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Anna University

for Affilated Engineering College - 2021 Regulation

PROGRESS THROUGH KNOWLEDGE

ECE Department

1st Semester | 2nd Semester | 3rd Semester | 4th Semester
5th Semester | 6th Semester | 7th Semester | 8th Semester

Click on Subject/Paper under Semester to enter.

1st Semester
- Professional English - I - HS3152
- Matrices and Calculus - MA3151
- Engineering Physics - PH3151
- Engineering Chemistry - CY3151
- Problem Solving and Python Programming - GE3151

2nd Semester
- Professional English - II - HS3252
- Statistics and Numerical Methods - MA3251
- Engineering Graphics - GE3251
- Physics for Electronics Engg - PH3254
- Basic Electrical & Instru Engg - BE3254
- Circuit Analysis - EC3251

3rd Semester
- Random Process and Linear Algebra - MA3355
- C Programming and Data Structures - CS3353
- Signals and Systems - EC3354
- Electronic Devices and Circuits - EC3353
- Control Systems - EC3351
- Digital Systems Design - EC3352

4th Semester
- Electromagnetic Fields - EC3452
- Networks and Security - EC3401
- Linear Integrated Circuits - EC3451
- Digital Signal Processing - EC3492
- Communication Systems - EC3491
- Environmental Sciences and Sustainability - GE3451

5th Semester
- Wireless Communication - EC3501
- VLSI and Chip Design - EC3552
- Transmission Lines and RF Systems - EC3551
- Elective 1
- Elective 2
- Elective 3

6th Semester
- Embedded Systems and IOT Design - ET3491
- Artificial Intelligence and Machine Learning - CS3491
- Open Elective-1
- Elective-4
- Elective-5
- Elective-6

7th Semester
- Human Values and Ethics - GE3791
- Open Elective 2
- Open Elective 3
- Open Elective 4

8th Semester
- Project Work / Intership

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All ECE Engg Subjects - [B.E., M.E.,]		(Click on Subjects to enter)
Circuit Analysis	Digital Electronics	Communication Theory
Basic Electrical and Instrumentation Engineering	Electrical Engineering and Instrumentation	Principles of Digital Signal Processing
Electronic Devices	Linear Integrated Circuits	Signals and Systems
Electronic Circuits I	Electronic Circuits II	Digital Communication
Transmission Lines and Wave Guides	Control System Engineering	Microprocessors and Microcontrollers
Computer Architecture	Computer Networks	Operating Systems
RF and Microwave Engineering	Medical Electronics	VLSI Design
Optical Communication and Networks	Embedded and Real Time Systems	Cryptography and Network Security
Probability and Random Processes	Transforms and Partial Differential Equations	Physics for Electronics Engineering
Engineering Physics	Engineering Chemistry	Engineering Graphics
Problem Solving and Python Programming	Object Oriented Programming and Data Structures	Environmental Science and Engineering
Principles of Management	Technical English	Total Quality Management
Professional Ethics in Engineering	Engineering Mathematics I	Engineering Mathematics II

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

B.E. Electronics and Communication Engineering

Anna University Regulation: 2021

EC3491 –COMMUNICATION SYSTEMS

II Year / IV Semester

Hand Written Notes

Unit – IV

DIGITAL MODULATION SCHEME

Prepared by,

Mrs. E. M. Uma selvi , AP/ECE

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UNIT-IV

DIGITAL MODULATION SCHEME

Geometric Representation Signals:-

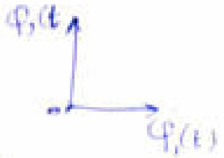
Consider a set of 'M' signals

$s_i(t)$ for $i = 1, 2, 3, \dots M$

Signals $s_i(t)$ to be represented as vectors in an N-dimensional space where $N \le M$

$$s_i(t) \longrightarrow s_i = \begin{bmatrix} s_{i1} \\ s_{i2} \\ \vdots \\ s_{iN} \end{bmatrix}$$

for $N = 2$, $s_i(t) \longrightarrow s_i = \begin{bmatrix} s_{i1} \\ s_{i2} \end{bmatrix}$



The axes are called basis function

$s_i(t)$ should be energy signals.

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Properties of basis functions:-

(1) Basis functions must be orthogonal (i.e. dot product of basis fn is zero)

(2) Basis function must have unit energy

Such basic fn is orthonormal basis fn

(ie) $\varphi_1(t), \varphi_2(t), \varphi_3(t), \dots \varphi_N(t)$; $N \le M$

Orthogonal $\Rightarrow$ $\int_0^T \varphi_i(t)\,\varphi_j(t)\,dt = \begin{cases} 0 & ; \text{if } i \ne j \\ 1 & ; \text{if } i = j \end{cases}$

Unit energy $\Rightarrow$ $\int_0^T \varphi_i^2(t)\,dt = 1$

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Signals $s_i(t)$ can be represented in terms of their vector s_i & basis function $\varphi_j(t)$ for $i = 1, 2, \dots M$ & $j = 1, 2, \dots N$.

$$s_i(t) = \sum_{j=1}^{N} s_{ij}\,\varphi_j(t) \quad \text{for } i = 1, 2, \dots M \longrightarrow (1)$$

→ vector representation of s_i.

(ie) $s_i(t) = s_{i1}\varphi_1(t) + s_{i2}\varphi_2(t) + s_{i3}\varphi_3(t) + \dots + s_{iN}\varphi_N(t)$

$$s_1(t) = s_{11}\varphi_1(t) + s_{12}\varphi_2(t) + \dots + s_{1N}\varphi_N(t)$$

$$s_2(t) = s_{21}\varphi_1(t) + s_{22}\varphi_2(t) + \dots + s_{2N}\varphi_N(t)$$

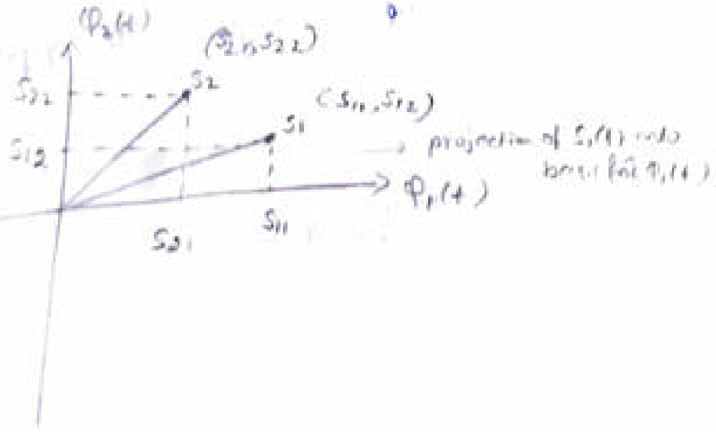
$$s_i(t) = s_i = \begin{bmatrix} s_{i1} \\ s_{i2} \\ \vdots \\ s_{iN} \end{bmatrix} \qquad s_1(t) = s_1 = \begin{bmatrix} s_{11} \\ s_{12} \end{bmatrix} \qquad s_2(t) = s_2 = \begin{bmatrix} s_{21} \\ s_{22} \end{bmatrix}$$

where $s_{ij} = \int_0^T s_i(t)\,\varphi_j(t)\,dt \longrightarrow (2)$

(ie) s_{ij} is the projection of $s_i(t)$ onto $\varphi_j(t)$.

$$s_{11} = \int_0^T s_1(t)\varphi_1(t)\,dt \qquad s_{21} = \int_0^T s_2(t)\varphi_1(t)\,dt$$

$$s_{12} = \int_0^T s_1(t)\varphi_2(t)\,dt \qquad s_{22} = \int_0^T s_2(t)\varphi_2(t)\,dt$$



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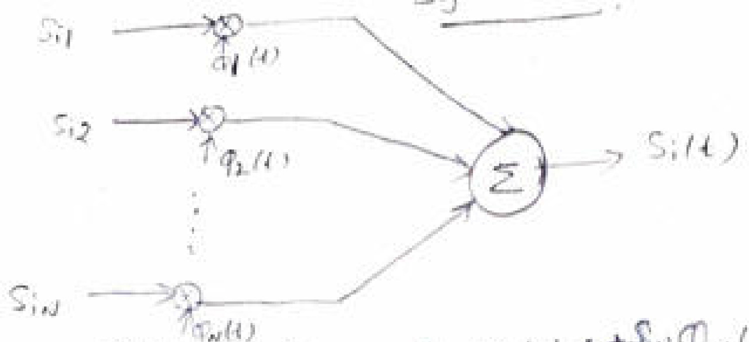
Synthesizer eqn for signal i,

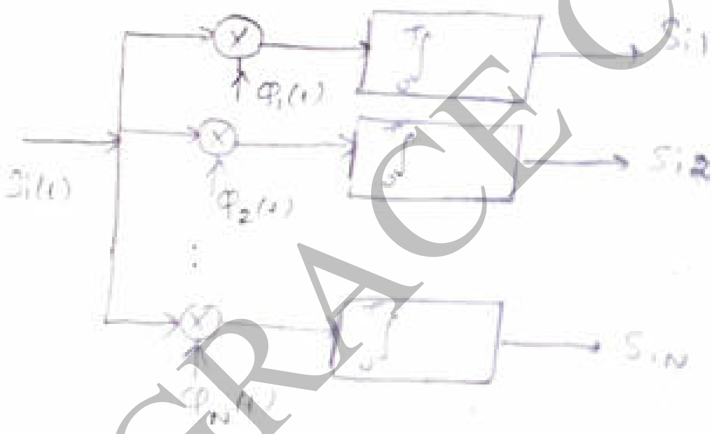
$$s_i(t) = \sum_{j=1}^{N} s_{ij}\,\phi_j(t) \quad \text{for } i = 1,2,\dots,M \ \& \ N \le M.$$

Synthesizer



$$s_i(t) = s_{i1}\phi_1(t) + s_{i2}\phi_2(t) + \dots + s_{iN}\phi_N(t)$$

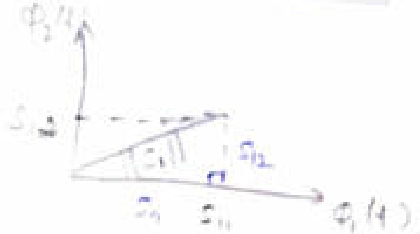
Analyzer



The process of analyzer is opposite of synthesizer

$$s_{ij} = \int_0^T s_i(t)\,\phi_j(t)\,dt$$

To find energy of s/l



$$s_i = \begin{bmatrix} s_{i1} \\ s_{i2} \end{bmatrix}$$

Norm of signal s_i denoted as $\|s_i\|$

↳ length of s/l s_i

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Use pythagorus theorem.

$$\|s_i\|^2 = s_{i1}^2 + s_{i2}^2$$

$$\|s_i\| = \sqrt{s_{i1}^2 + s_{i2}^2} \quad (\text{length of s/l } 's_i')$$

In an N-dimensional space (ie) $s_i = \begin{bmatrix} s_{i1} \\ s_{i2} \\ \vdots \\ s_{iN} \end{bmatrix}$

$$\|s_i\| = \sqrt{s_{i1}^2 + s_{i2}^2 + s_{i3}^2 + \dots s_{iN}^2}$$

In general,

$$\|s_i\| = \left(\sum_{j=1}^{N} s_{ij}^2\right)^{1/2} \longrightarrow (3)$$

Energy of $s_i(t)$ is,

$$E_i = \int_0^T s_i^2(t)\,dt$$

$\because$ vector form of s/l $s_i(t) \Rightarrow s_i = \begin{bmatrix} s_{i1} \\ s_{i2} \\ \vdots \\ s_{iN} \end{bmatrix}$

$$= \int_0^T s_i(t)\, s_i(t)\,dt$$

$$= \int_0^T \left[\sum_{j=1}^{N} s_{ij}\varphi_j(t)\right]\left[\sum_{k=1}^{N} s_{ik}\varphi_k(t)\right] dt$$

Interchanging the order of summation & integration

$$E_i = \sum_{j=1}^{N} s_{ij} \sum_{k=1}^{N} s_{ik} \underbrace{\int_0^T \varphi_j(t)\,\varphi_k(t)\,dt}_{\substack{=0 \text{ if } j \neq k \\ =1 \text{ if } j=k}}$$

$$= \sum_{j=1}^{N} s_{ij} \; \Sigma s_{ij} \rightarrow [\because j=k]$$

$$E_i = \sum_{j=1}^{N} s_{ij}^2$$

$$\|s_i\| = \left(\sum_{j=1}^{N} s_{ij}^2\right)^{1/2}$$

$$\therefore E_i = \|s_i\|^2 \qquad (\text{from } 3)$$

Energy of s/l = square of norm of s/l.

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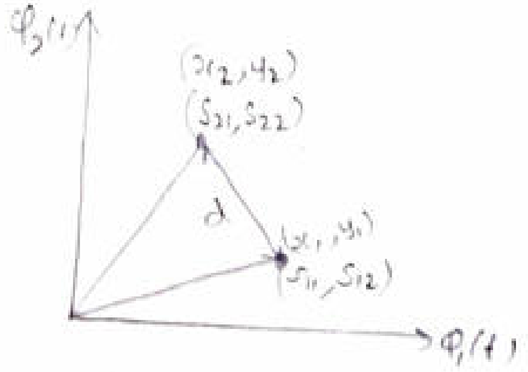
Distance b/w two s/l



$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

$$= \sqrt{(s_{11} - s_{21})^2 + (s_{12} - s_{22})^2}$$

In general,

$$d^2 = \sum_{j=1}^{N} (s_{ij} - s_{kj})^2$$

Distance b/w 2 signals $s_i(t)$ & $s_k(t)$ is,

$$\int_0^T [s_i(t) - s_k(t)]^2 dt = \sum_{j=1}^{N} (s_{ij} - s_{kj})^2$$

$$= \| s_{ij} - s_{kj} \|^2 \quad [\text{from eqn}$$

$$= d^2$$

$\| s_{ij} - s_{kj} \| \rightarrow$ Euclidean distance b/w the s/l s_i & s_k

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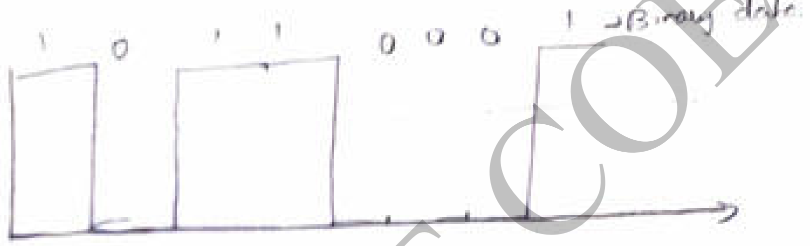
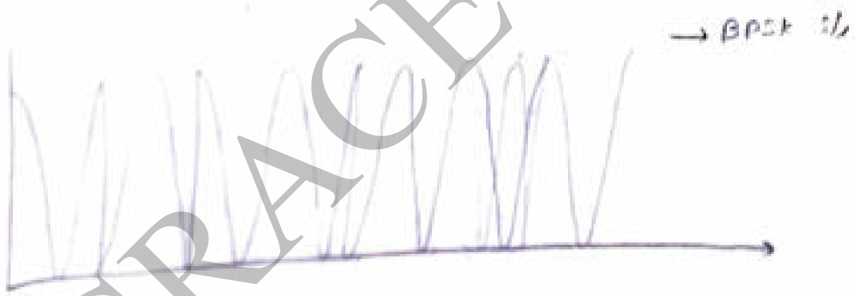
Binary Phase shift keying:

The phase of the output (carrier) signal gets shifted depending upon the i/p (message s/l)

Phase shift keying (PSK) is the digital modulation technique in which the phase of the carrier signal is changed by varying the sine & cosine inputs at a particular time.





In a coherent BPSK s/m,

$S_1(t) \rightarrow 1$

$S_2(t) \rightarrow 0$

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t)$$

$$S_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \pi)$$

$$= -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t)$$

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carrier s/l, $c(t) = A\cos(2\pi f_c t + \varphi)$

$1 \rightarrow S_1(t) = A\cos(2\pi f_c t + 0) \rightarrow (1)$

$0 \rightarrow S_2(t) = A\cos(2\pi f_c t) + \underbrace{\pi}_{180^\circ}) \rightarrow (2)$

$= -A\cos(2\pi f_c t) \rightarrow (2) \quad 0 \leq t \leq T_b$

$T_b \rightarrow$ bit duration, $T_b = \frac{K}{f_b}$ → integer

In digital modulation, Amplitude in terms of...

$E_b \rightarrow$ transmitted s/l energy per bit

$$E_b = \int_0^{T_b} s_1^2(t)\,dt$$

$$= \int_0^{T_b} A^2\cos^2(2\pi f_c t)\,dt \qquad \left[\because \cos^2\theta = \frac{1+\cos 2\theta}{2}\right]$$

$$= A^2\int_0^{T_b} \frac{1+\cos 4\pi f_c t}{2}\,dt$$

$$= \frac{A^2}{2}\left\{[t]_0^{T_b} + [0]\right\}$$

Energy of bit duration $\boxed{E_b = \frac{A^2 T_b}{2}}$

$$A^2 = \frac{2E_b}{T_b}$$

$$A = \sqrt{\frac{2E_b}{T_b}}$$

To find basis function:

By Gram-Schmidt orthogonalization procedure

$\boxed{N \leq M}$

$$\phi_1(t) = \frac{S_1(t)}{\sqrt{E_b}} = \frac{\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t)}{\sqrt{E_b}}$$

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$$\boxed{\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos(2\pi f_c t)}, \quad 0 \le t \le T_b$$

W.K.T, $S_2(t) = -S_1(t)$

One basis fn is reqd to represent both $S_1(t)$ & $S_2(t)$.

$\phi_2 = 0$.

Here, $N=1$, $M=2$.

From ① ⇒ $S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t)$

$= \sqrt{E_b} \sqrt{\frac{2}{T_b}} \cos(2\pi f_c t)$

$$\boxed{\begin{aligned} S_1(t) &= \sqrt{E_b}\,\phi_1(t) \\ S_2(t) &= -\sqrt{E_b}\,\phi_1(t) \end{aligned}} \quad \begin{aligned} &0 \le t \le T_b \\ &0 \le t \le T_b \end{aligned}$$

To find constellation point.

$$\boxed{S_{ij} = \int_0^{T_b} S_i(t)\,\phi_j(t)\,dt}$$

$i = 1, 2, \ldots M$ → no. of signals
$j = 1, 2, \ldots N$ → no. of basis fn

Here we have, $M=2$, $N=1$ ⇒ $N<M$ ⇒ $i = 1, 2$; $j = 1$

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

$= \int_0^{T_b} \sqrt{E_b}\,\phi_1^2(t)\,dt$

$= \sqrt{E_b} \underbrace{\int_0^{T_b} \phi_1^2(t)\,dt}_{\text{equal to } 1}$

$N=1$, BPSK → one dimensional modulation

$\int_0^{T_b} \phi_1^2(t)\,dt = 1$, orthonormal

$$\boxed{S_{11} = \sqrt{E_b}}$$

→ constellation point

$S_{21} = \int_0^{T_b} -\sqrt{E_b}\,\phi_1^2(t)\,dt$

$$\boxed{S_{21} = -\sqrt{E_b}}$$

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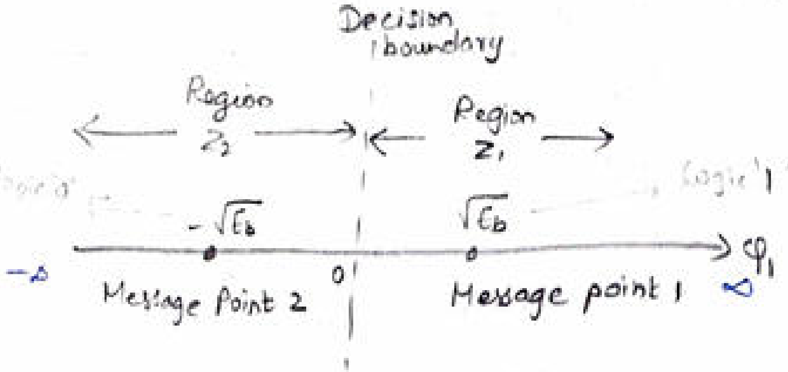
Constellation diagram:-

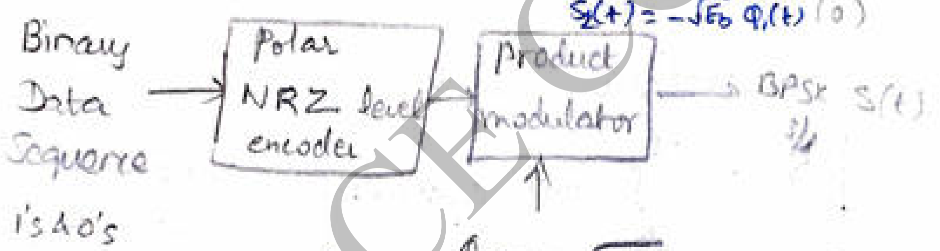
N=1 → one dimensional modulation $\varphi_1(t)$



BPSK - Transmitter:-

$S_1(t)=\sqrt{E_b}\,\varphi_1(t)$ (1)

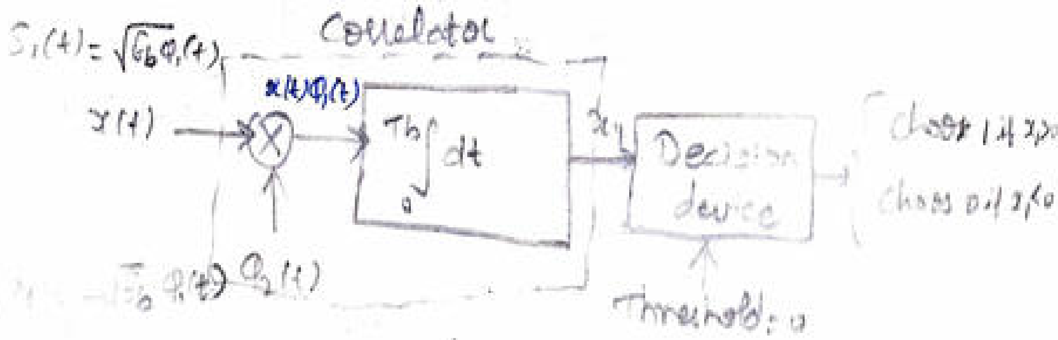
$S_2(t)=-\sqrt{E_b}\,\varphi_1(t)$ (0)



$\phi_1(t)=\sqrt{\frac{2}{T_b}}\cos(2\pi f_c t)$; $0\le t\le T_b$

Polar NRZ maps Binary data to $\sqrt{E_b}$ for logic '1' & $-\sqrt{E_b}$ for logic '0'

BPSK Receiver:-



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$x_i(t) = s_i(t) + n(t)$ — $n(t) \rightarrow$ AWGN. Additive White Gaussian Noise

$i = 1, 2, \quad x_1(t) = s_1(t) + n(t)$

$x_2(t) = s_2(t) + n(t).$

for AWGN, assumed, $\underset{\text{Mean}}{\mu = 0}$; $\underset{\text{Variance}}{\sigma_N^2 = \frac{N_0}{2}}$

$$x_1 = \int_0^{T_b} x(t)\,\phi_1(t)\,dt$$

If received s/l > 0 then value is 1

" " < 0 " " " '0'

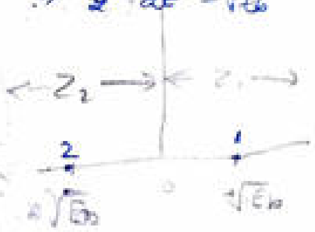
Error Probability of BPSK:-

Instead of receiving 1, the s/l may be received as '0', there error is occured. So error probability can be found for BPSK.

the set of points closest to message point 1 at $+\sqrt{E_b}$

the " " " " " " 2 at $-\sqrt{E_b}$

$$x(t) = \begin{cases} s_1(t) + n(t) = \sqrt{E_b}\,\phi_1(t) + n(t) \\ s_2(t) + n(t) = -\sqrt{E_b}\,\phi_1(t) + n(t) \end{cases}$$



$x_1 \rightarrow$ observation vector.

$$x_1 = \int_0^{T_b} x(t)\,\phi_1(t)\,dt.$$

Let's say, transmitted bit is '1'

$$x_1 = \int_0^{T_b} x(t)\,\phi_1(t)\,dt$$

$$= \int_0^{T_b} \left(\sqrt{E_b}\,\phi_1(t) + n(t)\right) \cdot \phi_1(t)\,dt.$$

$$= \sqrt{E_b}\left[\int_0^{T_b} \phi_1^2(t)\,dt + \int_0^{T_b} n(t)\,\phi_1(t)\,dt\right]$$

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$$\boxed{x_1 = \sqrt{E_b} + n}$$

$\left[\because \int_0^{T_b} \phi_1^2(t)\,dt = 1\right.$

$\int_0^{T_b} n(t)\,\phi_1(t)\,dt$

$n \to$ random

For bit '0'

$$x_1 = \int_0^{T_b} \left(-\sqrt{E_b}\,\phi_1(t) + n(t)\right)\phi_1(t)\,dt$$

$$= -\sqrt{E_b}\left[\underbrace{\int_0^{T_b} \phi_1^2(t)\,dt}_{=1} + \underbrace{\int_0^{T_b} n(t)\,\phi_1(t)\,dt}_{=n}\right]$$

$$\boxed{x_1 = -\sqrt{E_b} + n}$$

$\therefore$ observation s/g, $x_1 = \begin{cases} \sqrt{E_b} + n & \to \text{for '1'} \\ -\sqrt{E_b} + n & \to \text{for '0'} \end{cases}$

To find conditional prob density fn, find μ & σ^2

Mean of x_1,

$$E(x_1) = \begin{cases} E\sqrt{E_b} + E(n) \\ E(-\sqrt{E_b}) + E(n) \end{cases} = \begin{cases} \sqrt{E_b} + 0 \\ -\sqrt{E_b} + 0 \end{cases}$$

$$E(x_1) = \begin{cases} \sqrt{E_b} \\ -\sqrt{E_b} \end{cases}$$

Variance of x_1,

$$E(x_1 - \bar{x}_1)^2$$

for bit '1',

$$E(x_1 - \bar{x}_1)^2 = E\left[\left(\sqrt{E_b} + n - \sqrt{E_b}\right)^2\right]$$

$$= E(n^2) = \frac{N_0}{2}.$$

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for bit '0'

$$E(x_1-\bar{x}_1)^2 = E\left\{(-\sqrt{E_b}+n-(-\sqrt{E_b}))^2\right\}$$

$$= E(n^2) = \frac{N_0}{2}$$

Prob Density fnc of Gaussian Random variable,

$$f_X(x) = \frac{1}{\sqrt{2\pi\sigma^2}}\, e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

$X \rightarrow$ Random variable

$x \rightarrow$ value that X takes.

$\mu \rightarrow$ mean

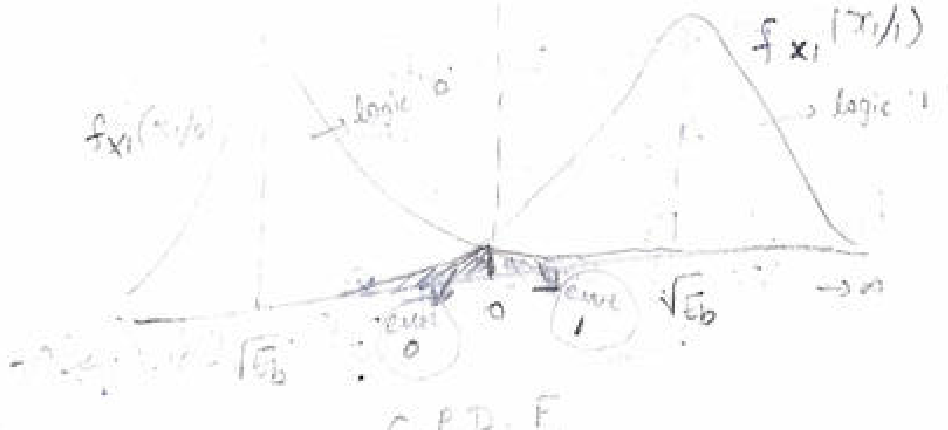
$\sigma^2 \rightarrow$ Variance

C.P.D.F of random variable X_1, given that
conditional
symbol 0 [ie, signal $s_1(t)$] was transmitted is given

$$f_{X_1}(x_1/0) = \frac{1}{\sqrt{2\pi N_0/2}}\, e^{-(x_1-(-\sqrt{E_b}))^2/2N_0/2}$$

$$= \frac{1}{\sqrt{\pi N_0}}\, e^{-\frac{(x_1+\sqrt{E_b})^2}{N_0}}$$

$$f_{X_1}(x_1/1) = \frac{1}{\sqrt{\pi N_0}}\, e^{-\frac{(x_1-\sqrt{E_b})^2}{N_0}}$$



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$$\int_0^\infty f_{x_1}(x_1/0)\,dx_1 \quad \text{infavor of } 1.$$

$$\int_{-\infty}^0 f_{x_1}(x_1/1)\,dx_1 \quad \text{infavor of } `0'$$

The conditional probability of the receiver deciding in favor of symbol 1, given that symbol '0' was transmitted, is,

$$\text{CPDF} \rightarrow f_{x_1}(x_1/0) = \frac{1}{\sqrt{\pi N_0}} e^{-\frac{(x_1+\sqrt{E_b})^2}{N_0}}$$

$$P_{10} = \int_0^\infty f_{x_1}(x_1/0)\,dx_1 = \int_0^\infty \frac{1}{\sqrt{\pi N_0}} e^{-\frac{(x_1+\sqrt{E_b})^2}{N_0}}\,dx_1$$

Complement error

$$= \frac{1}{\sqrt{\pi N_0}} \int_0^\infty e^{-\frac{(x_1+\sqrt{E_b})^2}{N_0}}\,dx_1$$

$$\text{Let } z = \frac{x_1+\sqrt{E_b}}{\sqrt{N_0}} \Rightarrow \sqrt{N_0}\,z = x_1+\sqrt{E_b}$$

$$\sqrt{N_0}\,dz = dx_1$$

Complementary error fn,

$$\boxed{\text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-z^2}\,dz}$$

$$\boxed{P_{10} = \frac{1}{\sqrt{\pi \cancel{N_0}}} \int_{\sqrt{E_b/N_0}}^\infty e^{-z^2} \cancel{\sqrt{N_0}}\,dz}$$

$\therefore$ for $x_1 = 0$, $z = \frac{\sqrt{E_b}}{\sqrt{N_0}}$

$x_1 = \infty$, $z = \infty$.

$$P_{10} = \frac{1}{\sqrt{\pi}} \int_{\sqrt{E_b/N_0}}^\infty \exp(-z^2)\,dz \left(\frac{2}{2}\right) = \frac{1}{2}\,\text{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$$

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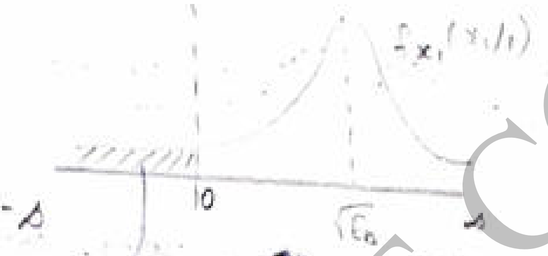
$$\boxed{P_{10} = \frac{1}{2}\,\text{erfc}\sqrt{\frac{E_b}{N_0}}} \rightarrow (A)$$

$$f_{x_1}(x_1/1) = \frac{1}{\sqrt{\pi N_0}}\, e^{-\frac{(x_1-\sqrt{E_b})^2}{N_0}}$$

$$P_{01} = \int_{-\infty}^{0} f_{x_1}(x_1/1)\,dx_1$$

$$= \int_{-\infty}^{0} \frac{1}{\sqrt{\pi N_0}}\, e^{-\frac{(x_1-\sqrt{E_b})^2}{N_0}}\,dx_1$$



$$1 - \int_{0}^{\infty} f_{x_1}(x_1/1)\,dx_1$$

$$P_{01} = 1 - \frac{1}{\sqrt{\pi N_0}}\int_{0}^{\infty} e^{-\frac{(x_1-\sqrt{E_b})^2}{N_0}} \Rightarrow z$$

$$z = \frac{x_1-\sqrt{E_b}}{\sqrt{N_0}} \Rightarrow \sqrt{N_0}\cdot z = x_1 - \sqrt{E_b}$$

$$\sqrt{N_0}\,dz = dx_1$$

limit changed

$$x_1 = 0 \Rightarrow z = -\frac{\sqrt{E_b}}{\sqrt{N_0}}$$

$$x_1 = \infty \Rightarrow z = \infty, \quad P_{01} = 1 - \frac{1}{\sqrt{\pi N_0}}\int_{-\sqrt{\frac{E_b}{N_0}}}^{\infty} e^{-z^2}\cdot\sqrt{N_0}\,dz$$

erfc

$$\frac{2}{2}\cdot\frac{1}{\sqrt{\pi}}\int_{-\sqrt{E_b/N_0}}^{\infty} e^{-z^2}\,dz$$

$$P_{01} = 1 - \frac{1}{2}\,\text{erfc}\left(-\sqrt{\frac{E_b}{N_0}}\right)$$

W.K.T, $\boxed{\text{erfc}(-x) = 2 - \text{erfc}(x)}$

$$\Rightarrow P_{01} = 1 - \frac{1}{2}\left[2 - \text{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)\right]$$

$$= 1 - 1 + \frac{1}{2}\,\text{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$$

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Prob of error for 1 in favor of 0 when symbol 1 is

$$\boxed{P_{01} = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)} \rightarrow (B)$$

From (A) & (B) $P_{10} = P_{01}$

Avg Probability of error $= \dfrac{P_{10} + P_{01}}{2}$

For BPSK,

$$\boxed{P_e = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)}$$

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Binary Frequency Shift keying (BFSK)

Defn: In a binary FSK, symbols 1 & 0 a[re] distinguished from each other by transmitting o[ne] of two sinusoidal waves that differ in freq by a fixed amount.

A typical pair of sinusoidal wave is gi[ven]

$$s_i(t) = \begin{cases} \sqrt{\dfrac{2E_b}{T_b}} \cos(2\pi f_i t), & 0 \le t \le T_b \\ 0, & \text{elsewhere} \end{cases} \rightarrow ①$$

where $i = 1, 2$ & $E_b \rightarrow$ fixed s/l energy per bit.

Transmitted frequency equals $f_i = \dfrac{n_c + i}{T_b} \rightarrow ②$

$i = 1, 2;$

$n_c \rightarrow$ fixed integer

$T_b \rightarrow$ Duration of a bit.

Symbol 1 is represented by $s_1(t)$

Symbol 0 " " " $s_2(t)$ ...

From Eqn ① $s_1(t)$ & $s_2(t)$ are orthogonal

The set of orthonormal basis function is,

$$\phi_i(t) = \begin{cases} \sqrt{\dfrac{2}{T_b}} \cos(2\pi f_i t) \; ; & 0 \le t \le T_b \\ 0 \; ; & \text{elsewhere} \end{cases} \rightarrow ③$$

where $i = 1, 2$, the coeff s_{ij} for $i = 1, 2$, $j = 1, 2$ is g[iven]

$$s_{ij} = \int^{T_b} s_i(t) \phi_j(t) \, dt$$

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$$= \int_0^{T_b} \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_i t) \sqrt{\frac{2}{T_b}} \cos(2\pi f_j t)\, dt$$

$$= \begin{cases} \sqrt{E_b} & , i = j \\ 0 & , i \neq j \end{cases} \rightarrow (4)$$

Thus a coherent binary FSK s/m is characterized by having a signal space that is two-dimensional (ie N=2) with 2 message points (ie; M=2). The two message points are defined by signal vectors.

$$S_1 = \begin{bmatrix} \sqrt{E_b} \\ 0 \end{bmatrix} \rightarrow (5)$$

$$S_2 = \begin{bmatrix} 0 \\ \sqrt{E_b} \end{bmatrix} \rightarrow (6)$$

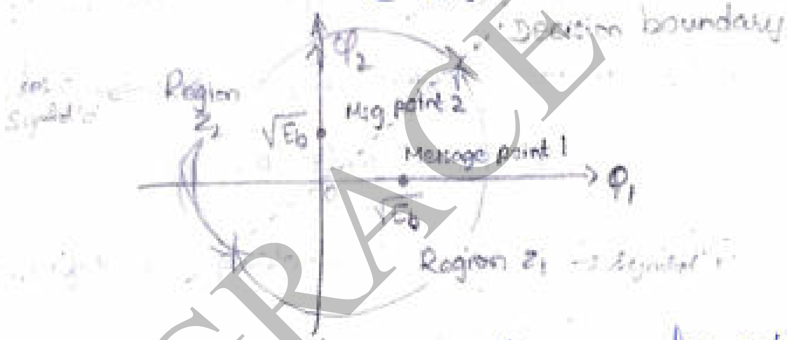

Fig: Signal space diagram for coherent binary FSK

Distance b/w 2 message points = $\sqrt{2E_b}$ (by pythagoras theorem)

The observation vector x has two elements x_1 & x_2 given by,

$$x_1 = \int_0^{T_b} x(t)\, \varphi_1(t)\, dt \rightarrow (7)$$

$$x_2 = \int_0^{T_b} x(t)\, \varphi_2(t)\, dt \rightarrow (8)$$

$x(t) \rightarrow$ received S/l.

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Given that symbol '1' was txed,

$$x(t) = s_1(t) + w(t) \longrightarrow (9)$$

$w(t) \rightarrow$ sample function of white Gaussian with $\sigma = 0$ & PSD $= N_0/2$

when symbol '0' was txed,

$$x(t) = s_2(t) + w(t) \longrightarrow (10)$$

* Applying decision rule, the receiver decides in favor of symbol 1 if the received signal point represented by observation vector x falls inside region Z_1. This occurs when $x_1 > x_2$.

* we have $x_1 < x_2$, the received s/l point falls inside region Z_2, the receiver decides in favor of symbol '0'.

* The decision boundary is defined by $x_1 = x_2$.

* Define a new Gaussian random V.ble 'L' whose sample value 'l' is equal to the difference between x_1 & x_2.

$$\boxed{l = x_1 - x_2} \longrightarrow (11)$$

Given that symbol '1' was txed, the Gaussian random variables X_1 & X_2 whose sample values are denoted by x_1 & x_2, have mean values

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equal to $\sqrt{E_b}$ & zero respectively.

The conditional mean of random variable L, given that symbol 1 was transmitted is,

$$E[L/1] = E[x_1/1] - E[x_2/1]$$
$$= +\sqrt{E_b} \longrightarrow (12)$$

On the other hand, given that symbol '0' was transmitted, x_1 & x_2 have mean values equal to zero & $\sqrt{E_b}$ respectively.

Conditional mean of random variable L, given that symbol '0' was txed.

$$E[L/0] = E[x_1/0] - E[x_2/0]$$
$$= -\sqrt{E_b} \longrightarrow (13)$$

The variance of random variables x_1 & x_2 are equal to $N_0/2$,

$$Var[L] = Var[x_1] + Var[x_2]$$
$$= \frac{N_0}{2} + \frac{N_0}{2}$$
$$= N_0 \longrightarrow (14)$$

When symbol '0' was txed, the c.p.d.f of random variable L is,

$$f_L(l/0) = \frac{1}{\sqrt{2\pi N_0}} \exp\left[-\frac{(l+\sqrt{E_b})^2}{2N_0}\right] \rightarrow (15)$$

Since the condition $x_1 > x_2$ or $l > 0$ corresponds to the receiver making a decision

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in favor of symbol 1, the ~~e.p.d~~.

Conditional probability of error, given that symbol '0' was transmitted,

$$P_e(0) = P(l > 0 / \text{symbol '0' was sent})$$

$$= \int_0^{\infty} f_L(l/0)\, dl.$$

$$= \frac{1}{\sqrt{2\pi N_0}} \int_0^{\infty} \exp\left[-\frac{(l+\sqrt{E_b})^2}{2N_0}\right] dl$$

Put $\frac{l+\sqrt{E_b}}{\sqrt{2N_0}} = z \rightarrow (17)$

Changing the variable of integration from l to z,

If $l = 0 \Rightarrow z = \sqrt{\frac{E_b}{2N_0}}$

$l = z\sqrt{2N_0} - \sqrt{E_b}$.

$dl = \sqrt{2N_0}\, dz$.

$$P_e(0) = \frac{1}{\sqrt{\pi\, 2N_0}} \int_{\sqrt{E_b/2N_0}}^{\infty} \exp(-z^2) \sqrt{2N_0}\, dz$$

$$= \frac{1}{\sqrt{\pi}} \int_{\sqrt{E_b/2N_0}}^{\infty} \exp(-z^2)\, dz$$

$$= \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{2N_0}}\right) \rightarrow (18)$$

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Probability error when symbol '1' is txed,

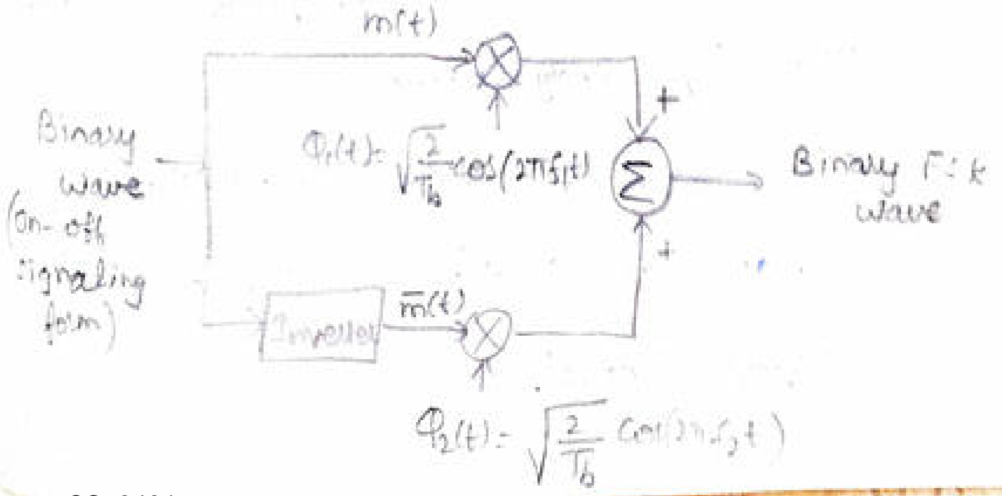
$$P_e(1) = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{2N_0}}\right) \rightarrow (21)$$

Avg prob. of symbol error for coherent binary FSK,

$$P_e = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{2N_0}}\right) \rightarrow (22)$$

Coherent BFSK	Coherent BPSK
(1) In probability of error, $P_e = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{2N_0}}\right)$ therefore we have to double $\frac{E_b}{N_0}$ in order to maintain same average error rate as in BPSK.	(1) Probability of error, $P_e = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$
(2) Distance b/w 2 msg points is $\sqrt{2E_b}$	(2) Distance b/w 2 msg points is $2\sqrt{E_b}$.
(3) It is a 2-dimensional modulation with ~~one~~ two basis function $\varphi_1(t)$ & $\varphi_2(t)$	(3) It is a one dimensional modulation with one basis function $\varphi_1(t)$.
(4) Two frequencies are used.	(4) Single frequency is used in the signal.

Generation of coherent BFSK



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Constant amplitude of $\sqrt{E_b}$ volts & symbol 'o' 'o' volts.

* By using an inverter in the lower channel we have symbol 1 at the i/p.

* We assume that when symbol 1 at the i/p, the oscillator with freq f_1 in the upper channel is switch on while f_2 is switched off, with the result 'f_1' is transmitted.

* Conversely, we have symbol 'o' at the i/p the vice versa takes place.

* We assume that 2 osc are synchronized so that o/p satisfy the requirements of the two orthonormal basis function $\phi_1(t)$ & ϕ_2

* The freq of the modulated wave is shifted with a continuous phase, in accordance with i/p binary wave.

* This form of digital modulation is referred as continuous-phase freq shift keying (CPFSK).

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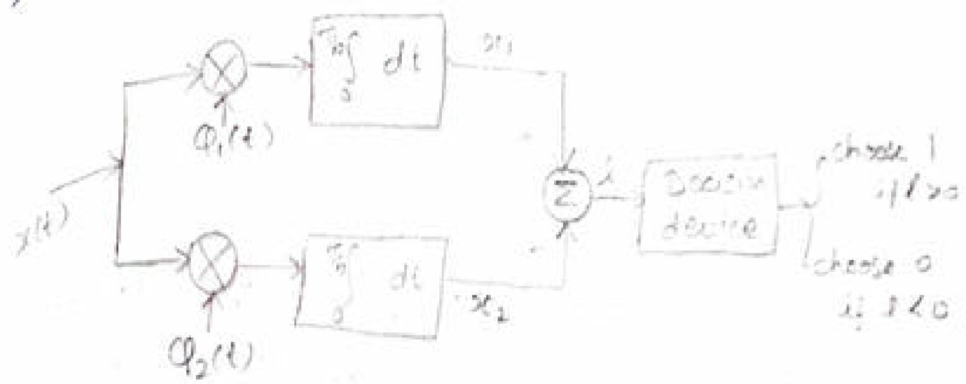
Detection :-



* In order to detect the original binary sequence, given the noisy received wave $x(t)$, we may use the receiver as shown in fig.
* It consist of two correlators with a common i/p, which are supplied with locally generated coherent reference s/l $\varphi_1(t)$ & $\varphi_2(t)$.
* The correlator o/p are then subtracted, one from the other & resulting difference, l, is compared with a threshold of zero volts.
* If $l > 0$, receiver decides in favor of '1'.
  If $l < 0$, " " " " of '0'.

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Quadrature Phase shift keying (QPSK).

In QPSK, the phase of the carrier takes on one of four equally spaced values such as $\pi/4$, $3\pi/4$, $5\pi/4$ & $7\pi/4$ as

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

$i = 1, 2, 3, 4$

$E \rightarrow$ fixed s/l energy per symbol.

$T \rightarrow$ symbol duration.

$f_c \rightarrow$ carrier freq $= \frac{n_c}{T} \Rightarrow n_c \rightarrow$ fixed integer

Each possible value of the phase corresponds to a unique pair of bits called dibit

Dibits are 10, 00, 01 & 11.

Using trigonometric identity,

$\boxed{\cos(A+B) = \cos A \cos B - \sin A \sin B}$

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

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Based on this representation, the following observations are made.

1. There are only two orthonormal basis function $\varphi_1(t)$ & $\varphi_2(t)$ contained in the expansion of $S_i(t)$.

$$\varphi_1(t) = \sqrt{\frac{2}{T}} \cos(2\pi f_c t) \quad : \quad 0 \le t \le T \rightarrow (3)$$

$$\varphi_2(t) = \sqrt{\frac{2}{T}} \sin(2\pi f_c t) \quad : \quad 0 \le t \le T \rightarrow (4)$$

2. There are four message points, and the associated signal vectors are defined by.

$$S_i = \begin{bmatrix} \sqrt{E} \cos\left((2i-1)\frac{\pi}{4}\right) \\ -\sqrt{E} \sin\left((2i-1)\frac{\pi}{4}\right) \end{bmatrix} \; : \; i = 1,2,3,4 \rightarrow (5)$$

$\therefore$ Four message point.

The elements of the s/l vector namely S_{i1} & S_{i2}.

$\cos\frac{\pi}{4} = \sin\frac{\pi}{4} = 1/\sqrt{2}$

Signal-space characterization of QPSK.

Value of i	i/p dibit $0 \le t \le T$	phase of QPSK s/l (radians)	Co-ordinates of message points S_{i1}	S_{i2}
1	10	$\pi/4$	$+\sqrt{E/2}$	$-\sqrt{E/2}$
2	00	$3\pi/4$	$-\sqrt{E/2}$	$-\sqrt{E/2}$
3	01	$5\pi/4$	$-\sqrt{E/2}$	$+\sqrt{E/2}$
4	11	$7\pi/4$	$+\sqrt{E/2}$	$+\sqrt{E/2}$

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Accordingly, a QPSK s/l is characterized by having a two-dimensional signal constellation (ie $N=2$) & 4 message points ($M=4$)

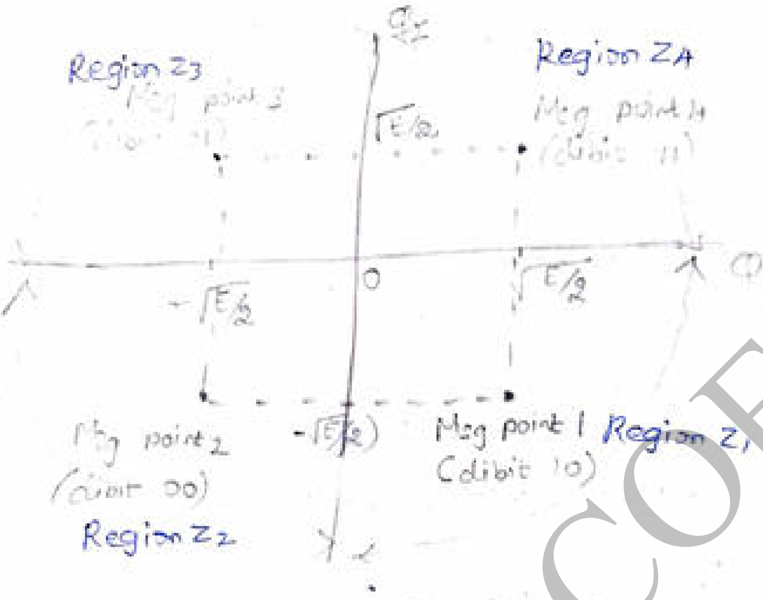
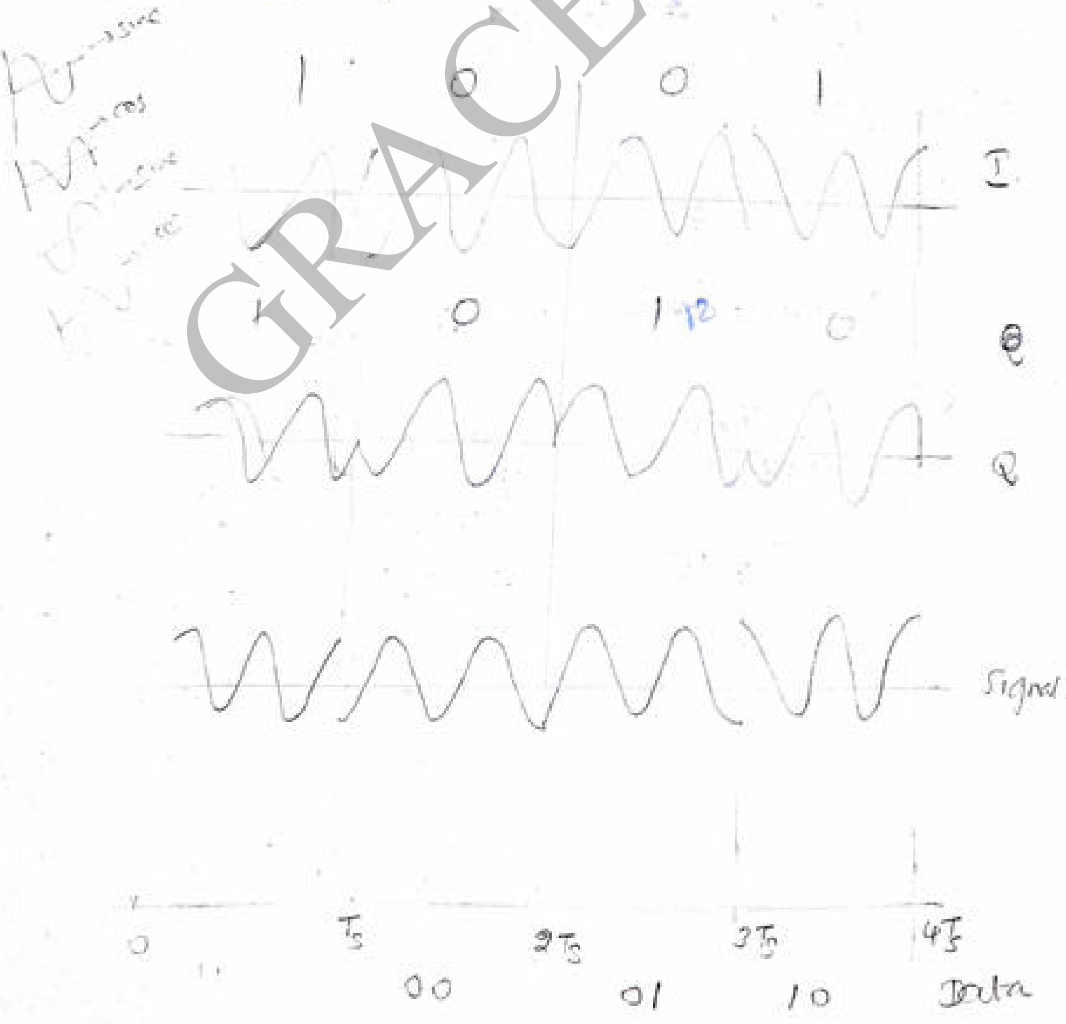


Fig: Signal space diagram.



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The received S/l $x(t)$ is,

$$x(t) = s_i(t) + w(t) \qquad 0 \le t \le T, \quad i = 1,2,3,4 \rightarrow (6)$$

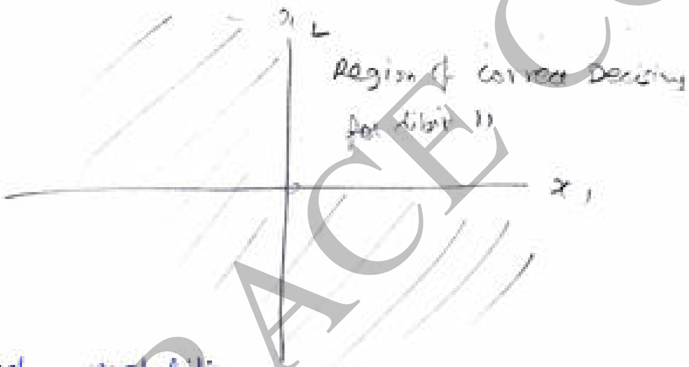
observation vector has 2 elements x_1 & x_2

Ist bit $\rightarrow$ $x_1 = \int_0^T x(t)\,\phi_1(t)\,dt$

$$= \sqrt{E}\cos\left[(2i-1)\frac{\pi}{4}\right] + w_1 \rightarrow (7)$$

2nd bit $\rightarrow$ $x_2 = \int_0^T x(t)\,\phi_2(t)\,dt$

$$= -\sqrt{E}\sin\left[(2i-1)\frac{\pi}{4}\right] + w_2 \rightarrow (8)$$



Correct probability

$$P_c = \int_0^{\infty} \frac{1}{\sqrt{\pi N_0}} \exp\left[-\frac{(x_1 - \sqrt{E/2})^2}{N_0}\right] dx_1 \quad \rightarrow x_1 > 0$$

$$\cdot \int_0^{\infty} \frac{1}{\sqrt{\pi N_0}} \exp\left[-\frac{(x_2 - \sqrt{E/2})^2}{N_0}\right] dx_2 \quad \rightarrow x_2 > 0$$

$$\frac{x_1 - \sqrt{E/2}}{\sqrt{N_0}} = \frac{x_2 - \sqrt{E/2}}{\sqrt{N_0}} = z \quad \left| \begin{array}{l} x_1 = z\sqrt{N_0} + \sqrt{E/2} \\ dx_1 = dz\sqrt{N_0} + 0 \\ dx_1 = \sqrt{N_0}\,dz \end{array} \right.$$

Changing variables of integration from x_1 & x_2 to z.

$$P_c = \left[\frac{1}{\sqrt{\pi}} \int_{-\sqrt{E/2N_0}}^{\infty} \exp(-z^2)\,dz\right]^2$$

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erfc → complementary error function (+ve to 0 & 0 to ∞) → limit

$$= \left[1 - \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E}{2N_0}}\right)\right]^2$$

$$P_c = 1 - \mathrm{erfc}\left(\sqrt{E/2N_0}\right) + \frac{1}{4}\,\mathrm{erfc}^2\left(\sqrt{E/2N_0}\right)$$

error Probability $P_e = 1 - P_c$

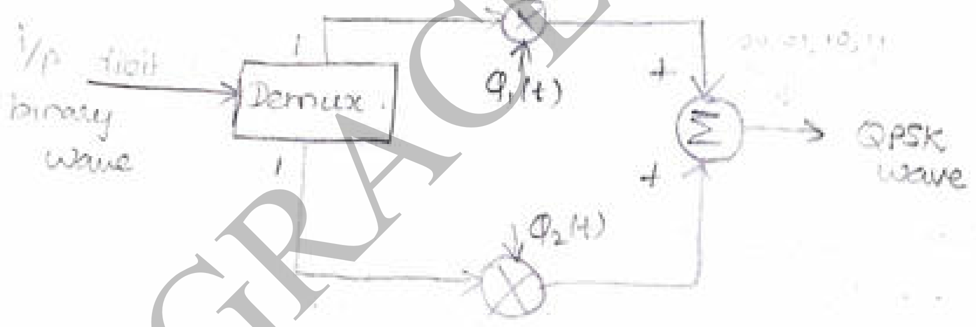
$$= 1 - \left(1 - \mathrm{erfc}\left(\sqrt{E/2N_0}\right) + \frac{1}{4}\,\mathrm{erfc}^2\left(\sqrt{E/2N_0}\right)\right)$$

$$P_e = \mathrm{erfc}\sqrt{\frac{E}{2N_0}} - \frac{1}{4}\,\mathrm{erfc}^2\left(\sqrt{E/2N_0}\right)$$

$$P_e \approx \mathrm{erfc}\sqrt{E/2N_0}$$

$$\boxed{P_e \approx \mathrm{erfc}\sqrt{\frac{E_b}{N_0}}} \qquad \because \boxed{E = 2E_b}$$

QPSK Transmitter.



* In QPSK ~~Receiver~~ transmitter, i/p binary sequence b(t) is represented in polar form, with symbols 1 & 0 represented by $+\sqrt{E_b}$ & $-\sqrt{E_b}$ volts.

* Demux separate this into 2 binary wave consisting of odd & even numbered i/p bits, denoted by $b_1(t)$ & $b_2(t)$ equal s_{i1} & s_{i2}.

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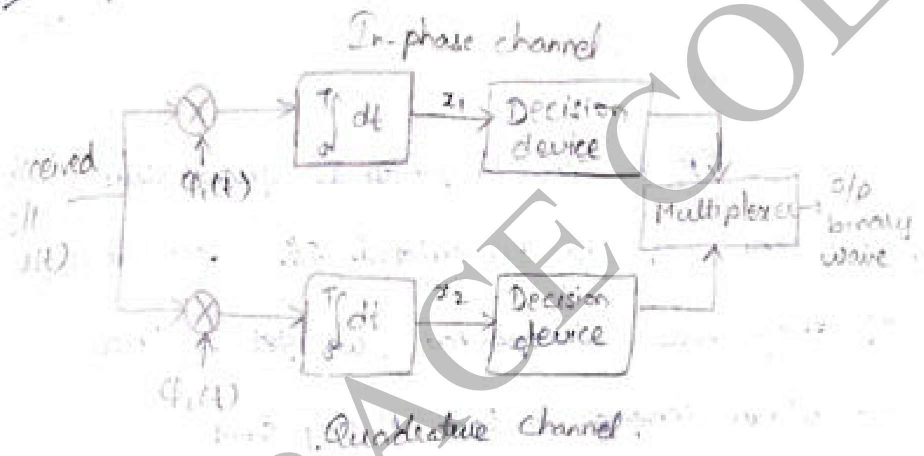
* $b_1(t)$ & $b_2(t)$ are used to modulate a pair of quadrature carriers or orthonormal basis function $\varphi_1(t) = \sqrt{\frac{2}{T}}\cos(2\pi f_c t)$

$$\varphi_2(t) = \sqrt{\frac{2}{T}}\sin(2\pi f_c t).$$

Finally two binary PSK waves are added to produce the desired QPSK wave.

QPSK Receiver:-



* It consist of a pair of correlators with a common i/p & supplied with a locally generated reference signal $\varphi_1(t)$ & $\varphi_2(t)$.

* Correlator o/p x_1 & x_2 are compared with a threshold of zero volts.

* If $x_1 > 0$, a decision is made in favor of symbol '1' for in-phase channel o/p.

* If $x_2 > 0$, decision is made in favor of symbol '1' for quadrature channel o/p.

* If x_1 (or) $x_2 < 0$, then decision made in favour of symbol '0'.

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* Finally these two binary sequences at the in-phase & quadrature channel o/p are combined in a multiplexer to reproduce the original binary sequence at the transmitter i/p with the minimum probability of symbol error.

Quadrature Amplitude Modulation (QAM):- (or) (QASK) (or) (QAPSK)

Introduction:-

In QPSK s/m, in phase & quadrature components of the modulated s/l are interrelated. If they are independent, we get a new modulation scheme called M-ary QAM.

In this QAM, carrier experience amplitude as well as phase modulation with respect to binary i/p signal.

Types:

Name	Bits per Symbol	No. of symbol (M)
4 QAM	2	$2^2 = 4$
8 QAM	3	$2^3 = 8$
16 QAM	4	$2^4 = 16$
32 QAM	5	$2^6 = 64$

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The general form of M-ary QAM is defined transmitted signal

by $S_i(t) = \sqrt{\frac{2E_i}{T}} \cos(\omega_c t + \varphi_i) \rightarrow (1)$

$S_i(t) = a_{i1}\varphi_1(t) + a_{i2}\varphi_2(t) \rightarrow (2) \quad i = 1, 2, \ldots M$

$\varphi_1(t) = \sqrt{\frac{2}{T}} \cos(\omega_c t)$

$\varphi_2(t) = \sqrt{\frac{2}{T}} \sin(\omega_c t)$

where a_{i1} & a_{i2} are PAM symbols $E_s = \frac{2(M-1)}{3}$

$(1) \Rightarrow S_i(t) = \sqrt{\frac{2E_i}{T}} \left[\cos(\omega_c t) \cos\varphi_i - \sin(\omega_c t) \sin\varphi_i \right]$

$$= \underbrace{\underbrace{\sqrt{E_i} \cos\varphi_i}_{a_{i1}} \; \underbrace{\sqrt{\frac{2}{T}} \cos(\omega_c t)}_{\varphi_1(t)}}_{\text{I: ASK \#1}} - \underbrace{\underbrace{\sqrt{E_i} \sin\varphi_i}_{a_{i2}} \; \underbrace{\sqrt{\frac{2}{T}} \sin\omega_c t}_{\varphi_2(t)}}_{\text{I: ASK \#2}}$$

If $M = 4$, a_{i1} and a_{i2}

$-\sqrt{M} + 1 \longrightarrow -\sqrt{M} + 1$

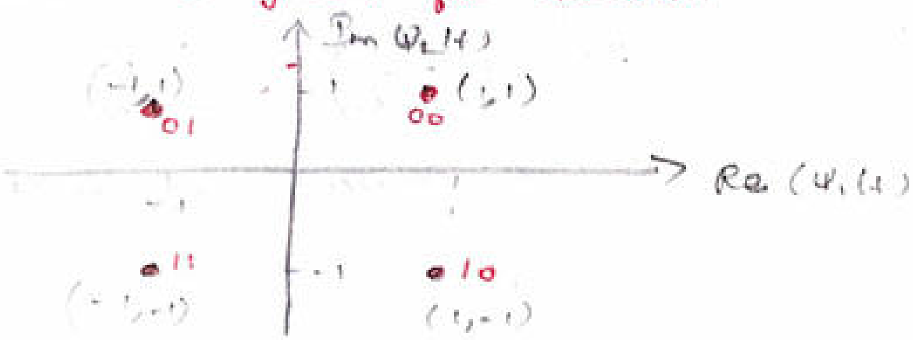
$\sqrt{M} - 1 \longrightarrow \sqrt{M} - 1$

ordered pairs are

$$\{a_{i1}, a_{i2}\} = \begin{bmatrix} (-\sqrt{M}+1, -\sqrt{M}+1) & (-\sqrt{M}+1, \sqrt{M}-1) \\ (\sqrt{M}-1, -\sqrt{M}+1) & (\sqrt{M}-1, \sqrt{M}-1) \end{bmatrix}$$

$$M = 4 \Rightarrow \begin{bmatrix} (-1, -1) & (1, 1) \\ (1, -1) & (1, 1) \end{bmatrix}$$

Constellation diagram for 4-QAM



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$$\log_2(M)$$

$M=16$, $\Downarrow$

a_{i1}	a_{i2}
$\sqrt{M}-1$	$\sqrt{M}-1$
$-\sqrt{M}+1$	$-\sqrt{M}+1$
$\sqrt{M}-3$	$\sqrt{M}-3$
$-\sqrt{M}+3$	$-\sqrt{M}+3$

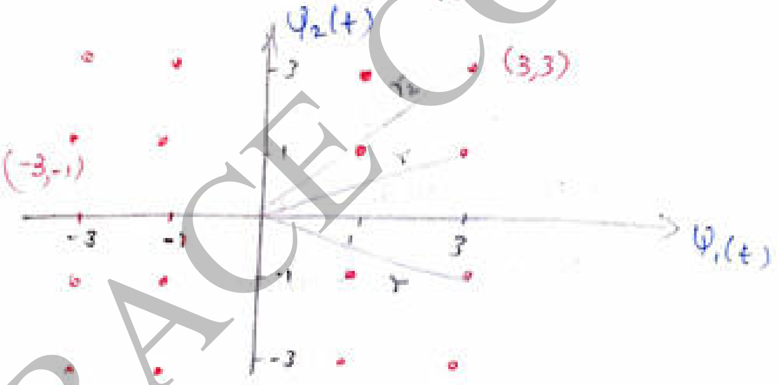
$\Rightarrow$ 4×4 Matrix:

Tot no. of values = 16 = 4

$\Rightarrow$ Size of matrix $(\log_2(4) \times 4)$

$$(a_{i1}, a_{i2}) \Rightarrow \begin{bmatrix} (-3,-3) & (-3,-1) & (-3,1) & (-3,3) \\ (-1,-3) & (-1,-1) & (-1,1) & (-1,3) \\ (1,-3) & (1,-1) & (1,1) & (1,3) \\ (+3,-3) & (3,-1) & (3,1) & (3,3) \end{bmatrix}$$

Constellation diagram:- (16-QAM)



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Probability of symbol error for M-ary QAM

1. The prob of correct detection for QAM is,

$$P_c = (1 - P_e')^2$$

$P_e' \rightarrow$ Prob of symbol error for either component.

2. $$P_e' = \left(1 - \frac{1}{L}\right) \operatorname{erfc}\left(\sqrt{\frac{E_0}{N_0}}\right)$$

$L \rightarrow$ Square root of M.

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3 The prob of symbol error for M-QAM is,

$$P_e = 1 - P_c$$
$$= 1 - (1 - P_e')^2$$
$$= 2P_e'$$

$$P_e = 2\left(1 - \frac{1}{\sqrt{M}}\right) \operatorname{erfc}\left(\sqrt{\frac{E_0}{N_0}}\right)$$

The average value of transmitted energy is,

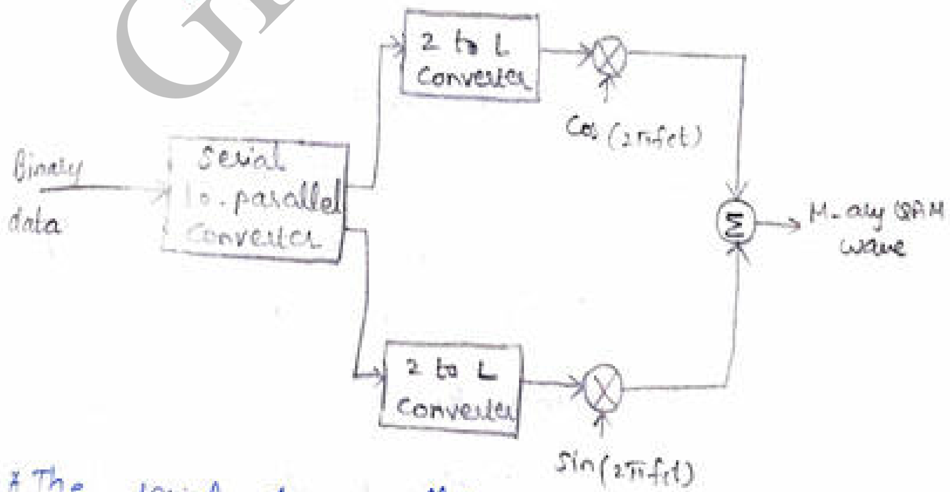
$$E_{av} = 2\left[\frac{2E_0}{L} \sum_{i=1}^{L/2} (2i-1)^2\right]$$

The multiplying factor of 2 accounts for the equal contribution made by the in-phase & quadrature components.

$$E_{av} = \frac{2(L^2-1)E_0}{3}$$
$$= \frac{2(M-1)E_0}{3}$$

$$P_e \simeq 2\left(1 - \frac{1}{\sqrt{M}}\right) \operatorname{erfc}\left(\sqrt{\frac{3E_{av}}{2(M-1)N_0}}\right)$$ is the desired result.

M-ary QAM Transmitter :-
Block diagram



* The serial-to parallel converter accepts a binary sequence at a bit rate $R_b = \frac{1}{T_b}$ and produce two parallel binary sequences

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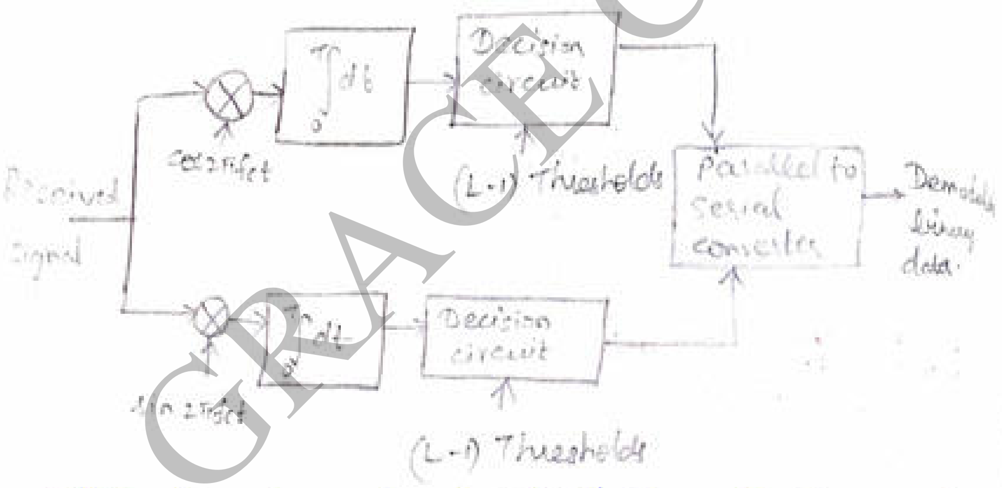
whose bit rates are $R_b/2$ each.

* The 2 to L level converters, where $L=\sqrt{4}$, generate polar L-level signals in response to the respective in-phase & quadrature channel inputs.

* Quadrature carrier multiplexing of the two polar L-level signals so generated produces the desired M-ary QAM signal.

QAM Receiver:-



* Decoding of each baseband channel is accomplished at the output of decision circuit.

* Decision ckt is designed to compared L-level signals against (L-1) decision thresholds.

* The two binary sequences so detected are then combined in the parallel to serial converter to reproduce the original binary sequence.

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Carrier Synchronization:-

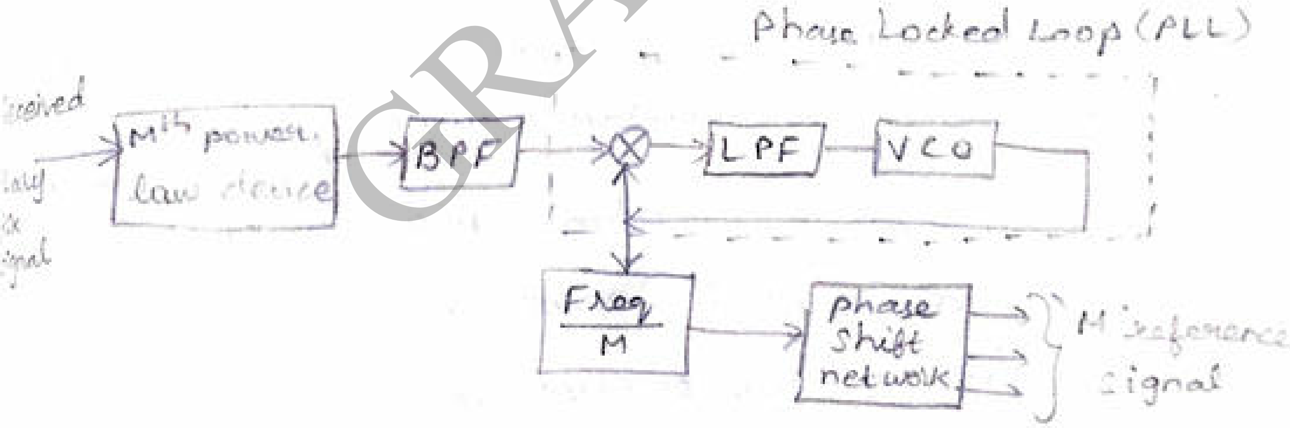
* In this method the data bearing signal is modulated on the carrier in such a way that the power spectrum of the modulated carrier signal contains a discrete component at the carrier frequency.

* The F.T of the modulated signal contains one component at f_c. Then the phase locked loop is used to track the carrier frequency.

* The output of the PLL is used as a reference signal for detection in the receiver.

The popular method for carrier recovery are i) M^{th} power loop
ii) Costas loop.

i) M^{th} Power loop:-



* This is the carrier recovery circuit for M-ary PSK.

* For the special case, M=2, the circuit is called Squaring loop. Here we encounter a phase ambiguity problem.

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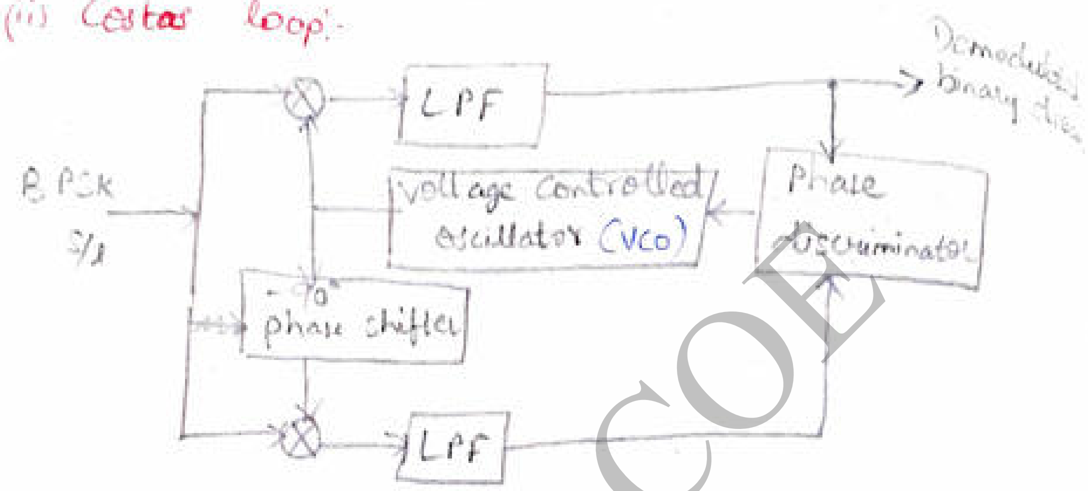
from the squaring device at its i/p end. it is clear that changing the sign of i/p s/l leaves the sign of the recovered carrier unaltered.

* Squaring loop exhibits a 180° phase ambiguity.

(ii) Costas loop:-



* The loop consist of two paths, inphase & quadrature that are coupled together via a VCO to form negative feedback system.

* When synchronization is attained, the demodulated data waveform appears at o/p of inphase path & quadrature path is zero under ideal condition.

* Costas loop also exhibits same phase ambiguity problem.

* One method of resolving phase ambiguity is to exploit differential encoding.

* Avg prob of symbol error for differentially encoded PSK

$$P_e = \operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right) - \frac{1}{2}\operatorname{erfc}^2\left(\sqrt{\frac{E_b}{N_0}}\right).$$

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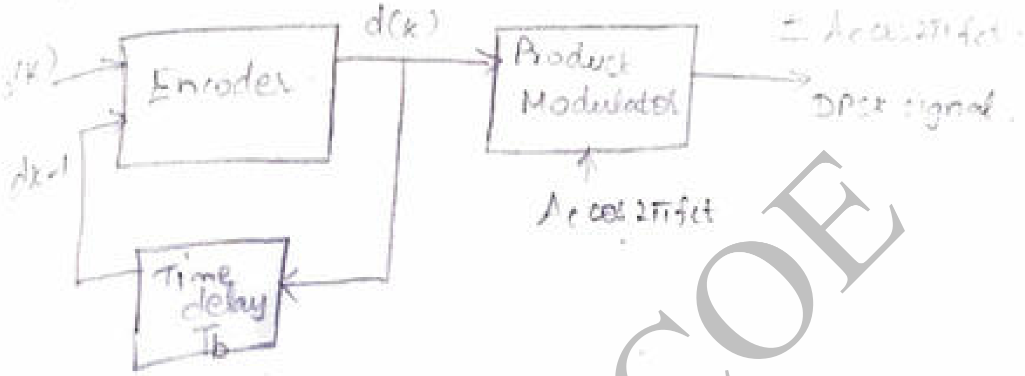
Non-coherent Receiver:-

→ Detecting without phase information

→ Therefore there is no need for synchronous

Differentially Phase Shift Keying:- (DPSK):

Generation:



Binary Data {b(k)} : 0 0 1 0 0 1 0 0 1 1

DPSK {d(k)} : 0 1 1 0 1 1 0 1 1 1

phase of DPSK(d_k): π 0 0 π 0 0 π 0 0 0

0 → π
1 → 0

d_{k-1} : 1 0 1 1 0 1 1 0 1 1

phase d_{k-1} : 0 π 0 0 π 0 0 π 0 0

Comparision o/p : − − + − − + − − + +
phase (d_k & d_{k-1})

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Matrices and Calculus - MA3151	Statistics and Numerical Methods - MA3251	C Programming and Data Structures - CS3353	Networks and Security - EC3401
Engineering Physics - PH3151	Engineering Graphics - GE3251	Signals and Systems - EC3354	Linear Integrated Circuits - EC3451
Engineering Chemistry - CY3151	Physics for Electronics Engg - PH3254	Electronic Devices and Circuits - EC3353	Digital Signal Processing - EC3492
Problem Solving and Python Programming - GE3151	Basic Electrical & Instru Engg - BE3254	Control Systems - EC3351	Communication Systems - EC3491
	Circuit Analysis - EC3251	Digital Systems Design - EC3352	Environmental Sciences and Sustainability - GE3451

5th Semester	6th Semester	7th Semester	8th Semester
Wireless Communication - EC3501	Embedded Systems and IOT Design - ET3491	Human Values and Ethics - GE3791	Project Work / Intership
VLSI and Chip Design - EC3552	Artificial Intelligence and Machine Learning - CS3491	Open Elective 2	
Transmission Lines and RF Systems - EC3551	Open Elective-1	Open Elective 3	
Elective 1	Elective-4	Open Elective 4	
Elective 2	Elective-5		
Elective 3	Elective-6		

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Computer Architecture	Computer Networks	Operating Systems
RF and Microwave Engineering	Medical Electronics	VLSI Design
Optical Communication and Networks	Embedded and Real Time Systems	Cryptography and Network Security
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