Unit - 3 & 4 5th SEM MADHURIMA MAM UNIT-IV

① I.T 35/- C.S

DIGITAL MODULATION TECHNIQUE

we know, height of an antenna $h = \lambda/4 = \frac{c}{4f}$.

$\therefore$ as $f \uparrow$, $\lambda \downarrow$ & $h \downarrow$.

Base band signals or message signals are of low frequencies. Less frequencies signals have high power. Hence base band signals can be directly transmitted through co-axial cables or twisted pair of wires. But to transmit base band signals over Radio links or satellite its spectrum has to be shifted to higher frequencies. This is acheived by using base band digital signal to modulate a sinusoidal carrier. This technique is known as Digital carrier modulation or digital pass band communication. They can be transmitted through band pass channel.

3 schemes → 1) ASK : amplitude shift keying
2) FSK : frequency " "
3) PSK : phase " "

These schemes can be implemented by 2 types of technique 1) Coherent 2) Non coherent.

These schemes can be Binary or M-ary.

Binary → out of 2 signals only one can be send.

M-ary → " " M signals " " " " "

$\therefore$ Band width Efficiency $\rho = \frac{R_b}{B} = \frac{\text{data rate (bits/sec)}}{Hz}$,

2

ASK

Input message signal :- bit stream (i.e digital baseband signal).

say, 10 11 00 101

The bit stream b(t) is represented in unipolar NRZ line code i.e 1 → A(V)

0 → 0(V)

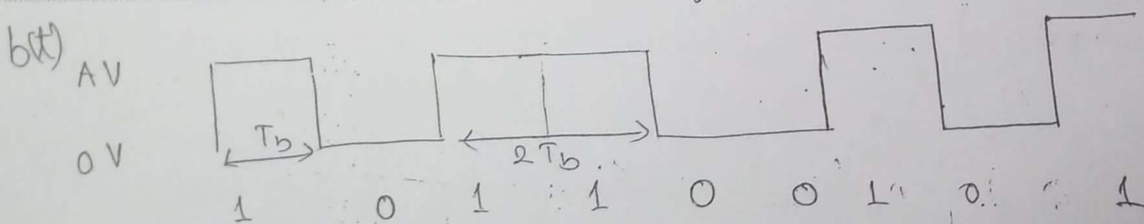
For bit 1 → one type of amplitude will be selected

" 0 → diff " " " " " "

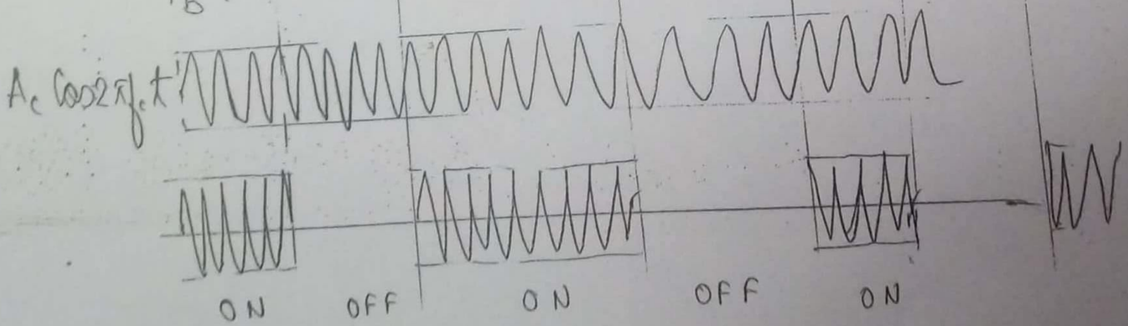
Let the carrier signal $c(t) = A \cos 2\pi f_c t$. ($f_c = \frac{n}{T_b}$)

∴ ASK output modulated wave can be represented as,

$$s(t) = \begin{cases} A \cos 2\pi f_c t \text{ ----- for bit 1} \\ 0 \text{ ----- for bit 0.} \end{cases}$$



T_b : bit duration.



$$\therefore s(t)_{ASK} = b(t)\, A \cos 2\pi f_c t \rightarrow \left\{ b(t) = \begin{cases} 0 \\ 1 \end{cases} \right.$$

The waveform of ASK seems to be ON-OFF, (3)
Hence it is also known as ON-OFF Keying or
OOK.

Now, $c(t) = A_c \cos 2\pi f_c t$

$\therefore$ Power $= P_s = \frac{A^2}{2}$ $\therefore$ $\boxed{A = \sqrt{2P_s}}$

Energy $= E_b =$ Power * Time $= P_s * T_b$.

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

$\therefore \boxed{A = \sqrt{\frac{2E_b}{T_b}} = \sqrt{E_b}\sqrt{2/T_b}}$

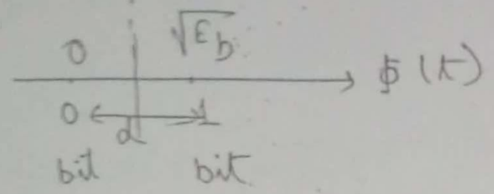
OTHER FORM OF ASK: —

$$s(t) = b(t)\, A \cos 2\pi f_c t$$
$$= b(t) \sqrt{2P_s} \cos 2\pi f_c t$$
$$= b(t) \sqrt{P_s T_b} \sqrt{2/T_b} \cos 2\pi f_c t$$
$$= b(t) \sqrt{P_s T_b}\, \Phi(t)$$
$$= b(t) \sqrt{E_b}\, \Phi(t)$$
$$= \begin{cases} \sqrt{E_b}\, \Phi(t) & \text{— for 1 bit} \\ 0 & \text{— for 0 bit} \end{cases}$$

$\Phi(t)$: carrier function or basis fn.

$\Phi(t) = \sqrt{2/T_b} \cos 2\pi f_c t$.

SIGNAL SPACE DIAGRAM:—



d = Euclidean distance

$= \sqrt{E_b} - 0 = \sqrt{E_b}$.

$= \sqrt{P_s T_b}$

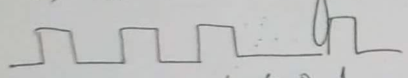
When $\sqrt{E_b}$ is multiplied by $\phi(t)$ we get 1 bit.

when 0 " " " $\phi(t)$ " " 0 bit.

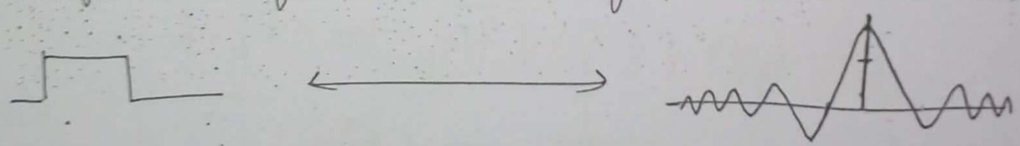
SPECTRUM:—

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

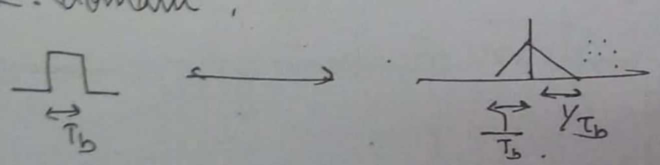
1) b(t) is a set of rectangular functions



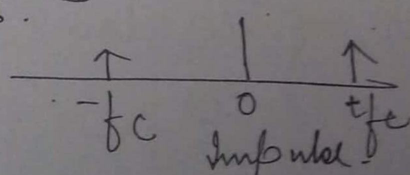
When we take Fourier transforms of rectangular fn. we get Sinc function in freq Domain.



Sinc fn requires ∞ b.w. but ∞ b.w is not possible hence it is pass through B.P.F & we only select the major lobe then we say rectangular fn in time domain produce a traingular fn. in freq. Domain.

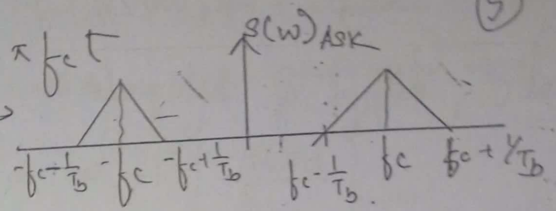


2) $\cos 2\pi f_c t$ ⟷



⑤

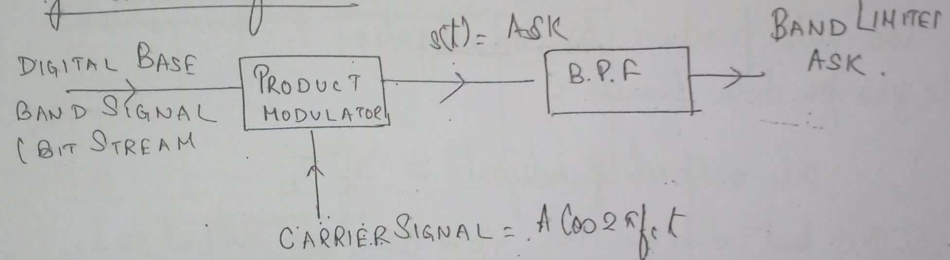
ASK o/p :- $b(t) \cos 2\pi f_c t$



$\therefore$ B.W $= \left(f_c + \frac{1}{T_b}\right) - \left(f_c - \frac{1}{T_b}\right)$

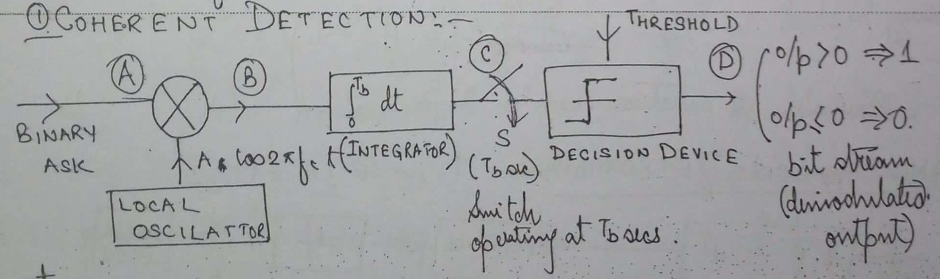
$= \frac{2}{T_b} = 2f.$ when $f = \frac{1}{T_b}.$

Generation of ASK :-



Detection of ASK :-

① COHERENT DETECTION :-



at, ~~A:- unipolar bit~~

at A, binary ASK signal has been received : $b(t) A \cos 2\pi f_c t$
or $b(t) \sqrt{2P_s} \cos 2\pi f_c t.$

at B, after multiplication with carrier (generated from Local oscillator) the o/p is $b(t) A^2 \cos^2 2\pi f_c t$

$= \frac{b(t) A^2}{2} [2 \cos^2 \omega_c t] = \frac{b(t) A^2}{2} (1 + \cos 2\omega_c t).$

(b) at B: $\dfrac{b(t)A^2}{2}\left[1 + \cos 2w_c t\right]$

at C, output of integrator is,

$$\int_0^{T_b} \frac{b(t)A^2}{2}\left[1 + \cos 2w_c t\right] dt$$

$$= b(t)\frac{A^2}{2}\cdot T_b + \int_0^{T_b} \frac{A^2}{2}\cos 2w_c t$$

$\left(w_c = 2\pi f_c = 2\pi \cdot \dfrac{n}{T_b}\right)$

cos will produce sin on integration & sin value will be zero for both limits.

$\therefore$ the output of integrator is $\dfrac{A^2}{2}T_b$.

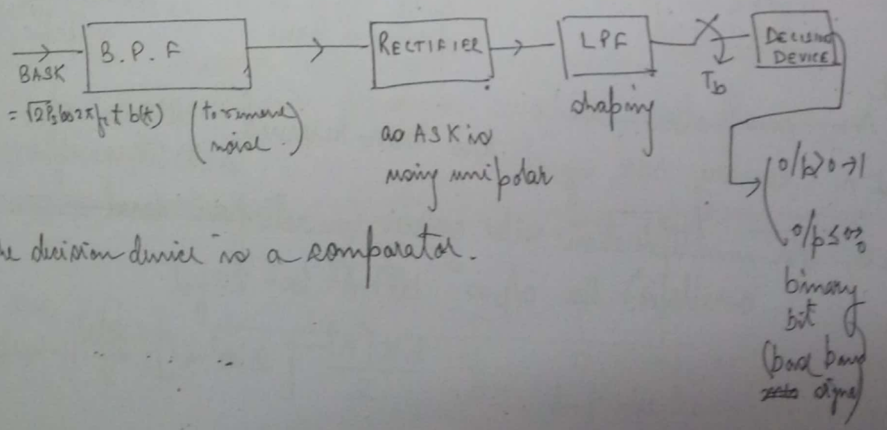
at the last step if the i/p is > 0 then output is 1.

o.w 0. Thus we get a bit stream.

Energy per bit $= \dfrac{E_1 + E_0}{2} = \dfrac{\frac{A^2T_b}{2} + 0}{2} = \dfrac{A^2T_b}{4}$

Threshold at detection can be $\dfrac{A^2T_b}{4}$

② NON COHERENT DETECTION:-



The decision device is a comparator.

FREQUENCY SHIFT KEYING (FSK)

INPUT base band or message signal is digital signal represented in bipolar NRZ format i.e

$b(t) = 1 \; 0 \; 1 \; 1 \; 0 \; 1$: say where

1 : +V & 0 → −V

- Let us introduce 2 unipolar signals (where 1 bit is represented by +1V & 0 with 0V for high logic & for lower logic 1 bit is by 0V & 0 bit with +V.)

b(t) (bit)	d(t)	$P_H(t)$	$P_L(t)$
1	+V	+1 V	0
0	−V	0 V	1 V

(analog value in bipolar format)

In FSK, for 1 bit one type of freq will be used & for 0 bit diff type of freq will be used.

Let $c_1(t) = A_c \cos w_{c_1} t = A_c \cos 2\pi f_{c_1} t \longrightarrow (1)$.

$c_2(t) = A_c \cos w_{c_2} t = A_c \cos 2\pi f_{c2} t \longrightarrow 0$

where $f_{c1} > f_{c2}$ say & $f_{c1} = n/T_b$ & $f_{c2} = \frac{n}{T_b}$.

∴ FSK modulated waveform is,

$$s(t) = \begin{cases} b(t).\ A_c \cos w_{c_1} t \longrightarrow 1 \text{ bit} \\ b(t)\ A_c \cos w_{c_2} t \longrightarrow 0 \text{ ''} \end{cases}$$

$$= \begin{cases} P_H(t)\ A_c \cos w_{c_1} t \longrightarrow 1 \text{ bit} \\ P_L(t)\ A_c \cos w_{c2} t \longrightarrow 0 \text{ ''} \end{cases}$$

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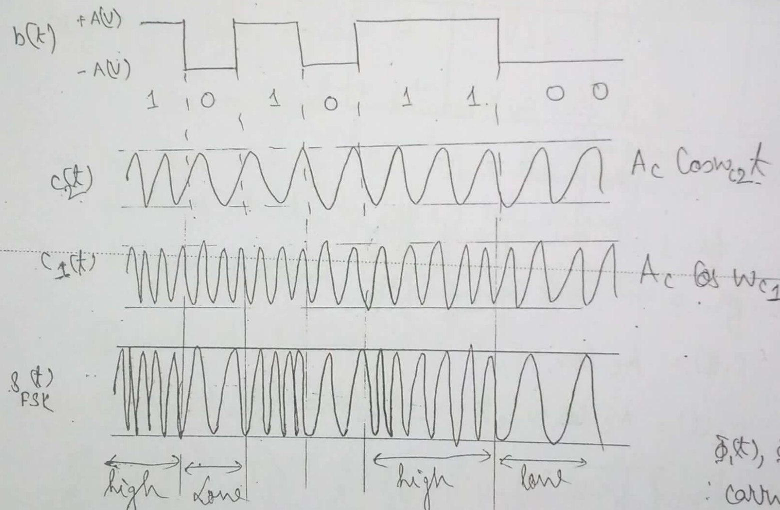
$$s(t) = \begin{cases} P_H(t)\sqrt{2P_s}\cos w_{c1}t \rightarrow 1 \\ P_L(t)\sqrt{2P_s}\cos w_{c2}t \rightarrow 0 \end{cases}$$

$$= \begin{cases} P_H(t)\sqrt{2/T_b}\cos w_{c1}t\,\sqrt{E_b} \rightarrow 1 \\ P_L(t)\sqrt{E_b}\,\sqrt{2/T_b}\cos w_{c2}t \rightarrow 0 \end{cases} \qquad \left[\ \sqrt{2P_s} = \sqrt{P_s T_B}\,\sqrt{2/T_b} = \sqrt{E_b}\,\sqrt{2/T_b}\right.$$

$$= \begin{cases} P_H(t)\sqrt{E_b}\,\Phi_1(t) \text{ ——— } 1 \\ P_L(t)\sqrt{E_b}\,\Phi_2(t) \text{ ——— } 0 \end{cases} \qquad \begin{aligned} \Phi_1(t) &= \sqrt{2/T_b}\cos w_{c1}t \\ \Phi_2(t) &= \sqrt{2/T_b}\cos w_{c2}t \end{aligned}$$

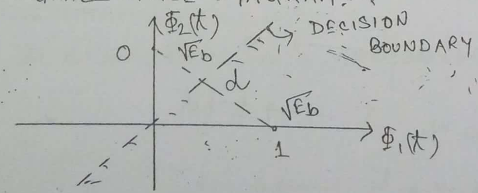
FSK WAVEFORM:—



$\Phi_1(t), \Phi_2(t)$: carrier or basis fn

$$\boxed{s(t) = P_H(t)\sqrt{E_b}\,\Phi_1(t) + P_L(t)\sqrt{E_b}\,\Phi_2(t)}$$

SIGNAL SPACE DIAGRAM:—

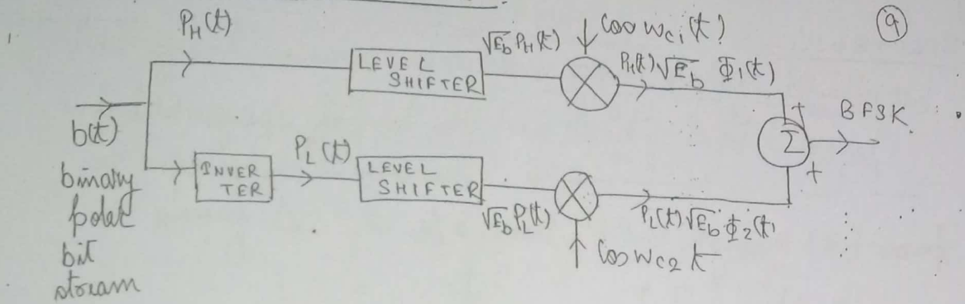


d is the Euclidean dist b/w 0 & 1 bit

$$d^2 = (\sqrt{E_b})^2 + (\sqrt{E_b})^2$$

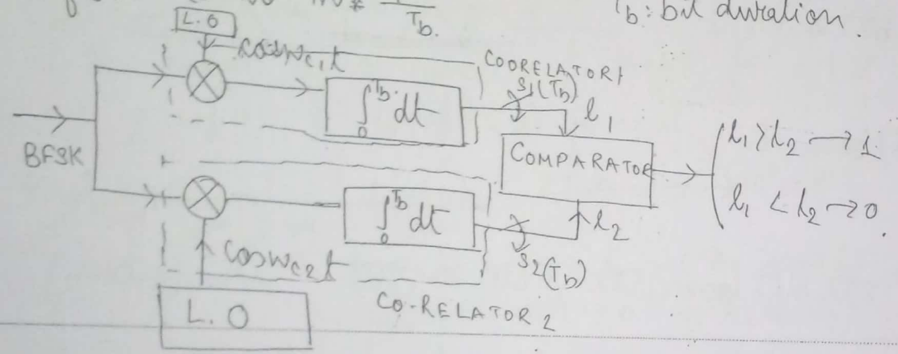
$$\boxed{d = \sqrt{2E_b}}$$

GENERATION OF BFSK :—



DETECTION OF BFSK :—

f_c or w_{c0} is $n * \frac{1}{T_b}$. T_b : bit duration.

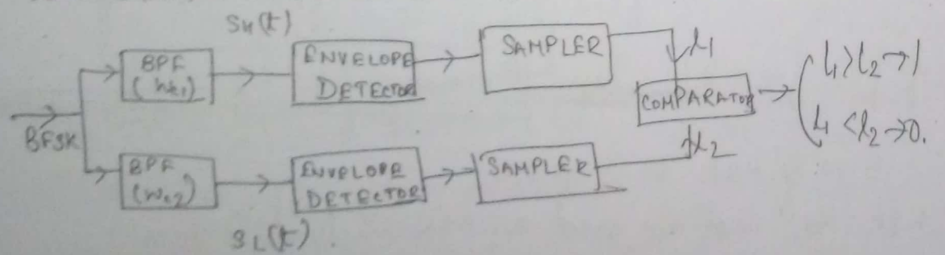


L.O: local oscillator.

BFSK $s(t) = P_H(t) \cos w_{c1} t\, A_c + P_L(t) A_c \cos w_{c2} t = s_H(t) + s_L(t)$

Using multiplier $\cos^2\theta$ is produced $= 1 + \cos 2\theta$
Then integration produces the 1st term as T_b & 2nd term as sin which then vanishes as for 0 & T_b it is zero.

NONCOHERENT DETECTION OF BFSK



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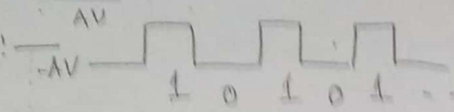
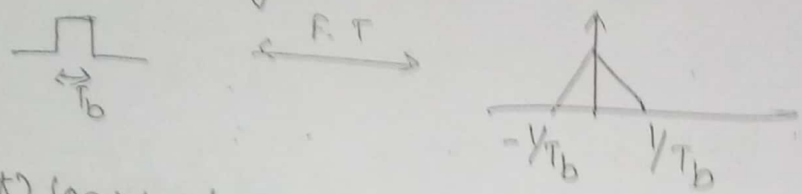
SPECTRUM:-

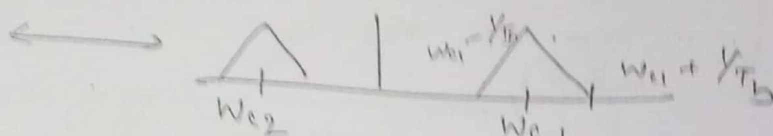
b(t) :-



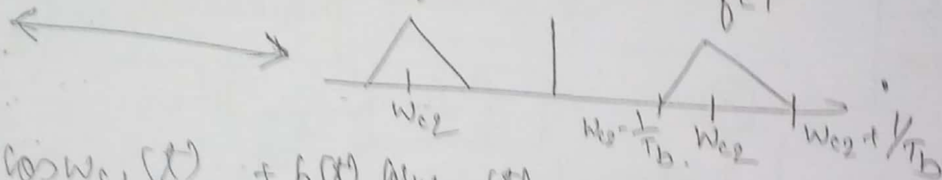
pass b(t) through B.P.F then o/p is Δ form.



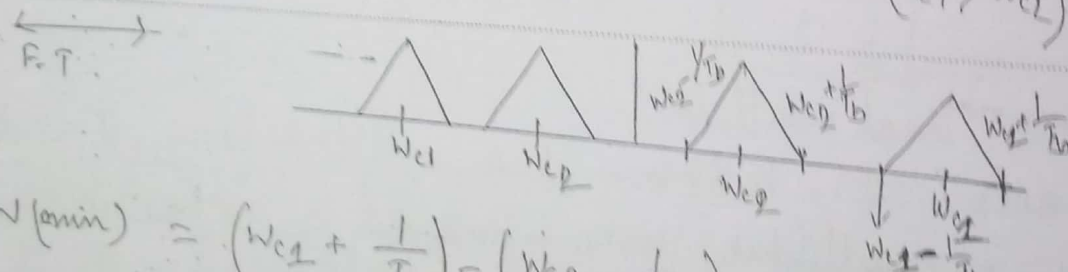
$b(t)\cos w_{c1} t$



$b(t)\cos w_{c2} t$



$\therefore\ s(t) = b(t)\cos w_{c1}(t) + b(t)\cos w_{c2}(t)$ where $(w_{c1} > w_{c2})$



$\therefore$ B.W (min) $= \left(w_{c1} + \frac{1}{T_b}\right) - \left(w_{c2} - \frac{1}{T_b}\right)$

$= w_{c1} - w_{c2} + 2/T_b$

$= f_{c1} - f_{c2} + \frac{2}{T_b} = f_{c1} - f_{c2} + 2f$

If $f_{c1} - f_{c2} = 2f$ then $\boxed{B.W_{min} = 2f + 2f = 4f}$

$\therefore$ B.W of FSK is > ASK

$\therefore$ FSK is not as good as ASK in terms of b.w.

Phase Shift Keying

Most efficient among all techniques. Higher bit rate.
input message signal or base band is digital signal in bipolar NRZ format

$\therefore$ $b(t)$ = 0 1 0 1 1 0 1 say
= {-A A -A A A -A A} Volts.

In PSK, for 1 bit one type of phase will be used
for 0 bit another type of " " "

Let the carrier signal be $c(t) = A_c \cos w_c t$ for 1 bit
& $c(t) = A_c \cos(w_c t + \theta)$ for 0 bit.

Normally the phase difference is taken as 180° or π.

$$\therefore s(t)_{PSK} = \begin{cases} A_c \cos w_c t \longrightarrow 1 \\ A_c \cos(w_c t + 180°) \longrightarrow 0 \end{cases} = \begin{cases} A_c \cos w_c t \\ -A_c \cos w_c t \end{cases}$$

$= d(t)\, A_c \cos w_c t$ $\longrightarrow$ where $d(t) = 1$ or -1

$d(t) = 1$ for 1.
$= -1$ for 0.

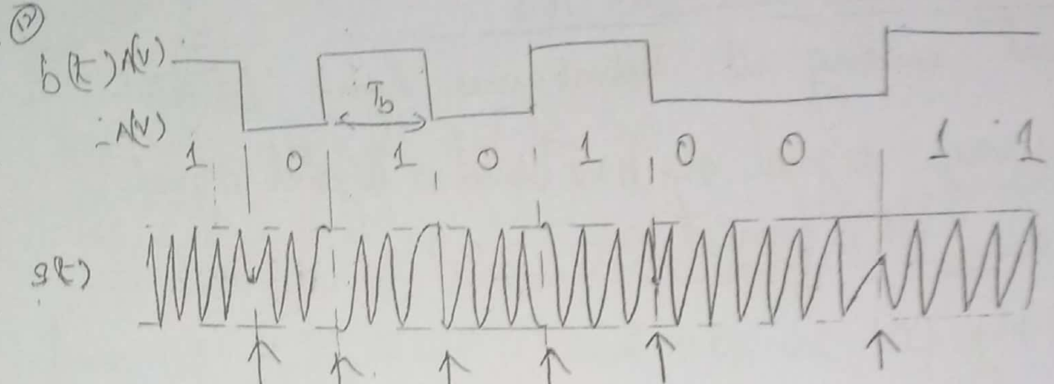
$$\therefore \boxed{\begin{aligned} s(t) &= d(t)\, A_c \cos w_c t \\ &= d(t) \sqrt{2P_s} \cos w_c t \\ &= d(t) \sqrt{E_b}\, \phi(t). \end{aligned}}$$

$\phi(t) = \sqrt{2/T_b} \cos w_c t.$

where $s_1(t) = \sqrt{E_b}\, \phi(t) \longrightarrow$ 1 bit

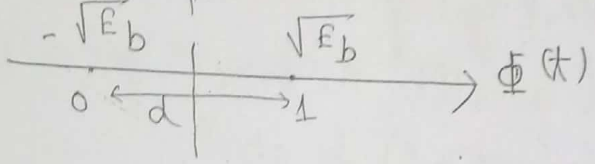
$s_0(t) = -\sqrt{E_b}\, \phi(t) \longrightarrow$ 0 bit

(12)



PHASE REVERSAL POINTS

(8) **SIGNAL SPACE DIAGRAM :-**

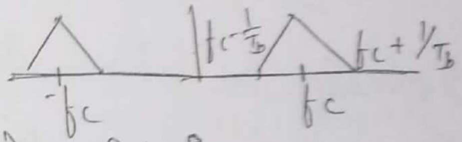


$d = \sqrt{E_b} - (-\sqrt{E_b})$

$= \sqrt{2E_b}$

BANDWIDTH :-

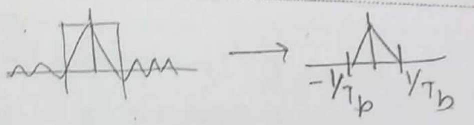
$s(t) = d(t) \cdot A_c \cos 2\pi f_c t \longleftrightarrow$



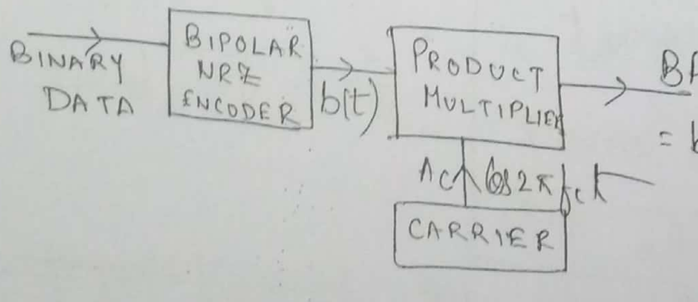
$\therefore B.W = \left(f_c + \frac{1}{T_b}\right) - \left(f_c - \frac{1}{T_b}\right) = 2/T_b = 2f$

where

$d(t) \longleftrightarrow$



GENERATION :-



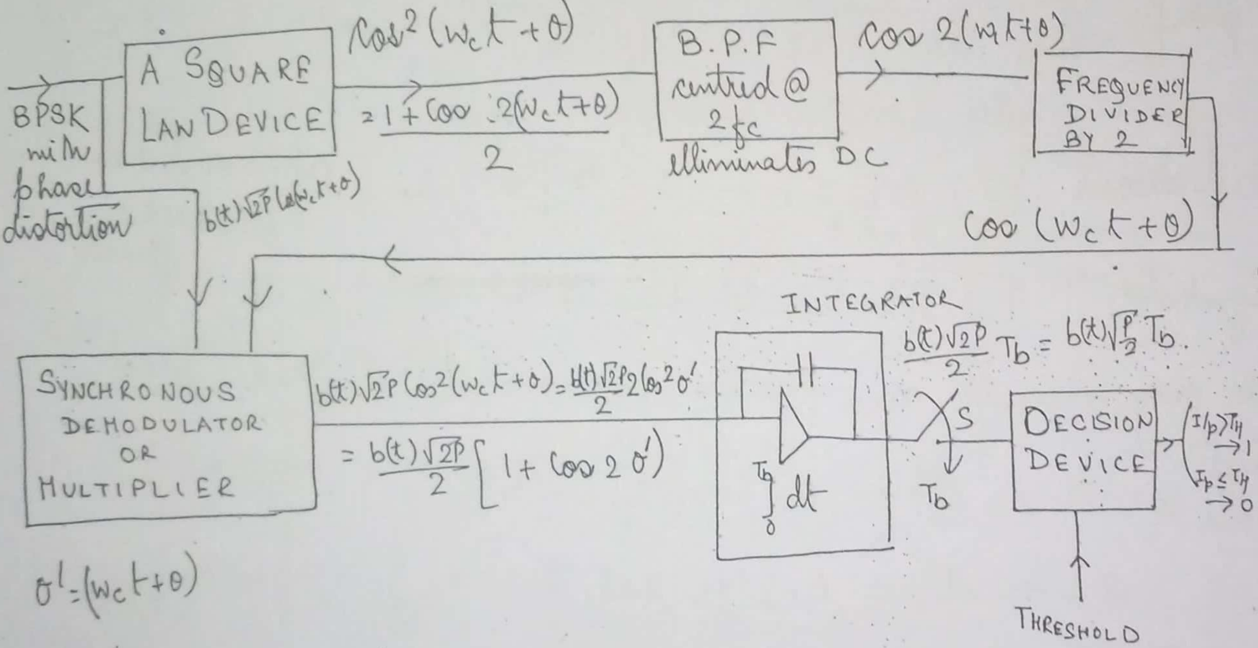
$= b(t)\sqrt{2P_s} \cos 2\pi f_c t$

DEMODULATION OF PSK:-

(13)

Let the PSK received at the receiver has phase distortion of $(+\theta)$,

$$s(t)_{BPSK} = b(t)\sqrt{2P}\cos(w_c t + \theta).$$



$\theta' = (w_c t + \theta)$

QUADRATURE PHASE SHIFT KEYING

The digital modulation techniques will be an efficient technique if the channel bandwidth is fully used. It is improved by used QPSK & MSK (minimum shift Keying).

In binary PSK we transmitt only 1 bit ⟶ ⊓ ⟷ for

Hence only one of 2 possible signals is transmitted during bit time interval T_b.

In M-ary any one out of M possible signals will be transmitted

In QPSK any " " 4 " " " " "

No. of possible signals $M = 2^n$

If $n = 1 \rightarrow M = 2$ Binary

$n = 2 \rightarrow M = 4$ Quad.

(13) In QPSK instead of sending 1 bit within the time we will send 2 bits and instead of 2 signals, any one signal will be sent out of 4 signals.

Using 2 bits 4 states or 4 symbols can be generated.

phase $\left[\begin{array}{l} \Phi = 180^\circ \\ \frac{\Phi}{4} = \frac{180}{4} = 45^\circ = \pi/4. \end{array}\right.$ → 4 symbols $\begin{bmatrix} 00 \\ 01 \\ 10 \\ 11 \end{bmatrix}$

bit stream 1 0 ; 0 ; 1 ; 1 ; 1 ; 0 ; 0 ; 1 represented in polar NRZ format

T_b.

Symbols $\boxed{0\ 0}$ $\boxed{1\ 1}$ $\boxed{1\ 0}$ $\boxed{0\ 1}$

We may transmit one carrier signals with different phase shifts.

$s(t)_{QPSK} =$ $00 \rightarrow s(t) = A_c \cos(2\pi f_c t - 3\pi/4)$

$01 \rightarrow s(t) = A_c \cos(2\pi f_c t - \pi/4)$

$10 \rightarrow s(t) = A_c \cos(2\pi f_c t + \pi/4)$

$11 \rightarrow s(t) = A_c \cos(2\pi f_c t + 3\pi/4)$

$\boxed{s(t) = A_c \cos(2\pi f_c t + \Phi(t))}$ $\Phi(t) = \{\pm 3\pi/4, \pm \frac{\pi}{4}\}$.

$\Phi(t)$ is the instantaneous phase value.

$s(t)_{QPSK}$ can also be represented as,

$$s(t)_{QPSK} = b_o(t) A_c \cos w_c t + b_e(t) A_c \sin w_c t.$$

where o: odd & e: even.

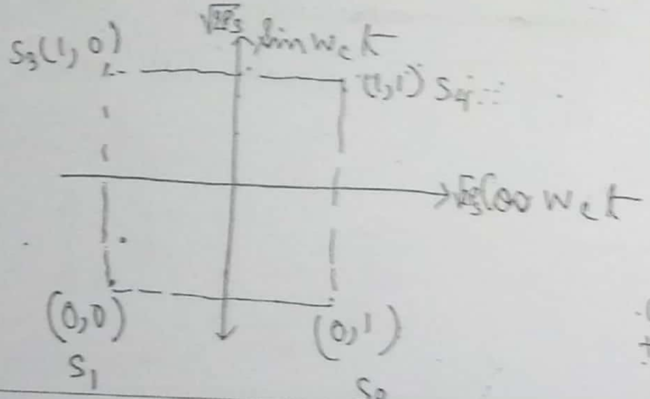
$b(t)$: 0 1 0 1 1 0 1 1 0

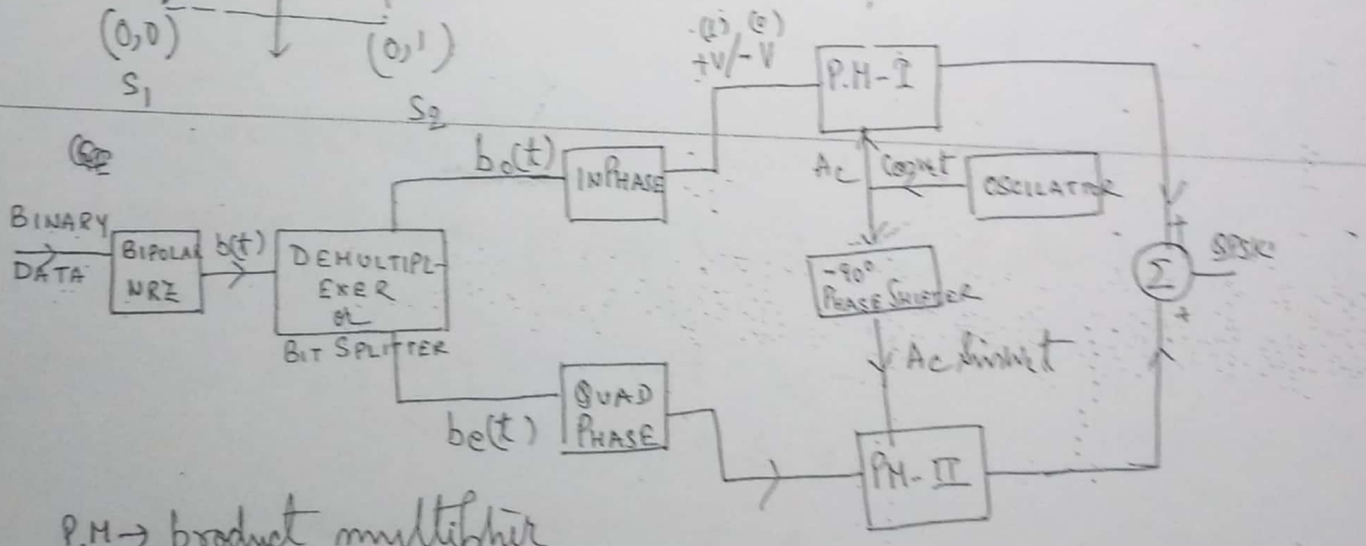
-V +V -V - - - - - - -

even odd.

GENERATION OF QPSK :-

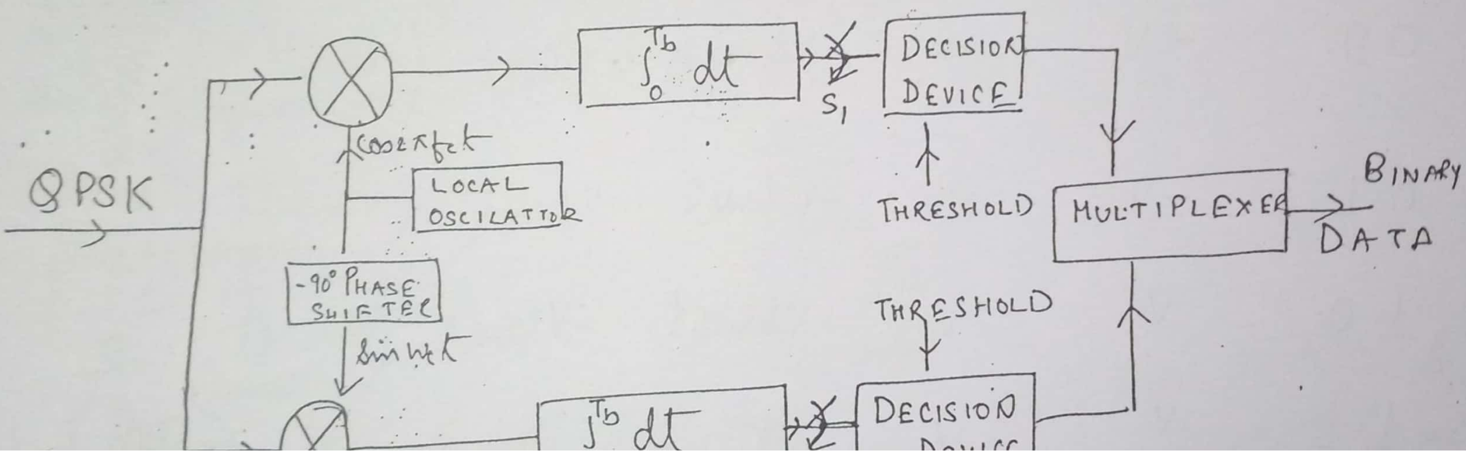
SYMBOL	$b_e(t)$	$b_o(t)$	PM-2	PM-1	O/P	QUADRANT
S_1 0 0	$-V$	$-V$	$-V \sin w_c t$	$-V \cos w_c t$	$(-V \sin w_c t - V \cos w_c t)$	3
S_2 0 1	$-V$	V	$-V \sin w_c t$	$+V \cos w_c t$	$(-V \sin w_c t + V \cos w_c t)$	4
S_3 1 0	V	$-V$	$V \sin w_c t$	$-V \cos w_c t$	$(V \sin w_c t - V \cos w_c t)$	2
S_4 1 1	V	V	$V \sin w_c t$	$V \cos w_c t$	$V(\sin w_c t + \cos w_c t)$	1





P.M → product multiplier

(16) QPSK RECEIVER :—



LINE CODING

Digital data can be transmitted by various transmission of line codes such as ON-OFF, polar, bipolar & so-on. This is line coding. For any line code the transmission bandwidth is less & probability of error of transmitting data is minimum.

① UNIPOLAR NON RETURN TO ZERO (UNIPOLAR NRZ):—

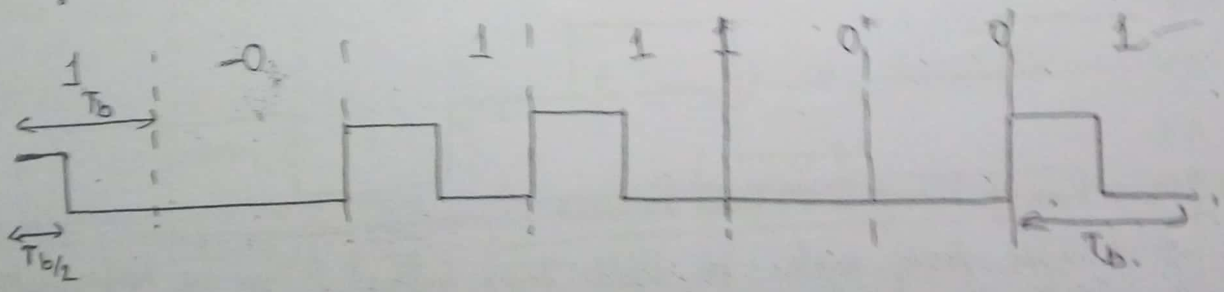
bit): 1 0 1 1 0 1 0 0 (say)

Here 1 represent A volts & 0 represents 0 volts for entire bit duration T_b say,

② UNIPOLAR RETURN TO ZERO (UNIPOLAR RZ):—

1 represents A volts for half bit duration & other half duration its value is 0 V.

$$1 = \begin{cases} A(V) & \cdots\ 0 < t < T_b/2 \\ 0(V) & T_b/2 \le t \le T_b \end{cases}$$

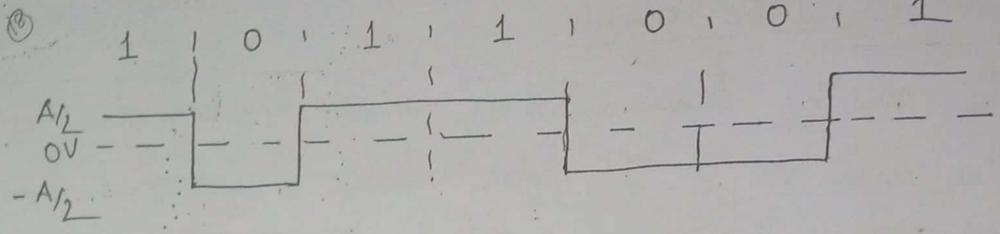


③ POLAR NRZ:—

$1 \rightarrow A/2\ V$ for T_b duration

$0 \rightarrow -A/2\ V$ for T_b "

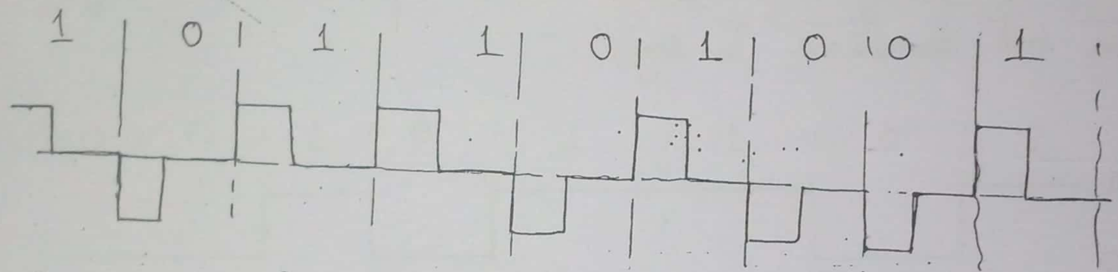
③



④ POLAR RETURN TO ZERO (POLAR RZ) :—

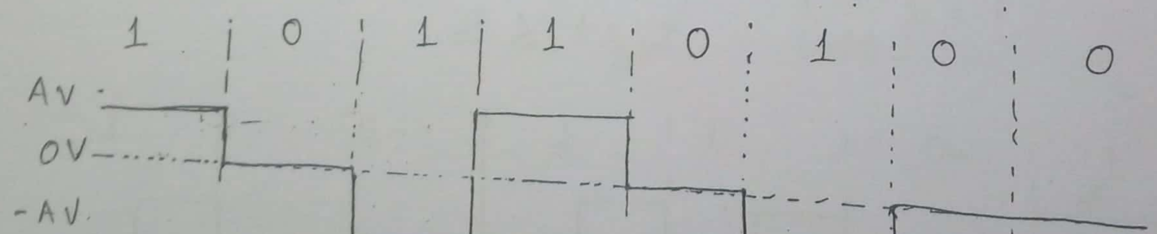
$1 \rightarrow \begin{cases} A/2 \text{ (volt)} & \text{for } 0 \leq t \leq T_b/2 \\ 0 \text{ (volt)} & T_b/2 \leq t \leq T_b \end{cases}$

$0 \rightarrow \begin{cases} -A/2 \text{ (volt)} & \text{for } 0 < t \leq T_b/2 \\ 0 \text{ (volt)} & T_b/2 \leq t \leq T_b \end{cases}$



⑤ BIPOLAR NON RETURN ZERO (BIPOLAR NRZ) or ALTERNATE MARK INVERSION (AMI) :—

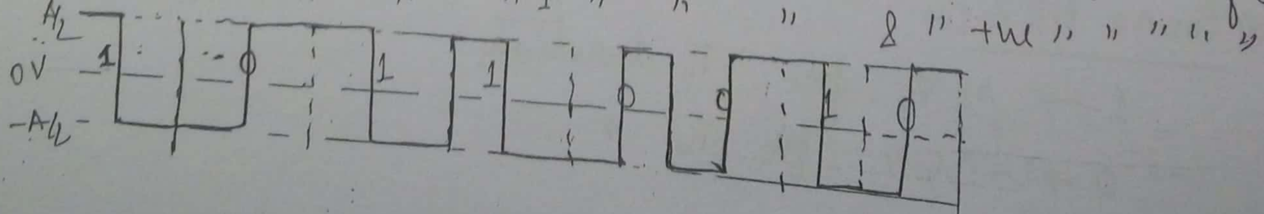
First 1 → A V for entire bit duration T_b.
Second 1 → -A V for " " " T_b.
0 bit → 0 V " " " " "



⑥ SPLIT PHASE MANCHESTER FORMAT :—

1 → +ve half cycle for half time interval & then -ve half cycle for 2nd half T_b

0 → -ve " " " 1st " " " & " +ve " " " " "



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INFORMATION AND CODING THEORY

If the rate of information from a source doesn't exceed the capacity of a given communication channel, then there exists a coding technique such that ~~the~~ information can be transmitted over the channel with arbitrary small freq. errors, despite the presence of noise.

INFORMATION MEASURE:-

Let us consider an information source emitting n possible symbols messages $m_1, m_2 \ldots m_n$ with probability of occurrence $p_1, p_2 \ldots p_n$ resp.

Let the information content in the k^{th} message or symbol $= I(m_k)$

Amount of information is inversely proportional to probability of occurrence of the message or symbol

$$I(m_k) \propto \frac{1}{p(m_k)}.$$

Let $p(m_k) : p_k$.

1) $I(m_k) = \log_b \frac{1}{p(m_k)} = -\log_b p(m_k)$

2) $I(m_k) = 0$ for $p(m_k) = 1 = p_k$.

$I(m_k) \geq I(m_j)$ if $p_k < p_j$

$I(m_k, m_j) = I(m_k) + I(m_j)$ if m_k & m_j are independent.

3) $I(m_k) \geq 0$ for $0 \leq p_k \leq 1$

Unit of $I(m_k)$ is bits if $b = 2$
is hartley or decit if $b = 10$
is nat or natural if $b = e$

UNIT	Bits (base-2)	Nats (base e)	Decits (base 10)
Bit (base-2)	—	$1\,bit = \frac{1}{\log_2 e} = 0.6932\,nats$	$1\,bit = \frac{1}{\log_2 10} = 0.3010\,decit$
NATS (base e)	$1\,nat = \frac{1}{\ln 2} = 1.44266\,bits$	—	$1\,nat = \frac{1}{\ln 10} = 0.4342\,decit$
DECIT (base 10)	$1\,decit = \frac{1}{\log_{10} 2} = 3.3219\,bits$	$1\,decit = \frac{1}{\log_{10} e} = 2.3026\,nats$	

$$\log_2 a = \frac{\log a}{\log 2} = \frac{\ln a}{\ln 2}$$

Q. A source generates one of 4 possible messages during each interval with probabilities $p_1 = \frac{1}{2}$, $p_2 = \frac{1}{4}$, $p_3 = p_4 = \frac{1}{8}$. Find the information content in each of these messages.

Ans) $I(m_1) = \frac{1}{\log_2(\frac{1}{2})} = -\log_2(\frac{1}{2}) = \log_2(2) = 1\,bit$

$I(m_2) = -\log_2(1/4) = \log_2(4) = 2\,bits$

$I(m_3) = -\log_2(\frac{1}{8}) = \log_2(2^3) = 3\,bits$

$I(m_4) = 3\,bits$

ENTROPY OR AVERAGE INFORMATION.

In any communication system an information source generates long sequence of symbols. Rather than to know information content in a single symbol it is more interesting to know average information generated by that source. To calculate average information certain assumptions are taken:-

(i) The source is stationary so that probabilities remains const with time.

(ii) The successive symbols are statistically independent and come from the source at an average rate of r symbols per sec.

Let source X produce n messages or symbols $m_1, \ldots, m_n$.

Information in k^{th} message $I(m_k)$ or symbol

Probability of occurrence of k^{th} message $=$ ~~log~~ $p_k = P(m_k)$

$\therefore$ Average information per source symbol $=$ mean value of $I(m_k)$

$$= H(X) = E[I(m_k)]$$

$$= \sum_{k=1}^{n} P(m_k)\, I(m_k)$$

$$= \sum p_k \log\left(\frac{1}{P(m_k)}\right) \quad \left[\because I(m_k) = \log\left(\frac{1}{p_k}\right)\right]$$

$$= -\sum p_k \log(p_k) \text{ bits/symbol.}$$

$$\therefore \boxed{H(x) = -\sum_{k=1}^{n} p_k \log(p_k) = H(M),} \text{ bits/symbol}$$

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22

ENTROPY = average information content per symbol

$= H(x)$

$= \sum p_k \log\left(\frac{1}{p_k}\right) = -\sum p_k \log(p_k)$ $\frac{\text{bits}}{\text{symbol}}$

INFORMATION RATE :-

If the time rate at which source X emits symbols is r symbols/sec, then information rate R of the source is given by; $R = rH(x)$ b/s.

$= \frac{\text{symbol}}{\text{s}} \times \frac{\text{Information bits}}{\text{symbol}}$

$=$ bits/sec.

→ The upper & lower boundary of $H(x)$ is:-

$\boxed{0 \leq H(x) \leq \log_2 M}$ where M is the size of the alphabet of X. $X\{\,\}_M$

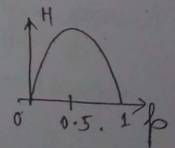
PROOF →

We know, $0 \leq P(m_k) \leq 1$,

then $\frac{1}{P(m_k)} \geq 1$.

& $\log_2 \frac{1}{P(m_k)} \geq \log_2 1$.

$\log_2 \frac{1}{P(m_k)} \geq 0$.



$\therefore H(x) = \sum_{k=1}^{M} P(m_k) \log_2 \frac{1}{P(m_k)} \geq 0$

$= \sum_{k=1}^{M} p_k \log \frac{1}{p_k} \geq 0 \Rightarrow \boxed{H(x) \geq 0}$ —(1)

$H(x) = 0$ only when $p_k = 0$ or 1.

Now let us consider 2 probability distributions (23)
$P(m_k) = p_k$ & $Q(m_k) = q_k$ on the alphabet
$\{m_k\}$ where $k = 1, 2 \ldots M$.

such that $\sum_{k=1}^{M} p_k = 1$ & $\sum_{k=1}^{M} q_k = 1$. — (2)

we know,

$$\sum_{k=1}^{M} p_k \log_2 \frac{q_k}{p_k} = \frac{1}{1}\left(\sum_{k=1}^{M} p_k \frac{\ln (q_k/p_k)}{\ln 2}\right)$$

$$= \frac{1}{\ln 2} \sum_{k=1}^{M} p_k \ln (q_k/p_k). \quad \text{— (3)}$$

using the inequality,

$$\boxed{\ln \alpha \leq \alpha - 1 \quad \text{for} \quad \alpha \geq 0}$$

(The inequality holds is equality when $\alpha = 1$)

we can write

$$\ln \frac{q_k}{p_k} \leq \frac{q_k}{p_k} - 1$$

$$\sum_{k=1}^{M} p_k \ln \frac{q_k}{p_k} \leq \sum_{k=1}^{M} p_k \left(\frac{q_k}{p_k} - 1\right)$$

$$= \sum_{k=1}^{M} \frac{q_k - p_k}{p_k} * p_k$$

$$= \sum_{k=1}^{M} (q_k - p_k) = \sum_{k=1}^{M} q_k - \sum_{k=1}^{M} p_k$$

$= 0$ using (2).

$$\therefore \sum_{k=1}^{M} p_k \ln \frac{q_k}{p_k} \leq 0 \quad \text{or} \quad \boxed{\sum_{k=1}^{M} p_k \log_2 \frac{q_k}{p_k} \leq 0}$$

using (3).

(iii) $\sum_{k=1}^{M} p_k \log_2 \frac{q_k}{p_k} \leq 0$ ——— (4).

It holds if $q_k = p_k$ for all k.

Let $q_k = \frac{1}{M}$ $k = 1, 2 \ldots M$.

Hence we get,

$$\sum_{k=1}^{M} p_k \log_2 \frac{1}{p_k M} = \sum p_k \log_2 \frac{1}{p_k} + \sum p_k \log_2 \frac{1}{M}$$

$$= - \sum p_k \log_2 p_k - \sum p_k \log_2 M$$

$$= H(x) - \log_2 M \sum_{k=1}^{M} p_k$$

$$= H(x) - \log_2 M \cdot 1$$

$\therefore$ From (4) we can write.

$$H(x) - \log_2 M \leq 0$$

$$\boxed{H(x) \leq \log_2 M} \quad - (5)$$

From (1) & (5) we can write.

$$\therefore 0 \leq H(x) \leq \log_2 M.$$

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Q. A discrete source emits one of five symbols once every milli sec with prob $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$ & $\frac{1}{16}$ resp. Determine source entropy & information rate

Ans) $H(x) = \text{entropy} = \sum p_k \log_2 \frac{1}{p_k}$

$$= \sum_{k=1}^{5} p_k \log_2 \frac{1}{p_k} \quad \text{bits/symbol}$$

$$= \frac{1}{2}\log_2(2) + \frac{1}{4}\log_2(4) + \frac{1}{8}\log_2(8) + \frac{1}{16}\log_2(16) + \frac{1}{16}\log_2(16)$$

$$= \frac{1}{2} + \frac{1}{2} + \frac{3}{8} + \frac{1}{4} + \frac{1}{4} = \frac{15}{8} = 1.8 \text{ bits/symbol}$$

$r = \text{symbol rate} = \frac{1}{T_b} = \frac{1}{10^{-3}} = 1000$ symbols/sec.

Information rate :- $R = rH(X) = 1000 \times 1.875$

$= 1875$ bits/sec

Q) The prob of the five possible outcomes of an experiment are given as $p(x_1) = \frac{1}{2}$; $p(x_2) = \frac{1}{4}$, $p(x_3) = \frac{1}{8}$, $p(x_4) = p(x_5) = \frac{1}{16}$. Determine entropy & information rate if there are 16 outcomes per sec.

$H(x) = \frac{15}{8} = 1.8$ bits/outcome.

$r = 16$ outcomes/sec.

$R = rH(x) = 16 \times \frac{15}{8} = 30$ bits/sec.

(26)

Q) An analog signal bandlimited to 10 KHz is quantized in 8 levels of a PCM system with prob $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{20}$, $\frac{1}{20}$ resp. Find $H(x)$ & R.

Ans) $f_s = 10 \times 2$ KHz $= 20$ KHz.

$H(x) = 2.84$ bits/message.

$r = 20\,000$

$R = r H(x) = 20000 \times 2.84 = 56800$ bits/sec.

CHANNEL CAPACITY :-

A communication channel is defined as the path or medium through which the symbols flow to the receiver end. A discrete memoryless channel (DMC) is a statistical model with a i/p X & an o/p Y.

$$\left.\begin{matrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{matrix}\right\} X \longrightarrow \boxed{P(y_k|x_k)} \longrightarrow Y \left\{\begin{matrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{matrix}\right.$$

Each possible input - output path is indicated by conditional probab $P(y_k|x_k)$.

The channel capacity per symbol of a DMC is

$$C_s = \max_{\{P(x_k)\}} I(X;Y) \text{ b/symbol.}$$

where maximization is done over all i/p Probab. distn. $P(x_k)$

(ii) Channel capacity per sec (C) :- If r symbols are transmitted in 1 sec then max rate of transmission of information per sec $\boxed{C = r C_s}$ bits/sec.

CHANNEL CAPACITY THEOREM :-

Bandwidth & noise power place a restriction upon the rate of information that can be transmitted by a channel. It is seen that in a channel which is disturbed by a white gaussian noise one can transmit at a rate of C bits per sec, where C is the channel capacity & is expressed as

$$\boxed{C = B \log_2 (1 + S/N)}$$

B = channel bandwidth in Hz

S = signal power

N = noise power.

ENTROPY CODING

The design of a variable length code such that its average codeword length approaches the entropy of DMS is often referred as ENTROPY CODING.

1) Shannon - Fano Coding

2) Huffman - coding.

(28)

~~SHANON - FA~~

SHANNON - FANO CODING :-

$X = \{ x_1 \; x_2 \; x_3 \; x_4 \; x_5 \; x_6 \}$

$\cdot 3 \quad \cdot 25 \quad \cdot 2 \quad \cdot 12 \quad \cdot 08 \quad \cdot 05 = P(x_k)$

1st step → arrange in decreasing order of prob.

X	P		Step - I	Step - II	III	IV	CODE
x_1	0.3	0.05	0	0			0 0
x_2	0.25	0.05	0	1			0 1
x_3	0.2	0.07	1	0			1 0
x_4	0.12	.04	1	1	0		1 1 0
x_5	0.08	.03	1	1	1	0	1 1 1 0
x_6	0.05		1	1	1	1	1 1 1 1

$H(x) = \sum p_k \log\left(\frac{1}{p_k}\right) = 2.36$ b/symbol.

code length $L = \sum p_k n_k$
$= 0.3 \times$ code length $+ 0.25 \times$ code length $+ 0.2 \times$ " " $+ 0.12 \times$ " " $+ \ldots$

$= 0.3 \times 2 + 0.25 \times 2 + 0.2 \times 2 + 0.12 \times 3 + 0.08 \times 4 + 0.05 \times 4$

$= 2.38$ b/symbol.

$\eta =$ efficiency $= H(x)/L = 0.99$. $\quad \frac{H(x)}{L \log M}$

(98)

~~SHANON - FA~~

SHANNON - FANO CODING :-

$$X = \{x_1 \; x_2 \; x_3 \; x_4 \; x_5 \; x_6\}$$

$$\cdot 3 \quad \cdot 25 \quad \cdot 2 \quad \cdot 12 \quad \cdot 08 \quad \cdot 05 = P(x_k)$$

1st step → arrange in decreasing order of prob.

X	P		Step - I	Step - II	III	IV	CODE
x_1	0.3		0	0			0 0
		0.05					
x_2	0.25		0	1			0 1
		0.05					
x_3	0.2		1	0			1 0
		0.08					
x_4	0.12		1	1	0		1 1 0
		.04					
x_5	0.08		1	1	1	0	1 1 1 0
		.03					
x_6	0.05		1	1	1	1	1 1 1 1

$$H(x) = \sum p_k \log\left(\frac{1}{p_k}\right) = 2.36 \text{ b/symbol}$$

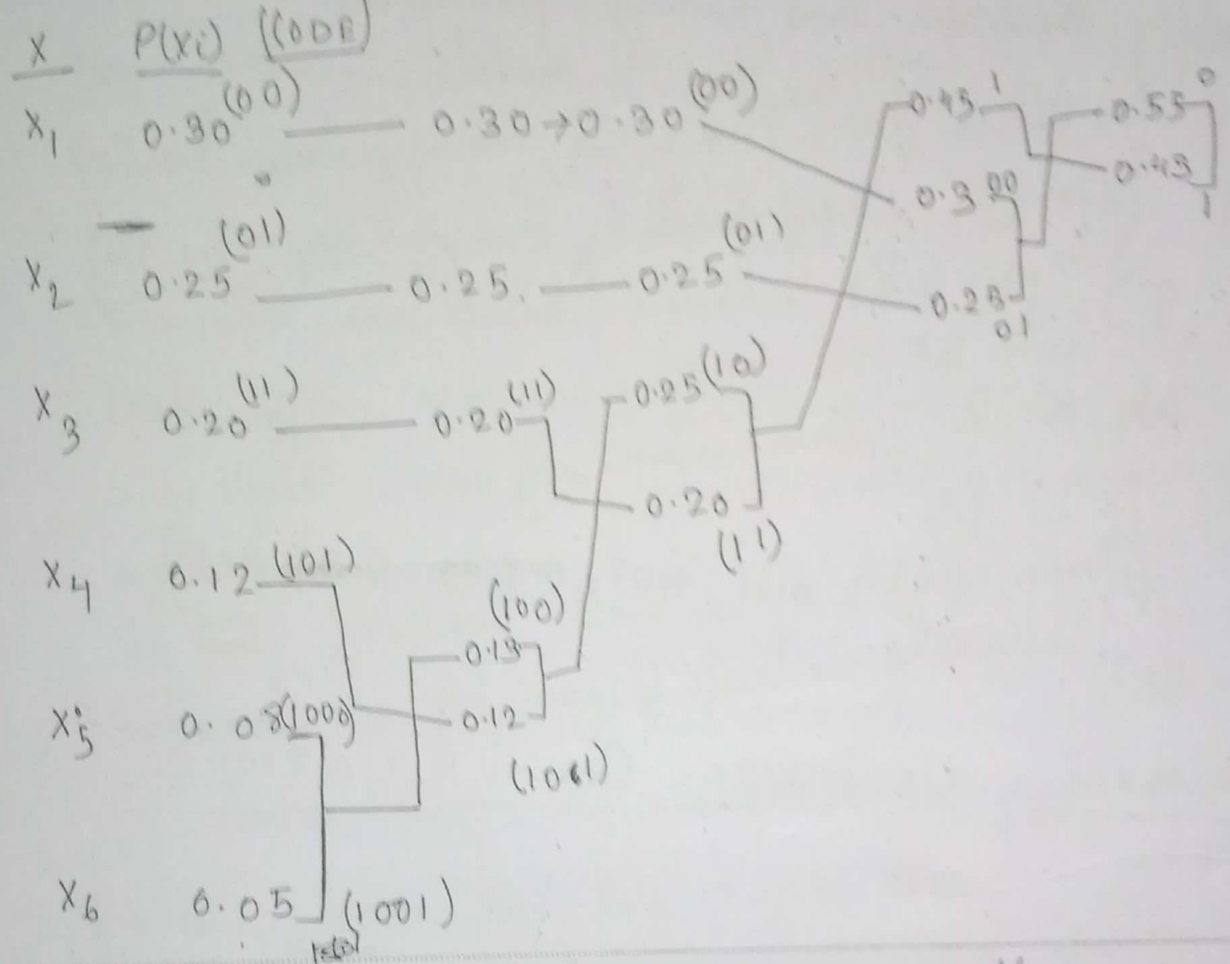
code length $L = \sum p_k n_k$ = $0.3 \times$ code length $+ 0.25 \times$ code length $+ 0.2 \times$ " " $+ 0.12 \times$ " " $+ \ldots$

$$= 0.3 \times 2 + 0.25 \times 2 + 0.2 \times 2 + 0.12 \times 3 + 0.08 \times 4 + 0.05 \times 4$$

$$= 2.38 \text{ b/symbol}$$

$$\eta = \text{efficiency} = H(x)/L = 0.99. \qquad \frac{H(x)}{L \log M}$$

HUFFMAN CODING:-



M = 2

$H(x) = 2.36$ b/symbol

$L = 2.38$ b/sym

$\eta = 0.99.$

If $M = 3$, then add last 3

& $\eta = \frac{H(x)}{L \log M}$

(36)

Q. Apply Shannon-Fano coding procedure for the following message ensemble :-

(a) $[X] = [x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5 \quad x_6 \quad x_7 \quad x_8]$

$[P] = [1/4 \quad 1/8 \quad 1/16 \quad 1/16 \quad 1/16 \quad 1/4 \quad 1/16 \quad 1/16]$

Take $M = 2$.

(b) $[X] = [x_1 \quad \ldots\ldots \quad x_7]$

$[P] = [0.4, 0.2, 0.12, 0.08, 0.08, 0.08, 0.4]$

$M = 2$.

ADVANTAGES OF DIGITAL COMMUNICATION:-

FIBER OPTICS

From Grahambell's time the 1st revolution in communication took place when the audio signals were converted into electrical forms & were transmitted on electrical wires & were converted back again into audio form. At that time the only objective was to communicate with the voice signals.

As time progressed band width requirement increased i.e frequency of operation increased.

E.M. SPECTRUM:-

INFRARED ⟵|⟶ ULTRA VIOLET

$f \rightarrow$	30M	300M	3G	30G	300G	3T	30T	300T	3000T
$\lambda \rightarrow$	10m	1m	10cm	1cm	1m.m.	.1m.m	10μm	1μm	0.1μm

CO-AXIAL CABLE (10m – 1m)

μ wave devices (10cm – 1m.m.)

OPTICAL FIBER (1μm – 0.1μm)

In optical fiber communication light signals are the carrier wave. Light sources are Laser.

ADVANTAGES OF OPTICAL COMMUNICATION:-

1) Ultra high band width (almost in THZ range)
2) Low loss (of about 0.2dB/km)
3) Low Electromagnetic Interference
4) Security of Transmission.
5) Low manufacturing cost.

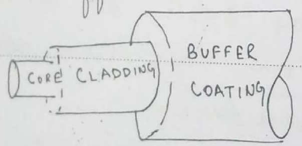
6) Low weight, low volume.

7) Point to point communication.

To travel a long distance the light waves used as carrier will to ~~require~~ a medium to travel. Glass is used as medium.

The optical fibre consists of a solid glass of cylinder called CORE. It is surrounded by a dielectric cladding which has a slight different property than that of core so that light can be guided in the fiber. Surrounding these 2 layers is a polymer buffer coating that protects the fiber from mechanical & electrical effect.

glass → SiO_2
silica.

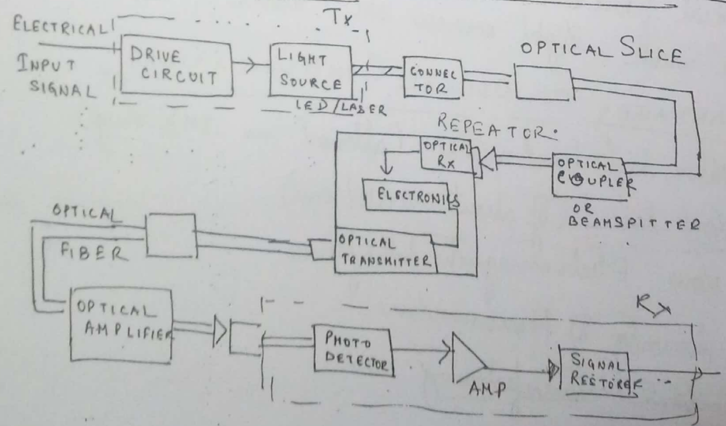


CORE'S r.i :- n_1

CLADDING's r.i :- n_2 $[n_1 > n_2]$

r.i.:- refractive index,

OPTICAL FIBER COMMUNICATION LINK



ELEMENTS OF COMMUNICATION LINK

(i) Transmitter :—

The light source LED or laser process the electrical signal and produces optical signal. ∵ ∴ LED uses spontaneous emission technology & LASER uses stimulated emission technology to produce light.

Drive circuit is used to stabilize the electrical input at light orange.

Optical coupler :— joins or divide the light rays into different paths.

When signal is attenuated while travelling then it is passed through Repeater to boost up the signal. In Repeater the light signal is detected, converted to electrical signal & amplified & then again converted to light signal & then passed.

Receiver :— There is a photo diode to detect the optical signal & convert into a electrical signal. The receiver has amplifier to boost up the signal.

Passive devices :— These are optical components that require no electronic control for their operation. optical isolators, connectors, slicers are the example.

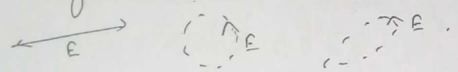
③ Characteristics of light :—

1) Intensity :— power / solid angle.

For a given power light if falls for a small solid ∡ then it is bright.

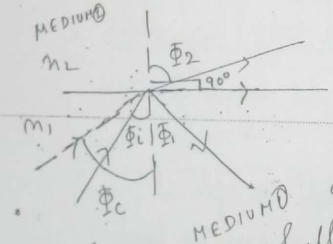
2) Wavelength (nm) : 3) Spectral width (purity of colour)

4) Polarization (linear, circular, elliptical)



POINT → PROPAGATION of light in any medium is dependent on its refractive index (R.I) $n = \frac{\text{speed of light in vacuum}}{\text{" " " in material}} = \frac{c}{v}$

// REFLECTION, REFRACTION AND SNELL'S LAW //



Φ_i = ∡ of incidence

Φ_1 = ∡ of reflection.

$\boxed{\Phi_i = \Phi_1}$ → Law of reflection.

Φ_2 = ∡ of refraction

$n_1 > n_2$

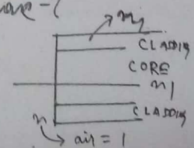
Snell's Law → $\boxed{n_1 \sin\Phi_i = n_2 \sin\Phi_2}$

, For critical ∡ Φ_c ∡ of refraction is 90°

For ∡ of incidence $\Phi_i > \Phi_c$ the rays will be reflected back in medium ① . This is total internal reflection.

Q) $\underbrace{n_1 = 1.480}_{\text{CORE}}$ $\underbrace{n_2 = 1.460}_{\text{CLADDING}}$ $\Phi_c = ?$ N.A = ?

acceptangle ∡ θ_{max} = ?



Ans) $\sin\Phi_c = \frac{n_2}{n_1}$ ① $\therefore \Phi_c = \sin^{-1}\left(\frac{1.46}{1.48}\right) = 0.82$

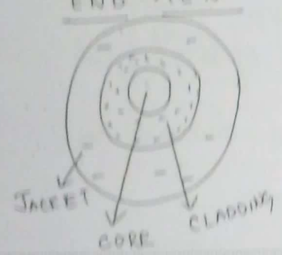
② N.A = $n \sin\theta_{max}$
$= \sqrt{n_1^2 - n_2^2} =$

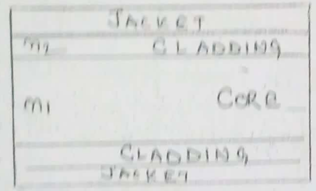
| ~~$\sin\theta_m$~~ ③ $\theta_{max} = \sin^{-1}(N A)$.

PRINCIPLE OF LIGHT PROPAGATION IN OPTICAL FIBER

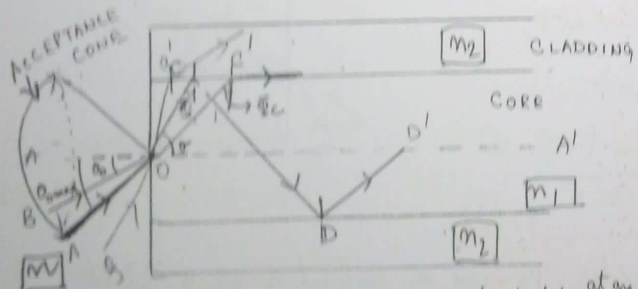
(35)

optical fibre is a very thin flexible cylindrical shape medium which consist of (a) core (b) cladding (c) jacket. core is the innermost glass section through which light propagates. Its refractive index is n_1. cladding is the glass coating surrounding core with refractive index (r.i) n_2. Here $n_1 > n_2$.





$\boxed{n_1 > n_2}$



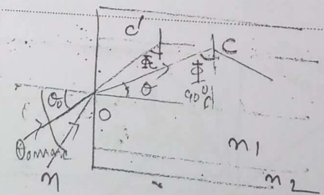
Let AA' be the axial optical axis. Rays can only enter through the open end of core tip. Let the ray BO is incident at pt O at an θ_0 as shown in diagram. As the ray passes from medium of r.i n & enters into core of r.i n_1 it gets refracted along OC.

At C i.e. at core cladding interface the rays undergo total internal reflection & follows path CD. Again at the other core cladding interface it encounters total internal

(8) reflection & thus again rays follows path DD'. Thus the ray travels within the core of the optical fibre with zigzag path.

Now let us consider the ray AO (red line) which is incident at the core-cladding interface at pt C' with critical angle. Hence at C' the angle of refraction is $\pi/2$. ~~Any ray~~ The ray AO is incident at O with $\angle \theta_{0max}$. It is seen any ray beyond θ_{0max} if ~~lost~~ incident at O; it is lost in the cladding as total internal reflection doesn't takes place (such as ray QOQ'). Hence θ_{0max} is the maximum angle within which all rays incident at O will pass within the optical fiber. Thus the cone formed by θ_{0max} at O as shown in fig is known as ACCEPTANCE CONE.

Applying Snell's law at O,



$$n \sin\theta_0 = n_1 \sin\theta$$

$$n \sin\theta_0 = n_1 \sin(90° - \Phi)$$

$$\boxed{n \sin\theta_0 = n_1 \cos\Phi} \quad — (1)$$

Let us know consider θ_{0max} a critical angle Φ_c at c',

$$n_1 \sin\Phi_c = n_2 \sin 90°$$

$$n_1 \sin\Phi_c = n_2 \Rightarrow \boxed{\sin\Phi_c = \frac{n_2}{n_1}}$$

$$\therefore \cos\Phi_c = \sqrt{1-\sin^2\Phi_c} = \sqrt{1-\left(\frac{n_2}{n_1}\right)^2} = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \quad — (2)$$

using (1) with θ_0 max we can write, (37)

$$n \sin\theta_{0max} = n_1 \cos\Phi_c = n_1 \cdot \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}} \quad (\text{from } (2))$$

$$n \sin\theta_0 max = \sqrt{n_1^2 - n_2^2}$$

$$\therefore \boxed{\sin\theta_{0max} = \frac{\sqrt{n_1^2 - n_2^2}}{n}}$$

This quantity is telling light collection efficiency. Hence ~~it is known as~~ Numerical Aperture (N.A) is known as

$$\boxed{N.A = n\left(\frac{\sqrt{n_1^2 - n_2^2}}{n}\right) = \sqrt{n_1^2 - n_2^2}}$$ If optical fibre is placed in air ($n = 1$).

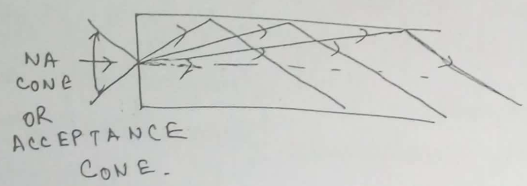
$$\boxed{N.A = n \sin\theta_{0max} = \sqrt{n_1^2 - n_2^2}}$$

as NUMERICAL APERTURE.

39

$$N.A = n \sin \theta_{0\,max} = \sqrt{n_1^2 - n_2^2}$$

greater the value of $\theta_{0\,max}$ greater light will be launched.



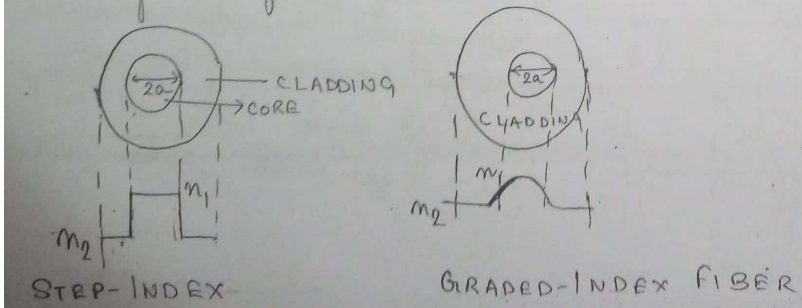
- optical fibre data speed is 5Gbps over 111 Km without repeaters.

OPTICAL FIBER TYPES

Variations in the material composition of the core and the cladding give rise to the two basic fiber types.

1) STEP-INDEX FIBER:— The refractive index of the core is uniform throughout & undergoes an abrupt change (or step) at the cladding boundary.

2) GRADED-INDEX FIBER :— The core refractive index varies as a function of the radial distance from the centre of the fiber.

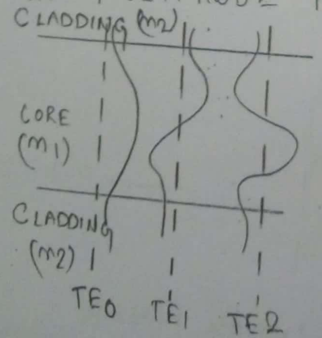


OPTICAL FIBER MODES

A finite set of rays at certain discrete ~~angles~~ greater than or equal to critical angle Φ_c is capable of propagating along a fiber. These angles are related to a set of EM wave patterns or field distributions called modes that can propagate along a fiber. Modes are the possible solutions of the Helmholtz wave equation obtained by combining Maxwell's equations & boundary conditions. These modes define the way the wave will travel in the space.

When the core diameter is in the order of 8 to 10 μm (which is few times the value of wavelength) ~~one and~~ only one single fundamental ray will travel along the straight line axis. Such a fiber is referred as SINGLE-MODE fiber. (This ray can have multiple or diff frequencies which are distributed in space and produces a single ray of light.

Fibers that have larger core diameters ($\geq 50 \mu m$) support many propagating rays or modes & are known as MULTIMODE fibers.



Field pattern of lowest-order Transverse Electromagnetic (TE) modes are shown. Subscript shows order of the mode.

In single mode TE 0 will ~~flow~~ propagate.

TE_0 → 0 zero crossing within guide

TE_1 → 1 " " " "

TE_2 → 2 " " " "

LOSSES IN OPTICAL FIBER :-

(41)

1) ABSORPTION
2) RAYLEIGH SCATTERING
3) MIE SCATTERING.

The ~~A~~ material can absorb light if the incident photon energy is equal to the band gap of the material. The fibre is made from silica oxides & other oxides. During manufacturing process, some molecules of the hydroxide anion OH^- often called hydrogen water molecule are incorporated in silica fibre which cannot be removed and are responsible for absorption of light when it propagates through the fibre.

When light rays strike an object the light is reflected into different directions, i.e if the light ray strikes a drop of water in atmosphere, it diffusely reflects light in several directions. It is called light scattering. In optical fiber due to impurity particle in the path of light in the core, the particle will scatter the light in another direction & thus affect the total internal reflection at the core - cladding interface. This will create loss in amount of light.

$$\Rightarrow \boxed{\text{Attenuation Loss} = \frac{10}{L} \log_{10} \left(\frac{P_{in}}{P_{out}} \right) \text{dB/km}}$$

Attenuation due to Rayleigh Scattering $\propto 1/\lambda^4$

(17)

LIGHT SOURCES

Laser → The expanded form of laser is light amplification by stimulated emission of radiation.

It is the device that creates & amplifies EM radiation of a specific freq. through the process of stimulated emission. The radiation emitted by a laser consists of a coherent beam of photons, all in phase & having the same polarisation.

ABSORPTION AND EMISSION OF RADIATION :-

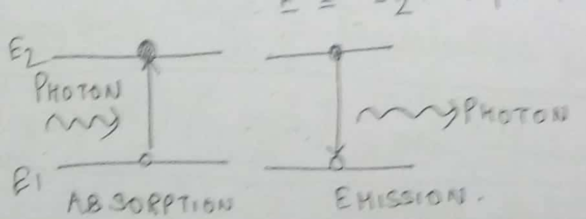
The interaction of light with matter takes place in discrete packets of energy or quanta called photons. From quantum theory it is known atoms exist only in discrete energy states such ~~as~~ that absorption & emission of light cause them to make a transition from one discrete energy state to another. The frequency of absorption or emission is;

$$E = E_2 - E_1 = h\nu \quad (h = 6.6 \times 10^{-34}\,Js)$$

Planck's const.

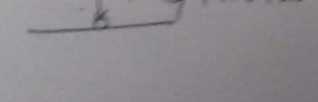
E_2

E_1

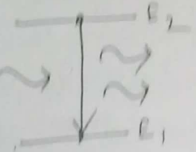


The emission process can occur in 2 ways:—

(a) by spontaneous emission in which the atom returns to the lower energy state in an entirely random manner.



b) by stimulated emission when a photon having an energy equal to the energy difference between two states $(E_2 - E_1)$ interacts with the atom in the upper energy state causing it to return to the lower energy state with the creation of a second photon.



Spontaneous emission is used by LED.
whereas stimulated " " " by LASER.
The photon produced by stimulated emission is generally of an identical energy to the one which caused it & hence light produced by them is of same freq.

EINSTEIN RELATIONS :-

Mathematically, Absorption, Spontaneous & stimulated emission are related as,

$$\frac{N_1}{N_2} = \frac{g_1 \exp(-E_1/kT)}{g_2 \exp(-E_2/kT)} = \frac{g_1}{g_2} \exp\left[\frac{(E_2 - E_1)}{kT}\right]$$

$$= \frac{g_1}{g_2} \exp(hf/kT)$$

N_1, N_2 : density of atoms in energy levels E_1 & E_2.
$g_1, g_2 \rightarrow$ degeneracies of the levels
k : Boltz's constant
T : absolute temp.

$$\frac{\text{Spontaneous em. rate}}{\text{stimulated emission rate}} = \exp(hf/kT) - 1$$
$$= \frac{1}{e^{hf/kT} - 1}$$

(iii) POPULATION INVERSION:—

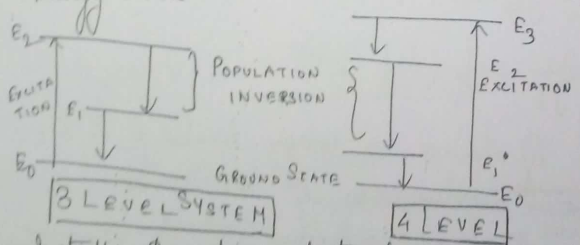
Under thermal equilibrium condition by Boltzmann distribution the lower energy level E_1 of the two level atomic system contains more atoms than the upper energy level E_2.

To achieve optical amplification a non-equilibrium distribution of atoms such that the population of upper energy level is greater than that of the lower energy level i.e $\boxed{N_2 > N_1}$ This condition is known POPULATION INVERSION (PI)

To achieve PI it is necessary to excite atoms into the upper energy level E_2 to obtain non equilibrium state. This process is achieved using an external energy source & the process name is pumping. Pumping is done by internal radiation.

[P.I : Population Inversion]

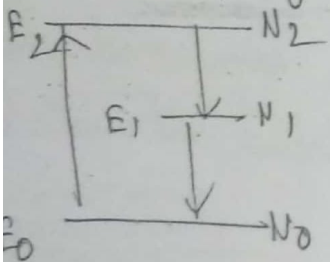
P.I. is obtained in systems with three or four energy levels.



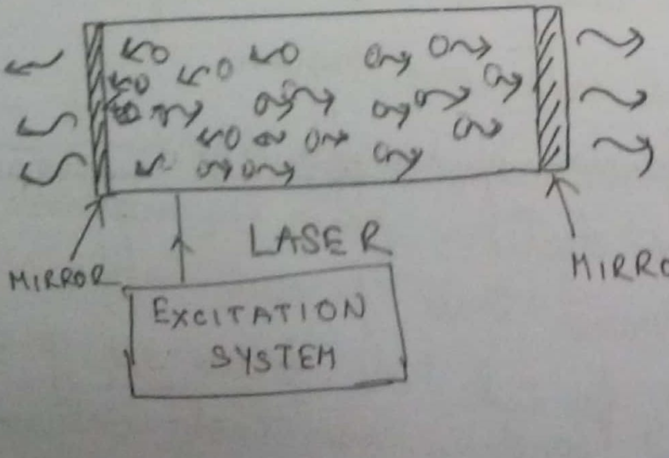
E_0 is ground state
E_1 is metastable state for 3 state system (& E_1, E_2 both are metastable states for 4 level states

Initially the atomic distribution will follow Boltzmann's law. With suitable pumping the electrons in some of the atoms may be excited from the ground state into higher energy levels E_2 (3 state)

Since E_2 is normal level, the electrons will rapidly decay by non - radiative process to either E_1 or directly to E_0. Hence empty states will always be provided in E_2. The meta stable level E_1 exhibits a much longer life time than E_2 which allows a large no of atoms to accumulate at E_1. Over a period the density of atoms N_1 in meta stable state E_1 increases above those in the ground state N_0 & thus population inversion is obtained b/w E_1 & E_0 & lasing action starts



⇒ <u>Light amplification</u> in the laser occurs when a photon colliding with an atom in the excited energy state cause stimulated emission of a second photon & both these photons release 2 or more photons. Continuation of this process creates an avalanche multiplication of photons & when Electromagnetic waves with these photons are in phase, amplified coherent emission is obtained.



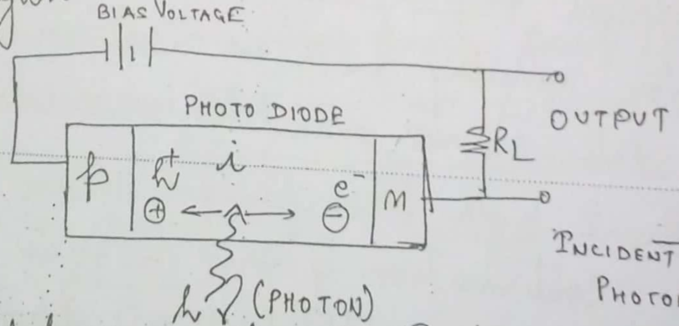
PHOTODIODES

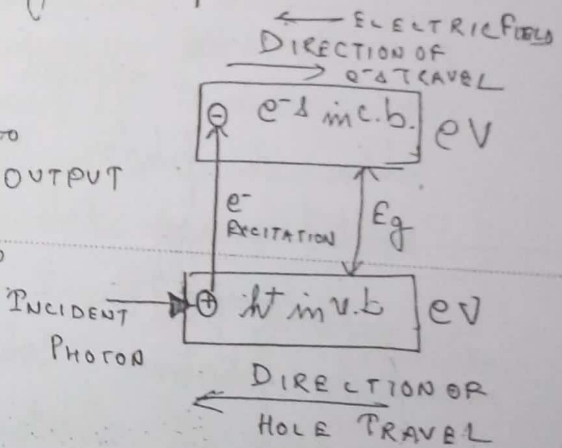
The first element of the receiver for optical communication is photodetector. The photodetector senses the light signal falling on it and converts the variation of the optical power to a correspondingly varying electric current.

OPERATION OF PIN PHOTODIODE →

Pin photodiode and Avalanche Photodiode (APD) are the two types of photodiodes.

P-I-N Photodiode consists of p and n semiconductor regions separated by a very lightly n- doped intrinsic (i) region





e: electron, h⁺: hole, Eg: band gap

In normal operation a reverse bias voltage is applied across the device so that no free electrons or holes exist in the intrinsic region.

An incident photon of energy equal to or greater than E_g excites an electron from the valance band to the conduction band. This process happens in intrinsic region & thus here free e- & hole pairs are generated. These charge carriers known as Photo carriers will be

swept out of the intrinsic region due to the application (47)
of external electric field across the device resulting in
current flow through the external circuit. This current is
known as photocurrent.

Say Power given is 10W.

In unit "decibal-watt" (dBW) $= 10\log_{10}\left(\frac{\text{Power}}{1W}\right)$

$$10W = 10\log_{10}\left(\frac{10W}{1W}\right) = 10\ dBW \ \underline{\text{Ans}}$$

In unit "decibal-milli watts (dBm)

$$= 10\log_{10}\left(\frac{\text{Power}}{1\text{ milli watt}}\right) = 10\log_{10}\left(\frac{\text{Power}}{1mW}\right)$$

$$= 10\log_{10}(\text{Power}) + 10\log_{10}\left(\frac{1}{mW}\right)$$

$$= 10\log_{10}(P) + 10\log_{10}\left(\frac{1}{10^{-3}}\right)$$

$$= 10\log_{10}(P) - 10\log_{10}(10^{-3})$$

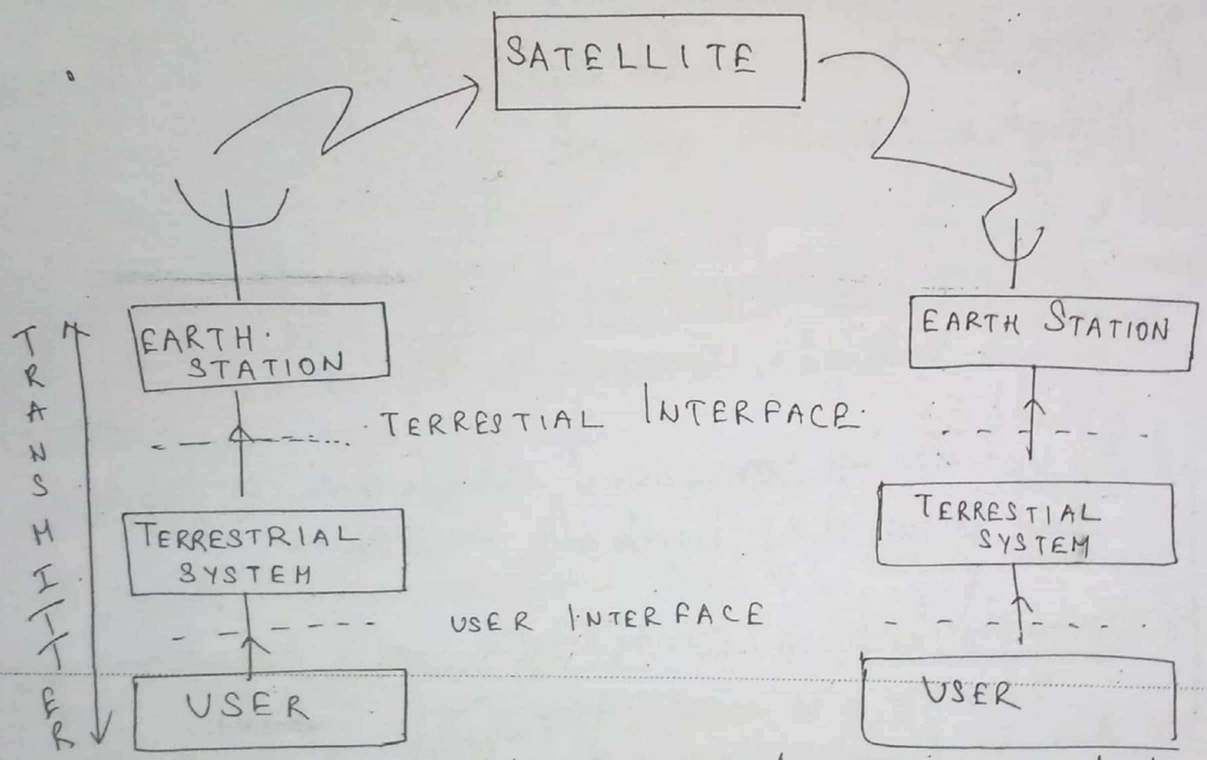
$$= 10\log_{10}P + 30.$$

$$\therefore 50W = 10\log_{10}(50) + 30 = 46.99\ dBm \ \underline{\text{Ans}}$$

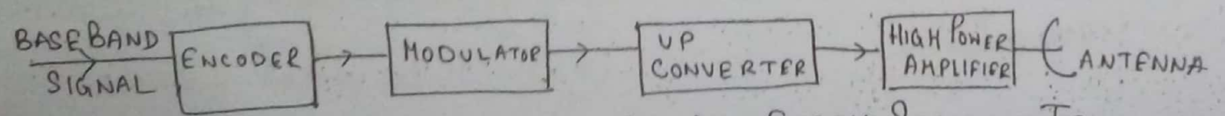
Amplitude	Frequency
2f	4f
High	Low
Poor	better than ASK
Simple	Moderately complex
100 bits/sec	1200 bits/sec

SATELLITE COMMUNICATION

The basic element of satellite communication system are 1) Earth station 2) Terrestial system 3) Users.
The basic structure of Sat comm :-



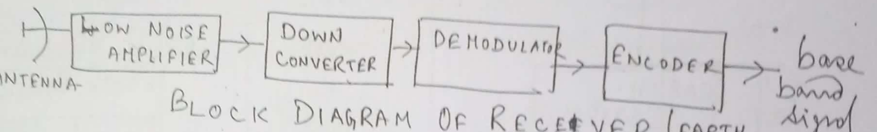
In Sat commn. satellite acts as relay or repeater which connects the 2 stations on earth or any users on earth. These users are connected by terrestial n/w which maybe a telephone switch or a dedicated link. The user generates a message or base band signal. The satellite consists of a large number of repeaters in space, that receives the modulated RF carrier in its uplink frequency



BLOCK DIAGRAM OF AN EARTH STATION TRANSMITTER

spectrum from all earth stations in the network,

(5) amplifies the carriers & retransmits them back to the earth stations in the down link frequency spectrum. To avoid interference downlink & uplink frequency spectrum should be different. The signal at the receiving earth stations is processed to get back the base band signal, it is sent to the user through a terrestrial network.



BLOCK DIAGRAM OF RECEIVER (EARTH STATION)

* For Uplink → commercial satellite use a frequency band of 500 MHz bandwidth near 6GHz.
* For Downlink → comm. sat. use a freq band of 500 MHz b.w near 4GHz.

→ This is known 6/4 GHz band.

ADVANTAGE of 6/4 GHz BAND ⇒ 1) no absorption of rain in this band.
2) less propagation problems.
3) no change of polarization when waves pass through ionosphere
4) Sky noise is low at 4GHz.

TRANSPONDER is transmitting & receiving equipment on satellite.

1) Communication satellite
2) Remote sensing "
3) Military satellite
4) weather satellite
5) Positioning satellite.

ADVANTAGES :-

1) Point to multipoint communication is possible
2) circuits for satellite can be installed rapidly. once the satellite is in position, earth stations can be installed & communication can be established within some days or even hours.
3) Mobile communications can be easily achieved.
4) Satellite communication has economical advantage i.e its cost is independent of distance.

SATELLITE ORBITS :-

A satellite is characterised by 2 attributes i.e Altitude & Inclination. Altitude refers to the height of the satellite from the surface of the earth. Inclination refers to the angle of rotation of a satellite with the horizontal.
According to altitude satellites are Low Earth orbit (LEO), Middle Earth orbit (MEO), Highly Eccentric orbit (HEO) & Geostationary Earth orbit (GEO).

(5) a) LEO:- Low earth orbit are launched at an altitude in the range 500 - 1500 Km. Rotational speed is 90 mins at a time in sight of 15 mins.
LEO are used for mobile communication & in surveying.

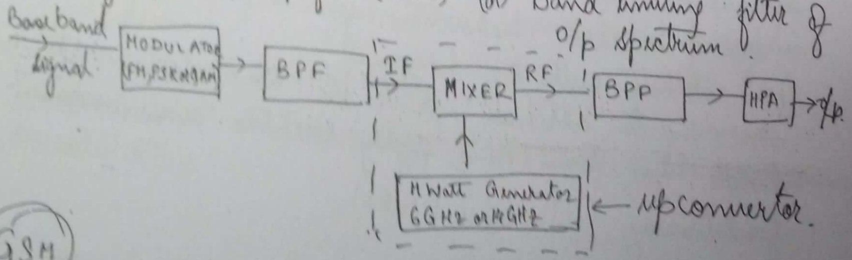
b) Middle earth orbit:- altitude → 5,000 - 10,000.
They have a rotational period of between 5-12 hours & a time in sight of 2-4 hours.
app:- data & telephony.

c) HEO:- altitude → 15,000 - 30,000 Km.
rotational period - 4 to 8 hrs
time in sight → 8 hrs.
HEOs are used for communication in polar regions.

d) Geo-stationary earth orbit (GEO):-
altitude 36,000 Km.
Rotational period - 24 hrs. Always in sight.
application:- TV, Radio & data communication.

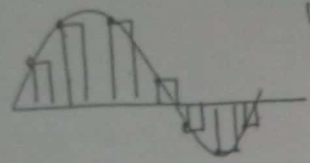
SATELLITE UP-LINK MODEL

(a) IF modulator (b) IF to RF microwave upconverter
(c) high power amplifier (HPA) (d) Band limiting filter of o/p spectrum.

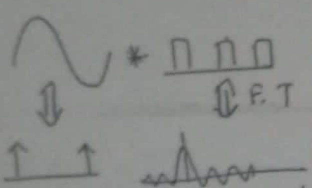


GSM

APERTURE EFFECT :— During flat-top sampling to convert varying amplitudes of pulse to flat top pulses we use a sinc function. Because of this, there would be decrease in the amplitude. This distortion is named as aperture effect



(To get flat-top the message signal was multiplied by a rectangular pulse)



F.T of cos is impulse, F.T of rectangular pulse is sinc.

ALIASING :— Aliasing is the error or distortion introduced due to overlapping of adjacent spectrums when the sampling is performed at a rate which is lower than Nyquist rate.