Chapter 6

Propagation Effects Due to Cross Polarization, Gain, and Space Diversity

6.1 Background

Three questions are broached in this chapter, namely:

1. During conditions under which fading occurs, are LMSS systems employing simultaneous transmissions at two polarizations (right hand circular and left hand circular) viable?
2. What are the relative fading effects for low and high gain antennas?
3. Do space diversity systems employing spaced dual antennas on a vehicle provide an advantage in reducing the likelihood of fading?

The above questions have been addressed by the authors through the analysis LMSS measurements at 1.5 GHz in Australia [Vogel et al., 1991].

6.2 Frequency Re-Use

By making repeated measurements at co- and cross-polarizations for selected runs during the Australian campaign, equi-probability "cross-polar isolation levels, CPI" were determined. These are given by

$$\mathrm{CPI(P)} = \frac{\mathrm{COPS(P)}}{\mathrm{CRPS(P)}} \tag{6.1}$$

where COPS and CRPS represent the co-polarization and cross-polarization signal levels at the equi-probability level of fade exceedance, P. The CPI (in dB) was found to follow the linear relation,

$$\mathrm{CPI} = -1.605\mathrm{A} + 18.94 \tag{6.2}$$

where A is the co-polarization fade (in dB).

The rms deviation between the "best fit linear" relation (6.2) and the data points for the corresponding runs was 0.4 dB. We note from the plot in Figure 6.1 that the isolation severely degrades as a function of fade level. For example, an approximate 11 dB isolation at a 5 dB fade is observed. This result suggests that the simultaneous employment of co- and cross-polarized transmissions in a "frequency re-use" system is implausible because of the poor isolation due to multipath scattering into the cross-polarized channel.

6.3 Distributions from Low and High Gain Receiving Antennas

During the Australian campaign, a number of repeated runs were executed in which high and low gain antennas were employed. The characteristics of these antennas are given in Table 6.1. Figure 6.2 shows a plot of the high gain receiver fade versus the low gain fade over the low gain fade interval of 0 to 15 dB. The data points were found to follow the linear relation

$$\mathrm{A(HG)} = 1.133\ \mathrm{A(LG)} + 0.51 \tag{6.3}$$

where A(HG) and A(LG) represent the high and low gain fades (in dB), respectively. Agreement between the relation (6.3) and the data points for A(HG) were within 0.2 dB rms.

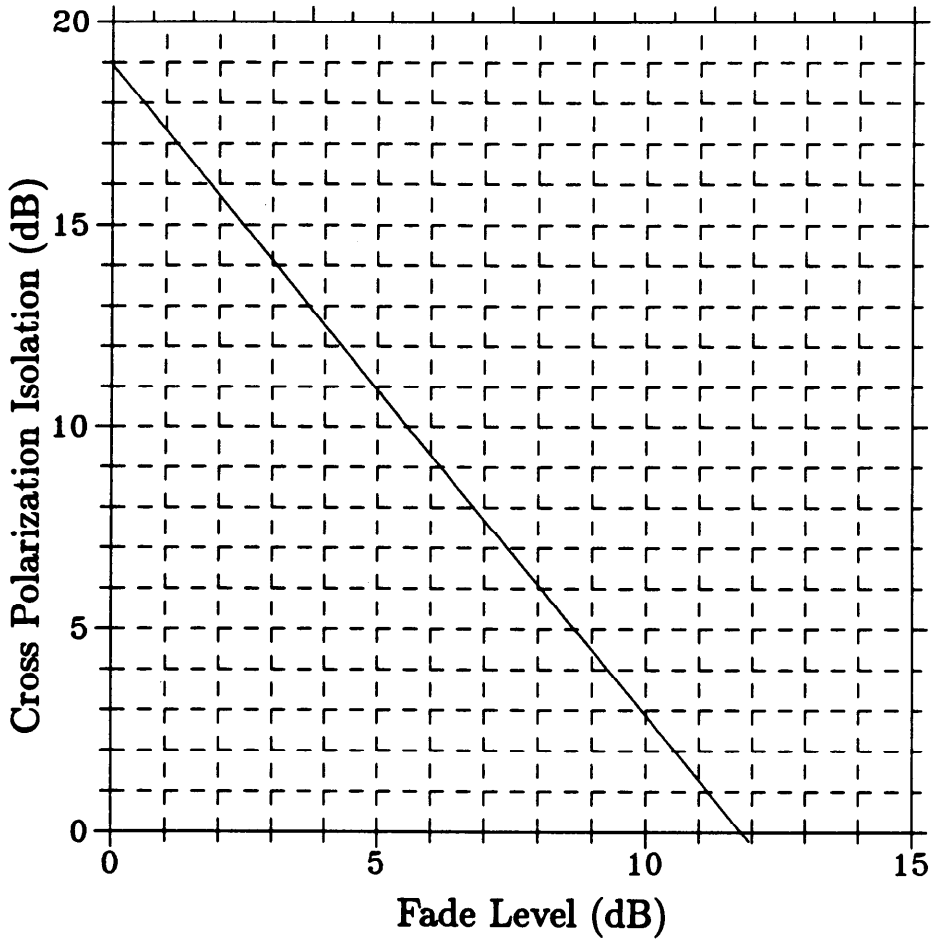

Figure 6.1: Cross-polarization isolation (CPI) as a function of co-polarization fade at equi-probability levels.

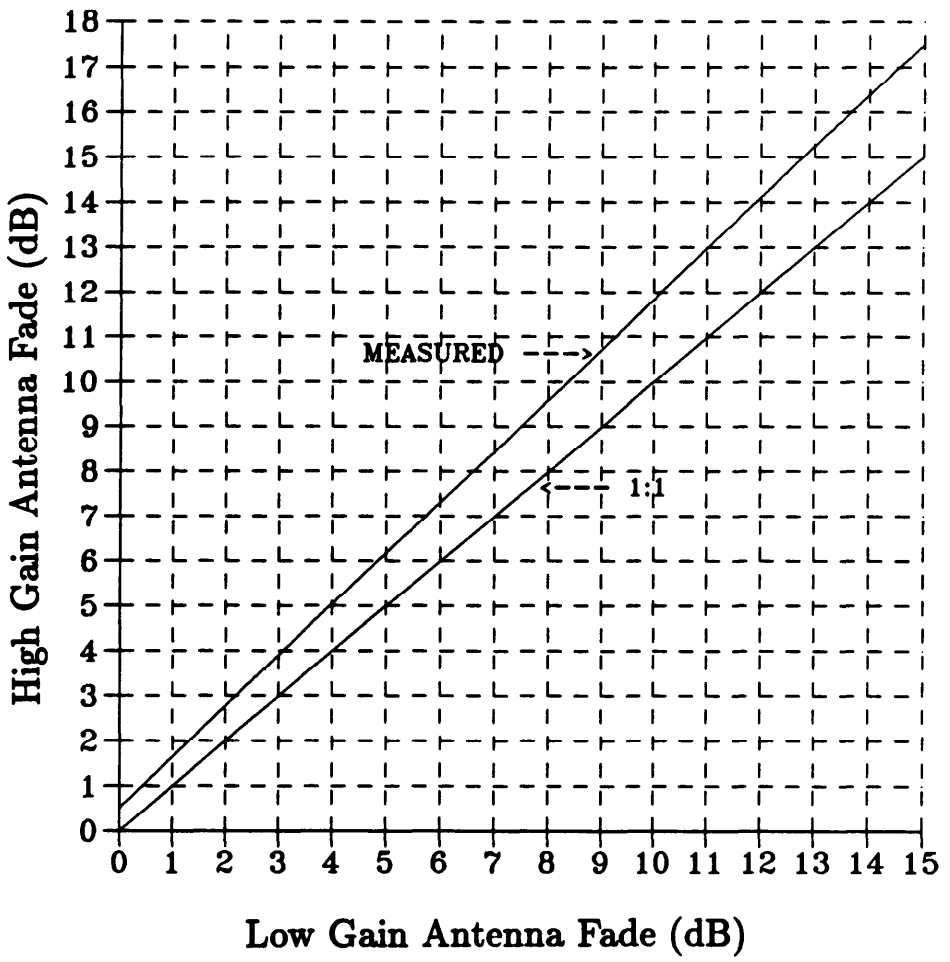

Figure 6.2: Fade for measured by high gain receiver system versus fade measured by low gain system at equi-probability levels.

Table 6.1: Summary of pertinent characteristics for high and low gain receiver antennas used during the Australian campaign [Vogel et al., 1991]

Characteristic	Low Gain	High Gain
Type	Crossed Drooping Dipoles	Helix
Gain (dB)	4	14
Nominal Pattern (El)	15° - 70° (Fixed)	45° (Principal Planes)
Nominal Pattern (Az)	omni-directional	45°
Polarization	LHCP or RHCP	RHCP or LHCP

We note that the high gain system experiences consistently more fading than the low gain case. For example at 3 and 14.5 dB (of low gain fades), the high gain fades are 4 and 17 dB, respectively, which represent 33% and 17% increases. This slight increase in attenuation for the high gain case occurs because less average power is received via multipath since the associated antenna beam is narrower. On the other hand, the azimuthally omni-directional low gain antenna receives more scattered multipath contributions resulting in an enhanced averaged received power. It is important to note that because the high gain antenna has 10 dB more gain associated with it, the net power received by it is still significantly higher than that received for the low gain case. Even at the 15 dB fade level (low gain receiver system), the net received power for the high gain mode is larger by 7.5 dB.

6.4 Diversity Operation

A space diversity simulation has been carried out employing the data base corresponding to 400 km of roadside tree shadowing measurements taken during the Australian campaign. Space diversity operation for LMSS configurations may be envisaged by the scenario of two spaced antennas mounted atop a vehicle where each antenna is fed to a separate receiver system. Because the signal levels at the two antennas are expected to be different at any instant of time, rapid switching between the two receiver outputs followed by subsequent processing should enable the larger signal to be accessed. Such a system should therefore require smaller fade margins for the same "signal access distance" than single terminal systems. The signal access distance represents that distance over which the received signal level operates within the designed fade margin.

Questions which have been broached are:

- What is the increase in "signal access distance" as a function of antenna spacing along the driving direction?
- What is the improvement in terms of reduced fading (enhanced signal) for a given "signal access distance" as a function of antenna spacing?

The first question is addressed employing the concept of "diversity improvement factor, DIF" and the second "diversity gain, DG," both of which are characterized in the following paragraphs.

6.4.1 Joint Probabilities

In Figure 6.3 are shown a family of cumulative fade distribution functions derived from the above mentioned simulation. The curve labeled d = 0 represents the single terminal cumulative fade distribution corresponding to data acquired from over 400 km of driving in Australia. The curves labeled d = 1 to 10 m represent the individual joint probability cumulative fade distribution for the indicated antenna separations (in the direction of vehicle motion). Such a distribution represents "the joint probability that two antennas spaced a distance d mutually exceed the abscissa value of fade." We note that the joint probabilities tend to coalesce with increasing antenna separation. That is, the fade distributions for 8 m and 10 m separations show insignificant differences.

6.4.2 Diversity Improvement Factor, DIF

The DIF is defined as

$$\mathrm{DIF}(A,d) = \frac{P_o(A)}{P_d(A)} \tag{6.4}$$

where $P_o(A)$ represents the single terminal probability distribution at the fade depth A, and $P_d(A)$ represents the joint probability distribution for an antenna spacing d assuming the same attenuation A is exceeded. These probabilities may be obtained from Figure 6.3. We note, for example, that DIF(8,1) $\approx$ 3 implies that when the antennas are separated 1 m,

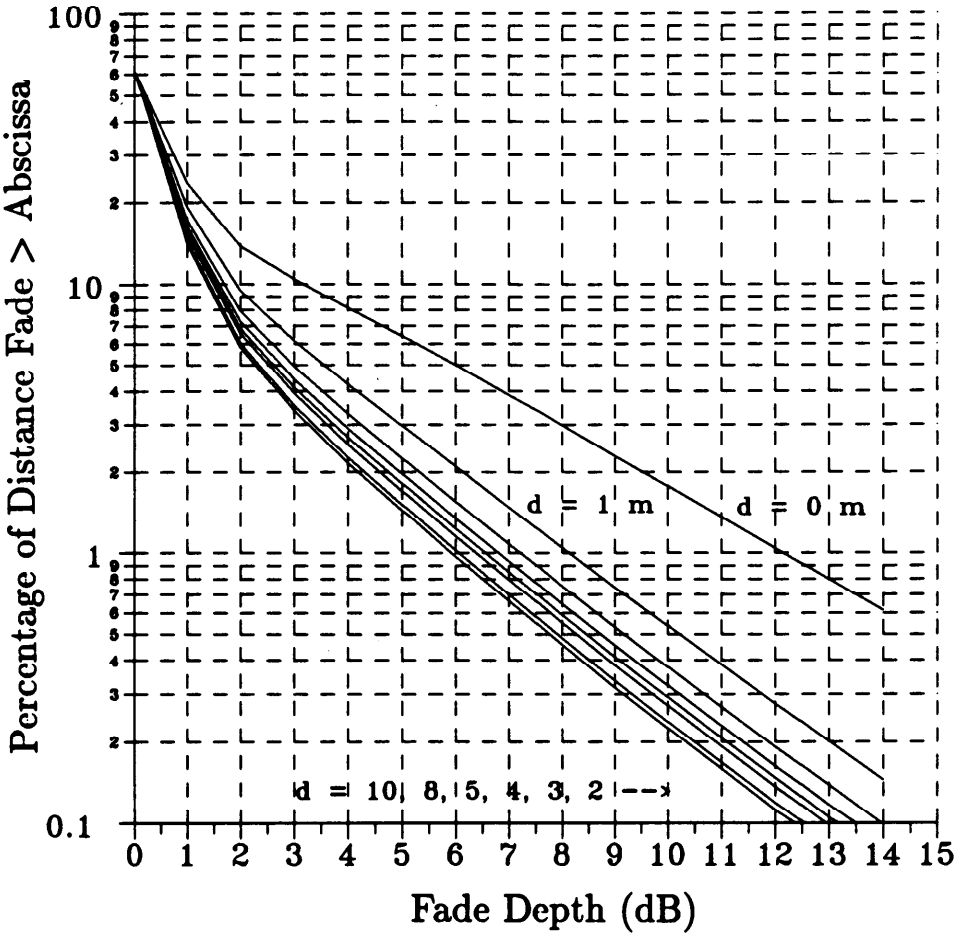

Figure 6.3: Single and joint probability fade distributions for mobile communications operating in a space diversity mode with antennas separated by the distance, d.

the distance over which the signal is received above noise is three times greater for diversity operation relative to the single terminal case assuming an 8 dB fade margin.

Employing the above results, a least square estimate of DIF was derived given by,

$$\mathrm{DIF}(A, d) = 1 + [0.2 \times \ln(d) + 0.23] \times A \tag{6.5}$$

where d is the antenna separation expressed in m and A is the fade depth in dB.

In Figure 6.4 are plotted a family of curves of DIF as a function of fade depth for antenna separations between 1 and 10 m. We note that at the larger separations for any given fade depth, the rate at which DIF increases diminishes rapidly.

6.4.3 Diversity Gain

The diversity gain is a concept defined by Hodge [1978] for an earth-satellite communications system involving two spaced antennas operating in a diversity mode in the presence of precipitation. This concept may also be applied to separated antennas atop a vehicle for LMSS scenarios. The diversity gain is defined as the fade reduction experienced while operating in the diversity mode at a given probability. It is equal to the difference in fades between the single terminal and joint probability distributions at a fixed probability level. For example, for 1% of the time (Figure 6.3) a fade depth of 12 dB will be encountered with no diversity ($d = 0$) and 8 dB with diversity assuming a 1 m separation ($d = 1$). Hence, operation in the diversity mode with a 1 m separation yields a diversity gain of 4 dB.

In Figure 6.5 are plotted the diversity gains versus antenna separations for a family of single terminal fade levels. Each single terminal fade uniquely defines a probability level. For example, an 8 dB fade occurs at a probability level of 3% as is noted from Figure 6.3 (for $d = 0$). Figure 6.5 shows that the effect of the antenna separation is dramatic the first 2 meters, whereas at larger spacings, relatively little additional fade reduction ensues. It might be suggested that at antenna spacings greater than the canopy width (e.g., 8 to 10 m), the diversity gain would show a noticeable improvement since one antenna would have an associated unshadowed line-of-sight during the time the line-of-sight for the other antenna is shadowed. This would be the case for a single tree scenario. However, the results depicted in Figure 6.5 correspond to cases where multiple trees exist along roads such that the canopies form a continuum of shadowing. Hence, the single tree model no longer holds.

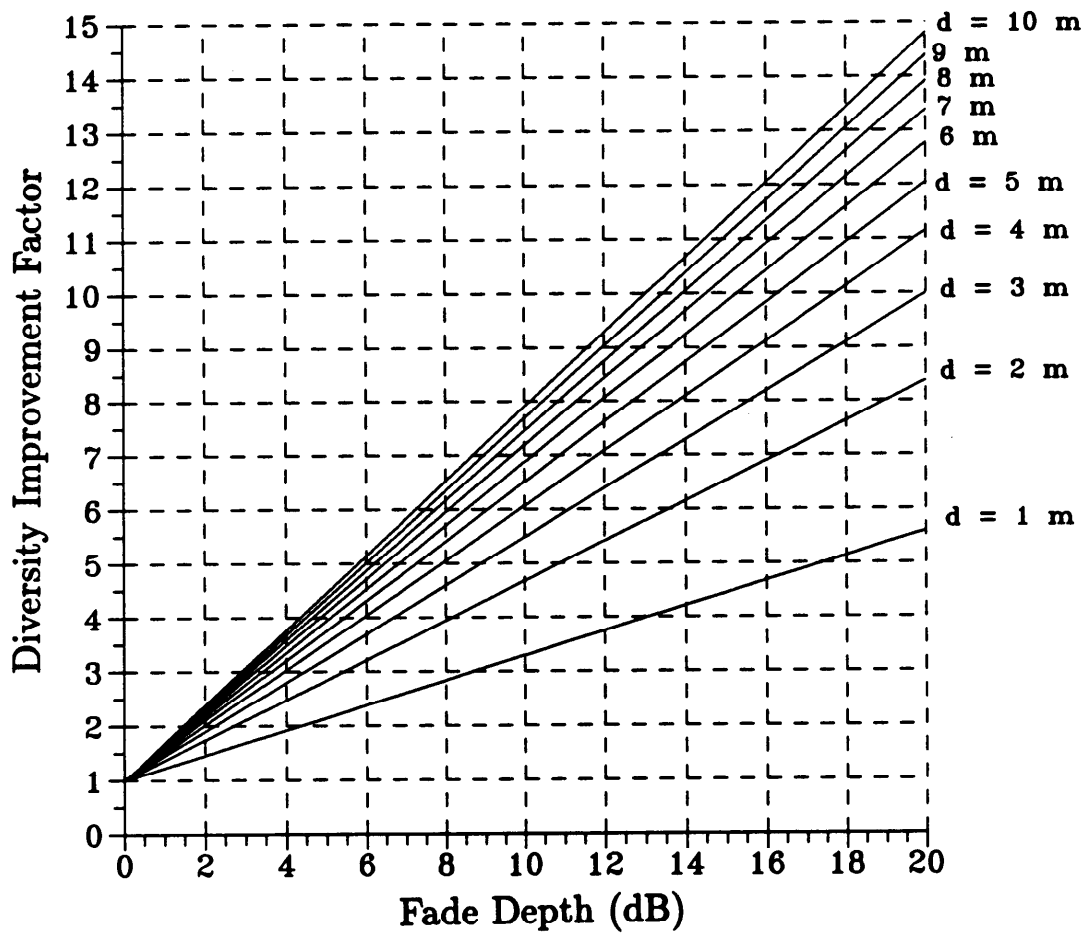

Figure 6.4: Diversity Improvement Factors (DIF) as a function of fade depth for a family of antenna separation distances.

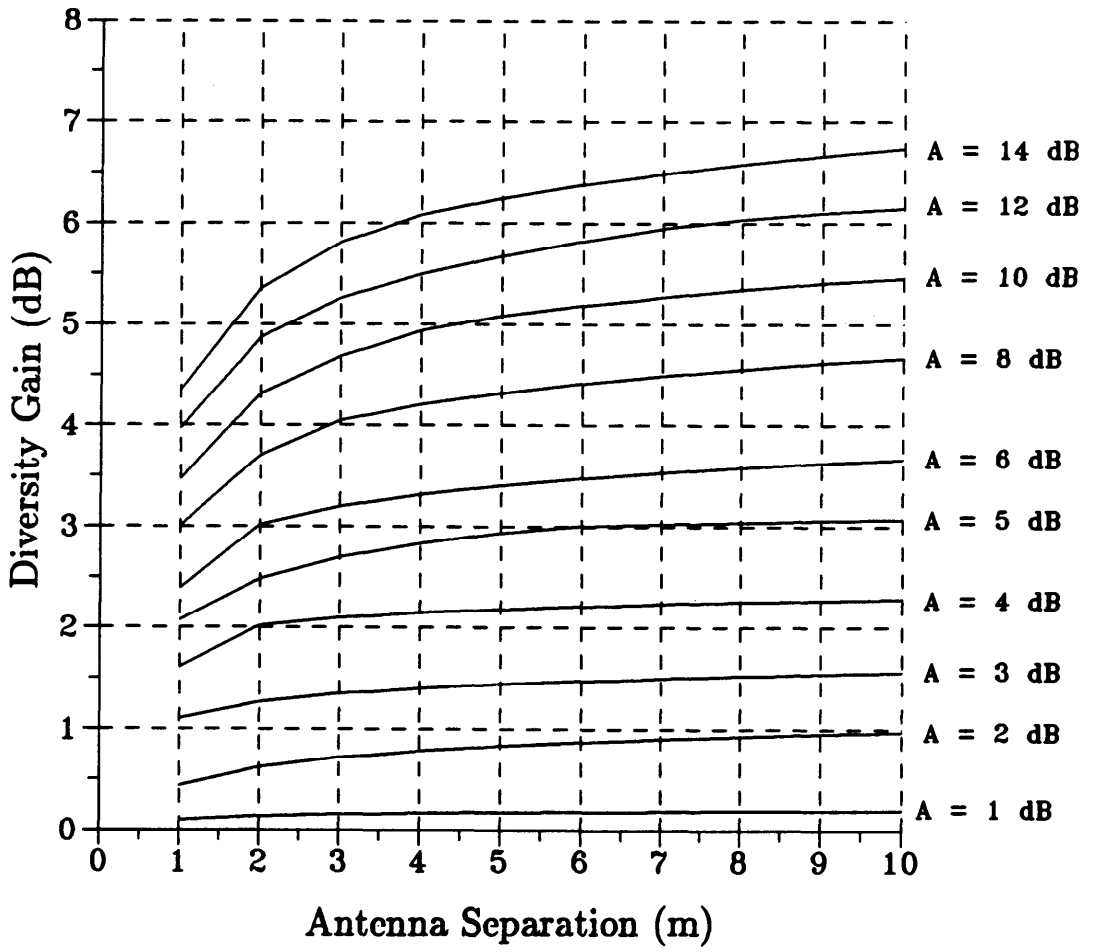

Figure 6.5: Diversity gain versus antenna separation distance for a family of single terminal fade levels.