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# L- & K-BAND LMSS PROPAGATION MEASUREMENTS USING MARECS-B, OLYMPUS, AND ACTS

W. J. Vogel and G. W. Torrence, EERL, The University of Texas

J. Goldhirsh and J. R. Rowland, APL, The Johns Hopkins University

**Abstract** -- L-Band measurements of LMSS propagation effects were last made at the end of 1988, but some voids were left in the data base, making modeling of low elevation roadside tree shadowing and multipath reflections difficult for some path geometries. Transmission of a pilot tone from MARECS-B at 55°West during Sep. and Dec. 91 gave an opportunity to fill the gaps in the experimental results. We describe two campaigns, during which fade data were obtained at elevation angles from 7° to 40°. Below 15°, specular terrain reflections in a non-shadowing, hilly environment were observed to introduce significant fading. Although the reflecting surface was at a distance of up to several km, it is shown that the reflected signals are delayed by less than 1 µs. Mobile measurements were also attempted receiving the 20 GHz Olympus beacon, but an antenna pointing problems restricted first results to straight-line driving.

## 1 Introduction

The performance of land mobile satellite systems (LMSS) is limited by propagation effects which generally occur in the vicinity of the mobile user. These effects depend entirely on the interaction between the environment around the user, i.e. its attenuation and reflection properties, with the particulars of the user's radio, such as antenna pattern, bandwidth, modulation, and coding. It is the task of the LMSS designer to chose the deterministic parameters of the system to either use the propagation effects to his or her advantage or to mitigate their negative impact on performance. The environment is not deterministic, however; it has to be described statistically. The purpose of propagation measurements is to support LMSS designers with pertinent information about the random transmission channel. Such support can take the form of measured transmission time series for use in simulators, algorithms which produce simulated time series given specific environmental and system parameters, or general models based on the statistical properties of the propagation processes.

The considerable measurement and modeling efforts undertaken by a large number of researchers up to 1991 have been summarized by Goldhirsh and Vogel [1], where it was noted that a lack of measurements at low elevation angles made it difficult to produce reliable models for systems operating under such conditions. The deficiency applied both to measurements of roadside tree shadowing and to terrain multipath. An opportunity to fill the gap in knowledge arose recently, when JPL scheduled a series of L-Band satellite transmissions from MARECS-B2 (a geostationary satellite located at 55° West) in support of the sound broadcast program. This involved transmission of a pilot tone with a frequency of 1545 MHz for several hours daily over a ten day period in September of 1991 and a five day period in December of 1991. For the first period, propagation measurements were obtained mainly along roads in the north-western quadrant of the US with elevation angles from 30° to below 10°. For the second period, measurements were obtained in the south-eastern US and in Central Maryland along the same system of roads where the authors previously made measurements using helicopters and satellites. In that case the elevation angle, above 40°, was higher than hitherto available with a satellite transmitter. The preliminary results of these two measurement campaigns are introduced in this paper.

Currently, LMSS is under development at L-Band. At the inception of the LMSS program it was believed that a frequency allocation would be obtained in the UHF region of the spectrum and several measurement campaigns were performed near 900 MHz, with some of the later measurements performed simultaneously at UHF and L-Band [2]. This permitted the derivation of frequency scaling relationships. In the future, and sooner on an experimental and exploratory basis [3], LMSS will also be implemented at higher frequencies, such as K-Band, using ACTS. Present knowledge does not permit frequency extrapolation from L-Band to K-Band. In pursuit of such frequency scaling relationships, initial mobile propagation measurements were performed at 20 GHz in Central Maryland in December of 1992 observing the beacon of Olympus at an elevation angle of 16°. The result from these measurements will be shown.

## 2 Fall 1991 L-Band Experiments

### 2.1 Objectives

Most of the LMSS propagation data collected by the authors before 1989 were measured using stratospheric balloons or helicopters in the south-western and south-eastern regions of the country, bounded by New Mexico in the west and Alabama in the east, in the mountainous region near Boulder, Colorado, and in Central Maryland with elevation angles between 20° and 60°. Satellite data were taken in Central Maryland with a 22° elevation angle and in south-eastern Australia with 50° and 40° elevation. Most of the data were taken in rural areas. The objective of this campaign was to fill several gaps in the existing data base. This translated into the goals to:

a. Collect systematic data in a shadowed suburban environment with a high gain and a low gain antenna.

b. Collect low elevation data to characterize multipath reflections from terrain.

c. Collect low elevation data for roadside tree shadowing to allow extension of the ERS model to angles below 20°.

### 2.2 Experimental Details

Fade data consisting of time series of in-phase and quadrature detector voltages sampled at a rate of 1000 sps were collected receiving the pilot tone transmitted from the

MARECS-B2 satellite at 55° West with elevation angles from 32° to 7° while driving in the western US. The transmissions were made available for a JPL SSB experiment typically for several hours each day from 9 to 24 September 1991. Measurements were made with a 12 dB gain tracking helix antenna built for the Olympus/ACTS experiment, thus testing the tracking mount under operational conditions, although relaxed in the required pointing accuracy. The 1 dB gain drooping dipole, the antenna used in many of the previous campaigns, was also used. The fade margin for the measurements was 28 dB for the tracking helix and 17.5 dB for the drooping dipole. About 46 hours of transmissions were monitored. The logistic and environmental measurement particulars are summarized in Table I below.

Table I: Summary of fade measurement parameters for September 1991

| When | Time | Elev. | Where | Remarks |
|---|---|---|---|---|
| 9 Sep 91 | 1 hr | 31° | Chicago suburb | Tree-lined streets, various antennas |
| 10 Sep 91 | 3.5 hrs | 31° | Chicago area | Residential and commercial suburban streets |
| 11 Sep 91 | 0.5 hrs | 28° | Wisconsin | IH-94, satellite off early |
| 12 Sep 91 | 3 hrs | 22° | North Dakota | Grassy hills, 4-5 dB slow variations due to specular refl. |
| 13 Sep 91 | 3 hrs | 16° | Montana | Trees, hills, mostly open |
| 14 Sep 91 | 4.25 hrs | 10° | Washington | Trees, rolling grass land, up to 20 dB variations observed without shadowing |
| 15 Sep 91 | 4 hrs | 7° | Seattle to Portland | Many trees, repeated runs with different antennas |
| 16 Sep 91 | 3.5 hrs | 10° | Oregon | Large signal variations due to forward reflections from smooth hill chains |
| 17 Sep 91 | 4.75 hrs | 14° | Nevada, Utah | Desert |
| 18 Sep 91 | 4.75 hrs | 21° | Colorado | Mountains, incl. Rocky Mntn. National Park, Boulder Canyon, Flatirons |
| 19 Sep 91 | 5 hrs | 22° | Colorado | Denver CBD and a park, then IH-25 South |
| 20 Sep 91 | 4.75 hrs | 28°-30° | Texas | Mostly rural flat farmland |

| | | | | |
|---|---|---|---|---|
| 23 Sep 91 | 2.5 hrs | 32° | Austin | Measurements under pecan tree and in Building BRC 16-4 and new residential neighborhood |
| 24 Sep | 1.5 hrs | 32° | Austin | Old neighborhood with many trees and downtown CBD |

## 2.3 Preliminary Results

The data have been converted to calibrated fade time-series and organized into runs, where each run represents an interval with consistent environmental conditions and the same receiving antenna. Fade and fade duration statistics remain to be determined. The data include extensive measurements at low elevation angles with some surprising results. We have observed forward specular reflections from inclined, smooth, grass-covered hill sides. These have been found to induce signal variations of many dB in the absence of any shadowing and could cause low-margin mobile systems to fail. Although these reflections can originate from surfaces at distances of the order of several km, they arrive from the same general direction as the satellite signal and it can be shown that their delay is small, typically less than 500 nsec.

# 3 Winter 1991 L-Band Experiments

## 3.1 Objectives

Several sets of systematic measurements were performed by the authors in the central Maryland region on a system of roads which includes a tree-lined controlled access four-lane divided highway (Rt. 295), a suburban arterial two-lane road (Rt. 108), bordered by utility lines, winding through an area of increasing development from woodland to suburban strip shopping centers with narrow setbacks, and a rural four-lane road (Rt. 32) through woodland and pastures with generous setbacks. Most of the measurements were made using a helicopter as transmitter platform, with elevation angles of 20° to 60°. One measurement campaign, in December of 1987, observed the MARECS-B2 satellite with an elevation angle of 21°. Since then, the satellite has been moved to a new orbit position at 55° West, resulting in an elevation angle of 40° in Central Maryland. The objectives of this second set of MARECS-B measurements therefore were to:

a. Obtain a set of fade data for the three-road system measured previously, but at the new elevation angle of 40°, to be used for testing the elevation angle scaling empirical roadside shadowing model.

b. On the way to Central Maryland, obtain fade data at elevation angles in the 30° to 40° range.

### 3.2 Experimental Details

About 14 hours of L-Band data were recorded with the same technical specifications as in the pervious campaign. The logistic and environmental measurement particulars are summarized in Table II below.

Table II: Summary of fade measurement parameters for December 1991

| When | Time | Elev. | Where | Remarks |
|---|---|---|---|---|
| 2 Dec 91 | 4 hrs | 32° | Houston to Eastern Louisiana | Woodlands, Tracking Helix and Drooping Dipole Antennas |
| 3 Dec 91 | 4 hrs | 36° | Montgomery, Al to Lavonia, GA | Woodlands, Drooping Dipole Antenna |
| 4 Dec 91 | 4 hrs | 40° | Richmond, VA to Columbia, MD | Woodlands, Drooping Dipole Antenna, Rt. 295 N & S, left & right lanes |
| 5 Dec 91 | 2 hrs | 40° | Central MD | Tracking Helix, Rts. 295, 108, 32 |

### 3.3 Preliminary Results

These data are still being organized into distinct runs in order to derive the cumulative distributions of calibrated fade depth and duration. An example of data taken along Rt. 295, showing the one-second maximum, average, and minimum is depicted in Figure x.

## 4 Winter 1991 K-Band Experiments using Olympus

### 4.1 Objectives

In December 1991, a novel measurement campaign was initiated in Central Maryland by observing 20 GHz beacon transmissions from the geostationary Olympus satellite with a land-mobile receiver. The overall objective of the campaign is to statistically assess fading effects due to roadside tree shadowing and terrain multipath at K-Band. Until now, at this frequency, space-to-earth propagation experiments were conducted with stationary earth sites and directed towards rain attenuation, site diversity, depolarization, and cloud scintillation. The measurements introduced here represent the first time that land-mobile satellite propagation data have been obtained at K-Band.

Previously, L-Band land-mobile propagation measurements were performed by the authors along roads in Central Maryland. These used as transmitter platform a satellite [1] and a helicopter [2]. The K-Band measurements were executed with an elevation angle of 16° along the same system of roads; namely, Routes 295, 108, and 32. The specific objectives of this experiment were, for the case in which deciduous trees were without leaves: [1] To determine the cumulative fade distributions and fade durations at 20 GHz for roadside tree environments. [2] To extend to K-Band an existing empirical fade distribution prediction model valid in the UHF to S-Band interval. [3] To establish a data base for 16° elevation angle K-Band fading for comparison and angle scaling with 40° K-Band fading data to be obtained later using the Advanced Communications Technology Satellite (ACTS). The same specific objectives will be pursued in follow-on measurements for the case in which deciduous trees are fully foliated.

### 4.2 Experimental Details

The experiment employed a gyro stabilized, computer controlled antenna system housed within a radome on the roof of a van. The vehicle also carried a satellite receiver and data acquisition system. The transmitted polarization alternated between vertical and horizontal at a 933 Hz rate, but the receiving antenna was circularly polarized, receiving power from either transmitter polarization state. During mobile operation, the antenna was to continuously track the Olympus satellite, just as it had done for the L-Band measurements. The tracking system derives long term azimuth stability from a flux-gate compass mounted on the rotating azimuth platform. After several failed attempts to maintain the satellite within the beamwidth of the antenna while the vehicle was changing directions, systematic tests revealed that the vehicle itself was magnetized and distorted the local earth magnetic field, resulting in pointing errors of up to ±10°. It is anticipated that the local effect can be compensated if the heading of the vehicle is known. At the time of the experiment no additional compass sensor was available and data acquisition had to be restricted to constant direction driving.

### 4.3 Preliminary Results and Plans

An example of the K-Band signal level is presented in Figure 1, in which the maximum, average, and minimum signal level for each of 160 consecutive seconds are displayed. These data were taken in Patapsco Park, while the vehicle slowly moved on a straight path, with the line-of-sight to the satellite obstructed by the crowns of bare deciduous trees and a few evergreens. Average fades of up to about 20 dB were observed. The range between maximum and minimum signal level indicates that the signal level undergoes fast dynamic changes as the central Fresnel zones of the transmission path intersects varying amounts of tree limbs. For this sample of data, to 10%-tile of the cumulative distribution has a fade value of 16.5 dB. For comparison, the ERS model for 20° elevation predicts a 10%-tile fade of 15.5 dB at L-Band. For trees without foliage, the attenuation may not be much more severe at K-Band than it is at L-Band.

We are currently upgrading the antenna tracker hardware and software in order to be able to make unrestricted motion measurements of fading at K-Band, again observing the Olympus satellite. Measurements in Central Maryland are planned for the summer and winter of 1992.

## 5 Conclusions

Of the three measurement campaigns described, two were fully successful in providing new information needed for LMSS systems design. Achievements of these campaigns included the observation of low elevation angle multipath reflections from hilly terrain and roadside tree shadowing at angles below those observed in earlier work. Satellite measurements at 40° elevation in Central Maryland will add to the confidence of helicopter data taken over the same system of roads. The large amount of new L-Band data obtained is still being analyzed. The measurements at K-Band were only partially successful because of antenna steering difficulties. The experience gained from this experiment, however, is being used to improve the antenna system for future Olympus and ACTS campaigns.

## Bibliography


1 Vogel, W. J. and J. Goldhirsh, *IEEE Trans. Antennas Propagat.*, **36**, pp. 104-113, 1988

2 Goldhirsh, J., and W. J. Vogel, *IEEE Trans. Antennas Propagat.*, **37**, pp. 489-498, 1989