

Characterisation of the LMS Propagation Channel at L- and S-bands: Narrowband Experimental Data and Channel Modelling

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Abstract

During the period 1983-1992 the European Space Agency (ESA) has carried out several experimental campaigns to investigate the propagation impairments of the Land Mobile Satellite (LMS) communication channel. A substantial amount of data covering quite a large range of elevation angles, environments and frequencies has been obtained. Results from the data analyses are currently used for system planning and design applications within the framework of the future ESA LMS projects. This comprehensive experimental data base is presently utilised also for channel modelling purposes and preliminary results are given in this paper. Cumulative Distribution Functions (PDF) and Duration of Fades (DoF) statistics at different elevation angles and environments have been also included.

1 Introduction

In the design stages of an LMS communication system information regarding the satellite-to-mobile propagation channel is needed to assess link availability objectives, modulation and coding schemes performance, protocols robustness and other system parameters. For conventional geostationary LMS systems, large fade margins are usually required to compensate for signal blockage due to man-made or natural obstacles and for multipath effects. These propagation impairments can be effectively mitigated by means of multisatellite constellations in stable elliptical or circular orbit configurations, in the latter case taking advantage of the in-built

network multivisibility; experimental data or equivalently empirical-statistical channel models are however needed to carry out design studies at system and subsystem levels.

In the field of LMS channel modelling and characterisation, ESA has embarked in a number of research projects involving both experimental and theoretical aspects. In this paper, data on first and second order statistics describing the main narrowband channel propagation features are reported for elevation angles from 20° up to 80° , for several environmental scenarios (open, wooded, suburban and urban) and frequencies (L- and, where possible, S-bands). Empirical models for fade prediction purposes and frequency and elevation scaling laws have been derived for tree-shadowed environments; they are also presented in the following sections.

2 ESA LMS experimental campaigns

The first ESA involvement in LMS experimental measurements dates back to 1983 when the project called PROSAT was first started. The field tests were carried out by using a CW signal up-linked at C-band from an ESA ground station in Villafranca (Spain) to INMARSAT Marecs-A satellite. The frequency of the unmodulated carrier in the down-link channel was of 1.54 GHz. During the first phase of the project, measurements were taken in Belgium and in The Netherlands in open rural, wooded and suburban areas at 27° of elevation angle. The second part of the experimental programme took place in 1987 in Sweden, France and Spain in similar environments, covering a range of elevation angles from 13° to 39° . Specific technical details on the equipment set-ups can be found in [1,2].

One of the problem areas identified by the PROSAT project results was the unrealistic link margin requirement for LMS systems operating at low elevation angles, due to frequent blockage by trees, buildings, bridges and so forth. It was therefore decided to undertake further research activities to address specifically the problem of characterising the LMS propagation channel at elevation angles greater than 40° . Use of highly elliptical orbit configurations, for instance, allows for users in Northern latitudes to be served at mean elevation angles in excess of 50° . In view of these considerations, an airborne experimental campaign was carried out at L- and S-bands (1.3 and 2.6 GHz, respectively) in different locations in North Yorkshire (UK), in cooperation with the British Radiocommunication Agency. Narrowband experimental data were collected in different areas and at elevation angles from 40° up to 80° ; further details are given in [3-5].

3 Selected experimental results

A representative sample of first and second order statistics is reported in this section with short descriptions of the environmental characteristics related to the areas under test.

One of the major problem encountered in our work has been the lack of characterisation data

for some specific experimental data files. Furthermore, operational conditions, reference levels, receiver dynamic ranges and antenna radiation patterns were different in the PROSAT project from the airborne campaigns. Finally, the range of elevation angles covered at L-band was larger than at S-band. In order to obtain a more congruent and comprehensive experimental data base it was then decided to carry out additional analyses to establish, at the maximum extent, a unique reference level. The parameters characterising the environments are given as follows:

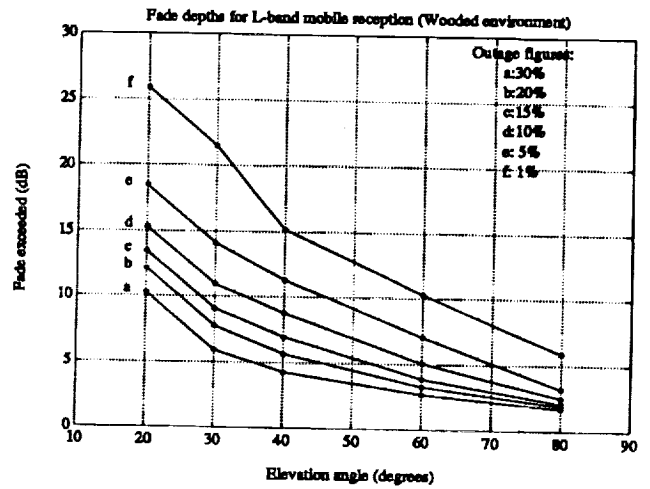
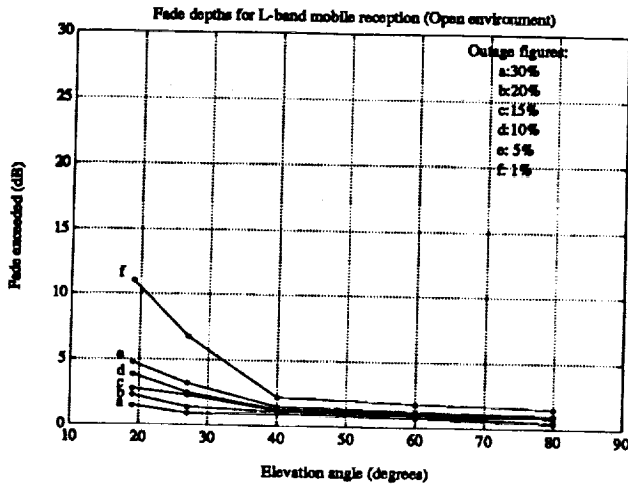
- Open environment; rural areas with no obstruction along the line-of-sight and occasional passing-by vehicles
- Tree-shadowed environment; rural areas with roadside trees of deciduous variety with Percentage of Optical Shadowing (POS) from 35% to 85% (2-5 meters distant from the road)
- Suburban environment; residential areas with detached two-three storeys houses and scattered trees in low density (10-20 meters distant from the road)
- Urban environment; medium to heavily built-up areas with three to seven storeys buildings and densely distributed utility poles and sign posts (data on urbanisation density were not available)

Taking into account all potential sources of errors, from the experimental set-up down to the data acquisition system, a confidence interval of $\pm 2.5\%$ should be considered for all the experimental data reported in this paper.

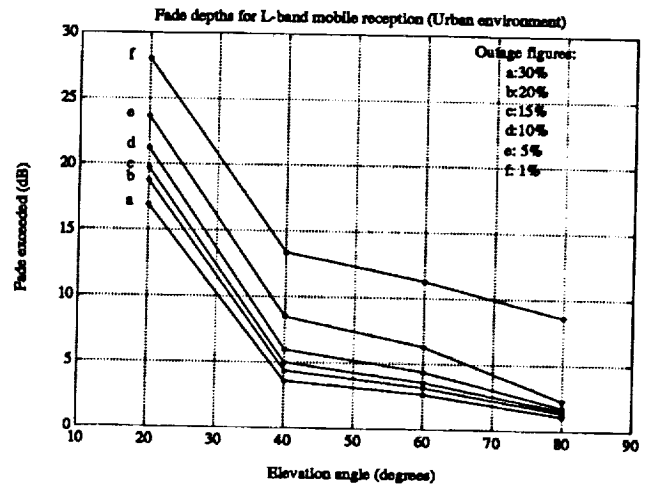
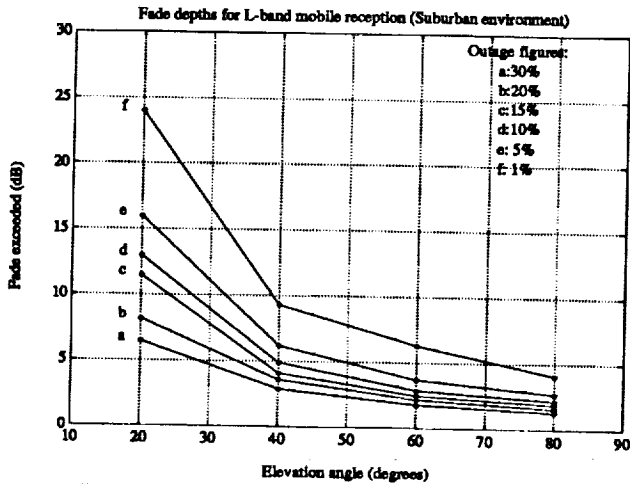
3.1 First order statistics

Fade Cumulative Distribution Functions (CDF) are given for elevation angles ranging from 20° up to 80° and for four different environments. Fade depths have been plotted versus elevation angle for each environment and for six different values of percentage of distance (of time, at constant vehicle speed) the fade is exceeded, i.e. link outage from a system engineer viewpoint. Figs. 1 to 4 combine the results of the measurement campaigns previously presented, at L-band (1.3 GHz).

In open rural areas, low implementation fade margins would be needed mostly to counteract residual multipath occurring at low and very low elevation angles; from 40° onward we are consistently within the error of the measurement equipment. The effect of trees shadowing and diffuse incoherent multipath becomes quite evident in wooded areas; on the other hand, these curves are computed on the basis of composite tree-shadowed environments where the POS value fluctuates between 35% and 85%, the latter representing somehow an operational scenario not so likely from the user point of view. In suburban environments, shadowing effects



Figs. 1 and 2. Fade depths vs. elevation angle, L-band (open and wooded environments)



Figs. 3 and 4. Fade depths vs. elevation angle, L-band (suburban and urban environments)

and multipath from nearby houses have a minor impact on the overall fade statistics; this is due, we believe, to the a lower POS figure (the average distance of the obstructing natural or man-made objects from the road is higher). It is however evident the effect of operating the communication LMS service at elevation angles greater than 40-50 degrees, especially when the satellite-to-mobile link availability requirement is not so stringent (less than 5 dB for 90% of the locations or time). As expected, urban areas present the harshest propagation conditions; at elevation angles lower than 30-40 degrees, the required fade margins are hardly affordable for any economically viable LMS system. The benefit of using high elliptical orbits is again

quite obvious. An additional plot is reported in Fig. 5 to allow for direct comparison between different environmental situations.

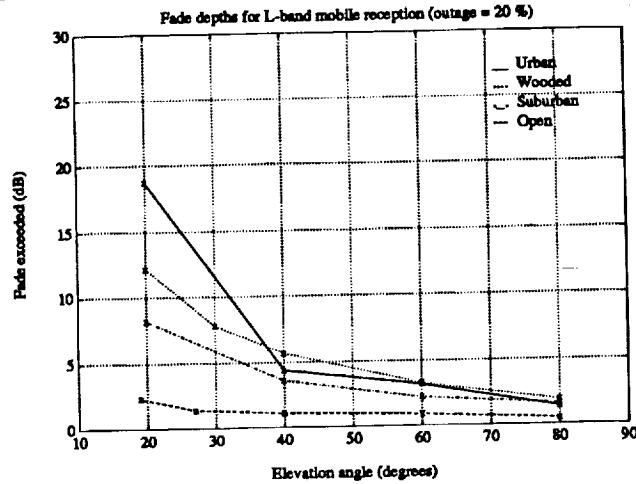
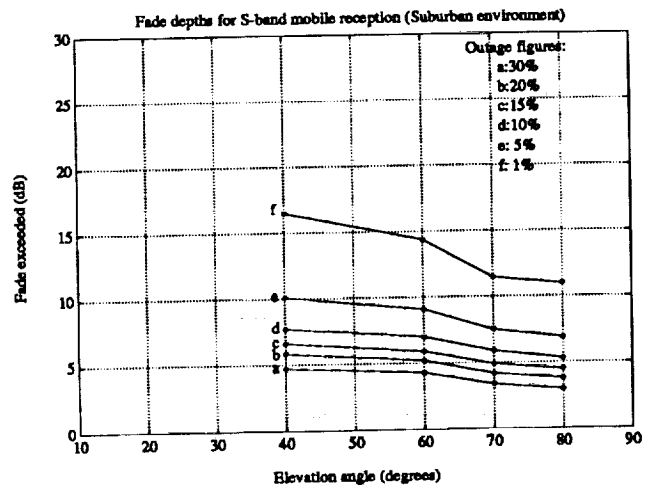
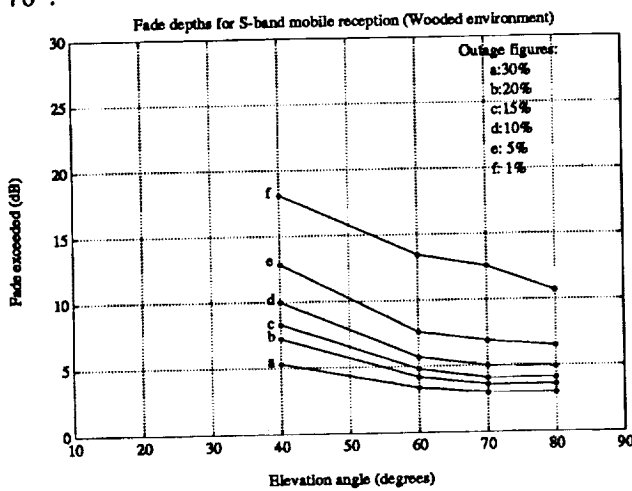


Fig. 5. Fade depths vs. elevation angle, L-band (outage=20%)

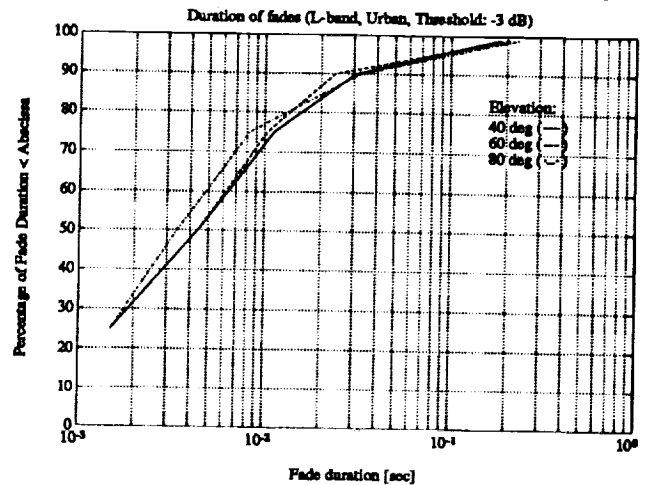
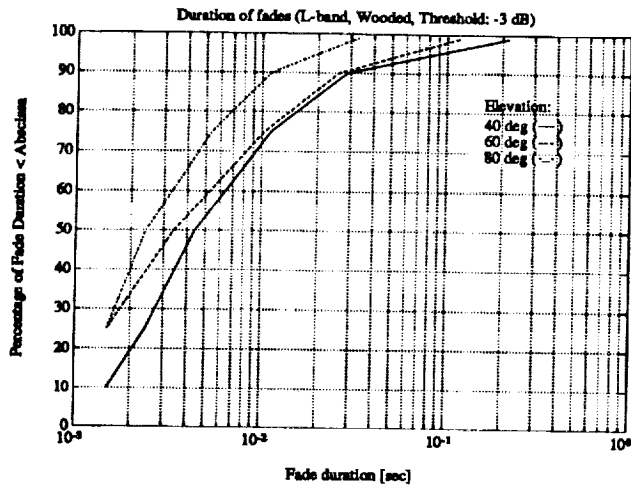
Two samples of the CDFs at S-band are also given in Figs. 6 and 7 for tree-shadowed and suburban environments. The S-band airborne experimental campaign was carried out by the University of Bradford in the same locations and roads, using a similar experimental equipment. Though the trees foliage was not exactly in the same conditions of the L-band field tests, interesting considerations can be drawn from the comparison; they are discussed in the modelling section. The curves presented cover of course only a limited range of elevation angles with respect to L-band; an intermediate situation was included at 70° and the results obtained seem to show very little differences, most likely due to a clear line-of-sight already present at 70°.



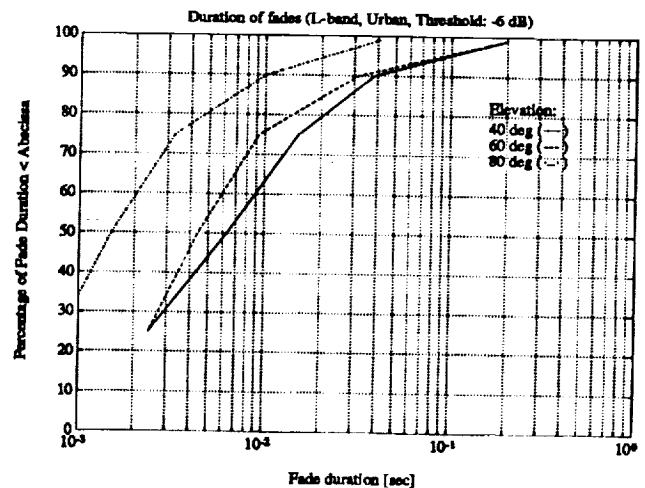
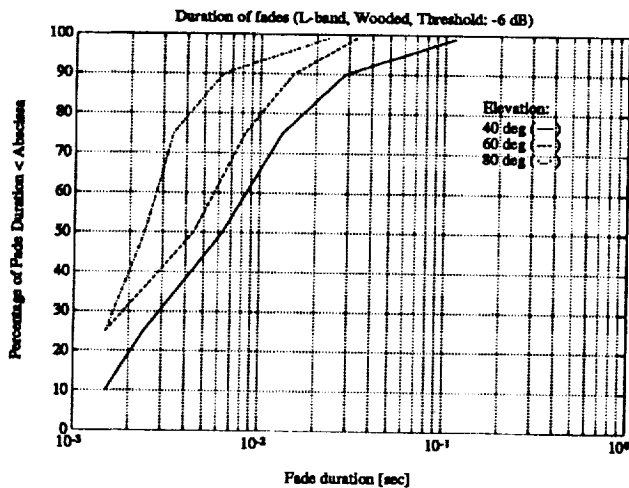
Figs. 6 and 7. Fade depths vs. elevation angle, S-band (wooded and suburban environments)

3.2 Second order statistics

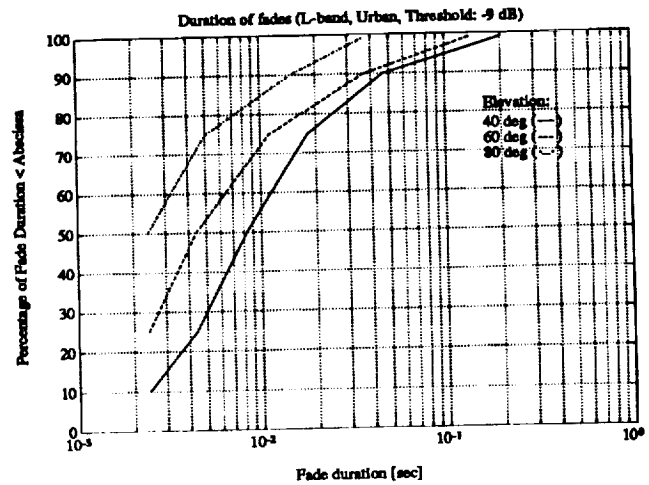
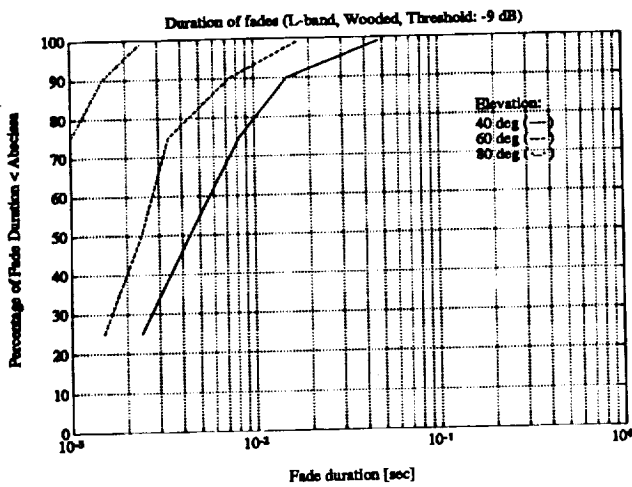
Material related to Average Fade Durations (AFD) and Level Crossing Rates (LCR) statistics for the PROSAT project has been already published []; we will therefore present in this chapter only data related to the airborne campaign. The full list of parameters include AFDs, LCRs, Duration of Fades and Connections, Time Shares of Fades and Connections. Due to the considerable amount of information, covering four elevation angles and four different environments, only Duration of Fades statistics will be shown; these data are currently used in ESTEC for the development of communication protocols and coding schemes for the ARCHIMEDES project.



Figs. 8 and 9. Duration of Fades, L-band (wooded and urban environments, thr.=-3 dB)



Figs. 10 and 11. Duration of Fades, L-band (wooded and urban environments, thr.=-6 dB)



Figs. 12 and 13. Duration of Fades, L-band (wooded and urban environments, thr.=-9 dB)

In Figures 8 to 13, durations of fades statistics relative to tree-shadowed and urban environments are presented for three different threshold levels. The average vehicle speed was of 8.6 and 17.9 m/s for the wooded and urban sections, respectively. Though second order statistical data are presently still to be fully analysed and subject to curve fitting, some preliminary considerations can be drawn from the diagrams given in the figures.

For any given threshold level, the percentage of fades with duration less than a specified value increases with the elevation angle; similarly, for any given percentage of fade events, the average duration decreases with the elevation angle. Finally, the number of fades for a given time duration increase with the threshold level, from -3 down to -9 dB. The rationale supporting these results is related to the fact that the number of natural or man-made objects shadowing the line of sight constantly decreases moving from 40° up to 80°.

If to each threshold level reported in the diagrams an equivalent system fade margin is associated, these results can be directly used in the design stages of the LMS main features at system level.

4 Channel modelling

On the basis of the experimental results obtained through numerous measurement campaigns, a consistent amount of in-house studies is currently carried out at ESTEC in the area of LMS channel modelling. Results of least square fitting for cumulative fade distributions and L-/S-band attenuation scaling factor are presented in this section; Duration of Fades curve fitting results will be soon made available.

4.1 The Modified ERS model

A modified version of the Empirical Roadside Shadowing model originally developed by Vogel and Goldhirsh, [6], has been recently elaborated and validated. In our Modified ERS (MERS) empirical model, the range of elevation angles spans from 20° up to 80° and the Percentage of Optical Shadowing (POS) from 35% to 85%; the roadside trees were also of deciduous variety. The model has been validated at L-band frequency only.

The empirical expression, obtained in two different forms by curve fitting the measured cumulative fade distributions, is given, in dB, by:

$$F(Pr, \theta) = -A(\theta)\ln(Pr) + B(\theta) \quad (1)$$

$$F(Pr, \theta) = \alpha(Pr)\theta^2 + \beta(Pr)\theta + \gamma(Pr) \quad (2)$$

where Pr is the percentage of the distance (and time, with a vehicle at constant speed) over which the fade is exceeded and θ is the elevation angle. With respect to the ERS model, we have extended and validated equations (1) and (2) for values of Pr up to 30%. In terms more familiar to system engineers, Pr is an indication of the outage experienced in the channel given a certain fade margin on the link. The parameters A and B , in dB, only depend on the elevation angle:

$$A(\theta) = a_1\theta^2 + a_2\theta + a_3 \quad (3)$$

with $a_1 = 1.117 \cdot 10^{-4}$, $a_2 = -0.0701$, $a_3 = 6.1304$

$$B(\theta) = b_1\theta^2 + b_2\theta + b_3 \quad (4)$$

with $b_1 = 0.0032$, $b_2 = -0.6612$, $b_3 = 37.8581$.

The coefficients α , β and γ in equation (2) depend only on the outage probability Pr ; they are reported in Table 1.

Pr (%)	$\alpha(Pr)$	$\beta(Pr)$	$\gamma(Pr)$
1	0.0038	-0.7147	38.7381
5	0.0021	-0.4605	26.4910
10	0.0026	-0.4603	23.1121
15	0.0030	-0.4815	21.4773
20	0.0033	-0.4851	20.0729
30	0.0032	-0.4533	17.4575

Table 1. MERS parameters, as in equation (2).

In Fig. 14, the parametrical curves obtained from the MERS model, equation (1), are plotted with the actual experimental data; the computed rms error is in this case 0.5 dB. For equation (2) the best fit to the experimental data was found to be practically the same.

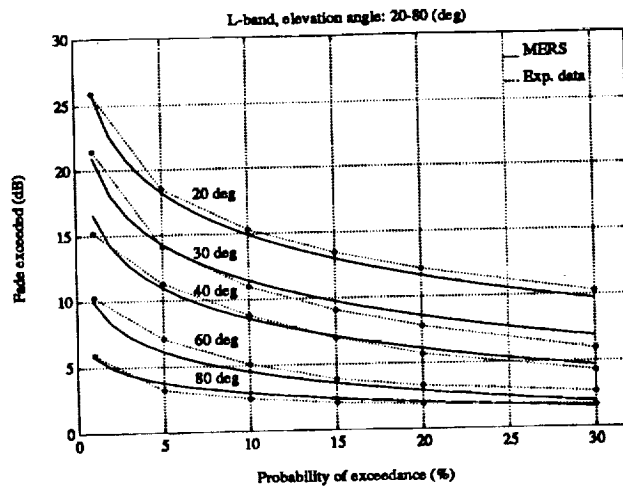


Fig. 14 MERS model vs. experimental data

4.2 S-band versus L-band attenuation scaling factor

From the comparison of the L- and S-band experimental data in tree-shadowed areas, an empirical law relating fade depths at equal probability levels has been derived. Though the measurements were not carried out simultaneously at L- and S-bands, the scaling factor was found to be approximately consistent with the square root of the frequencies ratio and with similar results obtained by Vogel, Goldhirsh and Hong, [7,8]:

$$F(f_{S\text{-band}}) \approx 1.41 F(f_{L\text{-band}}) \quad (5)$$

with $f_{S\text{-band}}=2.6$ GHz, $f_{L\text{-band}}=1.3$ GHz and where the coefficient 1.41 has an rms error of ± 0.5 dB over a fade exceedance range from 1% to 30 %.

5 Conclusions

In this paper, a comprehensive set of experimental results from LMS measurement campaigns at L- and S-bands has been presented. Cumulative fade distributions have been given for a wide range of operational scenarios, environments and elevation angles. Representative samples of duration of fades statistics have been also reported and discussed. Based on the experience gathered in the analyses of the experimental data, empirical fade prediction models have been developed and they are presently used in the preliminary design stages for future ESA LMS systems.

References

- [1] *PROSAT, Phase I Report*, ESA STR-216, May 1986
- [2] *Study of propagation factors applicable to Land Mobile Satellite Missions*, Final Report of ESA contract 6757, D.C.G. Ingenieros, December 1986, Madrid
- [3] M. Sforza, B. Arbesser-Rastburg, J.P.V.P. Baptista, *Propagation aspects for the planning of Land Mobile Satellite Systems*, Proceed. 14th Int. Comms. Satellite Systems Conf., March 22-24 1992, Washington, DC
- [4] H. Smith, M. Sforza, B. Arbesser-Rastburg, J.P.V.P. Baptista, *Propagation measurements for Land Mobile Satellite systems using high elliptical orbits*, Proceed. 2dn European Conf. Satellite Comms, October 22-24 1991, Liege
- [5] *Characterisation of the Land Mobile Satellite channel at L and S bands: narrowband measurements*, Final Report of ESA POs 104433/114473, University of Bradford, February 1993
- [6] W.J. Vogel, J. Goldhirsh, *Mobile Satellite System propagation measurements at L-band using MARECS-B2*, IEEE Trans. AP, vol. 38, pp. 259-264, Feb. 1990
- [7] W.J. Vogel, U.S. Hong, *Measurement and modeling of Land Mobile Satellite propagation at UHF and L-band*, IEEE Trans. AP, vol. 36, pp. 707-719, May 1988
- [8] J. Goldhirsh, W.J. Vogel, *Mobile Satellite System fade statistics for shadowing and multipath from roadside trees at UHF and L-band*, IEEE Trans. AP, vol. 37, pp. 489-498, Apr. 1989