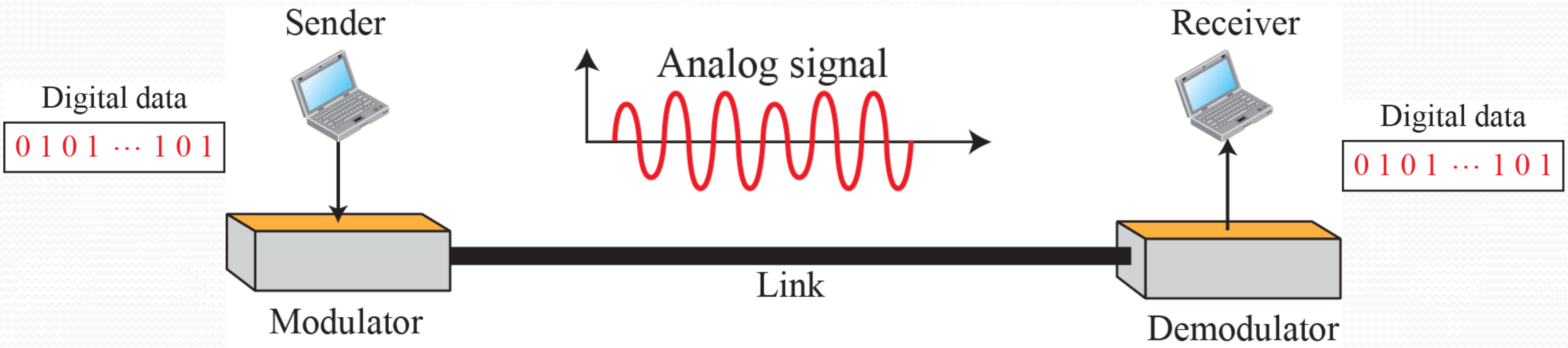
ITNT323

8- Digital Modulation

Digital Data, Analog Signal

Digital-to-analog modulation is the process of changing one of the characteristics of an analog signal based on the information in digital data. The next figure shows the relationship between the digital information, the digital-to-analog modulating process, and the resultant analog signal.

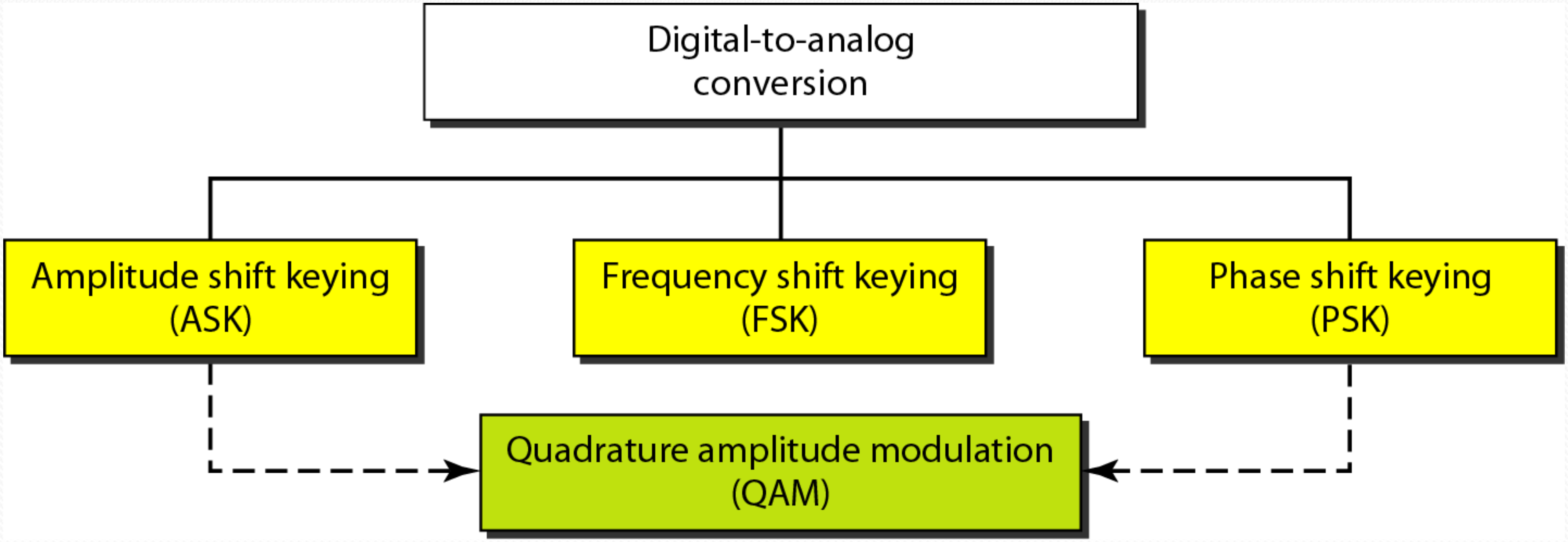
Digital-to-analog modulation



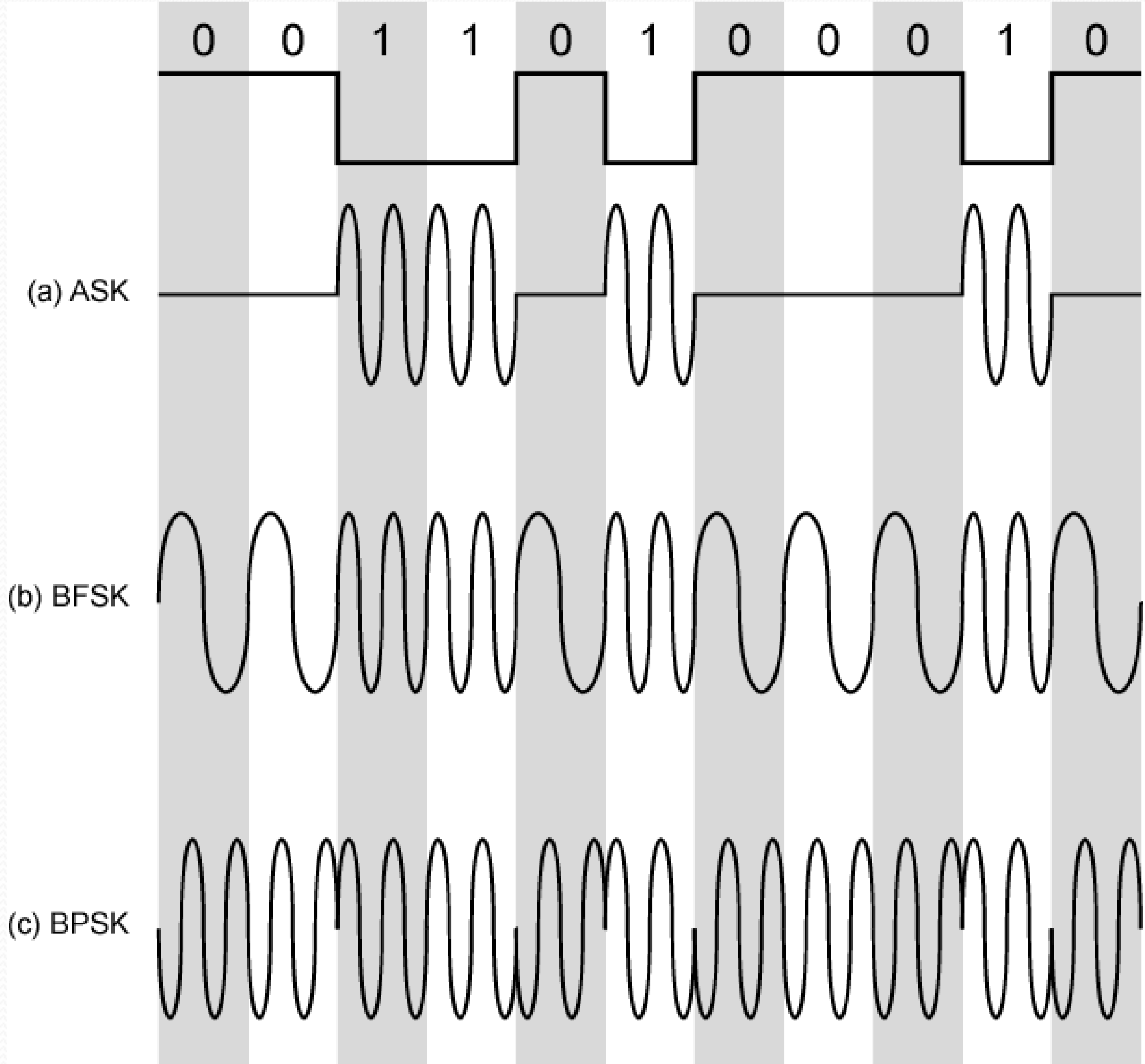
Digital Modulation Methods

1- amplitude shift keying (ASK) , in which the amplitude of a carrier is changed using the digital data.
2- frequency shift keying (FSK), in which the frequency of a carrier is changed using the digital data.
3- phase shift keying (PSK), in which the phase of a carrier signal is changed to represent digital data.
4- quadrature amplitude modulation (QAM), in which both amplitude and phase of acarrier signal are changed to represent digital data.

Types of digital to analog conversion



Modulation Techniques



1- Aspects of Conversion

Before we discuss specific methods of digital-to-analog modulation, two basic issues must be reviewed: bit and baud rates and the carrier signal.

Bit rate is the number of bits per second. Baud rate is the number of signal elements per second. In the analog transmission of digital data, the baud rate is less than or equal to the bit rate.

Example -1

An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate.

Solution

In this case, r = 4, S = 1000, and N is unknown. We can find the value of N from

$$S = N \times (1/r) \quad \text{or} \quad N = S \times r = 1000 \times 4 = 4000 \text{ bps}$$

Example -2

An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

Solution

In this example, S = 1000, N = 8000, and r and L are unknown. We first find the value of r and then the value of L.

$$S = N \times 1/r \longrightarrow r = N / S = 8000 / 10{,}000 = 8 \text{ bits/baud}$$

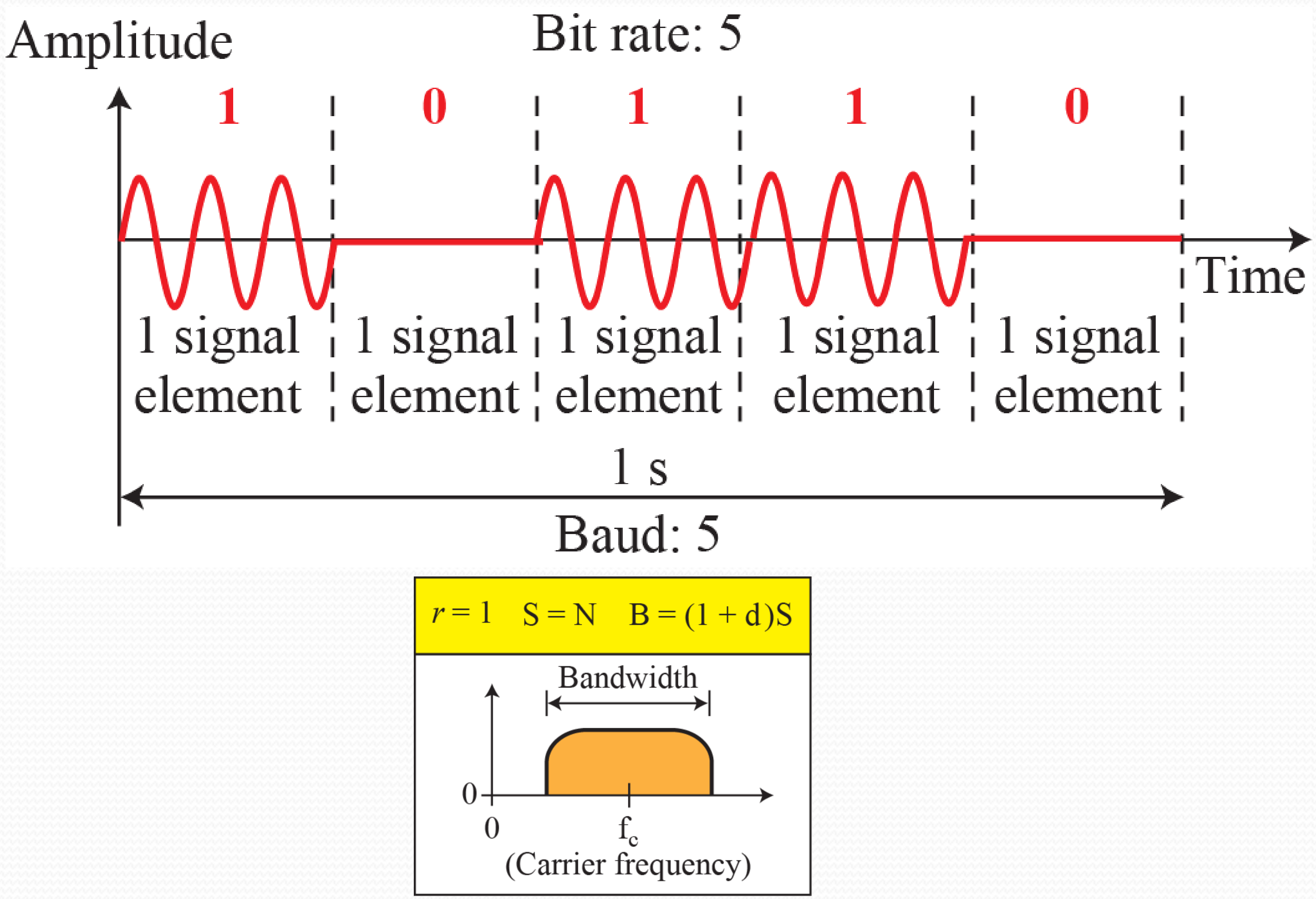
$$r = \log_2 L \longrightarrow L = 2^r = 2^8 = 256$$

2- Amplitude Shift Keying

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.

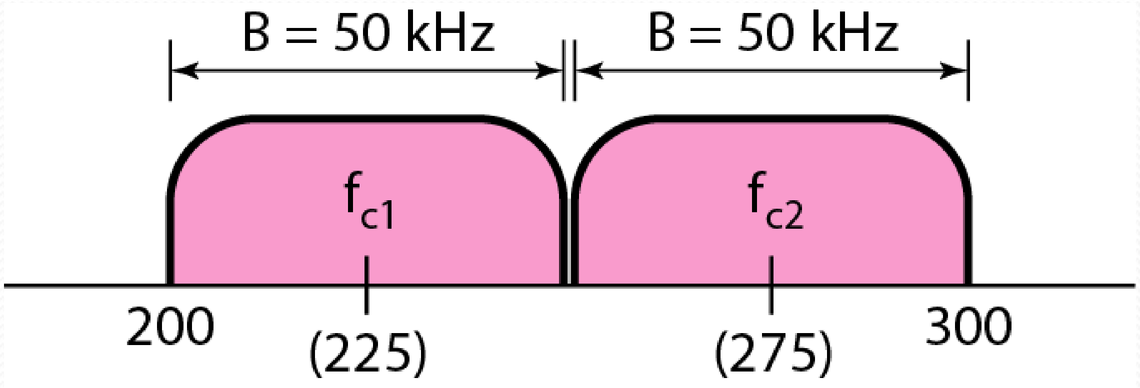
- **inefficient**
- **used for**
  - **up to 1200bps on voice grade lines**
  - **very high speeds over optical fiber**

Binary amplitude shift keying



The ASK technique is used to transmit digital data over optical fiber, where one signal element is represented by a light pulse while the other signal element is represented by the absence of light.

Bandwidth of a full-duplex ASK in previous example

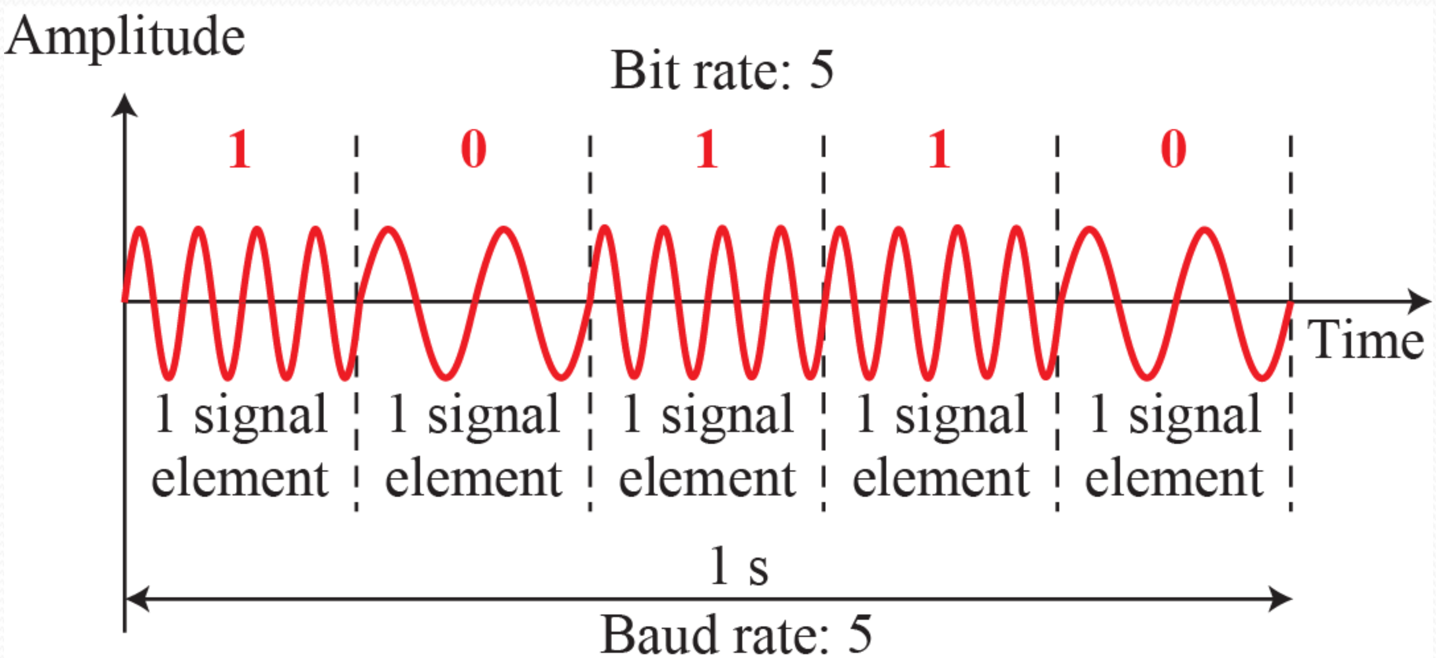


3- Frequency Shift Keying

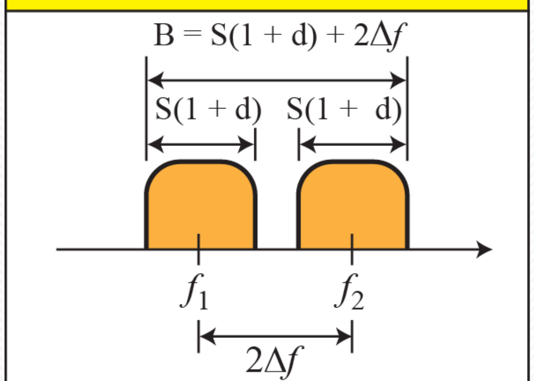
In frequency shift keying, the frequency of the carrier signal is varied to represent data. The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes. Both peak amplitude and phase remain constant for all signal elements.

- most common is binary FSK (BFSK)
- two binary values represented by two different frequencies (near carrier)
- less susceptible to error than ASK
- used for
  - up to 1200bps on voice grade lines
  - high frequency radio
  - even higher frequency on LANs using co-ax

Binary frequency shift keying



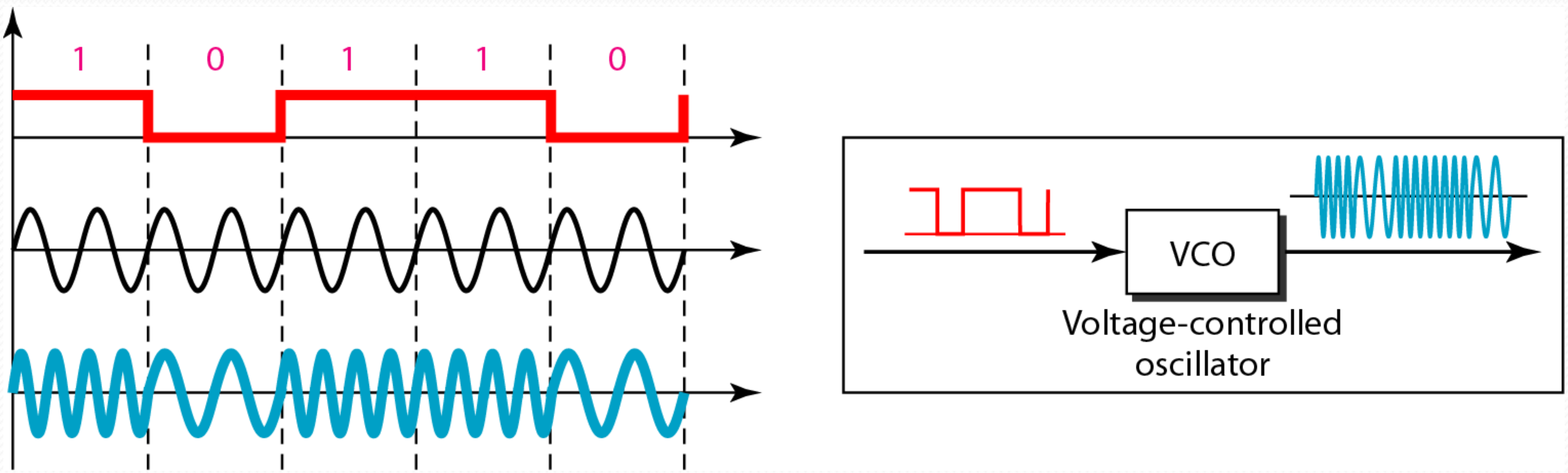
$r = 1 \quad S = N \quad B = (1 + d)S + 2\Delta f$



The most common form of **FSK** is binary FSK (BFSK), in which the two binary values are represented by two different frequencies near the carrier frequency, as shown in the Figure.

BFSK is less susceptible to error than ASK. On voice-grade lines, it is typically used up to 1200 bps. It is also commonly used for high-frequency (3 to 30 MHz) radio transmission. It can also be used at even higher frequencies on local area networks that use coaxial cable.

Implementation of BFSK



Multiple FSK

- each signalling element represents more than one bit
- more than two frequencies used
- more bandwidth efficient
- more prone to error

$$B = (1 + d) \times S + (L - 1)2\Delta f \rightarrow B = L \times S$$

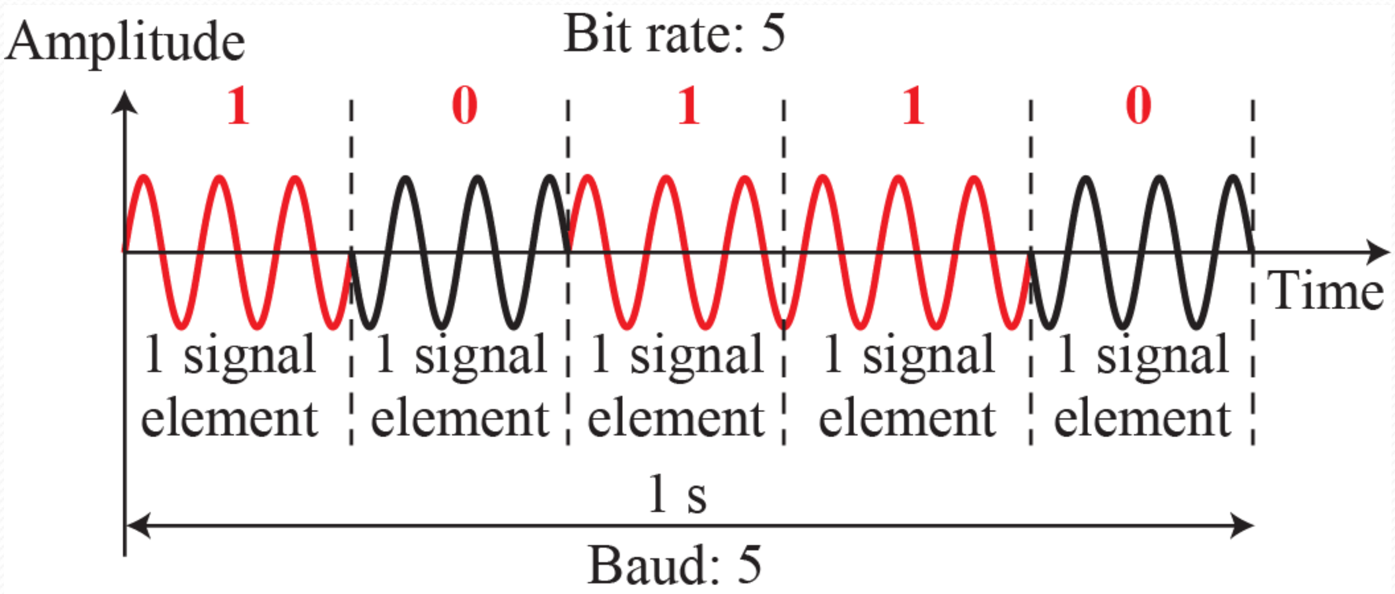
4 - Phase Shift Keying

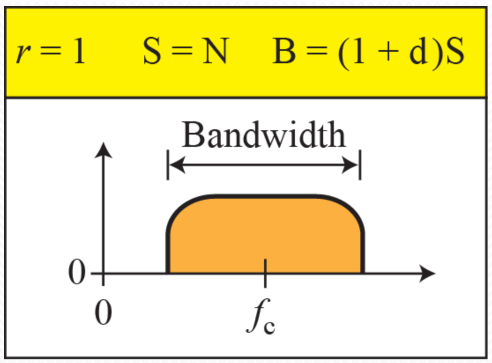
In phase shift keying, the phase of the carrier is varied to represent two or more different signal elements. Both peak amplitude and frequency remain constant as the phase changes. Today, PSK is more common than ASK or FSK. However, we will see shortly that QAM, which combines ASK and PSK, is the dominant method of digital-to-analog modulation.

- phase of carrier signal is shifted to represent data
- binary PSK
  - two phases represent two binary digits

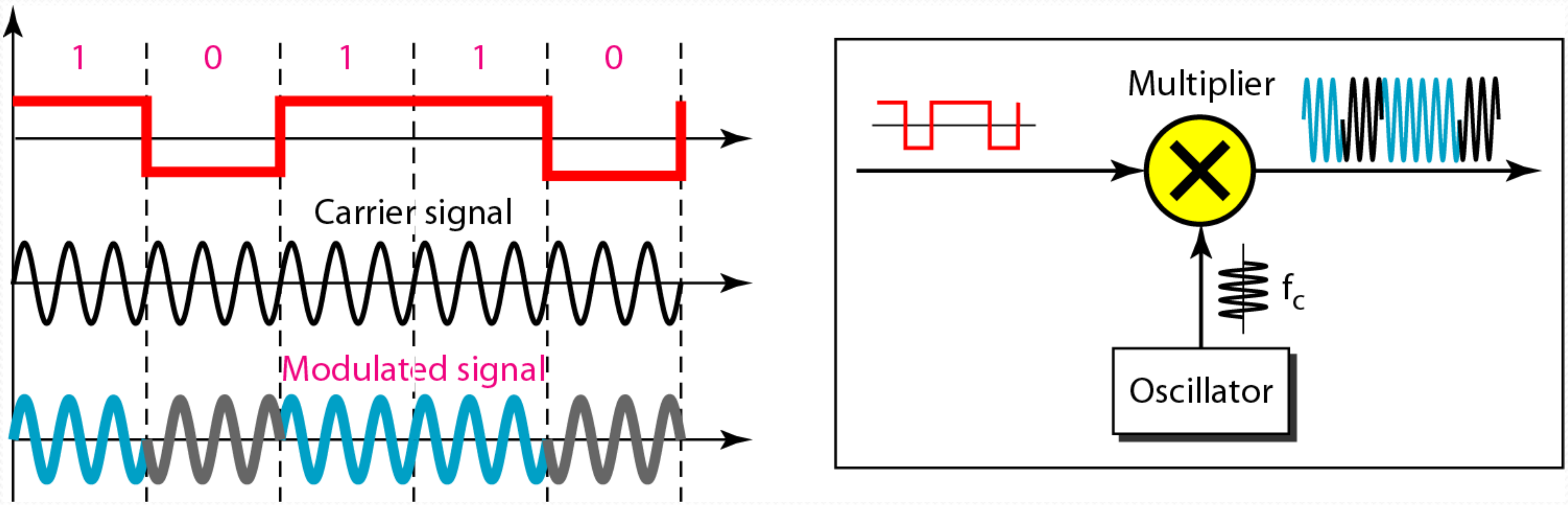
- In PSK, the phase of the carrier signal is shifted to represent data. The simplest scheme uses two phases to represent the two binary digits (Figure) and is known as binary phase shift keying.

Binary phase shift keying



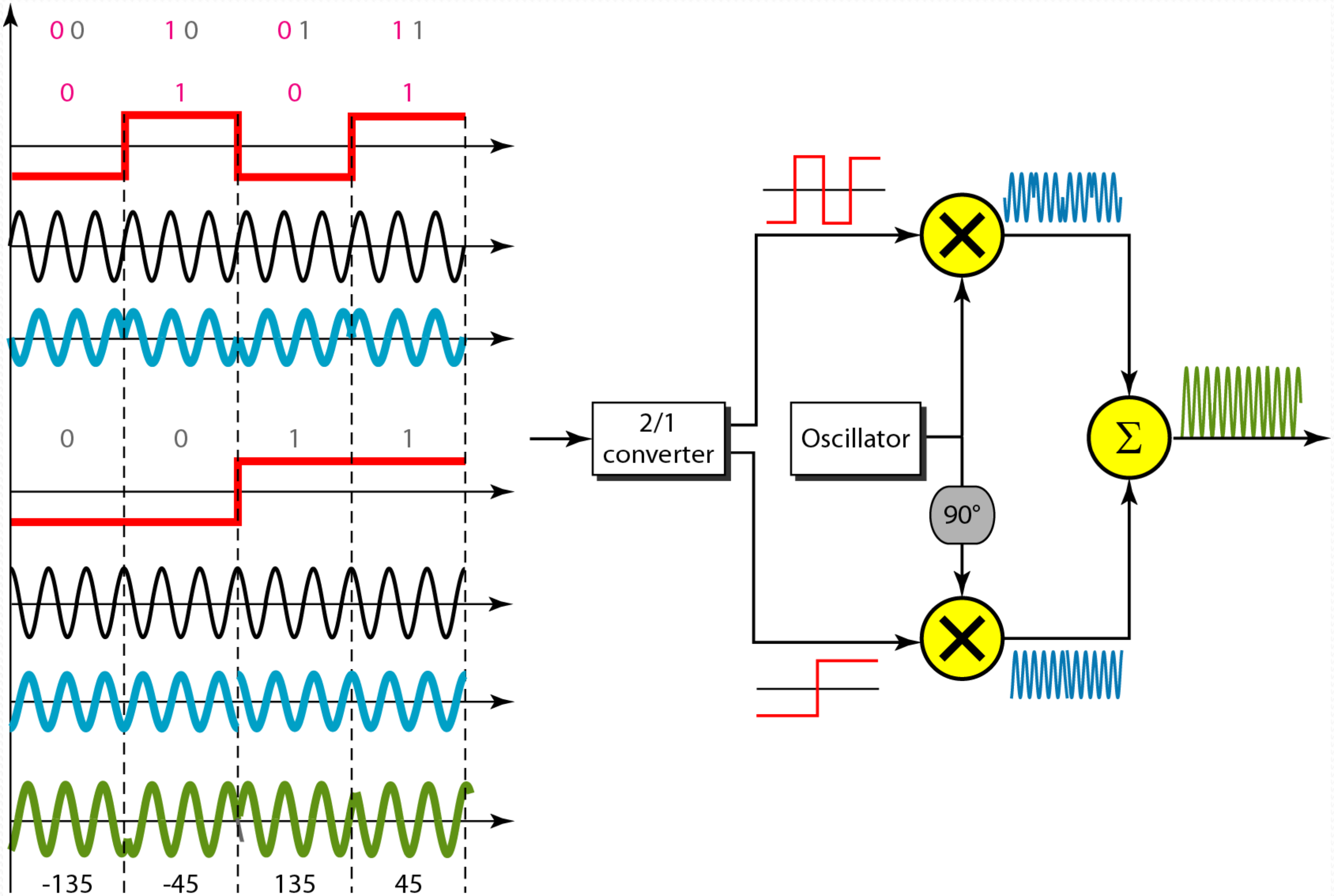


Implementation of BPSK



QPSK and its implementation

Each signal element represents two bits rather than one.



Example

Find the bandwidth for a signal transmitting at 12 Mbps for QPSK. The value of $d = 0$.

Solution

For QPSK, 2 bits are carried by one signal element. This means that $r = 2$. So the signal rate (baud rate) is $S = N \times (1/r) = 6$ Mbaud. With a value of $d = 0$, we have $B = S = 6$ MHz.

5 - Quadrature Amplitude Modulation

what if we alter two? Why not combine ASK and PSK? The idea of using two carriers, one in-phase and the other quadrature, with different amplitude levels for each carrier is the concept behind quadrature amplitude modulation (QAM).

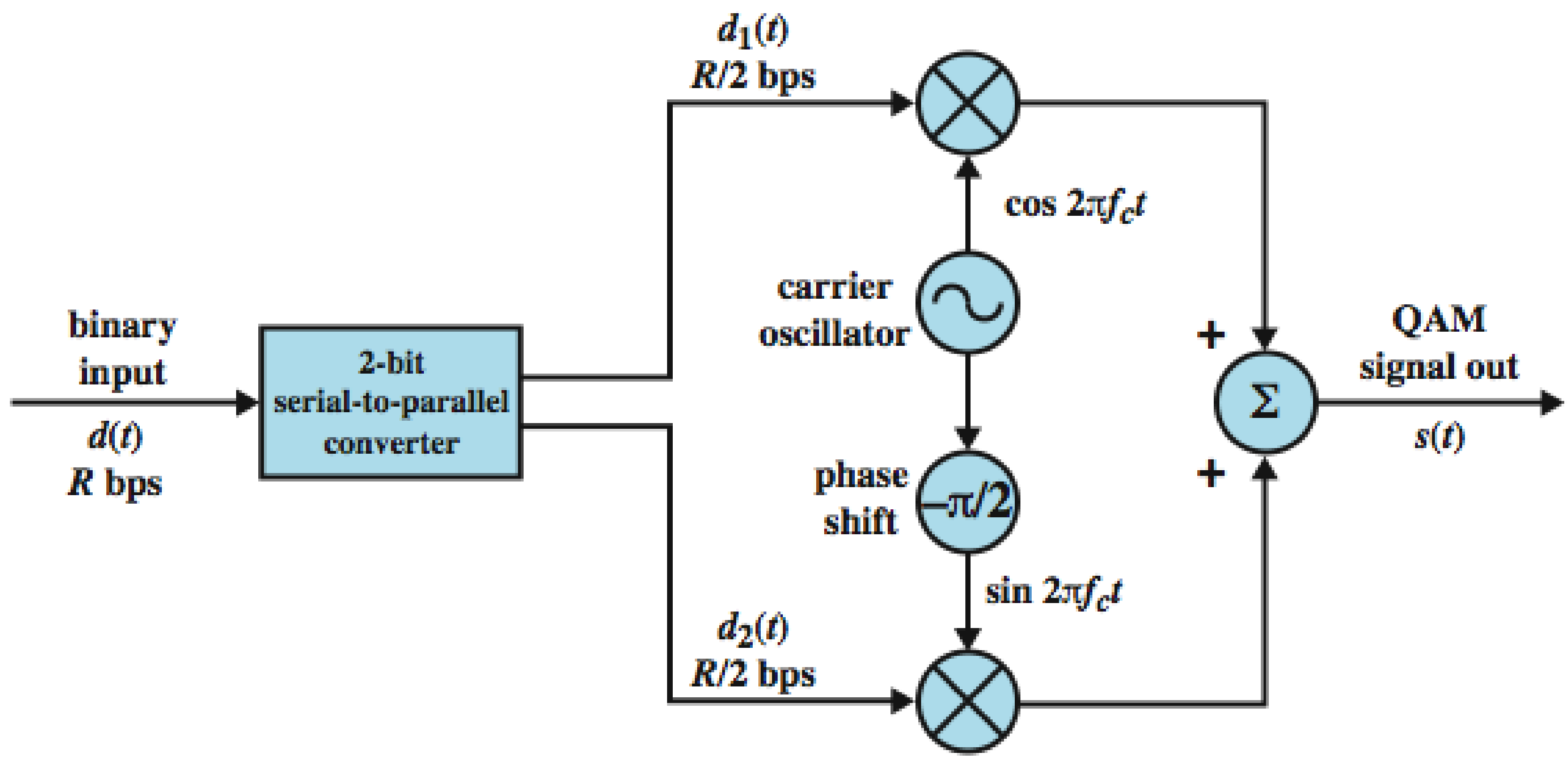
Quadrature amplitude modulation is a combination of ASK and PSK.

Quadrature Amplitude Modulation

- QAM used on asymmetric digital subscriber line (ADSL) and some wireless
- combination of ASK and PSK
- logical extension of QPSK
- send two different signals simultaneously on same carrier frequency
  - use two copies of carrier
  - each carrier is ASK modulated
  - two independent signals over same medium
  - demodulate and combine for original binary output

- The minimum bandwidth required for QAM transmission is the same as that required for ASK and PSK transmission. QAM has the same advantages as PSK over ASK.

QAM Modulator



- Figure shows the QAM modulation scheme in general terms. The input is a stream of binary digits arriving at a rate of R bps. This stream is converted into two separate bit streams of $R/2$ bps each, by taking alternate bits for the two streams. In the diagram, the upper stream is ASK modulated on a carrier of frequency f_c by multiplying the bit stream by the carrier. Thus, a binary zero is represented by the absence of the carrier wave and a binary one is represented by the presence of the carrier wave at a constant amplitude. This same carrier wave is shifted by 90˚ and used for ASK modulation of the lower binary stream. The two modulated signals are then added together and transmitted.

QAM Variants

- two level ASK
- four level ASK
- have 64 and 256 state systems
- improved data rate for given bandwidth
  - but increased potential error rate

Performance of Digital to Analog Modulation Schemes

- bandwidth
  - ASK/PSK bandwidth directly relates to bit rate
  - multilevel PSK gives significant improvements
- in presence of noise:
  - bit error rate of PSK and QPSK are about 3dB superior to ASK and FSK
  - for MFSK & MPSK have tradeoff between bandwidth efficiency and error performance

Further Reading:-

- Data Communications and Networking , Forouzan, 5e , Chapter **- 5**, **PP 136** .

- **اساسيات الاتصالات الرقمية: ص 124**