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TREE ATTENUATION AT 20 GHZ: FOLIAGE EFFECTS

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Abstract - Static tree attenuation measurements at 20 GHz (K-Band) on a 30° slant path through a mature Pecan tree *with* and *without* leaves have shown median fades exceeding approximately 23 dB and 7 dB, respectively. The corresponding 1% probability fades were 43 dB and 25 dB. Previous 1.6 GHz (L-Band) measurements for the bare tree case showed fades *larger* than those at K-Band by 3.4 dB for the median and *smaller* by approximately 7 dB at the 1% probability. While the presence of foliage had only a small effect on fading at L-Band (approximately 1 dB additional for the median to 1% probability range), the attenuation increase was significant at K-Band, where it increased by about 17 dB over the same probability range.

Introduction

First generation personal and mobile satellite communication systems will soon become operational at frequencies near 1.6 and 2.5 GHz (L- and S-Band). To ensure that these systems provide dependable services in the presence of fading caused by multipath or shadowing, their designers rely upon propagation results obtained by many researchers over the last decade [1]. The limited spectrum allocated to mobile satellite services at L- and S-band, however, has proponents of follow-on systems looking towards the 20/30 GHz region, where much more bandwidth is available, but where mobile propagation effects have not yet been characterized. It is anticipated that, at K-Band, the major causes of signal attenuation on mobile links will be blockage due to buildings, tree shadowing, and rain attenuation. This contribution describes a preliminary experiment performed to characterize what will probably be the most pervasive cause of mobile K-Band fading, namely tree shadowing, as suggested by horizontal path measurements at 29 GHz through single Pecan trees, which reported average attenuations of 32 dB to 18 dB for trees with and without leaves [2]. The results described here were derived from a configuration simulating a satellite-to-earth path. They revealed considerable fading at K-Band and significant difference between L- and K-Band in the seasonal variability of tree shadowing, i.e., the effect of foliage. The difference has implications on the success of fade mitigation techniques, such as error correction coding.

Measurement of Tree Attenuation

At the present time, options for performing mobile K-Band tree attenuation measurements on an elevated path in the U.S. are limited to observing the Olympus satellite beacon. While the Olympus beacon illuminates the eastern U.S. with an elevation angle of 16°, its low power requires at least a 60 cm diameter antenna to achieve a signal to noise ratio (SNR) of approximately 20 dB in a narrow-band receiver. There are several disadvantages to using such a large antenna. First, the narrow beamwidth (1.7°) makes a mobile platform from which to observe Olympus extremely difficult and expensive. Second, the tower measurements described here have demonstrated that a significantly higher fade margin is required than is realistically achievable for mobile scenarios using Olympus. Furthermore, aperture averaging of tree shadowing and multipath suppression may make results obtained with a large antenna not representative of mobile performance when using planned smaller antennas. Efforts are underway to execute an extensive land mobile satellite propagation campaign in Central Maryland and Alaska using the Advanced Communications Technology Satellite (ACTS) in its high gain mode, where a 50 dB SNR will be achieved with just an 8 cm diameter tracking antenna [3].

Experimental Details

In order to provide an estimate of the 20 GHz slant path attenuation expected from roadside trees for the planned mobile ACTS fade measurement experiment, a campaign was undertaken to measure the slant path stationary attenuation caused by trees at 19.6 GHz and to compare these results with earlier measurements at 1.6 GHz. Both sets of measurements were repeated for a Pecan tree *with* and *without* leaves to establish the seasonal variability of attenuation. An evergreen Magnolia tree was also tested at K-Band using a similar geometry. Table 1 summarizes the pertinent experimental parameters.

Table 1 EXPERIMENTAL PARAMETERS

	L-Band	K-Band
Frequency	1.6 GHz	19.6 GHz
Polarization	RHCP	Vertical
Transmitter Power	100 mW	1mW
Transmitter Beamwidth	90°	66°
Transmitter Height	20 m	18 m
Elevation Angle (Pecan/Magnolia*)	30°/NA	26°/61°
Range (Pecan/Magnolia*)	36/NA m	36/21 m
Receiver Beamwidth	90°	32°
Receiver Noise Temperature	< 400 K	< 400 K
Receiver Noise Bandwidth	1000 Hz	1000 Hz
Receiver Height	1.5 m	1.5 m
Dynamic Range	> 50 dB	> 50 dB

* NA denotes Not Available

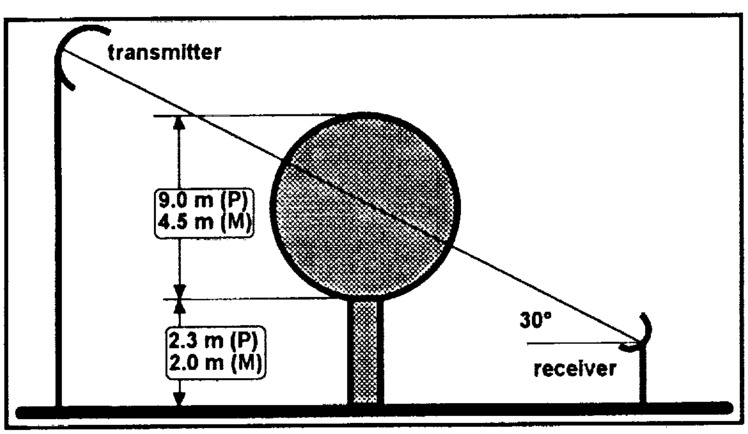

Fig. 1 Experimental Configuration for Pecan (P) and Magnolia (M) Trees with Foliage

The measurements at L-Band were performed on 13 December 1990 and 12 July 1991. The receiving antenna was mounted on a motorized positioner placed within the geometric shadow zone of a pecan tree (Figure 1). The antenna was moved slowly over a horizontal distance of several m, while the received power was sampled every 0.1 s for the duration of about 100 s. At K-Band, measurements were performed on 10 March 1993 and 11 May 1993 employing the same approximate geometry. The receiving antenna was hand-held and moved horizontally over a distance of several m, first in the shadow of the same Pecan tree, and then in the shadow of a nearby evergreen Magnolia tree (Figure 1). Quadrature detector receiver voltages were sampled at a 1000 Hz rate for several minutes. The path length within the crown was, on average, 9 m for the Pecan tree and 4.5 m for the Magnolia tree. The clear line-of-sight (LOS) level at both frequencies and each tree was determined by moving the receiver axially to a point where the signal path was unobstructed.

Results

Time series examples at the two measurement frequencies are plotted in Figure 2. The 1 s sample of the K-Band clear LOS signal (upper curve) shows the effect of multipath reflections. Even though the path from transmitter to receiver was unobstructed, the Pecan tree was within the field of view of both antennas. Forward- scatter from the Pecan tree causes constructive and destructive interference with the direct signal as relative phases change. The upper frequency of this variation equals the ratio of the relative speed of the receiver to the wavelength. Here it is below 10 Hz, indicating that relative motion between observer and the tree was below about 0.15 m/s. For the 1 s segment of data shown, the attenuation by the bare Pecan (second curve from top) was in the 2 to 7 dB range, compared to 8 dB and 20 dB for the 45 s data of L-Band attenuation (third curve from top on left). When the Pecan was in full foliage, the L-Band signal level decreased slightly below the bare case. On the other hand, the K-Band signal level decreased dramatically, showing fades in the 20 to 40 dB range (fourth curve from top on right). Similar fades were observed through an evergreen Magnolia tree with big, waxy leaves (fourth curve from top on left). We conclude from these results that foliage is a major contributor to signal attenuation at K-Band but not at L-Band, and that the wood part of the tree is predominantly responsible for attenuation in the lower frequency range.

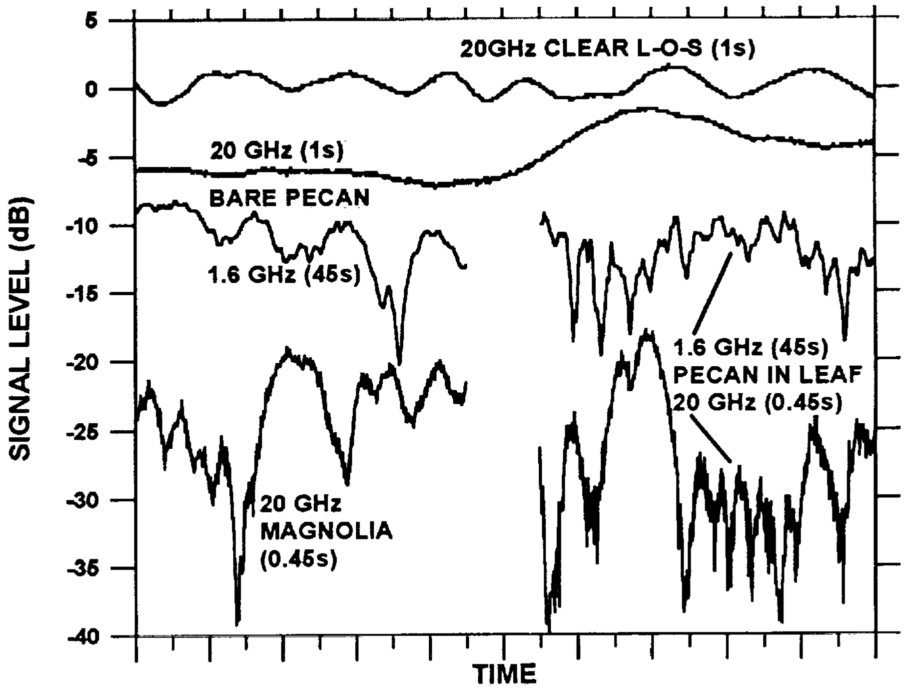

Fig. 2 Time Series Examples of Tree Shadowing Effects When the Receiver is in Motion

The cumulative distribution functions (CDFs) in Figure 3 give the fraction of locations at which fade levels were exceeded for cases in which the path was either entirely unobstructed (clear LOS) or entirely obstructed (tree shadow-ed). These distri-butions demonstrate that the presence of foliage increases the median L- and K-Band fading by approximately 1 and 17 dB vis-à-vis the bare tree case, respectively. Also apparent is that at L-Band fading can be higher than at K-Band for the bare tree case. This may be explained by noting that for the given geometry, the L-Band Fresnel zone diameter is about 2.7 m compared to 0.7 m at K-Band. Assuming the branches of a bare tree act similar to a conducting mesh, the L-Band Fresnel zone size is larger than the mesh scale at all receiver positions and the signal is always attenuated. In contrast, at K-Band there are many positions where the branch spacing is comparable to or larger than the K-Band Fresnel dimension. Hence, smaller attenuations are experienced for these geometries. On the other hand, at some locations (e.g., at the 1% probability), the openings between branches are smaller than the K-Band Fresnel dimension and significantly deeper fading occurs than at L-Band (e.g., 25 dB versus 18 dB). The measured median and 1% fades are summarized in Table 2 for the bare Pecan, Pecan with leaf, and Magnolia with leaf along with the estimated corresponding attenuation coefficients.

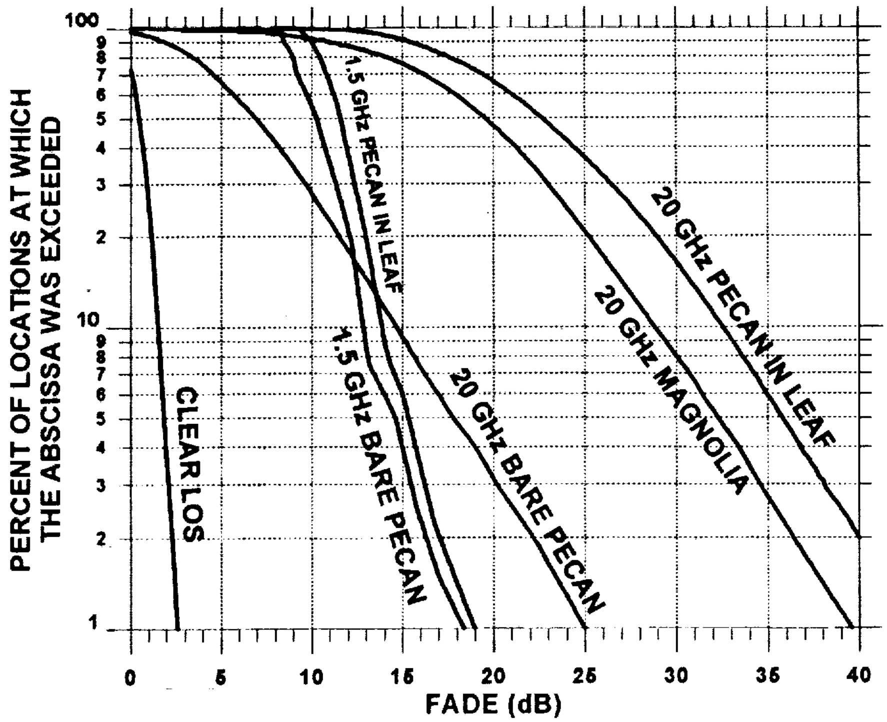

Fig. 3 The Cumulative Distribution Functions for the Clear LOS, as well as Pecan and Magnolia Trees *With* and *Without* Foliage

Table 2 MEDIAN AND 1% FADES AT L- AND K-BAND

		Total Fade (dB)		Attenuation Coefficient (dB/m)	
		L-Band	K-Band	L-Band	K-Band
Clear L-O-S	Median		0.5		
	1%		2.6		
Bare Pecan	Median	10.3	6.9	1.1	0.75
	1%	18.4	25.0	2.0	2.8
Pecan in Leaf	Median	11.6	22.7	1.3	2.5
	1%	18.6	43	2.1	4.8
Magnolia	Median		19.6		4.4
	1%		39.6		8.8

Summary and Conclusions

In preparation for planned mobile propagation measurements with ACTS, an experimental campaign was undertaken to establish the expected attenuation from tree canopies at 20 GHz. Median and 1% probability fades for the full foliage case were noted to be approximately 23 dB and 43 dB, respectively, for the Pecan tree. Attenuations of 20 dB (median) and 40 dB (1%) were experienced for the Magnolia tree.

An unexpected result was that the 20 GHz median attenuation for the Pecan tree without foliage was found to be approximately 3 dB smaller than the median attenuation at 1.6 GHz. This difference may be explained in terms of the relative dimensions of the spacing between branches and the relative Fresnel dimensions for the two frequencies at the tree location. The openings between branches for many receiver LOS aspects were comparable to or larger than the K-Band Fresnel dimension (0.7 m), whereas the branch spacing was always within the L-Band Fresnel dimension (2.7 m). There were, however, some receiver geometries for which the LOS aspect was such that the branch spacing was smaller than the K-Band Fresnel dimension, and significantly larger fading was measured for these cases (e.g., 8 dB larger at 1% probability). The attenuation scaling formulation relating the ratio of fades to the square root of the ratio of the frequencies, previously validated in the range between UHF (870 MHz) and S-Band (3 GHz) [1], was tested at K-Band. It was found not to be applicable between 1.6 GHz and 19.6 GHz for the Pecan tree case.

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