UNIT-V

1.Obtain the free space path loss from the transmitting end and the receiving end of the antenna. Derive the received power in dBm. How is the measured field strength converted into the receiver power?

Equivalent circuits of antennas:

The operating conditions of an actual antenna (Fig.1.1a) can be expressed in an equivalent circuit for both receiving (Fig. 1.lb) and transmitting (Fig.1.1c). In Fig. 1.1, Za is the antenna impedance; Zl is the load impedance, and Zt is the impedance at the transmitter terminal.

From the transmitting end (obtaining free-space path-loss formula):

Power Pt originates at a transmitting antenna and radiate out into space. (Equivalent circuit of a transmitting antenna is shown in Fig.1.1b.) Assume that an isotropic source Pt is used and that the power in the spherical space will be measured as the power per unit area. Thus power density, called the Poynting vector p or the outward flow of electromagnetic energy through a given surface area, is expressed as

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

A receiving antenna at a distance r from the transmitting antenna with an aperture A will receive power

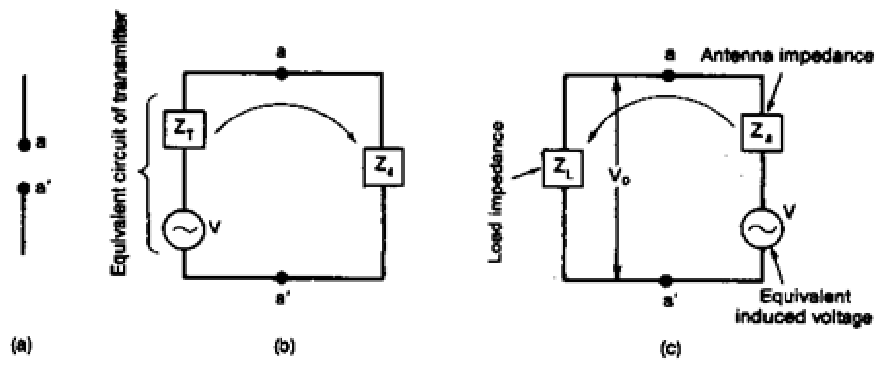


Fig.1.1 (a) An actual antenna;(b) equivalent circuit of transmitting antenna;(c) equivalent circuit of a receiving antenna

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

Figure 1.2 is a schematic representation of received power in space.
From the above equation we can derive the free-apace path-lose formula because we know the relationship between the aperture A and the gain G.

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

For a short dipole, G=1. Then

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

Substitution of the above equation yields the free-space formula

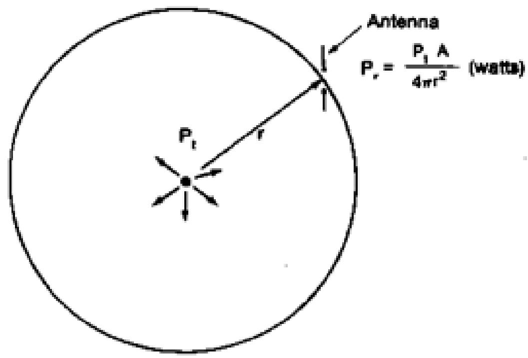


Fig.1.2 Received power in space

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

At the receiving end dBµV – dBm (decibels above 1µV – decibels above 1mW):

We can obtain the received power from the Fig.1.1c

$$P_r = \frac{V^2 Z_L}{(Z_L + Z_a)^2}$$

where V is the induced voltage in volts. For a maximum power delivery Zl=Za*, where the notation indicates complex conjugate. Then we obtain ZL + Z 2RL, where R1 is the real-load resistance. Equat ion (5.14) becomes

$$P_r = \frac{V^2}{4R_L}$$

Assume that a dipole or a monopole is used as a receiving antenna. The induced voltage V can be related to field strength E as

$$V = \frac{E\lambda}{\pi}$$

where E is expressed in volts or micro volts per meter

$$P_r = \frac{E^2\lambda^2}{4\pi^2 R_L}$$

If we set RL=50Ω, Pr in decibels above 1mW, and E in decibels (micro volts per meter)

$$P_r\,(\mathrm{dBm}) = E\,(\mathrm{dB\mu V}) - 113\ \mathrm{dBm} + 10\log\left(\frac{\lambda}{\pi}\right)^2$$

The notation “dBμV” in Eq. is a simplification of decibels above 1 μV/m, and has been accepted by the Institute of Radio Engineers. We can find the equivalent aperture A because the Poynting vector p can be expressed as

$$\rho = \frac{E^2}{Z_0}$$

Where Zo is the intrinsic impedance of the space (=120Π). By substituting we get the equivalent aperture A.

$$A = \frac{\lambda^2 Z_0}{4\pi^2 R_L}$$

Measuring field strength and converting it to received power:

Converting field strength in decibels above 1µV/m to power received in decibels above 1mW at 850 MHz by a dipole with a 50-Ω load is -132 dB.

$$P_r \quad \text{dBm} = E \quad \text{dB}\,(\mu\text{V/m}) - 132\ \text{dB}$$

$$\text{at 850 MHz}$$

$$39\ \text{dB}\,(\mu\text{V/m}) = -93\ \text{dBm}$$

The notation "39-dBµV contour" is commonly used to mean 39 dB (µV/m) in cellular system design. Equation is valid only at a given frequency (850 MHz), for a given antenna (rnonopole or dipole E,, antenna), and for a given antenna load (50 Ω). Otherwise the field strength and the power have to be adjusted accordingly.

Measuring the voltage Vo at the load terminal (Fig. 1.lc) and converting to received power:

Given Pr = (Vo/RL), where RL = 50 Ω we can obtain a relationship

$$0\ \text{dB}\mu\text{V}\ \langle=\rangle\ -107\ \text{dBm}$$

For example, if a voltage meter at Vo is 7 dBµV, then the received power is -100 dBm. Equation expresses a voltage-to-power antenna array ratio which varies with the load impedance but is independent of the frequency and the type of antenna.

2. What do you understand by engineering antenna pattern? Explain the corresponding pattern.

Sum-and-Difference Patterns - Engineering Antenna Pattern:

After obtaining a predicted field-strength contour we can engineer an antenna pattern to conform to uniform coverage. Far different antennae pointing in different directions and with different spacings, we can use any of a number of methods. If we know the antenna pattern and the geographic configuration of the antennae, a computer program can help us to find the coverage. Several synthesis methods can be used to generate a desired antenna configuration.

General formula:

Many applications of linear arrays are based on sum-and-difference patterns. The main beam of the pattern is always known as the sum pattern pointing at an angle θo. The difference pattern produces twin main beams straddling θo. When 2N elements are in in array, equispaced by a separation d, the general pattern for both sum and difference is

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

where β = wavenumber = $2\pi/\lambda$
I_n = normalized current distributions
N = total number of elements

For a sum pattern, all the current amplitudes are the same.

$$I_n = I_{-n}$$

For a difference pattern, the current amplitudes of one side (half of the total elements) are positive and the current amplitudes of the other side (half of the total elements) are negative.

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

Most pattern synthesis problems can be solved by determining the current distribution In. A few solutions follow.

Synthesis of sum patterns:

Dolph-Chebyshev synthesis of sum patterns: This method can be used to reduce the level of sidelobes; however, one disadvantage of further reduction of sidelobe level is broadening of the main beam.

Taylor synthesis: A continuous line-source distribution or a distribution for discrete arrays can give a desired pattern which contains a single main beam of a prescribed beamwidth and pointing direction with a family of sidelobes at a common specified level. The Taylor synthesis is derived from the following equation, where an antenna pattern F(θ) is determined from an aperture current distribution g(l)

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

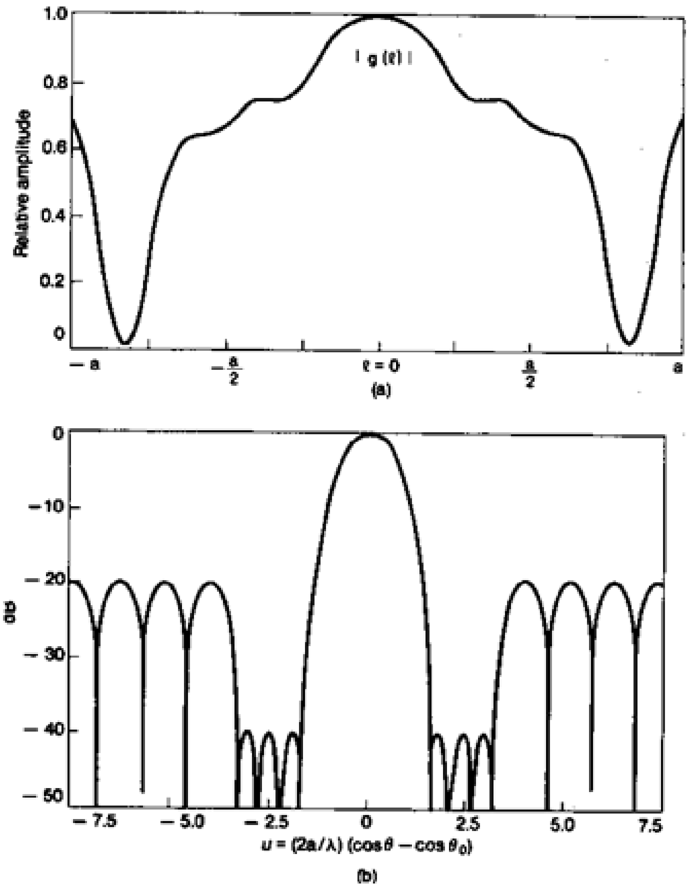


Fig.2.1. A symmetrical sum pattern (a) The aperture distribution for the two-antenna arrangement; (b) The evolution of a symmetrical sum pattern with reduced inner side lobes.

Symmetrical pattern: For production of a symmetrical pattern at the main beam, the current-amplitude distribution g(l) is the only factor to consider. The phase of the current distribution can remain constant. A typical pattern (Fig.2.1a) would be generated from a current-amplitude distribution (Fig.2.1b).

Asymmetrical pattern: For production of an asymmetrical pattern, both current amplitude g(l) and phase arg g(1) should be considered.

Synthesis of difference patterns (Bayliss synthesis):

To find a continuous line source that will produce a symmetrical difference pattern, with twin main beam patterns and specified sidelobes, we can set

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

For a desired difference pattern such as that shown in Fig. 2.2a, the current-amplitude distributions g(l) should be designed as shown in Fig. 2.2b and the phase arg g(1) as shown in Fig. 2.2c.

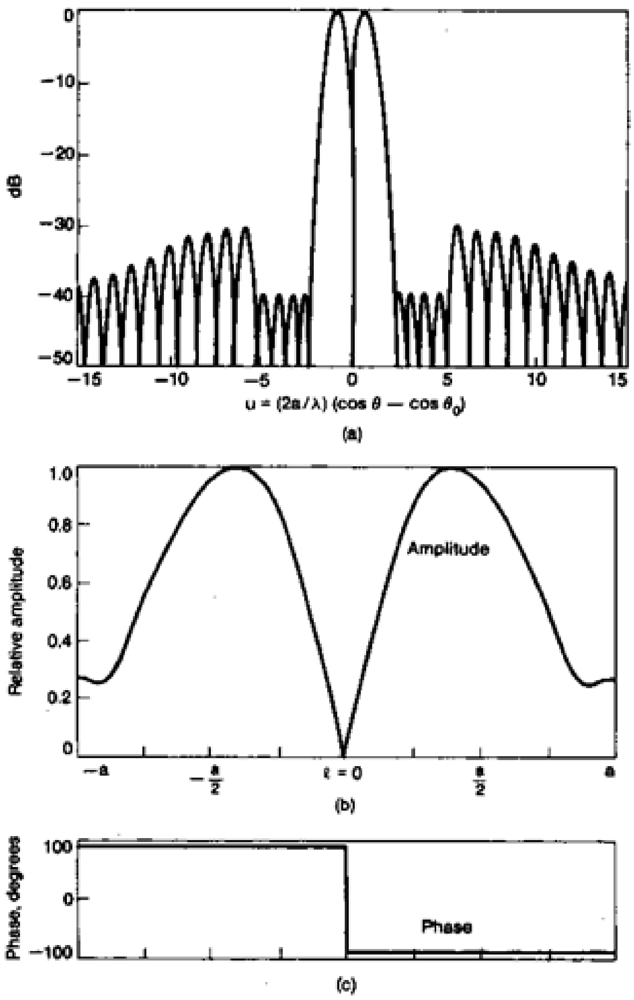


Fig.2.2 A symmetrical difference pattern (a) A modified Bayliss difference pattern; (b,c) Aperture distribution for the pattern

Null-free patterns:

In mobile communications applications, field-strength patterns without nulls are preferred for the antennas in a vertical plane. The typical vertical pattern of most antennas is shown in Fig. 2.3a. The field pattern can be represented as

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

where u = (2a/λ)(cos θ — cos θn). The concept is to add all (sin Πu)/(Πu) patterns at different pointing angles as shown in Fig. 2.3a. K is the maximum signal level. The resulting pattern does not contain nulls. The null-free pattern can be applied in the field as shown in Fig. 2.3b.

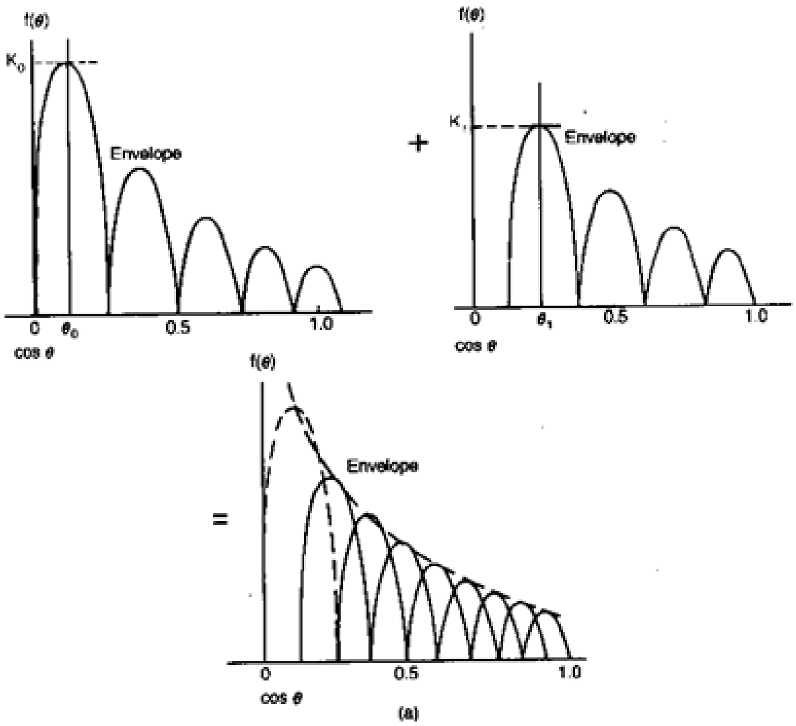


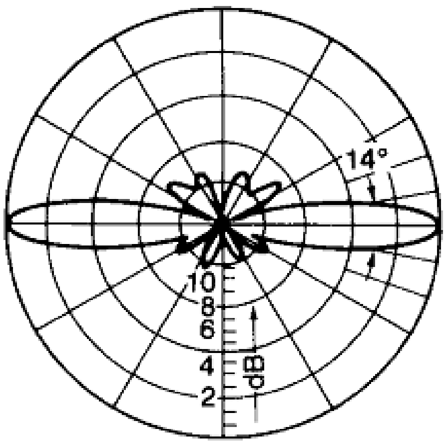
Fig.2.3. Null-free patterns (a) Formation of a null-free pattern

3. Concern to the cell site antennas explain start up configuration and abnormal antenna configuration of start up systems?

For Coverage Use: Omnidirectional Antennas

High-Gain Antennas: There are standard 6-dB and 9-dB gain omnidirectional antennas. The antenna patterns for 6-dB gain and 9-dB gain are shown in Fig.3.1

Start-Up System Configuration: In a start-up system, an omnicell, in which all the transmitting antennas are omnidirectional, is used. Each transmitting antenna can transmit signals from N radio transmitters simultaneously using a N-channel combiner or a broadband linear amplifier. Each cell normally can have three transmitting antennas which serve 3N voice radio transmitters simultaneously



Vertical
(a)

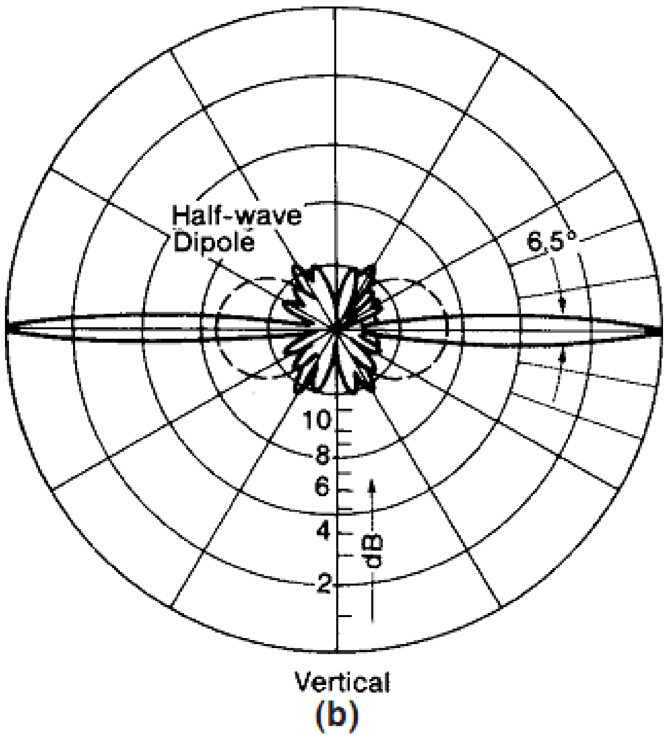


Fig.3.1 High-gain omnidirectional antennas (a) 6 dB (b) 9 dB

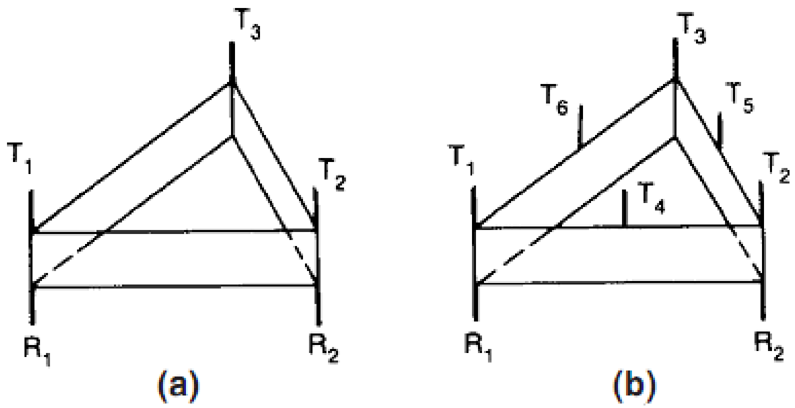


Fig.3.2. Cell site antennas for omni cells (a) for 3N channels; (b) for 6N channels

Each sending signal is amplified by its own channel amplifier in each radio transmitter, or N channels (radio signals) pass through a broadband linear amplifier and transmit signals by means of a transmitting antenna (see Fig.3.2a).

Two receiving antennas commonly can receive all 3N voice radio signals simultaneously. Then in each channel, two identical signals received by two receiving antennas pass through a diversity receiver of that channel. The receiving antenna configuration on the antenna mast is shown in Fig.3.2.cFor serving 6N voice radio transmitters from six transmitting antennas is shown in Fig.3.2(b).

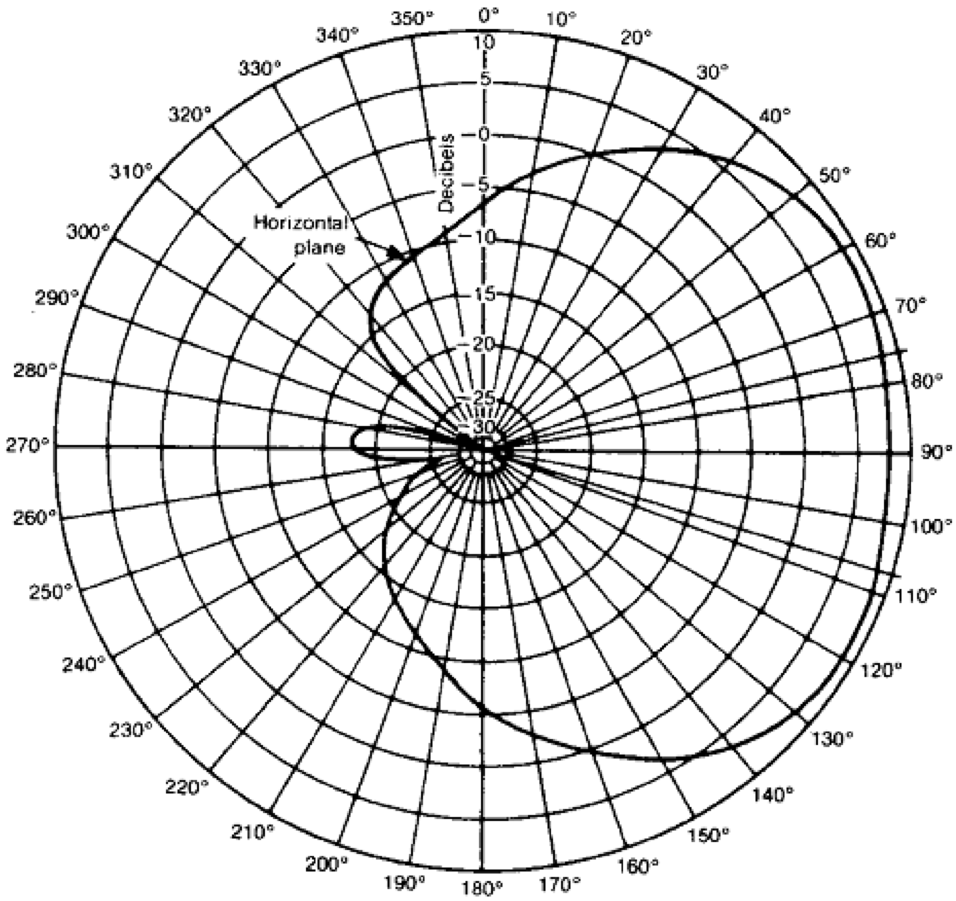
Abnormal Antenna Configuration: Usually, the call traffic in each cell increases as the number of customers increases. Some cells require a greater number of radios to handle the increasing traffic. An omnicell site can be equipped with up to 90 voice radios for AMPS systems. In such cases six transmitting antennas should be used as shown in Fig. 3.2b. In the meantime, the number of receiving antennas is still two. In order to reduce the number of transmitting antennas, a hybrid ring combiner that can combine two 16-channel signals is found. This means that only three transmitting antennas are needed to transmit 90 radio signals. However, the ring combiner has a limitation of handling power up to 600 W with a loss of 3 dB.

4. How interference can be reduced by using the directional antennas at the cell site?

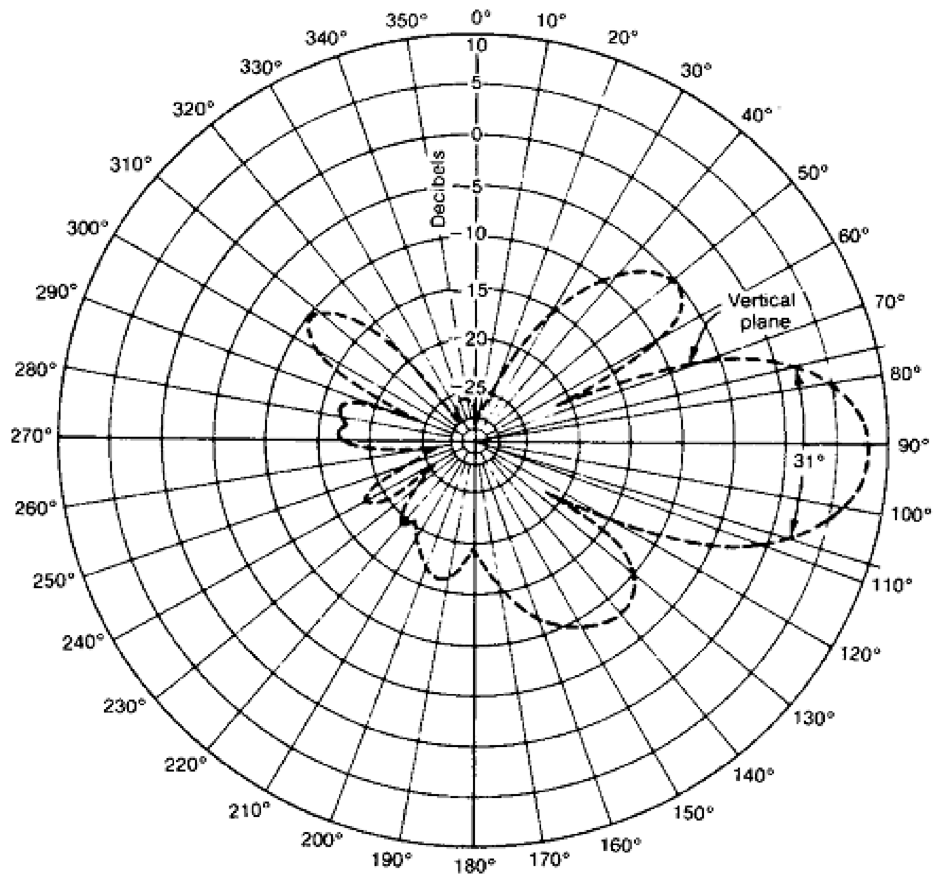
For Interference Reduction Use: Directional Antennas

When the frequency reuse scheme must be used in AMPS, cochannel interference will occur. The cochannel interference reduction factor $q = D/R = 4.6$ is based on the assumption that the terrain is flat. Because actual terrain is seldom flat, we must either increase q or use directional antennas.

Directional Antennas: A 120◦-corner reflector or 120◦-plane reflector can be used in a 120◦ -sector cell. A 60◦-corner reflector can be used in a 60◦-sector cell. A typical pattern for a directional antenna of 120◦ beamwidth is shown in Fig.4.1.


0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°
10
5
0
5
10
15
20
25
30
Decibels
Horizontal plane

(a)



(b)

Fig.4.1. Typical 8dB directional antenna pattern (a) Azimuthal pattern of 8dB directional antenna; (b) Vertical pattern of 8dB directional antenna

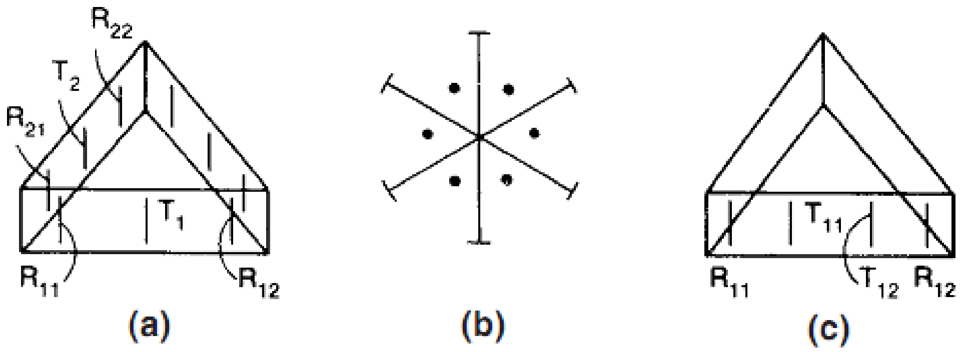


Fig.4.2. Directional antenna arrangement (a) 120◦ sector (45 radios); (b) 60◦ sector; (c) 120◦ sector (90 radios)

Normal Antenna (Mature System) Configuration:

1. K = 7 cell pattern (120◦sectors). In a K = 7 cell pattern for frequency reuse, if 333 channels are used, each cell would have about 45 radios. Each 120◦ sector would have one transmitting antenna and two receiving antennas and would serve 16 radios. The two receiving antennas are used for diversity (see Fig. 4.2a).

2. K = 4 cell pattern (60◦sectors). We do not use K = 4 in an omnicell system because the cochannel reuse distance is not adequate. Therefore, in a K = 4 cell pattern, 60◦ sectors are used. There are 24 sectors. In this K = 4 cell-pattern system, two approaches are used.

a. Transmitting-receiving 60◦sectors. Each sector has a transmitting antenna carrying its own set of frequency radios and hands off frequencies to other neighboring sectors or other cells. This is a full K = 4 cell-pattern system. If 333 channels are used, with 13 radios per sector, there will be one transmitting antenna and one receiving antenna in each sector. At the receiving end, two of six receiving antennas are selected for angle diversity for each radio channel (see Fig.4.2b).

b. Receiving 60◦sectors. Only 60◦-sector receiving antennas are used to locate mobile units and handoff to a proper neighboring cell with a high degree of accuracy. All the transmitting antennas are omnidirectional within each cell. At the receiving end, the angle diversity for each radio channel is also used in this case.

Abnormal Antenna Configuration: If the call traffic is gradually increasing, there is an economic advantage in using the existing cell systems rather than the new splitting cell system (splitting into smaller cells). In the former, each site is capable of adding more radios. In a K = 7 cell pattern with 120◦ sectors, two transmitting antennas at each sector are used (Fig.4.2c). Each antenna serves 16 radios if a 16-channel combiner is used. One observation from Fig. 4.2c should be mentioned here. The two transmitting antennas in each sector are placed relatively closer to the receiving antennas than in the single transmitting antenna case. This may cause some degree of desensitization in the receivers. The technology cited can combine 32 channels in a combiner; therefore, only one transmitting antenna is needed in each sector. However, this one transmitting antenna must be capable of withstanding a high degree of transmitted power. If each channel transmits 100 W, the total power that the antenna terminal could withstand is3.2 kW.

The 32-channel combiner has a power limitation which would be specified by different manufacturers. Two receiving antennas in each 120◦ sector remain the same for space diversity use.

5. Explain the antenna arrangement of space diversity used at cell site.

Space-Diversity Antennas Used at Cell Site:

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.

$$\eta = h/D = 11 \quad (8.13\text{-}1)$$

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 omnicell 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.

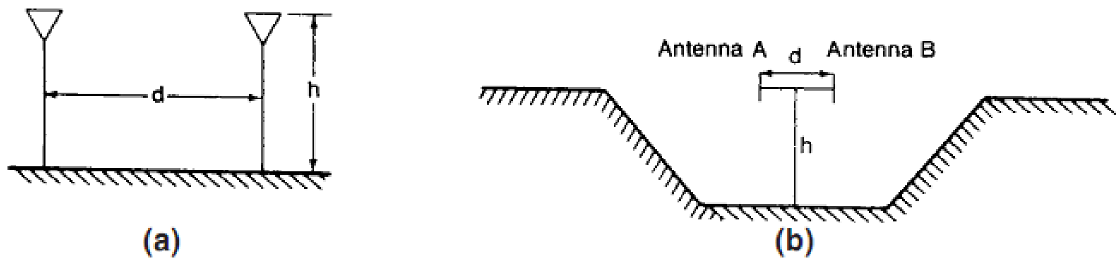


Fig.5.Diversity antenna spacing at cell site: (a) n=h/d (b) Proper arrangement with two antennas

6. Explain how umbrella pattern antennas are used as the cell site antennas.

Umbrella-Pattern Antennas:

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

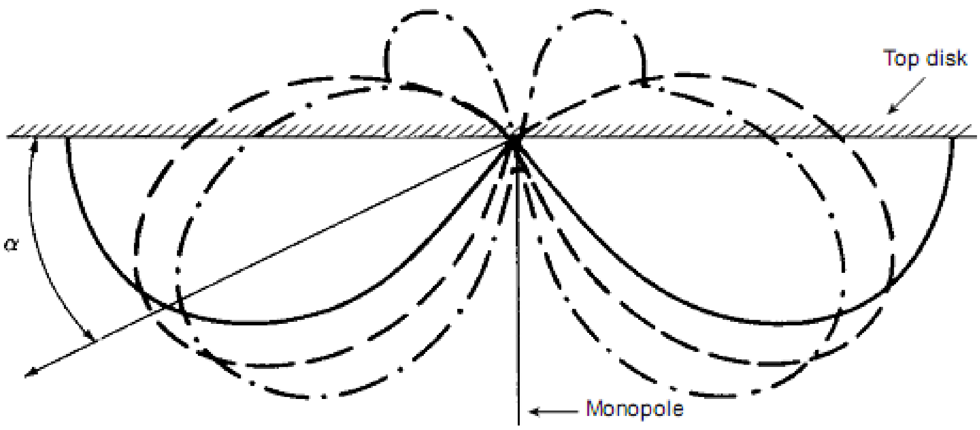


Fig.6.1.Vertical-plane patterns of quarter-wavelength stub antenna on infinite ground plane (solid) and on finite ground planes several wavelengths in diameter (dashed line) and about one wavelength in diameter (dotted line).

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. 6.1. 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.

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.6.2a. 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.

High-Gain Broadband Umbrella-Pattern Antenna: A high-gain antenna can be constructed by vertically stacking a number of umbrella-pattern antennas as shown in Fig.6.2b.

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

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

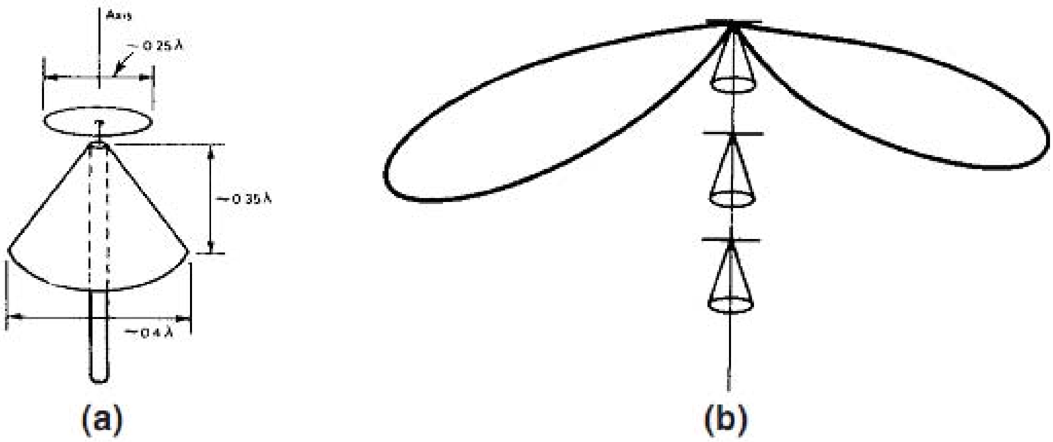


Fig.6.2. Discone antennas (a) Single antenna; (b) An array of antenna

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.

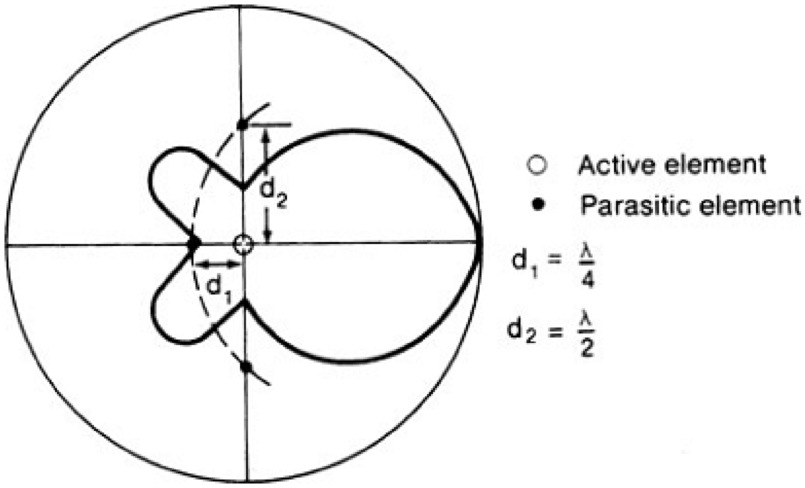


Fig.6.3. Application of parasitic elements

7. Explain in detail the unique situation of the antenna with neat diagram.

Antenna Pattern in Free Space and in Mobile Environments:

The antenna pattern we normally use is the one measured from an antenna range (open, nonurban area) or an antenna dark room. However, when the antenna is placed in a suburban or urban environment and the mobile antenna is lower than the heights of the surroundings, the cell-site antenna pattern as a mobile unit received in a circle equidistant around the cell site is quite different from the free-space antenna pattern. Consider the following facts in the mobile radio environment.

1. The strongest reception still coincides with the strongest signal strength of the directional antenna.

2. The pattern is distorted in an urban or suburban environment.

3. For a 120◦ directional antenna, the back lobe (or front-to-back ratio) is about 10 dB less than the front lobe, regardless of whether a weak sidelobe pattern or no sidelobe pattern is designed in a free-space condition. This condition exists because the strong signal radiates in front, bouncing back from the surroundings so that the energy can be received from the back of the antenna. The energy-reflection mechanism is illustrated in Fig.7.

4. A design specification of the front-to-back ratio of a directional antenna (from the manufacturer's catalog) is different from the actual front-to-back ratio in the mobile radio environment. Therefore the environment and the antenna beamwidth determine how the antenna

will be used in a mobile radio environment. For example, if a 60◦directional antenna is used in a mobile radio environment, the actual front-to-back ratio can vary

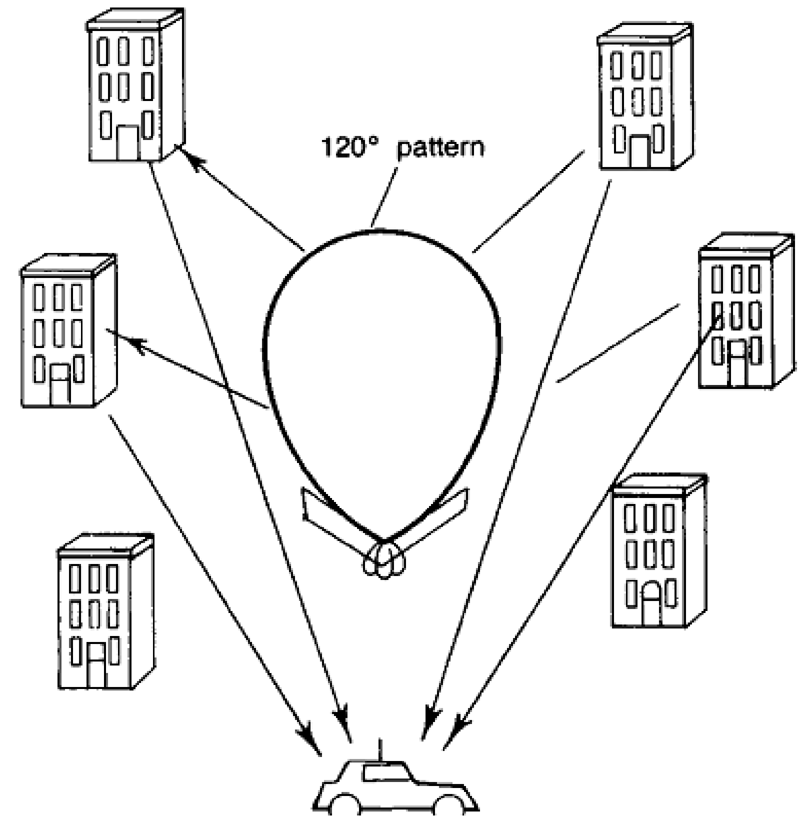


Fig.7. Front-to-back ratio of a directional antenna in a mobile radio environment

depending on the given environment. If the close-in man-made structures in front of the antenna are highly reflectable to the signal, then the front-to-back ratio of a low-master directional antenna can be as low as 6 dB in some circumstances. In this case, the directional antenna beamwidth pattern has no correlation between it measured in the free space and it measured in the mobile radio environment. If all the buildings are far away from the directional antenna, then the front-to-back ratio measured in the field will be close to the specified antenna pattern, usually 20 dB.

Regular Check of the Cell-Site Antennas:

Air-pressurized cable is often used in cell-site antennas to prevent moisture from entering the cable and causing excessive attenuation. One method of checking the cell-site antennas is to measure the power delivered to the antenna terminal; however, few systems have this capability. The other method is to measure the VSWR at the bottom of the tower. In this case the loss of reflected power due to the cable under normal conditions should be considered. For a high tower, the VSWR reading may not be accurate. If each cable connector has 1-dB loss due to energy leakage and two midsection 1-dB loss connectors are used in the transmitted systems, the reflected power Pb indicated in the VSWR would be 4 dB less than the real reflected power.

Choosing an Antenna Site:

In antenna site selection we have relied on the point-to-point prediction method, which is applicable primarily for coverage patterns under conditions of light call traffic in the system. Reduction of interference is an important factor in antenna site selection. When a site is chosen on the map, there is a 50 percent chance that the site location cannot be acquired. A written rule states that an antenna location can be found within a quarter of the size of cell R/4. If the site is an 8-mi cell, the antenna can be located within a 2-mi radius. This hypothesis is based on the simulation result that the change in site within a 2-mi radius would not affect the coverage pattern at a distance 8 mi away. If the site is a 2-mi cell, the antenna can be located within a 0.5-mi radius. The quarter-radius rule can be applied only on relatively flat terrain, not in a hilly area. To determine whether this rule can be applied in a general area, one can use the point-to- point prediction method to plot the coverage at different site locations and compare the differences. Usually when the point-to-point prediction method (tool) can be used to design a system, the quarter-radius rule becomes useless.

8. Explain in detail about minimum separation of cell-site receiving antennas.

Minimum Separation of Cell-Site Receiving Antennas:

Separation between two transmitting antennas should be minimized to avoid the intermodulation. 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.8). The difference in power reception between two antennas at different angles of arrival is shown in Fig. 8. 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. 8. 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.

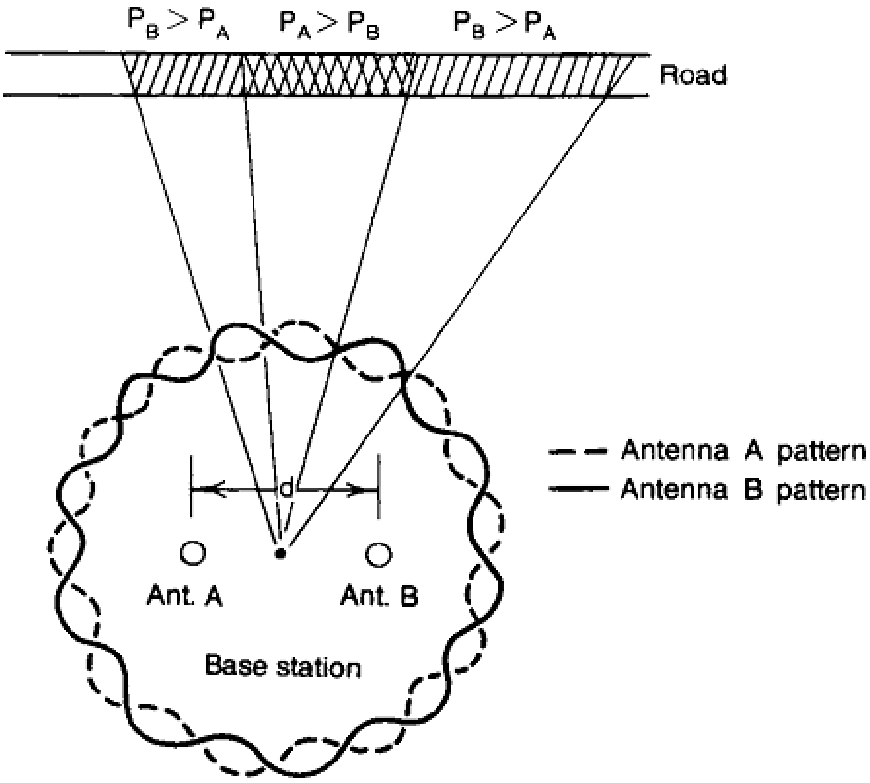


Fig.8. Antenna pattern ripple effect

9. Explain the following,

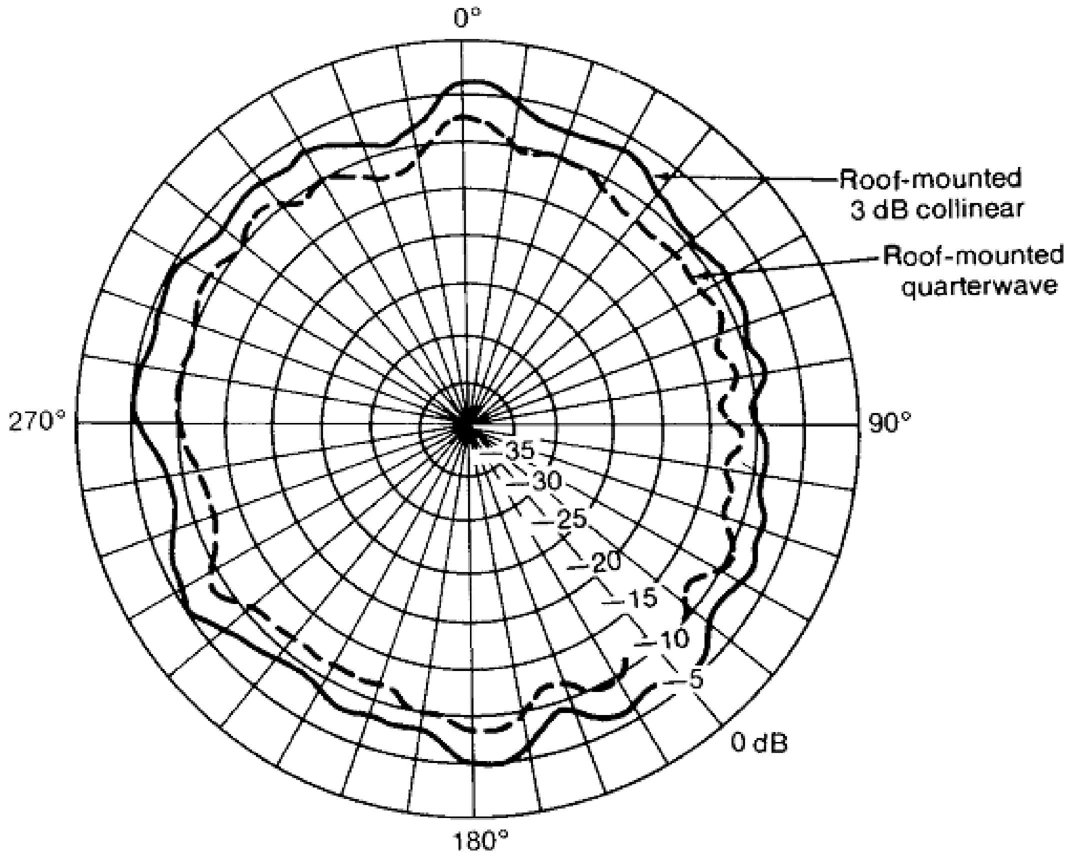
(a) Roof mounted antennas

(b) Glass mounted antennas

(c) Mobile high gain antennas.

Mobile Antennas:

The requirement of a mobile (motor-vehicle–mounted) antenna is an omnidirectional antenna that can be located as high as possible from the point of reception. However, the physical limitation of antenna height on the vehicle restricts this requirement. Generally, the antenna should at least clear the top of the vehicle. Patterns for two types of mobile antenna are shown in Fig. 9.1.



(a)

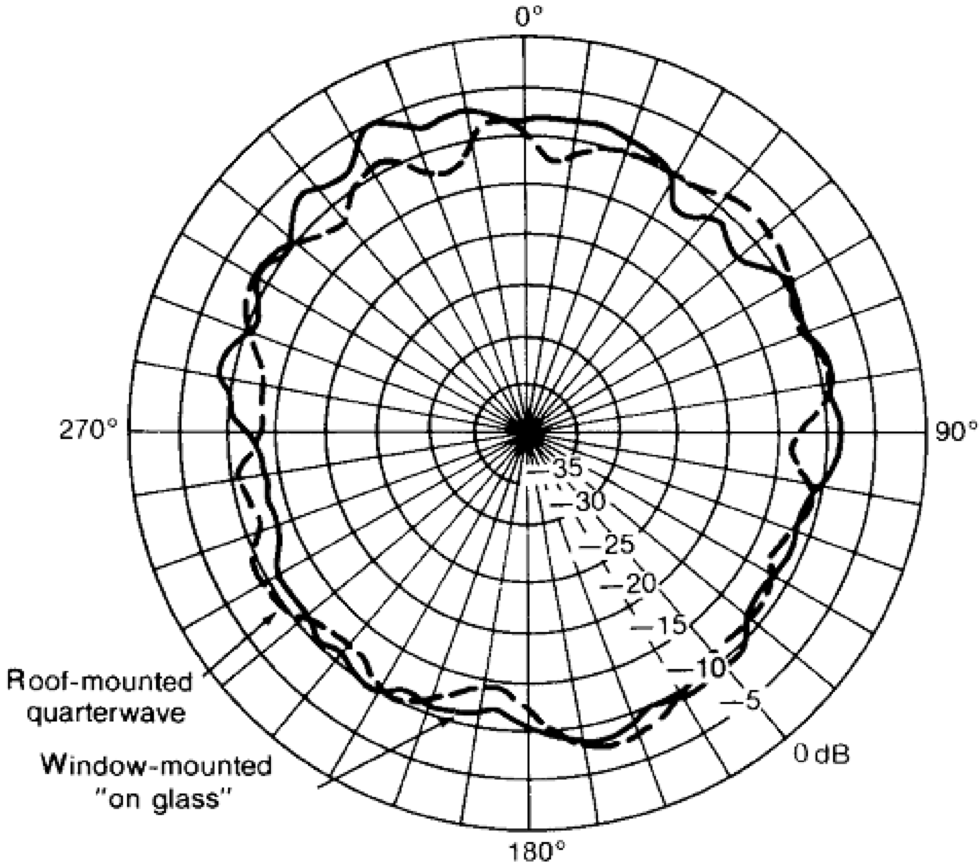


Fig.9.1. Mobile antenna patterns (a) Roof mounted 3-dB-gain collinear antenna versus roof-mounted quarter-wave antenna, (b) Window- mourned "on-glass" gain antenna versus roof-mounted quarter-wave antenna.

Roof-Mounted Antenna:

The antenna pattern of a roof-mounted antenna is more or less uniformly distributed around the mobile unit when measured at an antenna range in free space as shown in Fig.9.2. The 3-dBhigh-gain antenna shows a 3-dBgain over the quarter-wave antenna. However, the gain of the antenna used at the mobile unit must be limited to 3 dB because the cell-site antenna is rarely as high as the broadcasting antenna and out-of-sight conditions often prevail. The mobile antenna with a gain of more than 3 dB can receive only a limited portion of the total multipath signal in the elevation as measured under the out-of-sight condition.

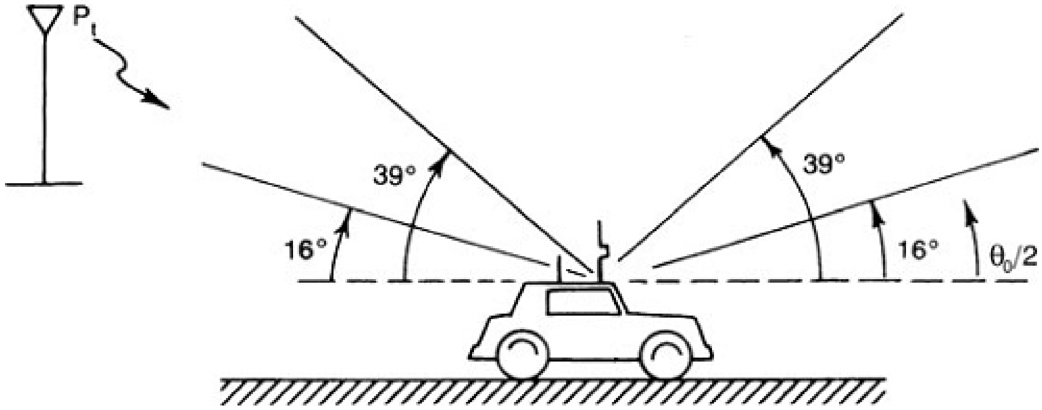


Fig.9.2. Vertical angle of signal arrival

Glass-Mounted Antennas:

There are many kinds of glass-mounted antennas. Energy is coupled through the glass; therefore, there is no need to drill a hole. However, some energy is dissipated on passage through the glass. The antenna gain range is 1 to 3 dB depending on the operating frequency. The position of the glass-mounted antenna is always lower than that of the roof-mounted antenna; generally there is a 3-dBdifference between these two types of antenna. Also, glass mounted antennas cannot be installed on the shaded glass found in some motor vehicles because this type of glass has a high metal content.

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 omnidirectional 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 an elevation coverage of 39◦ and one 4-dB-gain antenna (4-dB gain with respect to the gain of a dipole) with an elevation coverage of 16◦ and measured the angle of signal arrival in the suburban 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 beamwidth. 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◦

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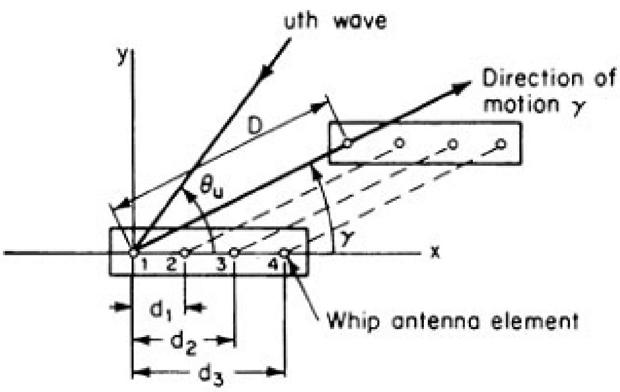
	Gain, dBi	Linear ratio	$\theta_0/2$, degrees
Whip antenna (2 dB above isotropic)	2	1.58:1	39
High-gain antenna	6	4:1	16
Low-gain antenna	4	2.5:1	24



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.

10. Explain the following,

(a) Horizontal oriented space diversity antenna

(b) Vertically Oriented space diversity antenna.

(a)Horizontally Oriented Space-Diversity Antennas:

A two-branch space-diversity receiver mounted on a motor vehicle has the advantage of reducing fading and thus can operate at a lower reception level. The advantage of using a space-diversity receiver to reduce interference. The discussion here concerns a space-diversity scheme in which two vehicle-mounted antennas separated horizontally by 0.5λ wavelength (15 cm or 6 in) can achieve the advantage of diversity. We must consider the following factor. The two antennas can be mounted either in line with or perpendicular to the motion of the vehicle. Theoretical analyses and measured data indicate that the inline arrangement of the two antennas produces fewer level crossings, that is, less fading, than the perpendicular arrangement does. The level crossing rates of two signals received from different horizontally oriented space-diversity antennas are shown in Fig.10.1.

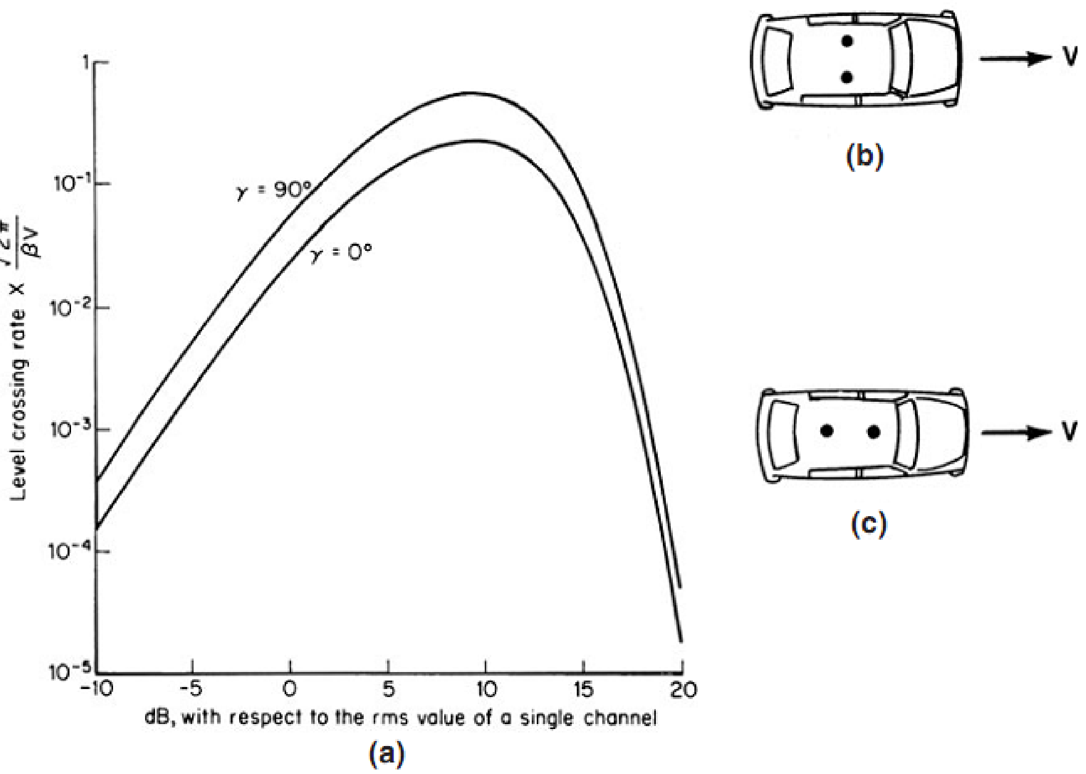


Fig.10.1. Horizontally spaced antennas. (a) Maximum difference in lcr of a four-branch equal-gain signal between a = 0 and a = 90 with antenna spacing 0.15λ; (b) Not recommended. (c) Recommended.

(b) Vertically Oriented Space-Diversity Antennas:

The vertical separation between two space-diversity antennas can be determined from the correlation between their received signals. The positions of two antennas X1 and X2 are shown in Fig.10.2. The theoretical derivation of correlation is

$$\rho\left(\frac{d}{\lambda},\theta\right) = \frac{\sin[(\pi d/\lambda)\sin\theta]}{(\pi d/\lambda)\sin\theta}$$

Equation is plotted in Fig.10.3. A set of measured data was obtained by using two antennas vertically separated by 1.5λ wavelengths. The mean values of three groups of measured data are also shown in Fig. 10.3. In one group, in New York City, low correlation coefficients were observed. In two other groups, both in New Jersey, the average correlation coefficient for perpendicular streets was 0.35 and for radial streets, 0.225. The following table summarizes the correlation coefficients in different areas and different street orientations.

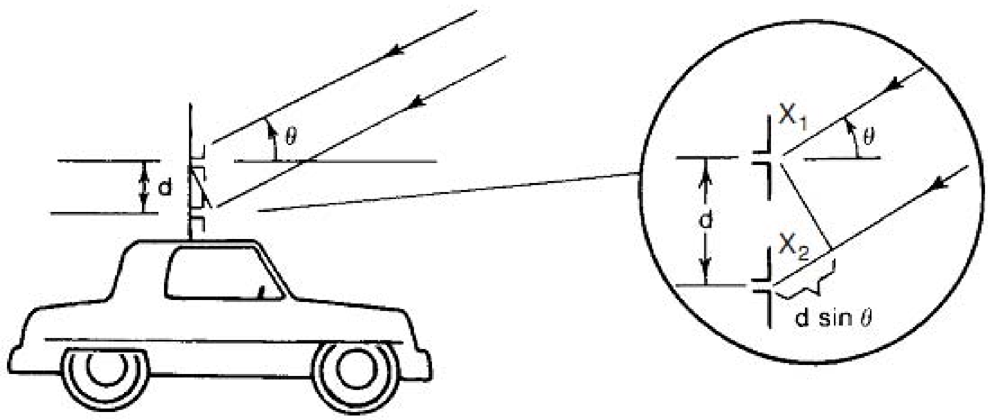


Fig.10.2. Vertical separation between two mobile antennas

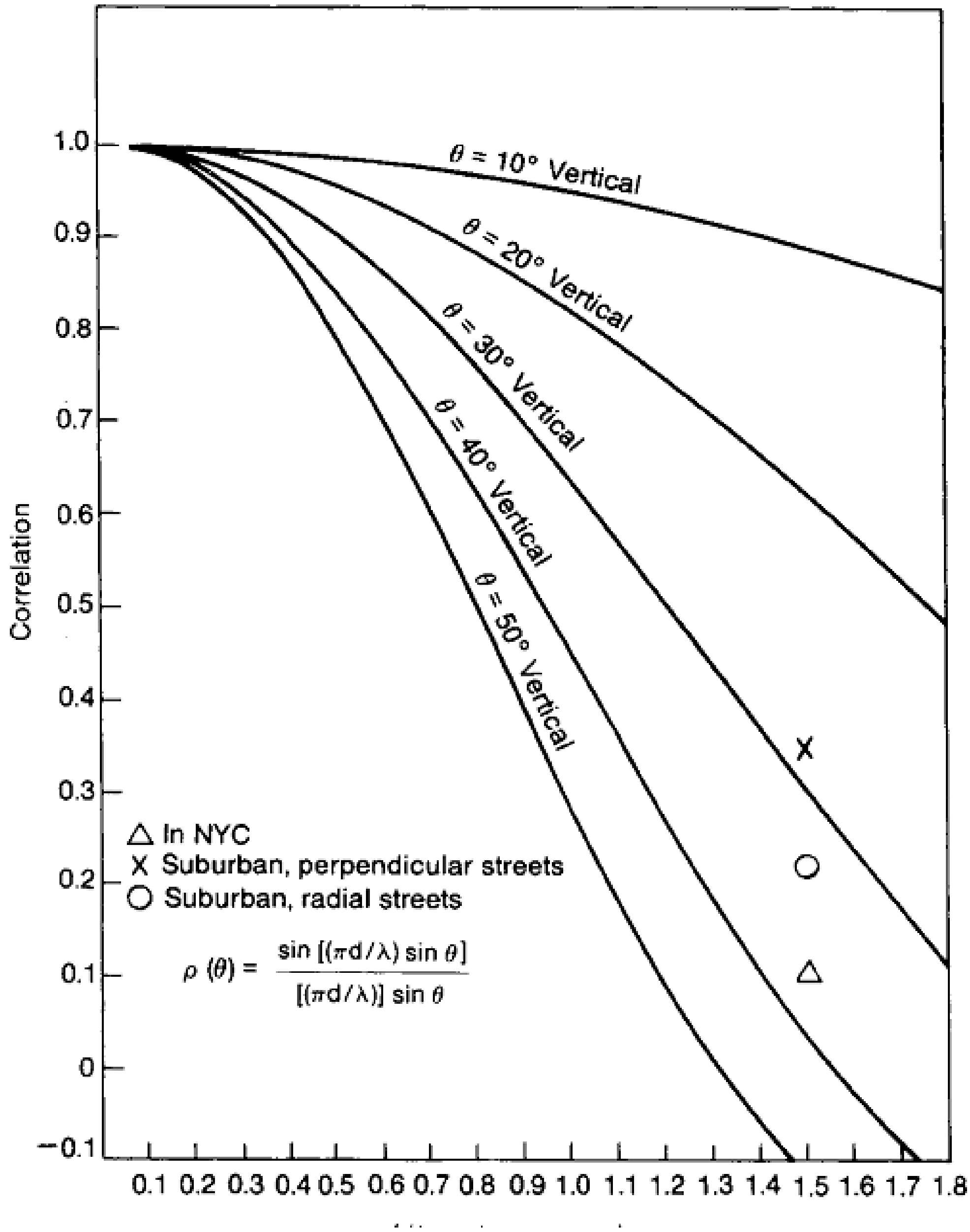


Fig.10.3. Two vertically spaced antennas mounted on a mobile unit

Area	Correlation Coefficient	
	Average	Standard Deviation
New York City	0.1	0.06
Suburban New Jersey		
Radial streets	0.226	0.127
Perpendicular streets	0.35	0.182

From Fig.10.3 we can also see that the signal arrives at an elevation angle of 29◦ in the suburban radial streets and 33◦ in the suburban perpendicular streets. In New York City the angle of arrival approaches 40◦

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