3.1 INTRODUCTION

INTRODUCTION TO DIGITAL COMMUNICATION:

Digital modulation: Digital Modulation is defined as changing the amplitude of the carrier signal with respect to the binary information or digital signal.

Bit rate is the number of bits transmitted during one second between the transmitter and receiver.

Baud rate is the rate of change of signal on transmission medium after encoding and modulation have occurred.

Digital communication is the physical transfer of data over Point-To-Point or Point-To-Multipoint communication channel. It is transfer of discrete messages. Digital communication plays a vital role in today's electronic world. Digital communication can be done over large distances through internet and other things.

Digital communication provides a seamless experience to customers and stakeholders – By eliminating the need for time-consuming face to face interactions, digital communication in various forms such as AI, chatbots and automation, makes it easier for customers to reach out to organizations at a time that is convenient.

These include **email, phone calls, video conferencing**, and many types of instant messaging like SMS and web chats. Even blogs, podcasts, and videos are consid

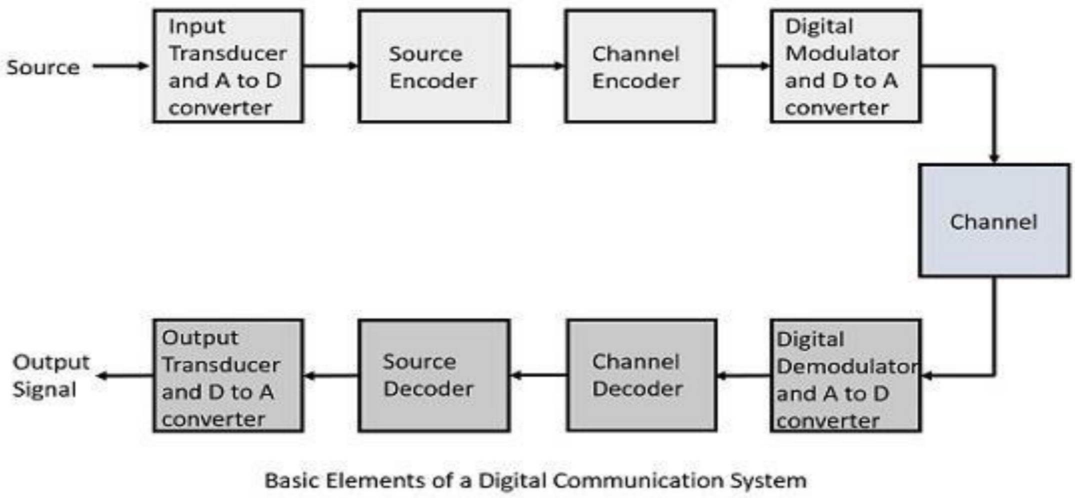


Figure 3.1.1 Basic Elements of a Digital Communication System

Source:

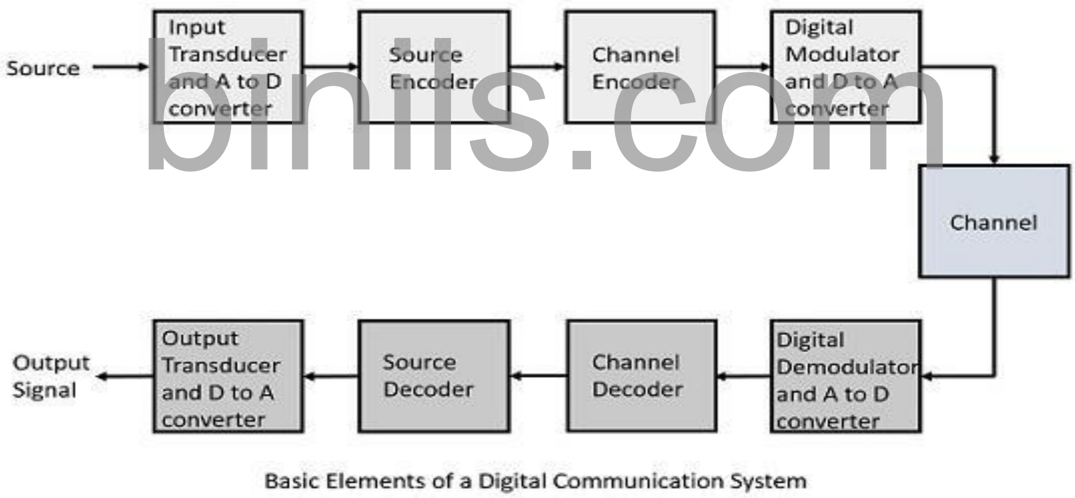


Figure 3.1.1 Basic Elements of a Digital Communication System

Source:

ered forms of digital communication.

- The source can be an analog signal. ...

Input Transducer:

- This is a transducer which takes a physical input and converts it to an electrical signal (Example: microphone). ...

Source Encoder:

- The source encoder compresses the data into minimum number of bits. This process helps in effective utilization of the bandwidth. It removes the redundant bits

Channel Encoder:

- The channel encoder, does the coding for error correction. During the transmission of the signal, due to the noise in the channel, the signal may get altered and hence to avoid this, the channel encoder adds some redundant bits to the transmitted data. These are the error correcting bits.

Digital Modulator:

- The signal to be transmitted is modulated here by a carrier. The signal is also converted to analog from the digital sequence, in order to make it travel through the channel or medium.

- **Channel:**
  - The channel or a medium, allows the analog signal to transmit from the

transmitter end to the receiver end.

Digital Demodulator:

- This is the first step at the receiver end. The received signal is demodulated as well as converted again from analog to digital. The signal gets reconstructed here.

Channel Decoder:

- The channel decoder, after detecting the sequence, does some error corrections. The distortions which might occur during the transmission, are corrected by adding some redundant bits. This addition of bits helps in the complete recovery of the original signal.

Source Decoder:

- The resultant signal is once again digitized by sampling and quantizing so that the pure digital output is obtained without the loss of information. The source decoder recreates the source output.

Output Transducer:

- This is the last block which converts the signal into the original physical form, which was at the input of the transmitter. It converts the electrical signal into physical output (**Example**: loud speaker).

Output Signal:

- This is the output which is produced after the whole process. **Example** − The sound signal received.
- This unit has dealt with the introduction, the digitization of signals, the advantages and the elements of digital communications. In the coming chapters, we will learn about the concepts of Digital communications

Bandwidth efficiency: Bandwidth efficiency is the ratio of the transmission bit rate to the minimum bandwidth required for a particular modulation

Advantages of Digital communications

- It has a better noise immunity
- Repeaters can be used between transmitters and receivers
- It becomes simpler and cheaper as compared to the analog communication

Disadvantages of Digital communications

- It requires a larger channel bandwidth
- Delta modulation needs synchronization incase of synchronous modulation

3.3 BINARY PHASE SHIFT KEYING

Binary Phase Shit Keying(BPSK)
Principle o BPSK

In binary phase shit keying (BPSK), binary symbol '1' and '0' modulate the phase of the carrier. Let the carrier be,

$$s(t) = A \cos(2\pi f_0 t) \quad \text{... (4.2.1)}$$

'A' represents peak value of sinusoidal carrier. In the standard 1Ω load register, the power dissipated will be

$$P = \frac{1}{2} A^2$$

$$\therefore \quad A = \sqrt{2P} \quad \text{... (4.2.2)}$$

When the symbol is changed, then the phase o the carrier is changed by degree (π radians)

Consider for example

$$\text{Symbol '1'} \Rightarrow s_1(t) = \sqrt{2P} \cos(2\pi f_0 t) \quad \text{... (4.2.3)}$$

if next symbol is '0' then,

$$\text{Symbol '0'} \Rightarrow s_2(t) = \sqrt{2P} \cos(2\pi f_0 t + \pi) \quad \text{... (4.2.4)}$$

Since $\cos(\theta + \pi) = -\cos\theta$, we can write above equation as,

$$s_2(t) = -\sqrt{2P} \cos(2\pi f_0 t) \quad \text{... (4.2.5)}$$

With the above equation we can define BPSK signal combinely as,

$$\boxed{s(t) = b(t)\sqrt{2P} \cos(2\pi f_0 t)} \quad \text{... (4.2.6)}$$

Here $b(t) = +1$ when binary '1' is to be transmitted

$= -1$ when binary '0' is to be transmitted

Graphical Representation of BPSK Signal

Fig 4.2.1 shows binary signal and its equivalent signal b(t).

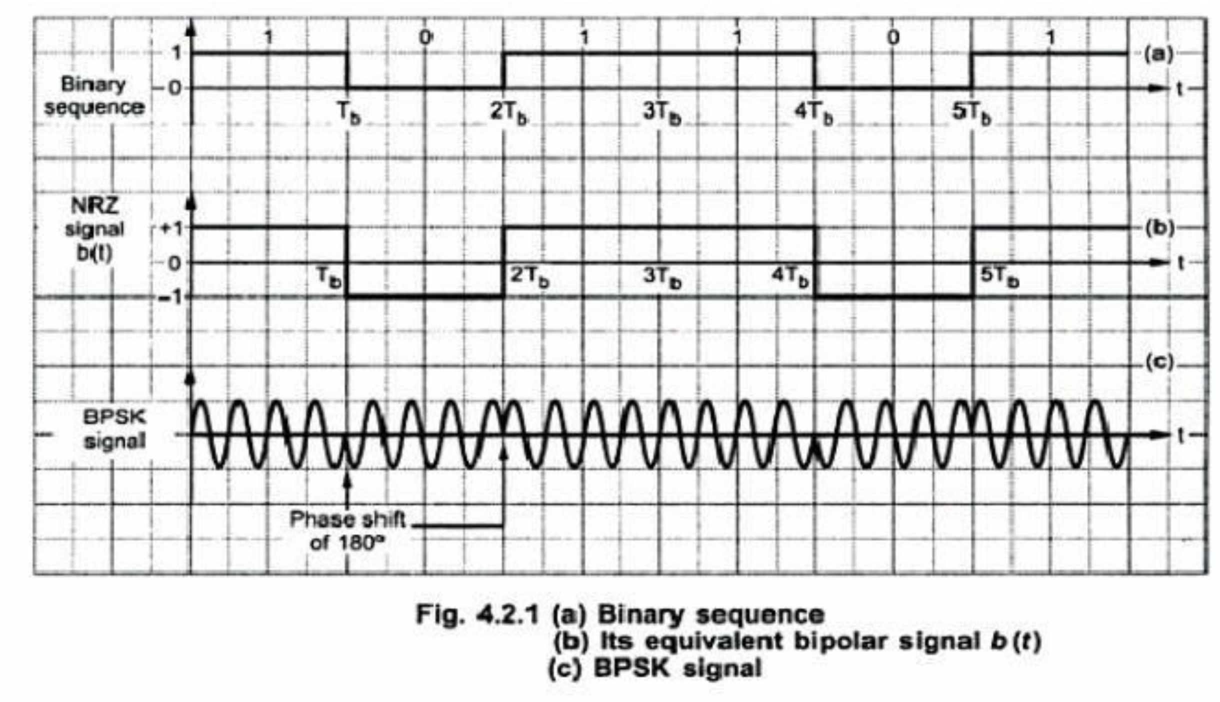


Figure 3.3.1 Graphical Representation of BPSK Signal

As can be seen from Fig. 3.3.2, the signal b(t) is NRZ bipolar signal. This signal directly modulated carrier $\cos(2\pi f_0 t)$.

Generation and Reception of BPSK Signal

Generation of BPSK Signal

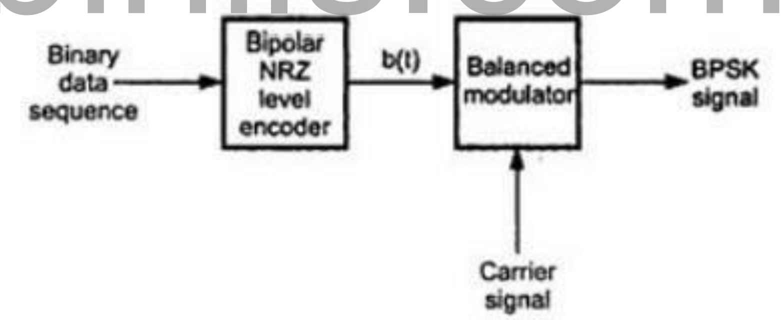


Figure 3.3.2 BPSK Generation Scheme

The BPSK signal can be generated by applying carrier signal to the balanced modulator.

The baseband signal b(t) is applied as a modulating signal to the balanced modulator. Ig 4.2.2 shows the block diagram of BPSK signal generator.

The NRZ level encoder converts the binary data sequence into bipolar NRZ signal.

Reception of BPSK Signal

Fig 4.2.3 shows the block diagram of the scheme to recover baseband signal from BPSK signal. The transmitted BPSK signal is,

$S(t) = b(t)\sqrt{2P}\cos(2\pi f_n t)$

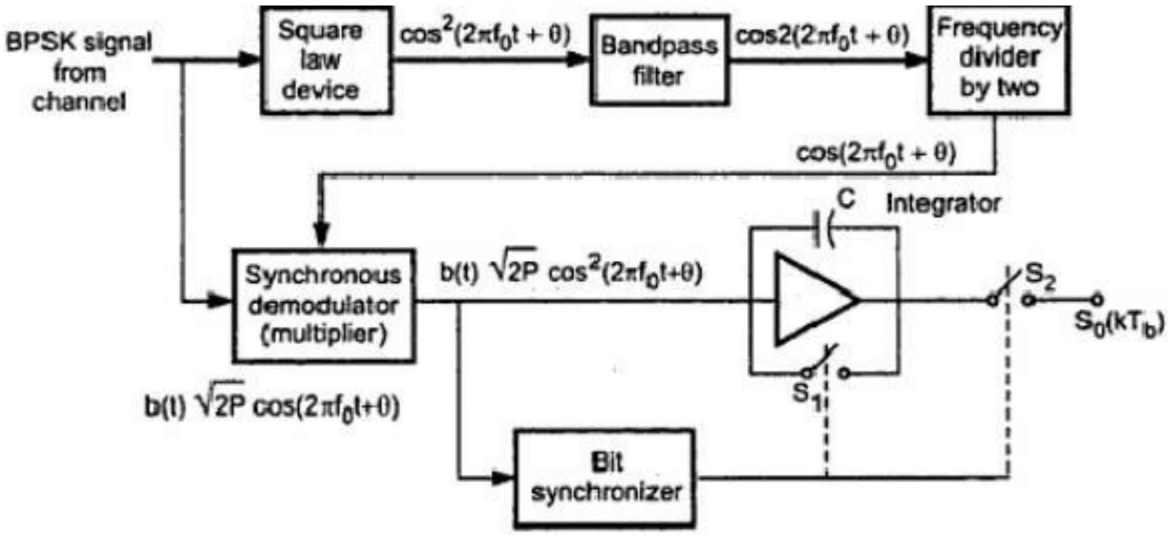


Figure 3.3.3 Reception of BPSK Sheme

Operation of the receiver

1) **Phase shift in received signal** : This signal undergoes the phase change depending upon the time delay from transmitter to receiver. This phase change is normally fixed phase shift in the transmitted signal. Let the phase shift be θ. Therefore the signal at the input of the receiver is,

$$s(t) = b(t)\sqrt{2P}\cos(2\pi f_0 t + \theta) \quad \text{... (4.2.7)}$$

2) **Square law device** : Now from this received signal, a carrier is separated since this is coherent detection. As shown in the figure, the received signal is passed through a square law device. At the output of the square law device the signal will be,

$$\cos^2(2\pi f_0 t + \theta)$$

Note here that we have neglected the amplitude, because we are only interested in the carrier of the signal.

We know that,

$$\cos^2\theta = \frac{1 + \cos 2\theta}{2}$$

$$\therefore \quad \cos^2(2\pi f_0 t + \theta) = \frac{1 + \cos 2(2\pi f_0 t + \theta)}{2}$$

Bandwidth of BPSK Signal

The spectrum of the BPSK signal is centered around the carrier frequency f_0.

If $f_b = \frac{1}{T_b}$, then for BPSK the maximum frequency in the baseband signal will be f_b see Fig. 4.2.6. In this figure the main lobe is centered around carrier frequency f_0 and extends from $f_0 - f_b$ to $f_0 + f_b$. Therefore Bandwidth of BPSK signal is,

$$BW = \text{Highest frequency} - \text{Lowest frequency in the main lobe}$$

$$= f_0 + f_b - (f_0 - f_b)$$

$$\therefore \quad \boxed{BW = 2f_b} \quad \text{... (4.2.21)}$$

Thus the minimum bandwidth of BPSK signal is equal to twice of the highest frequency contained in baseband signal.

3.2 PHASE SHIFT KEYING

Phase-shift keying (PSK) is a digital modulation process which conveys data by changing (modulating) the phase of a constant frequency reference signal (the carrier wave). The modulation is accomplished by varying the sine and cosine inputs at a precise time Usually, each phase encodes an equal number of bits.

The three primary digital modulation types - **PSK, frequency-shift keying (FSK) and amplitude-shift keying (ASK)** - modify base signals for data communication. PSK conveys data by modifying the phase of a signal Binary Phase-Shift Keying (BPSK): Simplest PSK type. Uses two phases separated by 180 degrees.

FREQUENCY SHIFT KEYING (FSK) , MINIMUM SHIFT KEYING (MSK)

Minimum Shift Keying (MSK) : The minimum frequency space that allows the 2 fsk representing symbols 0s and 1s. Thus CP (Continuous Phase) FSK signal with a deviation ratio if one half is defined as MSK.

Frequency Shift Keying (FSK) : Frequency Shift Keying is the as changing amplitude of the carrier signal with respect to the binary information or digital signal.

The advantages of Minimum Shift Keying :

MSK baseband waveform are smoother compared with QPSK MSK signals have continuous phase It does not have any amplitude variation

Frequency Shift Keying (FSK)

Transmitter

The 'N' successive bits are presented in parallel to digital to analog converter. These 'N' bits forms a symbol at the output of digital to analog converter. There will be total $2^N = M$ possible symbols. The symbol is presented every $T_s = N T_b$ period. The output o digital to analog converter is given to a frequency modulator. Thus depending upon the value of symbol, the frequency modulator generates the output frequency. For every symbol, the frequency modulator produces different frequency output. This particular frequency signal remains at the output or one symbol duration. Thus for 'M' symbols, there are 'M' frequency signals at the output of modulator. Thus the transmitted requencies are f_0, f_1, f_2, ...F_{M-1}, depending upon the input symbol to the modulator.

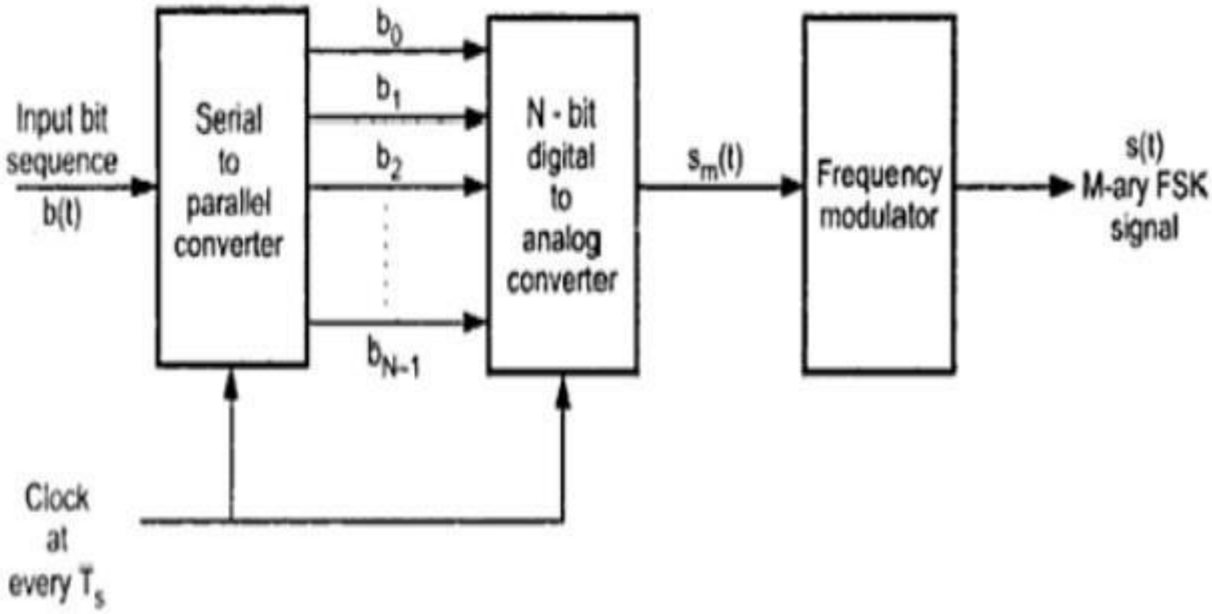


Figure 3.2.1 FSK Transmitter

Receiver

The M-ary PSM signal is given to the set of 'M' bandpass filters. The center frequencies of those filters are f_0, f_1, f_2,……… F_{M-1},. These filters pass their particular frequency and alternate others. The envelope detectors outputs are applied to a decision device. The decision device produces its output depending upon the highest input. Depending upon the particular symbol, only one envelope detector will have higher output. The outputs of other detectors will be very low. The output of the decision device is given to 'N' bit symbol in parallel. These bits are then converted to serial bit stream by parallel to serial converter. In some cases the bits appear in parallel. Then there is no use serial to parallel and parallel to serial converters.

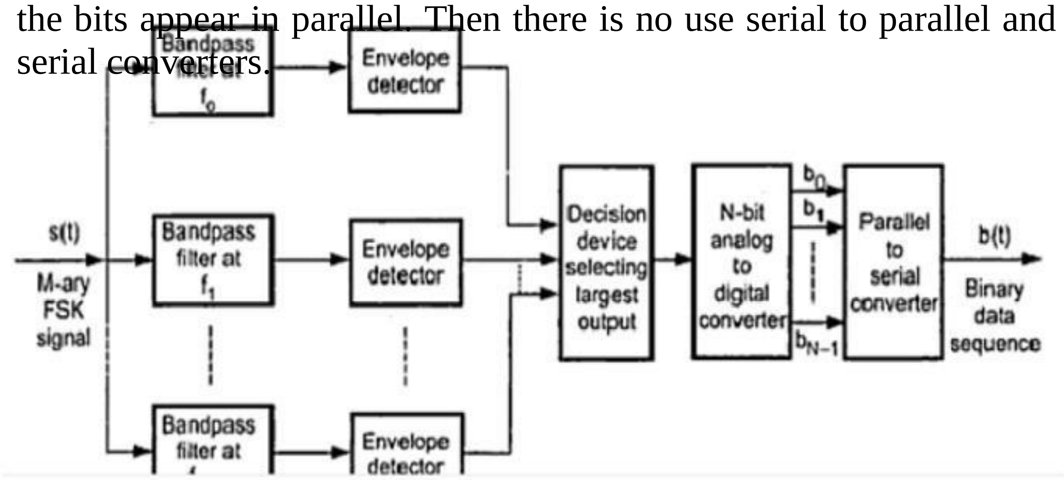


Figure 3.2.2 FSK Receiver

AMPLITUDE SHIFT KEYING (ASK) PHASE SHIFT KEYING (PSK):

Amplitude Shift Keying (ASK) : Amplitude Shift Keying is the as changing amplitude of the carrier signal with respect to the binary information or digital signal.

Define Phase Shift Keying (PSK): Phase Shift Keying is the changing amplitude of the carrier signal with respect to the binary information or digital signal

Concept Of Amplitude Shift Keying In Detail:

The amplitude shit keying is also called on-off keying(OOK). This is the simplest digital modulation technique. The binary input data is converted to unipolar NRZ signal. A product modulator takes this NRZ signal and carrier signal. The output of the product modulator is the ASK signal, which can be expressed mathematically as,

Here f_c is the carrier frequency
and d is the data bit, which is either 1 or 0.
Fig. 2.3.1 (a) shows the block diagram of the ASK modulator. The binary data sequence 'd' is given to the NRZ level encoder. This NRZ level encoder converts the input binary sequence to the signal suitable for product modulator. The product modulator also accepts a sinusoidal carrier of frequency f_c. The output o the product modulator is passed through a bandpass filter for bandwidth limiting. The output of the bandpass filter is the ASK signal. This signal and other waveforms are shown in Fig. 2.3.1(b). Observe that the ASK signal. And when d=1, $d=\sin(2\pi f_c t)$. The ASK is very sensitive to noise. It is used for very low bit rates less than around 100 bps. The only advantage of ASK is that it is very simple to implement.

Baud rate

Or ASK, the ASK waveform is changed at the bit rate. Hence Baud rate is given as,

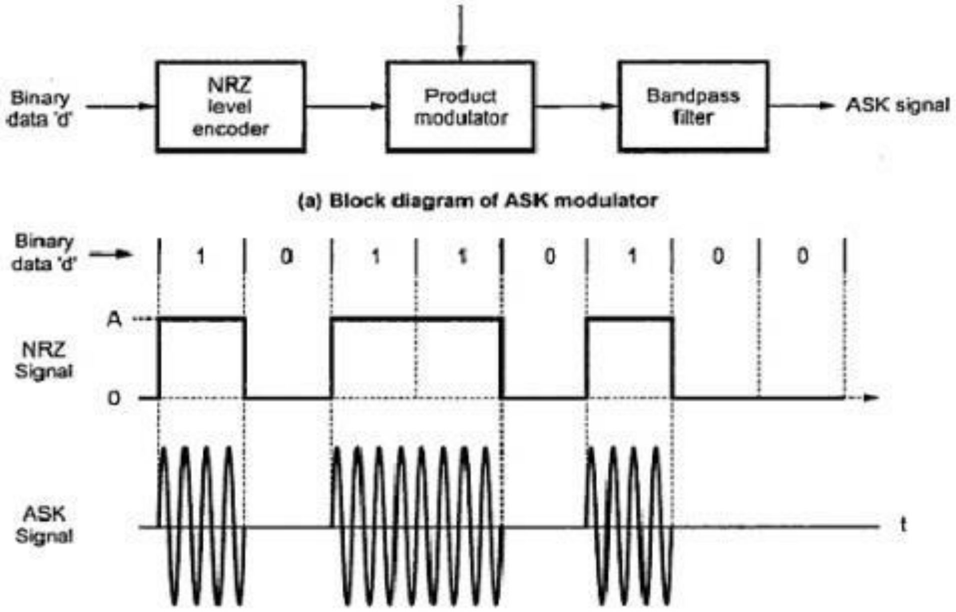


Figure 3.2.3 Amplitude Shift Keying

3.5Quadrature Phase Shift Keying

QUADRATURE PHASE SHIFT KEYING (QPSK) TECHNIQUES AND ITS BLOCK DIAGRAM:

- Very good noise immunity
- Effective utilization of available bandwidth
- Low error probability
- Very high bit rate data transmission

Quadrature phase shift keying (QPSK)

QPSK Transmitter

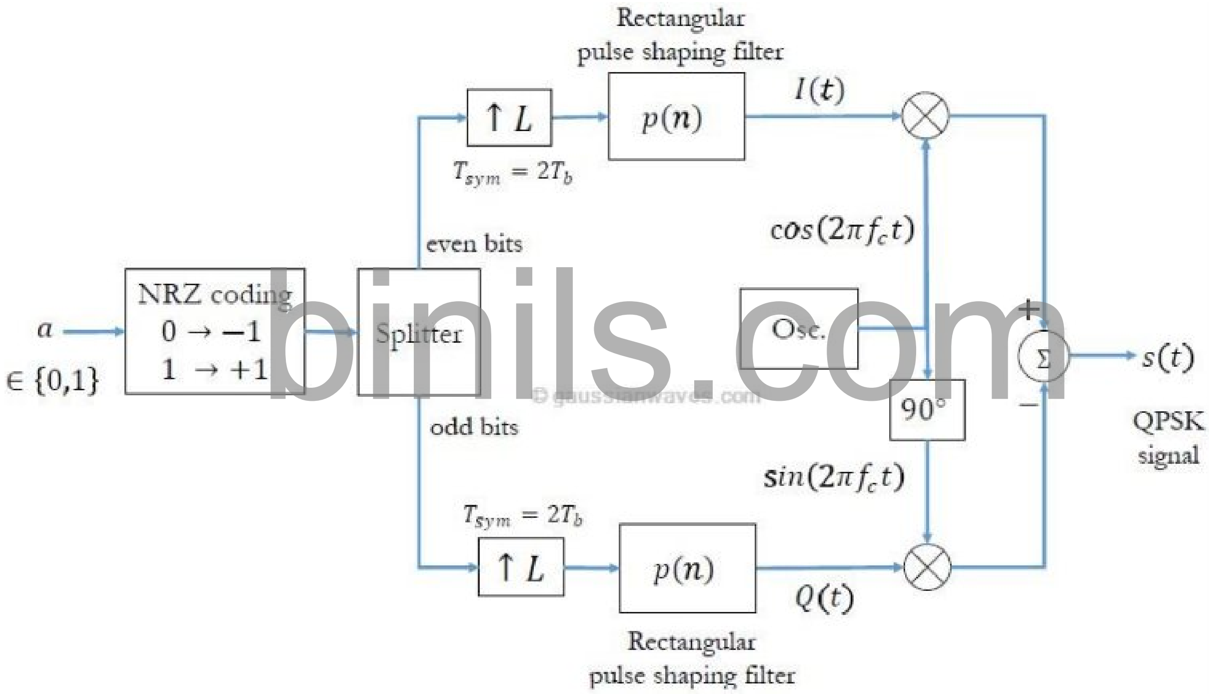


Figure 3.5.1 QPSK Transmitter

Quadrature Phase Shift Keying (QPSK) is a form of phase modulation technique, in which two information bits (combined as one symbol) are modulated at once, selecting one of the four possible carrier phase shift states.

$$\theta_n = (2n-1)\frac{\pi}{4} \qquad (2)$$

Therefore, the four possible initial signal phases are $\pi/4, 3\pi/4, 5\pi/4$ and $7\pi/4$ radians. Equation (1) can be re-written as

$$s(t) = A\ cos\theta_n\ cos(2\pi f_c t) - A\ sin\theta_n\ sin(2\pi f_c t)$$
$$= s_{ni}\phi_i(t) + s_{nq}\phi_q(t) \qquad (3)$$

The above expression indicates the use of two orthonormal basis functions: $\langle\phi_i(t), \phi_q(t)\rangle$ together with the inphase and quadrature signaling points: $\langle s_{ni}, s_{nq}\rangle$. Therefore, on a two dimensional co-ordinate system with the axes set to $\phi_i(t)$ and $\phi_q(t)$, the QPSK signal is represented by four constellation points dictated by the vectors $\langle s_{ni}, s_{nq}\rangle$ with $n = 1, 2, 3, 4$.

The QPSK transmitter, shown in Figure 1, is implemented as a matlab function ***qpsk_mod***. In this implementation, a splitter separates the odd and even bits from the generated information bits. Each stream of odd bits (quadrature arm) and even bits (in-phase arm) are converted to NRZ format in a parallel manner.

The timing diagram for BPSK and QPSK modulation is shown in Figure 2. For BPSK modulation the symbol duration for each bit is same as bit duration, but for QPSK the symbol duration is twice the bit duration: $T_{sym} = 2T_b$. Therefore, if the QPSK symbols were transmitted at same rate as BPSK, it is clear that QPSK sends twice as much data as BPSK does. After oversampling and pulse shaping, it is intuitively clear that the signal on the I-arm and Q-arm are BPSK signals with symbol duration $2T_b$ The signal on the in-phase arm is then multiplied by $cos(2\pi f_c t)$ and the signal on the quadrature arm is multiplied by $-sin(2\pi f_c t)$. QPSK modulated signal is obtained by adding the signal from both in-phase and quadrature arms.

Timing diagram for BPSK and QPSK modulation

The oversampling rate for the simulation is chosen as $L = 2f_s/f_c$, where f_c is the given carrier frequency and f_s is the sampling frequency satisfying Nyquist sampling theorem with respect to the carrier frequency ($f_s \geq fc$). This configuration gives integral number of carrier cycles for one symbol duration.

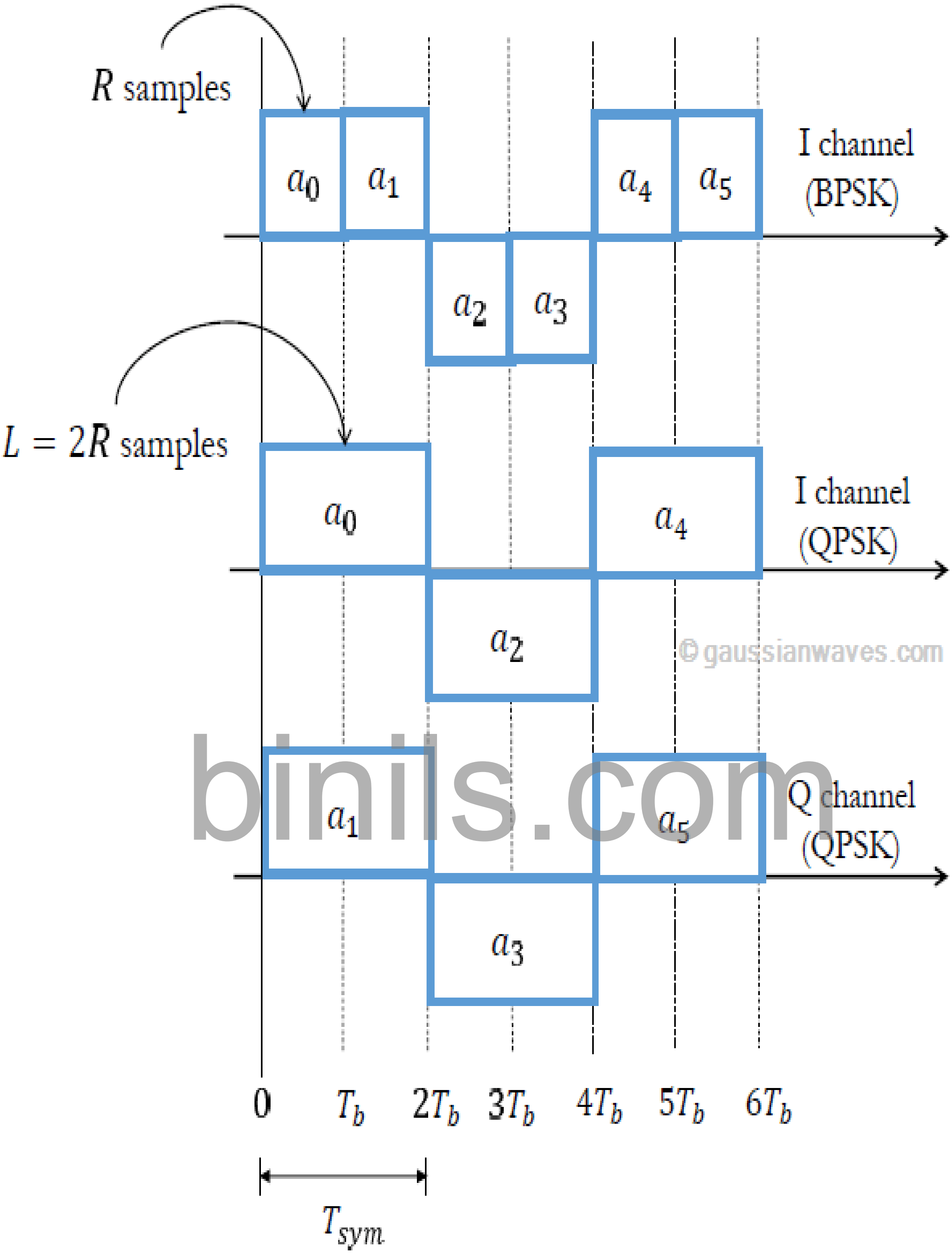


Figure 3.5.2 **Timing diagram for BPSK and QPSK modulations**

QPSK Receiver

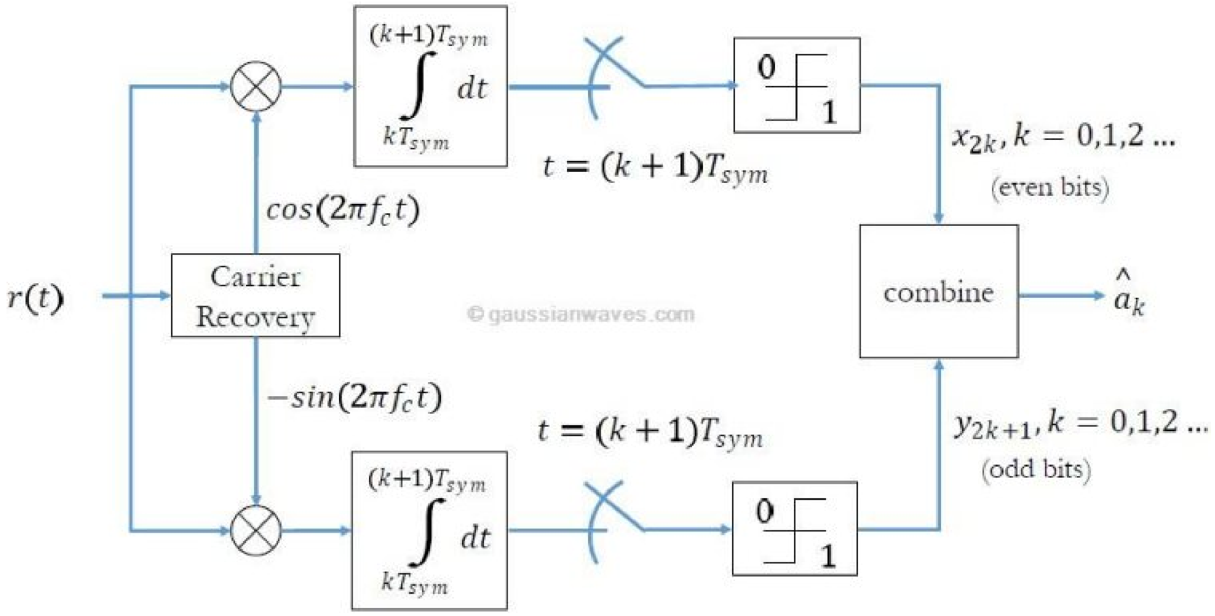


Figure 3.5.3 QPSK Receiver

Due to its special relationship with BPSK, the QPSK receiver takes the simplest form as shown in Figure 3. In this implementation, the I-channel and Q-channel signals are individually demodulated in the same way as that of BPSK demodulation. After demodulation, the I-channel bits and Q-channel sequences are combined into a single sequence. The function ***qpsk_demod*** implements a QPSK demodulator as per Figure 3.5.3

This is Synchronous reception. Therefore coherent carrier is to be recovered from the received signal s(t).

Compare binary PSK with QPSK.

BPSK QPSK

1. One bit forms a symbol. Two bits form a symbol.

2. Two possible symbols. Four possible symbols.

3. Minimum bandwidth is twice of fb. Minimum bandwidth is equal to fb.

4. Symbol duration = Tb. Symbol duration = 2Tb.

9. What are the advantages of M-ary signaling scheme?

1. M-ary signaling schemes transmit bits at a time.

2. Bandwidth requirement of M-ary signaling schemes is reduced.

The probability of error in M-Ary FSK as the value of m increases:

As the value of „M" increases, the Euclidean distance between the symbols reduces. Hence the symbols come closer to each other. This increases the probability of error in M-ary systems.

Correlative coding allows the signaling rate of 2B0 in the channel of bandwidth B0. This is made physically possible by allowing ISI in the transmitted signal in controlled manner. This ISI is known to the receiver. Hence effects of ISI are eliminated at the receiver. Correlative coding is implemented by duobinary signaling and modified duobinary signaling.

3.4 QUADRATURE AMPLITUDE MODULATION

Quadrature Amplitude modulation (QAM): QAM is a form of digital modulation similar to PSK except the digital information is contained in both the amplitude and phase of the transmitted carrier.

QAM is a combination of ASK and PSKTwo different signals sent simultaneously on the same carrier frequency ie,M=4, 16, 32, 64, 128, 256 As an example of QAM, 12 different phases are combined with two different amplitudes.

Since only 4 phase angles have 2 different amplitudes, there are a total of 16 combinations. With 16 signal combinations, each baud equals 4 bits of information (2 ^ 4 16).

Combine ASK and PSK such that each signal corresponds to multiple bits.

More phases than amplitudes. Minimum bandwidth requirement same as ASK or PSK

QAM (**quadrature amplitude modulation**) is a method of combining two amplitude modulation (AM) signals into a single channel. This approach helps double its effective bandwidth One signal is called the I signal, and the other is called the Q signal.

QAM is used extensively as **a modulation scheme for digital telecommunication systems**, such as in 802.11 Wi-Fi standards. Arbitrarily high spectral efficiencies can be achieved with QAM by setting a suitable constellation size, limited only by the noise level and linearity of the communications channel.

Orthogonal Frequency Division Multiplexing (OFDM) is an efficient modulation format used in modern wireless communication systems including 5G. OFDM combines the benefits of **Quadrature Amplitude Modulation** (QAM) and Frequency Division Multiplexing (FDM) to produce a high-data-rate communication system.

Quadrature Amplitude Modulation, QAM utilises both amplitude and phase components to provide a form of modulation that is able to provide high levels of spectrum usage efficiency.

QAM, quadrature amplitude modulation has been used for some analogue transmissions including AM stereo transmissions, but it is for data applications where it has come into its own. It is able to provide a highly effective form of modulation for data and as such it is used in everything from cellular phones to Wi-Fi and almost every other form of high speed data communications system.

Figure 3.4.2 Phase Angles

Quadrature amplitude modulation, QAM, when used for digital transmission for radio communications applications is able to carry higher data rates than ordinary amplitude modulated schemes and phase modulated schemes.

Basic signals exhibit only two positions which allow the transfer of either a 0 or 1. Using QAM there are many different points that can be used, each having defined values of phase and amplitude. This is known as a constellation diagram. The different positions are assigned different values, and in this way a single signal is able to transfer data at a much higher rate.

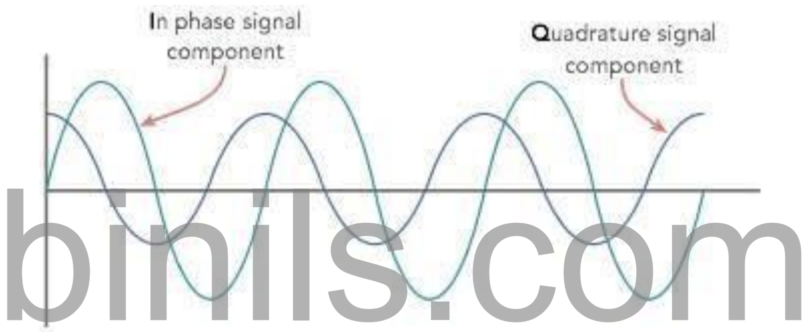
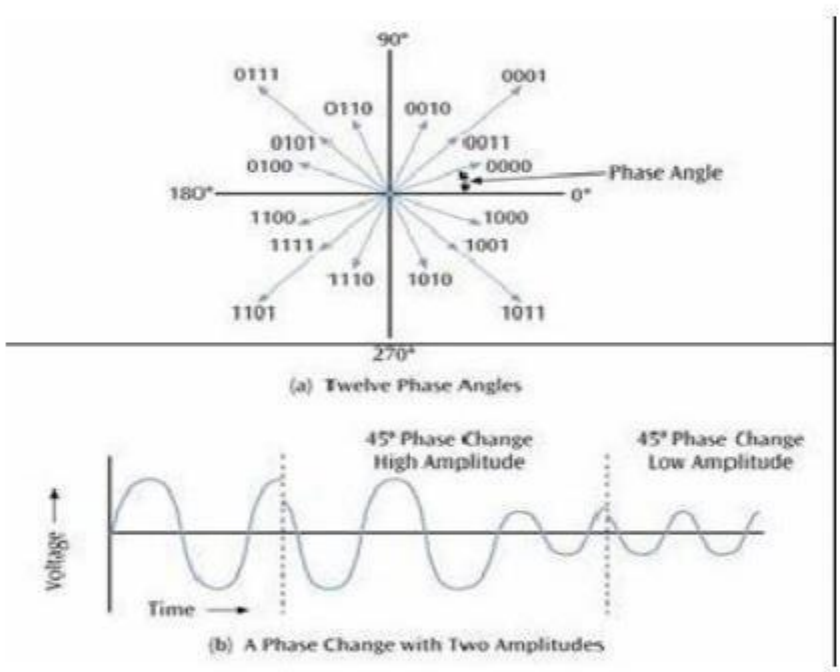


Figure 3.4.1 Quadrature Amplitude Modulation Concept



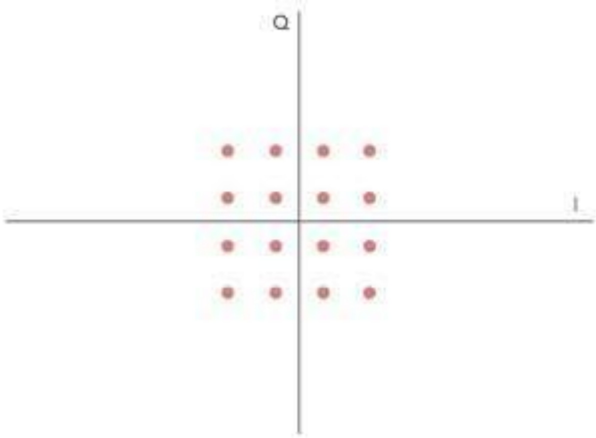


Figure 3.4.3 Constellation diagram for a 16QAM signal showing the location of the different Points

As shown above, the constellation points are typically arranged in a square grid with equal horizontal and vertical spacing. Although data is binary the most common forms of QAM, although not all, are where there constellation can form a square with the number of points equal to a power of 2 i.e. 4, 16, 64 , i.e. 16QAM, 64QAM, etc.

By using higher order modulation formats, i.e. more points on the constellation, it is possible to transmit more bits per symbol. However the points are closer together and they are therefore more susceptible to noise and data errors.

The advantage of moving to the higher order formats is that there are more points within the constellation and therefore it is possible to transmit more bits per symbol. The downside is that the constellation points are closer together and therefore the link is more susceptible to noise. As a result, higher order versions of QAM are only used when there is a sufficiently high signal to noise ratio.

To provide an example of how QAM operates, the constellation diagram below shows the values associated with the different states for a 16QAM signal. From this it can be seen that a continuous bit stream may be grouped into fours and represented as a sequence.

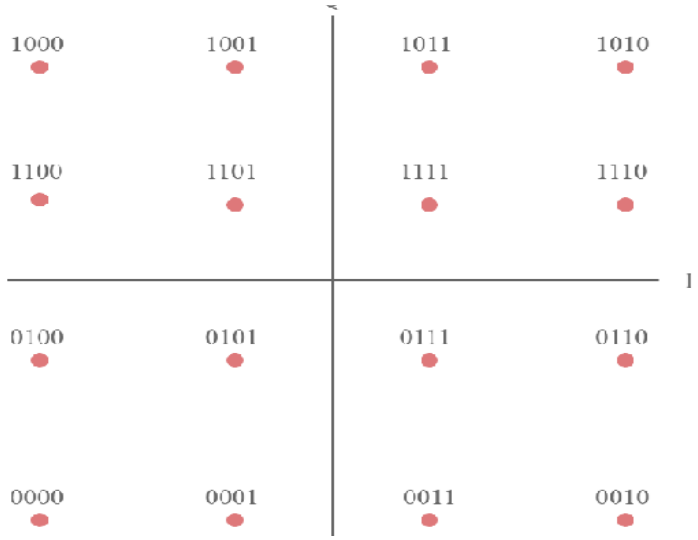


Figure 3.4.4 Bit sequence mapping for a 16QAM signal

Normally the lowest order QAM encountered is 16QAM. The reason for this being the lowest order normally encountered is that 2QAM is the same as binary phase-shift keying, BPSK, and 4QAM is the same as quadrature phase-shift keying, QPSK.

Additionally 8QAM is not widely used. This is because error-rate performance of 8QAM is almost the same as that of 16QAM - it is only about 0.5 dB better and the data rate is only three-quarters that of 16QAM. This arises from the rectangular, rather than square shape of the constellation.

QAM advantages and disadvantages

Although QAM appears to increase the efficiency of transmission for radio communications systems by utilising both amplitude and phase variations, it has a number of drawbacks. The first is that it is more susceptible to noise because the states are closer together so that a lower level of noise is needed to move the signal to a different decision point. Receivers for use with phase or frequency modulation are both able to use limiting amplifiers that are able to remove any amplitude noise and thereby improve the noise reliance. This is not the case with QAM.

The second limitation is also associated with the amplitude component of the signal. When a phase or frequency modulated signal is amplified in a radio transmitter, there is no need to use linear amplifiers, whereas when using QAM that contains an amplitude component, linearity must be maintained. Unfortunately linear amplifiers are less efficient and consume more power, and this makes them less attractive for mobile applications.