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RESULTS OF 1987 MSS HELICOPTER PROPAGATION EXPERIMENT AT UHF AND L BAND IN CENTRAL MARYLAND

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Abstract

This effort emphasizes several important results pertaining to a mobile satellite system propagation experiment performed in Central Maryland during June 1987. In particular, we examine fade distributions due to multipath and roadside trees at L Band (1.5 GHz) during a period in which the deciduous trees were in full blossom. We compare the multipath statistics for roadside trees with previous multipath measurements made in canyon terrain in North Central Colorado. Also examined is the repeatability of previous UHF measurements made in Central Maryland and the attenuation effects of foliage on trees at UHF. Fade duration for the multipath mode for fade levels of 5 dB and 10 dB is also presented.

1.0 Introduction

Designers of planned mobile satellite systems require information as to the extent of fading caused by shadowing and multipath from roadside trees and terrain. The Applied Physics Laboratory of the Johns Hopkins University and the Electrical Engineering Research Laboratory of the University of Texas at Austin conducted the fifth in a series of mobile satellite system experiments in June of 1987 in Central Maryland [Vogel and Goldhirsh, 1986; 1988, Goldhirsh and Vogel 1987; 1988a; 1988b]. The objectives of the June 1987 test were as follows: (1) Determine roadside tree fade distribution statistics for roadside tree shadowing and multipath geometries. (2) Determine fade distributions for various elevation angles, road types, and for lane of road driven. (3) Assess the variability of fade distribution statistics for combined road cases at the various elevation angles. (4) Express the overall fade distribution due to combined road cases in the form of convenient and accurate functional forms. (5) Obtain a scaling factor describing the ratio of UHF (870 MHz) and L Band (1.5 GHz) fades. (6) Obtain fade duration statistics. (7) Establish repeatability with previous measurements at UHF. (8) Compare L Band multipath measurements for roadside trees and previous canyon measurements. We describe here the results of objectives (5) through (8) as the others were previously presented by Goldhirsh and Vogel [1988a].

2.0 Background

The transmitter platform was a Bell Jet Ranger helicopter which carried L Band and UHF antennas on a steerable mount below the helicopter fuselage. The antennas transmitted right circular polarization and both had nominal beamwidths of 60°. Also located on the mount was a video camera. An observer inside the aircraft viewed the scene on a monitor and pointed (with remote controls) the mount in the direction of the mobile van which carried the receiving antennas and receivers operating at the corresponding frequencies. The receiver antenna gains were approximately omnidirectional in azimuth and the beamwidths (in elevation) were approximately 60° within the interval 15° to 75°. The received signal levels were sampled at a one kHz rate. The receiver gain settings and vehicle speeds were also measured.

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

Fade measurements due to shadowing were obtained for the geometry in which the helicopter traveled along a trajectory parallel to the van and the propagation path was normal to the line of roadside trees. Such a configuration is considered as a "worst case" for corresponding satellite paths as they give maximum attenuation. Fade measurements due to "multipath" were generated for the geometry in which the helicopter followed the van maintaining a nominal fixed geometry and a visible line of sight. Repeated runs were made for both measurement modes for elevation angles of 30°, 45°, and 60°. The nominal height of the aircraft was 300 m for all cases. The attenuation levels were derived by comparing the shadowed and unshadowed signals.

3.0 Repeatability and Seasonal Effects on Measurements

We address here the following questions: (1) How repeatable were the UHF measurements as compared to those derived in the previous years over the same roads? (2) What are the relative seasonal effects on the distributions for October 1985 which consisted of trees having 80% of full blossom with branches and leaves having low water content, March 1986 in which the deciduous trees were devoid of leaves, and June 1987 corresponding to 100% full blossom with branches and leaves having high water content? In Figure 1 we compare the October 1985, March 1986, and June 1987 UHF fade distributions for Route 295 south, right side of the road driving. The vertical scale represents the percentage of the distance the fade is greater than the abscissa and the ascissa corresponds to the fade depth in dB. Since the vehicle speeds were nominally constant for the individual runs, the ordinate may also represent the percentage of time the fade is greater than the abscissa value. The abscissa fade depth is taken between -6 dB and 28 dB where the negative fades represent constructive interference due to multipath. Figure 2 depicts the October 1985 and June 1987 distributions for left side of the road driving. The March 1986 distribution is not shown in this figure since no March measurements were implemented for this geometry. We note from Figure 1 that the October 1985 and June 1987 distributions are within 2 dB of each other at the 1% level and are nearly coincident above 2%. Figure 2 shows the October and March distributions to be nearly coincident. Since the dB differences of these two sets of curves give a measure of both the repeatability of the measurements and the relative seasonal effects, we may conclude that: (1) negligible seasonal effects exist between the October and June period, and (2) the repeatability of the measurements is generally smaller than one dB. The March 1986 distribution in Figure 1 (no leaves case) gives fades which are consistently smaller than those for October and June. For example, at the 1% and 10% levels the fades are at most 3 and 1 dB smaller during March. These represent seasonal fade reductions of less than 20%. We may conclude from these results that, on the average, the effects of leaves on trees are small for the dynamically acquired statistics. Stationary fade measurements made on individual trees at UHF gave consistently similar results (e.g., 14% to 40% reduction) [Goldhirsh and Vogel, 1987]. Although the seasonal effects on attenuation have been examined only at UHF, the results are not expected to differ significantly at L Band.

4.0 L Band-UHF Scaling Factor

Figure 3 shows equal percentage values of the ratio of L Band to UHF fades for eight runs at the elevation angle of 30^{o} (solid points). The dashed lines at the individual percentage values represent the +/- rms levels relative to the average for the respective percentage. The runs correspond to Routes 295 north and south for right and left lane driving and Routes 108 and 32 for both directions. The total road length for the combined runs (for each path angle) constitutes approximately 160 km. Shown in this figure are the ratios at the equal percentage values at 1, 2, 5, 10, 20, and 30% levels. Also plotted is the best fit linear line through the set of points. We note that these best fit ratios are approximately independent of percentage in the interval 1 to 30%. Similar results were derived for 45^{o} and 60^{o}. The overall ratio (all elevation angles) of L Band to UHF fade was noted to be

$$R_f = 1.35 \pm 0.1 \text{ (RMS)} \tag{1}$$

or

$$R_f = \left(\frac{f(\text{L Band})}{f(\text{UHF})} \right)^{0.551} \tag{2}$$

5.0 Fade Distributions Due to Multipath Geometries

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 fading due to multipath in this previous effort, the helicopter followed the van maintaining an unshadowed line of sight for the propagation paths. In a similar fashion, the multipath interference effects caused by roadside trees were also measured in Central Maryland during the June 1987 period. In Figure 4 are shown comparisons of multipath fade distribution for the roadside tree case (Route 295 S, right lane driving, 45° elevation), and the worst case fade distributions for the canyon terrain (Big Thompson Canyon, into and out of canyon at 45° elevation). The cartoon in the figure depicts the helicopter following the van at the fixed elevation angle. The roadside tree multipath fades at L Band are noted to be approximately 6 dB and 3 dB at the 1% and 10% levels, respectively. Virtually no differences were noted for the multipath distributions for the 30° and 60° elevation cases. We note that at the 1% level the canyon multipath fades flank those due to the roadside tree case by approximately +/- 1 dB. On the other hand, at the 10% level the tree fade exceeds both canyon cases by 1.3 dB. We thus observe that no excessive multipath conditions exist in mountainous terrain and that the distributions from roads having roadside trees may even exceed those for mountainous terrain.

6.0 Multipath Versus Shadowing

The dramatic effects of attenuation caused by shadowing at L Band are depicted in Figure 5. Shown is a comparison of the distributions corresponding to multipath and shadowing geometries for Route 295 south (right lane driving) at a path angle of 45°. We note 20 dB and 10 dB fades at the 1% and 10% levels, respectvely, for the shadowing case as compared to 6 dB and 3 dB for the multipath roadside tree case. The enhanced attenuation effects caused by shadowing relative to those from multipath have also been measured by other investigators [Jongejans et al, 1986].

7.0 Fade Duration Statistics

Fade durations distributions are presented in Figure 6 and 7. The curves in these figures correspond to the combined results of the eight shadowing runs described above for each of the indicated elevation angles and for 5 dB and 10 dB fade thresholds. In each of these figures two sets of statistics are presented; namely, "faded" (solid) and "unfaded" (dashed). These correspond to durations for which the attenuations are greater and less than the indicated fade thresholds, respectively. The vertical scales represent the percentage of the durations greater than the abscissa values which have been normalized to number of wavelengths; one wavelength at L band being 20 cm. The duration may alternately be expressed in terms of time duration by dividing by the vehicle speed. Hence, for a speed of 88 km/hr (24.4 m/s), the abscissa ranges in values from 8.2×10^{-4} seconds (.1 λ) to .82 seconds (100 λ). Also given in Figure 6 are the fade durations due to multipath at the 5 dB fade threshold. These were derived by combining the three elevation angle runs on Route 295 south (right side of the road driving). Recall, these data sets correspond to the geometry in which the helicopter followed the van while maintaining a visible line of sight.

Figures 6 and 7 show the distributions to systematically depend on elevation angle. That is, the lower the elevation angle, the greater the fade duration at any fixed percentage. This result is consistent with the fact that lower elevations result in more persistent shadowing. We also note from Figure 6 that a large difference in fade durations exists when comparing multipath with shadowing cases. This is attributed to the different characteristics of randomness of the received signals associated with multipath interference versus those associated with shadowing; i.e., absorption and scattering from trees, branches, and foliage. In comparing Figures 6 and 7, we note that the larger shadowing (10 dB versus 5 dB) thresholds result in smaller fade durations. This is again attributed to the nature of the absorption and scattering phenomena where deep fades of long duration are less likely than less intense fades of long duration. This is also consistent with the fact that there is a smaller dependence of elevation angle on fade duration for the 10 dB threshold than for the 5 dB case.

8.0 Summary

We summarize the salient results of this effort as follows:

(1) Although foliage on trees at UHF produces enhanced fade depths relative to the bare tree case (e.g., nominally 20% increase in attenuation), the dominant attenuation effects are caused by the branches and trunk of the trees. It is believed that similar results should apply at L Band although no measurements at this wavelength have been made to verify this.

(2) Repeatabilities of the measurements at UHF were found to be smaller than 10% in fade at the 1% and greater exceedance levels.

(3) The overall average best fit ratio of L Band to UHF fades (scaling factor) is 1.35 (+/- 0.1 rms), and it is relatively insensitive to the path angle and the exceedance percentage over the interval of 1% to 30%. This ratio is approximately equal to the square root of the ratio of frequencies (equation (1)). The above ratio was derived for an overall average road and driving condition corresponding to 24 runs (comprised of Route 295 right lane and left lane driving for north and south directions, Route 108 northeast and southwest directions, and Route 32 north and south directions for 30°, 45°, and 60° elevations (480 km of road).

(4) Attenuations caused by shadowing of roadside trees far exceed those due to multipath. For example, fading due to multipath at the 1% level was found to be approximately 6 dB as compared to fades as high as 25 dB due to shadowing at a 30° path angle.

(5) Fades due to multipath from roadside trees were found to be comparable and in many cases slightly larger (e.g., 1 to 2 dB) than those obtained in canyon terrain. This may be attributed to the fact that roadside trees are nearby and tall and therefore give rise to more appropriate scattering geometries for the given antenna pattern. The canopy tops of the trees may also represent more of an isotropic scatterer than nearby faceted canyon walls.

(6) Fade durations are elevation angle dependent for the shadowing geometry. For the multipath case, fade durations are dramatically smaller than those for shadowing cases at the same exceedance percentage.

9.0 Acknowledgements

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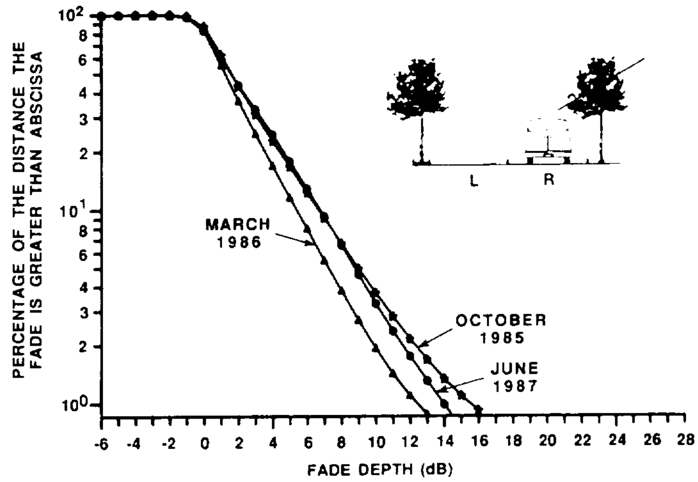

Figure 1 Cumulative fade distributions for various seasons (Route 295 South (RHS) - UHF at 45°)

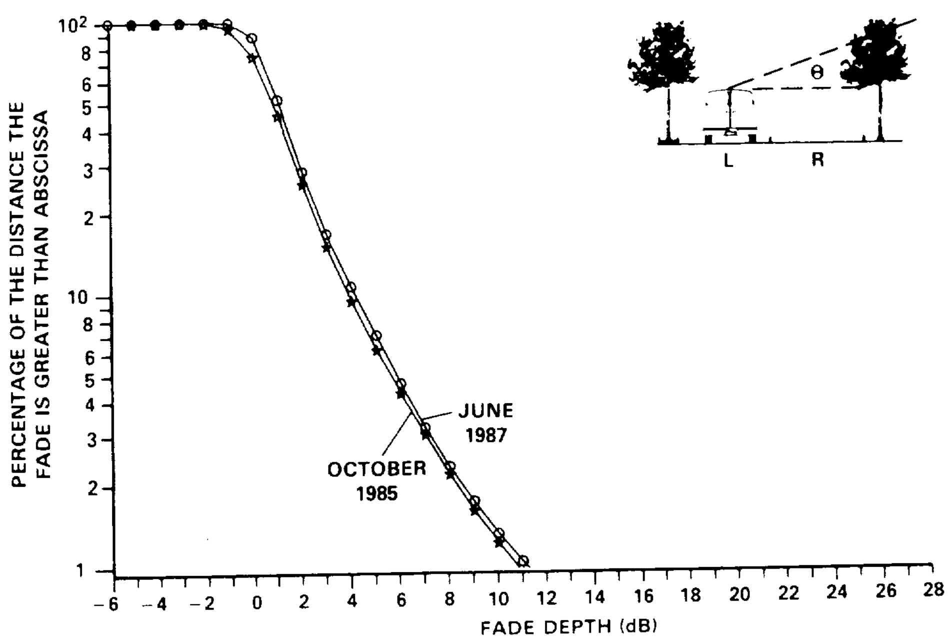

Figure 2 Cumulative distributions for Route 295 South (LHS) for October 1985 and June 1987 at UHF for 45°

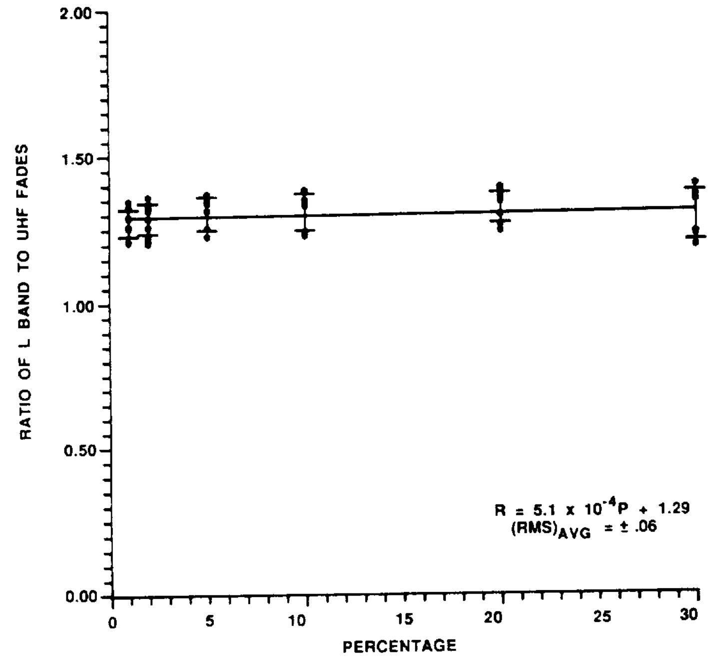

Figure 3 Ratio of L-band to UHF fades at equal percentages versus percentages of distance fade is exceeded (all roads - elevation angle = 30°)

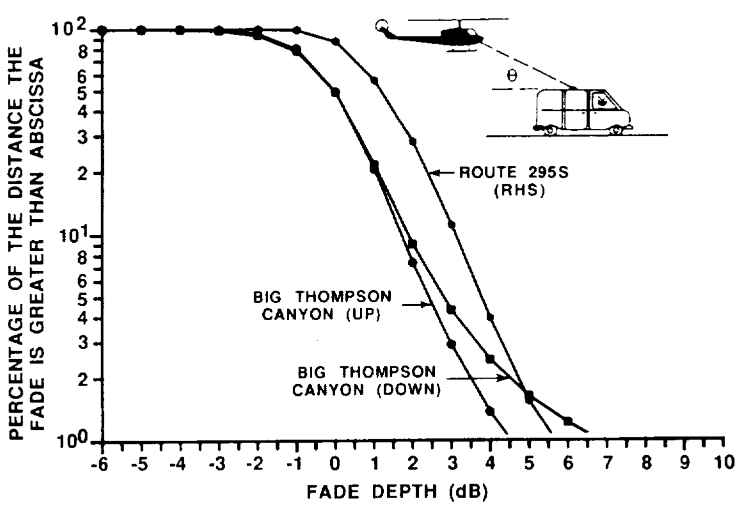

Figure 4 Comparison of cumulative fade distributions due to multipath (helicopter behind) at L-band at 45° for Big Thompson Canyon versus Route 295 South

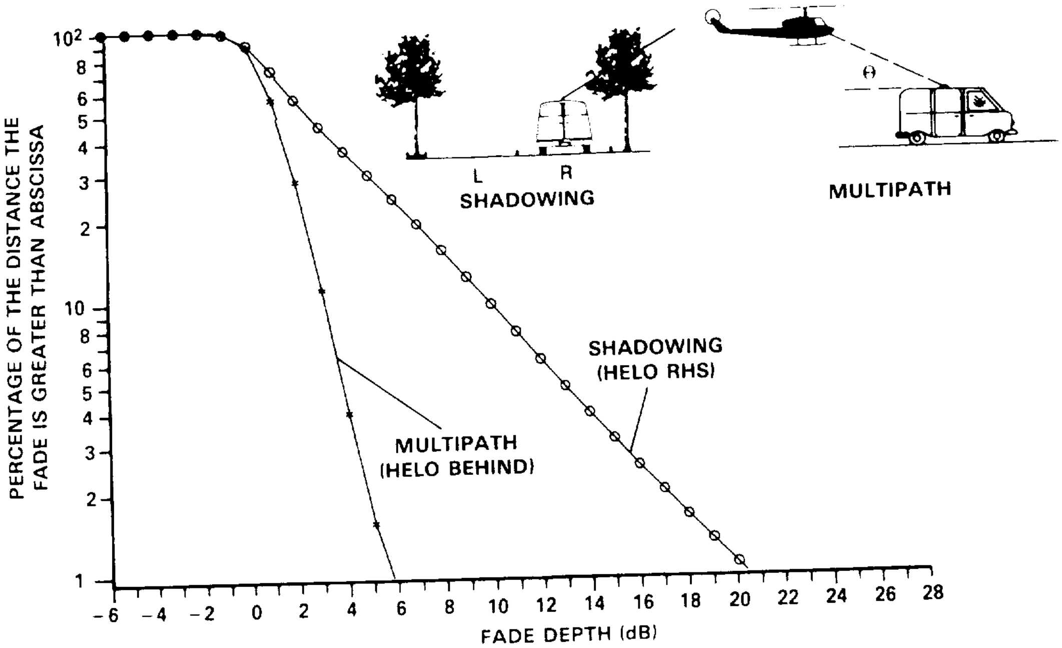

Figure 5 Comparison of cumulative fade distributions due to multipath and shadowing at elevation = 45° at L-band for Route 295 South

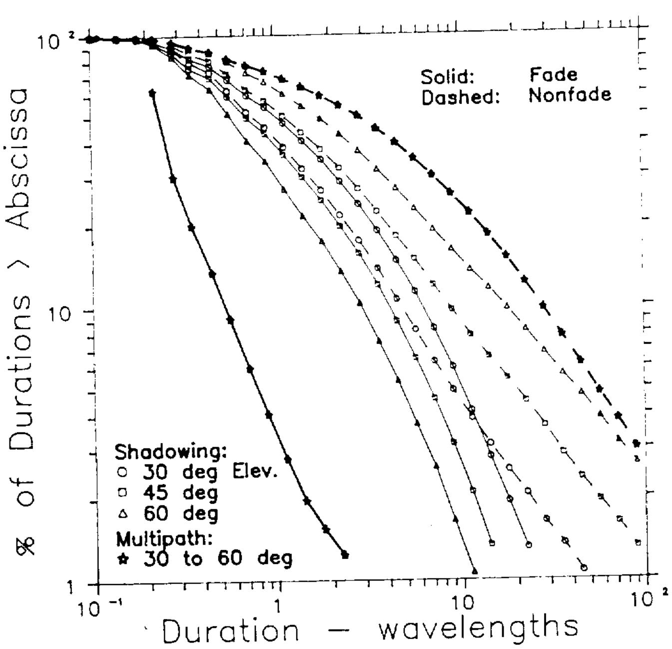

Figure 6 Fade and nonfade durations at L-band for 5 dB fade threshold

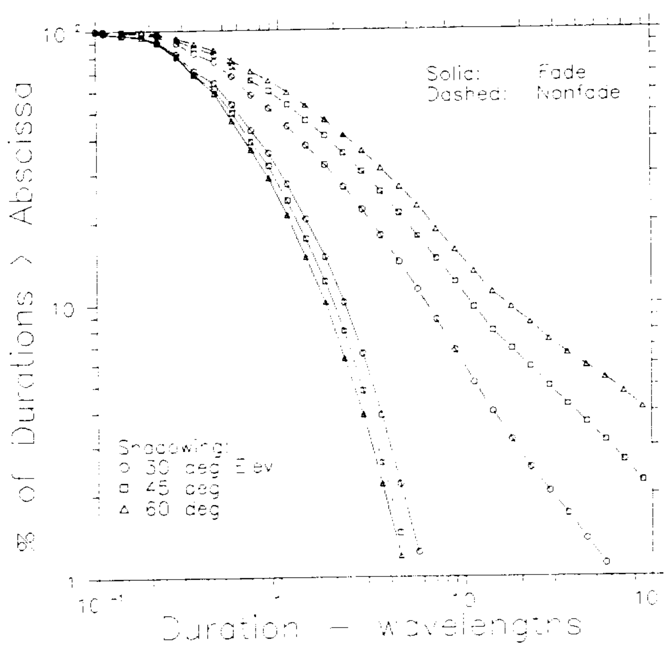

Figure 7 Fade and nonfade durations at L-band for 10 dB fade threshold