Digital Modulation Techniques

→ modulation is defined as the process by which some characteristic of a carrier is varied in accordance with a modulating signal.

→ In digital communications, the modulating signal consists of binary data. The data is used to modulate a carrier wave is usually sinusoidal with fixed frequency.

There are basically two types of transmission of digital signals.

Base band transmission :-

The digital data is transmitted over the channel directly. There is no carrier or any modulation. This is suitable for transmission over short distances.

Passband data transmission :-

The digital data modulates high frequency sinusoidal carrier. Hence it is also called digital c.w modulation. It is suitable for transmission over long distances.

Types of passband modulation :-

1. Amplitude shift Keying :- Amplitude of the carrier is switched depending on the input digital signal, then it is called Amplitude shift Keying.
2. phase shift Keying :- phase of the carrier is switched depending on the input digital signal, then it is called phase shift Keying.
3. Frequency shift keying :- Frequency of the carrier is switched depending on input digital signal, then it is called frequency shift keying.

→ The phase and frequency shift keying has constant amplitude. Because of constant amplitude of FSK & PSK the effect of non-linearities, noise interference is minimum on signal detection.

Types of Reception for Passband transmission :-

There are two types of methods for detection of passband signals.

Coherent (synchronous) detection :- In this method, the local carrier generated at the receiver is phase ~~located~~ locked with the carrier at the transmitter. Hence it is also called synchronous detection.

Non-coherent detection :- In this method, the receiver carrier need not be phase locked with transmitter carrier. Hence it is also called envelope detection. Non-coherent detection is simple but it has higher probability of error.

Requirements of Passband Transmission scheme :-

i) maximum data rate.
ii) minimum probability of symbol error.
iii) minimum transmitted power.
iv) maximum channel bandwidth.
v) maximum resistance to interfering signals.
vi) minimum circuit complexity.

Advantages of passband Transmission :-

1. long distance transmission.
2. Problems such as ISI and crosstalk are absent.
3. Passband transmission can take place over wireless channels also.
4. Large number of modulation techniques are available.

Drawbacks :-

- It is not suitable for short distance communication.

Coherent binary amplitude shift keying (OR) ON-OFF keying :-

Amplitude shift keying (ASK) or ON-OFF keying (OOK) is the simplest digital modulation technique. In this method, there is only one unit energy carrier and it is switched on or off depending upon the input binary sequence.

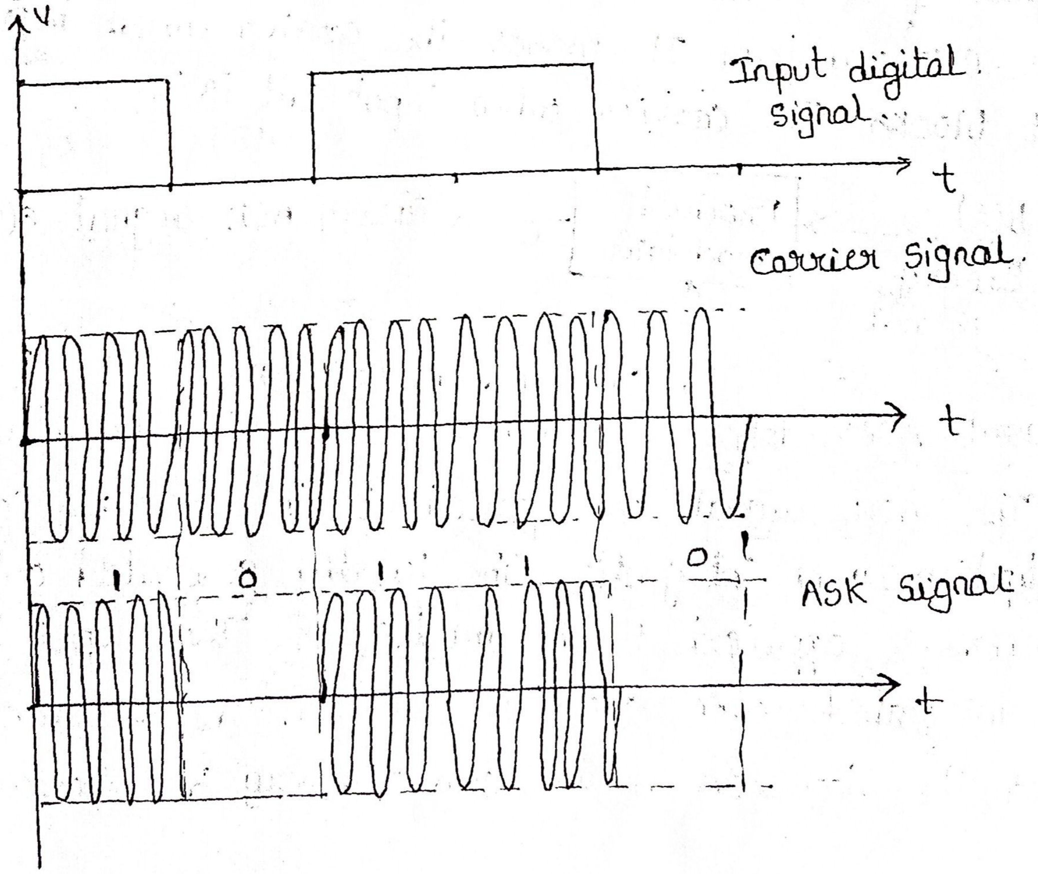
Expression and waveforms :-

The ASK waveform can be represented as.

$$s(t) = \sqrt{2P_s}\cdot\cos(2\pi f_c t) \quad (\text{for transmit '1'})$$

$$s(t) = 0 \quad (\text{for transmit '0'}).$$

To Transmit symbol '0', the signal $s(t) = 0$. no signal is transmitted. signal $s(t)$ contains some complete cycles of carrier frequency 'f_c'. Hence, the ASK wave form looks like an ON-OFF of the signal. Therefore, it is also known as the ON-OFF keying (OOK).

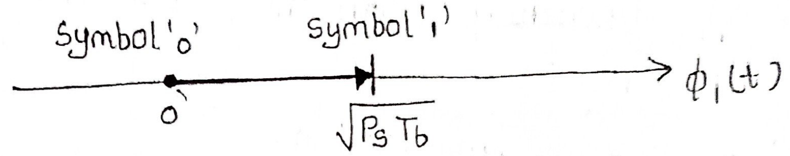


Signal space diagram of ASK :-

The ASK waveform of equation for symbol '1' can be represented as,

$$s(t) = \sqrt{P_s T_b} \cdot \sqrt{2/T_b} \cos(2\pi f_c t) = \sqrt{P_s T_b}\, \phi_1(t)$$

This means that there is only one carrier function $\phi_1(t)$. The signal space diagram will have two points on $\phi_1(t)$. one will be at zero and other will be at $\sqrt{P_s T_b}$.



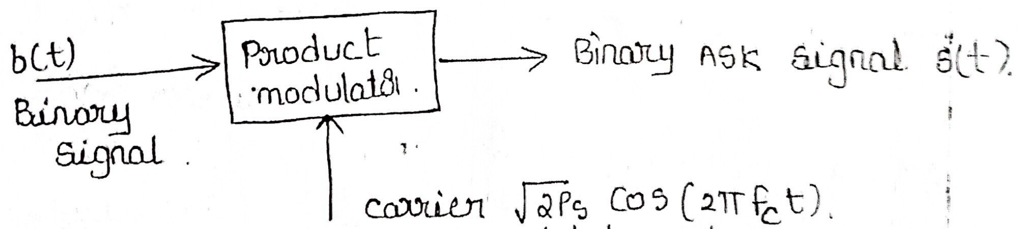
signal space diagram of ASK.

Thus, the distance between the two signal points is.

$$d = \sqrt{P_s T_b} = \sqrt{E_b}.$$

Generation of ASK signal :-

ASK signal may be generated by simply applying the incoming binary data and the sinusoidal carrier to the two inputs of a product modulator. The resulting output will be the ASK waveform. It passes the carrier when input bit is '1'. It blocks the carrier when input bit is '0'.



Coherent ASK detector or demodulation of Binary ASK signal :-

The ASK signal is applied to the correlator consisting of multiplier and integrator. The locally generated coherent carrier is applied to the multiplier. The output of multiplier is integrated over one bit period. The decision device takes the decision at the end of every bit period.

It compares the output of integrator with the threshold. Decision is taken in favour of '1' when threshold is exceeded. Decision is taken as '0' if threshold is not exceeded.

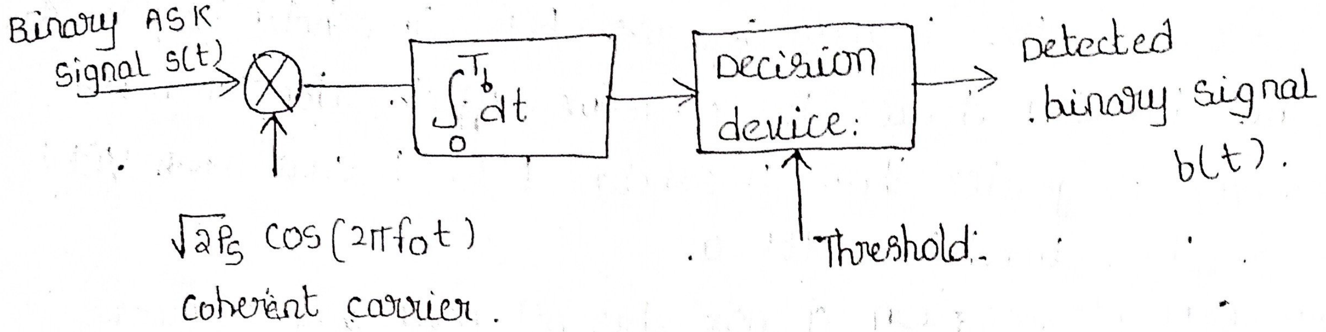


Fig. Block diagram of coherent ASK detector.

Non-coherent ASK detector :-

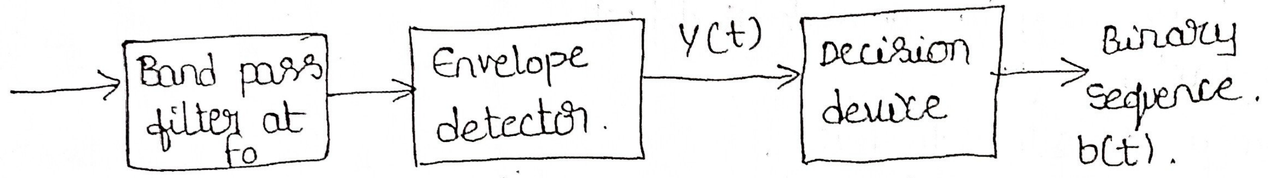


fig. Block diagram of non-coherent ASK detector.

In binary ASK case, the transmitted signal is defined as.

$$s(t) = \sqrt{2P_s} \cos(2\pi f_c t)$$

Binary ASK signal can also be demodulated non-coherently using envelope detector. This greatly simplifies the design consideration, required in synchronous detection. Non-coherent detection schemes do not require a phase-coherent local oscillator. This method involves some form of rectification and low pass filtering at the receiver. The received ASK signal is given to band pass filter. This band pass filter passes only carrier frequency f

→ The envelope detector generates high output voltage when carrier is present. when carrier is absent, there is only noise at the input of envelope detector. The decision device is basically a regenerator.

→ It generates the binary sequence b(t). Threshold is provided to the decision device to overcome effects due to noise when y(t) is greater than threshold b(t) = 1 and when y(t) is less than threshold. b(t) = 0.

→ Non-coherent reception of ASK does not need any carrier synchronization.

Features:-

1. BASK is simple.
2. It is easy to generate & detect.

Drawbacks:-

1. very sensitive to noise.
2. It finds limited application in data transmission.
3. It is used at very low bit rates, upto 100 bits per sec.

→ Binary Phase Shift Keying :- (BPSK)

Binary phase shift keying is used for high bit rates. In BPSK phase of the sinusoidal carrier changed according to the data bit to be transmitted.

Expression for BPSK :-

In a binary phase shift keying (BPSK), the binary symbols '1' and '0' modulate the phase of the carrier

the carrier is

$$s(t) = A\cos(2\pi f_c t).$$

A is represents peak value of sinusoidal carrier. For the standard 1Ω load resistor.

The power dissipated will be,

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

$$A = \sqrt{2P}$$

when the symbol is changed, then the phase of the carrier is changed by 180 degrees. for example.

for symbol '1'

$$S_1(t) = \sqrt{2P} \cos(2\pi f_c t)$$

for symbol '0'

$$S_2(t) = \sqrt{2P} \cos(2\pi f_c t + \pi)$$

$$\therefore \cos(\theta + \pi) = -\cos\theta$$

$$S_2(t) = -\sqrt{2P} \cos(2\pi f_c t)$$

with the above equations, we can define BPSK signal combinely as,

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

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

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

Generator of BPSK signal :-

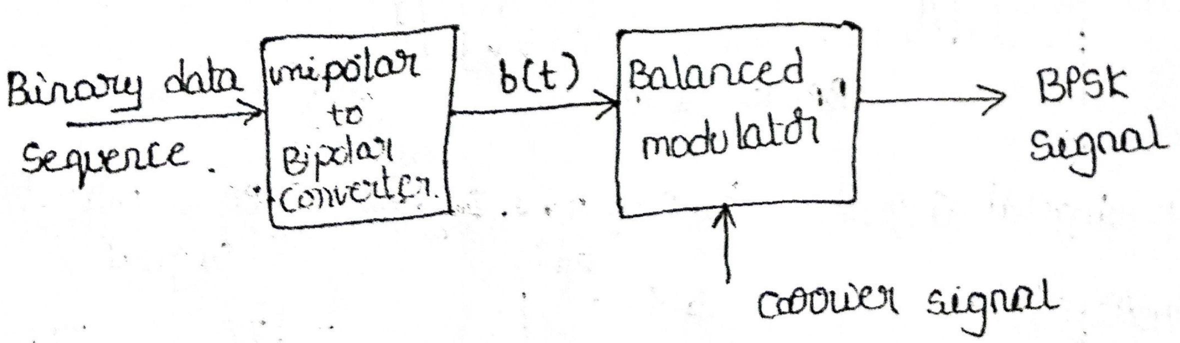
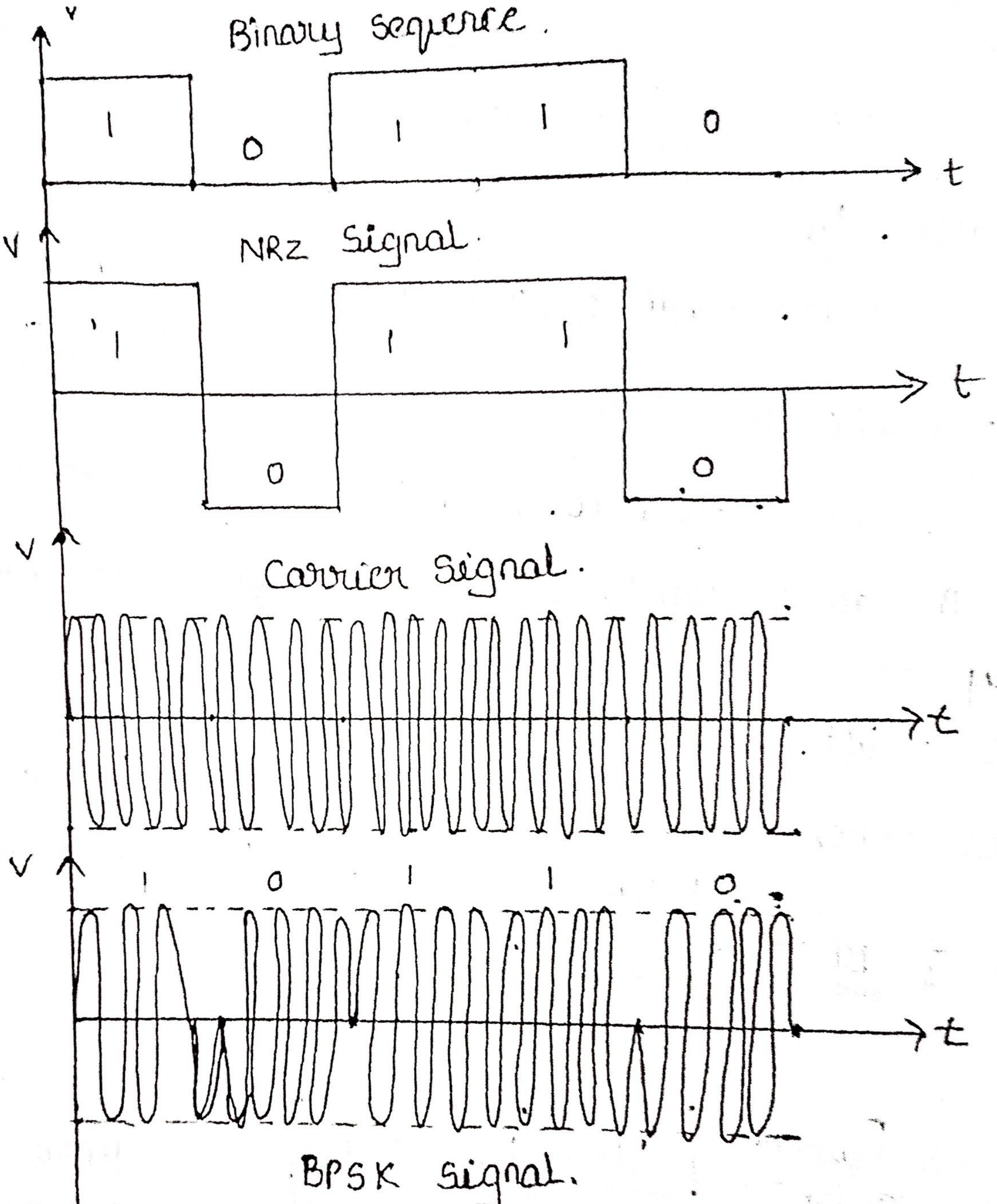


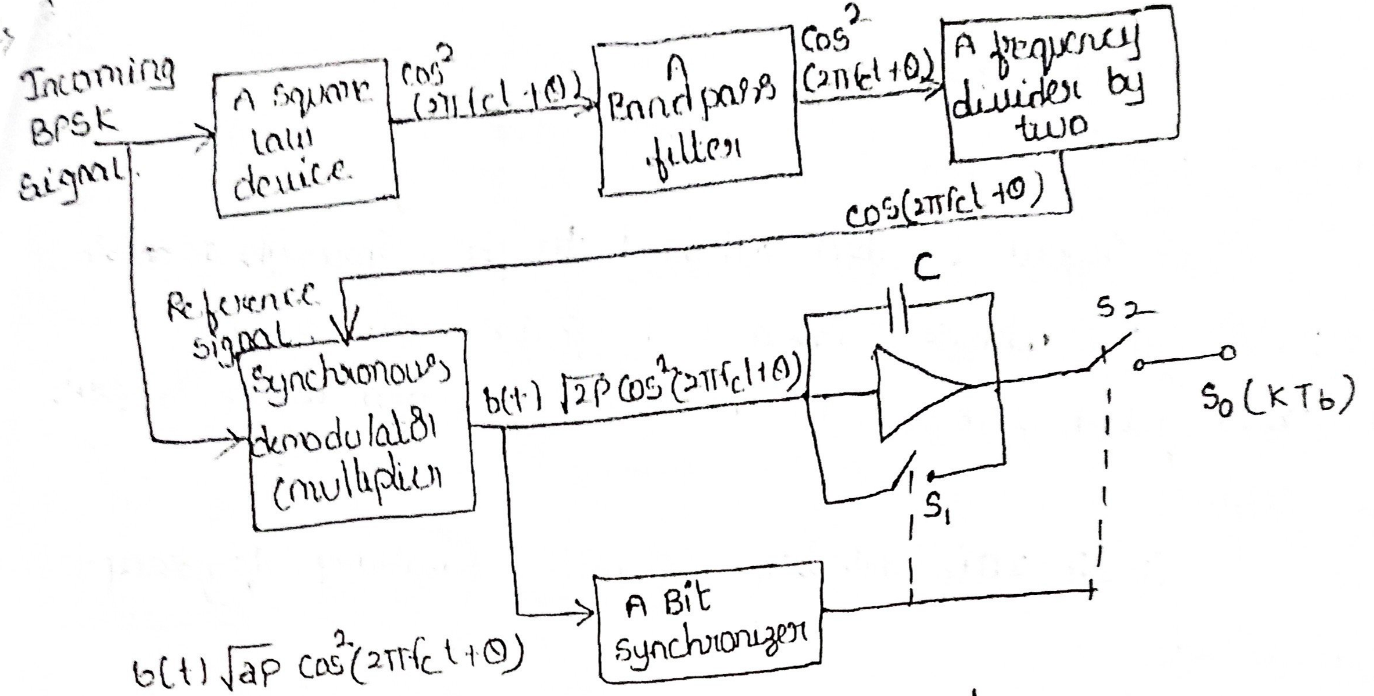
fig- Block diagram of Generation of BPSK Signal

BPSK signal is generated by applying carrier signal to a balanced modulator. The binary data signal (0's and 1's) is converted into a NRZ bipolar signal by an NRZ encoder. Here the bipolar signal b(t) is applied as a modulating signal to the balanced modulator. A NRZ level encoder converts the binary data sequence into bipolar NRZ signal.



input digital signal	binary NRZ signal b(t)	BPSK output signal
Binary '0'	b(t) = -1	$-\sqrt{2P}\cos(2\pi f_c t)$
Binary '1'	b(t) = 1	$+\sqrt{2P}\cos(2\pi f_c t)$

Coherent PSK signal :-



Coherent detection of PSK signal

The input 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 is θ. the signal at the input of the receiver is

$$s(t) = b(t)\sqrt{2P}\cos(2\pi f_c t+\theta).$$

Square law device :-

The received signal is allowed to pass through a square law device. The output of the square law device the signal will be $\cos^2(2\pi f_c t+\theta)$.

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

Therefore, we have.

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

$$= \frac{1}{2} + \frac{1}{2} \cos 2(2\pi f_c t + \theta)$$

↑ DC level.

Band pass filter :-

The signal is then allowed to pass through a pass bandpass filter whose passband is centered around 2fc. Bandpass filter removes the DC level of ½ and at the output, we obtain

$\cos 2(2\pi f_c t + \theta)$. This signal is having frequency equal to 2fc.

Frequency divider :- The signal is passed through a frequency divider by two. Thus at the output of frequency divider, we get a carrier signal whose frequency is fc that is $\cos(2\pi f_c t + \theta)$.

Synchronous demodulator :-

The synchronous demodulator multiplies the input signal and the recovered carrier. Therefore at the output of multiplier we get,

$$= b(t)\sqrt{2P}\cos(2\pi f_c t + \theta) \times \cos(2\pi f_c t + \theta)$$

$$= b(t)\sqrt{2P}\cos^2(2\pi f_c t + \theta)$$

$$= b(t)\sqrt{2P} \times \frac{1}{2}[1 + \cos 2(2\pi f_c t + \theta)]$$

$$= b(t)\sqrt{\frac{P}{2}}[1 + \cos 2(2\pi f_c t + \theta)]$$

it synchro ... and ... peri...

Bit synchronizer and integrator :-

The signal is then applied to the bit synchronizer and integrator. The integrator integrates the signal over one bit period. The bit synchronizer takes care of starting and ending times of a bit.

1. At the end of bit duration T_b, the bit synchronizer closes switch S_2 temporarily. This connects the output of an integrator to the decision device.

2. The synchronizer then opens switch S_2 and switch S_1 is closed temporarily. This resets the integrator voltage to zero. The integrator then integrates next bit.

Also, in the k^{th} bit interval, we can write output signal.

$$s_0(KT_b) = b(KT_b)\sqrt{\frac{P}{2}}\left[\int_{(K-1)T_b}^{KT_b} 1\,dt + \int_{(K-1)T_b}^{KT_b} \cos 2(2\pi f_c t + \theta)\,dt\right]$$

Here $\int_{(K-1)T_b}^{KT_b} \cos 2(2\pi f_c t + \theta)\,dt = 0$, since average value of sinusoidal waveform is zero. If integration is done over full cycles.

$$s_0(KT_b) = b(KT_b)\sqrt{\frac{P}{2}}\int_{(K-1)T_b}^{KT_b} 1\,dt.$$

$$= b(KT_b)\sqrt{\frac{P}{2}}\,[t]_{(K-1)T_b}^{KT_b}$$

$$= b(KT_b)\sqrt{\frac{P}{2}}\,[KT_b - (K-1)T_b]$$

$$= b(KT_b)\sqrt{\frac{P}{2}}\,[KT_b - KT_b + T_b$$

$$\boxed{s_0(KT_b) = b(KT_b)\sqrt{\frac{P}{2}}\,T_b}$$

This equation shows that the output of the receiver depends on input. This signal is then given to a decision device which decides whether transmitted symbol was zero or one.

A Geometrical Representation for BPSK Signals. –

The BPSK signal carries the information about two symbols. These symbols are symbol '1' and symbol '0'.

$$s(t) = \sqrt{2P}\cos(2\pi f_c t)\cdot b(t).$$

Rearrange the last equation as

$$s(t) = b(t)\cdot\sqrt{PT_b}\cdot\sqrt{\frac{2}{T_b}}\cos(2\pi f_c t)$$

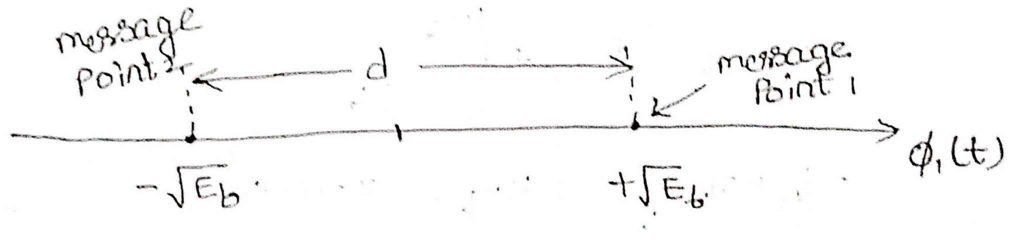
$$s(t) = b(t)\sqrt{PT_b}\cdot\phi_1(t) \quad \therefore \phi_1(t) = \sqrt{\frac{2}{T_b}}\cos(2\pi f_c t)$$

The bit Energy E_b is defined in terms of power 'P' and one bit duration T_b as,

$$E_b = PT_b \quad , \quad b(t) = \pm 1$$

$$s(t) = \pm\sqrt{E_b}\,\phi_1(t).$$

Thus, on the single axis of $\phi_1(t)$, there will be two points. One point will be located at $+\sqrt{PT_b}$ or $\sqrt{E_b}$ and other will be located at $-\sqrt{PT_b}$ or $-\sqrt{E_b}$.



Representation of BPSK Signal.

At the receiver end, the point at $+\sqrt{E_b}$ on $\phi_1(t)$ represents symbol '1' and point at $-\sqrt{E_b}$ represents symbol '0'. This separation is generally called distance 'd'.

$$d = \sqrt{E_b} - (-\sqrt{E_b}) = 2\sqrt{E_b}.$$

distance 'd' increases, the isolation between the symbols in BPSK signal is more, Thus, probability of error reduces.

Bandwidth for BPSK signal :-

The spectrum of the BPSK signal is centred around the carrier frequency fc.

If $T_b = \frac{1}{f_b}$, then $f_b = \frac{1}{T_b}$, for BPSK, the maximum frequency in the base band signal will be f_b.

B.W = highest frequency - lowest frequency.

$= f_c + f_b - (f_c - f_b)$

$= f_c + f_b - f_c + f_b$

$$B.W = 2f_b$$

Drawbacks of BPSK :- In BPSK receiver to generate the carrier in the receiver, squaring $b(t)\sqrt{2P}\cos(2\pi f_c t + \theta)$. If the received signal is $-b(t)\sqrt{2P}\cos(2\pi f_c t + \theta)$ then the squared signal remains same as before.

Therefore, it is not possible to determine whether the received signal is equal to b(t) or -b(t). This results in Ambiguity in the output signal.

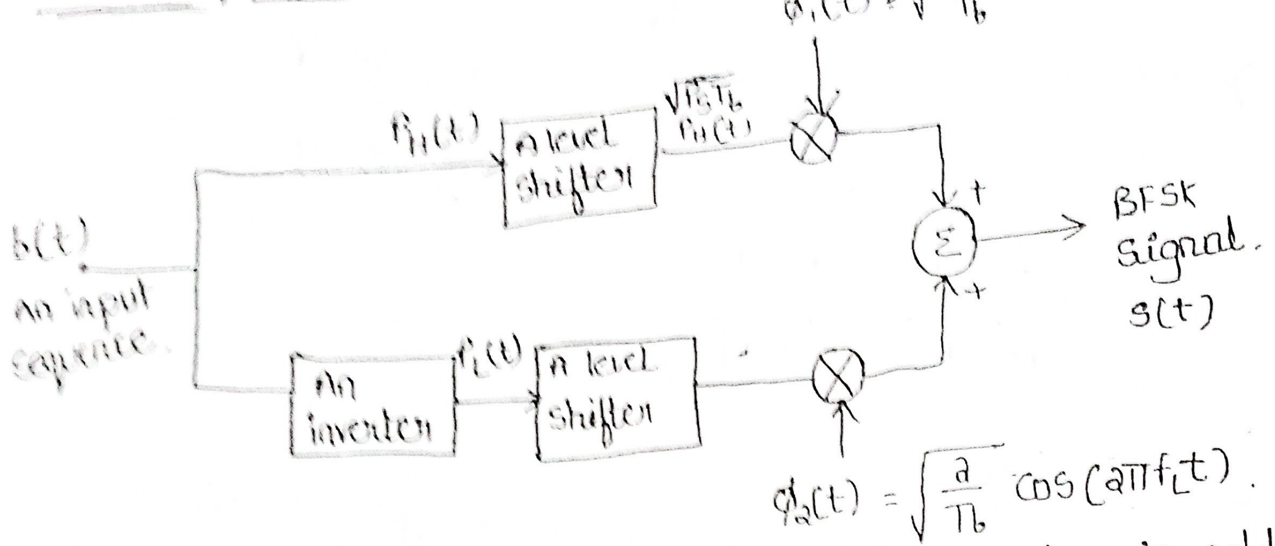
Binary Frequency Shift Keying (BFSK) :-

In binary frequency shift keying (BFSK), the frequency of a sinusoidal carrier is shifted according to the binary symbol. The frequency of a sinusoidal carrier is shifted between two discrete values. The phase of the carrier is unaffected. This means that we have two different frequency signals according to binary symbols.

If $b(t) = 1$, then $S_H(t) = \sqrt{2P_s}\cos(2\pi f_H t)$

If $b(t) = 0$, then $S_L(t) = \sqrt{2P_s}\cos(2\pi f_L t)$

<u>Generation of BFSK :-</u>



The input sequence $b(t)$ is same as $P_H(t)$. An inverter is added after $b(t)$ to get $P_L(t)$. The level shifter $P_H(t)$ and $P_L(t)$ are unipolar signals. The level shifter converts the +1 level to $\sqrt{P_s T_b}$ zero level is unaffected.

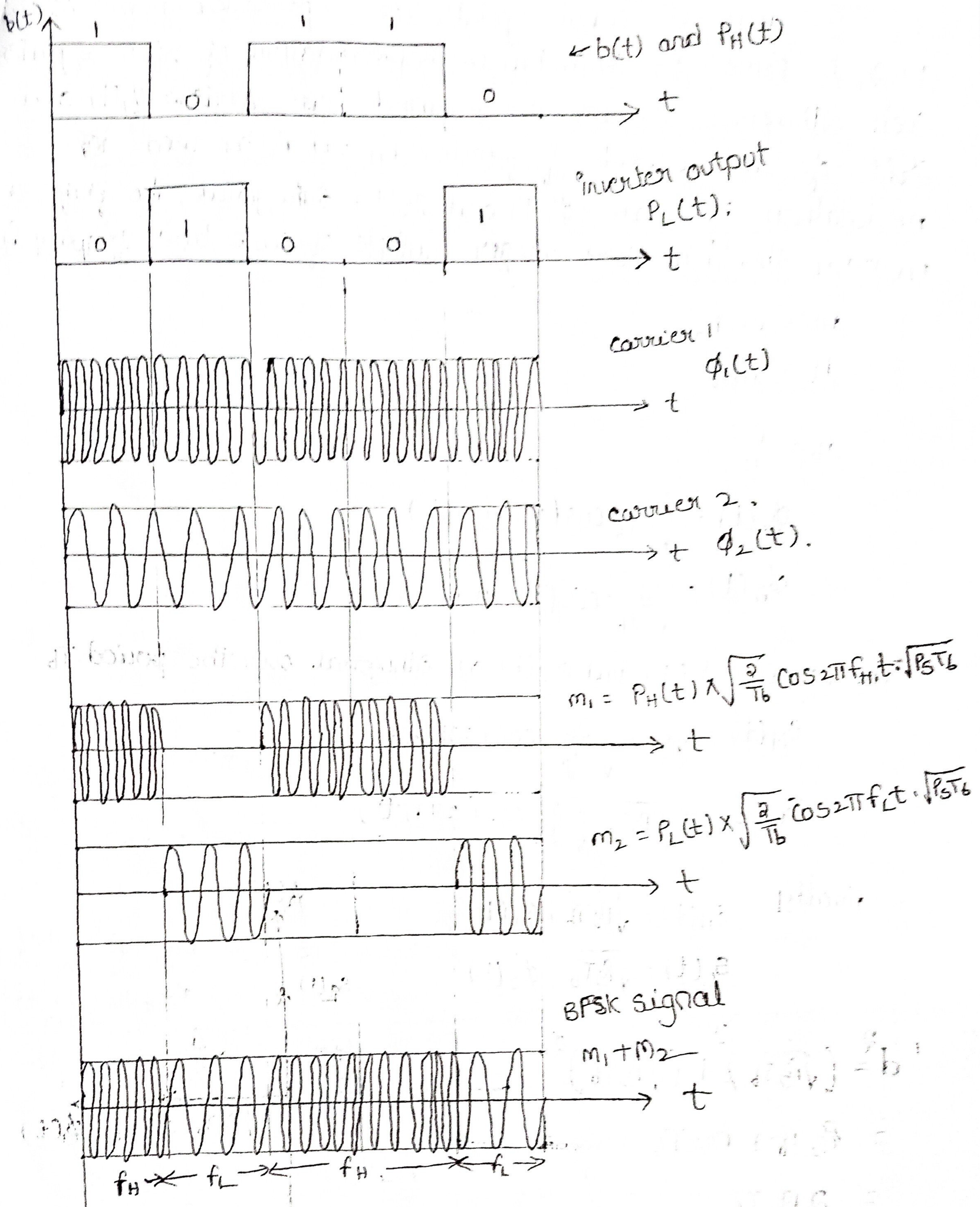
In other words, when a binary '0' is to be transmitted $P_L(t) = 1$ and $P_H(t) = 0$, and for a binary '1' is to be transmitted $P_H(t) = 1$ and $P_L(t) = 0$. Hence the transmitted signal will have a frequency either f_H & f_L. The two carrier signals $\phi_1(t)$ and $\phi_2(t)$ are used. $\phi_1(t)$ and $\phi_2(t)$ are orthogonal to each other. In one bit period of input signal $\phi_1(t)$ or $\phi_2(t)$ have integral number of cycles.

$$s(t) = \sqrt{2P_s}\cos(2\pi f_H t)\, P_H(t) + \sqrt{2P_s}\cos(2\pi f_L t)\, P_L(t)$$

$$= \sqrt{P_s T_b}\, P_H(t)\sqrt{\frac{2}{T_b}}\cos(2\pi f_H t) + \sqrt{P_s T_b}\, P_L(t)\sqrt{\frac{2}{T_b}}\cos(2\pi f_L t)$$

$$= \sqrt{E_b}\sqrt{\frac{2}{T_b}}\, P_H(t)\cos(2\pi f_H t) + \sqrt{E_b}\sqrt{\frac{2}{T_b}}\cos(2\pi f_L t)\, P_L(t)$$

Waveforms :-


b(t)
← b(t) and $P_H(t)$
inverter output $P_L(t)$;
carrier 1 $\phi_1(t)$
carrier 2. $\phi_2(t)$.
$m_1 = P_H(t) \times \sqrt{\frac{2}{T_b}} \cos 2\pi f_H t \cdot \sqrt{P_s T_b}$
$m_2 = P_L(t) \times \sqrt{\frac{2}{T_b}} \cos 2\pi f_L t \cdot \sqrt{P_s T_b}$
BFSK signal $m_1 + m_2$
f_H
f_L
t

Geometrical Representation of Orthogonal BFSK :-

The different signal points are represented geometrically. (coherent) For Geometrical representation of BFSK signals in ϕ_1, ϕ_2 plane. Two such orthogonal carriers are required. Two carriers $\phi_1(t)$ and $\phi_2(t)$ of two different frequencies f_H and f_L are used for modulation. To make $\phi_1(t)$ and $\phi_2(t)$ orthogonal, the frequencies f_H and f_L should be some integer multiple of base band frequency f_b.

$$f_H = m.f_b$$
$$f_L = n.f_b.$$

$$f_b = \frac{1}{T_b}$$

$$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos(2\pi\, m.f_b t)$$

$$\phi_2(t) = \sqrt{\frac{2}{T_b}} \cos(2\pi.\, n.f_b\, t)$$

The carriers $\phi_1(t)$ and $\phi_2(t)$ are orthogonal over the period T_b.

$$S_H(t) = \sqrt{P_S T_b}\sqrt{\frac{2}{T_b}} \cos(2\pi f_H t)$$

$$S_L(t) = \sqrt{P_S T_b}\sqrt{\frac{2}{T_b}} \cos(2\pi f_L t)$$

finally

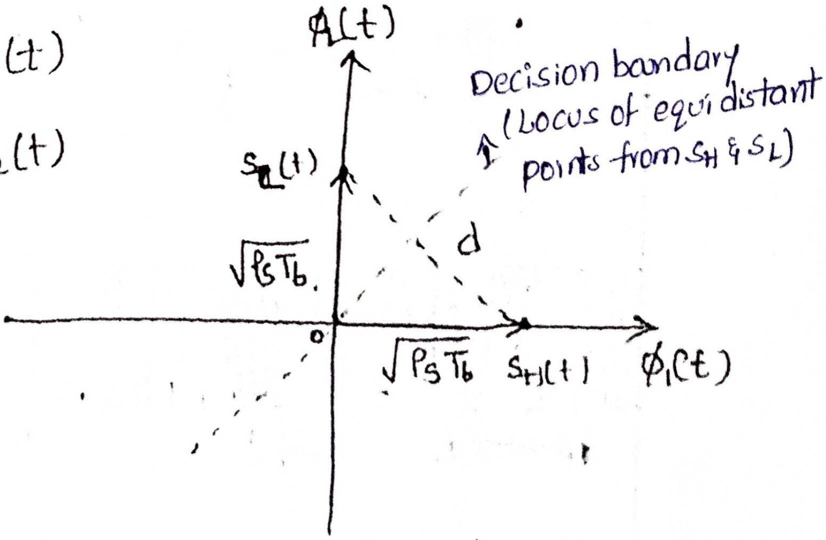
$$S_H(t) = \sqrt{P_S T_b} \cdot \phi_1(t)$$
$$S_L(t) = \sqrt{P_S T_b} \cdot \phi_2(t)$$

$$d^2 = \left(\sqrt{P_S T_b}\right)^2 + \left(\sqrt{P_S T_b}\right)^2$$

$$= P_S T_b + P_S T_b$$

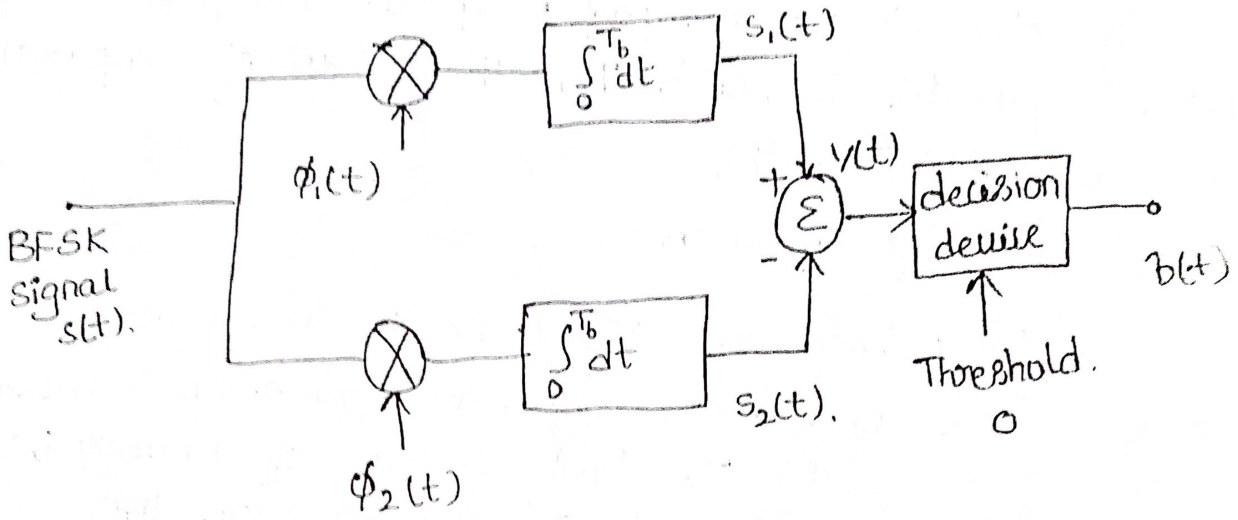
$$= 2 P_S T_b$$

$$d = \sqrt{2 P_S T_b} = \sqrt{2E_b}$$



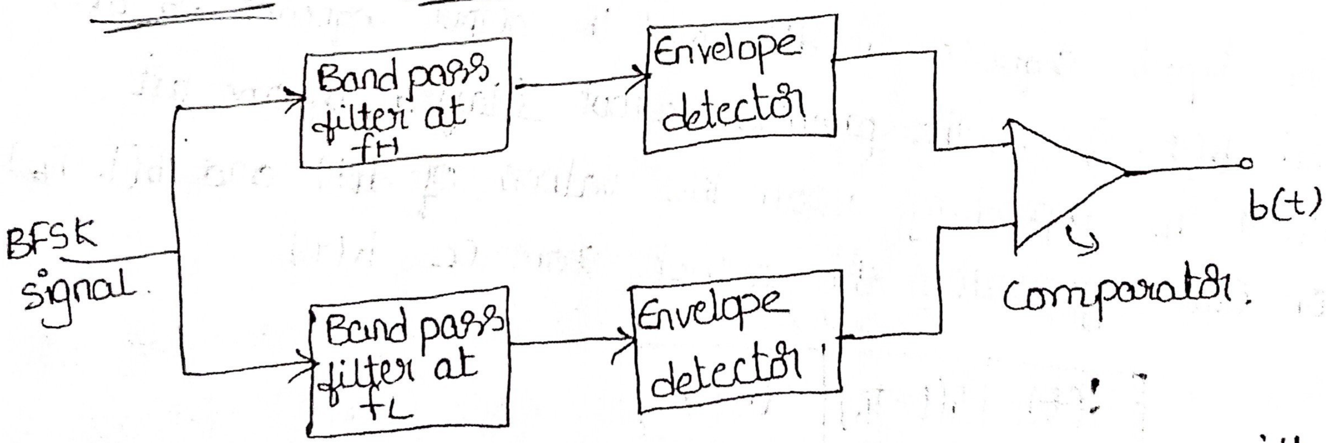
signal space representation of BFSK.

Coherent BFSK Receiver :-



There are two correlators for two frequencies of FSK signal. These correlators are supplied with locally generated carriers $\phi_1(t)$ and $\phi_2(t)$. If the transmitted frequency is f_H, then output $s_1(t)$ will be higher than $s_2(t)$. Hence $y(t)$ will be greater than zero. The decision device then decides in favour of binary '1'. If $s_2(t) > s_1(t)$ then $y(t) < 0$ and decision device decides in favour of 0.

Non-coherent BFSK Receiver :-



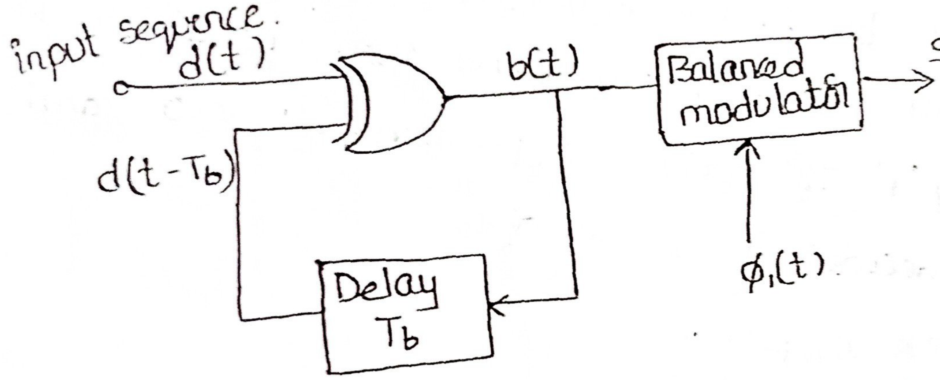
The receiver consists of two bandpass filters, one with carrier frequency f_H and other with centre frequency f_L. Since $f_H - f_L = 2f_b$. The outputs of filters do not overlap.

The outputs of filters are applied to envelop detectors. The outputs of detectors are compared by the comparator. If unipolar comparator is used, then the output of comparator is the bit sequence $b(t)$.

Differential Phase Shift Keying (DPSK) :-

Differential phase shift keying is the non-coherent version of the PSK. DPSK does not need a synchronous (coherent) carrier at the demodulator. The output sequence of binary bits is modified such that the next bit depends upon the previous bit. Therefore, in the receiver, the previous received bits are used to detect the present bit.

Generation of DPSK :-



$s(t) = b(t)\sqrt{2P}\cos(2\pi f_c t)$

$= \pm\sqrt{2P}\cos(2\pi f_c t)$

DPSK signal.

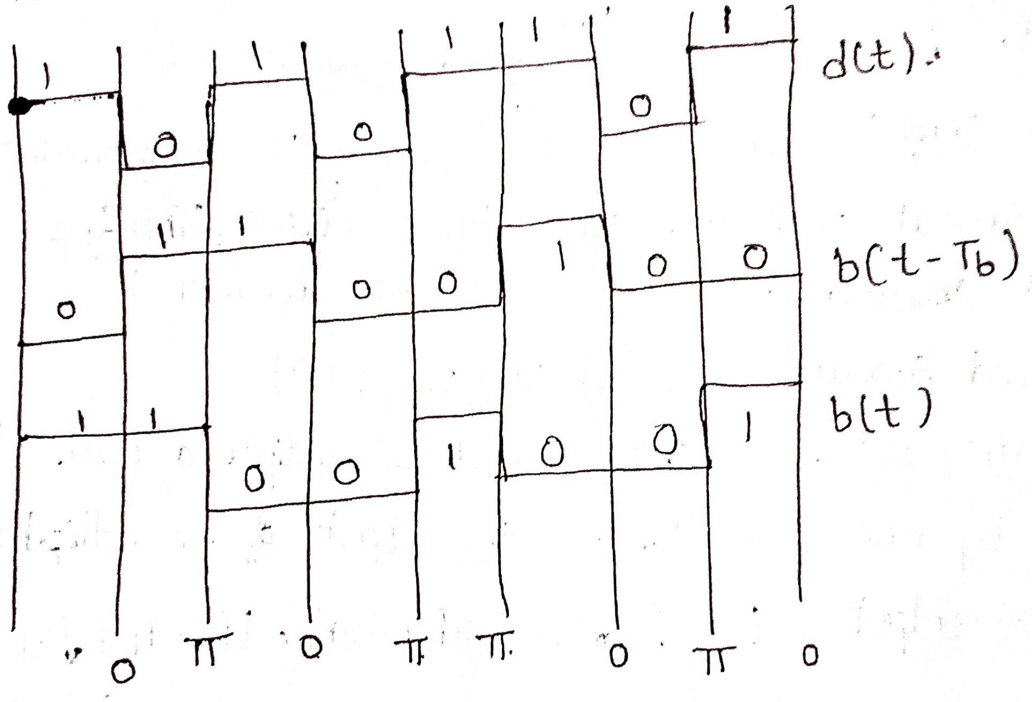
The input sequence is $d(t)$ and the output sequence is $b(t)$ and $b(t-T_b)$ is the previous output delayed by one bit period 'T_b'. Depending upon the values of $d(t)$ and $b(t-T_b)$, XOR Gate generates the output sequence $b(t)$.

$d(t)$	$b(t-T_b)$	$b(t)$
0 (-1V)	0 (-1V)	0 (-1V)
0 (-1V)	1 (1V)	1 (1V)
1 (1V)	0 (-1V)	1 (1V)
1 (1V)	1 (1V)	0 (-1V)

The data stream b(t) is applied to the input of the encoder. The output of the encoder is applied to one input of the product modulator. To the other input of this product modulator, a sinusoidal carrier of fixed amplitude and frequency is applied.

$$\boxed{b(t) = d(t) \oplus b(t - T_b)}$$

An arbitrary waveform d(t) is taken depending on this sequence, b(t) and $b(t - T_b)$ are found. while drawing the waveforms the value of $b(t - T_b)$ is not known. initially in first interval. Therefore it is assumed to be zero and then waveforms are drawn.



when $d(t) = 0$, $b(t) = b(t - T_b)$

$d(t) = 1$, $b(t) = \overline{b(t - T_b)}$

→ The sequence b(t) modulates the sinusoidal carrier. when b(t) changes the level, phase of the carrier is changed since b(t) changes its level only when d(t) = 1. It shows that phase of the carrier is changed only if d(t) = 1

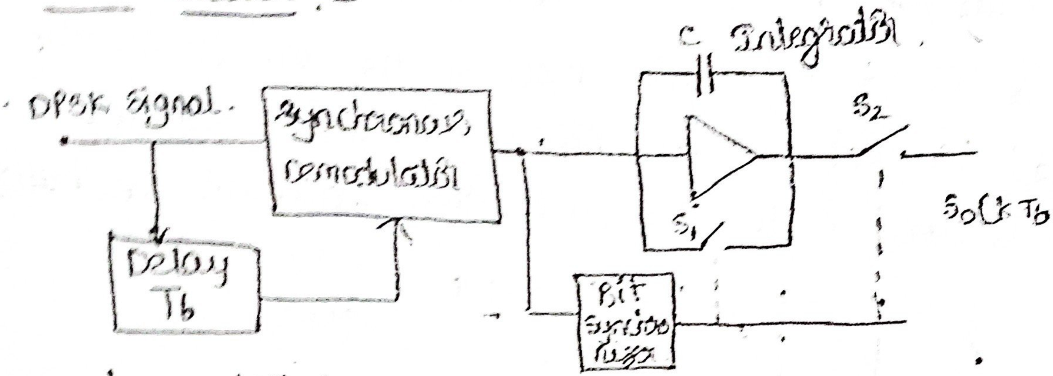
Always two successive bits are checked for any change of level. Hence one symbol has two bits.

Symbol duration $(T) = 2T_b$

The modulator output is $s(t) = b(t)\sqrt{2P}\cos 2\pi f_c t$

$s(t) = \pm\sqrt{2P}\cos 2\pi f_c t$.

DPSK Receiver :-



1. phase shift in received signal :- During the transmission, the DPSK signal undergoes some phase shift θ. Therefore the signal received at the input of the receiver is.

Received signal $= b(t)\sqrt{2P}\cos(2\pi f_c t + \theta)$.

2. multiplier output :- This signal is multiplied with its delayed version by one bit. Therefore the output of the multiplier is

multiplier output $= b(t)\sqrt{2P}\cos(2\pi f_c t + \theta) \times b(t - T_b)\sqrt{2P}$ $\cos[2\pi f_c(t - T_b) + \theta]$

$= b(t)\, b(t - T_b)\,(2P)\cos(\underbrace{2\pi f_c t + \theta}_{A})\cos(\underbrace{2\pi f_c(t - T_b) + \theta}_{B})$

$\therefore \cos(A).\cos(B) = \frac{1}{2}[\cos(A-B) + \cos(A+B)]$

$= b(t)\, b(t - T_b)\,(2P)\frac{1}{2}\cos(2\pi f_c t + \theta)\cos[2\pi f_c t - 2\pi f_c T_b + \theta]$

$$= b(t)\, b(t-T_b)\,(2P)\, \cos(2\pi f_c t + \theta)\cos(2\pi f_c t - 2\pi f_c T_b + \theta]$$

$$= b(t)\, b(t-T_b)\,(2P)\, \frac{1}{2}\left[\cos(2\pi f_c t + \theta - 2\pi f_c t + 2\pi f_c T_b - \theta] + \cos(2\pi f_c t + \theta + 2\pi f_c t - 2\pi f_c T_b + \theta)\right]$$

$$= b(t)\, b(t-T_b)\, P.\left[\cos(2\pi f_c T_b) + \cos(4\pi f_c t - 2\pi f_c T_b + 2\theta)\right]$$

$$= b(t)\, b(t-T_b)\, P\left\{\cos(2\pi f_c T_b) + \cos\left[4\pi f_c\left[t - \frac{T_b}{2}\right] + 2\theta\right]\right\}$$

f_c is the carrier frequency and T_b is one bit period. T_b contains integral number of cycles of f_c.

$$f_b = \frac{1}{T_b}. \qquad f_c = n f_b \Rightarrow f_0 = \frac{n}{T_b}$$

multiplier output $= b(t)\, b(t-T_b)\, P\left\{\cos 2\pi n + \cos\left[4\pi f_c\left[t - \frac{T_b}{2}\right) + 2\theta\right]\right\}$ $\therefore \cos 2\pi n = 1$

$$= b(t)\, b(t-T_b)\, P + b(t)\, b(t-T_b)\, P\cos\left(4\pi f_c\left(t - \frac{T_b}{2}\right) + 2\theta\right]$$

<u>Integrator</u>:- The above signal is given to the integrator. In the k^{th} bit interval, the integrator output can be written as.

$$s_0(KT_b) = b(KT_b)\, b[(K-1)T_b]\, P. \int_{(K-1)T_b}^{KT_b} 1\, dt + b(KT_b)\, b[(K-1)T_b]\, P \int_{(K-1)T_b}^{KT_b} \left[\cos\left(4\pi f_c\left(t - \frac{T_b}{2}\right) + 2\theta\right]dt$$

The integration of the second term will be zero since it is integration of carrier over one bit duration The carrier has integral number of cycles over one bit period hence integration is zero.

$$s_0(KT_b) = b(KT_b)\, b[(K-1)T_b]\, P\,[KT_b - (K-1)T_b]$$

$$= b(KT_b)\, b[(K-1)T_b]\, P\,[KT_b - KT_b + T_b]$$

$$= b(KT_b)\, b[(K-1)T_b]\, PT_b.$$

The product of $b(KT_b)$ and $b(K-1)T_b$ decides the sign of PT_b.

If $b(t)\, b(t-T_b) = 1V$ then $d(t) = 0$

$\therefore$ $b(t)$ and $b(t-T_b)$ both are $+1V$ or $-1V$

If $b(t)\, b(t-T_b) = -1V$ then $d(t) = 1$

That is $b(t) = -1V$, $b(t-T_b) = +1V$ and vice versa.

Therefore $b(t)\, b(t-T_b) = -1$.

Decision device:-

$$s_0(KT_b) = b(KT_b)[b(K-1)T_b]\, PT_b.$$

$$\text{If } s_0(KT_b) = \begin{cases} -PT_b, \text{ then } d(t) = 1 \text{ and} \\ +PT_b, \text{ then } d(t) = 0. \end{cases}$$

Bandwidth of DPSK:-

One previous bit is always used to define the phase shift in next bit, the symbol can be said to have two bits. Therefore one symbol duration (T) is equivalent to two bits duration ($2T_b$).

Symbol duration $T = 2T_b$

Bandwidth $B.W = \frac{2}{T}$

$= \frac{2}{2T_b}$

$= \frac{1}{T_b}$

$$\boxed{B.W = f_b}$$

Thus the minimum bandwidth in DPSK is equal to f_b, that is maximum baseband signal frequency.

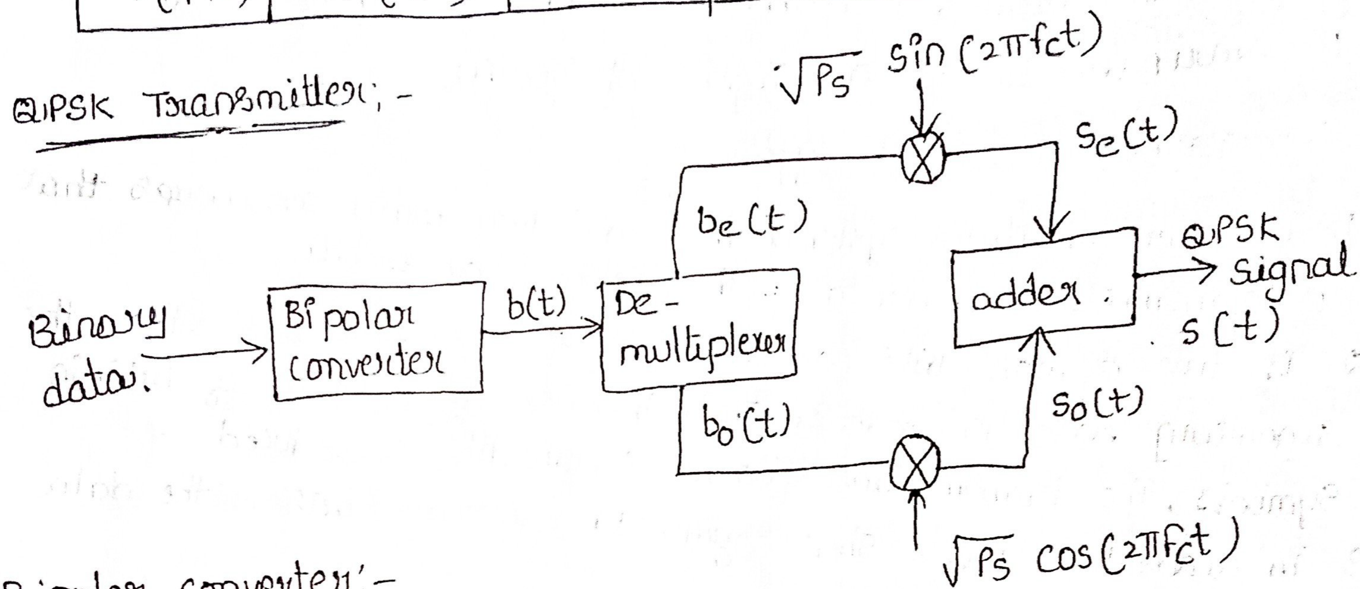
Quadrature Phase Shift Keying :-

1. In communication systems there are two main resources that is transmission power and the channel bandwidth.
2. If two or more bits are combined in some symbols, then the signalling rate is reduced. Thus because of grouping of bits in symbols, the transmission channel bandwidth is reduced.
3. In quadrature phase shift keying two successive bits in the data sequence are grouped together.
4. In BPSK we known that when symbol changes the level, the phase of the carrier is changed by 180°. Since there were only two symbols in BPSK, the phase shift occurs in two levels only.
5. In QPSK two successive bits are combined. This combination of two bits forms four distinct symbols. when the symbol is changed to next symbol the phase of the carrier is changed.

Symbol and corresponding phase shifts in QPSK :-

Input successive bits		Symbol	Phaseshift in carrier	
0 (-1)	0 (-1V)	S_1	$3\pi/4$	135°
0 (-1V)	1 (1V)	S_2	$5\pi/4$	225°
1 (+1V)	0 (-1V)	S_3	$\pi/4$	45°
1 (+1V)	1 (+1V)	S_4	$7\pi/4$	315°

QPSK Transmitter :-



Bipolar converter :-
The input binary sequence is first converted to a bipolar type of signal. This signal is called b(t). It represents binary '1' by +1V and binary '0' by -1V.

Demultiplexing :-
The demultiplexer divides b(t) into two separate bit streams of the odd numbered and even numbered bits. $b_e(t)$ represents even numbered sequence $b_o(t)$ represents odd numbered sequence.

Modulation of quadrature carriers :-

The bit stream $b_e(t)$ modulates carrier $\sqrt{P_s}\cos(2\pi f_c t)$ and $b_o(t)$ modulates $\sqrt{P_s}\sin(2\pi f_o t)$. These modulator are balanced modulator.

$$S_e(t) = b_e(t)\sqrt{P_s}\sin(2\pi f_c t)$$

$$S_o(t) = b_o(t)\sqrt{P_s}\cos(2\pi f_c t).$$

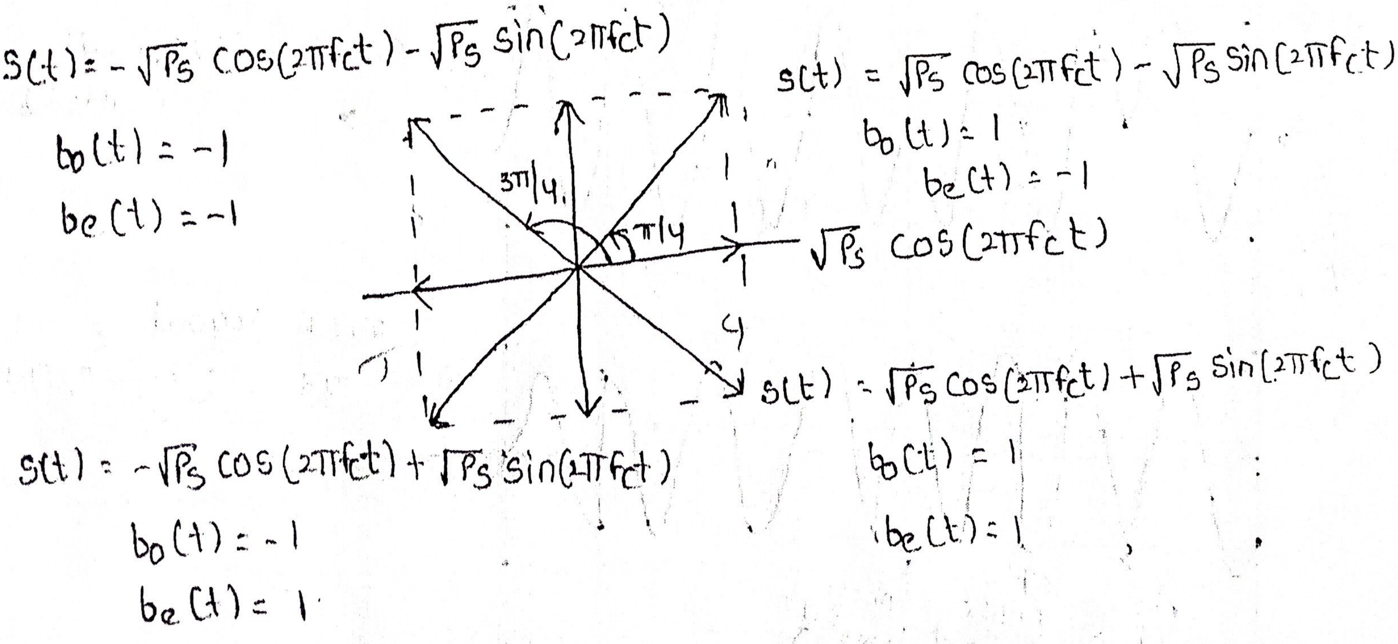
Thus $S_e(t)$ and $S_o(t)$ are basically BPSK signals and they are similar to BPSK. The only difference is that $T = 2T_b$. The value of $b_e(t)$ and $b_o(t)$ will be +1V or −1V.

Adder :- The adder adds these two signals $b_e(t)$ and $b_o(t)$. The output of the adder is QPSK signal

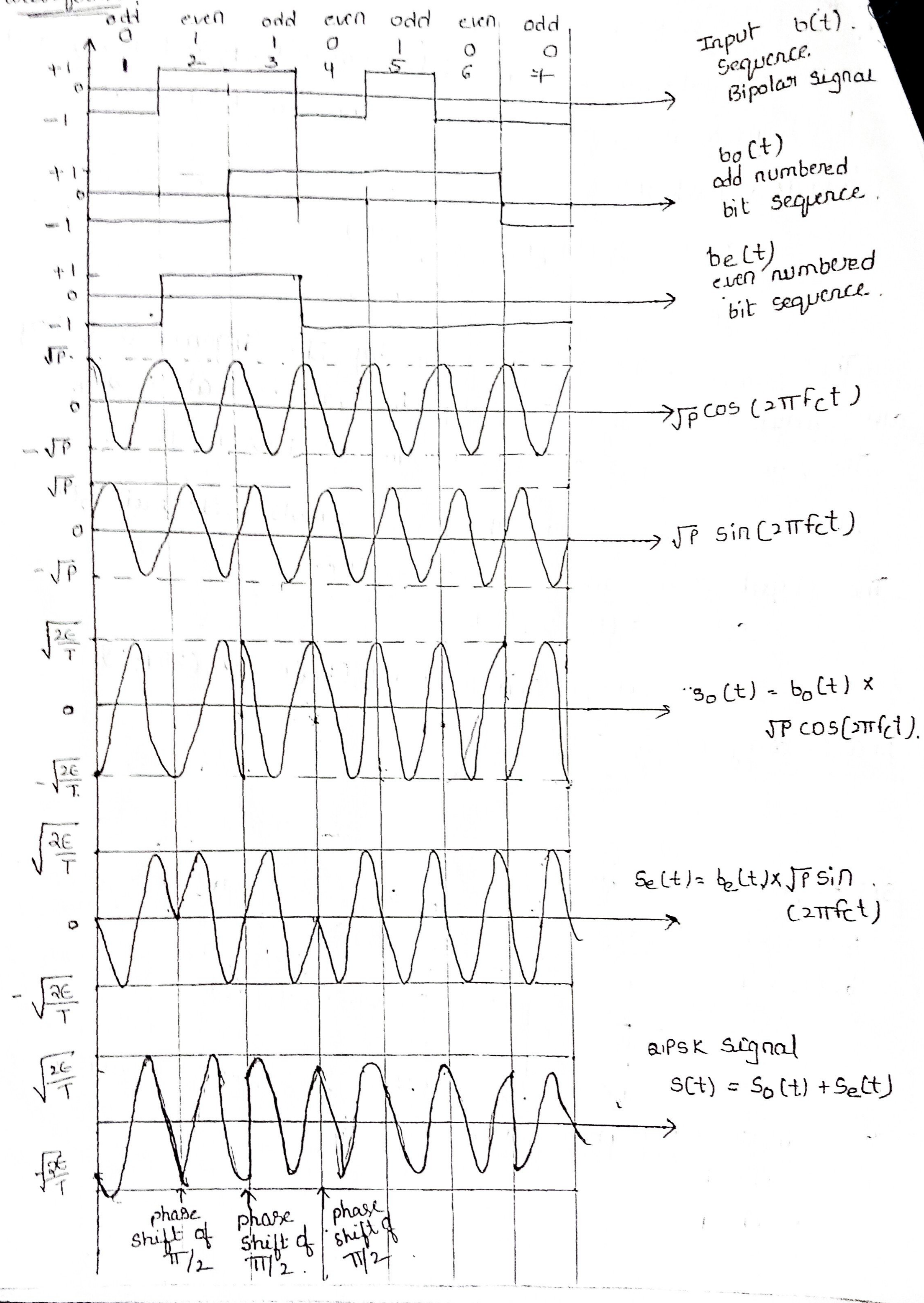
$$S(t) = S_e(t) + S_o(t)$$

$$= b_e(t)\sqrt{P_s}\sin 2\pi f_c t + b_o(t)\sqrt{P_s}\cos(2\pi f_c t).$$

phasor diagram of QPSK signal.

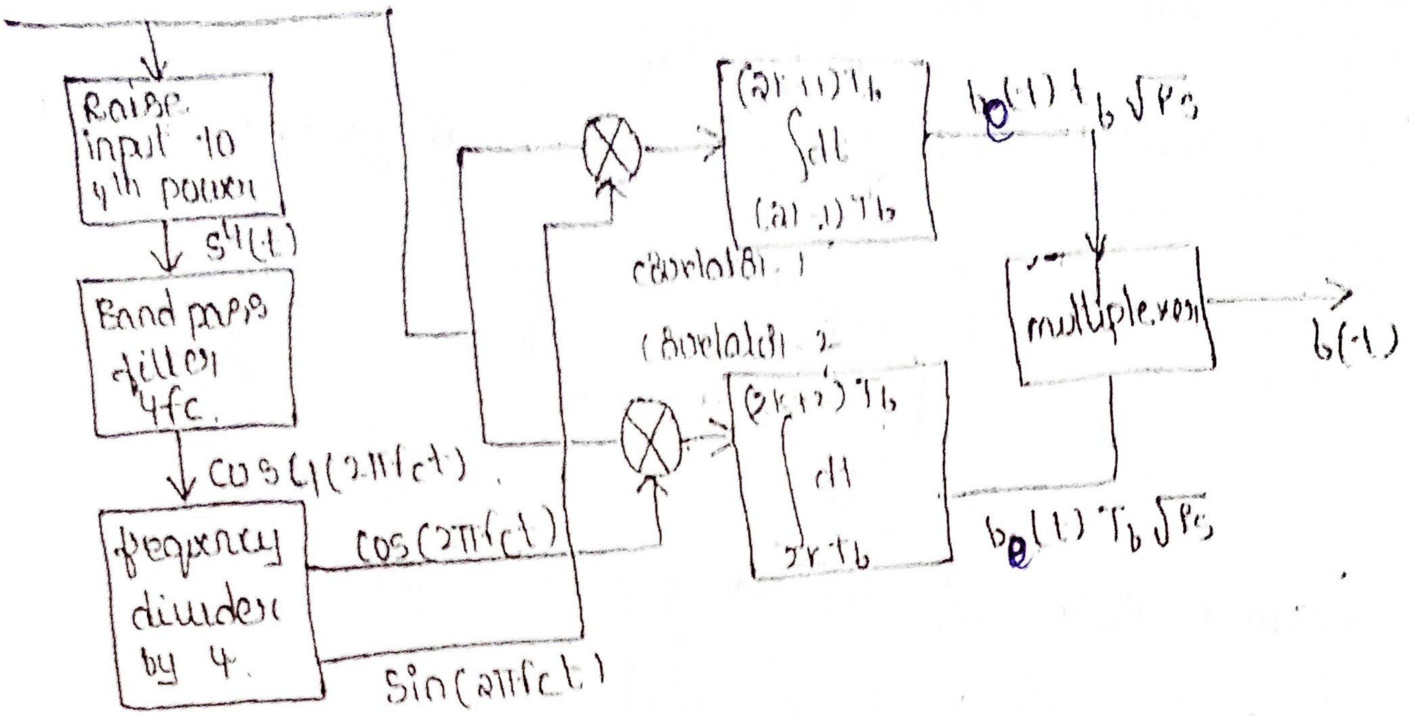


Waveforms :-



odd even odd even odd even odd
0 1 1 0 1 0 0
1 2 3 4 5 6 7
+1
0
-1
Input b(t). Sequence. Bipolar signal
$b_o(t)$ odd numbered bit sequence.
$b_e(t)$ even numbered bit sequence.
$\sqrt{P}$
$-\sqrt{P}$
$\sqrt{P}\cos(2\pi f_c t)$
$\sqrt{P}\sin(2\pi f_c t)$
$\sqrt{\frac{2E}{T}}$
$-\sqrt{\frac{2E}{T}}$
$\therefore s_o(t) = b_o(t) \times \sqrt{P}\cos(2\pi f_c t)$.
$s_e(t) = b_e(t) \times \sqrt{P}\sin(2\pi f_c t)$
QPSK signal
$s(t) = s_o(t) + s_e(t)$
phase shift of $\pi/2$
phase shift of $\pi/2$.
phase shift of $\pi/2$

QPSK Receiver:-



→ The received signal s(t) is first raised to 4th power i.e $s^4(t)$. Then it is passed through a band pass filter centered around 4fc. The output of the bandpass filter is a coherent carrier of frequency 4fc. This is divided by 4 and it gives two coherent carriers $\cos(2\pi f_c t)$ and $\sin(2\pi f_c t)$.

→ The coherent carriers are applied to two synchronous demodulators. These synchronous demodulators consists of multiplier and an integrator.

→ The integrator integrates the product signal over two bit intervals ($T_S = 2T_b$)

→ The outputs of the two integrators are sampled at the one bit period T_b. Hence the output of multiplexer is the signal b(t). That is, the odd and even sequences are combined by multiplexer.

$$s(t)\sin(2\pi f_c t) = b_0(t)\sqrt{P_s}\cos(2\pi f_c t)\sin(2\pi f_c t) + b_e(t)\sqrt{P_s}\sin^2(2\pi f_c t)$$

$$\int_{(2k-1)T_b}^{(2k+1)T_b} s(t)\sin(2\pi f_c t)dt = b_0(t)\sqrt{P_s}\int_{(2k-1)T_b}^{(2k+1)T_b}\cos(2\pi f_c t)\sin(2\pi f_c t)dt + b_e(t)\sqrt{P_s}\int_{(2k-1)T_b}^{(2k+1)T_b}\sin^2(2\pi f_c t)dt.$$

$$\sin x \cdot \cos x = \frac{1}{2}\sin(2x)$$

$$\sin^2(x) = \frac{1}{2}[1-\cos(2x)]$$

$$\int_{(2k-1)T_b}^{(2k+1)T_b} s(t)\sin(2\pi f_c t)dt = \frac{b_0(t)\sqrt{P_s}}{2}\int_{(2k-1)T_b}^{(2k+1)T_b}\sin(4\pi f_c t)dt + \frac{b_e(t)\sqrt{P_s}}{2}\int_{(2k-1)T_b}^{(2k+1)T_b} 1 \cdot dt$$

$$- \frac{b_e(t)\sqrt{P_s}}{2}\int_{(2k-1)T_b}^{(2k+1)T_b}\cos 4\pi f_c t \, dt.$$

In above equations, the first and third terms involves integration of sinusoidal carriers over two bit period. They have full cycles over two bit period and hence integration will be zero.

$$\int_{(2k-1)T_b}^{(2k+1)T_b} s(t)\sin(2\pi f_c t)dt = \frac{b_e(t)\sqrt{P_s}}{2}[t]_{(2k-1)T_b}^{(2k+1)T_b}$$

$$= \frac{b_e(t)\sqrt{P_s}}{2} \times 2T_b$$

$$= b_e(t)\sqrt{P_s} \cdot T_b.$$

...ilarly the output of lower integrator as $b_o(-1) \cdot \sqrt{P_s T_b}$.

...ignal space Representation of QPSK Signals :-

In QPSK depending upon the combination of two successive bits, the phase shift occurs in carrier.

$$S(t) = \sqrt{2P}\cos(2\pi f_c t + \theta) \quad \left[\theta = \frac{\pi}{4}, (or)\ \frac{3\pi}{4}\ (or)\ \frac{5\pi}{4}\ or\ \frac{7\pi}{4}\right)$$

it can be written as ..

$$S(t) = \sqrt{2P}\cos\left(2\pi f_c t + (2m+1)\frac{\pi}{4}\right] \quad \text{here } (m = 0,1,2,3)$$

$$\cos[A+B] = \cos A \cdot \cos B - \sin A \sin B.$$

The above equation expanded as

$$s(t) = \sqrt{2P}\cos(2\pi f_c t)\cos\left((2m+1)\frac{\pi}{4}\right] - \sqrt{2P}\sin(2\pi f_c t)\sin\left((2m+1)\frac{\pi}{4}\right]$$

$$s(t) = \sqrt{PT_S}\sqrt{\frac{2}{T_S}}\cos(2\pi f_c t)\cdot\cos\left(2m+1)\frac{\pi}{4}\right] - \sqrt{PT_S}\sqrt{\frac{2}{T_S}}\sin(2\pi f_c t)\sin\left((2m+1)\frac{\pi}{4}\right]$$

$$\phi_1(t) = \sqrt{\frac{2}{T_S}}\cos(2\pi f_c t), \quad \phi_2(t) = \sqrt{\frac{2}{T_S}}\sin(2\pi f_c t).$$

$$s(t) = \sqrt{PT_S}\,\phi_1(t)\cdot\cos\left[(2m+1)\frac{\pi}{4}\right] - \sqrt{PT_S}\,\phi_2(t)\sin\left((2m+1)\frac{\pi}{4}\right]$$

$$s(t) = \sqrt{PT_S}\times\frac{\sqrt{2}}{\sqrt{2}}\cos\left[(2m+1)\frac{\pi}{4}\right]\phi_1(t) - \sqrt{PT_S}\times\frac{\sqrt{2}}{\sqrt{2}}\sin\left[(2m+1)\frac{\pi}{4}\right]\phi_2(t)$$

$$s(t) = \underbrace{\sqrt{P\frac{T_S}{2}}\cdot\sqrt{2}\cos\left((2m+1)\frac{\pi}{4}\right]}_{b_o(t)}\phi_1(t) - \underbrace{\sqrt{P\cdot\frac{T_S}{\sqrt{2}}}\cdot\sqrt{2}\sin\left[(2m+1)\frac{\pi}{4}\right]}_{b_e(t)}\phi_2(t)$$

$$b_o(t) = \sqrt{2}\cos\left((2m+1)\frac{\pi}{4}\right) \qquad T_S = \text{symbol duration}$$

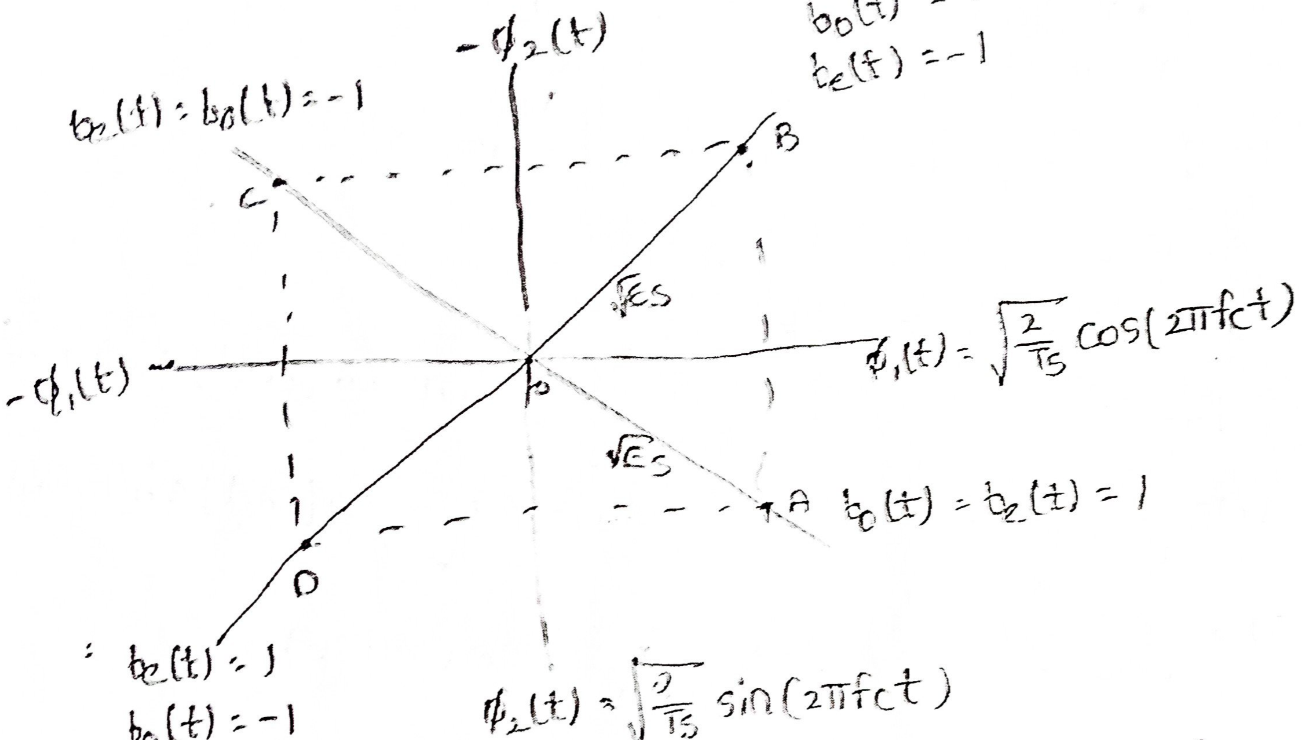
$$b_e(t) = -\sqrt{2}\sin\left[(2m+1)\frac{\pi}{4}\right] \qquad T_S = 2T_b.$$

$$T_b = \frac{T_S}{2}.$$

$s(t) = \sqrt{P_s T_b}\ b_o(t)\ \phi_1(t) + \sqrt{P_s T_b}\ b_e(t)\ \phi_2(t)$

$$E_b = P_s \cdot T_b$$

$$\boxed{s(t) = \sqrt{E_b}\ b_o(t)\,\phi_1(t) + \sqrt{E_b}\ b_e(t)\ \phi_2(t)}$$



The distance of any signal point from o is given as.

distance o to B. $= \sqrt{P_S T_b + P_S T_b}$

$$= \sqrt{2 P_S T_b} = \sqrt{2 P_S \frac{T_S}{2}}$$

$$= \sqrt{P_S T_S}$$

$$= \sqrt{E_S}.$$

Distance between signal points:-

for Example signal points 'A' and B are two nearest points since they differ by.

$$d^2 = (OA)^2 + (OB)^2$$

$$= \sqrt{E_S}^2 + \sqrt{E_S}^2$$

$$= \sqrt{2E_S} = \sqrt{2 . P_S . T_S} = \sqrt{2 . P_S . 2T_b}$$

$= \sqrt{2^2 \cdot P_s \cdot T_b}$

$= \sqrt{2^2} \cdot \sqrt{P_s \cdot T_b}$

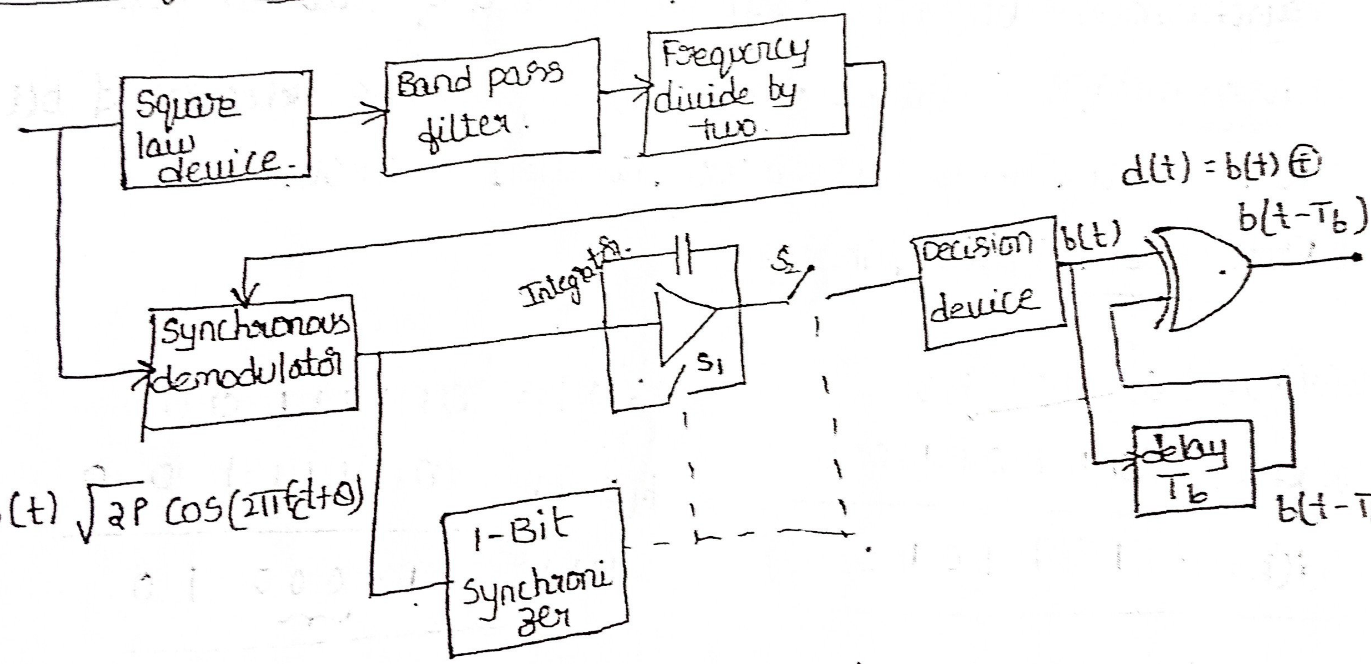
$= 2 \cdot \sqrt{P_s \cdot T_b}$

$= 2\sqrt{E_b}.$

Differentially Encoded PSK :- (DEPSK).

In DEPSK, the signal b(t) is recovered using coherent detection. The original sequence d(t) is obtained by decoding b(t). The transmitter of DEPSK system is exactly similar to DPSK.

Receiver of DEPSK signal :-



Receiver block diagram of DEPSK system.

The receiver of DEPSK is synchronous or coherent detector. The signal b(t) $\sqrt{2P}$ cos(2πf_ct + θ) is received at the receiver. It is applied to the square law device and synchronous demodulator. The square law device, band pass filter and frequency divider detect the coherent carrier signal. The recovered carrier is given to synchronous demodulator. The output of demodulator is given to integrator and bit synchronizer. The output of the integrator is sampled at times $t = KT_b$. This sampled signal $S(KT_b)$ is given to the decision device. The output of decision device is the sequence $b(t)$. $b(t)$ is given to one input of the EX-OR gate and its delayed version of $b(t-T_b)$ is given to other input. The output of EX-OR gate is the sequence $d(t)$.

Advantages and disadvantages :-

Advantages :- The main advantage of DEPSK is that it uses synchronous detection. Hence probability of error is reduced.

Disadvantages :- Since DEPSK uses synchronous detection of $b(t)$ its receiver is very complex, similar to BPSK.

- Errors occur in pairs in DEPSK :-

b(K)	0 1 1 0 1 1 0 0
b(K-1)	0 1 1 0 1 1 0 0
d(K) =	1 0 1 1 0 1 0

error free output.

b'(K) =	0 1 1 1 1 1 0 0
b(K-1) =	0 1 1 1 1 1 0 0
d(K)	1 0 0 0 0 1 0

one error is created in b(t).

In DPSK there is a tendency of occuring errors in pairs. But single error can also occur in DPSK. But in DEPSK, errors always occur in pairs. This is because in DEPSK we make decision in each bit interval about the value of b(t).

difference between modulation techniques –

Sl. No	Parameter	ASK	PSK	FSK	DPSK	QPSK
1.	modulation of	Amplitude	phase	frequency	phase	phase
2.	Bits per symbol	one	one	one	one	Two
3	Number of possible symbols $m = 2^N$	Two	Two	Two	Two	Four
4.	minimum distance	$\sqrt{E_b}$	$2\sqrt{E_b}$	$\sqrt{2E_b}$	–	$2\sqrt{E_b}$
5	Band width	$2f_b$	$2f_b$	$4f_b$	f_b	f_b
6.	symbol duration	T_b	T_b	T_b	$2T_b$	$2T_b$
7.	Detection method	coherent	coherent	non-coherent	non-coherent	coherent
8.	Equation of the transmitted signal s(t)	$s(t) = \sqrt{2P}\cos(2\pi f_c t)$	$s(t) = b(t)\sqrt{2P}\cos(2\pi f_c t)$	$s(t) = \sqrt{2P}\cos(2\pi f_c + d(t)\Omega)t$; Ω is frequency shift	$s(t) = b(t)\sqrt{2P}\cos(2\pi f_c t)$	$s(t) = \sqrt{2P}\cos[2\pi f_c t + (2m+1)\frac{\pi}{4}]$; $m = 0, 1, 2, 3$

M-ARY MODULATION TECHNIQUES

Basic Concept

In an M-ary signaling scheme, we can send one of the M possible signals such as $s_1(t)$, $s_2(t)$ ... $s_M(t)$ during each signaling interval of duration 'T' seconds. The no. of possible signals i.e M is given by

$$M = 2^N \quad \text{where, } N \text{ is an integer}$$

Advantage:

The M-ary schemes are preferred to the binary schemes when we want to conserve the channel bandwidth

Drawbacks:

The bandwidth conservation is achieved at the cost of following drawbacks:

1. Increase in transmitted power
2. Increase in error probability

Types of M-ary systems

1. M-ary PSK
2. M-ary QAM (Quadrature Amplitude Modulation)
3. M-ary FSK

→ M-ARY PHASE SHIFT KEYING (PSK)

BPSK transmits one bit at a time and it has only two symbols. Hence whenever the symbol is changed, the phase shift is

$$\text{phase shift in BPSK} = \frac{2\pi}{\text{No of symbols}} = \frac{2\pi}{2} = \pi \text{ or } 180^\circ$$

In QPSK two successive bits are combined to form 4 distinct symbols. Hence, whenever symbol is changed, the phase shift is

$$\text{phase shift in QPSK} = \frac{2\pi}{\text{No. of symbols}} = \frac{2\pi}{4} = \frac{\pi}{2} \text{ (or) } 90^\circ$$

This can be extended further for 'N' bits. If we combine 'N' successive bits, then there will be $2^N = M$ possible symbols.

Whenever the symbol is changed the phase shift is

$$\text{phase shift in M-ary PSK} = \frac{2\pi}{\text{No. of symbols}} = \frac{2\pi}{M}$$

The duration of each symbol will be NT_b thus

$$T_s = NT_b$$

Since there are M-symbols, this method is called M-ary PSK.

The transmitted waveform is represented in M-ary PSK as

$$s(t) = \sqrt{2P_s}\cos(2\pi f_0 t + \phi_m) \quad — (1)$$

where $\phi_m = (2m+1)\frac{\pi}{M}$ and $m = 0, 1, 2, \ldots M-1$

Signal space diagram:

The above equation can be expanded as

$$s(t) = \sqrt{2P_s}\cos(2\pi f_0 t)\cos\phi_m - \sqrt{2P_s}\sin\phi_m \sin(2\pi f_0 t)$$

Let us rearrange the above equation as

$$s(t) = \sqrt{P_s T_s}\sqrt{\frac{2}{T_s}}\cos\phi_m \cos(2\pi f_0 t) - \sqrt{P_s T_s}\sqrt{\frac{2}{T_s}}\sin\phi_m \sin(2\pi f_0 t)$$

$$s(t) = \sqrt{P_s T_s}\cos\phi_m\, \phi_1(t) - \sqrt{P_s T_s}\sin\phi_m\, \phi_2(t) \quad — (2)$$

where $\phi_1(t) = \sqrt{\frac{2}{T_s}}\cos(2\pi f_0 t)$ and $\phi_2(t) = \sqrt{\frac{2}{T_s}}\sin(2\pi f_0 t)$

The above two equations are orthonormal waveforms. Fig 1 shows the signal space diagram based on equation ②. The orthonormal carriers $\phi_1(t)$ and $\phi_2(t)$ form two axes. The signal points $s_0, s_1, s_2 \ldots s_{m-1}$ are placed on the circumference of the circle. The signal points are equispaced with the phase shift of $\frac{2\pi}{M}$. The distance of each signal point from the origin is $\sqrt{P_s T_s}$

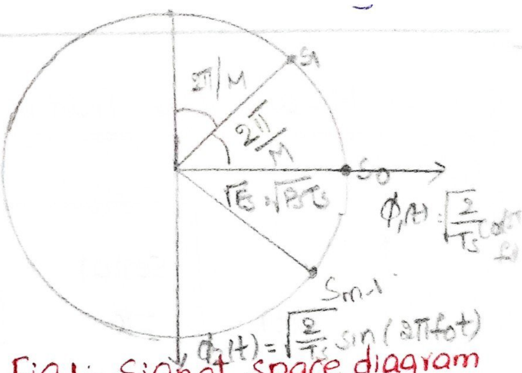


Fig 1: Signal space diagram

Power Spectral Density of M-ary PSK

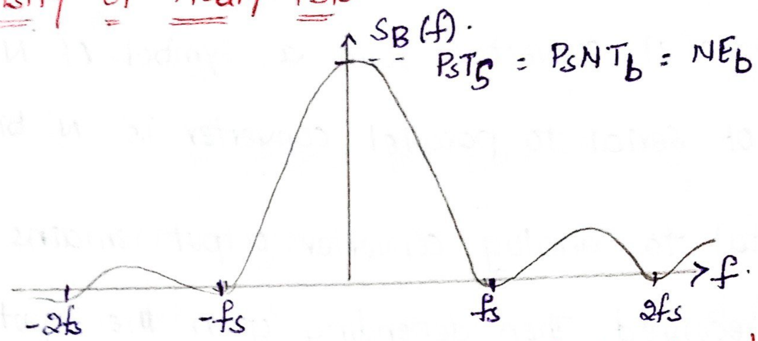


Fig 2: Plot of power spectral density of baseband M-ary PSK signal

Bandwidth of M-ary PSK

The Bandwidth required by the system is equal to the width of the main lobe i.e

$$BW = f_s - (-f_s) = 2f_s$$

$$= \frac{2}{T_s}$$

$$= \frac{2}{NT_b} = \frac{2f_b}{N}$$

where N is the no. of bits per symbol

The above equation shows that, as the no. of successive bits (N) per symbol are increased then bandwidth reduces

M-ary PSK Transmitter

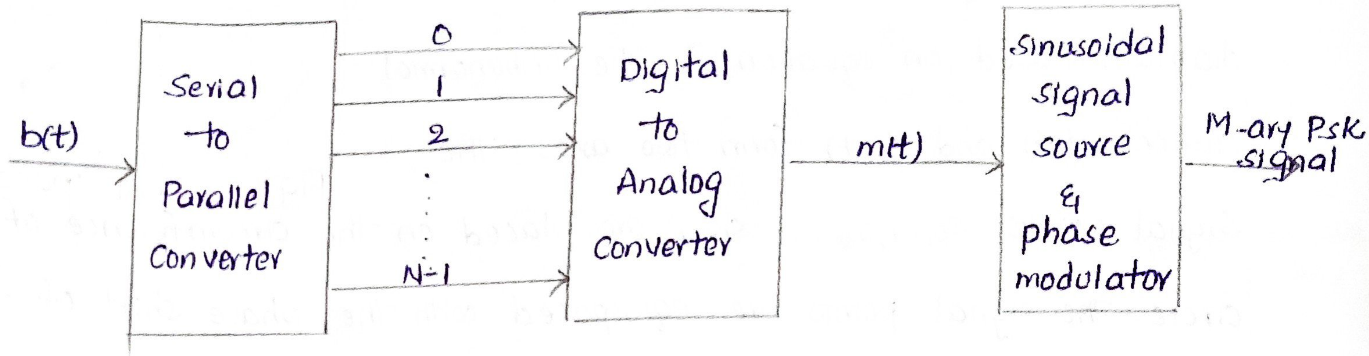


Fig 3: Transmitter block diagram

The above figure shows the simplified M-ary PSK transmitter. The serial to parallel converter form a symbol of 'N' successive bits. Then the output of serial to parallel converter is 'N' bit word.

The digital to analog converter output remains unchanged till last N^{th} bit is received. Then depending upon the input 'N' bits, the output D/A converter is defined. This output is m(t). Again the serial to parallel converter starts taking bits for next 'N' word.

The voltage m(t) is applied to modulator. This modulator modulates the phase of sinusoidal carrier depending upon the amplitude of the symbol m(t).

M-ary PSK Receiver

The fig 4 shows the receiver of M-ary PSK. It is similar to QPSK receiver. The input signal s(t) is raised to M^{th} power. The bandpass filter extracts the frequency component Mf_0. This frequency is divided by 'M' to obtain carrier frequency f_0. The coherent carriers are thus generated and applied to two multipliers.

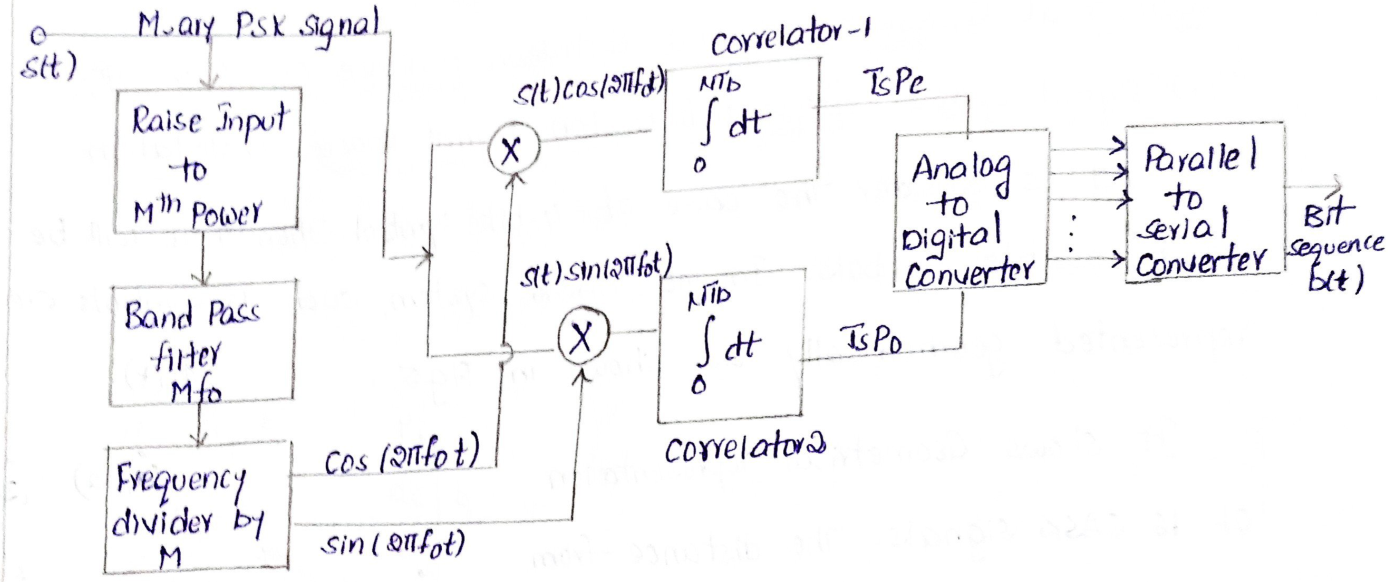


Fig4: M-ary PSK Receiver

The outputs of the multipliers are given to the integrators. The integrators integrate over the period of $T_s = NT_b$. The outputs of the integrators are sampled after the period T_s in every cycle and applied to the analog to digital converter. The integrator outputs are proportional to T_sP_e and T_sP_o. These voltages are applied to A/D converter, which reconstructs 'N' bit symbol. The 'N' bit symbol is given to the parallel to serial converter. It then generates the bit sequence b(t).

→ Quadrature Amplitude Shift keying (QASK) (or) QAM

In case of PSK systems all points lie on the circumference of the circle. This is because PSK signal has constant amplitude throughout. If amplitude of the signal is also varied, then the points will lie inside the circle also on the signal space diagram.

This increases the noise immunity of the system. Such system involves phase as well as amplitude shift keying. It is called quadrature amplitude phase shift keying simply (QASK). It is also

Called Quadrature amplitude Modulation (QAM)

Geometrical Representation and Euclidean distance of QASK signals (or) signal space Representation (or) signal space Constellation

Let us consider the case of 4-bit symbol. Then there will be $2^4 = 16$ possible symbols. In the QASK system, such 16 symbols are represented geometrically as shown in Fig 5.

It shows Geometrical representation of 16 QASK signals. The distance from the neighbouring points is $d = 2a$.

The average energy associated with the signal can be obtained as considering first quadrant

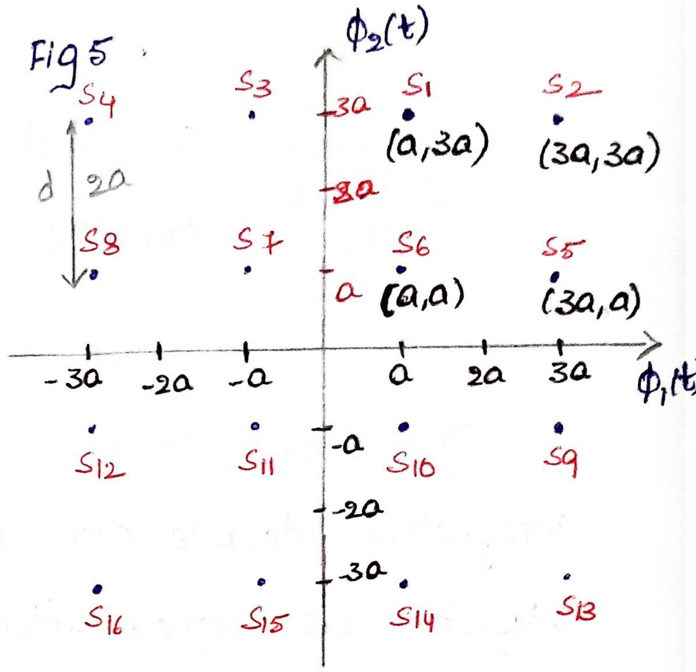


Fig 5: Geometrical Representation of 16 signals in QASK system

$$E_s = \frac{1}{4}\left[(a^2+a^2) + (9a^2+a^2) + (a^2+9a^2) + (9a^2+9a^2)\right]$$

$$= 10a^2$$

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

Since $d = 2a$, we have

$$d = 2\sqrt{0.1E_s} = \sqrt{0.4E_s}$$

The above relation gives the distance between two signal points in 16 QASK. In each symbol there are 4-bits. Hence bit energy and symbol energy are related as

$$E_s = 4E_b$$

We know that, $d = \sqrt{0.4E_s} = \sqrt{0.4 \times 4E_b} = \sqrt{1.6E_b}$

We know that the distance of QPSK is given as

$$d_{QPSK} = 2\sqrt{E_b}$$
$$= \sqrt{4E_b}$$

The distance for 16-ary PSK is

$$d_{16\,PSK} = 2\sqrt{E}\sin\frac{\pi}{16}$$
$$= 2\sqrt{4E_b}\sin\frac{\pi}{16} = 2\sqrt{0.15E_b} = \sqrt{0.6E_b}$$

Thus, the distance of 16 QASK is greater than 16-ary PSK where as it is less than QPSK.

→ Transmitter of QASK

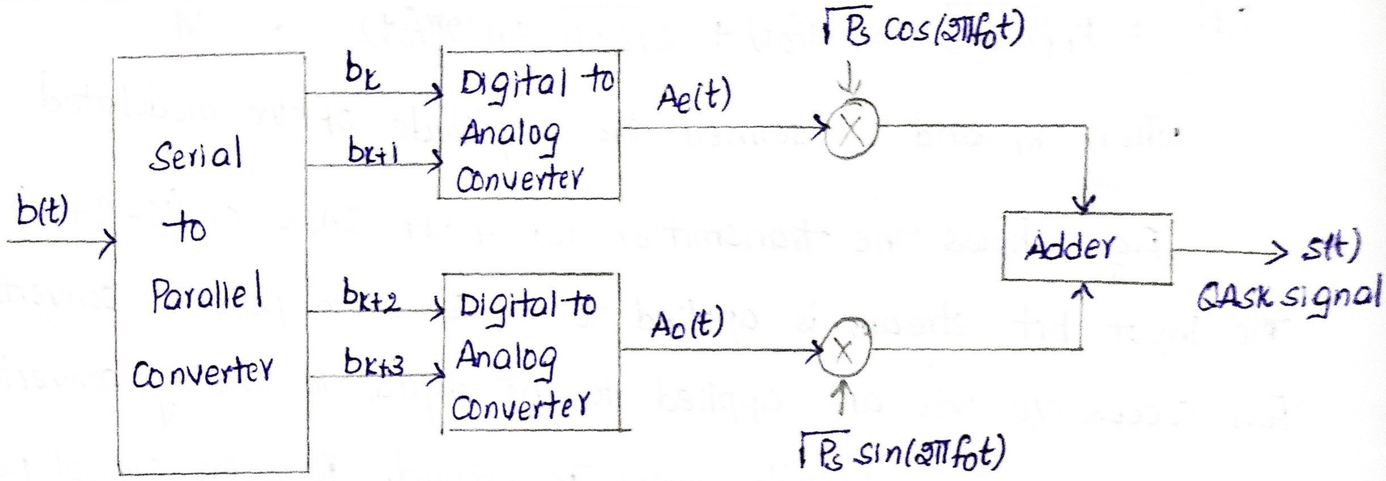


Fig 6: Generation of QASK signal

The QASK signal is represented as

$$s(t) = k_1 a\,\phi_1(t) + k_2 a\,\phi_2(t) \quad -①$$

Here. k_1 and k_2 will take values of ± 1 or ± 3. $\phi_1(t)$ and $\phi_2(t)$ are orthogonal carriers having the values as follows:

$$\phi_1(t) = \sqrt{\frac{2}{T_s}}\cos(2\pi f_0 t) \quad \text{and} \quad \phi_2(t) = \sqrt{\frac{2}{T_s}}\sin(2\pi f_0 t)$$

We know that the value of $a = \sqrt{0.1 E_s}$

The equation ① can be written as

$$s(t) = k_1 \cdot \sqrt{0.1 E_s} \left(\sqrt{\frac{2}{T_s}} \cos(2\pi f_0 t) \right) + k_2 \sqrt{0.1 E_s} \left(\sqrt{\frac{2}{T_s}} \sin(2\pi f_0 t) \right)$$

$$= k_1 \sqrt{0.2 \frac{E_s}{T_s}} \cos(2\pi f_0 t) + k_2 \sqrt{0.2 \frac{E_s}{T_s}} \sin(2\pi f_0 t) \quad - ②$$

We know that $E_s = P_s T_s$ — ③

Substitute the value of E_s in eq ②, we get

$$s(t) = k_1 \sqrt{\frac{0.2 P_s T_s}{T_s}} \cos(2\pi f_0 t) + k_2 \sqrt{\frac{0.2 P_s T_s}{T_s}} \sin(2\pi f_0 t)$$

$$s(t) = k_1 \sqrt{0.2 P_s} \cos(2\pi f_0 t) + k_2 \sqrt{0.2 P_s} \sin(2\pi f_0 t) \quad - ④$$

where k_1 and k_2 defined the amplitude of the modulated signal

Fig6 shows the transmitter for 4-bit QASK or (16-QASK) system. The input bit stream is applied to a serial to parallel converter. Four successive bits are applied to the digital to analog converters. These bits are applied after every T_s second. T_s is the symbol period and $T_s = 4T_b$.

Bits b_k and b_{k+1} are applied to upper digital to analog converter and b_{k+2} and b_{k+3} are applied to lower digital to analog converter.

Depending upon two input bits, the output of digital converter takes four output levels. Thus, $A_e(t)$ and $A_o(t)$ takes 4 levels depending upon combination of two input bits.

$A_e(t)$ modulates the carrier $\sqrt{P_s} \cos(2\pi f_0 t)$ and $A_o(t)$ modulates $\sqrt{P_s} \sin(2\pi f_0 t)$.

The adder combines two signals to give QASK signal. It is given as

$s(t) = A_e(t)\sqrt{P_s}\cos(2\pi f_0 t) + A_o(t)\sqrt{P_s}\sin(2\pi f_0 t)$ — (5)

If we compare the above equation with eq (4) then we write

$A_e(t)$ and $A_o(t) = \pm\sqrt{0.2}$ or $\pm 3\sqrt{0.2}$

→ Receiver of QASK signal

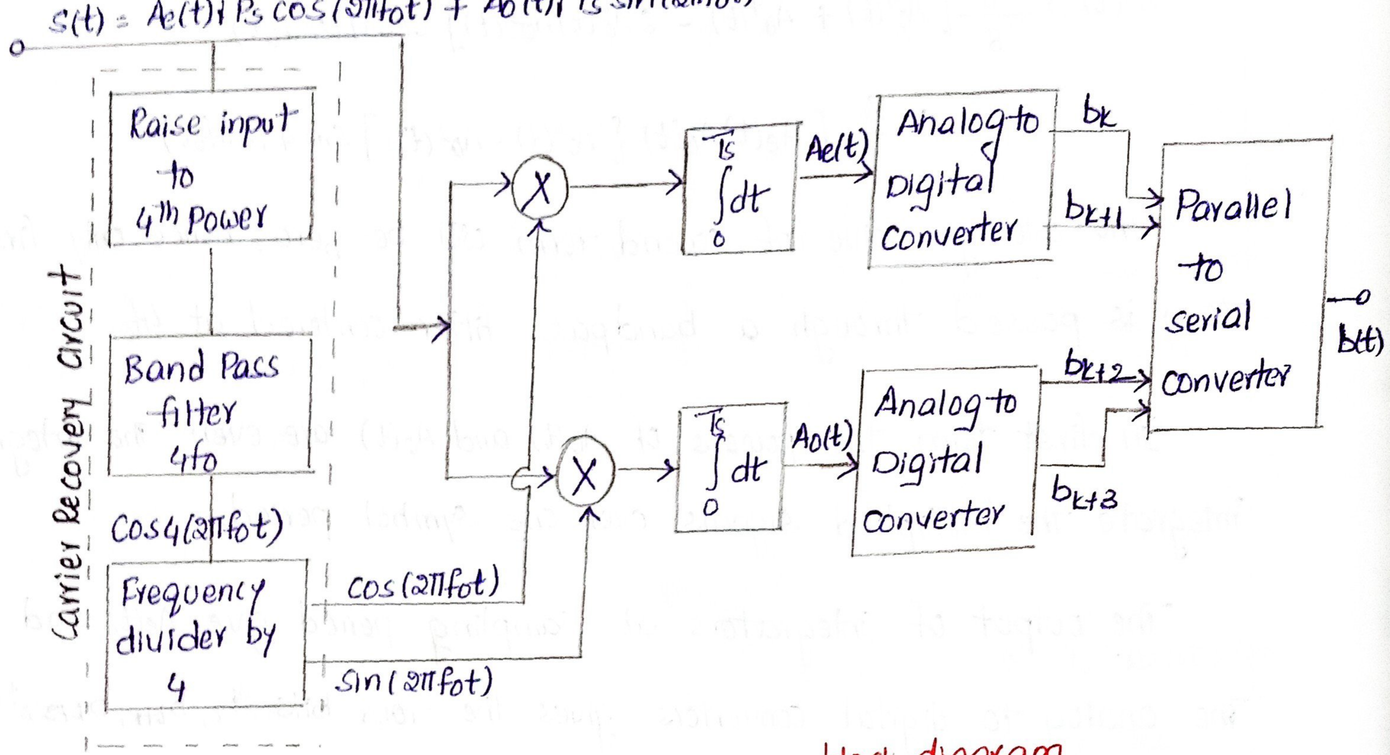


Fig 7: 4-bit QASK receiver block diagram

The Fig 7 shows the receiver of 16-QASK (4-bits QASK) system. The input signal s(t) is raised to 4th power. It then passed through a bandpass filter centered around the frequency $4f_0$ the signal is then divided in frequency by four. It gives a coherent carrier $\cos(2\pi f_0 t)$ and Quadrature carrier $\sin(2\pi f_0 t)$ is produced by phase shifting of 90° The inphase and quadrature coherent carriers are multiplied with QASK signal s(t).

Since the amplitudes of $A_e(t)$ and $A_o(t)$ are bit constant and equal

The 4^{th} power QASK signal is

$$s^4(t) = P_s^2 [A_e(t)\cos(2\pi f_0 t) + A_o(t)\sin(2\pi f_0 t)]^4$$

This signal is passed through a bandpass filter of $4f_0$. Therefore we will consider only the frequencies of $4f_0$ i.e

$$s^4(t) = \frac{P_s}{8}[A_e^4(t) + A_o^4(t) - 6A_e^2(t)A_o^2(t)] \cos 4(2\pi f_0 t)$$

$$+ \frac{P_s}{8}[A_e(t)A_o(t)\{A_e^2(t) - A_o^2(t)\}] \sin 4(2\pi f_0 t)$$

The average value of second term will be zero, hence only first term is passed through a bandpass filter centered at $4f_0$.

In first term the powers of $A_e(t)$ and $A_o(t)$ are even. The integrators integrate the multiplied signals over one symbol period.

The output of integrators at sampling period give $A_e(t)$ and $A_o(t)$. The analog to digital converters gives the four bits $b_k, b_{k+1}, b_{k+2}, b_{k+3}$. The parallel to serial converter then generates the bit sequence $b(t)$.

Bandwidth of QASK signal:

$$BW = f_s - (-f_s) = 2f_s$$

$$= \frac{2}{T_s} = \frac{2}{NT_b} = \frac{2f_b}{N}$$

The bandwidth and power spectral density of QASK is similar to that of M-ary PSK.

M-ary FSK

In BFSK we used only two symbols. This principle can be extended further to 'N' successive bits. These 'N' bits form $2^N = M$ different symbols. Every symbol uses separate frequency for transmission. Such system is called M-ary FSK system.

Transmitter of FSK:

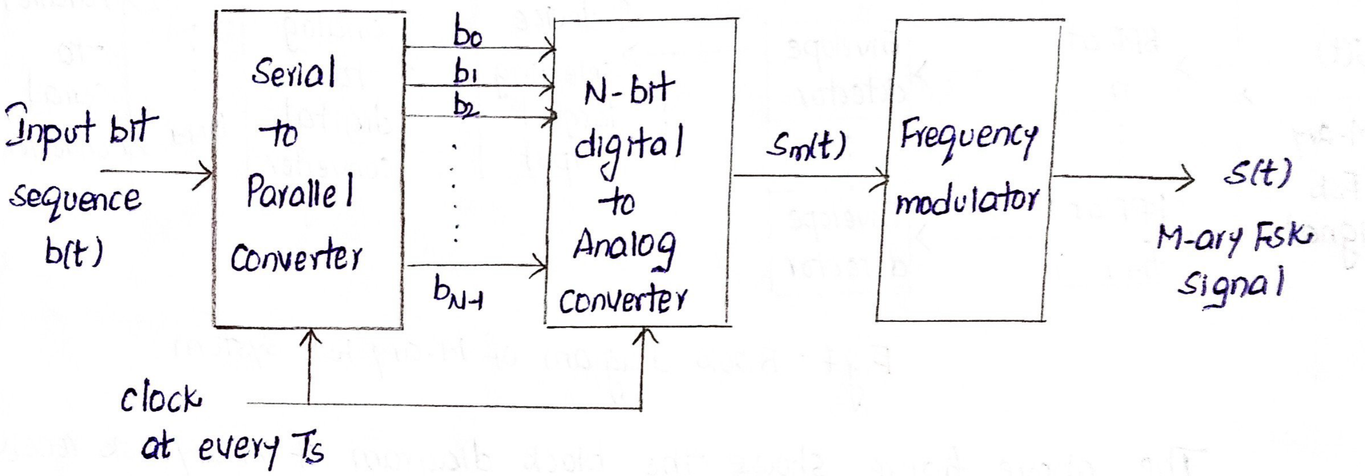


Fig 7: M-ary FSK transmitter

The above figure shows the M-ary 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 $T_s = NT_b$ period. The output of 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 for one symbol duration.

Thus for 'M' symbols, there are 'M' frequency signals at the output of modulator. Thus the transmitted frequencies are $f_0, f_1, f_2 \ldots f_{M-1}$ depending upon the input symbol to the modulator

→ Receiver of M-ary FSK

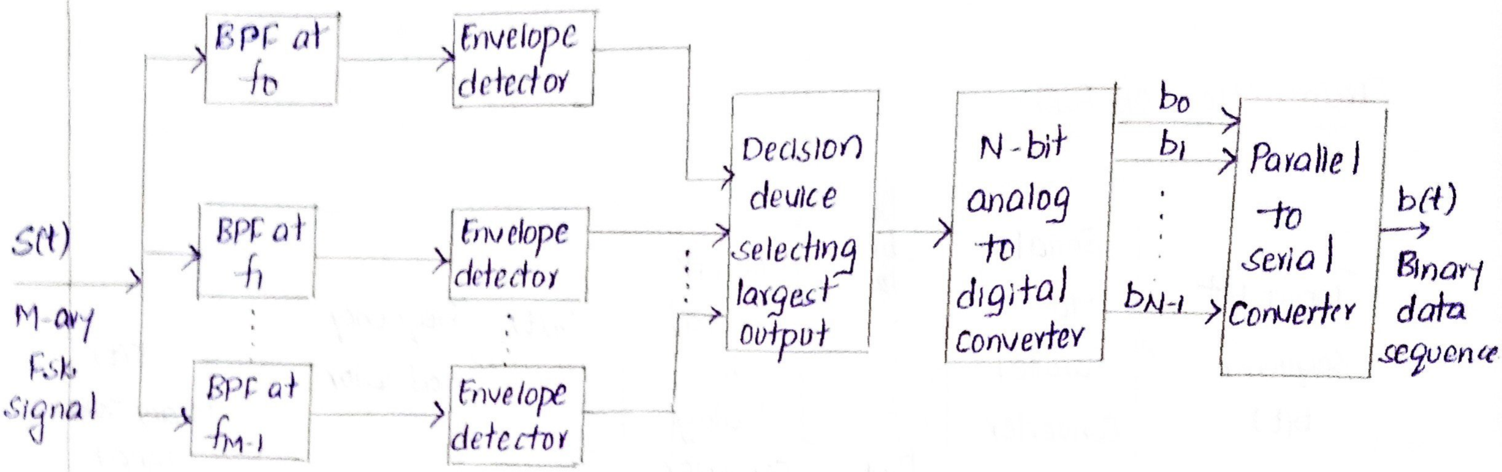


Fig 7: Block diagram of M-ary FSK system

The above figure shows the block diagram of M-ary FSK receiver. The M-ary FSK signal is given to the set of 'M' bandpass filters. The center frequencies of those filters are $f_0, f_1, f_2 \ldots f_{M-1}$. 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 analog to digital converter. The analog to digital converter output is the 'N' bit symbol in parallel. These bits are then converted to serial bit stream by parallel to serial converter.

Power Spectral Density of M-ary FSK

We know that M symbol $f_0, f_1, f_2 \ldots f_{m-1}$ frequencies are used for transmission. The probability of error is minimized by selecting those frequencies such that transmitted signals are mutually orthogonal.

If those frequencies are selected as successive even harmonics of symbol frequency f_s, then transmitted signals will be orthogonal.

Let's say that the lowest carrier frequency f_0 is the k^{th} harmonic of symbol frequency i.e

$$f_0 = kf_s$$

Then the other frequencies will be

$$f_1 = (k+2) f_s, \quad f_2 = (k+4) f_s \ldots \text{etc}$$

Thus every carrier frequency is separated by $2f_s$ from its nearest carriers. Fig 8 shows the power spectral density of BFSK.

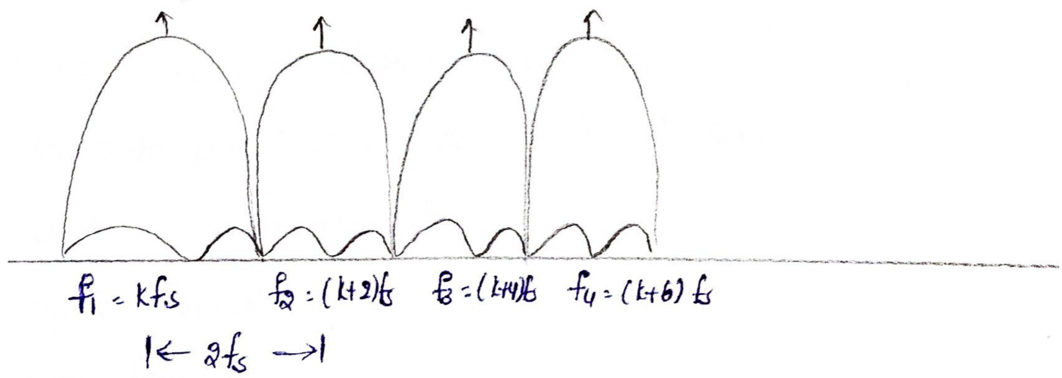


Fig 8 : Power spectral density M-ary FSK

In this plot the two symbol frequencies f_L and f_H are separated by $2f_s$

(Here $f_s = f_b$ for BFSK)

In fig 8, the separation between the two nearest main lobes is $2f_s$

Bandwidth of M-ary FSK

In fig 8, the width of one main lobe is $2f_s$. If there are M-symbols, the power spectral density spectrum will have 'M' lobes. Therefore the bandwidth of the system for M-symbols will be

$$BW = M \times (2f_s)$$

$$= 2Mf_s$$

We know that $M = 2^N$ and $T_s = N \cdot T_b$

$$\frac{1}{f_s} = \frac{N}{f_b} \Rightarrow f_s = \frac{f_b}{N}$$

$$= 2 \times 2^N \times \frac{f_b}{N}$$

$$BW = \frac{2^{N+1} \cdot f_b}{N}$$

On comparison of above equation with M-ary PSK bandwidth, it is clear that M-ary FSK needs comparatively large bandwidth.

→ Classification of Line codes

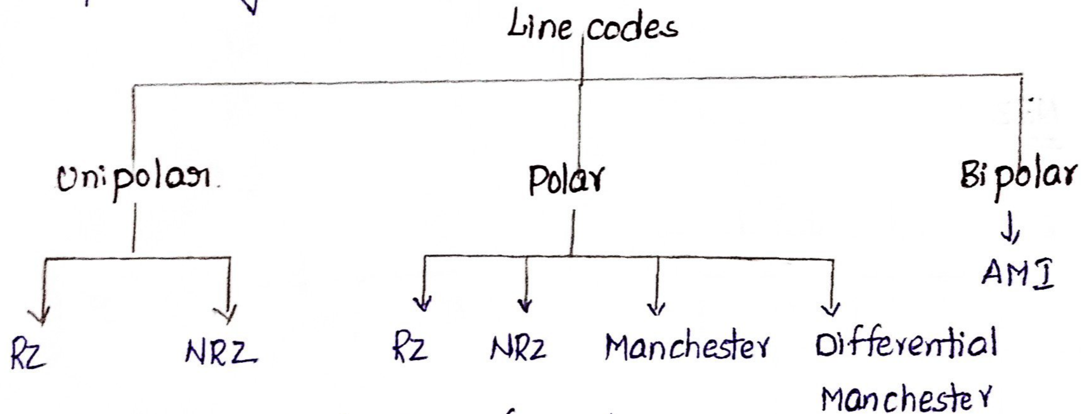
Basically, the line codes are divided into following three categories:

1. Unipolar codes
2. Polar codes
3. Bipolar codes

1. **Unipolar codes**: Unipolar codes use only one voltage level other than zero. Hence, the encoded signal will have either +A Volts value or '0'.

2. **Polar codes**: Polar coding uses two voltage levels other than zero such as $+A/2$ and $-A/2$ volts. This brings the dc level for some codes to zero which is a desired characteristics.

3. **Bipolar codes**: Bipolar coding uses three voltage levels positive, negative and zero. However, here, the zero level is always used for representing the '0' in the data stream at the input.



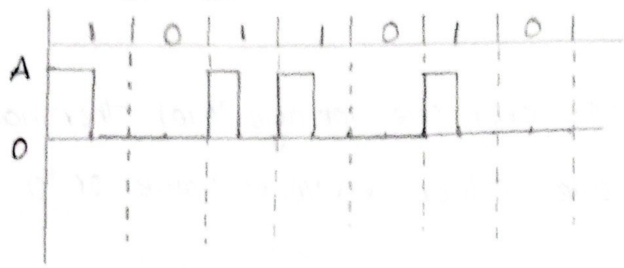
Some of the important PAM formats are:

1. Non-return to zero (NRZ) and Return to zero (RZ) unipolar format
2. NRZ and RZ polar format
3. NRZ bipolar format
4. Manchester format
5. Polar Quaternary NRZ format.

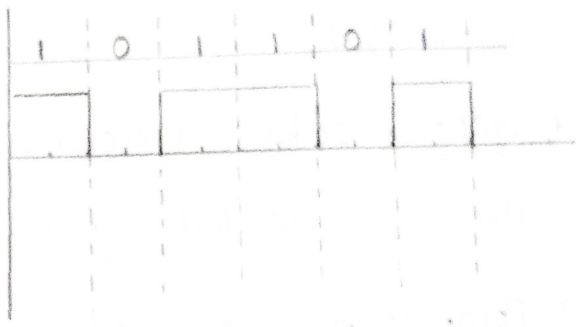
→ Unipolar RZ and NRZ

In this format, the waveform has a single polarity. The waveform can have +5 or +12volts when high. The waveform is simple on-off

(1) Unipolar RZ

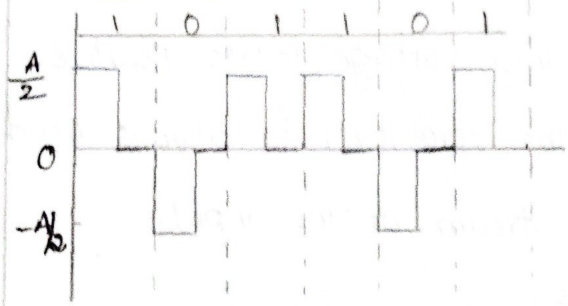


(2). Unipolar NRZ

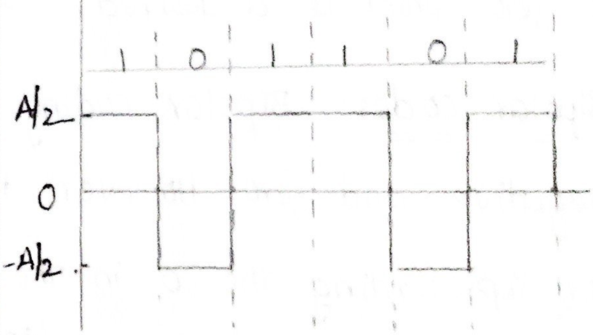


→ Polar RZ and NRZ

(1) Polar RZ



(2) Polar NRZ



→ Bipolar NRZ