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AN OVERVIEW OF THE TEXT "PROPAGATION EFFECTS FOR LAND-MOBILE-SATELLITE SYSTEMS: EXPERIMENTAL AND MODELING RESULTS"

Julius Goldhirsh* and Wolfhard J. Vogel#

*The Johns Hopkins University, Applied Physics Laboratory, Laurel, Maryland
#The University of Texas, Electrical Engineering Research Laboratory, Austin, Texas

Abstract – We present an overview of the contents of the text having the above title and which is now in the form of a *preliminary document* titled, "Propagation Handbook for Land-Mobile-Satellite Systems-Preliminary" [Goldhirsh and Vogel, 1991]. At this writing the text is undergoing peer review, and the final revised manuscript will be published in the near future as a NASA document. The text was inspired by a series of Land-Mobile-Satellite System (LMSS) experiments by the authors and other investigators at UHF and L-Band. The rationale for its writing is to place in a single document an overview of the previous propagation related salient experimental and modeling results pertaining to LMSS scenarios (see References).

It is apparent that LMSS propagation at UHF and L-Band can be seriously degraded because of attenuation (e.g., greater than 10 dB) caused by roadside tree shadowing. The extent of attenuation is shown to depend on such factors as the elevation angle to the satellite, the bearing of the line-of-sight path to the satellite relative to the line of roadside trees, the side of the road in which the vehicle is driven, the season, and the frequency. Multipath effects during line-of-sight communications are shown to cause less serious fading (e.g., smaller than 3 dB for 90% of the driving distance).

1. Introduction

During the period 1983-88 a series of experiments (Table 1) were undertaken by the Electrical Engineering Research Laboratory of the University of Texas and the Applied Physics Laboratory of The Johns Hopkins University in which propagation impairment effects were investigated for Land Mobile Satellite Service (LMSS) configurations. Prior significant LMSS propagation investigations were performed in Canada [Butterworth, 1984a; 1984b], and in Europe [Jongejans et al., 1986]. More recently, LMSS propagation measurements were reported from Australia [Bundrock, 1988], England [Renduchintala et al., 1990], and Spain, France, and Sweden [Benarroch et al., 1989].

The results described in this text are mostly derived from systematic studies of propagation effects for LMSS geometries in the United States associated with rural and suburban regions. Descriptions of these efforts have appeared in a number of technical reports, conference proceedings and publications (see References). The rationale for the writing of this text was to locate the salient and useful results in one single document for use by communications engineers, designers of planned LMSS communications systems, and modelers of propagation effects.

Table 1: Land-mobile propagation measurement campaigns of EERL, University of Texas, and APL, The Johns Hopkins University.

Date	Source	Location	Freq.	Objectives	Ref
10/83	Balloon	East Texas to Louisiana	UHF	First U.S. data set for, forested and rural roads (600 km), max el = 35°	V and H; 1988
1/84	Balloon	East Texas	UHF	150 km, max el = 30°	V and H; 1988
11/84	Balloon	East Texas to Alabama	UHF, L	Freq. comparison, El = 50°, variety of roads and terrain	
6/85	Remotely piloted aircraft	VA	UHF	Single tree attenuation, stationary receiver	V and G; 1986
10/85	Helicopter	Central MD	UHF	Systematic roadside tree, sampling, single tree attenuation in fall foliage	G and V; 1987
3/86	Helicopter	Central MD	UHF	Systematic roadside tree, sampling, no foliage	G and V; 1987
7/86	Balloon	East Texas to New Mexico	UHF, L	Open terrain, optical, sensor, 45°, scatter model	V and H; 1988
8/86	Helicopter	Colorado	UHF, L	Mountain roads, canyons multipath limits	V and G; 1988
6/87	Helicopter	Central MD	UHF, L	Systematic roadside tree sampling, full foliage	G and V; 1989
12/87	MARECS-B2	Central MD	L	Systematic roadside tree sampling, ERS model	V and G; 1990
10/88	ETS-V and INMARSAT	S.E. Austral.	L	Systematic roadside tree sampling, fade durations, diversity, cross pol	V et al.; 1991 H et al.; 1991

Where applicable, the authors have also liberally drawn from the results of the other related investigations. The results are presented in a "user friendly style" in the form of graphs, tables, and "best fit" analytic functions.

A "preliminary" version has been disseminated to reviewers for their comments and suggestions [Goldhirsh and Vogel, 1991]. The revised manuscript will be published as a NASA document in the near future.

2. Background

The propagation experiments by the authors were performed in the Southern United States (New Mexico to Alabama), Virginia, Maryland, Colorado, and South-Eastern Australia. These experiments were executed with transmitters on stratospheric balloons, remotely piloted aircraft, helicopters, and geostationary satellites (INMARSAT B-2, Japanese ETS-V, and INMARSAT Pacific). The earlier experiments were performed at UHF (870 MHz), followed by simultaneous measurements at L-Band (1.5 GHz) and UHF. The satellite measurements were performed only at L-Band. During these experiments, the receiver system was located in a van outfitted with the UHF and L-Band antennas on its roof, and receivers and data acquisition equipment in its interior.

3. Objectives

The general objectives of the above tests were to assess the various types of impairments to propagation caused by trees and terrain for predominantly rural and suburban regions where terrestrial cellular communication services are presently non-existent and commercially impractical. Data acquired from the above experiments and other investigations have provided insight into the following LMSS propagation related characteristics described in the planned text:

- Attenuation and attenuation coefficients due to various tree types for non-mobile cases and their relation to elevation angle and frequency (Chapter 2).
- Attenuation and related statistics of the attenuation of roadside trees, including seasonal and frequency effects (Chapter 3).
- Attenuation caused by mountainous and roadside tree environments where line-of-sight propagation is maintained (Chapter 4)
- Fade duration, non-fade duration and phase characteristics for road-side tree environments (Chapter 5)
- Effects on fade statistics employing different gain antennas, feasibility of frequency re-use, and space diversity modeling (Chapter 6)
- Modeling of propagation effects (Chapter 8)

Also included for completeness are fade distribution measurements obtained from various experimenters from different countries (Chapter 7).

We emphasize L-Band since The World Administration Radio Conference for Mobile Services (WARC-MOB-87) in 1987 has allocated frequencies in this band for both the uplink and downlink modes. In particular, the agreed uplink and downlink bands are: [1] 1631.5 to 1634.5 MHz and 1530 to 1533 MHz, respectively, and [2] 1656.5 to 1660.5 MHz and 1555 to 1559 MHz, respectively, where the first set of bands are to be shared with the maritime mobile satellite service [Bell, 1988].

The results and methods described here deal with propagation for mobile satellite geometries in suburban and rural environments for elevation angles generally above 15°. Results "not" covered are associated with measurements performed in urban environments which may efficiently be serviced by cellular communications. Also, not examined here are measurements which pertain to channel effects associated with wide bandwidth modulated signals; with the exception of fade and non-fade durations and phase spreads (Chapter 5).

4. Table of Contents

Although, as of this writing, the preliminary manuscript is undergoing peer review, the following contents (as they presently exist) should provide the flavor of the final text.

5. Salient Results and Conclusions

Some of the major conclusions that may be gleaned from the results in the text are summarized as follows:

1. An Empirical Roadside Shadowing (ERS) model developed by the authors may be used

to arrive at fade levels ranging from 3 dB to 26 dB over elevation angles between 20° and 60° over percentages ranging from 1% to 20% (percentage of the distance driven over which fades are exceeded). This model, which has as inputs elevation angle and percentage of distance driven, gives the fade exceedance. The model corresponds to average driving conditions (left and right side driving along multiple roads), a maximum shadowing line-of-sight orientation, and roads in which the percentage of optical tree shadowing ranged between 55% to 75%. It was validated by independent measurements in Australia [Vogel et al., 1991].

2. The attenuation may be scaled upwards or downwards between UHF (870 MHz) and L-Band (1..5 GHz) employing the square root of the ratio of the frequencies [Goldhirsh and Vogel, 1989]. The results of Bundrock and Harvey [1988] indicate this scaling may be extended to S-Band (e.g., 3 GHz).

3. Measurements made during a full blossom period in the summer and in the winter time during which deciduous trees are devoid of leaves have demonstrated that in the 1% to 30% percentage interval, approximately 80% of the signal attenuation is caused by the wood part of the trees (branches and trunk).

4. Significant fade reductions (e.g., 8 dB at 60 degrees elevation at L-Band) may be achieved by switching lanes.

5. Signal fading due to multipath is generally less than 3 dB for both mountain and roadside tree environments for 90% of the driving distance. The dominant attenuation is hence caused by shadowing of the line-of-sight path. These results presume an azimuthal omni-directional antenna with a beamwidth in elevation over the interval 15% to 75%.

6. Simulations using real data show that separated antennas may lead to significant fade reductions for diversity mode operations. For example, a 5 dB single terminal fade may be reduced to 3 dB, for a 1 m separation employing diversity operation. Rapid switching is implied (e.g., 10 milliseconds).

7. When the line-of-sight is completely blocked by continous obstacles such as mountains, buildings, or overpasses, not enough power is contributed by multipath scattering to enable communications through a satellite system with a commercially feasible fade margin of 6 to 12 dB. For such a case LMSS is not functional.

8. The model development efforts and comparison of experimental results with model results show:

   - When the propagation path is unshadowed, Rician statistics apply most of the time, although the K-factor (ratio of line-of-sight and multipath powers) cannot strictly be assumed constant.

   - When a single scatterer dominates, as might be the case with a utility pole, Rician statistics are no longer applicable.

   - Geometrical analytic models involving single point scatterers give time series fading results consistent with drive-by results associated with a single utility pole.

- More accurate model descriptions of "undshadowed propagation" than those given by existing Ricean multipath scatter models and geometric-analytic models are not necessary in that fading due to multipath is less than 3 dB for 90% of the driving distance.

6. Acknowledgments

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Handbooks of the NASA Propagation Program, Past History and Thoughts to the Future

Ernest K. Smith
NASA Propagation Information Center
ECE Department
University of Colorado

In this contribution I would like to say something about the history of handbooks in the NASA Propagation Program, review our options, and report on a luncheon meeting at the University Club on June 27, 1991.

1. The "handbooks" of the NASA Propagation Program were initiated, I believe, by Dr. Louis J. Ippolito when he was program manager. The current "Ippolito" series has progressed through four editions. I believe the first three were produced at ORI, Inc. under contracts which Dr. Ippolito managed. The third edition of this series is:

A) NASA Reference Publication 1082(03). **Propagation Handbook for Satellite Systems Design** ***A summary of Propagation Impairments on 10 to 100 GHz Satellite Links with Techniques for System Design***, by Louis J. Ippolito, R.D. Kaul and R.G. Wallace. June 1983 (468 pp).

The fourth edition was prepared by Dr. Ippolito personally after retiring from NASA in December 1983 through a contract from NASA/JPL to Westinghouse.

B) NASA Reference Publication 1082(04). **Propagation Effects Handbook for Satellite System Design** ***A Summary of Propagation Impairments to 10 to 100 GHz Satellite Links with Techniques for System Design***, by Louis J. Ippolito, February 1989.

A second series of current handbooks was initiated by me when I became JPL program manager in 1980 and interest in UHF and L-band was beginning to surface. Warren Flock was spending a year with me at JPL and took on the job of preparing a parallel "handbook" for frequencies between 100 MHz and 10 GHz. This text has now gone through two editions.

C) NASA Reference Publication 1108. **Propagation Effects on Satellite Systems at Frequencies Below 10 GHz** ***A Handbook for Satellite Systems Design*** by Warren L. Flock, December 1983 (420 pp).

D) NASA Reference Publication 1108(02). **Propagation Effects on Satellite Systems at Frequencies Below 10 GHz** ***A Handbook for Satellite Systems Design*** by Warren L. Flock, 1987 (502 pp).

Earlier "Handbooks" produced for the NASA Propagation Program or its predecessors and referenced in the literature include:

E) R. Kaul, R. Wallace and G. Kinal. **A Propagation Effects Handbook for Satellite Systems Design,** NASA Headquarters, Washington, D.C., Rep. ORI TR 1679, Mar. 1980.

F) R. Kaul, D. Rogers and J. Bremer. **A Compendium of Millimeter Wave Propagation Studies Performed by NASA**, ORI, TR 1278, Nov. 1977.

G) R.K. Crane and D.W. Blood. **Handbook for the Estimation of Microwave Propagation Effects - Link Calculations for Earth-Space Paths,** Doc. No. P 7376- TR1, ERT, Inc (Prepared for NASA Goddard) June 1979.

A new series of "Handbooks" was initiated by Dr. Faramaz Davarian who commissioned Julius Goldhirsh and Wolf Vogel to undertake handbooks on propagation for the mobile services, the first volume to be on the land mobile service. The first draft of this text has been distributed for review.

The immediate questions, as I understand it are: (1) Should the Flock and Ippolito series of handbooks be combined into one handbook? (2) Should the MSS section in the Flock handbook be removed and offered to the Goldhirsh-Vogel handbook? (3) Should the Goldhirsh-Vogel (G/V) handbook be called something else?

Definition of "Handbook": A manual; A concise reference book covering a particular subject (Webster's New Collegiate Dictionary).

2. There were three important contributions to the June 27 meeting. Faramaz Davarian's memo laid out the options as

A. Status quo including an LMSS Handbook.
B. Status quo except LMSS section is transferred from Flock to Goldhirsh-Vogel (G/V).
C. The Ippolito handbook remains unchanged but Flock and G/V are combined.
D. Ippolito and Flock are combined and the G/V series covers all MSS.

John Kiebler's input memo pointed out:

A. That it is difficult to combine handbooks.
B. G/V is not yet comprehensive.
C. Suggests integrating G/V into Flock or else publishing it as something other than a handbook.

Ernie Smith's contribution reviewed some texts called "handbooks" and suggested some other titles. He also pointed out that the Ippolito and Flock handbooks are written from two points of view. Ippolito is more directed to the systems engineer; Flock is more scholarly and gives the physical bases for model development. There is a lot of common ground in the two handbooks; both treat rain attenuation and depolarization, gaseous absorption, prediction techniques, and link budgets. There is relatively more attention to rain in the Ippolito handbook than in Flock. However, as would be expected, there is extensive treatment of the ionosphere and surface effects in Flock and not in Ippolito. There is also a difference in style. Ippolito is more of an engineer's approach, Flock has much more physics and is more academically oriented. As my undergraduate degree was in physics I relate more readily to Flock, but engineers may find the Ippolito approach more satisfying. There is some rationale for these two approaches. In the NBS Central Radio Propagation Laboratory (CRPL) the Radio Propagation Physics Division was concerned with ionospheric propagation while the Radio Propagation Engineering Division was concerned with tropospheric propagation. The two handbooks can be combined but something will be lost in the process.

Additionally, there is very little duplication of material between the Flock Chapter 6: Propagation Effects on Mobile-Satellite Systems, and the Goldhirsh/Vogel text; so the need to reduce duplication there is minimal.

3. At the luncheon meeting (attended by Davarian, Goldhirsh, David Rogers, Smith, and Vogel) Goldhirsh proposed the title for the G/V text: "Propagation Effects for Land Mobile Satellite Systems: Experiment and Modeling Results." Goldhirsh also suggested a hard cover for the volumes.

David Rogers, our advisory committee representative, made the following points:

1. Ionosphere scintillation will be very important at L-band at low latitudes and deserves mention in G/V.
2. The systems engineering approach is appropriate for the NASA Handbook series - they are the customers NASA is trying to reach.
3. A combined handbook 100MHz -100 GHz is desirable. It could be in two volumes.

The consensus, after discussion, was that of the cost of updating vs. combining the existing handbooks should be investigated. If the combining of the handbooks is possible then a good man willing to dedicate the order of 1 or more man-years would need to be identified.