UNIT III

CELL COVERAGE FOR SIGNAL AND TRAFFIC

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CELL COVERAGE FOR SIGNAL AND TRAFFIC (5.1)

INTRODUCTION

- Cell coverage can be based on signal coverage or on traffic coverage.
- The service area will be occuring in one of the following environments

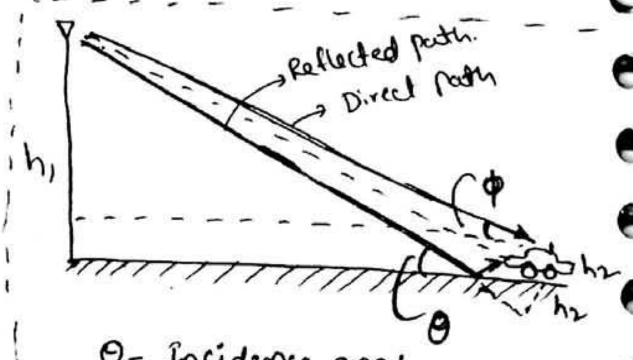
Human-made structures	Natural terrions
i) In an open area	i) Over flat terrians
ii) In an suburban area	ii) Over hilly terrians
iii) In an urban area.	iii) Over water
	iv) Through foliage areas.

- Signal coverage can be predicted by coverage prediction models.
- The results generated from the prediction model will differ depending on which service area is used.
- The model being introduced here is the point-to-point prediction model which would provide a standard deviation from the predicted value of less than 3dB.

FLAT TERRAIN & HILLY TERRAIN STRUCTURES

i) Ground incident angle & ground elevation angle. (FLAT TERRAIN)

- The ground incident angle 'θ' is the angle of wave arrival incidently pointing to the ground.
- The ground elevation angle 'φ' is the angle of wave arrival at the mobile unit
- Consider a flat terrian over which the mobile is moving at a distance 'd' from the antenna

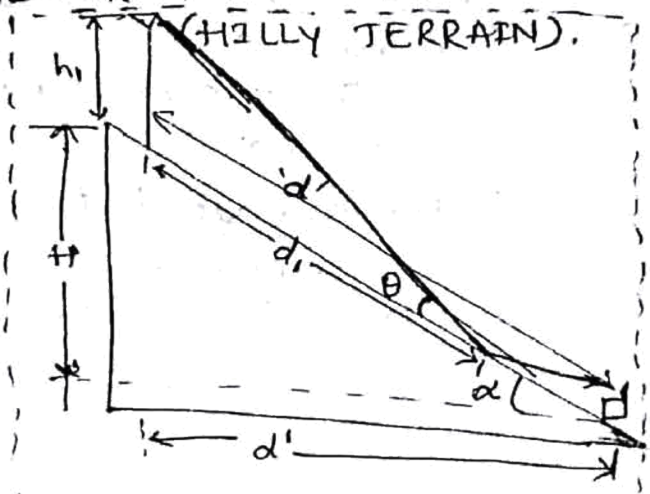


θ - Incidence angle
φ - elevation angle.
Fig: Coordinate sketch in a flat terrain.

- The signal travels from the antenna and two rays are considered here. (i) Direct path (ii) Reflected path.

2) GROUND REFLECTION ANGLE AND REFLECTION POINT (HILLY TERRAIN).

- Based on Snell's law, the Reflection angle & incident angle are the same.
- As long as the ~~Aa~~ Actual hilly slope is less than 10°, the reflection point on a hilly slope can be obtained by following the same method as if the reflection point were on flat ground.



A coordinate sketch in a hilly terrain.

- The two antennas (Base & mobile) have been placed vertically, not perpendicular to the sloped ground. The reason is that the actual slope of the hill is usually very small & the vertical stands for two antennas are correct.

Obtaining the Mobile Point-to-Point Model (Lee model)

- This mobile point-to point model is obtained in three steps
  (i) generate a standard condition
  (ii) obtain an area-to-area prediction model
  (iii) obtain a mobile point-to-point model using the area-to-area model as a base.

- This model is developed to separate two effects, one caused by the natural terrain contour & the other by the human-made structures, in the received signal strength.

A standard condition.

- To generate a standard condition & provide correction factors,
- The advantage of using these standard value is to obtain directly a predicted value in decibels above 1mW expressed in dBm.

Generating a standard conditions

Standard condition	Correction factors
At the Base Station	
Transmitted Power $P_t = 10W$ (40dBm)	$\alpha_1 = 10 \log \frac{P_t'}{10}$
Antenna height $h_1 = 100ft$ (30m)	$\alpha_2 = 20 \log \frac{h_1'}{h_1}$
Antenna gain $g_t = 6dB$/dipole	$\alpha_3 = g_{t_1}' - 6$
At the mobile Unit	
Antenna height $h_2 = 10ft$ (3m)	$\alpha_4 = 10 \log \frac{h_2'}{h_2}$
Antenna gain $g_m = 0dB$/dipole	$\alpha_5 = g_m'$

Obtaining area-to-area prediction curves for human-made structures

- The area-to-area prediction curves are different in different areas.
- All the areas are considered as flat even though non-flat areas. The reason is that area-to area prediction is an average process.
- The standard deviation of the average value indicates the degree of terrain roughness.

Effect of the human-made structures

- Since the terrain configuration of each city is different, and the human-made structure of each city is also unique, we have to find a way to seperate these two.
- The way to factor out the effect due to the terrain configuration from the manmade structures is to work out a way to obtain the path loss curve for the area as if the area were flat, even if it is not.
- The path-loss curve obtained on virtually flat ground indicates the effects of the signal loss due to solely human-made structures.
- Then the average path loss slope, which is a combination of measurements from high spots and low spots along different radio paths in a general area, represents the signal received as if it is from a flat area affected only by a different local human-made structured environment.

- 1 mi intercepts (or 1-km intercepts) as a starting point for obtaining the path loss curves.

- The difference in area-to-area prediction curves are due to the different man-made structures.

- Any area-to-area prediction model can be used as a first step toward achieving the point-to-point prediction model.

- One area-to-area prediction model which is introduced here can be represented by two parameters

(i) The 1-mi (or 1km) intercept point

(ii) The path-loss slope.

- The 1-mi intercept point is the power received at a distance of 1-mi from the transmitter.

- There are two general approaches to finding the values of the two parameters experimentally.

(i) Compare an area of interest with an area of similar human-made structures which presents a curve.

(ii) Setup a transmitting antenna at the center of a general area, the antenna location is not critical.

- Take six or seven measured data points around the 1-mi intercept and around the 10-mi boundary based on the high & low spots.

- Then compute the average of the 1 mi data points & of the 10-mi data points.

- By connecting the two values, the path-loss slope can be obtained.

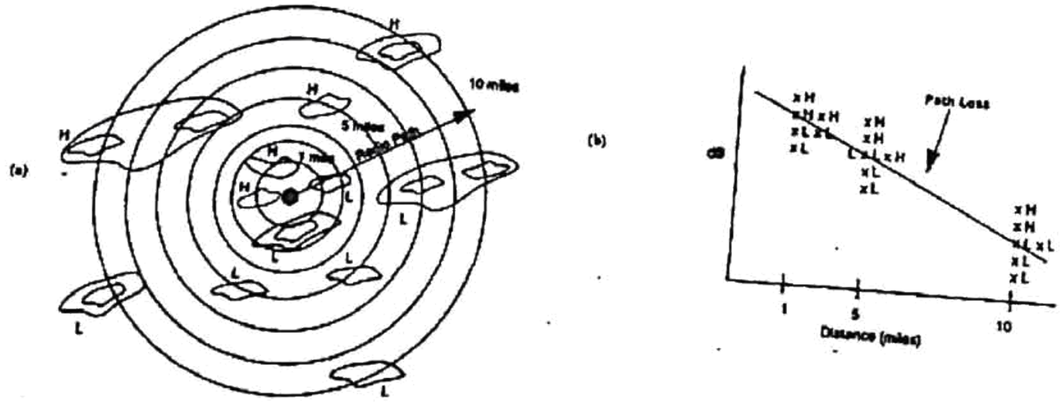
- If the area is very hilly, then the data points measured at a given distance from the base station in different locations can be far apart. In this case, we may take more measured data points to obtain the average path loss-slope.

- If the terrion of the hilly area is generally sloped, then we have to convert the data points that were measured on the sloped terrain to a fictitiously flat terrain in that area. The conversion is based on the effective antenna-height gain as

$$\Delta G = \text{effective antenna-height gain} = 20 \log \frac{h_e}{h_1}$$

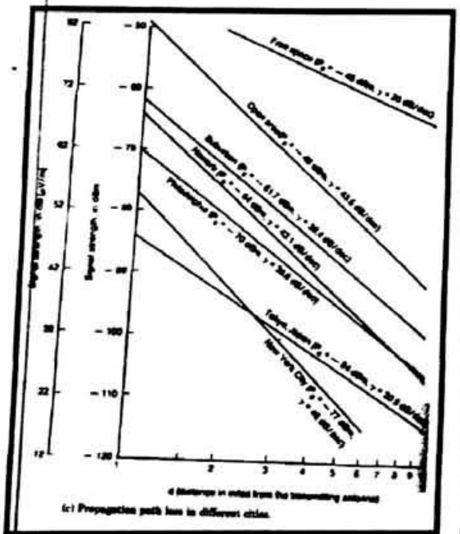
where h_1 is the actual height & h_e is the effective antenna height at either 1- or 10-mi locations.

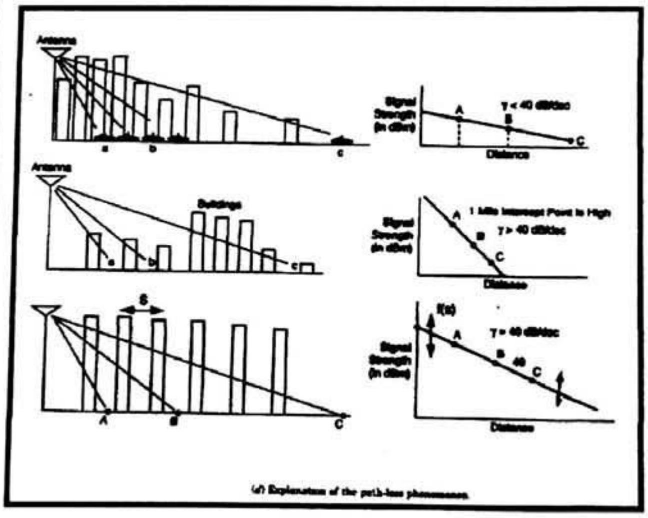
(iii) An explaination of the path loss phenomenon, the plotted curves have different 1-mi intercepts & diff. slopes.



Propagation path loss curves for human made structures
a)For selecting measurement areas b) path loss phenomenon

- when the base station antenna is located in the city then the 1-mi intercept could be very low & the slope is ~~deeper~~ flattened out
- when the base station is located outside the city, the intercept could be much higher and the slope is deeper
- when the structures are uniformly distributed, depending on the density S, the 1-mi intercept could be high or low but the slope may also keep at 40dB/dec.

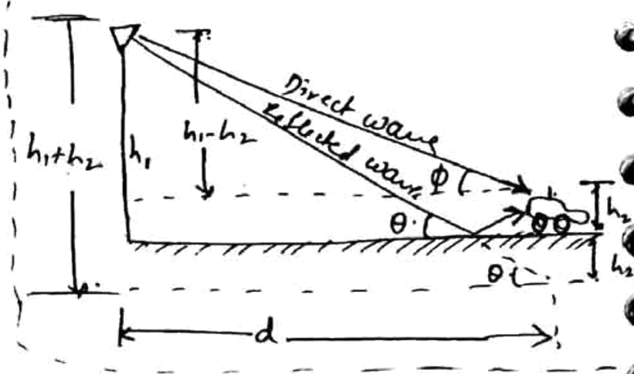

(c) Propagation path loss in different cities



(d) Explanation of the path-loss phenomenon

THE PHASE DIFFERENCE BETWEEN A DIRECT PATH & A GROUND REFLECTED PATH.

- Based on direct path & ground Reflected path.



$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 + a_v e^{j\Delta\phi}\right|^2$$

where a_v = the Reflection coefficient

$\Delta\phi$ = The phase difference b/w direct path & Reflected path.

P_0 = the transmitted power

d = the distance

λ = the wavelength.

- In a mobile environment $a_v = -1$ because of the small incident angle of the ground wave caused by a relatively low cell-site antenna height.

Thus,

$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 - \cos\Delta\phi - j\sin\Delta\phi\right|^2$$

$$= P_0 \frac{2}{(4\pi d/\lambda)^2}(1 - \cos\Delta\phi) = P_0 \frac{4}{(4\pi d/\lambda)^2} \sin^2\frac{\Delta\phi}{2}$$

where $\Delta\phi = \beta\Delta d$

and Δd is the difference $\Delta d = d_1 - d_2$

$$d_1 = \sqrt{(h_1+h_2)^2 + d^2}$$

$$d_2 = \sqrt{(h_1+h_2)^2 + d^2}$$

$\because$ Δd is much smaller than either d_1 or d_2.

$$\Delta\phi = \beta\Delta d \simeq \frac{2\pi}{\lambda}\frac{2h_1h_2}{d}$$

- Then the received Power becomes $P_r = P_0 \frac{\lambda^2}{(4\pi)^2 d^2} \sin^2 \frac{4\pi h_1 h_2}{\lambda d}$.

If $\Delta\phi$ is less than 0.6 rad, then $\sin(\Delta\phi/2) \approx \Delta\phi/2$
$\cos(\Delta\phi/2) \approx 1$

Simplifies to.

$$P_r = P_0 \frac{4}{16\pi^2 (d/\lambda)^2} \left(\frac{2\pi h_1 h_2}{\lambda d}\right)^2 = P_0 \left(\frac{h_1 h_2}{d^2}\right)^2$$

- we can deduce two relationships as follows

$$\Delta P = 40 \log \frac{d_1}{d_2} \quad \text{(a 40dB/dec path loss)}$$

$$\Delta G = 20 \log \frac{h_1'}{h_1} \quad \text{(an antenna height gain of 6dB/oct)}$$

- ΔP is Power difference in decibels between two different path lengths
- ΔG is gain (or loss) in decibels obtained from two different antenna heights at the cell site.

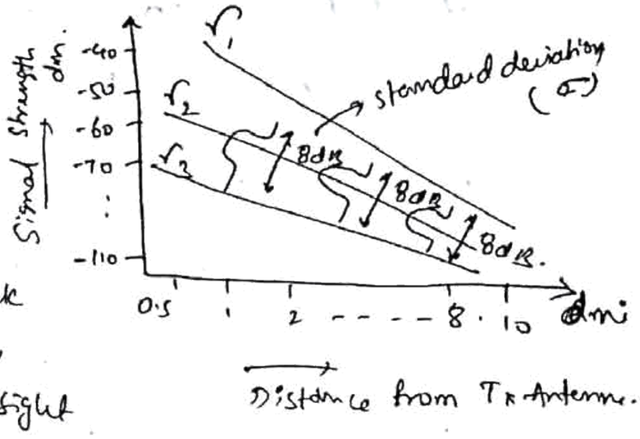
$$\Delta G' = 10 \log \frac{h_2'}{h_2} \quad \text{(an antenna height gain of 3dB/oct)}$$

Constant Standard Deviation

- when plotting signal strengths at any given radio-path distances, the deviation from Predicted values is approximately 8dB. This standard deviation of 8dB is roughly true in many different areas.
- The direct wave and the reflected wave are very strong if there is a line-of-sight path and two waves are weak if there is a out-of-sight path.
As considered to theoretical mode 40dB/dec path loss for both the cases.

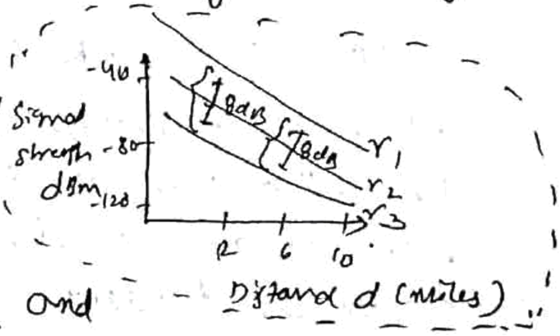
- The only difference between the two is the 1-mi intercept point.
→ The 1-mi intercept has different values for urban, and ~~open~~ open area, the value is high for open area & low for urban area.
- The standard deviation on the other hand is independent of environment and it remains same for different path loss curves

- The standard deviation from measured data along the prediction path is 8dB.
- It remains constant at 8dB, independent of signal strength
- The signal strength is low, weak and strong for out-of-sight, partial line-of-sight & line-of-sight respectively.



STRAIGHT-LINE PATH-LOSS SLOPE

- The path loss curves are measured in different areas. The complexity in measurement of path loss will depend upon the uniformity in distance between mobile unit & the base station.
- If the distance of the radio propagation paths from cell sites and the mobile are same then the measured signal strength for that distance can be applied for calculating the average value for path loss.
- The path loss deviation is 8dB in a terrain contour that is not flat is observed for a distance range from 1.6 to 15km (1 to 10 mi)
- These curves are named $\gamma_1, \gamma_2, \gamma_3$ and a uniform 8dB deviation is measured.



- The power received P_R is given as $P_R = P_0 - \gamma \log \frac{r}{r_0}$.

γ - path loss curves
$\gamma = 20$ - It is free space path loss
$\gamma = 40$ → It is mobile path loss.

- A confidence level can only be applied to the path loss curve when the standard deviation σ is known.
- The values at any given distance over the radio path are concentrated close to the mean and have a bell-shaped (normal) distribution.
- The probability that 50 percent of the measured data are equal to or below a given level is

$$P(x \geq c) = \int_{c}^{\infty} \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-A)^2/2\sigma^2} dx = 50\%$$

where 'A' is the mean level obtained along the path-loss slope

$$A = P_0 - \gamma \log \frac{r_1}{r_0}$$

- Thus level A corresponds to the distance r_1. If level 'A' increases, the confidence level decreases.

$$P(x \geq C) = P\left(\frac{x-A}{\sigma} \geq B\right)$$

- Let $C = B\sigma + A$,

For probability $P(x \leq C)$, 80% $C = A + (-0.85\sigma)$

For probability $P(x \leq C)$, 70% $C = A + (-0.55\sigma)$

$x \rightarrow$ measured data
$C \rightarrow$ confidence level.

GENERAL FORMULA FOR MOBILE RADIO PROPAGATION OVER THE WATER OR FLAT AREA

- First let us consider the general formula for mobile radio propagation path loss in an area say a suburban area.
- It has an one meter intercept in a suburban area is -61.7 as per the standard conditions shown below

standard condition

(i) At mobile unit

- Antenna height (h_1) = 10 feet [3mts]
- Antenna gain (g_m) = 0 dB/dipole antenna.

(ii) At the Base Station

- Transmitter power (P_t) = 10W [40dBm]
- Antenna height (h_2) = 100 feet [30mt]
- Antenna gain (g_t) = 6 dB/dipole Antenna.

- Consider the equations from the theoretical prediction model of gain and the equations from measured data;

Power difference between path lengths

$$\Delta P = 40 \log \left(\frac{d_1}{d_2}\right) \text{ (40 dB/dec)}$$

The gain/loss in dB measured from two Antennas at the cell site

$$\Delta G = 20 \log \left(\frac{h_2'}{h_2}\right)$$ an antenna height gain in 6dB/octet

- The Received power $P_r = P_0 - \gamma \log\left(\frac{r}{r_0}\right)$
- In a Suburban area

$$P_r = (P_t - 40) - 61.7 - 38.4 \log \frac{r_1}{1mi} + 20 \log \frac{h_1}{100ft} + 10 \log \frac{h_2}{10ft} + (G_t - 6) + G_m$$

- This equation is simplified as

$$P_r = P_t - 157.7 - 38.4 \log r_1 + 20 \log h_1 + 10 \log h_2 + G_t + G_m$$

- The most general formula is expressed as follows

$$P_r = P_t - k - \gamma \log r_1 + 20 \log h_1 + 10 \log h_2 + G_t + G_m$$

where

$$P_r = P_t - k \text{ at } r_1 = 1 \text{ mile}, h_1 = h_2 = 1', \& G_t = G_m = 0$$

- The value of k & γ will be different and needed to be measured in different human-made environments.

PROPAGATION OVER WATER OR FLAT OPEN AREA

- Propagation over water or flat open area is becoming a big concern because it is very easy to interferen with other cells if we donot make the correct arrangements.
- Interference resulting from propagation over the water can be controlled if we know the cause.
- The relative permittivity (ϵ_r) is same for different type of water i.e. it is same for fresh water & sea water but the conductivity is different for both water.
- The dielectric constant ϵ_c, relative permittivity (ϵ_r) and the conductivity (σ) are related as

$$\epsilon_c = \epsilon_r - j60\sigma\lambda.$$

where

$\lambda \rightarrow$ wavelength.

At 850 MHz 'λ' is 0.35 m

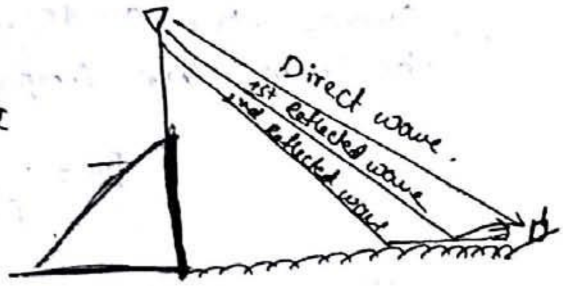
Therefore

$$\epsilon_c \text{ (seawater)} = 80 - j84$$

$$\& \ \epsilon_c \text{ (fresh water)} = 80 \cdot j0.021$$

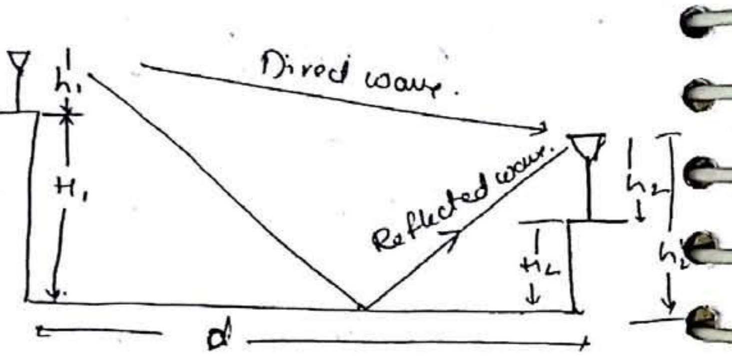
- According to the formula of reflection coefficients, with small incident angles the magnitude of reflection coefficient of both horizontally & vertically polorized waves comes close to '1', But are opposite in sign due to 180° phase change at the ground reflection point.

- Now consider a scenario



- figure comprises two antennas one at mobile unit & other at cell site
- These antennas are above the sea level, hence the Reflection points are generated.
  - One Reflection point is due to mobile unit & the other is reflected from the water surface and is a bit away from the mobile unit
  - The Reflection point near to the mobile unit is the one considered always.
- Now - we can calculate the formula to find field strength for point to point transmission & land to mobile transmission over flat area or water.

(1) Point-to point Transmission



- The point-to-point transmission between the fixed stations over the water or flat open land can be estimated as follows.

The Received power P_r

$$P_r = P_t \left(\frac{1}{4\pi d/\lambda} \right)^2 \left| 1 + a_v e^{-j\phi_v} \exp(j\Delta\phi) \right|^2 \quad \text{--- (I)}$$

P_t = transmitted power d - distance b/w two stations.

λ = wavelength a_v, ϕ_v = amplitude & phase of a complex reflection coefficient respectively.

- $\Delta\phi$ is the phase difference caused by the path difference Δd between the direct wave & reflected wave.

$$\Delta\phi = \beta \Delta d = \frac{2\pi}{\lambda} \Delta d .$$

- The first part of Eq (I) is the free space loss formula which shows the 20dB/dec slope, that is a 20-dB loss will be seen when propagating from 1 to 10km.

$$P_0 = \frac{P_t}{(4\pi d/\lambda)^2}$$

- The $a_v e^{-j\phi_v}$ are the complex reflection coefficients & can be found from the formula.

$$a_v e^{-j\phi_v} = \frac{\epsilon_c \sin\theta_1 - (\epsilon_c - \cos^2\theta_1)^{1/2}}{\epsilon_c \sin\theta_1 + (\epsilon_c - \cos^2\theta_1)^{1/2}}$$

- If the vertical incidence is small then θ is also very small, this result is

$$a_v = -1 \quad \& \quad \phi_v = 0 .$$

- ϵ_c dielectric constant is different for different media.
- However when $a_v e^{-j\phi_v}$ is independent of ϵ_c, the reflection coefficient remains -1 regardless of whether the wave is propagated over water, dry land, wet land, ice & etc.
- The eq (I) becomes

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2} |1 - \cos\Delta\phi - j\sin\Delta\phi|^2$$

$$= P_0 (2 - 2\cos\Delta\phi)$$

Since $\Delta\phi$ is a function of Δd & $\Delta d'$ can be obtained from following.

$$\Delta d = \sqrt{(h_1' + h_2')^2 + d^2} - \sqrt{(h_1' - h_2')^2 + d^2}$$

where $h_1' = h_1 + H_1$ & $h_2' = h_2 + H_2$

h_1, h_2 are actual heights & H_1 & H_2 are the heights of hills

Since $d >>> h_1'$ & h_2' then.

(S.E)

$$\Delta d \approx d\left[1+\frac{(h_1'+h_2')^2}{2d^2}-1-\frac{(h_1'-h_2')^2}{2d^2}\right]$$

$$\Delta d = \frac{2h_1'h_2'}{d}.$$

$$\therefore \Delta\phi = \beta\Delta d = \frac{2\pi}{\lambda}\cdot\frac{2h_1'h_2'}{d}$$

$$\boxed{\Delta\phi = \frac{4\pi h_1' h_2'}{\lambda d}} \quad \text{—(II)}$$

⇒ From eq (II) we can set up five conditions.

(i) $P_r < P_o$. The received power is less than the power received in free space i.e -

$$2-2\cos\Delta\phi < 1 \Rightarrow \Delta\phi < \frac{\pi}{3}.$$

(ii) $P_r = 0$ i.e.

$$2-2\cos\Delta\phi = 0 \text{ or } \Delta\phi = 0$$

(iii) $P_r = P_o$ i.e.

$$2-2\cos\Delta\phi = 1 \text{ or } \Delta\phi = \pm\pi/3.$$

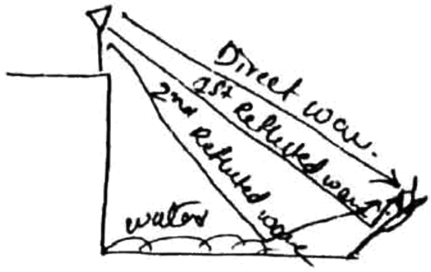
(iv) $P_r > P_o$ i.e

$$2-2\cos\Delta\phi > 1 \text{ or } \Delta\phi > \pi/3.$$

(v) $P_r = 4P_o$

$$2-2\cos\Delta\phi = \text{max} \quad \text{or} \quad \Delta\phi = \pi$$

(2) Land-to-mobile transmission



- There are always two equal strength reflected waves, one from the water & one from the proximity of the mobile unit, in addition to the direct wave.
- The Reflected power of the two reflected waves can reach the mobile unit without noticeable attenuation.
- The total received power at the mobile unit would be Obtained by Summing three components.

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2} \left| 1 - e^{j\Delta\phi_1} - e^{j\Delta\phi_2} \right|^2$$

- $\Delta\phi_1$ & $\Delta\phi_2$ are the path-length difference between the direct wave & two reflected waves Respectively.
- $\Delta\phi_1$ & $\Delta\phi_2$ are very small.

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2} \left| 1 - \cos\Delta\phi_1 - \cos\Delta\phi_2 - j(\sin\Delta\phi_1 + \sin\Delta\phi_2 \right|^2$$

- As $\Delta\phi_1$ & $\Delta\phi_2$ are very small

$$\cos\Delta\phi_1 \approx \cos\Delta\phi_2 \approx 1 \qquad \sin\Delta\phi_1 \approx \phi_1 \qquad \sin\Delta\phi_2 \approx \Delta\phi_2$$

Then

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2} \left| -1 - j(\Delta\phi_2 + \Delta\phi_2) \right|^2$$

$$= \frac{P_t}{(4\pi d/\lambda)^2} \left[1 + (\Delta\phi_1 + \Delta\phi_2)^2 \right]$$

- In most practical cases $\Delta\phi_1 + \Delta\phi_2 < 1$, then $(\Delta\phi_1 + \Delta\phi_2)^2 < 1$

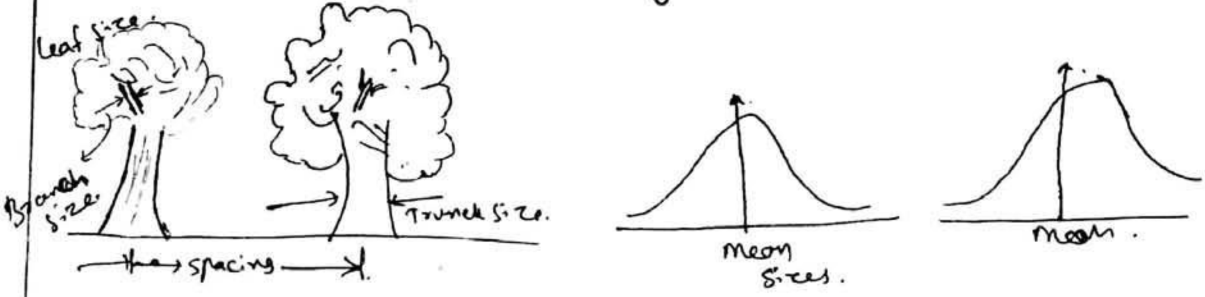
$\therefore$ $$P_r \simeq \frac{P_t}{(4\pi d/\lambda)^2}$$

→ The path loss for land-to-mobile propagation over land 40dB/dec, is different for land-to-mobile propagation over water.

- Propagation over water, the free-space path loss 20dB/dec is applied

FOLIAGE LOSS.

- Foliage loss is a very complicated topic that has many parameters and variations.
- The sizes of leaves, branches & trunks, the density & distribution of leaves, branches and trunks and the height of the tree relative to the antenna heights will all be considered.



A Characteristic of foliage environment.

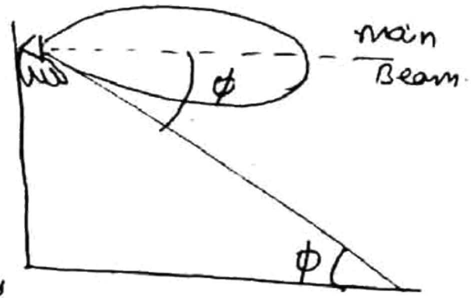
- There are three levels: truncks, branches & leaves and also of the density and spacing between adjacent trunks, branches and leaves.
- The texture & thickness of the leaves also count.
- For a system design, the estimate of the signal reception due to foliage loss doesnot need any degree of acuracy.
- A Rough estimate should be sufficient for the Purpose of system design.
- Sometimes the foliage loss can be treated as a wire-line loss, in decibels per foot or decibels per meter, when the foliage is uniformly heavy and the path lengths are short.
- when the path length is long and the foliage is non-uniform then decibels per octaves or decibels per decade is used.
- Foliage loss occurs w.r.t. the frequency to the fourth power ($\sim f^{-4}$).
- At 800MHZ the foliage loss along the radio path is 40dB/dec which is 20dB/dec more than the free space loss, with the same amount of additional loss for mobile communicati-

- If the situation involves both foliage loss and mobile communications, the total loss would be 60 dB/dec (= 20 dB/dec of free space loss + additional 20 dB due to foliage loss + additional 20 dB due to mobile communication).
- A foliage loss in a suburban area of 58.4 dB/dec

PROPAGATION IN NEAR-IN DISTANCE

(i) Why use a 1-mi intercept?

- The beam width of a high gain omni-directional antenna within a 1-mi radius in the vertical plane is usually narrow.
- If the mobile unit is within the 1-mi radius then this results in large elevation angle that make the mobile unit to be in shadow region and hence reduces the signal reception at the mobile unit to be in shadow region and hence reduces the signal reception at the mobile unit.



- The elevation angle and the reception level are inversely proportional to each other.
- The greater the elevation angle, the less is the reception level.
- An increase in elevation angle also causes mobile unit to remain in shadow region (outside the main Beam)
- Also the road orientation, in-line & perpendicular, close to the cell site can cause a big difference in signal reception levels (10-20dB) on those roads.
- The near-by surroundings of the cell site can bias the reception level either up or down when the mobile unit is within the 1-mi radius. when the mobile unit is 1-mi away from the cell site, the effect due to the near-by surroundings of the cell site becomes negligible.

- For land-to-mobile propagation, the antenna height at the cell site strongly affects the mobile reception in the field, therefore, mobile reception 1-mi away has to refer to a given base-station antenna height.

Curves for near-in propagation.

- Consider a suburban area as an example to calculate near-in distance propagation.
- At 1-mi intercept the received level is −61.7dBm based on the reference set of parameter i.e. antenna height is 30mts.
- If we increase the antenna height to 60mts, a dB gain is obtained,

→ 60 to 120mts increase another 6dB is obtained

→ A typical vertical beam width of 6dB antenna, at a mobile antenna height of 3mts (10ft) & distance 'd' as 100mt (328ft) the elevation angle & incident angle 10.72° & 11.77°. As incident angle is high, hence 40dB/dec is invalid at this point.

- If antenna beam is aimed at mobile unit following observation
  - 24 dB/dec slope for antenna height of 30mts
  - 22 dB/dec slope for antenna height of 60mts
  - 20 dB/dec slope for antenna height of 120mts.

Calculation of near-field propagation.

- The range d_f of nearfield can be obtained by letting $\Delta\phi$ be π

$$\Delta\phi = \frac{4\pi h_1 h_2}{\lambda d}$$

- As we are calculating near-field propagation hence $d \to d_F$

$$\Delta\phi = \frac{4\pi h_1 h_2}{\lambda d_f}$$

- The near-field d_f can be obtained by equating the path difference $\Delta\phi = \pi$

1) channel sharing & channel borrowing schemes are, to increase spectrum efficiency.
2) Increasing the efficiency of spectrum usage by using frequency reuse but results in different cochannel cells.

$$\Delta\phi = \frac{4\pi h_1 h_2}{\lambda d_F} = \pi$$

$$d_F = \frac{4\pi h_1 h_2}{\lambda \pi} \Rightarrow \boxed{d_F = \frac{4 h_1 h_2}{\lambda}}$$

- For best approximation purpose the signal received outside the field i.e. $(d > d_F)$, the mobile radio path loss formula can be used, given as

$$\boxed{P_r = P_t - 157.7 - 38.4 \log r_1 + 20 \log h_1 + 10 \log h_2 + G_t + G_m}$$

- If the signal received is within the field i.e $(d < d_F)$ then Free space loss formula can be used, given as

$$\boxed{P_r = \frac{P_t}{\left(\frac{4\pi d}{\lambda}\right)^2}}$$

LONG-DISTANCE PROPAGATION

- The advantage of a high cell site is that it covers the signal in a large area, especially in a noise-limited system.
- A noise-limited system gradually becomes an interference-limited system as traffic increases.
- Long-distance propagation also affects the interference.

(i) within an area of 50-mile radius.

- For a high site, the low-atmospheric phenomenon would cause the ground wave path to propagate in a non-straight line fashion.

- This situation is more pronounced over seawater because the atmospheric situations over the ocean, can be varied based on the different altitudes.
- The wave path can bend either upward or downward, then we may have experience that at one spot the signal may be strong at one time but weak at another.

(ii) At a distance of 320km (200 mile).

- For long distance propagation the tropospheric wave propagation proves more powerful at 800MHz. The signal can reach 200mi away.
- The reception of wave so far is due to sudden changes in the effective dielectric constant of troposphere.
- The Dielectric constant usually varies with temp.

$$\text{Temp} \propto \frac{1}{h} \quad \text{changes } 6.5\,^\circ C/km.$$

- Temperature at upper boundary of troposphere is "$-50^\circ C$"
- There are three ways in which a tropospheric wave is divided

(i) tropospheric Reflection (ii) tropospheric refraction (iii) Moistness.

(i) Tropospheric Reflection

- This Reflection will occur where there are abrupt changes in the dielectric constant of the atmosphere
- The Distance of propagation is much greater than the line-of-sight propagation.

(ii) Tropospheric Refraction

- This Refraction is a gradual bending of the rays due to the changing effective dielectric constant of the atmosphere through which the wave is passing.

(iii) moistness

- Actually water content has much more effect than temperature of the atmosphere and on the ~~man~~ manner on dielectric constant of the atmosphere in which the radio waves are affected. The water vapour pressure decreases as the height increases.

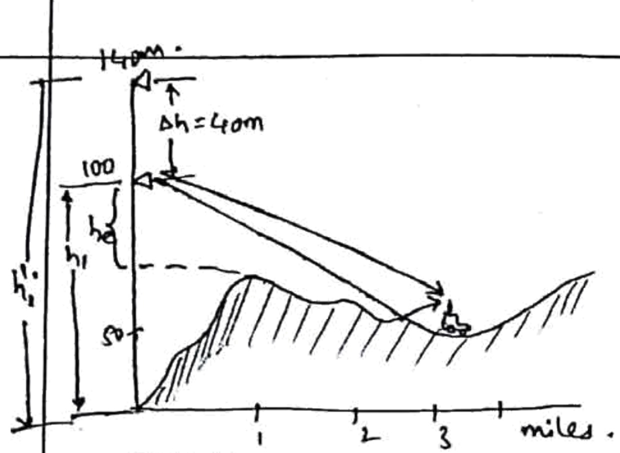
- If the refraction index decreases with height over a portion of the range of height, the rays will be curved downward & a condition known as trapping & duct propagation
- Troposphere wave propagation does cause interference & can only be reduced by umberella antenna beam pattern, or a low-power-low antenna-mast approach.

PATH LOSS FROM A POINT-TO-POINT PREDICTION MODEL.

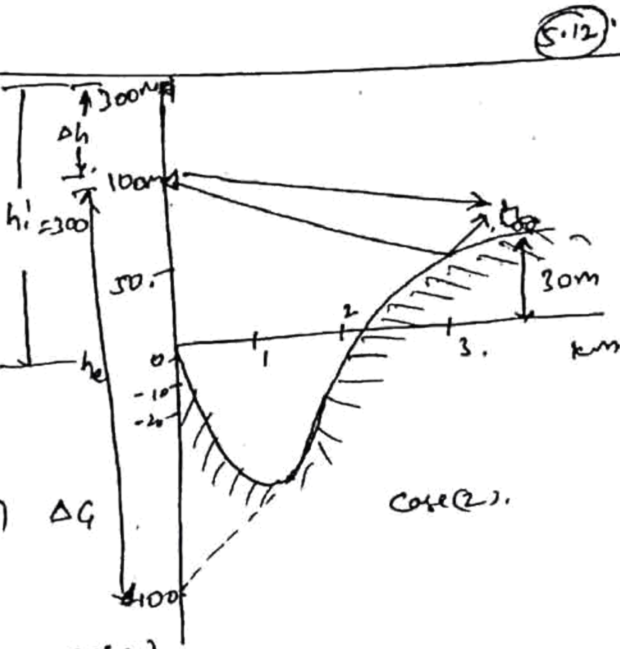
(i) In nonobstructive condition.
- In this condition, the direct path from the cell site to the mobile unit is not obstructed by the terrain contour.
- The non-obstructive direct path is a path unobstructed by the terrain contour.
- The line-of-sight path is a path which is unobstructed by the terrain contour & by man-made structures
- In the former case (non-obstructive), the cell-site Antenna can't be seen by the mobile user, whereas in the latter (line of sight) case it can be.
- In mobile environment, we donot often have line-of-sight conditions. we use direct path condition which are unobstructed by the terrain contour.
- under these conditions, the antenna height gain will be calculated for every location in which the mobile unit travel.

Finding Antenna height gain

1) First step to find Reflection Point
2) Second step is to extend the Reflection ground plane to the location of cell site Antenna by Drawing a tangent line to the ground curvature point.
3) Third step is to find effective height. It can be calculated at the point where the cell-site antenna ~~beam~~ location & Reflected ground plane meet.



case (1)



case (2).

4) Calculate antenna height gain ΔG

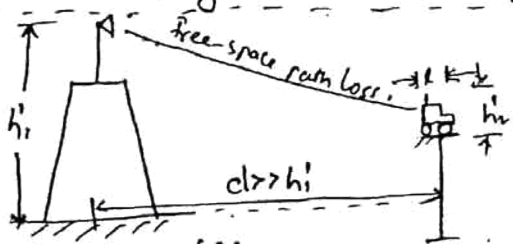
$$\Delta G = 20 \log \frac{h_e}{h_1}$$

$$\Delta G = 20 \log \frac{40}{100} = -8\text{dB (negative gain)}$$

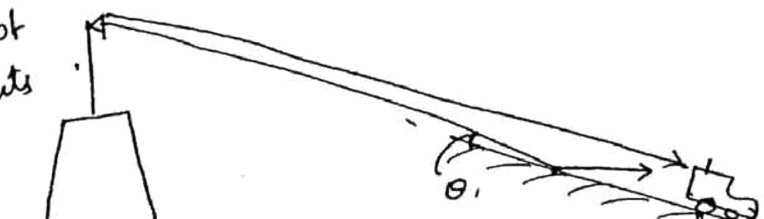
$$\Delta G = 20 \log \frac{200}{100} = 6\text{dB (Positive gain)}$$

- The Antenna height gain ΔG change as the mobile unit moves along the road. i.e the effective antenna height at the cell site changes as the mobile unit moves to a new location.

Another physical explanation of effective antenna height



(a)



Physical explanation of effective Antenna heights

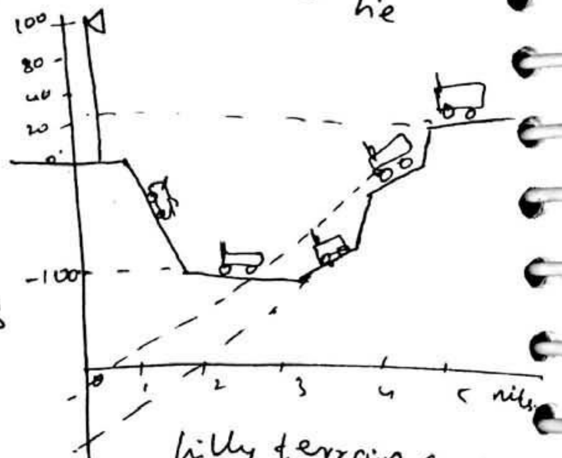
(i) case a:- 'H' is much larger than h_2 & length l of the floor
is roughly equal to the length of the vehicle
→ only direct wave & free-space path loss is applied to the
Situation which Provides a strong Reception.

(ii) case(b) :- The length 'l' is longer to allow a Reflection point to be generate on the floor.
- The two waves direct & Reflected, stronger the Reflected wave larger the path loss.
- Stronger Reflection wave occur at a very small incident angle θ.

(iii) case(c) :- Incident angle θ approaches to zero, the signal reception becomes very weak.
- The shadow-loss condition starts when both the direct wave & reflected wave have been blocked.
- when incident angle of a wave is very small two-conditions
(i) Sparse human-made structures or trees along the propagation path. when there are few human-made structures along the propagation path, the received power is always higher than when there are many.
(ii) Dense human-made structures along the propagation path there are 2 conditions
(a) A line-of-sight wave exists b/w the base station & the mobile unit
(b) The mobile unit is surrounded by the scatters. If the direct reception is blocked by the surrounding buildings, Rayleigh fading is observed.

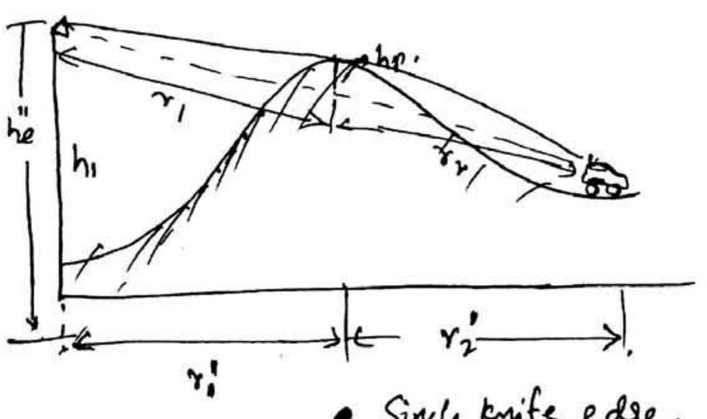
- In above two conditions the average received powers are not the same. However, if the reflected waves from surrounding buildings are very strong, the average received power from the two different conditions can be very close.

- If we don't take into account the changes in antenna height gain due to the terrain contour b/w the cell site & mobile unit the path-loss slope will have a standard deviation of 8dB.
- If we do take the antenna height gain into account, values generally have a standard deviation within 2 to 3 dB.
- The effects of terrain roughness as changing different effective antenna height h_e & h'_e at different positions of the mobile unit
- The effective antenna gain ΔG can be $\Delta G = 20 \log \frac{h_e}{h'_e}$
- point-to-point prediction is based on the actual terrain contour along a particular radio path, but area-to-area prediction is not.
i.e why area-to-area prediction has a standard deviation of 8dB but point-to-point has 2-~~to~~3 dB.

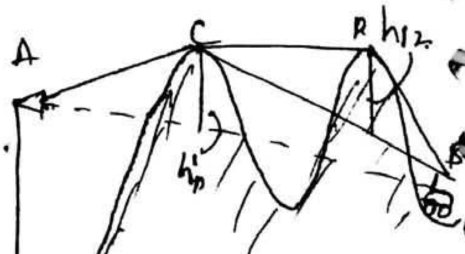


hilly terrain contour

(iii) IN OBSTRUCTIVE CONDITION.
- Direct path from the cell site to the mobile unit is obstructed by the terrain contour.
obtain diffraction loss.
- The diffraction loss can be found from a single knife edge or double knife-edge.



a Single knife edge.



Double knife edge.

Case(i)

- Find the four parameters for single-knife edge case (fig 1)
- Four parameter distance r_1 & r_2 from knife edge to the cell site & mobile unit, height of knife edge h_p & operation wave length λ, are used to find a new parameter V

$$V = -h_r \sqrt{\frac{2}{\lambda}\left(\frac{1}{r_1}+\frac{1}{r_2}\right)}$$

h_p is positive for fig 1 & Fig 2

h_p is negative for fig 3.

- when V is obtained, diffraction loss 'L' can be found approximately formula.

$1 \le V \Rightarrow L = 0\,dB$.

$0 \le V \le 1 \Rightarrow L = 20 \log(0.5 + 0.62V)$

$-1 \le V \le 0 \Rightarrow L = 20 \log(0.5\, e^{0.95V})$

$-2.4 \le V \le -1 \Rightarrow L = 20 \log\left(0.4 - \sqrt{0.1184 - (0.1V + 0.38)^2}\right)$

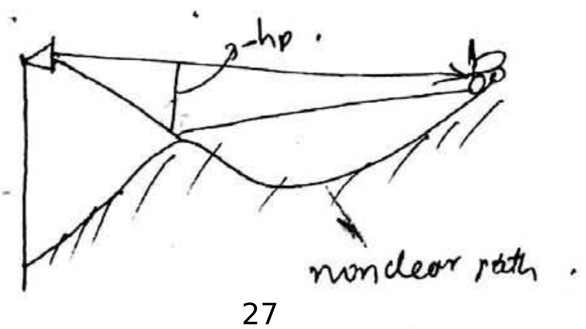
$V < -2.4 \Rightarrow L = 20 \log(-0.225/V)$.

Case (ii)

Double knife edge (fig 2), two knife edge can be formed by two triangle ACB & CDB

→ V can be calculated from V_1 & V_2 and corresponding L_1 & L_2

→ Total diffraction loss $L_t = L_1 + L_2$.



FORM OF A POINT-TO-POINT MODEL (General formula of lee model)

- The formula of the lee model can be stated simply in three cases

(1) Direct wave case: The effective antenna height is a major factor which varies with the location of the mobile unit while it travels.

(2) Shadow case: No effective antenna height exists. The loss is totally due to the knife-edge diffraction loss.

(3) Over the water condition: The free space loss is applied.

$P_r =$

Non obstructive path.

$$P_{r0} - \gamma \log \frac{r}{r_0} + 20 \log \frac{h_e'}{h_1} + \alpha$$

($P_{r0} - \gamma \log \frac{r}{r_0}$: human made structures; $20 \log \frac{h_e'}{h_1}$: terrain contour.)

Obstructive path

$$P_{r0} - \gamma \log \frac{r}{r_0} + 20 \log \frac{h_e''}{h_1} + L + \alpha$$

$$P_{r0} - \gamma \log \frac{r}{r_0} + L + \alpha \quad (h_e'' \approx h_1)$$

($P_{r0} - \gamma \log \frac{r}{r_0}$: Human made structures; $L + \alpha$: terrain contours.)

Land to mobile over water = a free space formula.

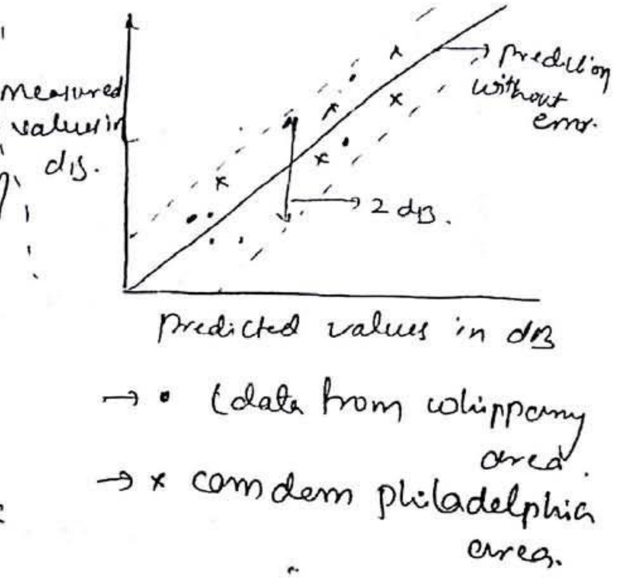
$$P_0(2 - 2\cos\Delta\phi)$$

Remarks

- Received power 'P' can't be greater than free space loss.
- The factor 'α' is known as the correlation factor it indicates either gain or loss
- The loss which arises due to choosing the cell site in forest is foliage loss. In order to avoid this loss, the cell site must not be a forest or else the antenna height at cell-site must be greater than trees in forest.

Merits of Point-to-point model

- The area-to-area model usually provides an accuracy of prediction with a standard deviation of 8 dB which means 68% of the actual path-loss data are within the ± 8 dB of the predicted value. The uncertainity range is too large.
- The Point-to-point model reduces the uncertainity range by including the detailed terrain contour information in the path-loss predictions.
- In analysis of Point-to-point method the predicted values were placed at x-axis & actual measured value at y-axis and it was a simple method.
- A line of 45° is shown is drawn between these two values & this 45° line is the errorless prediction line.
- This prediction model is very useful for cellular mobile communications.
- Largest difference b/w the predicted & measured value is around 3dB.



- The occurrence of handoffs in cellular mobile communications can be predicted with more accuracy in this model.

UNIT III

CELL SITE & MOBILE ANTENNAS

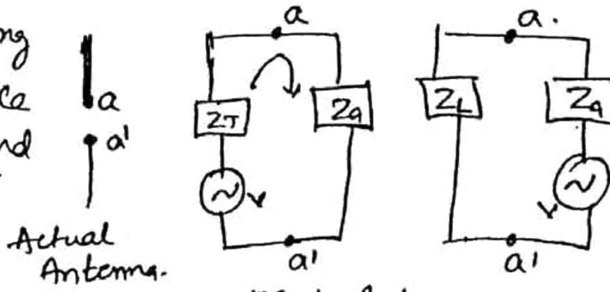
contents

UNIT - VI CELL SITE & MOBILE ANTENNAS

(6.V)

EQUIVALENT CIRCUIT OF ANTENNAS.

- consider an antenna and its equivalent circuit for Tx & Rx
- Power P_t Originates at a transmitting Antenna and radiates out into space (isotropic Antenna) P_t is used and that power in the spherical space will be measured as the power per unit area.



Z_a - Antenna impedence.
Z_L - Load impedance.
Z_T - impedance at transmitter
V - equivalent induced Voltage.

- This power density, called the Poynting vector ρ or the outward flow of electromagnetic energy through a given surface area

$$\rho = \frac{P_t}{4\pi r^2} \quad W/m^2.$$

- A Receiving Antenna at a distance 'r' from the transmitting antenna with an aperture 'A' will receive power.

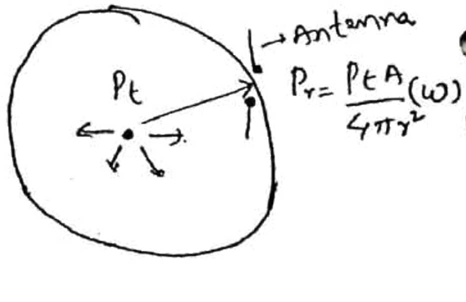
$$P_r = \rho A = \frac{P_t A}{4\pi r^2} \quad W.$$

- we have relationship between the aperture 'A' and gain 'G'

$$G = \frac{4\pi A}{\lambda^2}$$

→ for a short dipole $G = 1$, Then

$$A = \frac{\lambda^2}{4\pi}$$



→ $$\boxed{P_r = P_t \frac{1}{(4\pi r/\lambda)^2}}$$

SUM AND DIFFERENCE PATTERNS

- If we know the Antenna pattern and geographic configuration of the antennas, a computer program can help us to find the coverage Several synthesis methods can be used to generate a desired antenna configuration.
- many applications of linear arrays are based on sum-and-difference patterns.
- The mainbeam of the pattern is always known as the sum pattern pointing at angle θ_0.
- The difference pattern produces twin mainbeams straddling θ_0.
- when 2N elements are in an array, equispaced by a separation d, the general pattern for both sum and difference is

$$A(\theta) = \sum_{n=1}^{N} I_n \exp\left[j \frac{2n-1}{2} \beta d(\cos\theta - \cos\theta_0)\right] + I_{-n} \exp\left[-j \frac{2n-1}{2} \beta d(\cos\theta - \cos\theta_0)\right]$$

β = wave no. = $2\pi/\lambda$, I_n = normalized current distribution

N = total no. of elements.

- For sum pattern all the current amplitudes are the same $I_n = I_{-n}$
- For difference pattern, the current amplitudes at one side (half of total elements) are positive & current amplitudes of the otherside (half of the total elements) are negative

$$I_n = -I_{-n}$$

- Most pattern synthesis problems can be solved by determining the current distribution I_n

Synthesis of sum patterns.

(i) DOLPH – CHEBYSHEV SYNTHESIS OF SUM PATTERN.

Advantage:- This method can be used to reduce the level of Sidelobes.

Disadvantage:- The reduction of sidelobes level is broadening of the mainbeam.

(ii) Taylor Synthesis :- A continuous line-source distribution or a distribution for discrete arrays can give a desired pattern which contains a single mainbeam of a prescribed beamwidth & pointing direction with a family of sidelobes at a common specified level.

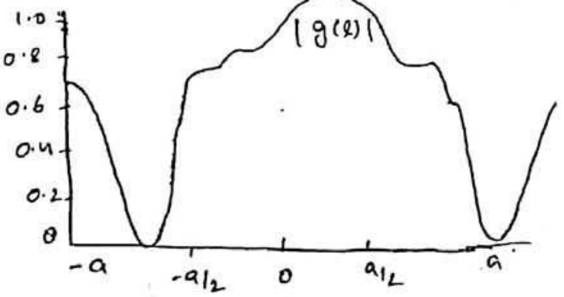
- Taylor synthesis is desired

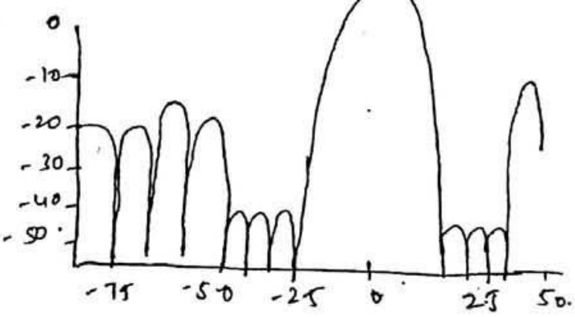
$$F(\theta) = \int_{-a}^{a} g(l)\, e^{j\beta l \cos\theta}\, dl.$$

$g(l)$ = be aperture current distribution.

(iii) Symmetrical pattern: For production of a symmetrical pattern at the mainbeam, the current amplitude distribution $|g(l)|$ is the only factor to consider.

- The phase of current distribution is remain constant





$u = (2a/\lambda)(\cos\theta - \cos\theta_0)$

(iv) Asymmetrical pattern.

For production of an asymmetrical pattern, both current amplitude $|g(l)|$ and phase $\arg g(l)$ should be considered.

(v) Synthesis of difference patterns. (Bayliss synthesis).

we can get $D(\theta) = \int_{-a}^{a} g(l)\, e^{j\beta l\cos\theta}\, dl.$

vi) Null-free patterns

- In mobile communications applications, field-strength patterns without nulls are preferred for the antennas in a vertical plane.
- The field pattern can be represented as

$$F(u) = \sum_{n=0}^{N} K_n \frac{\sin \pi u}{\pi u}$$

$$u = (2a/\lambda)(\cos\theta - \cos\theta_n)$$

➤ Antennas at cell site.

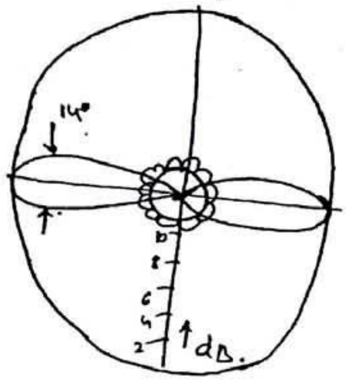
Omnidirectional Antennas

- The omnidirectional antennas have the characteristics of radiating uniformly in all directions.
- The standard high gain omnidirectional antenna are 6dB and 9dB gain antennas.
- It is always suggested that in a startup cellular system omnidirectional antenna should be used.

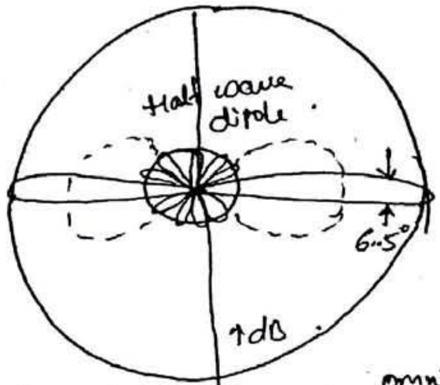
Start-up cellular system configuration

- For omnicells in start-up systems the cell-site antennas should be omni-directional.
- In general every cell will have three transmitting antennas (16 × 3 = 48 channels) that could serve 45 voice transmissions at a time.
- Channel amplifiers are used for amplifying its own signal that has to be sent. After 16 radio signal (16 channels) are passed through the channel combiner unit, at the receiving end, two antennas can receive all the 45 voice which were transmitted.

- In case two identical signals are received by these two receiving antennas then they would be sent to the diversity receiver of the corresponding channel. Thus receiving the different voice signals is done.



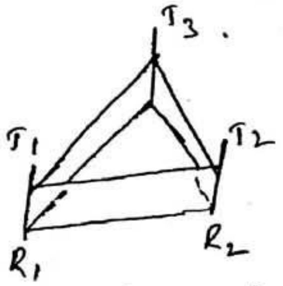
a) Vertical high gain omni directional Antenna of gain 6dB.



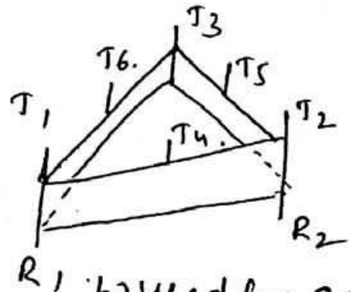
b) vertical high gain omni directional Antenna of gain 9dB.

ABNORMAL Antenna Configuration

- In cellular mobile system if the number of subscribers increase there will be more call traffic.
- In particular some cells would require more channels than other cells to meet the increasing call traffic.
- In general the omni cells will be provided with 90 voice channels.



a) used for 45 channel



b) used for 90 channels

- 90 voice channels - six antennas (T_1 to T_6) have to be used
- 45 voice channels - Three antennas (T_1 to T_3) have to be used.

- But though the number of transmitting antennas are more the receiving antennas are only two.

> Reducing Interference with Directional Antennas.

- For bandwidth saving in cellular mobile communication frequency reuse concept is used. But when reuse technique of repeatedly using same frequency is done there is a risk of cochannel interference.
- A standard value of cochannel interference reduction factor $q = D/R$ is applied but it suits for a flat terrain only.
- In mobile environment a flat terrain cannot be guaranteed. As the subscriber moves the signal has to propagate through different terrain contour a standard cochannel reduction factor is not suitable.
- using directional antennas is a better method to reduce interference.

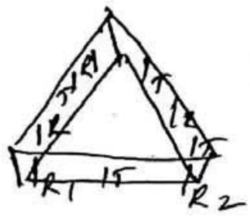
Directional Antenna Setup.

- In a cellular system using sectorization concept assume a 120° sectored cell here.
- For this cell a 120° corner reflector can be used. Likewise in a 60° sectored cell a 60° corner reflector can be used.

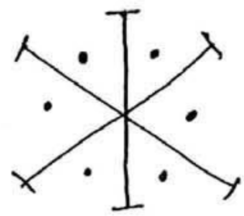
Normal Antenna System Configuration

- If the cluster size N=7 pattern then it means the 120° sectored cell.
- If frequency reuse technique is applied in this cell then 333 channels can be used here.
- Every sector of 120° is capable of serving 16 channels with one transmitting and two receiving antennas.

- on the Otherhand if a cluster size of N=4 pattern is used, 60° sectored cell is considered.
for Omni cell systems the cluster size of N=4 can't be used because of its inadequate reuse distance.
In such 60° sectored cell two different approaches are used
(i) Both transmitting and receiving are of 60° sectors. Each sector has an antenna that can carry its own set of frequency channels. It is known as N=4 cellular pattern.
In case 333 channels with 13 channels in one sector are used then one transmitting and one receiving antenna are used in one sector.
At the receiving end two receiving antennas out of six are selected so as to have angle diversity.



120° sector for 45 channels



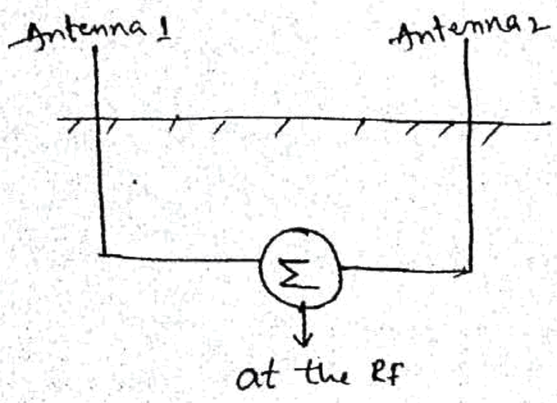
60° sector

120° sector for 90 channels

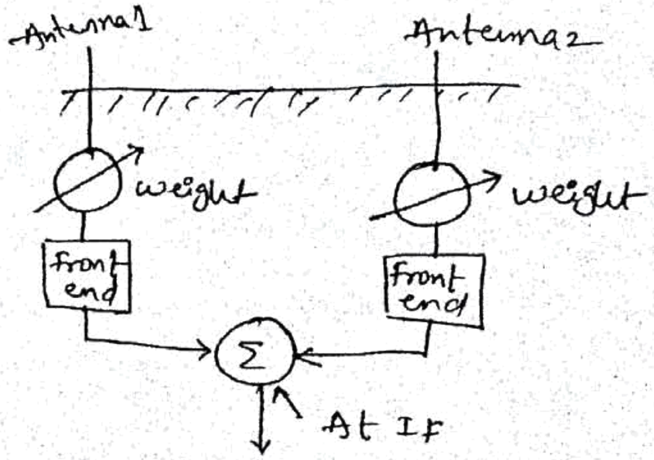
- finally consider a 'Receiving 60°' sectored case. The 60° sector receiving antennas are being applied for locating mobile units and it properly hand offs with high accuracy. The transmitting antenna systems are Omnidirectional within every cell in the area.'
- under abnormal antenna configuration if there is an increase in call traffic due to more number of subscribers the directional antenna arrangement can be used.
- For N=7 pattern with 120° sectors, each sector should have two transmitting antennas.

> SPACE DIVERSITY ANTENNAS.

- The diversity technique provide two or more number of inputs at the mobile reception end such that fading among these two inputs are not correlated
- In space diversity technique two antennas are seported by a distance 'd' so as to get the two input signal with low correlation among fading effects. The antenna would be at a height of 'h' from ground level at the cell site. As the distance 'd' between antennas varies with change in antenna height for both cellsite and mobile antenna.

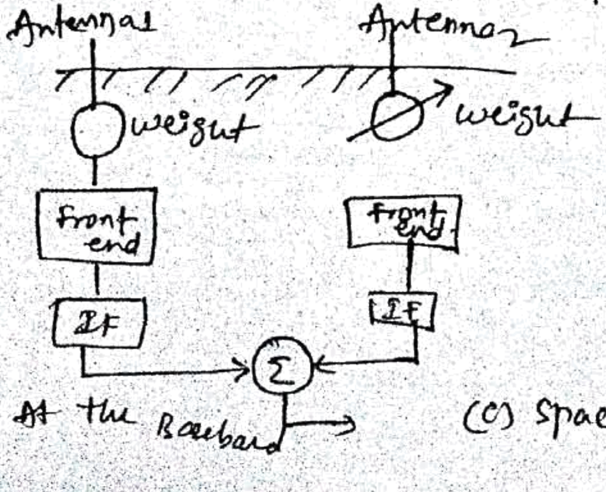


a) Directional array of Antenna



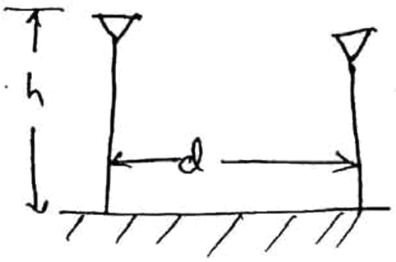
b) Space diversity combiner (at the IF)

- But the space diversity technique is combined either at baseband or at IF as shown below (b) & (c).

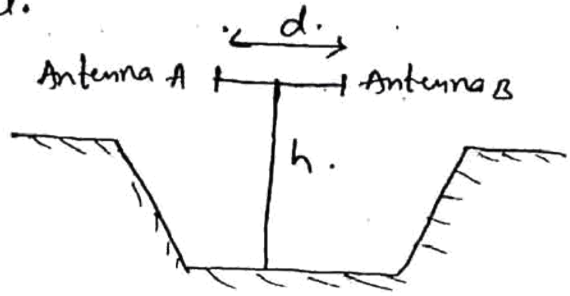


(c) Space diversity combiner.

- The maximal ratio combining can obtain maximum SNR at the output of IF.
- The summation of power outputs at baseband is equivalent to the maximal ratio combining method.
- The switch combined technique uses one RF signal only at a time for desired output signal.



Diversity antenna in cell site with $D = h/d$



Space diversity antenna with 'U' shaped terrain.

→ Degree of correlation b/w two fading signals. $\propto$ Degree of separation distance b/w antennas.

→ The fading is somewhat reduced when the two fading envelopes are combined.

$$\eta = \frac{h}{d}$$

h → height of antenna.
d → seperation distance.

→ $d \geq 14\lambda$ → 150 feet Antenna is Required
$d \geq 8\lambda$ → 100 feet " " "

→ In an omnicell the two space-diversity antennas has to be aligned with the terrain area.
- The space-diversity antennas separate only horizontally and hence horizontal separation should be done in the design.

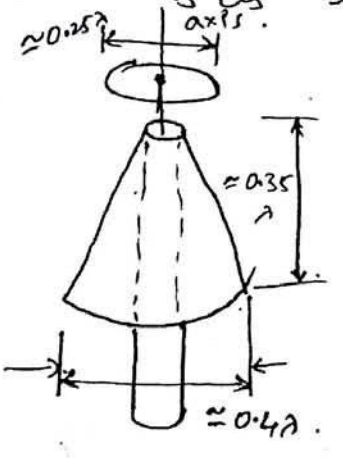
Umbrella pattern Antennas.

- In cell-site antennas used in mobile communication can be umbrella pattern antennas.
- There are many types of umbrella pattern antennas available. They are

(i) Broadband umbrella-pattern antenna.
(ii) Normal umbrella-pattern antenna.
(iii) High-gain broadband umbrella-pattern antenna.
(iv) Interference reduction antenna.

(i) ~~Broadb~~ Broadband umbrella-pattern antenna

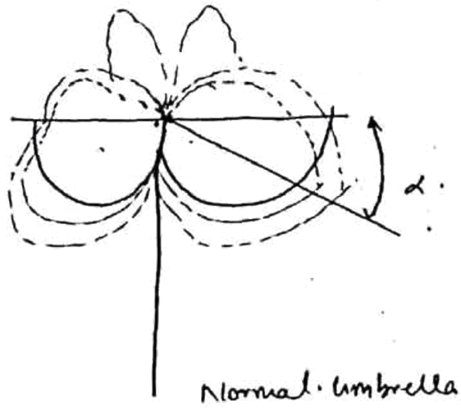
consider a bioconical antenna. one of its cones is extended to 180° so as to form a disk. It is called as discone antenna and acts as broadband umbrella-pattern



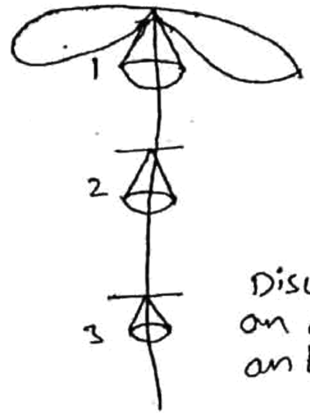
Single discone Antenna.

(ii) Normal umbrella-pattern antenna.

- For controlling the energy in a confined area, the umbrella-pattern antenna can be developed by using a monopole with a top disk.
- The size of the disk determines the tilting angle of the pattern. The smaller the disk, the larger the tilting angle of the umbrella pattern.



Normal umbrella pattern antenna.



Discone antenna. an array of antennas.

(iii) High-gain broadband umbrella-pattern antenna.

- A vertical stacking of number of umbrella-pattern antennas forms a high-gain antennas applicable for mobile transmissions
- If M is the number of antenna element, ϕ is the direction of the wave travel & 'd' is the spacing observed between element then E_0 for one umbrella pattern will be.

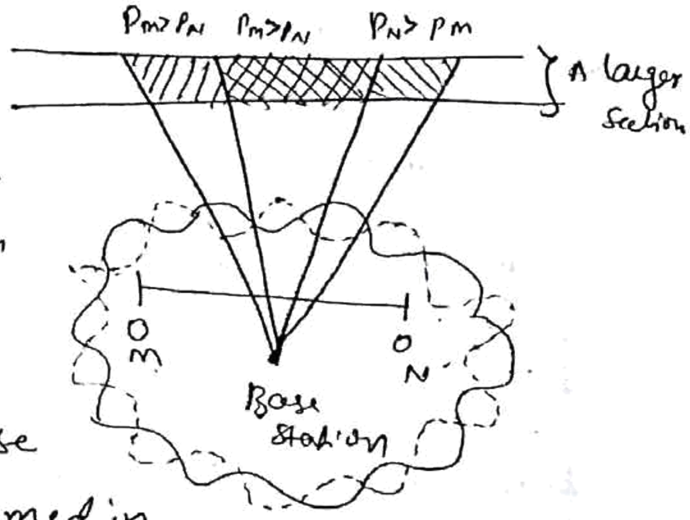
$$E_0 = \frac{\sin\left(\frac{Md}{2\lambda}\right)\cos\phi}{\sin\left(\frac{d}{2\lambda}\right)\cdot\cos\phi}.$$

(iv) Interference reduction Antenna.

The parasitic elements can be used for antenna configurations to reduce interferences. Here the parasitic elements are longer (1.05 times approx) than the active element so that reduction in interference is observed.

➤ MINIMUM SEPARATION OF CELL-SITE RECEIVING ANTENNAS

- TO Avoid the intermodulation problems the seperation distance 'd' between two transmitting antennas has to be minimized.
- In addition to this receiver desensitization is also minimized by reducing seporation distance between transmitting and receiving antennas.



- Consider a space-diversity receiver unit where two receiving antennas are used. The antennas are placed with minimum seporation distance. There will be near-field disturbance generation because of close spacing & ripples formed in the radiation pattern.
- The difference in the received power at different angle for the antennas M & N are shown.
- The difference in the power received at a point for the two antennas will be high if the antennas are closely spaced.
- This power reception now is not only confined to a smaller sector but a larger area.
- Now fading can't be reduced by using space diversity antennas due to close spacing.
- If the antennas at receiver are not closely spaced, fading can be controlled.

MOBILE ANTENNAS.

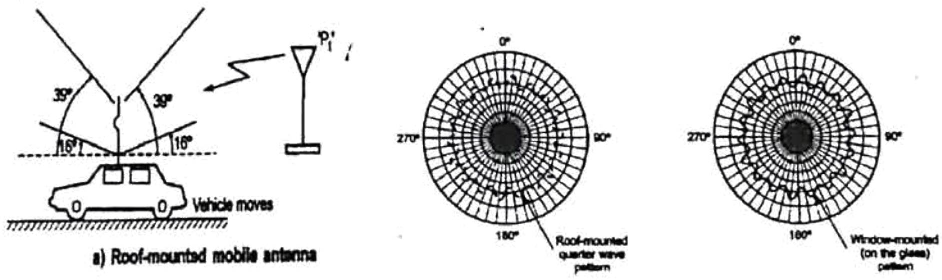
- The requirement of a mobile (motor-vehicle-mounted) antenna is an Omnidirectional antenna which can be located as high as possible from the point of reception.

- Generally the antenna should atleast clear the top of the vehicle.

- The Basic types of mobile Antennas are
  i) Roof mounted antennas. ii) Glass-mounted antennas
  iii) mobile high gain antennas iv) vertically oriented space-diversity antennas.
  v) Horizontally oriented space-diversity antennas.

(i) Roof mounted Antennas.

- The pattern of the mobile antenna is almost uniformly distributed around the mobile when measuring at an antenna distance in the free space.

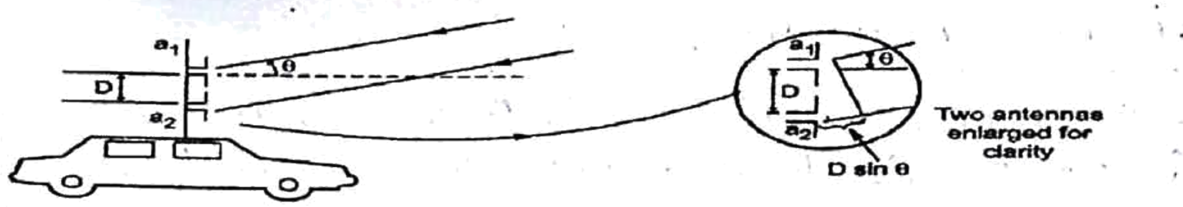


a) Roof-mounted mobile antenna

- A 3 dB antenna shows a 3 dB gain over that of the quarter-wave antenna. The gain of antenna that is used at the mobile has to be limited to 3-dB to avoid any out-of-sight conditions.

(ii) Vertically oriented Mobile Antennas.

- They are vertically oriented space diversity antennas. The vertical separation between the space-diversity can be found with the correlation between the received signal. Consider two vertically separated antennas a_1 & a_2 with distance 'D'



Vertically oriented antennas

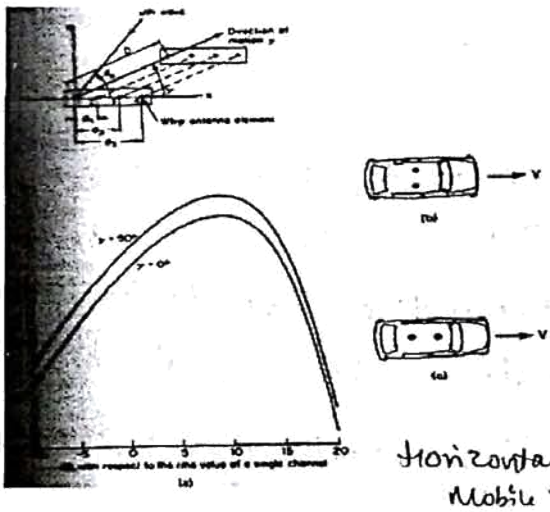
- The positions of antennas are p_1 & p_2. The correlation available will be like

$$\rho\left(\frac{D}{\lambda}, \theta\right) = \frac{\left(\sin\left(\frac{\pi D}{\lambda}\right)\sin\theta\right)}{\left(\frac{\pi D}{\lambda}\right)\sin\theta}.$$

- The elevation angle of signal arrival may vary according to the terrain arrangement.

(iii) Horizontally oriented mobile Antennas.

- Two vehicle-mounted antennas are separated horizontally say by 0.5λ. It can have the advantage of diversity reception.
- The Antennas can be set in a line with or be perpendicular.



Horizontal oriented Mobile Antenna.

(iv) mobile high gain Antenna

- In the directional Antenna, the antenna beam pattern is suppressed horizontally; in the high gain antenna, the pattern is suppressed vertically.

(iv) Glass-mounted antenna.

- In this type energy is coupled through the glass. Due to this it avoids the need of drilling a hole. At the same time a small portion of energy is dissipated on the passage. Depending on the operating frequency the antenna gain ranges b/w 1 to 3 dB.