Transmission of Digital Signal

Specific Instructional Objective

On completion, the students will be able to:

- Explain the need for digital transmission
- Explain the basic concepts of Line Coding
- Explain the important characteristics of line coding
- Distinguish among various line coding techniques
    - Unipolar
    - Polar
    - Bipolar

2.4.1 Introduction

A computer network is used for communication of data from one station to another station in the network. We have seen that analog or digital data traverses through a communication media in the form of a signal from the source to the destination. The channel bridging the transmitter and the receiver may be a guided transmission medium such as a wire or a wave-guide or it can be an unguided atmospheric or space channel. But, irrespective of the medium, the signal traversing the channel becomes attenuated and distorted with increasing distance. Hence a process is adopted to match the properties of the transmitted signal to the channel characteristics so as to efficiently communicate over the transmission media. There are two alternatives; the data can be either converted to digital or analog signal. Both the approaches have pros and cons. What to be used depends on the situation and the available bandwidth.

Now, either form of data can be encoded into either form of signal. For digital signalling, the data source can be either analog or digital, which is encoded into digital signal, using different encoding techniques.

The basis of analog signalling is a constant frequency signal known as a *carrier signal*, which is chosen to be compatible with the transmission media being used, so that it can traverse a long distance with minimum of attenuation and distortion. Data can be transmitted using these carrier signals by a process called *modulation*, where one or more fundamental parameters of the carrier wave, i.e. amplitude, frequency and phase are being modulated by the source data. The resulting signal, called *modulated signal* traverses the media, which is *demodulated* at the receiving end and the original signal is extracted. All the four possibilities are shown in Fig. 2.4.1.

Data	Signal	Approach
Digital	*Digital*	*Encoding*
Analog	*Digital*	*Encoding*
Analog	*Analog*	*Modulation*
Digital	*Analog*	*Modulation*

Figure 2.4.1 *Various approaches for conversion of data to signal*

This lesson will be concerned with various techniques for conversion digital and analog data to digital signal, commonly referred to as **encoding** techniques.

2.4.2 Line coding characteristics

The first approach converts digital data to digital signal, known as line coding, as shown in Fig. 2.4.2. Important parameters those characteristics line coding techniques are mentioned below.

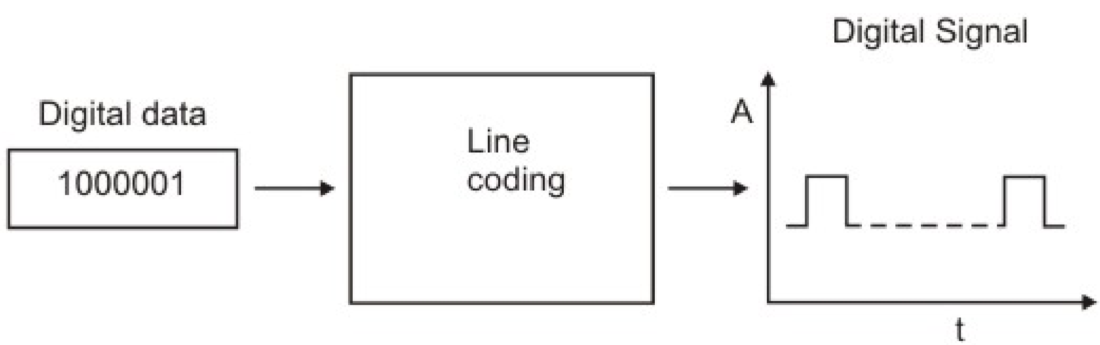


Figure 2.4.2 *Line coding to convert digital data to digital signal*

No of signal levels: This refers to the number values allowed in a signal, known as s**ignal levels**, to represent data. Figure 2.4.3(a) shows two signal levels, whereas Fig. 2.4.3(b) shows three signal levels to represent binary data.

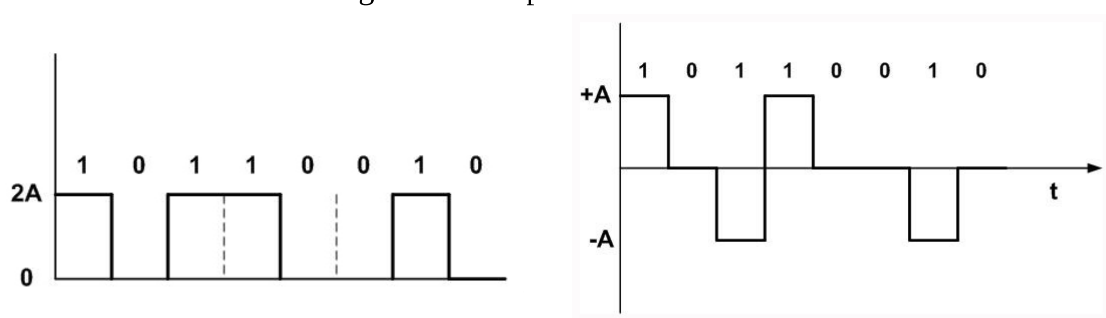
Bit rate versus Baud rate: The **bit rate** represents the number of bits sent per second, whereas the **baud rate** defines the number of signal elements per second in the signal. Depending on the encoding technique used, baud rate may be more than or less than the data rate.

DC components: After line coding, the signal may have zero frequency component in the spectrum of the signal, which is known as the direct-current **(DC) component**. DC component in a signal is not desirable because the DC component does not pass through some components of a communication system such as a transformer. This leads to distortion of the signal and may create error at the output. The DC component also results in unwanted energy loss on the line.

Signal Spectrum: Different encoding of data leads to different spectrum of the signal. It is necessary to use suitable encoding technique to match with the medium so that the signal suffers minimum attenuation and distortion as it is transmitted through a medium.

Synchronization: To interpret the received signal correctly, the bit interval of the receiver should be exactly same or within certain limit of that of the transmitter. Any mismatch between the two may lead wrong interpretation of the received signal. Usually, clock is generated and synchronized from the received signal with the help of a special hardware known as Phase Lock Loop (PLL). However, this can be achieved if the received signal is self-synchronizing having frequent transitions (preferably, a minimum of one transition per bit interval) in the signal.

Cost of Implementation: It is desirable to keep the encoding technique simple enough such that it does not incur high cost of implementation.



(a) (b)

Figure 2.4.3 *(a) Signal with two voltage levels, (b) Signal with three voltage levels*

2.4.3 Line Coding Techniques

Line coding techniques can be broadly divided into three broad categories: Unipolar, Polar and Bipolar, as shown in Fig. 2.4.4.

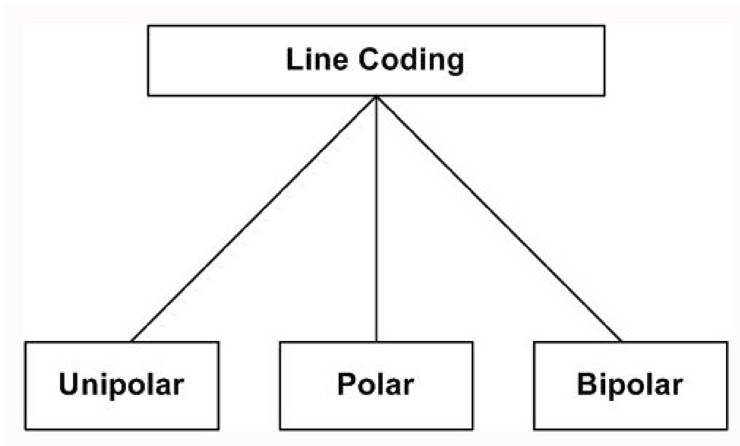


Figure 2.4.4 *Three basic categories of line coding techniques*

Unipolar: In unipolar encoding technique, only two voltage levels are used. It uses only one polarity of voltage level as shown in Fig. 2.4.5. In this encoding approach, the bit rate same as data rate. Unfortunately, DC component present in the encoded signal and there is loss of synchronization for long sequences of 0's and 1's. It is simple but obsolete.

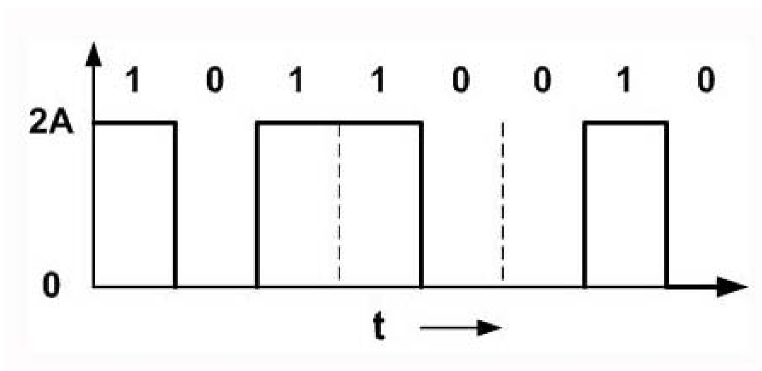


Figure 2.4.5 *Unipolar encoding with two voltage levels*

Polar: Polar encoding technique uses two voltage levels – one positive and the other one negative. Four different encoding schemes shown in Fig. 2.4.6 under this category discussed below:

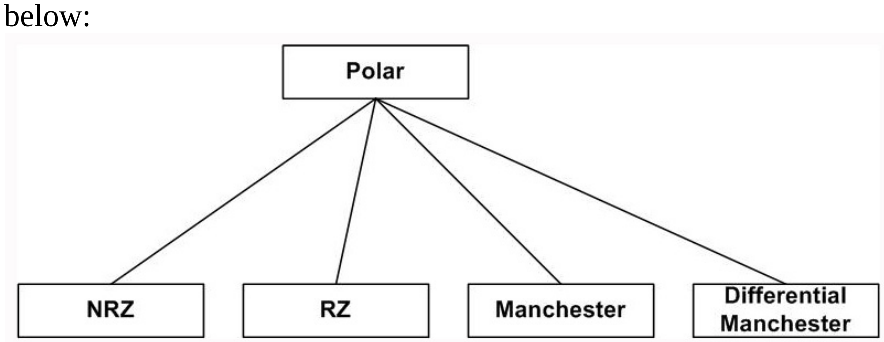
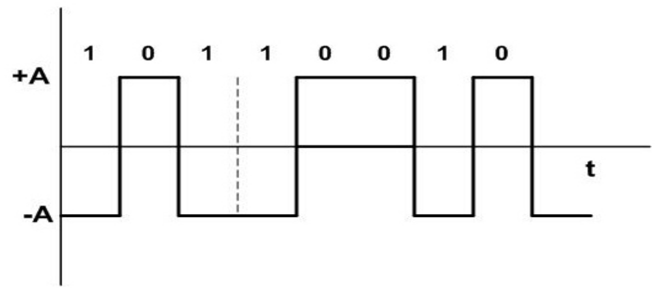
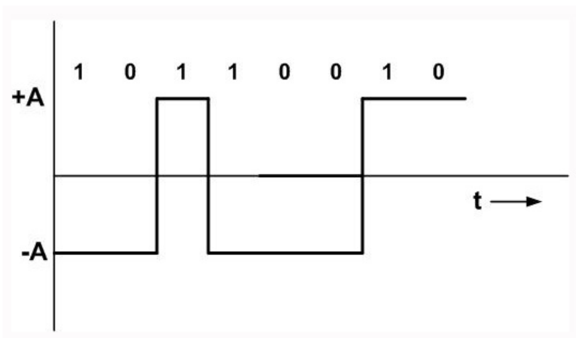


Figure 2.4.6 *Encoding Schemes under polar category*

Non Return to zero (NRZ): The most common and easiest way to transmit digital signals is to use two different voltage levels for the two binary digits. Usually a negative voltage is used to represent one binary value and a positive voltage to represent the other. The data is encoded as the presence or absence of a signal transition at the beginning of the bit time. As shown in the figure below, in NRZ encoding, the signal level remains same throughout the bit-period. There are two encoding schemes in NRZ: NRZ-L and NRZ-I, as shown in Fig. 2.4.7.



NRZ – L
1 = low level
0 = high level



NRZ – I

- ***For each 1 in the bit sequence, the signal level is inverted.***
- ***A transition from one voltage level to the other represents a 1.***

Figure 2.4.7 *NRZ encoding scheme*

The **advantages** of NRZ coding are:

- Detecting a transition in presence of noise is more reliable than to compare a value to a threshold.
- NRZ codes are easy to engineer and it makes efficient use of bandwidth.

The spectrum of the NRZ-L and NRZ-I signals are shown in Fig. 2.4.8. It may be noted that most of the energy is concentrated between 0 and half the bit rate. The main limitations are the presence of a dc component and the lack of synchronization capability. When there is long sequence of 0’s or 1’s, the receiving side will fail to regenerate the clock and synchronization between the transmitter and receiver clocks will fail.

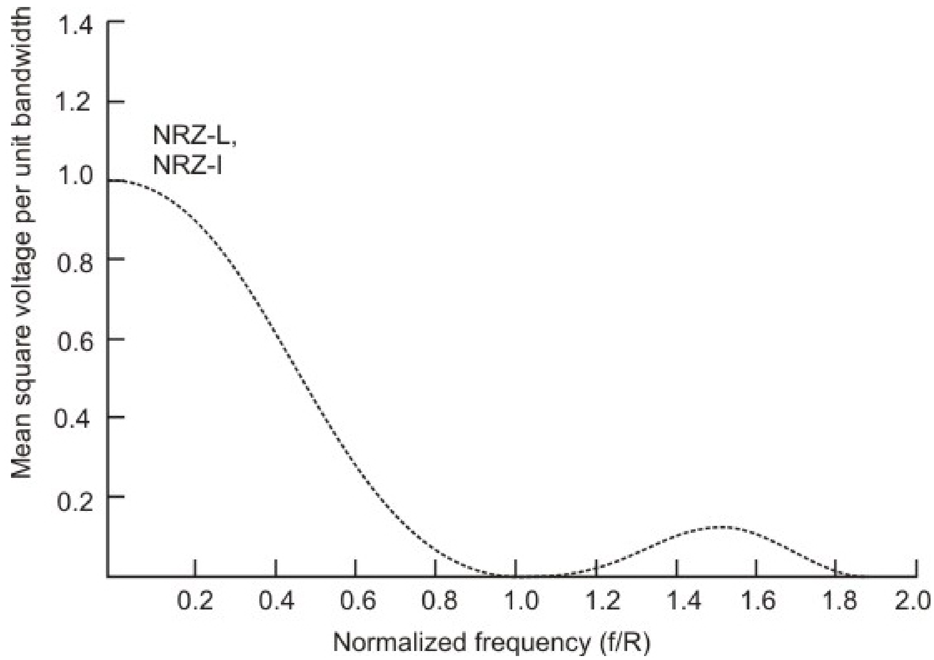


Figure 2.4.8 Signal spectrum of NRZ signals

Return to Zero RZ: To ensure synchronization, there must be a signal transition in each bit as shown in Fig. 2.4.9. Key characteristics of the RZ coding are:

- Three levels
- Bit rate is double than that of data rate
- No dc component
- Good synchronization
- Main limitation is the increase in bandwidth

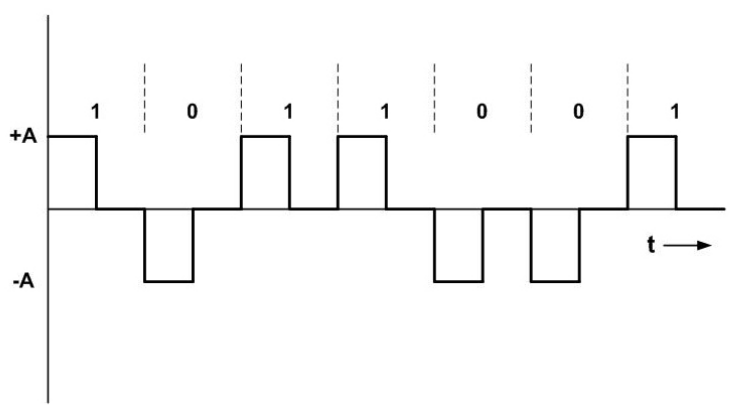


Figure 2.4.9 *RZ encoding technique*

Biphase: To overcome the limitations of NRZ encoding, biphase encoding techniques can be adopted. *Manchester* and *differential Manchester Coding* are the two common Biphase techniques in use, as shown in Fig. 2.4.10. In Manchester coding the mid-bit transition serves as a clocking mechanism and also as data.

In the standard Manchester coding there is a transition at the middle of each bit period. A binary 1 corresponds to a *low-to-high transition* and a binary 0 to a *high-to-low transition* in the middle.

In Differential Manchester, inversion in the middle of each bit is used for synchronization. The encoding of a 0 is represented by the presence of a transition both at the beginning and at the middle and 1 is represented by a transition only in the middle of the bit period.

Key characteristics are:

- Two levels
- No DC component
- Good synchronization
- Higher bandwidth due to doubling of bit rate with respect to data rate

The bandwidth required for biphase techniques are greater than that of NRZ techniques, but due to the predictable transition during each bit time, the receiver can synchronize properly on that transition. Biphase encoded signals have no DC components as shown in Fig. 2.4.11. A Manchester code is now very popular and has been specified for the IEEE 802.3 standard for base band coaxial cables and twisted pair CSMA/CD bus LANs.

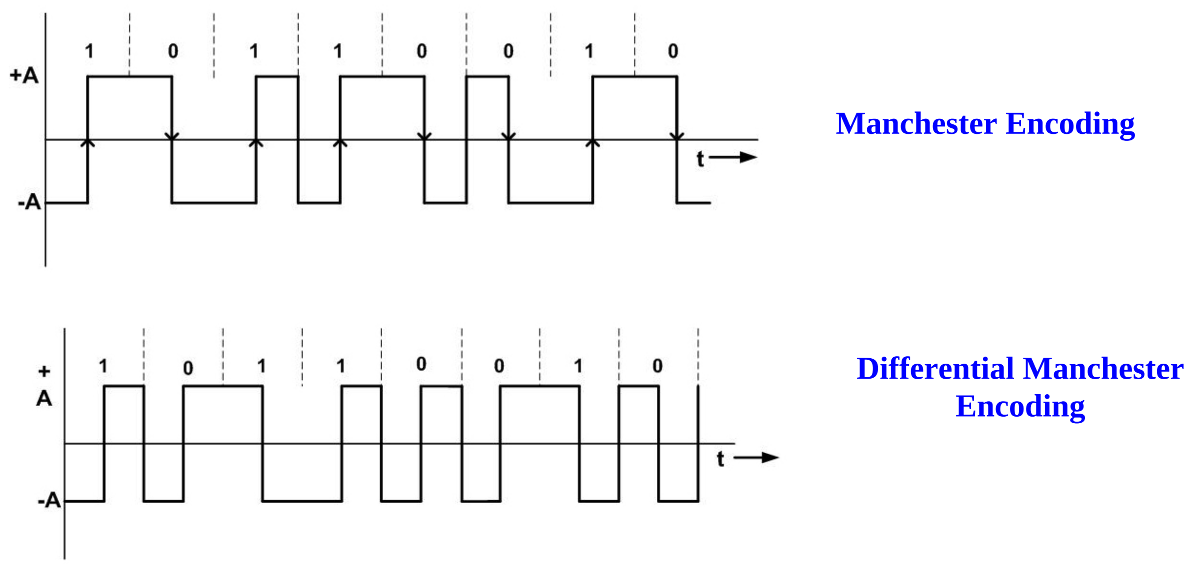


Figure 2.4.10 *Manchester encoding schemes*

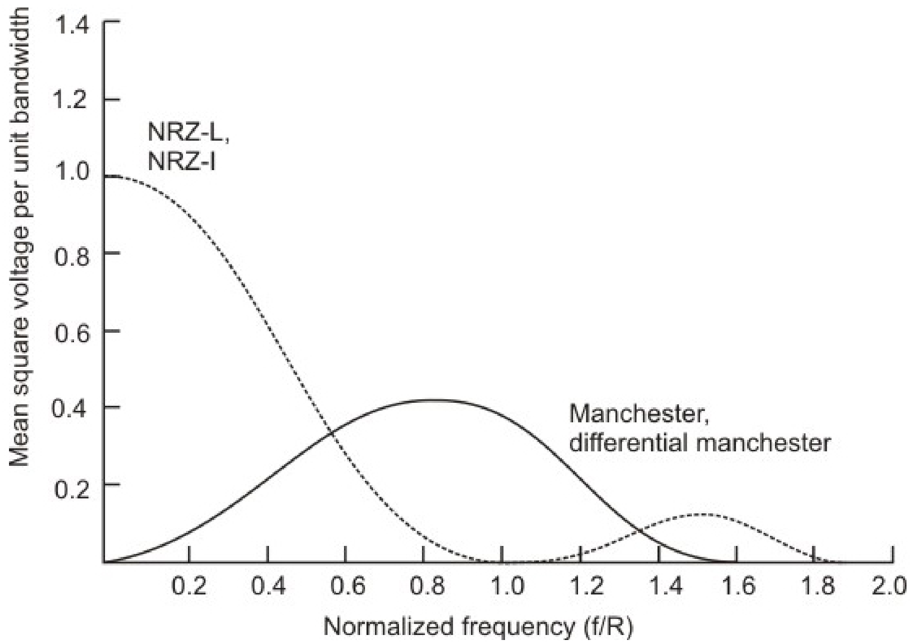


Figure 2.4.11 *Frequency spectrum of the Manchester encoding techniques*

Bipolar Encoding: Bipolar AMI uses three voltage levels. Unlike RZ, the zero level is used to represent a 0 and a binary 1's are represented by alternating positive and negative voltages, as shown in Fig 2.4.12.

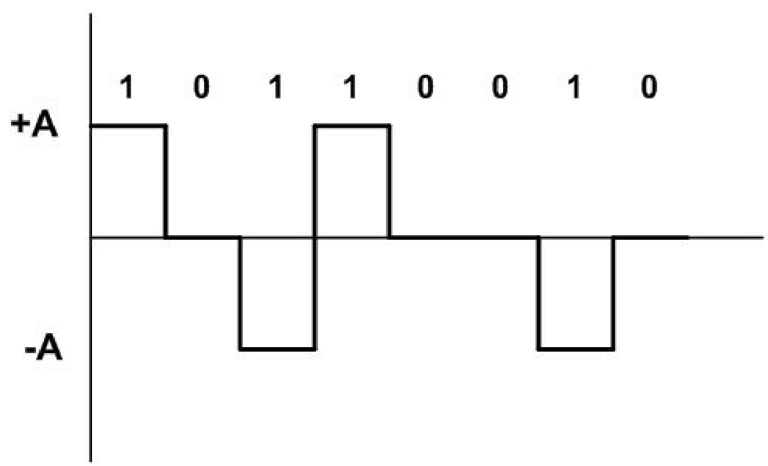


Figure 2. 4.12 *Bipolar AMI signal*

Pseudoternary: *This encoding scheme is same as AMI, but alternating positive and negative pulses occur for binary 0 instead of binary 1. Key characteristics are:*

- Three levels
- No DC component
- Loss of synchronization for long sequences of 0's
- Lesser bandwidth

Modulation Rate: Data rate is expressed in bits per second. On the other hand, modulation rate is expressed in bauds. General relationship between the two are given below:

$$D = R / b = R / \log_2 L$$

Where, D is the modulation rate in bauds, R is the data rate in bps, L is the number of different signal elements and b is the number of bits per signal element. Modulation rate for different encoding techniques is shown in Fig. 2.4.13.

Encoding Technique	Minimum	101010 . . .	Maximum
NRZ-L	0	1.0	1.0
NRZ-I	0	0.5	1.0
BIPOLAR-AMI	0	1.0	1.0
Manchester	1.O	1.0	2.0
Differential Manchester	1.0	1.5	2.0

Figure 2.4.13 *Modulation rate for different encoding techniques*

Frequency spectrum of different encoding schemes have been compared in Fig. 2.4.14.

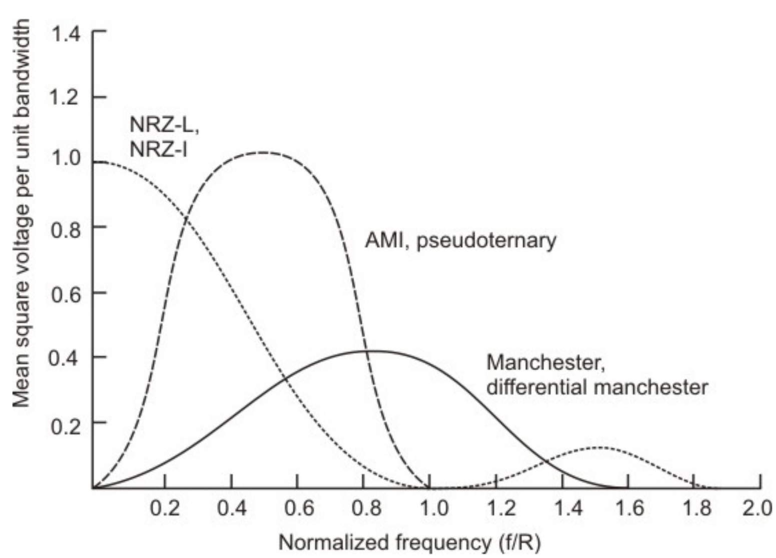


Figure 2.4.14 *Frequency spectrum of different encoding schemes*

Scrambling Schemes: *Extension of Bipolar AMI. Used in case of long distance applications. Goals:*

- No dc component
- No long sequences of 0-level line signal
- No increase in bandwidth
- Error detection capability
- Examples: B8ZS, HBD3

Bipolar with 8-zero substitution (B8ZS): *The limitation of bipolar AMI is overcome in B8ZS, which is used in North America. A sequence of eight zero's is replaced by the following encoding*

A sequence of eight 0's is replaced by 000+ - 0 + -, if the previous pulse was positive**.**
A sequence of eight 0's is replaced by 000 - + 0 + -, if the previous pulse was negative

High Density Bipolar-3 Zeros: *Another alternative, which is used in Europe and Japan is HDB3. It replaces a sequence of 4 zeros by a code as per the rule given in the following table. The encoded signals are shown in Fig. 2.4.15.*

HDB3 substitution rule		
Polarity of the Preceding pulse	Number of bipolar pulses (ones) since last substitution	
	odd	even
−	000 −	+ 00 +
+	000 +	− 00 −

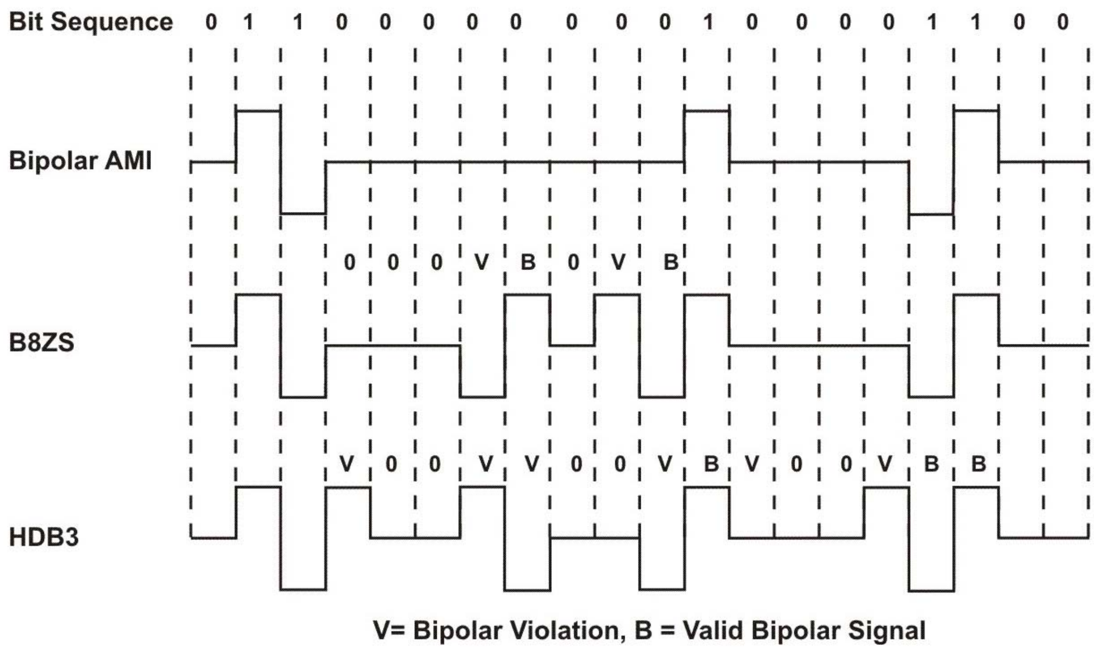


Figure 2.4.15 *B8ZS and HDB3 encoding techniques*