Chapter 4

Signal Degradation for Line-of-Sight Communications

4.1 Background

This chapter broaches the question, "What is the LMSS signal degradation for a configuration in which line-of-sight communications are maintained in an environment where multipath is prevalent?" The multipath environment may consist of roadside trees, utility poles, hills, and mountains. This question was addressed through the implementation of a series of experiments by the authors in central Maryland [Goldhirsh and Vogel, 1989], and north-central Colorado [Vogel and Goldhirsh, 1988].

A typical multipath scenario is one in which direct signals are received at the same time as indirect ones which arrive at the antenna via scattering from nearby trees, utility poles, other structures, and/or the side of a mountain. The sum total of received signals may add constructively or destructively resulting in signal enhancement or fade. The received power is a manifestation of the phasor sum of the direct transmission and the resultant indirect voltage levels which depend upon the scattering cross sections of the multipath reflectors, their number, their relative distances to the antenna, the received field polarizations, and the receiving antenna gain pattern function.

Simultaneous LMSS measurements were made at L-Band and UHF where the experimental parameters are described in Table 2.2. The receiving antennas were located on the roof of a van (2.4 m above the ground) where the pattern functions were nominally azimuthally omni-directional with a 3 dB beamwidth in elevation between 15° and 75°. Below 15°, the antenna gain function dropped off rapidly and any multipath arriving via scattering from surfaces near or below the horizontal were diminished by the pattern by at least 10 dB.

4.2 Multipath for A Mountain Environment

The results described here were obtained from LMSS line-of-sight measurements in canyon passes in north-central Colorado. The transmitter was on a helicopter which, for each run, flew behind a receiving mobile van and maintained a relatively fixed distance and path depression angle relative to the receiving antenna. The radiating antennas on the helicopter transmitted simultaneous L-Band (1.5 GHz) and UHF (870 MHz) cw signals. For each of the canyon roads driven, the wall facets were highly variable in height, orientation, foliage overlay, and distance from the roads. The mountain walls consisted of randomly oriented facets of rocks with protruding patches of trees. The roads through the canyons made many twists and turns, offering highly variable aspects to the multipath illumination scene. Such a scenario was considered as a worst case for multipath.

Figure 4.1 shows four cumulative fade distributions depicting "least square power curve fits" for the above described multipath scenario at frequencies of 870 MHz and 1.5 GHz and path elevation angle 30° and 45°. Each curve was derived from a subset of four runs taken in two canyon passes (Boulder and Big Thompson Canyons); a run representing measurements where the vehicle traveled up or down a canyon pass at a particular path elevation angle to the transmitter. The resultant curves define the combined distribution corresponding to a driving distance of 87 km through canyon passes. Each of the best fit power curves agree with the measured cumulative distribution data points to within 0.1 dB rms. As mentioned, simultaneous measurements at L-Band and UHF were made for each run. The distributions may be expressed by

P = 1% to 10%

$$P = aA^{-b} \tag{4.1}$$

where P is in %, A in dB, and a and b are tabulated in Table 4.1 at the two frequencies and

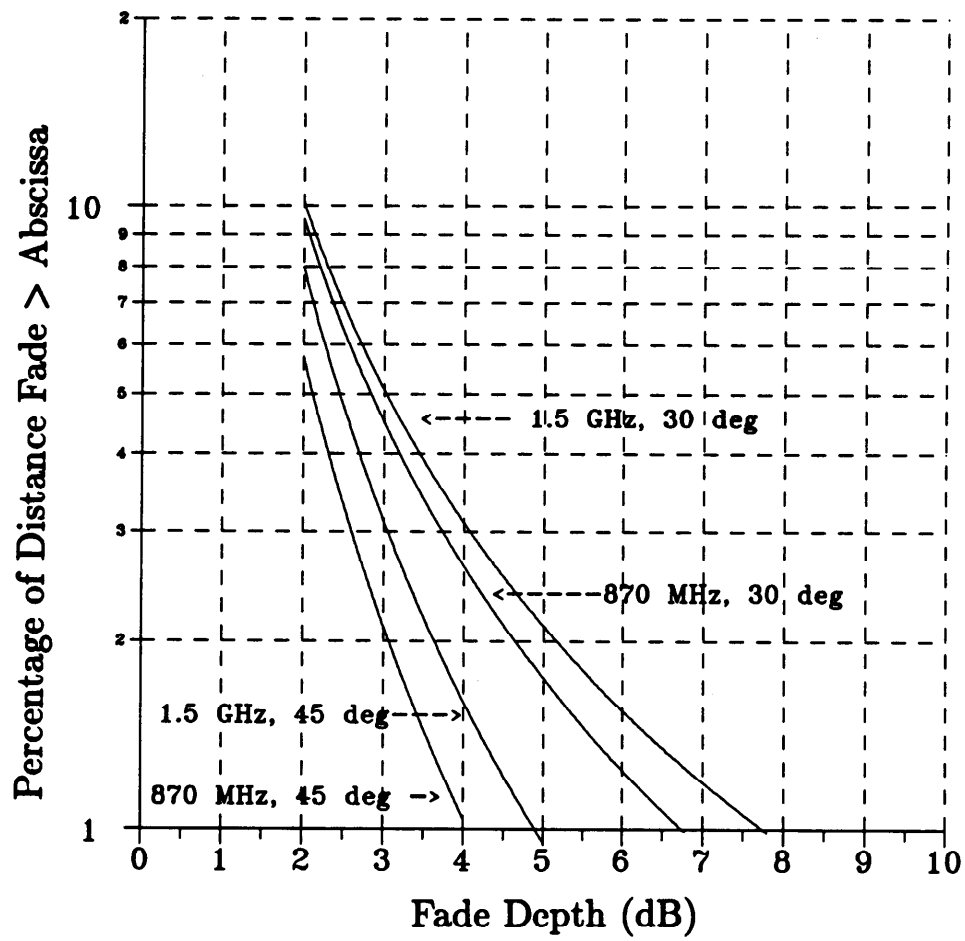

Figure 4.1: Best fits power curve cumulative fade distributions of form (4.1) for line of sight distributions in which multipath fading dominates for mountainous terrain.

Table 4.1: Coefficients a and b in formulation (4.1) describing best fit cumulative fade distribution for multipath in mountainous terrain

Frequency (GHz)	El = 30°			El = 45°		
	a	b	dB Range	a	b	dB Range
0.870	34.52	1.855	2–7	31.64	2.464	2–4
1.5	33.19	1.710	2–8	39.95	2.321	2–5

elevation angles.

We note from Figure 4.1 that over the percentage range of 1% to 10%, the fades due to multipath vary between 2 and 5 dB at 45°, and 2 and 8 dB at 30° elevation. The higher frequency (L-Band) exhibits slightly larger fades which are generally within 1 dB or less relative to UHF. The slightly larger fades at L-Band can be attributed to the small amount of tree fading which may have been present. There may also have been a presence of more reflecting facets on the canyon walls with sizes comparable to 20 cm (L-Band) or larger than does exist for the UHF case (34 cm). Such facets (L-Band case) would offer larger cross sections (Mie scattering) than facets whose dimensions were small relative to a wavelength (UHF case) where Rayleigh scattering is applicable.

Larger fades at the 30° elevation relative to 45° can be attributed to some tree shadowing where the smaller elevation angle offers more propagation path through the foliage and hence greater attenuation. It can also be attributed to the fact that multipath is dominated by illuminated surfaces closer to the vehicle; which implies lower reflecting heights and more shallow elevation angles.

4.3 Multipath Due to Roadside Trees

Similar types of line-of-sight measurements were performed by the authors in central Maryland along tree lined roads [Goldhirsh and Vogel, 1989] as were described for the mountainous terrain case in Section 4.2. That is, repeated measurement runs at 30°, 45°, and 60° were implemented with the helicopter following the vehicle and cumulative distributions were derived at both UHF and L-Band. The distributions were observed to be relatively insensitive

Table 4.2: Coefficients u and v in formulation (4.2) describing best exponential fit cumulative fade distributions for multipath for tree-lined roads.

Frequency (GHz)	u	v	Fade Range (dB)
0.870	127.7	0.8573	1–4.5
1.5	125.6	1.116	1–6

to path elevation. The three runs were combined into one distribution at each frequency comprising 75 km of driving. The resultant distributions were found to follow an exponential form given by,

<u>P = 1% to 50%</u>

$$P = u \exp(-vA) \tag{4.2}$$

where u and v are tabulated in Table 4.2 and the corresponding distributions are plotted in Figure 4.2.

The fades at the two frequencies fit very well an exponential function from 1 dB (at an exceedance of 40% to 50%) to approximately 4.5 to 5.5 dB (at an exceedance of 1%). We note a slight dependence exhibited due to frequency with L-Band giving approximately 1.5 dB greater fades at 1%. The indicated best fit exponentials were found to agree with each of the original measured cumulative distributions to within 0.2 dB. Fading due to multipath is presumed to emanate from scattering off of tree canopies which reradiate, more or less, isotropically in elevation angle. Such an explanation is consistent with the fact that the distributions were relatively insensitive to path elevation angle in the angular interval between 30° and 60°.

Enhanced fading due to multipath effects are expected for antennas pointed at lower angles (e.g., 5° to 20°) where scattering from tree canopies and trunks, other vehicles, and the road itself may be received with smaller antenna gain filtering. Also, a greater likelihood exists for shadowing to occur at the lower elevation angles.

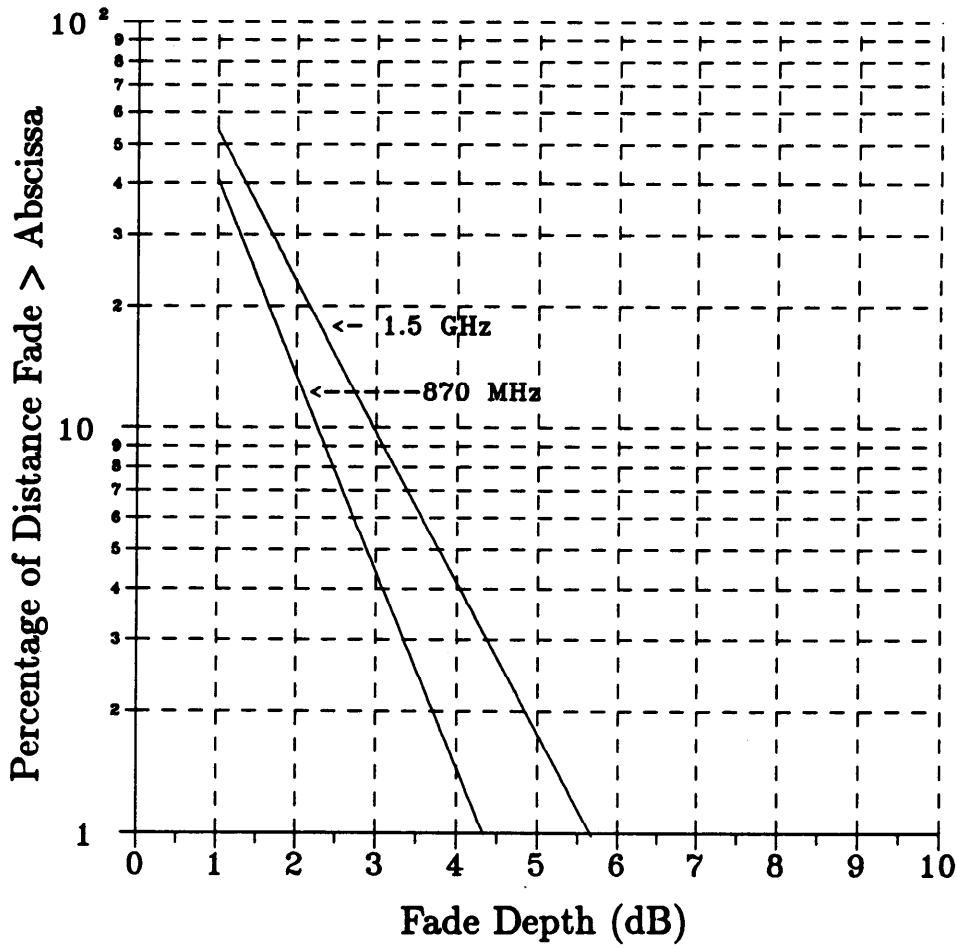

Figure 4.2: Best exponential fit cumulative fade distributions of the form (4.2) for line of sight distributions in which multipath fading dominates for tree-lined roads.