Chapter 4: Digital Pulse Modulation

4.1 What is Modulation?

Modulation is a process of changing the characteristics of a carrier signal like amplitude, frequency and width, etc. It is the process of adding information to the carrier signal. A carrier signal is a steady waveform with constant amplitude and frequency.

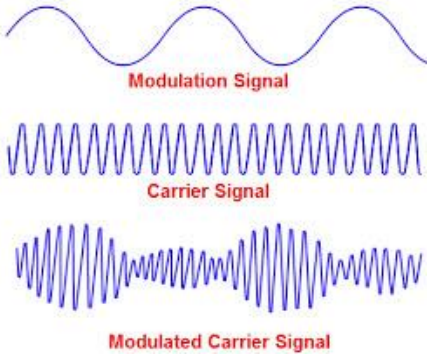


Figure 4.1: Concept of Modulation

Modulation is normally applied to electromagnetic signals like radio laser and optical signals. The Audio, video, images and text data are added to the carrier signal for transmission over telecommunication

- **Two types of modulation:**

1- **Digital modulation:** digital data (0, 1) is translated into an analog signal (baseband signal).

2- **Analog modulation:** the center frequency of the baseband signal generated by digital modulation is shifted up to the radio carrier.

4.2 Need for digital transmission

Digital modulation is required if digital data has to be transmitted over a medium that only allows analog transmission (modems in wired networks).

-Digital signals, i.e. 0/1, can be sent over wires using voltages.

- Wireless must use analogue sine waves.

1. **Noise immunity :** Digital signals are inherently less susceptible than analog signals to interference caused by noise because with digital signals it is not necessary to evaluate precise amplitude, frequency or phase. Instead it is evaluated whether pulse is above or below a prescribed reference level.
2. **Multiplexing :** Digital signals are better suited than analog for processing and combining using a technique multiplexing.
3. **Easy to store :** It is simple to store digital signals than analog signals.
4. **Resistant to additive noise :** Digital transmission systems are more resistant to analog system to additive noise because they use signal regeneration rather than signal amplification.
5. **Used for long distance :** Digital regenerators sample noisy signals and then reproduce an entirely new digital signal with the

same signal to noice ratio as the original transmitted signals. So digital transmitted signals can be transported over longer distance than analog signals.

6. **Transmission errors can be detected easily :** The transmission errors can be detected and corrected more easily and accurately than is possible with analog signals.

4.3 Pulse Code Modulation (PCM)

This is the most popular scheme used in digital communication systems. It allows analog information transmission as a digital signal. Basically it is a digital transmission system with an analog-to-digital converter (ADC) at the input and a digital-to-analog converter (DAC) at the output.

In PCM, the analog signal is sampled at discrete time intervals and then converted to a serial n-bit binary code for transmission. Where 'n' may be any positive integer greater than 1. Each code has the same number of bits and requires the same time for transmission. In PCM, the pulses are of fixed time duration and fixed amplitude. Logic 1 or logic 0 condition is represented as 'pulse' or 'no pulse' respectively.

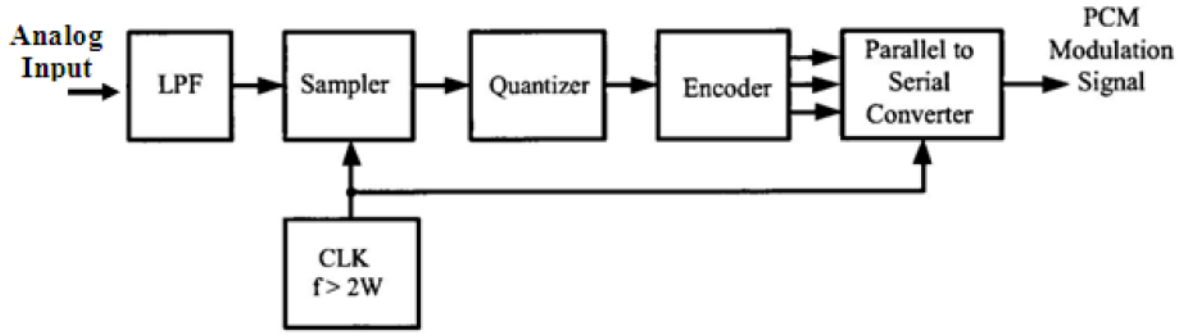


Figure 4.2: Block diagram of PCM modulation.

PCM essentially has three steps:

i. Sampling
ii. Quantization
iii. Encoding

i. **Sampling:** The analog signal is divided into discrete samples at a rate based on the Nyquist sampling theorem i.e. twice the signal bandwidth.

The output of the LPF is then fed to a sampler where the analog input signal is sampled at regular intervals. The sampling of the signal is done at the rate of f_s. This sampling frequency is so selected that it must follow the sampling theorem that is expressed as:

$$f_s \geq 2f_m$$

Where f_s is sampling frequency and f_m is the maximum frequency in the input signal.

ii. **Quantization:** The process of converting an infinite number of possibilities to a finite number of conditions is called quantization. In PCM, information is analog signal which has infinite number of amplitudes values. Therefore, convert an analog signal into a limited number of combinations. This is done in quantization process.

For *example:* Consider a sine wave with an amplitude varying between + 3V and -3V. It has every value possible between the range. With quantization, the total voltage range is subdivided into a smaller number of sub ranges. The following table shows a three bit sign magnitude code with eight possible combinations. Normally most significant bit (leftmost bit) is sign bit and two rightmost bits represent magnitude. This type of code is called folded binary code.

Table 2.1 Three bit PCM code

Decimal Value	PCM Code		
	Sign	Magnitude	
+3	1	1	1
+2	1	1	0
+1	1	0	1
+0	1	0	0
-0	0	0	0
-1	0	0	1
-2	0	1	0
-3	0	1	1

Assigning PCM codes to absolute magnitudes is called *quantizing*. The magnitude of a quantum is called the resolution which is equal to voltage of the minimum step size. In above table resolution is 1V. The smaller the magnitude of a quantum, the better the resolution and the more accurately the quantized signal will resemble the original analog information. Better resolution can be achieved by using a PCM code with more bits.

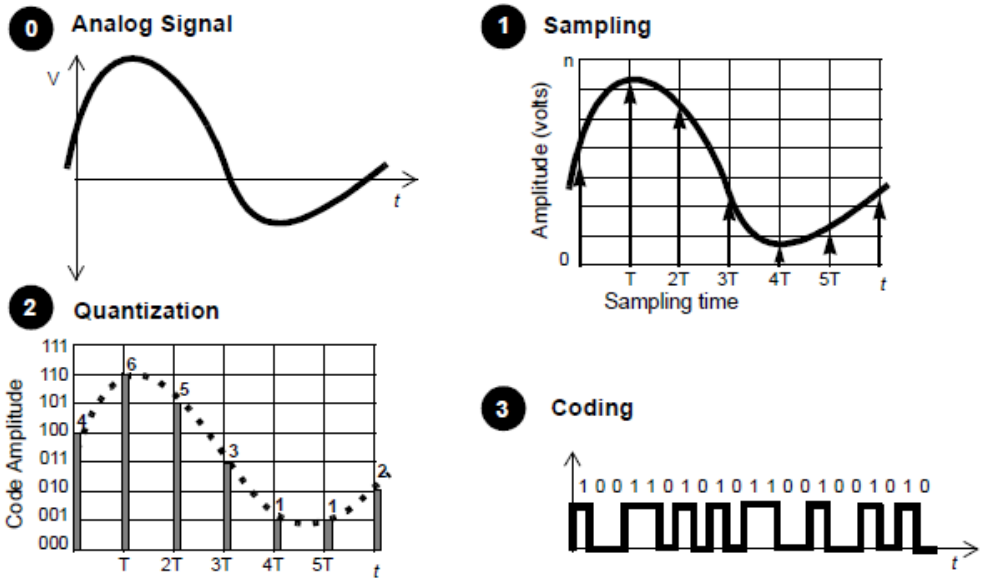


Figure 4.3: The three steps of digitalization of a signal: 1) sampling of the signal, 2) quantization of the amplitude, 3) and binary encoding.

iii. Encoding: The quantized samples are coded into binary bits. The digitization of analog signal is done by the encoder. It designates each quantized level by a binary code

PCM System

Figure 4.4 shows a simplified block diagram of a single channel, simplex PCM system.

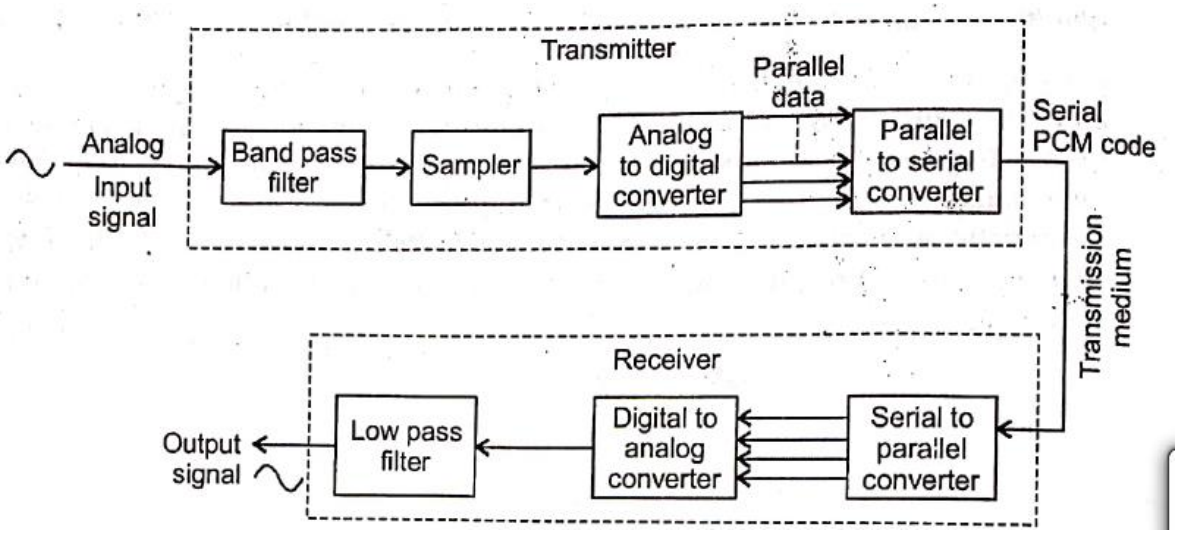


Figure 4.4: PCM system

The analog input is applied to band pass filter which remove high frequency components. The signal is periodically sampled and is converted to digital data using ADC. The digitally converted data is in parallel form. With the help of parallel to serial converter, it is converted into serial fashion, which is then transmitted over channel.

In the receiver the serial to parallel converter converts serial pulses received from the transmission line to parallel PCM code. The DAC converts the parallel PCM codes to analog to replicate the original analog signal.

4.4 Digital Modulation:

Quite often we have to send digital data through analog transmission media such as a telephone network. In such situations it is essential to convert digital data to analog signal. Basic approach is shown in Fig. 4.5. This conversion is accomplished with the help of special devices such as modem (modulator-demodulator) that converts digital data to analog signal and vice versa.

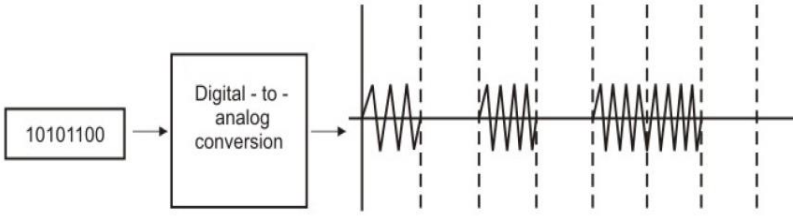


Figure 4.5: Conversion of digital data to analog signal.

Since modulation involves operations on one or more of the three characteristics of the carrier signal, namely amplitude, frequency and phase, three basic encoding or modulation techniques are available for conversion of digital data to analog signals as shown in Figure. 4.6. The three techniques, referred to as amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK), are discussed in the following sections of this lesson.

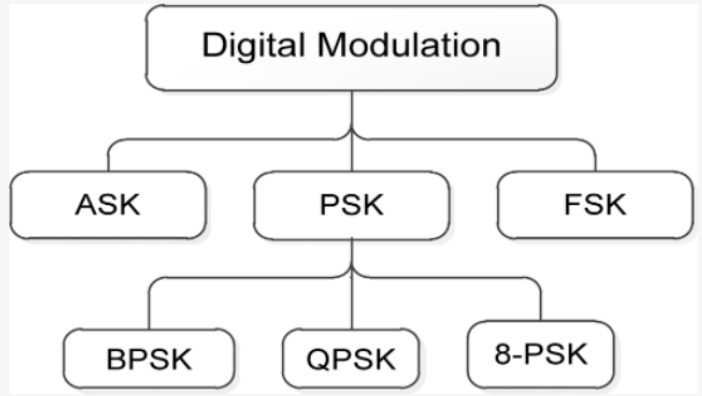


Figure 4.6: Types of Digital Modulation

4.4.1. Amplitude-shift keying (ASK):

In ASK, two binary values are represented by two different amplitudes of the carrier frequency as shown in the Figure. 4.7. The unmodulated carrier can be represented by

$$e_c(t) = E_c \cos 2\pi fct$$

The modulated signal can be written as

$$s(t) = k\, e_m \cos 2\pi f_c t$$
$$s(t) = A_1 \cos 2\pi f_c t \quad \text{for } 1$$
$$s(t) = A_2 \cos 2\pi f_c t \quad \text{for } 0$$

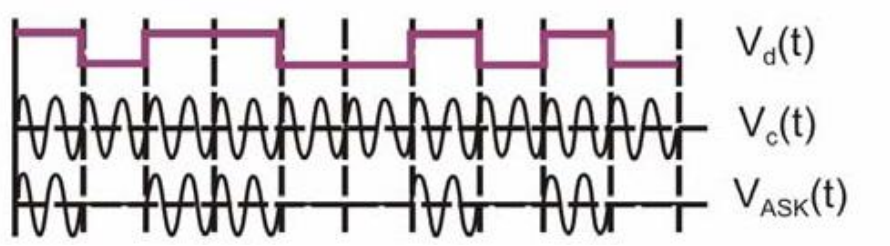


Figure: 4.7 ASK Waveform

Advantages: Simplicity.

Disadvantage: ASK is very susceptible to noise interference –noise usually (only) affects the amplitude, therefore ASK is the modulation technique most affected by noise

4.4.2. Frequency-shift keying (FSK):

In this case two binary values are represented by two frequencies near the carrier frequency as shown in figure 4.8

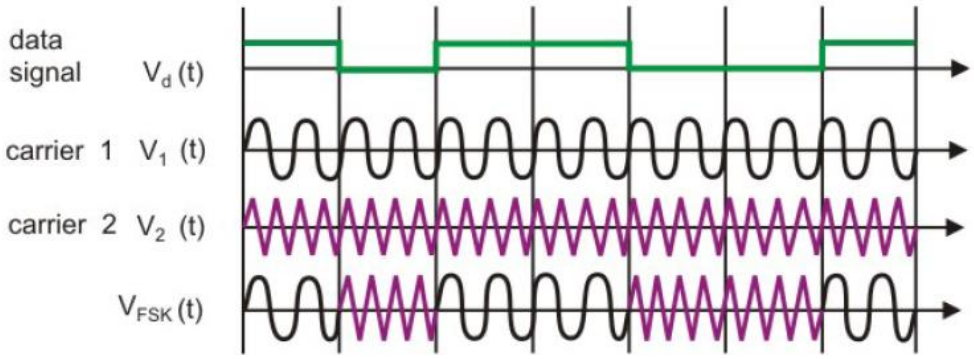


Figure 4.8: Frequency-shift keying (FSK)

In FSK two carrier frequencies f1 and f2 are used to represent 1 and 0 as shown in the above figure.4.8

Here's(t) = A cos 2πfc1t for binary 1
And s(t) = A cos 2πfc2t for binary 0
This method is less susceptible to errors than ASK. It is mainly used in higher frequency radio transmission.

Advantage: FSK is less susceptible to errors than ASK – receiver looks for specific frequency changes over a number of intervals, so voltage (noise) spikes can be ignored.

Disadvantage: FSK spectrum is 2 x ASK spectrum.

4.4.3. Binary Phase-shift keying (BPSK):

In this method, the phase of the carrier signal is shifted by the modulating signal with the phase measured relative to the previous bit interval. The binary 0 is represented by sending a signal of the same phase as the preceding one and 1 is represented by sending the signal with an opposite phase to the previous one as shown in Figure.4.9.

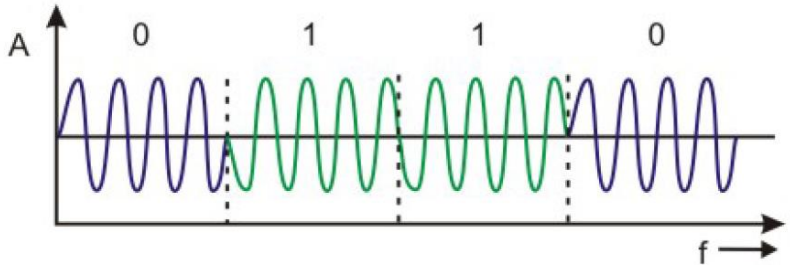


Figure 4.9 PSK diagram

In 2-PSK the carrier is used to represent 0 or 1.

$s(t) = A \cos(2\pi f_c t + \pi)$ for binary 1
$s(t) = A \cos(2\pi f_c t)$ for binary 0

Advantage:

1. PSK is less susceptible to errors than ASK, while itrequires/occupies the same bandwidth as ASK
2. More efficient use of bandwidth (higher data-rate) is possible, compared to FSK.

Disadvantage: more complex signal detection / recovery process than in ASK and FSK

4.4.4. Quadrature Phase-shift keying (QPSK):

For more efficient use of bandwidth Quadrature Phase-Shift keying (QPSK) can be used, where

$s(t) = A \cos(2\pi f_c t)$ for 00
$= A \cos(2\pi f_c t + 90)$ for 01
$= A \cos(2\pi f_c t + 180)$ for 10
$= A \cos(2\pi f_c t + 270)$ for 11

Here phase shift occur in multiple of 90^0 as shown in constallation diagram below figure 2.6

Bits	Phase
00	0
01	90
10	180
11	270

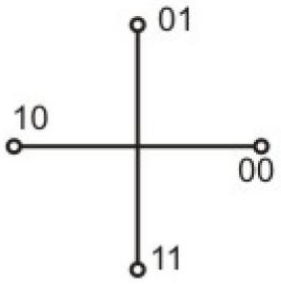
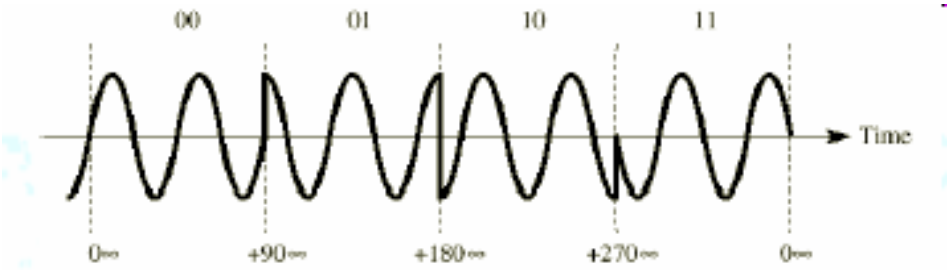


Figure.4.10: Constallation diagram of Quadrature Phase-shift keying (QPSK):



Advantage:

• Higher data rateobtain as compare to PSK (2 bits per bit interval), while bandwidth occupancy remains the same.

• 4-PSK can easily be extended to 8-PSK, i.e. n-PSK.

Disadvantage: more complex signal detection / recovery process than in ASK and FSK.

Question 1: Multiple choice questions

1. The sequence of operations in which PCM is done is……..

A]	Quantizing, sampling, encoding	B]	Quantizing, encoding, sampling
C]	Sampling, quantizing, encoding	D]	None of the above

2. The last step in Pulse code modulation is ……

A]	Quantizing	B]	sampling
C]	encoding	D]	Modulation

3. Quantization noise can be reduced by _____ the number of levels.

A]	Decreasing	B]	Increasing
C]	Doubling	D]	Squaring

4. In .....modulation technique, the frequency of carrier is varied according to digital signal.

A]	ASK	B]	FSK
C]	PSK	D]	None of these

5. In _____, to represent data , the Amplitude of the carrier signal is varied, and frequency and phase remain constant.

A]	ASK	B]	FSK
C]	PSK	D]	None of these

6. How many carrier frequencies are used in BFSK?

A]	1	B]	2
C]	3	D]	4

Short Answer Questions

1. Explain the need for digital modulation.
2. Explain the concept of ASK.
3. Explain the concept of FSK.
4. Explain the concept of PSK.

Long Answer Questions

1. What is PCM? Which steps are involved in PCM? Explain in detail.
2. Draw the block diagram of a PCM transmitter and explain the function of each block.
3. Give the concept of BPSK and QPSK.