Electrical Engineering

Communication Systems

Comprehensive Theory

with Solved Examples and Practice Questions

MADE EASY
Publications

MADE EASY Publications

Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016
E-mail: infomep@madeeasy.in
Contact: 011-45124660, 8860378007
Visit us at: www.madeeasypublications.org

Communication Systems

First Edition: 2015
Second Edition: 2016
Third Edition: 2017
Fourth Edition: 2018

Contents

Communication Systems

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8

Chapter 9

Chapter 10

CHAPTER 1

Introduction to Communication Systems

1.1 Historical Sketch

The development of communication technology has proceeded in step with the development of electronic technology as a whole. For example, the demonstration of telegraphy by Joseph Henry in 1832 and by Somual F.B. Morse in 1838 followed hard on the discovery of electromagnetism by Oeisted and Ampere early in 1820's. Similarly, Hertz's verification late in the 1880's of Maxwell's postulation (1873) predicting the wireless propagation of electromagnetic energy led within 10 years of the radio-telegraph experiments of Marconi and Popov. The invention of diode by Flaming in 1904 and of triode by deforest in 1906 made possible the rapid development of long distance telephony, both by radio and wireless.

1.2 Why Study Communication

The rapidly changing face of technology necessitates learning of new technology. Today the question is no longer in the field of invention but of innovation. The question today in the twenty first century in not how to transmit data from point A to point B but how efficiently can we do it. To be able to answer this question, first we should be able to diagnose the problem. This can be done only by studying communication from the beginning to its modern form.

1.3 What is Communication

In the most fundamental sense, communication involves implicitly the transmission of information from one point to another through a succession of processes, as described here:

1. The generation of a message signal: voice, music, picture, or computer data.
2. The description of that message signal with a certain measure of precisions, by a set of symbols: electrical, aural, or visual.
3. The encoding of these symbols in a form that is suitable for transmission over a physical medium of interest.
4. The transmission of the encoded symbols to the desired destination.
5. The decoding of the reproduction of the original symbols.
6. The re-creation of the original message signal, with a definable degradation in quality; the degradation is caused by imperfections in the system.

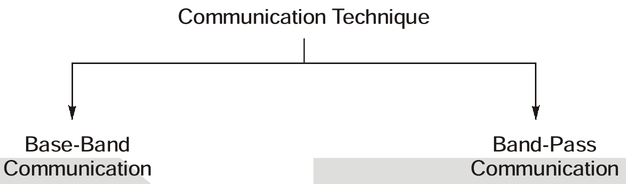
There are, of course, many other forms of communication that do not directly involve the human mind in real time. For example, in computer communications involving communication between two or more computers, human decisions may enter only in setting up the programs or commands for the computer, or in monitoring the results.

1.5 Modes of Communication

There are two basic modes of communication:

1. **Broadcasting**, which involves the use of a single powerful transmitter and numerous receivers that are relatively inexpensive to build. Here information-bearing signals flow only in one direction.
2. **Point-to-point communication**, in which the communication process takes place over a link between a single transmitter and a receiver. In this case, there is usually a bidirectional flow of information-bearing signals, which requires the use of a transmitter and receiver at each end of the link.

1.5.1 Communication Technique



1. Base Band Communication:

It is generally used for short distance communication. In this type of communication message is directly sent to the receiver without altering its frequency.

2. Band Pass Communication:

It is used for long distance communication. In this type of communication, the message signal is mixed with another signal called as the carrier signal for the process of transmission. This process of adding a carrier to a signal is called as modulation.

1.5.2 Need of Modulation

1. To avoid the mixing of signals

   All messages lies within the range of 20 Hz - 20 kHz for speech and music, few MHz for video, so that all signals from the different sources would be inseparable and mixed up. In order to avoid mixing of various signals, it is necessary to translate them all to different portions of the electromagnetic spectrum.

2. To decrease the length of transmitting and receiving antenna

   For a message at 10 kHz, the antenna length 'l' for practical purposes is equal to $\lambda/4$ (from antenna theory) i.e.,

$$\lambda = \frac{3\times10^8}{10\times10^3} = 3\times10^4 \text{ m}$$

and
$$l = \frac{\lambda}{4} = \frac{3\times10^4}{4} = 7500 \text{ m}$$

   An antenna of this size is impractical and for a message signal at 1 MHz

$$\lambda = \frac{3\times10^8}{10^6} = 300 \text{ m}$$

and
$$l = \frac{\lambda}{4} = 75 \text{ m (practicable)}$$

3. To allow the multiplexing of signals

   By translating all signals from different sources to different carrier frequency, we can multiplex the signals and able to send all signals through a single channel.

1.7 An Exam Oriented Approach

Communication is a modern technology is undergoing many changes. The main focus of a student should be to single out on optimum path in which he develops a theoretically strong background of the subject while keeping in mind that he should be able to solve questions asked in various exams using the theory they have studied. Focusing on one aspect leads to failure in written exam or in the interview. Thus this book and communication both have the same approach and that is "optimization" and being a communication engineer one should have this approach too.

Frequency (f) range	Wavelength (λ) range	EM Spectrum Nomenclature	Typical Application
30 – 300 Hz	$10^7 - 10^6$ m	Extremely low frequency (ELF)	Power line communication
0.3 – 3 kHz	$10^6 - 10^5$ m	Voice frequency (VF)	Face to face speech, communication intercom
3 – 30 kHz	$10^5 - 10^4$ m	Very low frequency (VLF)	Submarine communication
30 – 300 kHz	$10^4 - 10^3$ m	Low frequency (LF)	Marine communication
0.3 – 3 MHz	$10^3 - 10^2$ m	Medium frequency (MF)	AM broadcasting
3 – 30 MHz	$10^2 - 10^1$ m	High frequency (HF)	Landline telephony
30 – 300 MHz	$10^1 - 10^0$ m	Very high frequency (VHF)	FM broadcasting, TV
0.3 – 3 GHz	$10^0 - 10^{-1}$ m	Ultra high frequency (UHF)	TV, Cellular telephony
3 – 30 GHz	$10^{-1} - 10^{-2}$ m	Super high frequency (SHF)	Microwave oven, radar
30 – 300 GHz	$10^{-2} - 10^{-3}$ m	Extremely high frequency (EHF)	Satellite communication, radar
0.3 – 3 THz	0.1 – 1 mm	Experimental	For all new explorations
43 – 430 THz	7 – 0.7 μm	Infrared	LED, Laser, TV remote
430 – 750 THz	0.7 – 0.4 μm	Visible light	Optical communication
750 – 3000 THz	0.4 – 0.1 μm	Ultraviolet	Medical application
> 3000 THz	< 0.1 mm	X-rays, gamma rays, cosmic rays	Medical application

Table-1.1: *EM Spectrum*

◆

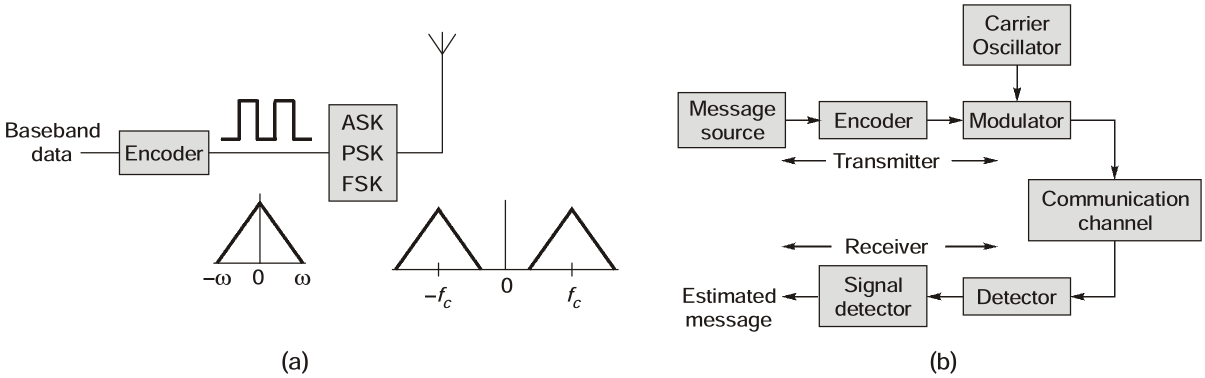
CHAPTER 8

Data Transmission Schemes

Introduction

As we have studied earlier about the base band pulse transmission, we have seen that the output of a PCM code system is a string of 1's and 0's. If they are to be transmitted over copper wires, they can be directly transmitted as appropriate voltage levels using line code. But if they are transmitted through space using antenna, some form of modulation has to be used.

In any event, the modulation process makes the transmission possible involves switching (keying) the amplitude, frequency or phase of sinusoidal carrier in some fashion in accordance with incoming data. Thus, there are three basic signalling schemes and they are known as amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK) and this is called **bandpass transmission of signals**.



(a) (b)

Figure-8.1 : *Bandpass modulation*

Process of bandpass transmission can be explained from *Figure-8.1 (b)* as follows. Message source emits symbols $m_1, m_2, \cdots m_m$ and let their probability of transmission is $p_1, p_2, \cdots p_m$. If not specified then we can assume that all symbols are equiprobable in transmission. Then probability of transmission of any symbol is

$$p(m_i) = \frac{1}{m} \text{ for } i = 1, 2, \cdots, m.$$

Then modulator takes the message source output m_i and codes it into distinct signals $s_i(t)$ suitable for transmission over the channel. The duration of $s_i(t)$ is same as that of symbol m_i i.e. T seconds. As $s_i(t)$ is of a finite duration, so its energy can be given as

$$E_i = \int_0^T s_i^2(t)dt$$

Let communication channel has two characteristics:

(a) It is linear and its bandwidth is wide enough to accommodate transmission of signal $s_i(t)$.

(b) Channel noise $w(t)$ is sample function of a zero mean white Gaussian noise process.

Hence, received signal can be expressed as

$$x(t) = s_i(t) + w(t) \qquad \begin{cases} 0 \le t \le T \\ i = 1, 2, \cdots M \end{cases}$$

The main task of receiver is to observe the signal $s_i(t)$ for 'T' duration and estimate the message symbol m_i from it. But this estimation is complex in the way that value of $s_i(t)$ may change due to presence of channel noise and receiver will make occasional errors. So, the receiver is to be designed to minimize probability of error, defined as

$$P_e = \sum_{i=1}^{M} p_i\, P(\hat{m} \ne m_i / m_i)$$

$$p_i = \text{Probability of sending signal } m_i$$

$P(\hat{m} \ne m_i / m_i)$ = Conditional error probability i.e. probability of receiving symbol $\hat{m}$ when signal m_i is sent where $\hat{m} \ne m_i$.

Note: Less is the probability of error, optimum is the receiver.

8.1 Geometric Representation of Signal

Before studying the modulation techniques in detail, we should have knowledge of how to represent the signals in space geometrically. The essence of geometric representation of signals is to represent any set of M energy signals as combination of N orthonormal basis functions, where $N \le M$.

$$\Rightarrow \qquad s_i(t) = \sum_{j=1}^{N} s_{ij}\, \phi_j(t) \qquad \begin{cases} 0 \le t \le T \\ i = 1, 2, \cdots M \end{cases}$$

where,

$$s_{ij} = \int_0^T s_i(t)\, \phi_j(t)dt \qquad \begin{cases} i = 1, 2, \cdots, M \\ j = 1, 2, \cdots, N \end{cases}$$

The real valued basis functions $\phi_1(t), \phi_2(t) \cdots \phi_N(t)$ are orthonormal if

$$\int_0^T \phi_i(t)\, \phi_j(t)dt = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \ne j \end{cases} \quad \begin{matrix} \text{...(i)} \\ \text{...(ii)} \end{matrix}$$

The (i) condition states that each basis function ($\phi_i(t)$) is normalized to have unit energy.

The (ii) condition states that all the basis functions $\phi_1(t), \phi_2(t) \cdots \phi_N(t)$ are orthogonal to each other over interval $0 \le t \le T$.

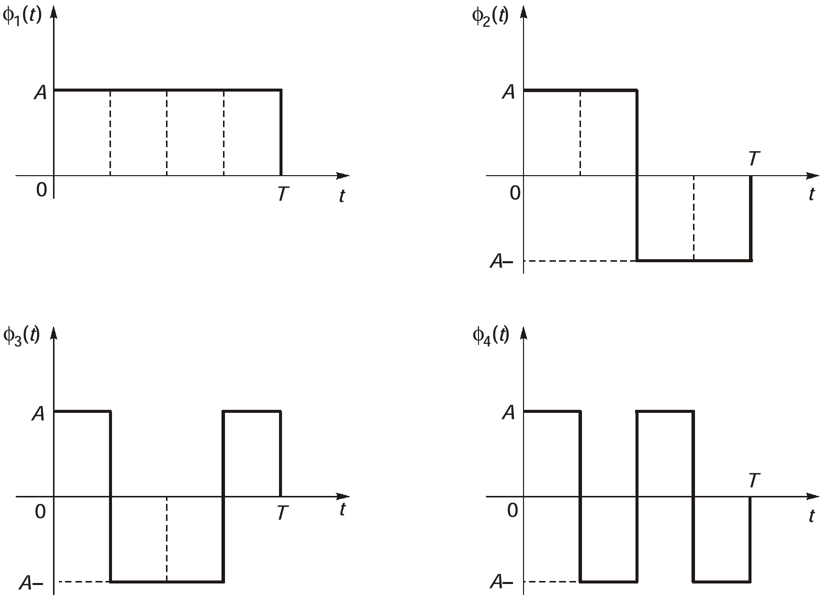


Figure-8.2 : *Example of four mutually orthogonal digital signals*

From the above figure $\int_0^T \phi_i(t)\,\phi_j(t)dt = 0$

Set of coefficients $\{s_{ij}\}_{j=1}^{N}$ may be viewed as an N-dimensional vector, denoted by s_i. s_i vector bears a one to one relationship with transmitted signal $s_i(t)$.

If there are N elements of the vectors s_i(i.e. $s_{i_1}, s_{i_2} \cdots, s_{i_N}$) operating as input, then $s_i(t)$ can be generated as follows:

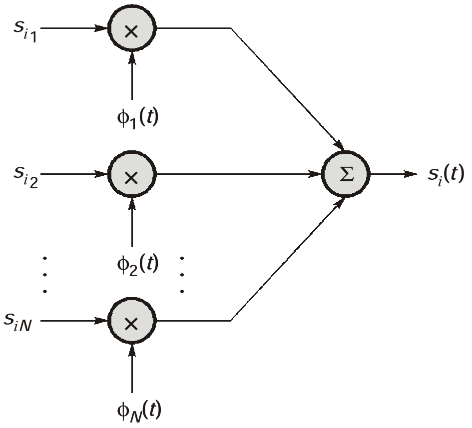


Figure-8.3: *Synthesiser*

$$\Rightarrow \; s_i(t) = s_{i_1}\,\phi_1(t) + s_{i_2}\phi_2(t) + \cdots + s_{i_N}(t)\,\phi_N(t)$$

- Conversely, if the signal $s_i(t)$ $\{i = 1, 2, \cdots, m\}$ is given, then analyser can be used to calculate the coefficients $s_{i_1}, s_{i_2}, \cdots s_{i_N}$.

8.7.4 Transmission Bandwidth

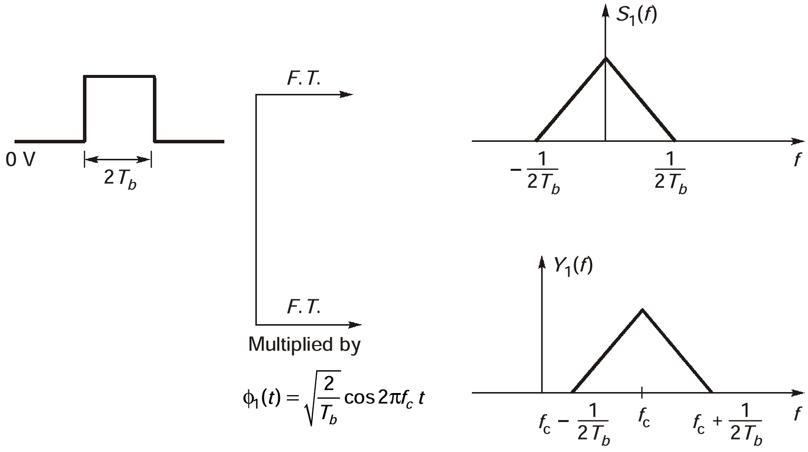


Figure-8.27

$$\text{Bandwidth} = \left(f_c + \frac{1}{2T_b}\right) - \left(f_c - \frac{1}{2T_b}\right) = \frac{1}{T_b} = r_b$$

8.7.5 Energy Per Symbol

Transmission of '00'

$$s_1(t) = -\sqrt{\frac{2E}{T_b}} \cdot \frac{1}{\sqrt{2}}\cos 2\pi f_c t - \sqrt{\frac{2E}{T_b}} \cdot \frac{1}{\sqrt{2}}\sin 2\pi f_c t$$

$$E(s_1(t)) = \int_0^{T_b} s_1^2(t)\,dt$$

$$\left(E_b = \frac{E}{2}\right)$$

$$= A_c^2 \int_0^{T_b} (-\cos 2\pi f_c t - \sin 2\pi f_c t)^2 \cdot dt$$

$$= \frac{E}{T_b}\int_0^{T_b} (\cos^2 2\pi f_c t + \sin^2 2\pi f_c t + 2\cos 2\pi f_c t \sin 2\pi f_c t)\,dt = \frac{E}{T_b}\left(\int_0^{T_b} 1\,dt\right) = E$$

$$\Rightarrow \quad E_s = \frac{2E}{2} = 2E_b$$

Similarly, it can be seen for rest of the symbolic that $E_s = 2E_b$ for 4-PSK

8.7.6 Signal Space Diagram

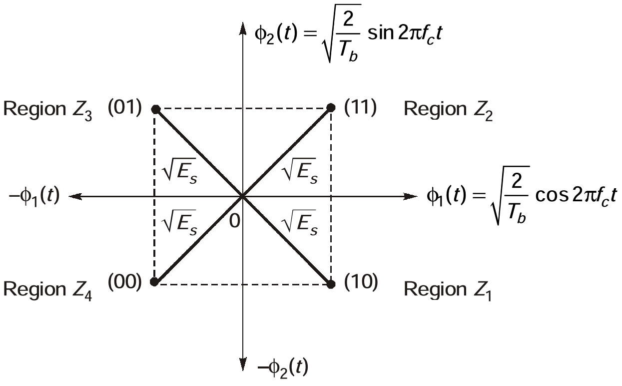


Figure-8.28

$$\text{Energy of symbol '11'} = (\text{Distance from origin})^2 = (\sqrt{E_s})^2 = E_s$$

and
$$E_s = 2E_b$$

Distance between signalling points, $d_{12} = \sqrt{2E_s}$

NOTE

For m-array PSK ;

- m possible signals are given as:

$$s_i(t) = \sqrt{\frac{2E}{T}}\cos\left(2\pi f_c t + \frac{2\pi}{M}(i-1)\right) \qquad i = 1, 2, \ldots M$$

$$E = \text{Signal energy per symbol}$$

$$f_c = \frac{n_c}{T} \; ; \; n_c = \text{fixed integer}$$

- Each $s_i(t)$ can be expressed with $\phi_1(t) = \sqrt{\frac{2}{T}}\cos 2\pi f_c t$ and $\phi_2(t) = \sqrt{\frac{2}{T}}\sin 2\pi f_c t$ i.e only two orthonormal basis functions. Hence, the signal constellation of M-ary PSK is 2-dimensional.
- Euclidean distance or distance between adjacent signalling points = d_{12}

$$d_{12} = 2\sqrt{E_s}\sin\frac{\pi}{M}$$

- Symbol duration of M-ary PSK is given by

$$T_s = T_b \log_2 M$$

- Symbol energy $E_s = NE_b \quad (N = \log_2 M)$

$$E_b = \text{Bit energy}$$

- Distance of each signal point from origin in M-ary PSK is $\sqrt{E_s}$.
- Bandwidth of M-ary PSK = $\frac{2R_b}{N}$.
- For error, compare the $d_{\min}$ (minimum distance between any signalling points) and d_{12} i.e. distance between adjacent signalling points is not compared.
- Baud rate = $\frac{\text{Bit rate}}{\log_2 M}$ (M = total symbols)

Example - 8.3 A QPSK modulator has an input data rate of 90 Mbps and a carrier frequency 65 MHz. The minimum double sided Nyquist bandwidth is _____ MHz.

Solution:

$$\text{Bandwidth efficiency} = \frac{\text{Bit rate}}{\text{Bandwidth}}$$

$$\frac{R_b}{B} = \frac{\log_2 M}{2} \qquad \text{Here,} \quad M = 4$$

$$\therefore \qquad \frac{R_b}{B} = 1 \quad \text{and} \quad B = R_b = 90\text{ MHz}$$

8.8 Quadrature Amplitude Modulation

In PSK technique, one symbol is distinguished from other in phase, but all the symbols are same in amplitude in *M*-ary PSK. As we know that, the ability of receiver to distinguish between one signal vector from another depends on distance between vector end points. Hence noise immunity will improve if signals differs not only in phase but also in amplitude. Such a system is called as amplitude and phase shift keying system. It is also known as quadrature amplitude modulation.

8.8.1 Signal Space Representation of QAM

We want to transmit a symbol consisting of 4-bits. This means that $N = 4$ and there are $2^4 = 16$ possible symbols. Hence the QASK system, we should be able to generate 16 different distinguishable signals. A possible geometric representation of 16 symbols is shown in figure. Each signal point is equally distant from its nearest neighbours.

The average normalized energy of each signal is given the average of the energy associated with signals in first quadrant.

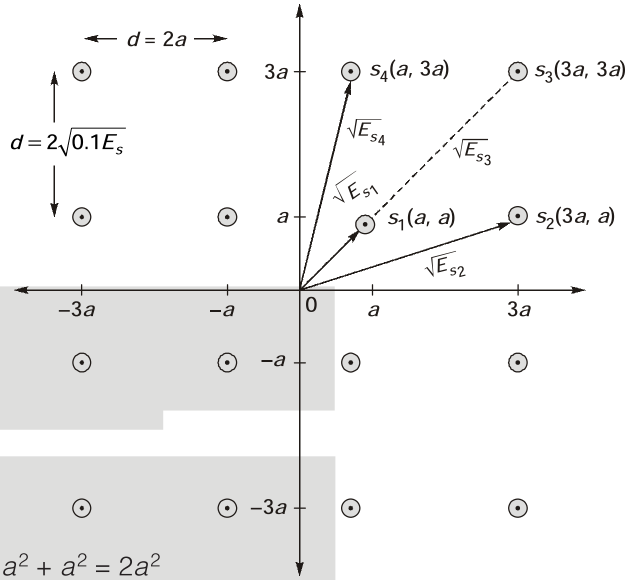


Figure-8.29

$$\therefore \quad E_s = \frac{E_{s_1} + E_{s_2} + E_{s_3} + E_{s_4}}{4}$$

From the figure,

$$E_{s_1} = (d_{11})^2 = a^2 + a^2 = 2a^2$$

$$E_{s_2} = (3a)^2 + a^2 = 10a^2$$

$$E_{s_3} = (3a)^2 + (3a)^2 = 18a^2$$

$$E_{s_4} = (a)^2 + (3a)^2 = 10a^2$$

$$E_s = \frac{2a^2 + 10a^2 + 18a^2 + 10a^2}{4} = \frac{40a^2}{4} = 10a^2$$

or

$$a = \sqrt{0.1E_s}$$

$$d = 2a$$

$$\Rightarrow \quad d = 2\sqrt{0.1E_s}$$

$$E_s = \text{Normalised symbol energy} = 4E_b$$

$$\Rightarrow \quad \boxed{a = \sqrt{0.4E_b}} \quad \text{and} \quad \boxed{d = 2\sqrt{0.4E_b}}$$

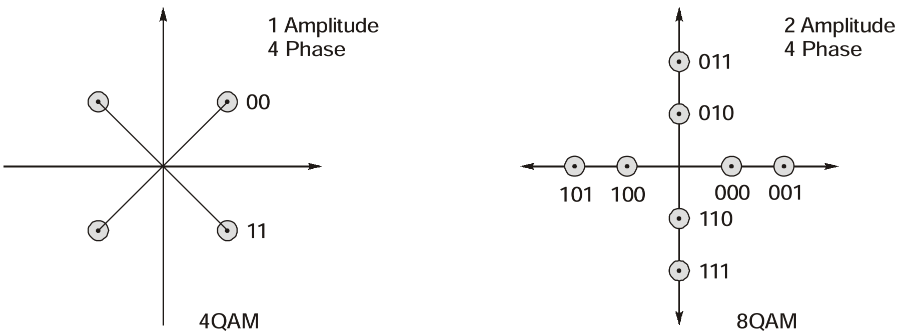


Figure-8.30