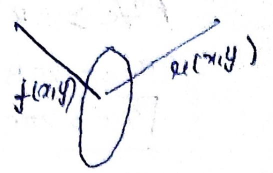
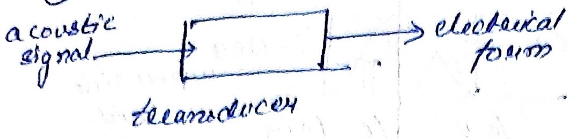
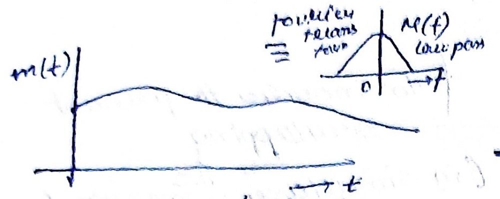
9/1/23

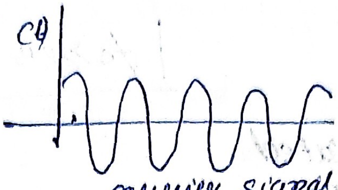


$f(x,y) = r(x,y) \times i(x,y)$
reflectance illumination
visual quality depends on these.





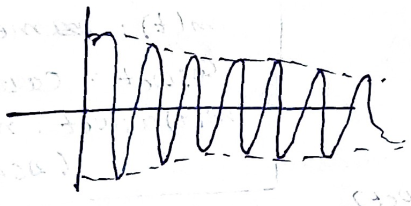
Base band signal



carrier signal

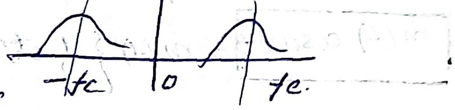
$c(t) = A\cos(\omega_c t + \theta_c)$ — amp, freq, phase

Carrier Modulation is the process by which some characteristics, of a high freq signal, carrier wave (amplitude, phase or freq) is varied in proportion to the base band signal or modulating signal.

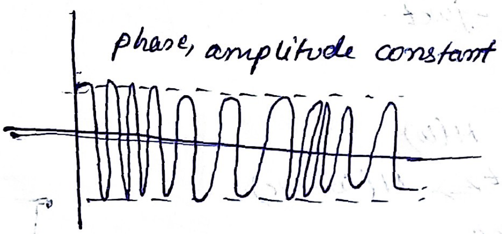


Amplitude modulated.

≡ fourier transform

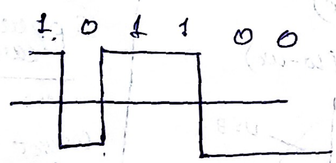


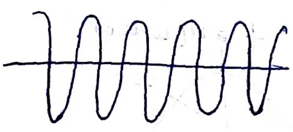
phase, amplitude constant



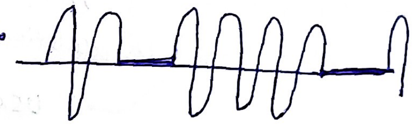
frequency modulated (many values of freq)

Eg)

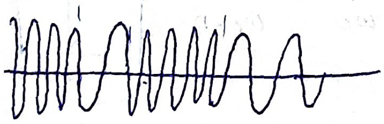




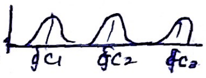
carrier.



Modulated.
Binary Amplitude Shift Keying
B(ASK)
(only two values of ampl).



Frequency modulated. (only two values of freq)



(frequency division Multiplexing)

Advantages of Modulation:

1) Ease of Radiation.

2) Simultaneous transmission of several message signals.

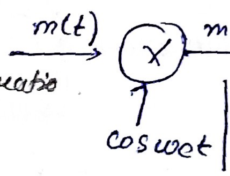
3)

Reliability — Bandwidth & average signal to noise ratio

[signal to interference plus noise] in multiple commⁿ.

- Analog quality is fidelity
- Digital → quality of reception is measured by bit error rate

criteria of reception → (delay, cost, distortion)



$m(t)\cos\omega_c t = \frac{1}{2} m(t)\, 2\cos\omega_c t$

$= \frac{1}{2}[m(t)]\{e^{j\omega_c t} + e^{-j\omega_c t}\}$

$= \frac{1}{2} m(t) e^{j\omega_c t} + \frac{1}{2} m(t) e^{-j\omega_c t}$

$FT[m(t)\cos\omega_c t]$

$= FT\left[\frac{1}{2}m(t)e^{j\omega_c t} + \frac{1}{2}m(t)e^{-j\omega_c t}\right]$

$= FT\left[\frac{1}{2}m(t)e^{j\omega_c t}\right] + FT\left[\frac{1}{2}m(t)e^{-j\omega_c t}\right]$

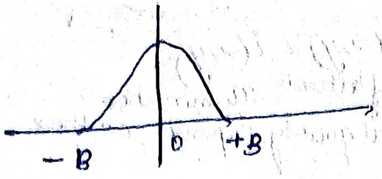
$\boxed{= \frac{1}{2} M(f-f_c) + \frac{1}{2} M(f+f_c)}$

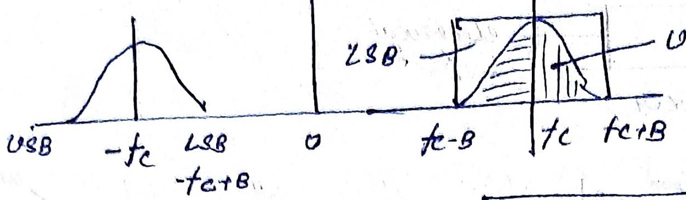
Base Band Signal.

$2f_c \geq 2B$

$2\pi f_c \geq 2\pi B$

$\boxed{\omega_c \geq 2\pi B}$





$\boxed{f_c \geq 2B}$ to inorder to prevent overlapping (in simultaneous message signal transmission)

Channel Bandwidth = 2B

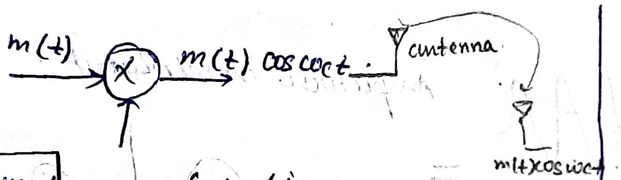
DSB

Double Side Band

(This amplitude modulated signal is called DSB)

DSB-SC

Double side base-sidline carrier



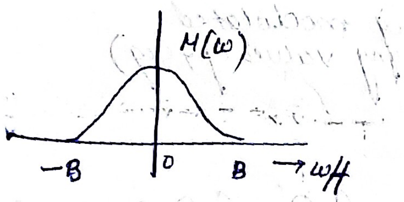
m(t) : message signal

$\cos\omega_c t$: carrier wave.

$m(t)\cos\omega_c t$: modulated wave (DSB-SC)

$$\boxed{m(t)\cos\omega_c t} = m(t)\left\{\frac{1}{2}e^{j\omega_c t} + \frac{1}{2}e^{-j\omega_c t}\right\}$$

$$= \frac{1}{2}m(t)e^{j\omega_c t} + \frac{1}{2}e^{-j\omega_c t}.$$



$m(t) \Longleftrightarrow M(\omega)$

$m(t)e^{j\omega_c t} \Longleftrightarrow M(\omega-\omega_c)$

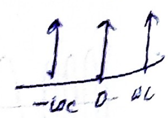
$m(t)e^{-j\omega_c t} \Longleftrightarrow M(\omega+\omega_c)$

- ease
- contain/convey any ...
- consume good amt of power

DSB suppressed carrier

as

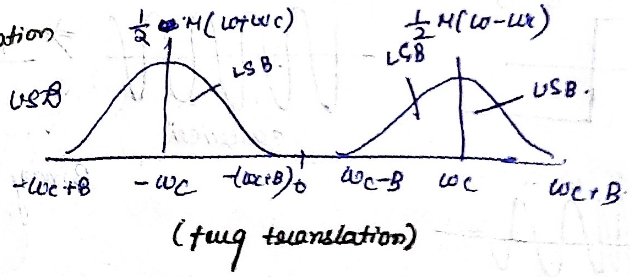
$\cos\omega_c t = \frac{1}{2}[e^{j\omega_c t} + ...$



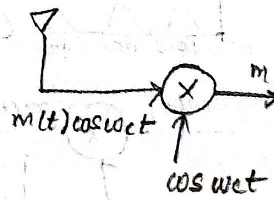
so it is essential to suppress the carrier.

demodulation

(some kind of alteration of any



(freq translation)



$m(t)\cos^2\omega_c t = \frac{1}{2}m(t) + \frac{1}{2}m(t)\cos 2\omega_c t$

$FT[m(t)\cos^2\omega_c t]$

$= FT[\frac{1}{2}m(t) + \frac{1}{2}m(t)\cos 2\omega_c t]$

$= FT[\frac{1}{2}m(t)] + \frac{1}{2}FT[m(t)\cos 2\omega_c t]$

$= \frac{1}{2}M(t) +$

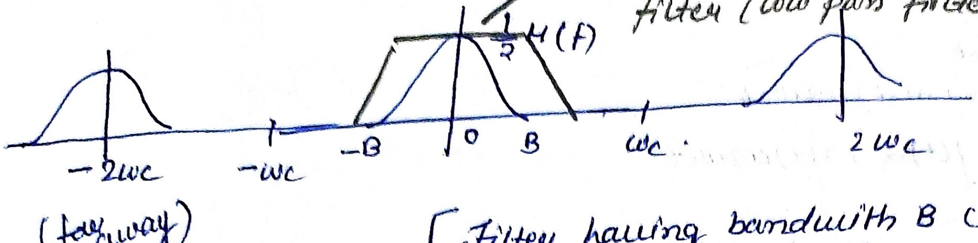
$\boxed{m(t)\cos^2\omega_c t}$ ⟶ can we get back m(t)?

$$\frac{1}{2}m(t)\,2\cos^2\omega_c t = \frac{1}{2}m(t)\{1+\cos 2\omega_c t\}$$

$$\boxed{\frac{1}{2}m(t)} + \frac{1}{2}m(t)\cos 2\omega_c t.$$

scale factor thing done

can take out this by using a filter (low pass filter)



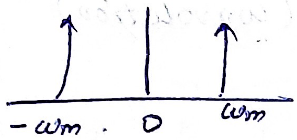
Time domain description / defn fails to sep the two parts but freq domain ~~domain~~ does.

[Filter having bandwith B can separate out the things. (Demodulated separated out the base band signal by passing them more $\cos(2w_c t)$]

Base band $\underset{}{\overset{\text{Modu}}{\rightleftarrows}}$ Band pass ??

Tone modulation system

$m(t) = \cos w_m t$

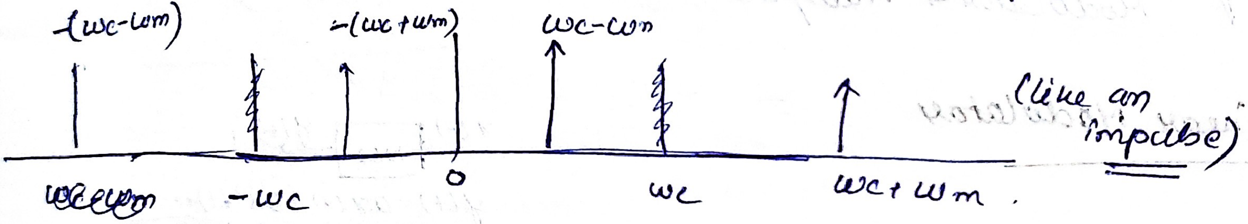


$m(t)\cos w_c t = \cos w_m t \cos w_c t$

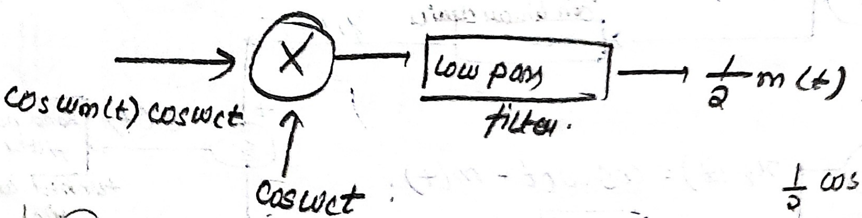
$= \frac{1}{2}(2\cos w_m t \cos w_c t)$

$= \frac{1}{2}(\cos(w_m + w_c)t + \cos(w_m - w_c)t)$

$= \frac{1}{2}\left[e^{j(w_c + w_m)t} + e^{-j(w_c + w_m)t} + e^{-j(w_m - w_c)t} + e^{j(w_m - w_c)t}\right]$

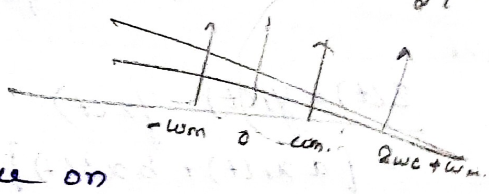


(like an impulse)



$\frac{1}{2}\cos w_m t + \frac{1}{2}2\cos w_m t \cos 2w_c t$

$= \frac{1}{2}[\cos(2w_c + w_m)t + \cos(2w_c - w_m)t]$



Notch filter → responsive on a single frequency
or Notch pass filter.

16/1.

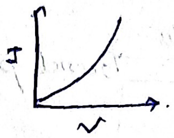
$m(t) \to \otimes \to m(t)\cos\omega_c t$, with $\cos\omega_c t$ into the multiplier

$y(t) = a\, m(t)\cos\omega_c t$

or $y(t) \propto m(t)\cos\omega_c t$

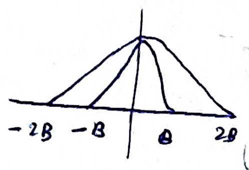
$x(t) \to \boxed{a} \to y(t)$ Amplifier

$y(t) = a x(t)$ $\quad y(t) = a x(t) + b x^2(t)$



In time domain

$m(t) \cdot m(t)$ (convolution)



$(\log(mt) + \log\cos\omega_c t =$

$\log m(t)\cos\omega_c t$

$\text{antilog}(\log m(t)\cos\omega_c t)$

$= m(t)\cos\omega_c t$

we are looking for modulator circuits.

Modulator → Multiplier Modulator X

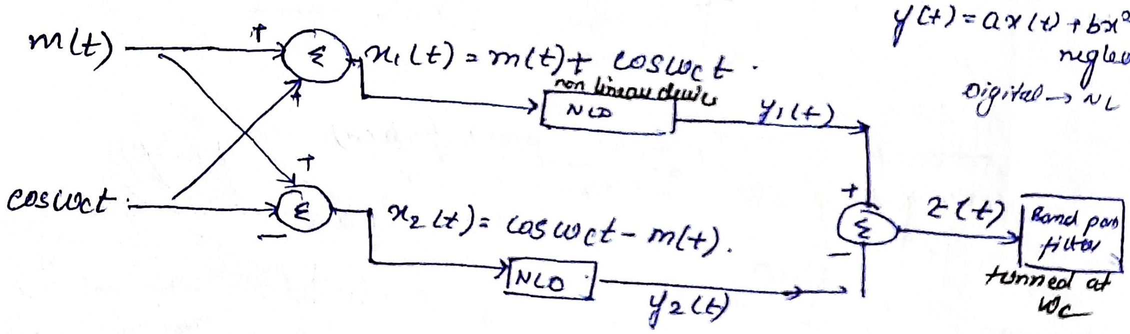
Non Linear Modulator

$x(t) \to \boxed{NLD} \to y(t)$

$y(t) = a x(t) + b x^2(t) + \cdots$

neglect rest

Digital → NL



$z(t) = y_1(t) - y_2(t)$

$= [a x_1(t) + b x_1^2(t)] - [a x_2(t) + b x_2^2(t)]$

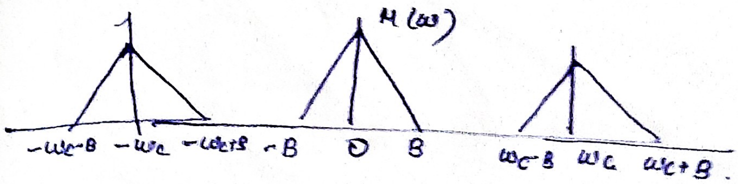
$= [a\{\cos\omega_c t + m(t)\} + b\{\cos\omega_c t + m(t)\}^2] -$

$[a\{\cos\omega_c t - m(t)\} + b\{\cos\omega_c t - m(t)\}^2]$

$= 2am(t) + (2b\, m(t)\cos\omega_c t)2$

$= 2am(t) + 4b\, m(t)\cos\omega_c t.$

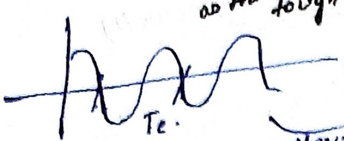
(message signal) (modulated signal)

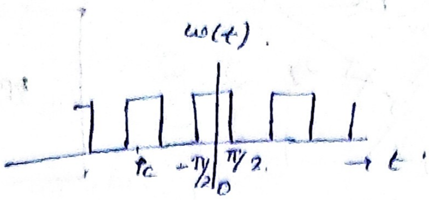


Periodic signal

$$\phi(t) = \sum_{n=0}^{\infty} C_n \cos(n\omega_c t + \theta_n).$$

as this is tough





$w(t)$.

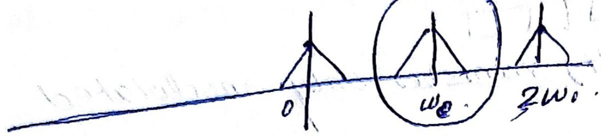
multi carrier signal.

alternate

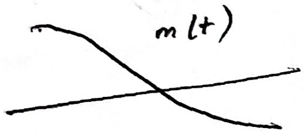
$$w(t) = \frac{1}{2} + \frac{2}{\pi}\left(\cos\omega_0 t - \frac{1}{3}\cos 3\omega_0 t + \frac{1}{5}\cos 5\omega_0 t\right).$$

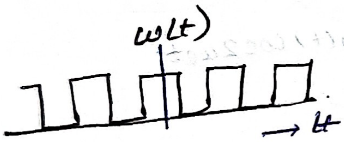
$$m(t)\phi(t) = \sum_{n=1}^{\infty} C_n m(t)\cos(n\omega_c t + \theta_n)$$

$$w(t)\,m(t) = \frac{1}{2}m(t) + \frac{2}{\pi}m(t)\{\cos\omega_c t + \ldots\}.$$



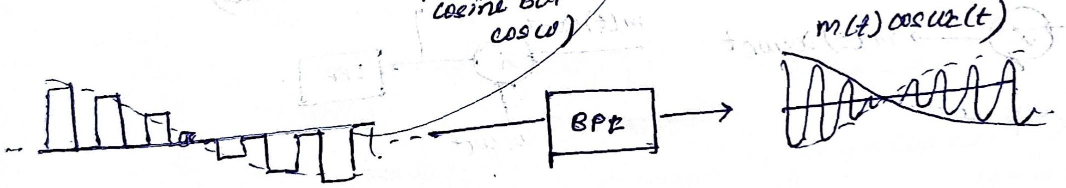
Infinite modulated signal, so to filter out the particular one we need a band pass filter

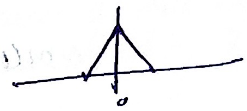




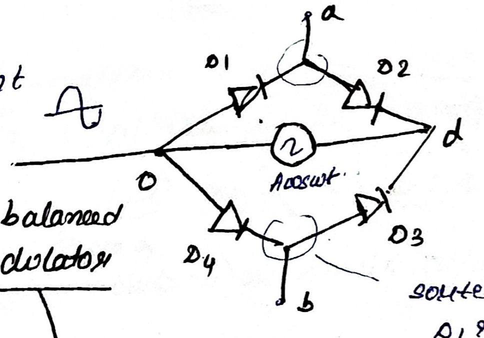
⇓ (contains many components of cosine but we cos ω)

frequency domain.





Switching arrangement



All four diodes are forward biased.

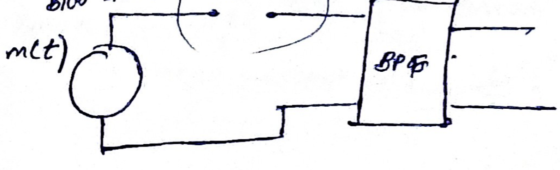
(Bridge diode circuit)

Single balanced Modulator

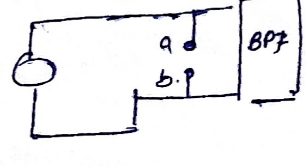
sorted as D_1 & D_4 forward biased.

a and b virtually same points.

Forward bias situation

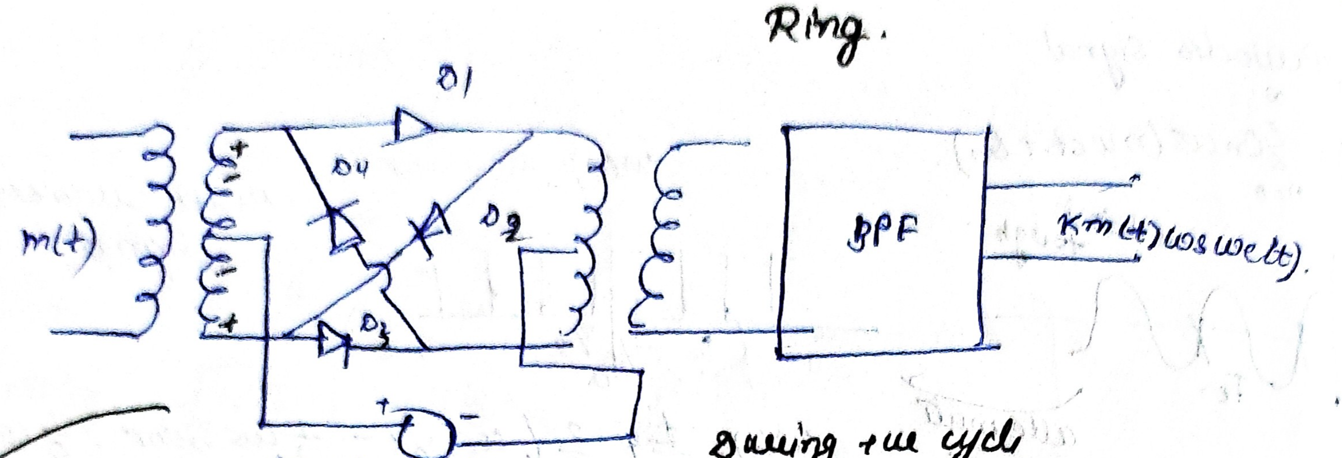


Reverse bias situation.



(here we get message signal as well) by using

Ring.



Considering a specific time interval

\+ -

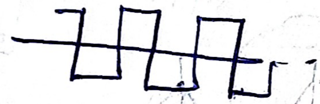
During +ve cycle

D1 & D3 forward

& D4, D2 – reverse (so act off)

(Earlier all 4 forward or all 4 reverse)

Switching function ⇒



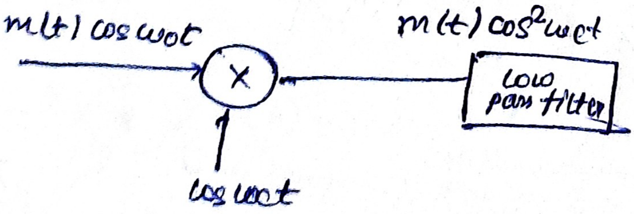
Hence m(t) vanishes only modulated.

Double balanced modulator

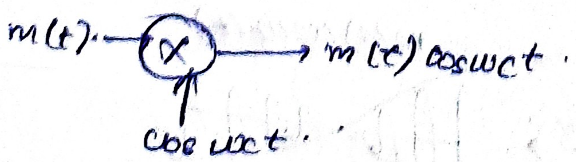
Receive → same freq & phase (amplitude doesn't matter)

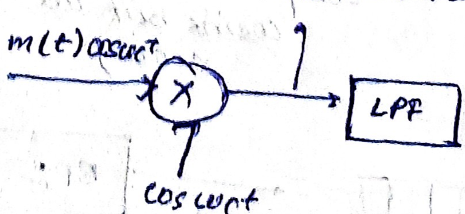
Demodulation :

$\rightarrow \frac{1}{2}(1+\cos 2\omega_c t)$.



$m(t) + m(t)\cos 2\omega_c t$





$m(t) \rightarrow \otimes \rightarrow$ RPF $\rightarrow$

$\cos\omega_c t$

1) Multiplier Modulator
2) Non linear
3) Switch → Single, → Double.

- Synchronous demodulator.

$m(t)\cos\omega_c t \rightarrow \otimes \rightarrow$ LPF $\rightarrow m(t)$

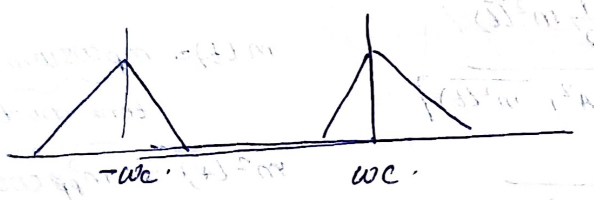
$\cos\omega_c t$

1) Complex Receiver circuit
2) A copy of carrier to be sent alongwith modulated signal.

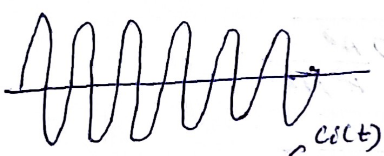
carrier consumes enormous (wastage) energy.

$$\varphi_{AM}(t) = A\cos\omega_c t + \underbrace{m(t)\cos\omega_c t}_{DSB-SC} = [A + m(t)]\cos\omega_c t$$

$$\varphi_{AM}(\omega) = \pi[\delta(\omega-\omega_c)t + \delta(\omega+\omega_c)t] + [M(\omega-\omega_c) + M(\omega+\omega_c)]$$

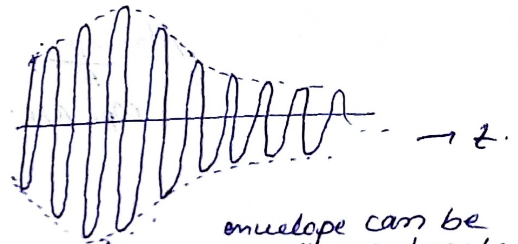


message:-



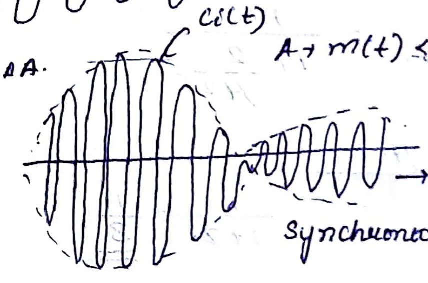
$\Rightarrow$

$A + m(t) \geq 0 \;\forall t$



envelope can be easily extracted if $A + m(t) \geq 0$

Else a part of this signal will be rectified.



$A + m(t) \leq 0 \;\forall t$

Synchronous.

Amp carrier > amp modulated signal. (envelope detection)

$A \rightarrow$ amplitude of ~~message~~ carrier signal.

$m_p \rightarrow$ amplitude of the message / modulating signal.

$\mu = \frac{m_p}{A}$ $\quad \boxed{0 \leq \mu \leq 1}$

Depth of modulator or modulation index.

$$\varphi_{AM}(t) = \underbrace{A\cos\omega_c t}_{carrier} + \underbrace{m(t)\cos\omega_c t}_{DSB-SC}$$

Mean / average carrier power :-

$$P_c = \frac{1}{T}\int_T \frac{A^2}{2} \, 2\cos^2\omega_c t \, dt = \frac{1}{T}\frac{A^2}{2}\int_T (1 + \cos 2\omega_c t)\,dt$$

$$= \frac{1}{T}\frac{A^2}{2}[T + 0]$$

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

Side band power:

$$P_S = \frac{1}{2}\overline{m^2(t)}.$$

Total power = $P_c + P_s$.

$$= \frac{A^2}{2} + \frac{1}{2}\overline{m^2(t)}.$$

$=$

Efficiency of a modulator:

$$\boxed{\eta = \frac{P_s}{P_s + P_c}}$$

$$= \frac{\frac{1}{2}\overline{m^2(t)}}{\frac{1}{2}[A^2 + \overline{m^2(t)}]}$$

$$= \frac{1}{1 + \frac{A^2}{\overline{m^2(t)}}}$$

$m(t) = m_p \cos \omega_m t$

tone modulation

$\overline{m^2(t)} = m_p^2 \cos^2 \omega_m$

$= \frac{m_p^2}{2}.$

$\mu = \frac{m_p}{A}$

$m_p = A\mu.$

$$= \frac{1}{1 + \frac{2A^2}{m_p^2}}.$$

$$= \frac{1}{1 + \frac{2A^2}{A^2\mu^2}}$$

$$= \frac{1}{1 + \frac{2}{\mu^2}}$$

Max $\mu = 1$

$$\therefore \frac{1}{1+2} = \frac{1}{3}$$

$$\eta = \frac{P_s}{P_T} = \frac{1}{3}.$$

P_s carries $1/3$ of P_T

$= 33\%$ of P_T, only carried by side band and remaining goes to carrier band (doesn't convey any message)

AM Amplitude of the modulated carrier is varied in accordance with the amplitude of the modulating signal.

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

$m(t)$

deviation in amplitude

$y_{AM}(t) = C_i(t)\cos\omega_c t$

$\Delta A = C_i(t) - A$

Instantaneous value amp.

unmodulated carrier amp

$$\boxed{\Delta A \propto m(t)}$$

$\Delta A = k\,m(t)$

$C_i(t) - A = k\,m(t) \Rightarrow \boxed{C_i(t) = A + k\,m(t)}$

$$\therefore\ y_{AM}(t) = [A + km(t)] \cos \omega_c t.$$

$$= A\cos\omega_c t + m(t)\cos\omega_c t.$$

$$= A\cos\omega_c t\left[1 + \frac{m(t)}{A}\right]$$

$V_C = E e^{-t/RC} = E(1 - t/RC)$

$\frac{dV_C}{dt} = \frac{-E}{RC} \geq \frac{dE}{dt}$

$E(t) = A(1 + \mu \cos \omega_m t) \cos \omega_c t$

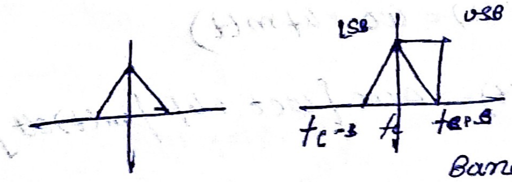
$E(t) = A(1 + \mu \cos \omega_m t)$

$\frac{dE}{dt} = -A\omega_m \mu \sin \omega_m t$

$\frac{A(1 + \mu \cos \omega_m t)}{RC} \geq -A \omega_m \mu \sin \omega_m t$

24/1

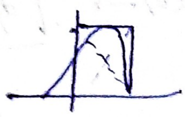
SSB (single side band) modulation.



complexity increases if we suppress carrier to save power.

Bandwidth B required (attempted for video signal transmission)

Not possible to design idea filter, any part will also be taken out → vestigual side band modulation. (VSB)

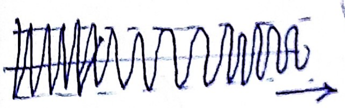


FM

Frequency Modulation

A cos ωct.

$\omega_i(t) = \omega_c t + k m(t)$



$\boxed{\omega_c + k m_p}$

$\boxed{\omega_c - k m_p}$

$\boxed{\text{Bandwidth} = 2 k m_p}$

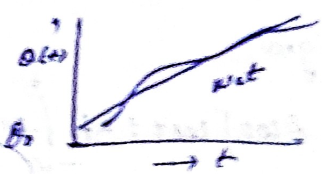
If $k \ll \omega_c$ then Bandwidth also small but wrong thinking!

Angle modulation → phase mod^n, → freq mod^n

$A \cos \theta(t)$

→ $\theta(t) = \omega_c t + \theta_0$

$\theta(t) = \omega_c t + \theta_0 + k_p m(t)$



$\varphi_{PM}(t) = A \cos \theta(t)$

Phase mod^n $= A \cos[\omega_c t + k_p m(t)]$

$\omega_i = \frac{d\theta}{dt} = \omega_c + k_p \frac{d(m(t))}{dt}$

$\Delta\omega = \omega_i(t) - \omega_c$ = change in freq

$\Delta\omega \propto m(t)$

$\Delta\omega = k_f m(t)$

In FM

Deviation in carrier freq is proportional to this message signal m(t)

$$\theta(t) = \int \omega_i(t)\,dt$$

$$= \int [\omega_c + k_f\, m(t)]\,dt$$

$$= \omega_c t + k_f \int m(t)\,dt$$

→ instantaneous carrier freq

$$\omega_i(t) - \omega_c = k_f\, m(t)$$

$$\omega_i(t) = \omega_c + k_f\, m(t)$$

φ_{FM} ·

$$A\cos\theta(t) = A\cos\left[\omega_c t + k_f \int m(t)\,dt\right]$$

$$m(t) \longrightarrow \boxed{\int dt} \xrightarrow{\int m(\alpha)\,d\alpha} \boxed{PM\ mod} \longrightarrow FM$$

$$m(t) \longrightarrow \boxed{d/dt} \longrightarrow \boxed{FM\ mod} \longrightarrow PM$$

Q) If $m(t) = \cos \omega_m(t)$

$c(t) = A_c \cos \omega_c t$.

Find $\varphi_{FM}(t)$

Angle Modulation:

or Exponential Modulation

$$A\cos\theta(t)$$

FM PM

$$\varphi_{PM}(t) = A\cos[\omega_c t + k_p m(t)]$$

$$\omega_i(t) = \frac{d\theta}{dt} = \omega_c + k_p \frac{dm(t)}{dt}$$

ω_c carrier freq

$m(t) \to$ message signal

$$\varphi_{FM}(t) = A\cos\left[\omega_c t + k_f \int_{-\alpha}^{t} m(\alpha)\,d\alpha\right]$$

$$m(t) \longrightarrow \boxed{\int dt} \xrightarrow{\int m(\alpha)\,d\alpha} \boxed{PM} \longrightarrow FM$$

$$m(t) \longrightarrow \boxed{\frac{d}{dt}} \xrightarrow{dm(t)/dt} \boxed{FM} \longrightarrow PM.$$

$$\hat{\int_{-\alpha}} m(\alpha)\, h(t-\alpha)\, d\alpha \longrightarrow \text{convolution.}$$

linear

$$m(t) \longrightarrow \underset{h(t)}{\boxed{H(s)}} \longrightarrow \boxed{\frac{1}{H(s)}} \longrightarrow m(t).$$

modulation fn
demodulation

(basic systems)

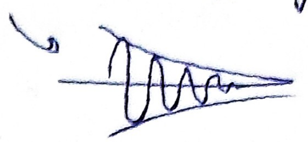
$s = j\omega$ fourier.

$s = \sigma + j\omega$ laplace.

$$F(s) = \int_{-\alpha}^{\alpha} f(t)\, e^{-st}\, dt \qquad s = \delta + j\omega$$

$$F(\omega) = \int_{-\alpha}^{\alpha} f(t)\, e^{-j\omega t}\, dt$$

$$e^{-j\omega t} = \cos\omega t - j\sin\omega t.$$



$$h(t) = k_p \overset{u(t)}{\delta(t)}$$

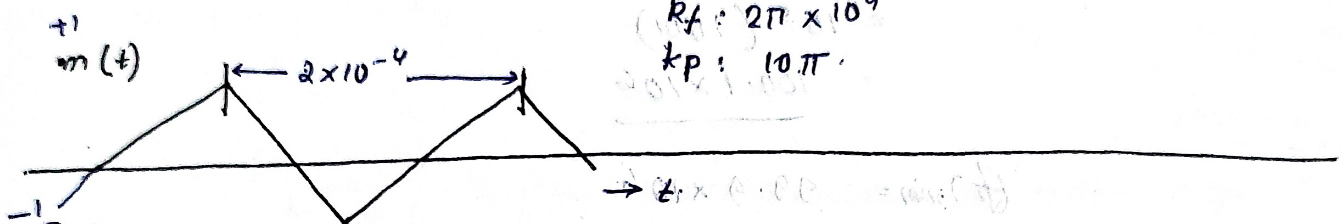
impulse signal is unit impulse

$$\underbrace{\int_{-\alpha}^{\alpha} m(\alpha)\, k_p \underset{u(t-\alpha)}{\delta(t-\alpha)}\, d\alpha}_{m(\alpha)}.$$

(proportionality const in case of FM)

$k_f = 2\pi \times 10^4$

$k_p = 10\pi.$



Prob

FM, PM = ? Carrier $f_c = 100\ MHz.$
$= 10^8\ Hz.$

FM = $f_i =$

$$\omega_i = \omega_c + k_f m(t)$$

$$f_i = f_c + \frac{k_f}{2\pi} m(t)$$

$$= 10^8 + 10^5 m(t)$$

$$(f_i)_{max} = 10^8 + 10^5 m(t)_{max}$$

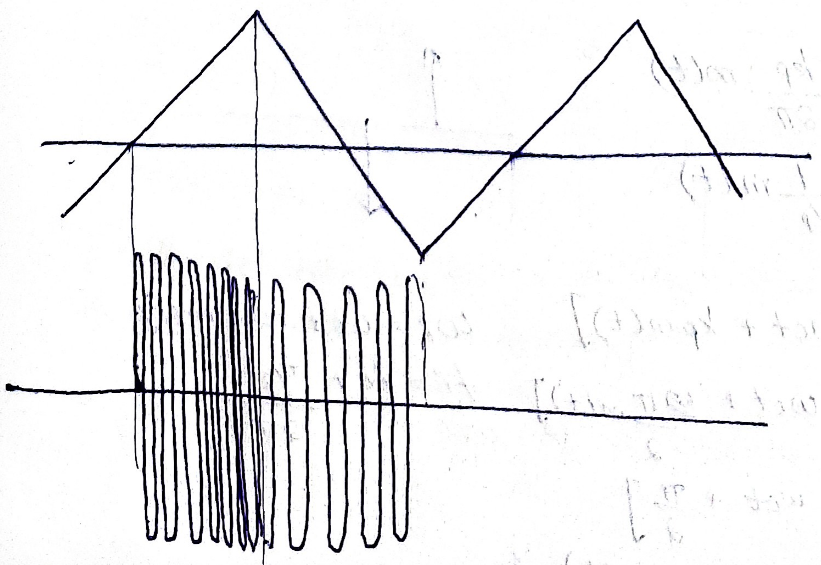
$$= 10^8 + 10^5. \quad 100.$$

$$= 10^5 \times (1001)$$

$$= \underline{100.1 \times 10^6} = \underline{100.1\ MHz}$$

$\cancel{= 100 + 0.1 \times 10^6}$

$$(f_i)_{min} = (100 - 0.1) \times 10^6 = \underline{99.9\ MHz}.$$



$\omega i = \omega c + k_p \dot{m}(t)$

PM $\quad f_i = f_c + \frac{k_p}{2\pi} \dot{m}(t)$

$= 10^8 + 5\,\dot{m}(t)$

$(f_i)_{max} = 10^8 + 5 \times \frac{2}{10^{-4}}$

$= 10^8 + 10 \times 10^4$

$= 10^8 + 10^5$

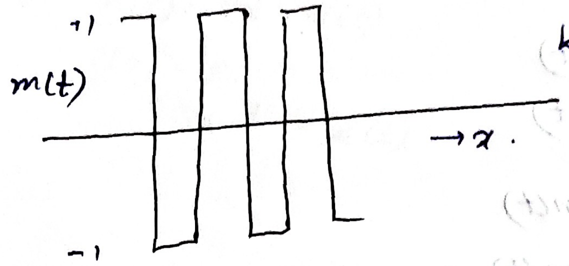
$= 10^5 (1001)$

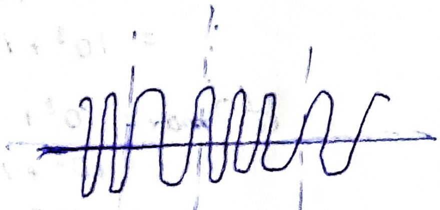
$= 100.1 \times 10^6$

$(f_i)_{min} = 99.9 \times 10^6$

$k_f = 2\pi \times 10^5$

$k_p = \pi/2$

8) 



$f_i = f_c + \frac{k_f}{2\pi} m(t)$

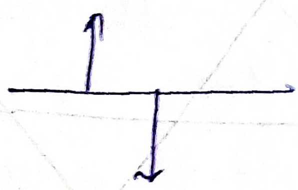
$(f_i)_{max} = 101.1$ MHz.

$(f_i)_{min} = 99.9$ MHz.

(B) FSK: BPSK Binary phase freq. Shift keying

PM $\rightarrow$ $f_i = f_c + \frac{k_p}{2\pi} m(t)$

$= f_c + \frac{1}{4} m(t)$



$\phi_{PM}(t) = A\cos[\omega ct + k_p m(t)]$

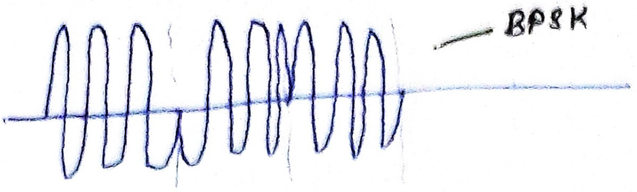
$= A\cos[\omega ct + \frac{\pi}{2} m(t)]$

$= A\cos[\omega ct + \frac{\pi}{2}]$

$= \begin{cases} -A\sin\omega ct & , m(t) = 1. \\ A\sin\omega ct & , m(t) = -1. \end{cases}$

$\omega_i = \omega c + 10\pi\, m(t)$

$f_i = f_c + \frac{\pi/2}{2\pi}$



— BPSK Binary phase shift keying

$\omega_c = k_f m(t)$

$f_i = \omega_c + k_f m(t)$

$= \omega_c - k_f m_p$

$\boxed{BW = 2k_f m_p}$

m_p → peak value of message signal.

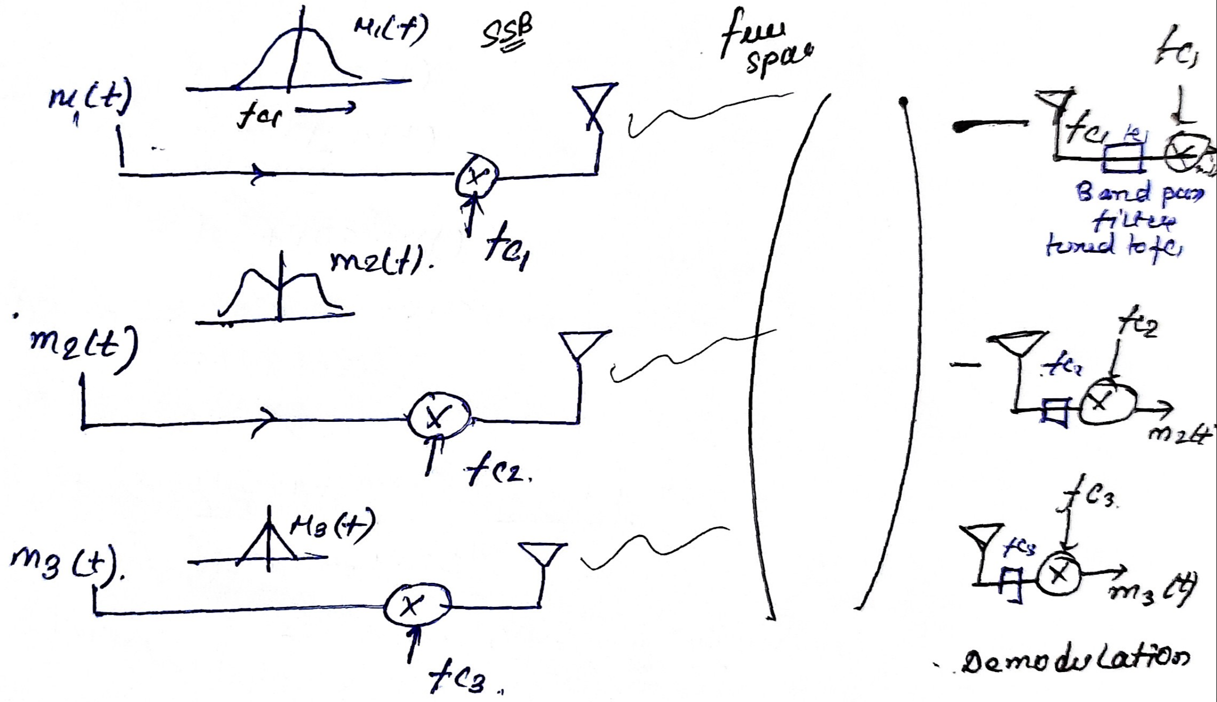
$2k_f m_t$ → deviation

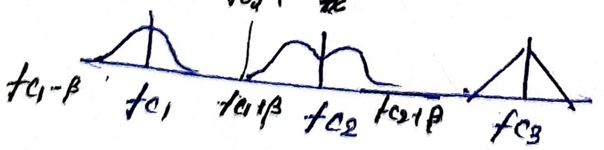
Multiplexing is the simultaneous transmission of several message signals through a common channel.

FDM

FDM

Frequency division multiplexing





In FDM, the available bandwidth is divided into diff sub-band. each sub band is assigned to individual message signal.

Analog Modulation - Pulse Modulation

① Pulse Amplitude Modulation (PAM)

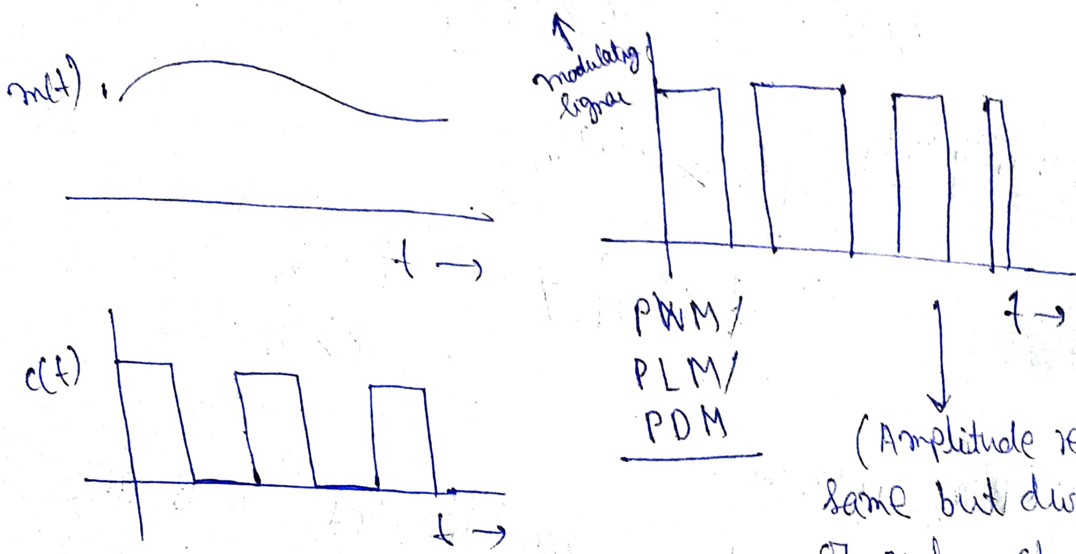
② " Time " (PTM) → PWM / PLM / PDM, PPM

① PAM: In PAM, the amplitudes of the pulse train (carrier signal) is varied in accordance with the amplitude of the modulating signal.

② PTM: - - - - - - -

- - - - - -

time of - - - - -



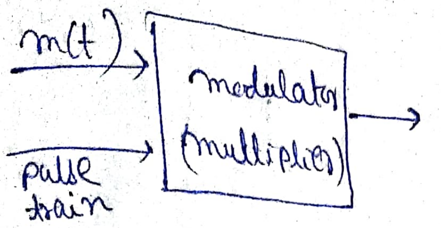
PWM/
PLM/
PDM

(Amplitude remains same but duration of pulse changes)

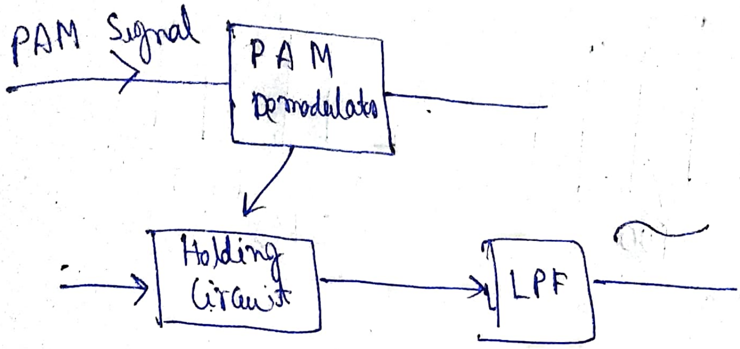
In PWM, the amplitude of pulses are same but duration or length of pulses change.

In PPM, both the amplitude and duration of pulses remain same (with respect to the carrier pulse train) but the position (lead or tail edge) of pulses get changed.

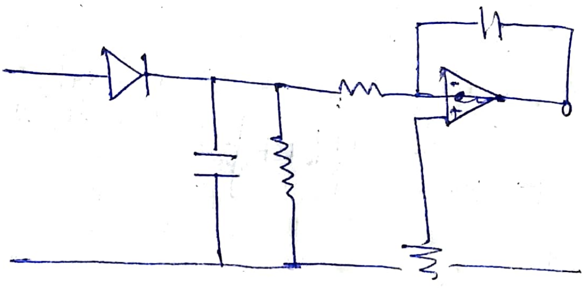
Generation of PAM:



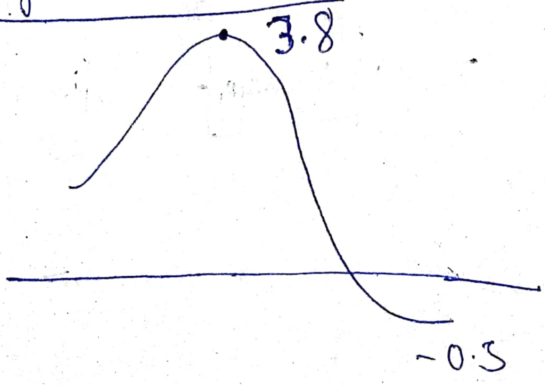
holding circuit by integration is demodulator.

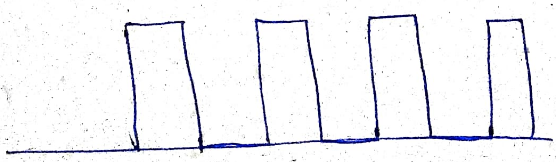


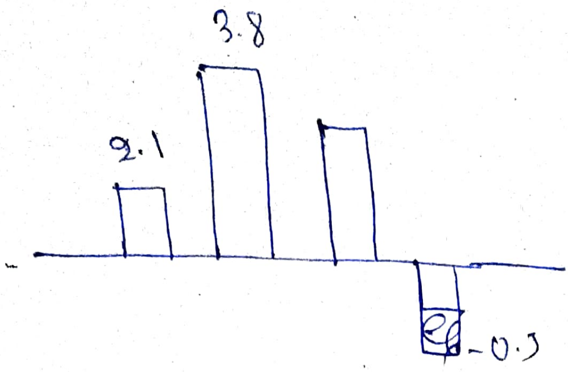
PAM:



Pulse Digital Modulation:

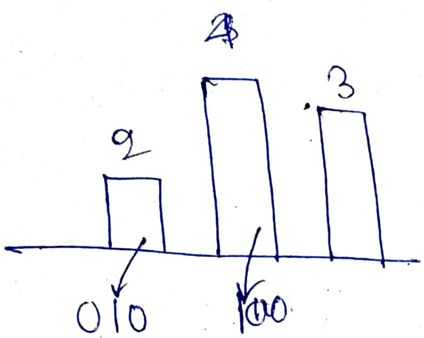




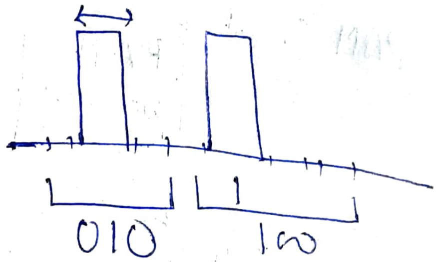


x	$y = Q(x)$
0.5 - 1.5	1
1.5 - 2.5	2
⋮	

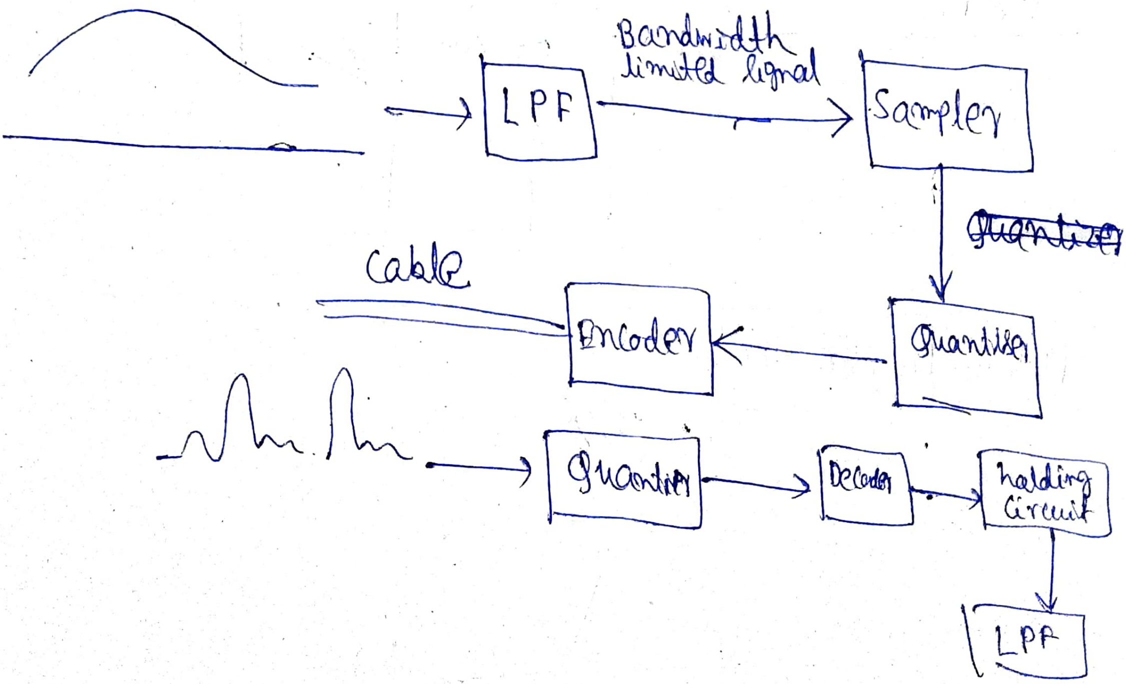
now Quantisation



now bit pattern (Encoder)



~~now bit p~~



$$\tilde{q}^2 = \overline{q^2} - (\overline{q})^2 = \frac{\Delta^2}{12} = \frac{4m_p^2}{12L^2} = \frac{1}{3}\frac{m_p^2}{L^2}$$

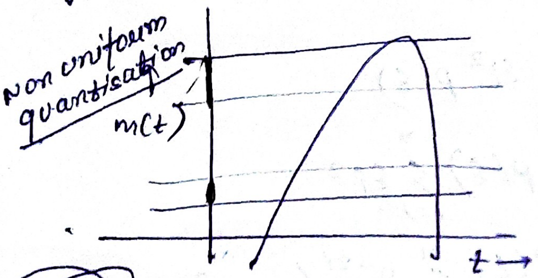
$$\Delta = \frac{2m_p}{L} \qquad L = 2^n$$

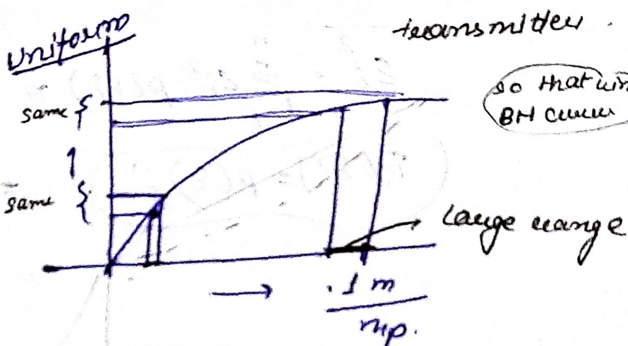
$$\frac{S}{N} = \frac{\overline{m^2(t)}}{\frac{1}{3}\frac{m_p^2}{L^2}} = \frac{3L^2\overline{m^2(t)}}{m_p^2}$$

quantisation noise

signal / noise

Constant value of $\frac{S}{N}$ also desirable. However, the expression shows $\frac{S}{N}$ depends on signal amplitude. So it's have constant S/N we need variable. Suppose Δ large stepsize for large amplitude of signals & small stepwise for small amp of signal





$\frac{S}{N}$ const

Non linear operation → compression.

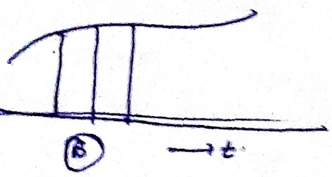
receiver

μ-law = $y = \frac{1}{\ln(1+\mu)} \ln\left(1+\mu\frac{m}{m_p}\right) \quad 0 \le \frac{m}{m_p} \le 1$ [USA & Japan]

A-law. $y = \begin{cases} \frac{A}{1+\ln A}\left(\frac{m}{m_p}\right) & 0 \le \frac{m}{m_p} \le \frac{1}{A} \\ \frac{1}{1+\ln A}\left(1+\ln\frac{Am}{m_p}\right) & \frac{1}{A} \le \frac{m}{m_p} \le 1 \end{cases}$

Small ampli → Large prob
large ampli → small prob

Bandwidth of PCM



① sampling ⇒ no. of samples (min) = 2B/sec

② quantization ⇒ no. of bits required to represent 2B samples are 2nB

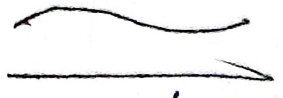
③ Encoding ⇒ $L = 2^n$

no. of bits required to transmitted in one second

2nB ⇒ rate is 2nB/sec.

Bandwidth = ~~...~~ . e

min = $\frac{\text{Min. rate}}{2} = \frac{2nB}{2} = nB$



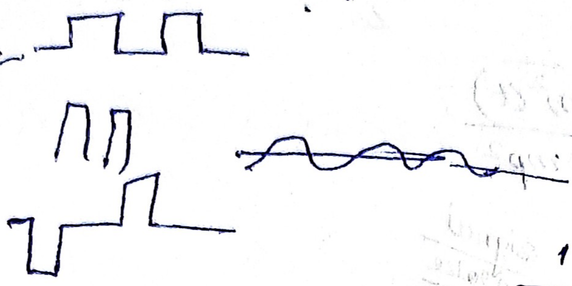
$t \rightarrow$

[1] 10

~~HH~~ 1010 $\Rightarrow$ 0010

$\frac{\varepsilon_i}{8}$

~~[illegible]~~ quantum.



$\frac{1110}{1100}$ $\frac{4}{2}$

m(t) 1110 $\Rightarrow$ non accuracy

$m - \bar{m}$

$\varepsilon_i = \bar{m} - \hat{m}$

$\sigma^2_{\varepsilon_i} = \overline{\varepsilon_i^2} - (\bar{\varepsilon_i})^2$

~~continuous~~ discrete random variable – this noise.

$\varepsilon_i = (2^{-1})F$

$\varepsilon_i = (2^{-1})(2m_p)$

$$\overline{\varepsilon_i^2} = \sum_{i=1}^{n} \varepsilon_i^2 \cdot p(\varepsilon_i) = \sum_{i=1}^{n} \varepsilon_i^2\, p(\varepsilon)$$

$p(\varepsilon_i) = p(\varepsilon)$

$$= p(\varepsilon)\sum_{i=1}^{n} \varepsilon_i^2$$

$$= p(\varepsilon)\sum_{i=1}^{n} 2^{-2i}(2m_p)^2$$

$$= 4m_p^2\, p(\varepsilon)\sum_{i=1}^{n} 2^{-2i}$$

$$= 4m_p^2\, p(\varepsilon)(2^{-2} + 2^{-4} + 2^{-6} + \cdots + 2^{-2n})$$

$$= 4m_p^2\, p(\varepsilon)\, 2^{-2}(1 + 2^{-2} + 2^{-3} + \cdots)$$

$$= 4m_p^2\, p(\varepsilon)\, 2^{-2}\{1(1-2^{-2n})\}\varepsilon_i$$

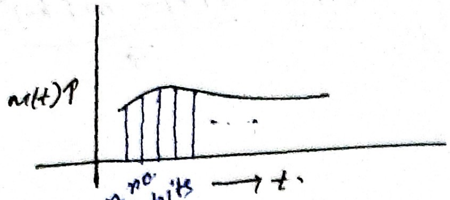
$$= (2^{-1})F$$

$$\bar{\varepsilon_i} = \sum_{i=1}^{n} \varepsilon_i\, p(\varepsilon_i) = p(\varepsilon)\sum_{i=1}^{n} \varepsilon_i$$

$$= p(\varepsilon)\{8 - 8 + 4 - 4 + \cdots\}$$

$$= 0$$

Analog $\rightarrow$ Digital



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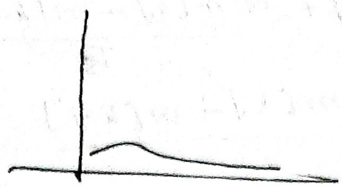
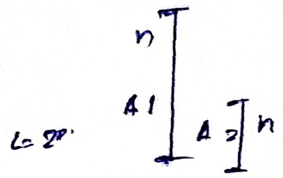


both waveform identical but does it serve purpose in receiver?

samples are highly correlated (Analog)



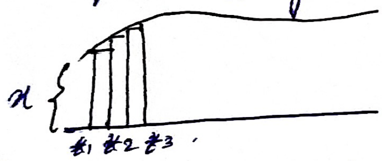
DPCM
Differential Pulse code Modulation.

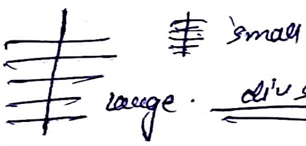
for same BW, quantisation noise power of PCM > .... DPCM.

$\Delta_1 = \frac{\text{high}}{L}$ $\Delta_2 = \frac{\text{Low amp}}{L}$

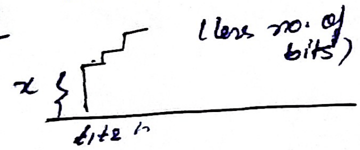
$\Delta_1 >> \Delta_2$

PCM (more no. of bits)





DPCM (less no. of bits)



$\Delta x << x_2$

for 'n' value

$L = 2^n$ → fixed.

	PCM	DPCM
t_1	x_1	x_1
t_2	x_2	$\Delta x = x_2 - x_1$

step size Δ_1 in PCM is $\frac{\text{Large amp}}{L}$

step size Δ_2 in DPCM is $\frac{\text{small amp}}{L}$

① For same bandwidth quantisation noise power is more in PCM than in DPCM.

⇒ SNR is Large in DPCM than in PCM.

② For same SNR, i.e. quantisation in noise power, BW in DPCM is smaller than PCM.

$m(t)$ $\dot{m}(t)$ $\ddot{m}(t)$ ....

$m(t+T_s) = m(t) + \frac{T_s}{1!}\dot{m}(t) + \frac{T_s^2}{2!}\ddot{m}(t) + \dots \approx m(t) + \frac{T_s}{1!}\dot{m}(t)$

$$m[k+1] = m(kT_s + T_s) = m((k+1)T_s) \approx m(k) + \cancel{T_s}\,\frac{m[k] - m[k-1]}{\cancel{T_s}}$$

$$\dot{m}(t) = \frac{m[k] - m[k-1]}{T_s}$$

$$\approx \frac{2m[k] - m[k-1]}{}$$

$$m[k+1] = a_0 m[k] + a_1 m[k-1] + a_2 m[k-2] + a_3 m[k-3] + \cdots + a_N m[k-N]$$