DIGITAL MODULATION: LINE CODING

Conditioning Digital Signals for Transmission on Physical Media

EEEN 464 – DIGITAL COMMUNICATION SYSTEMS

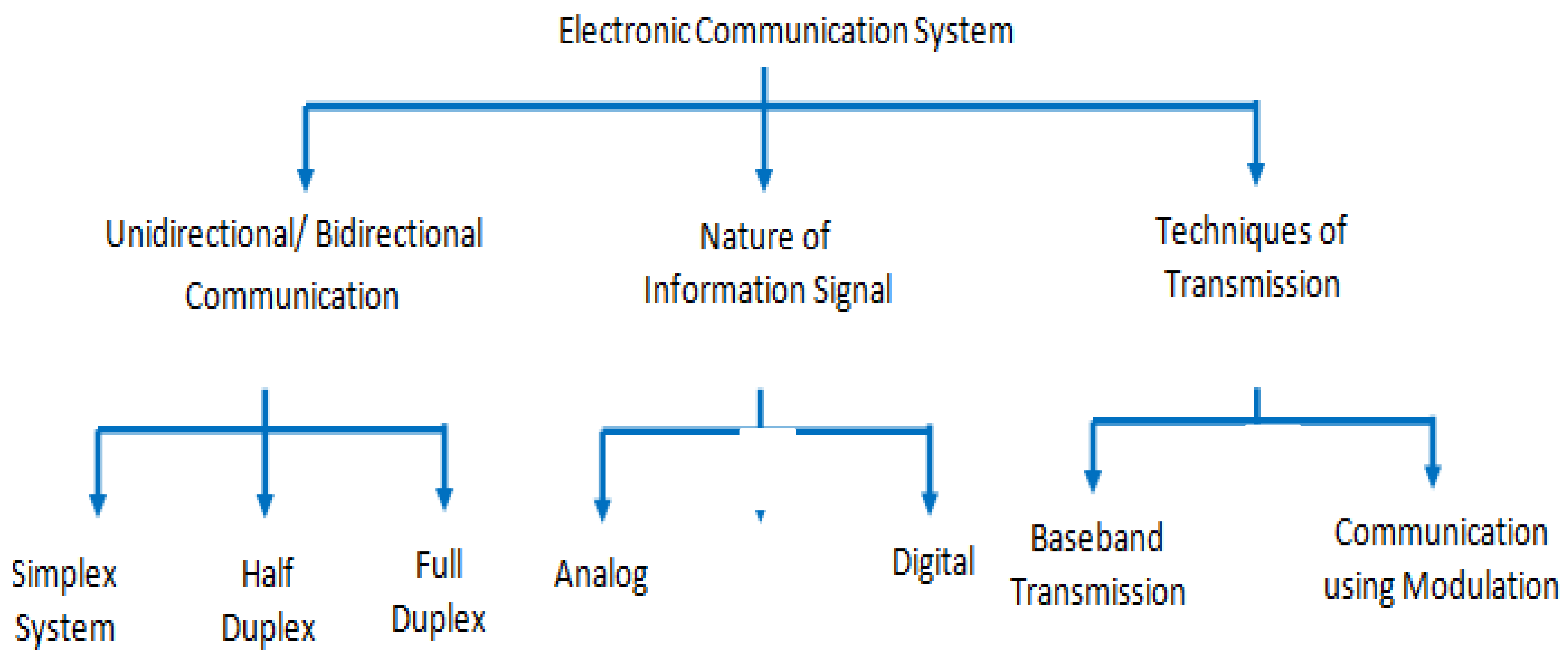
Friday, 20 February 2026

WHERE ARE WE IN THE SYLLABUS?

Course Content:

Signal digitization: Pulse Amplitude Modulation (PAM), sampling theorems and sampling circuits, Pulse code modulation (PCM). Quantization and signal conditioning: Uniform and non-uniform quantization; companding methods; vocoders; signal-to- quantization noise ratio. Waveform coding: Pulse transmission, PCM, Pulse-shaping; Delta modulation; adaptive delta modulation; Differential Pulse Code Modulation (DPCM), M-ary encoding. Digital Modulation: Amplitude shift keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Quadrature Amplitude Modulation (QAM) and Differential Phase Shift Keying (DPSK). Signal recovery in ASK, FSK and PSK; Gaussian Minimum Shift Keying (GMSK); Performance comparison. Information theory: information sources, entropy, channel capacity; Source Coding; entropy coding. Error control: Error control coding techniques; Transmission errors; Error detection methods; intersymbol interference and the eye pattern; Linear block codes; Cyclic codes; convolution codes. Multiplexing: Frequency division multiplex (FDM), Time Division Multiplexing (TDM), plesiochronous digital hierarchy (PDH). Spread spectrum communication: Direct sequence and frequency hopping methods; synchronization, spreading codes and their generation. Data transmission: Local data transmission protocals (Ethernet, token ring); Modems; high Asymmetric Digital subscriber line (ADSL); Very–high Speed Digital subscriber line (VDSL), integrated services digital network (ISDN).

RECAP - CLASSIFICATION OF ELECTRONIC COMMUNICATION

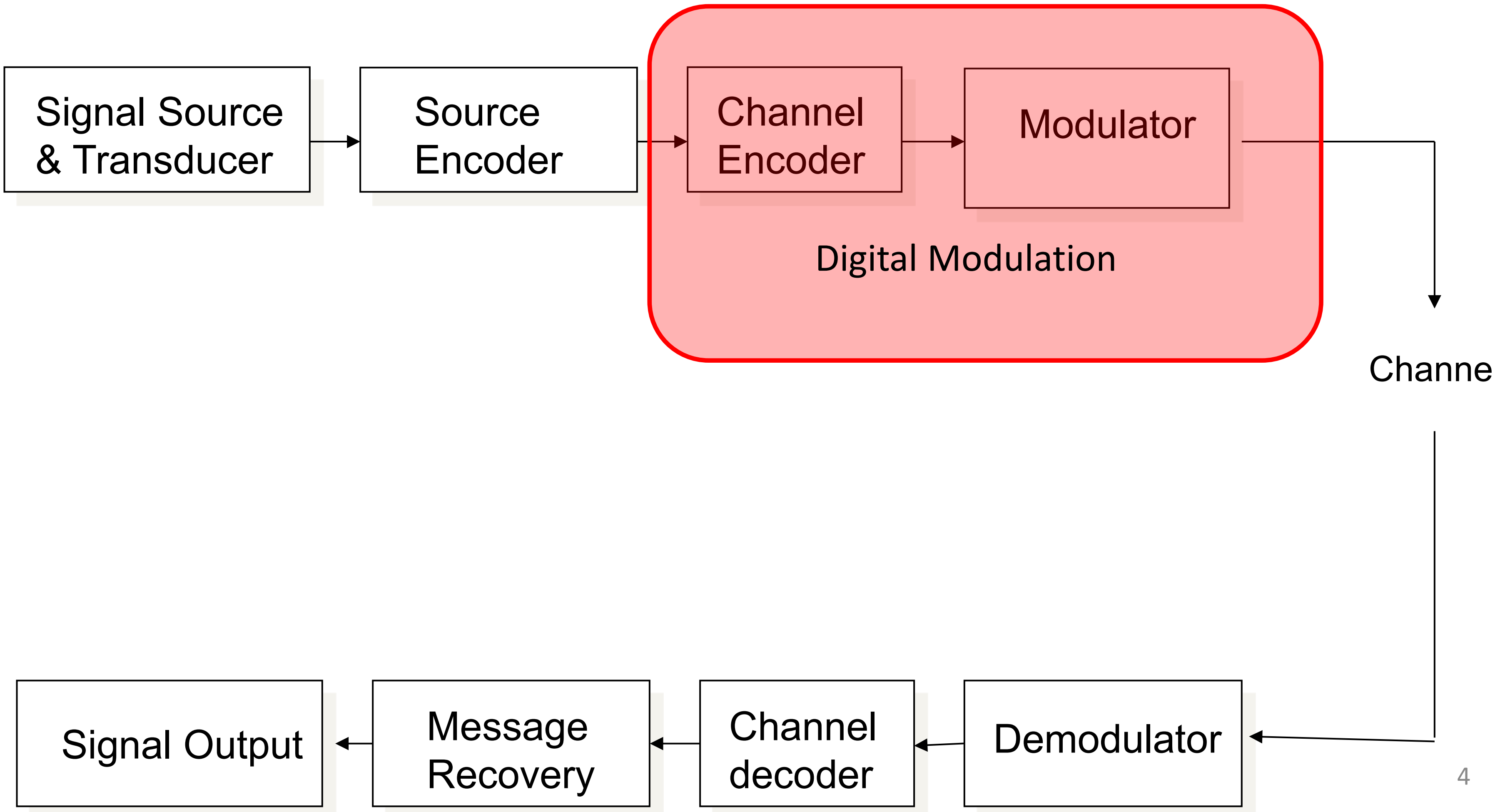


WHAT IS DIGITAL MODULATION?

Digital modulation refers to:

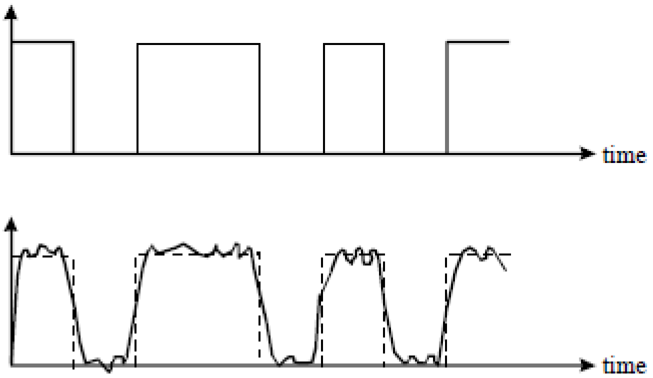
(a) conversion of digital signals to use the transmission media efficiently, and

(b) alteration of the characteristics of a carrier signal in conformity with a digital message signal.



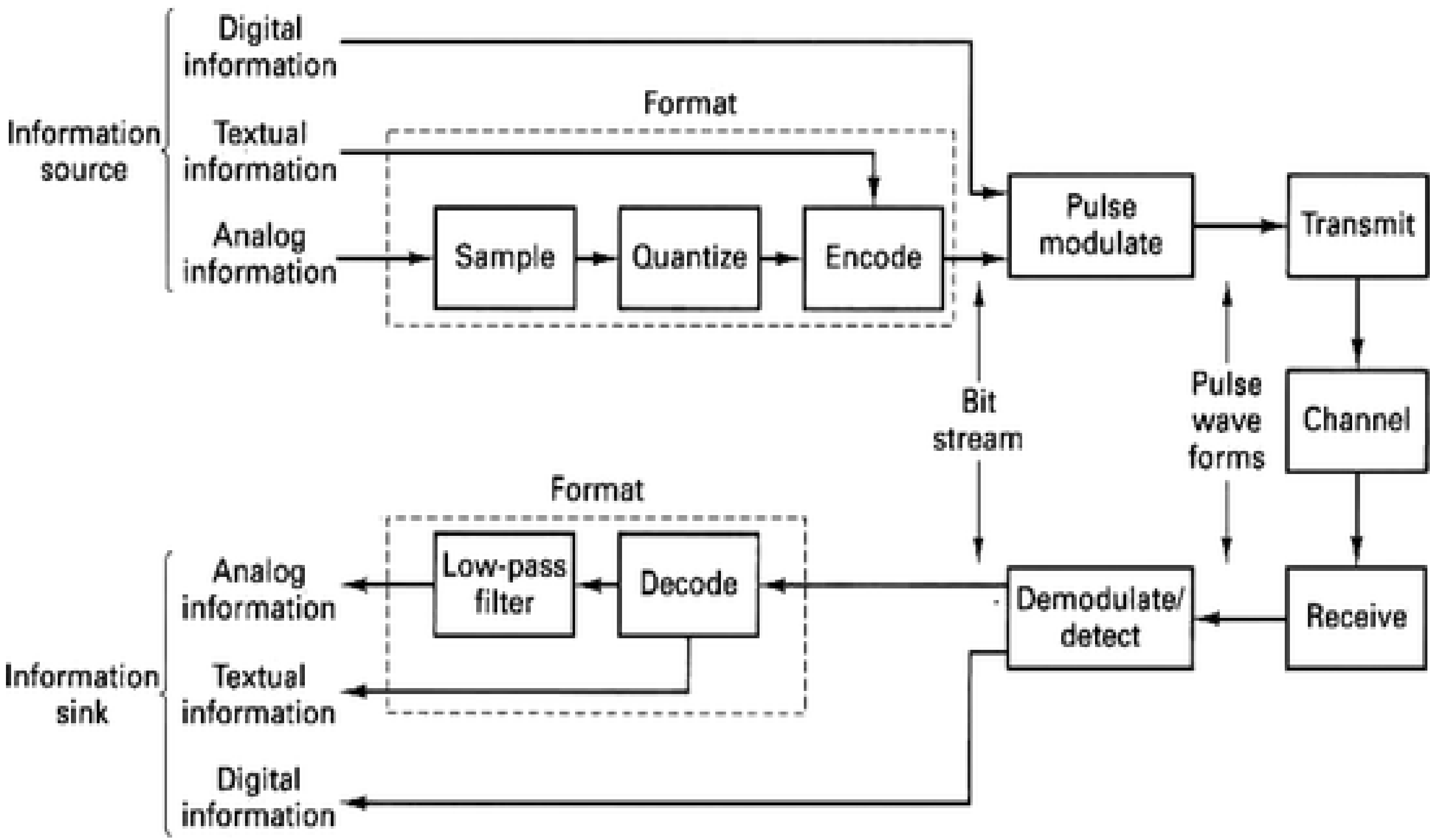
WHY DO WE USE DIGITAL BASEBAND MODULATION?

1. While analogue signal has a finite bandwidth, a digital stream or signal, with sharp transitions, has an infinite bandwidth.



2. Even if there is no loss or noise in the communication system, the received signal will have distortion due to the limited channel bandwidth.
3. To avoid or to reduce this signal distortion, we use baseband modulation techniques

BASEBAND COMMUNICATION SYSTEM



CHANEL/LINE CODING

1. Digital signal can be transmitted by various transmission (line) codes e.g. On-off, polar or bi-polar.
2. The Channel/Line coder must have the following properties:
   a) Use minimal transmission bandwidth.
   b) Use minimal transmission power for a given bandwidth
   c) Use minimal detection error probability.
   d) Must be able to detect and possibly correct errors.
   e) Have zero spectral density at $\omega = 0$ since significant power at low frequencies increases error (see DC wander).
   f) It must be possible to extract timing or clock information from the signal

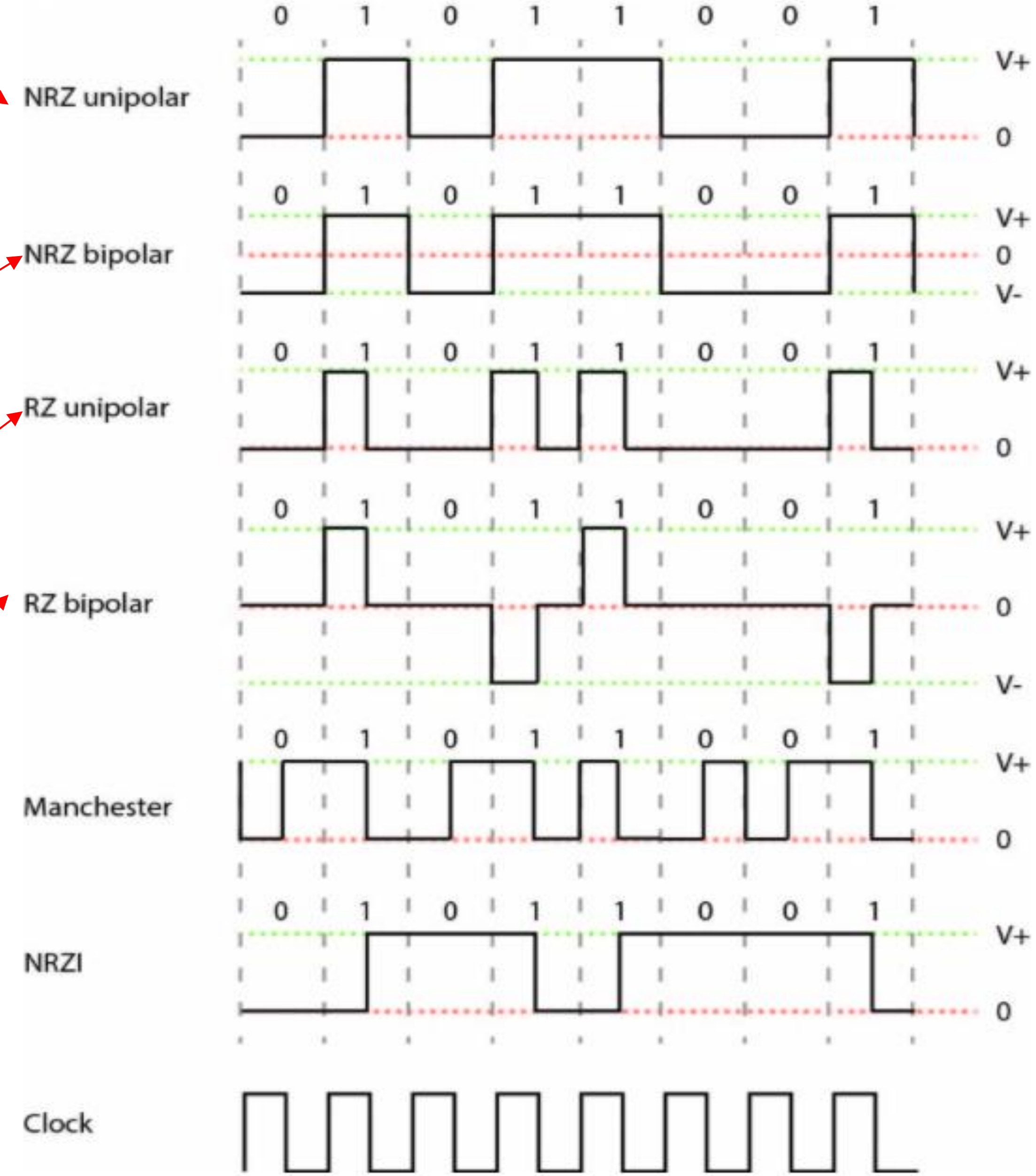
COMMON CHANNEL/LINE FOMATS

Non-Return to Zero with one polarity has a DC component

Non-Return to Zero with 2 polarities has no DC component

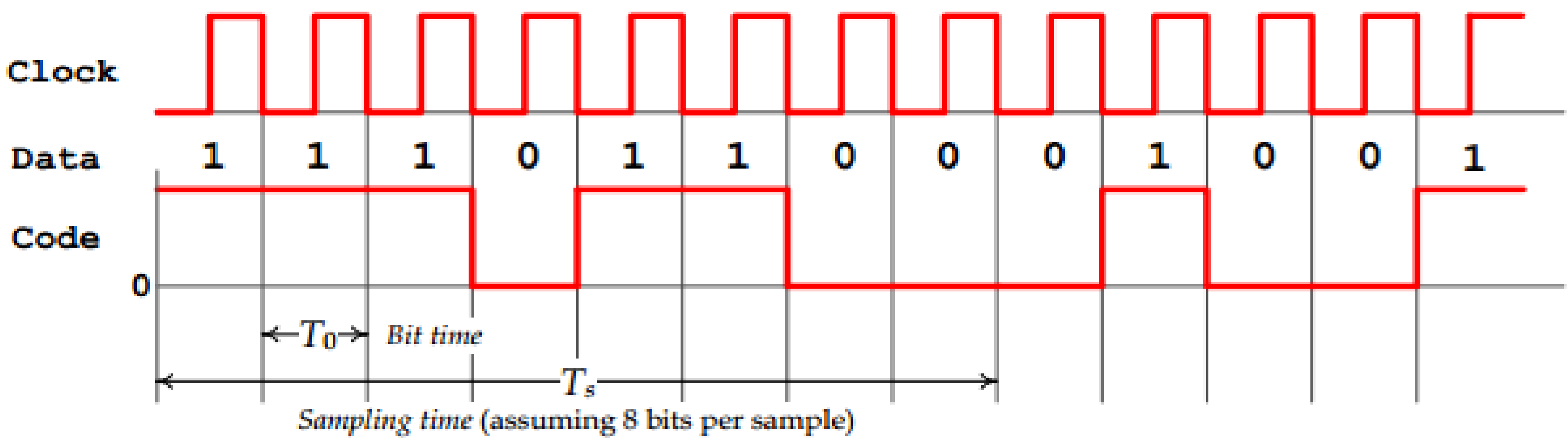
Return to Zero(RZ) with one polarity has DC value

Return to Zero(RZ) with 2 polarities has no DC component



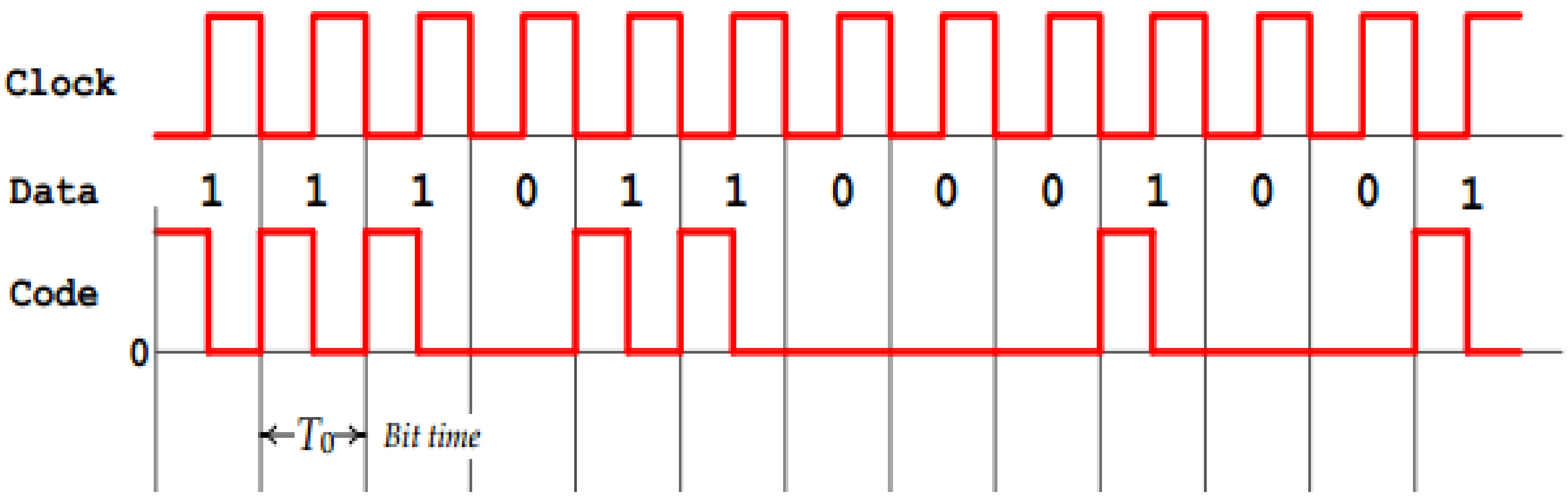
UNIPOLAR NRZ

1. The pulse does not return to zero on its own
2. ‘1’ gives a high voltage and a ‘0’ gives a low voltage.
3. The receiver must be synchronized to the transmitter through a separate clock circuit to detect unipolar NRZ signals



UNIPOLAR RETURN TO ZERO (RZ)

1. Unipolar Return to Zero (RZ) has single polarity, e.g. signal has +5V or +12V.
2. Voltage is high for half of the period for one.

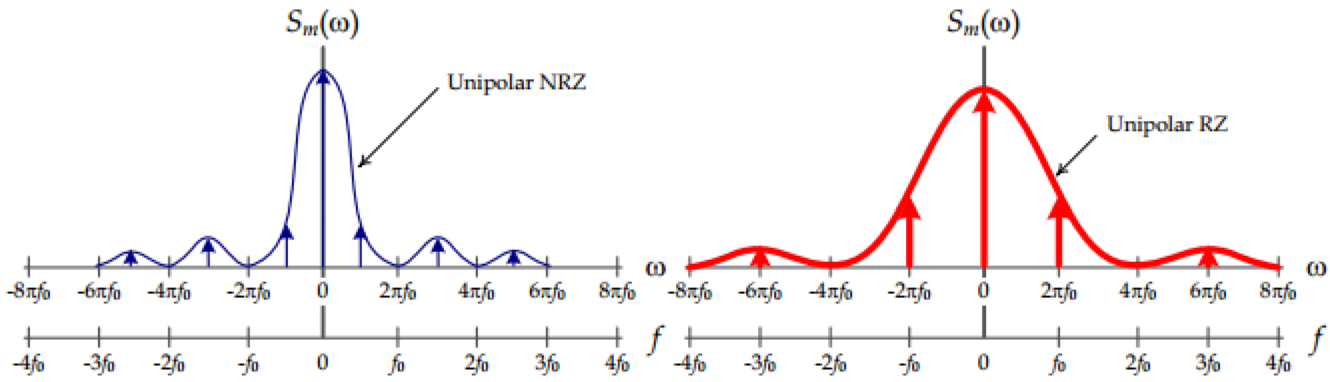


POINTS TO NOTE ABOUT UNIPOLAR RZ & NRZ

1. Because there is no separation between the pulses, the receiver needs to be synchronized with the source, i.e a common clock is required.
2. Unipolar RZ format has some average DC value that does not carry any information.
3. Unipolar RZ and NRZ formats are compatible with TTL logic.
4. Internal computer communication is usually unipolar

SPECTRAL REQUIREMENTS OF RZ AND NRZ

1. Each rectangular pulse in RZ is only half the length of the NRZ pulse.
2. This means that unipolar RZ requires twice the bandwidth of the NRZ code when operating at the same clock speed.



POLAR NRZ

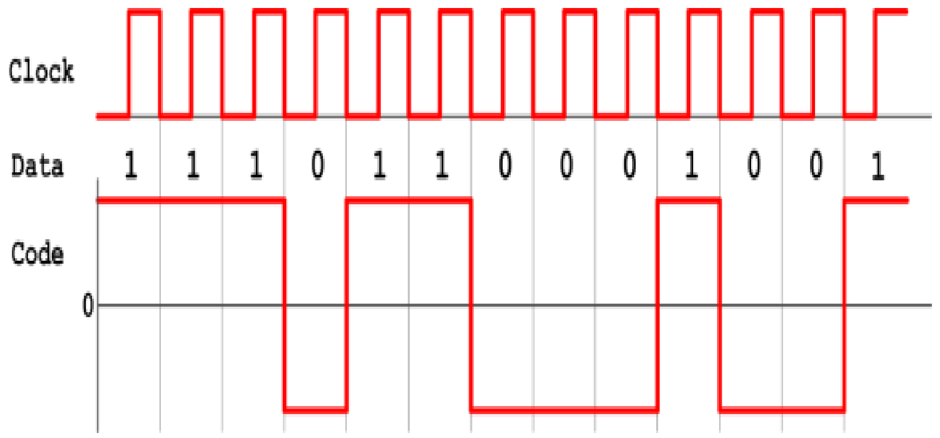
1. Symbol ‘1’ is represented by +ve voltage
2. symbol ‘0’ is represented by –ve voltage.

When Symbol ‘1’ is to be transmitted, the signal x(t) is:

$$x(t) = +\frac{A}{2} \qquad 0 \le t < t_b$$

When Symbol ‘0’ is to be transmitted, the signal x(t) is:

$$x(t) = -\frac{A}{2} \qquad 0 \le t < t_b$$



POLAR RZ

When Symbol '1' is to be transmitted, the signal x(t) is:

$$x(t) = \begin{cases} +\dfrac{A}{2} & 0 \leq t < \dfrac{T_b}{2} \\ 0 & \dfrac{T_b}{2} \leq t < T_b \end{cases}$$

When Symbol '0' is to be transmitted, the signal x(t) is:

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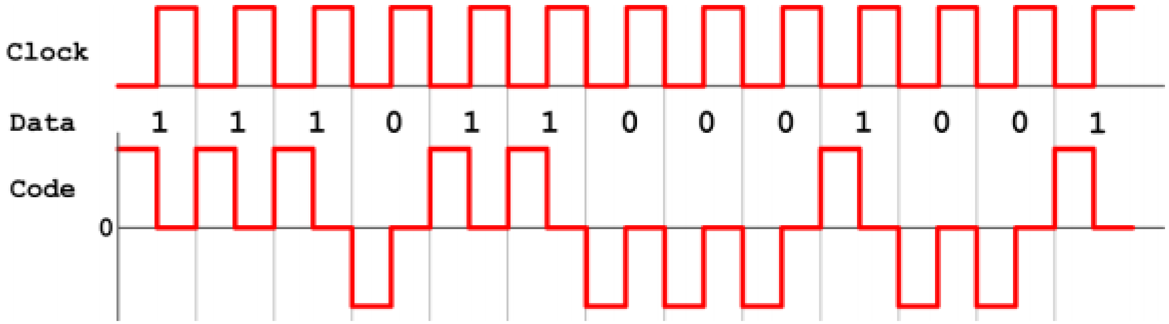
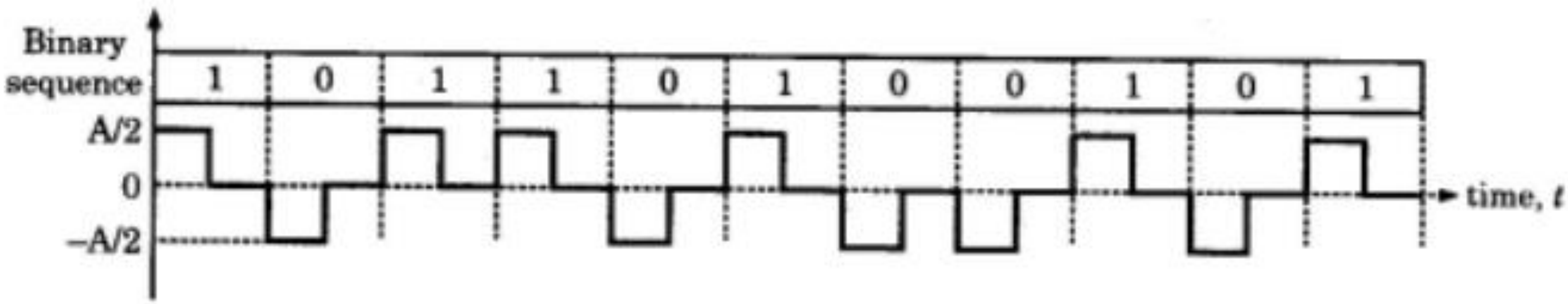


POINTS TO NOTE ABOUT POLAR NRZ & POLAR RZ

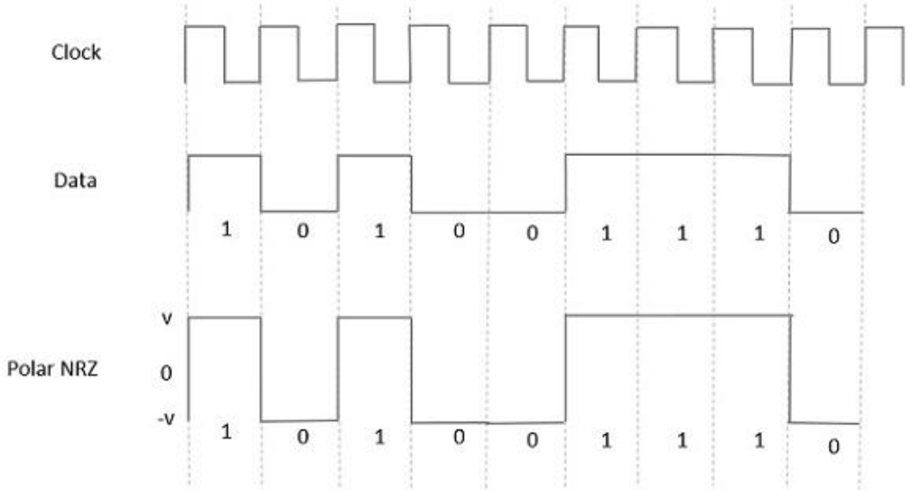
1. The average DC value is minimal in the waveforms
2. If the probability of occurrence of symbols ‘1’ and ‘0’ is the same, then the average DC component is zero.



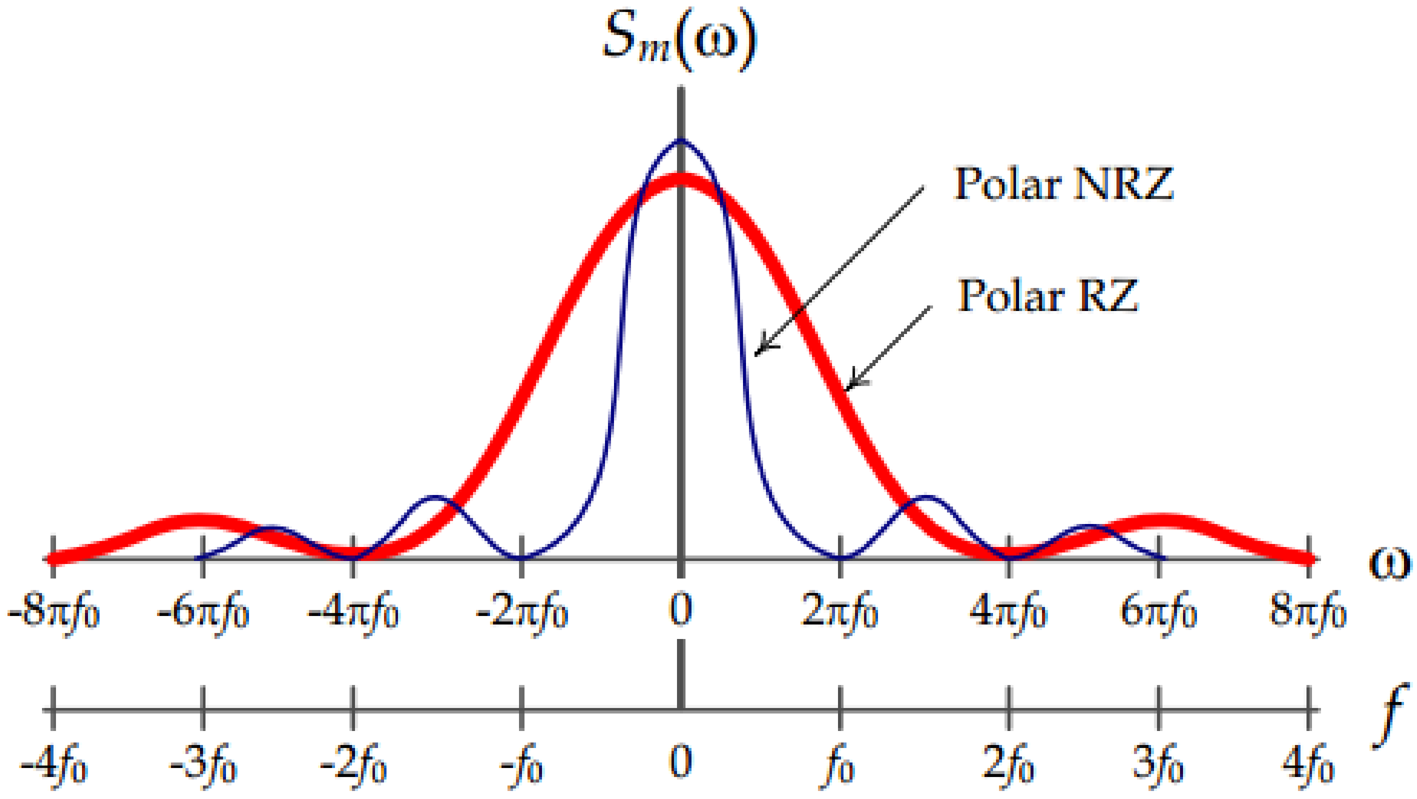
APPLICATIONS OF NRZ FORMATS

1. Signals transmitted on a computer motherboard often use **NRZ code**.

2. Local area Ethernet. e.g 1000BASE-SX and 1000BASE-LX use **polar NRZ**.

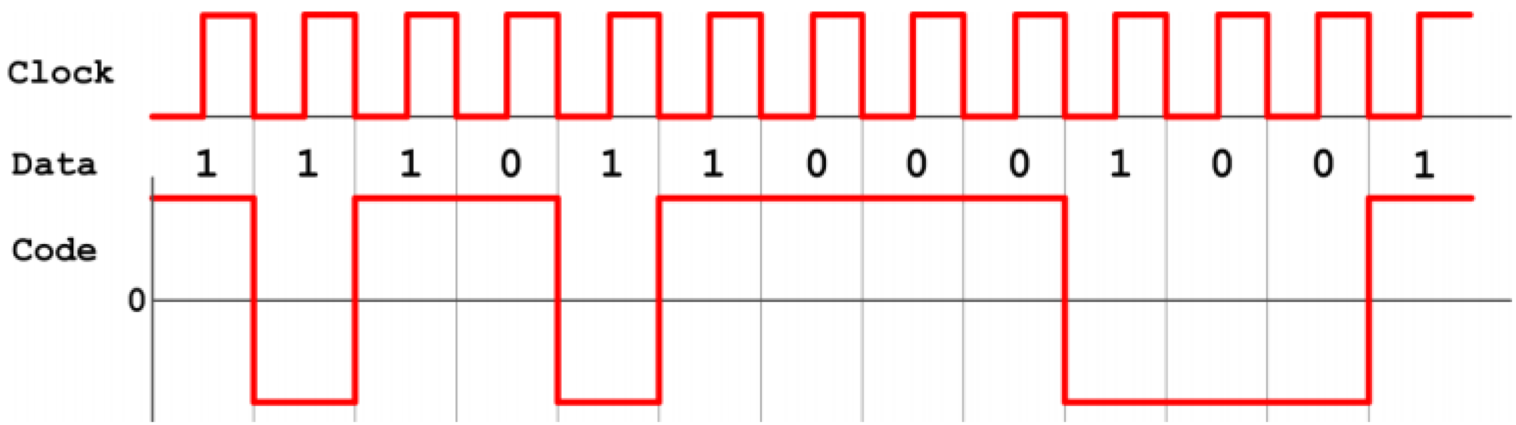


SPECTRA OF BIPOLAR RZ AND NRZ



BIPOLAR NRZ (ALTERNATE INVERSION – AMI)

- Successive 1's are represented by pulses with alternate polarity
- All 0's are represented by no pulses/no change



SPLIT PHASE MANCHESTER FORMAT

- Symbol '1' is transmitted by sending a +ve half interval pulse followed by a –ve half interval pulse.
- Symbol '0' is transmitted by sending a -ve half interval pulse followed by a +ve half interval pulse.

When Symbol '1' is to be transmitted, the signal x(t) is:

$$x(t) = \begin{cases} \frac{A}{2} & \text{for } 0 \le t < \frac{T_b}{2} \\ -\frac{A}{2} & \text{for } \frac{T_b}{2} \le t < T_b \end{cases}$$

When Symbol '0' is to be transmitted, the signal x(t) is:

$$x(t) = \begin{cases} -\frac{A}{2} & \text{for } 0 \le t < \frac{T_b}{2} \\ \frac{A}{2} & \text{for } \frac{T_b}{2} \le t < T_b \end{cases}$$

SPLIT PHASE MANCHESTER FEATURES

1. The output signal has an average value of zero irrespective of the probability of occurrence of symbols ‘0’ or ‘1’.

2. The receiver needs to have a sense of phase (polarity) of the signal, i.e phase synchronization.

POLAR QUATERNARY NRZ FORMAT

1. The message bits are arranged in blocks of two to result in four (4) possible combinations, i.e 00,01,10 and 11.
2. To each combination, an amplitude level is assigned.

MESSAGE COMBINATION	$X(r) = a_n$
00	-3A/2
01	-A/2
10	A/2
11	3A/2

POLAR QUATERNARY NRZ FORMAT

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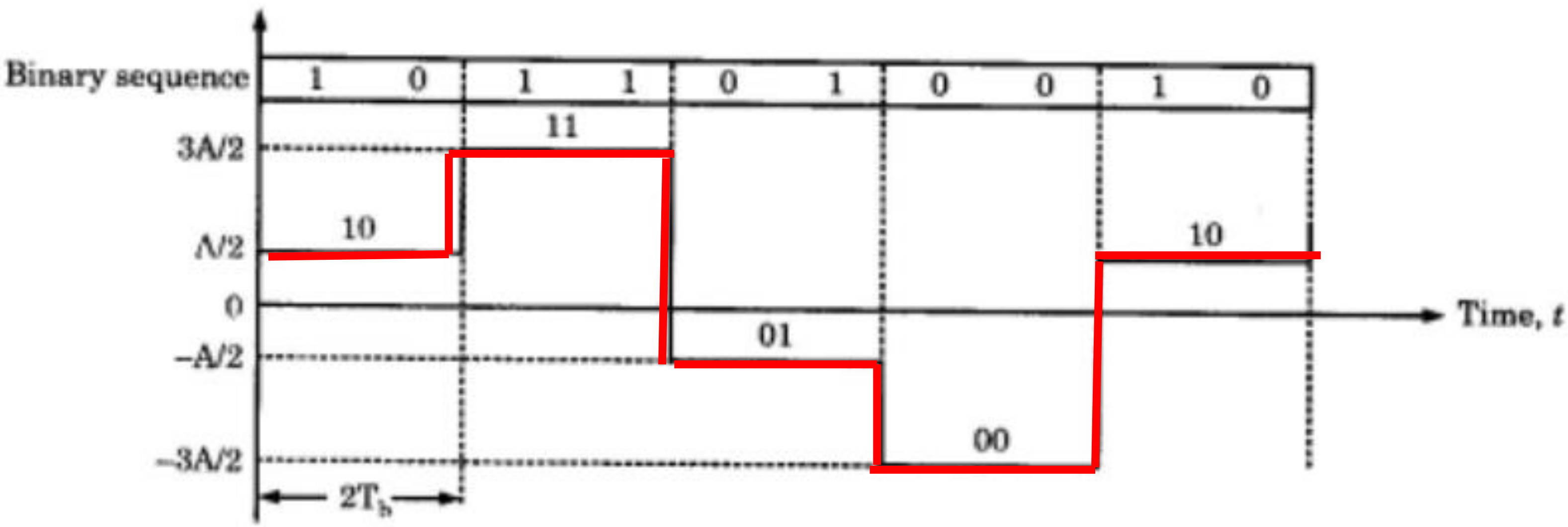


- For every two message bits, only one pulse is transmitted with duration $2T_b$

HIGH DENSITY BIPOLAR (HDB) SIGNALLING(1)

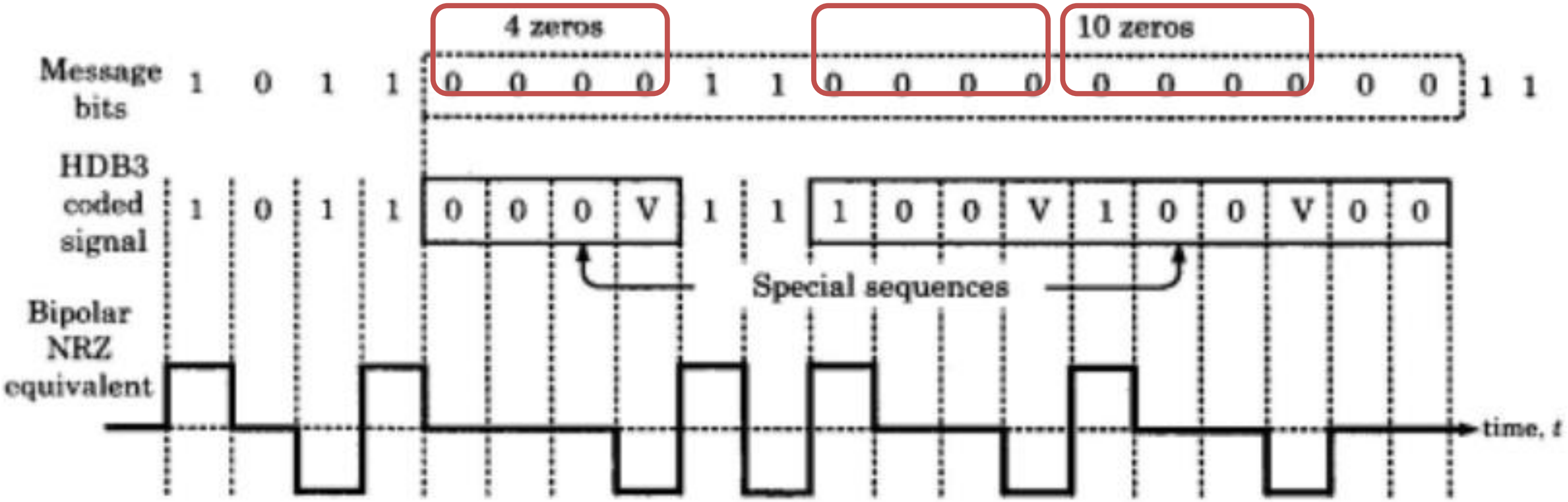
1. In the case of Bipolar NRZ or AMI, the signal is equal to zero when a binary ‘0’ is transmitted.
2. The same applies to Unipolar RZ and Unipolar NRZ.
3. The absence of a transmitted signal causes problems of synchronization when a long sequence of 0’s is to be received.
4. The problem is solved by adding pulses when long strings of zeros exceeding **N** are to be transmitted.
5. This type of coding is called High Density Bipolar Coding or Simply HDBN where **N = 1,2,3**.
6. The most commonly used HDB format is with N=3 or HDB3.

HIGH DENSITY BIPOLAR (HDB) SIGNALLING(2)

1. If in a message string bits N+1 consecutive ‘0’ bits occurs, they are replaced by a special binary sequence of N+1 bits.

2. This special binary sequence contains some ‘1’s which is necessary in for synchronization at the receiver.

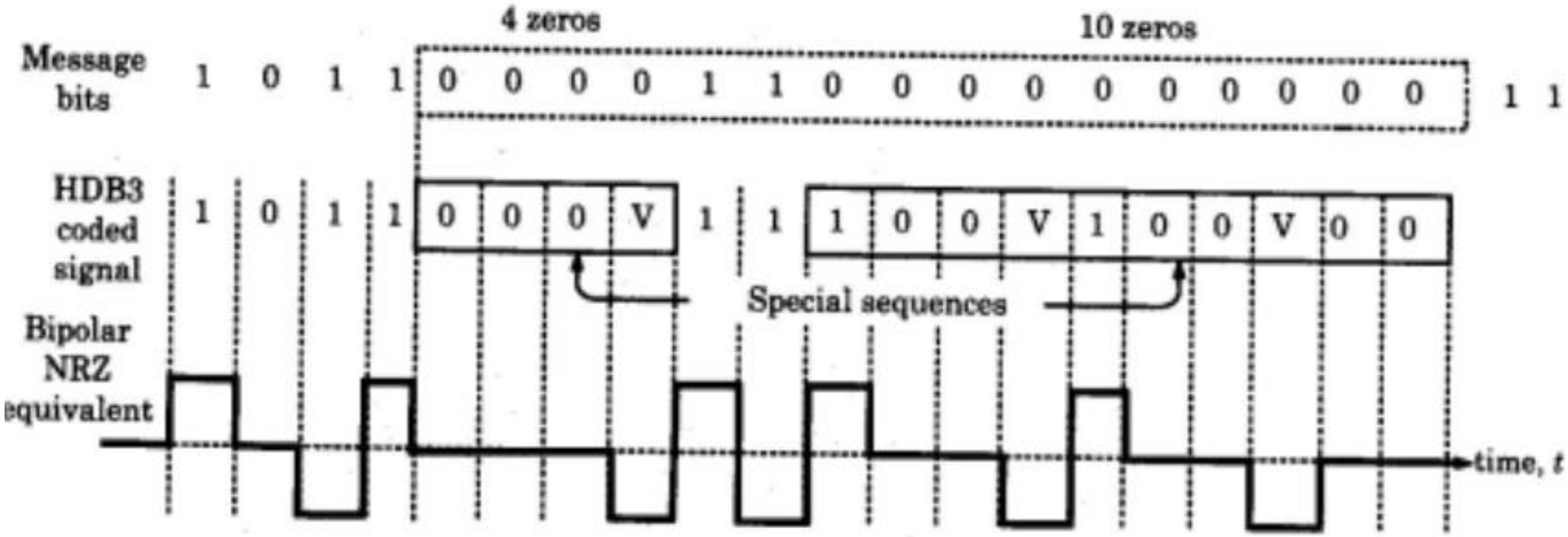
3. HDB3 uses 000V and B00V where both B and V are considered as ‘1’s.



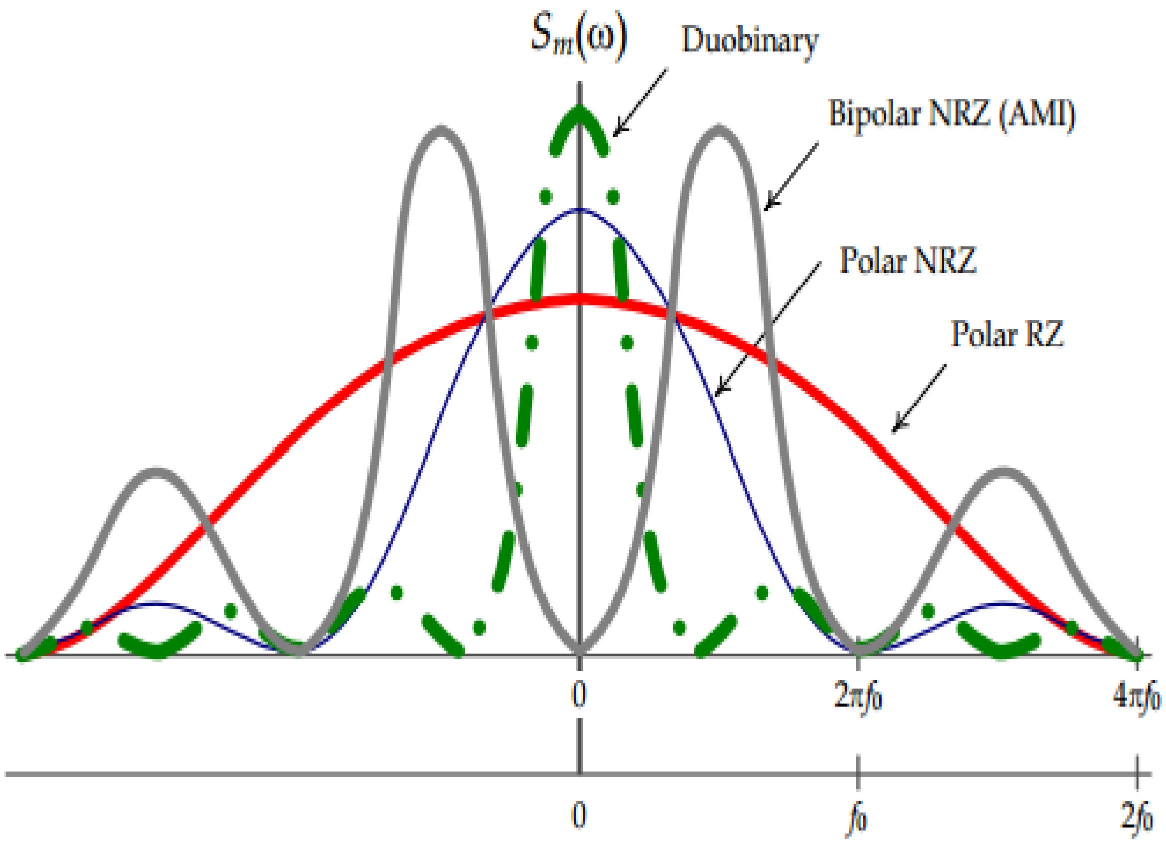
BINARY EIGHT ZERO SUPPRESSION (B8ZS) LINE CODE(1)

1. In order to have synchronization between the transmitter and the receiver, the line coded signal needs to cross the zero line frequently.
2. In the T_1 standard, for instance, no more that 15 zeros can be transmitted in succession.
3. **Binary Eight Zero Suppression (B8ZS)** line code was developed where if 8 zeros are detected in a message, a special 8-bit sequence containing bipolar violation is inserted

BINARY EIGHT ZERO SUPPRESSION (B8ZS) LINE CODE(1)



BANDWIDTH REQUIREMENTS OF VARIOUS LINE CODING SCHEMES



Line Code	Bandwidth
Unipolar NRZ	f_0
Unipolar RZ	$2\ f_0$
Polar NRZ	f_0
Polar RZ	$2\ f_0$
Bipolar NRZ	f_0
Duobinary	$f_0\ /\ 2$

COMPARISON OD VARIOUS LINE CODING SCHEMES

1. The various line coding schemes can be compared in accordance to:
    - a) Transmission of DC Component
    - b) Signalling rate
    - c) Noise Immunity
    - d) Synchronizing capability
    - e) Bandwidth requirements
    - f) Crosstalk

COMPARISON OF PERFORMANCE OF VARIOUS LINE CODES

PARAMETER	POLAR RZ	POLAR NRZ	AMI	MANCHESTER	POLAR QUATERNARY NRZ
Transmission of DC Component	Yes	Yes	No	No	Possible
Signalling Rate	$1/T_b$	$1/T_b$	$1/T_b$	$1/T_b$	$1/(2T_b)$
Noise Immunity	Low	Low	High	High	High
Synchronization Capability	Poor	Poor	Very Good	Very Good	Poor
Bandwidth Requirements	$1/T_b$	$1/T_b$	$1/T_b$	$1/T_b$	$1/(2T_b)$
Cross-talk	High	High	Low	Low	Low

EXAMPLE 1: LINE ENCODING

Encode the following data stream into

(i) Binary Return to Zero (RZ),

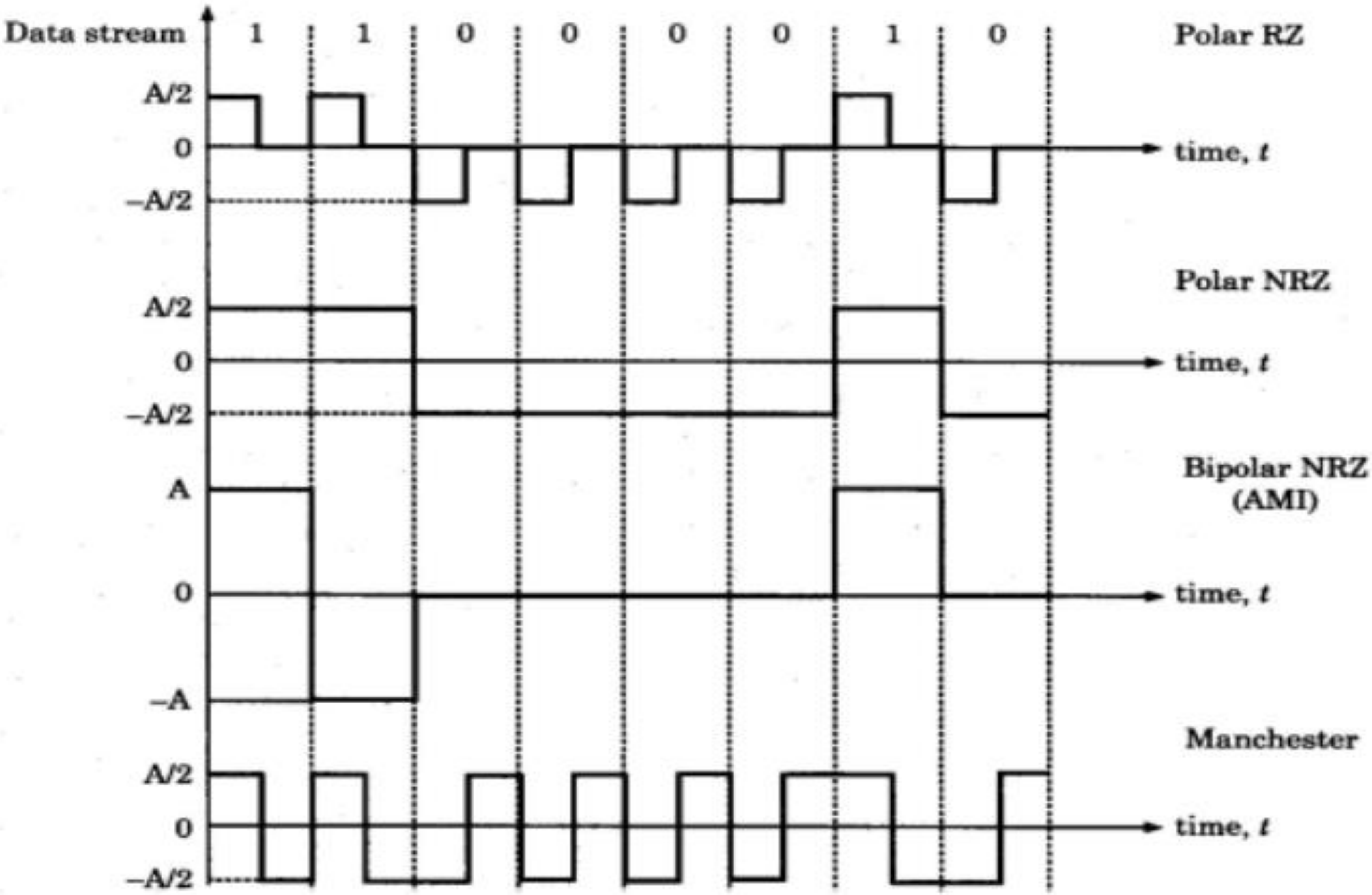
(ii) Non-return to zero (NRZ),

(iii)AMI and

(iv) Manchester.

11000010

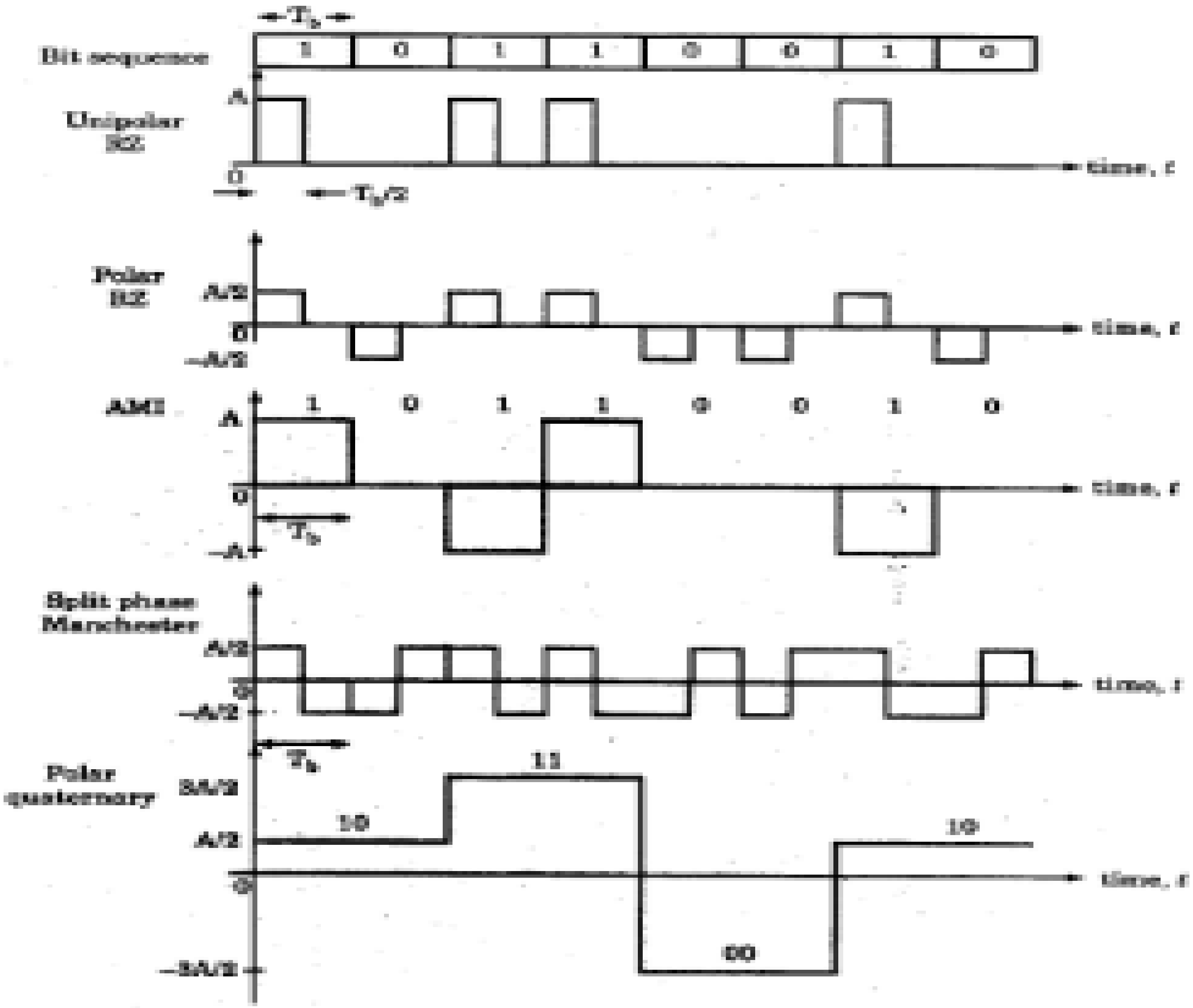
SOLUTION-EXAMPLE 1



EXAMPLE 2: LINE CODING

2. Given a bit sequence 10110010, draw the resulting waveform if the waveform is transmitted using:
   - (i) Unipolar RZ
   - (ii) Polar RZ
   - (iii) AMI
   - (iv) Split phase Manchester
   - (v) M-ary where M=4 or Polar Quaternary

SOLUTION EXAMPLE 2



SUMMARY - SOURCE CODING Vs CHANNEL (LINE) CODING

1. Source coding techniques, e.g. PCM and Delta Modulation are used to convert analogue signals to digital form.
2. Channel/Line coding techniques convert binary digits into another code which is more suitable to transmit over the channel/media.
3. Line coding must satisfy such requirements as:
   - (i) no DC component,
   - (ii) Ability to extract synchronization,
   - (iii) low crosstalk, and
   - (iv) low bandwidth.

GENERALIZED COMMUNICATION SYSTEM

Not present for baseband communication systems, e.g. Ethernet or PDH