Module 2

Data Communication Fundamentals

Lesson
6

Digital Data, Analog Signals

Specific Instructional Objective

On completion, the students will be able to:

- Explain the basic concepts of Digital data to Digital signal conversion
- Explain different aspects of ASK, FSK, PSK and QAM conversion techniques
- Explain bandwidth and power requirement

2.6.1 Introduction

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. 2.6.1. 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.

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 Fig. 2.6.2. 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. There are many situations where ASK and PSK techniques are combined together leading to a modulation technique known as Quardrature Amplitude Aodulation (QAM). In this lesson, these modulation techniques are introduced.

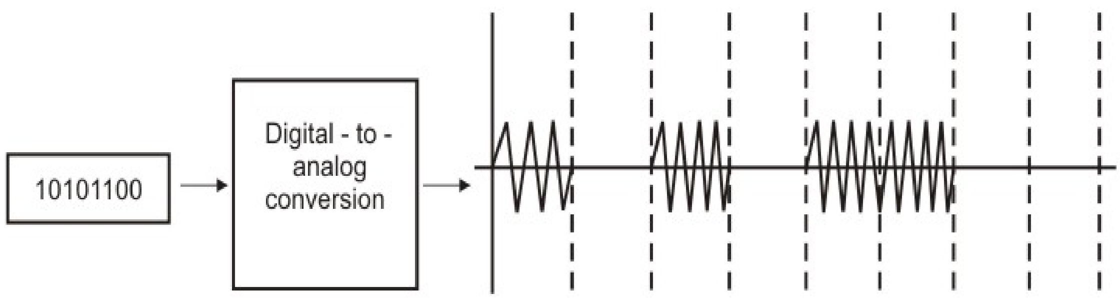

Figure 2.6.1 Conversion of digital data to analog signal

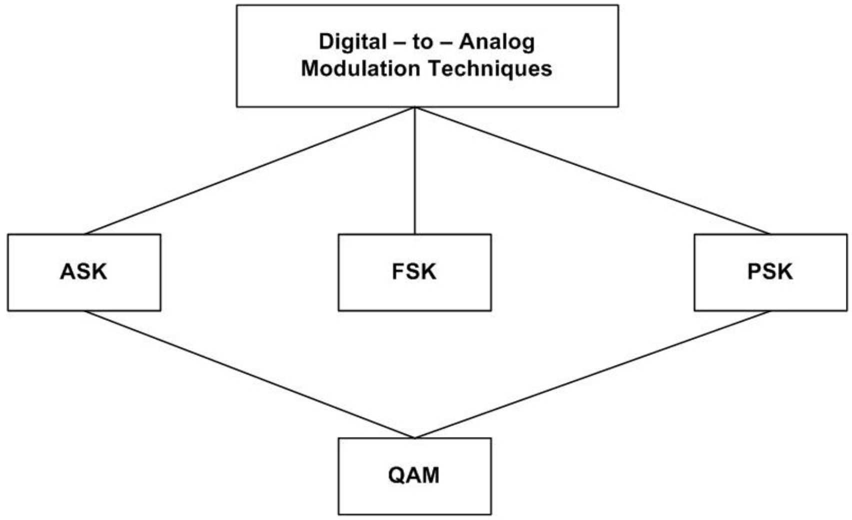

Figure 2.6.2 Types of digital-to-analog modulation

2.6.2 Amplitude-shift keying (ASK)

In ASK, two binary values are represented by two different amplitudes of the carrier frequency as shown in the Fig. 2.6.3. The unmodulated carrier can be represented by

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

The modulated signal can be written as

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

Special case: On/Off Keying (OOK), the amplitude $A_2 = 0$
ASK is susceptible to sudden gain changes and OOK is commonly used to transmit digital data over optical fibers.

Frequency Spectrum: If Bm is the overall bandwidth of the binary signal, the bandwidth of the modulated signal is $B_T = N_b$, where N_b is the baud rate. This is depicted in Fig. 2.6.4.

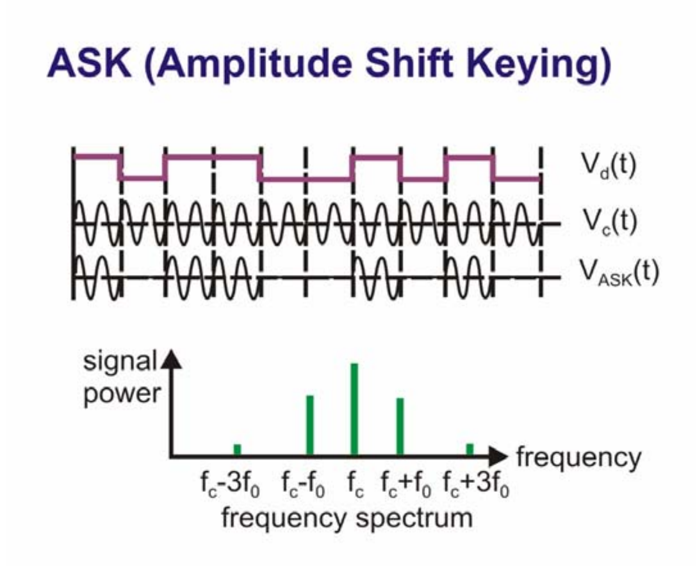

Figure 2.6.3 Amplitude shift-Keying

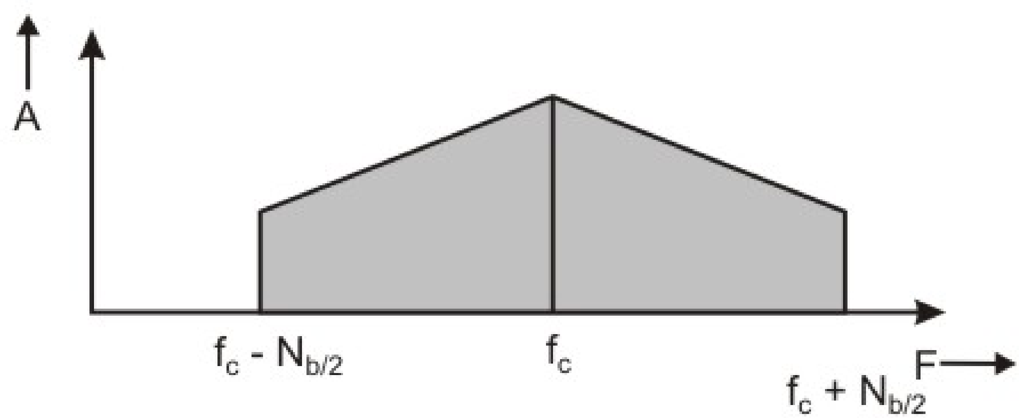

Fig 2.6.4 Frequency spectrum of the ASK signal

This method is very much susceptible to noise and sudden gain changes and hence it is considered as an inefficient modulation technique

2.6.3 Frequency-Shift Keying (FSK)

In this case two binary values are represented by two different frequencies near the carrier frequency as shown in Fig. 2.6.5.

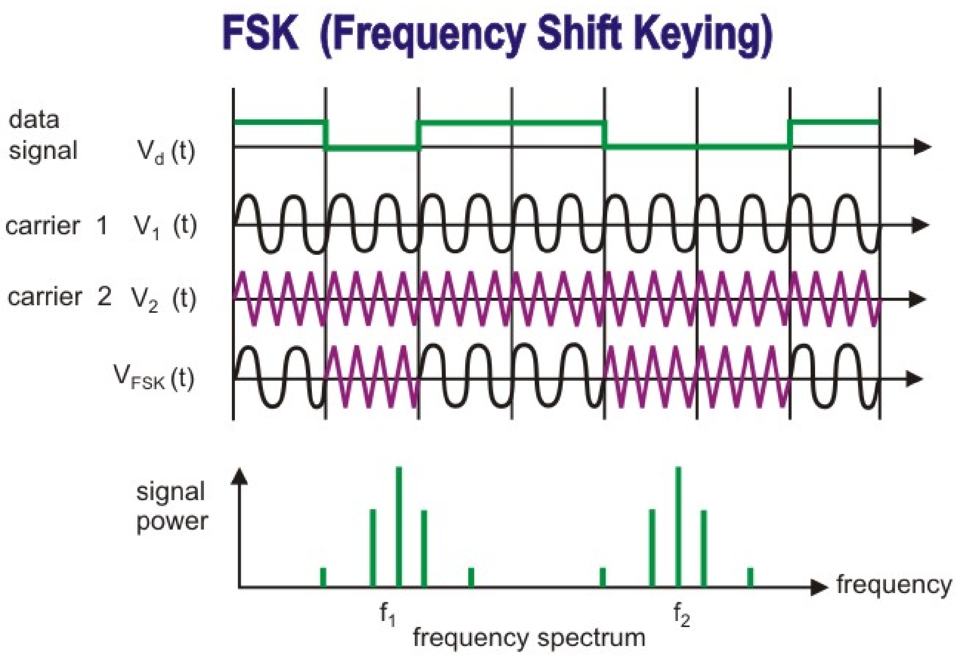

Figure 2.6.5 Frequency Shift-Keying

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

Here $s(t) = A \cos 2\pi f_{c1} t$ for binary 1
And $s(t) = A \cos 2\pi f_{c2} t$ for binary 0

This method is less susceptible to errors than ASK. It is mainly used in higher frequency radio transmission.

Frequency spectrum: FSK may be considered as a combination of two ASK spectra centered around f_{c1} and f_{c2}, which requires higher bandwidth. The **b**andwidth = $(f_{c2} - f_{c1}) + N_b$ as shown in Fig. 2.6.6.

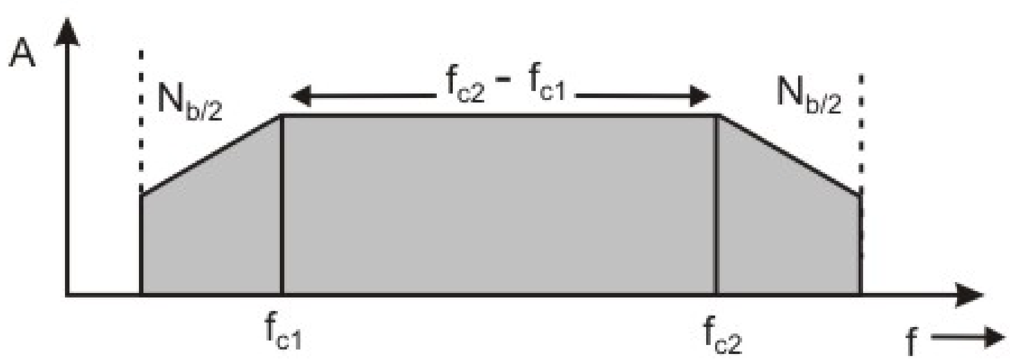

Figure 2.6.6 Frequency Spectrum of the FSK signal

2.6.4 Phase Shift Keying (PSK)

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 Fig. 2.6.7.

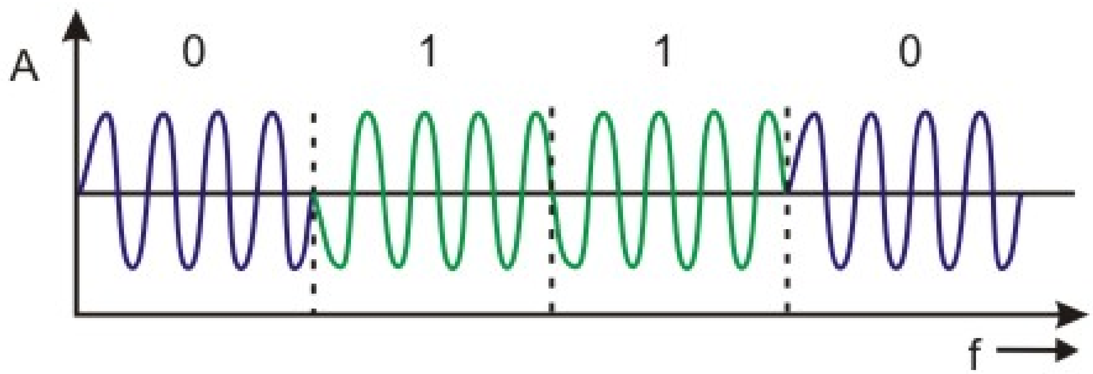

Figure 2.6.7 Phase-shift keying

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

The signal set can be shown geometrically in Fig. 2.6.8. This representation is called a **constellation** diagram, which provides a graphical representation of the complex envelope of each possible symbol state. The x-axis of a constellation diagram represents the in-phase component of the complex envelope, and the y-axis represents the quadrature component of the complex envelope. The distance between signals on a constellation diagram indicates how different the modulation waveforms are, and how well a receiver can differentiate between all possible symbols in presence of noise.

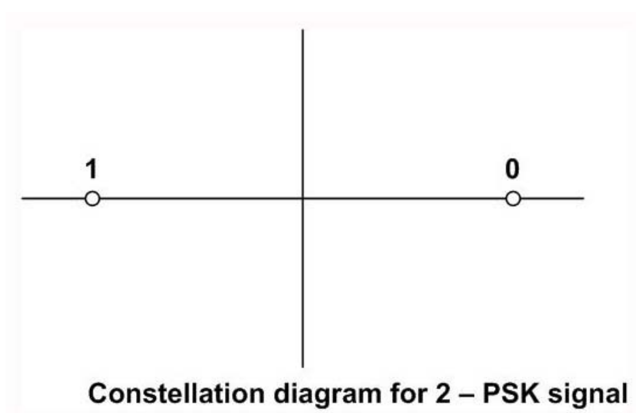

Figure 2.6.8 Constellation diagram for 2-PSK signal

M-ary Modulation: Instead of just varying the phase, frequency or amplitude of the RF signal, modern modulation techniques allow both envelope (amplitude) and phase (or frequency) of the RF carrier to vary. Because the envelope and phase provide two degrees of freedom, such modulation techniques map baseband data into four or more possible RF carrier signals. Such modulation techniques are known as **M-ary modulation**. In M-ary modulation scheme, two or more bits are grouped together to form symbols and one of possible signals $S_1(t)$, $S_2(t)$, …, $S_m(t)$ is transmitted during each symbol period T_s. Normally, the number of possible signals is $M = 2^n$, where n is an integer. Depending on whether the amplitude, phase or frequency is varied, the modulation is referred to as M-ary ASK, M-ary PSK or M-ary FSK, respectively. M-ary modulation technique attractive for use in bandlimited channels, because these techniques achieve better bandwidth efficiency at the expense of power efficiency. For example, an 8-PSK technique requires a bandwidth that is $\log_2 8 = 3$ times smaller than 2-PSK (also known as BPSK) system. However, M-ary signalling results in poorer error performance because of smaller distances between signals in the constellation diagram. Several commonly used M-ary signalling schemes are discussed below.

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

$$
\begin{aligned}
s(t) &= A\cos(2\pi f_c t) && \text{for } 00 \\
&= A\cos(2\pi f_c t + 90) && \text{for } 01 \\
&= A\cos(2\pi f_c t + 180) && \text{for } 10 \\
&= A\cos(2\pi f_c t + 270) && \text{for } 11
\end{aligned}
$$

Here phase shift occurs in multiple of 90° as shown in constellation diagram of Fig. 2.6.9.

Bits	Phase
00	0
01	90
10	180
11	270

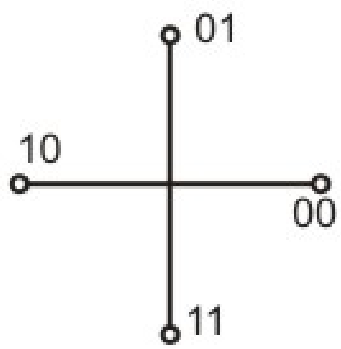

Figure 2.6.9 Constellation diagram for Quadrature PSK (QPSK) signal

8-PSK: The idea can be extended to have 8-PSK. Here the phase is shifted by 45° as shown in Fig. 2.6.10.

Bits	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	220
111	315

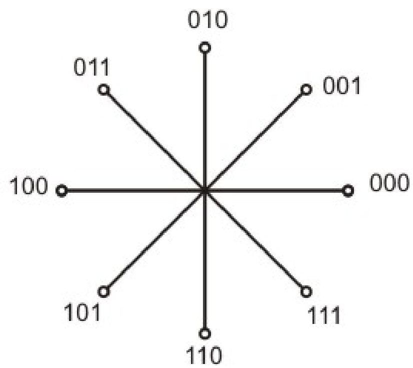

Figure 2.6.10 Constellation diagram for 8-PSK signal

QAM (Quadrature Amplitude Modulation): Ability of equipment to distinguish small differences in phase limits the potential bit rate. This can be improved by combining ASK and PSK. This combined modulation technique is known Quardrature Amplitude Modulation (QAM). It is possible to obtain higher data rate using QAM. The constellation diagram of a QAM signal with two amplitude levels and four phases is shown in Fig. 2.6.11. It may be noted that M-ary QAM does not have constant energy per symbol, nor does it have constant distance between possible symbol values.

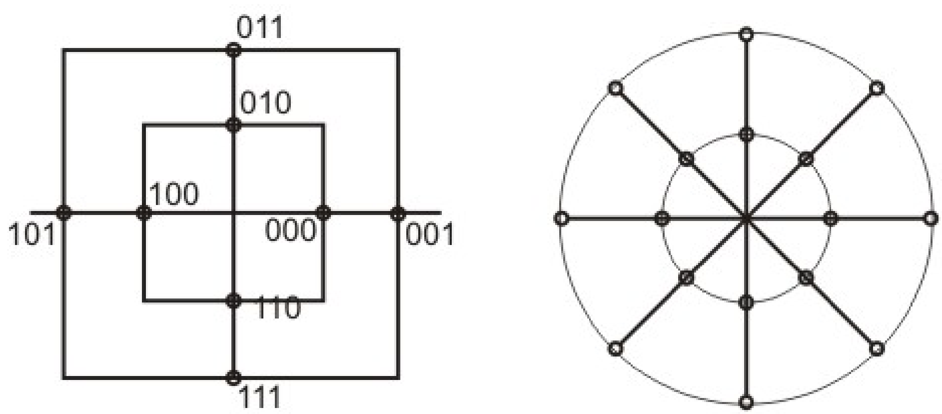

Figure 2.6.11 Constellation diagram for a QAM signal

Bit rate and Baud rate: Use of different modulation techniques lead to different baud rates (number of signal elements per second) for different values of bit rates, which represents the numbers of data bits per second. Table 2.6.1 shows how the same baud rate allows different bit rates for different modulation techniques. The baud rate, in turn, implies the bandwidth requirement of the medium used for transmission of the analog signal.

Table 2.6.1 Bit rate for the same bit rate for different modulation techniques

Modulation Technique	Baud rate	Bit rate
ASK, FSK,2-PSK	N	N
4 PSK	N	2N
8 PSK	N	3N
16 QAM	N	4N
32 QAM	N	5N
64 QAM	N	6N
128 QAM	N	7N
256 QAM	N	8N

Review Questions

Q1. What are the possible digital-to-analog modulation techniques?
Ans: Three possible digital-to-analog modulation techniques are:

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

Q2. **Why PSK is preferred as the modulation technique in modems?**
Ans: In PSK scheme it is possible to send a signal having more than one digital value. The approach is known as Quadrature PSK.

Q3. Out of the three digital-to-analog modulation techniques, which one requires higher bandwidth?
Ans: For a given transmission bandwidth, higher data rate can be achieved in case of PSK. In other words, in PSK higher channel capacity is achieved although the signaling rate is lower.