8

SIGNAL ENCODING

Unit Structure

8.0 OBJECTIVES

The objectives of this chapter are:

1. Understand what is signal encoding
2. Different ways of converting analog signal to digital
3. Different ways of converting digital signal to analog
4. Modulation

8.1 INTRODUCTION TO SIGNAL ENCODING

- Data can be analog or digital, so can be the signal that represents it.
- **Signal encoding** is the conversion from analog/digital data to analog / digital signal.

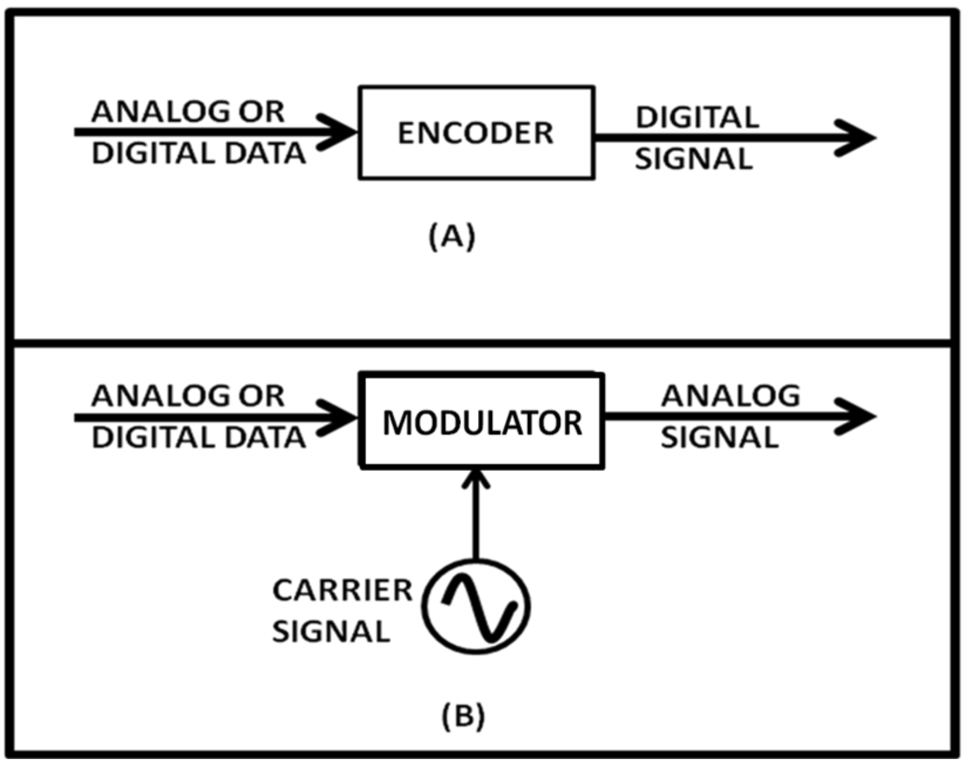


Figure: Signal Encoding

In the Figure above,

A) Demonstrates Digital Signaling where data from an analog/digital source is encoded into Digital Signal

B) Demonstrates Analog signaling in which the analog/digital source modulates a continuous carrier signal to produce an analog signal.

The possible encodings are:

1. Digital data to Digital Signal
2. Digital data to Analog Signal
3. Analog data to Digital Signal
4. Analog data to Analog Signal

8.2 SYNCHRONIZATION

- In order to receive the signals correctly, the receivers bit intervals must correspond exactly to the senders bit intervals.
- The clock frequency of the transmitter and receiver should be the same.
- If the clock frequency at the receiver is slower or faster than the bit intervals are not matched and the received signal is different than the transmitted one.

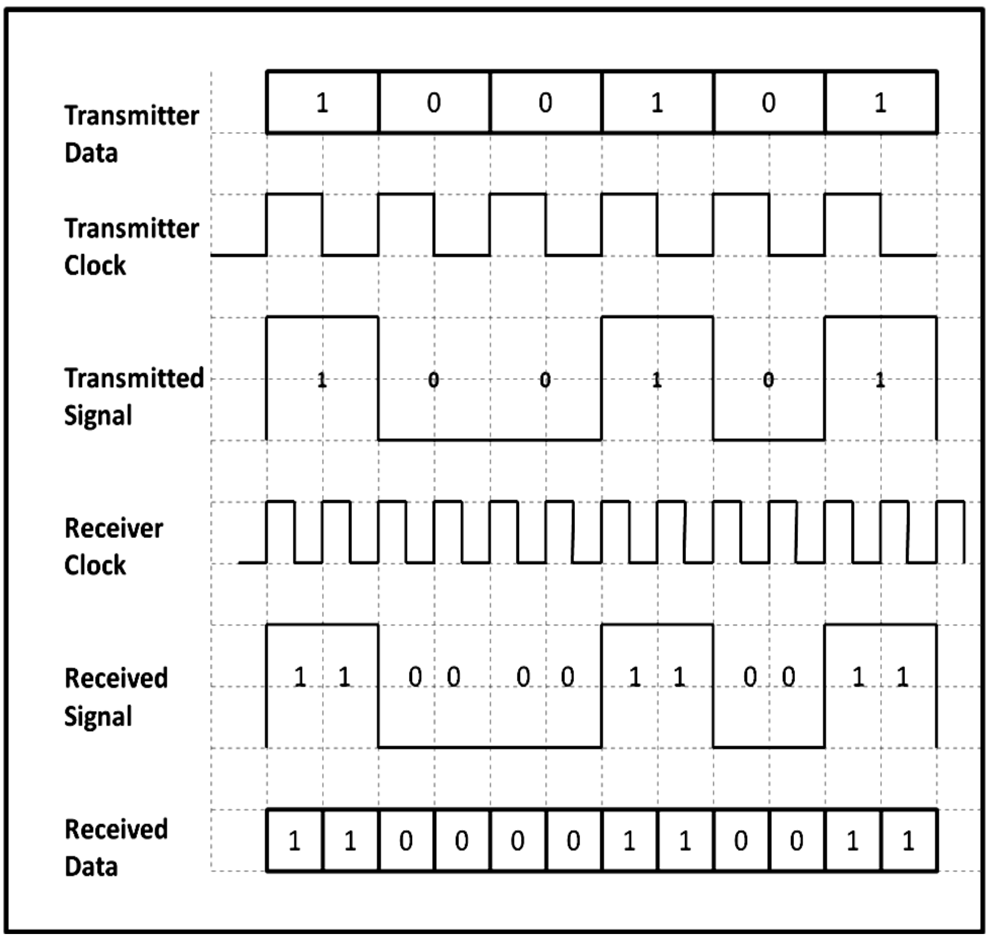


Figure : Synchronization

- In the above figure, the receiver clock frequency is twice that of the transmitter frequency. Hence the received data is totally different than the transmitted one

- To avoid this, receiver and transmitter clocks have to be **synchronized.**

- To achieve this the transmitted digital signal should include timing information which forces synchronization

8.3 Digital Data to Digital Signal

Coding methods Coding methods are used to convert digital data into digital signals.

There are two types of coding methods:

1 Line Coding
2 Block Coding

Scrambling is also one of the ways to convert digital data to digital signals but is not used.

8.3.1 Line Encoding

It is the process of converting Digital data into digital signal.

In other words, it is converting of binary data(i.e. A sequence of bits) into digital signal (i.e. a sequence of discrete, discontinuous voltage pulses)

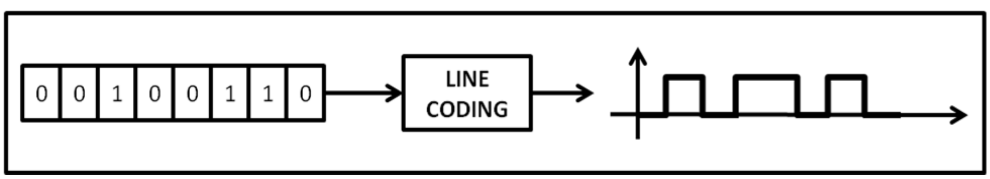


Figure: Line Coding

8.3.2 Classification of Line Codes

The following figure shows the classification of Line coding schemes:

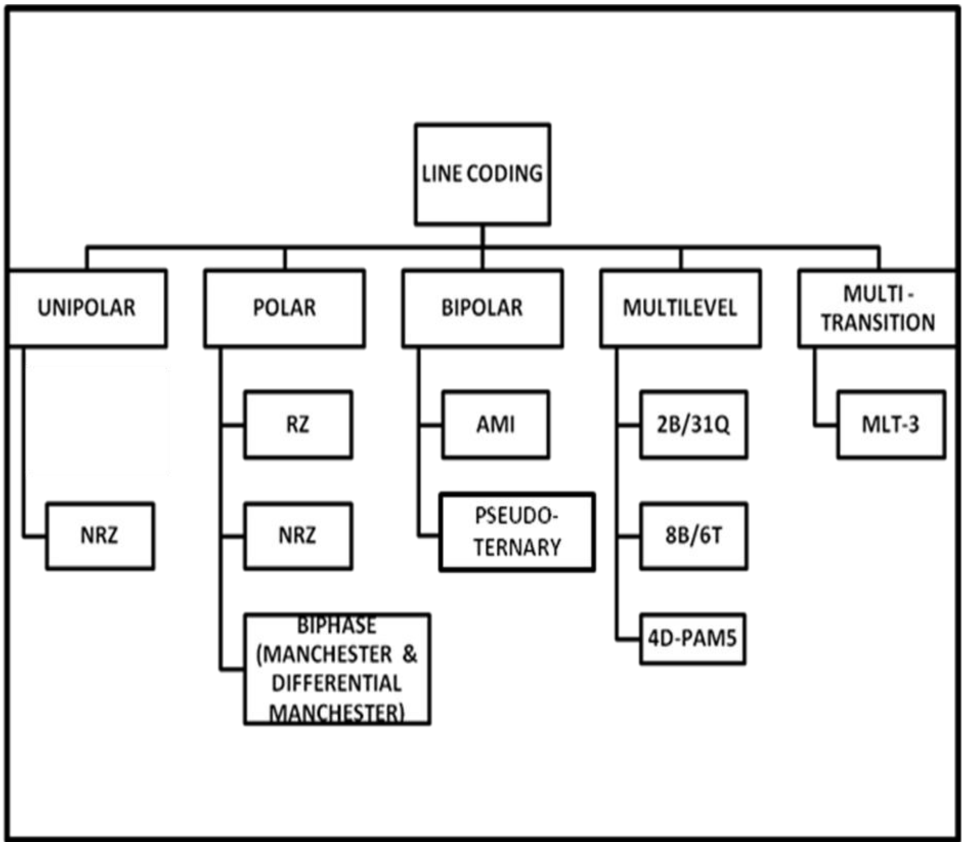


Figure : Classification of line coding schemes

8.3.2.A Unipolar

- All signal levels are either above or below the time axis.
- NRZ - Non Return to Zero scheme is an example of this code. The signal level does not return to zero during a symbol transmission.

8.3.2.B Polar

- **NRZ-voltages** are on both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages. E.g. +V for 1 and -V for 0.

- There are two variations:
  - **NZR - Level (NRZ-L)** - positive voltage for one symbol and negative for the other
  - **NRZ - Inversion (NRZ**-I) - the change or lack of change in polarity determines the value of a symbol. E.g. a “1” symbol inverts the polarity a “0” does not.

- **Polar – RZ**
  - The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.

- Each symbol has a transition in the middle. Either from high to zero or from low to zero

- More complex as it uses three voltage level. It has no error detection capability

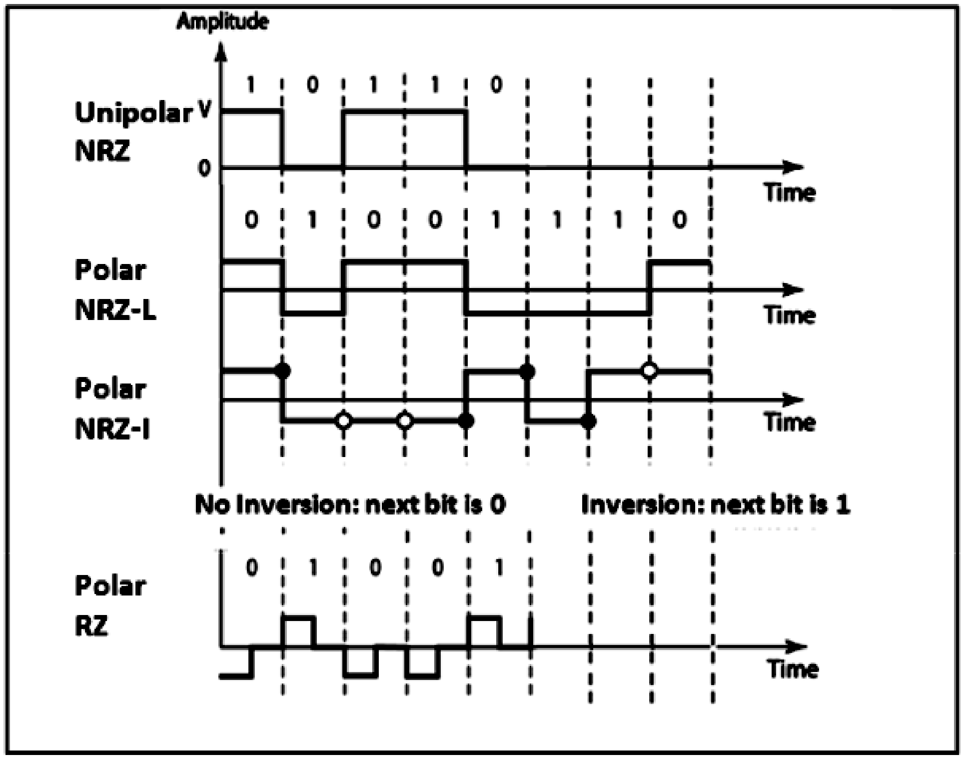


Figure : Unipolar(NRZ) & Polar(RZ & NRZ) Encoding

- **Polar - Biphase: Manchester and Differential Manchester**
  - **Manchester coding** is a combination of NRZ-L and RZ schemes.
    - Every symbol has a level transition in the middle: from high to low or low to high.
    - It uses only two voltage levels.

  - **Differential Manchester coding** consists of combining the NRZ-I and RZ schemes.
    - Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value. One symbol causes a level change the other does not.

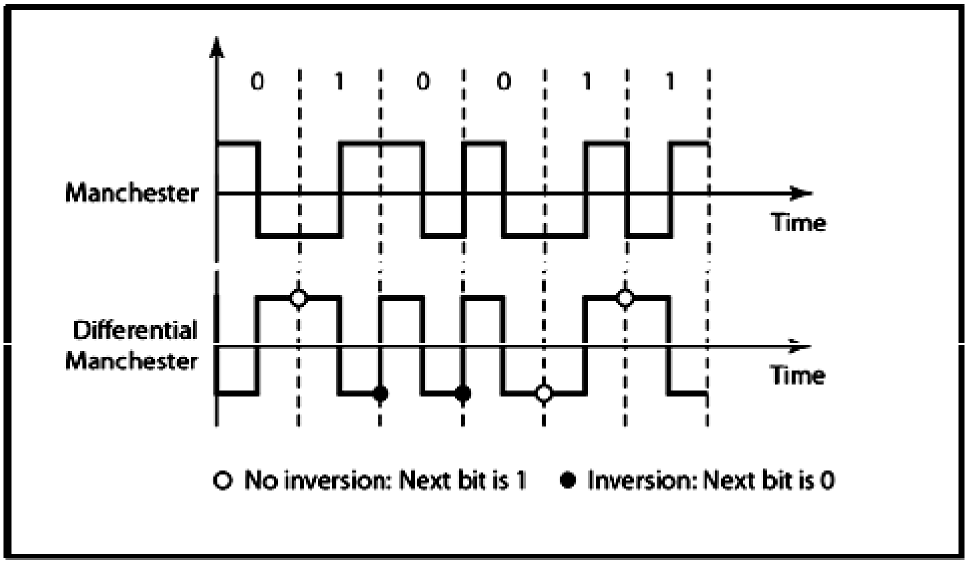


Figure : Polar biphase: Manchester and differential Manchester coding schemes

8.3.2.C Bipolar - AMI and Pseudoternary

- This coding scheme uses 3 voltage levels: - +, 0, -, to represent the symbols

- Voltage level for one symbol is at “0” and the other alternates between + & -.

- **Bipolar Alternate Mark Inversion (AMI)** - the “0” symbol is represented by zero voltage and the “1” symbol alternates between +V and -V.

- **Pseudoternary** is the reverse of AMI

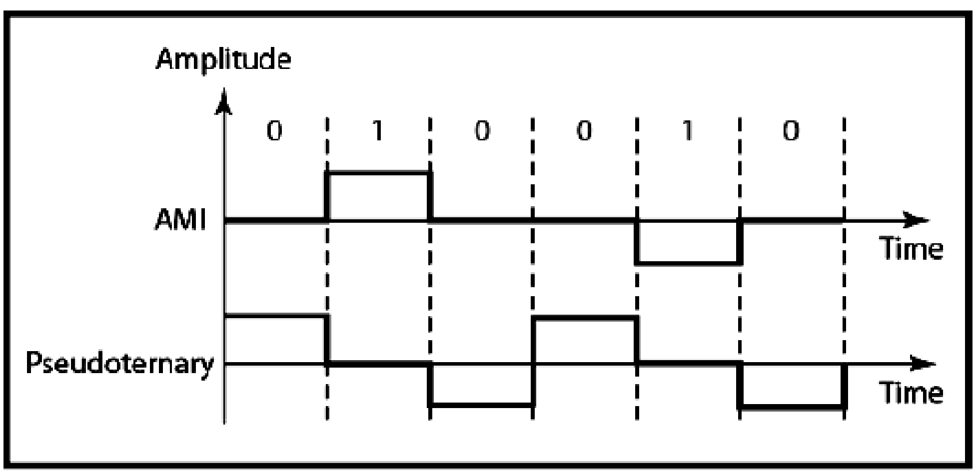


Figure: Bipolar coding scheme - AMI and Pseudoternary

8.3.2.D Multilevel

- Here the number of data bits is increased per symbol to increase the bit rate.
- 2 types of data element a 1 or a 0 are available, it can be combined into a pattern of ***n*** elements to create $\boldsymbol{2^m}$ symbols.
- Using L signal levels we can have ***n*** signal elements to create $\boldsymbol{L^n}$ signal elements. The following possibilities can occur:
- With 2^m symbols and L^n signals:
    - If $2^m > L^n$ then we cannot represent the data elements, we don't have enough signals.
    - If $2^m = L^n$ then we have an exact mapping of one symbol on one signal.
    - If $2^m < L^n$ then we have more signals than symbols and we can choose the signals that are more distinct to represent the symbols and therefore have better noise immunity and error detection as some signals are not valid
- These types of codings are classified as **mBnL** schemes. In ***mBnL*** schemes, a pattern of *m* data elements is encoded as a pattern of *n* signal elements in which $\boldsymbol{2^m \leq L^n}$.
- **2B1Q (**two binary, one quaternary**)**
- Here m = 2; n = 1 ; Q = 4. It uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal.

	Positive level	Negative level
Next Bits	Next Level	Next Level
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

Transition Table

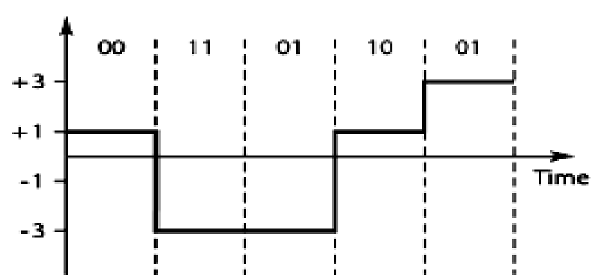


Figure: Multilevel coding scheme : 2B1Q

- **8B6T(**eight binary, six ternary**)**
  - Here a pattern of 8 bits is encoded a pattern of 6 signal elements, where the signal has three levels
  - Here m = 8; n = 6 ; T = 3
  - So we can have 2^8 =256 different data patterns and 3^6 =478 different signal patterns.

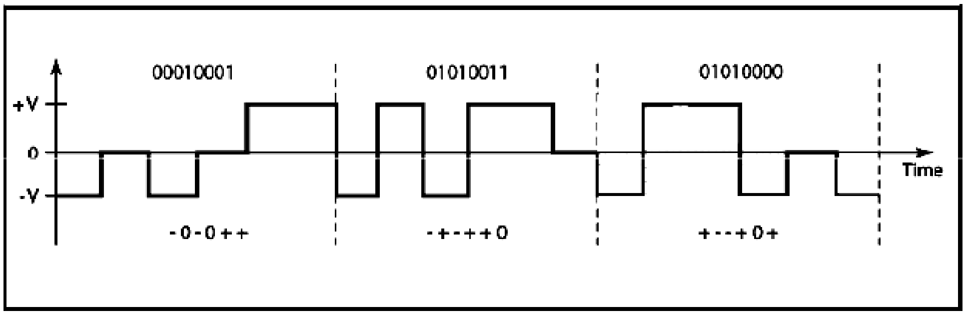


Figure : Multilevel coding scheme : 8B6T

- **4D-PAM5** (Four Dimensional Five-Level Pulse Amplitude Modulation)
  - **4D -**means that data is sent over four channels at the same time.
  - It uses five voltage levels, such as -2, -1, 0, 1, and 2.

8.3.2.E Multitransition

- Because of synchronization requirements we force transitions. This can result in very high bandwidth requirements -> more transitions than are bits (e.g. mid bit transition with inversion).

- Codes can be created that are differential at the bit level forcing transitions at bit boundaries. This results in a bandwidth requirement that is equivalent to the bit rate.

- In some instances, the bandwidth requirement may even be lower, due to repetitive patterns resulting in a periodic signal.

- **MLT-3**
  - Signal rate is same as NRZ-I
  - Uses three levels (+*v,* 0, and - *V)* and three transition rules to move between the levels.
    - If the next bit is 0, there is no transition.
    - If the next bit is 1 and the current level is not 0, the next level is 0.
    - If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.

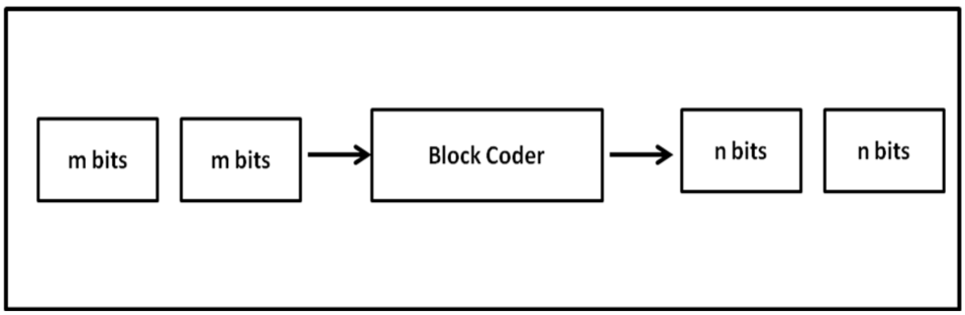
8.3.3 Block Coding

- Block coding adds redundancy to line coding so that error detection can be implemented.

- Block coding changes a block of *m* bits into a block of *n* bits, where *n* is larger than *m.*

- **Block coding is referred to as an *mB/nB* encoding technique.**

- The additional bits added to the original “m bits” are called parity **bits** or **check bits**



m : message bits

Figure : Block Coding

Example: 4B/5B encoding

Here a 4 bit code is converted into a 5 bit code

8.4 Analog data to analog signal

8.4.1 Modulation

- The Process of converting analog data to analog signal is called Modulation.
- Modulation is used to send an information bearing signal over long distances.
- Modulation is the process of varying some characteristic of a periodic wave with an external signal called carrier signal.
- These carrier signals are high frequency signals and can be transmitted over the air easily and are capable of traveling long distances.
- The characteristics (amplitude, frequency, or phase) of the carrier signal are varied in accordance with the information bearing signal(analog data).
- The information bearing signal is also known as the modulating signal.

- The modulating signal is a slowly varying – as opposed to the rapidly varying carrier frequency.

8.4.2 Types of Modulation:

Signal modulation can be divided into two broad categories:

- Analog modulation and
- Digital modulation.

- **Analog or digital** refers to how the data is modulated onto a sine wave.
- If analog audio data is modulated onto a carrier sine wave, then this is referred to as **analog modulation**.
- **Digital modulation** is used to convert digital data to analog signal. Ex ASK, FSK, PSK.

8.4.2.1 Analog Modulation can be accomplished in three ways:

1. Amplitude modulation (AM)
2. Frequency modulation (FM)
3. Phase modulation (PM).

8.4.2.1.1 Amplitude modulation (AM)

- Amplitude modulation is a type of modulation where the amplitude of the carrier signal is varied in accordance with modulating signal.
- The envelope, or boundary, of the amplitude modulated signal embeds modulating signal.
- Amplitude Modulation is abbreviated *AM*.

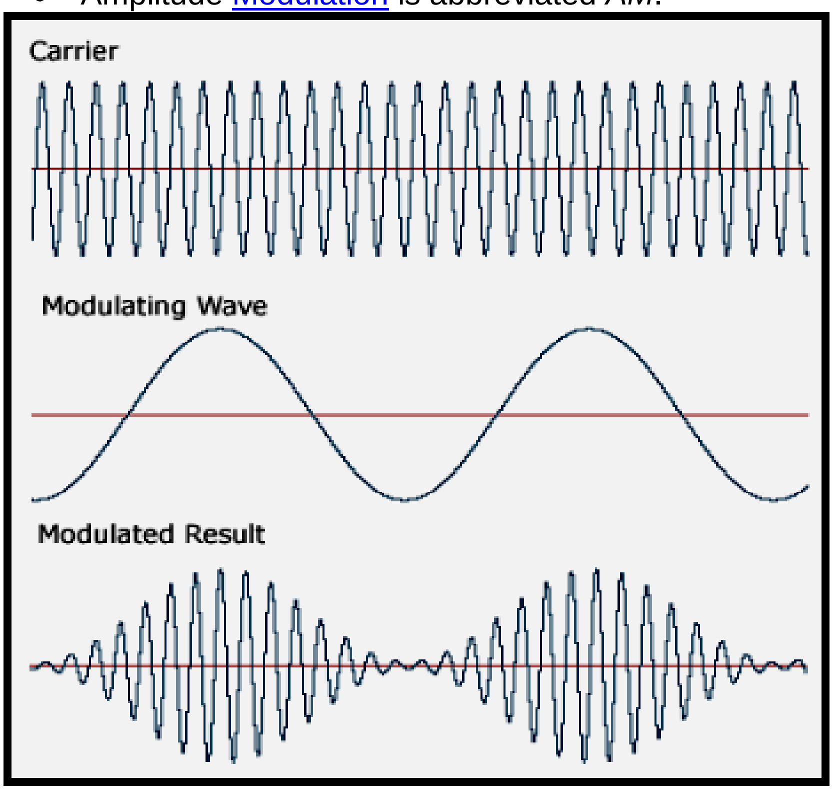


Figure : Amplitude modulation (AM)

8.4.2.1.2 Frequency modulation (FM)

- Frequency modulation is a type of modulation where the frequency of the carrier is varied in accordance with the modulating signal. The amplitude of the carrier remains constant.

- The information-bearing signal (the modulating signal) changes the instantaneous frequency of the carrier. Since the amplitude is kept constant, FM modulation is a low-noise process and provides a high quality modulation technique which is used for music and speech in hi-fidelity broadcasts.

- Frequency Modulation is abbreviated *FM*.

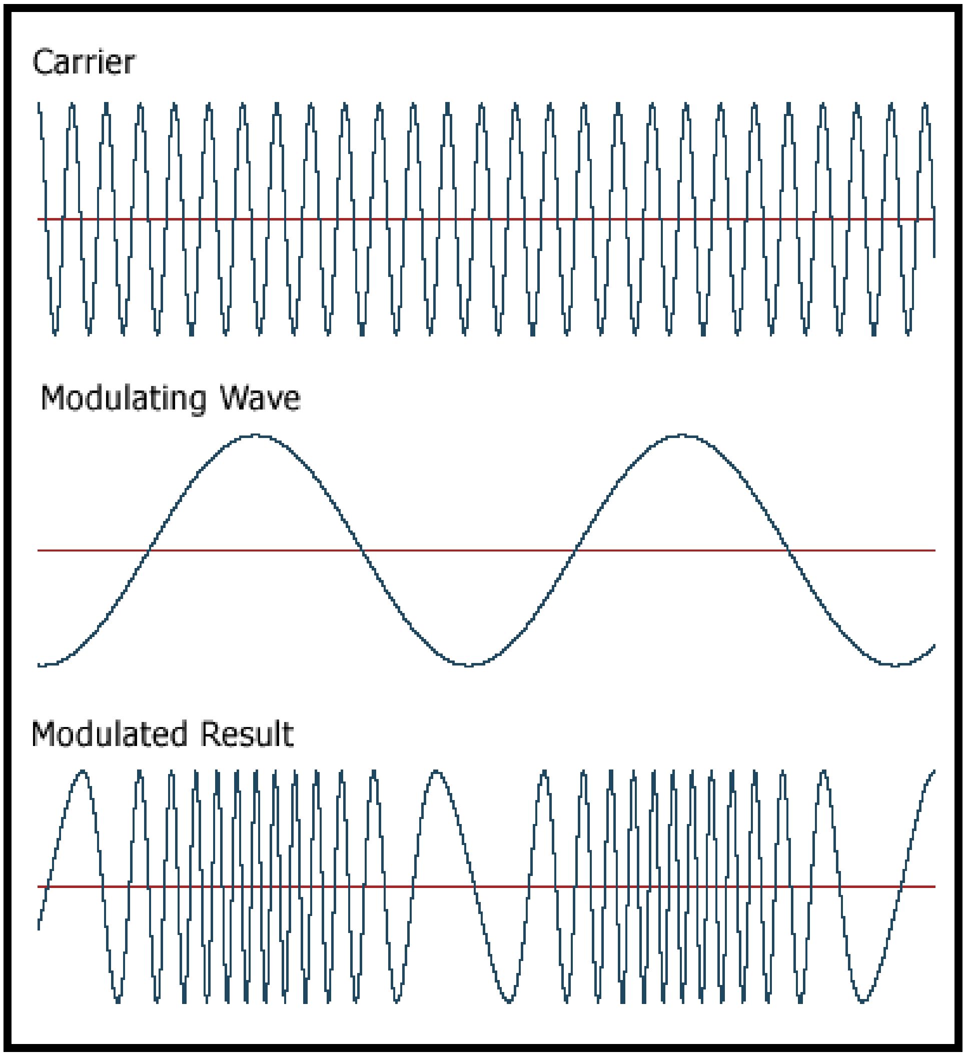


Figure : Frequency modulation (FM)

8.4.2.1.3 Phase modulation (PM).

- In phase modulation, the instantaneous phase of a carrier wave is varied from its reference value by an amount proportional to the instantaneous amplitude of the modulating signal.

- Phase Modulation is abbreviated *PM*.

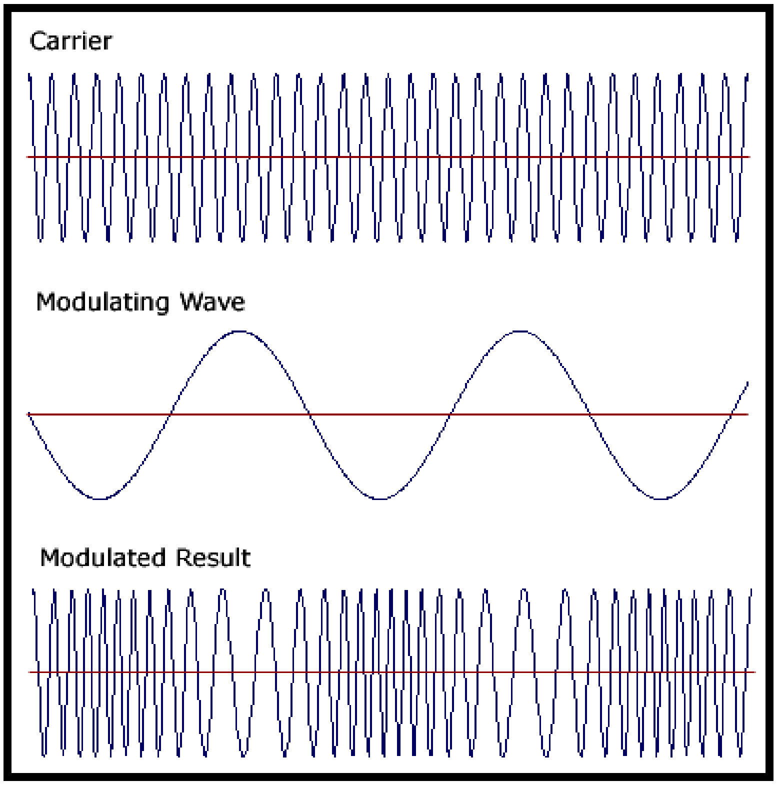


Figure : Phase modulation (PM).

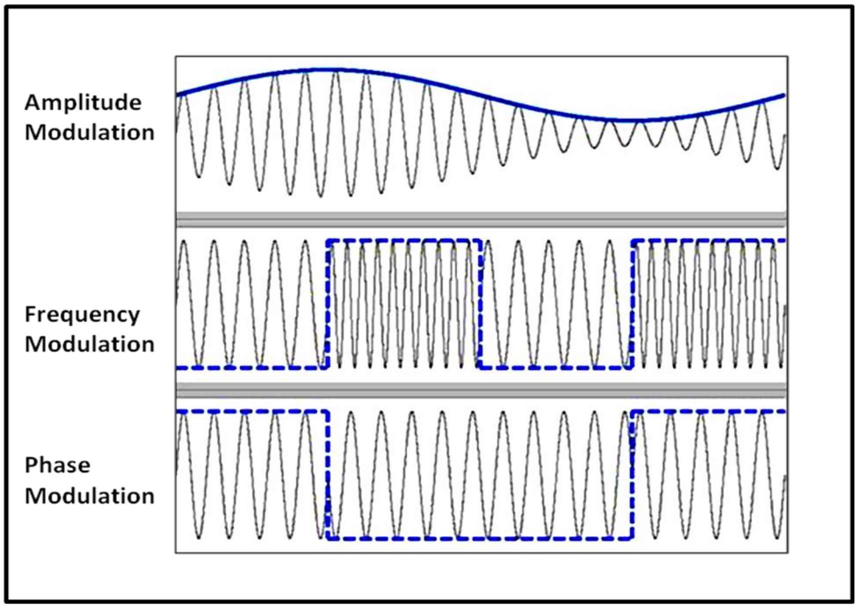


Figure : Comparison of AM, FM & PM

8.4.2.2 Digital Modulation Types(Digital to Analog signal conversion)

- **Digital modulation** is used to convert digital data to analog signal.
- **It can be accomplished in the following ways:**
  1. ASK
  2. FSK
  3. PSK
  4. QAM

8.4.2.2.1 Amplitude Shift Keying (ASK)

- In amplitude shift keying, the amplitude of the carrier signal is varied to create signal elements.
- Both frequency and phase remain constant while the amplitude changes.

- **Binary ASK (BASK)**
  ASK is normally implemented using only two levels and is hence called binary amplitude shift keying.
  Bit 1 is transmitted by a carrier of one particular amplitude.
  To transmit Bit 0 we change the amplitude keeping the frequency is kept constant

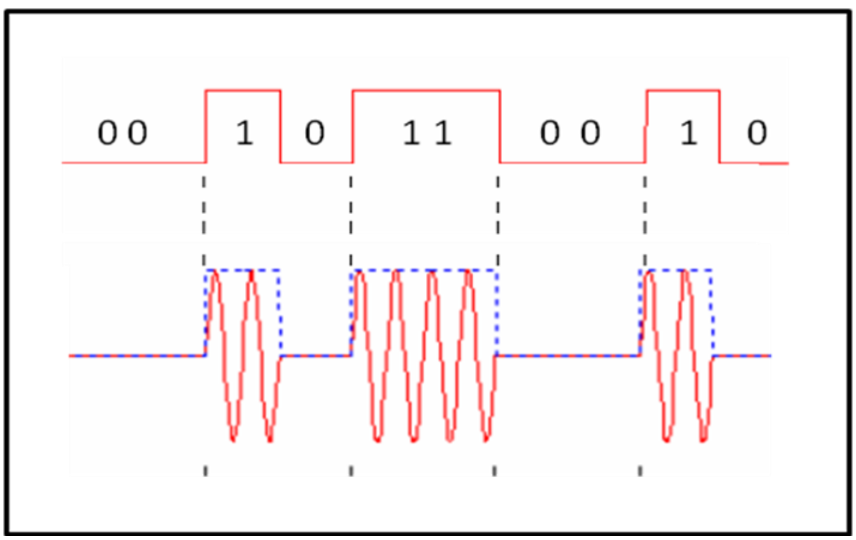


Figure : Amplitude Shift Keying (ASK

8.4.2.2.2 Frequency Shift Keying (FSK)

- In Frequency shift keying, we change the frequency of the carrier wave.
- Bit 0 is represented by a specific frequency, and bit 1 is represented by a different frequency.
- In the figure below frequency used for bit 1 is higher than frequency used for bit 0

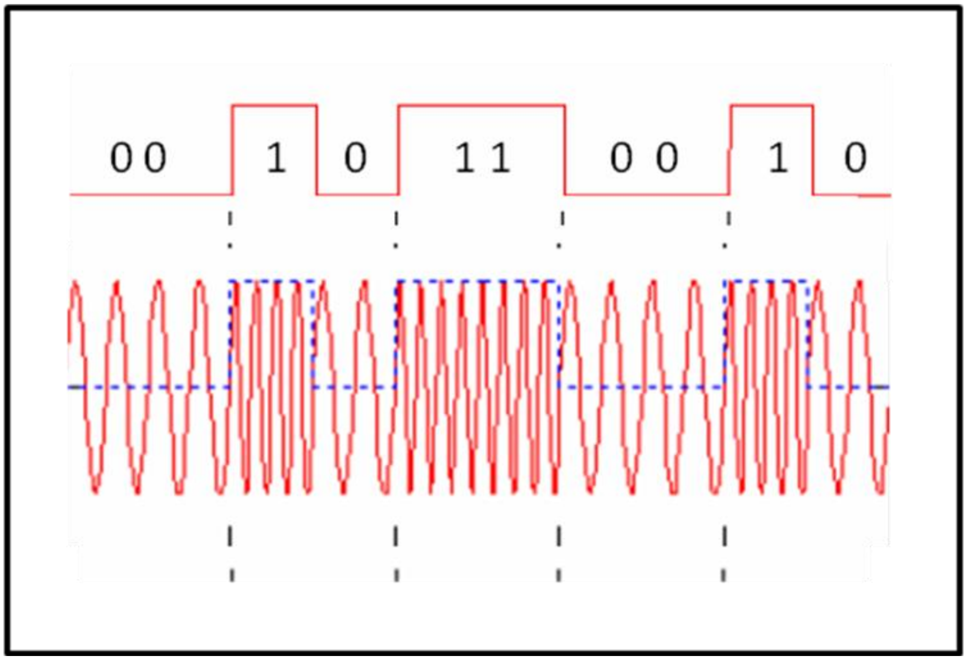


Figure : Frequency Shift Keying (FSK)

8.4.2.2.3. Phase Shift Keying (PSK)

- Phase shift keying (PSK) is a method of transmitting and receiving digital signals in which the phase of a transmitted signal is varied to convey information.
- Both amplitude and frequency remain constant as the phase changes.
- The simplest from of PSK has only two phases, 0 and 1.
- If the phase of the wave does not change, then the signal state stays the same (low or high).
- If the phase of the wave changes by 180 degrees, that is, if the phase reverses, then the signal state changes (from low to high or from high to low)

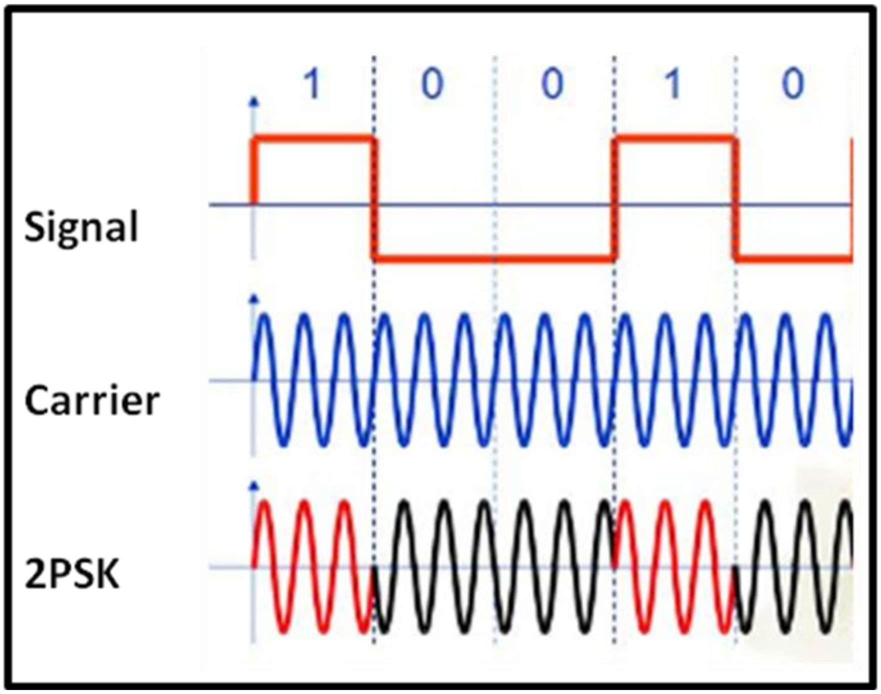


Figure: Phase Shift Keying (PSK)

8.4.2.2.4 QAM

- The concept of Quadrature Amplitude Modulation (QAM) involves use of two carriers, one for phase and the other for quadrature, with different amplitude levels for each carrier.
- It is a combination of ASK & PSK.

8.4.2.2 Analog to Digital Conversion using modulation

The definition of the term modulation is described in the next section. Here we discuss 3 modulation techniques:

1. PAM
2. PCM
3. PWM

8.4.2.3.1 PAM (Pulse Amplitude Modulation)

Pulse Amplitude Modulation refers to a method of carrying information on a train of pulses, the information being encoded in the amplitude of the pulses.

8.4.2.3.2 PCM (Pulse Code Modulation)

- PCM is a general scheme for transmitting analog data in a digital and binary way, independent of the complexity of the analog waveform. With PCM all forms of analog data like video, voice, music and telemetry can be transferred.

- To obtain PCM from an analog waveform at the source (transmitter), the analog signal amplitude is sampled at regular time intervals. The sampling rate (number of samples per second), is several times the maximum frequency of the analog waveform. The amplitude of the analog signal at each sample is rounded off to the nearest binary level (quantization).

- The number of levels is always a power of 2 (4, 8, 16, 32, 64, ...). These numbers can be represented by two, three, four, five, six or more binary digits (bits) respectively.

- At the destination (receiver), a pulse code demodulator converts the binary numbers back into pulses having the same quantum levels as those in the modulator. These pulses are further processed to restore the original analog waveform.

8.4.2.3.3 PWM (Pulse Width Modulation)

- Pulse Width Modulation refers to a method of carrying information on a train of pulses, the information being encoded in the width of the pulses. In applications to motion control, it is not exactly information we are encoding, but a method of controlling power in motors without (significant) loss.

- There are several schemes to accomplish this technique. One is to switch voltage on and off, and let the current recirculate through diodes when the transistors have switched off. Another technique is to switch voltage polarity back and forth with a full-bridge switch arrangement, with 4 transistors.

- This technique may have better linearity, since it can go right down to an cycles, and may jitter between minimum duty cycles of positive and negative polarity.

- In battery systems PWM is the most effective way to achieve a constant voltage for battery charging by switching the system controller's power devices on and off.

The generation of exact working PWM circuitry is complicated, but it is extremely conceptually important since there is good reason to believe that neurons transmit information using PWM spike trains.

8.5 REVIEW QUESTIONS

1. Explain the different ways of converting data to signal and viceversa.
2. Eplain in detail what is signal encoding
3. What are the different ways of converting analog data to digital data?
4. What is modulation? What are its two types?

8.6 REFERENCES & FURTHER READING

1. Data Communication & Networking – Behrouz Forouzan.
2. Computer Networks – Andrew Tannenbaum

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