CELLULAR & MOBILE COMMUNICATION

LECTURE NOTES

B.TECH (IV-I SEM-R20)

(2023-24)

PREPARED BY

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JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B.Tech (ECE)– IV-I Sem

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(20A04703c) CELLUAR & MOBILE COMMUNICATIONS
(Professional Elective Course –V)

Course Objectives:

- To explain cell coverage for signal and traffic, diversity techniques and mobile antennas by the use ofEngineering Mathematics.
- To present impairments due to multipath fading channel, fundamental techniques to overcome different fading effects, frequency management, Channel assignment and types of handoffs.
- To teach concepts and solve problems on mobile antennas and cellular systems.

Course Outcomes:

- Know about cell coverage for signal and traffic, diversity techniques and mobile antennas by the use ofEngineering Mathematics
- Explain impairments due to multipath fading channel, fundamental techniques to overcome differentfading effects, frequency management, Channel assignment and types of handoff
- Apply concepts to solve problems on mobile antennas and cellular systems
- Analyze Co-channel and Non Co-channel interferences, different Hand-offs and dropped call rates
- Evaluate performance of dropped call rate and false alarm rate
- Compare different handoffs

UNIT I

Introduction to Cellular Mobile Radio Systems: Limitations of Conventional Mobile Telephone Systems, Basic Cellular Mobile System, Uniqueness of Mobile Radio Environment, Mobile Fading Characteristics, Operations of Cellular Systems, Evolution of Cellular Systems.

Fundamentals of Cellular Radio System Design: Concept of Frequency Reuse, Co-Channel Interference, Co- Channel Interference Reduction Factor, Desired C/I from a Normal Case in an Omni Directional Antenna System, System Capacity, Trunking and Grade of Service, Improving Coverage and Capacity in Cellular Systems- CellSplitting, Sectoring, Microcell Zone Concept.

UNIT II

Cell Coverage for Signal and Traffic: Signal Reflections in Flat and Hilly Terrain, Effect of Human Made Structures, Phase Difference between Direct and Reflected Paths, Constant Standard Deviation, Straight Line Path Loss Slope, General Formula for Mobile Propagation Over Water and Flat Open Area, Near and Long Distance Propagation, Path Loss from a Point to Point Prediction Model in Different Conditions, Merits of Lee Model.

Cell Site and Mobile Antennas: Space Diversity Antennas, Umbrella Pattern Antennas, Minimum Separation of Cell Site Antennas, Mobile Antennas.

UNIT III

Co-Channel Interference Reduction: Measurement of Real Time Co-Channel Interference, Design of Omnidirectional and directional Antenna System, Antenna Parameters and Their Effects, Diversity Techniques-Space Diversity, Polarization Diversity, Frequency Diversity, Time Diversity.

Non-Co-Channel Interference: Adjacent Channel Interference, Near End Far End Interference, Cross Talk, Effects on Coverage and Interference by Power Decrease, Antenna Height Decrease, Effects of Cell Site Components.

UNIT IV

Frequency Management and Channel Assignment: Numbering and Grouping, Setup Access and Paging Channels, Channel Assignments to Cell Site and Mobile Units, Channel Sharing and Borrowing, Sectorization, Overlaid Cells, Non Fixed Channel Assignment.

UNIT V

Handoffs and Dropped Calls: Handoff Initiation, Types of Handoff, Delaying Handoff, Advantages of Handoff, Power difference Handoff, Forced Handoff, Mobile Assisted and Soft Handoffs, Intersystem Handoff, Introduction to Dropped Call Rates and their Evaluation.

System Evaluation: Performance Evaluation, Blockage, Dropped-call rate, Signaling Evaluation- False Alarm Rate, Word error rate consideration and calculations, Measurement of averaged received signal level and level crossings.

Textbooks:

1. W.C.Y. Lee, Mobile Cellular Telecommunications, McGraw Hill, 2nd Edn., 1989.
2. Theodore. S. Rapport, Wireless Communications, Pearson Education, 2nd Edn., 2002.

References:

1. W.C.Y Lee, Mobile Communications Engineering-Theory and Applications, McGraw Hill, Second Edition, ,2014.
2. Gordon L. Stuber, Principles of Mobile Communications, Springer International, 2nd Edn., 2001.
3. Simon Haykin, Michael Moher, Modern Wireless Communications, Pearson Education, 2005.

UNIT-II (A)

CELL COVERAGE FOR SIGNAL AND TRAFFIC

SIGNAL REFLECTIONS IN FLAT AND HILLY TERRAIN

The ground incident angle and the ground elevation angle over a communication link are described as follows. The ground incident angle 0 is the angle of wave arrival incidentally pointing to the ground as shown in Fig. 1.1. The ground elevation angle is the angle of wave arrival at the mobile unit as shown in Fig. 1.1

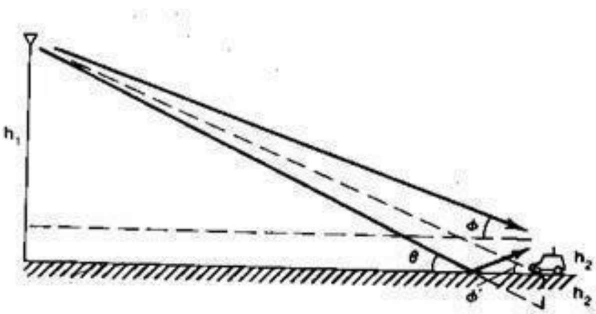

Figure 1.1 Representation of Ground Incident Angle θ and Ground Elevation Angle φ

Based on Snell's law, the reflection angle and incident angle are the same. Since in graphical display we usually exaggerate the hilly slope and the incident angle by enlarging the vertical scale, as shown in Fig. 1.2, then as long as the actual hilly slope is less than 100, the reflection point on a hilly slope can be obtained by following the same method as if the reflection point were on flat ground. Be sure that the two antennas (base and 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 and the vertical stands for two antennas are correct. The scale drawing in Fig. 1.2 is somewhat misleading however, it provides a clear view of the situation.

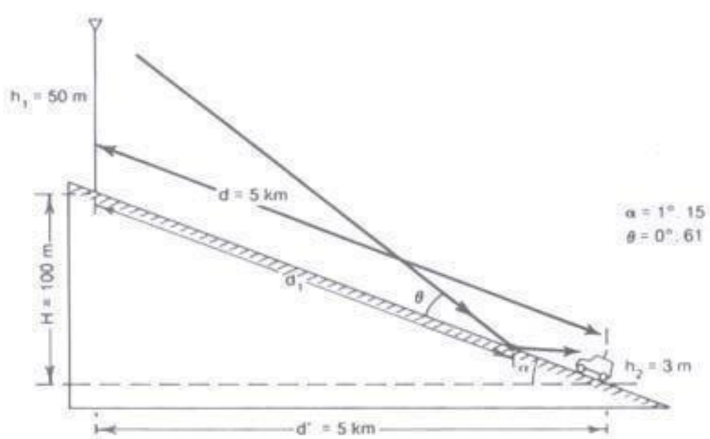

Fig 1.2 Ground reflection angle and reflection point

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 separate these two. The way to factor out the effect due to the terrain configuration from the man-made 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. This means that the different path loss curves obtained in each city show the different human-made structure in that city. To do this, we may have to measure signal strengths at those high spots and also at the low spots surrounding the cell sites, as shown in Fig. 4.3*a*. Then the average path loss slope (Fig. 4.3*b*), 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. We are using 1-mi intercepts (or, alternatively, 1-km intercepts) as a starting point for obtaining the path loss curves.

Therefore, the differences in area-to-area prediction curves are due to the different man-made structures. We should realize that measurements made in urban areas are different from those made in suburban and open areas. The area-to-area prediction curve is obtained from the mean value of the measured data and used for future predictions in that area. Any area-to-area prediction model[1–28] 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[10] can be represented by two parameters. (1) the 1-mi (or 1-km) intercept point

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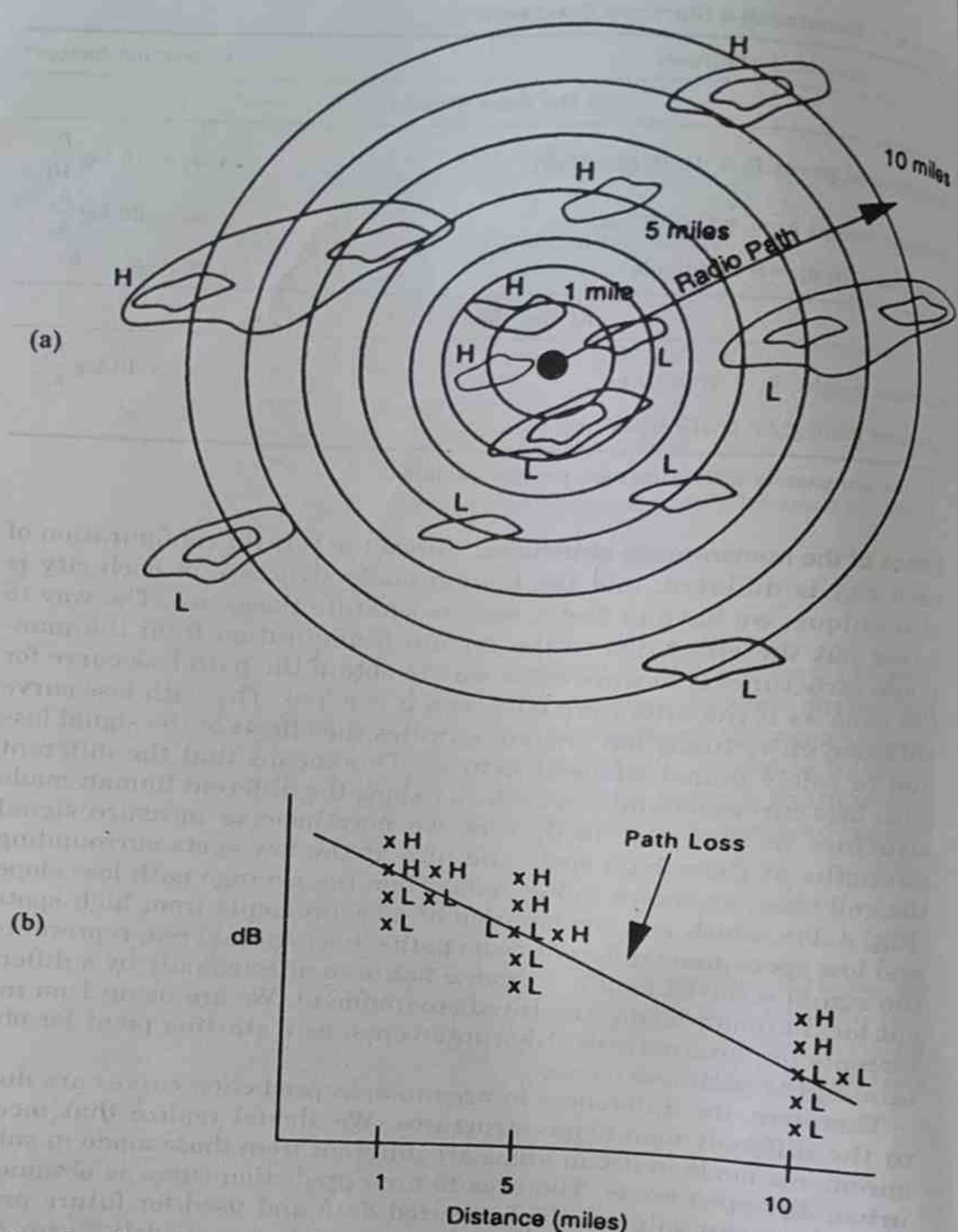

Figure 4.3 Propagation path loss curves for human-made structures. (*a*) For selecting measurement areas (*b*) path loss phenomenon.

and (2) 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.

1. Compare an area of interest with an area of similar human-made structures which presents a curve such as that shown in Fig. 4.3*c*. The suburban area curve is a commonly used curve. Since all suburban areas in the United States look alike, we can use this curve for all suburban areas. If the area is not suburban but is similar to the city of Newark, then the curve for Newark should be used.

2. If the human-made structures of a city are different from the cities listed in Fig. 4.3*c*, a simple measurement should be carried out. Set up a transmitting antenna at the center of a general area. As long as the building height is comparable to the others in the 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 and low spots. Then compute the average of the 1 mi data points and 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 terrain 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[29]

$$\Delta G = \text{effective antenna-height gain} = 20 \log \frac{h_e}{h_1} \qquad (4.2\text{-}1)$$

where h_1 is the actual height and h_e is the effective antenna height at either the 1- or 10-mi locations. The method for obtaining h_e is shown in the following section.

3. An explanation of the path-loss phenomenon is as follows. The plotted curves shown in Fig. 4.3*c* have different 1-mi intercepts and different slopes. The explanation can be seen in Fig. 4.3*d*. When the base station antenna is located in the city, then the 1-mi intercept could be very low and the slope is flattened out, as shown by Tokey's curve. When the base station is located outside the city, the intercept could be much higher and the slope is deeper, as shown by the Newark curve. When the structures are uniformly distributed, depending on the density (average separation between buildings) s, the 1-mi intercept could be high or low, but the slope may also keep at 40 dB/dec.

PHASE DIFFERENCE BETWEEN THE DIRECT PATH AND THE REFLECTED PATH

Based on a direct path and a ground reflected path, the equation

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

where a_v = the reflection coefficient
$\Delta\phi$ = the phase difference between a direct path and a reflected path
P_0 = the transmitted power
d = the distance
λ = the wavelength

Indicates a two-wave model which is used to understand the path-loss phenomenon in a mobile radio environment. It is not the model for analyzing the multipath fading phenomenon. In a mobile environment av = - 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, $\Delta d = d_1 - d_0$, from Fig. 4.4.

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

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

Since Δd is much smaller than either d_1 or d_2,

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

Then the received power of Eq. (4.2-3) 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 $\sin(\Delta\phi/2) \approx \Delta\phi/2$, $\cos(\Delta\phi/2) \approx 1$,

$$P_r = P_0 \frac{4}{16\pi^2(d/\lambda)^2}\left(\frac{2\pi h_1h_2}{\lambda d}\right)^2 = P_0\left(\frac{h_1h_2}{d^2}\right)^2$$

, thus

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

$$\Delta G = 20 \log\frac{h'_1}{h_1} \qquad \text{(an antenna height gain of 6 dB/oct)}$$

Where P is the power difference in decibels between two different path lengths and G is the gain (or loss) in decibels obtained from two different antenna heights at the cell site. From these measurements, the gain from a mobile antenna height is only 3 dB/oct, which is different from the 6 dB/oct . Then

$$\Delta G'' = 10 \log \frac{h'_2}{h_2}$$

CONSTANT STANDARD DEVIATION ALONG A PATH-LOSS SLOPE

When plotting signal strengths at any given radio-path distance, the deviation from predicted value. is approximately 8 dB.1012 This standard deviation of 8 dB is roughly true in many different areas. The explanation is as follows. When a line-of-sight path exists, both the direct wave path and reflected wave path are created and are strong. When an out-of-sight path exists, both the direct wave path and the reflected wave path are weak. In either case, according to the theoretical model, the 40-dB/dec path-loss slope applies. The difference between these two conditions is the 1-mi intercept (or 1-km intercept) point. It can be seen that in the open area, the 1-mi intercept is high. In the urban area, the 1-mi intercept is low. The standard deviation obtained from the measured data remains the same along the different path-loss curves regardless of environment.

Support for the above argument can also be found from the observation that the standard deviation obtained from the measured data along the predicted path-loss curve is approximately 8 dB. The explanation is that at a distance from the cell site, some mobile unit radio paths are line-of-sight, some are partial line-of-sight, and some are out-of-sight. Thus the received signals are strong, normal, and weak, respectively. At any distance, the above situations prevail. If the standard deviation is 8 dB at one radio-path distance, the same 8dB will be found at any distance. Therefore a standard deviation of 8 dB is always found along the radio path as shown in Fig.3

The standard deviation of 8 dB from the measured data near the cell site is due mainly to the close-in buildings around the cell site. The same standard deviation from the measured data at distant locations is due to the great variation along different around the cell site. The same standard deviation from the measured data at a distant location is due to the great variation along different radio paths.

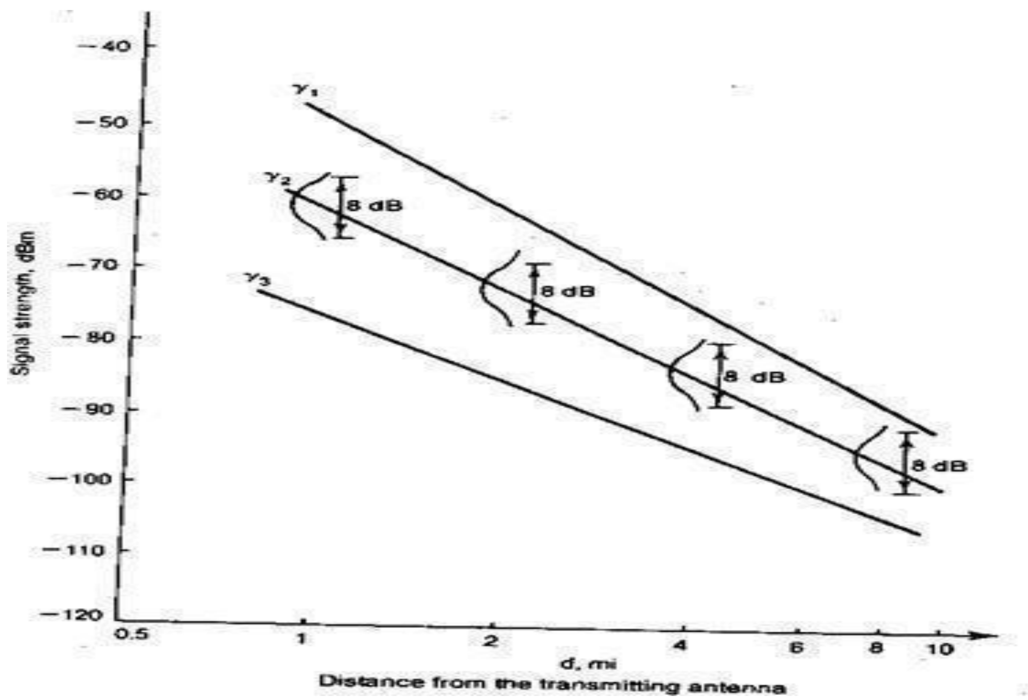

Fig 3 An 8-dB local mean spread

MERITS OF POINT-TO-POINT MODEL

The area-to-area model usually only provides an accuracy of prediction with a standard deviation of 8 dB, which means that 68 percent of the actual path-loss data are within the ± 8 dB of the predicted value. The uncertainty range is too large. The point-to-point model reduces the uncertainty range by including the detailed terrain contour information in the path-loss predictions.

The differences between the predicted values and the measured ones for the point-to-point model were determined in many areas. In the following discussion, we compare the differences shown in the Whippany, N.J., area and the Camden- Philadelphia area. First, we plot the points with predicted values at the x-axis and the measured values at the y-axis, shown in Fig. 4. The 450 line is the line of prediction without error. The dots are data from the Whippany area, and the crosses are data from the Camden-Philadelphia area. Most of them, except the one at 9 dB, are close to the line of prediction without error.

The mean value of all the data is right on the line of prediction without error. The standard deviation of the predicted value of 0.8 dB from the measured one.

In other areas, the differences were slightly larger. However, the standard deviation of the predicted value never exceeds the measured one by more than 3 dB. The standard deviation range is much reduced as compared with the maximum of 8 dB from area-to-area models. The point-to-point model is very useful for designing a mobile cellular system with a radius for each cell of 10 mi or less. Because the data follow the log- normal distribution, 68 percent of predicted values obtained from a point-to-point prediction model are within 2 to 3 dB. This point-to-point prediction can be used to provide overall coverage of all cell sites and to avoid co-channel interference. Moreover, the occurrence of handoff in the cellular system can be predicted more accurately.

The point-to-point prediction model is a basic tool that is used to generate a signal coverage map, an interference area map, a handoff occurrence map, or an optimum system design configuration, to name a few applications.

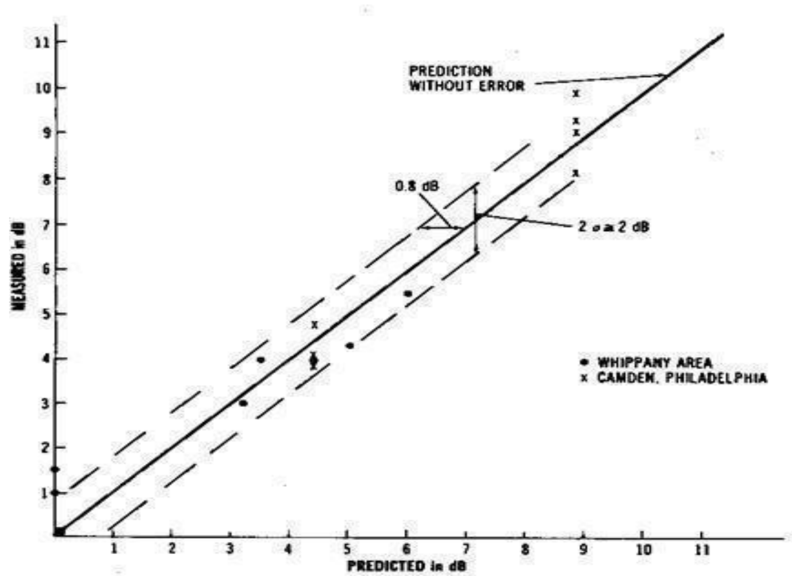

Fig.4. Indication of errors in point-to-point predictions under non obstructive conditions.

EFFECT OF PROPAGATION OF MOBILE SIGNALS OVER WATER AND FLAT OPEN AREA

PROPAGATION OVER WATER OR FLAT OPEN AREA:

Propagation over water or fiat open area is becoming a big concern because it is very easy to interfere with other cells if we do not make the correct arrangements. Interference resulting from propagation over the water can be controlled if we know the cause. In general, the permittivity's Er of seawater and freshwater are thesame, but the conductivities of seawater and fresh water are different. We may calculate the dielectric constants Ec where Ec = Er - j60σλ. Thewavelengthat850MHz is0.35m.ThenEo(sea water) =80 - j84 and Ec (fresh water)=80- jO.021.

However, based upon the reflection coefficients formula with a small incident angle both the reflection coefficients for horizontal polarized waves and vertically polarized waves approach 1. Since the 180* phase change occurs at the ground reflection point, the reflection coefficient is -1. Now we can establish a scenario, as shown in Fig 10.1 Since the two antennas, one at the cell site and the other at the mobile unit, are well above sea level, two reflection points are generated. The one reflected from the ground is close to the mobile unit; the other reflected from the water is away from the mobile unit. We recall that the only reflected wave we considered in the land mobile propagation is the one reflection point which is always very close to the mobile unit. We are now using the formula to find the field strength under the circumstances of a fixed point-to-point transmission and a land-mobile transmission over a water or flat open land condition.

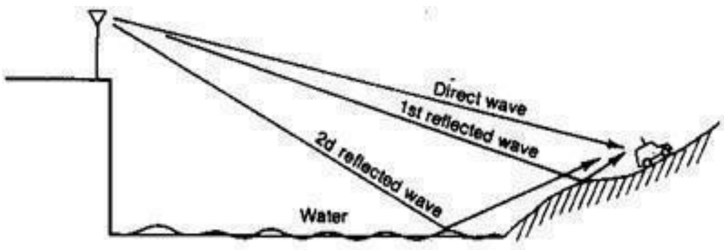

Fig 10.1.A model for propagation over water

BETWEEN FIXED STATIONS: 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,* can be expressed as (see Fig.10.2)

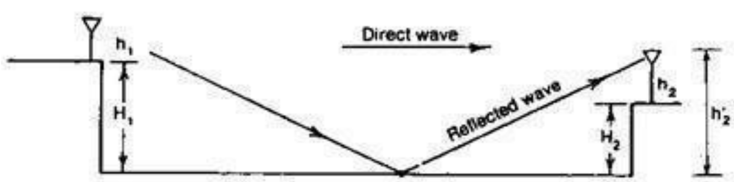

Fig 10.2.Propagation between two fixed stations over water or flat open land.

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

where P_t = transmitted power
d = distance between two stations
λ = wavelength
a_v, ϕ_v = amplitude and phase of a complex reflection coefficient, respectively

_ϕis thephasedifferencecaused bythepath difference Mbetweenthedirectwave and thereflectedwave, or

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

The first part of i.e. the free-space loss formula which shows the 20 dB/dec slope; that is, a 20-dB loss will

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

be seen when propagating from 1 to 10 km.

The complex reflection co-efficient and can be found from the formula

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

When the vertical incidence is small, θ is very small and

$$a_v \approx -1 \qquad \text{and} \qquad \phi_v = 0$$

It can be found from equation. Ec is a dielectric constant that is different for different media. The reflection coefficient remains -1 regardless of whether the wave is propagated over water dry land, wet land, Ice, and so forth. The wave propagating between fixed stations is illustrated in Fig. 10.2.

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

since _ϕ is a function of d and d can be obtained from the following calculation. The effective antenna height at antenna 1 is the height above the sea level.

$$h_1' = h_1 + H_1$$

The effective antenna height at antenna 2 is the height above the sea level.

$$h_2' = h_2 + H_2$$

As shown in Fig.10.2 where h1 and h2 are actual heights and H1and H2 are the heights of hills. In general, both antennas at fixed stations are high, so the resection point of the wave will be found toward the middle of the radio path. The path difference d can be obtained from Fig. 10.2 as

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

Since $d \gg h_1'$ and h_2', then

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

Then

$$\Delta\phi = \frac{2\pi}{\lambda}\frac{2h_1'h_2'}{d} = \frac{4\pi h_1'h_2'}{\lambda d}$$

Examining Eq. (8.3-6), we can set up five conditions:

1. $P_r < P_0$. The received power is less than the power received in free space; that is,

$$2 - 2\cos\Delta\phi < 1 \quad \text{or} \quad \Delta\phi < \frac{\pi}{3}$$

2. $P_r = 0$; that is,

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

3. $P_r = P_0$; that is,

$$2 - 2\cos\Delta\phi = 1 \quad \text{or} \quad \Delta\phi = \pm 60^\circ = \pm\frac{\pi}{3}$$

4. $P_r > P_0$; that is,

$$2 - 2\cos\Delta\phi > 1 \quad \text{or} \quad \frac{\pi}{3} < \Delta\phi < \frac{5\pi}{3}$$

5. $P_r = 4P_0$; that is,

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

4.5 Propagation in Near-in Distance

4.5.1 Why use a 1-mi intercept?

1. Within a 1-mi radius, the antenna beamwidth, especially of a high-gain omnidirectional antenna, is narrow in the vertical plane. Thus the signal reception at a mobile unit less than 1 mi away will be reduced because of the large elevation angle which causes the mobile unit to be in the shadow region (outside the main beam). The larger the elevation angle, the weaker the reception level due to the antenna's vertical pattern, as shown in Fig. 4.11.
2. There are fewer roads within the 1-mi radius around the cell site. The data are insufficient to create a statistical curve. Also the road orientation, in-line and perpendicular, close to the cell site can cause a big difference in signal reception levels (10–20 dB) on those roads.
3. 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.

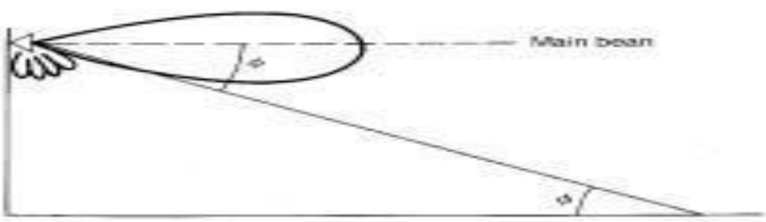

Figure 4.11 Elevation angle of the shadow of the antenna pattern.

4. 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.

4.5.2 Curves for near-in propagation

We usually worry about propagation at the far distance for coverage purposes. Now we also should investigate the near-in distance propagation. We may use the suburban area as an example. At the 1-mi intercept the received level is −61.7 dBm based on the reference set of parameters; i.e., the antenna height is 30 m (100 ft). If we increase the antenna height to 60 m (200 ft), a 6-dB gain is obtained. From 60 to 120 m (200 to 400 ft), another 6 dB is obtained. At the 120-m (400-ft) antenna height, the mobile received signal is the same as that received at the free space.

The antenna pattern is not isotropic in the vertical plane. A typical 6-dB omnidirectional antenna vertical beamwidth is shown in Fig 4.12. The reduction in signal reception can be found in the figure and is listed in the table below.

At $d = 100$ m (328 ft) [mobile antenna height = 3 m (10 ft)], the incident angles and elevation angles are 11.77° and 10.72°, respectively.

Antenna height h_1, m (ft)	Incident angle θ, degrees	Elevation angle ϕ, degrees	Attentuation α, dB
90 (300)	30.4	29.6	21
60 (200)	21.61	20.75	16
30 (100)	11.77	10.72	6

4.6 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 where usually different frequencies are repeatedly used in different areas. However, we have to be aware of the long-distance propagation phenomenon. A noise-limited system gradually becomes an interference-limited system as the traffic increases. The interference is due to not only the existence of many cochannels and adjacent channels in the system, but the long-distance propagation also affects the interference.

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

4.6.2 At a distance of 320 km (200 mi)

Tropospheric wave propagation prevails at 800 MHz for long-distance propagation; sometimes the signal can reach 320 km (200 mi) away.

The wave is received 320 km away because of an abrupt change in the effective dielectric constant of the troposphere (10 km above the surface of the earth). The dielectric constant changes with temperature, which decreases with height at a rate of about 6.5°C/km and reaches −50°C at the upper boundary of the troposphere. In tropospheric propagation, the wave may be divided by refraction and reflection.

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.

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.

Moistness. Actually water content has much more effect than temperature on the dielectric constant of the atmosphere and on the manner in which the radio waves are affected. The water vapor 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, and a condition known as *trapping*, or *duct propagation*, can occur. There are surface ducts and elevated ducts. Elevated ducts are due to large air masses and are common in southern California. They can be found at elevations of 300 to 1500 m (1000 to 5000 ft) and may vary in thickness from a few feet to a thousand feet. Surface ducts appear over the sea and are about 1.5 m (5 ft) thick. Over land areas, surface ducts are produced by the cooling air of the earth.

4.8 Form of a Point-to-Point Model

4.8.1 General formula

We form the model as follows:

$$P_r = \begin{cases} \text{nonobstructive path} = P_{r_0} - \gamma \log \dfrac{r}{r_0} + 20 \log \dfrac{h'_e}{h_1} + \alpha \\ \\ \text{obstructive path} = P_{r_0} - \gamma \log \dfrac{r}{r_0} + L + \alpha \\ \\ \text{land-to-mobile over water} = \text{a free-space formula} \\ \qquad\qquad\qquad\qquad\qquad\qquad \text{(see Sec. 4.3)} \end{cases} \tag{4.8-1}$$

Remarks

1. The P_r cannot be higher than that from the free-space path loss.
2. The road's orientation, when it is within 2 mi from the cell site, will affect the received power at the mobile unit. The received power at the mobile unit traveling along an in-line road can be 10 dB higher than that along a perpendicular road.
3. α is the corrected factor (gain or loss) obtained from the condition (see Sec. 4.2.1).
4. The foliage loss (Sec. 4.4) would be added depending on each individual situation. Avoid choosing a cell site in the forest. Be sure that the antenna height at the cell site is higher than the top of the trees.

4.8.2 The merit of the point-to-point model

The area-to-area model usually only provides an accuracy of prediction with a standard deviation of 8 dB, which means that 68 percent of the actual path-loss data are within the ± 8 dB of the predicted value. The uncertainty range is too large. The point-to-point model reduces the uncertainty range by including the detailed terrain contour information in the path-loss predictions.

The differences between the predicted values and the measured ones for the point-to-point model were determined in many areas. In the following discussion, we compare the differences shown in the Whippany, N.J., area and the Camden-Philadelphia area. First, we plot the points with predicted values at the x-axis and the measured values at the y-axis, shown in Fig. 4.20. The 45° line is the line of prediction without error. The dots are data from the Whippany area, and the crosses are data from the Camden-Philadelphia area. Most of them, except the one at 9 dB, are close to the line of prediction without error. The mean value of all the data is right on the line of prediction without error. The standard deviation of the predicted value is 0.8 dB from the measured one.

In other areas, the differences were slightly larger. However, the standard deviation of the predicted value never exceeds the measured one by more than 3 dB. The standard deviation range is much reduced as compared with the maximum of 8 dB from area-to-area models.

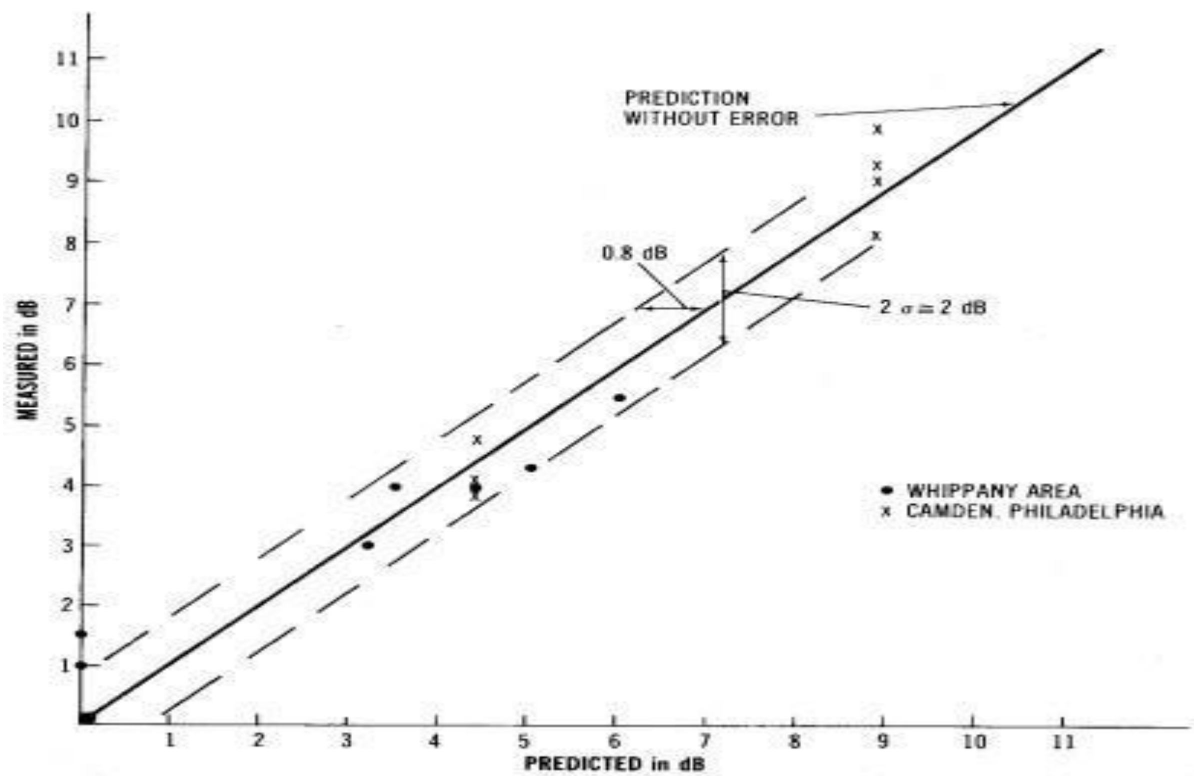

Figure 4.20 Indication of errors in point-to-point predictions under nonobstructive conditions. (*After Lee, Ref. 42.*)

UNIT II (B)

CELLSITE AND MOBILE ANTENNAS

SPACES-DIVERSITY ANTENNAS

Two-branch space-diversity antennas are used at the cell site to receive the same signal with different fading envelopes, one at each antenna. The degree of correlation between two fading envelopes is determined by the degree of separation between two receiving antennas. When the two fading envelopes are combined, the degree of fading is reduced. Here the antenna setup is shown in Fig. 5a.

Equation is presented as an example for the designer

to use. $\eta = h/D = 11$ (8.13-1)

Where h is the antenna height and D is the antenna separation. From Eq., the separation $d \geq 8\lambda$ is needed for an antenna height of 100 ft (30 m) and the separation $d \geq 14\lambda$ is needed for an antenna height of 150 ft (50 m). In any Omni cell system, the two space-diversity antennas should be aligned with the terrain, which should have a U shape as shown in Fig.5b. Space-diversity antennas can separate only horizontally, not vertically; thus, there is no advantage in using a vertical separation in the design.

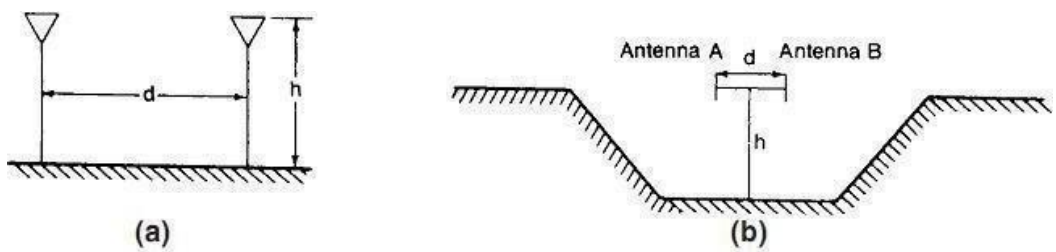

Fig.6.10.Diversity antenna spacing at cell site: (a) n=h/d (b) Proper arrangement with two antennas

UMBRELLAS-PATTERN ANTENNAS

In certain situations, umbrella-pattern antennas should be used for the cell-site antennas.

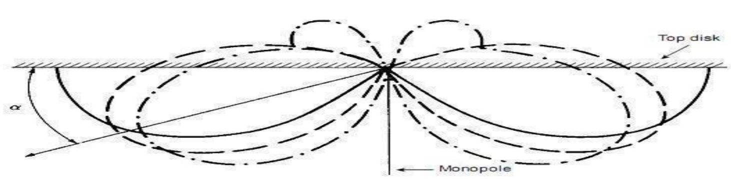

Fig. Vertical-plane patterns of quarter-wavelength stub antenna on infinite ground plane (solid) and on finite ground planes several wavelengths in diameter (dashed line) and about one wavelength in diameter (dotted line).

i) 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 (top-loading) as shown in Fig. 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.

ii) BROADBAND UMBRELLA-PATTERN ANTENNA:

The parameters of a Discone antenna (a bio conical antenna in which one of the cones is extended to 180◦ to form a disk) are shown in Fig. The diameter of the disk, the length of the cone, and the opening of the cone can be adjusted to create an umbrella-pattern antenna.

iii) INTERFERENCE REDUCTION ANTENNA:

A design for an antenna configuration that reduces interference in two critical directions (areas) is shown in Fig.6.3. The parasitic (insulation) element is about 1.05 times longer than the active element.

iv) HIGH-GAIN BROADBAND UMBRELLA-PATTERNANTENNA:

A high-gain antenna can be constructed by vertically stacking a number of umbrella- pattern antennas as shown in Fig.

$$E_0 = \frac{\sin[(Nd/2\lambda)\cos\phi]}{\sin[(d/2\lambda)\cos\phi]} \cdot \text{(individual umbrella pattern)}$$

where ϕ = direction of wave travel
N = number of elements
d = spacing between two adjacent elements

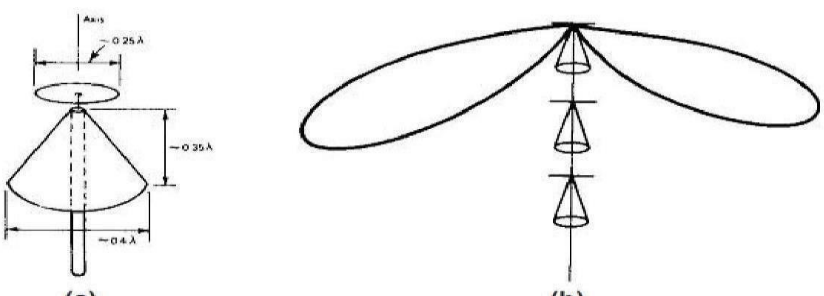

Fig. Discone antennas (a) Single antenna; (b) An array of antenna

MINIMUM SEPARATION OF CELL-SITE RECEIVING ANTENNAS

Separation between two transmitting antennas should be minimized to avoid the inter modulation. The minimum separation between a transmitting antenna and a receiving antenna is necessary to avoid receiver desensitization. Here we are describing a minimum separation between two receiving antennas to reduce the antenna pattern ripple effects. The two receiving antennas are used for a space-diversity receiver.

Because of the near field disturbance due to the close spacing, ripples will form in the antenna patterns (Fig.). The difference in power reception between two antennas at different angles of arrival is shown in Fig. . If the antennas are located closer; the difference in power between two antennas at a given pointing angle increases. Although the power difference is confined to a small sector, it affects a large section of the street as shown in Fig. .

If the power difference is excessive, use of space diversity will have no effect reducing fading. At 850 MHz, the separation of eight wavelengths between two receiving antennas creates a power difference of ±2 dB, which is tolerable for the advantageous use of a diversity scheme.

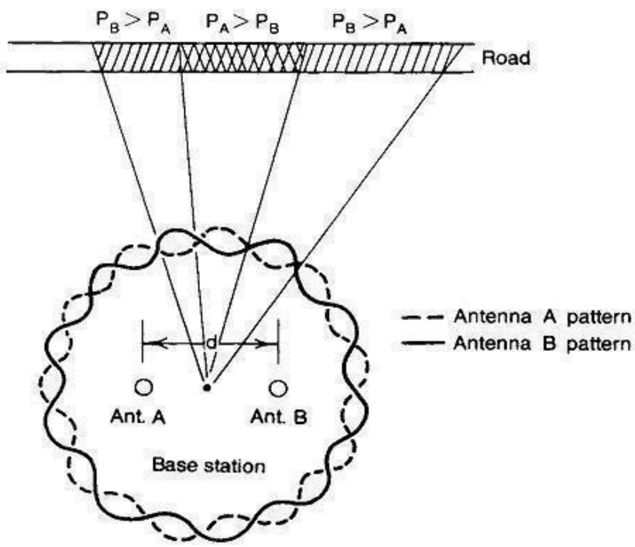

Fig. Antenna pattern ripple effect

MOBILE HIGH-GAIN ANTENNAS:

A high-gain antenna used on a mobile unit has been studied. This type of high-gain antenna should be distinguished from the directional antenna. In the directional antenna, the antenna beam pattern is suppressed horizontally; in the high-gain antenna, the pattern is suppressed vertically.

To apply either a directional antenna or a high-gain antenna for reception in a radio environment, we must know the origin of the signal. If we point the directional antenna opposite to the transmitter site, we would in theory receive nothing. In a mobile radio environment, the scattered signals arrive at the mobile unit from every direction with equal probability. That is why an Omni directional antenna must be used.

The scattered signals also arrive from different elevation angles. Lee and Brandt used two types of antenna, one $\lambda/4$ whip antenna with elevation coverage of 39◦ and one 4-dB-gain antenna (4-dB gain with respect to the gain of a dipole) with elevation coverage of 16◦ and measured the angle of signal arrival in the subur ban Keyport-Matawan area of New Jersey. There are two types of test: a line-of-sight condition and an out- of-sight condition. In Lee and Brandt's study, the transmitter was located at an elevation of approximately 100 m (300 ft) above sea level.

The measured areas were about 12 m (40 ft) above sea level and the path length about 3 mi. The received signal from the 4-dB-gain antenna was 4 dB stronger than that from the whip antenna under line-of- sight conditions. This is what we would expect.

However, the received signal from the 4-dB-gain antenna was only about 2 dB stronger than that from the whip antenna under out-of-sight conditions. This is surprising. The reason for the latter observation is that the scattered signals arriving under out-of- sight conditions are spread over a wide elevation angle. A large portion of the signals outside the elevation angle of 16◦ cannot be received by the high-gain antenna. We may calculate the portion being received by the high-gain antenna from the measured beam width. For instance, suppose that a 4:1 gain (6 dBi) is expected from the high-gain antenna, but only 2.5:1 is received. Therefore, 63 percent of the signal is received by the 4-dB-gain antenna (i.e., 6 dBi) and 37 percent is felt in the region between 16 and 39◦

Therefore, a 2- to 3-dB-gain antenna (4 to 5 dBi) should be adequate for general use. An antenna gain higher than 2 to 3 dB does not serve the purpose of enhancing reception level. Moreover, measurements reveal that the elevation angle for scattered signals received in urban areas is greater than that in suburban areas.

	Gain, dBi	Linear ratio	$\theta_0/2$, degrees
Whip antenna (2 dB above isotropic)	2	1.58:1	39
High-gain antenna	6	4:1	16
Low-gain antenna	4	2.5:1	24