Chapter 2

Attenuation Due to Individual Trees: Static Case

2.1 Background

A typical scenario in which fading occurs is depicted in Figure 2.1 which shows a vehicle receiving satellite transmissions. The vehicle, which has an antenna mounted on its roof, is presumed to be at a distance of 10 - 20 m from the roadside trees, and the path to the satellite is generally above 20° in elevation. The antenna is to some extent directive in elevation such that multipath from lower elevation (i.e., near zero degrees and below) is filtered out by the antenna gain pattern characteristics. Although there exist azimuthal multipath contributions, shadowing from the canopies of one or two trees gives rise to the major attenuation contributions. That is, the signal fade for this case is due primarily to scattering and absorption from both branches and foliage where the attenuation path length is the interval within the first few Fresnel zones intersected by the canopies.

This geometry is in contrast to the configuration in which the transmitter and receiver are located near the ground and propagation takes place through a grove of trees as shown in Figure 2.2. The attenuation contribution for this configuration is a manifestation of the combined absorption and multiple scattering from the conglomeration of tree canopies and trunks. An estimation of the attenuation coefficient from attenuation measurements

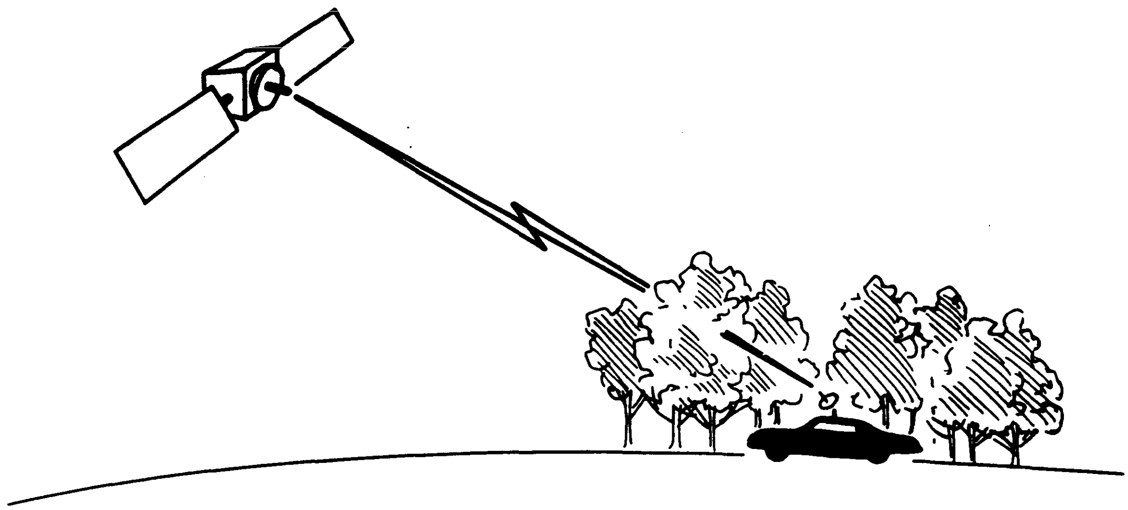

Figure 2.1: LMSS propagation path shadowed by the canopies of one or two trees in which the attenuation path length is relatively well defined.

requires a knowledge of the path length usually estimated to be the "grove thickness". This thickness may encompass a proportionately large interval of non-attenuating space between the trees. Hence attenuation coefficients as derived for groves of trees [Weissberger, 1982] may underestimate the attenuation coefficient vis a vis those derived for path lengths intersecting one or two contiguous canopies for LMSS scenarios.

Static measurements of attenuation due to isolated trees for LMSS configurations have been systematically performed by only few investigators in the 800 MHz band; namely, Butterworth [1984b], Vogel and Goldhirsh [1986], and Goldhirsh and Vogel [1987]. Ulaby et al. [1990] measured the attenuation properties at 1.6 GHz associated with attenuation through a canopy of foliage comprised of closely spaced trees. Yoshikawa and Kagohara [1989] report briefly on ETS satellite transmissions at 1.5 GHz through a "shade" of trees.

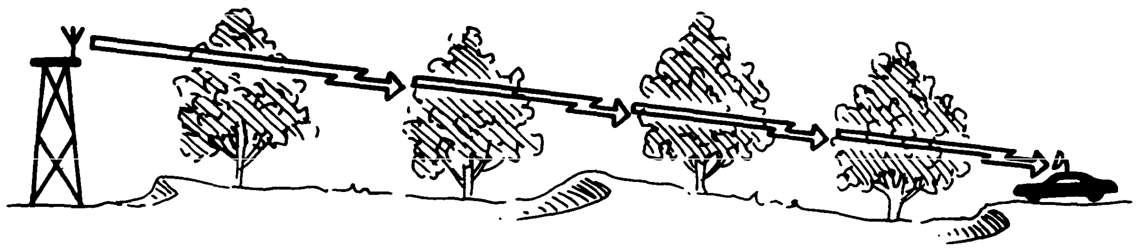

Figure 2.2: Low elevation propagation through a grove of trees giving rise to ambiguity in attenuation path length.

2.2 Attenuation and Attenuation Coefficient

For those cases in which shadowing dominates, the attenuation primarily depends on the path length through the canopy, and the density of foliage and branches in the Fresnel region along the line-of-sight path. The receiver antenna pattern may also influence the extent of fading or signal enhancements via the mechanism of multipath scattering from surrounding trees or nearby illuminated terrain. An azimuthally omni-directional antenna (such as that used for the measurements described here) is more susceptible to such multipath scattering than a directive antenna. Nevertheless, the authors found through measurements and modeling considerations for LMSS geometries, the major fading effect is a result of the extent of shadowing along the line-of-sight direction.

In Table 2.1 is given a summary of the single tree attenuation results at 870 MHz (circularly polarized transmissions) based on the measurements by the authors [Vogel and Goldhirsh, 1986; Goldhirsh and Vogel, 1987] who employed transmitter platforms such as remotely piloted aircraft and helicopters. In Table 2.2 are given the transmitter and receiver characteristics for both the static and mobile measurements. (The static measurements were performed only at UHF.) The attenuations were calculated by comparing the power changes for a configuration in which the receiving antenna (on the roof of a van) was "in front of" and "behind" a particular tree. The former and latter cases offered non-shadowed and maximum shadowing conditions, respectively, relative to the line of sight propagation path from the transmitter on the aircraft to the stationary receiver. During each flyby, the signal levels as a function of time were expressed in terms of a series of median fades derived from 1024 samples measured over one second periods. The attenuation assigned to the particular flyby was the highest median fade level observed at the measured elevation angle. It may be deduced that the motion of the transmitter aperture and the receiver sampling rate of 1024/s resulted in more than 200 independent samples averaged each second. This sample size is normally adequate to provide a well defined average of a noisy signal The individual samples from which the median was derived over the one second period were observed to fluctuate on the average ± 2 dB about the median due to the influence of variable shadowing and multipath.

The first column in Table 2.1 lists the trees examined where the presence of an asterisk corresponds to measurement results at Wallops Island, VA in June 1985 (remotely piloted aircraft), and the absence of the asterisk represents measurements in Central MD in October 1985 (helicopter). During both measurement periods, the trees examined were approximately in full foliage conditions. The second and third columns labeled "Largest" and "Average" represent respectively, the largest and average values of attenuation (in dB) derived for the sum total of flybys for that particular tree. The fourth and fifth columns denote the corresponding attenuation coefficients derived from the path length through the canopy. The path length was estimated from measurements of the elevation angle, the tree dimensions, and the relative geometry between the tree and the receiving antenna height. The dependence of the attenuation on elevation angle is described in Section 2.4. We note that the Pin Oak attenuation as measured at Wallops Island (with asterisk) is significantly larger than that measured in Central Maryland (without asterisk) because the former tree had a significantly greater density of foliage over approximately the same path length interval. This result demonstrates that a description of the attenuation from trees for LMSS scenarios may only be handled employing statistical processes.

Butterworth [1984b] performed single tree fade measurements at 800 MHz (circularly polarized transmissions) at seven sites in Ottawa, Canada over the path elevation interval 15° to 20°. The transmitter was located on a tower and receiver measurements were taken at a height of 0.6 m above the ground. Measurements were performed from April 28 to November 4, 1981 covering the period when leaf buds started to open until after the leaves

Table 2.1: Summary of Single Tree Attenuations at f = 870 MHz

Tree Type	Attenuation (dB)		Attenuation Coef. dB/m	
	Largest	Average	Largest	Average
Burr Oak*	13.9	11.1	1.0	0.8
Callery Pear	18.4	10.6	1.7	1.0
Holly*	19.9	12.1	2.3	1.2
Norway Maple	10.8	10.0	3.5	3.2
Pin Oak	8.4	6.3	0.85	0.6
Pin Oak*	18.4	13.1	1.85	1.3
Pine Grove	17.2	15.4	1.3	1.1
Sassafras	16.1	9.8	3.2	1.9
Scotch Pine	7.7	6.6	0.9	0.7
White Pine*	12.1	10.6	1.5	1.2
Overall Average	14.3	10.6	1.8	1.3

had fallen from the trees. A cumulative distribution of foliage attenuation readings covering a 19 day period in June 1981 was noted to be lognormal, where the fades exceeded 3 and 17 dB for 80% and 1% of the measured samples, respectively. The median attenuation was approximately 7 dB with an approximate median attenuation coefficient of 0.3 dB/m (24 m mean foliage depth).

The average attenuation coefficient of Butterworth is noted to be smaller than those measured by the authors in Central Maryland and Virginia. The disparity between these results is believed to be due to differences in the methods of averaging, the heights of the receiver, and the interpretation of the shadowing path length as previously described. The results in Table 2.1 may be used by the designer interested in *worst case attenuations* for individual trees.

Table 2.2: Summary of Experimental Parameters Associated with Source and Receiver System Platforms

	L-Band	UHF
Source Platform:		
Antenna Types	Spiral/Conical	Microstrip
Polarization	RHC	RHC
Antenna Beamwidths	60°	60°
Platform Type	Bell Jet Ranger Helo	Remotely Piloted Aircraft
Receiver Platform:		
Antenna Type	Crossed Drooping Dipoles	
Polarization	Right Hand Circular	
Beamwidths	60°(15°to75°)	
Bandwidth (KHz)	0.5	
Sampling Rate (KHz)	1	
Frequencies (MHz)	1502	870
Data Recorded	Quadrature Detected Outputs	Power
	Elapsed Time, Vehicle Speed	

2.3 L-Band Versus UHF Attenuation Scaling Factor: Static Case

To the authors' knowledge, systematic tree measurements at L-Band for different tree types and elevation angles have not been executed, although fade measurements due to roadside trees were noted by Yoshikawa and Kagohara [1989] who received left hand circularly polarized transmissions from the Japanese satellite ETS-V at an elevation of 47°. They reported that attenuations in the "shade" of trees at L-Band ranged between 10 and 20 dB.

Ulaby et al. [1990] measured the attenuation properties at 50° elevation associated with transmission at 1.6 GHz through a canopy of red pine foliage in Michigan at both horizontal and vertical polarizations. The path length through the canopy was approximately 5.2 m and the average attenuations measured at horizontal and vertical polarizations were 9.3 dB and 9.2 dB. Their measurements gave rise to an average attenuation coefficient of approximately 1.8 dB/m. Combining this result at L-band with the average value of 1.3 dB/m at UHF given in Table 2.1 suggests the following

$$A(f_L) \approx A(f_{UHF})\sqrt{\frac{f_L}{f_{UHF}}} \qquad \text{(dB)}. \tag{2.1}$$

For the frequencies considered

$$\left\{ \begin{array}{l} f_L = 1.6 \text{ GHz} \\ f_{UHF} = 870 \text{ MHz} \end{array} \right. \tag{2.2}$$

the scaling factor relation is

$$A(f_L) \approx 1.36 A(f_{UHF}) \qquad \text{(dB)}. \tag{2.3}$$

A comparison of the actual attenuation measurements at 1.6 GHz and 870 MHz resulted in 1.38 as the scaling factor. It is interesting to note that an identical expression as given by (2.1) was derived by the authors for the dynamic case employing simultaneous measurements at 1.5 GHz and 870 MHz (described in Section 3.5).

2.4 Effects on Attenuation Caused by Season and Path Elevation Angle

The attenuation effects caused by trees, with and without foliage, versus path elevation angle have also been explored for individual tree measurements by Goldhirsh and Vogel [1987]. The path elevation angle dictates the path length through the canopy. For the case in which the foliage and/or density of branches comprising the canopy decrease with increasing height, it should be expected that the smaller the elevation angle (relative to the horizontal), the larger the path length through the canopy, and the greater the corresponding attenuation. Figure 2.3 shows linear least square results of attenuation versus path elevation angle derived from measurements on the Callery Pear tree in October 1985 (full foliage) and March 1986 (bare branches).

The best linear fit results in Figure 2.3 may be expressed as follows:

For θ Between 15° to 40°

$$\text{Full Foliage}: \quad A(\theta) = -0.48\theta + 26.2 \quad \text{(dB)} \tag{2.4}$$

and

$$\text{Bare Tree}: \quad A(\theta) = -0.35\theta + 19.2 \quad \text{(dB)} \tag{2.5}$$

where θ is the elevation angle in degrees. The above results were obtained for a configuration in which the receiving antenna was 2.4 m from the ground (on top of a van) and at a horizontal distance of 8 m from the trunk of the tree whose height was 14 m. The diameters of the base and top of the canopy were approximately 11 and 7 m, respectively. The percentage rms deviations of the data points relative to the best fit expressions (2.4) and (2.5) were 15.3% and 11.1% (1.7 dB and 1.2 dB), respectively.

We derive from (2.4) and (2.5) the average condition

f = 870 MHz; El = 15° to 40°

$$A(\text{full foliage}) \approx 1.35A(\text{bare tree}) \quad \text{(dB)} \tag{2.6}$$

which states that for the static case, the maximum attenuation contribution from the Callery Pear tree with leaves (at 870 MHz) is nominally 35% greater than the attenuation (in dB) without leaves. Hence, the predominant attenuation arises from the tree branches via the

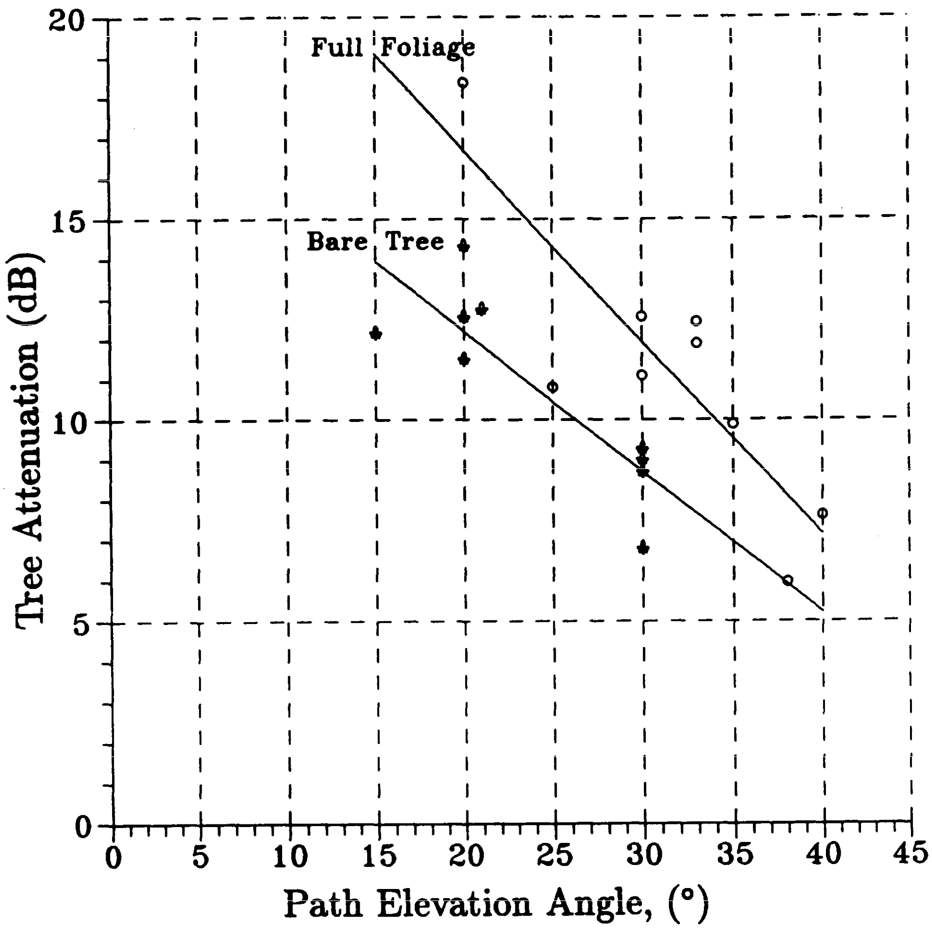

Figure 2.3: Least square linear fits of attenuation versus elevation angle for propagation through the canopy of a Callery Pear Tree at 870 MHz for a LMSS Configuration.

mechanism of absorption and the scattering of energy away from the receiver. The conclusion that the wood part of the tree is the major contributor to attenuation has also been substantiated for the mobile case (Chapter 3).

The results described in Figure 2.3 pertain to the attenuation caused by a single tree canopy in the angular range 15° to 40°. Smaller elevation angles for practical earth-satellite scenarios imply absorption and scattering from multiple tree trunks and canopies. This corresponds to the *grove case* as depicted in Figure 2.2. Hence, a description of the tree spacing, canopy dimensions, and the path length through the grove of trees are necessary to properly quantify results at elevation angles smaller than 15°.