9.1 Types of Bandpass Modulation :

- We have discussed the baseband pulse transmission earlier.
- In baseband pulse transmission, the input data is represented in the form of a discrete PAM signal (line codes).
- These signals are transmitted over the communication channel.
- However in the digital passband transmission which is discussed in this chapter, the digital input data is used to modulate a sinusoidal carrier.
- These signals are transmitted over a bandpass channel.
- The examples of bandpass channels are microwave radio link or a satellite channel.
- There are three basic signaling schemes used in passband data transmission :
  1. Amplitude Shift Keying (ASK)
  2. Phase Shift Keying (PSK)
  3. Frequency Shift Keying (FSK).
- These are similar to Amplitude Modulation (AM), Phase Modulation (PM) and Frequency Modulation (FM) respectively.

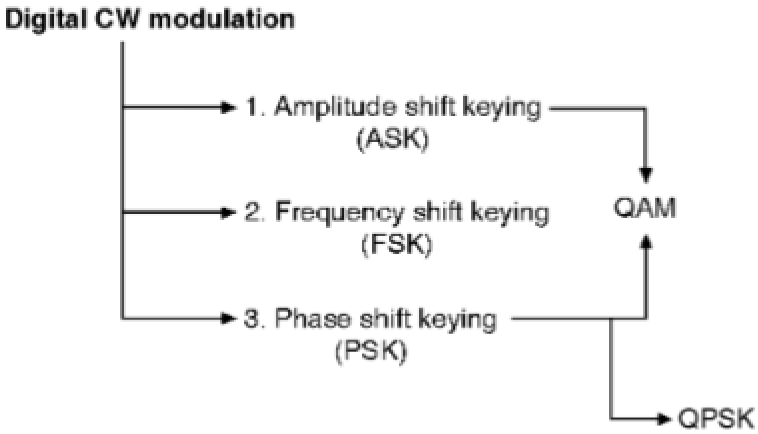
9.2 Digital Bandpass Modulation Techniques : **MU : May 11**

- There are three basic types of modulation techniques for the transmission of digital signals.
- These methods are based on the three characteristics of a sinusoidal signal; amplitude, frequency and phase.
- The corresponding modulation methods are then called as :
  1. Amplitude Shift Keying (ASK)
  2. Frequency Shift Keying (FSK)

3. Phase Shift Keying (PSK)

4. Quadrature Phase Shift Keying (QPSK) or 4-PSK.

- QPSK is a multilevel modulation in which four phase shifts are used for representing four different symbols.
- The digital band pass modulation techniques are also known as the digital continuous wave (CW) techniques.
- It is also called as digital to analog modulation.
- Fig. 9.2.1 shows the classification of digital CW modulation systems.



(L-62) **Fig. 9.2.1 : Types of digital to analog modulation**

9.3 Amplitude Shift Keying (ASK) :

Definition :

– ASK is the digital carrier modulation in which the amplitude of the sinusoidal carrier will take one of the two predetermined values in response to 0 or 1 value of digital input signal.

9.3.1 Generation and Waveforms :

– Amplitude shift keying (ASK) is the simplest type of digital CW modulation.

– Here the carrier is a sinewave of frequency f_c.

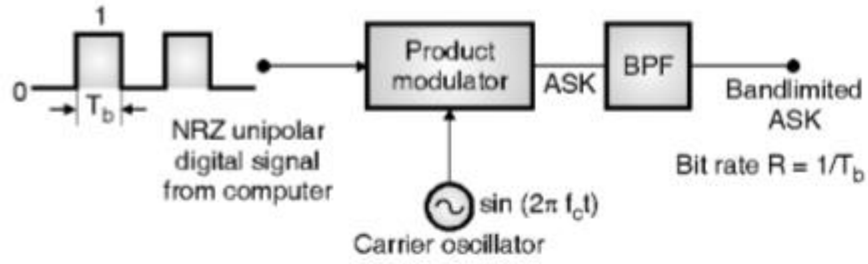
– We can represent the carrier signal mathematically as follows :

$$e_c = \sin (2\pi f_c t) \qquad ...(9.3.1)$$

– The digital signal from the computer is a unipolar NRZ signal which acts as the modulating signal.

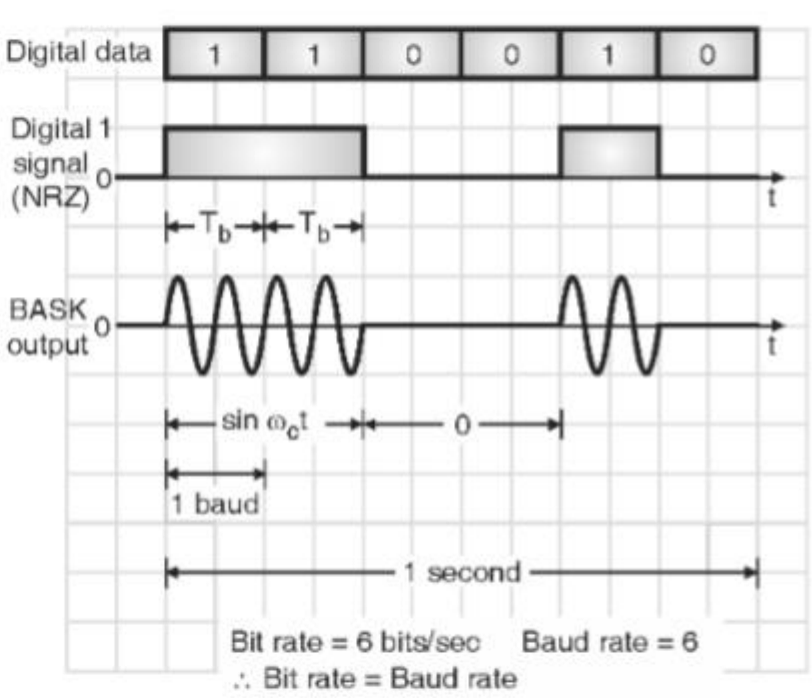
– The ASK modulator is nothing but a multiplier followed by a band pass filter as shown in Fig. 9.3.1(a).

– Due to the multiplication, the ASK output will be present only when a binary "1" is to be transmitted.



(L-64) **Fig. 9.3.1(a) : ASK generator**

- The ASK output corresponding to a binary "0" is zero as shown in Fig. 9.3.1(b).



(L-901(a)) **Fig. 9.3.1(b) : ASK waveforms**

- From the waveforms of Fig. 9.3.1(b) we can conclude that the carrier is transmitted when a binary 1 is to be sent and no carrier is transmitted when a binary 0 is to be sent.

Mathematical expression :

– The ASK signal can be mathematically expressed as follows :

$$V_{ASK}(t) = d \sin(2\pi f_c t) \qquad ...(9.3.2)$$

where d = Data bit which can take values 1 or 0.

$$\left.\begin{aligned} \therefore\ V_{ASK}(t) &= \sin(2\pi f_c t) && \text{when } d = 1 \\ \text{and}\quad V_{ASK}(t) &= 0 && \text{when } d = 0 \end{aligned}\right\} \qquad ...(9.3.3)$$

9.3.2 ASK Receiver :

Block diagram :

– The coherent receiver for an ASK signal is shown in Fig. 9.3.2 in which a locally produced synchronized carrier is applied to a multiplier.

Operation :

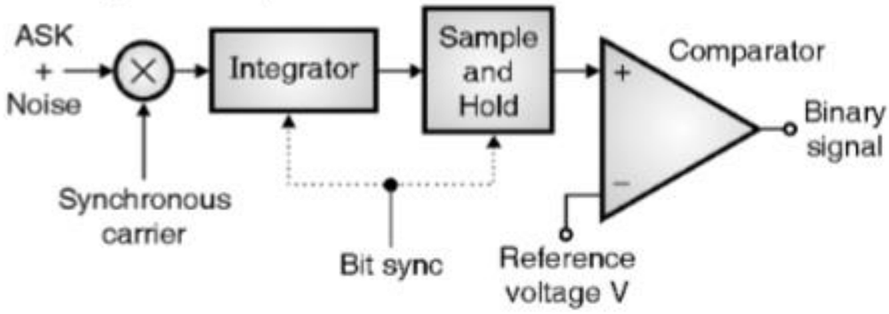
– The ASK signal alongwith noise is also applied to the multiplier.

– The multiplier output is then applied to an integrator which integrated over one bit duration T_b.

– The integrator output is sampled at a particular instant corresponding to the maximum possible value of output and the sampled value is held by the sample and hold circuit.

– The output of sample and hold circuit is compared with a reference voltage V by a comparator.

- If the S/H output is less than V, then comparator output is low which indicates that the received ASK signal is 0.
- If the S/H output is greater than V, then comparator output is high which indicates that the received ASK signal corresponds to 1.



(E-363) Fig. 9.3.2 : Coherent ASK receiver

- Thus at the receiver output we recover the original binary signal.

9.3.3 Merits and Demerits of ASK :

- The advantage of using ASK is its simplicity. It is easy to generate and detect.
- However its disadvantage is that it is very sensitive to noise, therefore it finds limited application in data transmission.
- ASK system uses and amplitude modulated carrier to transport the digital information. It is a relatively low cost, low quality type of digital modulation.

9.3.4 Application :

- ASK is not used in many applications. One of its applications is very low speed telemetry circuits.

9.4 Frequency Shift Keying (FSK) :

Definition :

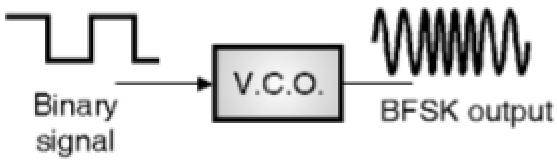
– FSK is a digital modulation system in which, the frequency of a sinusoidal carrier is shifted between two discrete values in responses to the value of the digital input signal (0 or 1).

– One of these frequencies (f_1) represents a binary "1" and the other value (f_0) represents a binary "0".

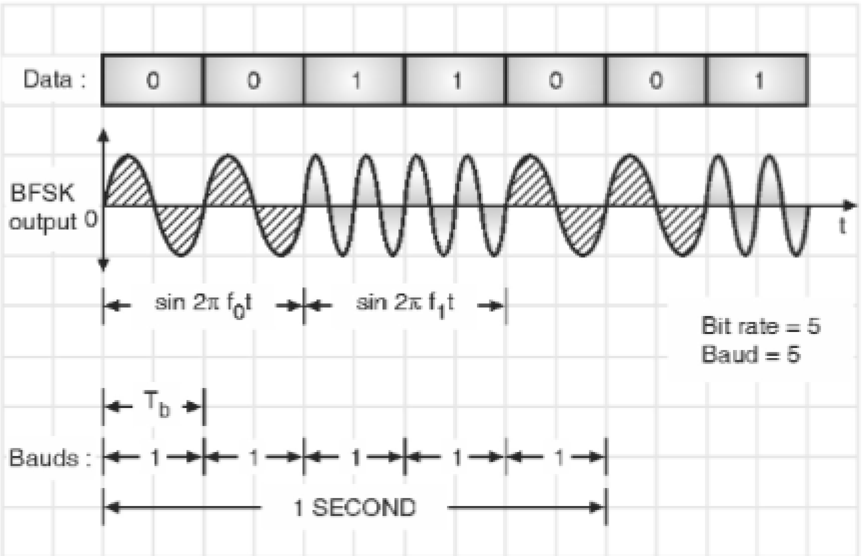
Waveforms :

– The representation of digital data using FSK is as shown in Fig. 9.4.1(b).

– Note that there is no change in the amplitude of the carrier.



(L-785) Fig. 9.4.1(a) : FSK generation



(L-902) Fig. 9.4.1(b) : Representation of digital signal using FSK

9.4.1 FSK Generation :

Block diagram and working :

- Refer to the FSK generator shown in Fig. 9.4.1(a). It is basically a voltage controlled oscillator (VCO) which produce sinewaves at frequencies f_1 and f_0, respectively.
- Corresponding to binary 0 input, the VCO produces a sinewave of frequency f_0 whereas corresponding to binary 1 input, the VCO produces a sinewave of frequency f_1. ($f_1 > f_0$).
- Thus we obtain the binary FSK (BFSK) signal at the output of VCO corresponding to the input digital data bits.

Mathematical expression :

- The FSK is mathematically expressed as follows :

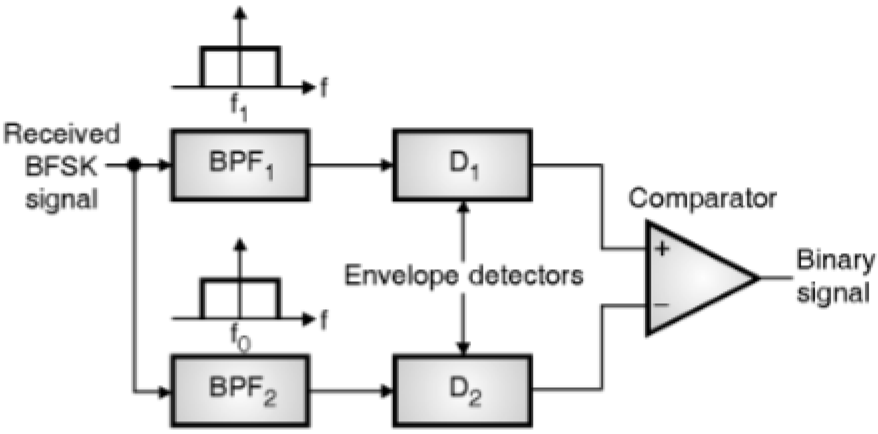
$$V_{FSK}(t) = \sin 2\pi f_0 t \text{ ...for 0 input}$$

$$= \sin 2\pi f_1 t \text{ ...for 1 input}$$

9.4.2 FSK Detection :

Block diagram :

- The FSK receiver block diagram is as shown in Fig. 9.4.2.
- It is supposed to regenerate the original digital data signal from the FSK signal at its input.



(E-1092) Fig. 9.4.2 : FSK receiver

Working :

- The receiver consists of two band pass filters one with center frequency "f_0" and the other with a center frequency of "f_1".
- The envelope detectors are simple diode detectors which rectify and filter their inputs, to generate a dc voltage proportional to the ac input.
- Suppose a binary "1" is received. That means the received signal will be,

$$V_{BFSK}(t) = \sin(2\pi f_1 t) \qquad \ldots(9.4.1)$$

- Thus the BPF_1 will pass this signal to D_1. The output of BPF_2 will be 0, hence the output of D_2 is zero.

- Therefore the comparator output will be positive representing a logic "1".
- Similarly if a binary "0" is received, the received FSK signal will have a frequency "f_0".
- The output of BPF_1 will be zero. The BPF_2 will pass this signal to D_2 to produce a proportional dc voltage. Output of D_1 is zero.
- Therefore comparator output will be zero which represents a logic "0".
- Thus the original data is recovered by the receiver.

9.4.3 Advantages of FSK :

1. FSK is relatively easy to implement.
2. It has better noise immunity than ASK. Therefore the probability of error free reception of data is high.

9.4.4 Disadvantages of FSK :

1. The major disadvantage is its high bandwidth requirement as discussed earlier.
2. Therefore FSK is extensively used in low speed modems having bit rates below 1200 bits/sec.
3. The FSK is not preferred for the high speed modems because with increase in speed, the bit rate increases.
4. This increases the channel bandwidth required to transmit the FSK signal.
5. As the telephone lines have a very low bandwidth, it is not possible to satisfy the bandwidth requirement of FSK at higher speed. Therefore FSK is preferred only for the low speed modems.

9.4.5 Application :

– FSK is used for the low data rate MODEMs.

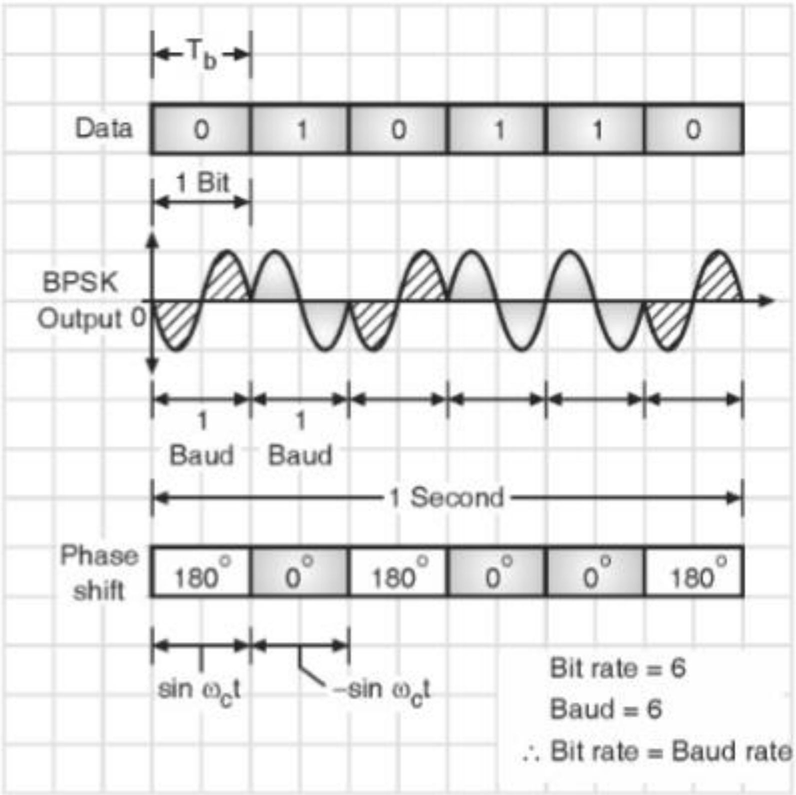
9.5 Phase Shift Keying (PSK) :

Definition :

- Binary phase shift keying is the digital modulation system in which the phase shift of the sinusoidal carrier is shifted between two values (0° and 180°) in response to the value of digital input signal (0 or 1).
- Phase Shift Keying (PSK) is the most efficient of the three modulation methods.
- Therefore it is used for high bit rates. In PSK, phase of the sinusoidal carrier is changed according to the data bit to be transmitted.

Waveforms :

- Fig. 9.5.1(a) shows the simplest form of PSK called Binary PSK (BPSK).
- The carrier phase is changed between 0° and 180° by the bipolar digital signal.
- A bipolar NRZ signal is used to represent the digital data at the input.



(E-2004) Fig. 9.5.1(a) : Binary Phase Shift Keying (BPSK)

Mathematical expression :

– The BPSK signal can be represented mathematically as :

$$V_{BPSK}(t) = \sin(2\pi f_c t) \quad \text{when binary "0" is to be represented}$$

$$\text{And} \quad V_{BPSK}(t) = -\sin(2\pi f_c t)$$

$$= \sin(2\pi f_c t + \pi) \quad \text{when binary "1" is to be represented.}$$

– Combining the two conditions we can write

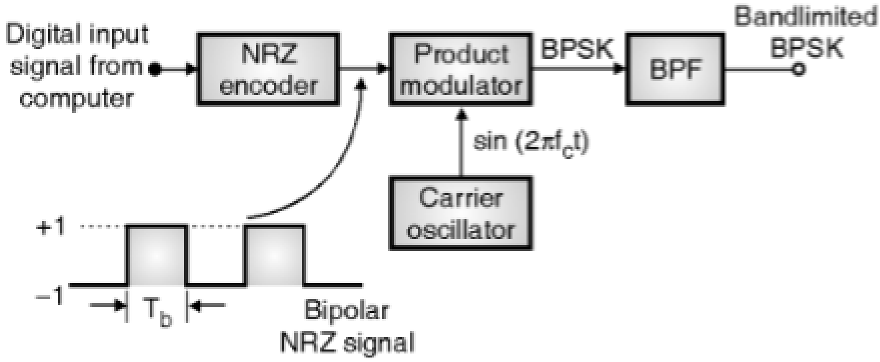
$$V_{BPSK}(t) = d \sin(2\pi f_c t) \qquad ...(9.5.1)$$

where $\quad d = \pm 1$

9.5.1 BPSK Generation :

Block diagram :

– The BPSK generation takes place as shown in Fig. 9.5.1(b).



(L-81) **Fig. 9.5.1(b) : BPSK generation**

– The binary data signal (0s and 1s) is converted into a NRZ bipolar signal by an NRZ encoder, which is then applied to a multiplier (balanced modulator).

– The other input to the multiplier is the carrier signal ($2\pi f_c t$).

– The data bits 0s and 1s are converted into a bipolar NRZ signal "d" as shown in the following table.

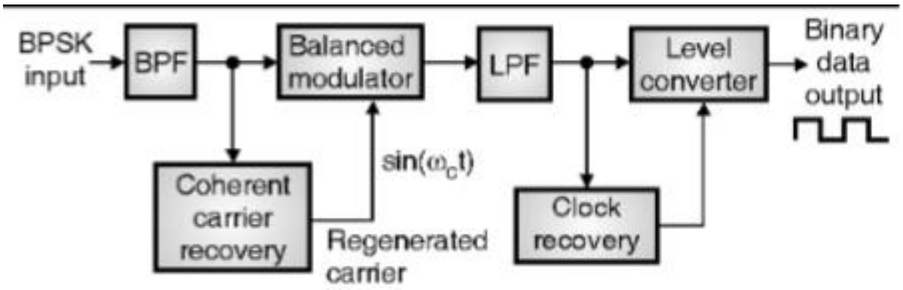
NRZ signal "d" as shown in the following table.

Digital signal	Bipolar NRZ signal	BPSK output
Binary 0	d = 1	$V_{BPSK}(t) = \sin(2\pi f_c t)$
Binary 1	d = – 1	$V_{BPSK}(t) = -\sin(2\pi f_c t)$

9.5.2 BPSK Receiver :

Block diagram :

- The block diagram of a BPSK receiver is shown in Fig. 9.5.2.
- The input BPSK signal can be either + sin ω_c t or – sin ω_c t representing either logic 1 or 0 respectively.



(E-373) **Fig. 9.5.2 : BPSK receiver**

Operation :

- The coherent carrier recovery circuit detects and regenerates a carrier signal sin ω_ct.
- This regenerated carrier has the same frequency and phase as the carrier used at the transmitter.
- So the regenerated carrier is known as coherent carrier, which is phase and frequency synchronized with the transmitter.
- The filtered BPSK signal alongwith the regenerated carrier is applied to a balanced modulator which acts as a product detector.

$$\therefore \quad \text{B.M. output} = \text{BPSK} \times \text{Regenerated carrier}$$

$$= (\pm \sin \omega_c t \times \sin \omega_c t = \pm \sin^2 \omega_c t)$$

$$\text{But} \quad \sin^2 \theta = \frac{1}{2} - \frac{1}{2} \cos 2\theta$$

$$\therefore \text{B.M. output} = \underbrace{\pm \frac{1}{2}}_{\text{DC term}} \underbrace{\mp \frac{1}{2} \cos 2\omega_c t}_{\text{Second harmonic}}$$

(E-1459)

- The BM output consist of a dc term and a term having frequency twice the carrier frequency (Second harmonic term).
- The BM output is passed through LPF which allows only the second harmonic term to pass through and blocks the dc component.

$$\therefore \quad \text{LPF output} = \mp \frac{1}{2} \cos 2\omega_c t$$

- The LPF output is applied to the level detector and clock recovery circuit. At the output of level detector we get the following output.

$$-\frac{1}{2} \cos \omega_c t \rightarrow \frac{1}{2} \text{ V (logic 1)}$$

$$-\frac{1}{2} \cos \omega_c t \rightarrow -\frac{1}{2} \text{ V (logic 0)}$$

- Thus the binary signal is obtained at the output.

9.5.3 Advantages of BPSK :

1. BPSK has a bandwidth which is lower than that of a BFSK signal.
2. BPSK has the best performance of all the systems in presence of noise. It gives the minimum possibility of error.
3. BPSK has a very good noise immunity.

9.5.4 Disadvantage of BPSK :

- The only disadvantage of BPSK is that generation and detection of BPSK is not easy. It is quite complicated.

9.5.5 Applications :

- Phase shift keying is the most efficient of the three modulation methods and it is used for high bit rates even higher than 1800 bits/sec.
- Due to low bandwidth requirement the BPSK modems are preferred over the FSK modems, at higher operating speeds.

9.5.6 Comparison of Binary Modulation Systems : MU : Dec. 09, Dec. 14, Dec. 18

University Questions

Q. 1 Compare : ASK and FSK **(Dec. 09, 5 Marks)**

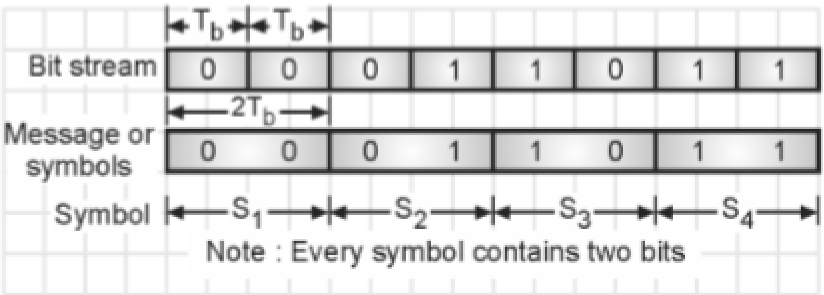
Q. 2 Compare ASK, PSK, FSK modulation techniques. **(Dec. 14, Dec. 18, 5 Marks)**

Sr. No.	Parameter	Binary ASK	Binary FSK	Binary PSK
1.	Variable characteristic.	Amplitude	Frequency	Phase
2.	Bandwidth (Hz)	2R	$\lvert f_1 - f_0 \rvert + (1 + r) R$	(1+ r) R
3.	Noise immunity.	low	high	high
4.	Error probability	high	low	low
5.	Performance in presence of noise.	Poor	Better than ASK	Better than FSK
6.	Complexity	Simple	Moderately	Very
7.	Bit rate	Suitable upto 100 bits/sec.	Suitable upto about 1200 bits/sec.	Suitable for high bit rates.
8.	Detection method.	Envelope	Envelope	Coherent

9.6 Quadrature or Quaternary Phase Shift Keying (QPSK) :

- QPSK is a type of PSK in which the phase shift of analog carrier can take one of the four different values such as 90°, 180°, 270° and 360° to represent four different input symbols. Each input symbol is made of two bits (00, 01, 10 or 11).
- The modulation schemes discussed so far are all two level modulation. (ASK and BPSK), because they can represent only two states of the digital data (0 or 1).
- Therefore the bit rate and the baud rate are same for these systems.
- The maximum bit rate which can be achieved using ASK, BFSK or BPSK systems does not meet the requirements of data communication systems.
- This happens due to the limited bandwidth of the telephone voice channel.
- We can keep the baud rate same and increase the bit rate by using multilevel modulation techniques.
- In this type of systems, the data groups are divided into groups of two or more bits and each group of bits is represented by a specific value of amplitude, frequency or phase the carrier.
- QPSK (Quadrature PSK) is an example of such multilevel phase modulation.
- In QPSK system two successive bits in a bit stream are grouped together to form a message and each message is represented by a distinct value of phase shift of the carrier.

– The process of combining two successive bits is demonstrated in Fig. 9.6.1.



(E-381) **Fig. 9.6.1 : Grouping of bits in QPSK**

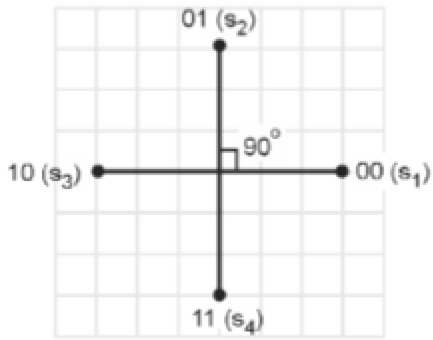
– Each symbol or message contains two bits. So the symbol duration $T_S = 2\ T_b$.

Constellation diagram :

– These symbols are transmitted by transmitting the same carrier frequency at four different phase shifts as shown in Table 9.6.1 and Fig. 9.6.2.

Table 9.6.1 : Phase shift in QPSK

Symbol	Phase
00 (S_1)	0
01 (S_2)	90
10 (S_3)	180
11 (S_4)	270



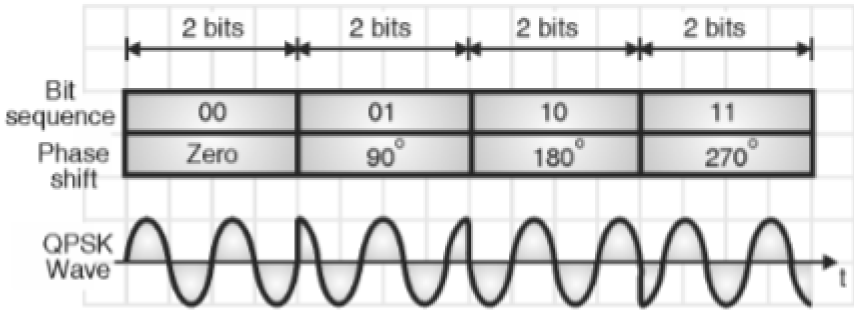
(E-382) Fig. 9.6.2 : Constellation diagram of QPSK

– Since there are four phase shifts involved, this system is called as quadrature PSK or 4-PSK system.

– If the symbol 00 is to be transmitted then we have to transmit a carrier at 0° phase shift. If 01 is to be transmitted, then the same carrier is transmitted with a phase shift of 90°.

– Similarly the message 10 and 11 are transmitted by transmitting the carrier at 180° and 270° respectively.

– This concept will be clear after referring to the QPSK waveform of Fig. 9.6.3.



(E-383) Fig. 9.6.3 : Waveforms of QPSK

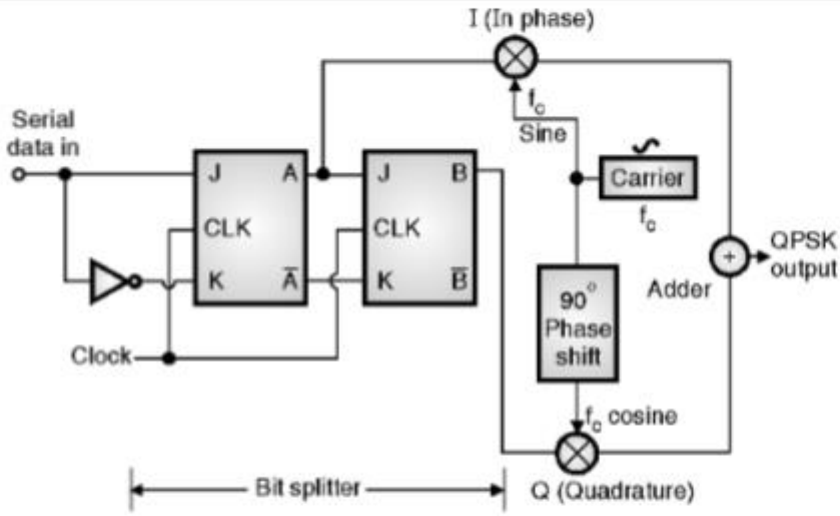
Baud rate :

– As illustrated in Fig. 9.6.3, the baud rate for QPSK is half of the bit rate.

9.6.1 QPSK Transmitter :

Block diagram :

– A QPSK modulator circuit is as shown in Fig. 9.6.4.



(L-783) **Fig. 9.6.4 : QPSK transmitter**

Operation :

- The input serial data stream is sampled as an entire character by a 2 bit shift register and converted to a parallel output signal by a clock pulse.
- This shift register circuit is called bit splitter.
- The output of Most Significant Bit (MSB) register of the bit spliter is channel to I modulator.
- The modulator with no carrier phase shift is called I modulator because it is 'In' phase with carrier oscillator.
- The Least Significant Bit (LSB) of the register is directed to Q-modulator.
- This is the modulator with the 90° phase shifted carrier i.e. carrier with quarter wave out of phase

- This is the modulator with the 90° phase shifted carrier i.e. carrier with quarter wave out of phase from the carrier oscillator (Q modulator).
- The output of each balanced modulator (I and Q modulator) is a BPSK signal i.e. there is no phase shift for '0' input bit and 180° phase shift for bit I.
- There is extra phase shift at 90° for Q modulator.
- The output of balance modulators are linearly added producing QPSK signal.

Symbol transmission rate :

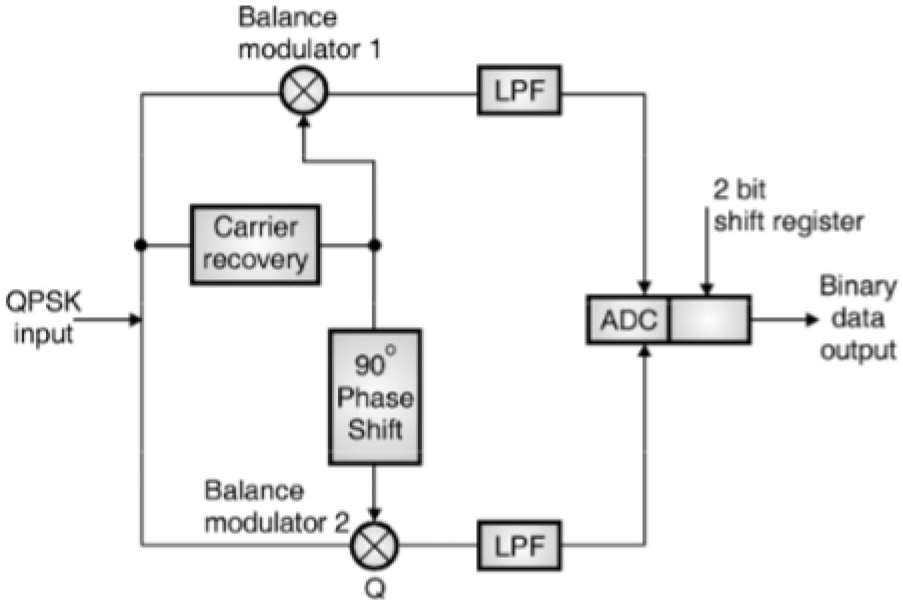
- In QPSK two bits are grouped together to form a symbol. Therefore when the symbols are transmitted, the signal changes occur at the symbol rate which is half the bit rate.

$\therefore$ The symbol time $T_s = 2T_b$ ...(9.6.1)

9.6.2 QPSK Receiver :

Block diagram :

- A QPSK demodulator circuit is as shown in Fig. 9.6.5.



(E-1401) Fig. 9.6.5 : QPSK demodulator

Operation :

- It consist of carrier recovery circuit that senses the carrier frequency and suppress it to balance modulator I and after 90° phase shift to the other balance modulator.
- The output of two modulator is filter and then analog information is converted into digital two bit data i.e. dibit.
- There dibits and combine in a shift register and shifted out to produce the original data.

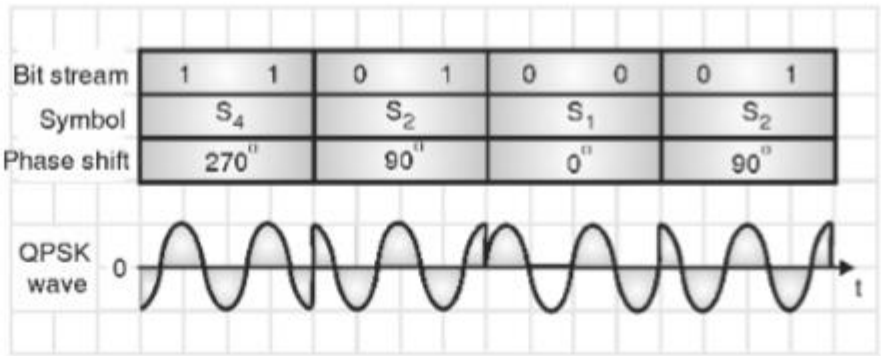
9.6.3 QPSK Waveforms :

- The following example illustrates how to draw the QPSK waveforms.

Ex. 9.6.1 : For the following data stream draw the QPSK (4 PSK) signal. 11010001

Soln. :

- The required waveform is shown in Fig. P. 9.6.1. Note that the carrier frequency has not been changed at all.
- Only the phase shift is being changed according to the symbol.



(G-856) **Fig. P. 9.6.1**

9.6.4 Advantages of QPSK : **MU : May 14**

University Questions

Q. 1 What are the advantages of QPSK system ?

(May 14, 5 Marks)

1. Very good noise immunity.
2. Baud rate is half the bit rate therefore more effective utilization of the available bandwidth of the transmission channel.
3. Low error probability.

– Due to these advantages the QPSK is used for very high bit rate data transmission.

9.6.5 Disadvantage :

– The generation and detection of QPSK is complex.

9.6.6 Applications :

1. High speed modems.
2. Digital TV.
3. Communication between earth stations and space shuttles.