Module -31

Line Coding

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Learning outcome –

After studying this module, you will be able to:

1. Understand the Concept of Line Coding
2. Learn the characteristics of Line Coding
3. Understand the requirements of Line Coding
4. Distinguish among different line coding techniques
5. Comparison of the various line coding techniques

1. Introduction

The long haul communication systems typically involve serial transmission of data either synchronous or asynchronous. Such serial transmission of data over the coaxial cables, optical fiber or RF link requires the suitable encoding of binary data so that highs and lows in the signal can be detected appropriately. Also the signal during transmission through any type of communication channel wired or wireless suffers from attenuation and distortion, which is more severe in long haul data transmission channel. Hence for efficient communication, tuning the signal properties to the characteristics of physical channel is necessary.

Information to be transmitted can be encoded in either digital or analog signal using different encoding techniques.

Line coding refers to the process of converting a sequence of binary digits i.e., bits or digital data into a digital signal. Line coding is implemented for digital transmission of binary information. As seen in fig 1, at the sending end digital data are encoded into a digital signal and at the receiving end original digital data is recovered by decoding the digital signal.

Data are encoded in a way that the timing information of the bit stream is maintained and the logic levels 1's and 0's can be detected.

The major application of line coding in data communication is to perform base band modulation of the digital data.

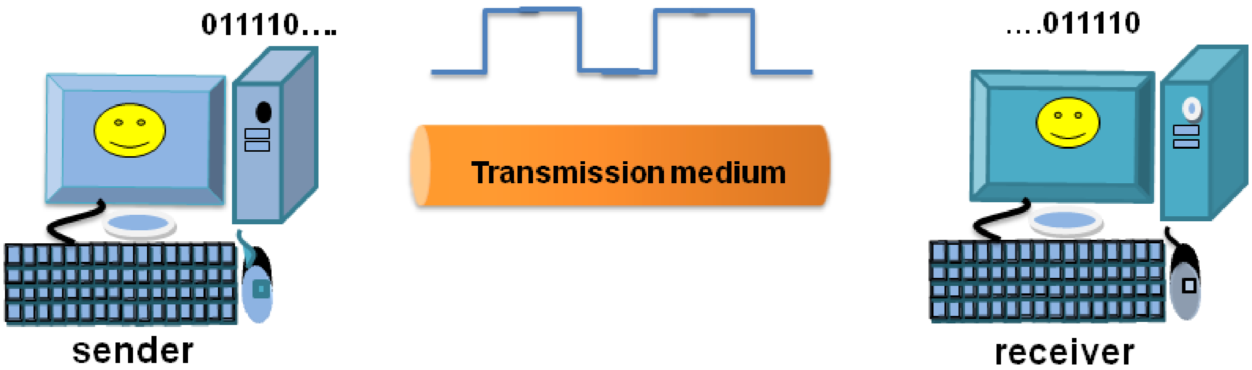

Figure 1: Line coding

2. Characteristics of Line Coding

The common characteristics of line coding are mentioned in Fig 2:

- Data Rate
- Signal Rate or Baud Rate
- Bandwidth
- DC components
- Baseline wandering
- Self Synchronization
- Error Detection
- Noise Immunity
- Complexity and implementation cost

Figure 2: Line Coding Characteristics

1. **Data Rate:** It represents the number of data bits transmitted per second. The unit is bits per second. The data rate should be increased to increase the data transmission speed.
2. **Signal Rate or Baud Rate**: Baud rate is the measure of signaling element or symbols sent per second. A symbol in some case could be a binary logic level 0 or 1. In that case, baud rate is equal to bit rate. In other cases, the symbol is one of the several discrete signal amplitudes or phase shifts each representing two or more data bits. The unit is baud. Baud rate can be more or less than the data rate. The signal rate should be decreased to decrease the bandwidth requirements.
3. **Bandwidth**: Bandwidth is the frequency range over which an information signal is transmitted. It dictates the amount of data sent over time and influences the choice of digital modulation scheme. Digital signal has theoretically infinite bandwidth but practically the effective bandwidth is finite. The baud rate determines the digital signal bandwidth required.
4. **DC components**: Very low frequencies around zero which are the consequence of existence of constant voltage level in a digital signal are known as Direct current or DC components. These components significantly induce problems in the systems using transformer coupling and since most channels are band pass, they may not support the low frequency signals. Hence line coding schemes with no DC components are required for such systems.
5. **Baseline wandering**: A receiver will evaluate the average power of the received signal (called the baseline) and use that to determine the value of the incoming data elements. If the incoming signal does not vary over a long period of time, the baseline will drift and thus cause errors in detection of incoming data elements. A good line encoding scheme will prevent long runs of fixed amplitude.
6. **Self Synchronization:** The clocks at the sender and the receiver must have the same bit interval. If the receiver clock is faster or slower it will misinterpret the incoming bit stream. A transmitted self synchronizing digital signal includes timing information in the data. Clock signal is recovered from the receiving bit sequence by observing the transitions and if sufficient transitions exist, a good recovery of the clock is guaranteed. Such a signal is said to be self-clocking.
7. **Error Detection:** Ideally digital communication system should be free from any error that gets incorporated into the data during transmission. Hence it is desirable to implement some modifications in the data allowing built in error detection capabilities. This can enhance the receiver's capability to detect and correct error. The transmission system used and adopted digital encoding techniques influence the error detection and correction.

8. **Noise Immunity:** The selected encoding scheme should be immune to noise and external interferences. We are already aware that any signal during transmission through any type of communication channel suffers from attenuation and distortion. So the requirement is to encode the signal using an encoding scheme imparting high noise immunity.
9. **Complexity and implementation cost:** An encoding scheme that is complex, is costly to implement. Interpretation of any scheme that involves more signal levels is difficult. So the encoding technique should be simple so as to prevent high cost of implementation.

3. Various Line Coding Scheme:

Line codes are classified according to the assigned polarity of voltage levels to represent the binary data. We can categorize line coding schemes into three major types as shown in fig 3.

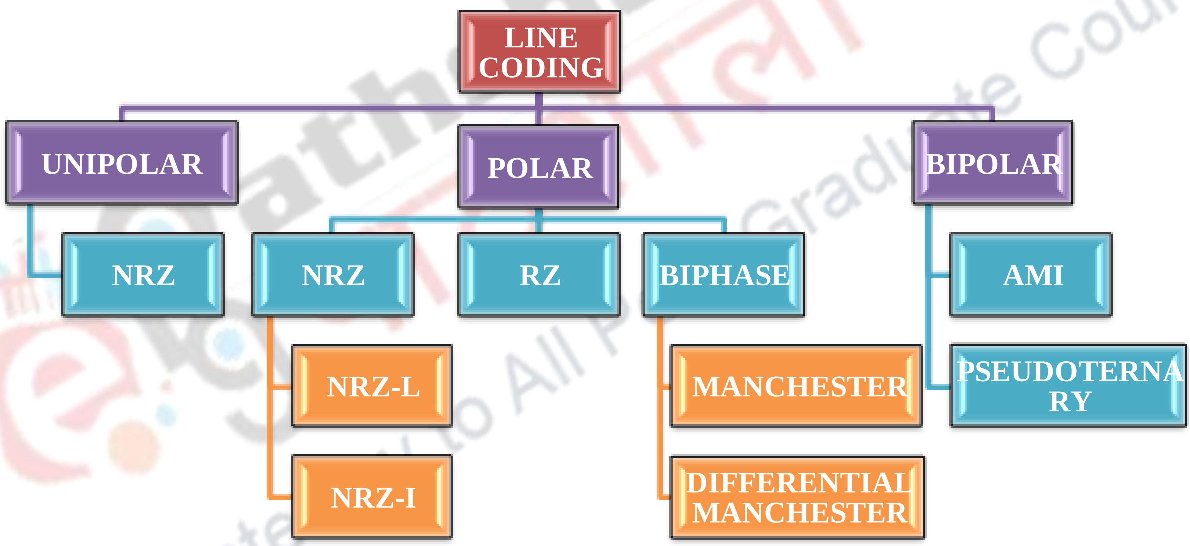

Figure 3: Line Coding Schemes

3.1 Unipolar line coding: This type of scheme makes use of one polarity of voltage to represent logic states. More precisely, positive voltage is used to represent a logic high state and an idle line or zero to represent low logic low state. Here the baud rate is same as the data rate. This encoding scheme, suffers from the disadvantage of having undesirable DC component present in the signal encoded and for long sequence of 0's and 1's there will be loss of synchronization. Though unipolar is a simple scheme, but it is not preferred for long haul communication. This type of line coding scheme is also called on–off keying (OOK). As shown in fig 4, unipolar line coding can be classified into two major types, Non Return to zero (NRZ) and Return to zero (RZ).

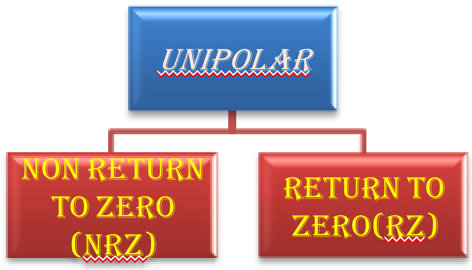

Figure 4: Unipolar Line Coding

3.1.1 Unipolar Non Return to zero (NRZ):

In NRZ line coding, logic 1 is represented by a non-zero voltage level, precisely a positive voltage and logic 0 is indicated by a zero voltage level as shown in fig 5. The signal level does not return to zero for the entire bit interval during the transmission of a signal. In unipolar NRZ encoding, the signal level remains constant throughout the bit-interval. The encoded signal has an undesirable DC component and lack of self synchronizing capabilities.

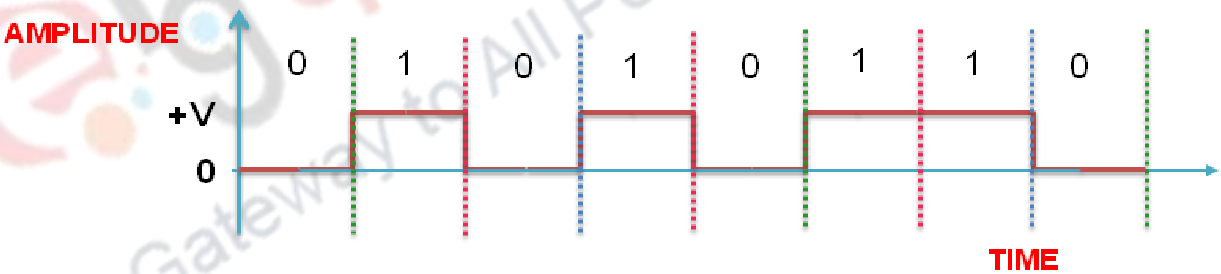

Figure 5: NRZ Line Coding

The main features of Unipolar NRZ are follows:

- Ease of generation, requires only a single power supply.
- Relatively low bandwidth
- The transmission normalized power for a single bit per unit line resistance is double than their polar counterparts.

- Prone to baseline wandering and DC components.
- It has no synchronization or any error detection.
- It is simple but costly in power consumption.
- Not used normally in data communication.

3.1.2 Unipolar Return to zero (RZ):

NRZ coding suffers from lack of synchronization, non-zero dc component and baseline wandering. To overcome the shortcomings of the NRZ, return to zero (RZ) code was developed.

This scheme like NRZ, also make use of only single voltage polarity with zero to determine the binary logic state. As shown in fig 6, in RZ line coding, logic 1 is represented by a non-zero voltage level, precisely a positive voltage during a portion of the bit interval and a transition to zero at the middle point of the bit interval. Logic 0 is indicated by a zero voltage level during the entire bit interval. Therefore a RZ signal pulse is only half the length of NRZ pulse. This implies that unipolar RZ requires twice the bandwidth of the NRZ code. The main advantage of unipolar RZ is, ease of generation since it implements a single power supply.

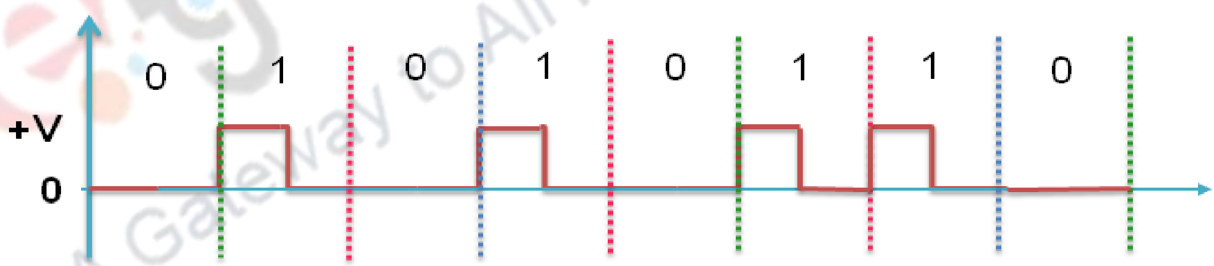

Figure 6: RZ Line Coding

Features:

- Ease of generation as it uses single power supply.
- More bandwidth requirement.
- It has a nonzero dc component leading to dc wandering.

- Along string of 0’s will lack pulse transitions and could lead to loss of synchronization.
- There is no error detection capability and, hence, performance monitoring is not possible.

3.2 Polar line coding:

This line encoding method uses two voltage levels of opposite polarity and equal magnitude that is, one positive and the other one negative to represent the two binary states 0 and 1. As shown in fig7, it can be classified into three major types, Non Return to zero (NRZ), Return to zero (RZ) and Biphase.

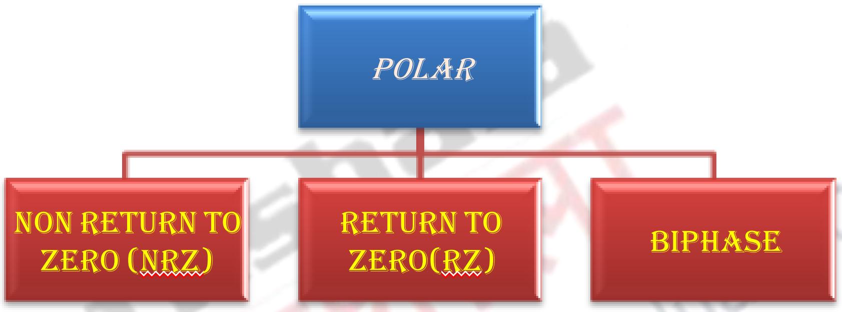

Figure 7: Polar Line Coding

3.2.1 Polar Non Return to zero (NRZ):

It is the most common and easy way to transmit binary data where a positive voltage level represents one bit and an equal magnitude negative voltage level represents the other. Also, here the signal level remains constant throughout the bit-interval. The average dc component is zero.

As the polar NRZ signal has more r.m.s value than their unipolar counterparts, they can carry more energy. This will aid in better signal to noise ratio at the receiving end. The drawback of polar NRZ, however, is that it lacks error detection capability when the transmitted signal has a long sequence of 0’s or 1’s. This problem is overcome in polar RZ signals, as the signal drops to zero in the middle of each bit interval.

The Polar NRZ code is used to transmit signals on a computer motherboard. It is also used Fiber-based Gigabit Ethernet.

There are two types of NRZ polar encoding schemes as seen in fig 8 namely, Non-Return-to-Zero-Level (NRZ-L) and Non-Return-to-Zero, Invert (NRZ-I).

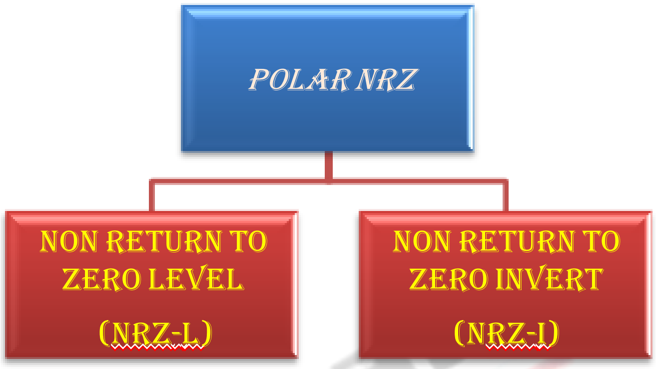

Figure 8: Polar NRZ Line Coding

Features:

- The average dc component is zero.
- Has more r.m.s value than unipolar NRZ, so can carry more energy.
- Better signal to noise ratio at the receiving end.
- Lacks error detection capability.

3.2.1.1 Non-Return-to-Zero, Level (NRZ-L)

In NRZ-L, the voltage level determines the bit value. Binary 1 is represented by a negative voltage and Binary 0 is represented by a positive voltage as shown in fig 9. This encoding scheme suffers from the issue of baseline wandering.

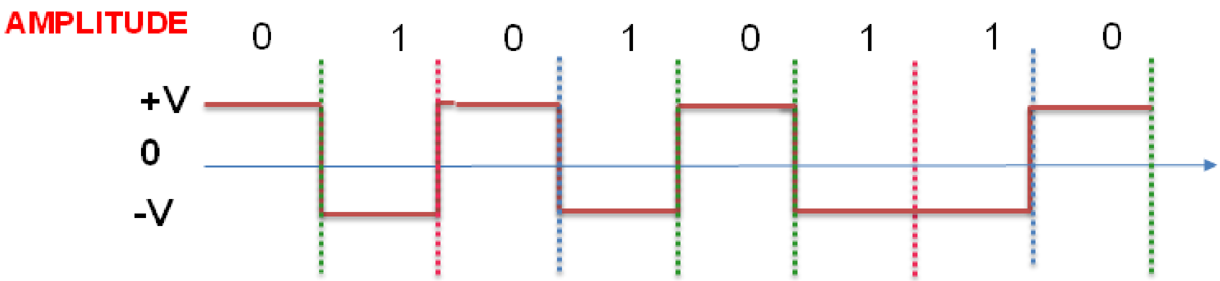

Figure 9: Polar NRZ-L Line Coding

One of the applications of NRZ-L is in the **RS-232 serial** port communication.

3.2.1.2 Non-Return-to-Zero, Invert (NRZ-I)

In NRZ-I, transition or no transition in the voltage level determines the bit logic. If the bit that is being transmitted is at logic 1, a transition from one voltage level to other takes place. If the transmitted bit is at logic 0 there is no transition of voltage level. When bit 1 arrives, the signal level is inverted, as seen in the fig. 10.

This is the code used on compact discs (CD), USB, and on fiber-based Fast Ethernet at 100-Mbit/s (100Base-FX).

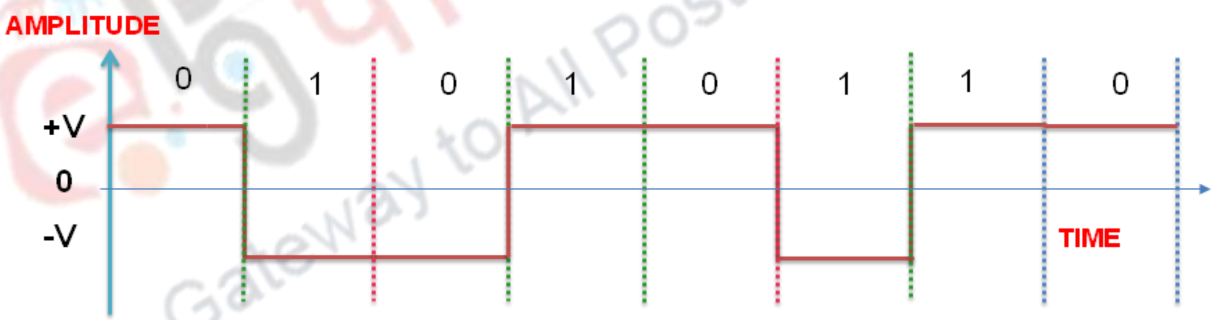

Figure 10: Polar NRZ-I Line Coding

3.2.2 Return-to-Zero (RZ)

The major limitation of the NRZ and unipolar RZ is the lack of synchronization between the transmitter and receiver clocks. This in turn does not allow the receiver to detect the end of one bit and start of the next bit in the received data stream. Also such encoded signals have non zero dc components. Such deficiencies are overcome by some modifications imparted to the coding scheme which involves the use of polar and bipolar signals.

A polar return to zero (RZ) has three voltage levels – positive, negative and zero to encode the data stream. This scheme requires two transitions per bit interval for data encoding. Hence the encoded signal requires higher bandwidth. Fig 11 shows the polar RZ encoding scheme. A transition from negative voltage to zero voltage level indicates logic 0, where as a transition from positive voltage to zero voltage level indicates logic 1.

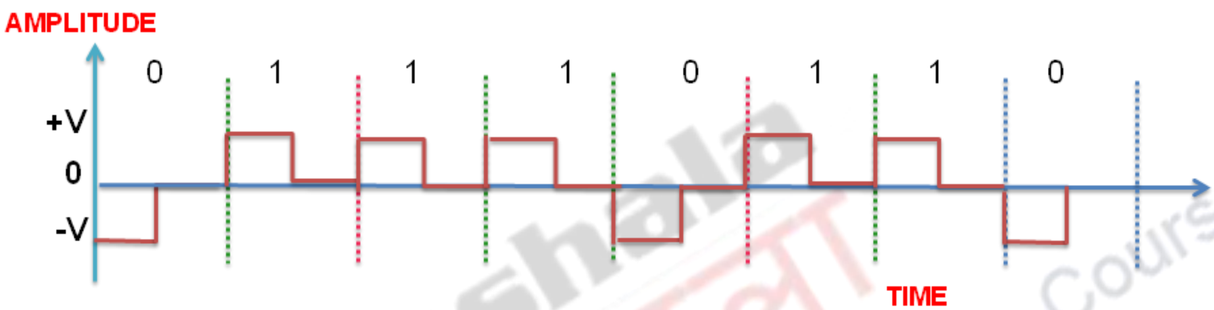

Figure 11: Polar RZ Line Coding

With the increase in the number of transitions, the synchronization between the transmitter and receiver is good leading to the self synchronizing capability. There is no dc component and baseline wandering problem in this scheme. One of the major issues with this scheme is the complexity in generating the code which incur due to the use of three voltage levels. Keeping in mind the deficiencies of this code, it has now been replaced by other efficient codes like Manchester and Differential Manchester.

3.2.3 Biphase Encoding Scheme

In order to overcome the limitations of NRZ encoding, biphase encoding techniques are used. The most common biphase techniques are *Manchester* and *Differential Manchester Coding*. Such encoding techniques are phase encoded code.

3.2.3.1 Manchester coding

This code uses two voltage levels, positive and negative of equal magnitude to represent logic states. Each bit of data is represented by at least one transition in the middle of the bit interval. During the first half of the bit interval, the signal pulse has one voltage level and in the second half, it moves to the other voltage level.

The code is also called biphase as it uses two phases, a signal pulse with a 0 phase is used to represent one binary logic and signal pulse with 180°phase to represent the other. It is a combination of *NRZ-L* and *RZ* schemes as shown in fig 12. Binary 0 is represented by a high to low voltage transition at the mid bit interval. Binary 1 is indicated by a low to high voltage transition at the mid bit interval.

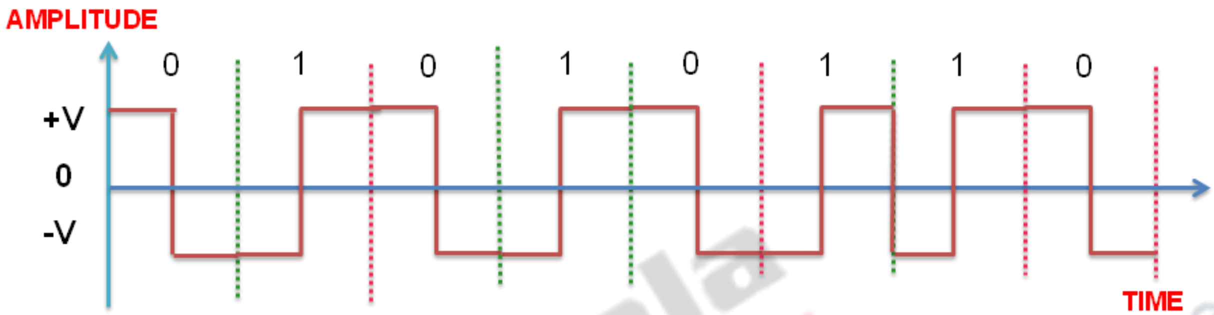

Figure 12: Manchester Line Coding

Since each data bit is represented by at least one mid bit transition, it has the ability of self synchronization allowing easy clock recovery of clock at the receiving end from the data stream. Also no DC component is present in the encoded signal.

The major disadvantage of this type of coding is the requirement of a higher bandwidth which is almost twice of *unipolar or polar NRZ.*

Manchester coding is used Ethernet based local area networks.

3.2.3.2 Differential Manchester coding

Like Manchester coding, it uses two voltage levels to represent logic states as shown in fig 13. Each bit of data is represented by at least one transition in the middle of the bit interval. The bit value at the beginning of the bit interval determines the logic state. The code also uses two phases to represent binary logic states as is used in Manchester coding. It is a combination of *NRZ-I and RZ* schemes. It has the ability of self synchronization, dc component is absent in the encoded signal. It requires twice of *unipolar or polar NRZ* bandwidth.

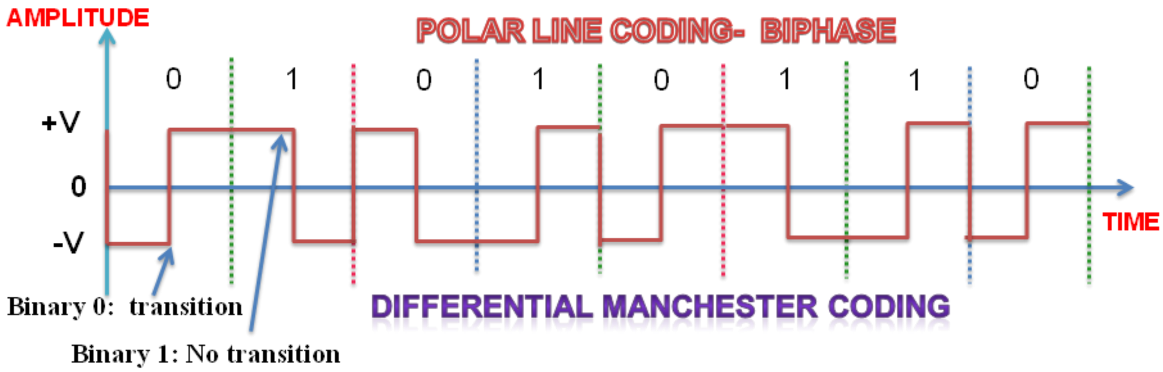

Figure 13: Differential Manchester Line Coding

Differential Manchester coding is utilized in token ring network, in magnetic and optical storage.

3.3 Bipolar line coding

A bipolar encoding uses a three-voltage-level signal positive, negative and zero to represent logic states. Bipolar signals may be RZ or NRZ. The presence of alternating code in this encoding prevents the build-up of a DC voltage in transmission lines.

The existence of long sequence of 0's and 1's produces no transitions in the data stream, and therefore the loss of synchronization arises. Here, there is no mid bit transition. Hence lesser bandwidth is required.

The most common bipolar encoding techniques as shown fig 14 are alternate mark inversion (AMI) and Pseudoternary coding.

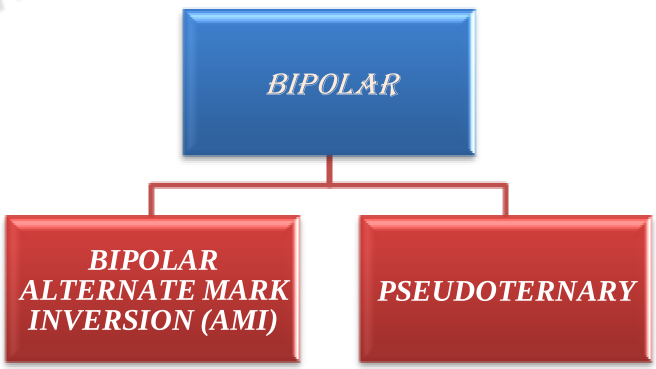

Figure 14: Bipolar Line Coding

3.3.1` Alternate mark inversion (AMI)

Bipolar AMI - Amplitude Mark Inversion coding technique uses three voltage levels- positive, negative and zero to represent the binary states. One logic state is represented by zero level and the other alternates between positive and negative voltage level. As seen in the fig 15, unlike Return to Zero, zero level represent binary 0 while binary 1 alternates between positive and negative voltage level. Hence this code is known as Alternate Mark Inversion.

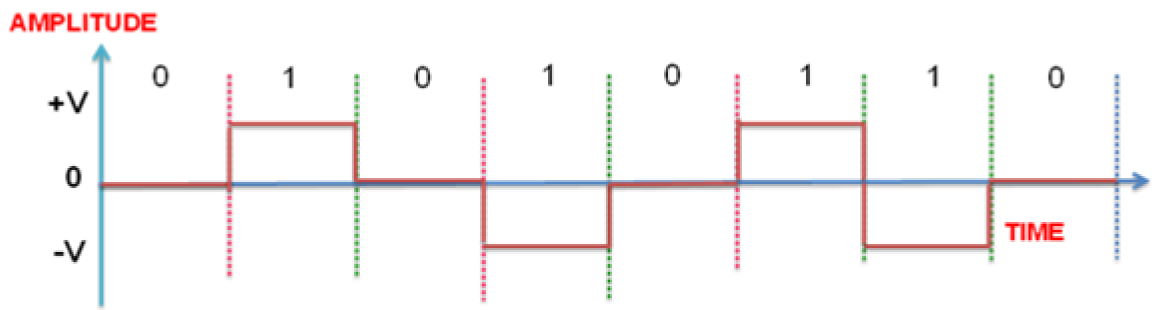

Figure 15: Alternate mark inversion (AMI)

In AMI, long run of 0's produces no transitions in the data stream and a loss of synchronization is possible. AMI coding was used in first-generation digital telephony PCM networks.

3.3.2 Pseudoternary coding:

The term Pseudoternary refers to the use of 3 encoded signal levels to represent two–level (binary) data. The alternating positive and negative pulses represent binary 0. As seen from the fig 16, first binary zero is indicated by +V and second binary zero by –V. Pseudoternary is the reverse of AMI.

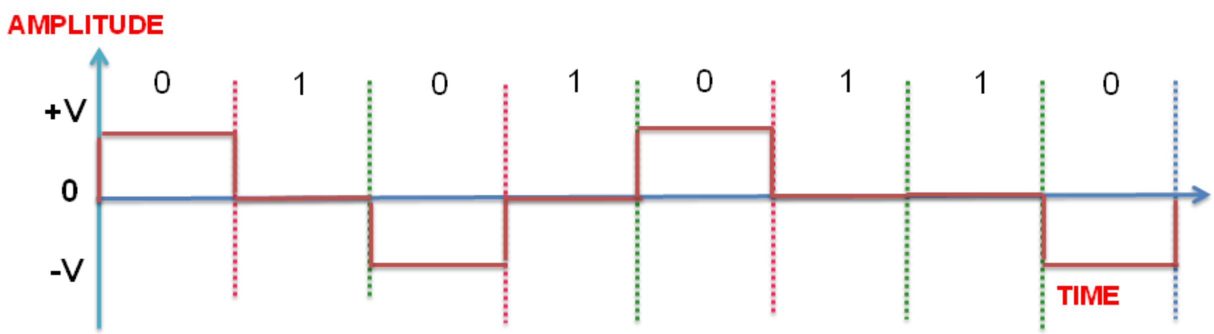

Figure 16: Pseudoternary coding

4. Comparison of the Line Coding Schemes

Based on what different types of encoding schemes discussed so far, comparisons of their features are indicated by table-1. Starting with the bandwidth requirements of each code, unipolar NRZ, polar NRZ and Differential NRZ have low bandwidth requirement, bandwidth requirement of Manchester coding is high and that of Differential Manchester coding is moderate. However, we have seen that Manchester and Differential Manchester encoding gives very good synchronization facility. That means a signal with long sequence of 0s or 1s it will not lead to synchronization failure as the receiver will regenerate the signal without any problem.

Unipolar NRZ has high DC component which makes them unsuitable for long haul communication where as polar NRZ, polar RZ, Manchester, Differential Manchester, AMI, and Pseudoterenary coded signals have no dc component present.

Code	***Bandwidth requirement***	***Synchronization***	***DC Component***
Unipolar NRZ	*Low*	*Loss of synchronization*	*High*
Polar NRZ	*Low*	*Loss of synchronization*	*Zero*
Unipolar RZ	*Twice of UNRZ*	*Loss of synchronization*	*High*
Polar RZ	*High*	*Good*	*Zero*
Manchester	*High*	*Good*	*Zero*
Differential Manchester	*Moderate*	*Good*	*Zero*
AMI	*low*	*Loss of synchronization*	*Zero*
Pseudoterenary	*low*	*Loss of synchronization*	*Zero*

Table 1: Comparison of various line coding schemes

Now let us see the representation of a binary data sequence 01110110 in fig 17 using different line coding techniques studied so far.

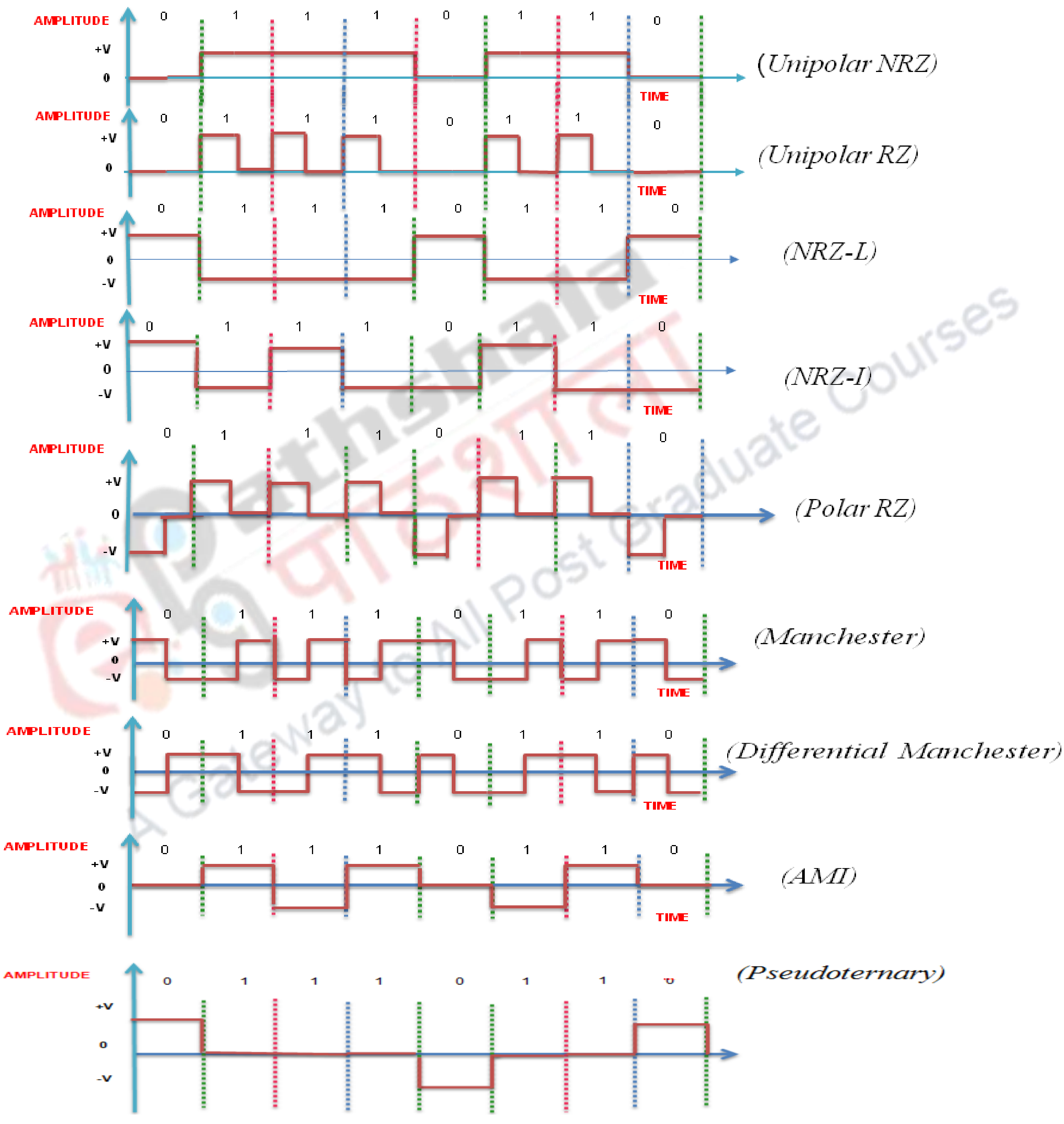

Figure 17: Waveforms of different line coding techniques

5. Summary

We this lesson, we have learnt the following:

- Line coding refers to the process of converting a sequence of binary digits i.e., bits or digital data into a digital signal. Line coding implemented for digital transmission of binary information.
- The major characteristics of line coding are: data rate, baud rate, bandwidth, dc components, baseline wandering, self synchronization, error detection, noise immunity, complexity and implementation cost.
- Line codes are classified according to the assigned polarity of voltage levels to represent the binary data. We can categorize line coding schemes into three major types: unipolar, bipolar and polar line coding scheme.
- Unipolar line coding scheme makes use of one polarity of voltage to represent logic states. More precisely, positive voltage is used to represent a logic high state and an idle line or zero to represent low logic low state. Here the baud rate is same as the data rate. This encoding scheme, suffers from the disadvantage of having undesirable DC component present in the signal encoded and for long sequence of 0's and 1's there will be loss of synchronization.
- Unipolar line coding scheme is also called on–off keying (OOK) and can be classified into two major types, Non Return to zero (NRZ) and Return to zero (RZ).
- Polar line encoding method uses two voltage levels of opposite polarity and equal magnitude that is, one positive and the other one negative to represent the two binary states 0 and 1. It can be classified into three major types, Non Return to zero (NRZ), Return to zero (RZ) and Biphase.
- As the polar NRZ signal has more r.m.s value than their unipolar counterparts, they can carry more energy. This will aid in better signal to noise ratio at the receiving end. The polar NRZ lacks the error detection capability.
- A bipolar encoding uses a three-voltage-level signal positive, negative and zero to represent logic states. Bipolar signals may be RZ or NRZ. The presence of alternating code in this encoding prevents the build-up of a DC voltage in transmission lines. Lesser bandwidth is required for transmission.

The most common bipolar encoding techniques are alternate mark inversion (AMI) and Pseudoternary coding.