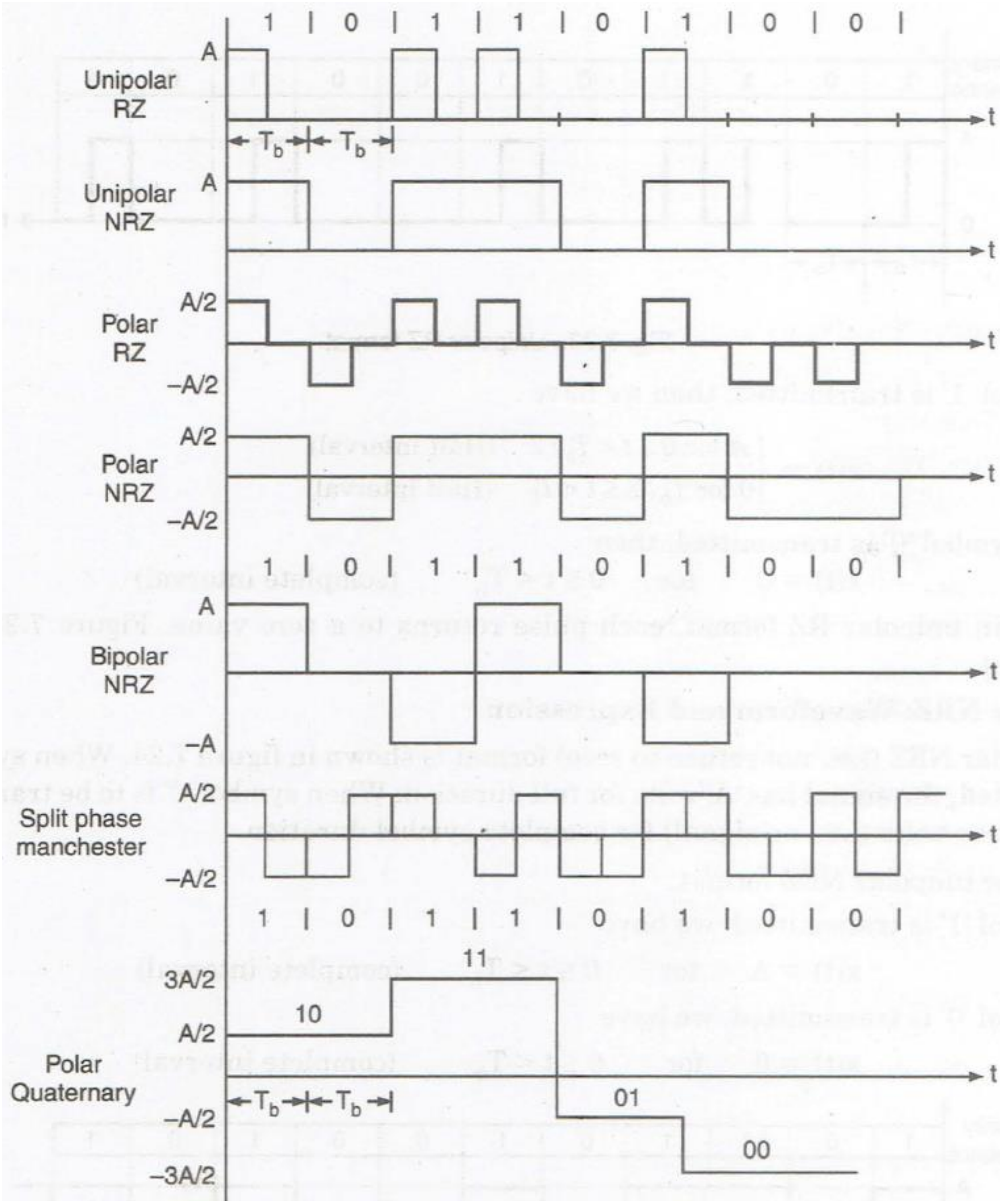
Line Coding, Applications

Line Coding (Pulse Format)

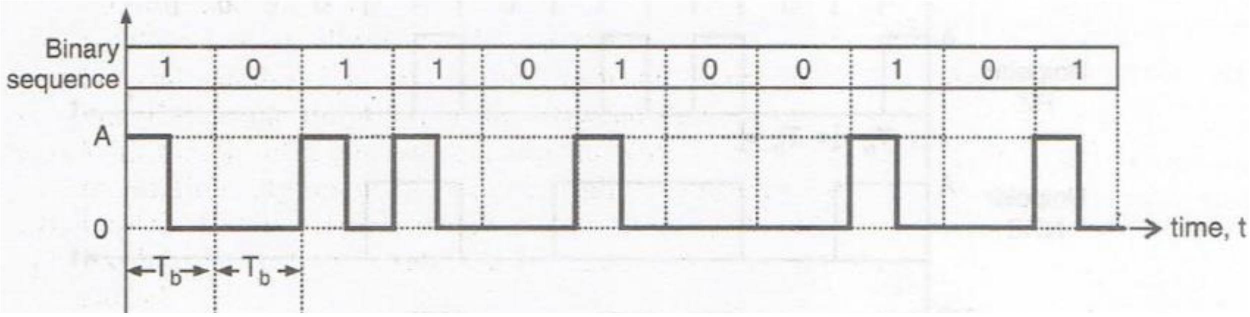
- The digital data can be transmitted by various transmission or line codes such as on-off, polar, bipolar and so on.
- This is called line-coding. Each type of line-code has its advantages and disadvantages.
- Thus, among other desirable properties, a line code must have the following properties:
  1) **Transmission bandwidth:** For a line-code, the transmission bandwidth must be as small as possible.
  2) **Power efficiency:** For a given bandwidth and a specified detection error probability, the transmitted power for a line code should be as small as possible.
  3) **Error detection and correction capability.**
  4) **Favorable power spectral density:** It is desirable to have zero power spectral density (PSD) at $\omega = 0$ (i.e., dc) since ac coupling and transformers are used at the repeaters.
  5) **Adequate timing content:** It must be possible to extract timing or clock information from the signal.
  6) **Transparency:** It must be possible to transmit a digital signal correctly regardless the pattern of **1**'s and **0**'s.

Some of the important PAM formats or line coding techniques arer:

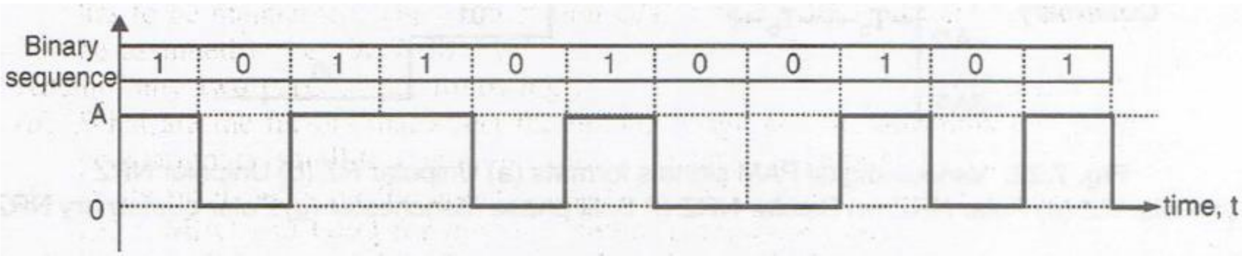
(i) Non-return to zero (**NRZ**) and return to zero (**RZ**) unipolar formats.
(ii) **NRZ** and **RZ** polar formats.
(iii) **NRZ** bipolar format.
(iv) **Manchester** format.
(v) Polar quaternary **NRZ** format.


1 0 1 1 0 1 0 0
A
Unipolar RZ
t
Tb Tb
A
Unipolar NRZ
t
A/2
Polar RZ
–A/2
t
A/2
Polar NRZ
–A/2
t
1 0 1 1 0 1 0 0
A
Bipolar NRZ
–A
t
A/2
Split phase manchester
–A/2
t
1 0 1 1 0 1 0 0
11
3A/2
10
A/2
Polar Quaternary
–A/2
01
00
–3A/2
t
Tb Tb

- Unipolar **R**eturn to **Z**ero (**RZ**)
- The message samples have two cases:
  1) If '**0**' transmitted: **no pulse** transmitted
  2) If '**1**' transmitted: a **pulse of value 'A'** is transmitted where the period of '**A**' is $\frac{T_b}{2}$



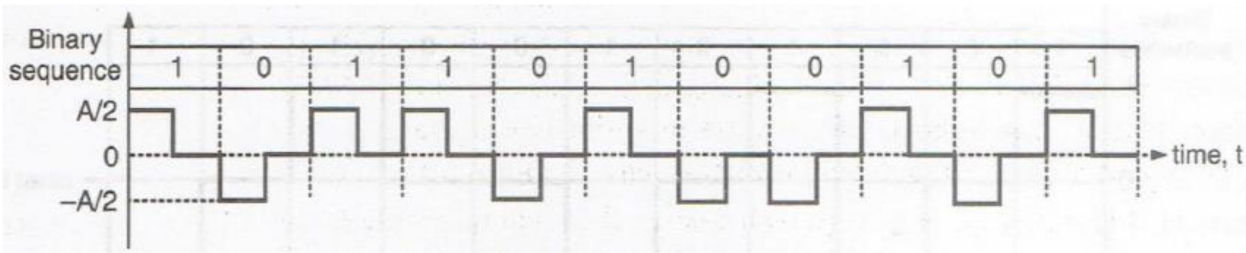
- Unipolar **N**on **R**eturn to **Z**ero (**NRZ**)
- The message samples have two cases:
  1) If '**0**' transmitted: **no pulse** transmitted
  2) If '**1**' transmitted: **'A'** is transmitted for the whole period, where the period of '**A**' is T_b



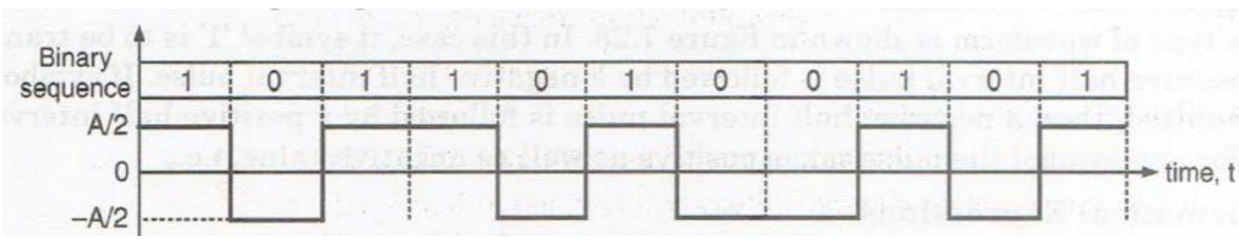
Notes:

1) For **NRZ** format, it may be observed that the pulse does not return to zero on its own. If symbol '**0**' is to be transmitted, then pulse becomes zero.
2) Internal computer waveforms are usually of unipolar NRZ type.
3) Because, there is no separation between the pulses, therefore, the receiver needs synchronization to detect **unipolar NRZ pulse**.
4) As compared to **RZ** format, **NRZ** pulse width is more. Thus, energy of the pulse is more.
5) However, unipolar format has some average DC value. This DC value does not carry any information.

- Polar **R**eturn to **Z**ero (**RZ**)
- The message samples have two cases:
  1) If ‘**1**’ transmitted: **A/2** transmitted for half period ($\frac{T_b}{2}$)
  2) If ‘**0**’ transmitted: **-A/2** transmitted for half period ($\frac{T_b}{2}$)



- Polar **N**on **R**eturn to **Z**ero (**NRZ**)
- The message samples have two cases:
  1) If ‘**1**’ transmitted: **A/2** transmitted for all period (T_b)
  2) If ‘**0**’ transmitted: **-A/2** transmitted for all period (T_b)

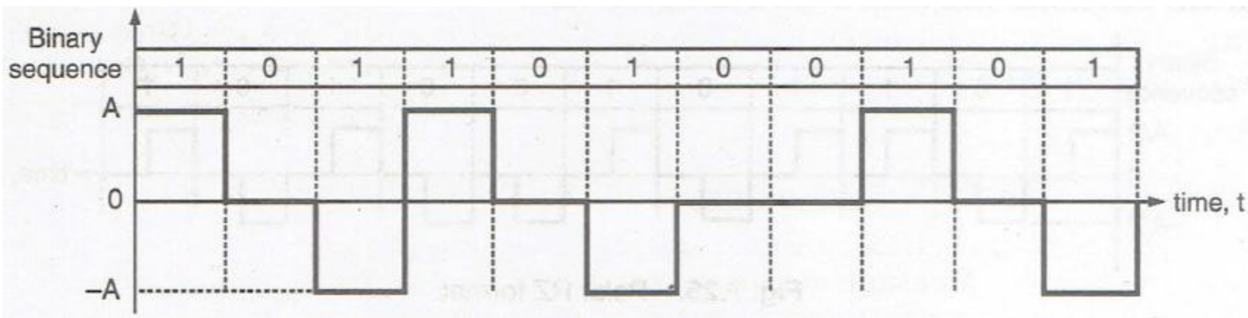


Notes:

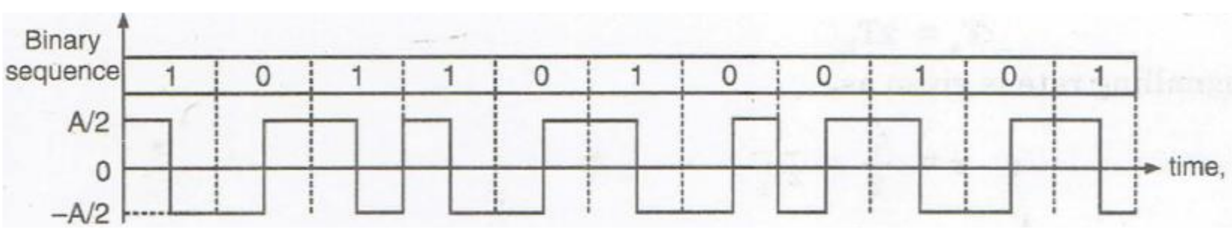
1) Since polar **RZ** and **NRZ** formats are bipolar, therefore, **the average DC value is minimum** in these waveforms.
1) If probabilities of occurrence of symbols '**1** 'and '**0**' **were same**, then average “DC” components of the waveform would be **zero**. In other words, if ‘1’ and ‘0’ have same probability, DC ≈ 0.

- Bipolar **N**on **R**eturn to **Z**ero (**NRZ**) [Alternate Mark Inversion (**AMI**)]
- The message samples have three cases:
  1) If '**1**' transmitted: **A** transmitted for all period (T_b)
  2) If '**0**' transmitted: **no pulse** transmitted for all period (T_b)
  3) If '**1**' transmitted: **-A** transmitted for all period (T_b)

In other words, successive 1's have alternating polarity.



- Split Phase Manchester
- The message samples have two cases:
  1) If '**1**' transmitted: $x(t) = \begin{cases} \frac{A}{2} & for\ 0 \le t < \frac{T_b}{2} \\ -\frac{A}{2} & for\ \frac{T_b}{2} \le t < T_b \end{cases}$
  2) If '**0**' transmitted: $x(t) = \begin{cases} -\frac{A}{2} & for\ 0 \le t < \frac{T_b}{2} \\ \frac{A}{2} & for\ \frac{T_b}{2} \le t < T_b \end{cases}$



Notes:

1) The primary advantage of this format is that ***irrespective*** of the probability of occurrence of symbol **'1'** and **'0'** the waveform has zero average value. Therefore by this mode, the power saving is quite more.
2) However, the drawback of this format is that it requires absolute sense of polarity at the receiver end.

- <u>Polar Quaternart **N**on **R**eturn to **Z**ero (**NRZ**)</u>
- The message samples have four amplitude levels:
    1) If '**00**' transmitted: **-3A/2** transmitted for period ($2T_b$)
    2) If '**01**' transmitted: **-A/2** transmitted for period ($2T_b$)
    3) If '**10**' transmitted: **A/2** transmitted for period ($2T_b$)
    4) If '**11**' transmitted: **3A/2** transmitted for period ($2T_b$)

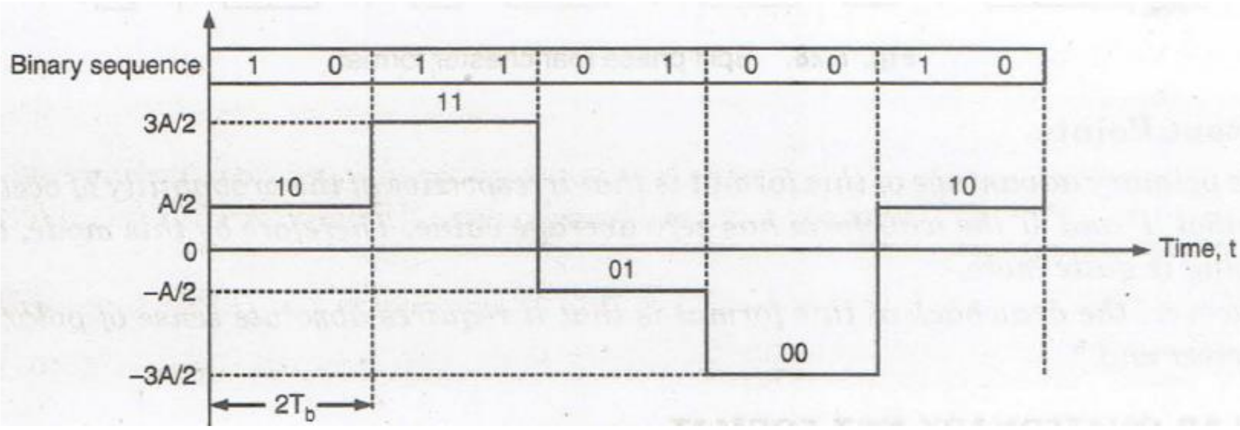


TABLE 7.7. Performance Comparison of Various Line Codes

S. No.	Parameter of Comparison	Polar RZ	Polar NRZ	AMI	Manchester	Polar Quaternary NRZ
1.	Transmission of DC component	Yes	Yes	No	No	Possible
2.	Signalling rate	$1/T_b$	$1/T_b$	$1/T_b$	$1/T_b$	$1/2\ T_b$
3.	Noise immunity	Low	Low	High	High	High
4.	Synchronizing capability	Poor	Poor	Very good	Very good	Poor
5.	Bandwidth requirement	$1/T_b$	$1/2\ T_b$	$1/2\ T_b$	$1/T_b$	$1/2T_b$
6.	Crosstalk	High	High	Low	Low	Low

EXAMPLE 7.7. Encode the following binary data stream into return to zero (RZ), Non-return to zero (NRZ), AMI and Manchester codes.

Data stream: 1 1 0 0 0 0 1 0

Solution: The line coding formats for the given data stream will be as shown in figure 7.35.

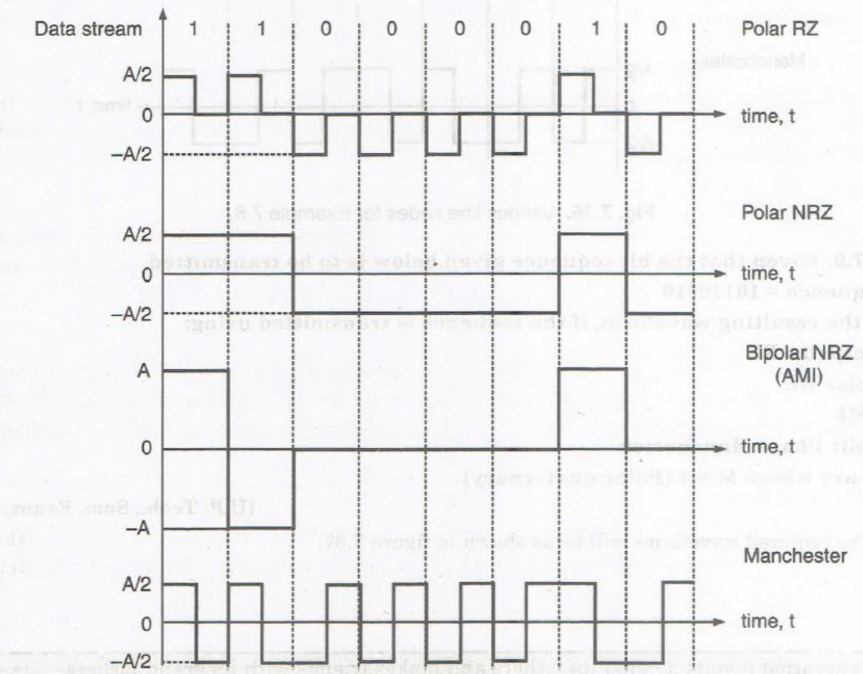
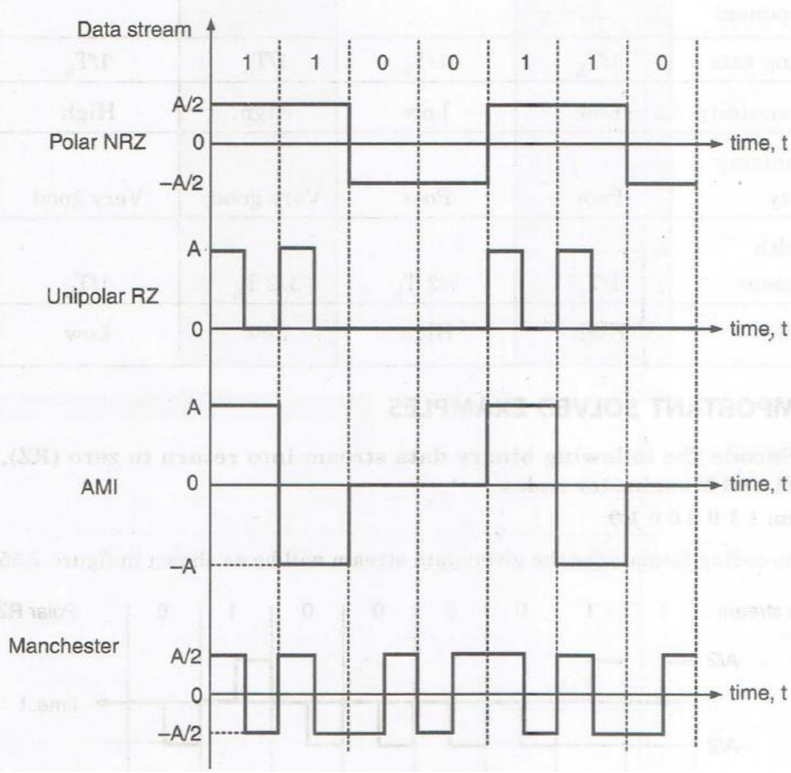


Fig. 7.35.

EXAMPLE 7.8. Draw the following data formats for the bit stream 1 1 0 0 1 1 0:

(i) Polar NRZ
(ii) Unipolar RZ
(iii) AMI
(iv) Manchester

Solution: The data formats will as shown in figure 7.36.



EXAMPLE 7.9. Given that the bit sequence given below is to be transmitted

Bit sequence = 10110010

Draw the resulting waveform, if the sequence is transmitted using:

(i) Unipolar RZ
(ii) Polar RZ
(iii) AMI
(iv) Split Phase Manchester
(v) M-ary where M = 4 (Polar quaternary)

(U.P. Tech., Sem. Exam., 2003-04)

Solution: The required waveforms will be as shown in figure 7.37.

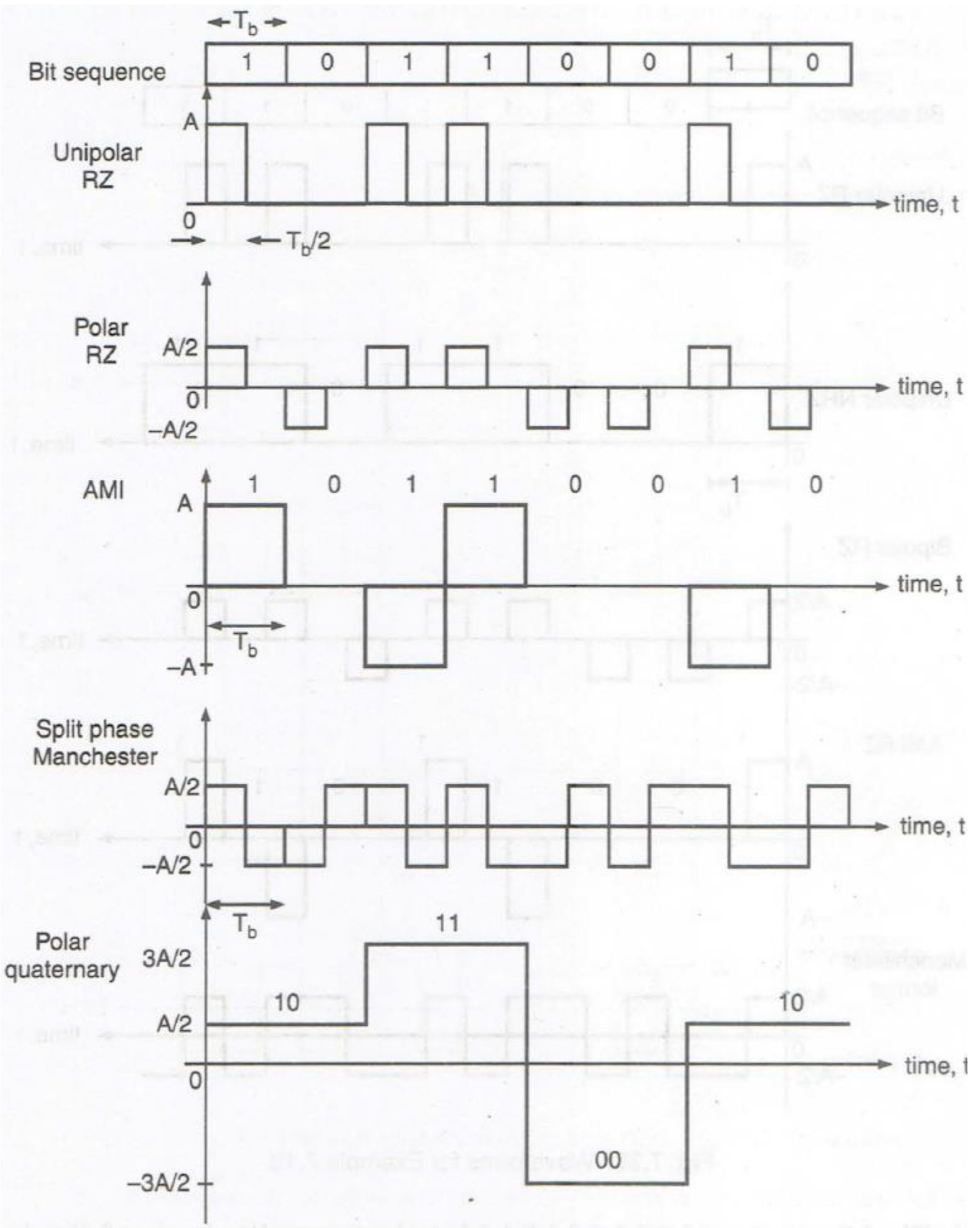


Fig. 7.37. Waveforms for Example 7.9

EXAMPLE 7.10. Which are the desirable properties of digital waveform? To transmit a bit sequence 10011011, draw the resulting waveforms using:

(i) Unipolar RZ
(ii) Unipolar NRZ
(iii) Bipolar RZ
(iv) AMI RZ
(v) Manchester.

Solution: For the properties of the line codes please study the related text.

The required waveforms have been drawn in figure 7.38.

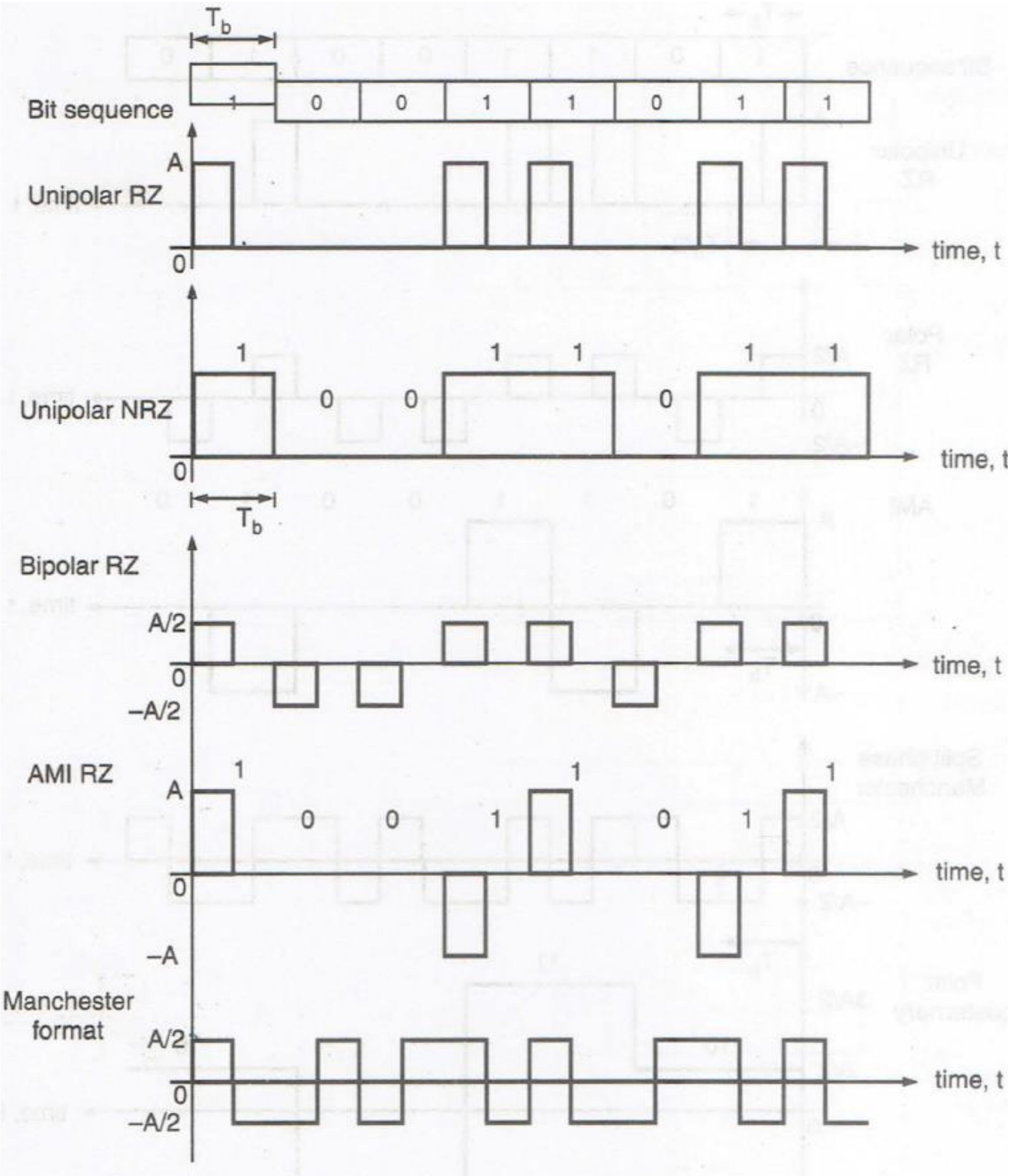


Fig. 7.38. Waveforms for Example 7.10.

EXAMPLE 7.11. The bit sequence 1 0 1 1 1 0 1 0 1 1 is to be transmitted using following formats:

(i) Unipolar RZ and NRZ

(*ii*) Bipolar RZ and NRZ

(iii) Split-phase Manchester

(iv) Polar quaternary NRZ.

Draw all the waveforms.

Solution: The required waveforms will be as shown in figure 7.39.

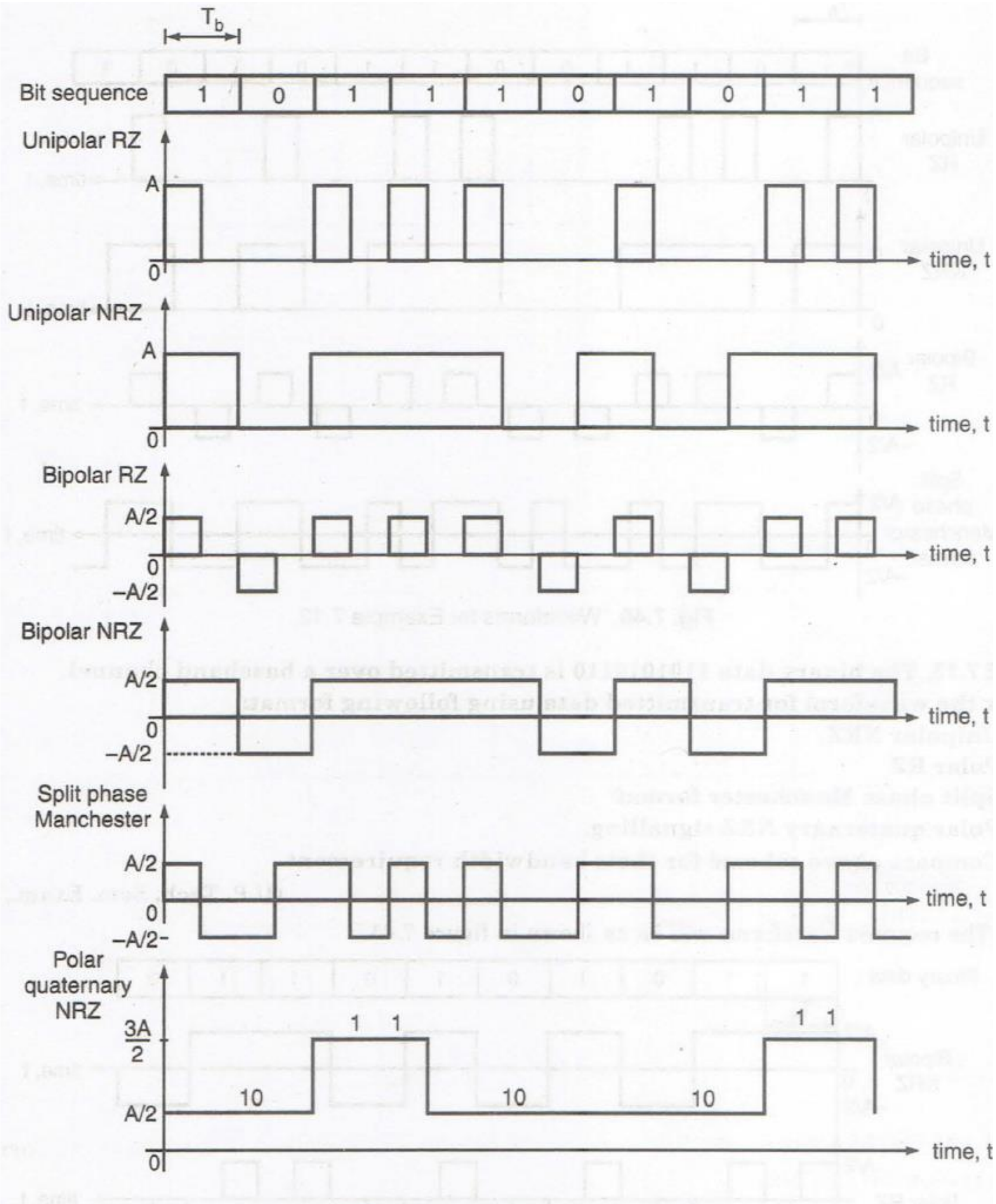


Fig. 7.39. Waveforms for Example 7.11.

EXAMPLE 7.12. The binary data 101100110101 is transmitted over a baseband channel. Draw the waveform for the transmitted data using following formats:

(i) Unipolar RZ

(ii) Unipolar NRZ

(iii) Bipolar RZ

(iv) Split-phase Manchester

Compare above schemes for their BW requirements.

Solution: The required waveforms will as shown in figure 7.40.

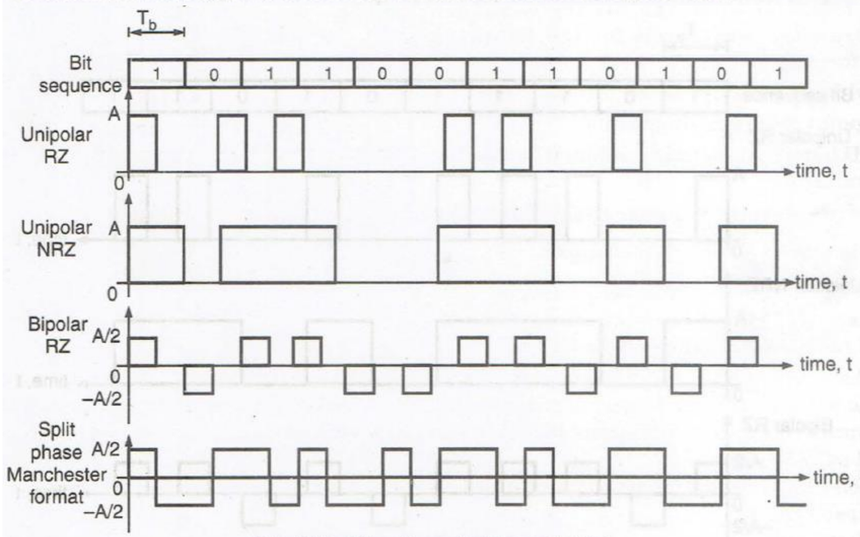


Fig. 7.40. Waveforms for Example 7.12.

EXAMPLE 7.13. The binary data 1101010110 is transmitted over a baseband channel. Draw the waveform for transmitted data using following format:

(i) Unipolar NRZ

(ii) Polar RZ

(iii) Split phase Manchester format

(iv) Polar quaternary NRZ signalling.

Compare above scheme for their bandwidth requirement.

(U.P. Tech, Sem. Exam.

Solution: The required waveforms will be as shown in figure 7.41.

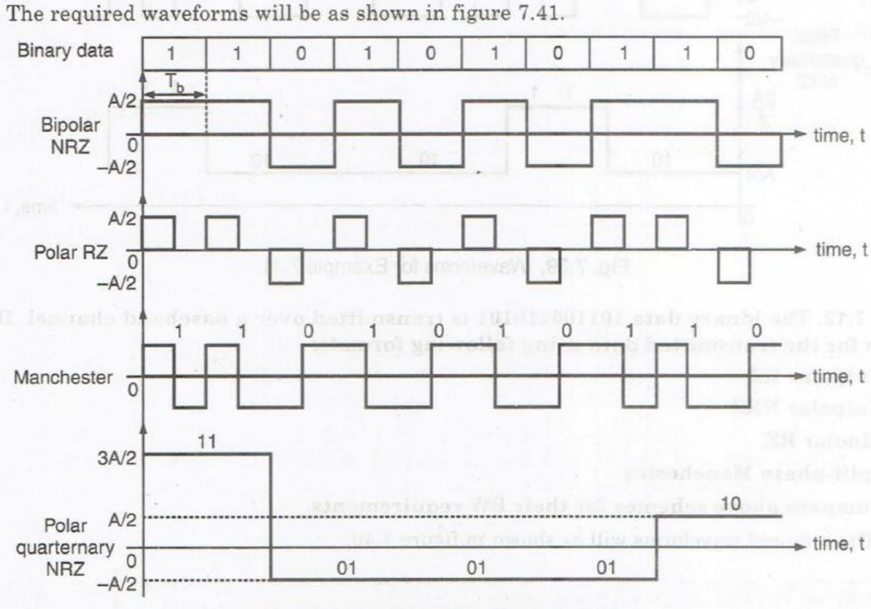


Fig. 7.41. Waveforms for Example 7.13.

EXAMPLE 7.14. Consider the binary sequence 0100101. Draw the waveforms for the following signalling formats:

(i) Unipolar NRZ signalling format

(ii) Bipolar RZ signalling format

(iii) AMI (alternate mark inversion) RZ signaling format.

(U.P. Tech, Semester Exam., 2002-2003)

Solution: Figure 7.42 shows all the formats.

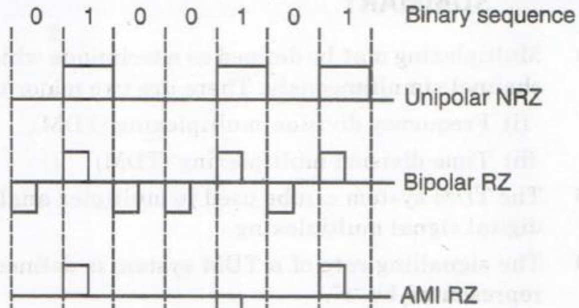


Fig. 7.42. Signaling formats for Example 7.14

EXAMPLE 7.15. Discuss the advantages and disadvantages of the three signalling formats illustrated in figure 7.42 of example 7.14.

Solution: The unipolar NRZ signalling format, although conceptually simple, has certain disadvantages. There are no pulse transitions for long sequences of 0s or 1s, which are necessary if one wishes to extract timing or synchronizing information, and there is no way to detect when and if an error has occurred from the received pulse sequence.

The bipolar RZ signalling format guarantees the availability of timing information, but there is no error detection capability.

The AMI RZ signalling format has an error detection property, if two sequential pulses (ignoring intervening 0s) are detected with the same polarity, it is evident, it is evident that an error has occurred. However, to guarantee the availability of timing information, it is necessary to restrict the allowable number of consecutive 0s.

EXAMPLE 7.16. Consider a binary sequence with a long sequence of 1s followed by a single 0 and then a long sequence of 1s. Draw the waveforms for this sequence, using the following signalling formats:

(i) Unipolar NRZ signalling

(ii) Bipolar NRZ signalling

(iii) AMI RZ signalling

(iv) Split-Phase (Manchester) signalling

Solution: Figure 7.43 shows all the required formats.

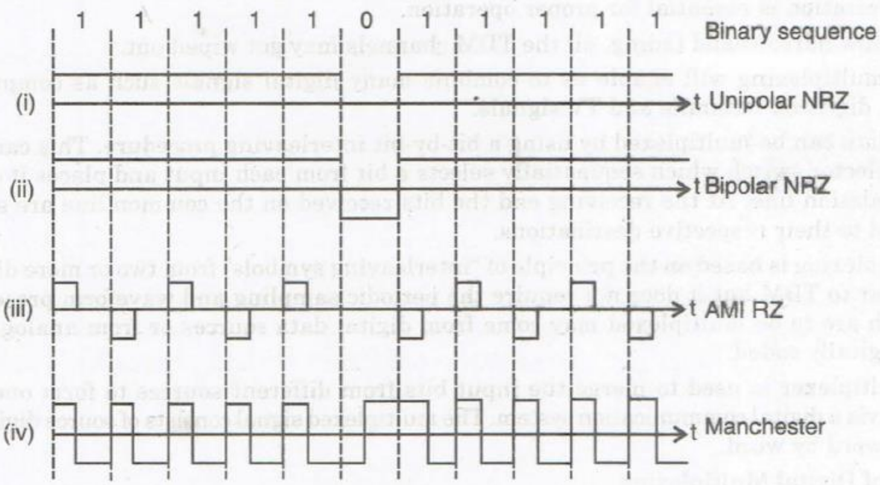


Fig. 7.43.

SUMMARY

- Multiplexing may be defined as a technique which allows many users to share a common communication channel simultaneously. There are two major types of multiplexing techniques. They are as under:
  (i) Frequency division multiplexing (FDM),
  (ii) Time division multiplexing (TDM)
- The TDM system can be used to multiplex analog or digital signals, however it is more suitable for the digital signal multiplexing.
- The signalling rate of a TDM system is defined as the number of pulses transmitted per second. It is represented by "r".
- TDM system is supposed to have its signalling rate as high as possible. It is evident from the expression above that the signalling rate can be increased by increasing the sampling rate f_s and/or the number of input signals N.
- The multiplexed PAM signals can be received properly if and only if the transmitter and receiver commutators are synchronized to each other in terms of the speed and the position. In order to ensure synchronization, a marker pulse is introduced at the end of each frame in the transmitted signals.
- Crosstalk basically means interference between the adjacent TDM channels it is the unwanted coupling of information from one channel to the other. The guard time T_g is the time spacing introduced between the adjacent TDM channels.
- The communication channel over which the TDM signal is travelling should ideally have an infinite bandwidth in order to avoid the signal distortion. However, in practice, all the communication channels have a finite bandwidth. Such channels are known as the bandlimited channels.
- One more cause for the crosstalk between the adjacent TDM signals is the use of bandlimiting filters. Because of these filters, the shapes of the TDM pulses are distorted and they get overlapped and crosstalk will take place.
- The crosstalk resulting from the pulse overlap can be reduced by introducing guard time of sufficient duration between the adjacent TDM pulses. The guard time is denoted by T_g.
- Advantages of TDM
  (i) Full available channel bandwidth can be utilized for each channel.
  (ii) Intermodulation distortion is absent.
  (iii) TDM circuitry is not very complex.
  (iv) The problem of crosstalk is not severe.
- Disadvantages of TDM
  (i) Synchronization is essential for proper operation.
  (ii) Due to slow narrowband fading, all the TDM channels may get wiped out.
- The digital multiplexing will enable us to combine many digital signals such as computer outputs, digital voice, digitized facsimile and TV signals.
- The digital data can be multiplexed by using a bit-by-bit interleaving procedure. This can be achieved by using a selector switch which sequentially selects a bit from each input and places it over the high speed transmission line. At the receiving end the bits received on the common line are separated out and delivered to their respective destinations.
- Digital multiplexing is based on the principle of "interleaving symbols" from two or more digital signals. This is similar to TDM but it does not require the periodic sampling and waveform preservation. The signals which are to be multiplexed may come from digital data sources or from analog sources that have been digitally coded.
- A digital multiplexer is used to merge the input bits from different sources to form one signal from transmission via a digital communication system. The multiplexed signal consists of source digits interleaved bit by bit or word by word.
- Advantages of Digital Multiplexing
  (i) Hardware cost reduction due to the use of digital ICs.
  (ii) Power cost reduction due to use of regenerative repeaters.
  (iii) More flexibility as compared to the analog multiplexers.

- DS0, DS1, DS2, ... etc. are the names of the services. The telephone companies use the T lines (T – 0, T – 2) ... etc.) to implement these services.
  The T lines have capacities which precisely match with the bit rates of the corresponding services.
- When a large number of PCM signals are to be transmitted over a common channel, multiplexing of these PCM signals is required.
- When the PCM-TDM system is being used for the telephony, it is expected to transmit certain signalling and supervisory signals alongwith the speech information. The signalling information consists of the signals such as a call is being initiated or a call is being terminated, or the address of calling party etc.
- The pulse code modulation (PCM), Delta modulation (DM), Adaptive delta modulation (ADM) etc. are used to convert an analog signal to digital data. This digital data is the sequence of binary symbols.
- The output of a multiplexer is coded into electrical pulses or waveforms for the purpose of transmission over the channel. This process is known as line coding or transmission coding.
- There are several possible ways of assigning waveforms (i.e., pulses) to the digital data. In the binary case (two symbols), for example, conceptually the simplest line code is on-off, where a 1 is transmitted by a pulse p(t) and a 0 is transmitted by no pulse (i.e., zero signal).
- Another line code that in the past appeared promising is the (and modified) proposed by Lender. Although this code is better than the bipolar in terms of bandwidth efficiency, it has lost its appeal due to some practical problems and will not be discussed here.
- Regenerative repeaters are used at regularly spaced intervals along a digital transmission line to detect the incoming digital and regenerate new clean pulses for further transmission along the line. This process periodically eliminates, and thereby combats, the accumulation of noise and signal distortion along the transmission path.
- The timing signal (i.e., the resonant circuit output) is sensitive to the incoming bit pattern. In the on-off or bipolar case, a 0 is transmitted by "no pulse". Hence, if there are too many 0's in a sequence (no pulses), there is no signal at the input of the resonant circuit and the sinusoidal output of the resonant circuit starts decaying, thus causing error in the timing information.
- The digital data may be transmitted by various transmission or line codes such as on-off, polar, bipolar and so on. This is called line-coding. Each type of line-code has its advantages and disadvantages.
- For a line-code, the transmission bandwidth must be as small as possible.
- For a given bandwidth and a specified detection error probability, the transmitted power for a line code should be as small as possible.
- It must be possible to detect and preferably correct detection errors. For example, in a bipolar case, a signal error will cause bipolar violation and thus can easily be detected.
- It must be possible to extract timing or clock information from the signal.
- It must be possible to transmit a digital signal correctly regardless of the pattern of 1 s and 0 s.

GLOSSARY

1. **Multiplexing :** The transmission of more than one information signal over a single channel.
2. **Framing bits :** Bits added to a digital signal to help the receiver to detect the beginning and end of data frames.
3. **Line code :** A system for translating logic ones and zeros into voltage or current levels for transmission.
4. **Negative logic :** A logic system in which a low level represents logic one and a high level represents logic zero.
5. **NRZ (non-return-to-zero) code :** A data line code in which the voltage or current does not necessarily return to zero between bits.
6. **Positive logic :** A logic system in which a high level represents logic one and a low level represents logic zero.
7. **RZ (return-to-zero) code :** A line code in which the voltage or current returns to zero at the end of each bit period.
8. **Unipolar code :** A line code in which the polarity of the voltage or the direction of the current remains the same at all times.
9. **Vocoder :** Circuit for digitizing voice at a low data rate by using knowledge of the way in which voice sounds are produced.

SHORT QUESTIONS WITH ANSWERS

Q.1. What do you mean by Multiplexing?

Ans. Multiplexing may be defined as a technique which allows many users to share a common communication channel simultaneously. There are two major types of multiplexing techniques. They are as under:

(i) Frequency division multiplexing (FDM),

(ii) Time division multiplexing (TDM).

Q.2. Explain Frequency Division Multiplexing (FDM).

Ans. This technique permits a fixed frequency band to every user in the complete channel bandwidth. Such frequency slot is allotted continuously to that user. As an example consider that the channel bandwidth is 1 MHz. Let there be ten users, each requiring upto 100 kHz bandwidth. Then the complete channel bandwidth of 1 MHz can be divided into ten frequency bands, i.e. each of 100 kHz and every user can be allotted one independent frequency band. This technique is known as **Frequency Division Multiplexing** (FDM).

Q.3. What is Transmission Bandwidth of a PAM/TDM Channel?

Ans. The minimum transmission bandwidth of a PAM-TDM channel is given by

$$BW = \frac{1}{2}\,(\text{signalling rate})$$

Therefore, minimum transmission bandwidth $BW \geq \frac{1}{2} \times 2N\, f_m$

Hence, minimum transmission bandwidth $BW = Nf_m$.

Q.4. What is Crosstalk in PAM/TDM System?

Ans. Crosstalk basically means interference between the adjacent TDM channels. Infact, it is the unwanted coupling of information from one channel to the other. The guard time 'T_g' is the time spacing introduced between the adjacent TDM channels.

Q.5. Write the Advantages of TDM.

Ans. (i) Full available channel bandwidth can be utilized for each channel.

(ii) Intermodulation distortion is absent.

(iii) TDM circuitry is not very complex.

(iv) The problem of crosstalk is not severe.

Q.6. Write the Disadvantages of TDM.

Ans. (i) Synchronization is essential for proper operation.

(ii) Due to slow narrowband fading, all the TDM channels may get wiped out.

Q.7. Explain the Principle of Digital Multiplexing.

Ans. Digital multiplexing is based on the principle of "interleaving symbols" from two or more digital signals. This is similar to TDM but it does not require the periodic sampling and waveform preservation. The signals which are to be multiplexed may come from digital data sources or from analog sources that have been digitally coded. A digital multiplexer is used to merge the input bits from different sources to form one signal from transmission via a digital communication system. The multiplexed signal consists of source digits interleaved bit-by-bit or word-by-word. The important functions that must be performed by a multiplexer are as under:

(i) To establish a frame, a frame consists of at least one bit from every input.

(ii) A number of unique bits slots within the frame should be assigned to each input.

(iii) To insert control bits for frame identification and synchronization.

(iv) To make allowance for any variations of the input bit rates.

Q.8. How can you classify Digital Multiplexers?

Ans. The various digital sources that are to be multiplexed will have different bit rates. In practice, the bit rate variation possess the most serious design problem and leads to the three categories of multiplexers, as under:

(i) Synchronous multiplexers (ii) Asynchronous multiplexers

(iii) Quasi-synchronous multiplexers.

Q.9. Write the advantages of Digital Multiplexing.

Ans. (i) Hardware cost reduction due to the use of digital ICs.

(ii) Power cost reduction due to use of regenerative repeaters.

(iii) More flexibility as compared to the analog multiplexers.

Q.10. What is Baseband binary data transmission system?

Ans. The data transmission system which makes use of a baseband channel for transmitting a binary data is known as baseband data transmission, i.e., the system using a channel whose bandwidth is equal to the bandwidth of the message signal, called a baseband channel is referred to as baseband data transmission system.

Q.11. What is a Baseband binary PAM system? Explain.

Ans. Pulse amplitude modulation scheme is a system in which the amplitude of discrete pulses (carrier) vary along with the message signal. Thus, baseband binary PAM system is the scheme in which the amplitude transmitted pulses take any one of the two amplitude levels, i.e., either 1 (or) 0.

REVIEW QUESTIONS

1. What do you mean by multiplexing? Explain TDM and FDM.
2. Explain a PAM/TDM system in detail with a block diagram and write briefly about the following:
   (i) frame (ii) signalling rate
   (iii) transmission BW (iv) synchronization
   (v) crosstalk (vi) guard time
3. Explain the principle of digital multiplexing. What are the types of digital multiplexers?
4. Explain multiplexing hierarchy for digital communication.
5. Explain the difference between bandpass transmission and passband transmission.
6. Explain various PAM digital formats.
7. Explain the followings:
   (i) Intersymbol Interference, (ii) Eye pattern
8. What is Line coding ? Explain.
9. What are the properties of Line coding?
10. Draw the block diagram of a baseband digital communications of various blocks.
11. What is Nyquist criterion of zero ISI ? Explain.
12. Why do we need to use the discrete PAM formats?
13. State the important properties of line codes.
14. What is the meaning of word "RZ".
15. State true or false
    (a) The dc value of unipolar RZ format is zero.
    (b) The unipolar NRZ signal used two different amplitudes
    (c) Polar NRZ format has a zero dc value
16. In the bipolar NRZ or AMI line codes, the binary 0 is represented by
    (a) alternate zeros and ones. (b) alternate + A and – A amplituds.
    (c) zero amplitudes
17. The synchronization at the receiver is better for:
    (a) Bipolar RZ (b) Bipolar NRZ (c) Manchester

NUMERICAL PROBLEMS

1. Represent the data 10110100 using the following digital data formats with the help of neat figures:
   (i) Unipolar RZ (ii) Unipolar NRZ
   (iii) Split phase Manchester.
2. Given the binary sequence 1101110, draw the transmitted pulse waveform for
   (i) AMI RZ signalling format, and (ii) Split-phase (Manchester) signalling format.