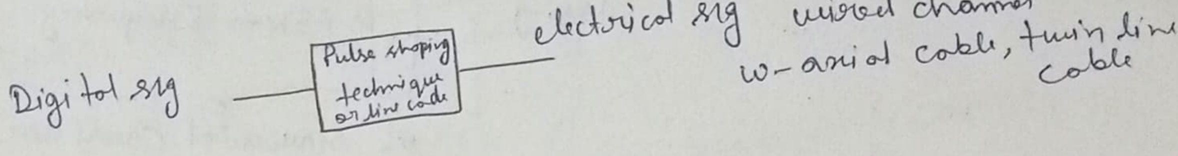
Unit-2

In the baseband pulse transmissed a data stream is in the form of discrete PAM signal is transmitted directly low pass channel.



Digital Passband Transmission:
The incoming data stream is modulated on to a carrier (usually sinosoidal) with fixed frequency limits imposed by a band pass channel of interest. It is suitable for transmission over long distance.
communication channel may be microwave radio link, a satellite channel or the light

Band Pass Digital Modulation:
Transmission, Possible involving switching (Keying) the amplitude, frequency or phase of sinosoidal carrier in accordance with the incoming data.

Digital Modulation Techniques:

- ASK (Amplitude Shift Keying) → BASK → Amplitude of carrier sig changes acc. to message sig
- PSK (Phase shift Keying) → BPSK, QPSK, M-ary PSK
- FSK (frequency shift Keying) → BFSK, MSK, GSMK
- Hybrid Technique: QAM (PSK + ASK) → OFDM, DTH TV

Primary Features of Digital Modulation Technique:-

Tx data [binary data] — Symbol '0', Symbol '1' $\xrightarrow{\text{Modulation Process}}$ switching or Keying

$\left\{\begin{array}{l} \text{BASK} \rightarrow \text{amplitude} \\ \text{BPS} \rightarrow \text{Phase} \\ \text{BFSK} \rightarrow \text{Frequency} \end{array}\right.$

of sinusoidal carrier between a pair of possible values acc. with symbol '1',

Sinusoidal Carrier:-

$$C(t) = A_c(t)\cos[\theta_c(t)]$$

$A_c(t)$ → Time varying amplitude carrier wave

$\theta_c(t)$ → angle of carrier wave (rad)

$$\theta_c(t) = \omega_c t + \phi_c(t)$$

ω_c → carrier freq^n (rad/sec)

$$\omega_c = 2\pi f_c$$

f_c → Hz.

BASK → f_c & ϕ_c : Constant

→ $A_c(t)$ is keyed b/w the two possible value to represent symbol '0' and '1'.

BPSK → $A_c(t)$ & f_c : Constant

→ ϕ_c is keyed b/w two possible values (0°) & 180° to represent symbol '0' and '1'.

BFSK → A_c & ϕ_c : Constant

→ f_c is keyed b/w two possible values to represent symbol '0' & '1'.

05/03/25

* **Digital Continuous Modulation Schemes:-**
(Shift Keying)

Carrier Sig → Continuous wave

Message Sig (Binary data) → Modulation → ASK & PSK & FSK } → Sinusoidal carrier properties binary symbol 0/1

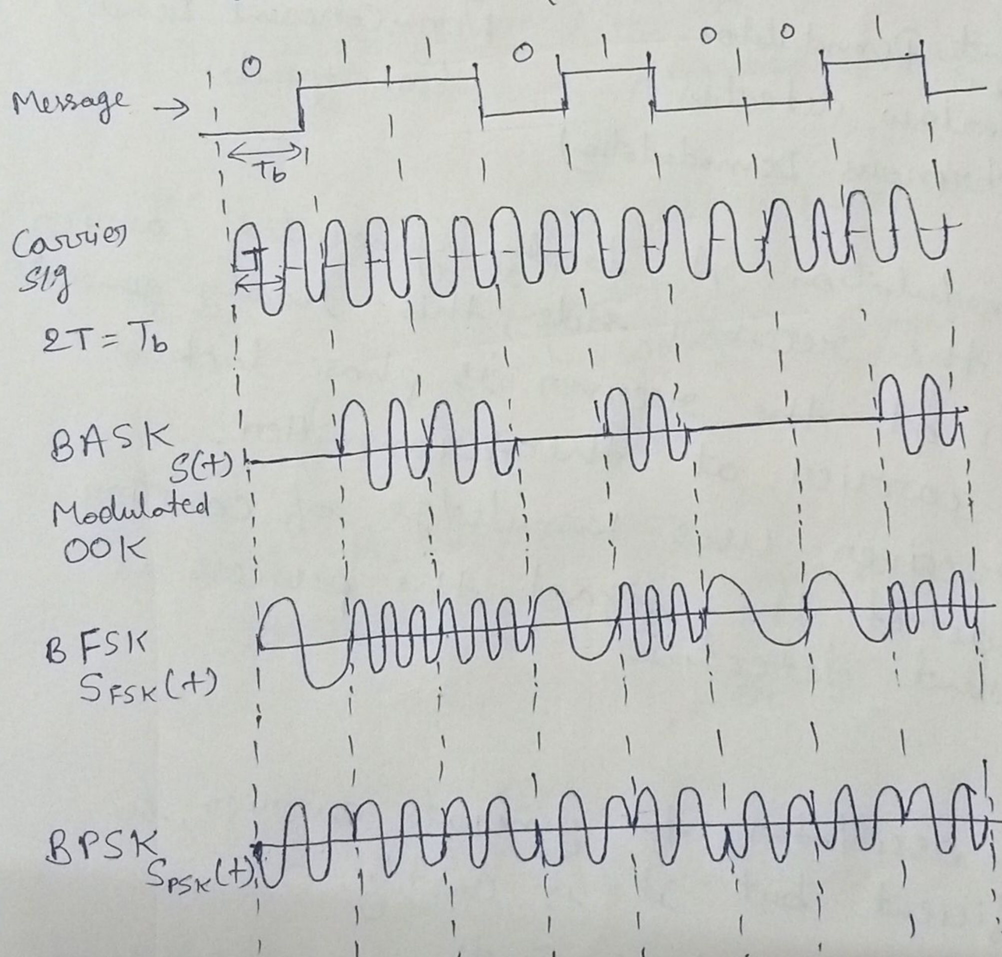
hybrid modulation

→ BASK → { Carrier wave = 0, $A_c = 0$ for symbol '0'
Carrier wave = A_c, for symbol '1'

BFSK → { for symbol '1' → $f_c = f_1 = 3$ cycle/sec
for symbol '0' → $f_c = f_2 = 1$ cycle/sec, $f_2 \ll f_1$

BPSK

$T_b \rightarrow$ bit period or symbol period



BPSK →
{ Symbol '1' → $\theta = 0°$
Symb '0' → $\theta = 180°$

$C(t) = A\cos(\omega_c t + \phi)$

$S(t) = \begin{cases} A\cos\omega_c t; & \text{for '1'} \quad 0 \le t \le T_b \\ -A\cos\omega_c t; & \text{for '0'} \quad 0 \le t \le T_b \end{cases}$

⇒ Although in a continuous wave modulation it is usually difficult to distinguish b/w phase & freq^n modulated signal by merely looking at their waveform, this is not true for PSK & FSK signal.

⇒ Unlike ASK signal both PSK & FSK sig have a const. envelope. Therefore PSK & FSK are prefered to ASK sig for passband data transmission over non-linear channel.

* **Demodulation / Detection of passband Transmission :-**

Coherent Demodulation or Squarlaw detection (Synchronous Demodulation)

Non-Coherent Demod^n / Envelope de

1) Coherent Demodulation : A locally generated carrier is used at the receiver side, this locally generated sin. carrier at the receiver is phase locked with the carrier at the transmitter.

⇒ When the receiver uses knowledge of carrier phase to detect the signal the process is called Coherent detection

Disadvantage:

⇒ We need an oscillator to generate carrier, so it is insufficient but it is costly

application: PSK, FSK, ASK, Continuous phase mod^n, hybrid

~~PER~~

2) Non-Coherent

⇒ When the receiver does not ~~s~~ utilize such phase reference information, this process is called non-coherent detection

⇒ No need to be phase locked

Advantage:

⇒ It is a simple, low cost but lower SNR of received signal. and increased PER

Application:

Differential phase shift Keying (DPSK), FSK, ASK, CPM

06/03/25

* **Waveform Amplitude Coefficient:-**

$$c(t) = A_c \cos(w_c t + \phi) \quad \text{—} \quad (1)$$

↳ interms of symbol energy/bit

PSK, FSK, ASK

$$s(t) = \underbrace{\sqrt{\frac{2E_i}{T}}}_{\text{waveform amplitude coefficient}} \cos(w_i t + \phi_i)$$

assume $\phi = 0$ for convenience

$$c(t) = A_c \cos w_c t \quad \text{—} \quad (2)$$

average Power of carrier sig $P = \frac{A_c^2}{2}$

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

put A_c in (2)

$$c(t) = \sqrt{2P} \cos w_c t \quad \text{—} \quad (3)$$

If we have symbol energy = $E_b \xrightarrow{n=1}$ bit energy

E_b or $E \rightarrow$ symbol energy

Symbol duration = T or T_b

$$P = \frac{E}{T} \text{ or } \frac{E_b}{T_b} \rightarrow n=1$$

then $c(t) = \sqrt{\frac{2E_b}{T_b}} \cos w_c t$

$$\boxed{c(t) = \sqrt{\frac{2E}{T}} \cos w_c t} \quad \text{--- (4)}$$

We shall use either amplitud notation A_c in eq^n (1) or the designation $\sqrt{\frac{2E}{T}}$. Since the energy of received sig is key parameter in determinig the error performance of detection process, it is often more convenient to use the Amplitude notation in eq^n (4) bcz it fascilited solving directly for the porobobility of error P_E.

$P_E \propto$ signal energy

as $P_E = f(E)$

<u>Note</u>: In practice we assume unit energy mesured over one symbol duration i.e. $E = 1\,J$.

then $c(t) = \sqrt{\frac{2}{T}} \cos w_c(t)$ ← Digital demodulation

↓ By using linear modulation (BASK, BFSK, BPSK)

$$s(t) = b(t) \cdot c(t) = b(t) \cdot \sqrt{\frac{2}{T}} \cos w_c t \quad \text{--- (6)}$$

$b(t)$ → incoming message sig

$c(t)$ → Carrier wave

assuming $f_c \gg W$, where W is bandwidth of binary wave $b(t)$.

Calculation of transmitted sig energy:-

Express of transmitted sig energy per bit

$$E_b = \int_0^{T_b} |s(t)|^2 dt = \int_0^{T_b} |b(t)|^2 |c(t)|^2 dt$$

$$E_b = \int_0^{T_b} |b(t)|^2 \cdot \frac{2}{T_b} \cos^2 \omega_c t \, dt$$

$$= \frac{2}{T_b} \int_0^{T_b} |b(t)|^2 \frac{(1+\cos 2\omega_c t)}{2} dt$$

$$= \frac{1}{T_b} \int_0^{T_b} |b(t)|^2 dt + \frac{1}{T_b} \int_0^{T_b} |b(t)|^2 \underbrace{\cos 2\omega_c t}_{0} \, dt$$

$$\boxed{E_b = \frac{1}{T_b} \int_0^{T_b} |b(t)|^2 dt} \quad \text{— (A)} \quad (\text{if } |b(t)| \text{ is constant})$$

* Basic Digital - Continuous wave modulation technique:

1) Amplitude Shift Keying (ASK):

It is a basic & fundamental digital - Continuously mod^n technique in which the amp. of carrier wave varies w.r.t the amplitude of digital message sig.

⇒ In ASK, the two binary waves are represented by two diff. amp. of carrier wave. ~~So~~ generally one of the amp. is zero, that is one binary digit is represented by ~~a~~ absence of carrier wave other binary wave is represented by the presence of carrier wave with const. amp.

⇒ For M-ary ASK signaling technique, the general analytic expression is

$$S_i(t) = \underbrace{\sqrt{\frac{2E_i(t)}{T}}}_{\text{amplitude term}} \cos(\omega_c t + \phi) \; ; \quad 0 \leq t \leq T$$

$i = 1, 2, \ldots, M$

ω_c & ϕ = Constant

Where the amp. term will have M discrete values. In an M-ary signaling we ~~can~~ may send any one of M possible signal, during each signaling duration

$M = 2^n \rightarrow n$ - integer or no. of bits in each symbol

$T = nT_b$

~~The~~ where T_b is the bit duration.

* BASK (Binary Amplitude Shift Keying) :-

In BASK, $M = 2$, $n = 1 \rightarrow$ each symbol denoted by 1 bit Corresponding two waveform types.

~~In BAS~~

BASK,

$S_1(t) = \sqrt{\frac{2E}{T}} \cos(\omega_c t)$; $0 \leq t \leq T$ for symbol '1'

$S_2(t) = 0$; $0 \leq t \leq T$ for symbol '0'

$= b(t) \cdot \sqrt{\frac{2}{T}} \cos \omega_c t$

$\downarrow$

Unipolar NRZ line Code

S/b $1 \rightarrow$ '1' $b(t) \rightarrow +A$

'0' $b(t) \rightarrow 0$

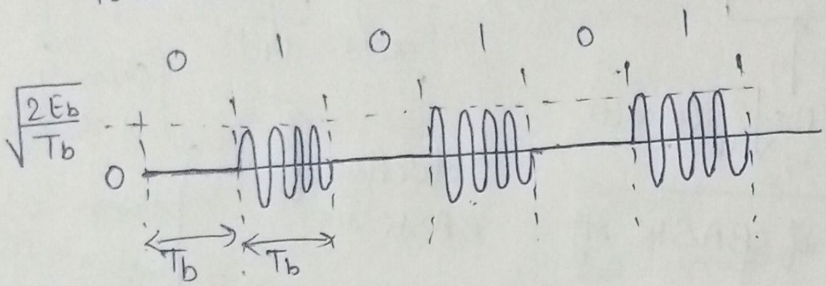
07/03/25

* Representation of waveform of a BASK signal:-

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(\omega_c t) \quad ; \quad 0 \leq t \leq T_b \rightarrow \text{for symbol '1' is transmitted (Carrier is present)}$$

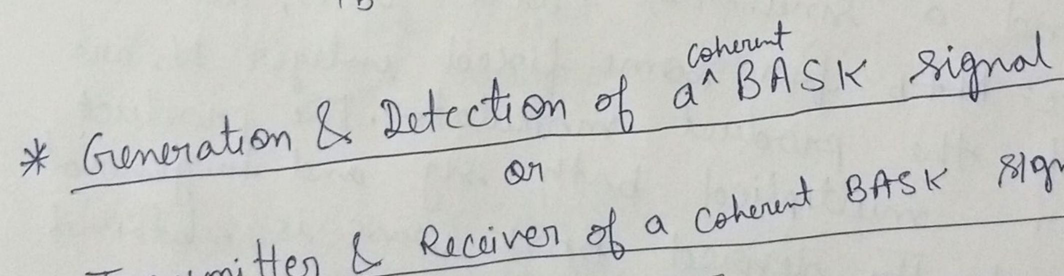
$$S_2(t) = 0 \quad ; \quad 0 \leq t \leq T_b \rightarrow \text{for symbol '0' is transmitted (Carrier is absent)}$$

Q if we have binary data sequence 010101 is transmitted with $f_c = 4 f_b$. Draw the waveform of resultant BASK sig.



$$T_c = \frac{T_b}{4}$$

$$T_b = 4T_c$$



* Generation & Detection of a coherent BASK signal:-

or

Transmitter & Receiver of a Coherent BASK signal:-

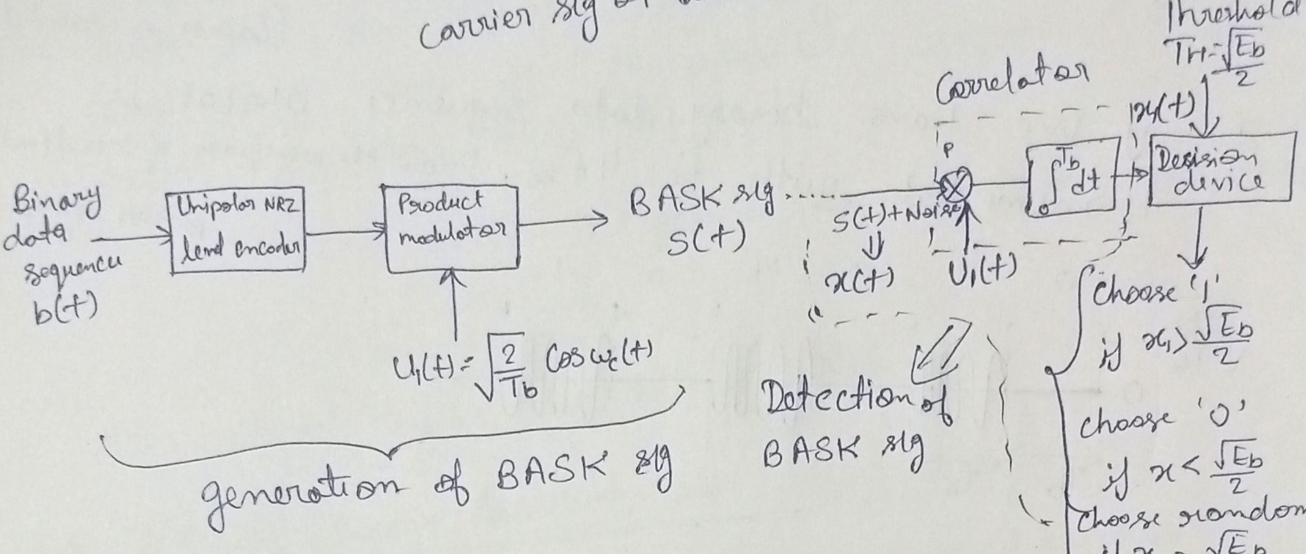
$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(\omega_c t) = \sqrt{E_b}\sqrt{\frac{2}{T_b}} \cos(\omega_c t) \, ; \, 0 \leq t \leq T_b \rightarrow \text{for '1'}$$

$$S_2(t) = 0 \quad ; \quad 0 \leq t \leq T_b \rightarrow \text{for '0'}$$

⇒ BASK technique is also name as On-off Keying (OOK) modulation technique, where Binary data stream b(t) is defined by in terms of bit energy.

$$b(t) = \begin{cases} E_b ; & \text{for binary symbol '1'} \\ 0 ; & \text{for " " '0'} \end{cases}$$

$$S_1(t) = \sqrt{E_b} \times \underbrace{\sqrt{\frac{2}{T_b}} \cdot \cos w_c t}_{\text{carrier sig or orthonormal sig}}$$



Working of receiver:

At the transmitting end, the i/p bit stream $b(t)$ is represented in an unipolar NRZ waveform having amplitude $\sqrt{E_b}$ for symbol '1' and 0 for symbol '0'. This signal transmission encoding is performed by unipolar level encoder. The resulting binary wave and a sinusoidal carrier $U_1(t)$, whose freq^n $f_c = N f_b$ for some fixed integer N, are applied to the product modulator. The product modulator multiplied both sig and to generate BASK signal. The desired BASK wave is obtained at the O/P of modulator.

Working of Detector:-

To detect the original binary sequence of 1s and 0s, we apply the noise BASK sig $x(t)$ to a correlator, which is also supplied with a locally generated coherent ref. sig $U_1(t)$. The correlator o/p ~~is~~ $x_1(t)$ is compared with a threshold level of $\frac{\sqrt{E_b}}{2}$ in ~~the~~ decision device. The decision device is decied whether bit '0' or bit '1' is transmitted acc. to it's threshold value.

08/03/25

* Constellation (Signal-Space) Diagram of BASK signal:-

⇒ The signal Constellation diagram is similar to the phasor diagram, but the entire phasor is not drawn. The signal costellation diagram shown only relative position of the peak of the phasor. It is generally a Geometrical representation of a digital modulated signal.

⇒ It display the sig as ~~the~~ a 2-D plane,

⇒ Using Constellation diagram we can calculate the transmitted sig energy. with the help of transmitted sig energy, we can calculate BER and P_E.

⇒ The sig constellation diagram also known as state-space diagram of any modulated sig.

Given:-

$S_1(t) = S_{11} U_1(t) + S_{12} U_2(t)$

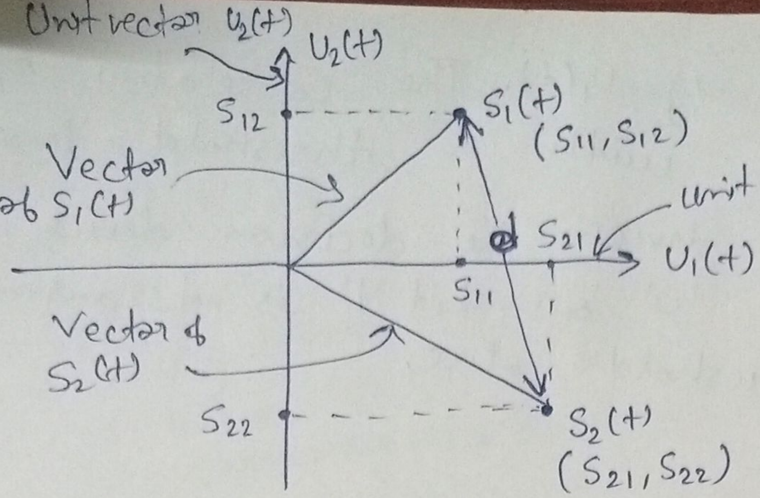
$S_2(t) = S_{21} U_1(t) + S_{22} U_2(t)$

$S_1(t), S_2(t) \rightarrow$ expression in Orthonormal basis functions. (using digital modulation)

modulated message sig

$U_1(t), U_2(t) \longrightarrow$ Orthonormal functions.

$S_{11}, S_{12}, S_{21}, S_{21} \rightarrow$ Expansion Coefficient



Signal-Space diagram of two signal

⇒ Distinguishability is measured by the distⁿ b/w the two coordinate points representing $S_1(t)$ & $S_2(t)$, i.e. by the magnitude of the distⁿ b/w two sig vector.

$$\boxed{d = |S_1(t) - S_2(t)| = \sqrt{(S_{11} - S_{21})^2 + (S_{12} - S_{22})^2}}$$

In BASK,

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos w_c t \quad ; \quad 0 \leq t \leq T_b \text{ for symbol '1'} \quad \text{— (1a)}$$

$$S_2(t) = 0 \quad ; \quad 0 \leq t \leq T_b \text{ for symbol '0'} \quad \text{— (1b)}$$

Represent $S_1(t)$ & $S_2(t)$ in terms of orthonormal fxn by using Gram schmit procedure

$$S_{11} = \left[\int_0^{T_b} S_1^2(t)\, dt\right]^{1/2}$$

put $S_1(t)$ value from eqⁿ (1a)

$$S_{11} = \left[\int_0^{T_b} \left(\sqrt{\frac{2E_b}{T_b}} \cos w_c t\right)^2 dt\right]^{1/2} = \left[\frac{2E_b}{T_b} \int_0^{T_b} \cos^2 w_c t \, dt\right]^{1/2}$$

$$S_{11} = \left[\frac{2E_b}{T_b} \underbrace{\int_0^{T_b} 1\, dt}_{\frac{T_b}{2}} + \underbrace{\int_0 \frac{\cos 2w_c t}{2}\, dt}_{0}\right]^{1/2} =$$

$S_{11} = \sqrt{E_b}$ — (2)

$$U_1(t) = \frac{S_1(t)}{S_{11}}$$

$$= \frac{\sqrt{\frac{2E_b}{T_b}} \cos w_c t}{\sqrt{E}} \quad ; \quad 0 \le t \le T_b$$

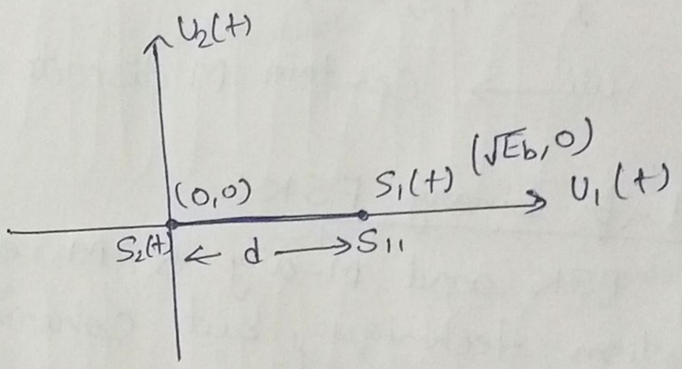
$$U_1(t) = \sqrt{\frac{2}{T_b}} \cos w_c t \quad ; \quad 0 \le t \le T_b \quad \text{— (3)}$$

as $S_2(t) = 0$, $S_{12} = 0$, $S_{21} = 0$, $S_{22} = 0$ $\Rightarrow$ $S_2(t) \rightarrow (0,0)$

OR

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos w_c t \quad ; \quad 0 \le t \le T_b$$

$$= \underbrace{\sqrt{E_b}}_{S_{11}} \cdot \underbrace{\sqrt{\frac{2}{T_b}} \cos w_c t}_{U_1(t)} \quad ; \quad 0 \le t \le T_b$$



Distance b/w two message sig

$$d = \left[(S_{11} - S_{21})^2 + (S_{12} - S_{22})^2 \right]^{1/2}$$

$$d = \sqrt{E_b}$$

26/03/25

* Frequency Shift Keying (FSK):-

⇒ The freq^n of carrier signal varying wrt your message signal or modulating signal. The general analylitic ~~operation~~ Expression of FSK modulation

$$S_i(t) = \begin{cases} \sqrt{\frac{2E}{T}} \cos(w_i t + \phi) & ; \; 0 \le t \le T \\ 0 & ; \; \text{otherwise} \end{cases}$$

where $E \rightarrow$ Transmitted symbol energy/bit

$T \rightarrow$ Symbol duration

$i = 1, 2, \ldots, M$

$w_i \longrightarrow$ Contain M discrete values of frequencies.

⇒ Coherent ~~B~~ binary FSK:-

→ M-ary PSK and M-ary QAM are linear digital modulation technique, but coherent FSK ~~are~~ non-linear method ~~of~~ for passband digital transmission

→ In BFSK system, symbol '1' & '0' are distinguish from each other by transmitting one of two sin. wave that differ in ~~to~~ freq^n by a fixed amount.

→ A typical pair of sin-wave is ~~dif~~ discribe by in BFSK

$$S_i(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} \cos(w_i t + \phi) & ; \; 0 \le t \le T_b \\ 0 & ; \; \text{otherwise} \end{cases} \quad \text{—(1)}$$

$\boxed{i = 1, 2}$ $(M = 2)$

$E_b \to$ ~~Transmi~~ transmitted symbol energy / bit

$T_b \to$ bit period

$\Rightarrow$ The transmitted freqⁿ is

$$f_i = \frac{n_c + i}{T_b} = (n_c + i) f_b \quad \text{--- (2)}$$

where $n_c \to$ fix integer

assume $n_c = 1$

$f_1 = 2 f_b$

$f_2 = 3 f_b$

$$S_1(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} \cos f_1 t ; & 0 \leq t \leq T_b \\ 0 & ; \text{otherwise} \end{cases} \quad \text{--- (3)}$$

$\rightarrow$ if symbol '1' is transmitted

$$S_2(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} \cos f_2 t & ; 0 \leq t \leq T_b \\ 0 & ; \text{otherwise} \end{cases} \quad \text{--- (4)}$$

$\rightarrow$ if symbol '0' is transmitted

~~There~~ From eqⁿ (3) & (4),

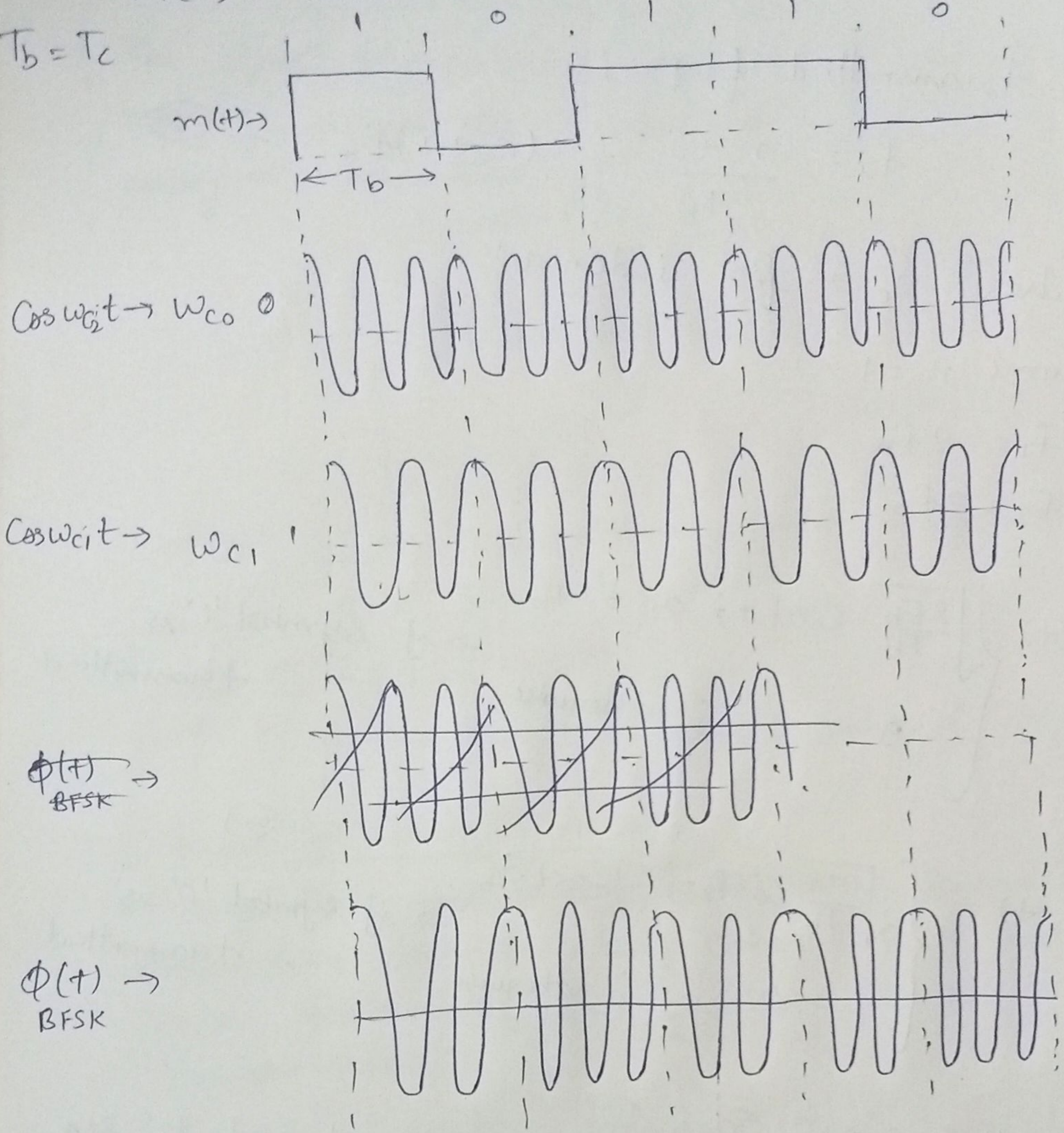
$\Rightarrow$ There are two different linear independent sig.

so two orthogonal pair are required.

$\Rightarrow$ Assume symbol '1' is transmitted at low freqⁿ and symbol '0' is transmitted at high freqⁿ.

* Signal waveform representation in BFSK :-

$m(t) = 10110$



Note: It is a contⁿ phase signal in the sense that the phase continuity is always mainten, including the interbit switching time. This form of digital modulation is known as continuous phase freqⁿ shift keying.

From eqⁿ (3) and (4) we observe directly that the signal $S_1(t)$ and $S_2(t)$ are orthogonal, but not normalized to have unit energy.

* <u>Signal Space or Constellation Diagram for BFSK:-</u>

- BFSK is characterized by two message points represented by space vector $S_1(t)$ and $S_2(t)$ vector in 2-D signal space.

In BFSK s/m:-

$$S_{BFSK}(t) = \begin{cases} S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_1 t) \; ; \; 0 \le t \le T_b \rightarrow \text{If '1' is trans.} \\ S_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_2 t) \; ; \; 0 \le t \le T_b \rightarrow \text{" '0' " "} \end{cases} \quad -(1)$$

$f_1 = nf_b$, $f_2 = mf_b$; where m, n are integers

for orthogonal signal, considering $S_1(t)$ and $S_2(t)$ are orthogonal signal then

$$\int_0^{T_b} S_1(t) S_2(t) \, dt = \begin{cases} 0 \; ; \; \text{if } 1 \ne 2 \\ \sqrt{E_b} \; ; \; \text{if } 1 = 1 \end{cases} \quad -(2)$$

The most useful form for set of orthogonal basis fxn

$$\phi_i(t) = \begin{cases} \sqrt{\frac{2}{T_b}} \cos(2\pi f_i t) \; ; \; 0 \le t \le T_b \\ 0 \; ; \; \text{otherwise} \end{cases} \quad -(3)$$

where $i = 1, 2$ correspondingly, the coefficient S_{ij} for $i = 1, 2$ and $j = 1, 2$ is defined by

$$\boxed{S_{ij} = \int_0^{T_b} S_i(t) \, \phi_j(t) \, dt} \quad \begin{matrix} i = 1, 2 \\ j = 1, 2 \end{matrix}$$

$$S_{ij} = \begin{cases} \sqrt{E_b} & ; \ i=j \\ 0 & ; \ i \neq j \end{cases} \quad \text{— (4).}$$

Now express $S_1(t)$ and $S_2(t)$ in terms of Gram schmidt orthogonalization procedure

Case 1:

for signal $S_1(t)$ message coordinates are

$$S_{11} = \int_0^{T_b} S_1(t)\, \phi_1(t)\, dt$$

$$= \int_0^{T_b} \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_1 t) \cdot \sqrt{\frac{2}{T_b}} \cos 2\pi f_1 t \cdot dt$$

$$\boxed{S_{11} = \sqrt{E_b}} \quad \text{— for symbol '1'} \quad \text{— (a)}$$

$$\phi_1(t) = \frac{S_1(t)}{S_{11}}$$

$$\phi_1(t) = \begin{cases} \sqrt{\frac{2}{T_b}} \cos 2\pi f_1 t & ; 0 \leq t \leq T_b \\ 0 & ; \text{otherwise} \end{cases} \quad \text{— (b)}$$

$$S_{12} = \int_0^{T_b} S_1(t)\, \phi_2(t)\, dt$$

$$= \int_0^{T_b} \left(\sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_1 t \cdot \sqrt{\frac{2}{T_b}} \cos 2\pi f_2 t \right) dt$$

$$\boxed{S_{12} = 0} \quad \text{— (c)}$$

Signal vector $\overline{S_1} = \begin{bmatrix} E_b \\ 0 \end{bmatrix}$ ← message point for symbol '1'

Case 2: for signal $S_2(t)$,

$$S_{21} = \int_0^{T_b} S_2(t)\,\phi_1(t)\,dt$$

$$= \int_0^{T_b} \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_2 t \cdot \sqrt{\frac{2}{T_b}} \cos 2\pi f_1 t \, dt$$

$$\boxed{S_{21} = 0} \quad \text{— (d)}$$

$$S_{22} = \int_0^{T_b} S_2(t)\,\phi_2(t)\,dt$$

$$= \int_0^{T_b} \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_2 t \cdot \sqrt{\frac{2}{T_b}} \cos 2\pi f_2 t \, dt$$

$$\boxed{S_{22} = \sqrt{E_b}} \quad \text{— (e)}$$

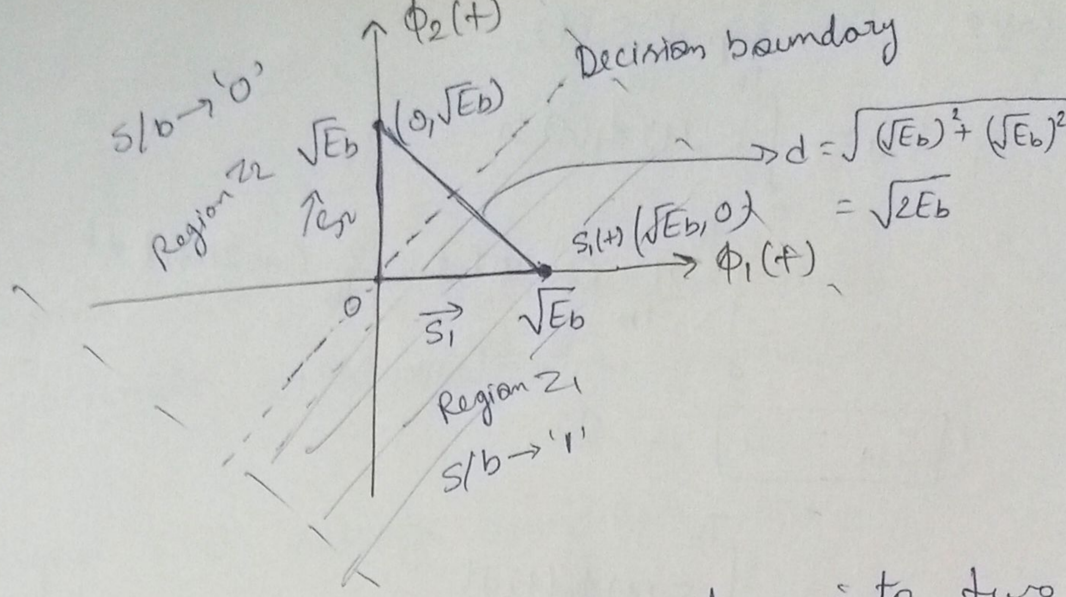
$$\phi_2(t) = \frac{S_2(t) - S_{21}\phi_1(t)}{S_{22}}$$

$$\phi_2(t) = \begin{cases} \sqrt{\frac{2}{T_b}} \cos 2\pi f_2 t & ; 0 \le t \le T_b \\ 0 & ; \text{otherwise} \end{cases} \quad \text{— (f)}$$

$$\vec{S_2} = \begin{bmatrix} 0 \\ \sqrt{E_b} \end{bmatrix} \leftarrow \text{message}$$

BFSK in terms of orthonormal basis fxn

$$s(t) = \begin{cases} S_1(t) = \sqrt{E_b}\,\phi_1(t) & \longrightarrow \text{symbol '1'} \\ S_2(t) = \sqrt{E_b}\,\phi_2(t) & \longrightarrow \text{symbol '0'} \end{cases}$$

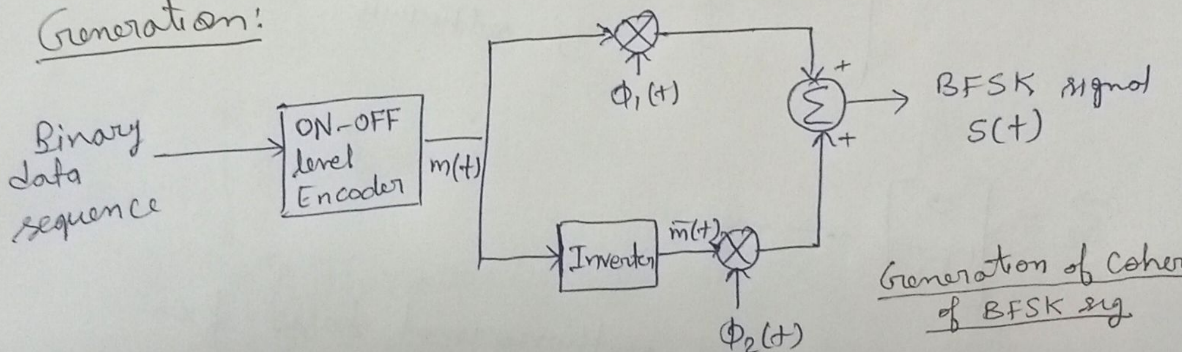


Decision boundary separate the entire plane into two different region, Region Z_1 shown s/b '1' and region Z_2 shown s/b '0'. The distⁿ b/w two message points S_1 and S_2 is $d = \sqrt{2E_b}$.

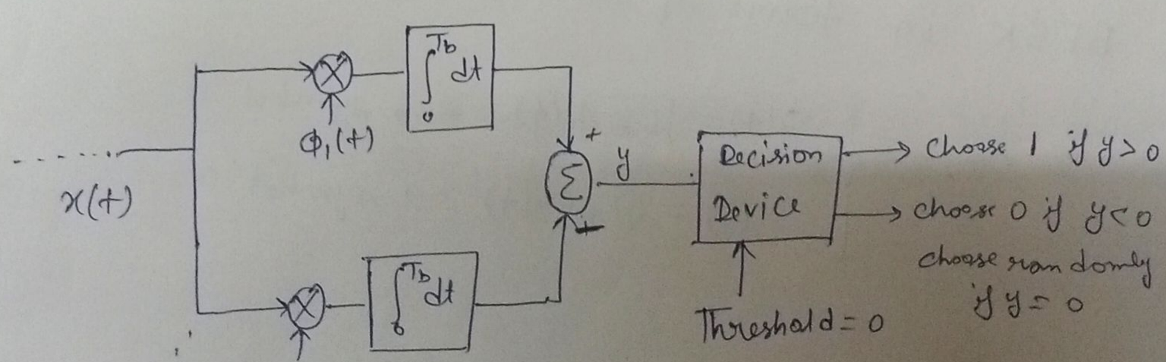
Threshold value is equal to zero because decision boundary passing through origion.

* Generation and detection of Coherent BFSK sig:-

Generation:



Generation of Coherent of BFSK sig.



Detection of coherent BFSK sigs

• Working:

⇒ The incoming binary data sequence is first applied to an ON-off bit Level encoder, at the o/p of which symbol '1' is represented by a constant amp. $\sqrt{E_b}$ and symbol '0' is represented by 0volts. Encoder ensure that m(t) is an Unipolar NRZ waveform.

⇒ By using inverter in the lower channel, when symbol '1' at the i/p the oscillator with freq^n f_1 in the upper channel is switched ON, while, the oscillator with freq^n f_2 in lower channell is switched off, with the result that freq^n f_1 is transmitted. Conversly, when we have symbol '0' at the i/p the oscillator in upper channel is switched off and the oscillator in lower Channel is switched ON; with the result freq^n f_2 is transmitted.

⇒ To detect the original binary sequence, given the noisy received sig $x(t)$. It consist of two co-relator with the common i/p which are supplied with localy generated coherent sig $\phi_1(t)$ & $\phi_2(t)$. The corelator o/p are then subtracted one from the other, then resulting difference signal is compared with threshold value of 0volts.

28/03/25

* Phase shift Keying (PSK):

In PSK, carrier phase wave varies corresponding to the msg sig. The general analytic expression for PSK is

$$S_{PSK}(t) = \begin{cases} \sqrt{\frac{2E}{T}} \cos(\omega_c t + \phi_i(t)) , & 0 \le t \le T \\ 0 , & \text{otherwise} \end{cases} \quad \text{--- (1)}$$

where $i = 1, 2, 3, \dots M$

$\phi_i(t) \rightarrow$ M descrete value of phase

$E \rightarrow$ symbol energy

$T \rightarrow$ symbol duration

Typically, $\phi_i(t) = \frac{2\pi}{M} i$; where $i = 1, 2, \dots M$ — (2)

using (1) & (2), we get

$$\underset{\text{Generalised}}{S_{PSK}(t)} = \begin{cases} \sqrt{\frac{2E}{T}} \cos(\omega_c t + \frac{2\pi i}{M}) ; & 0 \le t \le T \\ 0 ; & \text{otherwise} \end{cases}$$

$M = 2 \Rightarrow 2^n = 2 \Rightarrow n = 1$

In BPSK, the transmitted sig is a sinsoid of fixed amplitude. It has one fixed phase, when the data is at one level & when the data is at other level, the phase is different by 180°.

In coherent BPSK sys. the pair of sig $S_1(t)$ & $S_2(t)$ use to represent binary s/m '1' & '0' resp. & is defined by

$(i=1)$ $S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(\omega_c t + \pi)$, $0 \le t \le T_b$

(for symbol '0') $= -\sqrt{\frac{2E_b}{T_b}} \cos \omega_c t$ — (a) (i=2) $S_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos w_c t \quad , 0 \le t \le T_b$ — (b)

(for symbol '1')

using eqⁿ (a) & (b), the generalised form of BPSK wave, is given as

$$S_{BPSK}(t) = \begin{cases} b(t)\sqrt{\frac{2E_b}{T_b}} \cos w_c t & ; 0 \le t \le T_b \\ 0 & ; \text{otherwise} \end{cases} \quad \text{— (c)}$$

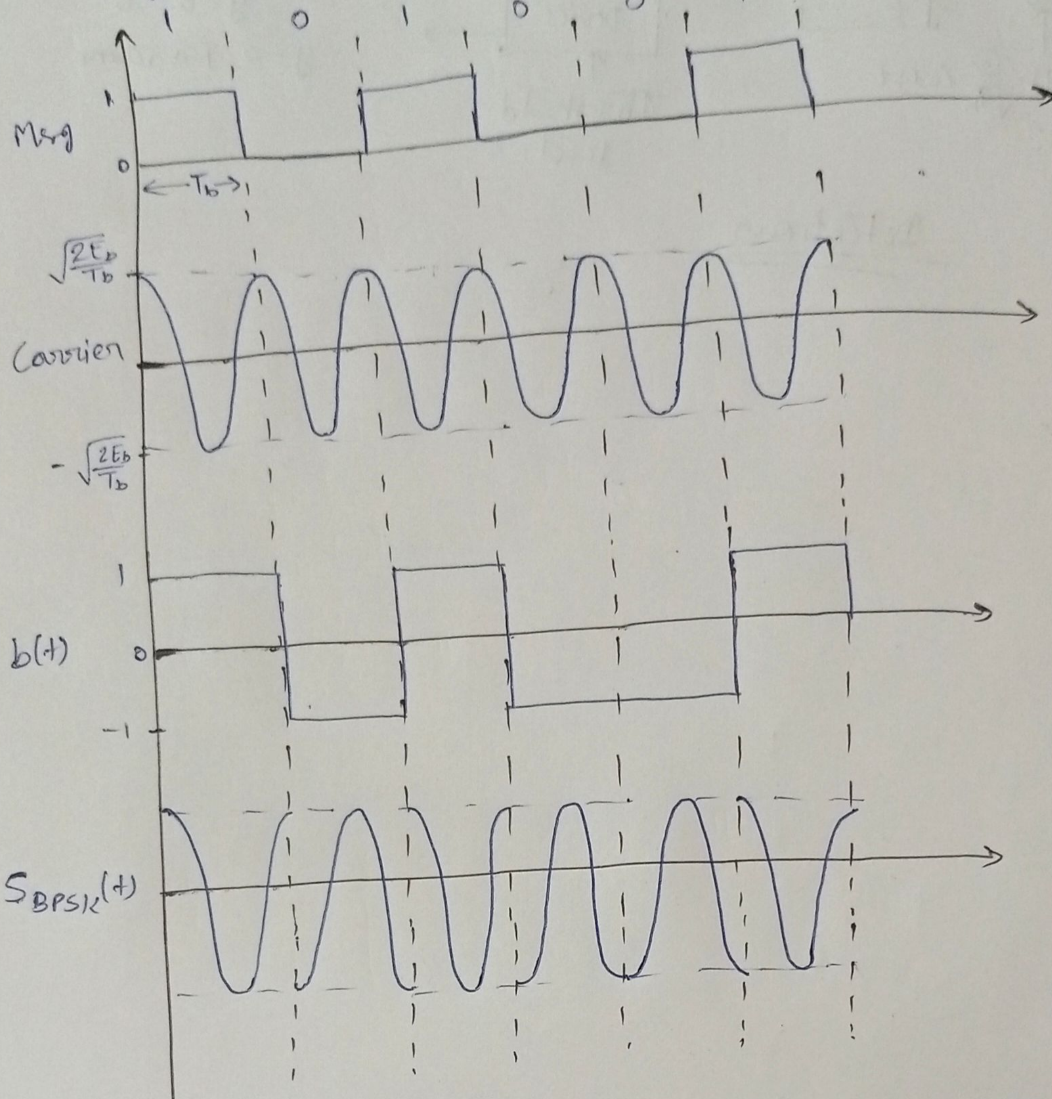
where $b(t) = \begin{cases} +1V & \text{for symbol '1'} \\ -1V & \text{for symbol '0'} \end{cases}$ — (d)

In BPSK, the data $b(t)$ is a stream of binary digits with voltage level at +1V & -1V.

For Coherent detection, to ensure that each transmitted bit contain an integral no. of cycles of carrier wave $T_b = nT_c$.

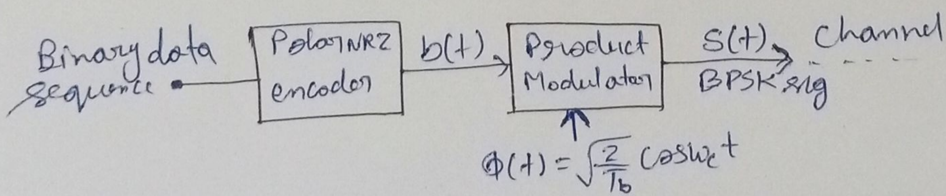
* Waveform representation of BPSK sig:-

Msg sig = 101001, Carrier wave · $T_b = T_c \Rightarrow f_c = f_b$

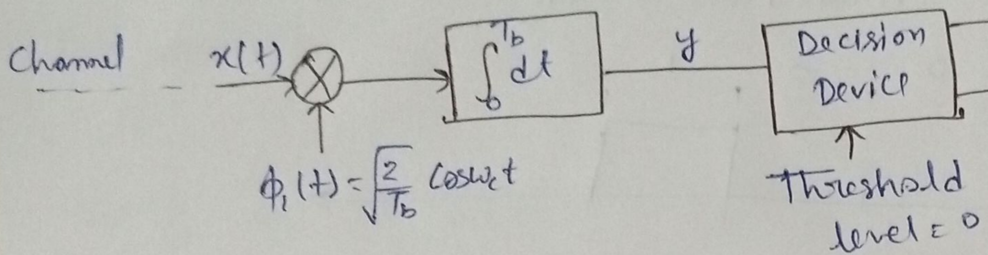


Note: If the modulated data stream consist of alternating 1's & 0's there would be such an abrupt phase change at each ~~tran smissi~~ transition.

* Generation & detection of Coherent BPSK signal:-



Generation



choose if $y > 0$: '1'

$y < 0$: '0'

$y = 0$; Random

Detection

2/04/25

* PSD & Bandwidth of BPSK signal:-

$$g(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t \; ; & 0 \le t \le T_b \\ 0 \; ; & \text{otherwise} \end{cases}$$

Pulse shaping fxn → $g(t)$ → when 1 is transmitted

$-g(t)$ → when 0 is transmitted

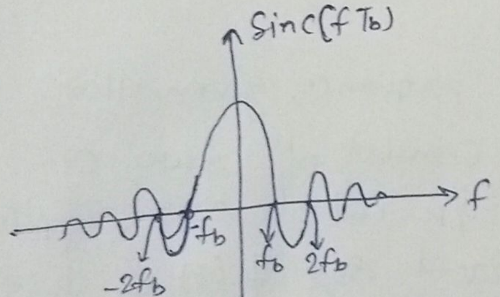
→ PSD of random process = $\dfrac{\text{ESD of } g(t)}{\text{Symbol duration}}$

→ ESD of $g(t)$ = $\dfrac{|G(\omega)|^2}{\text{Symbol duration}}$

→ $\underbrace{\text{PSD of BPSK signal}}_{S_B(f)} = \frac{1}{4}\left[S_x(f-f_c) + S_x(f+f_c)\right]$

→ $S_x(f) = 2E_b \,\text{Sinc}^2(fT_b)$ — ①

$$\boxed{S_B(f) = \frac{E_b}{2}\left[\text{sinc}^2 (f-f_c)T_b\right] + \frac{E_b}{2}\left[\text{sinc}^2 (f+f_c)T_b\right]} \text{ — ②}$$



So,

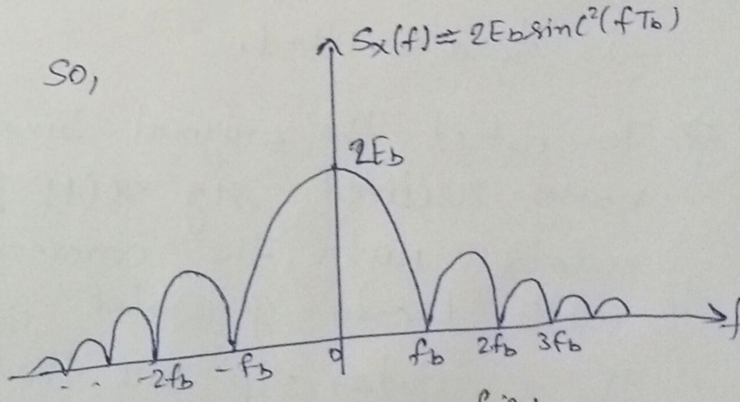


fig 1

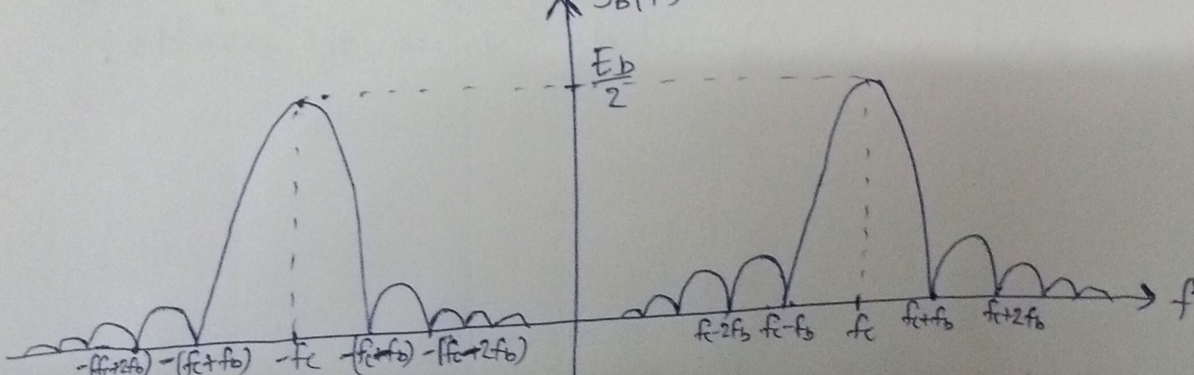


fig 2

Bandwidth of BPSK signal:-

⇒ Considered the PSD spectrum of BPSK signal (fig 2, fig 1) the main lobe of spectrum is centered across the carrier frequency (f_c).

→ In the main lobe the highest freq^n is $f_c + f_b$ and the minimum freq^n of the main lobe is $f_c - f_b$

→ Considered T_b is 1 bit duration

$$f_b = \frac{1}{T_b}$$, where f_b → max. freq in the baseband sig

→ The B.W. of BPSK signal is given by

$$BW_{BPSK} = \left(\begin{matrix} \text{Highest} \\ \text{freq} \end{matrix} - \begin{matrix} \text{lowest} \\ \text{freq}^n \end{matrix} \right) \text{ in the main lobe}$$

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

$$\boxed{BW = 2f_b}$$

→ B.W. of BPSK is equal to twice of the max. freq^n in the baseband signal.

* Quadrature phase shift keying (QPSK):-

→ One important role in the design of the digital communication system for reliable performance it has PER → probability of error.

⇒ The efficient utilization of channel B.W.

⇒ In BPSK when data stream whose bit duration is T_b is to be transmitted by BPSK, the channel B.W. must be nominally ($2f_b$) [where $f_b = \frac{1}{T_b}$]

⇒ B.W. Conserving Modulation technique known as Coherent quadri phase shift keying, which is an eg. of Quadrature carrier multiplexing

⇒ QPSK allows bits to be transmitted using half the B.W.

⇒ ~~In~~ QPSK is a form of PSK in which two bits are modulated at once.

⇒ QPSK allows the signal to carry twice as much info. than ordinary PSK using the B.W., So we can increase data rate.

⇒ QPSK is generally used in satellite transmission of M-PAG, Cable modem, a cellular phone system.

Definition:

→ QPSK is the type of phase shift keying where two bits of data are transmitted per symbol, effectively doubling the data rate compared to BPSK by maintaining the same B.W.

→ In particular the phase of the carrier takes on one-forth equally space values such as $\pi/4$, $3\pi/4$, $5\pi/4$ and $7\pi/4$.

→ For the set of values the transmitted signal is as:-

$$S_i(t) = \sqrt{\frac{2E}{T}} \cos\left(2\pi f_c t + \frac{(2i-1)\pi}{4}\right) \; ; 0 \leq t \leq T \quad \text{—— (2)}$$

$$0 \quad ; \text{elsewhere}$$

where, $i \rightarrow 1, 2, 3, \ldots$

$E \rightarrow$ transmitted sig energy per symbol

$T \rightarrow$ signal duration

$f_c \rightarrow$ Carrier freq^n

Each possible value of phase correspond to a unit 2-bit.

→ Each possible value of phase correspond to a unit 2-bit.

→ Ex: we may choose the 4-going sets of values to represent the gray encoded set of 2-bit such as:- 10, 00, 01, 11

$10 \to S_1$, $00 \to S_2$, $01 \to S_3$, $11 \to S_4$

QPSK

Symbol	Gray Code	Phase shift
$S_1(t)$	10	$\pi/4$
$S_2(t)$	00	$3\pi/4$
$S_3(t)$	01	$5\pi/4$
$S_4(t)$	11	$7\pi/4$

09/04/25

* Signal Space diagram of QPSK :-

$M = 4, \; 2^2 \rightarrow 2^n \rightarrow n = 2$ bits

$$S_i(t) = \begin{cases} \sqrt{\frac{2E}{T}} \cos\left(2\pi f_c t + (2i-1)\frac{\pi}{4}\right) & ; 0 \leq t \leq T \\ 0 & ; \text{elsewhere} \end{cases}$$

$T \rightarrow$ symbol duration – 2 bit

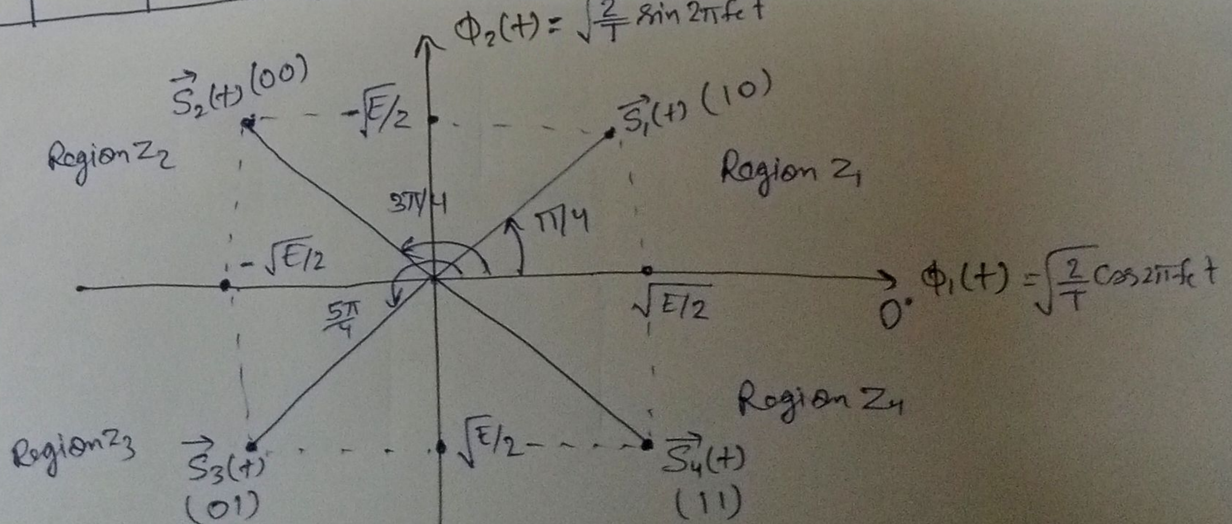
1 bit duration = T_b

2 bit, $T = 2T_b$

$$S_i(t) = \underbrace{\sqrt{E}\cos\left[(2i-1)\right.}_{S_{i1}} \underbrace{\sqrt{\frac{2}{T}}\cos 2\pi f_c t}_{\substack{\text{orthonormal basis fxn} \\ \phi_1(t)}} - \underbrace{\sqrt{E}\sin(2i-1)}_{S_{i2}} \underbrace{\sqrt{\frac{2}{T}}\sin 2\pi f_c t}_{\phi_2(t)}$$

$i = 1, 2, 3, 4$

		QPSK	S_{i1}	S_{i2}	
$S_1(t)$	10	$\pi/4$	$\sqrt{E/2}$	$-\sqrt{E/2}$	$\rightarrow i=1$
$S_2(t)$	00	$3\pi/4$	$-\sqrt{E/2}$	$-\sqrt{E/2}$	$\rightarrow i=2$
$S_3(t)$	01	$5\pi/4$	$-\sqrt{E/2}$	$+\sqrt{E/2}$	$\rightarrow i=3$
$S_4(t)$	11	$7\pi/4$	$\sqrt{E/2}$	$\sqrt{E/2}$	$\rightarrow i=4$



⇒ According a QPSK sig as a 2-D signal Constellation (i.e. $N = 2$) ~~(i.e. $M=4$)~~ and 4-message point ($M=4$) whose phase angle increase in counter clock wise dirn.

⇒ Distance of signal points from origin e.g.
$s_1(t) \rightarrow d = \sqrt{E}$

→ The points which differ in a single bit are separated by the distance of $2\sqrt{E}$

→ As with BPSK, the QPSK signal has minimum avg. energy

* QPSK Waveform representation:

Q.1 The input binary sequence is 01101000 and $f_c = f_b$ then generate its QPSK waveform.

Sol Step 1: The given sequence is divided into two other sequences consisting of odd and even no. of bits of the i/p sequence.

Step 2: The waveform representing the two component of the QPSK signal

$$s_o(t) = s_{i1}\phi_1(t)$$

$$s_e(t) = s_{i2}\phi_2(t)$$

are also shown resp.

these two waveform may individually be viewed as example of BPSK sig

Step 3: Adding them we get the QPSK waveform.

$$S_i(t) = \underbrace{\sqrt{E}\cos\left((2i-1)\frac{\pi}{4}\right)}_{b_o(t)} \sqrt{\frac{2}{T}}\cos 2\pi f_c t + \underbrace{\sqrt{E}\left(-\sin\left((2i-1)\frac{\pi}{4}\right)\right)}_{b_e(t)} \sqrt{\frac{2}{T}}\sin 2\pi f_c t$$

$b_1\ b_2\ b_3\ b_4\ b_5\ b_6\ b_7\ b_8$

$0\ 1\ 1\ 0\ 1\ 0\ 0\ 0$ symbol duration $T_s = 2T_b$

$b_o(t) = (b_1, b_3, b_5, b_7) = 0110 \rightarrow$

$b_e(t) = (b_2, b_4, b_6, b_8) = 1000$

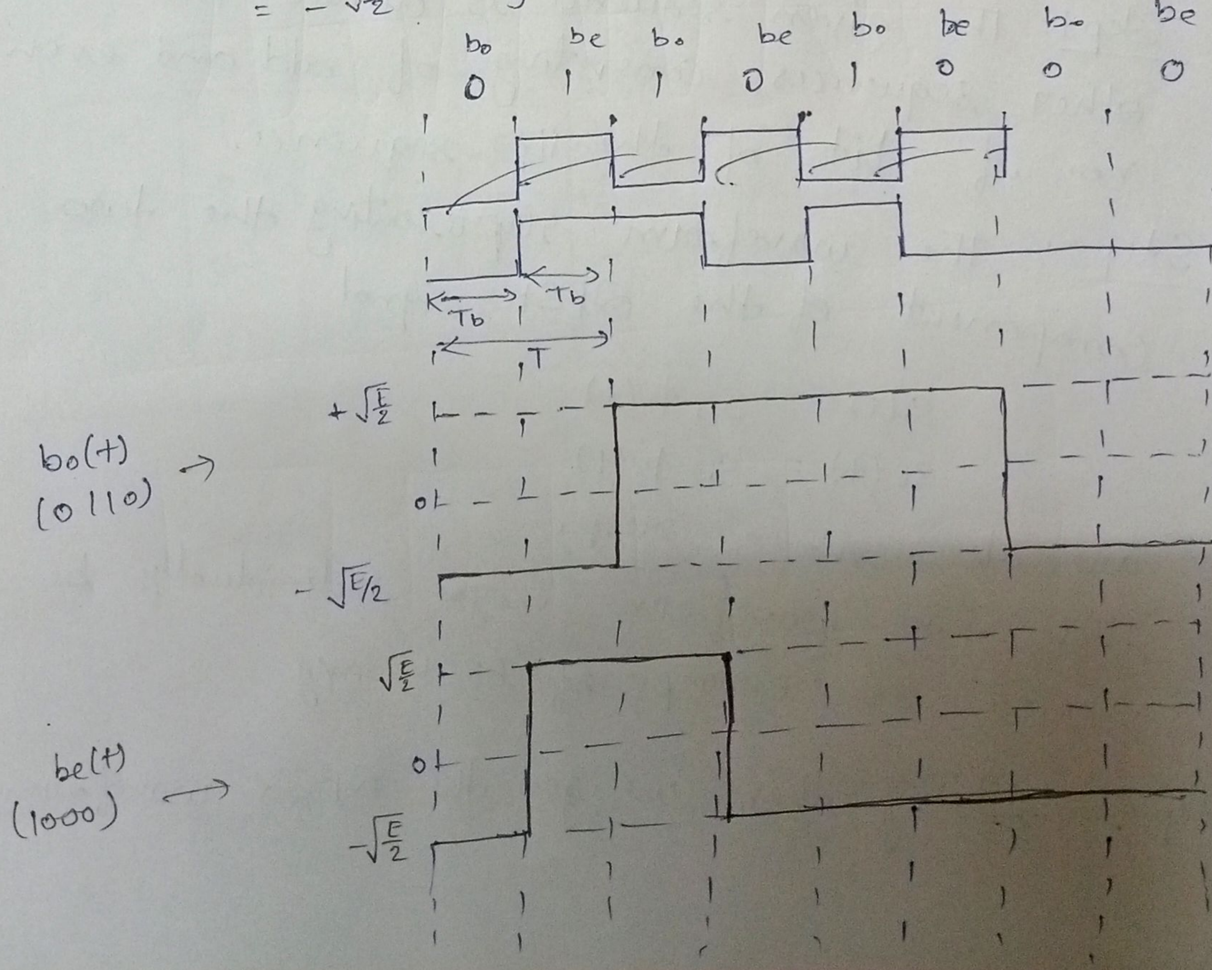
$S_i(t) = \sqrt{E}\, b_o(t) \sqrt{\frac{2}{T}} \cos 2\pi f_c t + \sqrt{E}\, b_e(t) \sin 2\pi f_c(t)$

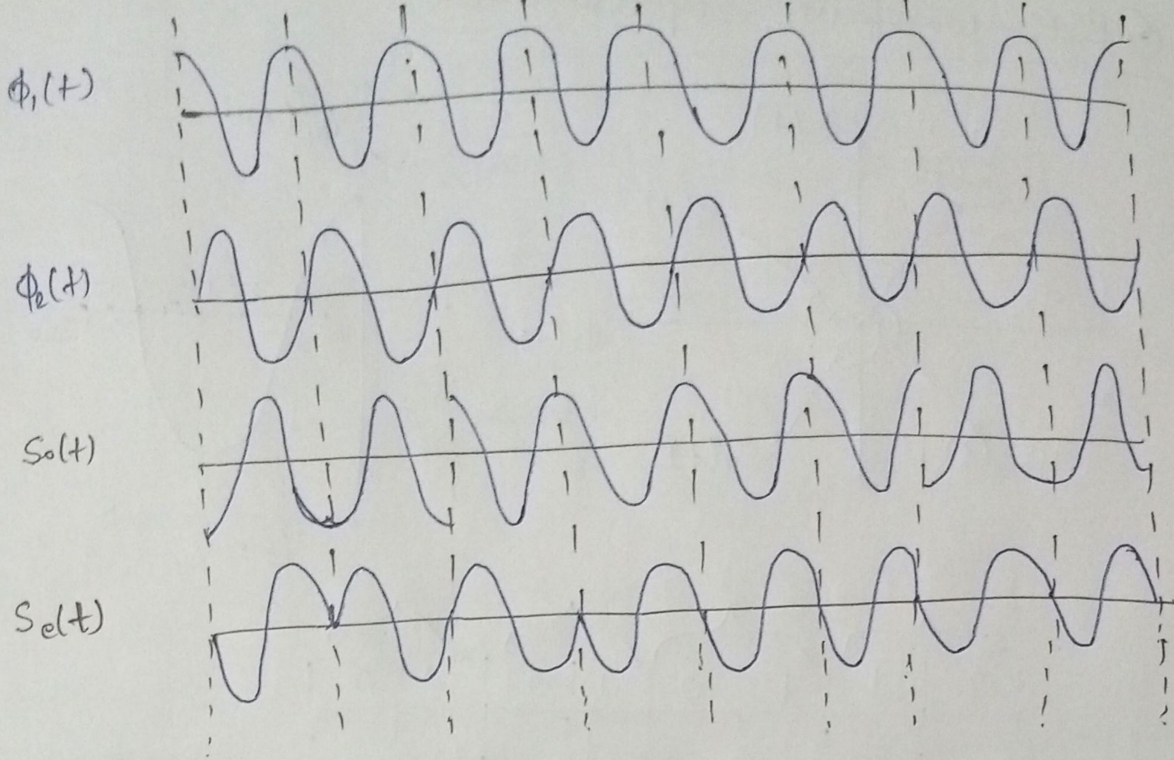
$b_o(t) = +\sqrt{\frac{E}{2}}$ if $b_o(t) = '1'$

$-\sqrt{\frac{E}{2}}$ if $b_o(t) = '0'$

$b_e(t) = +\sqrt{\frac{E}{2}}$ if $b_e(t) = '1'$

$= -\sqrt{\frac{E}{2}}$ if $b_e(t) = '0'$





$S_o(t) = b_o(t) \times \phi_1(t)$

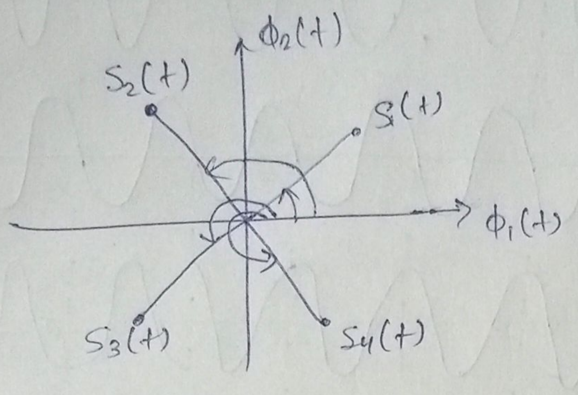
1 BPSK sig

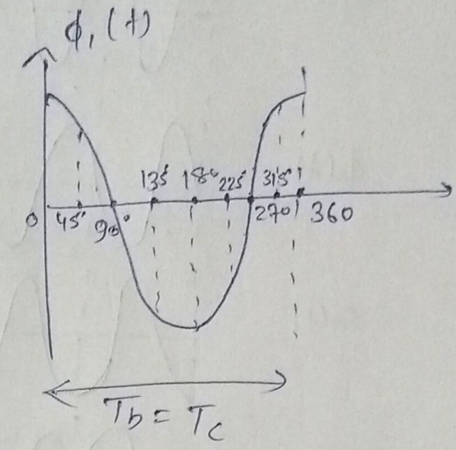
$S_e(t) = b_e(t) \times \phi_2(t)$

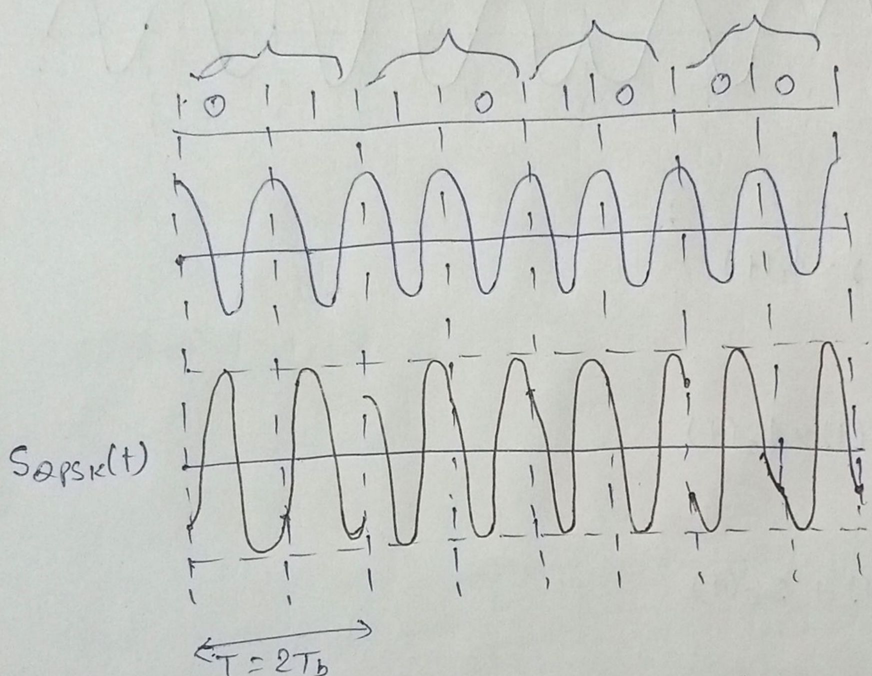
2 BPSK sig

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

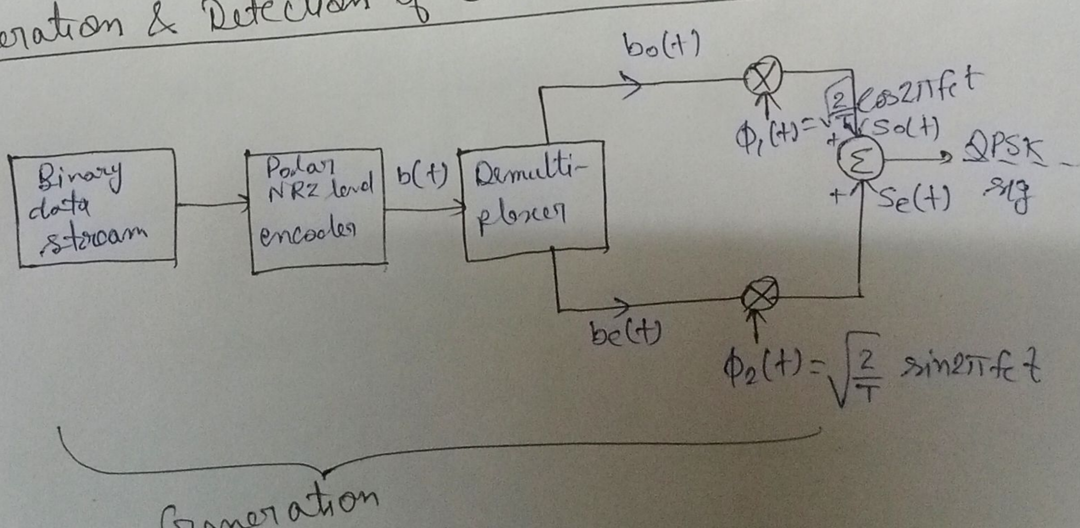
QPSK - waveform representation

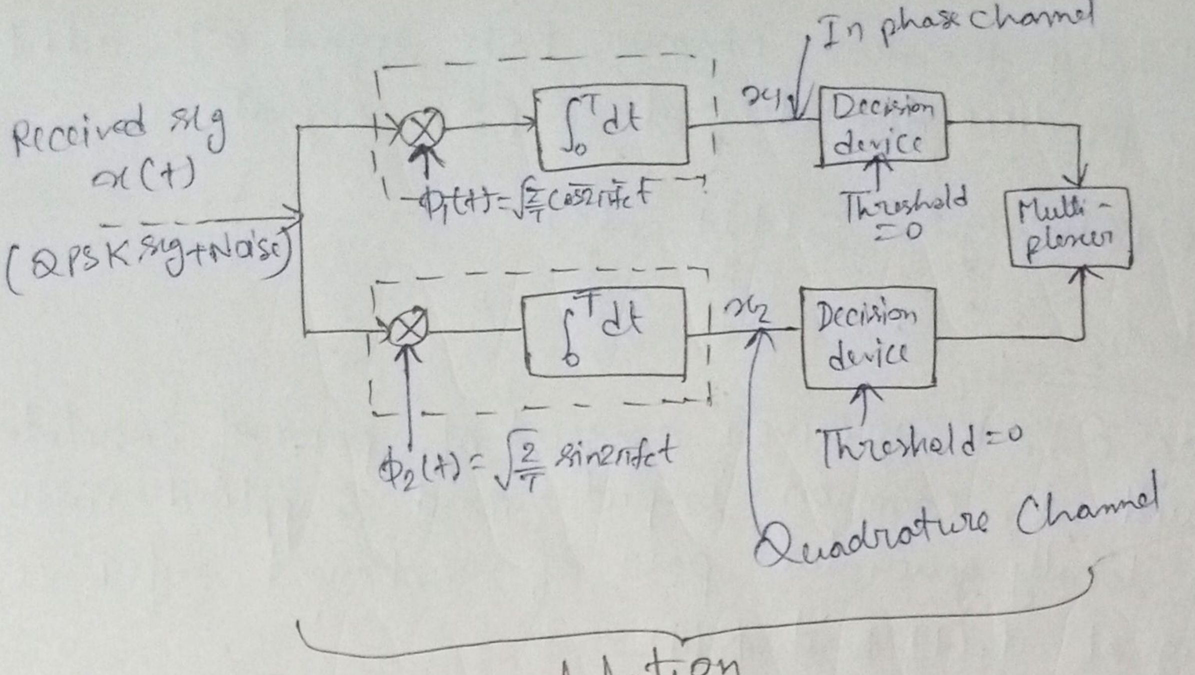






* Generation & Detection of Coherent QPSK signals





Demodulation

Generation:
The incoming data sequence (which is unipolar NRZ) first tranform into polar form by NRZ level encoder. The symbol '1' is represented by $\sqrt{\frac{E}{2}}$ and symbol '0' is represented $-\sqrt{\frac{E}{2}}$
Then the signal pass demultiplexer, the de-multiplexer divide binary wave into two binary wave $b_o(t)$ and $b_e(t)$ consisting odd and even no. bits. Each bit is present in even and odd part has a period of Ts(symbol duration) is equat to $2T_b$.
⇒ The two binary wave $b_o(t)$ & $b_e(t)$ are use to modulate a pair of quadrature carriers $\phi_1(t)$ and $\phi_2(t)$ the result is a pair of binary PSK signal which maybe detected independently due to orthogonality of $\phi_1(t)$ and $\phi_2(t)$

⇒ finally the two binary PSK signal are added to produce the desired QPSK signal

$$\text{QPSK sig} = S_o(t) + S_e(t)$$

Detection :-

⇒ The QPSK receiver consist of pair of corelator with a common input and supplied with a locally generated pair of coherent reference signal $\phi_1(t)$ and $\phi_2(t)$

⇒ The coorelator o/p x_1 and x_2 produce in response to the received signal $x(t)$ are each compared with a threshold of '0'. If x_1, x_2 is greater zero, a decision is made in favour of symbol '1' and if x_1 and x_2 is less than '0' a decision device made in favour of symbol '0'

⇒ finally there are two binary sequence at the inphase and quadrature channel o/p are combined in multiplexer to reproduce the original binary sequence at the transmitter i/p with minimum ~~PBER~~ Prob of error in an additive white Gaussian channel.

Detection

16/04/25

* **Power Spectral density of QPSK signals & transmission Bandwidth of QPSK signals:**

$$S_{QPSK}(t) = \begin{cases} \sqrt{\frac{2E}{T}} \cos\left(2\pi f_c t + (2i-1)\frac{\pi}{M}\right) & ; 0 \le t \le T \\ 0 & ; \text{otherwise} \end{cases}$$

$$S_{\cancel{QPSK}}(t) = \underbrace{\sqrt{\frac{2E}{T}} \cos(2i-1)\frac{\pi}{4} \cos 2\pi f_c t}_{\text{In phase component}} \cancel{+} - \underbrace{\sqrt{\frac{2E}{T}} \sin(2i-1)\frac{\pi}{4} \sin 2\pi f_c t}_{\text{Quadrature component}}$$

$$s(t) = b(t)\sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t \quad 0 \le t \le T_b$$

$$b(t) = \begin{cases} +1 \longrightarrow \text{'1'} \\ 0 \longrightarrow \text{'0'} \end{cases}$$

$$y(t) = x(t) \cos(2\pi f_c t + \theta)$$

$\downarrow$ PSD

$$S_Y(f) = \frac{1}{4}\left[S_X(f-f_c) + S_X(f+f_c)\right\}$$

$$g(t) = +\sqrt{\frac{2E_b}{T_b}} \quad \text{or} \quad -\sqrt{\frac{2E_b}{T_b}}$$

⇒ Binary wave at the i/p of modulator is random with symbol 1 & 0 being equally likely & with the symbol transmitted during adjecent time slot being stastically independent.

Depending on the bits send during the sig in interval 0 to $2T_b$, inphase component equal $g_I(t)$ or $-g_I(t)$, Similarly for the quadrature component. The symbol shaping fn ~~$g_I(t)$~~.

$$g_I(t) = \begin{cases} \sqrt{\frac{E}{T}}, & 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases}$$

So inphase and quadrature component has common PSD i.e.

$$S_I(f) = E\, \text{sinc}^2(fT)$$

$$S_Q(f) = E\, \text{sinc}^2(fT)$$

⇒ The inphase & quadrature component are stastically independent accirdy to the baseband power spectral density of the QPSK signal

$$S_{QPSK}(t) = S_I(f) + S_Q(f)$$
$$= 2E\, \text{sinc}^2(fT)$$

if 1 bit energy $= E_b$, $\therefore E = 2E_b$
" " duration $= T_b$, $\therefore T = 2T_b$

then $\boxed{S_{QPSK}(t) = 4E_b\, \text{sinc}^2(2fT_b)}$

$T_s = 2T_b$

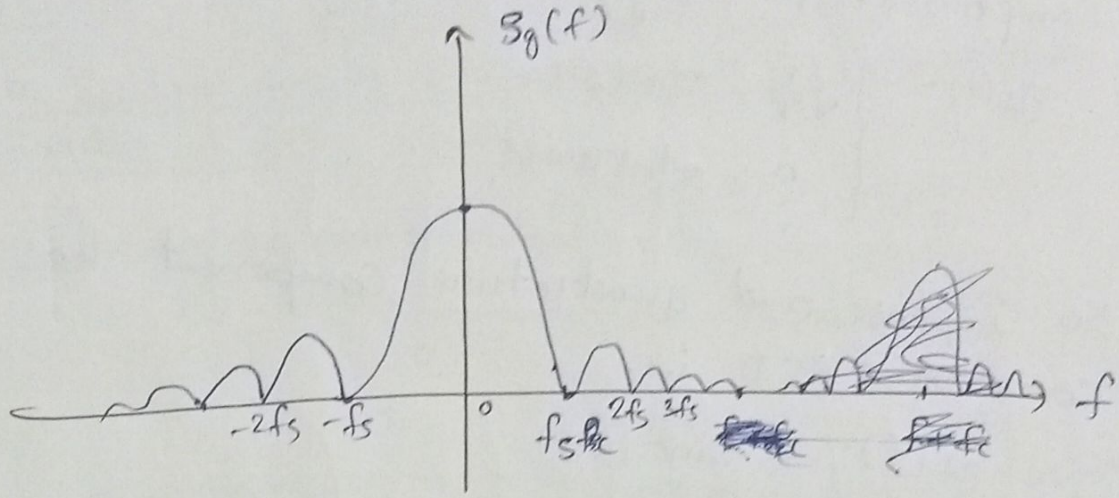
$f_s = \frac{1}{2} f_b$

The PSD of $S_{QPSK}(t)$ is a frequency shifting version of $S_g(f)$, except for scaling factor

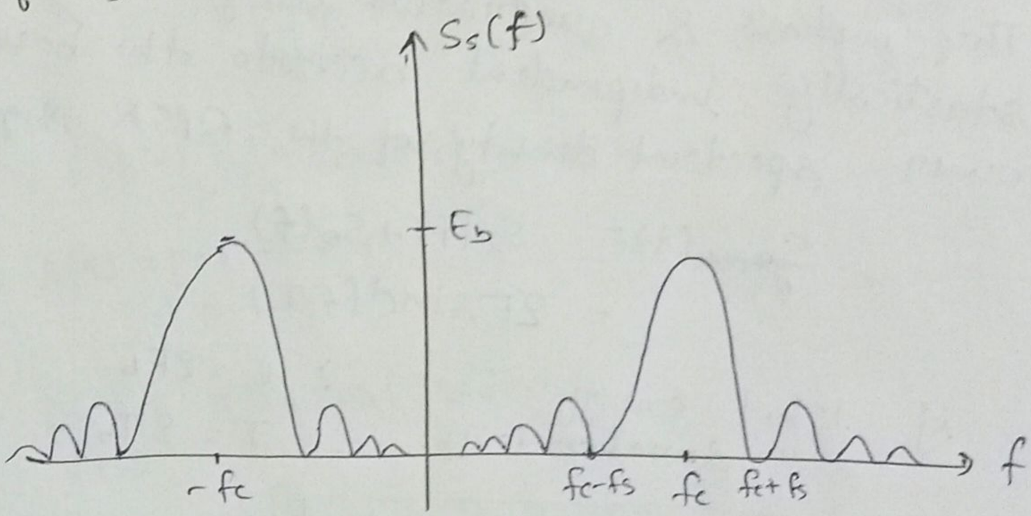
$$S_s(f) = \frac{1}{4}\left[S_g(f-f_c) + S_g(f+f_c) \right]$$

$$= \frac{\cancel{4}E_b}{\cancel{4}}\left[\text{sinc}^2\{(f-f_c)2T_b\} \right] + \frac{\cancel{4}E_b}{\cancel{4}}\left[\text{sinc}^2\{(f+f_c)2T_b\} \right]$$

$$= E_b\left[\text{sinc}^2((f-f_c)\underbrace{2T_b}_{T_s}) + \text{sinc}^2((f+f_c)\underbrace{2T_b}_{T_s}) \right]$$



PSD of $S_s(f)$:-



Txn B.W = Higher freq^n − lower freq^n (in main lobe)

$= f_c + f_s - f_c + f_s = 2f_s$

$$BW = \frac{2}{T_s} = \frac{\cancel{2}}{\cancel{2}T_b} = f_b \Rightarrow \boxed{BW = f_b}$$

So we can say that BW of QPSK sig is f_b whereas BW in the BPSK signal is $2f_b$, here BW is reduced in QPSK sig bcz we are considering two bits at a time.

* ## M-ary Digital Modulation scheme:-

In an M-ary digital Modulation scheme, send anyone of ~~of~~ M possible signal during each symbolint of duration T. In all most all applilation $M = 2^m$ where m is an integer in this case the symbol duration $T = mT_b$ where T_b is the bit duration. The symbol by ~~sinoio~~ sinusoid of duration T_s which differ from one another by $\frac{2\pi}{M}$.

M-ary modulation are prefered over binary modulation scheme for transmitting digital data over bandpass channel when the requirment to conserve the BW at the expension of both increase power and increase sys. complexity.

- ### M-ary PSK:-

In M-ary PSK the available phase of 2π rad is apartion equally and in a discrete way among the M transmitted signal, then the phase modulated signal S_i

$$\boxed{S_i(t) = \sqrt{\frac{2E}{T}} \cos\left(2\pi f_c t + \frac{2\pi}{M} i\right)} \quad ; \; i = 0, 1, 2, \ldots M-1 \quad (15)$$

$$0 \leq t \leq T$$

E → signal energy per symbol, T → symbol duration

17/04/25

$$S_i(t) = \underbrace{\sqrt{E}\cos\left(\frac{2\pi}{M} i\right)}\underbrace{\sqrt{\frac{2}{T}}\cos 2\pi f_c t}_{\text{Inphase}} + \underbrace{\left\{-\sqrt{E}\sin\left(\frac{2\pi i}{M}\right)\right\}}\underbrace{\sqrt{\frac{2}{T}}\sin 2\pi f_c t}_{\text{quadrature}} \quad (2)$$

The descrete coefficient $\sqrt{E}\cos\left(\frac{2\pi i}{M}\right)$ and $-\sqrt{E}\sin\frac{2\pi i}{M}$ are resp. refers to as inphase and quadrature components of M-ary PSK signal $S_i(t)$.

Now we have

$$\left\{\left[\sqrt{E}\cos\frac{2\pi i}{M}\right]^2 + \left[\sqrt{E}\sin\frac{2\pi i}{M}\right]^2\right\}^{1/2} = \sqrt{E} \quad - (3)$$

for all i

accordingly M-ary PSK modulation has the unique property that the inphase & quadrature component of the modulated sig $S_i(t)$ are interrelatted in such a way that the descrete envelope of signal is constant to remain constant at the value $\sqrt{E}$.

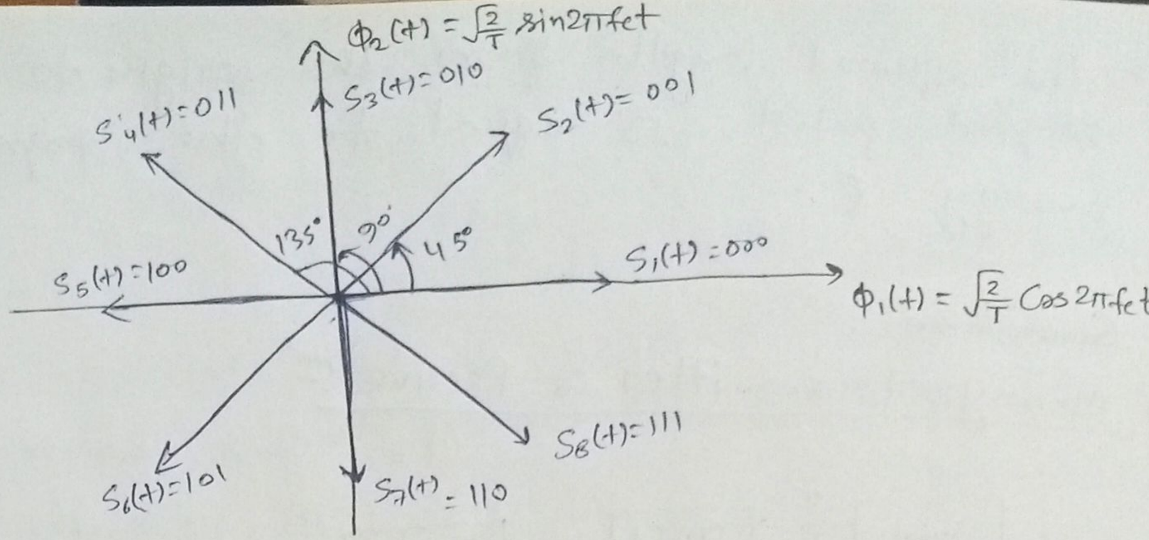
Signal-space & waveform representation of M-ary

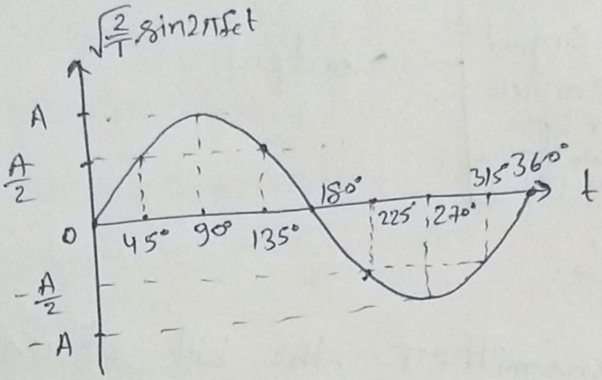
PSK :-

Let $M = 8$, $2^3 = 2^m \Rightarrow m = 3$

angles- $i = 0$, to 7

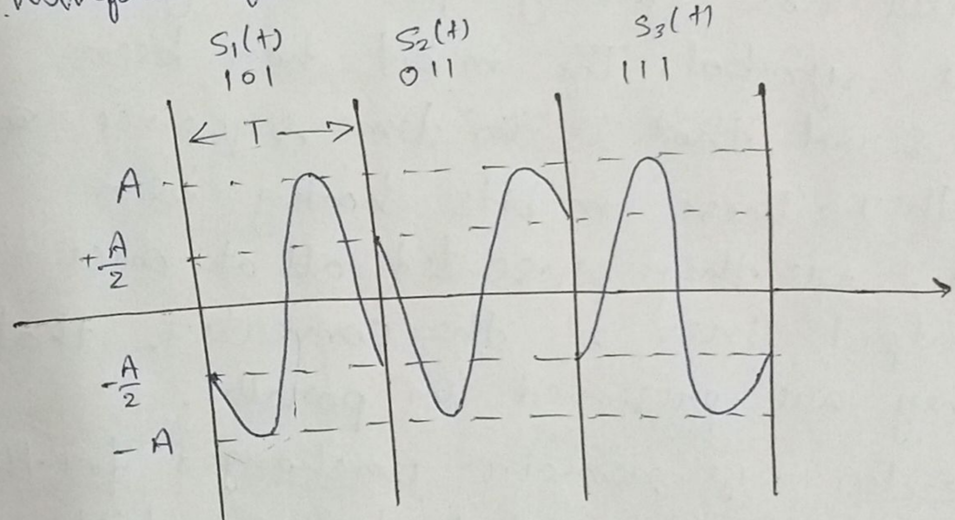
$= 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°$





Assume $b(t) = \underline{101}\,\underline{011}\,\underline{111}$,

Waveform for M-ary PSK ($M=8$) :-



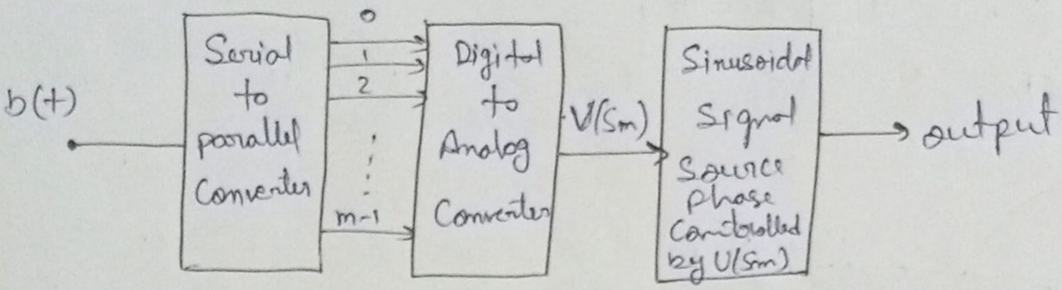
⇒ M-ary PSK is described in geometric term by a consolation of M-signal point distributed uniformaly on the circle of radius $\sqrt{E}$.

⇒ Each signal point in the sig. space diagram correspond to the signal $S_i(t)$ of eqn (1) for a particular value of index i.

⇒ The squared length from the origin to each signal point is equal to the signal energy E.

~~Generation~~

* M-ary PSK transmitter & Receiver:-



M-ary transmitter:

Transmitter: At the transmitter the bit stream b(t) is applied to the serial to parallel converter, this converter has facility for storing the m bit of a symbol. The m bit have been presented serial, that is in time sequence one after another. These m bits having been assembled, are then presented all at once on m-output lines of the converter, that is they are presented in parallel.

The converter o/p remain unchanged for the duration mT_b of a symbol during which time the converter is assembling a new bit of message.

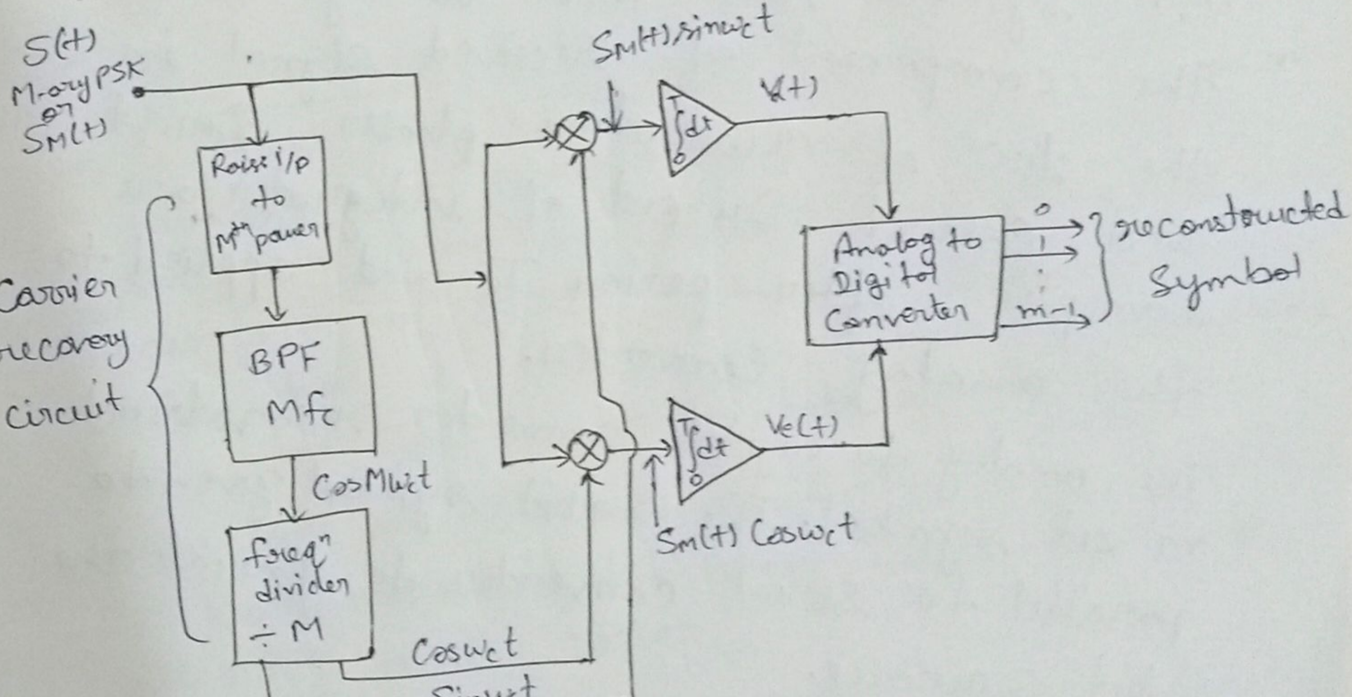
⇒ Digital to analog converter generate N output voltage which assume one of $2^m = N$ different values in a one to one correspond to the

M possible symbol applied to it's input. The output of DAC $V(S_m)$ which depend on the symbol $S_i(t)$ ($i = 0$ to $M-1$).

⇒ finally $V(S_m)$ is applied as a controlled i/p to a special type of constant amplitude sinusoidal signal source whose phase $\left(\frac{2\pi}{M} i\right)$ is determine by $V(S_m)$, All together then the o/p of fixed amp. sin. waveform whose phase has a one to one correspond to the assemble m-bit symbol. The phase can change once per symbol time.

18/04/25

* Non Coherent Detection of M-ary PSK Signals:-



$$S_i(t) = \left\{\sqrt{E_s}\cos\left(\frac{2\pi}{M} i\right)\right\}\sqrt{\frac{2}{T_s}}\cos\omega_c t - \left\{\sqrt{E_s}\sin\left(\frac{2\pi}{M} i\right)\right\}\sqrt{\frac{2}{T_s}}\sin\omega_c t,$$

$$0 \le t \le T_s$$

$i = 0, 1, 2, \dots M-1$

Working: M-ary i/p signal raise to the Mth power, then passed to the BPF. The BPF is extract the freqⁿ component Mf_0. This frequency is divide by M by freqⁿ divider to obtain the carrier signal of freqⁿ fc.

The coherent carriers are generated and they applied to corellator. The correlator consist of multiplier and integrator. Since there is no ~~scattering~~ of starring of the part of symbol. The integrator integrate the over T_s (mT_b). The integrater o/p is voltage whose amp. is proportional to E_e and E_o respectively and change at the symbol rate. These voltage measure the component of received signal in the dirⁿ of quadrature phaser $\sin w_c t$ and $\cos w_c t$. Output of integrater are sampled after period T_s and applied to the analog converter.

The analog to digital converter reconstruct m bit symbol. The m bit symbol given to parallel to serial converter to generate the bit sequence.

Advantage of PSK System:-

1) PSK sys. transmit information through signal phase not through signal amplitude. Hence the system has great merit in situation where, on account of vagaring of transmission medium, the Received signal varies in amplitude.

* Minimum Shift Keying (MSK):-

⇒ MSK is a special form of CPSK (Continuous phase shift Keying), the binary modulation process uses the different value for the freq^n excersion, with a result this new freq^n excerssion ~~technique~~ of a modulated wave offers supperior spectral properties to CPSK.

Difference b/w QPSK and MSK :-

⇒ In MSK the baseband waveform, that multiply the quadrature carrier, is much smoother than the adrupt rectangular waveform of QPSK. While the spectrum of MSK has a main lobe which is 1.5 time as wide as the main lobe of QPSK, the Side lobe in MSK are relatively much smaller in comparision to the main lobe this make filtering much easier.

⇒ The waveform of MSK exhibit phase continuity, that is there are no abrupt phase change as in QPSK as a result we avoid the intersymbol interference caused by non-linear amplifier.