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Results of Multiband (L, S, Ku Band) Propagation Measurements and Model for High Elevation Angle Land Mobile Satellite Channel

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1.0 Introduction

Signal propagation in the land mobile satellite (LMS) service is an important consideration due to its critical impact on the overall economic and commercial viability of the system. At frequencies allocated for LMS systems, shadowing of the line-of-sight (LOS) signal as well as multipath propagation phenomena can severely impair the link availability. In particular, as most of the studies have shown, the shadowing of LOS signal causes long and deep fades in a variety of mobile environments due to the inherent nature of the channel between the satellite and a mobile. Roadside obstacles, such as buildings, trees, utility poles etc., in the immediate vicinity of a mobile and the surrounding terrain are major sources of signal shadowing in LMS links. Therefore, a proper knowledge of link degradation is essential for cost-effective planning of a satellite based mobile communication system.

This paper reports on the results of a propagation campaign undertaken to characterise the fading nature of LMS channel at high elevation angles. It was envisaged that one of the most important physical variable contributing to the amount of LOS signal shadowing is the elevation angle of the satellite [1]. At higher elevation angles to the satellite, less obstructions in the direct satellite-to-mobile path would therefore amount to statistically better link availability. Narrowband channel measurements were carried out at three RF frequencies corresponding to L (1.3 GHz), S (2.32/2.45 GHz) and Ku (10.4 GHz) bands. The campaign itself was divided into two phases to observe the effects of seasonal variation of foliage on the roadside trees. First phase measurements were carried out in September 1991 when trees were in full foliage. The second phase measurements were made during the early spring of 1992 (April 1992); during the time of year when leaves on the deciduous trees were beginning to reappear. Details of the experiment design and procedures adopted for the measurements are contained in [2] for interested readers. In the following sections some important aspects from the statistical analysis of the propagation data are presented.

2.0 Channel Characteristics:

The narrowband measurements of the LMS channel at L, S and Ku-band were analysed off-line to evaluate the first and second order statistics. These statistics provide useful information on channel behaviour as a function of frequency, elevation angle and mobile environment. The relative effect of foliage density on signal fading for the above mentioned variables is obtained by comparing the statistics from the two measurement phases.

2.1 First Order Statistics:

CDF's of Phase-I Measurements: Figure 1 shows the cumulative distribution functions (CDFs) based on the statistical analysis of the channel recordings, made in the environment considered as suburban for this study, during the first phase of measurement campaign in September 1991. CDF curves corresponding to the 60° and 80° elevation angles for all three frequencies are included. It is clear from the curves that as the elevation angle increases fade depth reduces for equiprobable link availability. For example, link margins of the order of 16.5, 18.5 and 27.5 dB are required to provide reliable communication for 99% of the time at L, S and Ku band frequencies, respectively, at 60° elevation angle. When elevation angle to the transmitting source is 80°, the corresponding margins reduce to 12, 16 and 26 dB respectively. The improvement in the required link margins as a result of the increase in the elevation angle stands at 27% for L-band, 13.5% for S-band and 5.5% for Ku-band, demonstrating maximum advantage to be gained at L-band.

Analysis of measurements made in another environment with heavy tree shadowing, considered as wooded for this study, show that signals suffer higher attenuations as compared to those in the suburban environment at 60°, but there is marked improvement at 80°. The L-band attenuation for 99% availability in the wooded environment was found to be 18.5 dB at 60° which reduced to about 8 dB at 80° elevation angle, an improvement of 57%. At Ku-band, the attenuation levels for the same link probability were 28 and 24 dB corresponding to elevation angles of 60° and 80° respectively, the improvement in this case was only 14%. Less signal degradation at higher elevation angle for the wooded environment may be explained in terms of the nature of trees in the wooded environment that constituted the major shadowing source. Non-deciduous coniferous trees dominated the tree population in the wooded environment which are believed to have contributed less to the signal shadowing at 80°.

In the mobile environment considered as open for this study, signal degradation was found to be limited compared to the attenuations experienced in the other two environments. The analysis results confirmed that in the absence of any major shadowing or scattering sources (apart from occasional overhead bridges) signals generally did not experience long or deep fades. At 1% outage probability, fades in the range of 2-4 dB were observed for L, S and Ku-band signals.

CDF's of Phase-II Measurements: Figure 2 contains the measurement results for the suburban environment obtained during the second phase. Sharp reductions in attenuations result when elevation angle is increased from 60° to 80°. It is interesting to note, however, that 60° curves at all frequencies are very similar to those obtained during the first phase. The sharp reduction in fades at 80° may be attributed to the reduced foliation of deciduous trees, which dominated the tree population in the suburban environment, during the early spring time. At 1% link outage probability, the improvement in link margins was 79% at L-band, 62% at S-band and 69% at Ku-band when the elevation angle increased from 60° to 80°. The results show the extent of influence of foliage on the fade depth especially at higher elevation angles, and highlight the significance of physical conditions in a mobile channel influencing link margin requirements.

Since the tree population in the wooded environment was predominantly non-deciduous, there was minimal seasonal effect as far as defoliation was concerned. This was reflected in the marginal difference in attenuation levels at all frequencies when compared to respective phase-I wooded environment results. The maximum difference was observed at Ku-band where an almost uniform difference of 4 dB was observed at all significant link availability levels. The difference at S and L-band reduced as the frequency decreased. Such an observation implies that mobile channel behaviour is sensitive to the radio-frequency.

2.2 Second Order Statistics:

Second order statistics evaluated from the channel measurements and presented here include signal level crossing rate and average fade durations. Such information, particularly average fade durations, are useful in determining optimum parameters of communication subsystems such as modulation, coding and transmission data rates for digital systems etc. [3].

Figures 3 and 4 illustrate level crossing rates (LCR) for the suburban environment derived from phase I and II measurements. The level crossing rate has been normalised to signal wavelength. In all cases the rate of level crossing in a positive direction peaks around the 0 dB level, indicating the presence of LOS signal for most of the time. Rapid fluctuations near LOS level imply the presence of weak diffusely scattered signals and hence received signal may reasonably be assumed to be Rician distributed, although this has not been confirmed analytically. As the frequency increases, the level crossing rates drop indicating deeper signal attenuation. The effect of reduced shadowing of LOS at higher elevation angles is evident from peaks of LCR curves near 0 dB level. Figures 5 and 6 show average fade duration (AFD) curves for the suburban environment from phase-I and II. Similar observations can be made from these curves. The availability of unshadowed LOS signal is clear from reduced fade durations near 0 dB level in all cases. It is worth mentioning at this point that the second order statistics are sensitive to sampling rates at which the analog signals are digitised for computer analysis. The vertical dotted lines in all second order plots indicate the attenuation level beyond which there could be little statistical confidence in the second order statistics. Therefore, care must be exercised in interpreting results above the fade level indicated.

3.0 Models

The results from the Multiband Campaign have been further analysed using statistical distributions and the model proposed by Lutz, et al,[6]. As shown by Table 1. the analysed results compare favourably with the statistics presented by Lutz in the suburban and wooded categories for the higher elevation angles considered.
An example of Shadow Factor verses Elevation Angle for the suburban category is shown by Figure 7. This shows the general trend that the shadow factor reduces as the elevation angle increases, thus providing a more reliable communication channel.

An empirical model has been developed to predict the required system margin for the specified link availability as a function of RF frequency ($1.3 < f < 10.4$ GHz) and elevation angle ($60^o < \phi < 80^o$) for average shadowing conditions. The model, Empirical Fading Model (EFM), is given by :-

$$M\ (\mathrm{dB}) = A.\mathrm{Ln(p)} + C$$

Where : M corresponds to the required link margin for the specified outage probability, p (%), in the range of 1 to 20, and f is frequency in GHz. The constants A and C are determined as follows:-

$$A = 0.029\phi - 0.182f - 6.315$$

$$C = -0.129\phi + 1.483f + 21.374$$

Further work comparing the above model with that of the Empirical Roadside Shadowing Model, (ERS),[7] and CCIR Model [8] has been carried out in order to enhance the range of elevation angles of these models. A combined model for L-Band has been derived in a similar form to that given above and in [7]. A typical comparison of the models for 10% fade exceedance level is shown by Figure 8, as well as the combined model. The model Suburban/Rural Empirical Fading Model (S/REFM), is given by :-

$$M\ (\mathrm{dB}) = B.\mathrm{Ln(p)} + D$$

Where :-

$$B = 23.5f - 0.108\phi + 0.0018\phi\text{^}2 - 38.5$$

$$D = -58.5f - 0.375\phi + 121.5$$

And

M and f are defined as above and p (%) is in the range of 5 to 20.

4.0 Conclusion

The LMS channel behaviour may be summarised as:

* As the path elevation angle to the satellite increases, the attenuation due to shadowing and multipath the channel conditions reduce.

* In general, signal attenuation increases as a function of increasing radio-frequency.

* The effect of foliage density on the attenuation level has been found to be significant, particularly at higher elevation angles.

* The fading character of the LMS channel is significantly dependent upon the type of surrounding environment.

These conclusions tend to substantiate the general trend of various findings from other propagation studies carried out under different terrain types, and in most cases in different geographical locations i.e., Europe, the United States and Australia, and at various RF frequencies. Limited data exist at frequencies and elevation angles considered during this study. However, results from propagation studies elsewhere [4], [5] at comparable elevation angles, RF frequencies and mobile environments are in reasonably good agreement with the statistical results presented here. This experiment is believed to be the first ever attempt to cover such a wide range of frequencies and high elevation angles simultaneously. The results presented in Section 2. provide indications on the link margin requirements for frequencies in L, S and Ku bands at elevation angles above 60°.

The Centre for Satellite Engineering Research (CSER) is further pursuing the propagation issues of mobile-satellite channel by planning a wideband channel measurement campaign at L and S bands. The results of the wideband sounding are expected to provide useful information, particularly on the coherence bandwidth and delay spread of the channel, and the effect of RF frequency, elevation angle and mobile environment on such parameters. These parameters are believed to be important in determining the optimum signalling format, signal modulation and channel coding schemes for future mobile/personal satellite communication systems.

References:

[1] University of Surrey: *'A Study on the Feasibility of High Elevation Angle Propagation Experiment Applicable to Land Mobile Satellite Services'*, ESA contract 8084/88/NI/PB, 1989

[2] Butt, G., Evans, B.G., Richharia, M.: *'Narrowband Channel Statistics from Multiband Propagation Measurements Applicable to High Elevation Angle Land Mobile Satellite Systems'*, IEEE Journal on Selected Areas in Communications, vol. 10, no. 8, October 1992, pp.1219-1226

[3] Parsons, J.D.: *'The Mobile Radio Propagation Channel'*, Pentech Press, London, 1992

[4] Goldhrish, J., Vogel, W.J.: *'Mobile Satellite System Fade Statistics for Shadowing and Multipath from Roadside Trees at UHF and L-band'*, IEEE Transactions on Antennas & Propagation, vol.37, no.4, April 1989, pp.489-498

[5] Smith, H., Sforza, M., Arbesser-Rastburg, B., Baptista, J.P.V., Barton, S.K.: *'Propagation Measurements for S-band Land Mobile Satellite Systems using Highly Elliptical Orbits'*, Proceedings of Second European Conf. on Satellite Communications, Liege Belgium, 22-24 October 1991, pp.517-520

[6] Lutz, E., et al.,*'The Land Mobile Satellite Communication Channel - Recording, Statistics, and Channel Model'*, IEEE Transactions on Vehicular Technology, Vol 40, No.2, May 1991

[7] Goldhirsh, J., Vogel, W.J.: *'Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results'*, NASA Reference Publication 1274, February 1992

[8] CCIR XVIth Plenary Assembly, Geneva, *'Factors Affecting the Choice of Antennas for Mobile Stations of the Land Mobile-Satellite Service'*, Report 925-1 1986

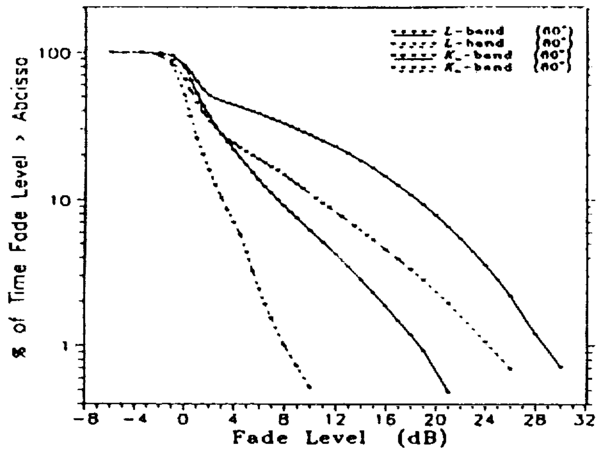

Figure 1: CDFs for the Suburban environment (*Phase-I*)

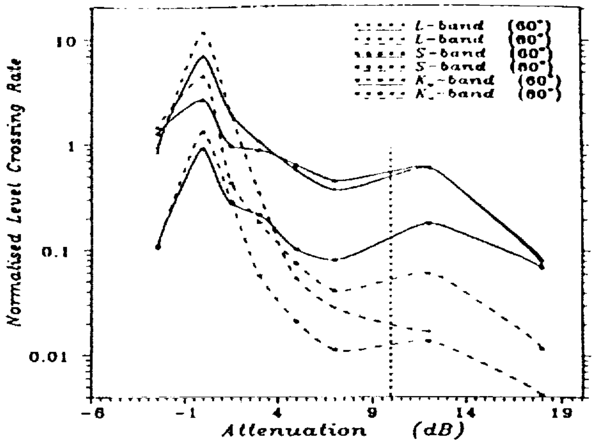

Figure 4: Normalised LCR for the Suburban environment (*Phase-II*)

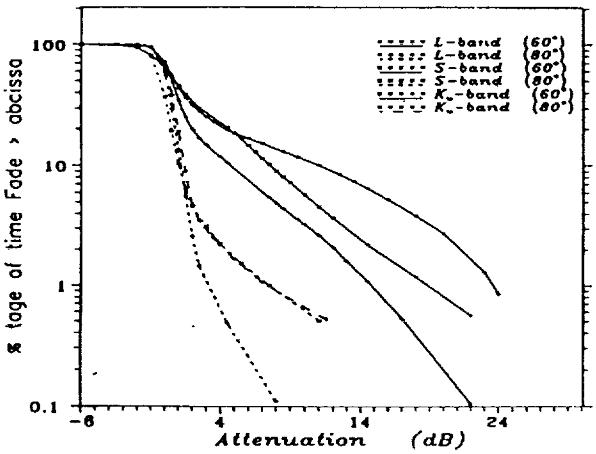

Figure 2: CDFs for the Suburban environment (*Phase-II*)

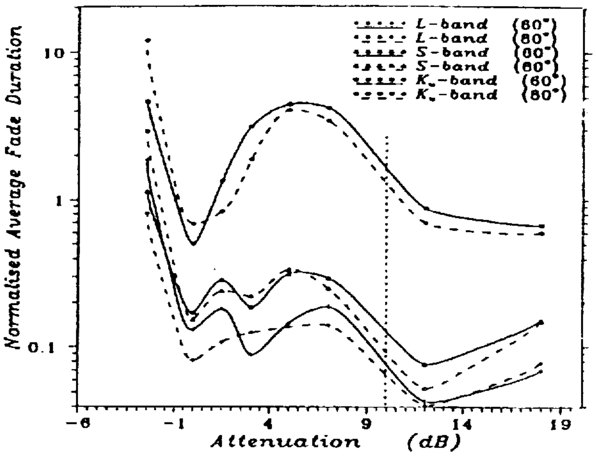

Figure 5: Normalised AFD for the Suburban environment (*Phase-I*)

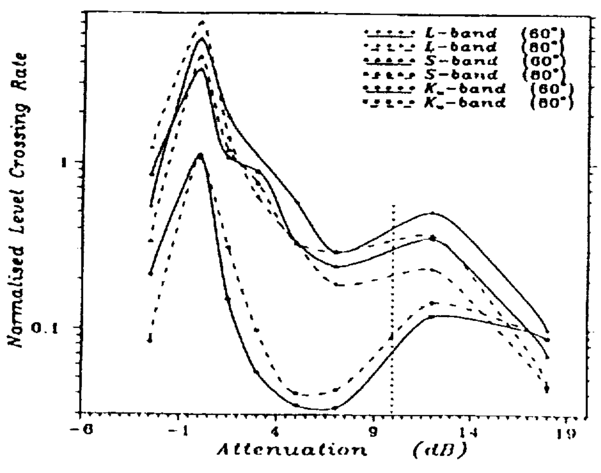

Figure 3: Normalised LCR for the Suburban environment (*Phase-I*)

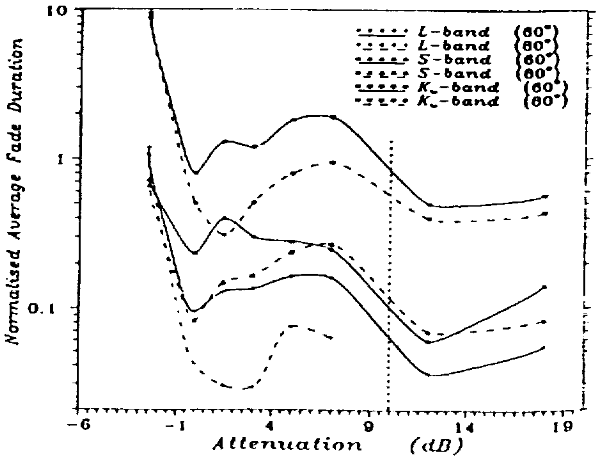

Figure 6: Normalised AFD for the Suburban environment (*Phase-II*)

Table 1: ***Comparison of Parameters of the Analog Channel Model as proposed by Lutz et al***

Elevation Angle	Environmental Category	Time-Share Factor (A)	10Log(c)	Mean Value (µ)	Standard Dev. (Δ)	Antenna Gain dBi
13	City	0.89	3.9	-11.5	2.0	3.0
18	City	0.80	6.4	-11.8	4.0	3.0
21	City	0.57	10.6	-12.3	5.0	5.0
24	City	0.66	6.0	-10.8	2.8	3.0
34	City	0.58	6.0	-10.6	2.6	3.0
43	City	0.54	5.5	-13.6	3.8	3.0
60	**Suburban**	**0.224**	**13.23**	**-6.1**	**2.8**	**4.0**
70	**Suburban**	**0.03**	**14.68**	**-6.1**	**2.2**	**4.0**
80	**Suburban**	**0.007**	**17.70**	**-6.4**	**3.2**	**4.0**
13	Highway	0.24	10.2	-8.9	5.1	3.0
24	Highway	0.25	11.9	-7.1	6.0	3.0
34	Highway	0.008	11.7	-8.8	3.8	3.0
43	Highway	0.002	14.8	-12.0	2.9	3.0
24	Wooded	0.59	9.9	-9.3	2.8	3.0
24	Wooded	0.54	10.7	-5.3	1.3	5.0
60	**Wooded**	**0.655**	**10.58**	**-6.3**	**2.5**	**4.0**
70	**Wooded**	**0.378**	**13.95**	**-6.9**	**5.1**	**4.0**
80	**Wooded**	**0.077**	**10.84**	**-5.1**	**3.1**	**4.0**

Where :-

c = The direct-to-multipath signal power ratio in dB

µ = The mean power level decrease in dB

Δ = The standard deviation of the power level due to shadowing in dB

Fig 7: Shadow Factor vs Elevation Angle for Sub-urban Category

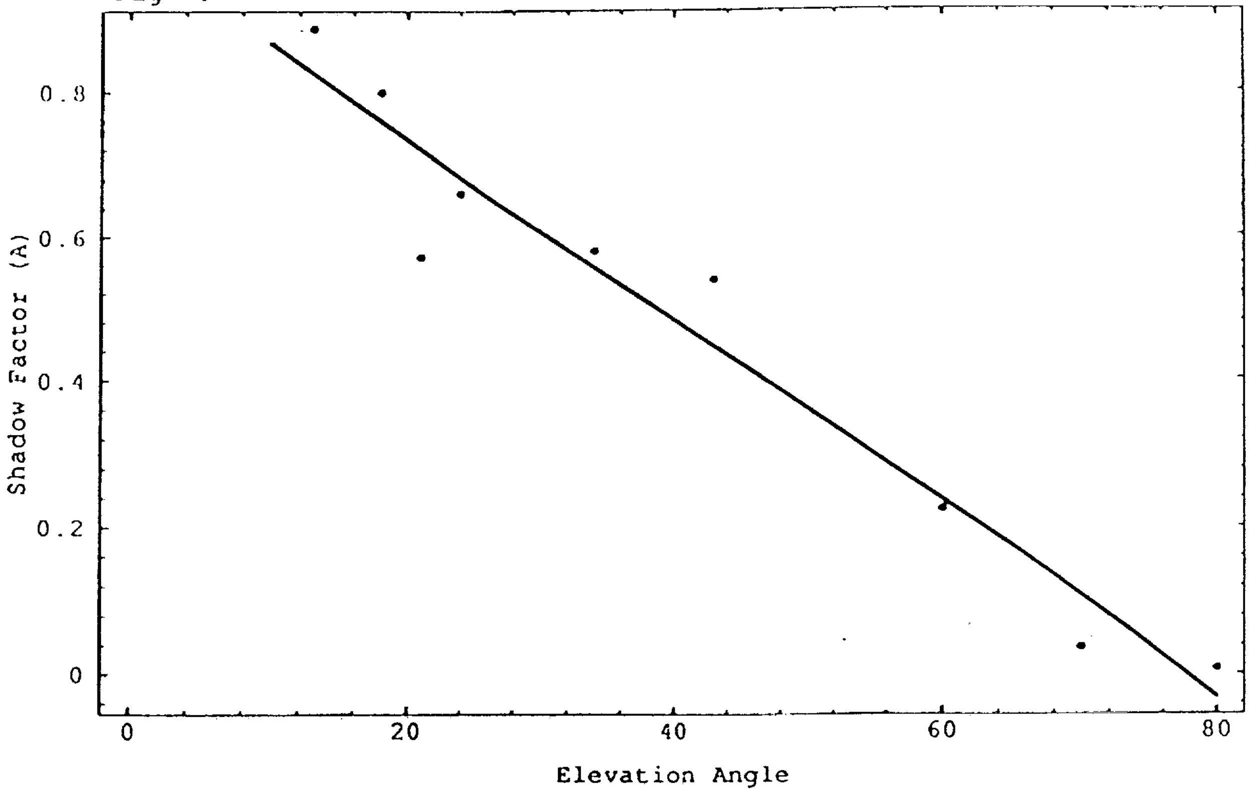

Fig 8: Comparison of CCIR,ERS,and EFM Models at L-Band.