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PROPAGATION EFFECTS BY ROADSIDE TREES MEASURED AT UHF AND L-BAND FOR MOBILE SATELLITE SYSTEMS

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ABSTRACT

During June 1987, The Applied Physics Laboratory of the Johns Hopkins University and the Electrical Engineering Research Laboratory of the University of Texas at Austin performed the fifth in a series of cooperative propagation field tests related to planned Mobile Satellite Systems (MSS). These tests were performed in Central Maryland and involved a helicopter and mobile van as the source and receiving platforms, respectively. Whereas, the previous measurements in Central Maryland were performed only at UHF (870 MHz), the June 1987 tests were implemented at both UHF (870 MHz) and L band (1.5 GHz) during a period in which the trees were in full blossom and contained maximum moisture. Cumulative fade distributions were determined from the data for various fixed elevation angles, side of the road driving, and road types for both worst and best case path geometries and for overall average road conditions.

INTRODUCTION

The results described here add to the existing data base of propagation measurements at L Band (1.5 GHz) [see references]. They are considered particularly useful in that systematic propagation effects are derived from repeated and controlled runs pertaining to different path elevation angles, road types, and path geometries defining "shadowing" and "multipath" modes. In addition, simultaneous L Band and UHF measurements were performed for the purpose of establishing scaling factors applicable to previous UHF (870 MHz) measurements [Vogel and Goldhirsh, 1986; Goldhirsh and Vogel, 1987]. Since the source platform was a helicopter and the receiver was located on a mobile van, control of the propagation path geometry enabled systematic determination of fade distributions for various road types, fixed elevation angles, and propagation path aspects.

EXPERIMENTAL ASPECTS

Transmitter Platform

The source platform was a Bell Jet Ranger Helicopter carrying two antenna systems. The UHF antenna (870 MHz) consisted of a microstrip configuration, and the L Band antenna (1.5 GHz) was a helix. Both radiated right hand circular polarizations with beamwidths nominally 60^{o}. The two antennas were located on a steerable mount below the aircraft with the pointing controlled by an observer inside the helicopter. Also located on the steerable mount was a video camera. The experimenter within the aircraft observed the scene viewed by the camera as it appeared on a TV screen. In this manner, the geometrical pointing axis of the antennas was nearly coincident with the direction to the van location. The pilot maintained a height of nominally 300 m above the van employing a barometer/altimeter system. For each run, the depression angle relative to the horizontal (elevation angle at the van) was maintained fixed employing an angle gauge with a digital readout of angle which also appeared on the TV screen. With the height and depression angle kept nominally constant through pilot maneuvering of the aircraft, the range to the van was also maintained fixed at nominally 600 m, 430 m, and 350 m corresponding to the respective elevation angles of 30^{o}, 45^{o}, and 60^{o}.

Receiver System

The receiving antennas were mounted on the van roof and consisted of crossed drooping dipoles which have relatively flat elevation pattern function values with nominal half beamwidths within the interval 75^{o} to 15^{o}. Below 15^{o} the gain function drops off rapidly and any multipath arriving via scatter from objects near or below the horizontal is diminished by the pattern by at least 10 dB or more. The receiver systems inside the van were connected through data acquisition electronics to an IBM PC compatible computer. The received data were sampled at a rate of 1 KHz and stored on sequential records containing 1024 samples. In addition to recording the UHF and L Band received signal levels, the vehicle speed and receiver gain settings were also recorded once per second.

Road Features

Replicating the roads of previous tests, measurements were made along three stretches of roads in Central Maryland. These were: (1) Route 295 north and south between Routes 175 and 450, a distance of 25 km (2) Route 108 southwest and northeast between Routes 32 and 97, a distance of 15 km, and (3) Route 32 north and south between Routes 108 and 70, a distance of 15 km. Route 295 is a popular four lane highway (connecting Baltimore and Washington DC). This road contains pairs of lanes carrying traffic in opposite directions with trees located along

75% of the extreme sides and along 35% of the center median. Route 108 is a relatively narrow two lane rural road containing approximately 55% roadside trees along the stretch examined. Route 32 is also a two lane rural road with more sparsely placed trees displaced further away from the sides and containing approximately 30% trees.

Attenuation resulting from roadside tree shadowing was obtained for the geometry in which the helicopter traveled along a trajectory parallel to that of the van such that the propagation path was normal to the line of roadside trees. Such a configuration is considered "worst case" for corresponding satellite paths as they give maximum attenuation. The dB attenuation levels were computed by comparing the shadowed and unshadowed signal levels corresponding to a fixed elevation angle run. The unshadowed signal levels were sampled at stretches of road containing no roadside trees such as at interchanges.

Eight cumulative fade distributions were generated for each fixed elevation angle run corresponding to 30^{o}, 45^{o}, and 60^{o}. These eight runs correspond to the following pairs of cases: (1) right lane driving north and south on Route 295, (2) left lane driving north and south on Route 295 (3) driving northwest and southeast on Route 108, and (4) driving north and south on Route 32.

CUMULATIVE FADE DISTRIBUTIONS DUE TO SHADOWING GEOMETRIES

UHF and L Band Fades

Of the three roads sampled, Route 295 gave the highest fades and for this reason we emphasize the results for this road. In Figures 1 - 3 are given cumulative fade distributions at both UHF and L Band for the case in which the path elevation angles were 30^{o}, 45^{o}, and 60^{o}, respectively. For this cases, the van traveled south in the right lane of Route 295 where the propagation path is to the right as depicted in the indicated cartoons. The ordinate represents the percentage of the distance exceeded such that the fade is greater than the abscissa value. Since in most instances the speed was maintained relatively fixed, the ordinates for these distributions and others shown here may also be considered to represent "the percentage of time" the fade is greater than the abscissa value. The negative values of fade depths in the abscissas represent signal enhancement caused by multipath constructive interference.

Dependence of Fade Distributions on Elevation Angles

In Figure 4 are shown the cumulative fade distributions at L Band for Route 295 south (right hand side driving) for the three elevation angles considered. We note a significant dependence on elevation angle; the smaller the angle, the larger the fade for any given percentage. This strong dependence on elevation angle is explained with reference to the cartoon in Figure 4 for which a reduction in path length through the foliage occurs as the elevation angle increases.

Comparison of Fade Distributions for Different Road Types

In Figure 5 is depicted an example set of distributions in which the L Band fade distributions (path elevation angle of 45^{o}) for Routes

295 south (right lane driving and helicopter on the right side), 108 southwest (helicopter on the left) and 32 south (helicopter on the left). These results demonstrate that different types of roads and path orientations may result in both similar and dissimilar type distributions.

Right Side Versus Left Side Driving

In a previous effort [Goldhirsh and Vogel, 1987], right side of road versus left side of road driving was found to have a marked effect on the corresponding UHF fade distributions. This was consistently found to be the case for L Band. In Figure 6 is given a pair of fade distributions for 60^o path elevation, respectively, derived for right and left side driving runs as characterized by the indicated cartoon. We note significant fade reductions for left lane driving relative to the right lane case. This is understood through an examination of the cartoons which depict a smaller propagation path through the tree canopies when the vehicle is located at greater distances from it. We have also noted a strong angle dependence (not shown here) in which significantly larger fade differences (right side versus left side) are noted at the higher elevation angles relative to those for the smaller [Goldhirsh and Vogel, 1988].

Best Fit Distributions

In Figures 7 (a), (b) and (c) are plotted the combined distributions derived from the eight shadowing runs (previously described) corresponding to each elevation angle. The three sets of points in each figure represent the median (center set of points), the 10 and 90 percentile cases (upper and lower sets of points). Also plotted for each set of points is the corresponding "least square" logarithmic fit, where the fade depth F in (dB) and the percentage P are considered to be the dependent and independent variables, respectively. The equations defining the least squares fits are given in the above mentioned figures. These curves were generated from the distribution of 90 second distributions (file size). The 10 and 90 percentiles indicate the variability of the statistics for the average road traveled for a 90 second sampling. Ninety seconds fortuitously may represent the nominal time of a single mobile telephone call.

FADE DISTRIBUTIONS DUE TO MULTIPATH

Fade distributions for multipath geometries in mountainous and canyon terrain were previously measured by Vogel and Goldhirsh [1988]. To insure that the phenomenon examined was caused by fading due to multipath in this previous effort, the helicopter followed the van maintaining unobstructed line of sight propagation paths. In a similar fashion, the multipath shadowing effects caused by roadside trees were also measured in Central MD during the June 1987 period. In Figure 8 are shown fade distributions at UHF and L Band for the above described multipath geometry for Route 295 south (right hand side driving) at the respective angles of 30^o, 45^o, and 60^o. The corresponding cartoon in the figure depicts the helicopter following the van at the fixed elevation angle. We have noted (not shown) that the L Band fades slighly and consistently exceed those at UHF by 1 to 2 dB in this percent range.

Except at the 15^{o} path elevation angle, no angle dependence exists in the distribution characteristics. The dominant multipath most likely arises from scatter from the tops of nearby tree canopies and poles. For direct ray propagation paths at the higher elevation angles (30^{o} and above), the dominant contributions of the direct and multiply scattered rays arise from incident energy at the higher antenna gain function values [Vogel and Hong, 1988]. Negligible contributions should arise due to scattering from nearby vehicles and from reflections from the ground since the corresponding ray paths are incident at the antenna at angles near the horizontal where the gain function is at least 10 dB down. At 15^{o}, enhanced fades are noted to occur consistent with the above interpretation. That is, the significant multipath energy is incident at the higher gain function levels and combines with the direct ray path energy incident at the antenna at a consistently reduced gain value.

In comparing the distributions corresponding to multipath from roadside tree (Figure 8) relative to those obtained for mountainous and canyon terrain (not shown here) [Vogel and Goldhirsh, 1988; Goldhirsh and Vogel, 1988], the distributions are not significantly different. In fact, the multipath tree distributions may even exceed those for mountainous terrain. In comparing the distributions for shadowing and multipath, dramatic differences do arise. For example, we note 20 dB and 10 dB fades at the 1% and 10% levels, respectvely, for the shadowing case at 45^{o} elevation (Figure 2) as compared to 6 dB and 3 dB for the multipath roadside tree case (Figure 8).

CONCLUSIONS

We may conclude the following from the above described distributions. Unless otherwise specified, these characteristics pertain to L Band:

(1) Worst case fades due to shadowing occur at the smaller elevation angles (e.g., 30 degrees) (Figure 4).

(2) The best fit ratio of L Band to UHF fades (scaling factor) is in the range of 1.3 to 1.4 and is independent of exceedance percentage over the interval of 1% to 30%. These ratios are relatively insensitive to elevation angle [Goldhirsh and Vogel, 1988].

(3) Changing the lane of the road may lead to a considerable fade difference which is path angle dependent (Figure 6).

(4) Cumulative fade distributions follow with good approximations "logarithmic" least square fits in the exceedance interval between 20% and 1% (Figures 7 (a), (b), (c). These best fit distributions correspond to the median, 10 and 90 percentile cases, and the corresponding equations are defined for the various elevation angles. These best fit curves correspond to the condition where the fade and exceedance percentage are the dependent and independant variable, respectively.

(5) Attenuation caused by shadowing of roadside trees considerably exceeds that due to multipath (Figures 1 and 8).

(6) The extent of fading due to multipath is dependent on the

receiving antenna pattern. The results are consistent with the fact that multipath is likely to arise from scattering from nearby tops of trees and poles.

(7) Attenuation caused by multipath from roadside trees was found to be comparable and in many cases slightly larger (e.g., 1 to 2 dB) than those obtained in canyon terrain [Vogel and Goldhirsh, 1988]. This may be attributed to the fact that roadside trees are nearby, tall and therefore give rise to more appropriate scattering geometries for the given antenna pattern (as described in the above paragraph). The canopy tops of the trees may also represent more of an isotropic scatterer than nearby faceted canyon walls.

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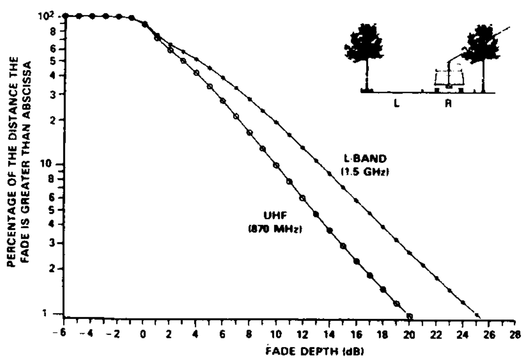

Fig. 1 Cumulative distributions for Route 295 South (RHS) 30^{o} elevation for L-band and UHF - June 1987

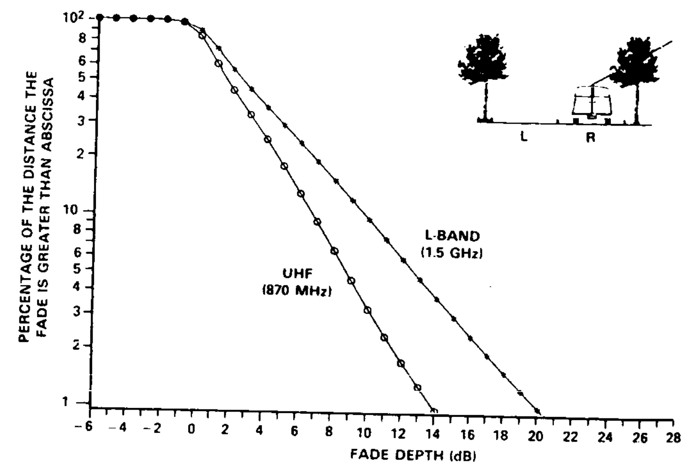

Fig. 2 Cumulative distributions for Route 295 South (RHS) 45^{o} elevation for L-band and UHF - June 1987

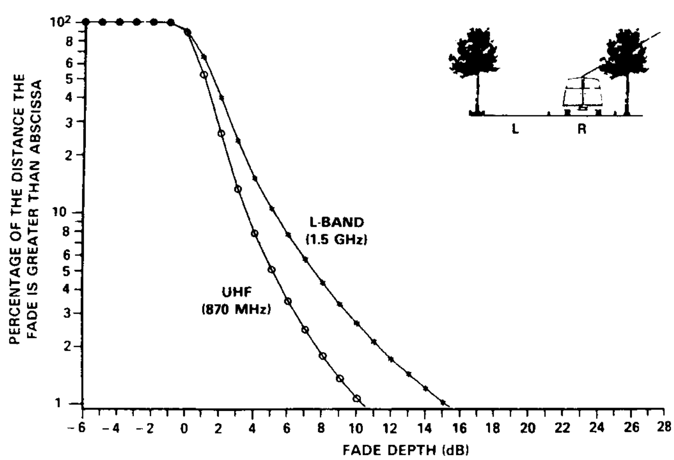

Fig. 3 Cumulative distributions for Route 295 South (RHS) 60^{o} elevation for L-band and UHF - June 1987

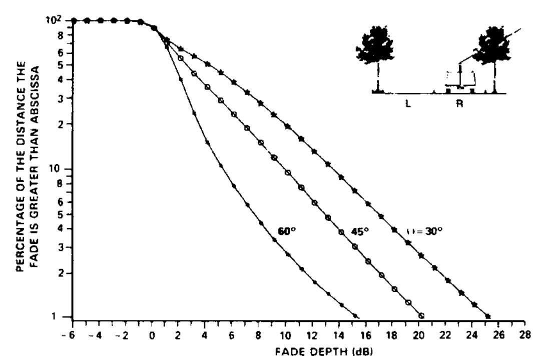

Fig. 4 Cumulative distributions for Route 295 South (RHS) comparison for different elevation angles at L-band

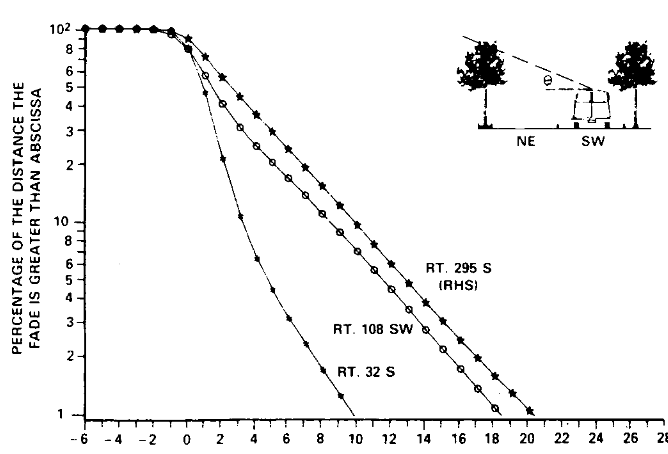

Fig. 5 Comparison of cumulative fade distributions for various roads at an elevation angle of 45^{o} for L-band

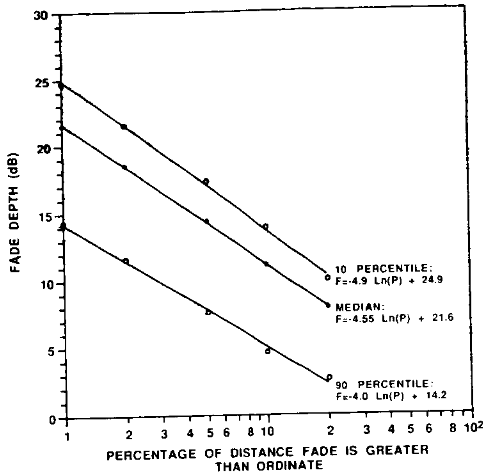

Fig. 7-a Best fit cumulative median fade distribution with 10 and 90 percentile bounds (elevation angle = 30^o)

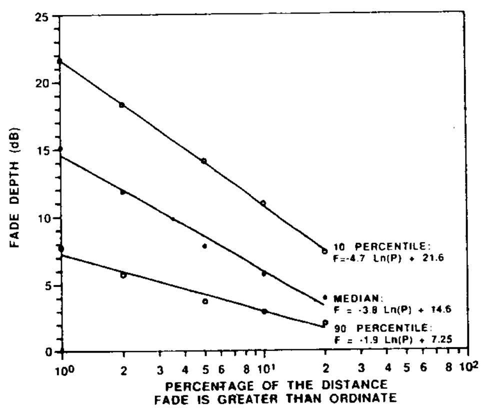

Fig. 7-b Best fit cumulative median fade distribution with 10 and 90 percentile bounds (elevation angle = 45^o)

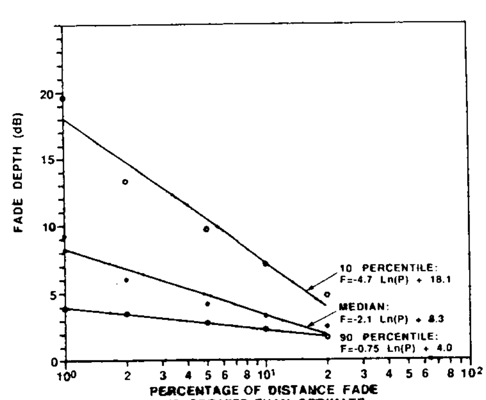

Fig. 7-c Best fit cumulative median fade distribution with 10 and 90 percentile bounds (elevation angle = 60^o)

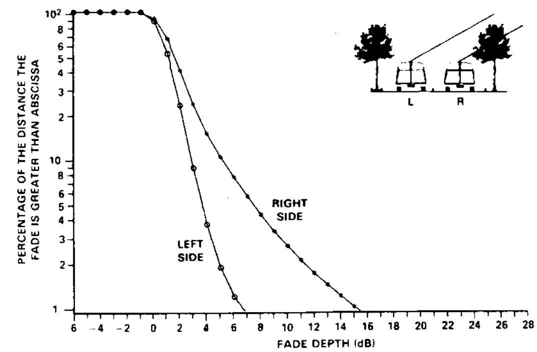

Fig. 6 Cumulative distributions for Route 295 South for right and left side of road driving L-band at 60^o

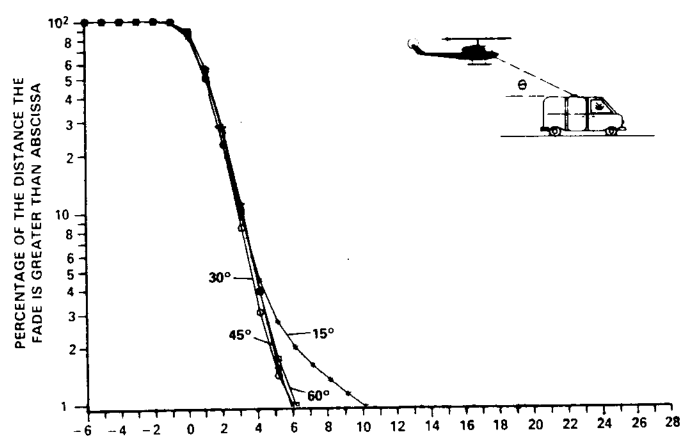

Fig. 8 Comparison of cumulative fade distributions due to multipath at various elevation angles at L-band Route 295 South (RHS)