Appendix E

EMS NOTIFICATION USING CELLULAR TELEPHONES

This appendix examines the use of the cellular telephone in an ACN system. After a description of the system, RF propagation issues are discussed.

E.1 CELLULAR TELEPHONE SYSTEM OPERATION

To understand how the cellular telephone system can support an ACN system, it is first necessary to understand the basic system operation. This appendix describes the system operation, the antennas commonly employed by a telephone, and changes to the current system that will be implemented in the near future.

E.1.1 OPERATIONAL OVERVIEW

A cellular telephone is a mobile radio transceiver that is designed specifically to permit wireless access to the PSTN. The interface between the mobile phone and the PSTN is provided by a series of fixed radio transceivers (also known as cell sites or base stations) scattered throughout a region. The placement of the base station is intended to provide gapless radio coverage of the region. Figure E-l (Reference E-1) shows cellular telephone coverage in the Continental U.S. Thousands of base stations are required to obtain this level of coverage.

The area served by a single base station is called a "cell" and is usually represented by a hexagon. Cell size is a function of the expected number of users within the cell. This is a result of a key feature of the cellular telephone system called frequency reuse. Frequency reuse involves dividing the total number of channel frequencies available for cellular telephones into groups. Then, a group of frequencies is assigned to an individual cell. If the transmit power is low enough to prevent propagation of the radio signal into nearby cells, then the group of frequencies can be reused. A typical reuse pattern is shown in Figure E-2. Therefore, the total system capacity can be increased by increasing the number of cells and consequently reducing individual cell size.. As a result, urban cell radii can be as small as l/2 mile. On the other hand, in rural areas where the density of users is less, cell radii can be as large as 15 miles. This implies that the demand for a cellular channel in a rural area may be as high or even higher than an urban cell.

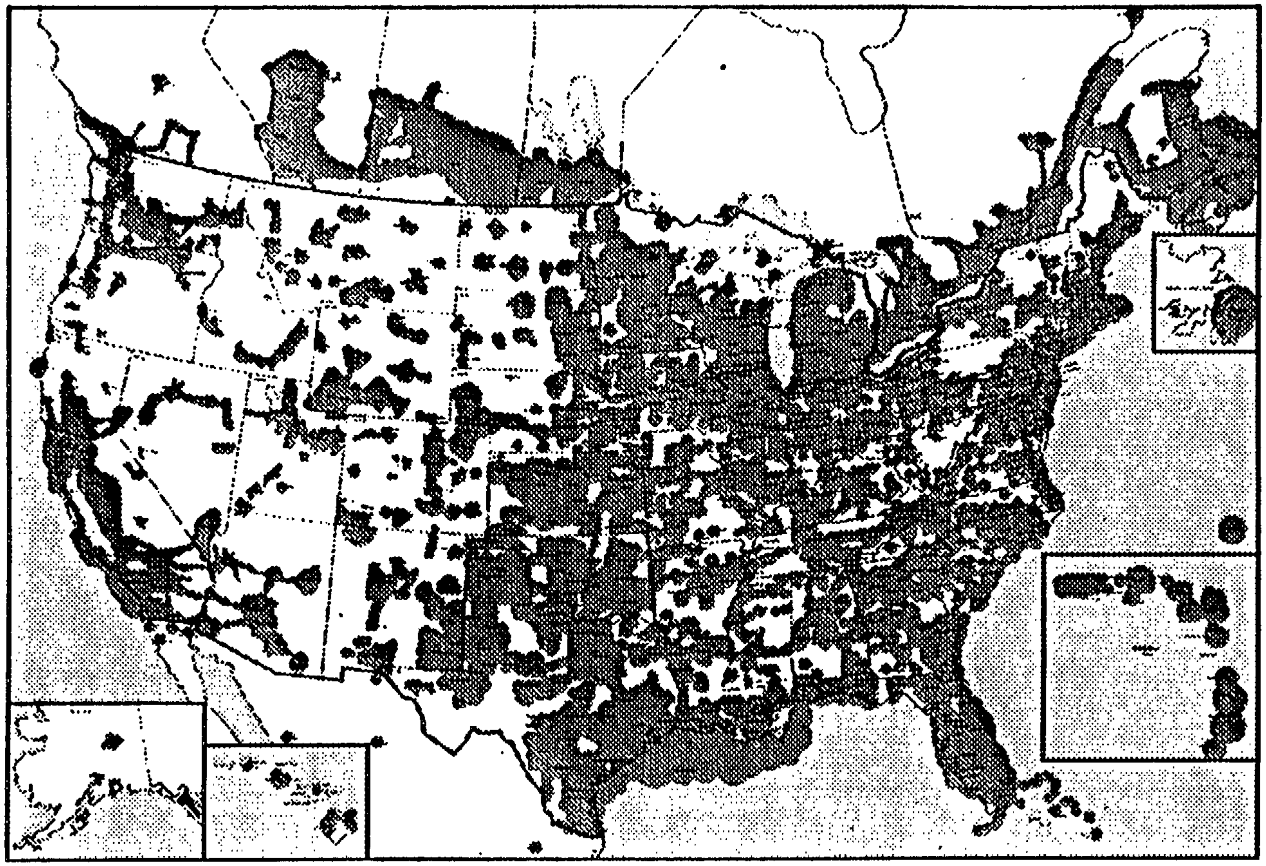

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Figure E-1 Cellular Telephone Service Areas

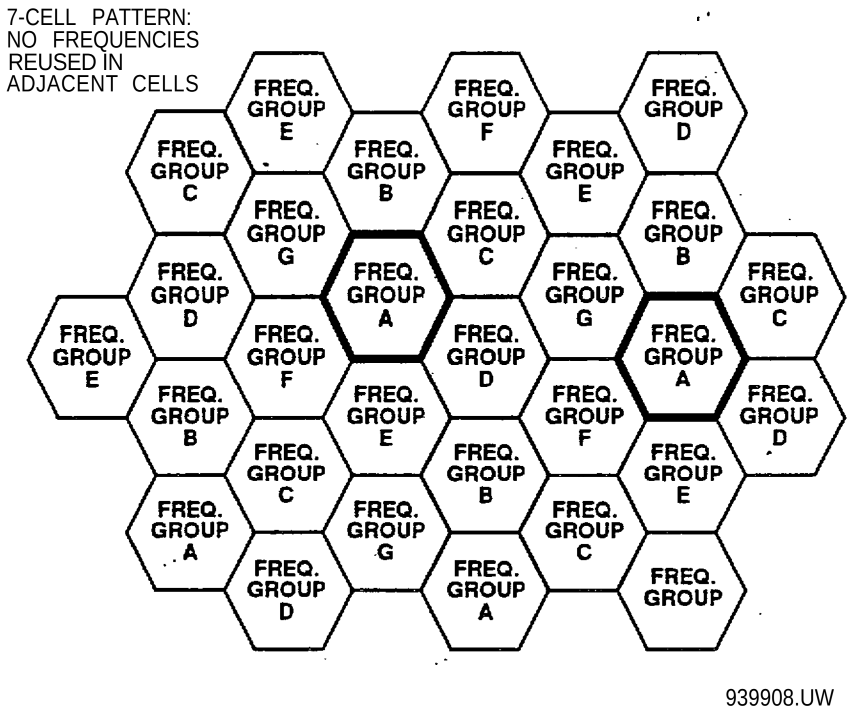

Figure E-2 cellular Telephone Frequency Reuse Pattern

The Federal Communications Commission has allocated 832 channel pairs for the AMPS, the current U.S. cellular phone system. A channel pair consists of two 30-kHz-wide channels, one assigned to mobile transmissions (reverse link) and the other assigned to base station transmissions (forward link), which permits simultaneous communications in both directions. Mobile transmit frequencies fall in the band between 824-849 MHz while the 869-894 MHz band is dedicated for basestation transmissions. The two 30-kHz channel pairs are always 45 MHz apart.

Within each market area (e.g., the Baltimore-Washington region) two cellular providers may be licensed. The spectrum is divided so that each provider has 416 channel pairs. If a 7-cell frequency reuse pattern is used, 59 channel pairs are available per cell. However, cell sectorization and other implementation issues can reduce the number of channels available in a given location to less than 20. With a limited number of channels available per cell, it is possible for the cell to be overloaded. In such a case, anyone attempting to place a call will receive a busy signal. To obtain a connection, the caller must redial until one of the channels becomes available. An automatic redial capability will be required for a cellular-telephone-based ACN system due to the possibility of an overloaded cell.

There are two types of channels, set-up channels and voice channels. Each cell site is assigned at least one set-up channel pair. When a mobile phone is turned on, it scans the forward set-up channels for the strongest signal. This defines which cell the mobile is in. To initiate a call, the mobile unit waits until the set-up channel is free, (detected by monitoring the content of the message from the base station) and then transmits a request for service. The base station responds by assigning a pair of unused voice channels to the mobile unit. The call then proceeds on the voice channels.

If a mobile unit moves from one cell to another during a conversation, an automatic handoff between cells occurs. The operations of the cells are coordinated by an MTSO. When a mobile unit moves out of a cell, the MTSO determines which cell the mobile unit has moved into by examining signal strengths. The MTSO selects an open channel in the new cell and instructs the mobile unit to switch to that channel. This is accomplished by temporarily replacing the voice transmission with a control message instructing the mobile unit to tune to a new voice channel pair. The users do not actually hear the data transmission because it is blanked from their speaker. If the user is transmitting data instead of voice, the channel blanking results in a loss of data, unless an appropriate error detection and retransmission scheme is used.

Voice transmissions are sent using analog frequency modulation while the modulation for both set-up and handoff messages is binary frequency shift keying (a digital signaling technique). Because the voice transmission is analog, the system is referred to as being analog. If a mobile unit wishes to send digital information rather than voice, a modem must be used.- The modem modulates the subscriber's digital information into an analog waveform that can pass through the 3-kHz bandwidth allowed for voice. This signal can also pass through the PSTN and be received by a compatible modem at the destination. Therefore, if the in-vehicle component of an ACN system produces a non-voice crash message, it will be necessary for the.system to include modems in the mobile unit and EMS dispatch center. On the other hand, if the vehicle can synthesize a voice message, then no modems will be required

E.f.2 CELLULAR ANTENNAS

The most vulnerable portion of an ACN system is its communications antenna, which must remain intact during the crash to allow EMS notification (unlike the crash sensors and vehicle location system). Therefore, it is necessary to consider antenna, performance as a function of type and mounting location.

There are two common types of cellular antennas, quarter-wave monopoles and 3-dB collinears. These are shown in Figure E-3. The azimuthal antenna patterns of both of these antennas are nearly omnidirectional when mounted on the roof of a car. This is shown in Figure E-4 (Reference E-2). The slight variations in the pattern are due to the vehicle structure. As the name implies, the 3-dB collinear generally provides 3-dB (two times) more gain than the monopole at low elevation angles. This is illustrated more clearly by examining the elevation antenna patterns shown Figure E-5 (Reference E-3). The monopole has a single null at 90 degrees. The collinear has a null near 35 degrees as well as at 90 degrees but has a stronger main lobe at 0 degree and at 180 degrees. Therefore, the collinear antenna gives the mobile better connectivity, assuming the antenna is oriented perpendicular to the ground. However, if the antenna is tilted towards or away from the base station by more than 30 degrees (which may occur if a vehicle leaves the

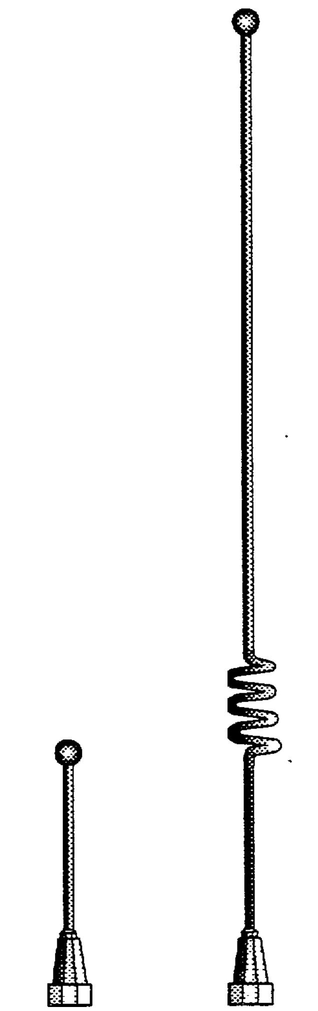

Figure E-3 Quarter-Wave Monopole and 3-dB Collinear Antenna

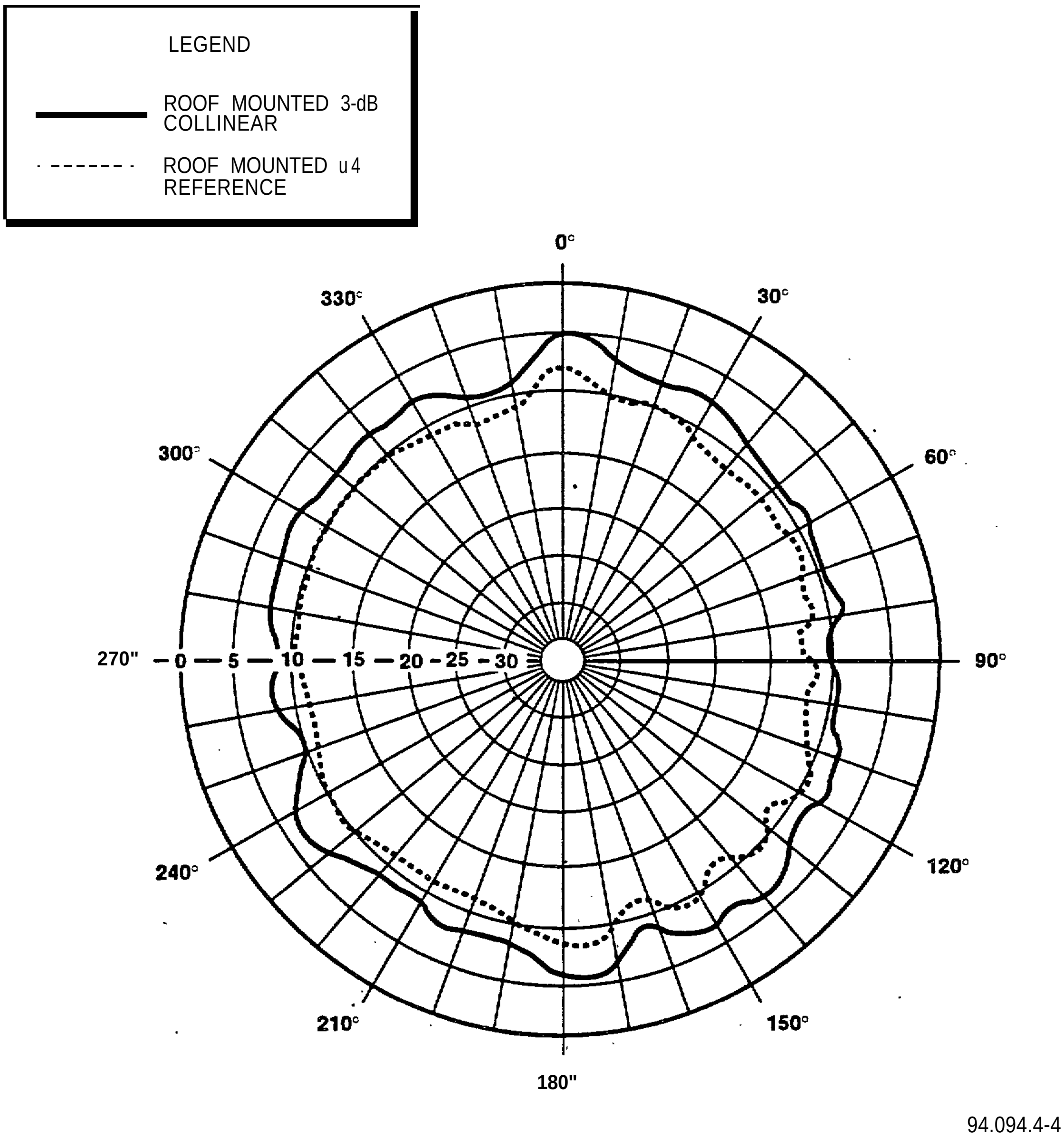

Figure E-4 Propagation Patterns of Roof-Mounted 3-dB Collinear and Quarter-Wave Monopole Antennas

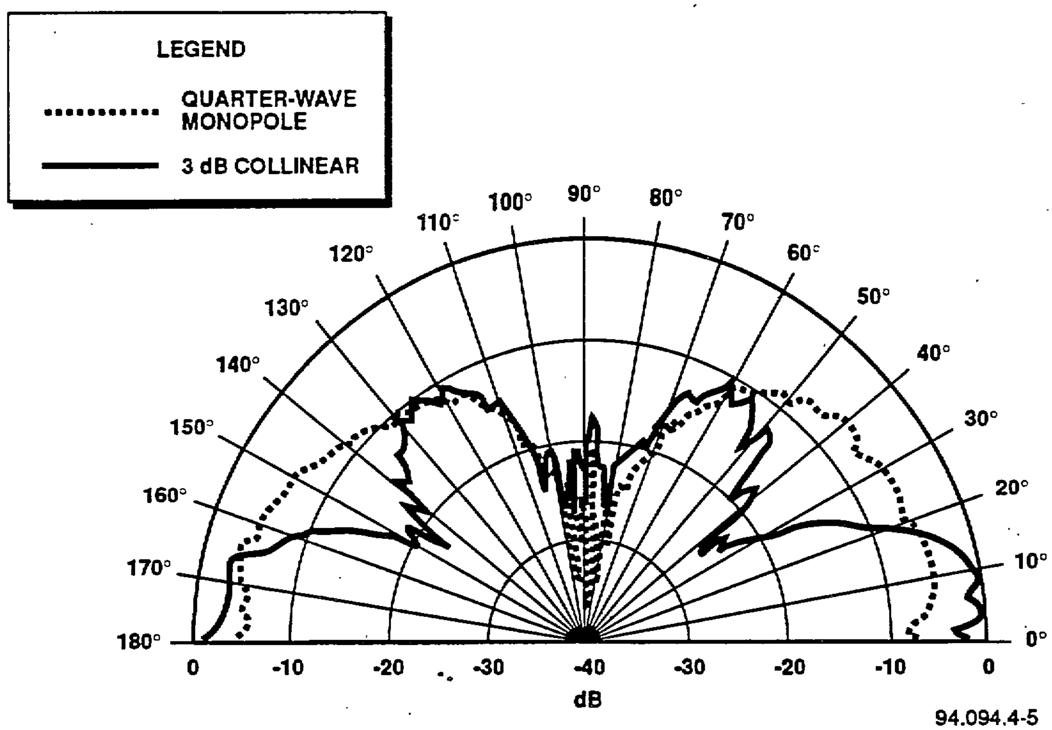

Figure E-5 Elevation Patterns of Quarter-Wave Monopole and 3-dB Collinear Antennas

roadway), the monopole antenna may provide better performance. Interestingly, neither antenna can minimize polarization loss. This is the loss in signal power due to tilting of the antenna in the plane that is perpendicular to a line drawn between the mobile unit and base station antenna. The theoretical power loss is given by Equation E-1.

$$P_L = \cos^2\Phi \qquad \text{(E-1)}$$

where Φ is the relative tilt angle between base and mobile antenna.

When these antennas are mounted in locations other than on the roof, the pattern can be significantly altered. Figure E-6 (Reference E-2) shows a comparison between a commonly used "on glass" 3-dB collinear and a quarter-wave monopole mounted in the center of the roof. The front of the car is at zero degree and the on-glass antenna was mounted on the passenger side of the windshield. Compared to Figure E-4, the gain of the collinear is seen to be reduced by the on-glass mounting. Figure E-7 (Reference E-2) shows a comparison between a 3 dB collinear and a quarter-wave monopole mounted on the trunk. Significant reductions in the gain can be seen toward the front of the vehicle, especially for the shorter monopole. Figure E-8 (Reference E-4) shows a comparison between a 3-dB antenna mounted on the roof of a car and the same antenna inside the car. There is an average reduction of about 5 dB with some nulls going deeper. The figure also shows the antenna pattern of the interior mounted antenna tilted at 45 degrees. Several

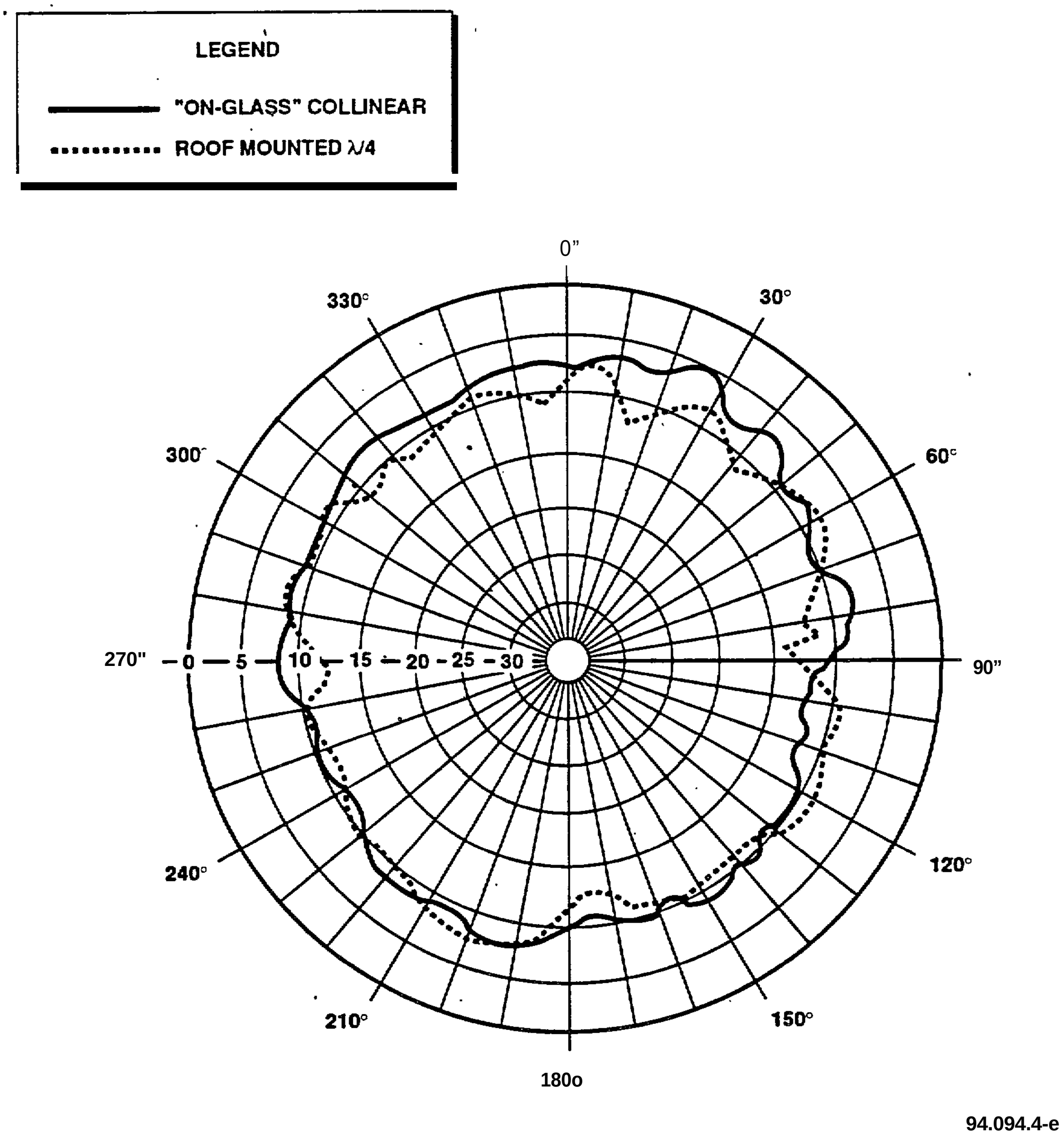

Figure E-6 Comparison of On-Glass Collinear: and Roof-Mounted Quarter-Wave Monopole Antennas

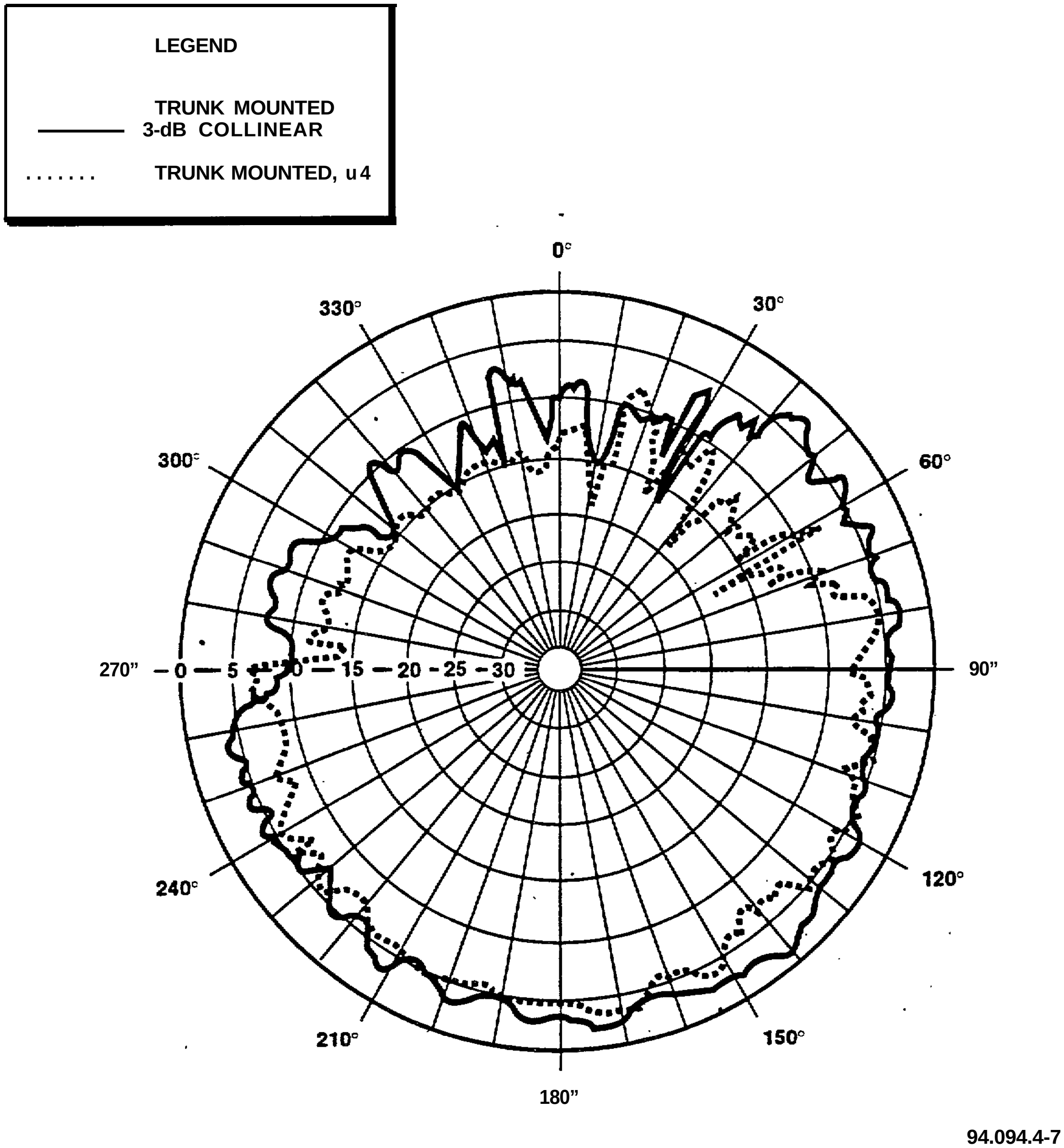

Figure E7 Comparisonof Trunk-Mounted 3-dB Co&near and Quarter-Wave Monopole Antennas

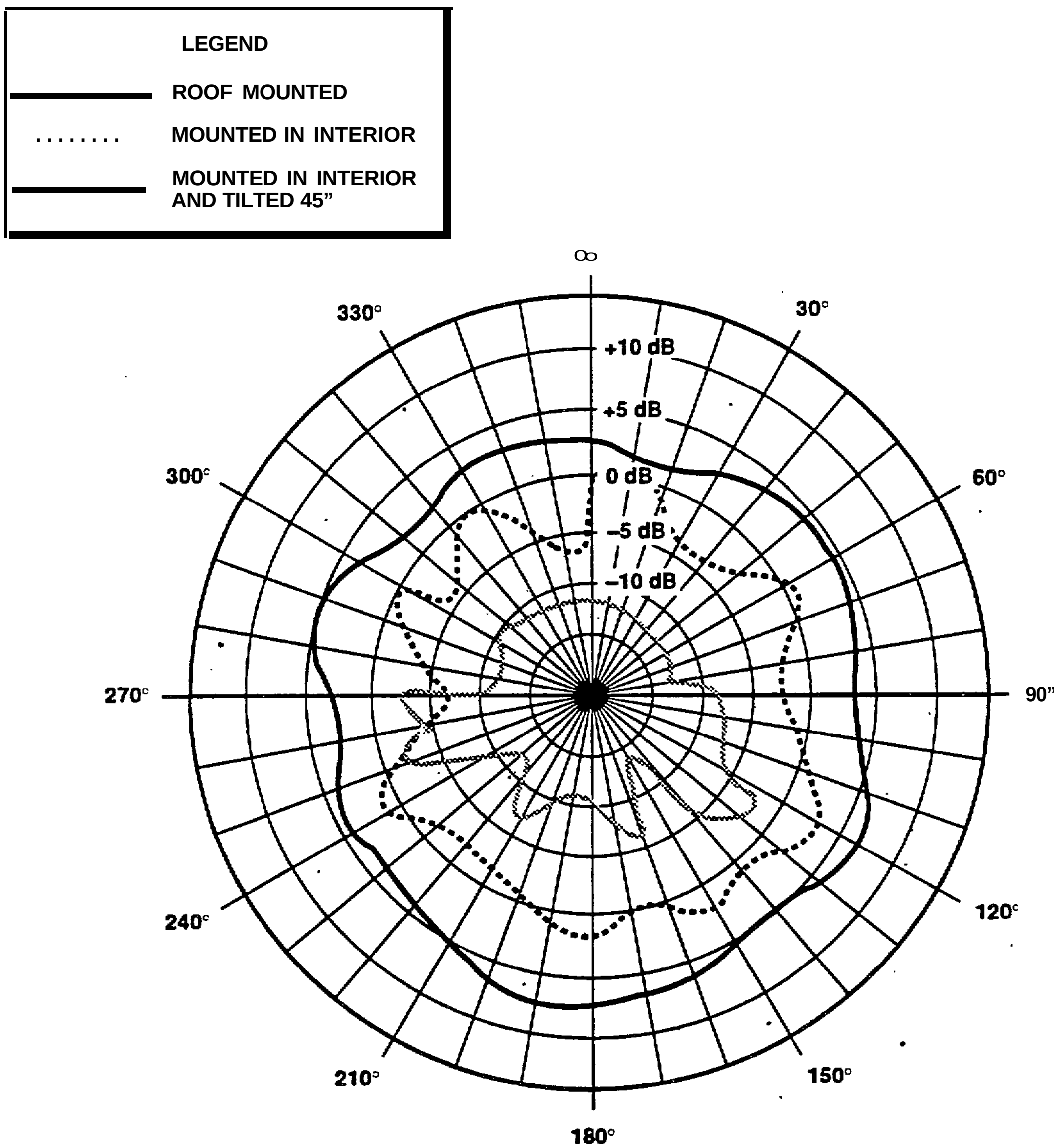

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Figure E-8 Propagation Patterns of 3dB Collinear Antenna Mounted on Roof, in Interior, and Tilted in Interior

nulls can be seen that are caused by vehicle obstructions along with a generally oblong pattern. The pattern is reduced significantly along the 0- to 180-degree plane by the elevation antenna pattern being near the null at 35 degrees. The reduction along the 90- to 270-degree plane is less because only the polarization loss of 3 dB is present.

Other types of antennas have been developed for use with cellular telephones. These include flat antennas that may be more survivable than the monopole or collinear antennas due to their low profile. However, measurements indicate that flat antennas have nearly 10 dB less gain at low elevation angles compared to collinear antennas. These antennas significantly degrade link availability.

Based on the discussion above, a roof-mounted collinear or quarter-wave monopole antenna will provide the mobile unit with the best connectivity. However, this arrangement may not provide maximum survivability. Damage to long antenna cable runs or vehicle rollover may cause antenna failure. Therefore, it is necessary to consider the use of multiple antennas' to increase survivability. The antennas could be placed at various locations around the car. One possible combination is a roof-mounted antenna, an internal antenna near the dash, and an internal antenna near the rear window. The disadvantage of the use of multiple antennas is the cost. Not only does the cost increase due to multiple antennas, but the cellular telephone must be able to select among antennas.

E.1.3 CHANGES TO THE CELLULAR TELEPHONE SYSTEM

There are two new digital cellular telephone standards being implemented today, TDMA and CDMA. These systems will increase the capacity of the existing.. cellular infrastructure by using digital voice- encoding techniques which are more bandwidth efficient. A dual-mode AMPS and TDMA system is specified in the EIA/TIA interim standards IS-54, IS-55, and IS-56. These systems will provide AMPS service on a portion of a cell's channels while another portion will provide TDMA service. Users will be able to use either their AMPS phones or dual-mode phones. The dual-mode phones will use TDMA where available and AMPS where TDMA is not available. While several cellular providers are beginning to provide dual-mode TDMA service, a dual-mode AMPS and CDMA system is not expected until 1995. These systems are specified in the EIA/TIA interim standards IS-95, IS-97, and IS-98. Conversion to dual-mode systems are first occurring in large urban areas where demand is near capacity. In rural areas, the conversion may not occur for many years. Conversion of any market area to a system without AMPS is unlikely in the foreseeable future.

Note that the new digital systems will eventually permit direct access.-to the digital waveform. Therefore, modems will not be required to transmit data over the phone. However, it is not clear when this capability will become available. A near-term option for transmitting digital data with the cellular phone system is with the new CDPD system. The system is just becoming operational in certain areas. This system uses the cellular frequencies and infrastructure but does not establish a continuous link. Instead, packets of data are sent on channels that are not currently being used for voice traffic. This allows a waveform and protocol to be used that are designed for transmitting data rather than voice... The system should be able to provide a more reliable and timely communication path than a standard phone link and modem.

E.2 RADIO FREQUENCY PROPAGATION

Other than signal attenuation resulting from free space path loss, there are two significant physical processes that impact RF propagation in the 800- to 900-MHz band; they are shadowing and multipath. Shadowing occurs when there are objects in the signal path between the cell site and the mobile telephone that obstruct or absorb the transmitted signal. This produces holes in the coverage of a cell site by reducing the average received signal power level. Multipath is a result of the reflections of a transmitted signal. Due to the reflections, multiple paths from a transmitter to a receiver are created. When the signals that propagate over the multiple paths combine, they can add constructively or destructively, either increasing or decreasing received signal power levels, respectively. The resulting effect is known as multipath fading. The fading causes the received signal power level to fluctuate about the average received signal power level. The magnitude and duration of the fades are dependent upon a number of factors including the sources of reflections and the velocity of the communicators. This section discusses the results of field testing designed to characterize both these effects and their impact on an ACN system.

E.2.1 SHADOWING

Figure E-9 (Reference E-5) is representative of the difference between ideal (cell hexagonal) and actual cell site coverage. Ideally, the coverage area would be a circle centered on the base station whose radius was equal to the maximum communication range. The maximum communication range is a function of free space path loss where the received power level decreases proportionally to $1/R^2$ (R is the range from the base station). However, the figure indicates that actual coverage areas are not circular but patchy. The holes in coverage are a result of obstructions such as hills, trees, and buildings. Operational systems typically have coverage ratios on the order of 90% to 95% of the ideal area (which is better than Figure E-8 implies). Note that the level of coverage is dependent on the type of cellular phone and its antenna. Hand-held units have a maximum transmit power of 0.6 watt while other units can transmit up to 3 watts. Therefore, a hand-held unit may have noticeably less coverage area than a unit installed in a vehicle due to lower power and less antenna gain. .

Shadowing caused by obstructions blocking the signal path is most severe in urban or mountainous regions where buildings or the terrain irregularities create radio shadows. While radio waves are able to diffract or "bend" around objects to some extent, higher frequencies are not able to "bend" as much and thus experience high attenuation when they are blocked by objects. Absorption of signal power by foliage can also cause shadowing to occur. Reference E-6 states that for cellular telephone frequencies the average attenuation through trees is from 0.18 dB/meter to 0.19 dB/meter. Therefore, a stand of trees does not need to be very wide to produce significant attenuation. Measurements taken on wooded roads have also shown that attenuation in the summer averages 5 dB greater than attenuation in the winter (Reference E-7).

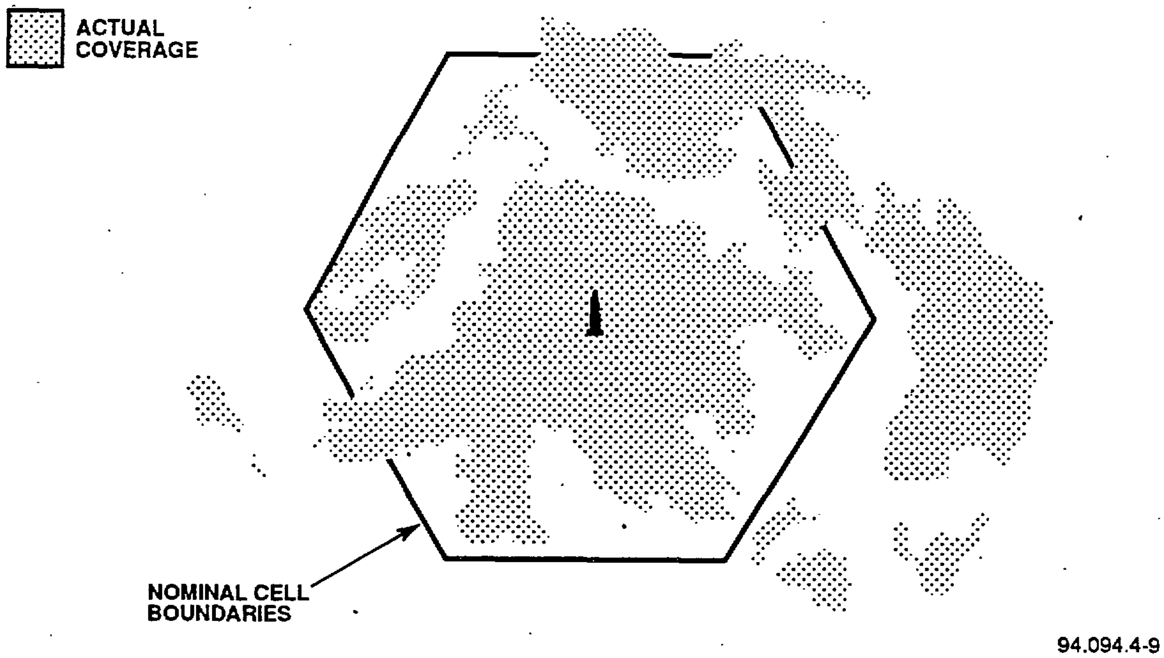

Figure E-9 Ideal versus Actual Cell Coverage

To examine the effects of shadowing, the signal power levels of a forward set-up channel were measured from several locations around a cellular telephone base station. All measurements were made using a quarter-wave monopole antenna. The locations were selected due to the topographic or man-made features between the base station and the test location. Figure E-10a shows the test locations relative to the base station and Figure E-10b shows the elevation profiles between the locations and the base station. (The profiles only indicate locations where terrain obstructions occur.) Site A is in clear view of the 150-ft tall base station tower. Site B is partially obstructed by buildings and foliage. Site C is located in the Middle Patuxent River valley and is completely obstructed by foliage and terrain. Site D is partially obstructed by foliage. Site E, like Site C, is located in the Middle Patuxent River Valley. Figure E-11 shows the signal power level measured as the data collection vehicle proceeded north on Route 29 from Johns Hopkins Road (Test Site D) to the bridge over the Middle Patuxent River (Test Site E). During the first 20 sec, the vehicle was on top of the hill. From 20 to 60 sec, the vehicle was descending towards the river. The vehicle was stopped at about 70 sec. A significant decrease in signal power is seen as the vehicle rounded the crest of the hill at about 25 sec. The overall loss between the top and bottom of the hill is around 20 dB. If free space path loss was the only source of signal power attenuation, then the difference between the top and bottom of the hill should have only been about 6 dB because the range to the base station doubled. The additional 14 dB of loss is primarily due to shadowing caused by descending into the river valley. In this case, the shadowing is not severe enough to affect normal cellular telephone connectivity because the signal power level was high enough to permit communications even in the nulls. However, steeper valleys or valleys further from the base station could cause a loss of communications. Note that there are several other processes illustrated by Figure E-11 which are related to multipath. This figure will be revisited in the multipath discussion.

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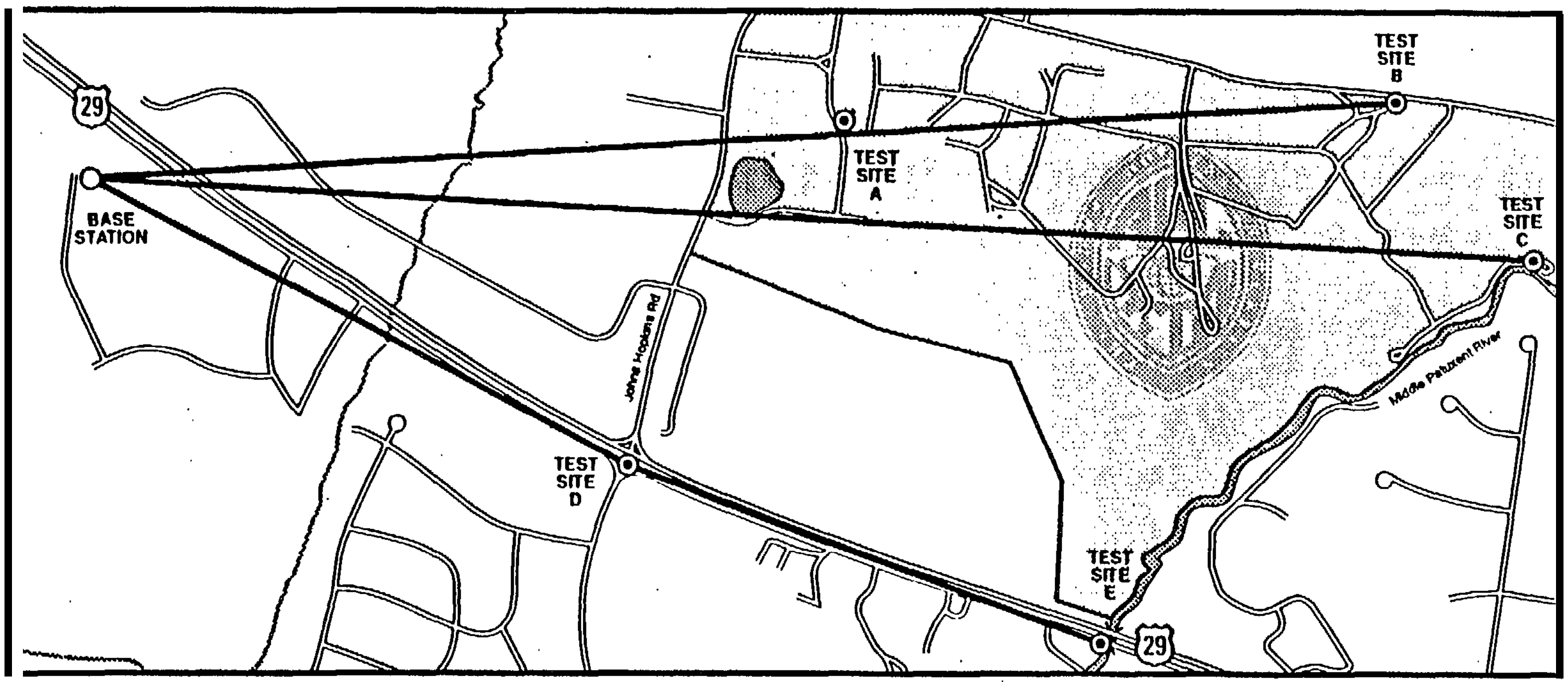

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Figure E-1Oa Test Sites Relative toCellular Telephone Base Station (Overhead View)

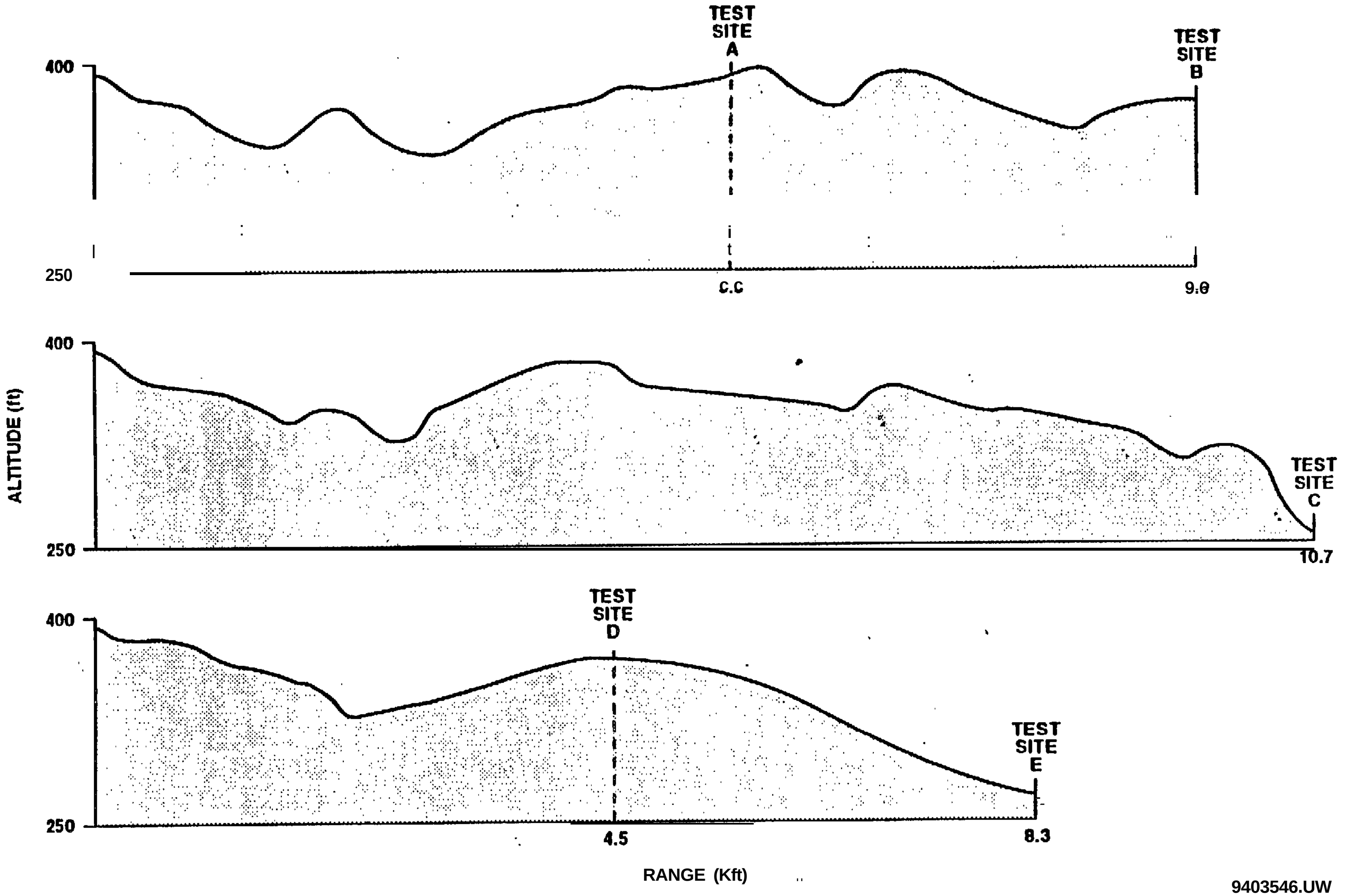

Figure E10b Elevation Profiles Along Lines of-Sight from the Cellular Telephone Base Station to Test Sites

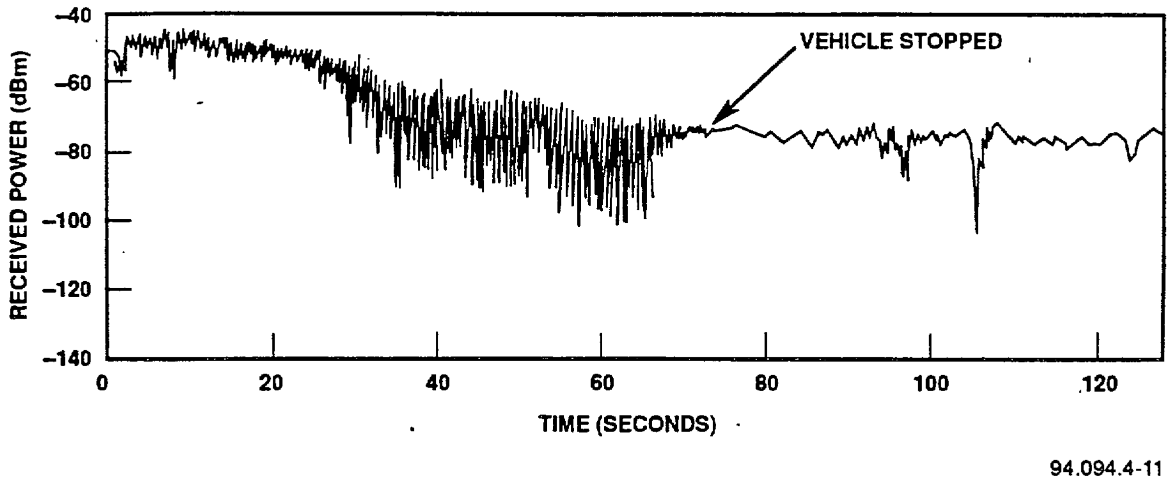

Figure E-11 Signal Power Level Traveling North on Route 29

Additional data showing the effect of shadowing were collected at sites A, B, and C. Figure E-12 shows the average signal power received at these three points. A free space path loss curve is drawn through the site A data point to emphasize power loss that can be attributed to shadowing at the other sites. It is clear that the obstructions are reducing the received power significantly. For example, the difference in average power between site A and C is almost 40 dB more than would be predicted based on free space path loss. An examination of Figure E-9b indicates that the loss is a result of shadowing caused by the greater than 100-foot difference in elevation between site A and C.

The data presented in this section illustrate the significant impact of shadowing on average signal power. The data imply that there are areas around a cell site where communications will not be possible under any conditions. In these cases, the loss of power is substantial and there are no modifications that can be made to a cellular telephone that can mitigate the effect. Fortunately, many cellular providers are currently attempting to identify areas in radio shadows so that corrective measures can be taken. This will decrease the amount of area where radio shadows occur, but will not eliminate them.

The data also indicate that there are areas where shadowing can decrease average signal strength to a low enough level such that multipath fading may cause the instantaneous signal level to drop below the minimum required by the cellular telephone. In these areas, it is necessary to understand the characteristics of fading if a high degree of connectivity is required. These characteristics are discussed in the next section.

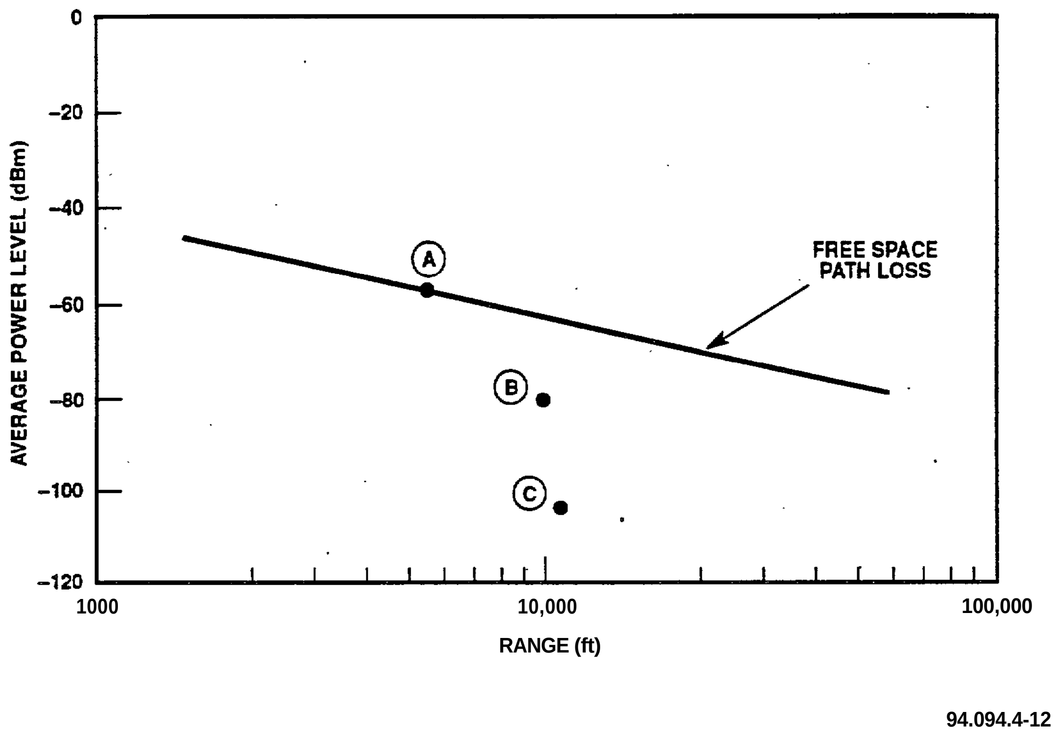

Figure E-12 Measured Signal Power Levels Compared to Free Space Path loss

E.2.2 MULTIPATH

Figure E-13a shows a typical multipath environment. Because each path can have a different length, the signals arriving at the receiver have different phases; When these signals combine, interference occurs. Figure E-14 shows the effects of interference. If the phases match, the interference is termed constructive and the combined signal is stronger than a signal from any one path. If the phases do not match, the interference is termed destructive and the combined signal is weaker than a signal from any one path. It is theoretically possible for the signals to combine in such a manner that they completely cancel, resulting in zero received signal power. A multipath environment occurs when there are a large number of paths from transmitter to the receiver and the signal phases on the individual paths are uniformly distributed causing the locations of the peaks and nulls of signal power to vary randomly. This is typically the case for mobile communications. Note that constructive multipath fading may be caused by a non-direct communications path around an obstacle as illustrated in Figure E-13b.

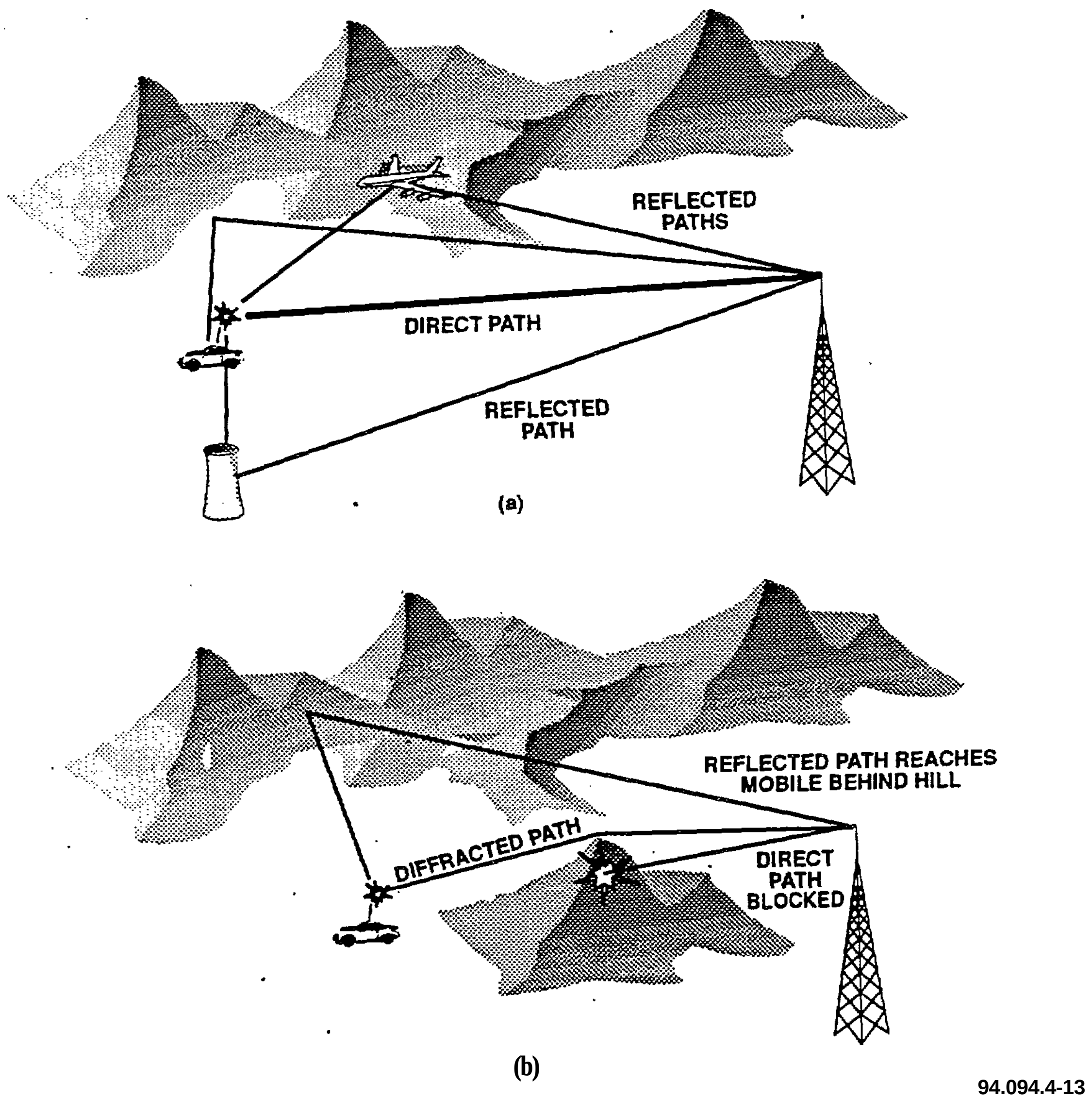

Figure El3 Multipath Propagation

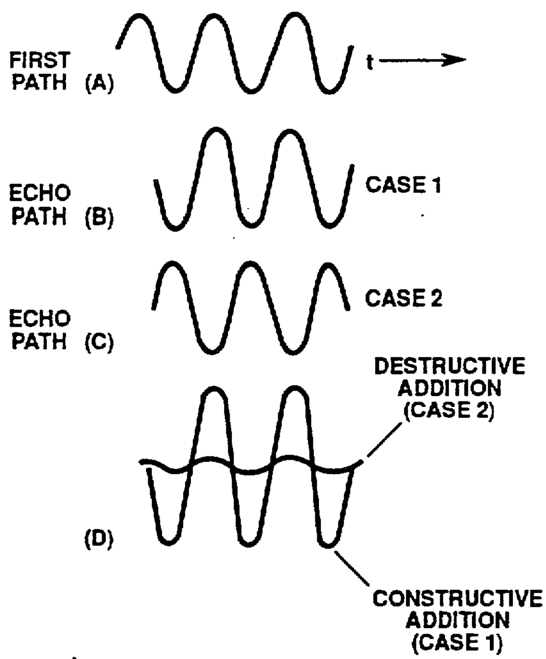

Figure E-14 Constructive and Destructive Addition of Two Transmission Paths

If a vehicle is moving through a multipath environment, the received signal power will vary randomly. In an area with a strong main signal and weaker reflections, the variations in the received amplitude will be small because the reflections are not large enough to cancel the main signal. This generally occurs in areas where there is a line-of-sight path to the transmitter or very little shadowing. An example of this is shown in Figure E-11 during the first 20 sec of data collection where the vehicle was on top of the hill in sight of the base station. As the strength of the main signal decreases, received signal power variations increase. This is because the reflections are closer to the strength of the main signal and thus have a larger impact on it. In Figure E-11, the variations increased between 25 and 40 sec as the vehicle descended the hill. At the 60-sec mark, the variations are over 25 dB.

The vehicle came to a stop around 70 sec and the rate at which the signal varied changed drastically. Deep nulls were still generated, as can be seen at 105 sec (Figure E-11), but they did not occur as frequently and lasted longer when they did occur. It can be concluded that while the vehicle is operating, its motion caused the lengths of the different signal paths to change rapidly and thus the multipath fading to fluctuate rapidly. The faster the motion, the faster the variations. When the vehicle was stationary, the signal path lengths did not change as often (or at all). This resulted in a lower fading rate. Note that if the reflectors are all stationary and signal path attenuation does not change with time, then the multipath environment would be static and fading would only be observed during motion. However, many reflectors are not stationary, such as cars driving nearby or wires moving in the wind. This is the reason that a deep fade occurred while the vehicle was stopped on the side of the road.

Figure E-15 shows data collected from stationary antennas at sites A, B, and C. The top curve, taken from site A, shows little variation, as expected in an area with a strong direct path to the transmitter. The two short fades at 37 and 100 sec occurred when cars passed between the receiver and the cell tower. The middle curve, taken at site B, indicates that fade depths averaged several dB. In this case, buildings and terrain reduced the average signal power by shadowing. This allows multipath signals to affect the received power level more significantly. The bottom curve, taken from site C, has very large variations. This indicates how significant multipath fading is in a weak signal environment like that found in a deep valley. The difference in variations between sites is even more apparent when the amplitude distributions for the data collected at sites A and C are compared. The distributions are shown in Figures E-16 and E-17, respectively. They are plotted with a Rician curve fitted through the data points. A Rician amplitude distribution is expected when operating in a multipath fading environment with a dominant signal path. At site A, a strong direct path between base station and receiver causes a narrow Rician distribution to occur. The distribution is confined to a few dB range. Like the site D data, the direct path is strong compared to the reflected paths. Thus, there is little fluctuation in signal power. Although site C is obstructed by terrain and foliage, a dominant signal path also exists. It is formed by stationary objects. Since the dominant path signal power level is similar to the signal power level propagating over other reflected paths, the effect of the other paths on the instantaneous power level is substantial. This is shown by the distribution's greater than 20-dB range.

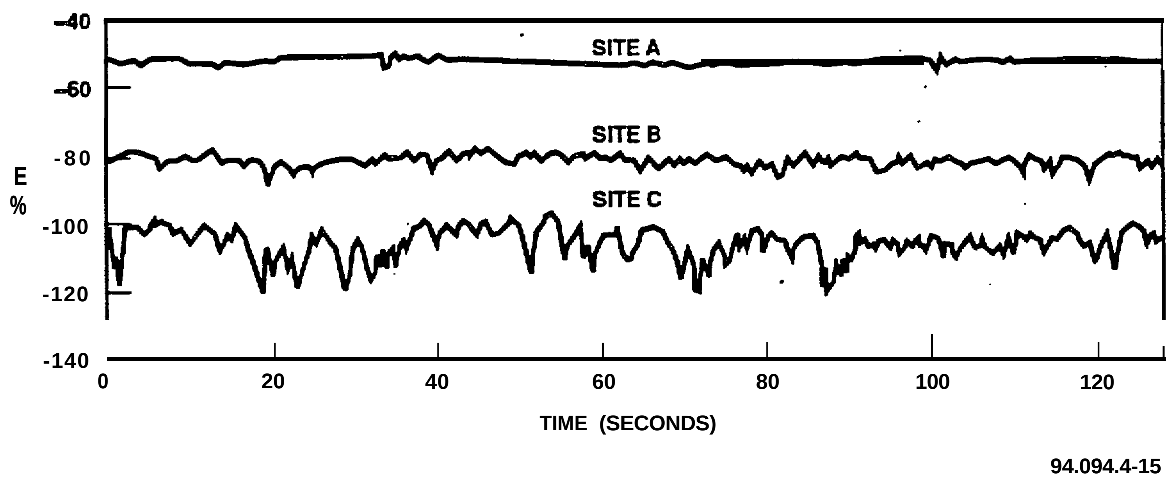

Figure E-15 Signal Fluctuations Due to Multipath

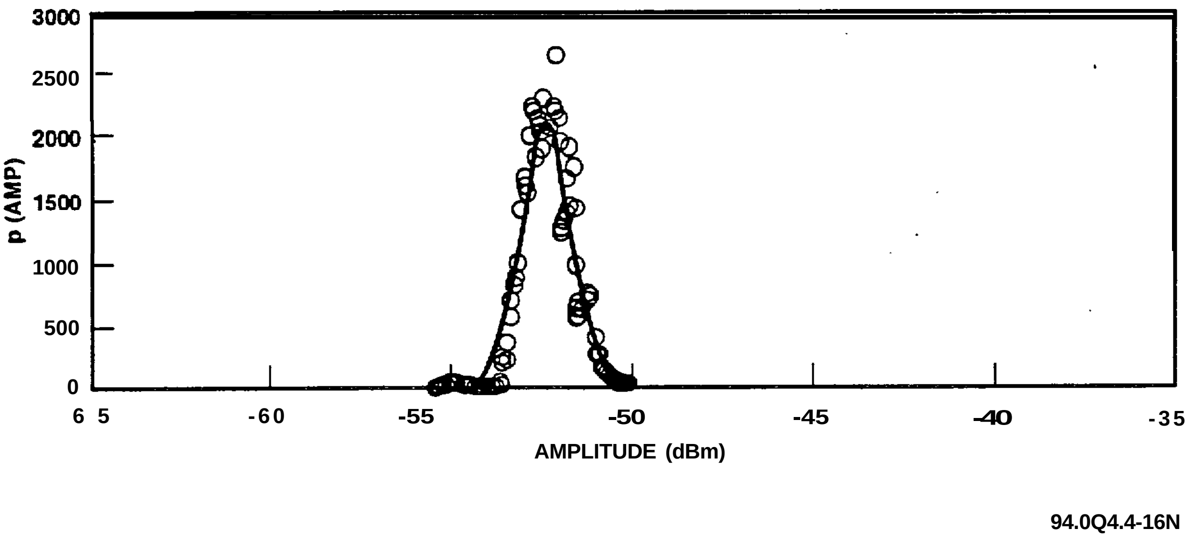

Figure El6 Signal Power **Distribution** from **Site A**

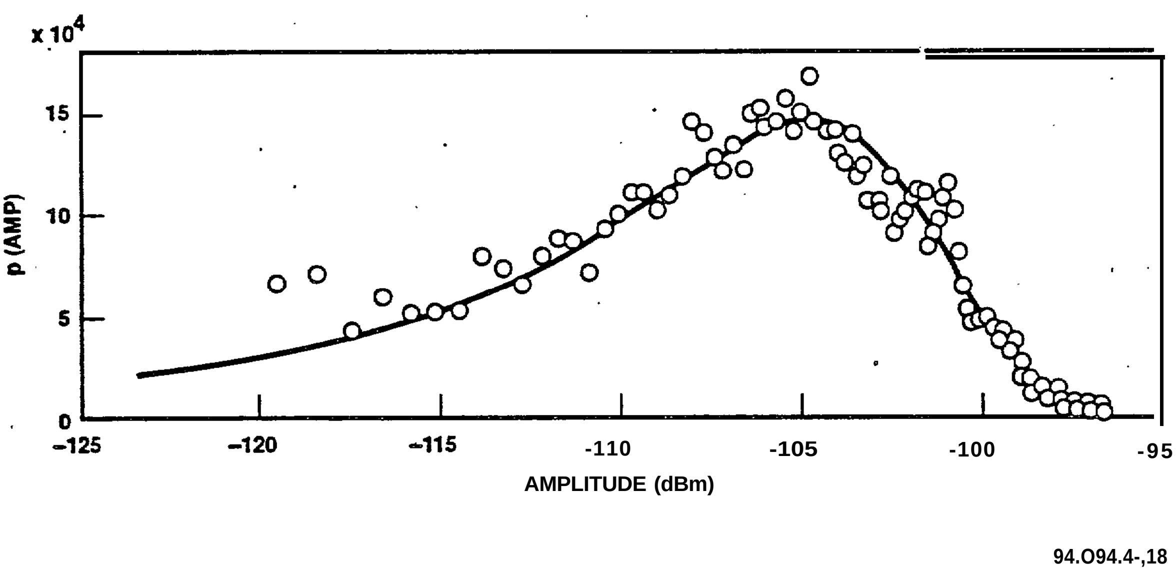

Figure E-17 Signal Power Distribution from Site C

It is not clear how significant the distrubution's tail is due to the noise floor at approximately -119 dBm. Note that a cellular telephone requires approximately 6 dB signal-to-noise ratio (SNR) to operate satisfactorily. Therefore, assuming that external noise is .the limiting factor, fades below -113 dBm should cause a loss of link at site C. A phone call was placed from this location and occasional fades were heard.

To compare the effects of mobile (the basis for cellular telephone design) and fixed (ACN scenario) operation on multipath fading, signal strength data were collected while the test vehicle was driven at 10mph along the river at site C. The data are shown in Figure E-18 and the amplitude distribution is shown in Figure E-19. Figure E-19 indicates that the fixed and mobile signal amplitude distributions are similar. However, there is a small difference in the type of distribution. The data in Figure E-19 are fitted with a Rayleigh curve. This is typical of the mobile fading environment where there is no dominant signal path. Since the vehicle is moving, there is no dominant path created by stationary or slowly varying reflectors.

Although the amplitude distributions are not significantly different, the rate and duration of the fades are. Figure E-20 shows the average fade rates and average fade durations for data collected at site C. The rates are shown as a function of amplitude. The difference between stationary and mobile fades is quite apparent. For example; in the 10-mph case, fades below -113 dBm occurred at an average rate of 10 Hz and lasted an average of 10 msec. However, in the stationary case, fades below -113 dBm occurred less frequently (at an average rate of 0.2 Hz) but lasted longer (an average of 350 msec). As a reference, the average power for the signals was -104.7 dBm.

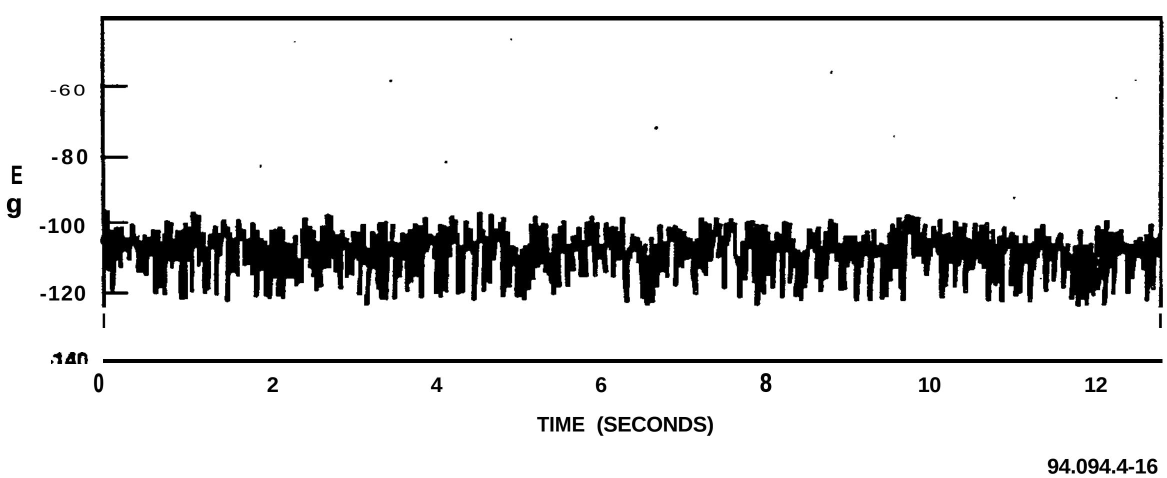

Figure El8 Signal Power Variation Experienced by a Vehicle Moving at 10 mph

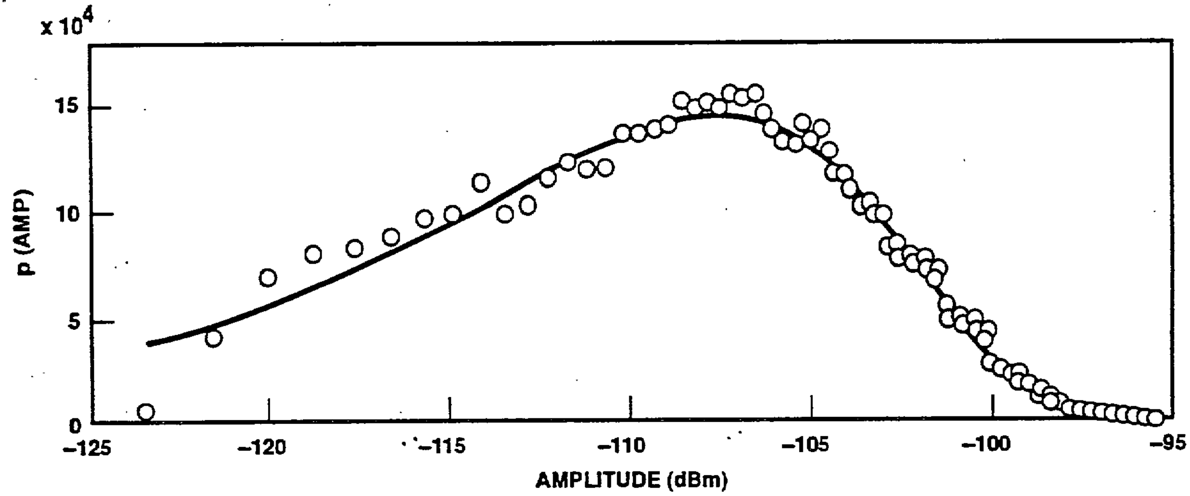

Figure E-19 Signal Power Distribution for Measurements Taken at 10 mph

A commonly used equation for the average rate of fades, also known as level crossing rate, is

$$\text{Crossing Rate} = \sqrt{2 \cdot \pi} \cdot f_m \cdot \frac{R}{\sqrt{2} \cdot \sigma_r} \cdot \exp\left[-\left(\frac{R}{\sqrt{2} \cdot \sigma_r}\right)^2\right] \qquad \text{(E-2)}$$

where $2\sigma_r^2$ is the average envelope power, R is the signal amplitude level that is being crossed, and $f_m = v/\lambda$ is the maximum Doppler frequency from the vehicle's motion. This equation closely follows the data for the 10-mph case, as shown by a plot of Equation E-2 (solid line) in Figure E-20a. If a vehicle's speed goes to zero, $f_m = 0$, the level crossing rate goes to zero; this implies that the reflecting objects are all stationary and there are no fades. While the rate of variations is significantly slower, our data clearly show that variations do occur even when the receiver is stationary. This is because the maximum Doppler frequency is not solely dependent on the vehicle's motion but also on the motion of objects in the surrounding environment. This is significant because it implies that a vehicle's antenna is not likely to come to rest in a stationary null, but rather that nulls may slowly pass through the vehicle's location as a function of time. Similar results can be seen in Figure E-19b, which shows a theoretical fade duration curve. Theoretically, when vehicle speed goes to zero, fade duration should become infinitely long. However, the movement of objects in the surrounding environment causes fading to occur.

If the multiple signal paths are significantly different in length, then the location of nulls at a given time is also frequency dependent. While one frequency may experience a null in a given location, another frequency may not. The frequency separation required for channel independence is known as the coherence bandwidth. For the cellular environment this is typically less than 100 kHz. The duplex operation of the cellular system requires transmission and reception on different frequencies. These are separated by 45 MHz, significantly greater than the coherence bandwidth. In addition, call set-up occurs on dedicated control channels that are usually separated from the conversation channels by more than the coherence. bandwidth. For a ceIlular call to be successfully established, all four frequencies must have a sufficient SNR. This implies that the effects of fading may have to be addressed on multiple channels, which complicates the problem.

E.3 TECHNIQUES TO MITIGATE THE EFFECTS OF FADING

Because multipath causes signal fluctuations, techniques can be employed to reduce the impact of destructive fading and take advantage of constructive fading (to combat shadowing). Two techniques that an ACN system can employ are time diversity and space diversity. Time diversity is a technique that has been used by the cellular telephone industry to combat fading. However, the implementation of time diversity has been based on the fading characteristics of a mobile telephone call. Based on Figures 4-9, E-15, and E-20, it is clear that the statistics of a mobile call are very different than a call placed from a fixed location (i.e., the crash site). The cellular system repeats important control messages several times to help combat fading that is on the order of milliseconds. For communications from a fixed location, data must be repeated at a rate on the order of seconds, rather than milliseconds. For an ACN system, simply continuing to try to place a call until successful is a simple means of implementing time diversity. Once a call is established, messages should be repeated until an acknowledgment of a correct message is received. If the call is dropped because of a long fade before the acknowledgment is received, the process should start over. Again, this is a concern for the stationary communication scenario because the fade duration is an order of magnitude greater than in the mobile scenario.. Time diversity will not increase the cost of an ACN system and can be used to ensure a message is successfully received, providing the fading is not severe enough to prevent a call from ever being placed or maintained. If the fading is too severe, spatial diversity can be used to help maintain the link and reduce the number of repeats necessary.

Originally, it was expected the multipath environmerit would be static. If an antenna came to rest in a nuli, the vehicle would not be able to notify the EMS dispatcher. Spatial diversity would be necessary to find a location that was not in a null. Our data show that the signals do vary in time, and thus, less expensive time diversity can provide significant help. However, spatial diversity can be effective, especially in areas with very weak signals. Spatial diversity, also known as antenna diversity, involves using two or more receive antennas in different locations. This, of course, assumes that more than one antenna survives. The required physical separation to achieve independent paths is around l/2 wavelength, or 6 to 7 inches. On antennas separated by this distance or more, the fades will generally be independent. Figure E-21a shows two independent signals, rl(t) and r2(t). Figure E-20b shows the output of a switched combiner that selects the strongest signal. Although fades can still occur on the combined signal, they are less likely and not as long. Base stations often use antenna diversity for improved reception. In the U.S., mobiles do not generally use antenna diversity as *communications have proven to be adequate without it. Antenna diversity is more

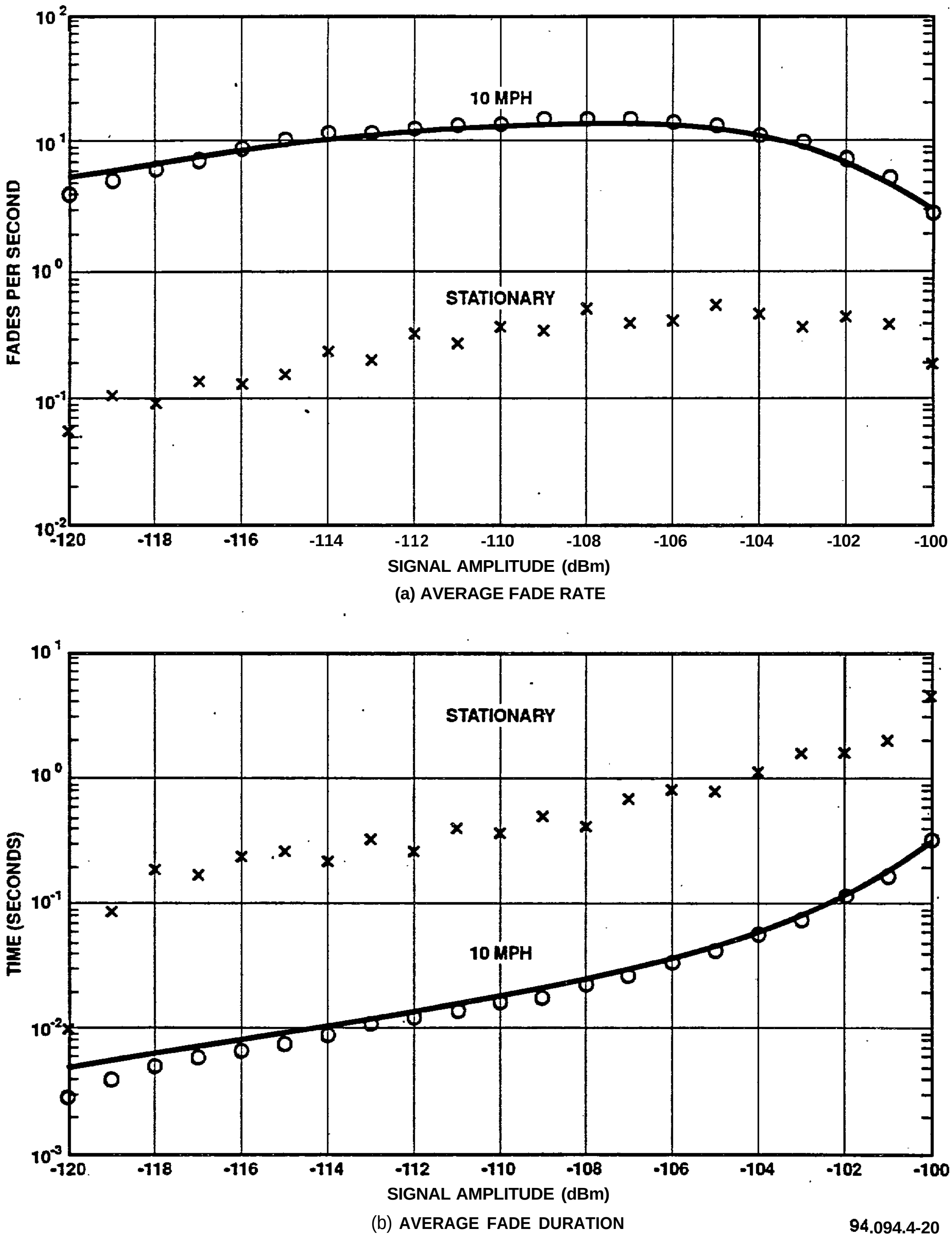

Figure E-20 Fade Rates and Duration

expensive due to the increased cost of multiple antennas, their installation, and the electronics to select or combine the antennas. However, if multiple antennas are required to ensure survivability, the additional cost of combining the surviving antennas in a diversity receiver is expected to be small. The rate of sampling and switching between antennas must be greater than the fade rate. For a mobile, this rate is rather fast. For a stationary antenna, the rate is slow and this may further reduce the extra cost of employing antenna diversity.

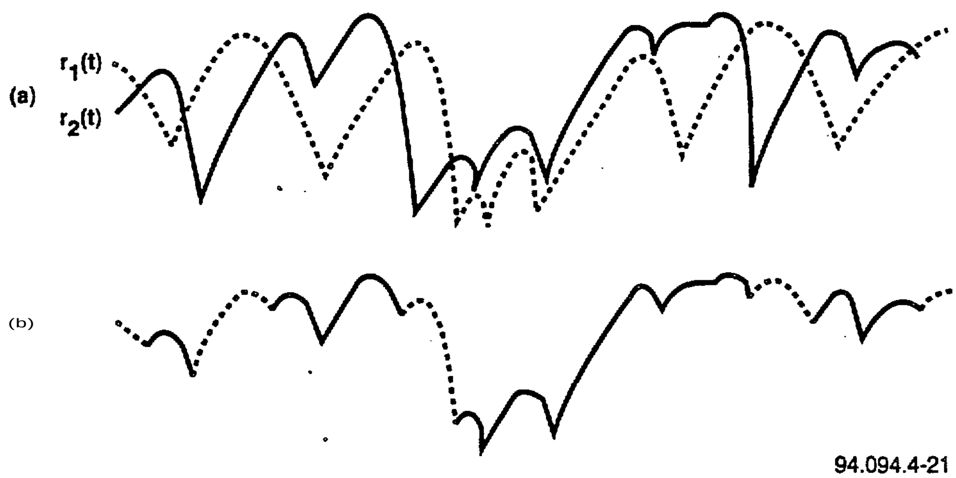

Figure E21 Switch Combining

E.4 SUMMARY

Although the cellular telephone system can be used to support ACN (in areas with base station coverage), there are two principle propagation effects that hinder cellular connectivity. Shadowing causes a reduction in the average signal strength and an increase in the effects due to multipath. A decrease in the average signal power will increase the number of nulls that go below the minimum acceptable SNR and will increase the width of nulls below that level. The average received signal power is limited by the maximum transmitted power, the propagation paths, and the antenna gains. It is difficult to change the maximum transmit power and not possible to change the propagation paths. A higher gain antenna can improve the SNR to the point where the noise level is limited by received noise rather than internal noise. Unfortunately, high gain antennas are physically vulnerable. They are somewhat large and should be placed on the roof of the vehicle. If only one antenna is used, it may not survive and communications would then be impossible. If multiple antennas are used, there is a greater chance of one surviving, but the surviving antenna may not have a high gain. Thus, of the factors that could improve the average SNR, only the antenna can be controlled and it is subject to. the physical constraint of being able to survive, a crash.

Multipath fading causes variations of the instantaneous signal strength around the average signal strength. The rate and duration of the fading are dependent on the velocity of the vehicle. As the vehicle moves faster, the duration of the fades also increases. If the vehicle is stationary (as in the CAN scenario), then theoretically, no fading occurs. This implies that only spatial diversity would be appropriate for ACN. However, the data indicate that fading occurs even when the communication terminal is stationary because of movement of signal reflectors andattenuators in the surrounding codes can be designed specifically f9r stationary communications to enhance operation of the cellular telephone (or any other 800-MHz land mobile radio system) in areas with marginal signal strength.

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