UNIT II

Co-Channel Interference

Co-channel Interference.

- The frequency-reuse method is useful for increasing the efficiency of spectrum usage but results in co-channel interference because the same frequency channel is used repeatedly in different cochannel cells.

Measurement of real time co-channel interference.

- when the carriers are angularly modulated by the voice signal and the RF frequency difference between them is much higher than the fading frequency, measurement of the signal carrier-to-interference ratio C/I reveals the signal is

$$e_1 = S(t) \sin(\omega t + \phi_1) \quad \text{--- (1)}$$

and the interference is

$$e_2 = I(t) \sin(\omega t + \phi_2) \quad \text{--- (2)}$$

The received signal is

$$e(t) = e_1(t) + e_2(t) = R \sin(\omega t + \psi) \quad \text{--- (3)}$$

where

$$R = \sqrt{[S(t)\cos\phi_1 + I(t)\cos\phi_2]^2 + [S(t)\sin\phi_1 + I(t)\sin\phi_2]^2} \quad \text{--- (4)}$$

and

$$\psi = \tan^{-1} \frac{S(t)\sin\phi_1 + I(t)\sin\phi_2}{S(t)\cos\phi_1 + I(t)\cos\phi_2} \quad \text{--- (5)}$$

- The envelope R can be simplified in (4) & R^2 becomes.

$$R^2 = \{ S^2(t) + I^2(t) + 2S(t)I(t)\cos(\phi_1 - \phi_2) \} \quad \text{--- (6)}$$

- Following Kozono and Sakamoto's analysis of eq ⑥ the term $S^2(t) + I^2(t)$ fluctuates close to the fading frequency V/λ and the term $2S(t)I(t)\cos(\phi_1 - \phi_2)$ fluctuates to a frequency close to $d/dt(\phi_1 - \phi_2)$, which is much higher than the fading frequency.
- Then the two parts of the squared envelope can be separated as

$$X = S^2(t) + I^2(t) \quad \text{—— (7)}$$

$$Y = 2S(t)I(t)\cos(\phi_1 - \phi_2) \quad \text{—— (8)}$$

- Assume that the random variables $S(t)$, $I(t)$, ϕ_1 & ϕ_2 are independent, then the average processes on X and Y are.

$$\overline{X} = \overline{S^2(t)} + \overline{I^2(t)} \quad \text{—— (9)}$$

$$\overline{Y^2} = 4\,\overline{S^2(t)}\,\overline{I^2(t)}\,(1/2) = 2\,\overline{S^2(t)}\,\overline{I^2(t)} \quad \text{—— (10)}$$

- The signal-to-interference ratio r becomes

$$r = \frac{\overline{S^2(t)}}{\overline{I^2(t)}} = k + \sqrt{k^2 - 1} \quad \text{—— (11)}$$

where

$$k = \frac{\overline{X^2}}{\overline{Y^2}} - 1 \quad \text{—— (12)}$$

- The sampling delay time Δt should be small enough to satisfy

$$S(t) \approx S(t+\Delta t), \quad I(t) \approx I(t+\Delta t) \quad \text{—— (13)}$$

$$\cos[\phi_1(t) - \phi_2(t)]\cos[\phi_1(t+\Delta t) - \phi_2(t+\Delta t)] \approx 0 \quad \text{—— (14)}$$

- Determine the delay time Δt to meet the reaurement of eq (13) for this calculation is difficult and is a drawback to this measurement technique.
- Therefore, real-time cochannel interference measurement is difficult to achieve in practice.

Design of Antenna system

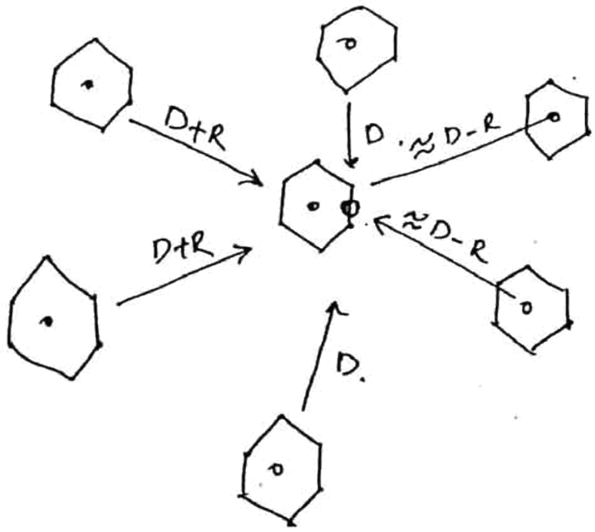
> Design of Omni-directional Antenna

- The design of on omni-directional antenna under the practical case condition can be explained by considering the worst case.
- This case is at the location where the mobile unit would receive the following signals.

They are

1. strong interference from all interfering cell sites
2. weakest signal from its own cell.

- The value of $q = 4.6$ is valid for a normal interference case in a $K=7$ cell pattern.



Cochannel interference (a worst case).

- Figure shows the location of the mobile unit at the cell boundary 'R' in the worst case.
- The two distances of D-R, two distances of D and two distances of D+R include the distance of separations from all six co-channel interfering sites.
- From the mobile radio propagation rule of 40dB/dec. we can obtain

$$C \propto R^{-4} \quad \& \quad I \propto R^{-4}.$$

- Then the carrier to interference ration, C/I is obtained as

$$\frac{C}{I} = \frac{R^{-4}}{2(D-R)^{-4} + 2D^{-4} + 2(D+R)^{-4}}$$

$$= \frac{R^{-4}}{R^{-4}\left[2\left(\frac{D}{R}-1\right)^{-4} + 2\left(\frac{D}{R}\right) + 2\left(\frac{D}{R}+1\right)^{-4}\right]}$$

$$= \frac{1}{2(q-1)^{-4} + 2q^{-4} + 2(q+1)^{-4}} \quad \text{(1)} \qquad \because q = \frac{D}{R}$$

For a K=7 range cell pattern.

$$q = \frac{D}{R} = \sqrt{3K} = \sqrt{3\times7} = \sqrt{21} = 4.6.$$

Sub. 'q' value in equation (1)

$$\frac{C}{I} = \frac{1}{2(4.6-1)^{-4} + 2(4.6)^{-4} + 2(4.6+1)^{-4}} = 17.35dB.$$

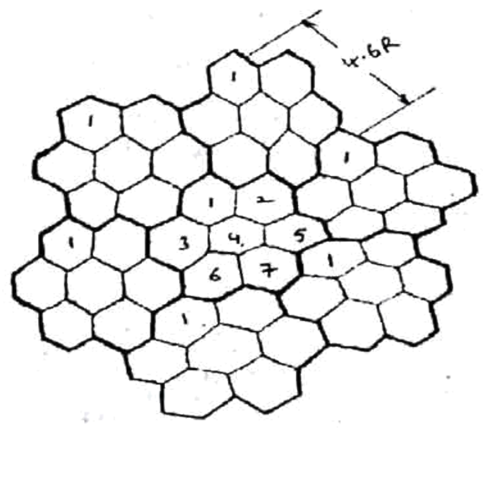
- The above obtained value is less than 18dB. For the worst case, we may consider the shortest distance i.e.

(D-R) for all six interferces. Thus eq ① can be reduced to

$$\frac{C}{I} = \frac{R^{-4}}{6(D-R)^{-4}} = \frac{R^{-4}}{6R^{-4}\left(\frac{D}{R}-1\right)^{-4}}$$

$$= \frac{1}{6(q-1)^{-4}} = \frac{1}{6(4.6-1)^{-4}} = 14.47\,dB.$$

- Generally, the carrier to interference ratio, C/I received is always lower than 17 dB and could be 14 dB due to following reasons
  - (i) Imperfect site locations
  - (ii) Rolling nature of the terrion configuration.
- In a heavy traffic situation, we can easily obtain the instance mentioned above. Thus we can dealt with the system which is defined around the C/I of the worst case.
- Hence, the K=7 cell pattern can't provide a sufficient frequency reuse distance separation i.e. insufficient cochannel interference reduction factor, q.



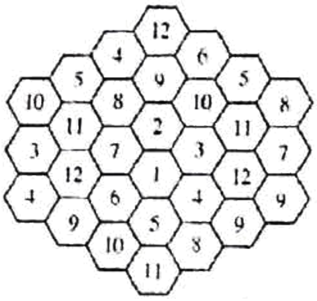
- For $k=12$ reuse cell pattern

$$q = \frac{D}{R} = \sqrt{3k} = \sqrt{3\times12} = 6.$$

Sub q value in eq ① we have.

$$\frac{C}{I} = \frac{1}{2(6-1)^{-4} + 2(6)^{-4} + 2(6+1)^{-4}} = \frac{1}{5.576\times10^{-3}} = 22.54\,dB$$

- The obtained value is higher than 18 dB.



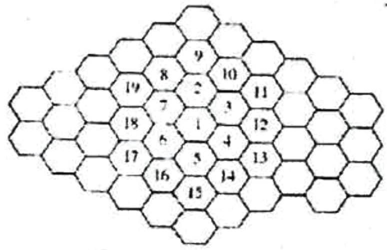
$k=12$ cell pattern

- Hence the $k=12$ cell pattern provides a sufficient frequency reuse distance separation i.e. sufficient co-channel interference reduction factor, q.

- For $k=19$ reuse cell pattern.

$$q = \frac{D}{R} = \sqrt{3k} = 7.55$$

Sub 'q' value in eq ① we have.



$$\frac{C}{I} = 26.83\,dB.$$

- The above obtained value is much higher than 18 dB. Thus, the $k=19$ cell pattern provides a sufficient frequency reuse distance separation i.e. sufficient cochannel interference reduction factor q.

> Design of a Directional Antenna systems.

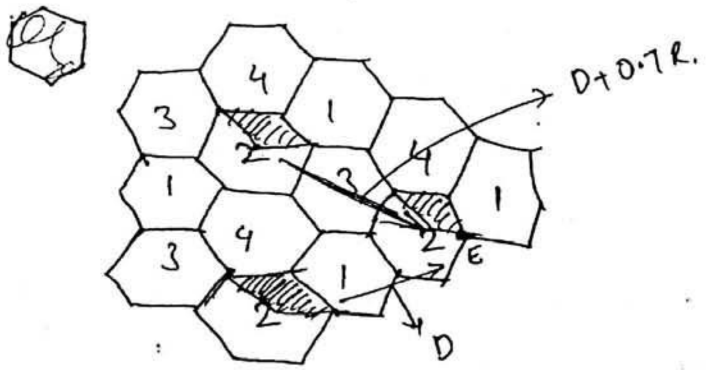
- In a particular cell frequency reuse pattern, the following points must be considered for increase in the call traffic. They are

1. Efficient usage of frequency spectrum
2. Avoid increasing the number of cells, k.

- The increase in number of cells, k can be avoided by using a directional antenna arrangement.
- This antenna arrangement can be used to ~~relative~~ reduce the co-channel interference.
- In this type of arrangement, each cell is divided into three or six sectors and a set of frequencies are assigned to each sector.

Directional Antennas in k=4 cell pattern.

(i) 3-sector case.



- The worst case situation of two co-channel cells in which cell is divided into three sectors by using three 120°- beam directional antennas.
- The interference experienced by the mobile unit at position 'E' will be lesser in the upper shaded cell sector than in the lower shaded cell sector site.

- The distance between the mobile unit & the two interfering antennas is roughly D+(R/2).

Then the value of C/I ratio for the worst case can be obtained by considering distances from two interferers to the position E as "D+0.7" & D will be

$$\frac{C}{I}\text{(worst case)} = \frac{R^{-4}}{(D+0.7R)^{-4}+D^{-4}}$$

$$= \frac{R^{-4}}{R^{-4}\left[\left(\frac{D}{R}+0.7\right)^{-4}+\left(\frac{D}{R}\right)^{-4}\right]}$$

$$= \frac{1}{(q+0.7)^{-4}+q^{-4}} \qquad \because q=\frac{D}{R}$$

For a K=4 cell pattern.

$$q=\frac{D}{R}=\sqrt{3K}=\sqrt{3\times4}=3.46$$

Sub 'q' value in the above equation we have.

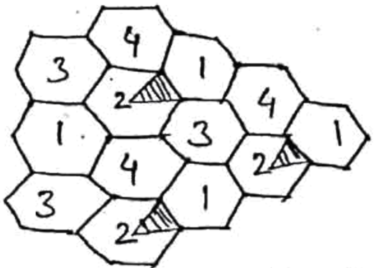
$$\frac{C}{I}=\frac{1}{(3.46+0.7)^{-4}+(3.46)^{-4}} = 97.09$$

$$\frac{C}{I} = 19.87\text{ dB} \quad \text{———} (2)$$

- In the worst case, the C/I ratio received by a mobile unit from the 120° directional antenna sector system is greater than 18 dB. Thus, the co-channel interference can be reduced by using directional antenna sectors.

- Due to heavy traffic area as a result of irregular terrain contour and imperfect site locations, the C/I ratio must be 6dB less than that in eq(2). Thus remaining 13.87 dB is not acceptable.

(ii) 6-Sector case



- Worst case situation of two co-channel cells in which cell is divided into six sectors by using six 60°-beam directional antennas.
- In 6-sector case, only one instance of interference can occur in each sector, Thus the respective carrier to interference ratio is obtained as

$$\frac{C}{I}(\text{worst case}) = \frac{R^{-4}}{(D+R^{-4})} = \frac{R^{-4}}{R^{-4}\left(\frac{D}{R}+1\right)^{-4}}$$

$$= (q+1)^4 \quad \boxed{\because q = \frac{D}{R}}$$

For $k=4$ cell pattern $q = 3.46$ then —— (3)

$$C/I = (3.46+1)^4$$

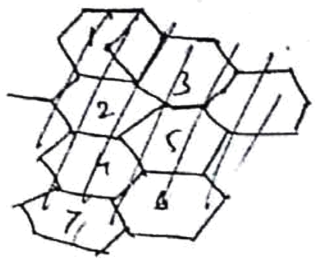
$$\frac{C}{I} = 25.97 \text{ dB} \quad \text{—— (4)}$$

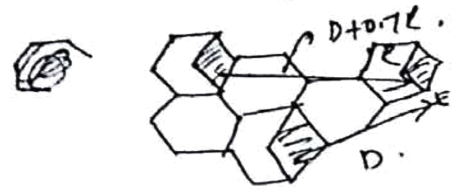
- Thus, the above obtained value shows a further improvement in signal to interference ratio i.e. reduction in co-channel interference.
- Similar to 3-sector subtract 6dB from eq (4) we get 19.97 dB is still more than our actual requirement.
- The 60° sector configuration can be used to reduce co-channel interference during the heavy traffic.

Directional Antennas in $K=7$ cell patterns

- The procedure used to obtain the carrier to interference ratio is same as the procedure used for $K=4$ cell pattern

(i) 3-Sector Case





- The carrier to interferance ratio in a 120° directional antenna system (N=7). Thus, the corresponding carrier to interference ratio is obtained as

$$\frac{C}{I}\text{(worst case)} = \frac{R^{-4}}{(D+0.7R)^{-4} + D^{-4}} = \frac{R^{-4}}{R^{-4}\left[\left(\frac{D}{R}+0.7\right)^{-4} + \left(\frac{D}{R}\right)^{-4}\right]}$$

$$= \frac{1}{(q+0.7)^{-4} + q^{-4}} \quad \text{------ (5)}$$

For a $K=7$ cell pattern

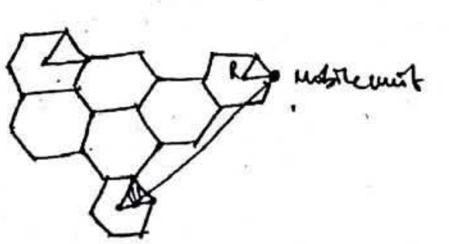
$$q = \frac{D}{R} = \sqrt{3K} = \sqrt{3 \times 7} = 4.6.$$

Sub 'q' value in equation (5) we have.

$$\frac{C}{I} = \frac{1}{(4.6+0.7)^{-4} + (4.6)^{-4}} = 24.56\text{ dB} \quad \text{------ (6)}$$

- If 6 dB is subtracted from the result of equation (6) the remaining 18.56 dB is still very useful. Thus, 120° sector configuration of $K=7$ cell pattern used to reduce co-channel interference in heavy traffic conditions.

(ii) 6- Sector Case



- The carrier to interference ratio in a 60° directional antenna system (N=7), in which there is only one interference at a distance of "D+0.7R". Then the Respective carrier to interference ratio is obtained as

$$\frac{C}{I}(\text{worst case}) = \frac{R^{-4}}{(D+0.7R)^{-4}} = \frac{1}{(q+0.7)^{-4}} \quad \text{—— (7)}$$

For a K=7 cell pattern q=4.6 then

$$\frac{C}{I} = \frac{1}{(4.6+0.7)^{-4}} = 28.97\,dB. \quad \text{—— (8)}$$

- If 6dB is subtracted from the result of equation (8) the remaining 22.97dB is still very useful. Thus, a 60° sector configuration of K=7 cell pattern is also used to reduce co-channel interference in heavy traffic conditions.

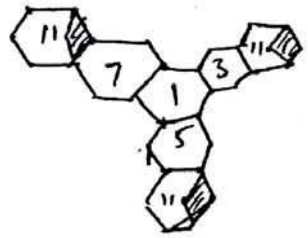
- However, this antennas system has the following drawbacks.

1) Allowing only fewer channels in a 60° sector,
2) Trunking efficiency decreases.

Directional Antennas in K=12 cell Pattern

(i) 3-sector case.

- The procedure used to obtain the carrier to interference ratio is same as the procedure used for K=4 cell pattern symbol.



- The figure shows the carrier to interference ratio in a 120° directional antenna system (N=12)

$$\frac{C}{I}(\text{worst case}) = \frac{R^{-4}}{(D+0.7R)^{-4}+D^{-4}} = \frac{R^{-4}}{R^{-4}\left[\left(\frac{D}{R}+0.7\right)^{-4}+\left(\frac{D}{R}\right)^{-4}\right]}$$

$$= \frac{1}{(q+0.7)^{-4}+q^{-4}} \quad — (9)$$

For K=12 cell pattern.

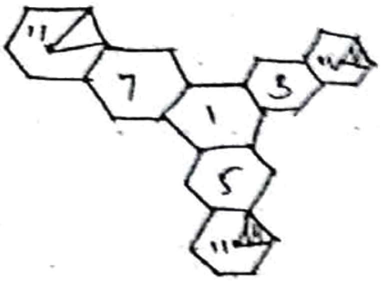
$$q=\frac{D}{R} = \sqrt{3K} = \sqrt{3\times 12} = 6.$$

Sub q value in (9)

$$\frac{C}{I} = \frac{1}{(6+0.7)^{-4}+(6)^{-4}} = 28.97\,dB. \quad (10)$$

- If 6 dB is subtracted from the result of eq (10), the remaining 22.97dB is still very useful.

(ii) 6-Sector case.



- From figure shows the carrier to interference ratio in a 60° directional antenna system (N=12), in which there is only one interferer at a distance of "D+0.7R". Then the respective carrier to interference ratio is obtained as

$$\frac{C}{I}\text{ (worst case)} = \frac{R^{-4}}{(D+0.7R)^{-4}} = \frac{1}{(q+0.7)^{-4}}$$

For K = 12 cell pattern q = 6 then

$$\frac{C}{I} = \frac{1}{(6+0.7)^{-4}} = 33.04\ dB.$$

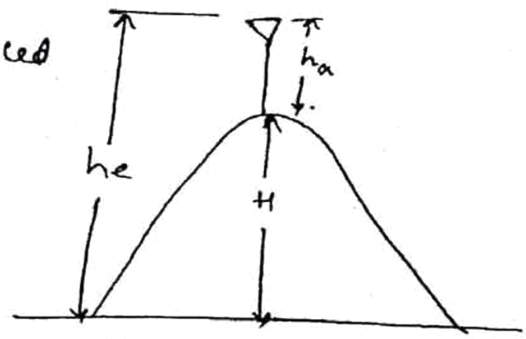
- If 6 dB is subtracted from the above result, remaining 27.04 dB is still adequate.

Effect of Antenna Height on co-channel interference.

- A proper antenna height at the cell site is also a factor that effects the co-channel Interference.
- By reducing antenna height (i.e. by reducing the spread of signal to large area) the cochannel interference is also reduced.
- Though, this is an easy technique but generally not preferred because it doesnot work under all terrain conditions.
- The three main terrain structures and the effect of this technique in these areas are as follows.

(1) On a high spot (Like on a Hill).

- Figure shows a setup of antenna placed on a top of a hill



An Antenna on a high hill

- Let, the height of hill be 'H'
- Let 'ha' be the height of antenna and 'he' the effective height of the antenna calculated relatively with the mobile unit.
- The effective height of the antenna is given as

$$h_e = h_a + H.$$

- If the antenna height is reduced by half, then the new effective height is given as.

$$h_{e_1} = \frac{h_a}{2} + H.$$

- The reduction in gain (G) due to reducing the height is calculated as

$$G = 20 \log_{10}\left(\frac{0.5h_a + H}{h_a + H}\right)$$

$$G = 20\log_{10}\left(1 - \frac{0.5h_a}{h_a + H}\right).$$

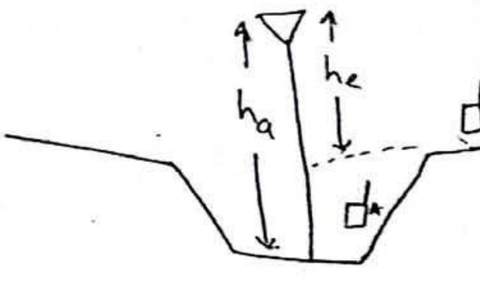
Since $h_a <<<< H$ & $h_a + H >>>>> 0.5h_a$, $\frac{0.5h_a}{h_a+H} <<< 1$

$$\therefore G = 20\log_{10}(1) = 0dB.$$

- we can conclude that by reducing the height of an antenna the power quantities received by either mobile unit or the cell site donot change.
- Hence, we can apply this technique on hilly region to reduce Co-channel Interference.

2) In a valley Region

- figure shows the setup of an antenna placed in a valley.
- Now, they are two values of effective height in this case depending on the position of the mobile unit



Antenna placed in a valley.

Case (i): As shown in figure, mobile unit 'A' is at a area adjacent to the cell site antenna. Hence the effective antenna remains equal to the actual antenna height.

$$\therefore h_e = h_a.$$

- If the antenna is reduced by half, then the new effective antenna height becomes

$$h_{er} = \frac{h_a}{2}$$

- Therefore, the reduction in gain is obtained as

$$G = 20 \log_{10} \left(\frac{h_a/2}{h_a} \right) = -6\,dB$$

- Therefore, the power reduction in power values observed either at mobile unit or cell side is by a value of '6dB'

Case ii:- mobile unit B is at higher position w.r.t cell site antenna.

- The effective height of the antenna is given as

$$h_e = h_{eb}$$

where 'h_{eb}' is a value lesser than the actual height of antenna i.e $h_{eb} < h_a$.

- when the antenna height is reduced by half and let us assume $h_{eb} = \frac{2}{3} h_a$.
- Then, the new effective antenna height is calculated as

$$h_{er} = \frac{1}{2} h_a - \left(h_a - \frac{2}{3} h_a\right) = \frac{1}{6} h_a.$$

Hence the reduction in gain is calculated as

$$G = 20 \log \left(\frac{1/6\, h_a}{2/3\, h_a} \right) = -12\,dB.$$

- Thus, the reduction in power value at both the cell site & mobile unit is by a factor '12 dB'
- Therefore, this method can be applied to certain extend for reducing CCI.

(3) In a Forest Region

- If trees available in the path of transmission of signal then there would be severe losses.
- Hence in forest areas reducing antenna height may not be good procedure to adopt for the sake of reducing co-channel interference.
- It is better to note that the antenna level should not be lower than the tree top level.

Antenna Parameters & their Effects

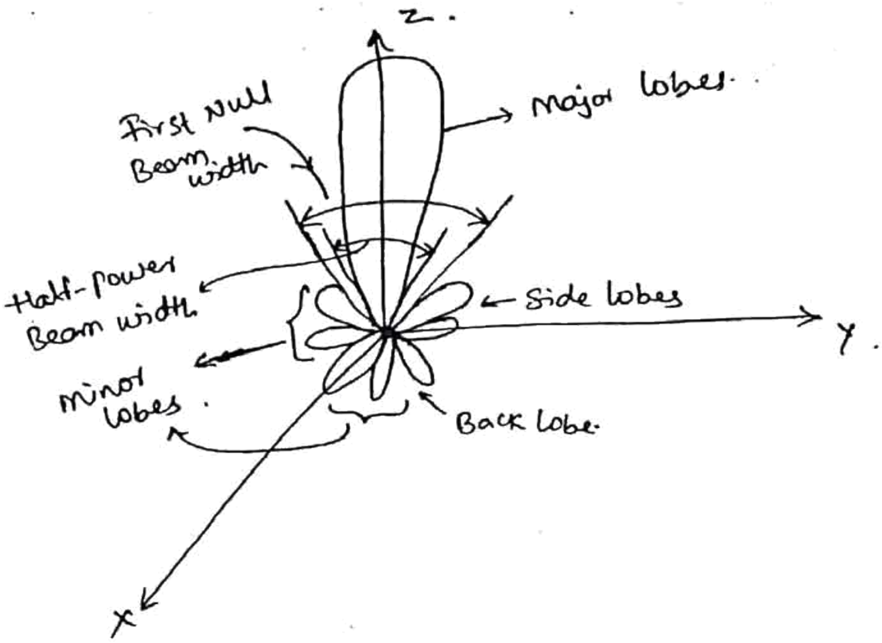
- The Performance of antenna can be described by various parameters. Every antenna parameter will effect on the performance efficiency of antenna.
- The different antenna parameters and their effects

1) Radiation pattern
2) Beamwidth
3) Gain
4) power density
5) Radiation intensity
6) Directivity
7) Efficiency
8) Effective aperture
9) Antenna Bandwidth
10) Front-to-Back ratio
11) Polarization
12) Input Impedance.

1) Radiation pattern

- An Antenna is a fundamental radiating component of an electrical system that links free space with the receiver.
- The energy radiated by an antenna is not uniform in all the directions. It is strong in one direction & weak or zero in some other direction.
- The amount of energy being radiated in a direction is measured as the field strength at a point located at distance from the antenna.
- The radiation pattern or an antenna pattern is nothing but a mathematical function or it is a graphical representation of radiation properties as a function of the space coordinates.

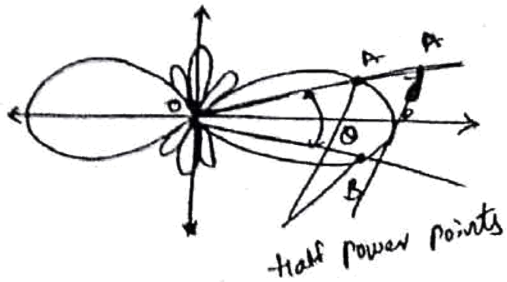
- The radiation pattern of antenna is usually measured in far-field.



- In the radiation pattern of antenna, the major & minor lobes are shown.
- The power received at a constant distance (radius) is known as power pattern. But graphical representation of spatial variation of magnetic or electric field along a constant distance (radius) is said to be a field pattern.
- If sidelobes are minimum or zero in a pattern such a system is said to be an efficient antenna system

(2) Beam width

For an antenna it is a measure of directivity. It is an angular width (in degrees) that is measured on the pattern between two points where the power radiated falls to half of it's maximum value. It is known as "half power Beam width."



Beam with Angle (AOB)

- In radiation pattern the angle 'AOB' is the beamwidth of antenna used.

Effects of Beam width: The direction of signal reception can be determined by the type of beam in the radiation pattern. It is known by a narrow beam.

$$\text{Directivity } D \propto \frac{1}{\text{Beam width}}$$

- Thus, if the beamwidth is narrow the directivity or gain of the antenna is high. The Beam width of antenna is affected by several factors like shape of radiation pattern, wavelength (λ), Radius of antenna aperture etc.

3) Antenna gain: The performance of antenna is measured in terms of gain.

- The directivity & gain are closely related.
- Directivity is a measure that expresses only the directional properties of antenna system.

But the term gain is defined as ratio of maximum radiation intensity in a particular direction to the maximum intensity from the reference antenna having power input level in same direction.

$$\text{Gain (G)} = \frac{\text{maximum radiation intensity from test antenna setup}}{\text{maximum radiation intensity from a reference antenna having same power output}}$$

- The gain defined above didnot include antenna efficiency. If the reference antenna is an isotrophic antenna with 100% efficiency η, the gain will be,

$$G = \frac{\text{max. radiation intensity w.r.t a test antenna}}{\text{Radiation intensity from an isotropic antenna}}$$

Directive gain: It is defined as the ratio of antenna radiation intensity in the direction to that of the average radiation power level.

$$\text{Directive gain} = \frac{\text{Radiation intensity in a given direction}}{\text{Average radiated power level}}$$

Power gain: In a given direction power gain is defined as the ratio of radiation intensity to that total average input power.

$$\text{Power gain} = G_p = \frac{\text{Radiation intensity in a particular direction.}}{\text{Total average power input.}}$$

4) Power density

- The electromagnetic waves are generally used to transport the data through a guiding medium or a wireless medium from one point to another point.

~~The electromagnetic waves are generally used to transport the data through~~

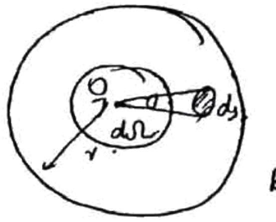
- The electromagnetic fields are associated with energy & power. The amount of power associated with it is expressed by an instantaneous poynting vector as,

$$\boxed{W = E \cdot H}$$

where W is instantaneous poynting vector
E is instantaneous electric field intensity
H is instantaneous magnetic field intensity

5) **Radiation intensity**: The radiation intensity in a direction is "The power per unit solid angle" or it is the power radiated from the antenna per unit solid angle. It is denoted as ϕ or U.

- The unit of the power & solid angle (in SI units) are watts & steradian and thus the radiation intensity quantity is watts per radian square.



Radiation intensity

- Let the ds is elemental surface area, r is the radius & dΩ be the solid angle

Then $d\Omega = \frac{ds}{r^2}$ or $ds = r^2 d\Omega$.

6) <u>Directivity</u>: It is nothing but the maximum directive gain of the antenna or the directivity of an antenna setup is defined as ratio of radiation intensity in a particular direction to the radiation intensity averaged in all the directions.

It is denoted as D.

$$D = \frac{\text{max. radiation intensity of the test or subject antenna.}}{\text{Avg. intensity of radiation of the test antenna.}}$$

- Directivity is dimensionless (constant quantity).
- If the solidangle is narrow then directivity will be high.

Directivity ∝ solid angle under measurement.

- D & G related as $\boxed{KD = G}$

K – efficiency factor
D – Directivity
G – Gain.

- If the losses are minimum in an antenna. Then gain G will be maximum and it will approximately equal to directivity D. Thus for a high efficient system the directivity will also be high.

• Efficiency factor $k = 1$ for 100% efficient system

$k < 1$ for a lossy system.

- Thus in designing an antenna for cell site directivity of antenna should be high.

7. **Efficiency:** The antenna efficiency is defined as the ratio of power radiated to that of the total power input given to the antenna. It is denoted as 'η'

$$\text{Antenna efficiency} = \eta = \frac{\text{Total power radiated}}{\text{Total input power}}.$$

- If the current I flows in antenna, then,

$$\eta = \frac{I^2 R_r}{I^2 (R_1 + R_r)} \quad (\text{or}) \quad \eta = \left(\frac{R_r}{R_1 + R_r}\right) 100\%$$

R_1 - ohmic loss Resistance of antenna.

R_r = Radiation resistance

$R_1 + R_r$ = Total effective resistance.

8. **Effective Aperture**

- The maximum effective aperture is denoted as effective aperture

- It is defined as the ratio of maximum received power to that of the power density of the incident wave.

$$\therefore A_{e(max)} = \frac{\text{Maximum received power}}{\text{Power density of incident wave}}$$

9) Antenna bandwidth:

The bandwidth of antenna is influenced by several Parameters and it is defined in many ways as listed below.

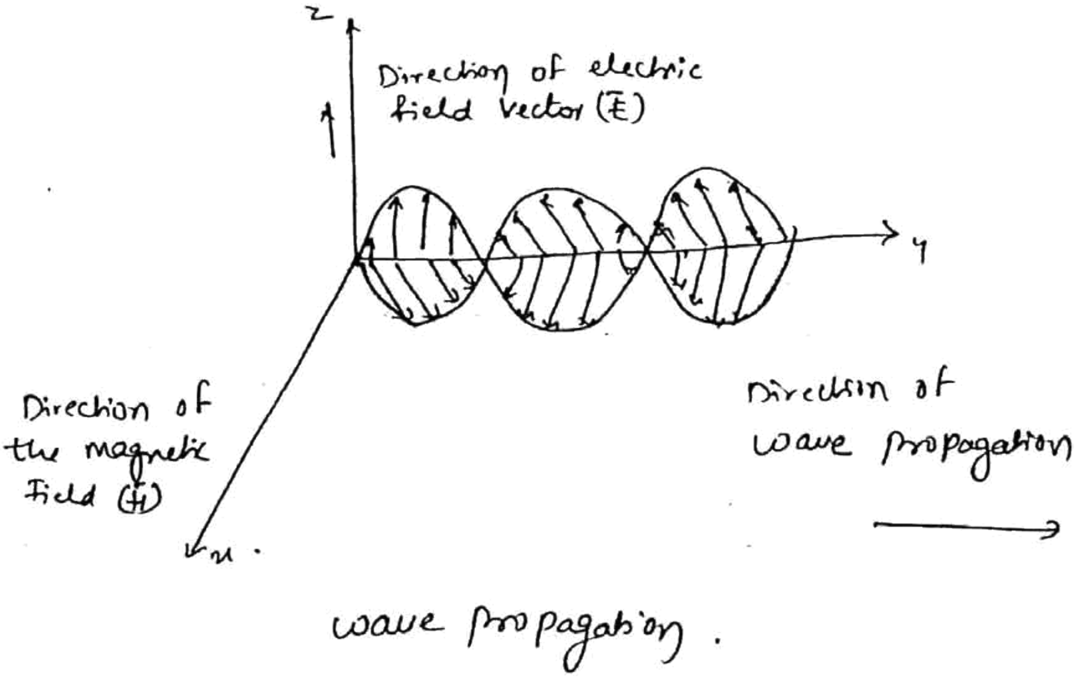
- Antenna bandwidth is defined as the range of frequencies in which the antenna performance meets a specific standard
- It is the bandwidth in which Gain (G) is higher than an acceptable value.
- It is the bandwidth in which the given front-to-back ratio (FTB) is achieved.
- It is the bandwidth in which the Standing wave Ratio (SWR) is maintained below the selected value.

10) Front-to-back ratio: The Front-to-back ratio is defined as the ratio of Power radiated in the desired direction to that of the power radiated in opposite directions.

$$FTB = \frac{\text{Power radiated in the desired direction}}{\text{Power radiated in the opp. direction.}}$$

11) <u>Polarization</u>: An antenna polarization is defined as the polarization of the wave radiated (transmitted) in a given direction.

- It describes above the electric vector quantity $\bar{E}$. The electric vector $\bar{E}$ & magnetic vector $\bar{H}$ are perpendicular to each other
- polarization of an electromagnetic wave is defined as the wave radiated or received by the antenna in a particular direction.
- The antenna is said to be either vertically polarized or horizontally polarized.
- If there is an undesired polarization from antenna is observed it is called as cross polarization.



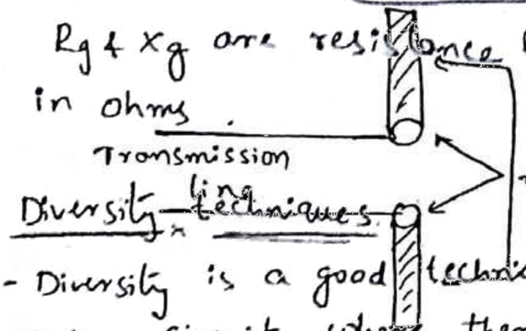
wave propagation.

12) Antenna input impedance:- The antenna input impedance or self impedance (i.e. the impedance at a point where input to antenna is supplied). It is also known as feed point impedance or driving point impedance.

- If the antenna is attached to generator 'g' which has internal impedance Z_g, showing the impedance that is offered to transmission line by antenna.

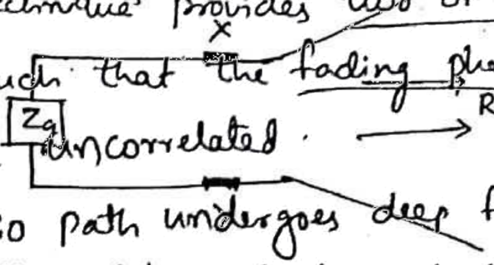
$$Z_g = R_g + jX_g$$

R_g & X_g are resistance & reactance of associated generator in ohms.



Transmission line with Antenna as load.

- In case if the antenna is loseless then the terminal impedance will be equal to the self-impedance of the antenna.



- Transmitting antenna input impedance ... terminal input.

- If input impedance where there is no load attached the antenna impedance is expressed as

$$Z_A = R_A + jX_A$$

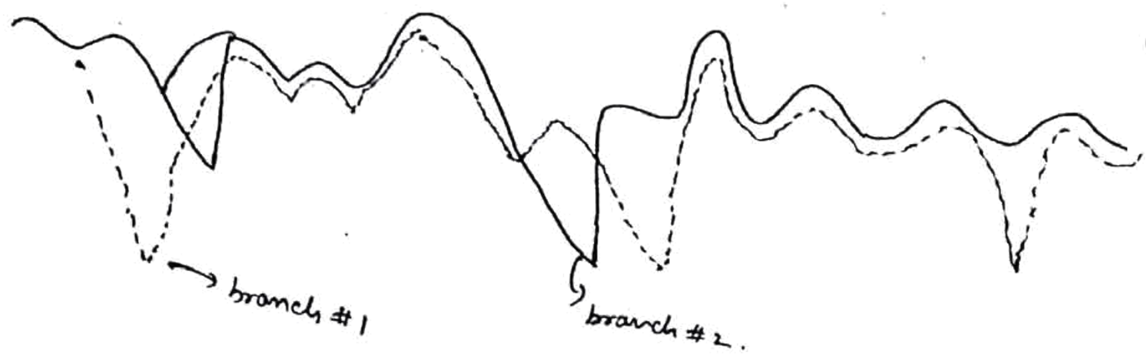
Z_A → Antenna impedance at terminal x-y in ohms

X_A → Antenna Reactance "

R_A → Antenna Resistance "

Diversity techniques

- Diversity is a good technique applied in mobile communication receiver circuits where there is multipath environments.
- Diversity scheme refers to a method for improving the reliability of a message signal by using two or more communication channels with different characteristics.
- Diversity technique provides two or more inputs at the receiver such that the fading phenomena among these inputs are uncorrelated.
- If one radio path undergoes deep fade at a particular point, another independent (or atleast highly uncorrelated) path may have a strong signal at input.
- If probability of a deep fade in one channel is p, then the probability for N channel is p^N.
- Diversity play an important role in combatting fading & cochannel interference and avoid error bursts.



Received signal level variations at various diversity branches.

Important Diversity Techniques:-

Types of Diversity techniques

1) Time diversity technique
2) Frequency diversity technique
3) Space diversity technique
4) Polarization diversity technique.
5) Directional diversity technique
6) path diversity technique.

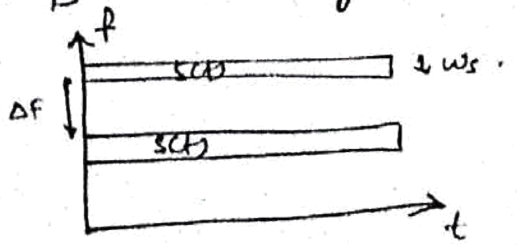
1) Time diversity technique:-

- In time diversity method, the information is transmitted repeatedly at specific time spacing that which would exceed the Coherence time of the mobile channel, and this will lead to repetition of signals for several times; irrespective of fading conditions.

- Thus, when an identical information is sent for different time slots, it is possible to obtain diversity branch signals.
- The time diversity technique is well suited for spread spectrum CDMA system, in which RAKE receiver is used for reception.

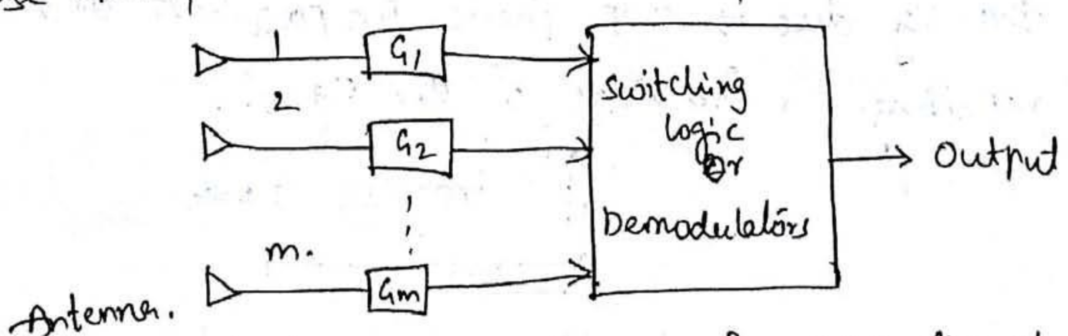
2) Frequency Diversity

- In this method of frequency diversity, the information is transmitted on many carrier frequencies.
- The idea behind this is that if the frequencies are separated by more than that of the Coherence Bandwidth of the mobile channel would be uncorrelated with each other and it will not experience same fading status.
- frequency diversity consumes extra Bandwidth.
- The frequency diversity scheme is applied in microwave field whenever line of sight (LOS) links is used, i.e. in LOS links they may carry many channels in the frequency division multiplex mode (FDM).
- There are chances of deep fades in frequency diversity due to tropospheric propagation and the resulting refractions of the signal.



3) Space diversity technique

- The space diversity scheme is also called as "antenna diversity scheme."
- In conventional methods of wireless communications, the availability of direct path between transmitter and receiver is not assured. Hence the occurance of Rayleigh fading will be present.
- In the space diversity scheme the receiver configuration is quite simple. Several number of diversity branches are selectable. For producing diversity reception at each and every cell site, multiple base station receiving antennas are used effectively.
- However, since the important scatterers are generally on the ground in the vicinity of the mobile, the base station antennas must be spaced considerably far apart to achieve decorrelation.
- separations on the order of several tens of wavelengths are required at the base station.
- space diversity can thus be used at either mobile or base station or both.



Generalized Block diagram for space diversity space diversity reception methods can be classified into four categories.

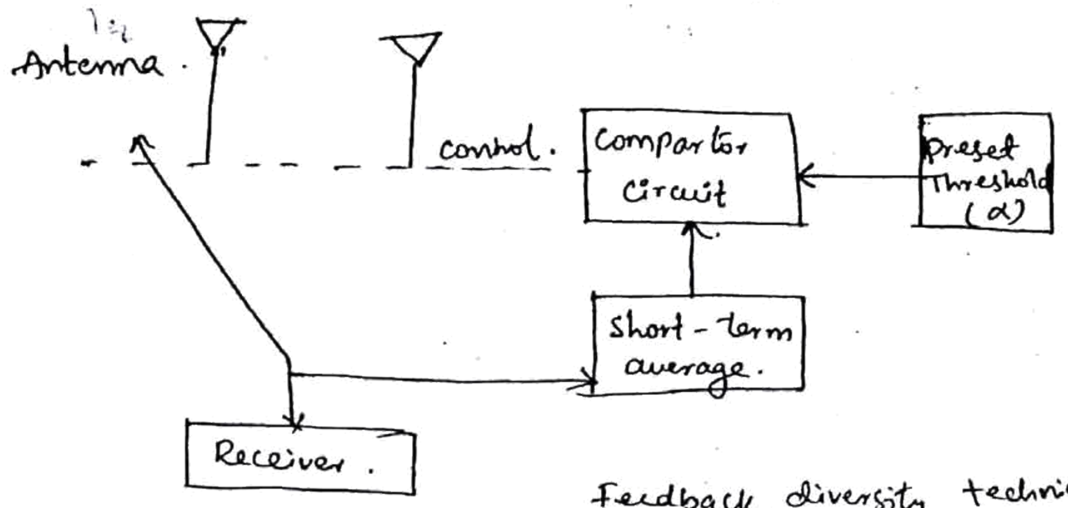
(a) Selective diversity
(b) feedback diversity
(c) maximal ratio combining
(d) Equal gain diversity combining.

(a) Selective diversity

- Selective diversity is the simplest diversity technique, where 'm' demodulators are used to provide 'm' diversity branches whose gains are adjusted to provide the same average SNR for each branch.
- Then antenna signals will be sampled.
- Finally the best signals that possess good signal strength will be sent to a demodulator.
- Practical diversity system has to be designed carefully such that reciprocal of that mobile signal fading rate is longer than the internal time constant values of selective diversity circuitry.

b) Feedback Diversity.

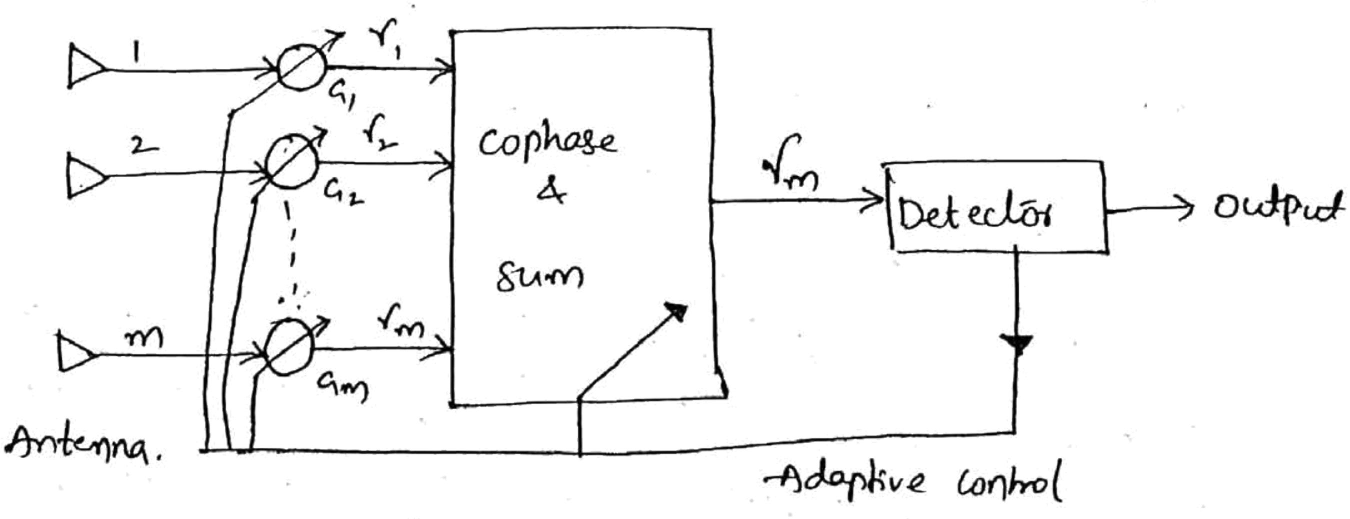
- The feedback diversity technique is also known as scanning diversity.
- In this method the 'n' signals are scanned in a proper sequence and monitored to pick a signal in the sequence which is above the preset threshold value say 'α'.



Feedback diversity technique.

- This signal is then received until it falls below threshold and the scanning process is again initiated.
- But the demerit of this method is that the fading level reduction is less than the other diversity techniques.
- The merit of this method is that it is very simple to implement - only one receiver is required.

c) Maximal Ratio combining Technique.



maximal Ratio combiner.

- In this method, the signals from all of the 'M' branches are weighted according to their individual signal voltage to noise power ratios and then summed.
- Here, the individual signals must be cophased before being summed, which generally requires an individual receiver and phasing circuit for each antenna element.
- In the output, signal of maximal ratio combiner will be such that the sum of individual signal to noise ratio (SNR) values will be equal to the SNR of output signal measured.

Advantages

1) maximal ratio combinerer generates an acceptable SNR value
2) Accuracy is high.
3) produces best reduction of fading.

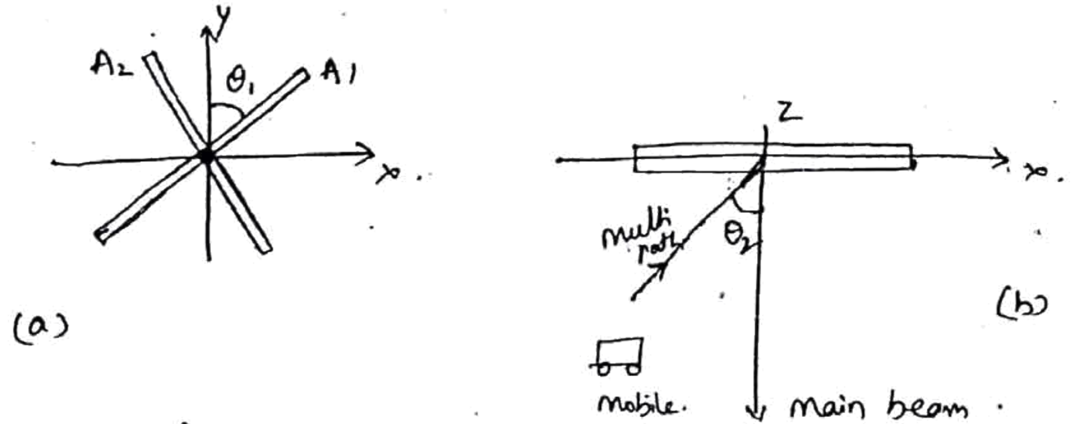
d) Equal gain combining.

- In the equal gain combining, all the diversity branches are coherently added with a same weighting factor.
- The signals from each branch are co-phased to provide equal gain combining diversity.
- when compared to maximal ratio combining, the configuration of this method is simple.
- one of the demerit of this method is that it degrades the SNR value by 0.5dB at the output of combiner if two branches are involved.

- If ten branches are involved in the reception, then the SNR degradation would be roughly upto 1dB value.

4) Polarization diversity

- In Polarization diversity both horizontal & vertical polarization are involved.
- In case if a signal is transmitted by a pair of polarized antennas and they are received by another pair of antennas, then two uncorrelated fading signals will be received because different fading variations are experienced by horizontal and vertical polarizations and due to different reflection coefficient values of the tall bulidings walls.
- The measured vertical & horizontal polarization signal paths between base station and mobile is found to be uncorrelated.
- There will be an amount of dependence of received polarization on transmitted polarization.
- It is interesting to note that whenever the radio path meets an obstacle the polarization diversity was observed to decrease the multipath delay spread with decreasing the power received.



model for the Base station
Polarization diversity

a) Polarization diversity w.r.t x-y plane
b) Polarization diversity w.r.t x-z plane.

- Consider that a signal is being transmitted with horizontal or vertical polarization from a mobile unit. This signal is received by polarization diversity antenna say with two diversity branches.

- Assume that the polarization diversity antenna consists of two antenna elements say A_1 & A_2 making an angle of $\pm\theta_1$ with that of the y axis. Then a mobile station is located in a particular direction that makes an ~~angle~~ offset angle θ_2 from the direction of mean beam of the diversity antenna.

- The two signals a & b that arrive at base station are

$$a = r_1 \cos(\omega t + \phi_1)$$

$$b = r_2 \cos(\omega t + \phi_2)$$

in which a and b are levels of the received signal when $\theta_2 = 0$, Assume that r_1 & r_2 possess independent Rayleigh distributions and the phase angles ϕ_1 & ϕ_2 have independent uniform distribution values.

- The correlation coefficient of the signals received at A_1 & A_2 can be determined by three factors

1) polarization Angle.
2) cross polarization discrimination
3) offset angle from that of the main beam direction of diversity antenna setup.

- Thus, polarization diversity is one of the best technique in diversity reception and it can be applied for mobile unit & base station..

5) Directional Diversity

- The received signals would arrive from different incident angles due to any one of the propogation mechanisms namely reflection diffraction or scattered signals around the mobile terminal.
- By using selective directive antennas the indepedent faded signals can be received. This type of diversity is suitable to apply in mobile terminal end where limited directions of signals at base station is linked.

6) Path Diversity

- In path Diversity method, the signals are coherently combined. That is both the direct & delayed signal components are combined together.
- Thus, the diversity branches are generated only after signal reception, and this method is also called as "Implicit diversity."

Advantages

1) No extra power is required
2) No extra antennas are required
3) No extra frequency spectrum is required.

Demerits

- This diversity method is very sensitive to Rayleigh fading conditions and hence the propagation path conditions has to be given more attention.

(3.1)

Co-channel Interference.

- The frequency-reuse method is useful for increasing the efficiency of spectrum usage but results in co-channel interference because the same frequency channel is used repeatedly in different cochannel cells.

Measurement of real time co-channel interference.

- when the carriers are angularly modulated by the voice signal and the RF frequency difference between them is much higher than the fading frequency, measurement of the signal carrier-to-interference ratio C/I reveals the signal is

$$e_1 = S(t) \sin(\omega t + \phi_1) \quad \text{--- (1)}$$

and the interference is

$$e_2 = I(t) \sin(\omega t + \phi_2) \quad \text{--- (2)}$$

The received signal is

$$e(t) = e_1(t) + e_2(t) = R \sin(\omega t + \psi) \quad \text{--- (3)}$$

where

$$R = \sqrt{[S(t)\cos\phi_1 + I(t)\cos\phi_2]^2 + [S(t)\sin\phi_1 + I(t)\sin\phi_2]^2} \quad \text{--- (4)}$$

and $$\psi = \tan^{-1} \frac{S(t)\sin\phi_1 + I(t)\sin\phi_2}{S(t)\cos\phi_1 + I(t)\cos\phi_2} \quad \text{--- (5)}$$

- The envelope R can be simplified in (4) & R^2 becomes

$$R^2 = \{S^2(t) + I^2(t) + 2S(t)I(t)\cos(\phi_1 - \phi_2)\} \quad \text{--- (6)}$$

UNIT II

NON – CO – CHANNEL INTERFERENCE

Content

- Adjacent channel interference
- Near end – far end interference
- Cross talk
- **Effect of coverage and interference by power decrease , Antenna height decrease**
- **Effect of cell site components**
- **UHF TV interference**

(UNIT-IV)

Non-Co-Channel Interference

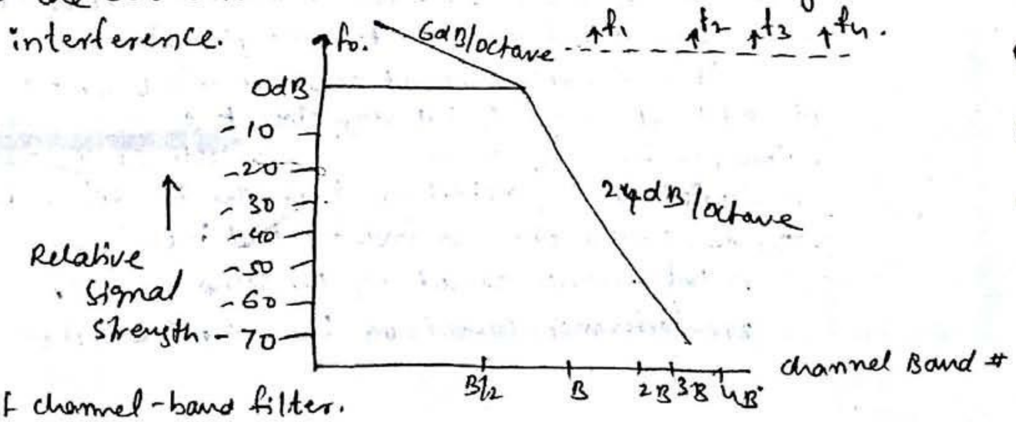
4.1

ADJACENT-CHANNEL INTERFERENCE

- Adjacent-channel interference is a broad term. It includes next-channel (the channel next to the operating channel) interference and neighbouring-channel (more than one channel away from the operating channel) interference.
- Adjacent-channel interference can be reduced by the frequency assignment.
- Adjacent-channel interference can be eliminated on the basis of the channel assignment, the filter characteristics and the reduction of near-end-far-end (ratio) interference.
- Adjacent channel interference is again classified into two types as mentioned
(i) Next-channel interference (ii) Neighbouring channel interference.

Next-channel interference.

- The next-channel interference will arrive at the mobile unit from other cell sites if the system is not designed properly.
- A mobile unit initiating a call on a control channel in a cell may cause interference with the next control channel at another cell site.
- The methods for reducing this next-channel interference use the receiving end.
- The channel filter characteristics are a 6 dB/oct slope in the voice band and a 24 dB/oct falloff outside the voice-band region.
- If the next-channel signal is stronger than 24dB, it will interfere with the desired signal. The filter with a sharp falloff slope can help to reduce all the adjacent-channel interference, including the next-channel interference.



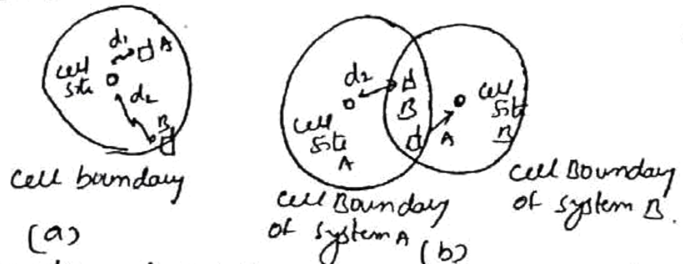
characteristics of channel-band filter.

Neighboring - channel interference

- The channels which are several channels away from the next channel will cause interference with the desired signal.
- usually, a fixed set of ~~varying~~ serving channels is assigned to each cell site. If all the channels are simultaneously transmitted at one cell site antenna, a sufficient amount of band isolation b/w channel is required to reduce intermodulation products. otherwise it will cause the interference.

Near-End-far-End Interference.

(1) In one cell: Because motor ~~veh~~ vehicles in a given cell are usually moving, some mobile units are close to the cell site and some are not.
- The close-in mobile unit has a strong signal which causes adjacent-channel interference
- In these situation near-end-far-end interference can occur only at the reception point in the cell site.

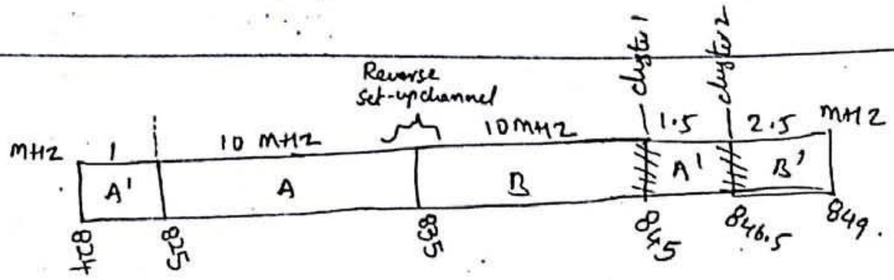


Near-end-far-end interference
(a) In one cell
(b) In two system cell

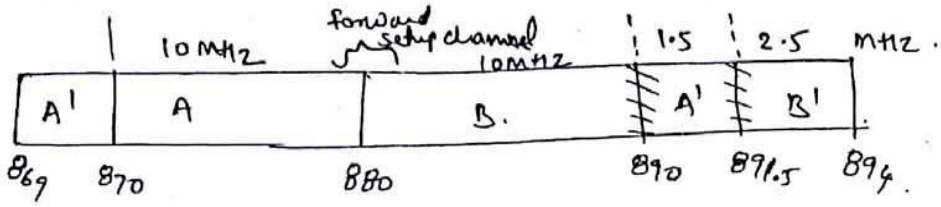
- If a separation of 5B (five channel Bandwidths) is needed for two adjacent channels in a cell in order to avoid the near-end-far-end interference, it is then implied that a minimum separation of 5B is required between each adjacent channel used with one cell.
- Because the total frequency channels are distributed in a set of frequency channels assigned in their corresponding cells C_1, C_2, C_3 & C_4. N cells, each cell only has $1/N$ of the total frequency channels.

(2) In cells of Two systems.

- In these case, adjacent channel interference can occur at both cell site & mobile unit.
- For instance, mobile unit 'A' can be located at the boundary of its own home cell 'A' in system 'A' but very close to cell 'B' of system "B".
- The other situation would occur if mobile unit B were at the boundary of cell B of system B but very close to cell "A" of system "A"
- Thus, the frequency channels of both cells of the two systems must be coordinated in the neighborhood of the two-system frequency bands.
- The two causes of near-end-far-end interference is
  1) Interference caused on the setup channels
  2) Interference caused on the voice channels.



Reverse channels.



Forword channels..

(1) Interference caused on the setup channels

- Two systems try to avoid using the neighborhood of the set-up channels.

(2) Interference caused on the voice channels

There are two clusters of frequency as shown in fig. which may cause adjacent-channel interference and should be avoided. The channel seporation can be based on two assumptions.

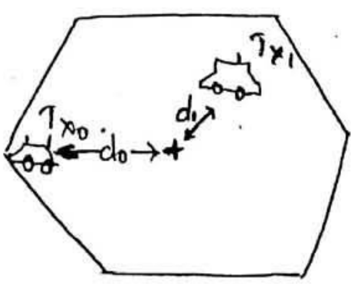
(a) Received interference at the mobile unit

The mobile unit is located away from its own cell site but only 0.25 mi away from the cell site of another system.

(b) Received interference at the cell site

The cell site is located 10 mi away from its own mobile unit but only 0.25 mi from the mobile unit of another system.

Effect on Near-end mobile units



d_0 = 10 miles

d_1 = 0.25 miles

T_{x0} = the desired Signal

T_{x1} = the interferred Signal.

Near-end-for-end ratio interference.

Avoidance of near-end-far-end interference

- The near-end mobile units are the mobile units which are located very close to the cell site. These mobile units transmit with the same power as the mobile units which are far away from the cell site.
- The distance d_0 between a calling mobile transmitter and a base station receiver is much larger than the distance d_1 between a mobile transmitter causing interference and the same base station receiver.
- Therefore, the transmitter of the mobile unit causing interference is close enough to override the desired base-station signal.
- This interference, which is based on the distance ratio, can be expressed as

$$\frac{C}{I} = \left(\frac{d_0}{d_1}\right)^{-\gamma} \quad \gamma \text{ - path loss slope.}$$

- The ratio d_1/d_0 is the near-end-far-end ratio.
- The effect of the near-end-far-end ratio on the carrier-adjacent-channel interference ratio is dependent on the relative positions of the moving mobile units.
- For example, if the calling unit is 10 miles away from base station receiver and mobile unit causing the interference is 0.25 miles away from the base station receiver, for interference received at base station with $\gamma=4$ the carrier-to-interference ratio is given by.

$$\frac{C}{I} = \left(\frac{d_0}{d_1}\right)^{-\gamma} = \left(\frac{10}{0.25}\right)^{-4} = (40)^{-4} = -64\,dB$$

- This means that the interference is stronger than the desired signal by 64 dB. And this is reduced only by frequency separation with narrow filter characteristics.
- For reducing this type of interference a frequency separation with narrow filter characteristics.
narrow filter characteristics. 'B' & 'L' is the filter characteristics
- Consider a filter of channel 'B' & 'L' is the filter characteristics then, the required channel separation is given by

$$\boxed{\text{Frequency band separation} = 2^{G-1} B}$$

where
$$\boxed{G = \frac{\gamma \log_{10} \frac{d_0}{d_1}}{L}}$$

* dBi - decibel isotropic * dBm decibel milliwatt

Non-linear Amplification

- when the near-end mobile unit is close to the cell site, its transmitted power is too strong and saturates the IF log amplifier if the received signal at the cell site exceeds -55 dBm.
- Assume that the mobile unit transmitted power is 36dBm and the antenna gain is 2dBi. The power plus gain is 38dBm. The receiver power is -55dBm at the cell site.
- The propogation loss L = 38 dBm - (-55 dBm) = 93dB.
- The free space loss, which is the maximum distance within which the saturation of the IF amplifier will occur.
- The calculation of free-space loss versus distance at 850MHz is as follows

$$-55\text{dBm} = 10\log\frac{P}{(4\pi)^2(d/\lambda)^2}$$

$$= 38\text{dBm} - 20\log 4\pi - 20\log(d/\lambda)$$

$$20\log_{10}(d/\lambda) = 55 + 38 - 22 = 71$$

$$(d/\lambda) = 10^{71/20} = 3548$$

$$d = 3548\lambda = 4115\text{ ft} = 1241\text{ m} = 1.24\text{ km}.$$

- This means that when the mobile unit is within 1.24 km of the cell site boundary, it is possible to saturate the IF Amplifier, and it is likely that intermodulation will be generated because of the nonlinear portion of the characteristics.
- If the intermodulation (Im) product matches the frequency channel of another mobile unit far away from the cell sites where reception is weak, then the IM can interfere with the other frequency received at the cell site.

CROSS TALK.

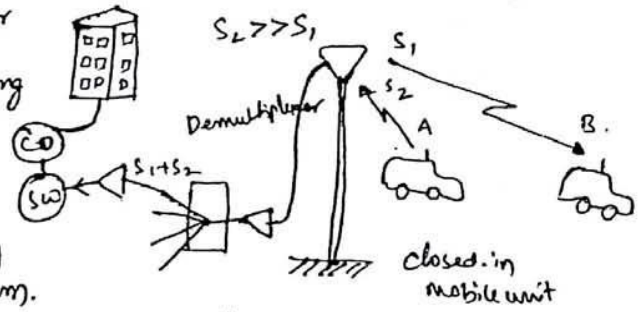
- when the cellular Radio system was designed, the system was intended to function like a telephone wire line.
- In a mobile cellular system there is a pair of frequencies, occupying a bandwidth of 60kHz, which we simply call a "channel".
- Because of paired-frequency, coupling through the two-wire-four-wire hybrid circuitry at the telephone central office, it is possible to hear voices in both frequencies, simultaneously while scanning on only one frequency in the air.

A frequency of 30kHz for Received path & other 30 kHz for a transmitted path.

- This phenomenon doesnot annoy cellular mobile users; when they talk they also listen to themselves through the phone receiver. They are not even aware that they are listening to their own voices.
- This unnoticeable cross-talk phenomenon in frequency pairs has no major impacts on both wire telephone line & cellular mobile performance
- But when real cross talk occurs it has a larger impact on the cellular mobile system than on the telephone line, because the amount of cross talk could potentially be doubled since cross talk occurring on one frequency will be heard on the other (paired) frequency.
- The cross talk effect is twofold.

A number of situations are conducive to cross talk.

- **Near-end mobile unit**
  - cross talk can occur when one mobile unit (A) is very close to the cell site and other (B) is far from the cell site.
  - Both units are calling to their land-line
  - The strong signal can generate strong cross talk while the received signal from mobile unit B is 30dB weaker than signal A.
  - Near-end mobile units can belong to one system or to another system.



Cross-talk Phenomenon.

If the foreign (another) system units are operating in the new allocated spectrum channels, cross talk can occurs.
- when the mobile unit is close to the cell site & the cell site is capable of reducing the power of the mobile unit, the near-end mobile interference can be reduced.

- **Close-in mobile unit**
  - when the mobile unit is very close to the cell site and if the reception at the cell site is greater than -55dBm, the channel preamplifier at the cell site can become saturated & produce IM as a result of the non-linear portion of the amplification.
  - These IM products are the spurious (unwanted freq) signal which leaks into the desired signal & produces cross talk.

Co-channel cross talk

The cochannel interference reduction ratio 'q' should be as large as possible to compensate for the cost of site construction and the limitation of available channels at each cellular site.

The channel combiner

- The signal isolation among the forward voice channels in a channel combiner is 17dB.
- The loss resulting from inserting the signal into the combiner is about 3dB.
- The requirement of IM product suppression is about 55dB. If one outlet is not matched well, the signal isolation is less than 17dB. Therefore, for each channel an isolator is installed to provide an additional 30-dB of isolation with a 0.5 dB insertion loss.
- This isolator prevents any signal from leaking back to the power amplifier.

Telephone-line Cross Talk

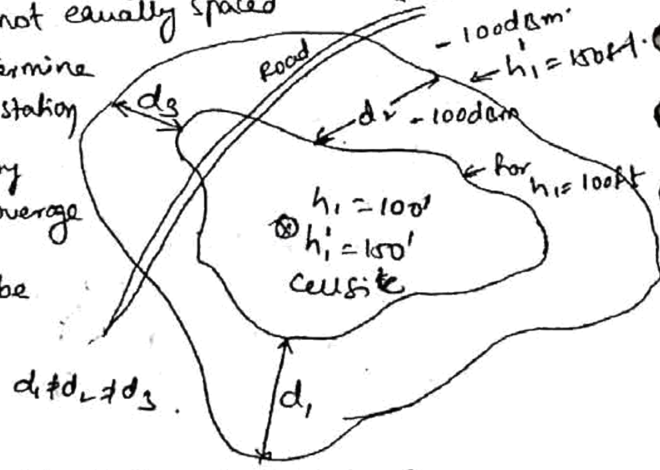
- Sometimes cross talk can result from cable imbalance or switching error at the central office and be conveyed to the customer through the telephone line.
- Minimize this type of cross talk, should be given the same priority as reducing the no. of call drops.

EFFECT ON COVERAGE AND INTERFERENCE BY APPLYING POWER DECREASE, ANTENNA HEIGHT DECREASE

- Communication engineers sometimes encounter situations where coverage must be reduced to compensate for interference.
- There are several ways of doing this
 (i) Reorienting the directional-Antenna patterns
 (ii) changing the antenna beamwidth
 (iii) synthesizing the antenna pattern
 (iv) Decreasing the power
 (v) Decreasing the Antenna height.

Choosing a proper cell site

- A typical contour is shown. Because of the irregular terrain contours, contours between different reception levels are not equally spaced
- when a cell site is selected, we must determine whether an ultra high frequency (UHF) TV station is nearby and whether any future nearby ongoing construction would affect signal coverage from the cell site later.
- we must check the local noise level and be sure that no spurious signals fall in the cellular frequency band.



Signal strength Contour shape.

- Finally, if we are using an existing multiantenna tower, we must ensure that the grounding and shielding are adequate. Otherwise the interference level could become very high and weaken cell-site operation.

Power decrease.

- As long as the setup of the antenna configuration at the cell site remains the same, and if the cell-site transmitted power is decreased by 3dB, then the reception at the mobile unit is also decreased by 3dB.
- This is one-on-one (i.e. linear) correspondence and thus is easy to control

Antenna height decrease.

- When antenna height is decreased, the reception power is also decreased

$$\text{Antenna height gain (or loss)} = 20 \log \frac{h'_{e_1}}{h_{e_1}}$$

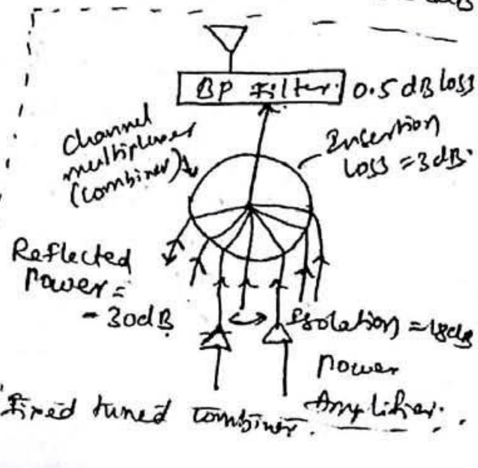
- The formula is based on the difference between the old & new effective antenna heights and not on the actual antenna heights.
- The effective antenna height is the same as the actual antenna height only when the mobile unit is travelling on flat ground.
- For decreasing antenna height in a hilly area, the signal-strength is different from the situation of power decrease. Therefore a decrease in antenna height would affect the coverage; thus antenna height becomes very difficult to control in an overall plan.

EFFECTS OF CELL-SITE COMPONENTS.

(i) Channel combiner: - At the transmitter side a fixed tuned channel combiner unit is used. In every cell site also a channel combiner circuit is installed.

* fixed channel combiner at the transmitting end.

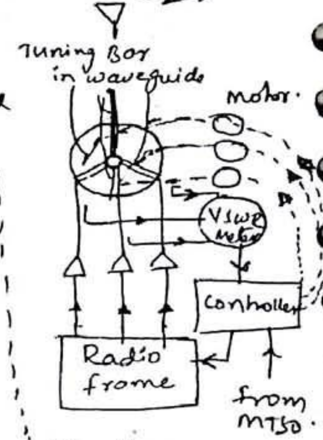
- But if the channels in the system if each one of them is feed to their own antenna then it is possible to eliminate the necessity of a channel combiner.
- The transmitted channels has to be combined with two main criteria namely
(i) maximum signal isolation between the radio channels
(ii) minimum insertion loss.
- A conventional combiner has a 16-channel combined capacity based on the frequency subset of 16-channels and it causes each channel to lose 3dB from inserting the signal through the combiner.
- The signal isolation is 17dB because each channel is 630kHz or 21 channels apart from neighbouring channels.
- The intermodulation at the multiplexer is controlled by ferrite isolators, which provide a 30dB reverse loss.
- The intermodulation (IM) products are atleast 55dB down from the desired signals.
- Therefore, the IM will not affect channels within the transmitted band design from this



- Each cable fed into a combiner must be properly shielded. Because it is a nonlinear device, undesired signal leakage into another channel would occur before the combiner can produce the IM products, which would in turn, produce cross-coupled interference. Therefore proper shielding & impedance match are very important.

A Frequency agile combiner

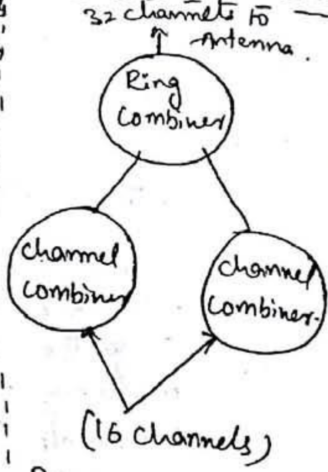
- This combiner is capable of retuning to any frequency by remote control in real time. The remote control device is a microprocessor.
- The combiner is a waveguide-resonator combiner with a tuning bar in each input waveguide.
- The bar is mechanically rotated by a motor and the voltage standing wave ratio (VSWR) can be measured when the motor starts to turn.
- The controller receives an optimum reading after a full turn and is stopped at that position by the controller.
- The controller also have self-adjusted potential.
- This combiner can be used when a dynamic frequency assignment is applied.
- This kind of combiner can also be designed to be tuned electronically.



Tunable combiner.

A Ring Combiner.

- A Ring combiner is used to combine two groups of channels into a single output.
- The insertion loss is 3dB & the signal isolation between channels is 35 to 40dB.
- The function of Ring combiner is to combine two 16-channel combiners into one 32-channel output. Therefore all 32-channels can be used by a single transmitting antenna.
- If all the channel-transmitted power are low, it is possible to combine more than 32 channels by using two or three ring combiners before feeding them into one transmitting antenna.
- The frequency offset of 315kHz is between two regular combiners.



RING COMBINER.

(ii) Demultiplexers at the Receiving end.

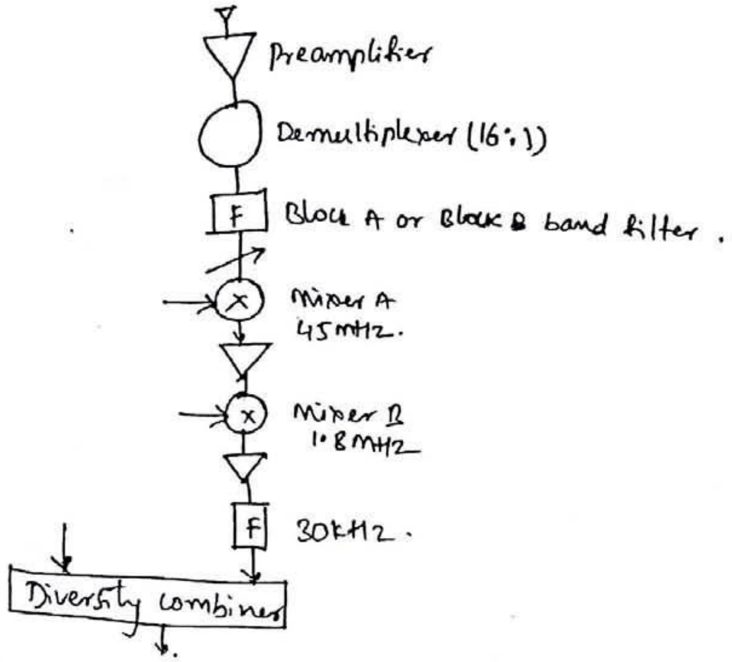
- A demultiplexer is used to receive 16-channels from one antenna.
- Then each receiving antenna output passes through a 25-dB gain amplifier to a demultiplexer.
- The demultiplexer output has a 12-dB loss from the split of 16-channels

$$\text{Split Loss} = 10 \log 16 = 12\,dB$$

- The IM product at the output of the demultiplexer should be 65 dB down
- If the undesired mobile unit is close to the cell site, then the preamplifier becomes saturated & generated IM at the output of the amplifier these IM products could be felt in one of the weak signal.

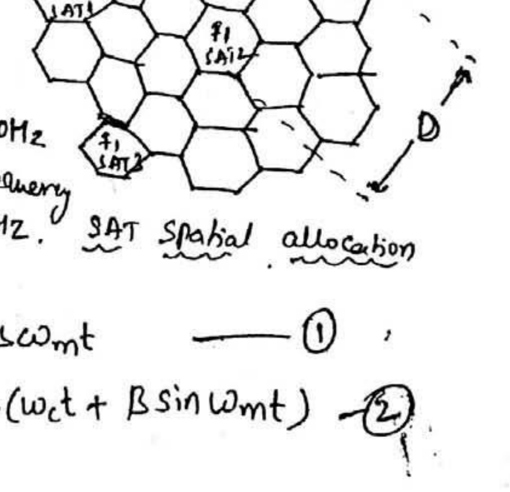
(iii) SAT Tone..

A typical cell-site channel Receiver.



(iii) SAT Tone.

- The major function of a supervisory Audio tone (SAT) is to ensure that a SAT Tone is sent out at the cell site, is received by the mobile unit on a forward voice channel, is converted on a corresponding reverse voice channel, and is then sent back to the cell site within 5s. If the time out is more than 5s, the cell site will terminate the call.
- Every cell site has been assigned to one of three sat tones.
- The cells have the same SAT tones, and the same channels are separated by $\sqrt{3}D$, which is farther than the co-channel distance D.
- Therefore, a receiver located at either the cell site or at the mobile unit receiving the same frequency with different SAT tones will terminate the call.



SAT Spatial allocation

Characteristics of SAT

- There are three SAT tones 5970Hz, 6000Hz, 6030Hz spaced 30Hz apart. They are narrowband frequency modulated (FM) with a deviation of $f_\Delta = 2\,kHz$. The modulation index is $\beta = 1/3$.
- Let SAT tone signal be $x(t) = A_m \cos \omega_m t$ —— (1)

Modulated carrier is $x_c(t) = A_c \cos(\omega_c t + \beta \sin \omega_m t)$ —— (2)

where $\beta = (A_m f_\Delta / f_m)$.

- Let the Amplitude modulation $A_m = 1$, thus, since β is small, ② becomes

$$x_c(t) = A_c \cos(\omega_c t) + \frac{A_c \beta}{2} \times \cos[2\pi(f_c+f_m)t] - \frac{A_c\beta}{2}\cos[2\pi(f_c-f_m)t]$$

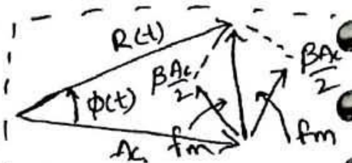
$$= R(t)\cos[\omega_c t + \phi(t)] \quad \text{—— ③}$$

where

$$R(t) \simeq \sqrt{A_c^2 + \left(2\,\frac{\beta}{2} A_c \sin\omega_m t\right)^2}.$$

$$= A_c\left[1 + \frac{\beta^2}{4} - \frac{\beta^2}{4}\cos 2\omega_m t\right] \quad \text{—— ④}$$

$$\phi(t) \simeq \arctan\left[\frac{2(\beta/2)A_c \sin\omega_m t}{A_c}\right] \simeq \beta \sin\omega_m t \quad \text{—— ⑤}$$



Narrowband FM for SAT

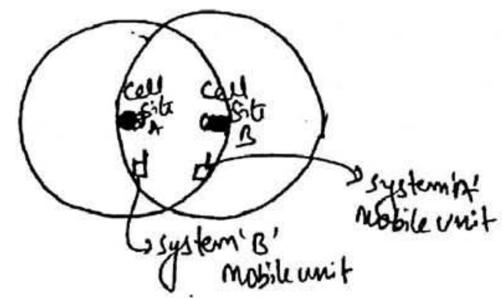
- Eq ④ Represents an FM condition in which the amplitude of the carrier always remains constant.
- The filter bandwidth of the SAT tone detector relates to call-drop timing, which should be based on the unacceptable voice quality level.
- In theory this level is different in different environment. Usually the smaller the filter bandwidth, the lower the call drop rates. But the voice quality may be very poor before dropping the calls.

Interference between Systems.

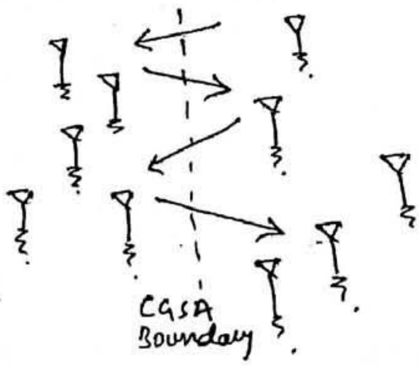
- The interference between the systems can be analyzed w.r.t one city or with consideration of adjacent cities also.

In one city

- Let us assume that there are two systems operating in one city, if a mobile unit of system A is closer to a cell site of system B while a call is being initiated through system A, adjacent channel interference or IM can be produced if the transmitted frequency of mobile unit A is close to the convered band of the received preamplifier at cell site B.



Intersystem Interference.



- These IM products will then leak into the receiving channel of system B and cross talk will occur. This cross talk can be heard not only at the land-line side but also at the mobile unit because of the unique characteristics
- This cross talk situation can be reduced by any of the following measures
(i) All cell sites in the two systems can be located together (colocated)
(ii) Adjacent channels (4 or 5 channels) at each interface of the ~~no~~ newly assigned voice channels between two of the systems should be done.
(iii) To prevent a strong mobile signal from saturating the preamplifier at the cellsite, a foreign-system signal should be -55 dBm down from the cell-site reception point.

In adjacent cities

- Two systems operating at the same frequency band and in two adjacent cities or areas may interference with each other if they donot coordinate their frequency channel use. Most cases of interference are due to cell sites at high altitudes.
- In any start-up system, a high-altitude cell site is always attractive to the designer. Such a system can cover a larger area, and, in turn, fewer cell sites are needed. However, if the neighbouring city also uses the same system block, then the result is strong interference, which can be avoided by the following methods.
(i) The operating frequencies should be coordinated between two cities. The frequencies used in one city should not be used in the adjacent city. This arrangement is useful only for two low-capacity systems.
(ii) If both systems are high capacity, then decreasing the antenna heights will result in reduction of the interference not only within each system but also b/w the two systems.
(iii) Directional antennas may be used.

UHF TV Interference

- Two types of interference can occur between UHF television & 850 MHz cellular mobile phones.

Interference to UHF TV receivers from cellular mobile transmitters.

- A wide range of frequency band separation is available between the UHF TV broadcast transmitters & the cellular mobile phones & hence there is only a less risk of interference from cellular mobile phone towards the TV transmitters.
- But ~~it~~ if the cell site transmission frequency is approximately 90 MHz above that of the towards a television transmitter or if the cell-site receiver is at a distance of 2 mt or less than 1 mt away from the television station it may induce image interferences.

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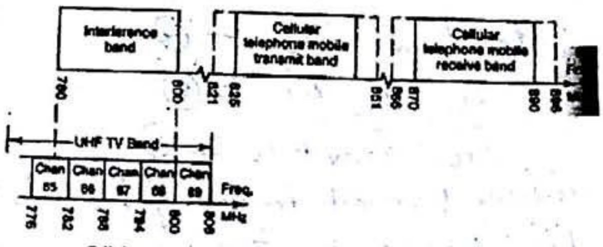

Cellular telephone frequency plan.

- Some UHF TV channels overlap cellular mobile channels.
- These two types of services can interfere with each other only under the following conditions

(i) Band region with overlapping frequencies: Two services have been authorized to operate within the same frequency band region.

(ii) Image interference region: The TV receiver or the cellular receiver can receive two transmitted signals, for instance, one from a TV channel & one from a cellular system, and produce a third-order intermodulation product which falls within the TV or the mobile receive band.

Let

f_{TM} = mobile transmit frequency

= f_{RC} = cell-site receive frequency = $f_{TC} - 45$ MHz

f_{RM} = mobile Receive frequency

= $f_{TM} + 45$ MHz = cell site transmit frequency.

$f_{T,TV}$ = TV transmit frequency.

$f_{R,TV}$ = TV Receive frequency

- Third-order intermodulation gives the following results in two cases of interfering UHF TV receivers.

<u>Case 1</u>: Let

$$2 f_{TM} - f_{T,TV} = f_{RM} \quad \text{—①}$$

$$f_{TM} = f_{RM} - 45 \quad \text{—②}$$

then $$f_{TM} = f_{T,TV} + 45 \quad \text{—③}$$

Since the mobile transmit frequency f_{TM} lies in the 825-to 845 MHz band, and the TV transmit frequency $f_{T,TV}$ lies in the 780-to 800 MHz band, f_{TM} will interfere with the TV receiver, This interference region is called the image interference region.

Case(ii) Let $2f_{RC} - f_{T,TV} = f_{TC}$ — (4)

$f_{RC} = f_{TC} - 45$ — (5)

$f_{TC} = f_{T,TV} + 90$ — (6)

Because the cell-site transmit frequency f_{TC} lies in the 870 to 890 MHz band & $f_{T,TV}$ lies in the 780 to 800MHz band, f_{TC} will interfere with the TV receiver. This interference region is called the image interference region.

- In these two cases an image-interference rejection range of 40 to 50 dB isolation across the UHF TV band is required to prevent this interference. The results from the two cases are as follows

Case 1: when the mobile transmitter is located near a TV receiver

• The minimum grade B television service contour of an accepted TV receiver level is -63 dBm with a receiver antenna gain of 6dB reffering to dipole gain

• Since the cellular telephone mobile unit has an effective radiated power of about 37dBm, the path loss between the TV receiver & mobile unit must exceed 100dB (-63+37).

Case 2:- when the cell site transmitter is located near a TV receiver.

Interference of cellular mobile receivers by UHF TV transmitters

- This type of image interference can occur in the following four cases.

Here the image-interference region will be the same as that described in previous section but in reversed direction.

Case 1:- Let $2f_{TM} - f_{T,TV} = f_{Rm}$

then $2f_{TM} = 2(f_{Rm} - 45)$

& $f_{T,TV} = 2f_{TM} - f_{Rm} = f_{Rm} - 90$ MHz.

Because the mobile unit receiver frequency f_{Rm} lies in the 870-890MHz band, $f_{T,TV}$ which lies in the 780-800 MHz band, will interfere with the mobile unit receiver.

Case 2: Let $2f_{RC} - f_{T,TV} = f_{TC}$

Then $f_{RC} = f_{TC} - 45$

& $f_{RC} = 2f_{RC} - f_{T,TV} - 45 = f_{T,TV} + 45$

Since the cell-site Receiver frequency f_{RC} lies in the 825-to 845 MHz band $f_{T,TV}$, which lies in the 780-to-800MHz band, will interfere with the cell-site receiver

- There are two additional, but less important, cases.

<u>case 3</u>: when a mobile Receiver approaches a TV transmitter, it is easy to find that transmission from the TV station will not interfere with the reception at the mobile receiver

<u>case 4</u>:

- when the cell-site receiver is only 1 mi or less away from the TV station, interference may result.
- when the cell-site is very close to the TV station, the interference decreases as a result of the two vertical narrow beams pointing at different elevation levels.
- It is advisable to mount a cell-site antenna in the same vicinity as the TV station antenna if the problems of shielding and grounding can be controlled.