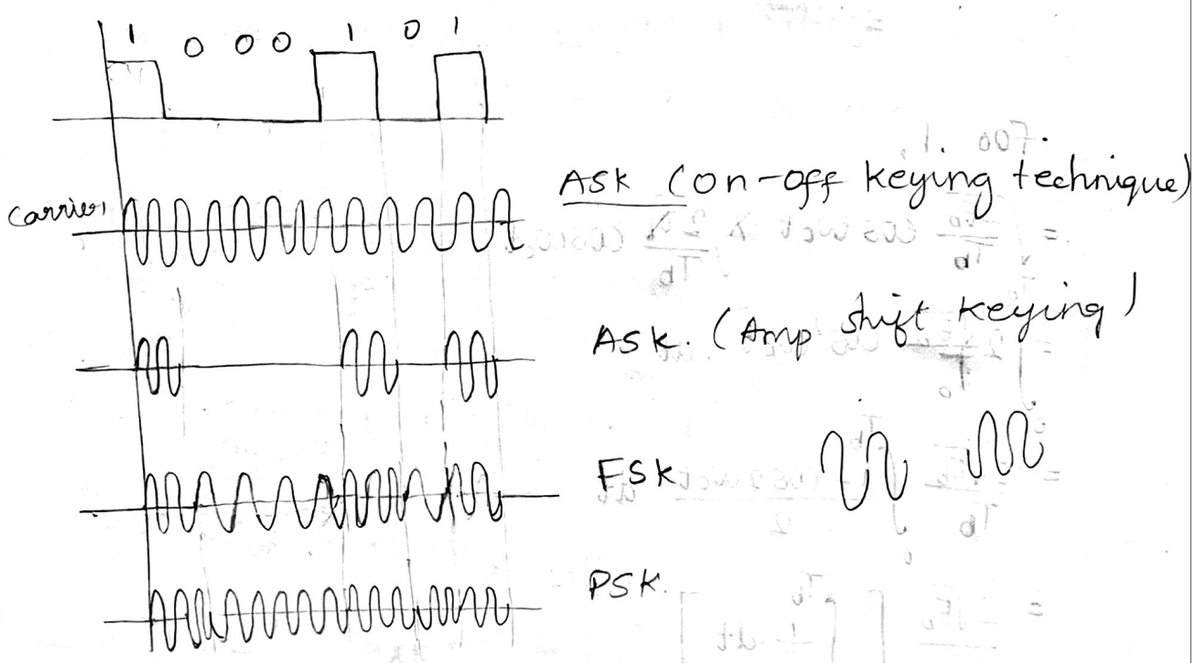
UNIT-2f

Digital modulation

i/p →

Carrier →

Modulated signal → CT but carrying digital data.



Binary Phase Shift Keying (BPSK)

$E = PT$ Power $= \frac{E}{T} = \frac{V^2}{R}$ — ①

Transmitted Signal

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t \rightarrow \text{for binary 1}$$

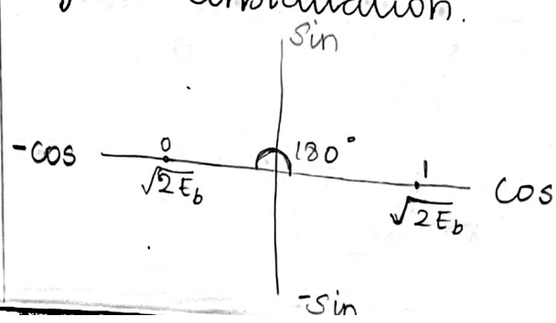
$0 < t < T_b$

$$S_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + 180^\circ) \rightarrow \text{for binary}$$

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

$$\boxed{S_2(t) = -S_1(t)} \rightarrow \text{Antipodal signal.}$$

Signal Constellation.



$T_b = 1$

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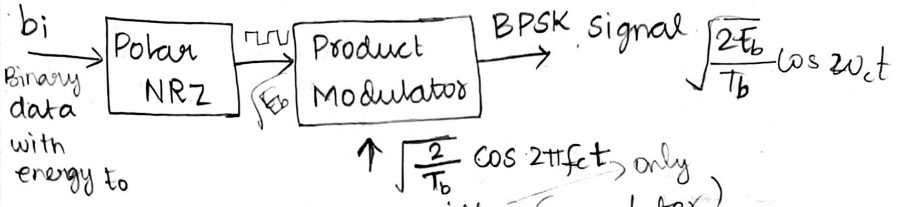
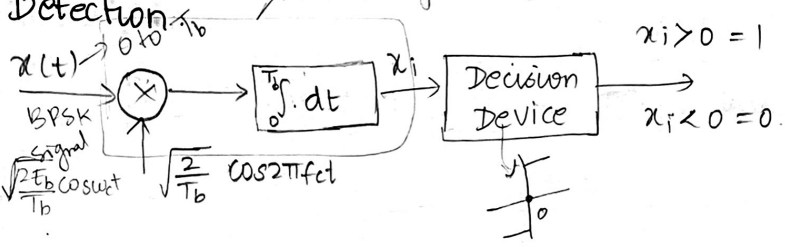
Generation.



Detection



for 1,

$$= \int_{T_b} \sqrt{\frac{2E_b}{T_b}}\cos\omega_c t \times \sqrt{\frac{2E_b}{T_b}}\cos\omega_c t$$

in BPSK a carrier carrying 1 bit

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

$$= \frac{2\sqrt{E_b}}{T_b}\int_0^{T_b}\frac{1-\cos 2\omega_c t}{2}\cdot dt$$

$$= \frac{2\sqrt{E_b}}{T_b}\left[\int_0^{T_b}\frac{1}{2}\cdot dt\right] - \int_0^{T_b}\cos 2\omega_c t \cdot dt$$

harmonics.

$$= \frac{2\sqrt{E_b}}{T_b}\times\frac{1}{2}\left[t\right]_0^{T_b}$$

$$= \frac{\sqrt{E_b}}{T_b}\cdot T_b = \sqrt{E_b}$$

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PROBABILITY OF ERROR IN BPSK.

$$P_E = P_0 P_{10} + P_1 P_{01}$$

Propability of occurence of $P_0, P_1 = 1/2$.

$$P_E = \frac{1}{2}\left[P_{10} + P_{01}\right]$$

$1 \rightarrow \sqrt{E_b}$.

$0 \rightarrow -\sqrt{E_b}$

Assume symbol 0 was transmitted but the decision region is associated with symbol 1. The probability density function of i/p of the decision device,

P_{10}

$$f\left(x_i/0\right) = \frac{1}{\sigma_0\sqrt{2\pi}} \exp\left[\frac{-(x_i - (-\sqrt{E_b}))^2}{2\sigma_0^2}\right]$$

$$= \frac{1}{\sigma_0\sqrt{2\pi}} \exp\left(\frac{-(x_i + \sqrt{E_b})^2}{2\sigma_0^2}\right)$$

σ_0^2 = Noise Power $= \frac{N_0}{2}$.

$$f\left(\frac{x_i}{0}\right) = \frac{1}{\sqrt{\frac{N_0}{2}}\sqrt{2\pi}} \exp\left(\frac{-(x_i + \sqrt{E_b})^2}{2\,\frac{N_0}{2}}\right)$$

$$= \frac{1}{\sqrt{\frac{N_0}{2}}\sqrt{2\pi}} \exp\left(\frac{-(x_i + \sqrt{E_b})^2}{N_0}\right)$$

$$P_{10} = \int_0^\infty f\left(\frac{x_i}{0}\right) \cdot dx_i$$

$$P_{10} = \frac{1}{\sqrt{\pi N_0}} \int_0^\infty \exp\left[\frac{-(x_i + \sqrt{E_b})^2}{N_0}\right] \cdot dx_i$$

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

$$= \frac{\sqrt{N_0}}{\sqrt{\pi}\sqrt{N_0}} \int_{-}^\infty \exp(-z^2) \cdot dz$$

$$z = \frac{x + \sqrt{E_b}}{\sqrt{N_0}}$$

$$dz = \frac{dx_i}{\sqrt{N_0}}$$

$$dx_i = \sqrt{N_0} \cdot dz$$

when $x_i \rightarrow 0$ $\quad z \rightarrow \frac{\sqrt{E_b}}{N_0}$

when $x_i \rightarrow \infty$ $\quad z \rightarrow \infty$

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RT
P 01

$$= \frac{1}{\sqrt{\pi}} \int_{\sqrt{\frac{E_b}{T_b}}}^{\infty} \exp(-z^2) \cdot dz.$$

$$\operatorname{erfc}(u) = \frac{2}{\sqrt{\pi}} \int_{\sqrt{E_b}}^{\infty} \exp(-y^2) \cdot dy.$$

$$P_{10} = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$$

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

$$P_E = \frac{1}{2} \operatorname{erfc}(\sqrt{SNR})$$

$$P_{01} = \int_{-\infty}^{0} f\left(x_i / 1\right) dx_i$$

$$P_{01} = 1 - \int_{0}^{\infty} \exp\left(\frac{-(x_i - \sqrt{E_b})^2}{N_0}\right) \cdot dx_i$$

$$z = \frac{x_i - \sqrt{E_b}}{\sqrt{N_0}} \quad ; \quad \sqrt{N_0} \cdot z = x_i - \sqrt{E_b}$$

$$\sqrt{N_0} \cdot dz = dx_i$$

when

$x_i \to 0 \quad z \to -\frac{\sqrt{E_b}}{\sqrt{N_0}}$

$x_i \to \infty, \quad z \to \infty$

$$P_{01} = 1 - \frac{\sqrt{N_0}}{\sqrt{\pi N_0}} \int_{-\sqrt{\frac{E_b}{N_0}}}^{\infty} e^{-x^2} \cdot dz$$

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

$$\operatorname{erfc}(-x) = 2 - \operatorname{erfc}(x)$$

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

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

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Pass band → modulated Signal.

$$P_{01} = \frac{1}{2} \operatorname{erfc}\sqrt{\frac{E_b}{N_0}}$$

$$\operatorname{erfc}(u) = \int_u^{\infty} e^{-z^2} \cdot dz$$

∴ In BPSK, bit rate = baud rate

QUADRATURE PHASE SHIFT KEYING (QPSK)

Quad → 4

M → no of carriers available.

N → no of bits to be grouped.

a carrier carrying 2 bits in QPSK

$M = 2^N$ I/P → 0, 1 bits.

1 0 1 1 1 0 0 1

Symbol

10 => Tx'r C-1 (Carrier 1)

01 => Tx' C-2

00 => Tx' C-3

11 => Tx' C-4.

Order of modulation "higher is the order of modulation higher the data rate"

8PSK > QPSK > BPSK

Symbol is a grp of bit.

Bit rate : no of bits transmitted per second.

Baud rate : no of symbols transmitted per second.

8-PSK

In 8-PSK there are 8 carriers are available

$M = 2^N$.

$8 = 2^3$ $N = 3$.

In 8-PSK a carrier carrys 3 bits

In 16-PSK a carrier carrys 4 bits

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QPSK (Quadrature Phase Shift Keying)

Tx'd QPSK is given by

$$S_i(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left(\omega_c t + (2i-1)\frac{\pi}{4}\right)$$

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left(\omega_c t + \frac{\pi}{4}\right)$$

$$S_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left(\omega_c t + \frac{3\pi}{4}\right)$$

$$S_3(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left(\omega_c t + \frac{5\pi}{4}\right)$$

$$S_4(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left(\omega_c t + \frac{7\pi}{4}\right)$$

$\overset{C_1}{\frac{\pi}{4}}$, $\overset{C_2}{\frac{3\pi}{4}}$, $\overset{C_3}{\frac{5\pi}{4}}$, $\overset{C_4}{\frac{7\pi}{4}}$. phase shift is multiples of $\pi/4$.

Phase difference of two carrier is $\frac{\pi}{2}$ (90°)

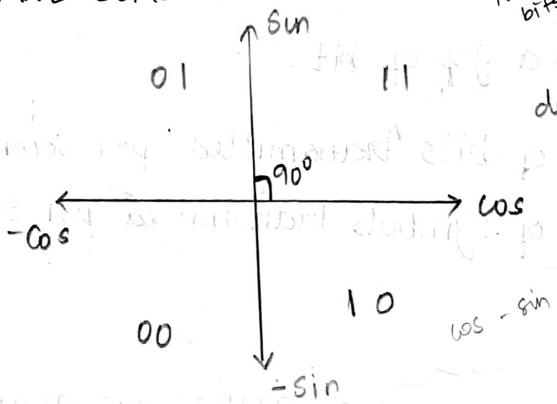
1 2 3 4 5 6 7 8

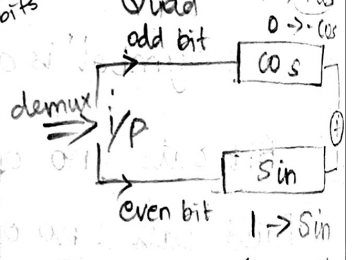
1 0 1 1 1 0 0 1

odd → 1110, even → 0101

Position bits

SIGNAL CONSTELLATION.





2-parallel BPSK
QPSK,

Higher the order of modulation higher the bit rate also higher the error rate due to the complexity of receiver.

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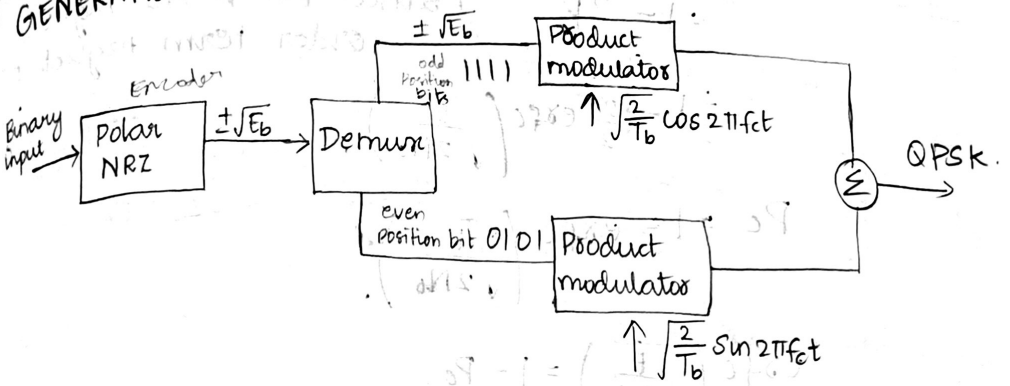
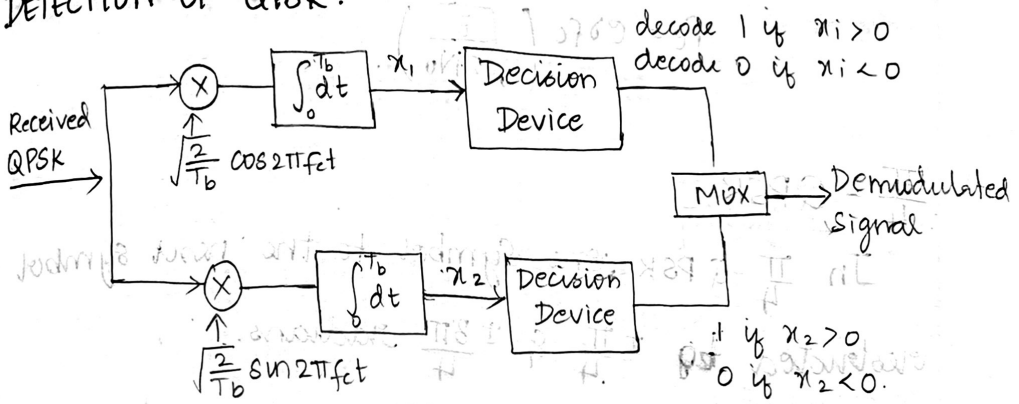
1011101

GENERATION OF QPSK.



DETECTION OF QPSK.



PROBABILITY OF ERROR FOR QPSK.

$2^2 \Rightarrow$ Symbol 2 bit

Let E be the Symbol energy and E_b be the bit energy. In QPSK $E = 2E_b$.

$$E_b = \frac{E}{2}.$$

Average Probability of error of each channel (2 channel) is P',

$$P' = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right) = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E}{2N_0}}\right)$$

Correlator decision is the combined effect of two channels

P_c is the probability of taking correct decision.

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

$$= (1 - P')^2$$

$$= 1 - 2P' + (P')^2$$

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PSK, QPSK, BFSK, QAM

$= 1 - 2p'$ (since p'^2 is the higher order term neglect p'^2)

$$\doteq 1 - \frac{2}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E}{2N_0}}\right).$$

$P_c + P_e = 1$

$$P_c = 1 - \mathrm{erfc}\left(\sqrt{\frac{E}{2N_0}}\right).$$

$$\mathrm{erfc}\left(\sqrt{\frac{E}{2N_0}}\right) = 1 - P_c.$$

$$P_e = \mathrm{erfc}\left(\sqrt{\frac{E}{2N_0}}\right).$$

$\frac{\pi}{4}$ - QPSK

In $\frac{\pi}{4}$-QPSK, one symbol to the next symbol is restricted to $\pm\frac{\pi}{4}$ & $\pm\frac{3\pi}{4}$ radians.

$\cos(2\pi f_c t + \frac{\pi}{4})$

$00 \rightarrow \frac{\pi}{4}$ $\quad 10 \rightarrow -\frac{\pi}{4}$

$\cos(2\pi f_c t + 3\pi/4)$

$01 \rightarrow \frac{3\pi}{4}$ $\quad 11 \rightarrow -\frac{3\pi}{4}$.

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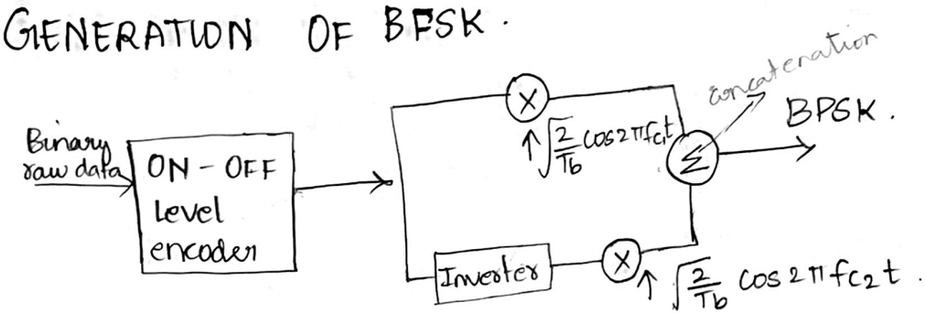
BFSK (Binary Frequency Shift Keying)

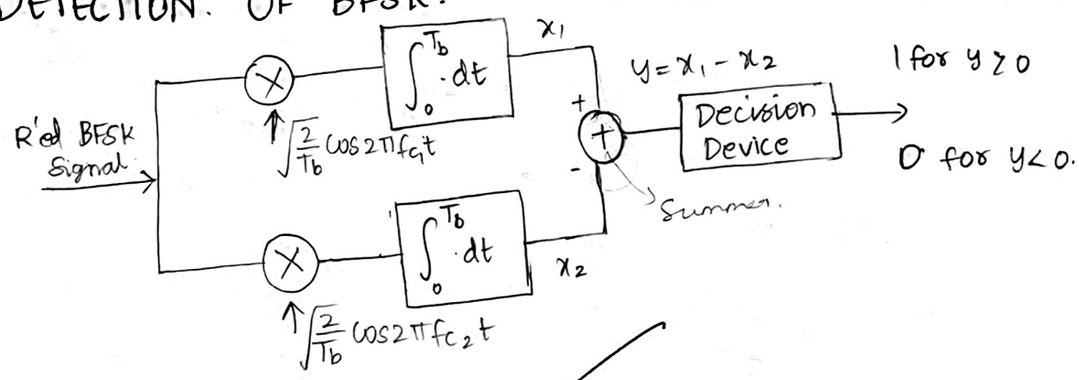
Carrier - 1 $\Rightarrow \sqrt{\frac{2}{T_b}} \cos 2\pi f_{c_1} t \longrightarrow 1$

Carrier - 2 $\Rightarrow \sqrt{\frac{2}{T_b}} \cos 2\pi f_{c_2} t \longrightarrow 0.$

GENERATION OF BFSK.



DETECTION OF BFSK.



PROBABILITY ERROR FOR BFSK.

$$P_E = P_0 P_{10} + P_1 P_{01}$$

$$P_E = \frac{1}{2}\left[P_{10} + P_{01}\right].$$

P_{10}

Assume that binary 0 was transmitted but the received bit is associated with symbol 1.

The variance of the received signal is given by the variance of channel 1 & channel 2

$$\text{Noise power} = \sigma_0^2 = \frac{N_0}{2} + \frac{N_0}{2} = N_0$$

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$$P_{10} = \int_0^{\infty} f\left(\frac{x_i}{0}\right) \cdot dx_i$$

$\sigma_0^2 = N_0$

$\sigma_0 = \sqrt{N_0}$

$$f\left(\frac{x_i}{0}\right) = \frac{1}{\sigma_0 \sqrt{2\pi}} \exp\left(\frac{-(x_i + \sqrt{E_b})^2}{2\sigma_0^2}\right)$$

$0 \to -\sqrt{E_b}$

$1 \to \sqrt{E_b}$.

$$= \frac{1}{\sqrt{N_0}\sqrt{2\pi}} \exp\left(\frac{-(x_i + \sqrt{E_b})^2}{2 N_0}\right).$$

$$= \frac{1}{\sqrt{2\pi N_0}} \exp\left(\frac{-(x_i + \sqrt{E_b})^2}{2N_0}\right)$$

$$P_{10} = \frac{1}{\sqrt{2\pi N_0}} \int_0^{\infty} \exp\left(\frac{-(x_i + \sqrt{E_b})^2}{2N_0}\right) \cdot dx_i$$

$$P_{10} = \frac{\sqrt{2N_0}}{\sqrt{2\pi N_0}} \int_{\sqrt{\frac{E_b}{2N_0}}}^{\infty} \exp(-z^2) \cdot dz.$$

$$z = \frac{x_i + \sqrt{E_b}}{\sqrt{2N_0}}$$

$$dz = \frac{dx_i}{\sqrt{2N_0}}$$

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

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

when $x_i \to 0$ $z = \frac{\sqrt{E_b}}{\sqrt{2N_0}}$

$$\operatorname{erfc}(u) = \frac{2}{\sqrt{\pi}} \int_u^{\infty} \exp(-y^2) \cdot dy$$

when $x_i \to \infty$ $z \to \infty$

$$P_{10} = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{2N_0}}\right).$$

$$P_{01} = \int_{-\infty}^{0} f\left(\frac{x_i}{1}\right) \cdot dx_i$$

$$= 1 - \int_0^{\infty} \exp\left(\frac{-(x_i - \sqrt{E_b})^2}{2N_0}\right) \cdot dx_i$$

$$P_{01} = 1 - \frac{1}{\sqrt{2\pi N_0}} \int_{-\sqrt{\frac{E_b}{2N_0}}} e^{-x^2} \cdot dz$$

$$z = \frac{x_i - \sqrt{E_b}}{\sqrt{2N_0}}$$

$$\sqrt{2N_0} \cdot z = x_i - \sqrt{E_b}$$

$$\sqrt{2N_0} \cdot dz = dx_i$$

$$\operatorname{erfc}(-x) = 2 - \operatorname{erfc}(x)$$

when

$x_i \to 0$ $z \to \frac{-\sqrt{E_b}}{\sqrt{2N_0}}$

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

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

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$$P_{01} = \frac{1}{2} \operatorname{erfc} \sqrt{\frac{E_b}{2N_0}}$$

$$P_E = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{SNR}{2}}\right).$$

29/10/20

MODULATION TECHNIQUE	PROBABILITY OF ERROR
BPSK	$\frac{1}{2} \operatorname{erfc}(\sqrt{SNR})$
QPSK	$\operatorname{erfc}\left(\sqrt{\frac{E}{2N_0}}\right)$
BFSK	$\frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{SNR}{2}}\right)$

QUADRATURE AMPLITUDE MODULATION (QAM) QPSK + PAM

Mathematical expression,

The transmitted QAM signal is given by,

$$S_k(t) = \sqrt{\frac{2E_b}{T_b}}\, a_k \cos 2\pi f_c t - \sqrt{\frac{2E_b}{T_b}}\, b_k \sin 2\pi f_c t \quad \text{—(1)}$$

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

$\phi_2(t) = \sqrt{\frac{2}{T_b}} \sin 2\pi f_c t$.

$a_k = a$

$b_k = 3a$

$a_k = \sqrt{E_b}$

4-QAM ⇒ 4 carriers

$\sqrt{M} = L$

M → no of carriers

L → no of amplitude levels

a - 00

3a - 01

a - 11

3a - 10

rewritting (1), we get

$$S_k(t) = \sqrt{E_b}\, a_k \phi_1(t) - \sqrt{E_b}\, b_k \phi_2(t) \quad 0 < t < T_b.$$

M- QAM

For a M-QAM system, the no of distinct amplitude levels is given by.

$$\sqrt{M} = L$$

where M → no. of carriers

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for 4 - QAM

$\sqrt{4} = 2$

$L = 2$

So the two amplitude levels are $a, 3a$.

where $a = \sqrt{E_b}$

for 16 - QAM

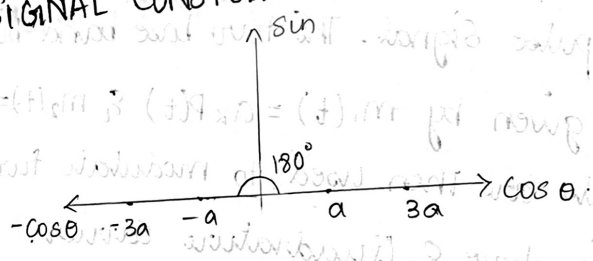
$\sqrt{16} = L$

$L = 4$

So the four amplitude levels are $\pm a, \pm 3a$

where $a = \sqrt{E_b}$

SIGNAL CONSTELLATION FOR 4-QAM.



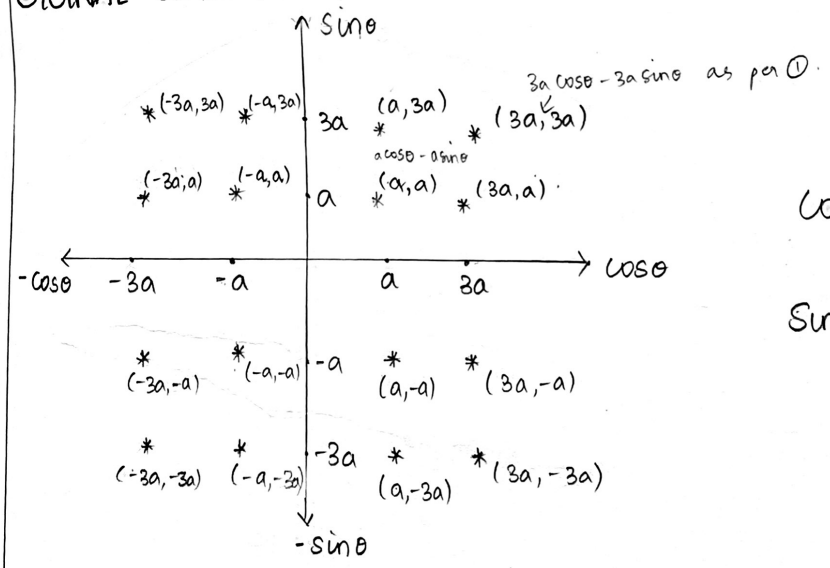
00 → $a\cos\theta$

01 → $-a\cos\theta$

11 → $3a\cos\theta$

10 → $-3a\cos\theta$.

SIGNAL CONSTELLATION FOR 16-QAM.



Cos carrier → Inphase Carrier

Sin carrier → Quadrature Carrier

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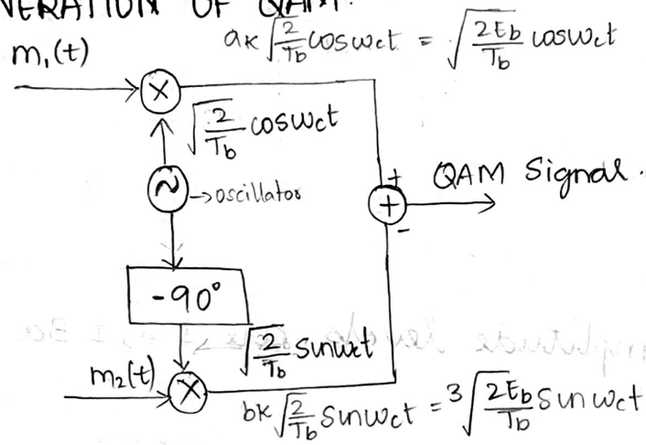
Modulation scheme that uses two carrier signals of same frequency but inphase and quadrature phase of carrier signal are independently amplitude modulated by discrete amplitude levels.

GENERATION OF QAM.



QAM Signal $= a_k\sqrt{\frac{2}{T_b}}\cos\omega_c t - b_k\sqrt{\frac{2}{T_b}}\sin\omega_c t$

Generation of QAM is directly based on ① let $P(t)$ be the baseband pulse signal. The two base band binary digital signal are given by $m_1(t) = a_k P(t)$ & $m_2(t) = b_k P(t)$ These digital signals are then used to modulate two carriers which are inphase (cos) & Quadrature (sin) carrier.

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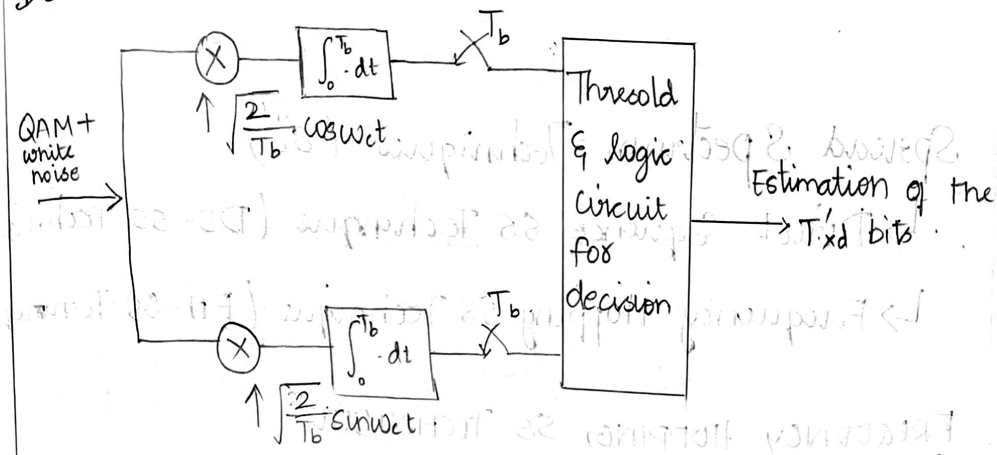
DETECTION OF QAM.



The receiver has two correlation units one for inphase carrier and other for quadrature carrier. The correlator outputs are sampled every ~~after~~ T_b seconds and fed to the threshold device and logic circuit for taking decision on which a_K & b_K are transmitted and then decide on which of the m possible signals has been transmitted during the symbol interval T_b.

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→ Hoffmann Coding → Shannon fano → Block Codes → SS technique
Coding → channel Capacity formula → OFDM

UNIT - 5 : SPREAD SPECTRUM TECHNIQUES.

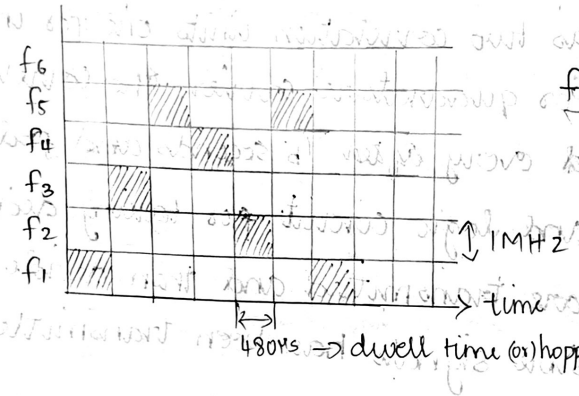
↓
multi band Communication
(or) wide band.

Spread Spectrum Techniques (SS)

↳ Direct Sequence SS Technique (DS-SS Technique)

↳ Frequency Hopping SS Technique (FH-SS Technique)

FREQUENCY HOPPING SS TECHNIQUE.



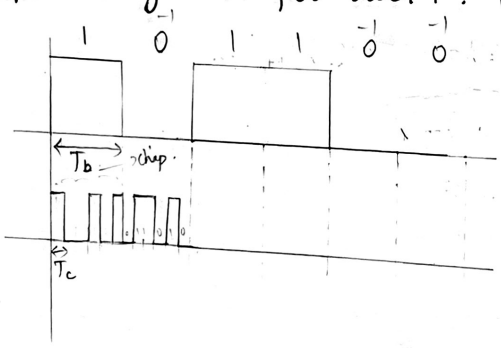
$f_1\ f_3\ f_5\ f_4\ f_2\ f_5\ f_1$
↓
Spreading Code

DIRECT SEQUENCE SS Technique. (CDMA)

Code division multiple access

User 1. Data - 1 0 1 1 0 0

Spreading Code for user 1. 1 0 0 1 0 1 (i.e 1 -1 -1 1 -1 1)



$1 \times (1\ -1\ -1\ 1\ -1\ 1)$
$-1 \times (1\ -1\ -1\ 1\ -1\ 1)$
$1 \times (1\ -1\ -1\ 1\ -1\ 1)$
$1 \times (1\ -1\ -1\ 1\ -1\ 1)$
$-1 \times (1\ -1\ -1\ 1\ -1\ 1)$
$-1 \times (1\ -1\ -1\ 1\ -1\ 1)$

$T_b = N T_c$

$T_b \rightarrow$ bit duration $N \rightarrow$ Code length.

$T_c \rightarrow$ chip duration

$$\text{Gain} = \frac{T_b}{T_c}$$

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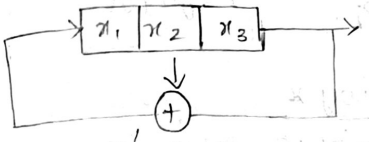
PN Seq

GENERATION OF CODE



$x_1' = x_2 \oplus x_3$

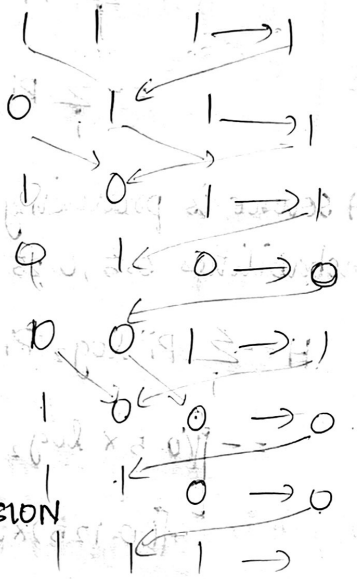
$x_1' = x_2 \oplus x_3$

shift	x_1'	x_1	x_2	x_3
0				
1				
2				
3				
4				
5				
6				
7				

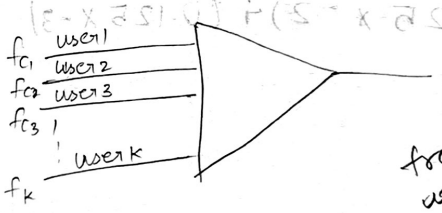
$N = 2^m - 1$

N → length of code.
m → no of shift register

1 1 1 0 1 0 1



ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING. (QAM)



transmitted word or code word → message + parity

V → code words
U → data
G → Generator

CODING TECHNIQUES

→ SOURCE CODING → ASCII (Text) PCM, DPCM, DM (Audio, Video)

→ CHANNEL CODING → Secure data while transmitting
(Generator matrix)

CODE WORD

(Data + parity)

Amount of Information

Entropy (H) is the measure of amount of information per symbol.

Amount of information $\frac{1}{\alpha}$ probability of occurence

$$I = \frac{1}{P}$$

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$$H = \sum_i P_i \log_2 \frac{1}{P_i} \text{ bits/symbol.}$$

$$\log_2 x = \frac{\log x}{\log 2} = \frac{\log x}{0.3010}$$

$$= \sum_i P_i \log_2 (P_i)^{-1}$$

$$= -\sum_i P_i \log_2 P_i$$

1. A source is producing 4 symbols A, B, C & D with probabilities 0.5, 0.25, 0.125 & 0.125

$$H = -\sum_i P_i \log_2 P_i$$

$$= -\{[(0.5 \times \log_2(0.5)) + [0.25 \times \log_2(0.25)] + [0.125 \times \log_2(0.125)] + [(0.125) \times \log(0.125)]\}$$

$$= -[(0.5 \times -1) + (0.25 \times -2) + (0.125 \times -3) + (0.125 \times -3)]$$

$$= 1.75.$$

FIXED LENGTH CODDE WORD.

$U \cdot G = V$.

$V \rightarrow$ Code word.

$U \rightarrow$ data

$G \rightarrow$ Generator matrix

Variable length coding TECHNIQUE

1. Huffmann Coding Technique
2. Shannon fanno Coding Technique

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For problem 1 device binary code using Shannon's Fanno coding technique.

Step 1 : Arrange the symbols in the decreasing order of probability

divide into two halves

	1st level	2nd level	3rd level
A = 0.5	0		
B = 0.25	1	0	
C = 0.125	1	1	0
D = 0.125	1	1	1

	length
Code A = 0	1
Code B = 10	2
Code C = 110	3
Code D = 111	3

Code efficiency $(\eta) = \frac{H}{L}$

Direct
freq hopping
Shannon
Huffman

$L \rightarrow$ average length.

$$L = \sum_i n_i P_i = n_1 P_1 + n_2 P_2 + n_3 P_3 + n_4 P_4$$

$$= 1(0.5) + 2(0.25) + 3(0.125) + 3(0.125)$$

$$= 1.75.$$

Code efficiency $\eta = \frac{H}{L} = \frac{1.75}{1.75} = 100\%.$

HUFFMAN

A discrete memoryless source is described by the alphabets $\{x_1, x_2, x_3, x_4, x_5, x_6\}$ with probabilities $\{1/32, 1/8, 1/2, 1/16, 1/32, 1/4\}$ Design a huffman code for the above source and find the code efficiency.

$\{0.03125, 0.125, 0.5, 0.0625, 0.03125, 0.25\}$.

Step 1 :

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x_3	0.5	0.5	0.5	0.5	0.5
x_6	0.25	0.25	0.25	0.25	0.5
x_2	0.125	0.125	0.125	0.25	
x_4	0.0625	0.0625	0.125		
x_5	0.03125	0.0625			
x_1	0.03125				

Code	length
$x_3 = 1$	1
$x_6 = 01$	2
$x_2 = 100$	3
$x_4 = 1000$	4
$x_5 = 00000$	5
$x_6 = 10000$	5

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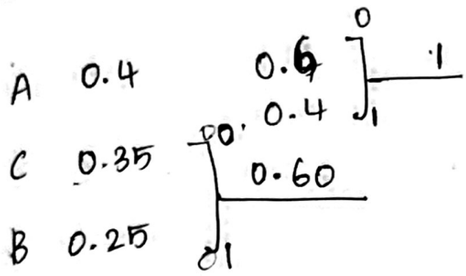
2. A discrete memoryless source produces symbols A, B & C with probability 0.4, 0.25, 0.35 respectively device the Huffman Code for the above source.



A = 1 – 1

B = 01 – 2

C = 00 – 2

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