Satellite & Mobile Communication Network

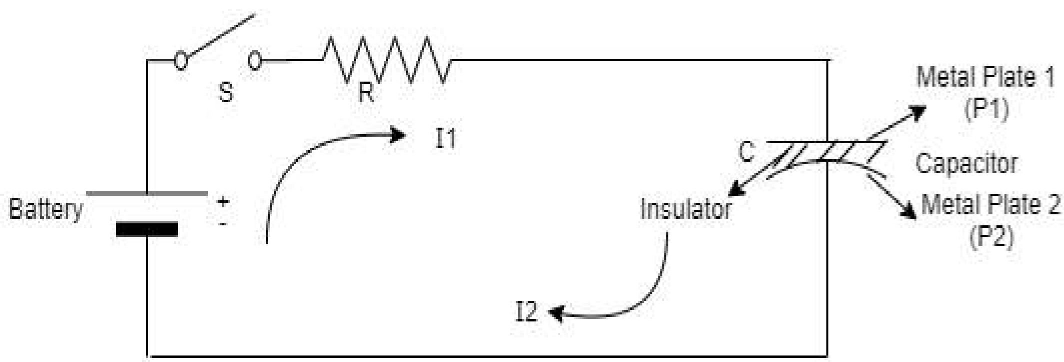
10.08.2020

1. **Wired medium**
    a. Electrical medium : signal runs in terms of voltage and current
        i. Twisted pair (e.g., telephone wire)
        ii. Coaxial cable
    b. Optical medium : signal runs in terms of light
        i. Optical fibre
2. **Wireless medium** : signal runs/travels in terms of electromagnetic signals. $\vec{E}\,field\ +\ \vec{H}\,field$
    a. Space
        i. Aero space
        ii. Absolute space

- $\vec{E}\,field$ (electrical field)
    - Put positive charge, electric charge exerts equal negative charge, so we know the electrical field is set up.
    - Positive charge has set the electric field infinitely.
- $\vec{H}\,field$ (magnetic field)
    - To set up a magnetic field, we need a north pole, south pole and magnitude. The North pole is set to magnitude m.
    - $magnitude \propto \frac{1}{dist}$
- When we connect a battery in a circuit, voltage is set up.
  $I\ =\ \frac{V}{R}$
  where I = current, R = resistance
  Signal is in terms of I and V.
- When there is a static charge ⟶ electric field
- When there is a moving charge ⟶ magnetic field

12.08.2020

1. waveElectromagnetic :
    a. $\vec{E}$ field (Electrical field)
    b. $\vec{H}$field (Magnetic field)
    c. Both are vectors.
    d. $\vec{E}$field and $\vec{H}$field produced naturally at right angles.
    e. Direction of propagation of Electromagnetic field is at right angle to the plane of $\vec{E}$and $\vec{H}$ field.
2. Constant voltage source



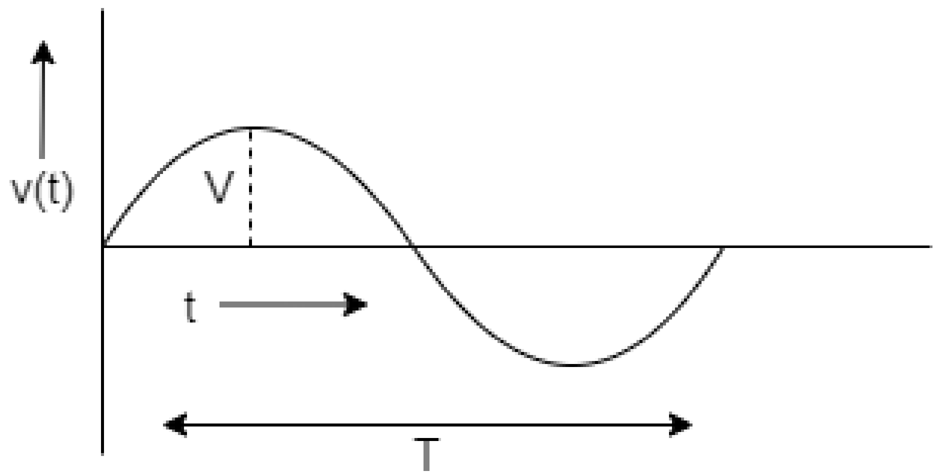
    a. Initial current (I_1) ON switch (S)
       ON = $\frac{V}{R}$ = **Conduction current**
    b. This shall put +ve charge (Q) on P_1plate.
    c. Create an electric field $\vec{E}$through an insulator.
    d. This electric field $\vec{E}$shall displace positive charge Q from P_2.
    e. So there will be current from plate P_2.
    f. According to **Kirchhoff's law** $I_1 \;=\; I_2$.
    g. No current really flows through the insulator of the capacitor.
    h. But to justify Kirchhoff's law there must be some virtual current through the insulator. This virtual current is known as the **Displacement current**.

3. Varying voltage

$v(t) = V sin(2\pi f t + \phi)$

This is graphically presented as :

Case 1 : $\phi = 0$

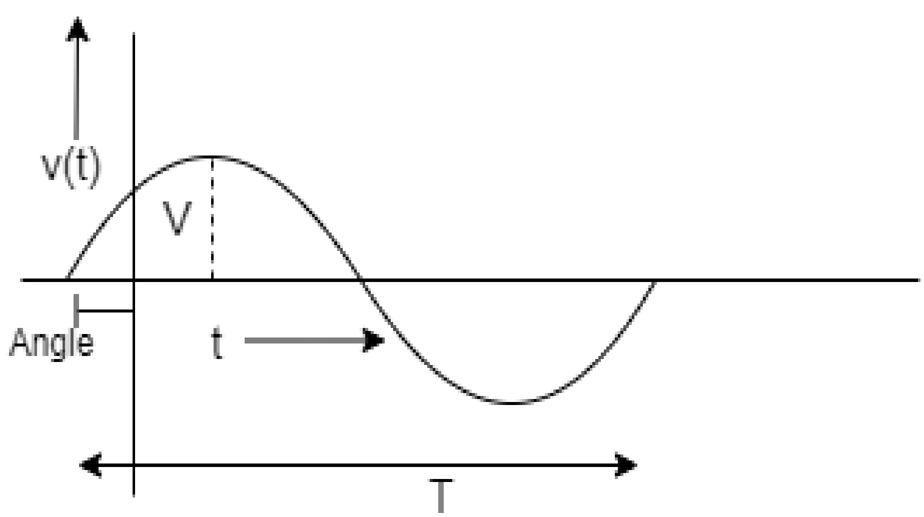


$V = Amplitude$

$T = Time\ period$

$f = \frac{1}{T} = Cyclic\ frequency$

Case 2 : $\phi = \theta$



Angle = Theta = θ

2πangle for one time period T :

a. $2\pi \rightarrow T\ (Time)$

$1 \rightarrow \frac{T}{2\pi}$

$\theta = \frac{T\theta}{2\pi}$ radian

b. We say this sine wave is leading by an angle θ w.r.t earlier wave.

c. Three parameters of sine wave:

$v(t) = Vsin(2\pi ft + \phi)$

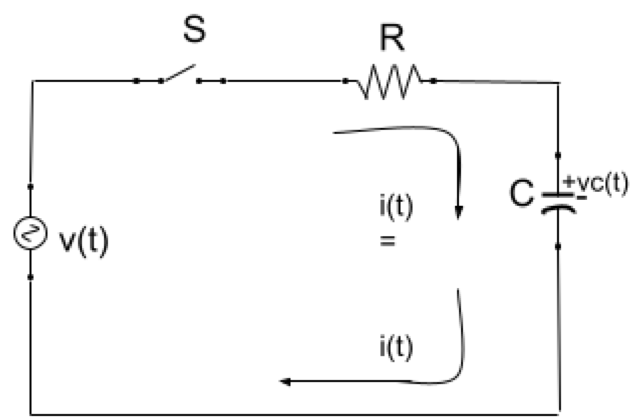
$v(t) = Instantaneous\ value\ of\ the\ sine\ wave$

$V = Amplitude$

$f = \frac{1}{T} = Cyclic\ frequency$

$\phi = Phase\ angle$

4. $\frac{v(t) - vc(t)}{R} = i(t) = displacement\ current$



a. Say switch S is ON at **t = 0** and capacitor voltage $vc(0^{-}) = 0$

$vc(0) = 0$, as a capacitor cannot charge instantaneously.

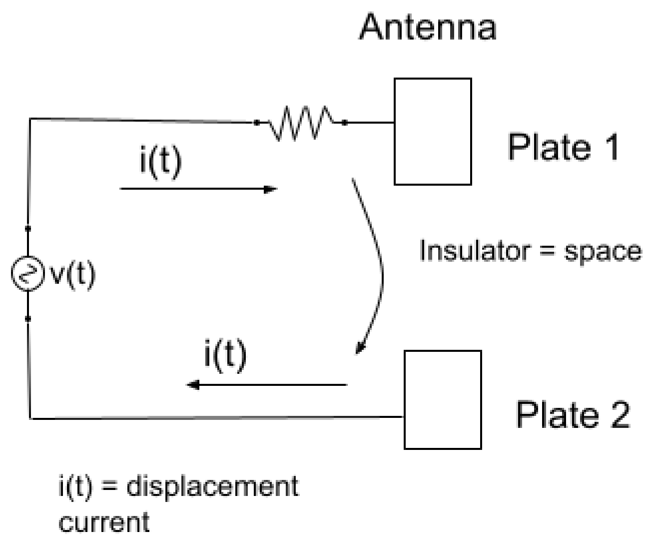
b. At **t**, current $vc(t) = some\ positive\ value$

c. $i(t) = \frac{v(t) - vc(t)}{R}$

d. Displacement current at t = i(t)

5. Time varying conduction current in circuit, i(t)

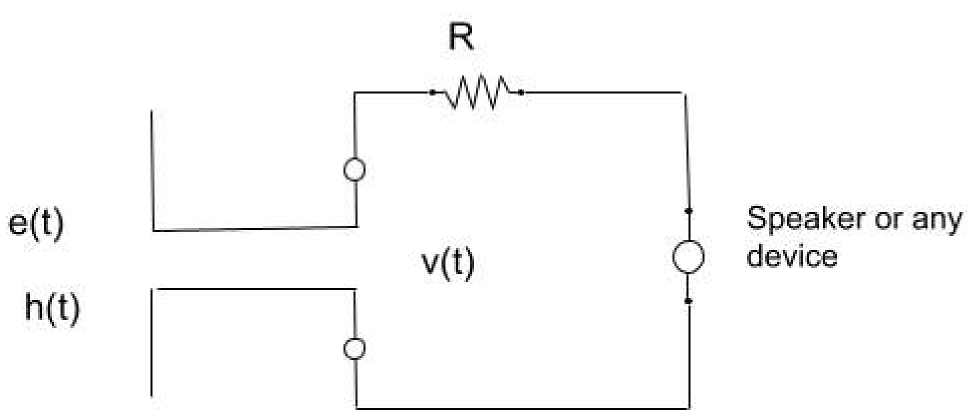
Time varying displacement current in space(air) = i(t)



6.

a. Initially, there should be time varying $\vec{e}(t)$in insulated space(sinusoid, if v(t) is sinusoid)
b. This results in time varying displacement current in space = i(t)
c. i(t) → According to Biot-Savat law, this will give rise to magnetic field (time varying) $\vec{h}(t)$.
d. If v(t) is sinusoid, then $\vec{e}(t)$and $\vec{h}(t)$will also be sinusoid.
e. So in space there will be $\vec{e}(t)$and $\vec{h}(t)$→ electromagnetic field → it will travel in all directions.

7. Receiving antenna



Case 1: When $\vec{e}(t)$is horizontal (perpendicular to the rod)

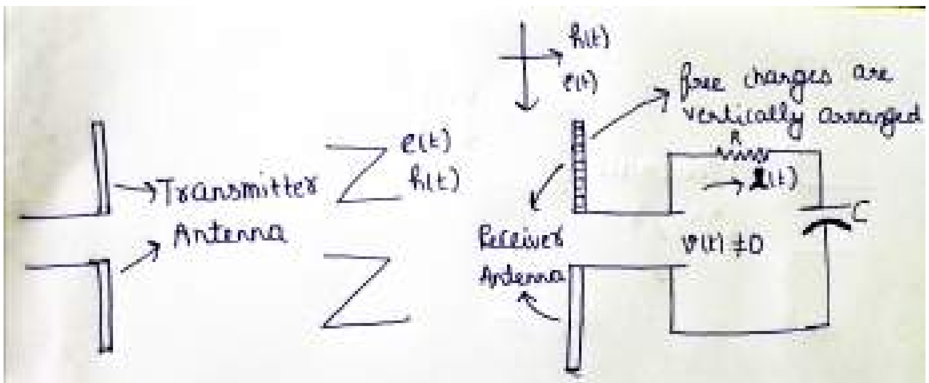
$v(t) \ = \ 0$

Case 2: When $\vec{e}(t)$is vertical (parallel to the rod)

$v(t) \neq 0$

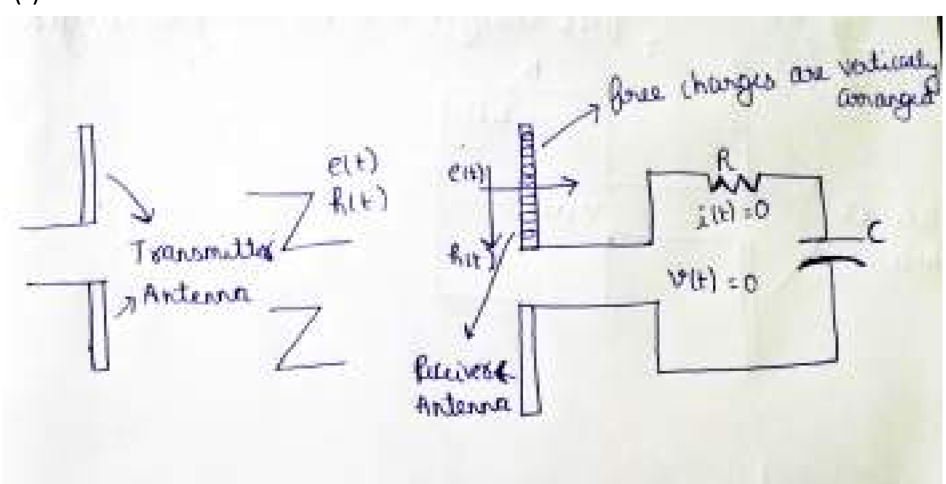
18.08.2020

1. e(t) vertical to the vertical antenna



   a. Free charges are arranged vertically.
   b. e is also arranged vertically.

2. e(t) horizontal to the vertical antenna



   a. Free charges are arranged vertically.
   b. e exerted horizontally.

3. Adjustment of the receiving antenna is required by rotation.
4. Electromagnetic wave equation :

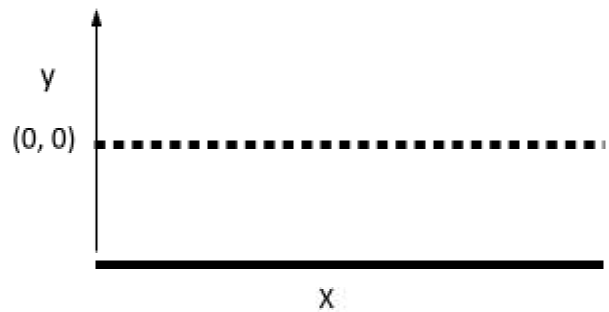
$$\vec{e}(t, x) = Esin(2\pi ft + \frac{2\pi}{\lambda}x)$$

$$\vec{h}(t, x) = Hsin(2\pi ft + \frac{2\pi}{\lambda}x)$$

$where$ E = Amplitude of Electrical field
H = Amplitude of Magnetic field
f = Cyclic frequency
λ = Wavelength

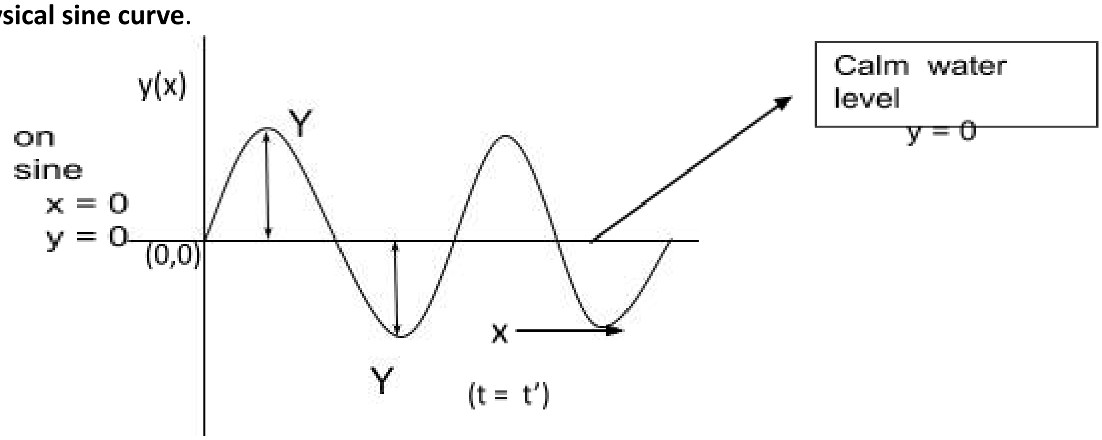
To understand and derive the above equation as a function of t(time) and x(space), let's take the example of a water wave of a lake.

5. Calm Lake

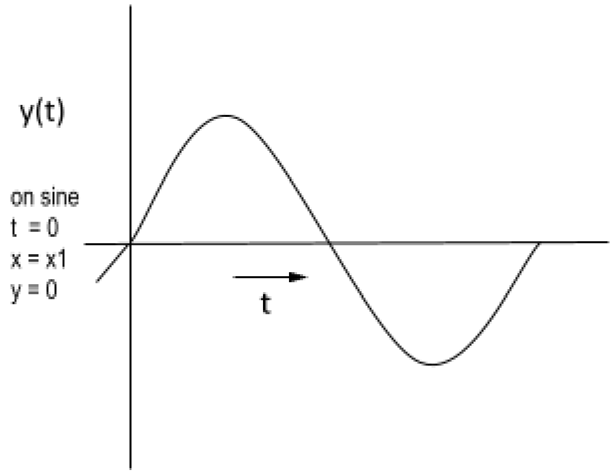


At any x y(x) = 0

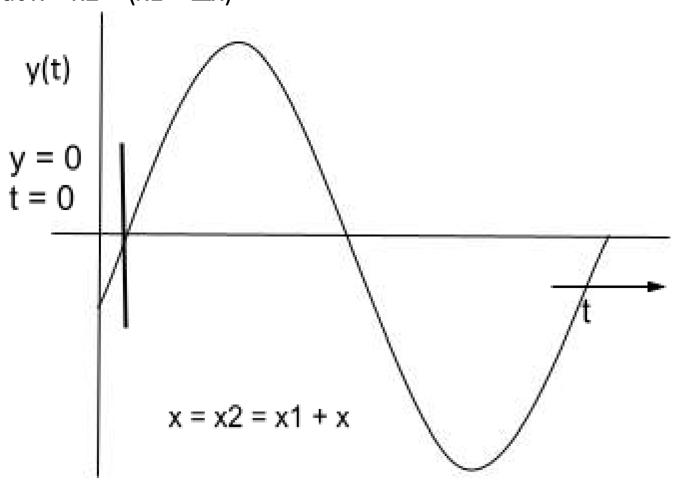
6. When water wave is set up in the lake :
   At time t = t', look at all x points
   Y = Amplitude
   There is a **physical sine curve**.



7. Look at the wave at any point x = x1 where the wave starts.
   Look at the time variation.

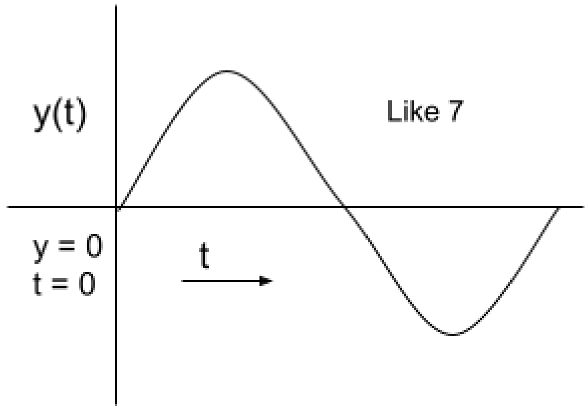


Variation at x = x2 = (x1 + Δx)



Lagging by angle Θ
So here, wave starts at Θ angle
2π => T
x = x3, x4, x5 where x1<x2<x3…<x5…
The wave starts at a later point of time.

8. We say the wave travels.
9.



At $x = x_1$

$y(t) = Ysin(2\pi ft)$

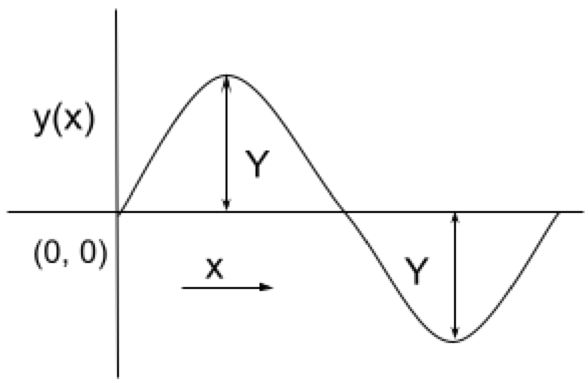
f = cyclic frequency = $\frac{1}{T}$

T = time period

At $x = x_2$

$y(t) = Ysin(2\pi ft - \theta)$

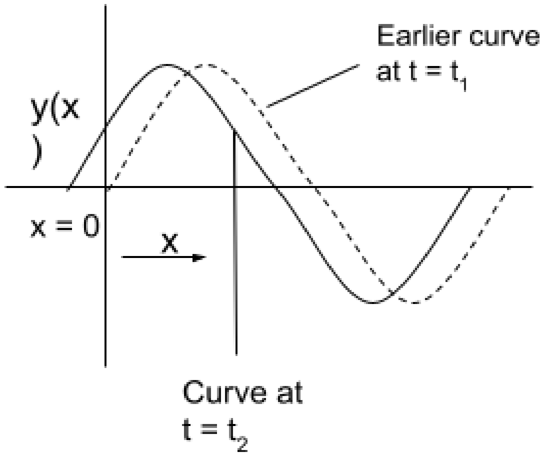
10. Now look at the variation of y w.r.t space.
    At any time $t = t_1$, look at all x points, you will see a sine wave.



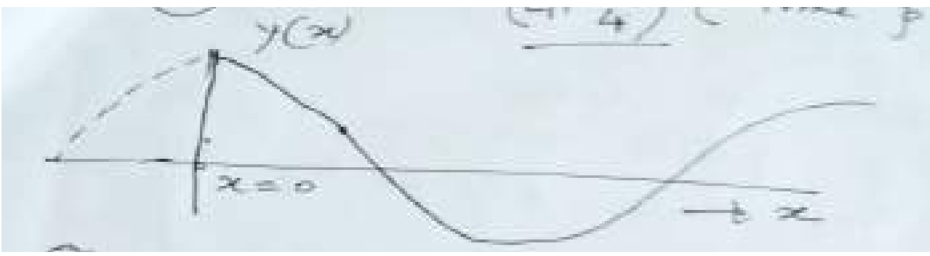
$$y(x) = Ysin(\beta x)$$

where = constant

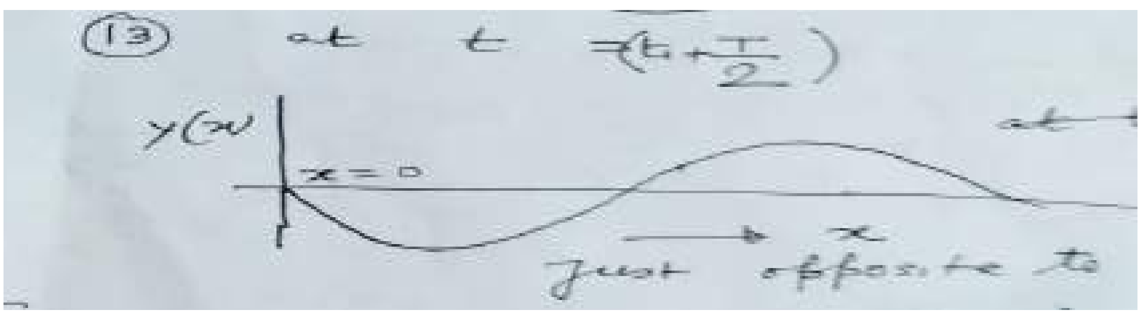
11. Look at all x points at another time t = t2 = (t1 + Δt)



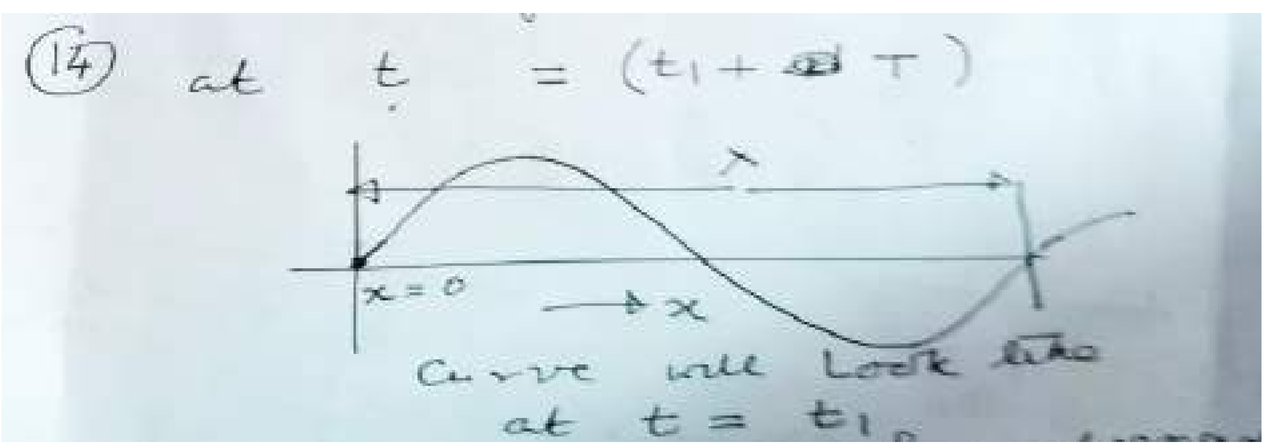
12. At $t = t_1 + \frac{T}{4}$(time period)



13. At $t = t_1 + \frac{T}{2}$



14. At $t = t_1 + T$



We say the wave has advanced at a length of λ in time T.

path length λ ⟶ T ⟶ 2*π Angle
In time T change
path changes by λ
The Angle changes by 2*π

λ ⟶ 2*π
path change — Angle change

1 ⟶ 2*π/ λ Angle change

x path change ⟶ 2*π*x/λ Angle change
= β * x
where β = 2*π/ x

15. Therefore the variation of the wave w.r.t. x where t is constant.

$$y(x) = Ysin(\frac{2\pi x}{\lambda})$$

16. We already know variation of the wave w.r.t. t where x = constant

$$y(t) = Ysin(\frac{2\pi t}{T})$$
$$= Ysin(2\pi ft)$$

Now combining 15 and 16 variation w.r.t **t** (time) and **x** (space)

$$y(t,\ x) = Ysin(\ 2\pi ft\ + \frac{2\pi x}{\lambda})$$

where the constant

$\lambda = wavelength = distance\ between\ two\ consecutive\ space\ points\ with\ the\ same\ phase$
$(both\ y = 0\ or\ both\ y = Y)\ at\ a\ particular\ time\ t = t$

17. From 14 we have seen that the wave advances/travels λdistances in time T

T time ⟶ λ distance

1 time ⟶ $\frac{\lambda}{T} = f\ *\ distance$

Velocity of wave $v = f\lambda$

18. In a similar manner $v(t)$ of transmitter antenna is $Vsin(2\pi ft)$

Then,

$$\vec{e}(t) = Esin(2\pi ft)$$
$$\vec{h}(t) = Hsin(2\pi ft)$$

where transmitter antenna point $x = 0$.

Therefore, the wave equation at distance x from transmitter antenna:

$$\vec{e}(t,\ x)\ =\ Esin(2\pi ft\ +\frac{2\pi x}{\lambda})$$

$$\vec{h}(t,\ x)\ =\ Hsin(2\pi ft\ +\frac{2\pi x}{\lambda})$$

19. Particle mode and wave mode energy transfer:

   a. **Particle Mode:**

      A particle of mass m and velocity v has kinetic energy:

      $$E\ =\ \frac{1}{2}mv^2$$

      If you throw this particle to a football on still water, the football starts moving. Here the energy is transformed in particle mode. The particle carrying energy actually moves.

   b. **Wave Mode:**

      You stir water at the edge of the pond → wave set up → in the wave no water particle moves from the mean position → wave reaches the ball and moves it.

24.08.2020

1. The electromagnetic wave equation :

   E field :

   $$\vec{e}(t,\ x)\ =\ \vec{E}sin(2\pi ft\ +\ 2\pi x/\lambda)$$
   $$\vec{h}(t,\ x)\ =\ \vec{H}sin(2\pi ft\ +\ 2\pi x/\lambda)$$

   $\vec{E} =\ amplitude\ of\ electric\ field$

   $f\ =\ frequency$

   $\lambda\ =\ wavelength$

   $\vec{H} =\ amplitude\ of\ magnetic\ field$

2. $x\ =\ amount\ of\ space\ the\ wave\ travels\ in\ time\ "T"$

   Also, $\lambda\ =\ distance\ between\ two\ consecutive\ points\ in\ space\ with\ the\ same\ phase$

   - 0 phase - 0 amplitude value
   - 90 phase - maximum amplitude value

3. $v\ =\ f\lambda$

   v = velocity of the wave

4. $Power \propto E^2$

   E = amplitude of electric field

Electromagnetic Spectrum :

1. Medium Wave : 530 KHz - 1602 KHz

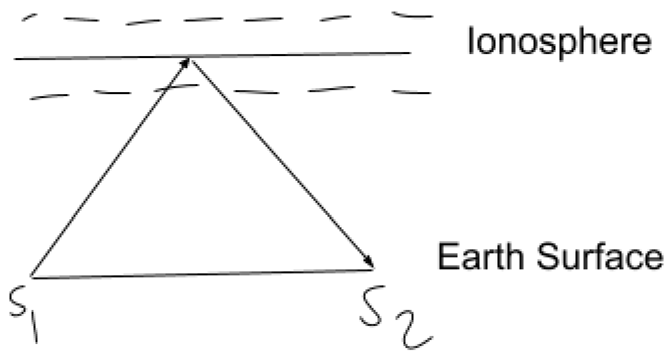
   Use :

   - Medium wave Radio
   - Hops along the surface of earth

2. Short Wave (HF Band) : 3MHz - 30MHz

   Use :

   - Short wave radio transmission for long distances



3. Very High Frequency (VHF) : 30MHz - 300MHz

   Use :

   - FM Radio
   - TV transmission

4. Ultra High Frequency (UHF) : 300MHz - 3000MHz (3GHz)

   Use :

   - TV broadcasting
   - Mobile Cellular Phone broadcasting

5. Microwave : 1GHz - 1000GHz

   Use :

   - WLAN
     - S band : (2.4GHz + 80MHz)
     - C band : (5GHz + 80MHz)

   L band : 1 - 2GHz

   S band : 2 - 4GHz

   C band : 4 - 8GHz

   X band : 8 - 12GHz

   Ku band : 12 - 18GHz

   K band : 18 - 26.5GHz

   Ka band : 26.5 - 40GHz

Properties of microwave:

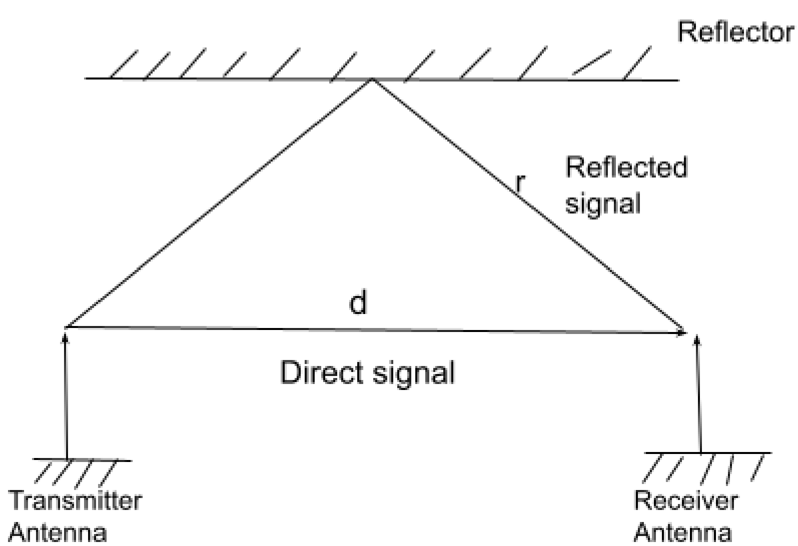
1. Line of sight propagation like light.

2. Absorbed by fog, vegetation, rain.
3. Signal strength in free space $\propto \frac{1}{x^2}$(x = distance from transmitter antenna)
4. **Reflection:**
    - Full in metal
    - Partial in insulator

    Refraction:
    - 0 in metal
    - Partial in insulator

    i. Wave cannot travel through metal
    ii. Wave travels through insulator
5. Multipath fading starts from UHF

Multipath fading



Distance travelled by **direct signal** = d
Distance travelled by **reflected signal** = r

1. $e(t, x) = Esin(2\pi ft + \frac{2\pi}{\lambda}x)$
2. $e_d(t, d) = Esin(2\pi ft + \frac{2\pi}{\lambda}d)$
3. $e_r(t, r) = Esin(2\pi ft + \frac{2\pi}{\lambda}r)$
4. Effective signal at the receiver

$$e_e = e_d(t, d) + e_r(t, r)$$
$$= Esin(2\pi ft + \frac{2\pi}{\lambda}d) + Esin(2\pi ft + \frac{2\pi}{\lambda}r)$$

5. Let $r = d + \lambda$

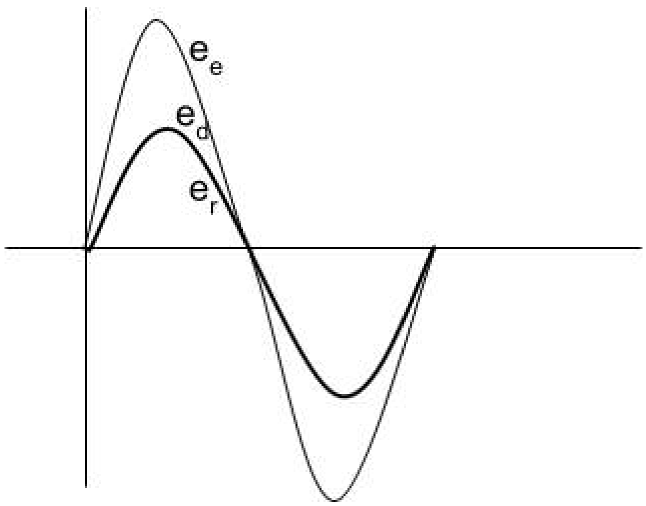
$$e_e = E sin(2\pi f t + \frac{2\pi}{\lambda} d) + E sin(2\pi f t + \frac{2\pi}{\lambda}(d + \lambda))$$

$$= E sin(2\pi f t + \frac{2\pi}{\lambda} d) + E sin(2\pi f t + \frac{2\pi}{\lambda} d + 2\pi)$$

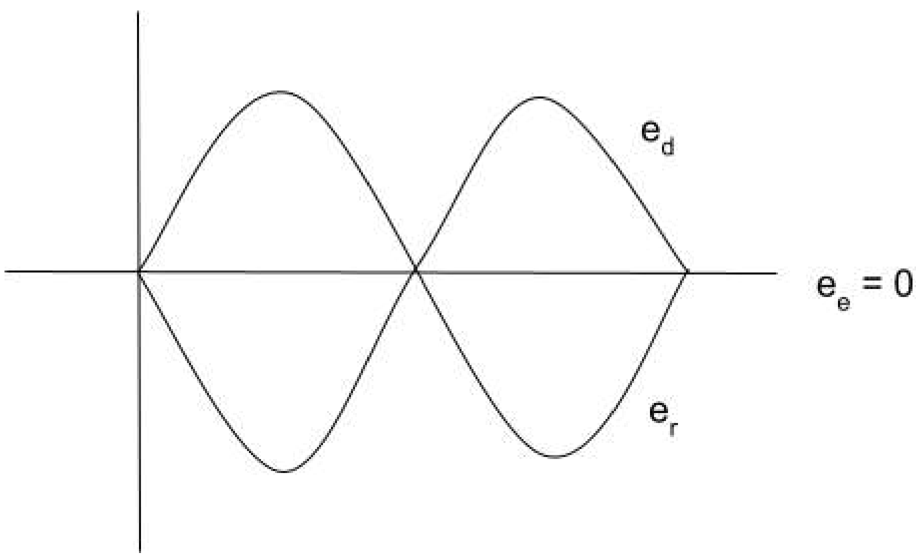
$$= 2E sin(2\pi f t + \frac{2\pi}{\lambda} d)$$

Signal strength doubles due to constructive interference

→ No multipath fading

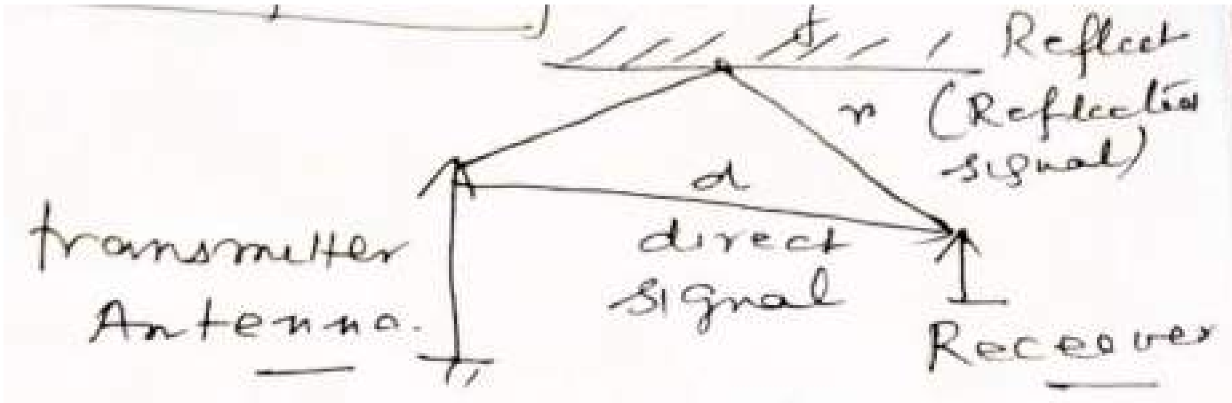


6. $r = d + \frac{\lambda}{2}$ Full fading



25.08.2020

1. **Multiple Fading**



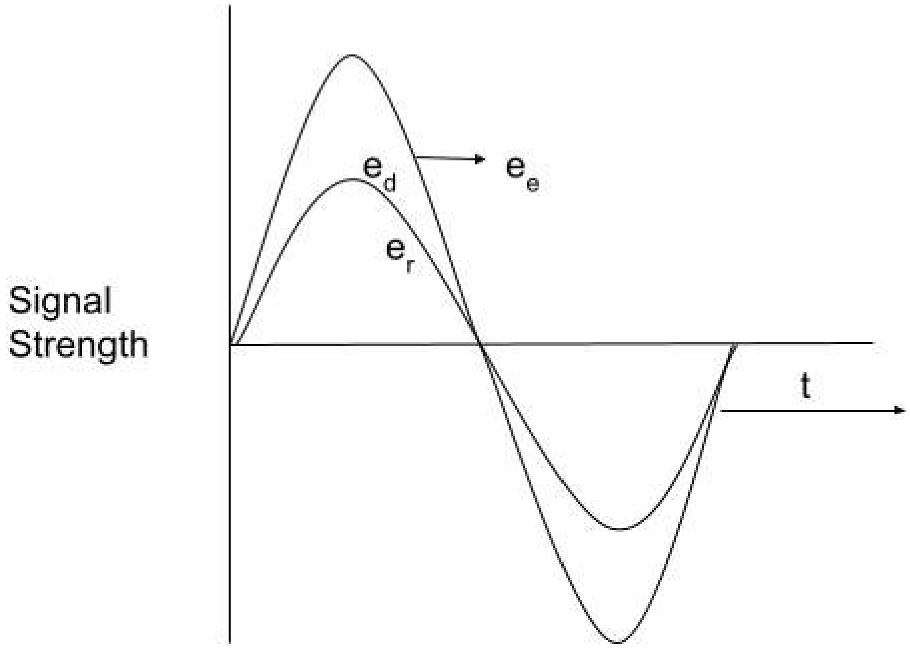
Distance travelled by direct signal = d
Distance travelled by reflected signal = r

a. $e(t, x) = E\, sin(2\pi ft + \frac{2\pi}{\lambda}x)$
b. $e_{d(t,\, d)} = E\, sin(2\pi ft + \frac{2\pi}{\lambda}d)$
c. $e_{r(t,\, r)} = E\, sin(2\pi ft + \frac{2\pi}{\lambda}r)$

Effective signal at the receiver

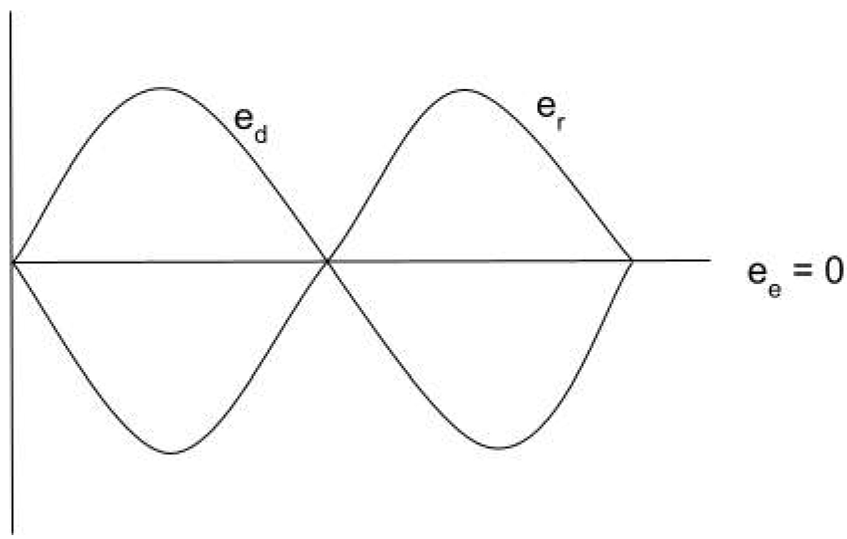
d. $e_e = e_d(t, d) + e_r(t, r)$
   $= Esin(2\pi ft + \frac{2\pi}{\lambda}d) + Esin(2\pi ft + \frac{2\pi}{\lambda}r)$
e. **Case 1:**
   Let $r = d + \lambda$
   $e_e = Esin(2\pi ft + \frac{2\pi}{\lambda}d) + Esin(2\pi ft + \frac{2\pi}{\lambda}(d + \lambda))$
   $= Esin(2\pi ft + \frac{2\pi}{\lambda} + 2\pi)$
   $= Esin(2\pi ft + \frac{2\pi}{\lambda}d) + Esin(2\pi ft + \frac{2\pi}{\lambda}d + 2\pi)$
   $= 2Esin(2\pi ft + \frac{2\pi}{\lambda}d)$

   Signal strength doubles due to constructive interference → No multiple fading.



f. **Case 2:**

$$r = d + \frac{\lambda}{2}$$



Full Multipath Fading

$$e_{d(t,\,d)} = E\sin(2\pi f t + \frac{2\pi}{\lambda} d)$$

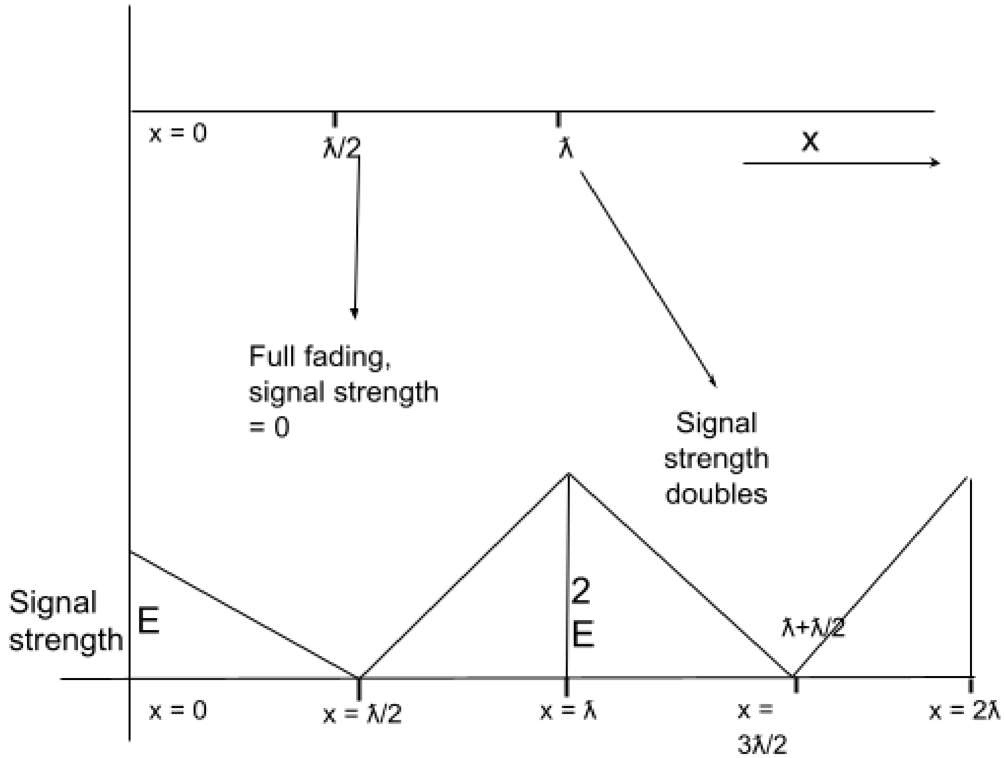
$$e_{r(t,\,r)} = E\sin(2\pi f t + \frac{2\pi}{\lambda} d + \pi)$$

$$= -E\sin(2\pi f t + \frac{2\pi}{\lambda} d)$$

$e_e = e_d(t, d) + e_r(t, r) = 0$

g. Case 3:

$$r = d + x$$



h. If a person talks while walking towards x direction:
   i. At $x = \frac{\lambda}{2}$, signal = 0 → call drop
   ii. At $\frac{\lambda}{2} < x <= \lambda$ → signal strength increasing → better conversation
   iii. At $\lambda < x <= \frac{3\lambda}{2}$ → again signal strength decrease

   Signal strength varies in congested areas (with building, mountains, while a person moves).

i. Signal strength in the basement of the house, here also the signal strength varies:
   i. At some points there is signal
   ii. At some other points there is no signal

Definition of Signal

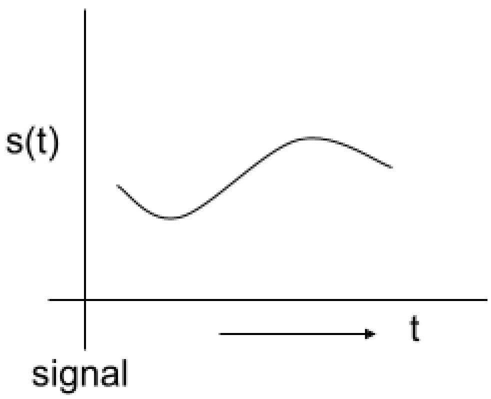
A time varying **physical quantity** using which data is transmitted from one computer to another computer using a communication **medium**.

1. Physical Quantity:
   a. Voltage/ current (electrical signal)
   b. Light intensity (optical signal)
   c. E and H field (electromagnetic signal)

2. Medium:
    a. Twisted pairs (signal is electric)
    b. Coaxial cable (signal is electric)
    c. Optical fibre (signal is light)
    d. Space (signal is electromagnetic)

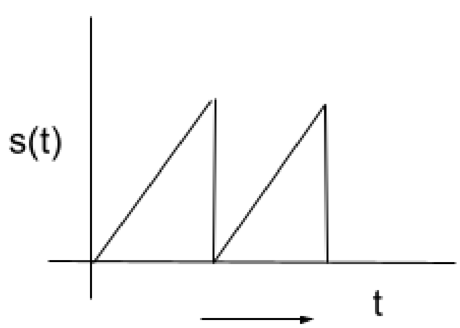
SIGNALS

1. **Analog:**
   Signal s(t) varies continuously

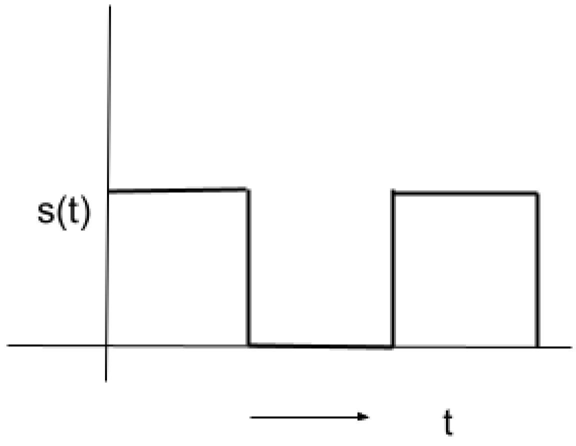


   If signal s(t) is continuous function with time → Analog signal
   Example: sine function

2. **Discrete:**
   If s(t) is a non-continuous function of time.
    i.



    ii.

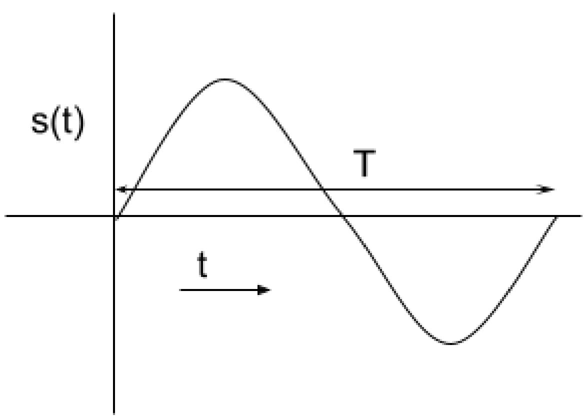


Square wave

Analog Signal

1. **Pure Analog Signal** with simple frequency.

   $f = \frac{1}{t}$

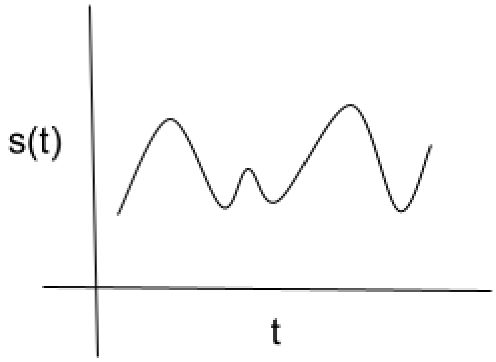


2. **Composite Analog Signal** with many frequencies consisting of many sine waves.

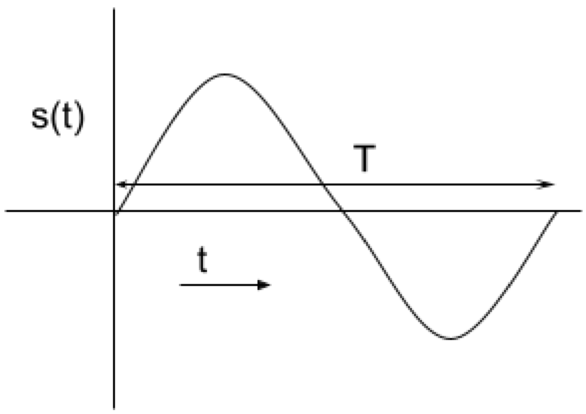
   f_h = highest frequency

   f_l = lowest frequency

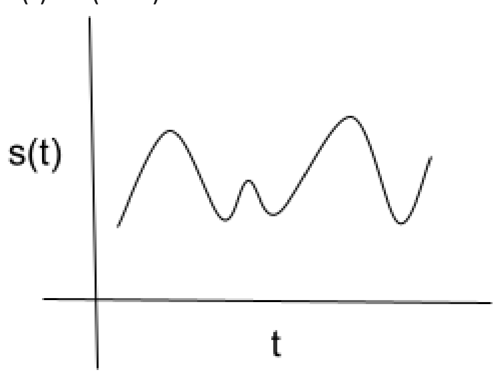
   BW = $f_h - f_l$



1. **Periodic Analog Signal:**
   If there exists constant T such that s(t) = S(T + t) for all t.

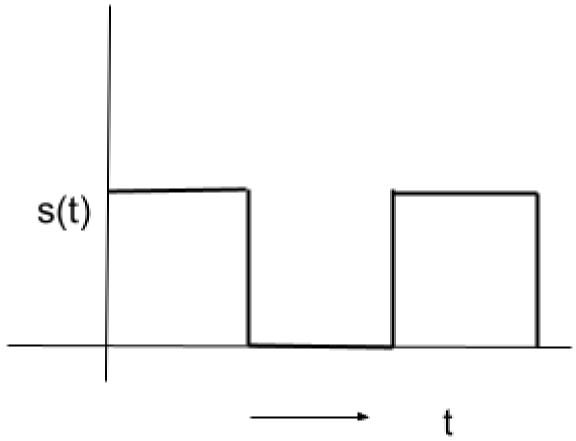


2. **Non Periodic Analog Signal:**
   If s(t) ≠ S(t + T)



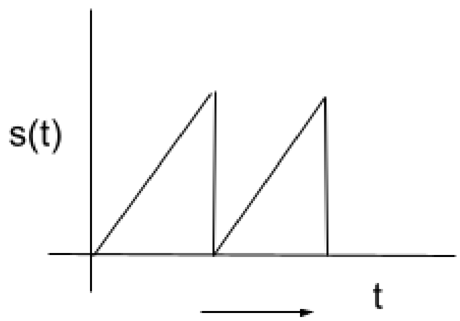
Digital Signal

1. **Digital Signal:**



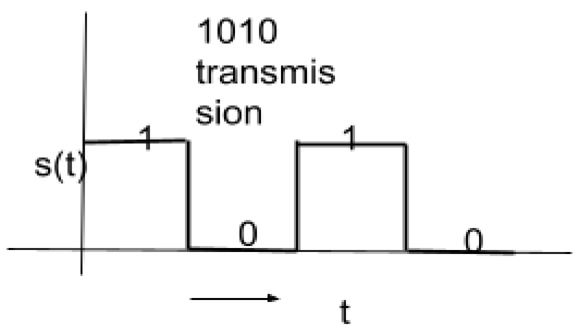
Square wave

2. **Saw Tooth:**



1. **Periodic Digital Signal:**

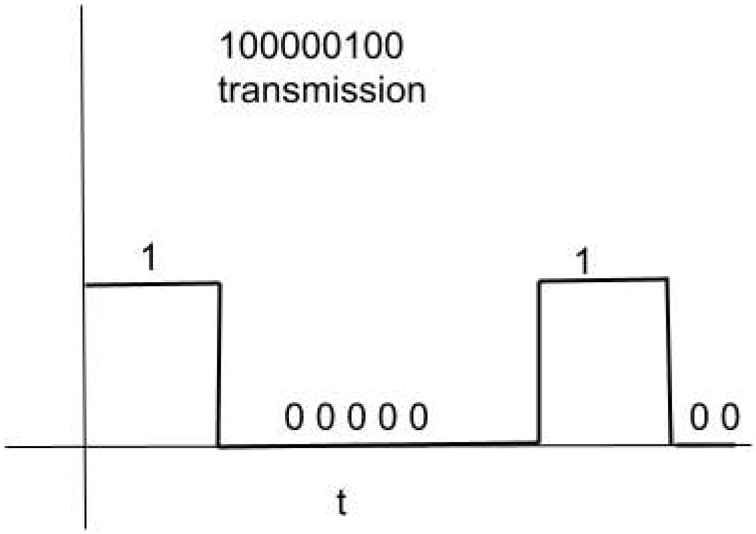
   s(t) = s(T + t)



Digital Periodic
Signal

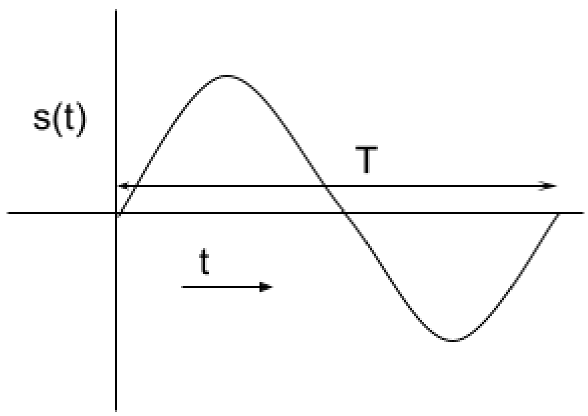
2. **Non-Periodic Digital Signal:**

   s(t) ≠ s(T + t)



Periodic Signal

1. Analog Signal

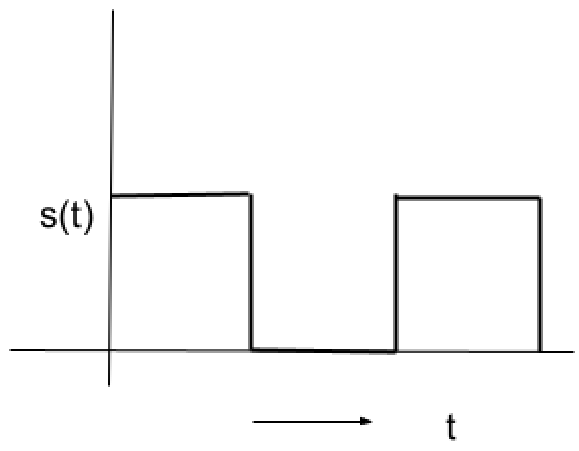


Pure analog signal: s(t) = s(t + T)

Only one frequency: $f = \frac{1}{T}$

Is it only one sine wave → NO

2. Square wave



Square wave

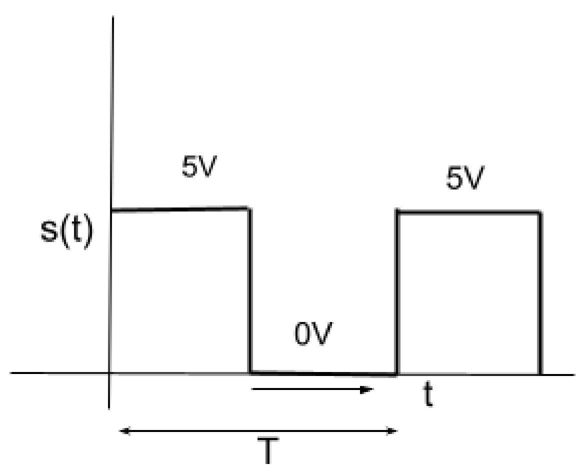
s(t) = s(t + T)

Fourier Analysis: If any function s(t) = s(t + T), then it can be analysed by Fourier series:

$$s(t) = \frac{c}{2} + \sum_{n=1}^{\infty} A_n sin(2\pi nft) + \sum_{n=1}^{\infty} B_n cos(2\pi nft)$$

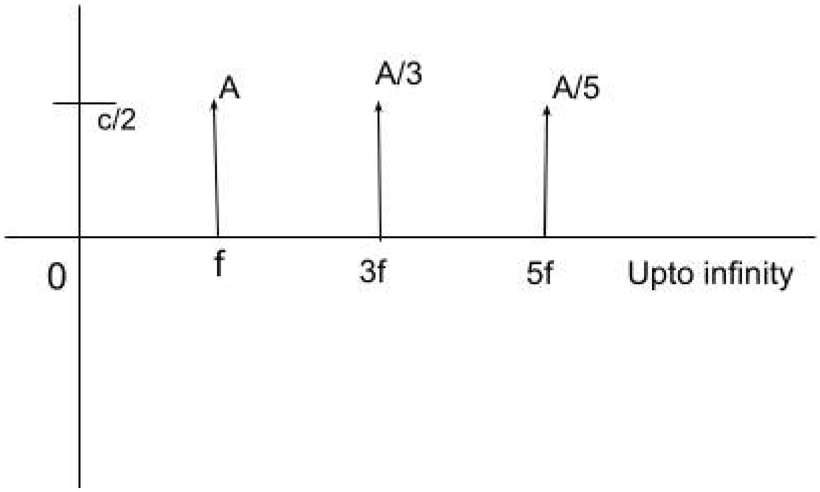
where, $f = \frac{1}{T}$

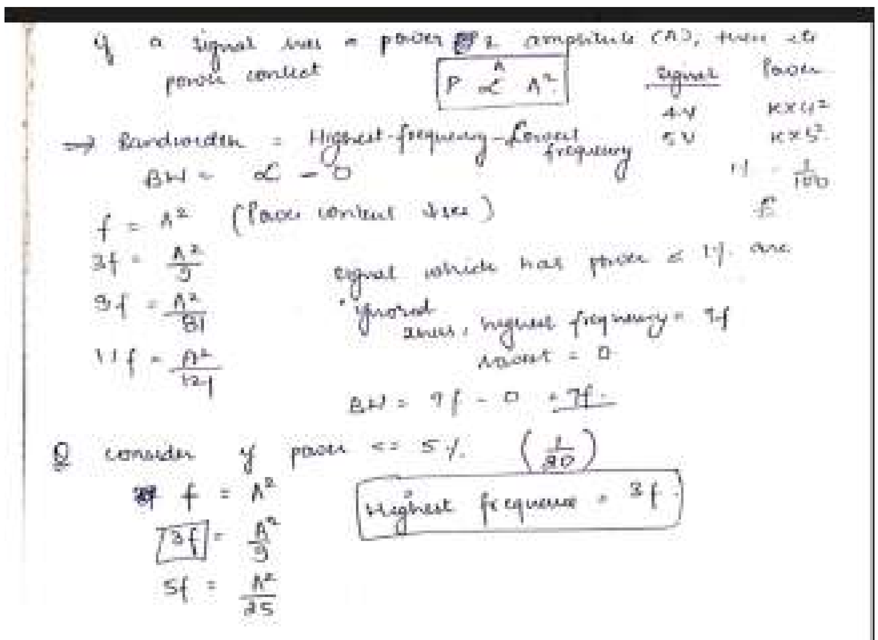
If c = 5V



After Fourier analysis,

$$s(t) = \frac{5}{2} + Asin(2\pi ft) + \frac{A}{3}sin(3ft) + \frac{A}{5}sin(5ft)$$





If a signal has ∝ power ∝ amplitude (A), then its power content $\boxed{P \propto A^2}$

Signal	Power
4V	$K \times 4^2$
5V	$K \times 5^2$

1% = $\frac{1}{100}$

⇒ Bandwidth = Highest frequency − Lowest frequency

BW = ∞ − 0

$f = A^2$ (Power content here)

$3f = \frac{A^2}{9}$

$9f = \frac{A^2}{81}$

$11f = \frac{A^2}{121}$

signal which has power < 1% are ignored

thus, highest frequency = 9f

lowest = 0

BW = 9f − 0 = 9f.

Q consider if power <= 5% $\left(\frac{1}{20}\right)$

$f = A^2$

$\boxed{3f} = \frac{A^2}{9}$

$5f = \frac{A^2}{25}$

$\boxed{\text{Highest frequency} = 3f}$

Signal Representation:

1. Time domain
2. Frequency domain

- Absolute

  $B_{W\,absolute} = \alpha - 0 = \alpha$

- Effective

  $B_{W\,effective} = f_c - 0$

  $= nf - 0$

  $= nf$

  where,

value of n depends on the applications,
f_c = cutoff frequency

If we want n = 10 for cutoff frequency,

$A_n = \frac{1}{10}A$

$Amplitude\ of\ cutoff\ frequency = \frac{1}{10} of\ amplitude\ of\ fundamental\ frequency(f)$

Then,

$B_{W\ effective} = 10f$

$f = \frac{1}{T}$ → fundamental frequency

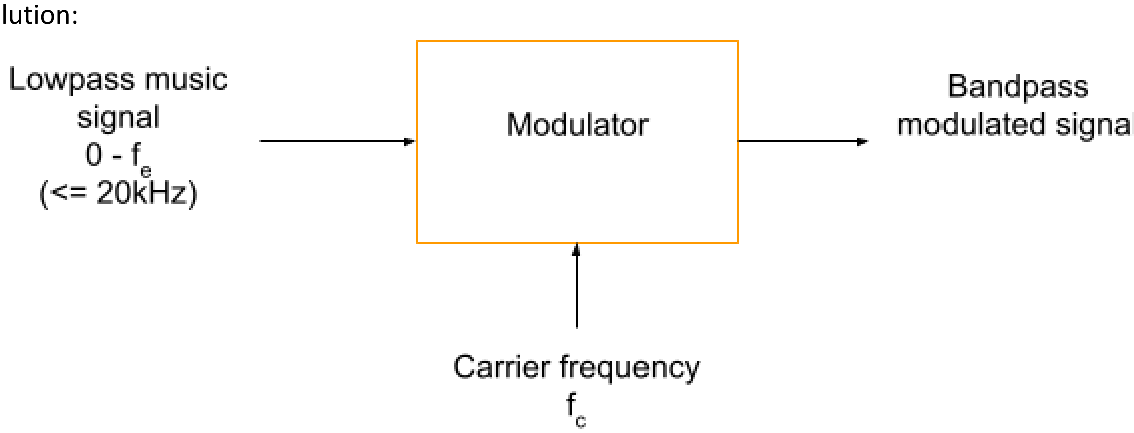
01.09.2020

1. Transmission over space:
    a. Analog signal transmission
        i. Analog voice
            1. Music (0 - 20kHz)
            2. Telephone (0 - 4kHz)
        ii. TV
            1. Video (0 - 5MHz)
            2. Audio (0 - 20kHz)
    b. Digital signal transmission : we'll do it later.
2. Analog music transmission over space :
   Say we have n number of sources:

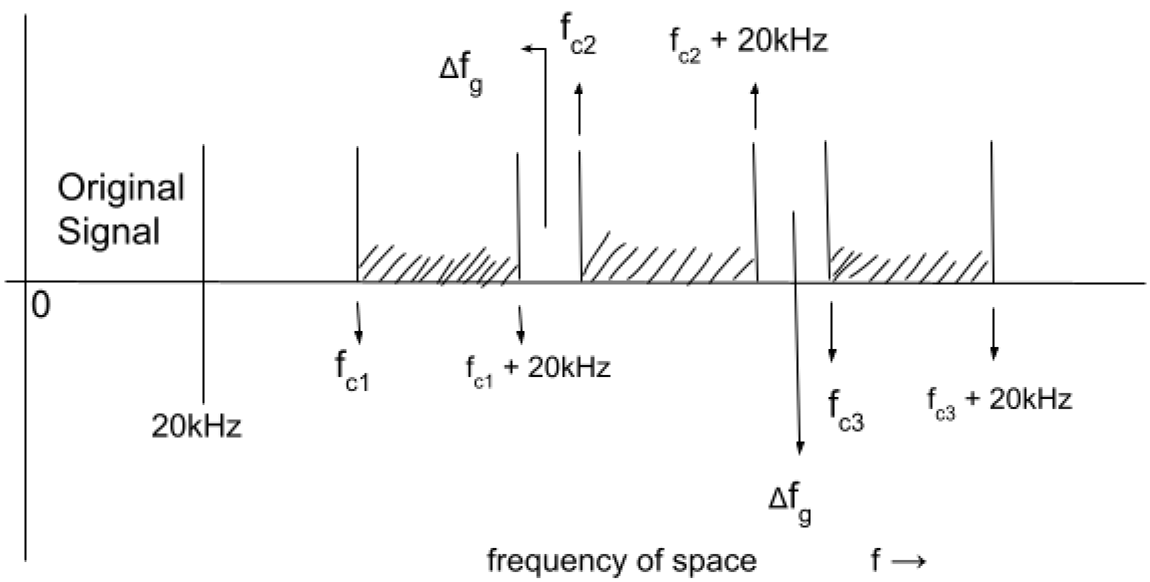
Sources	→	Bandwidth
S_1	→	0 - 20kHz
S_2	→	0 - 20kHz
.		
.		
.		
S_n	→	0 - 20kHz

Low Pass Signal

3. When all sources transmit their music signal, all will collide in the space.
4. Signals
    a. Lowpass (music) ⟶ 0 - f_e
    b. Bandpass (modulated signal) ⟶ f_L - f_H
    c. Highpass ⟶ f_H - ∞ [no relevance]
5. Solution:

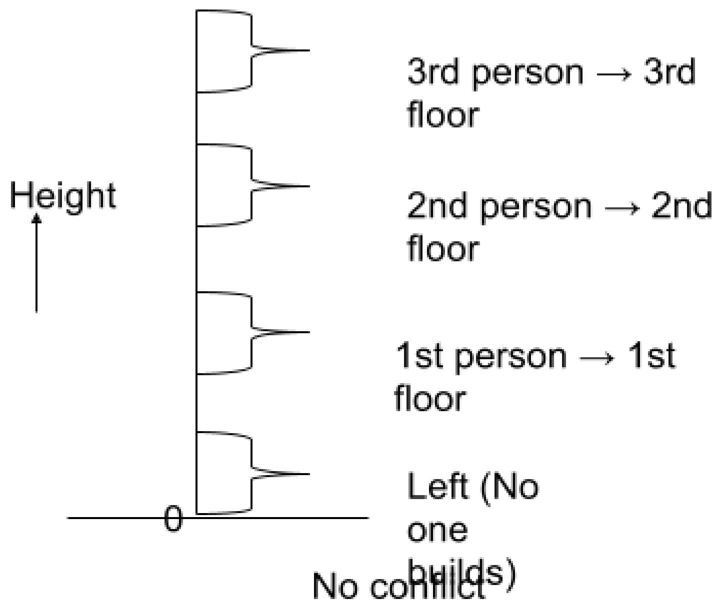


6. Modulation types
    a. Amplitude Modulation (AM)
    b. Frequency Modulation (FM)
    c. Phase Modulation (PM) [not used]
7. Amplitude modulated music:
    a. Bandpass signal: $f_c \rightarrow f_c + 20$kHz, bandwidth of each channel.
    b. $0 \rightarrow 20$kHz lowpass signal is transformed to f_c to $f_c + 20$kHz bandpass signal.
8. Frequency modulation:
    a. $0 \rightarrow 20$kHz lowpass signal is transformed to f_c to f_c + 5x20kHz bandpass signal by frequency modulation.
9. Frequency Division Multiplexing in AM music transmission

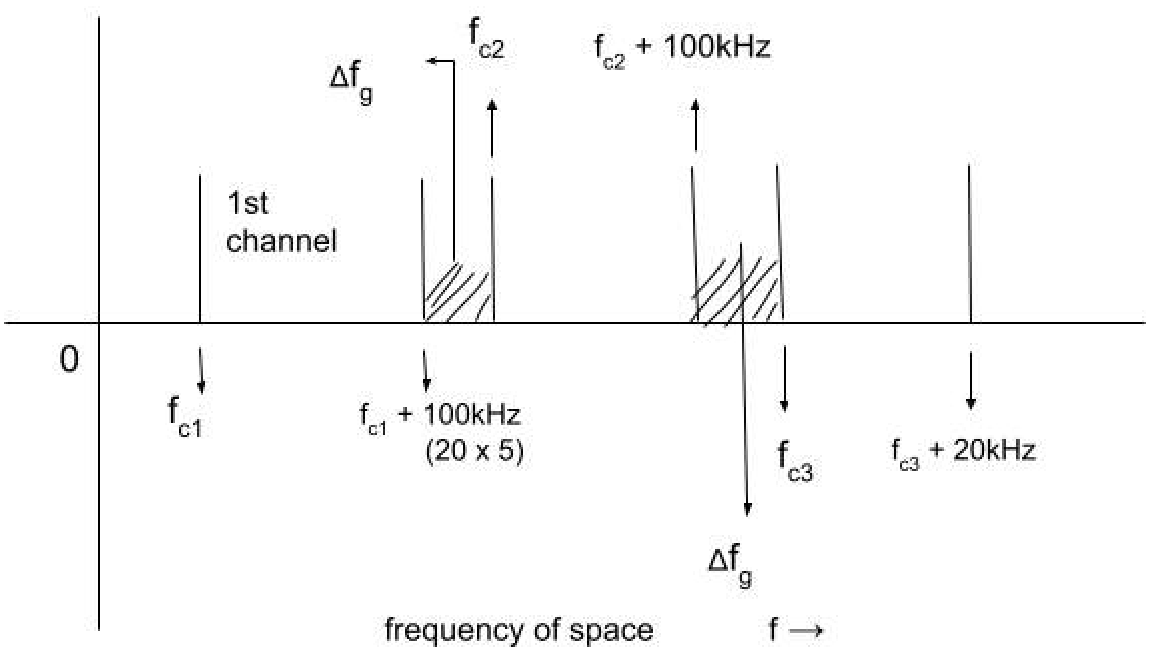


$$f_{c2} = f_{c1} + 20\ kHz + \Delta f_g$$
$$f_{c3} = f_{c2} + 20\ kHz + \Delta f_g$$
Δf_g = guard band to stop interference between two consecutive channels

10. Each low pass music signal ⇒ Band pass music signal
    (0 - 20 kHz) ($f_c \rightarrow f_c$ + 20 kHz by modulation)
11. House building analogy with modulation
    a. One piece of land on the ground floor. N number of parties want to build on ground floor ⇒ conflict
    b. Each builds their house in multistoried fashion leaving ground floor



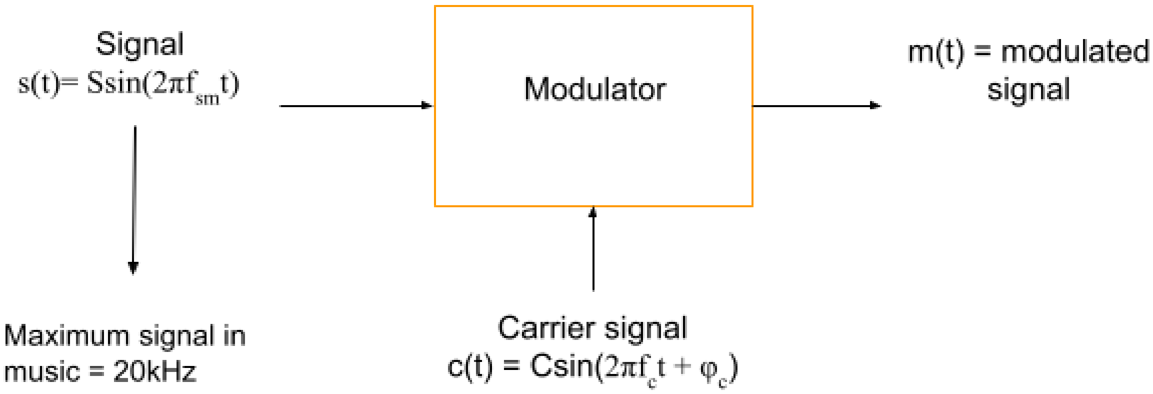
12. Frequency Division Multiplexing (FDM) for Frequency Modulation



$$f_{c2} = f_{c1} + 100\,kHz\,(5 * 20) + \Delta f_g$$

$$f_{c3} = f_{c2} + 100\,kHz + \Delta f_g$$

13.



14. Amplitude Modulation

$m(t) = (C + k_a s(t))\, sin(2\pi f_c t + \phi_c)$

15. Frequency Modulation

$m(t) = Csin(2\pi(f_c + k_f s(t))t + \phi_c)$

C and ϕ_c are constant, f_c varies

16. Phase Modulation

$m(t) = Csin(2\pi f_c t + (\phi_c + k_p s(t)))$

C and f_c are constant, ϕ_c varies

k_a = proportional constant for amplitude modulation
k_f = proportional constant for frequency modulation
k_p = proportional constant for phase modulation

02.09.2020

1. Carrier Signal:

$$c(t) = Csin(2\pi f_e t + \phi_e) \qquad \text{[eqn 1]}$$

2. Music Signal:

$$s(t) = Ssin(2\pi f_{sm} t) \qquad \text{[eqn 2]}$$

where, s(t) = music signal

f_{sm} = music signal maximum frequency (20 kHz)

3. Let amplitude modulated signal be

$$m_a = [C + k_a s(t)]sin(2\pi f_c t + \phi_c)$$

Here the amplitude of the carrier is varied according to the instantaneous value of the music signal s(t).

And f_c and ϕ_c = constant.

4. Assume $\phi_c = 0$

$$m_a = [C + k_a s(t)]sin(2\pi f_c t)$$

$$= [C + k_a Ssin(2\pi f_{sm} t)]sin(2\pi f_c t)$$

$$= Csin(2\pi f_c t) + k_a Ssin(2\pi f_{sm} t) * sin(2\pi f_c t)$$

$$\Rightarrow \quad m_a = Csin(2\pi f_c t) + \frac{k_a S}{2} 2sin(\phi)sin(\theta)$$

where, $\phi = 2\pi f_c t$

$\theta = 2\pi f_{sm} t$

$$\Rightarrow \quad m_a = Csin(2\pi f_c t) + S'[cos(\phi - \theta) - cos(\phi + \theta)]$$

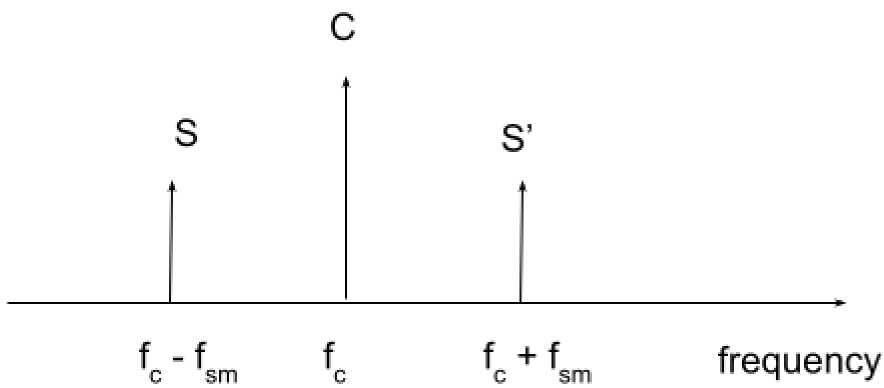
where, $S' = \frac{k_a S}{2}$

$\Rightarrow \quad m_a = C sin(2\pi f_c t) + S' cos(2\pi(f_c - f_{sm})t) - S' cos(2\pi(f_c + f_{sm})t)$

$= C sin(2\pi f_c t) + S' sin(2\pi(f_c t - f_{sm})t + \frac{\pi}{2}) + S' sin(2\pi(f_c + f_{sm})t + \frac{\pi}{2})$

Time domain representation of the modulated signal.

5. Frequency domain representation of the modulated signal



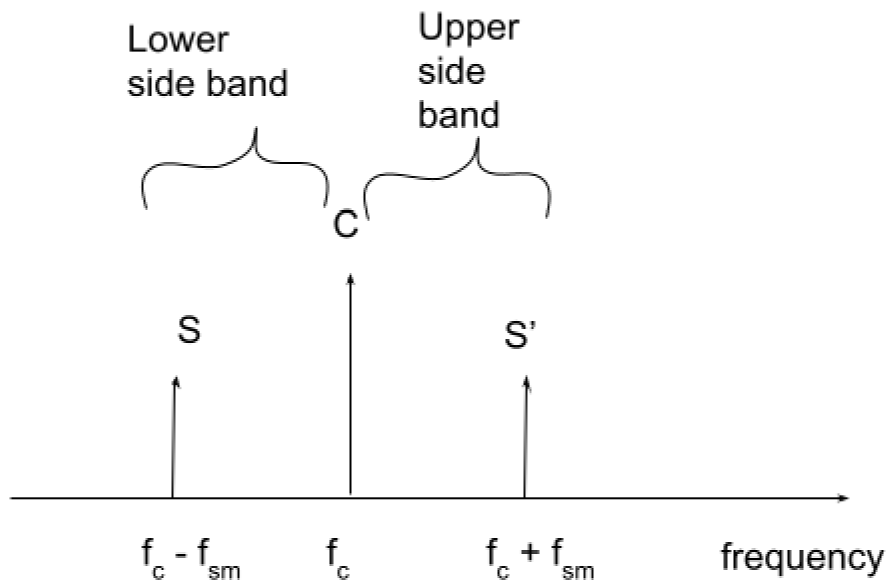
where, f_{sm} = 20 kHz

6. So, bandwidth of the modulated signal

$m_a(t) = (f_c + f_{sm}) - (f_c - f_{sm})$

$= 2f_{sm} = BW\ of\ the\ channel$

7. Bandwidth of the original signal= f_{sm}
8. So, bandwidth of the channel = 2 x BW of the music signal
9.



10. In a modulated signal, $(f_c - f_{sm})$ to $(f_c + f_{sm})$ preserves the characteristics of the signal f_{sm} along with the carrier.
11. Demodulation:

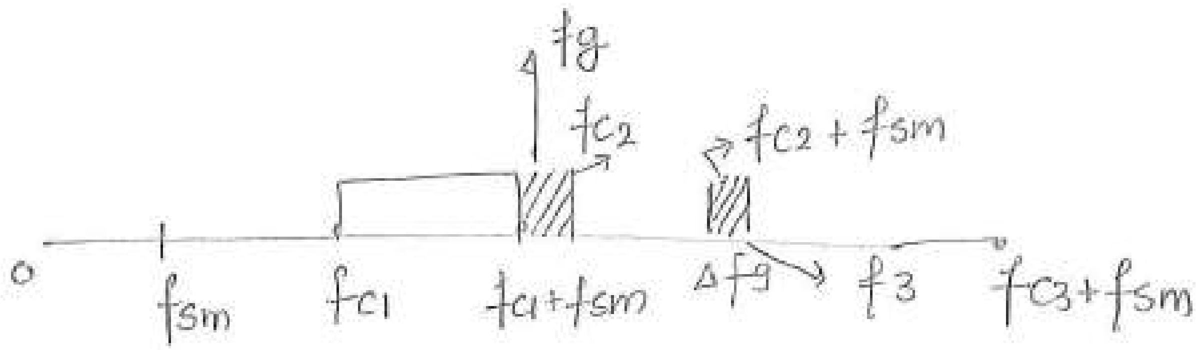
    Eliminating the carrier signal f_c from eqn 2 of the modulation and getting back f_{sm}.

    But BW = $2f_{sm}$.
12. From the upper side band also, we can do demodulation: f_c to $(f_c - f_{sm})$.

    Eliminate the carrier frequency f_c and we get back f_{sm}.

    But BW required = f_{sm} only.

    But some loss of quality.
13. We can do demodulation from the lower side band also with some loss of quality.
14. Therefore, with loss of some quality, instead of transmitting the whole of $m_a(t)$, we can send the upper side band or lower side band and demodulate the receiver end.
15. Assume we always send the upper side band in the FDM system.



Question :

Assume in a FDM system of music transmission

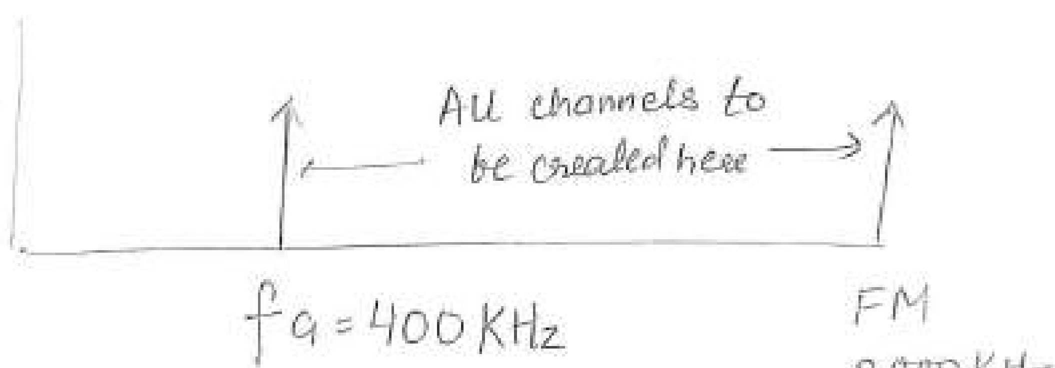
f_{c1} = lowest carrier = 400 kHz

f_{sm} = bandwidth of the music signal = 20 kHz

Guard band = 2 kHz

f_M = highest frequency of the medium = 2 MHz

Calculate how many channels n can be created using FDM?



$$f_M - f_c = n f_{sm} + (n - 1) \Delta f_g$$

where there are n channels and (n - 1) guard bands.

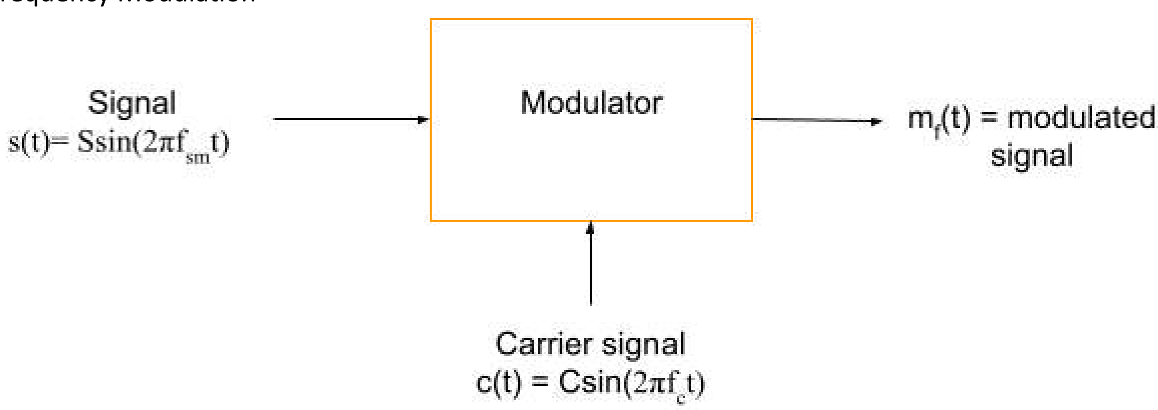
2000 – 400 = 20n + (n - 1)x2

n = 72

⇒ We take the floor value of n (round off the lower integer).

04.09.2020

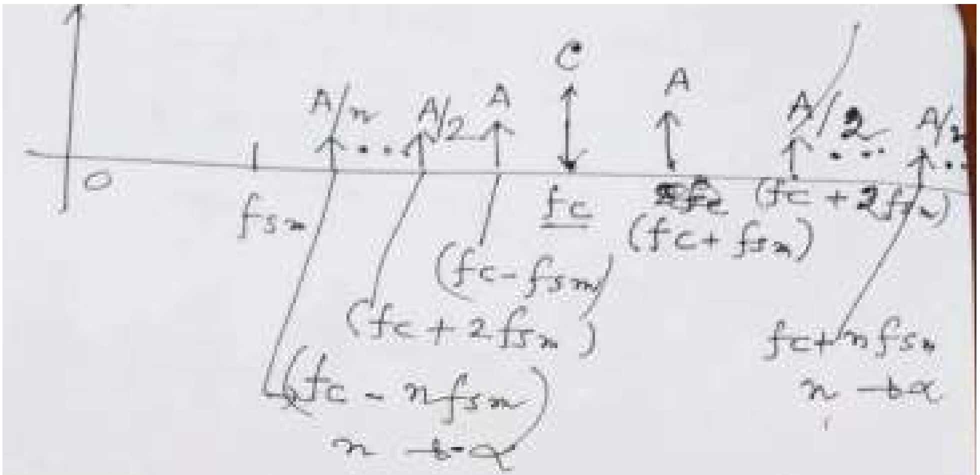
1. Frequency Modulation



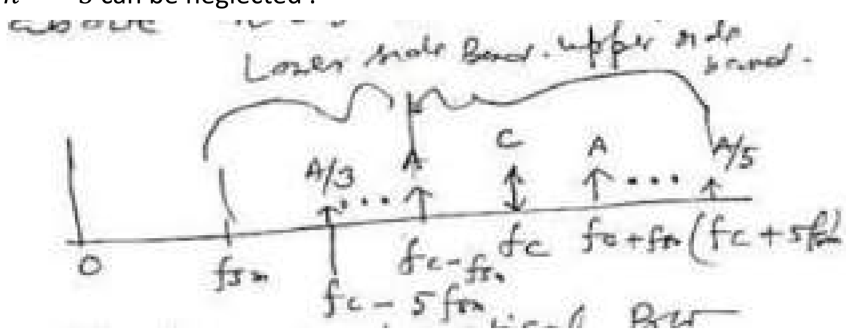
$$m_f(t) = Csin(2\pi(f_c + k_f s(t))t)$$
$$= Csin(2\pi(f_c + k_f Ssin(2\pi f_{sm} t))t)$$

- A sine function within a sine function, so analysis can be done by simple trigonometric process.
- Solution for m(t) in time domain done through very complicated higher engineering mathematics whose result is being presented in the following diagram in frequency domain.

2.

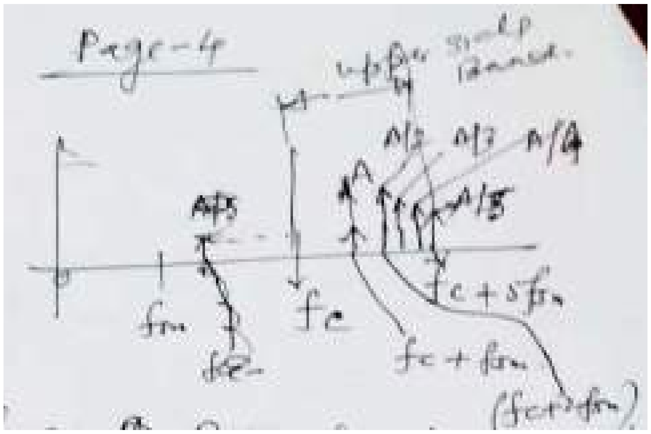


3. A = Amplitude of the first frequency above f_{sm} + f_c (or below)
   Ideal BW of m(t) ⇒ Frequency modulated signal
   $= (f_c + nf_{sm}) - (f_c - nf_{sm})$
   $= 2nf_{sm}$ $[n \rightarrow \infty]$
   $= \infty$
4. But we see as n increases, the amplitude decreases. Inverse as n increases, power decreases inversely as n^2.
5. It has been practically overserved that with n > 5 , the power is so small that frequency above $n = 5$ can be neglected .



   Effective or practical BW
   $BW_e = (f_c + 5f_{sm}) - (f_c - 5f_{sm})$
   $= 10f_{sm}$
6. Now with very insignificant loss of quality either the lower or upper side band can be transmitted , like amplitude modulation.

7. Assume that we shall transmit the upper side band for FDM (Frequency Division Multiplexing) to create many channels.
8.



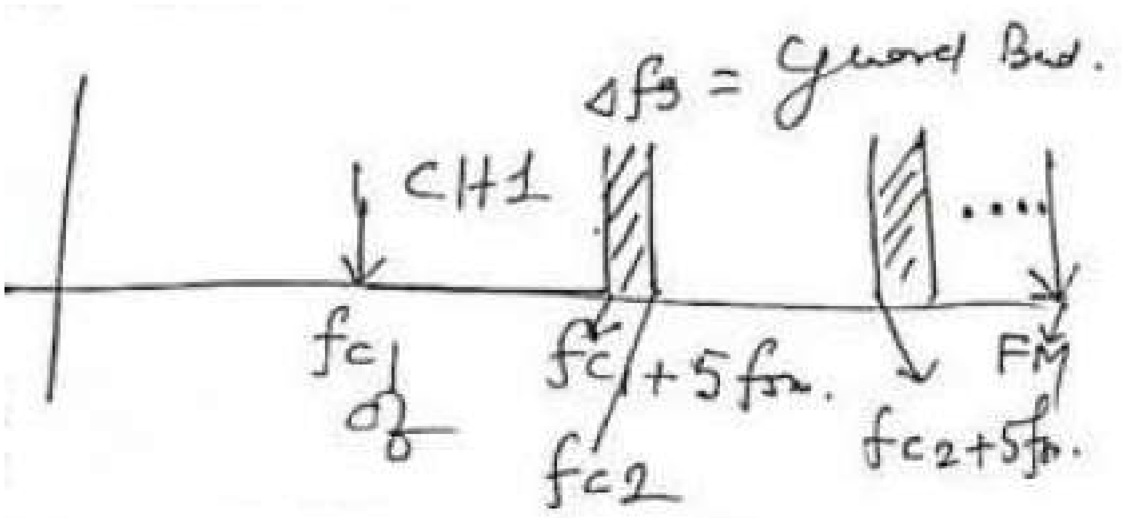
9. Therefore, BW_e for transmission purpose

   $= (f_c + 5f_{sm}) - (f_c)$

   $= 5f_{sm}$
10. For music f_{sm} = 20 kHz. Therefore, the bandwidth of the music channel for FM = 100 kHz.
11. For AM transmission, bandwidth for AM channel = 20 kHz.
12. Then why do we go for FM with 5 times channel Bandwidth?
    Because the total number of channels over a given bandwidth of space will be very lesser.
13. We shall still choose FM music for quality.
    In AM, both signal s(t) and noise signal changes the amplitude of the carrier but frequency of carrier is not changed.
14. After demodulation at receiver noise will come along with the noise signal s(t) which cannot be separated.
15. In FM, the noise will change the amplitude of the carrier but signal s(t) will change the frequency.
16. So after demodulation, the noise can be filtered out from the signal.
17. So, the quality of music signals is very good in FM.
18. The Transmission range of AM music is in medium wave range.
19. Transmission of FM music is from 90 MHz to 108 MHz (in High Frequency or HF range).

PROBLEM : FDM in FM

1. Lowest Carrier = 400 kHz
2. Bandwidth of music signal = 20 kHz
3. Guard band = 2 kHz
4. Highest frequency allocated FM = 2 MHz
5. Upper sideband is used



Let n be the no. of channels.
FM - f_{c1} = n * $5f_m$ + (n-1)Δf_g
Calculate n and take its floor value.

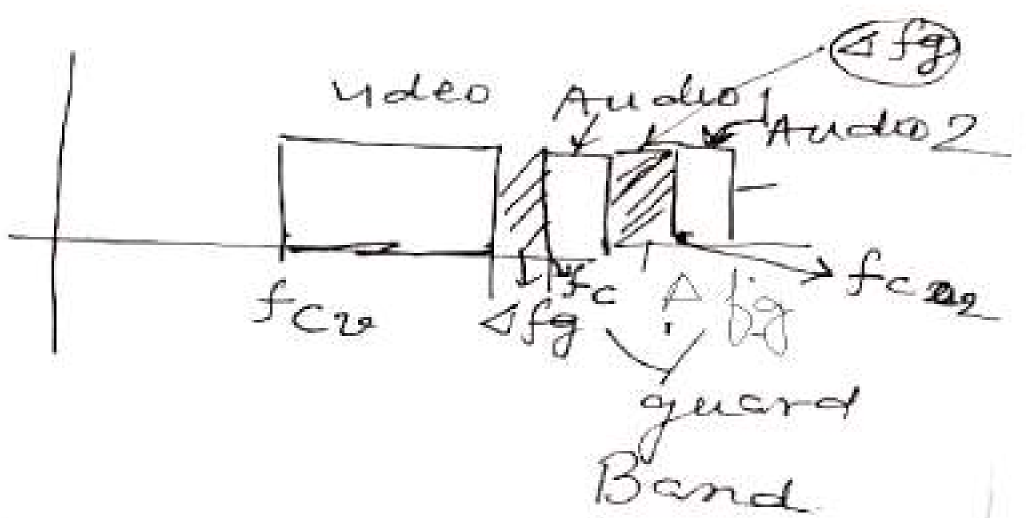
07.09.2020

TV Transmission

1. TV Signal:
   Video: 0 to 5 MHz
   Audio Music: 0 to 20 KHz

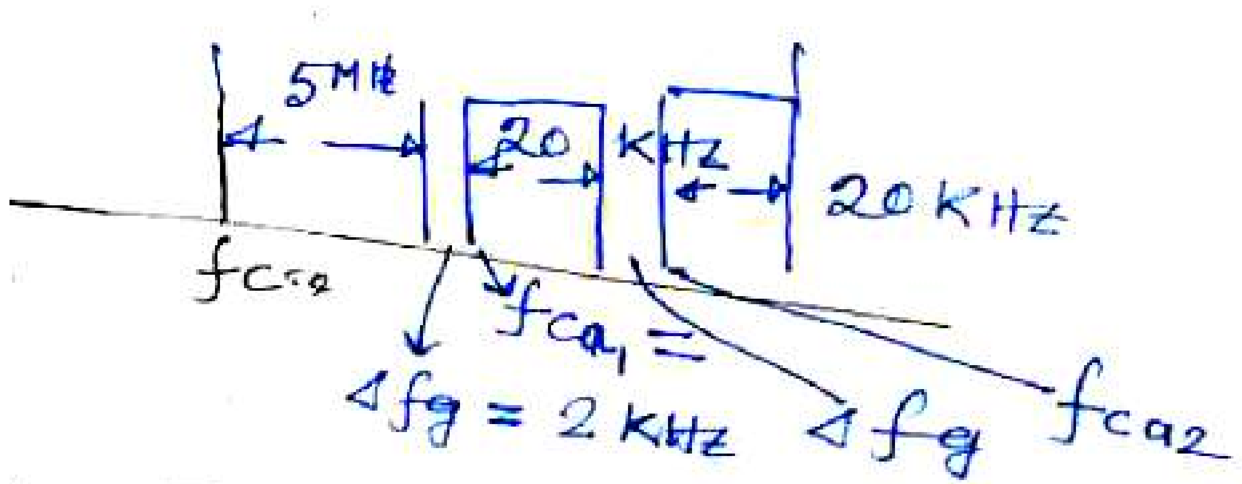
2. TV Music ⇒ Stereo

2 audio channels in the image below



f_{cv} = carrier for video
f_{ca1} = carrier for audio channel 1
f_{ca2} = carrier for audio channel 2

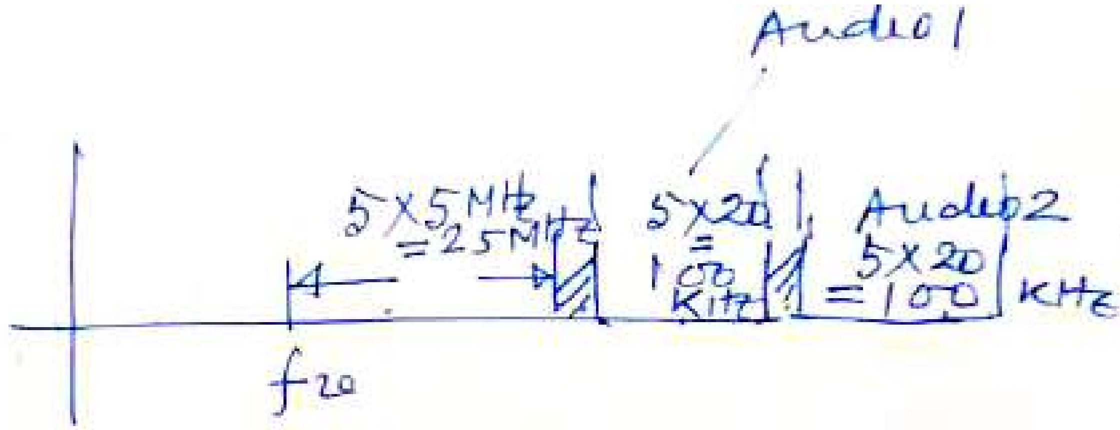
3. Assume both video and audio music Amplitude Modulated:



Neglecting guard band

Total TV bandwidth required	=	5 MHz + 2 * 20 KHz
	=	5.040 MHz

4. Assume all frequency modulated video and audio:

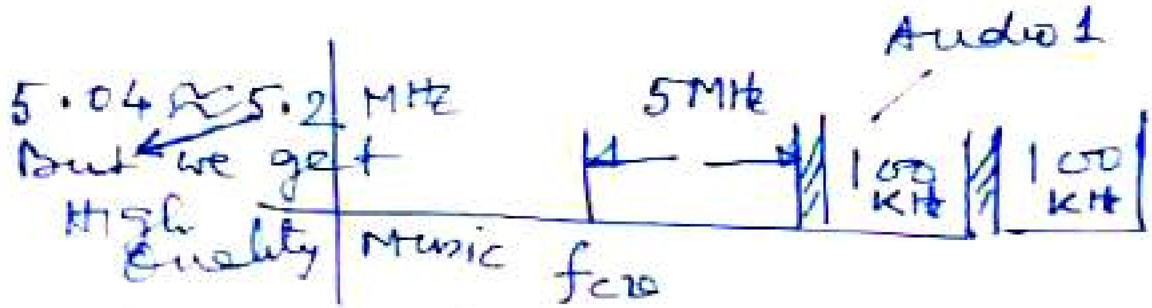


Total bandwidth required = 25 MHz + (100 + 100) KHz

= 25.2 MHz

Because of very high channel bandwidth, video FM is discarded.

5. Video AM and Audio FM:



Total bandwidth = 5 MHz + 200 KHz

= 5.2 MHz

6. From (3) BW_{Total} = 5.04 MHz

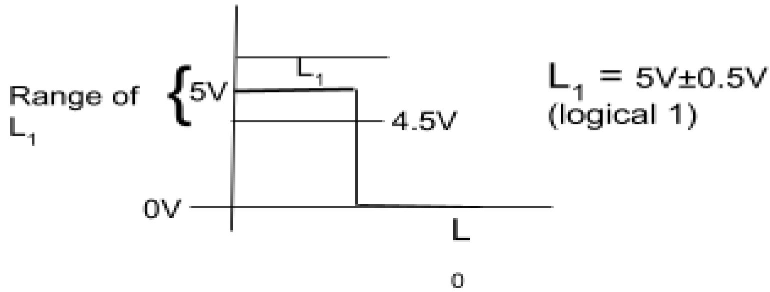
   From (5) BW_{Total} = 5.2 MHz

Analog vs Digital Transmission

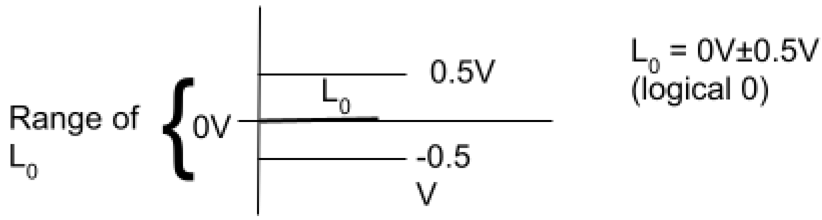
Quality of transmission of digital signals is much better than the analog signal + other benefits. **Why?**

1. Digital signal after some distance of propagation can be regenerated to its original form which the analog signal cannot be.

   a.



b.

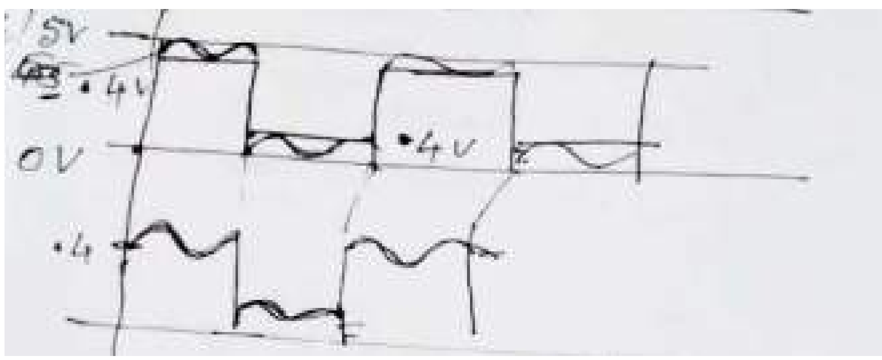


Suppose our transmission sequence is 1010…

L_1 affected by -0.4V noise (negative noise)

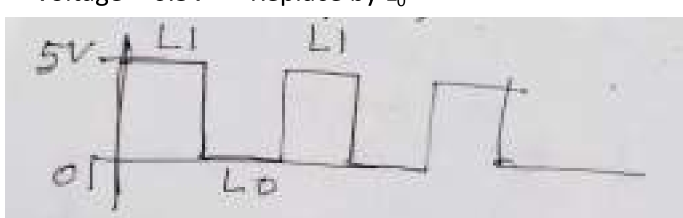
L_0 affected by +0.4V noise (positive noise)

c.



d. At receiver 4.5V ≤ voltage ⇒ Replace by L_1

Voltage ≤ 0.5V ⇒ Replace by L_0



e. Then amplified to compensate for the power loss.

Whole process is the regeneration of digital signals.

$Regeneration = Amplification + Reshaping$

f. If there is a positive noise > 0.5V then 0's will be affected and signal cannot be reshaped.

g. If there is negative noise where mod value > 0.5V then digital 1's will be affected.

h. Above (f) and (g) will cause transmission error which can be taken care of by digital transmission by error coding and retransmission scheme.

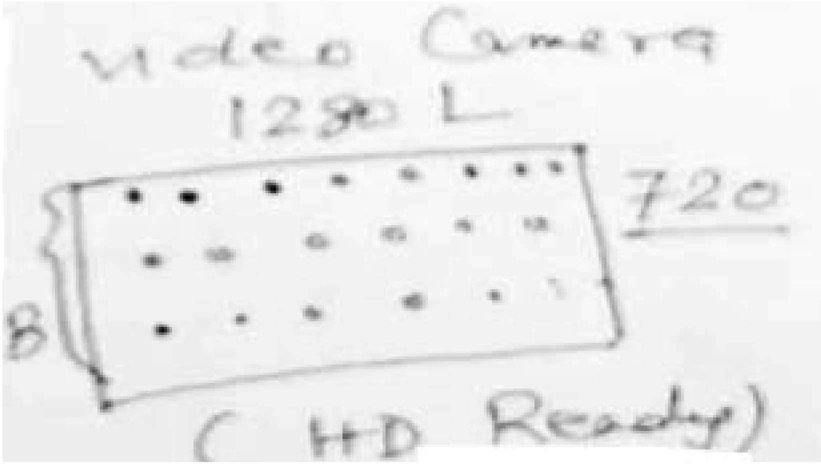
None of the above can be taken care of in analog transmission.

2. Digital data can be stored and processed by digital computer. This cannot be done for analog signal of analog transmission.
3. Due to the above capability (2) of digital computers the following can be done for only digital transmission.
    a. Data can be compressed to save transmission bandwidth.
       For example:
        - Digital music can be compressed using the MP3 algorithm.
        - Digital video can be compressed using MPEG4 compression algorithm.

       These compression algorithms are lossy.
        - Not Suitable for computer data.
            - Banking
            - Student result
        - But suitable for video and music.
    b. Data can be encrypted and decrypted to stop data surveillance by intruders over space.
    c. In case of transmission error:
        i. Error detecting codes (CRC) algorithm can be used to identify if any transmission error has taken place.
        ii. If so, then there can be an error recovery algorithm (like stop and wait, sliding window) protocol algorithm can be executed to take care of transmission error.
        iii. Also error correcting codes can be used but (i) and (ii) is used for computer data communication.

1. Digitization of Voice
    a. If a signal has got maximum frequency f_{sm}, then according to Nyquist criteria or theorem.
       No. of samples per second = $2 * f_{sm}$
    b. Each sample is digitized using n bit/sample.
       So total transmission rate of voice/music = $2 * f_{sm} * n$
    c. For telephonic voice, f_{sm} = 4 kHz
       n = 8 bit
       Data rate for telephonic voice = 4 * 2 * 8 = 64 kbps
    d. For music, f_{sm} = 20 kHz
       n = 16 bit
       Data rate for music for mono music = 20 * 2 * 16 kbps
    e. For stereo music = 2 * Mono channel
    f. Actually music bandwidth = 21.5 kHz (Not 20 kHz)
       Calculate value of 2 * 21.5 * 2 * 16 kbps
       ⇒ Uncompressed Stereo bandwidth music
       ⇒ MP3 compression 144 kbps

2. Video Digitization: Digital Video Camera



a. HD TV Resolution : 1280 x 720 pixel
b. Today aspect ratio = (B/L) = $(3/4)^2$ = 9/16
c. Earlier aspect ratio = ¾
d. One Screen = One Frame = 1280 x 720 pixel
   Each pixel:
   - R ⇒ 8 bit
   - G ⇒ 8 bit
   - B ⇒ 8 bit
e. One TV frame = 1280 * 720 * 24 bit
f. To bring continuity of motion picture 50 frames/second
g. Total data rate after Digitization = 1280 * 720 * 24 * 50
h. Compressed by MPEG4 (MP4) = 2 to 6 Mbps (variable bit rate)
i. Example:
   - Classroom video = 2 Mbps
   - Horse race or mountain range = 6 Mbps

Conclusion:

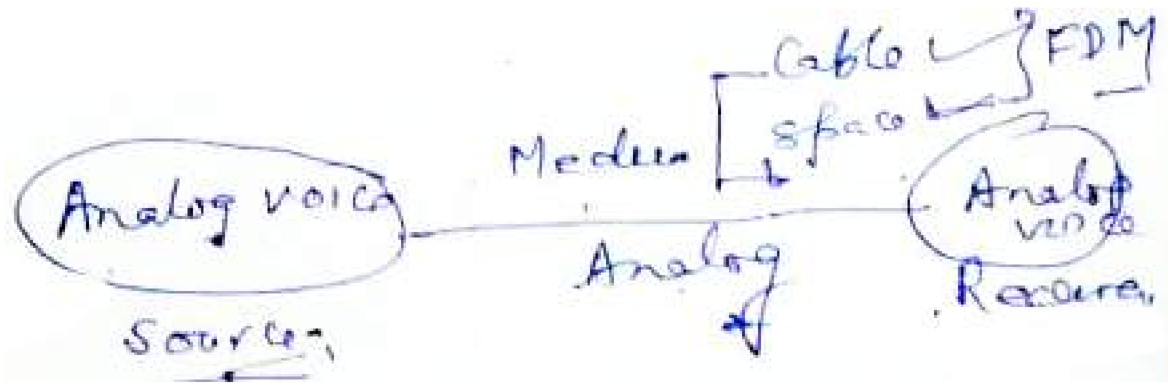
Due to lot of advantages of digital transmission today

1. Computer data ⇒ originally digital
2. Telephonic voice ⇒ Digitized at 64kpbs
3. MP3 music ⇒ digitized compressed
4. MPEG4 video ⇒ digitized compressed

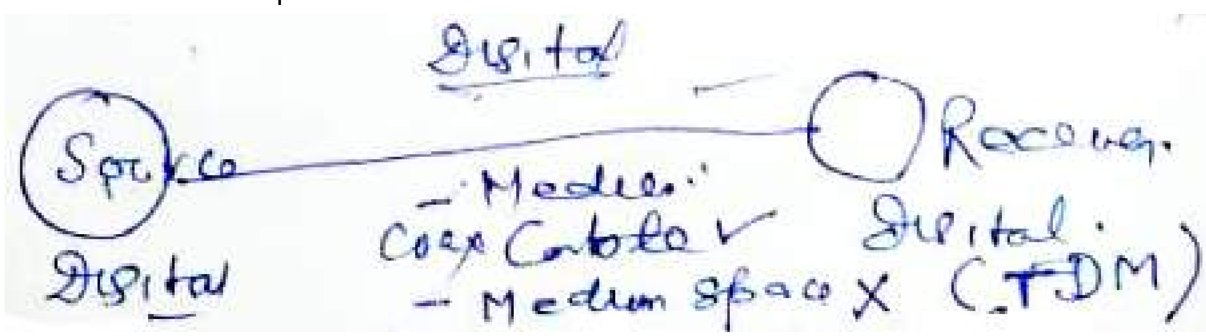
08.09.2020

Distinction between Digital/Analog Transmission and Digital/Analog Communication

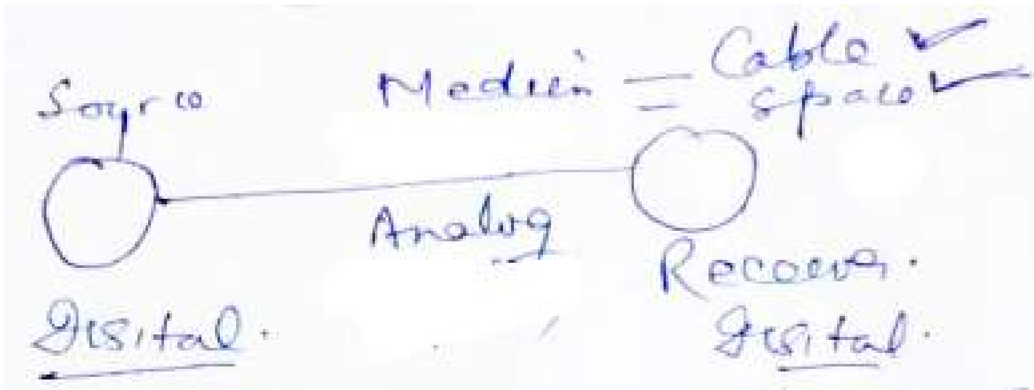
1. Transmission is w.r.t media.
2. Communication is w.r.t end to end basis.
3. Transmission of multiple sources FDM



    a. Communication is analog.
    b. Transmission is analog.
    c. Example of transmission of analog music/TV in space.
4. Transmission of multiple sources TDM



    a. Communication is digital.
    b. Transmission is digital.
    c. Fully digital.
    d. Example of digital transmission over cable.
    e. Enjoys all benefits of digital communication.
5. Multiple source digital transmission FDM

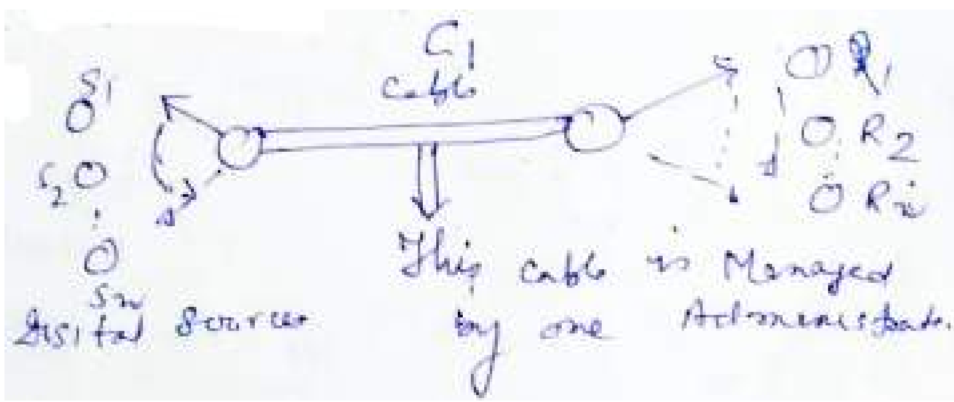


a. Communication is digital.
b. Transmission is analog.
c. Enjoys all benefits of digital communication except digital regeneration.

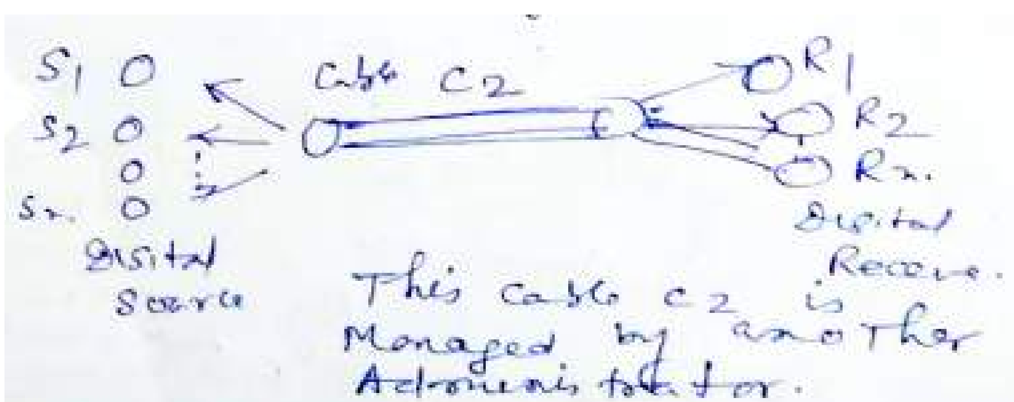
Thus, (5) shall be the focus of our learning for digital communication/analog transmission over space.

For digital communication over space, why is TDM not possible?

1. Cable TDM ⇒ possible
   a.

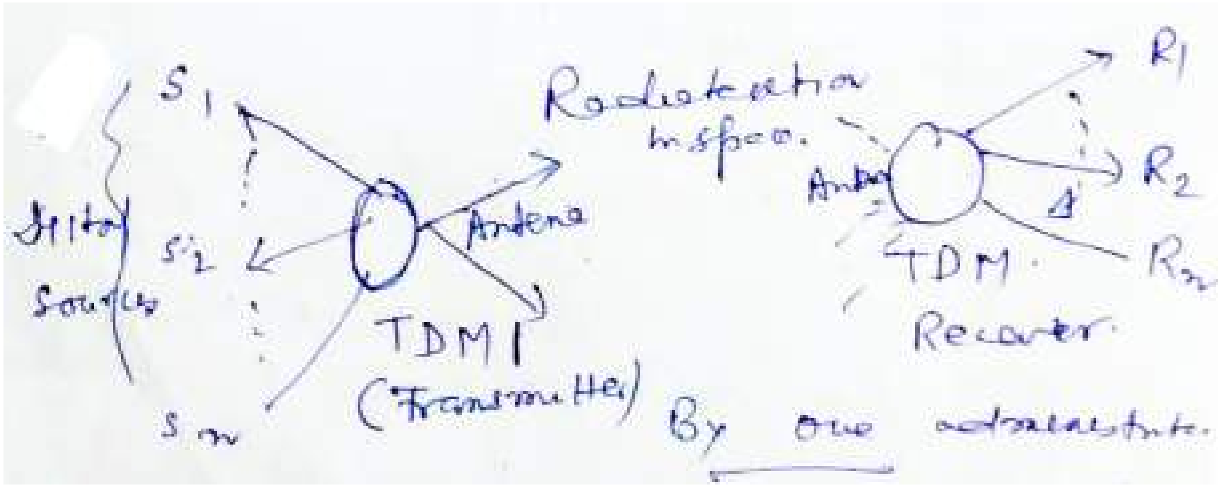


   b.

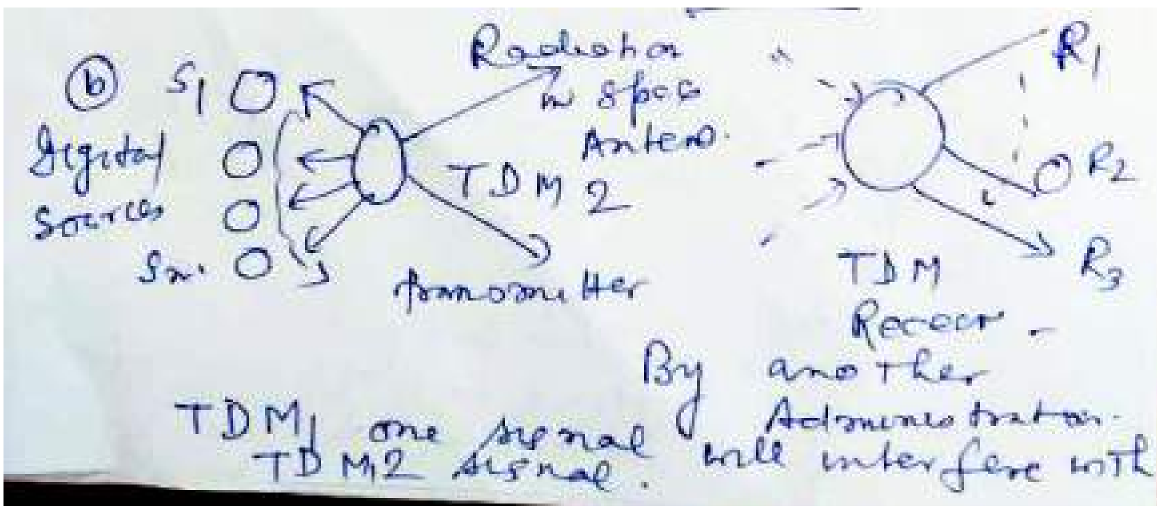


   c. No radiation from cabe C_1 to C_2 or vice versa. Even they are kept at short distances.

2. Space TDM (transmission of multiple digital sources using Time Division Multiplexing).
    a. .



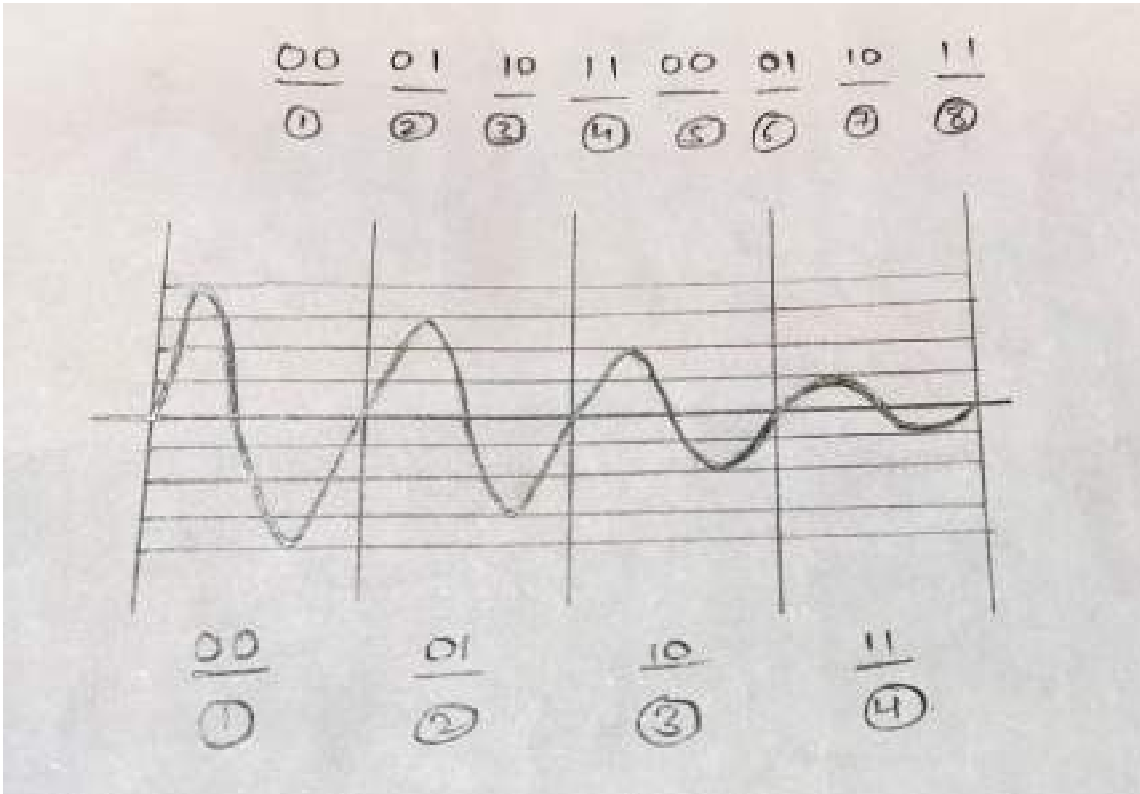
    b.



11.09.2020

16.09.2020

1. **MULTI-LEVEL ASK**
    a. Now suppose our date is :



    b. Here the bandwidth (BW) of the channel shall be :-
        BW = Baud rate
    as baud rate change is a dominant factor.
    c. Suppose if bandwidth (BW) allocated = x
    So baud rate = x
    Digital bit rate = x * log2(4) = x*2 = 2x
    d. If V = number of amplitude levels
    Then digital bit rate = baud Rate * log2(V)
    Where baud rate = BW
    e. Now as long as the bandwidth of the channel is fixed , baud rate is fixed.
    So digital bit rate ∝ log2 (number of levels created)
    f.
        i. Now suppose the power rating of modulator = P(fixed)
        ii. P ∝ C^2 **=>** P = KC^2
        where, k is prop contant
        C is amplitude of carrier
        So C = (P/K)^½

iii. Suppose we create V number of amplitude levels
ΔV (Difference between successive amplitude levels) = C/V

iv. As V increases, **ΔV** decreases

v. If **ΔV** is too small then it may be corrupted by noise.

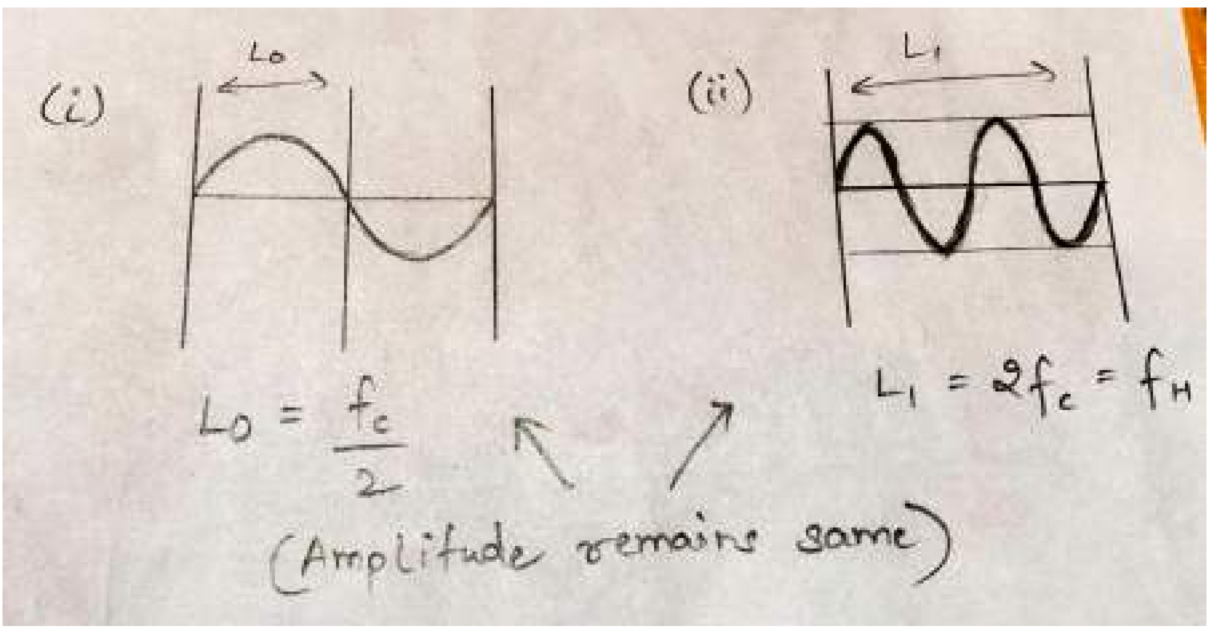
vi. **ΔV ∝ N/S**

vii. **V ∝ S/N** where S is signal value, N is noise value
So we have a maximum value V = number of levels depending on the noise environment.
Less Noise => More S/N value => More V => More digital bit rate

viii. So we cannot increase V beyond Limit

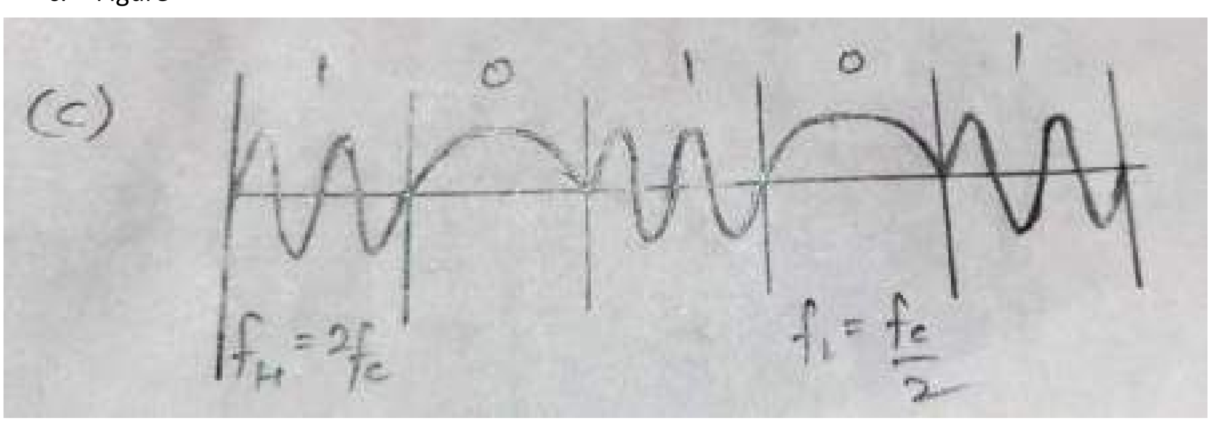
2. FREQUENCY SHIFT KEYING (FSK)

a. 2 level FSK

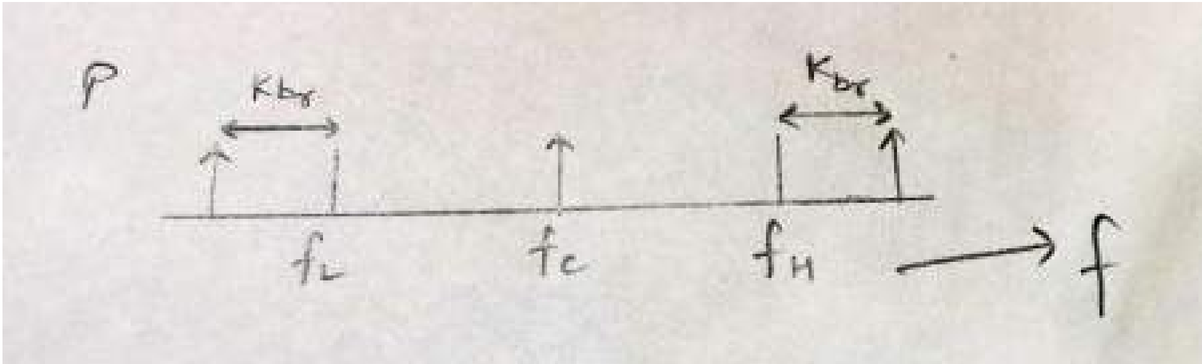


b. Data = 101010…....

c. Figure



d. Bandwidth of the channel (BW) = (fH + kf * br) - (fL + kf * br)



BW = (fH - fL) + 2 * kf * br
Assume kf is ½, then :-
BW = (fH - fL) + br
So now,
Br(FSK) = BW - (fH - fL) < Br(ASK)

FSK IS NOT USED IN DIGITAL MODULATION.

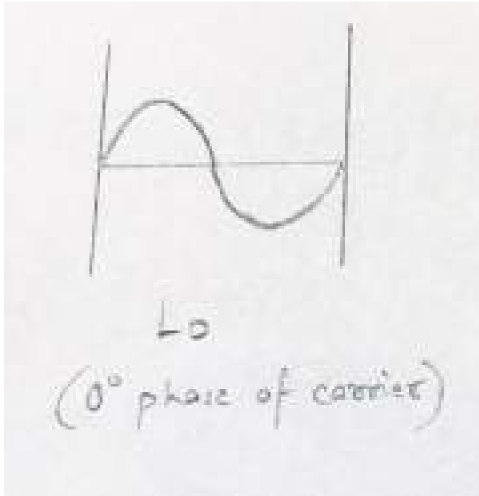
3. PHASE SHIFT KEYING (PSK) -

a. 2 level PSK
fc(t) = C * sin(2π fct + ϕc)
where c and fc are constant
Φc is phase of the carrier

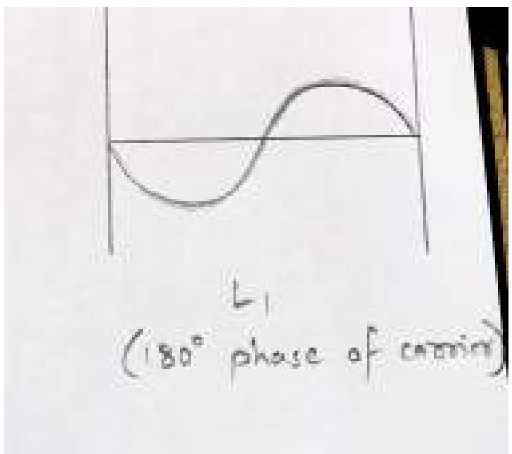
i. Phase corresponding to L0 = Φc + kp * 0
= Φc
= 0°

ii. Phase corresponding to L1 = Φc + kp * 5
= 0 + 180
= 180°

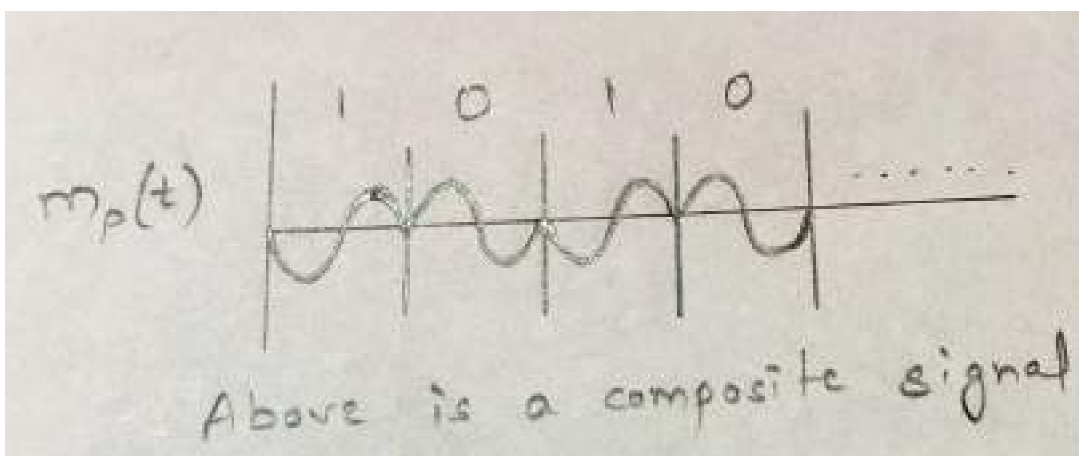
iii. Signaling element for L0



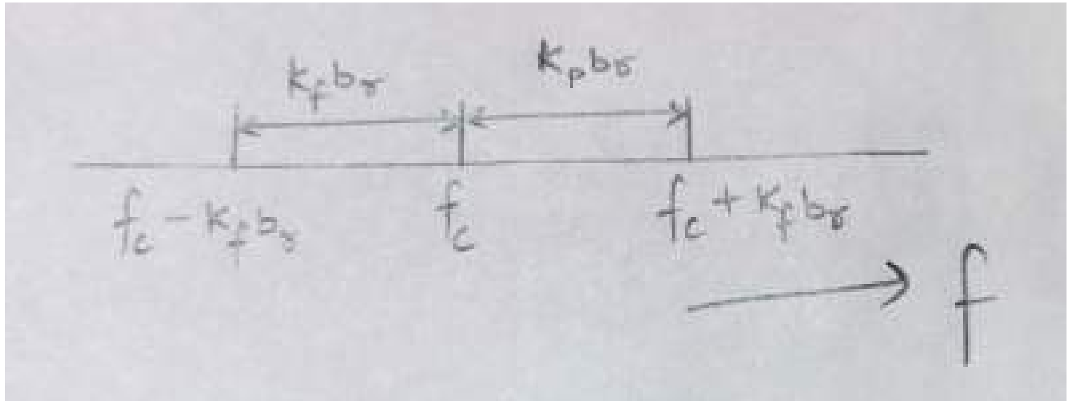
iv. Signaling element for L1



v. 10101010…… transmitted



vi. BW of the channel :-

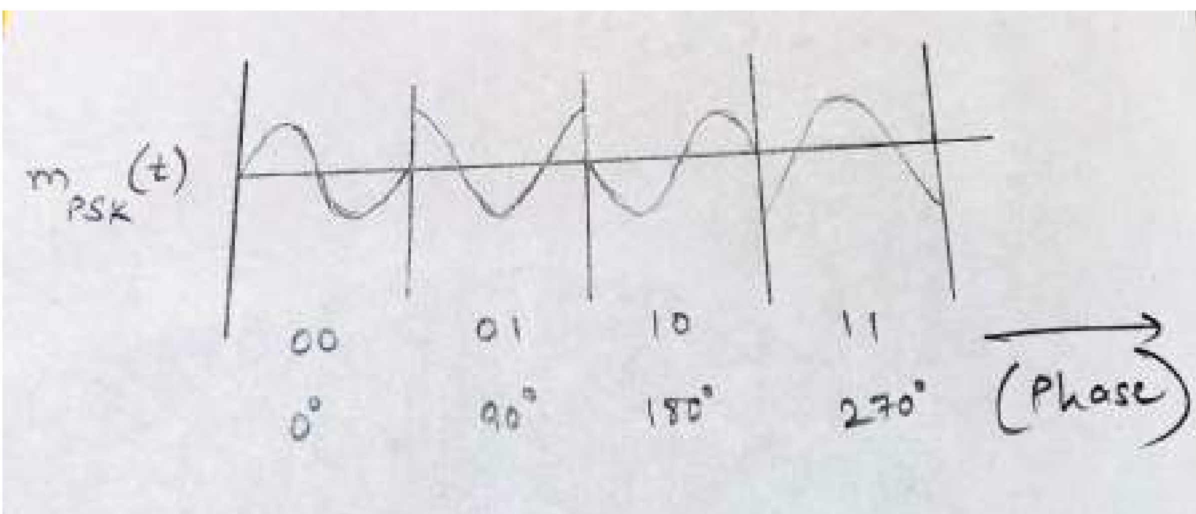


BW(PSK) = (fc + kp * br) - (fc - kp * br)
= 2 * kp * br
= br (As kp = ½) (like ASK)

vii. Digital data rate :- br * log2(2)
= br

viii. Multilevel PSK (4 levels) -
Four phases say :- **0° => 00**
90° => 01
180° => 10
270° => 11

Suppose we are required to send the bit stream 0001101100….



ix. Bandwidth of the channel will be the same as 2 level PSK as it primarily depends on baud rate (effect of phase change for 4 level and for 4-PSK and effect of phase change for 2-PSK is negligible).

x. Digital data rate = br * log2V

= BW * log2V

Where V is the number of phase levels

xi. Limit of V :-

Since noise doesn't effect phase V(PSK) can be much than V(ASK)

2 PSK => V = 2

4 PSK => V = 4

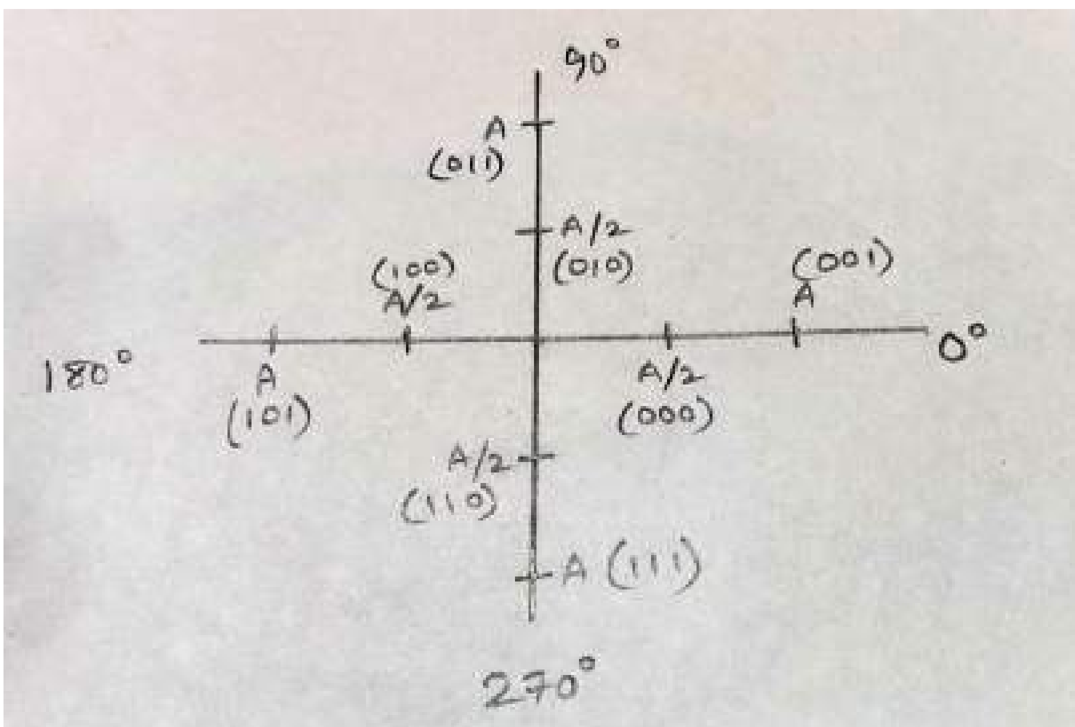
8 PSK => V = 8

.

.

.

4. **QAM -**
   a. In QAM we combine ASK and PSK to make QAM (Quadrature Amplitude Modulation)
   b. Suppose Maximum Amplitude level for ASK for a particular noise environment = VA = 4
   c. Maximum phase level (depends on the phase detector of DeModulator) = VP = 8
   d. V = VA * VP = 4 * 8 = 32, will create 32 - QAM
   e. Assume VA = 2 (A/2), VP = 4 (P1, P2, P3, P4)
      Constellation Pattern = (0, 90, 180, 270)
      Each point is denoted by (A, P) ordered pair :
      (A/2 , P1) (A, P1)
      (A/2 , P2) (A, P2)
      (A/2 , P3) (A, P3)
      (A/2 , P4) (A, P4)



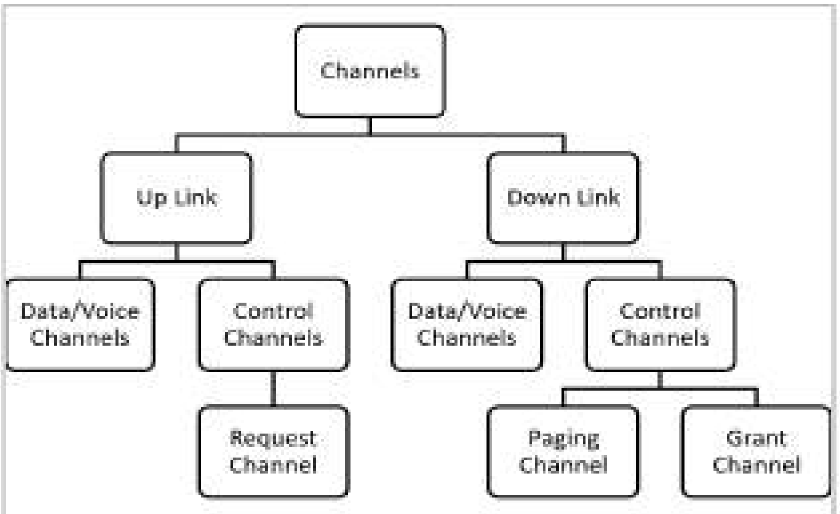
Now 3 bits can be transmitted by one element

f. Data Rate (QAM) = Br * log2(VA * VP)

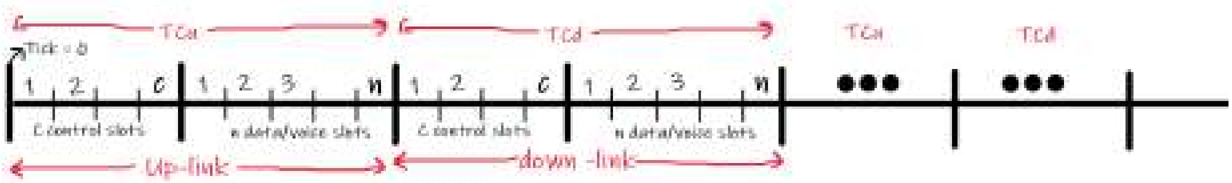
[23.09.2020, 06.10.2020, 07.10.2020] → Notes

09.10.2020

1.



2. **Control Channel Creation**

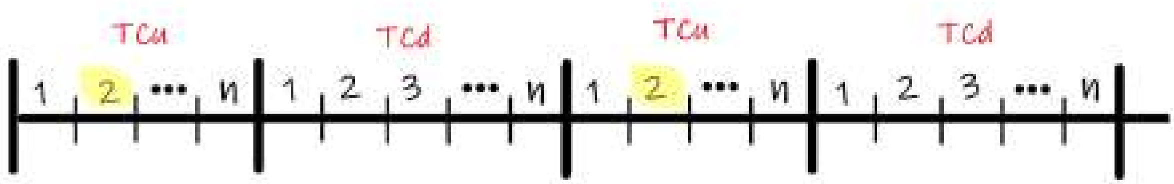


3. **Problem:**

Total B. Wt = 4 MHz

Modulation = 4-QAM

Data rate of each channel = 10 kbps



- Consider 2nd Up-link channel
- Now only one ΔT slot out of 2n slots *(2n = total up-link + down-link slots or channels)*
    - In FDMA/FDD, one slot of ΔT slot out of n slots

o BW of transmission in each slot, $BWu = \frac{BWt}{2}$

Now, the bandwidth of transmission in each slot :

$$BWt = 2BWu$$

a. Total $BWt = 4Mhz$ *(Up-link + Down-link)*

b. Total Baud rate, $brt = 4\times10^{6}$ band/sec

c. Modulation 4-QAM, $V = 4$

d. Total digital data rate (up-link + down-link)

$$drt = 4\times2$$

$$= 8\times10^{6} \text{ bps}$$

e. Average data rate of each channel $= \frac{8\times10^{6}}{2n}$

(As each slot is getting only 1 channel/slot out of 2n slots)

f.

⇨ $\frac{8\times10^{6}}{2n} = 10\times10^{3}$

⇨ $n = \frac{8\times10^{6}}{2\times10^{4}}$

$= 400$ *(Same as FDMA/FDD)*