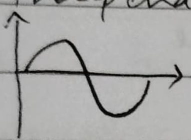
_/_/_

Signal (electromagnetic waves)
Any physical quantity that varies with time, space or any other independant variable. eg, audio signals, radio signals, etc.

Signals can be represented as a function of one or more independant variables. eg, $S_1(t) = 7t$, $S_2(t) = 7t^2$,
↳ 1D signal



$S_3 = x + y + 3y^2$
↳ 2D signal

⇒ 1D signal - function of a single independant variable, eg speech

Note speech waves can be converted to electrical signals using a microphone.

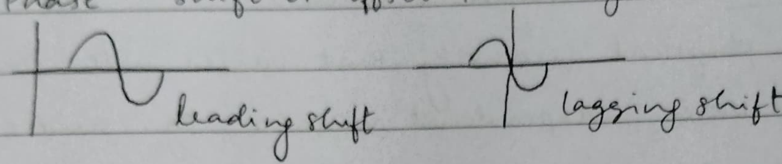
⇒ multidimensional signals - function of 2 or more independant signals. eg. photographs (2D), video (3D)

⇒ multichannel signals - generated by multiple sources or sensors. eg. EEG

Characteristics

⇒ Amplitude - max. displacement of wave from time axis
• determines the strength of the signal
⇒ Frequency - rate of repetition of the signal's wave form in a second. no of cycles in a second
⇒ Time Period - time taken by a signal to complete one full cycle. $\boxed{T = 1/F}$

⇒ Phase - shift or offset in its origin.

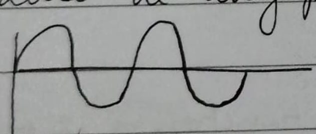


CLASSIFICATION

Analogue | Digital

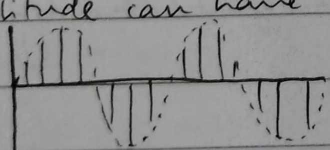
ANALOGUE

⇒ amplitude of analogue signals can have any value at any point of time.

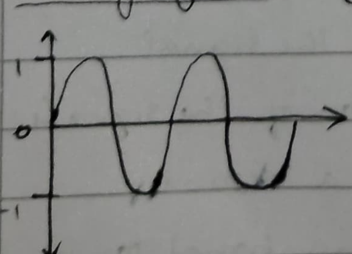


DIGITAL

⇒ amplitude can have finite / discrete values.



<u>Binary signal</u> (type of digital signal)



amplitude = 1

continuous & discrete time signals

→ continuous - Signals will contain values for all real numbers along time axis

→ discrete - contains values at equally spaced intervals along the time axis

periodic & non periodic signals.

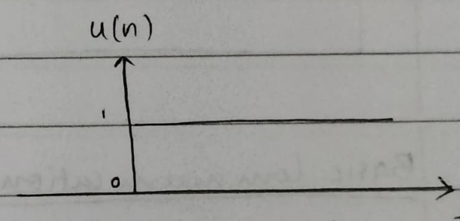
→ periodic - for each time period, equal no. of cycles

→ non periodic - no. of cycles vary ~~of~~ for each time period.

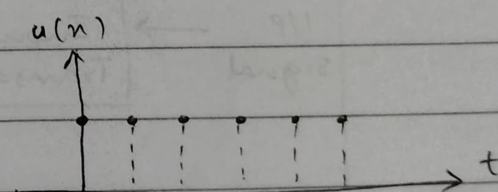
Elementary Signals

1. Unit Step Signal

$$u(n) = \begin{cases} 1, & n \geq 0 \\ 0, & n < 0 \end{cases}$$

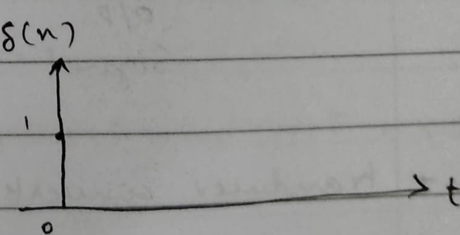


discrete form (Sampling)



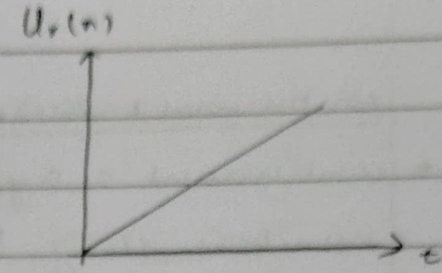
2. Unit impulse signal

$$\delta(n) = \begin{cases} 1, & n = 0 \\ 0, & n \neq 0 \end{cases}$$



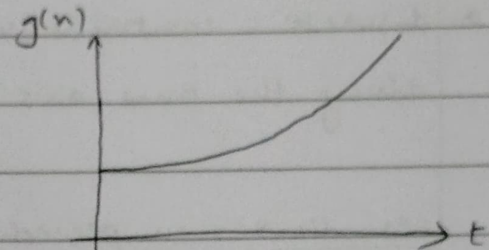
3. Ramp Signal

$$u_r(n) = \begin{cases} n, & n \geq 0 \\ 0, & n < 0 \end{cases}$$



4. Exponential Signal

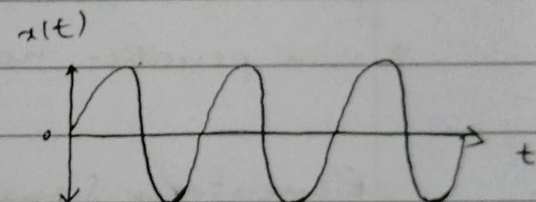
$$g(n) = \begin{cases} a^n, & n \geq 0 \\ 0, & n < 0 \end{cases}$$



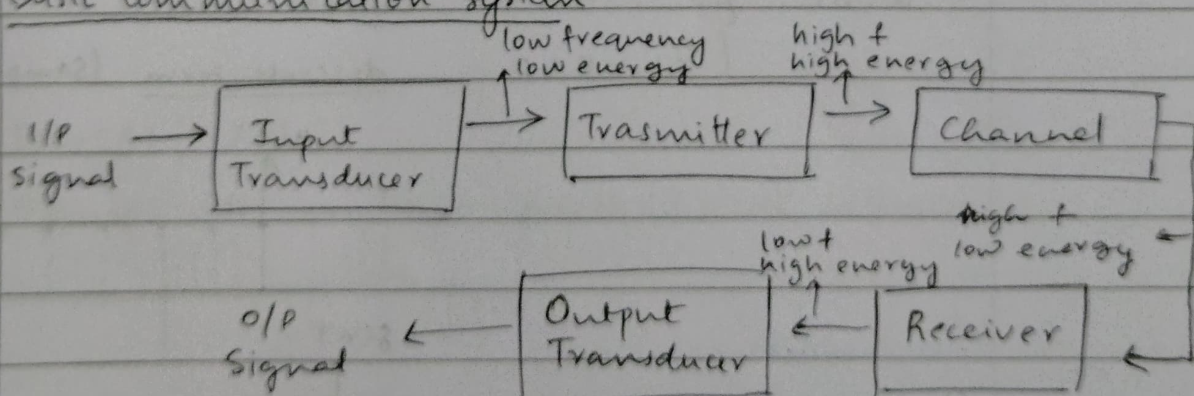
5. Sinusoidal Signal

ost common

$$\boxed{x(t) = A\sin(2\pi f t + \phi)}$$



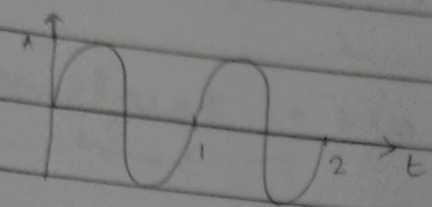
Basic Communication System

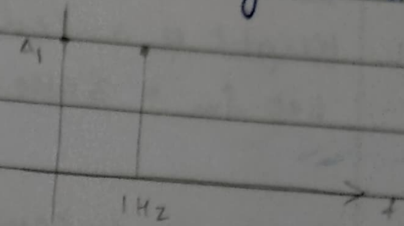


- tranducer converts non electrical signals to electrical signals
- an transmitter contains stuff like amplifier, modulator, mixer, filter, etc

Time Domain

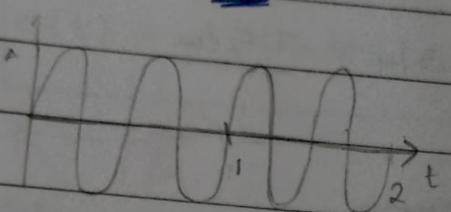
Frequency Domain

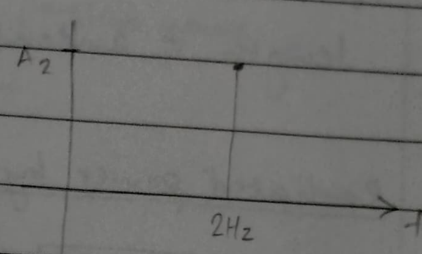




T = 1sec

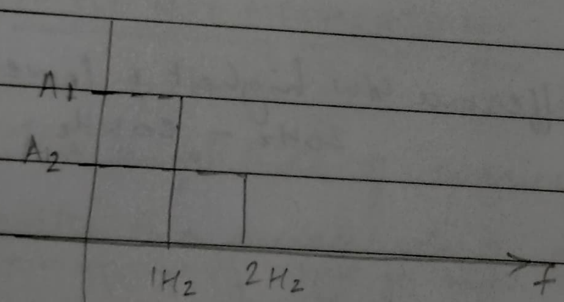
F = 1/T = 1 Hz





T = 0.5 sec

F = 1/T = 2 Hz



Modulation (Carrier signal)

→ has frequency, amplitude but does not contain any information

→ process of modification of carrier signal wrt modulating signal

→ high frequency signal, carries message signal, message signal is also known as modulating signal

__/__/__

Need For modulation

1. **Height of antenna**

Let $f_m = 3\,kHz$; $\lambda = c/f = \dfrac{3 \times 10^8}{3 \times 10^3} = 100\,km$

length of antenna $= \lambda/4 = \dfrac{100}{4} = 25\,km$

$f_c = 1\,GHz$, $\lambda = 0.3\,m$

length of antenna $= 3/4 = 7.5\,cm$

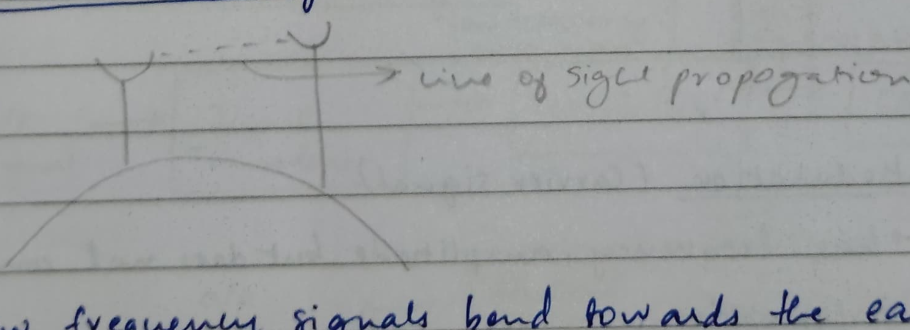
2. **Radiated power by antenna**

$$\boxed{P_r \propto 1/\lambda^2}$$

3. High Bandwidth (Difference b/w highest & lowest frequency)

20Hz - 20kHz

4. narrow bending



low frequency signals bend towards the earth.

modulated signal ⇒ Passband Signal

modulating signal ⇒ Baseband Signal

modulation

Types of modulation
- Analogue
  - Amplitude
  - Angle
    - frequency
    - phase
- Digital

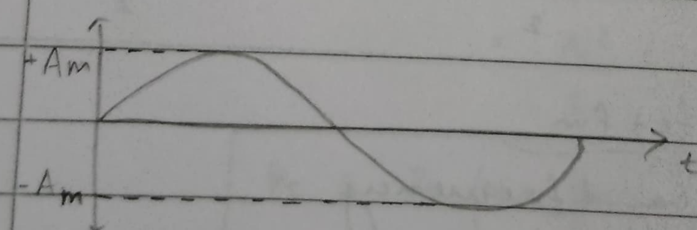
$$\boxed{c(t) = A_c \sin(2\pi f_c t + \phi)}$$ → sine wave

AMPLITUDE MODULATION

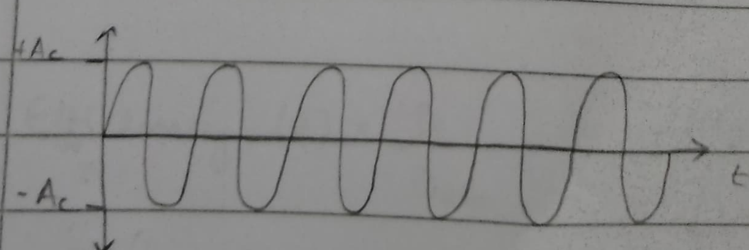
The amplitude of carrier signal is varied in accordance with the amplitude of modulating signal.

modulating, $m(t) = A_m \sin(2\pi f_m t)$

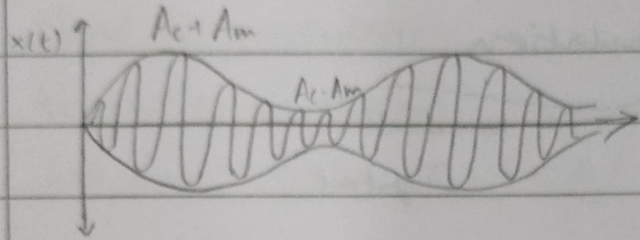
carrier, $c(t) = A_c \sin(2\pi f_c t)$



modulating signal



carrier signal



Amplitude modulated signal

$$x(t) = (A_c + m(t))\sin 2\pi f_c t$$

$$= \cancel{A_c(1+} (A_c + A_m \sin 2\pi f_m t)\sin 2\pi f_c t$$

$$= A_c\left(1 + \frac{A_m}{A_c}\sin 2\pi f_m t\right)\sin 2\pi f_c t$$

$$= A_c\left(1 + \mu \sin 2\pi f_m t\right)\sin 2\pi f_c t$$

$$\boxed{x(t) = A_c \sin 2\pi f_c t + \mu A_c \sin 2\pi f_c t \sin 2\pi f_m t}$$

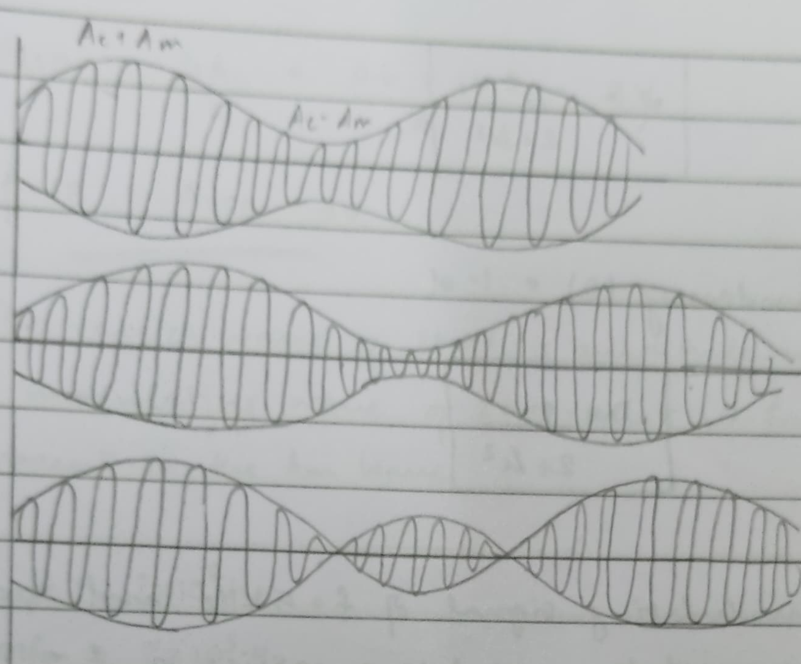
↳ sin A sin B

μ = modulation index

$$= A_c \sin 2\pi f_c t + \mu \frac{A_c}{2}\left(\cos 2\pi (f_c - f_m)t - \cos 2\pi (f_c + f_m)t\right)$$

$$\boxed{x(t) = A_c \sin 2\pi f_c t + \frac{\mu A_c}{2}\cos 2\pi (f_c - f_m)t - \frac{\mu A_c}{2}\cos 2\pi (f_c + f_m)t}$$

$$f_c,\ \underbrace{f_c - f_m,\ f_c + f_m}_{\text{side band frequency}}$$



Transmitted power, efficiency and redundancy of amplitude modulated wave

Transmitted power $= P_c + P_s$

$= P_c + P_{LSB} + P_{USB}$

$$= \frac{A_c^2}{2} + \frac{1}{2}\left(\frac{\mu A_c}{2}\right)^2 + \frac{1}{2}\left(\frac{\mu A_c}{2}\right)^2$$

$$= \frac{A_c^2}{2} + \frac{\mu^2 A_c^2}{4}$$

$$\boxed{P_T = P_c\left(1 + \frac{\mu^2}{2}\right)}$$

$$\text{Efficiency } (\eta) = \frac{P_s}{P_{total}} = \frac{1/4\, A_c^2 \mu^2}{\frac{A_c^2}{2}\left(1 + \frac{\mu^2}{2}\right)}$$

$$\boxed{\eta = \frac{\mu^2}{2+\mu^2}}$$

Redundancy (D) = $1-\eta$

$$\boxed{D = \frac{2}{2+\mu^2}}$$

1. A modulating signal of $f = 5\,kHz$ and peak voltage of 6V is used to modulate a carrier of $f = 10\,MHz$ & $V_{peak} = 10V$. Determine the modulation index, f_{LSB}, f_{USB}, ~~and~~ A_{LSB}, A_{USB}.

$f_m = 5\,kHz$ $\quad$ $f_c = 10\,MHz$

$A_m = 6V$ $\quad$ $A_c = 10V$

modulating index $(\mu) = \frac{A_m}{A_c} = \frac{6}{10} = \underline{\underline{0.6}}$

$f_{LSB} = f_c - f_m$

$= 10 \times 10^6 - 5 \times 10^3$

$= 10000 \times 10^3 - 5 \times 10^3$

$= 10^3 (9995) = \underline{9995 \times 10^3\ Hz} = \underline{9.995\ MHz}$

$f_{USB} = f_c + f_m$

$= 10^3 (10000 + 5) = 10005 \times 10^3$

$$\boxed{\eta = \frac{\mu^2}{2+\mu^2}}$$

Redundancy (D) = $1-\eta$

$$\boxed{D = \frac{2}{2+\mu^2}}$$

1. A modulating signal of $f = 5\,KHz$ and peak voltage of 6V is used to modulate a carrier of $f = 10\,MHz$ & $V_{peak} = 10V$. Determine the modulation index, f_{LSB}, f_{USB}, ~~and~~ A_{LSB}, A_{USB}.

$f_m = 5\,KHz$ $\quad$ $f_c = 10\,MHz$

$A_m = 6\,V$ $\quad$ $A_c = 10V$

modulating index $(\mu) = \frac{A_m}{A_c} = \frac{6}{10} = \underline{\underline{0.6}}$

$f_{LSB} = f_c - f_m$

$= 10 \times 10^6 - 5 \times 10^3$

$= 10000 \times 10^3 - 5 \times 10^3$

$= 10^3 (9995) = \underline{9995 \times 10^3\,Hz} = \underline{9.995\,MHz}$

$f_{USB} = f_c + f_m$

$= 10^3 (10000 + 5) = 10005 \times 10^3$

$= \underline{10.005\,MHz}$

$$A_{LSB} = \frac{\mu A_c}{2} = \frac{0.6 \times \cancel{10}\ 5}{\cancel{2}} = 3V$$

$$A_{USB} = A_{LSB} = 3V$$

2. The carrier wave of 2MHz is amplitude modulated by a modulating wave of 2KHz. What all frequencies will be present in the Am wave.

$f_c = 2 \times 10^6 Hz$

$f_m = 2 \times 10^3 Hz$

$f_c, f_c - f_m, f_c + f_m$

$f_c = 2 \times 10^6 Hz = 2MHz$

$f_c - f_m = 2000 \times 10^3 - 2 \times 10^3$

$= 1998 \times 10^3 = 1.998 MHz$

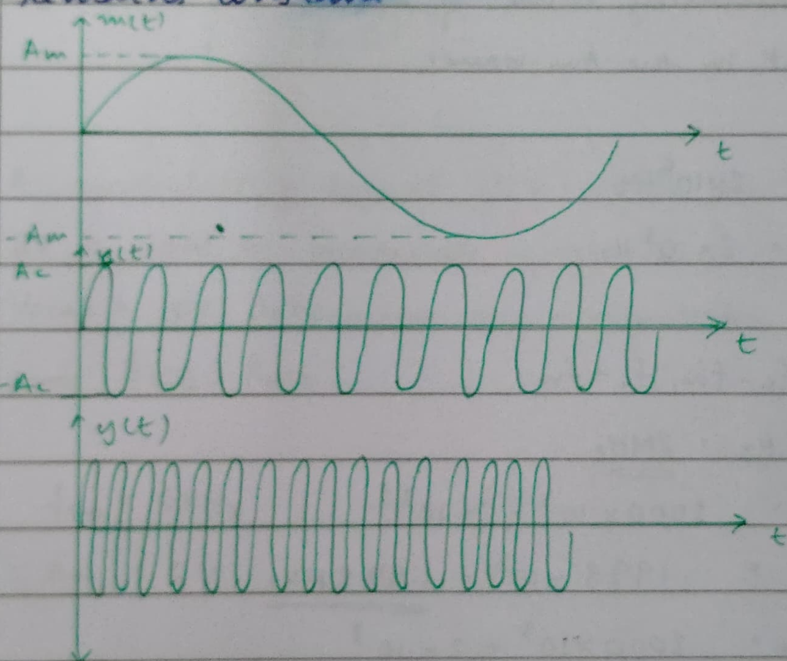
$f_c + f_m = 2000 \times 10^3 + 2 \times 10^3$

$= 2.002 MHz$

$\therefore$ frequencies =

Frequency modulation

- The frequency of carrier signal is varied in accordance with the instantaneous amplitude of modulating signal.
- The amplitude & phase of the fm modulated signal remains constant.



- The frequency of modulation wave ↑ when the amplitude of the modulating signal ↑

- The frequency of modulated wave remains constant and is equal to the frequency of carrier signal, when the amplitude of modulating signal is zero.

$m(t) = A_m \cos 2\pi f_m t$

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

$y(t) = A_c \cos \theta_i(t)$; θ = angular ~~frequency~~ displacement

Angular frequency $\omega_i = \dfrac{d}{dt}\theta_i(t)$

$$2\pi f_i = \frac{d}{dt}\theta_i(t)$$

$$\boxed{\theta_i t = 2\pi \int_0^t f_i \, dt} \quad -① $$

$f_i \propto m(t)$

frequency sensitivity

$f_i = f_c + k_f m(t)$ $-②$

put ② in ①

$$\theta_i(t) = 2\pi \int_0^t f_c + k_f m(t)\, dt$$

$$= 2\pi \int_0^t f_c + k_f A_m \cos 2\pi f_m t \, dt$$

$$= 2\pi \left[f_c t + k_f A_m \frac{1}{2\pi f_m} \sin 2\pi f_m t \right]$$

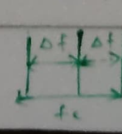
$$= 2\pi f_c t + \frac{k_f A_m}{f_m} \sin 2\pi f_m t$$

$$\boxed{\theta_i(t) = 2\pi f_c t + \frac{\Delta f}{f_m} \sin 2\pi f_m t}$$

Δf = frequency deviation

$= k_f A_m$

$\Delta f \propto A_m$



$\theta_i(t) = 2\pi f_c t + k_f \sin 2\pi f_m t$; k_f = mod. index $= \frac{\Delta f}{f_m} = \frac{k_f A_m}{f_m}$

FM Modulated Signal,

$$\boxed{y(t) = A_c \cos(2\pi f_c t + k_f \sin 2\pi f_m t)}$$

$$\boxed{\text{Deviation Ratio} = \frac{\text{max. frequency deviation}}{\text{max. modulating frequency}}}$$

<u>Applications</u>

⇒ FM Radio

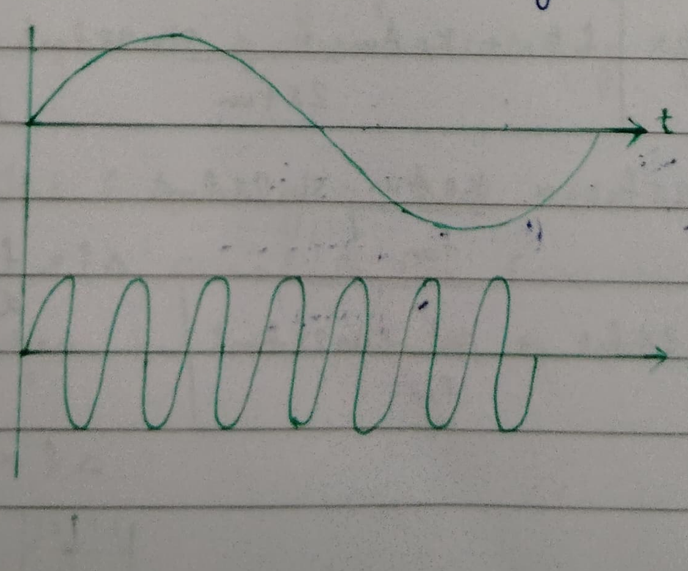
⇒ satellite communication

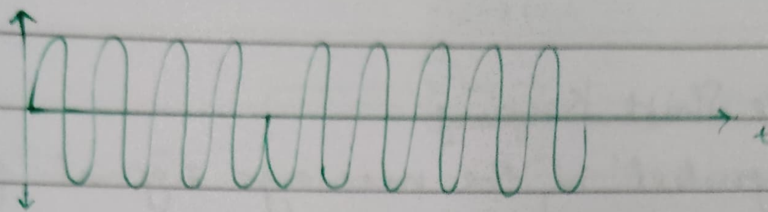
⇒ TV sound Broadcasting

<u>PHASE MODULATION</u>

⇒ Phase of the carrier signal is varied in accordance with the instantaneous amplitude of modulating signal

⇒ Amplitude and frequency remains the same.





$m(t) = A_m \cos 2\pi f_m t$

$c(t) = A_c \cos(2\pi f_c t + \phi_i)$

$\phi_i \propto m(t)$

$\phi_i = k_p m(t)$

phase sensitivity

modulated signal $s(t) = A_c \cos(2\pi f_c t + k_p m(t))$

$= A_c \cos 2\pi f_c t + k_p A_m \cos 2\pi f_m t$

$$\boxed{s(t) = A_c \cos 2\pi f_c t + k_p \cos 2\pi f_m t}$$

modulating index

Applications:

⇒ Mobile Communication

⇒ Wifi Transmission.

Digital Signal

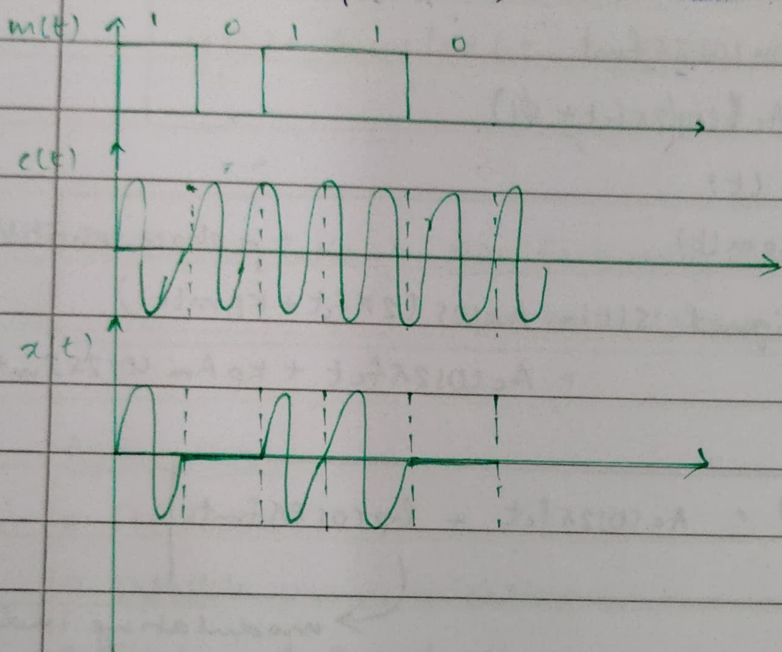
⇒ modulating signal is digital, carrier signal is analogue

⇒ modulation technique is known as shift keying

⇒ 3 types of shift keying
- amplitude
- frequency
- phase

Amplitude Shift Keying

⇒ Each symbol in the message signal gives a unique amplitude to the carrier wave.



$m(t) \rightarrow \otimes \rightarrow \boxed{BPF}$

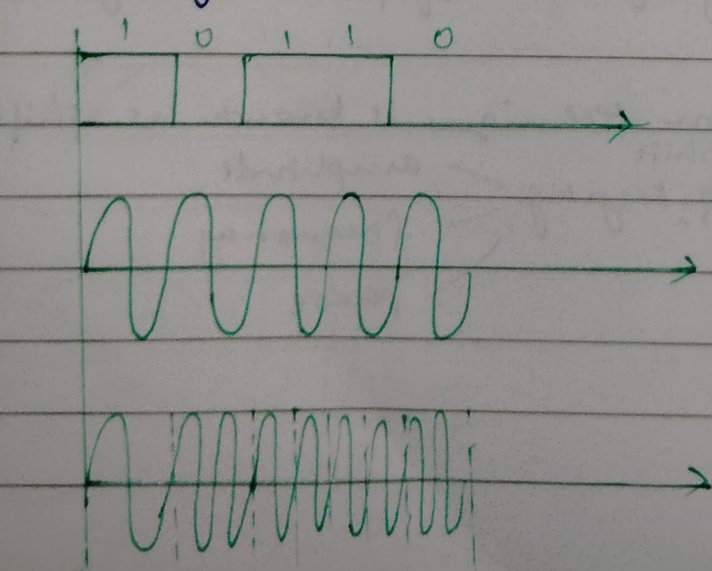
$\uparrow$

$c(t)$

Band Pass Filter

→ Frequency Shift

Each symbol in the message signal gives a unique frequency to the carrier wave.



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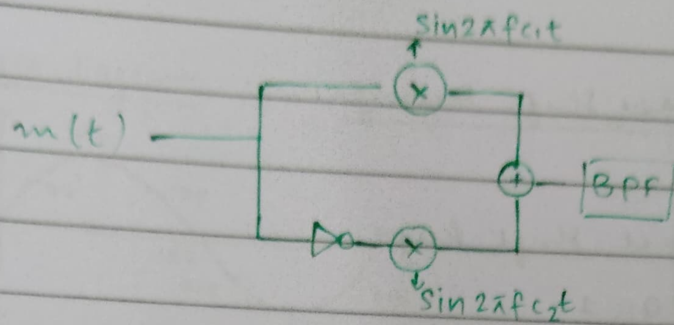
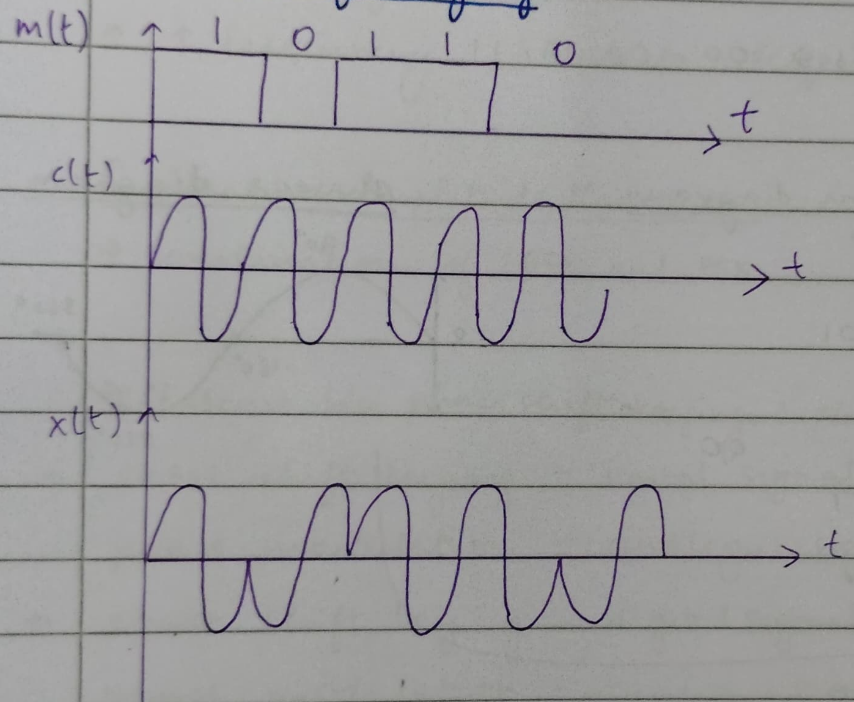


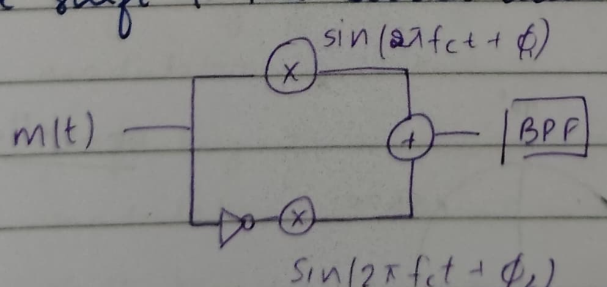
Phase Shift Keying



$A_c \sin(2\pi f_c t + \phi)$

ϕ_1 ϕ_2

each symbol in the message signal gives a unique phase shift to the carrier wave.



$f_c \Rightarrow$ ~~fc~~ f_{c1}, f_{c2}

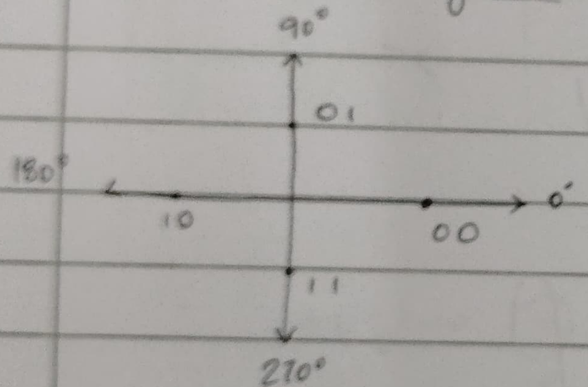
Types of Phase Shift Keying

⇒ Binary phase shift key
$0^\circ - 0$, $180 - 1$

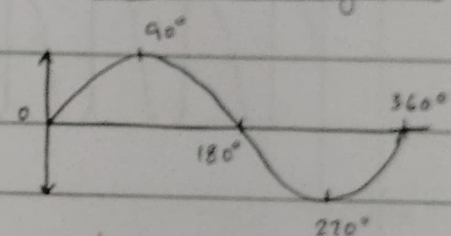
⇒ Quadrature phase shift key
0°, 90°, 180°, 270°

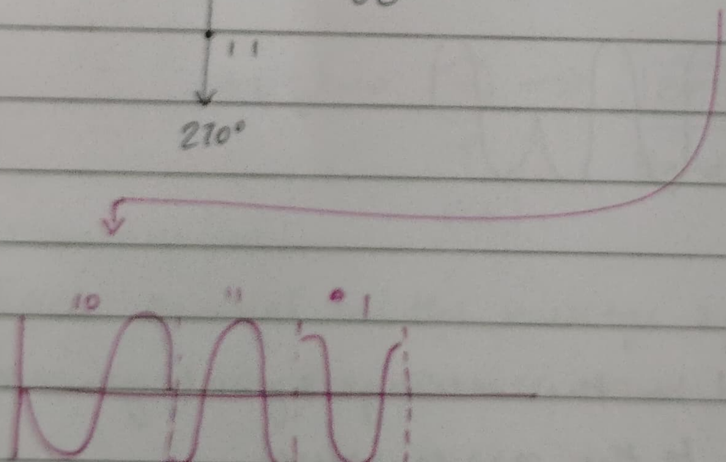
4 symbols ⇒ 00, 01, 10, 11

Constellation diagram

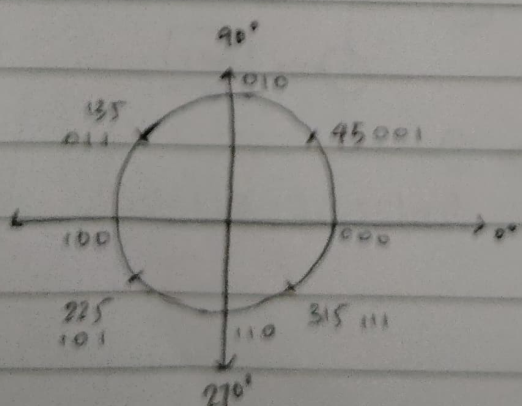


Phasor diagram





8 PSK

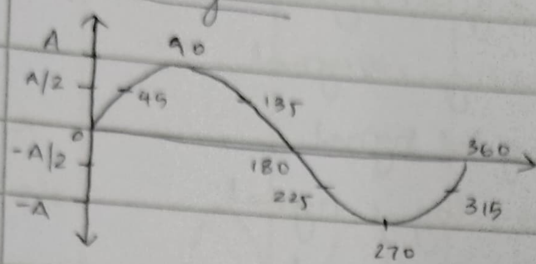


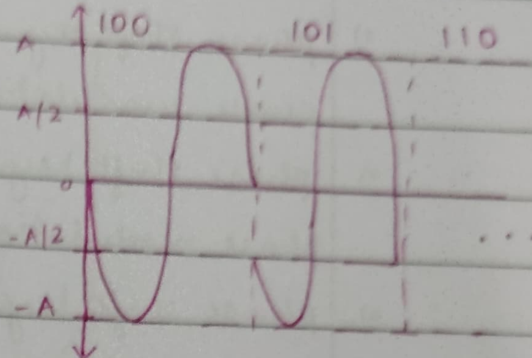
Constellation diagram

Phasor

__/__/____

phasor diagram





⇒ ↓ wavelength

⇒ ↑ frequency , (leads to interference)

Quadrature Amplitude Modulation

⇒ Combination of ASK and PSK

Difference b/w phase shift keying & phase modulation

⇒ phase shift keying - digital signal
phase modulation - analogue signal

⇒ phase shift keying - digital signal
phase modulation - analogue signal

⇒ phase shift keying - digital signal
phase modulation - analogue signal

⇒ phase shift keying - digital signal
phase modulation - analogue signal

⇒ phase shift keying - digital signal
phase modulation - analogue signal

⇒ phase shift keying - digital signal
phase modulation - analogue signal

⇒ phase shift keying - digital signal
phase modulation - analogue signal

=) phase shift keying - ~~th~~ digital signal
phase modulation - analogue signal
=) phase shift keying - digital signal
phase modulation - analogue signal
=) phase shift keying - digital signal
phase modulation - analogue signal

Quadrature Amplitude Modulation

=) combination of ASK & PSK

2QAM → BPSK

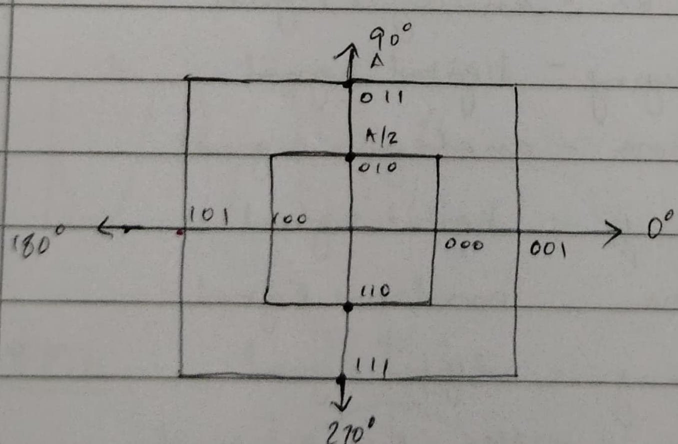
4QAM → QPSK

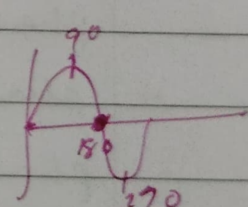
similar error rate { 8QAM →

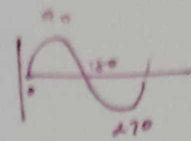
16QAM → more preferred (more data can be transmitted)

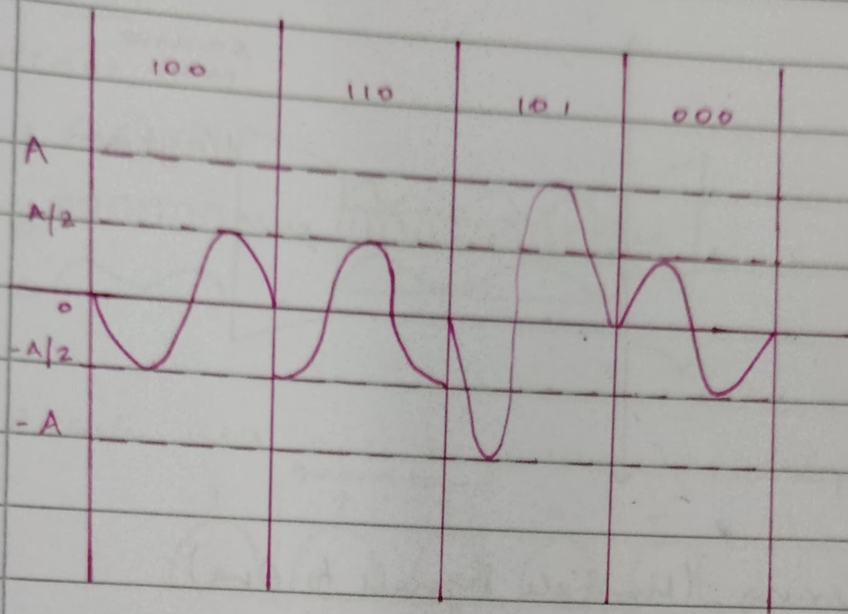
32QAM →

:

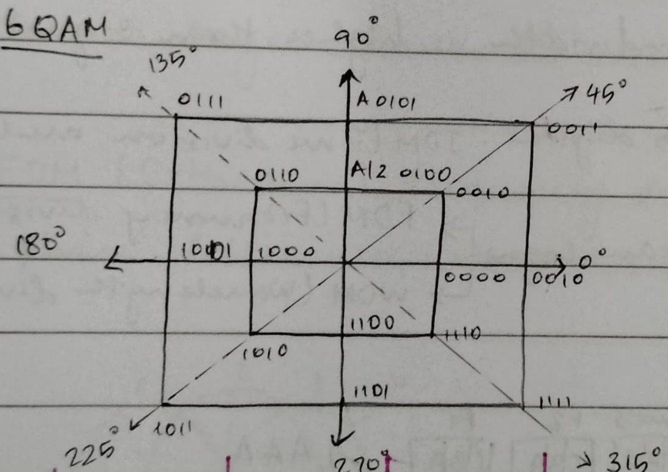




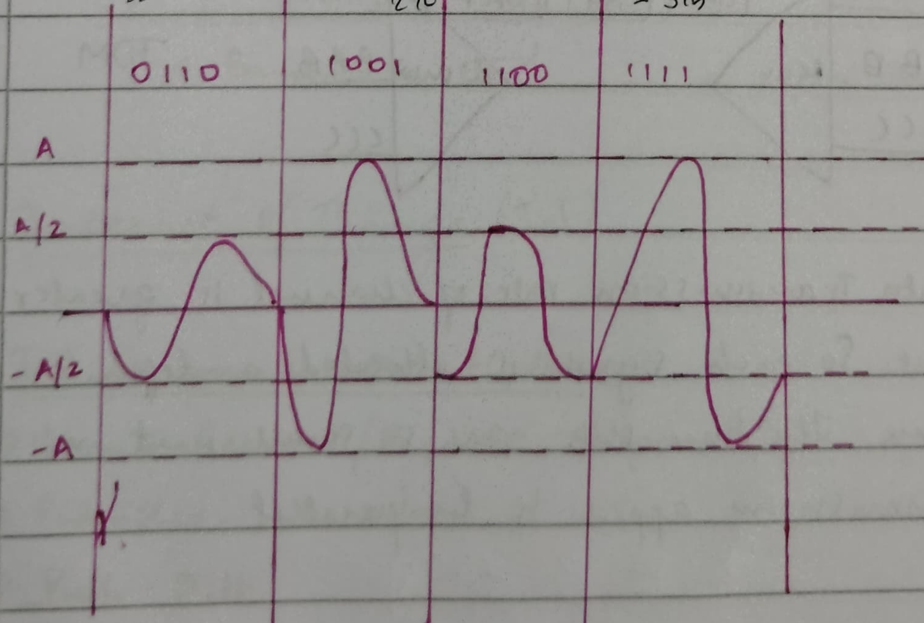


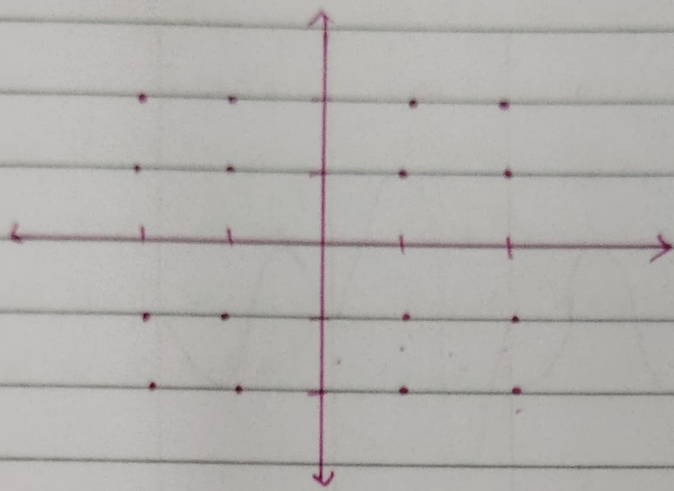


16QAM



cross constellation diagram.





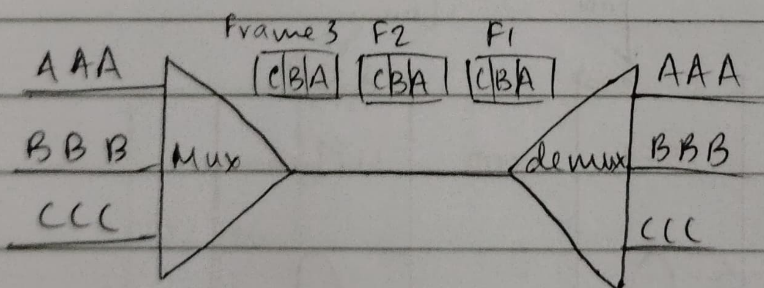
square ~~cross~~ constellation diagram

Multiplexing (Multiple Signals to One)

Mux & Demux

1) Channel Bandwidth is higher than signal bandwidth.

- Multiplexing
  - → digital : TDM (Time division multiplexing)
  - → analogue
    - → FDM (Frequency division)
    - → WDM (Wavelength division)

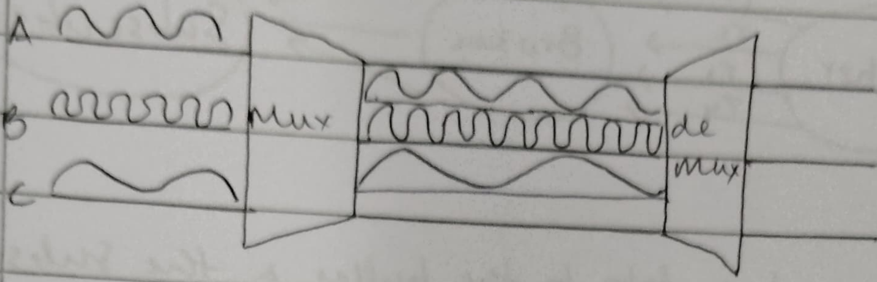


TDM

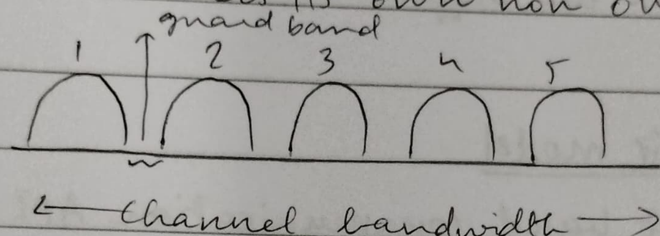
2) Data Transmission rate of channel is greater than the source. So each signal is allocated a definite amount of time. The time slots are so small that all the transmissions appear to be parallel.

__/__/__

FDM



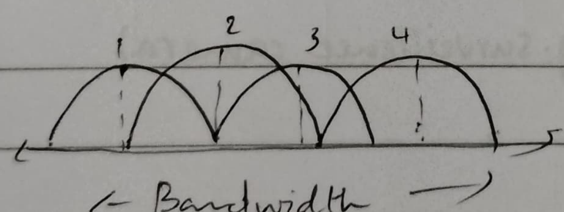
⇒ each user uses its own non overlapping frequency



⇒ Disadvantage : Bandwidth wastage.

OFDM (Orthogonal frequency division multiplexing)

⇒ phase difference between 2 signals is 90°



Internet of Things (IoT)

IoT Communication Models

⇒ Client - Server / Request - Response

⇒ Publisher - Subscriber

⇒ Push - Pull