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K/Ka-band Channel Characterization for Mobile Satellite Systems

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ABSTRACT

Mobile satellite systems allow truly ubiquitous wireless communications to users anywhere and anytime, NASA's Advanced Communications Technology Satellite (ACTS) provides an ideal space-based platform for the measurement of K/Ka-band propagation characteristics in a land mobile satellite application. Field tests for K-band propagation were conducted in three basic environments: clear line-of-sight (LOS) highways, lightly shadowed suburban, and heavily shadowed suburban. Preliminary results of these field tests indicate very little multipath for rural environments and for clear LOS links while deep fades were experienced in shadowed areas, especially those where tree canopies covered the road.

INTRODUCTION & OBJECTIVES

A mobile satellite system like the ACTS Mobile Terminal (AMT) is affected by shadowing and multipath propagation due to roadside obstacles and terrain conditions. The degree of shadowing depends on the intersecting path length with roadside obstacles. Many parameters affect the intersecting path, like path elevation angle, azimuth elevation to the satellite, nature and geometry of the obstacle (tree, utility pole), obstacles set back from the road, lane and direction driven, size and type of road driven (rolling/flat, straight/road bends), etc. In addition, the antenna pattern, the environment, rural/suburban, the season, and the carrier frequency, also affect the degree of shadowing.

The objectives of the K/Ka-band mobile propagation experiments are to measure and analyze fading characteristics of the K/Ka-band channel. The analysis involves examining multipath, shadowing and blockage effects and comparing them with previous results from UHF and L-band models [1].

NASA's ACTS satellite provides a stationary K/Ka-band platform ideally suited to the measurement of K/Ka-band propagation characteristics in a land mobile satellite application. Field tests conducted during the first seven months of 1994 using the AMT provide data which can be used to characterize the channel. This paper describes the field tests, the experimental aspects, the data analysis procedures, and the measurement results of the K/Ka-band channel characterization for Mobile Satellite Systems.

EXPERIMENTAL ASPECTS

JPL has developed a proof-of-concept breadboard mobile terminal system to operate in conjunction with ACTS at K/Ka-band [2]. As depicted in Figure 1, this system comprises a bent pipe propagation link connecting terminals at fixed and mobile sites. A CW signal from a tone generator at 3.373 GHz was provided at the upconverter input of the Link Evaluation Terminal (LET) at the NASA Lewis Research Center (LeRC) in Cleveland, Ohio. This resulted in an uplink signal of 29.634 GHz and a downlink transmission at 19.914 GHz using the microwave switch matrix mode (MSM) of ACTS. These downlink signals were received at various locations around the Pasadena, CA area using the AMT tracking antenna with an EIRP of 22 dBW.

The AMT is equipped with a small (8” x 3“), high-gain, reflector antenna [3], which tracks the satellite signal in azimuth for a fixed elevation angle (46° for these experiments).

The antenna is mechanically steered and acquires and tracks the satellite over the entire 360° of azimuth with a pointing error of <0.2°. Vehicle turn rates of up to 45° per second can be accommodated. The antenna has a G/T of -6 dB/K over a bandwidth of 300 MHz. The 3-dB beamwidth is+ 9° in elevation and* 6° in azimuth. The antenna pointing system enables the antenna to track the satellite for all practical vehicle maneuvers.

A key function of the receiver system is pilot tracking and Doppler pre-compensation. The down-converted pilot is tracked in a phase-locked loop and used as a frequency reference in the mobile terminal. The tracked pilot is also processed in analog hardware and mixed with the up-converted data signal from the modem to pre-shift it to offset the Doppler on the return link. In addition, the pilot in-phase and quadrature voltages (noise bandwidth = 1.5 kHz) are provided to the data acquisition system for link characterization.

The Data Acquisition System ([IAS) measures in-phase, quadrature-phase and non-coherent pilot voltages at a sampling rate of 4 kHz. These parameters are stored on 5 Gbyte Exabyte tapes for off-line evaluation. The vehicle position, vehicle velocity, and time stamp are sampled once per second. These parameters are based on data from the GPS (Global Positioning System) receiver. The DAS also provides real-time displays of these parameters to aid the experimenters in the field.

The field tests were conducted in three basic environments: 1) rural freeway which was free of obstructions except for occasional overpasses, 2) lightly shadowed suburban environments with occasional obstructions from buildings, utility poles, and trees, and 3) heavy shadowed suburban environments. The predominant vegetation in categories 2 and 3 was a mixture of magnolia, palm, oak, pine, cedar, and eucalyptus trees. The types of trees encountered on each road are listed in Table 2. Details on selected runs are listed in Table 3.

MEASUREMENT RESULTS

Consistent with data analysis techniques used to characterize the UHF and L-band mobile satellite channels [4,5,6], frequency histograms representing the cumulative fade depth distributions were constructed using the pilot data measured during the test runs.

Data Analysis Procedure

In computing the cumulative fade depth, N samples of pilot envelope data were first collected from a clear line-of-sight segment, i.e.,

$$E_i^{CLS} = \sqrt{I_i^2 + Q_i^2}\,,\ i = 1,2,\ldots,N.$$

The M samples of pilot envelope data collected were normalized using:

$$\hat{E}_i^{FADE} = \frac{\sqrt{I_i^2 + Q_i^2}}{E_{ref}^{CLS}} \equiv \frac{E_i^{FADE}}{E_{ref}^{CLS}}\,,\ i = 1,2,\ldots M$$

where E_{ref}^{CLS} is the clear line-of-sight pilot level.

Since the pilot envelope data collected during the fade, E_i^{FADE}, is smaller in magnitude relative to the clear-line-of-sight data, we note that:

$$\hat{E}_i^{FADE} < 1.$$

We can therefore define a fade level, F_i, in dB:

$$F_i = 10\log_{10}(\hat{E}_i^{FADE}).$$

The cumulative fade depth distribution is then computed by dividing the range interval of the fade data:

$$\left[0, \max_{1\le i\le M}\{|F_i|\}\right],$$

into N_F amplitude bins of size AF. Thus,

$$\Delta F N_F = \max_{1\le i\le M}\{|F_i|\}.$$

The bin size, AF, is chosen to produce a smooth, continuous distribution curve. The variable D_j is then chosen to represent the number of fade samples,

$$F_i\,(1 \le i \le M),$$

satisfying the inequality: 0> $F_i \ge X_j$, where $X_j = j\Delta F$. This is repeated for j = 1 to N_F. The cumulative fade depth distribution is finally computed as D_j/M, and is plotted vs. the fade level, X_j - (AF / 2).

It should be noted that this calculation applies only to data collected while the velocity of the mobile receiver is constant. As such, the aforementioned procedure must be modified to remove any biases introduced by the non-constant velocity.

Preliminary Results

A comparison of the frequency histograms of the cumulative fade depth distributions for representative runs is shown in Figure 2. The shape of each of the curves is typical for mobile satellite channels. The slope from the reference level to 2-3 dB below is steep and consistent with a Ricean characteristic. A transition region, or “knee” (at 3-5 dB fade levels) precedes a less steep curve for deeper fades. This shallow curve is characteristic of heavy shadowing. These characteristic curves have also been observed on other K-band propagation experiments [7].

It was found that rural freeway roads (clear line-of-sight to the satellite) exhibited fading of 1 dB or more at the 1% fading level. Canopied, suburban roads exhibited fading of greater than 30 dB at the 1 % level. Broad suburban roads exhibited fades of 8 dB or more at the 1% *level* in the good lane, and fades of 27-30 dB at the 1% level in the bad lane. This characteristic (of good lanes and bad lanes) magnifies the importance of so-called "lane- diversity". A quantitative description of these results is given in Table 3. The last column in this table (labeled 1% Fade Level) lists the fade (in dB) exceeded at the 1 % probability level.

Included in the plot in Figure 2 are dashed curves labeled "Total Shadow" and "Total LOS". The "Total Shadow" curve was generated from data measured while the mobile terminal moved very slowly (<3m/h) on a road completely covered by tree canopies. No unobstructed line-of-sight view to the satellite existed so this data represents a completely shadowed condition. The "Total LOS" curve was generated from data measured while the mobile was traveling on a freeway. The route was free of any obstructions which could cause shadowing thus providing a clear line-of-sight path to the satellite throughout the entire run.

The curves labeled "Run 1", 'Run 6, etc., appear to be a linear combination of the curves labeled "Total Shadow" and "Total LOS". Such a combination is consistent with the Lutz model [5] which attributes the shape of the histogram to a time share between total obstruction and line-of-sight propagation characteristics.

CONCLUSIONS

The preliminary results of these field tests indicate very little multipath in rural environments and when a clear LOS path exists (as expected with a narrow beam antenna). Fades were very deep in shadowed areas, especially those with tree canopies covering the road and blocking the LOS signal. These results are consistent with the results of others studying the K-band mobile satellite propagation characteristics. In addition, the form of the preliminary results agrees with that predicted by the Lutz model.

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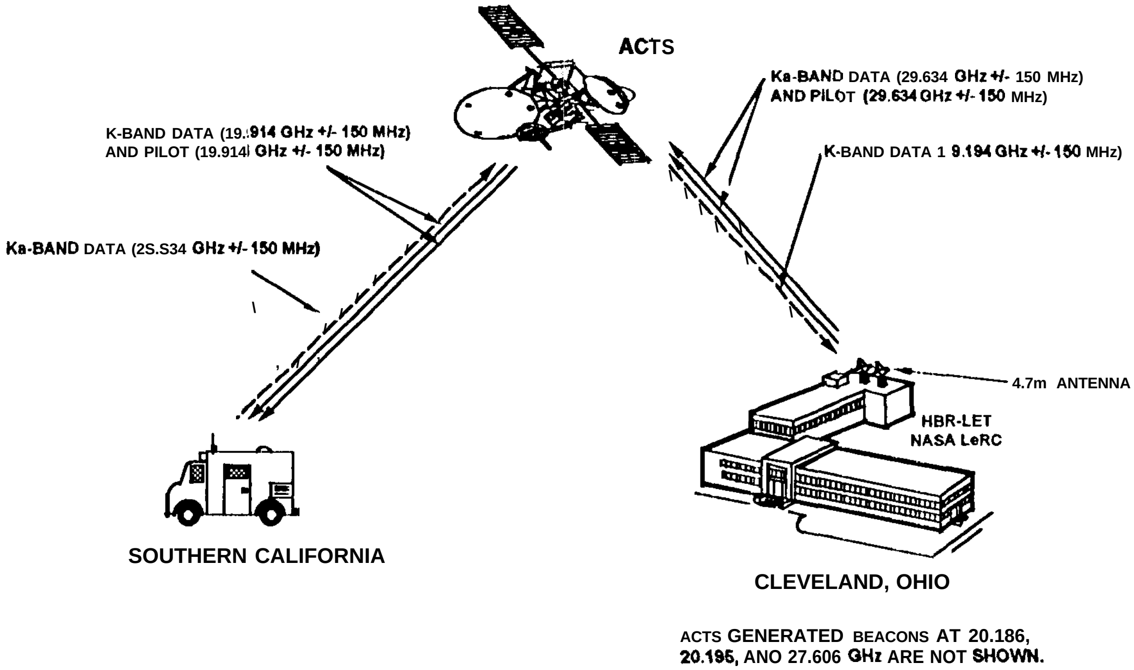

Figure 1: Experimental Configuration for AMT Propagation Experiments

Table 2: Listing of Roads with Types of Trees

Roads Traveled	Category	Types of Trees (in descending order)
Arroyo Blvd.	3	Coastal Live Oak (many canopies), Holly Oak, California Sycamore, Deadora Cedar, California Pepper 1 ree
Grand St.	3	Coastal Live Oak (many canopies), Southern Magnolias, Holly Oak
Orange Grove Blvd.	2-3	Southern Magnolia, Fan and Date Palm, Coastal Live Oak, California Pepper Tree

Table 3: Listing of Runs with Road Types and Characteristics

Run Number	Road Traveled	Category	1% Fade Level
212194: LOS	I-21O	1	1 dB
719194:1	Orange Grove Blvd., southbound, right lane	2-3	8 dB
7/9/94:3	Grand Ave., northbound	3	>>30 dB
7/9/94:5	Orange Grove Blvd., northbound, right lane	2-3	>>30 dB
7/9/94:6	Grand Ave., southbound	3	>>30 dB
7/9/94:7	Orange Grove Blvd., northbound, left lane	2-3	27 dB
719194:12	Arroyo Blvd., southbound	3	>>30 dB
7/9/94: 14	Arroyo Blvd., northbound	3	>>30 dB

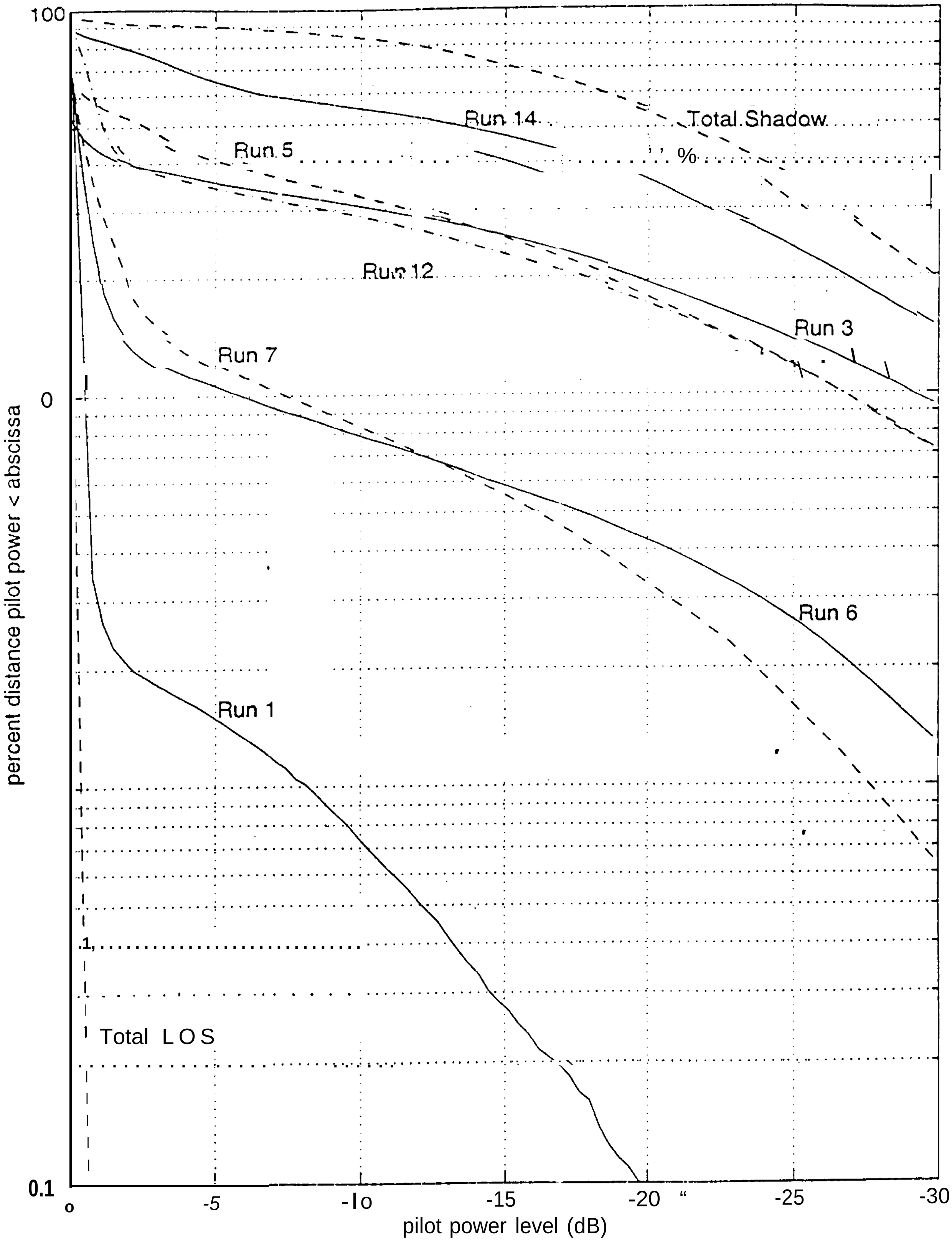

Figure 2: Comparisons of Frequency Histograms of Cumulative Fade Distributions for Various Runs on 9 July 1994 in the Pasadena Area