MODULE - 3

Signal Encoding Techniques

Digital data → Digital signal

- Unipolar
- Polar
- Multilevel
- Biphase

Digital data → Analog signal

- ASK
  Amp. shift Key
- FSK
  Freq. shift Key
- PSK
  Phase shift Key
- QAM

Analog data → Digital signals

- PCM
  Pulse Code Modulatⁿ
- DM
  Delta modulatⁿ

Analog data → Analog signals

- AM
- FM
- PM

Digital data ——→ Digital signal

Line encoding
Block coding
Scrambling

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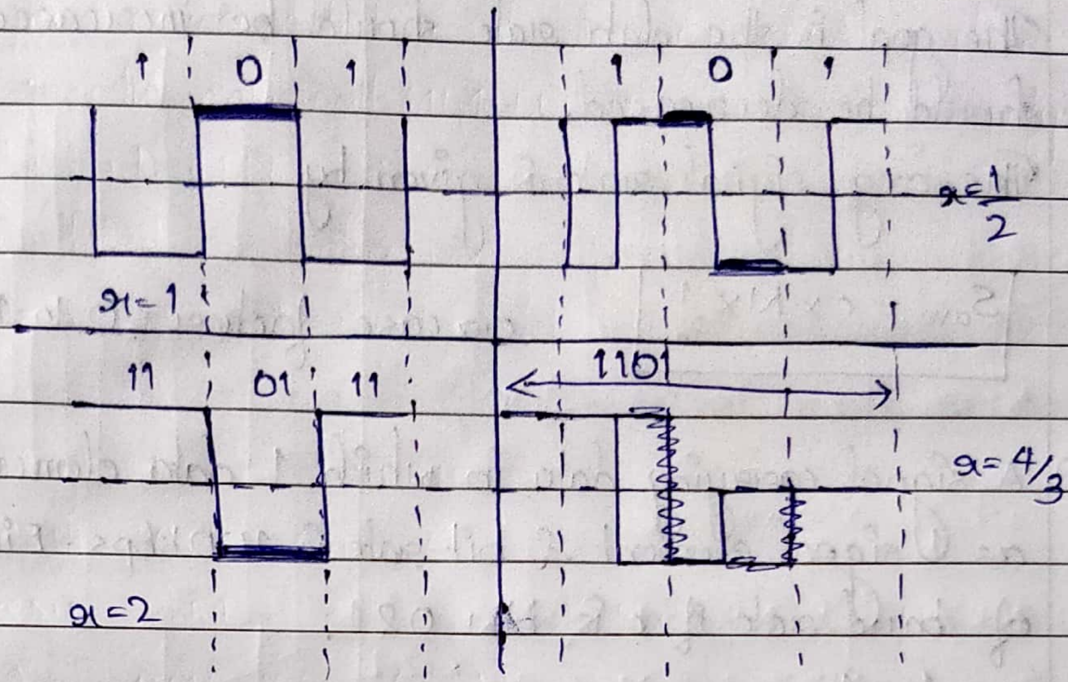

~~Data rate~~, $r = \frac{\text{Data Element}}{\text{Signal Element}}$

Data Element & Signal Element

It is the smallest entity of info & signal element is the shortest unit of digital signals. Data elements are carried by signal elements. The ratio r specifies the no. of data elements carried by each signal element. Data rate is the no. of data elements sent in 1s, also known as bit rate (bps)

Signal rate is the no. of signal elements sent in 1s given in baud. It is also known as pulse rate / modulatn rate / baud rate

The relationship btw data rate (N) & signal rate (S) is given as $\boxed{S = \frac{N}{r}}$

The goal is the data rate should be increased & signal rate should be decreased.

The avg signal rate is given by

$$\boxed{S_{ave} = c \times N \times \frac{1}{r}}$$

$c \rightarrow$ case factor = 0 to 1

① A signal carrying data in which 1 data element is encoded as ① signal element & bit rate is 100 kbps. Find avg value of baud rate if c is btw 0 & 1.

ans $r = \frac{1}{1} = 1$

$N = 100\text{kbps} = 1 \times 10^5 \text{ bps}$

$c = 0.5$

$S_{ave} = 0.5 \times 10^5 \times 1 = 50\text{k baud}$

$$\boxed{B_{min} = c \times N \times \frac{1}{r}}$$ → Min. bandwidth

$$\boxed{N_{max} = B \times r \times \frac{1}{c}}$$ → Max. data rate

Baseline wandering (Problem)
DC Component (Problem)
Self-Synchronizatn (")
Error correctn

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Baseline Wandering

When coding a digital signal, the receiver calculates a running avg of the received signal power which is given as baseline. The incoming signal power is evaluated against the baseline to determine the value of data element. A long string of 0's or 1's cause a drift in baseline called as baseline wandering

DC Component Problem

The digital signal having const. voltage level present problems that cannot pass the low frequencies & those freq.s around 0 are called DC components

eg: Telephone lines less than 200Hz cannot pass the freq.s
Hence avoid DC component problem

Self - Synchronizatn

To correctly interpret the sender's bit intervals to receiver's bit intervals, a self-synchronizing signal can be used. It includes timing info in the signal that is being transmitted

Built-in Error Detectn & Correctn

They can be used.

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Line Coding

Converting digital data into digital signal

(1) Unipolar NRZ

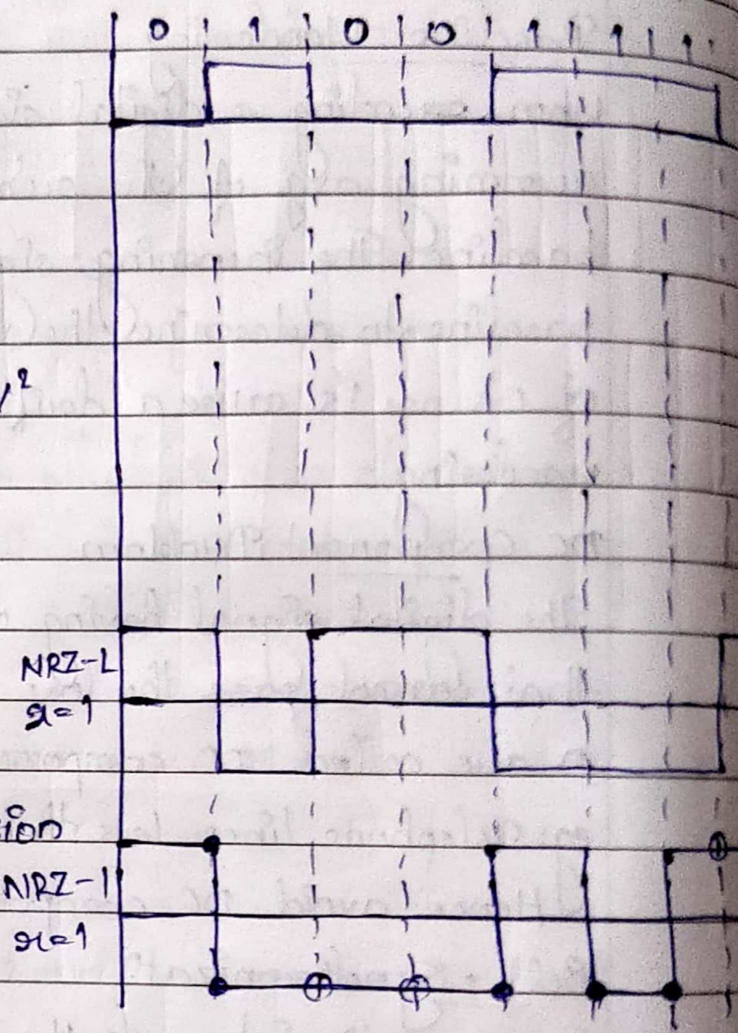
It is called as NRZ because it does not return to 0 at the middle of the bit.

+ve. voltage → 1 , 0 voltage → 0

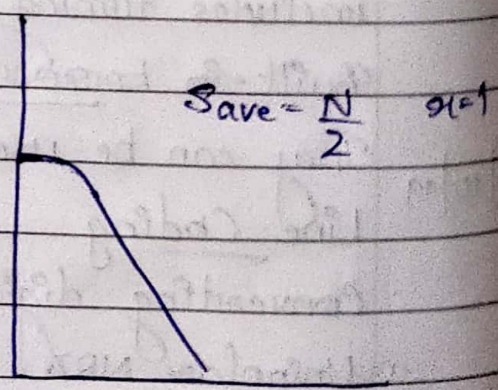
Disadvantages
(i) Costly
(ii) DC component problem
(iii) Self-sync problem
(iv) Baseline wandering
Normalized Power $= \frac{1}{2} \times V^2$

where $V \rightarrow$ voltage

(ii) NRZ-L & NRZ-I
Polar NRZ-L & NRZ-I
NRZ-I   Level of voltage
If next bit is 0 → No inversion
" " " " 1 → Inversion
$S_{ave} = \frac{N}{2}$



Disadvantages
(i) Baseline wandering problem is more in NRZ-L than in NRZ-I
(ii) Synchronizat^n problem
(iii) DC component "
(iv) Change in polarity causes error
NRZ-L → Level of voltage determines value of bit



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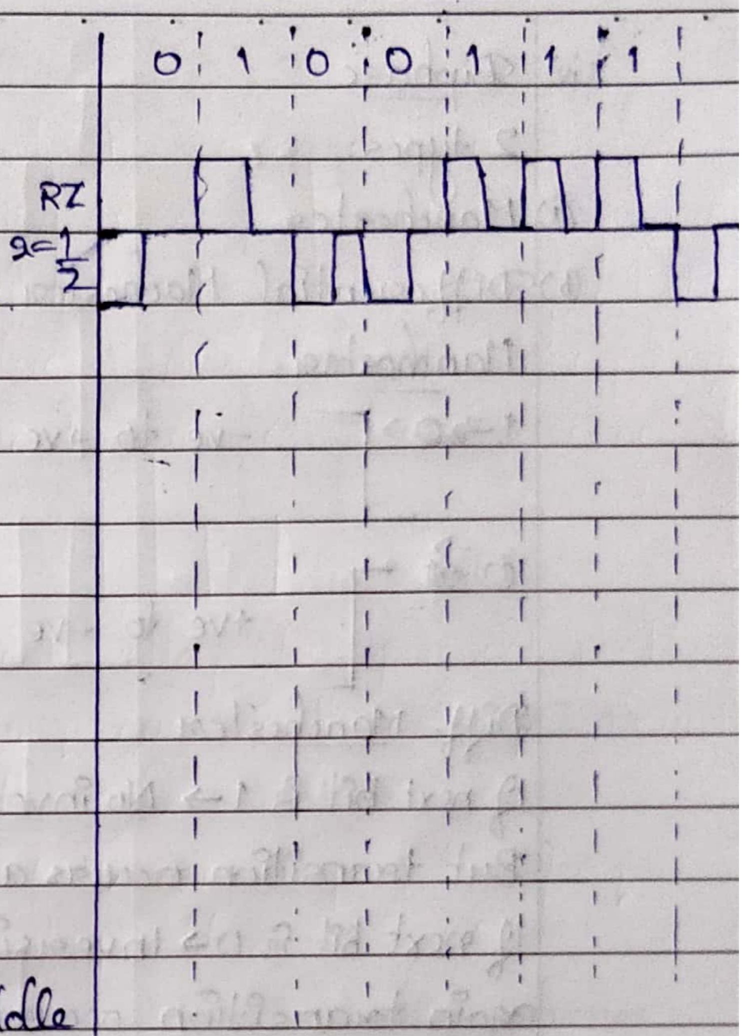
NRZ-I → Change or lack of change determines value of bit

No inversion if next bit is 0

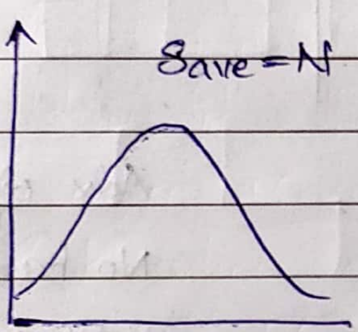


(iii) RZ

Return to Zero (Polar)

3 levels → 0, +ve & -ve

$S_{ave} = N$



Signal goes to 0 in the middle of the bit.

Advantages

(i) No DC component problem

(ii) " synchronizatn "

Disadvantages

(i) Sudden change in polarity may cause 1 to be read as 0 or vice-versa.

(ii) It requires greater bandwidth since 2 signals are needed to encode a bit

(iii) It is more complex since it has 3 levels of voltage.

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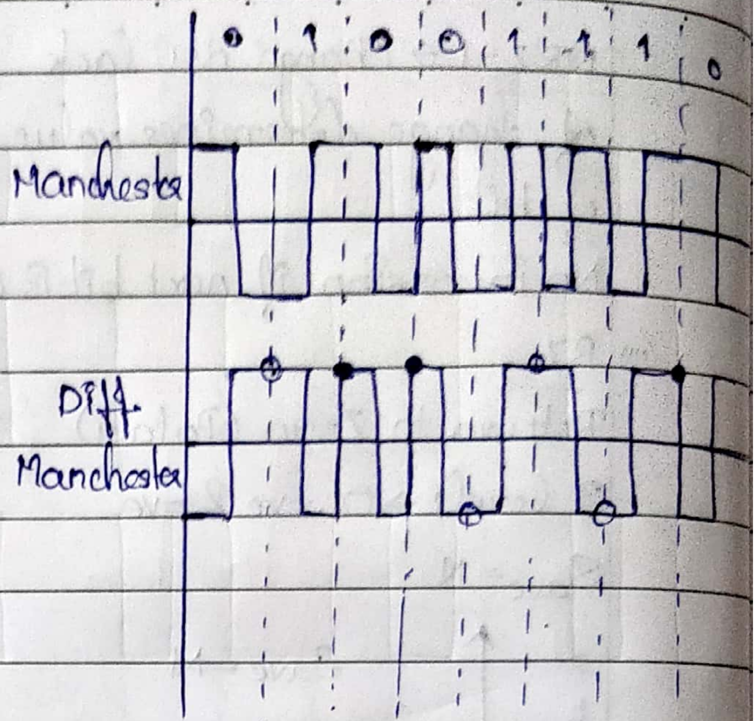
(iv) Biphase

2 types:

(a) Manchester

(b) Differential Machester



Manchester

1 → -ve to +ve

0 → +ve to -ve

Diff. Manchester

If next bit is 1 → No inversion. But transition occurs at middle

If next bit is 0 → Inversion. But again transition occurs at middle

Adv. of Manchester

No baseline wandering & DC comp. problem

Disadv

Signal rate is high

(v) Bipolar

2 types:

(a) Alternate Mark Inversion (AMI)

(b) Pseudo ternary

AMI

AMI has 3 voltages → +ve, -ve & 0

It has 1 data element as 0 & mark denotes 1 which alternates btw +ve & -ve

Pseudo ternary

Opposite of AMI

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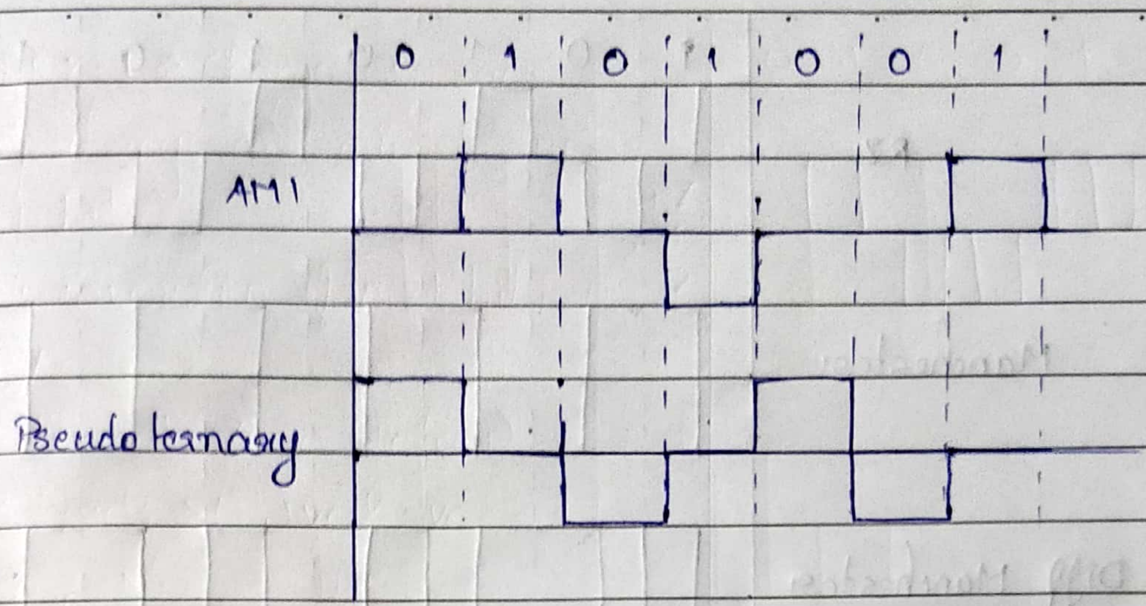


Advantage

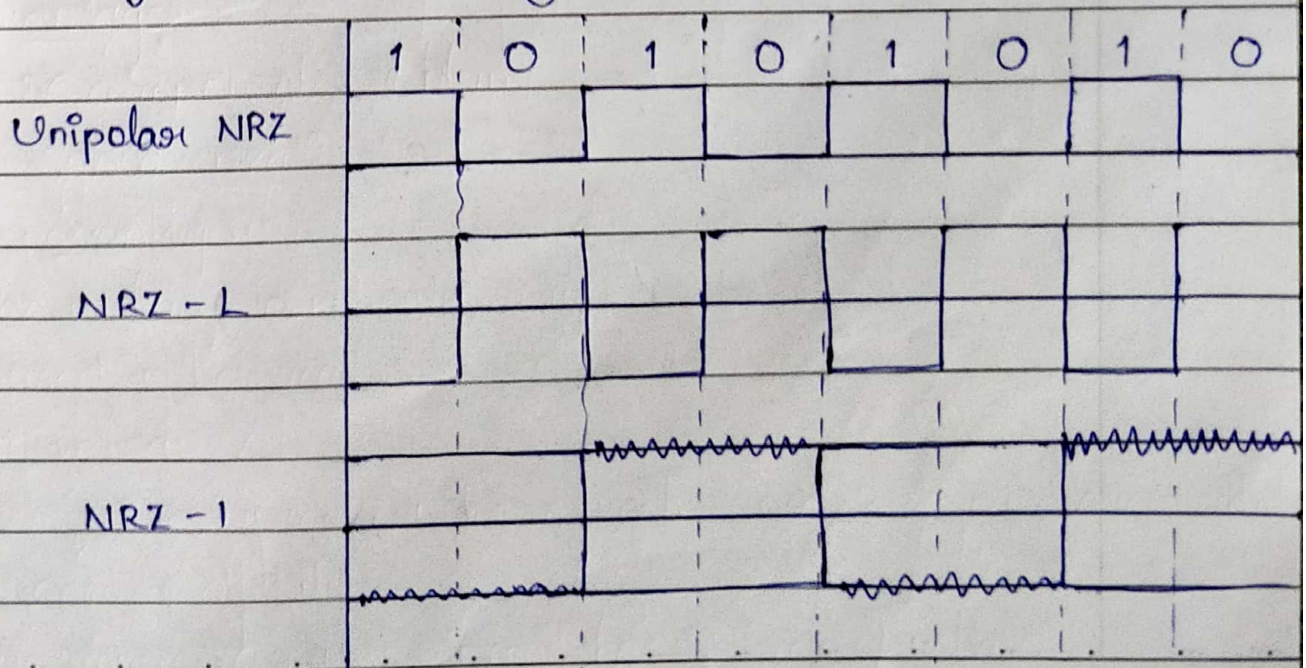
No DC comp. problem because long sequence of 0's & 1's alternates btw +ve & -ve

Disadvantage

Synchronizatn problem

① Encode bit stream 10101010 into line coding schemes assuming last level has negative.

ans



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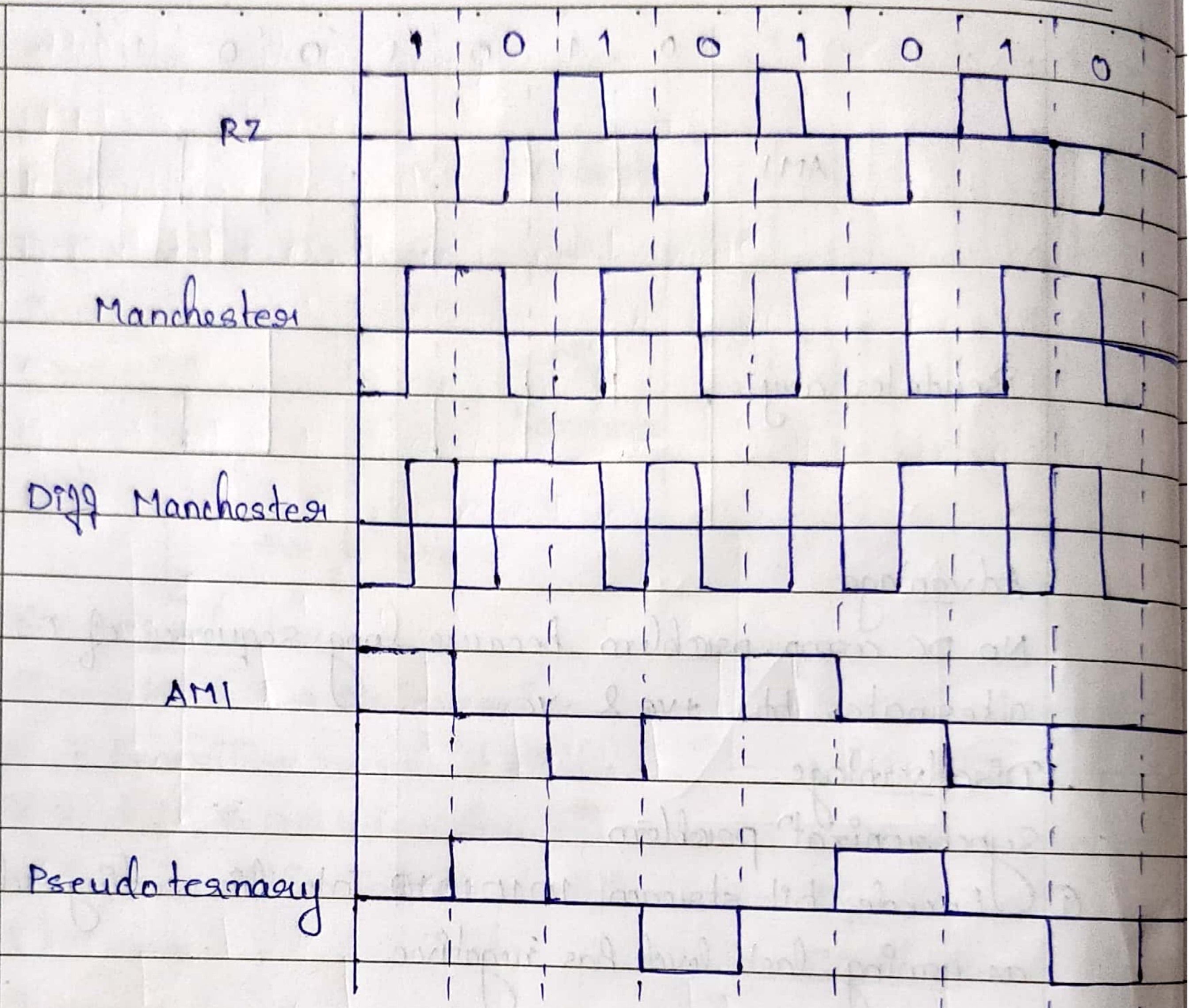

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Bipolar C/Cs

It is a better alternative to NRZ

Multilevel Schemes

- In these schemes we ↑ the no. of data bits/symbol thereby ↑ing the bit rate
- Since it is binary data we only have 2 types of data elements a 1 or 0
- We can combine 2 data elements into pattern of "m" elements to create "2^m" symbols

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- If we have L signal levels, we can use "n" signal element to create L^n signal elements.

Code C/Cs

- If $2^m > L^n$ then we cannot represent data elements, we don't have enough signals.
- If $2^m = L^n$ then we have an exact mapping of 1 symbol on 1 signal.
- If $2^m < L^n$ then we have more signals than symbols & we can choose the signals that are more distinct to represent symbols & therefore have better noise immunity & error detectⁿ.

Note:- In mBnL schemes, a pattern of m data elements is encoded as a pattern of n signal elements in which $2^m < L^n$.

- L = B binary, L = T for 3 ternary, L = Q for 4 quaternary.

Multilevel using Multiple Channels

- In some cases, we split the signal txm up & distribute it over several links.
- The separate segments are transmitted simultaneously. This reduces signalling rate per link → lower bandwidth

xD - YYYZ → No. of levels

X division (No. of wires (splits))

YYY → Type of modulatⁿ

eg: 4D-PAM5 → 5 levels

4 → 4 wires

PAM → Pulse amp. mod.

Multitransition Coding

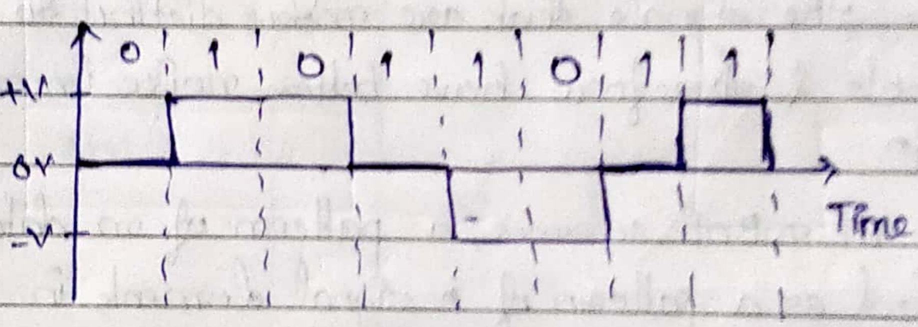
MLT-3 scheme

In multilevel transitⁿ, rules are:

(i) If next bit is 0, there is no transitⁿ

(ii) " " " " 1 & current level is not 0, then next level is 0

(iii) If next bit is 1, & current level is 0, then next level is opposite of last non-zero level



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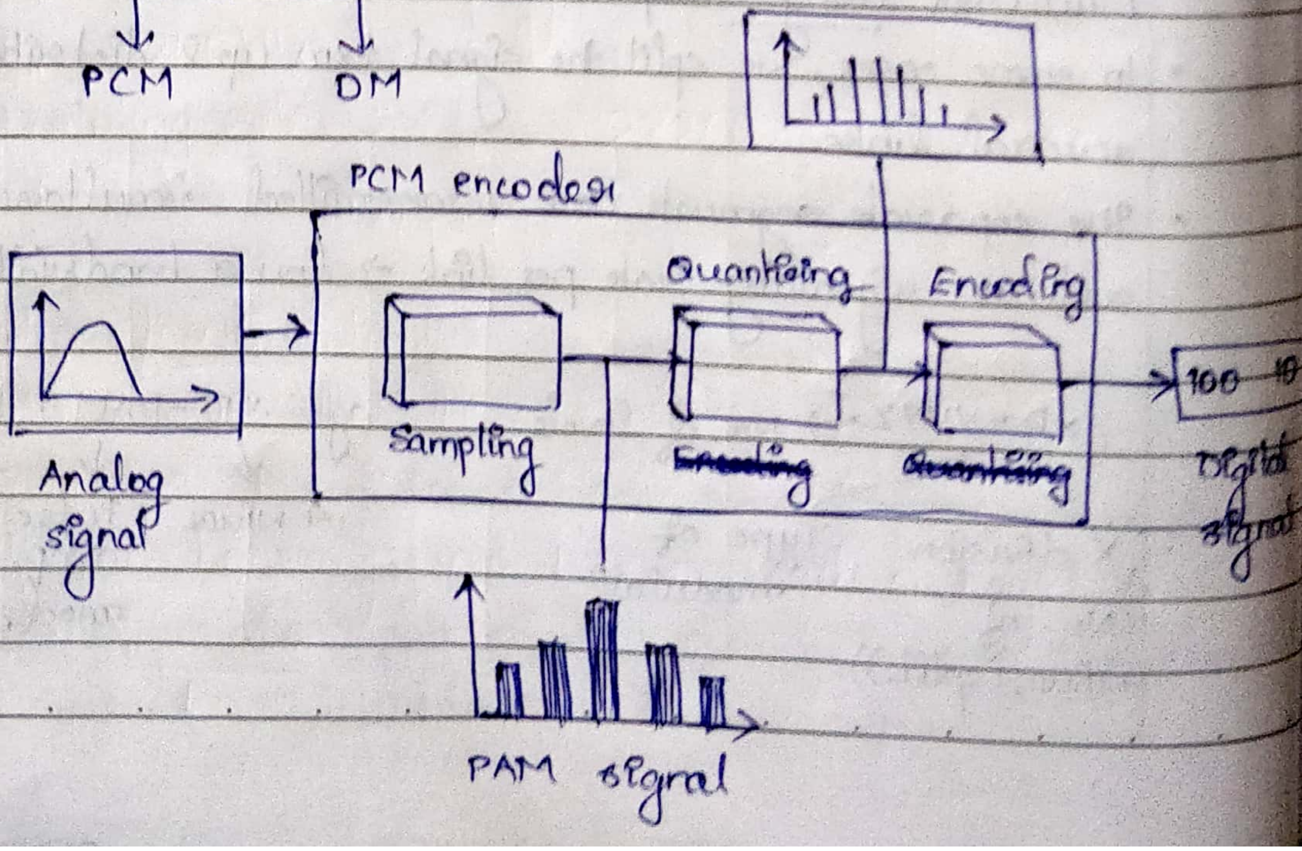
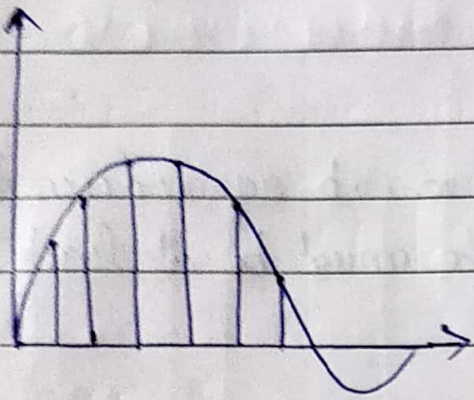
Analog to Digital ~~PCM~~

PCM   DM

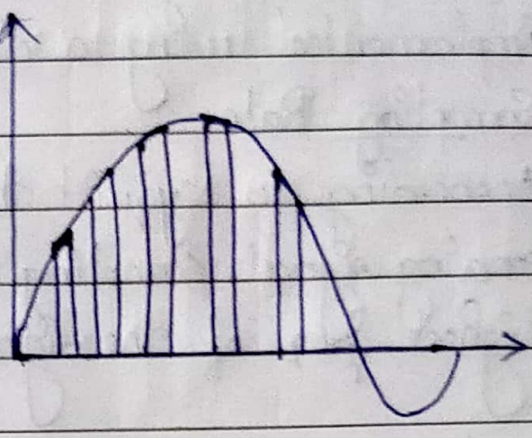


Sampling

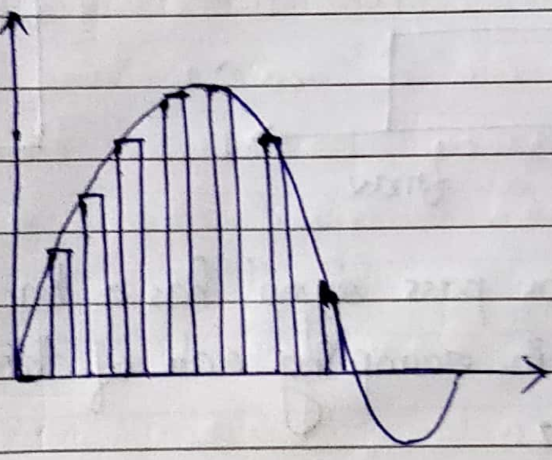
~~Ideal~~



Ideal



Natural



Flat top sampling

Analog signal is sampled at every T_s second. It is known as sampling period.

Sampling freq., $f_s = \frac{1}{T_s}$

In ideal sampling, the pulses are sampled which cannot be implemented in real time. In natural sampling the high speed switch is turned on for small period when sampling

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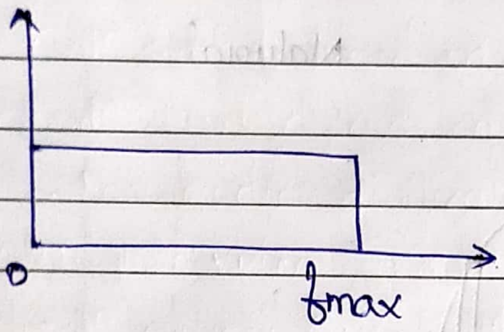
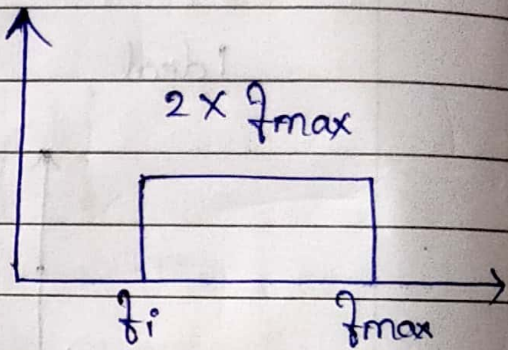
occurs. It retains shape of signal.
Flat top sampling is also known as sample & hold, which is implemented using a ckt.

Sampling Rate

According to Nyquist theorem, to reproduce the original analog signal, sampling rate must be at least 2x the highest freq. of the signal.





(1) A complex low pass signal has a bandwidth of 200 kHz. What is the min. sampling rate of this signal?

ans: $f_{max} = 200 kHz$

Sampling rate $= 2 \times f_{max} = 2 \times 200 \times 1000 Hz$ ~~= 400000~~

$= 400000$ samples/sec

Steps for Quantisat^n

(i) We assume that the original analog signal has amplitude b/w V_{max} & V_{min}.

(ii) Divide the range into L zones, each of height Δ

$$\Delta = \frac{V_{max} - V_{min}}{L}$$

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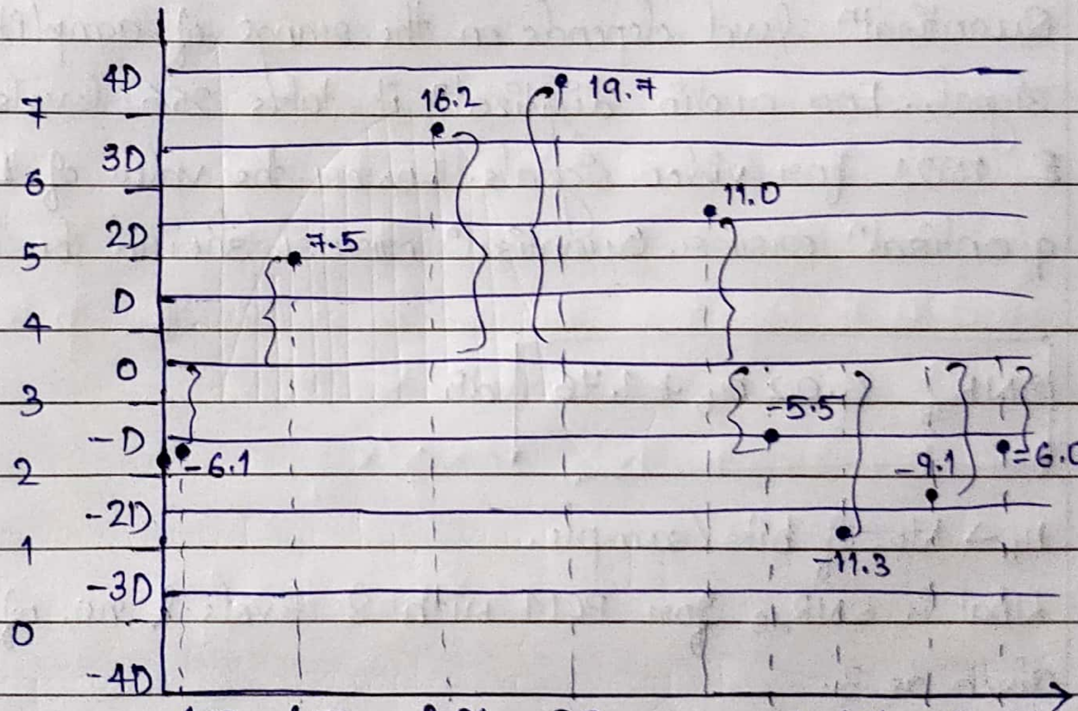
(iii) Assign quantised values of 0...(L-1) to the midpoint of each zone

(iv) Approximate the values of sampled amplitude to quantised values.

eg: A sampled signal has amplitude b/w -20V to +20V & has 8 levels

L=8

$$\Delta = \frac{20-(-20)}{8} = \frac{40}{8} = 5$$



Normalized PAM values (distance of points above & below 0)	-1.22	1.50	3.24	3.9	2.2	-1.1	-2.26	-1.9	-1.1
Normalized quantized values	-1.5	1.5	3.5	3.5	2.5	-1.5	-2.5	-1.5	-1.5
Normalized error	-0.28	0	0.26	-0.4	0.3	-0.4	-0.24	0.4	-0.4
Encoding	2	5	7	7	6	2	1	2	2

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Digital signal → Binary representatⁿs of quantised values

2 5 7 7 6 2 1 2 2

010 101 111 111 110 010 001 010 010

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Quantisatⁿ process selects the quantisatⁿ values from middle of each zone.

Normalized error = Normalized quantised value − Normalized amplitude value

Quantisatⁿ code is based on quantisatⁿ levels.

Quantisatⁿ level depends on the range of amplitudes of analog signal. For audio digitizatⁿ it takes 256 levels & around 1024 for video signals. Lower the value of L, more is the quantisatⁿ error. Quantisatⁿ error should be btw $+\frac{\Delta}{2}$ & $\frac{-\Delta}{2}$

$$\boxed{SNR_{dB} = 6.02\, n_b + 1.76} \text{ dB}$$

n_b → No. of bits/sample.

1. What is SNR_{dB} for PCM with 8 levels & no. of bits/sample given as 3.

ans $n_b = \log_2 L = 3$

$SNR_{dB} = 6.02 \times 3 + 1.76 = \underline{\underline{19.82 \text{ dB}}}$

Uniform vs Non-uniform Quantisatⁿ

If the distributⁿ of amplitude in analog signal is not uniform then the height of the signal Δ is not fixed.

Data is greater at the lower amplitudes & lesser near the higher amplitudes.
Non-uniform quantisatn can be reduced by using a process called companding i.e. the signal is reduced for larger values at the ~~centre~~ sender & expanded at the receiver after conversion. Companding gives greater weight to strong signal & less weight to weak or noise.

Encoding

After the sample is quantised n_b to be encoded is determined from quantisatn level L.

$n_b = \log_2 L$

Bit rate = Sampling rate x No. of bits per sample
$= f_s \times n_b$

① We want to digitize human voice. What is the bit rate, assuming 8 bits per sample? (freq range → 0-4000 Hz)

ans. Sampling rate, $f_s = 2 \times f_{max} = 2 \times 4000 = 8000 Hz$

Bit rate = Sampling rate x No. of bits per sample
$= 8000 \times 8$
$= 64000$ bps
$= \underline{64 kbps}$

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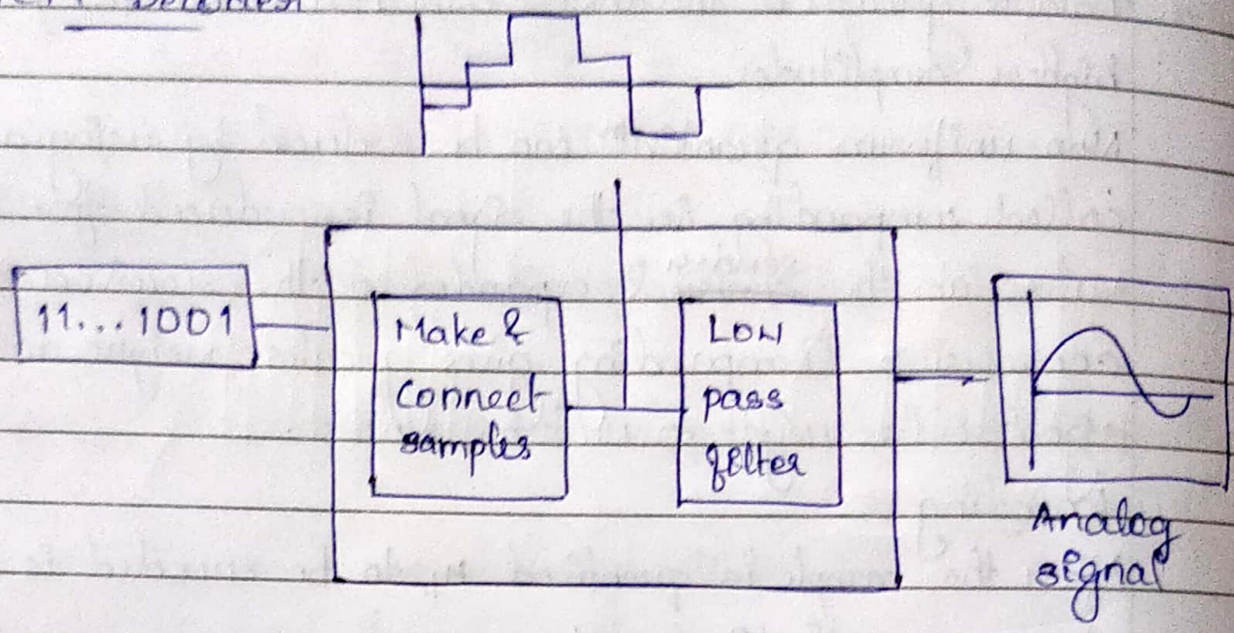
PCM Decoder



Decoder uses circuitory to convert codewords to pulse by holding the amplitude until the next pulse. The resulting staircase signal is passed through low pass filter to smooth it out into the analog signal, The filter has same cut-off freq. as the sender

Min. Bandwidth, $B_{min} = c \times N \times \frac{1}{r}$

$$= c \times n_b \times f_s \times \frac{1}{r}$$

$$= c \times n_b \times 2 \times B_{analog} \times \frac{1}{r}$$

If $c = \frac{1}{2}$ & $r = 1$,

$$\boxed{B_{min} = n_b \times B_{analog}}$$

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① We have low pass analog signal of 4kHz. If signal is digitized with 8 bits per sample, what is the min. bandwidth required?

ans: $n_b = 8$ bits/sample

$B_{analog} = 4kHz = 4000Hz$

$B_{min} = n_b \times B_{analog}$

$= 8 \times 4000$

$= \underline{32kHz}$

$$\boxed{N_{max} = 2 \times B \times \log_2 L \text{ bps}}$$

$$\boxed{B_{min} = \frac{N}{2 \times \log_2 L}}$$

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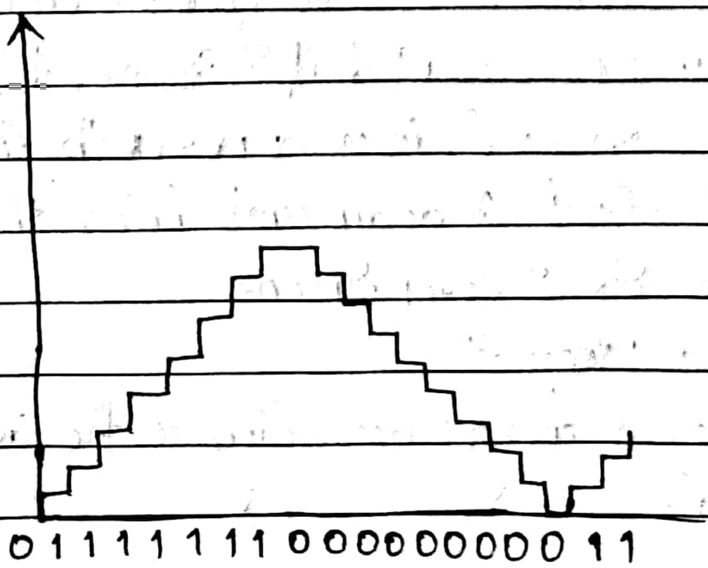
Delta Modulation



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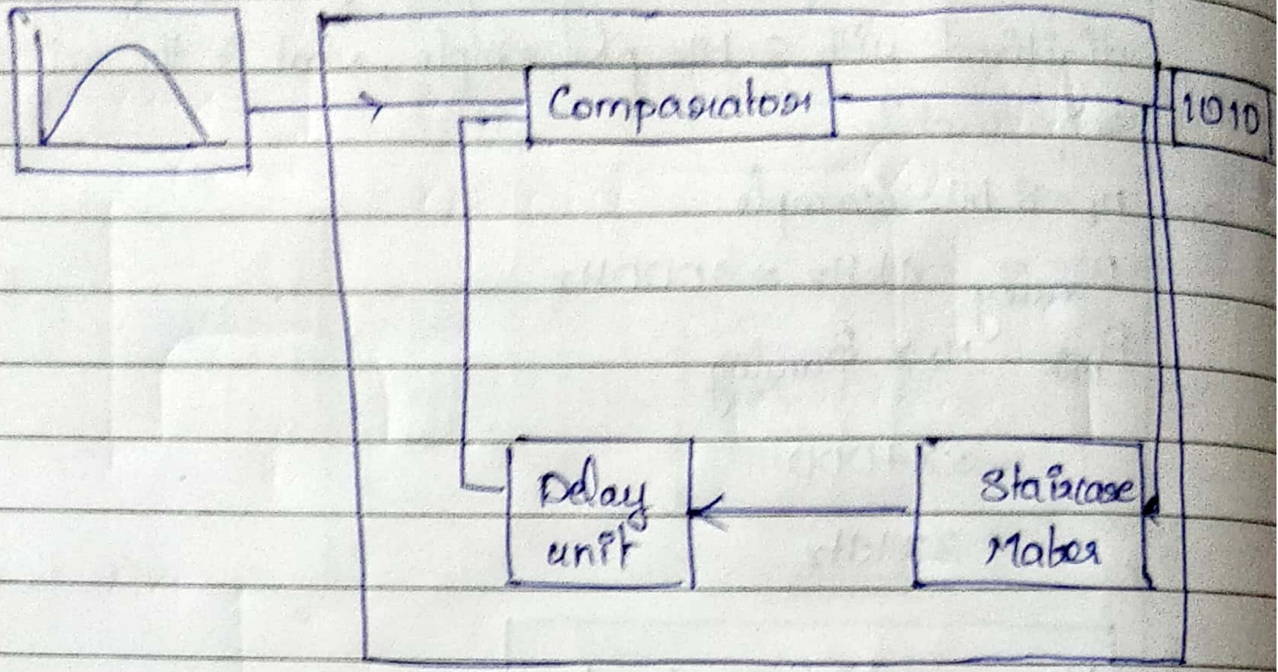

To reduce the complexity of PCM, delta modulatⁿ is used. It finds the change from the prev. sample. There are no codewords here. The bits are sent one after the other. At the sender site, a stream of bits from an analog signal records the small +ve or -ve changes called as delta. If delta is +ve, it records a 1 & if it is -ve, it records a 0. At each sampling interval, it compares with the last value of the staircase signal. A delay unit holds the staircase funct for a period btw 2 comparisons.

Adaptive Delta Modulatⁿ

The value of delta changes according to the amplitude of the analog signal.

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Digital to Analog Conversion

ASK   FSK   PSK

① An analog signal has a bit rate of 8000 bps & a baud rate of 1000 bauds. How many data elements are carried by each signal element? How many signal elements do we need?

ans. $S = 1000$ bauds

$N = 8000$ bps

$r = \frac{N}{S} = \frac{8000}{1000} = 8$ bits/baud

$c = 1$

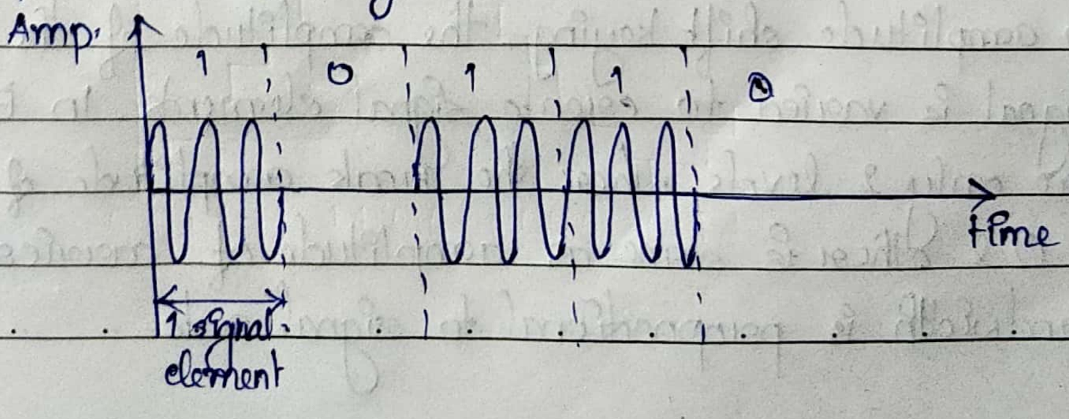
$r = \log_2 L$

$\Rightarrow L = 2^r = 2^8 = 256$ levels

Carrier Signal

In analog txm, the sending device produces a high freq. signal that acts as a base for the info signal called as carrier signal/freq.

Amplitude Shift Key (ASK)



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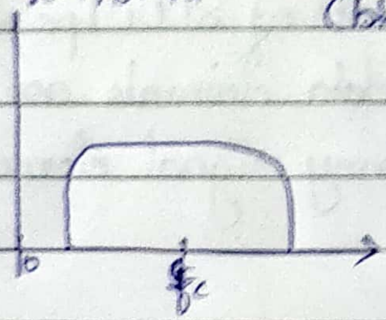
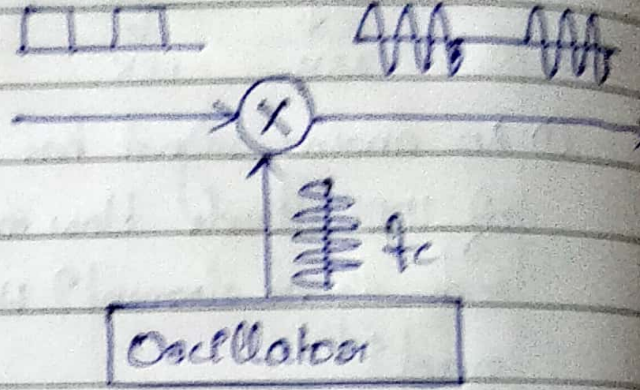
BASK → Binary ASK or ON-OFF Keying

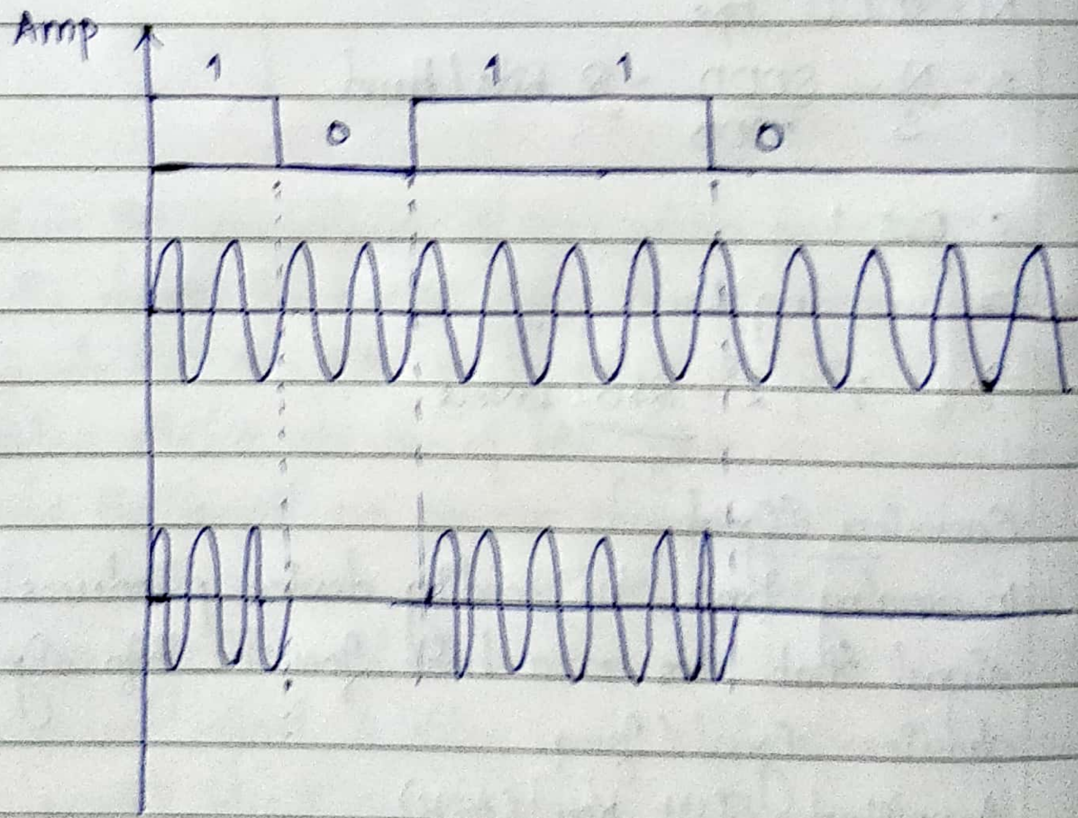
$\boxed{B = (1+d)S}$

d → case factor (btw 0 & 1)

r = 1, S = N







In amplitude shift keying, the amplitude of the carrier signal is varied to create signal elements. In BASK there are only 2 levels where the peak amplitude of 1 signal level is 0 & other is same as amplitude of carrier freq. The bandwidth is proportional to signal rate

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$B = (1+d)S$

where d lies btw 0 & 1

The middle of the bandwidth is the carrier freq.

① Available bandwidth of 100kHz from 200 to 300kHz. What is the carrier freq. & bit rate if d=1 when data is modulated by ASK?

ans: $B = 100\,kHz$

$d = 1$

$r = 1$

$1 \times 10^5 = 2 \times S$

$\Rightarrow S = 5 \times 10^4 = \underline{50\ kbaud}$

$S = c \times N \times \frac{1}{r}$

$\Rightarrow N = S \times r \times \frac{1}{c} = 50 \times 1 \times \frac{1}{1} = \underline{50\,kbps}$

$f_c = \underline{250\,kHz}$ (Middle of bandwidth)

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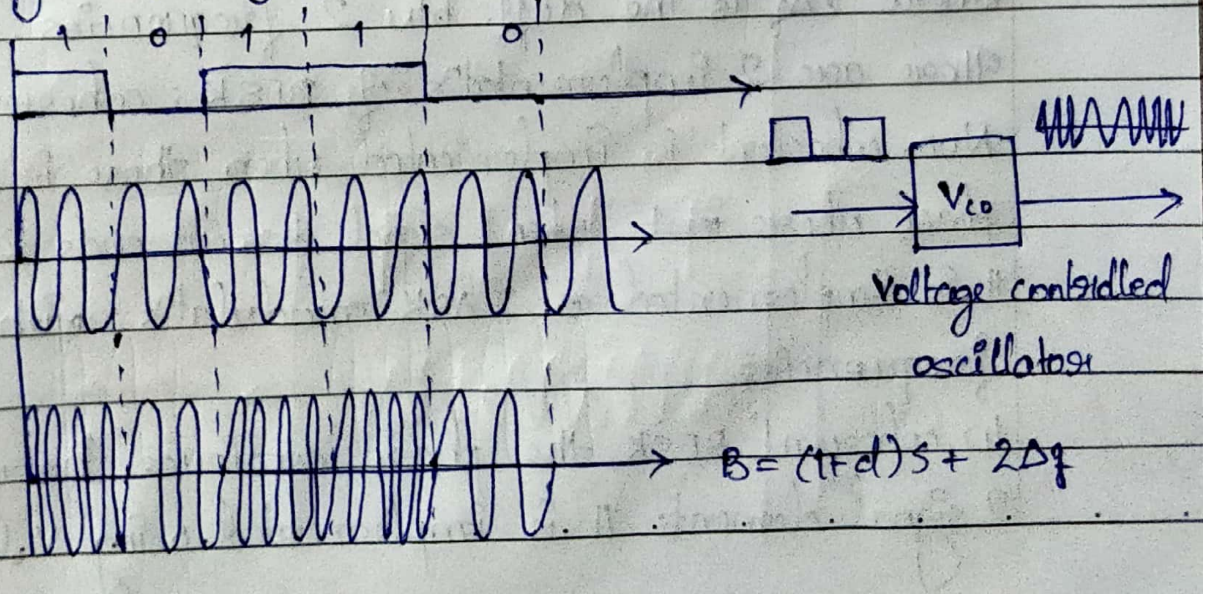
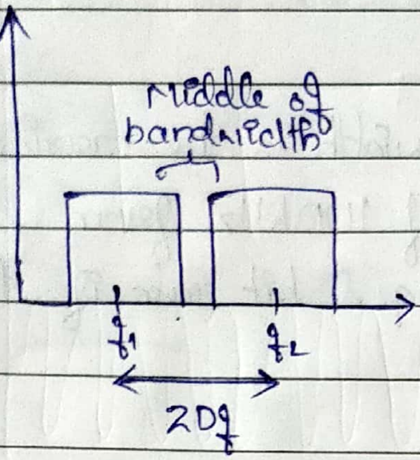
Frequency Shift Keying (FSK)



$B = (1+d)S + 2\Delta f$



$d \rightarrow$ case factor

$\Delta_f \rightarrow$ Diff btw 2 frequencies f_1 & f_2

Binary FSK (BFSK)

- Non-coherent → 2 ASK signals are combined
- Coherent → V_{co}

In FSK, the freq of the carrier signal is varied to represent the data. The freq of the modulated signal is const for durat^n of 1 signal element, but changes for the next signal element. Amp & phase remain const. FSK bandwidth is calculated by $B = (1+d)S + 2\Delta_f$

where $2\Delta_f$ is the diff. btw 2 frequencies.

There are 2 implementat^{n}s of BFSK: coherent & non-coherent. Non-coherent is implemented when there is discontinuity in phase where ~~when~~ 1 signal element ends & the next begins. It is implemented as 2 ASK modulat^{n}s, with 2 carrier frequencies.

In coherent BFSK, the phase continues through boundary of 2 signal elements. It is implemented using V_{co} which changes its freq. according to i/p voltage. In case of multilevel FSK,

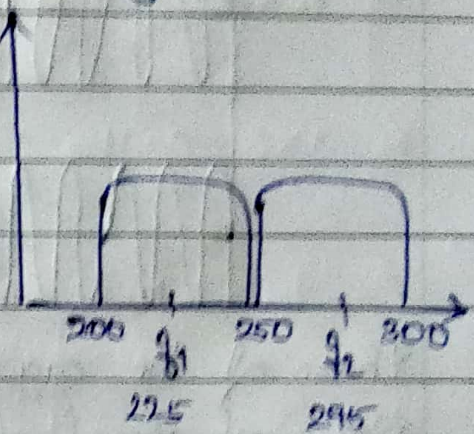
$B = (1+d)S + (L-1)2\Delta_f$

① Same problem ① in ASK. What should be the carrier freq. & bit rate if we modulate using FSK with $d=1$?

ans. $B = 100\,kHz = 1\times10^5\,Hz$

$d = 1$

$2\Delta_f = 275 - 225 = 50\,kHz$
$= 5\times10^4\,Hz$



$B = (1+d)S + 2\Delta_f$

$10^5 = 2S + 5\times10^4$

$\Rightarrow 2S = 10^5 - 5\times10^4$

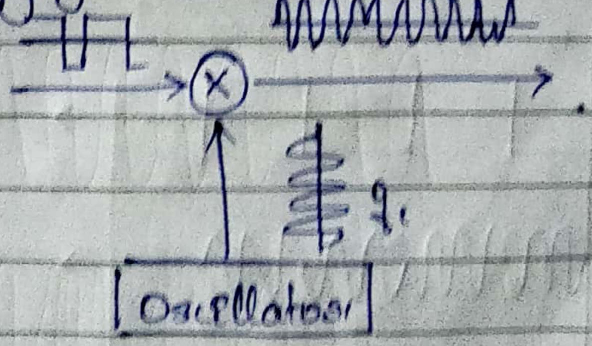
$\Rightarrow 2S = 5\times10^4$

$\Rightarrow S = 2.5\times10^4$

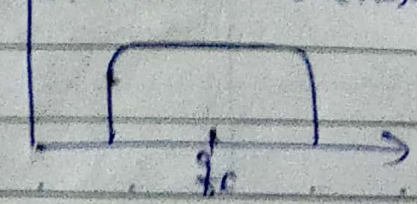
$\Rightarrow S = 25$ kbaud

$S = \frac{N}{r} \Rightarrow N = r\times S = 1\times25 = 25$ kbps

Phase Shift Keying (PSK)



$r=1$ $S=N$ $B=(1+d)S$



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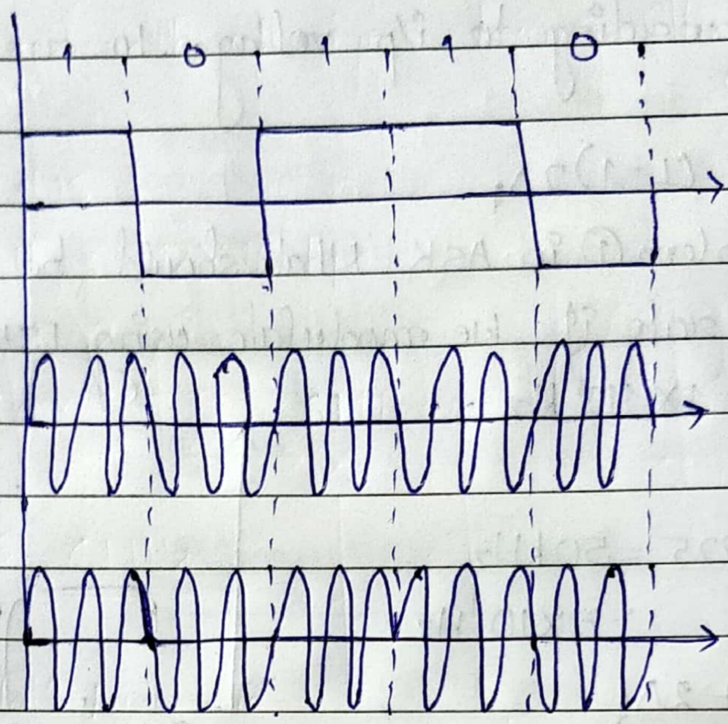
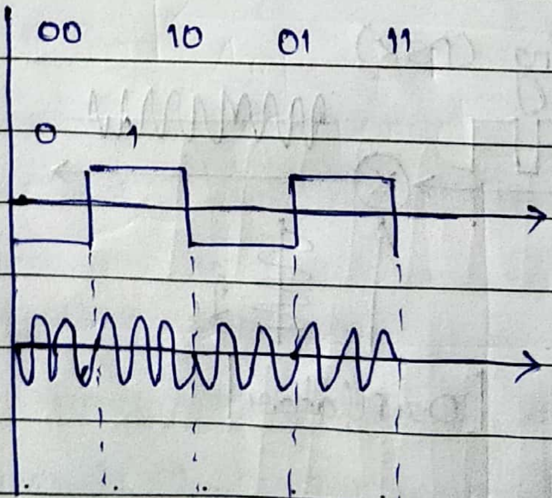


Phase of the carrier signal is varied to represent 2 or more different signal elements. Peak amp. & freq. remain const.
In BPSK, the 2 signal elements have a phase of 0° & other 180°.

BPSK is superior to ASK since it is less susceptible to noise. It is superior to BFSK since it doesn't require 2 carrier signals. But it requires complex hardware

QPSK



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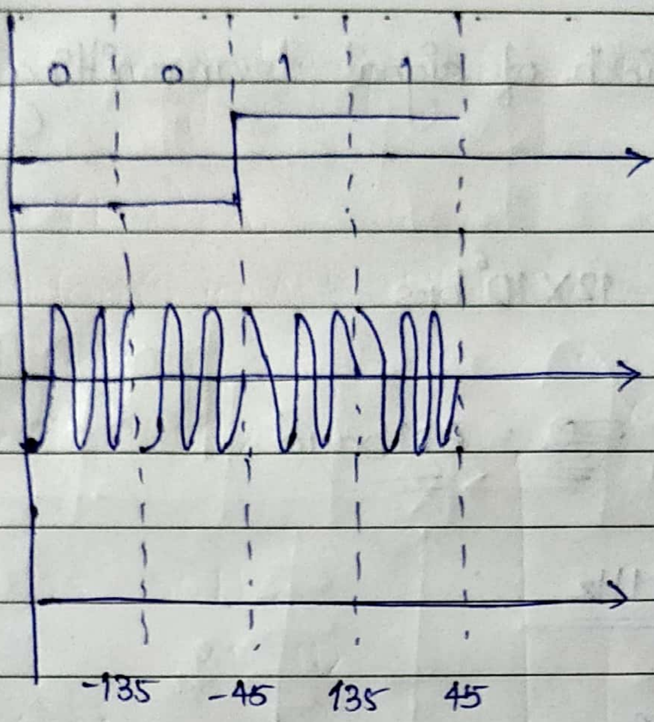
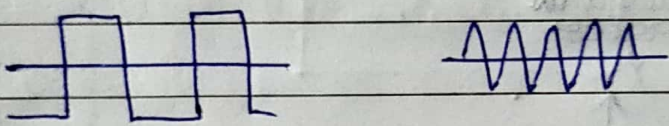
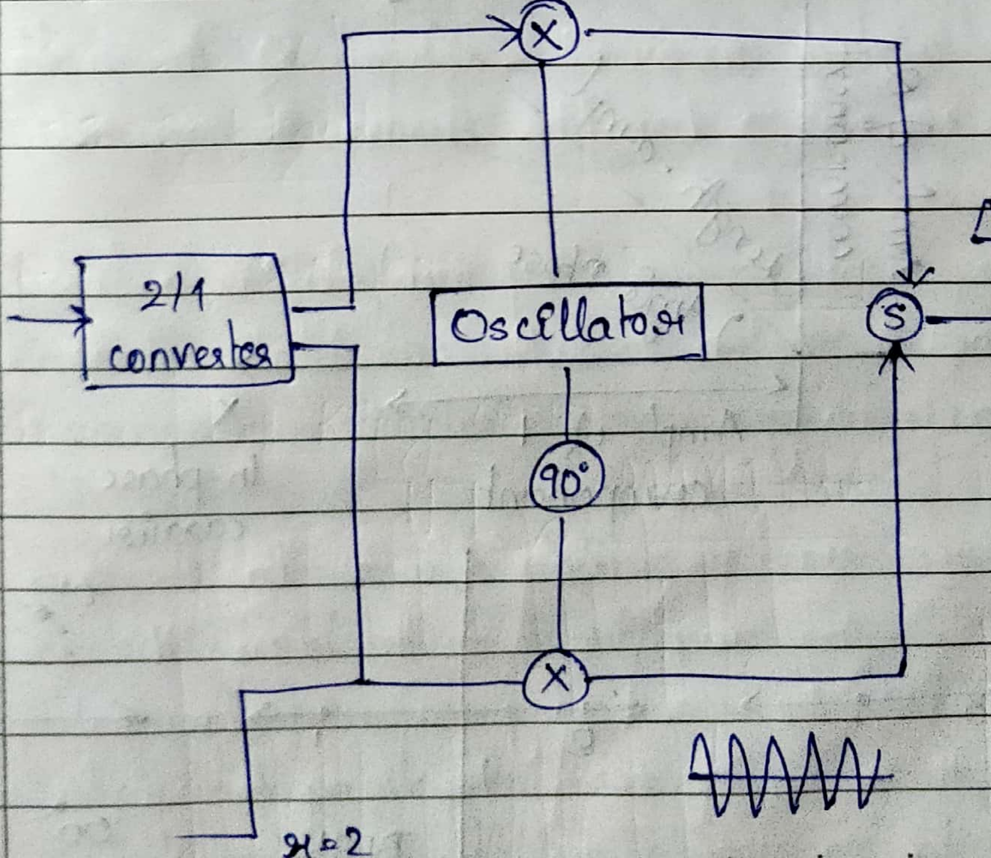
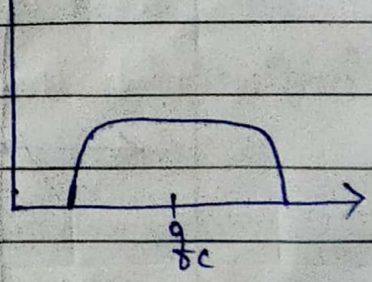






r=1 S=N B=(1+α)...



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Q) Find bandwidth of signal transmitting 12 Mbps for QPSK.

d=0

ans- $B = (1+d)S$

$N = 12\text{ Mbps} = 12 \times 10^6$ bps

d=0   r=2

$S = N \times \frac{1}{r} = 6$ Mbaud

$B = 1 \times 6 = 6$ MHz

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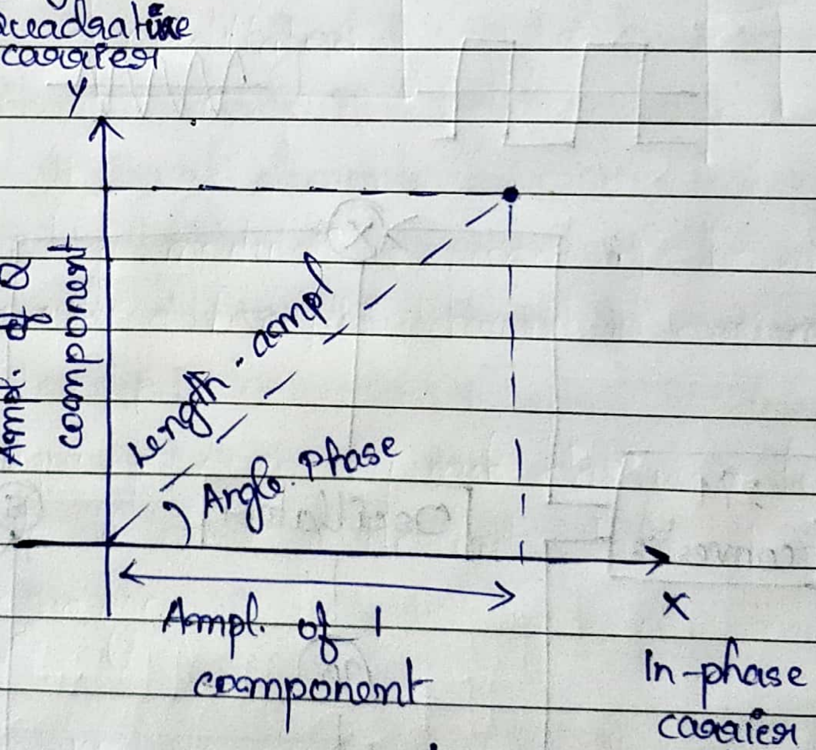
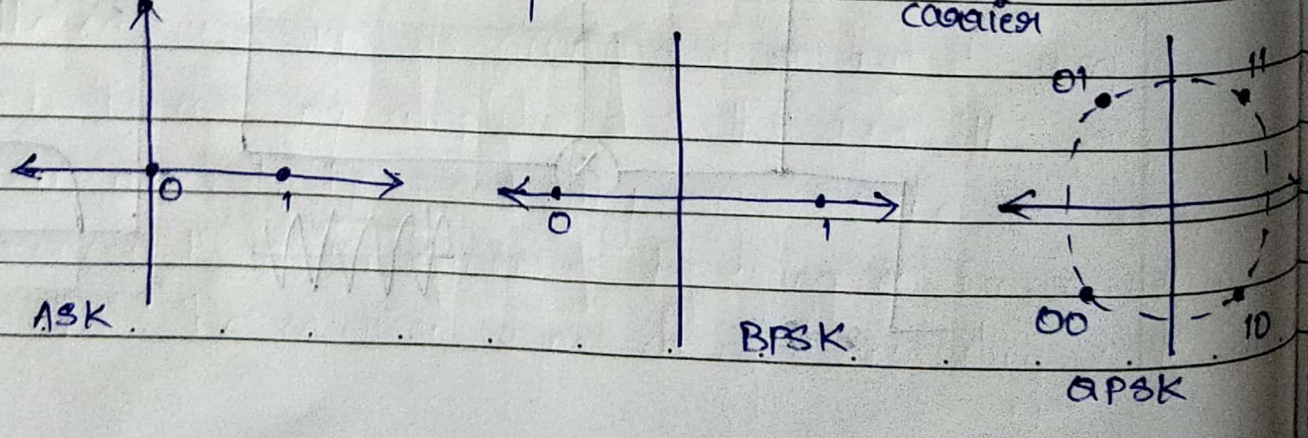
Constellatⁿ Diagram





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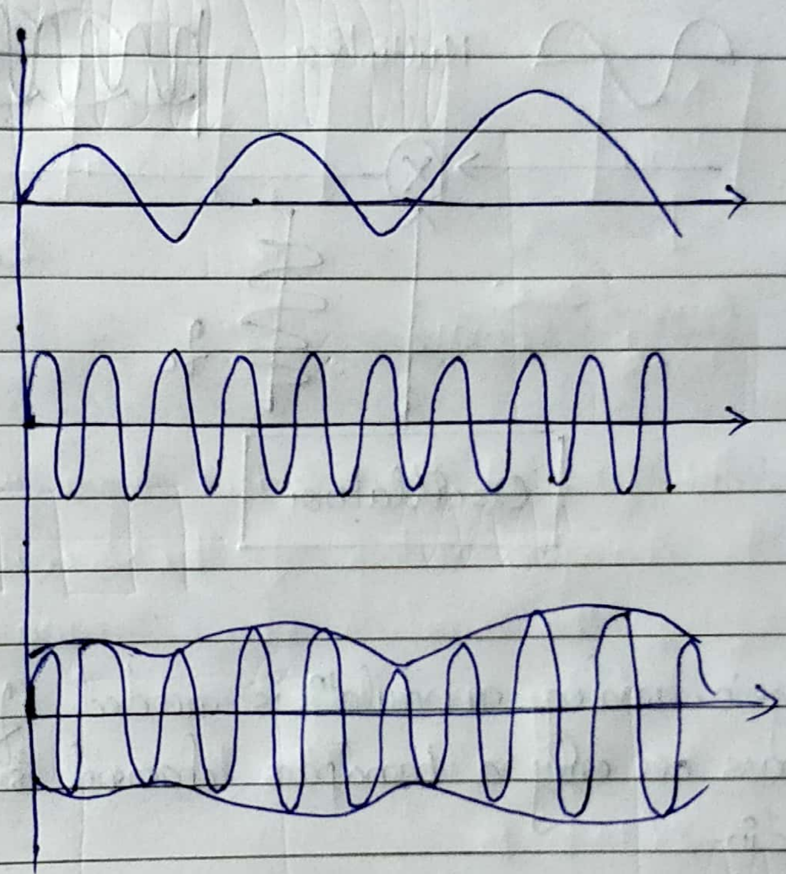
Analog Data to Analog Signal

AM FM PM



Constellat^n diagram defines the ampl. & phase of a signal element when 2 carriers are used. It is used for dealing with multilevel ASK or PSK or QAM.

A signal element type is represented as a dot (•). The X-axis is related to in-phase carrier & Y-axis is related to quadrature carrier. The project^n of the point on X-axis defines the peak ampl. of in-phase component & project^n on Y-axis defines peak ampl. of quadrature.

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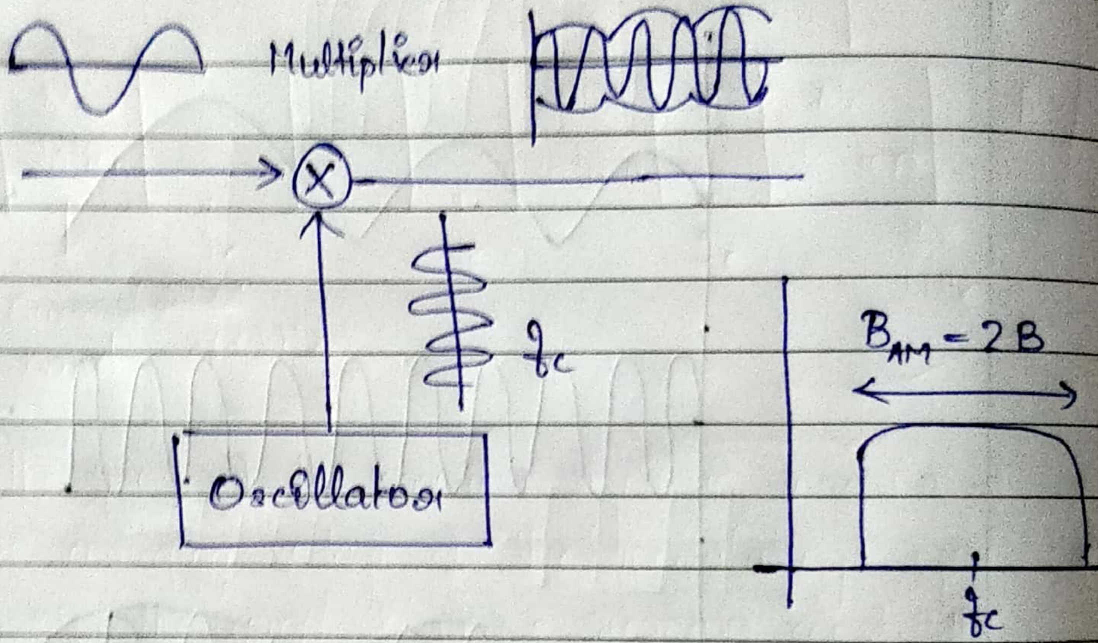
component. The length of the point to the origin is the peak ampl. of the signal element & the angle that the line makes with the x-axis is the phase



Analog-to-analog modulatⁿ is needed if the medium is bandpass or only a bandpass channel is available.
eg: Radio
The analog signal produced by each statⁿ is a low-pass signal & to be able to listen to different statⁿs, it is shifted to a different range.

AM

The carrier signal is modulated so that it's ampl. varies with the changing amplitudes of the signal. The freq. & phase remain const. The modulating signal is the envelope of the carrier. It is implemented by using a simple multiplier so that the carrier signal changes according to the ampl

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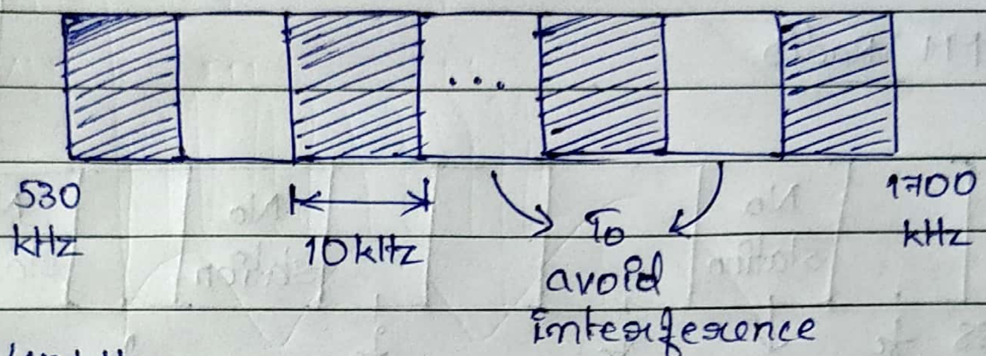
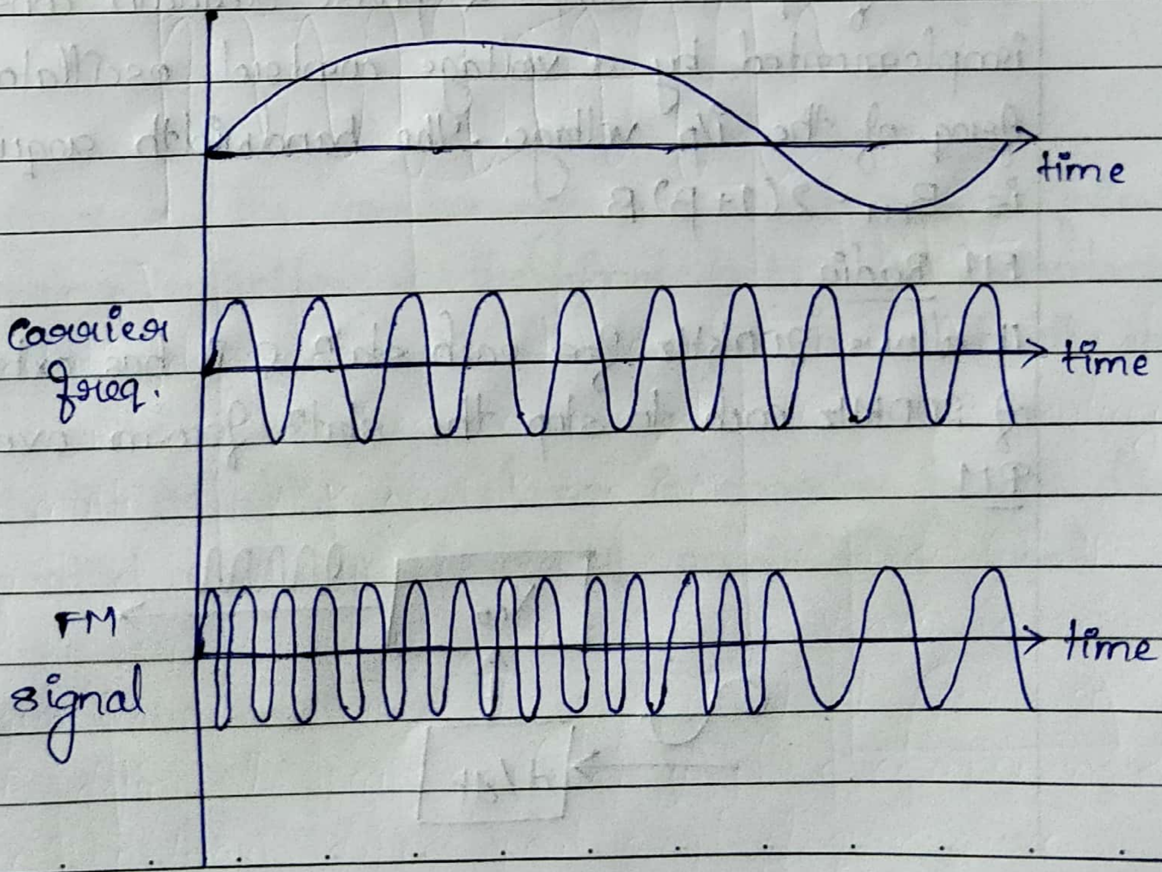
of the modulating signal.
Total bandwidth required, $B_{AM} = 2B$



~~5kHz / 10kHz~~

The bandwidth of audio signal is 5kHz. Hence an AM radio statn has bandwidth of 10kHz. Each statn's carrier freq is separated from it's either side by 10kHz to avoid interference.



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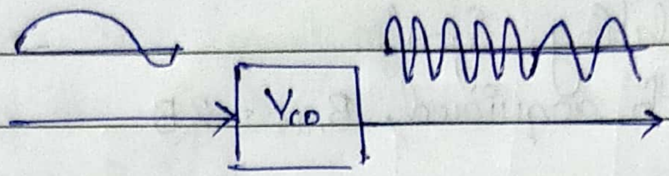
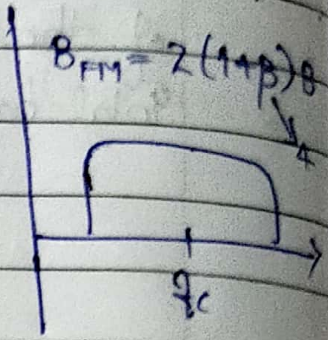
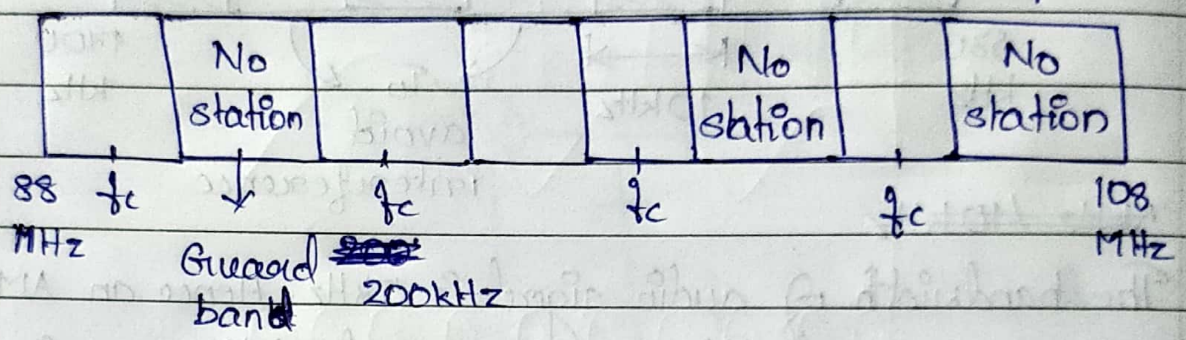




FM Radio



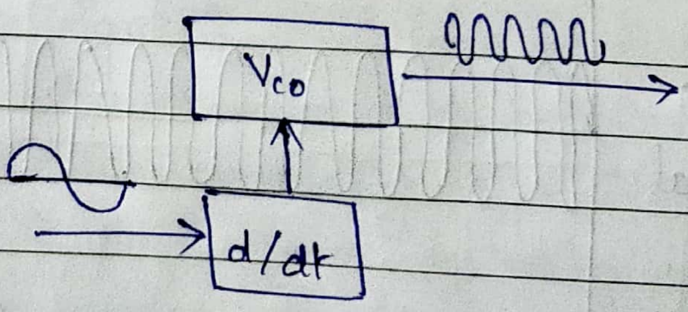
$\beta \to$ Mod. factor

In FM, the freq. of the carrier signal is modulated to follow the changing voltage of the modulating signal based on it's freq. The ampl. & phase remain const. It is implemented by a voltage control oscillator based on the freq. of the i/p voltage. The bandwidth required for FM is $B_{FM} = 2(1+\beta)B$

FM Radio

It allows 200kHz for each statn & it has extra guard band of 200kHz each to stop the statn from overlapping

PM



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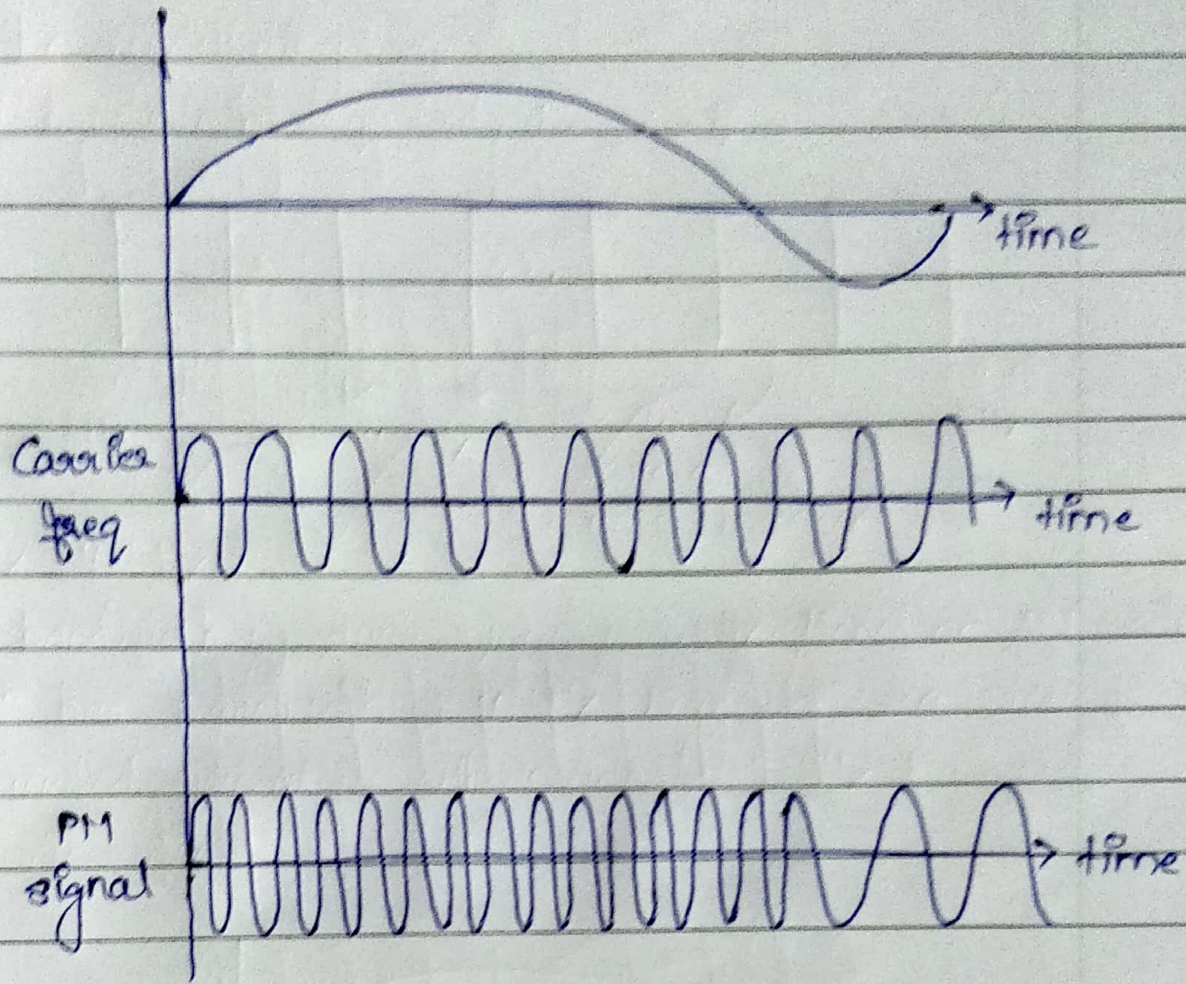

The phase of the carrier signal is modulated to follow the change in voltage of the signal. In FM, the instantaneous change in carrier freq. is directly proportional to the ampl. of modulating signal.

In PM, the instantaneous change in carrier freq. is directly proportional to the derivative of modulating signal.

$\beta = 1 \rightarrow$ Narrow band

$\beta = 3 \rightarrow$ Wide band