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# Systems Implications of L-Band Fade Data Statistics for LEO Mobile Systems

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## Abstract

This paper examines and analyzes research data on the role of foliage attenuation in signal fading between a satellite transmitter and a terrestrial vehicle-mounted receiver. The frequency band of measurement, called L-Band, includes the region 1610.0 to 1626.5 MHz. Data from tests involving various combinations of foliage and vehicle movement conditions clearly show evidence of fast fading (in excess of 0.5 dB per millisecond) and fade depths as great or greater than 16 dB. As a result, the design of communications link power control that provides the level of accuracy necessary for power sensitive systems could be significantly impacted. Specific examples of this include the communications links that employ Code Division Multiple Access (CDMA) as a modulation technique.

## INTRODUCTION

The research discussed in this paper focuses on the propagation of L-Band communication signals from satellites to ground-based, mobile receivers. More specifically, the test involved the collection and measurement of RF time-series data. The receiver was mounted on a vehicle traveling through wooded terrain. An aircraft-mounted transmitter provided a signal representative of a Low Earth Orbit (LEO) satellite for a portion of the test, while a geosynchronous satellite was used as a second signal source. Two runs were selected from the collected data as representative of the test results; Run 769: Moderately wooded area (vehicle receiver), simulated LEO satellite transmitter (aircraft). Run 343: Heavily wooded area (vehicle receiver), geostationary satellite transmitter. During run 769, the speed of the test vehicle varied between 10 and 20 miles per hour. In run 343, the test vehicle's speed was held constant at 25 miles per hour. Figures 1 through 5 show run 769 data, and Figures 6 through 10 show run 343 data. Measurements were performed by Dr. W. Vogel of the University of Texas.

## Review of Fade Data

The fade data (figures 1, 2, 6, and 7) illustrates a slowly varying mean value of fade and a more rapidly varying deep fade component (10 to 20 dB). The figures also reveal a very fast component, which is generally accepted to be caused by scattering. Some researchers model this as a Rayleigh process whose mean is a Lognormal distribution. Other models have also been developed (references 1, 2 and 3).The timeseries of figures 1, 2, 6, and 7 provide a measure of fade rate (their rise and decay times), which is a function of vehicle speed as well as shadowing. This test measures rates of change that exceeded 0.5 dB per millisecond.

**Fade Duration and Level Crossing Rate**

Fade duration is the length of time that a received signal is under a specified threshold (i.e., a fade margin value -- relative to unobstructed line-of-sight). Thresholds of 4, 10, and 16 dB have been considered. Level Crossing Rate (LCR) is defined as the rate at which a fading waveform crosses a specified threshold (4, 10, or 16 dB) in one direction. The LCR is calculated as a distribution for the selected thresholds. Fade durations and LCRs are shown in figures 3, 5, 8, and 10, respectively.

## CDMA CONSIDERATIONS

Power control is the single most important system requirement for Direct-Sequence Code Division Multiple Access (DS-CDMA). The power of each user accessing a cell must be controlled to ensure that resources are shared equitably among users and that the capacity is maximized (reference 4, page 305). Recent studies (5) indicate that CDMA capacity could be quite sensitive to power control accuracy. In fact, accuracy of 1 dB or better would be needed. System user capacity must be reduced to maintain the voice quality objective, for a given power control accuracy. The reverse link to a satellite receiver suffers a time varying attenuation when the line-of-sight from a mobile user transmitter is shadowed by tree foliage. The same applies in the forward direction (from the satellite to a ground-based mobile receiver). In both cases, the signal's rate of change is primarily related to the speed of the vehicle and the density of foliage. Satellite motion is of less significance. During a shadow period, the signal level reaching a receiver can easily vary 5 to 20 dB, thus decreasing the received Eb/(No+Io) with deleterious effects on voice quality. The following procedure can be used to compensate for shadowing. Transmit power could be adjusted dynamically with a closed-loop power control to compensate more precisely for a time varying fading due to foliage. Considering the up-link, if a user is traveling through a forested area, the received power level would be measured at the ground station gateway. A command signal would be sent to the subscriber unit in order to adjust its power to compensate for the up-link fade. Unfortunately, there is a time delay as a result of the round trip (user-satellite-user). In the case of a LEO satellite at 400 nautical miles altitude, the user-satellite-user delay is about 10 milliseconds for high grazing angles and 30 milliseconds for low grazing angles. The delay with a LEO at 800 nm altitude is 20 to 60 milliseconds. Medium earth orbit satellite (MEO) systems have higher delays (120 milliseconds) but less variation over the field-of-view. During the propagation delay time, the differential between the fade level and the corrective signal can reach several dB (perhaps 5 to 10), rendering power control ineffective. A fade event could even disappear entirely, leading to overcorrection. The above closed loop power control has to be used especially when the downlink frequency is different from the uplink (for example, L-band up/ S-band down) because the fades tend to be uncorrelated. If L-band is used on both the uplink and downlink, time-division duplexing (TDD) has to be used. Measurement of downlink fade can in principle be used to control uplink power. Suppose a fade measurement is made at time (t1). For a typical 60 millisecond TDD frame, the next uplink transmit burst will occur 30 milliseconds later. By that time the fading channel would have changed considerably. In any of these two cases the time delay will cause a power control error of several dB.

## TEST RESULTS, RUN 769

### Time-series Waveforms and Differential Variation of Fade Depths

Two fade regions were examined to obtain a more complete statistical description of fade variations for the recorded time-series. The first fade region was in the vicinity of the 5.0 dB absolute fade area, and the second was in the 10.0 dB area. The objective was to evaluate fade variation over an interval of (t) milliseconds for each of the regions. In figure 3, the results are presented as the probability that the fade variation over the interval exceeds a specified amount (dB). For example, the fade in the 5.0 dB area during an interval of 32 milliseconds varies by more than 2 dB for 50% of the time. At the 30% probability level, the fade variation is about 3.5 dB.

### Fade Duration Statistics and Level Crossing Rates

Figure 4 illustrates the cumulative probability of exceeding a given fade duration. Typical durations of 10 to 30 milliseconds, 50% of the time are observed. This is consistent with deep short duration fades as exhibited by the parent time-series data waveforms. The level crossing rate is the number of times the fade time-series waveform crosses a stated threshold in a positive direction. Figure 5 shows the distribution of level crossings per second. At the 50% point, the LCR is about 2 per second for a 16 dB threshold, 6 per second for a 10 dB threshold, and 4 per second for a 4 dB threshold.

## TEST RESULTS RUN 343

Samples of the time-series data for run 343 are illustrated in figures 6, 7. It should be noted that the fade slopes are greater than those of run 769, which is primarily due to the somewhat higher test vehicle speed used in run 343, as well as higher density foliage. Figure 8 shows the statistical fade changes for run 343. The differential fade variation is typically greater than 4.0 dB over a time interval of 32 milliseconds about 50% of the time. Likewise, it is about 8.0 dB for the same time interval, for 10% of the time. Fade duration statistics in figure 9 show durations typically between 5 and 7 milliseconds. Figure 10 illustrates the level crossing rates for run 343. At the 50% point, the LCR is 12 per second for a 16 dB threshold, 16 per second for a 10 dB threshold, and 18 per second for a 4 dB threshold.

## CONCLUSIONS

The test results reveal it is highly unlikely that a 1 dB power control accuracy can be maintained when communicating in a tree-shadowed environment even using a closed-loop power control system. The fade situation is nominally severe for heavily wooded areas and degrades further as vehicle speed increases. Tree shadowing produces fast-varying shadowing. Any system design based on a slow-varying shadow model is grossly inadequate in self-interference-limited satellite CDMA systems. Further analysis and simulation is recommended to evaluate CDMA capacity and voice quality over a mobile LEO satellite link.

## REFERENCES


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5. E. Kudoh, and T. Matsumoto. "Effect of Transmitter Power Control Imperfections on Capacity of DS/CDMA Cellular Mobile Radios," IEEE, International Communications Conference (ICC-92), Chicago, June 1992.

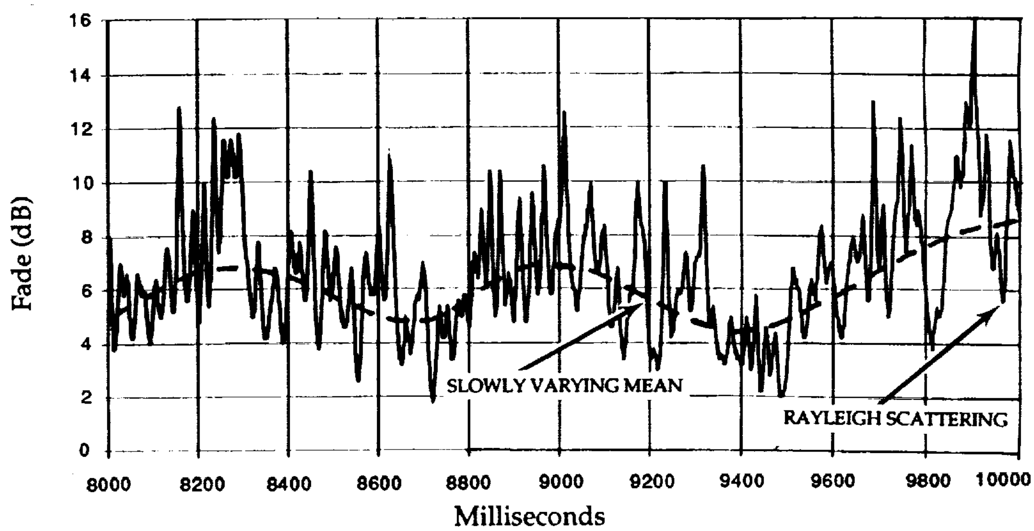


Figure 1. Run 769 Time-Series Waveform 8-10 Sec

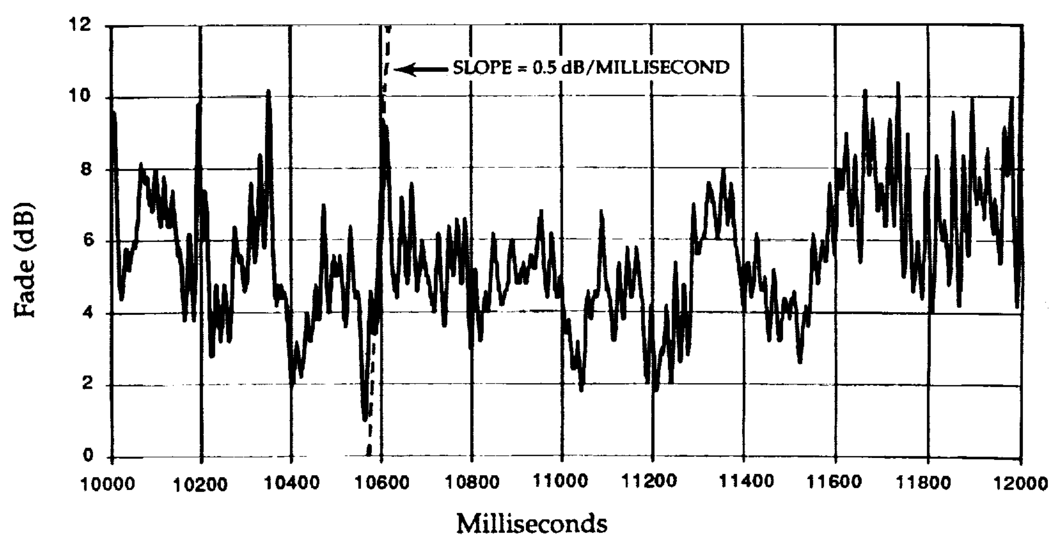


Figure 2. Run 769 Time-Series Waveform 10-12 Sec

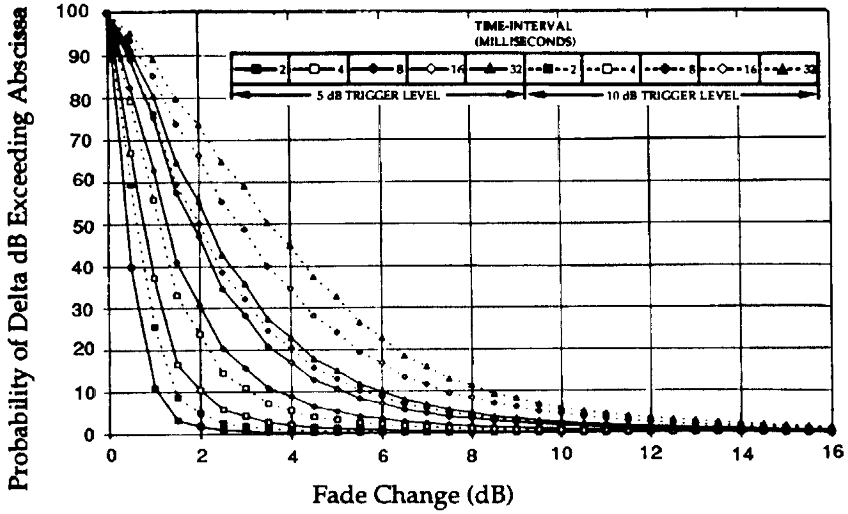


Figure 3. Run 769 Cumulative Probability Distribution of Fade

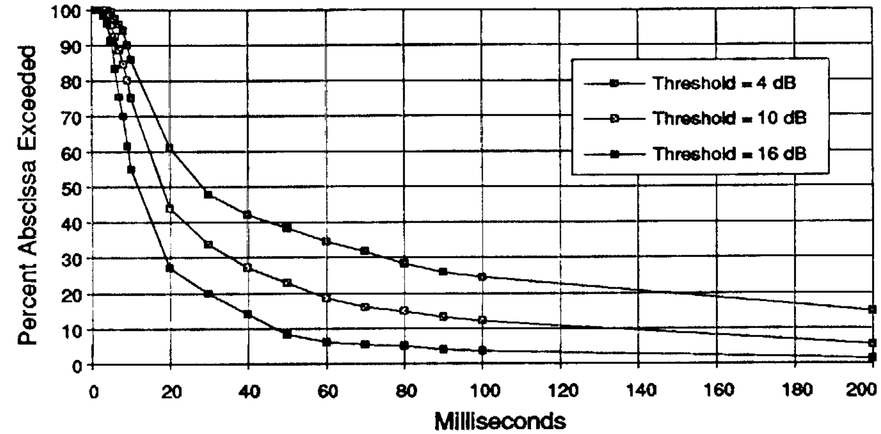


Figure 4. Run 769 Duration Statistics (10-20 MPH)

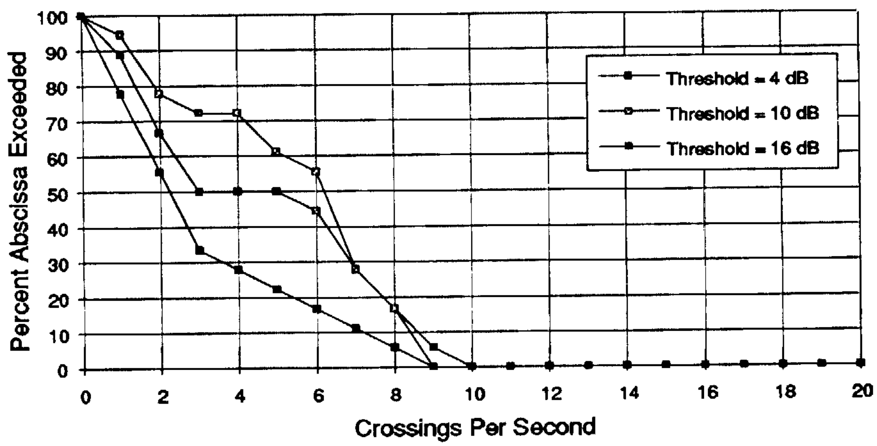


Figure 5. Run 769 Level Crossing Rate

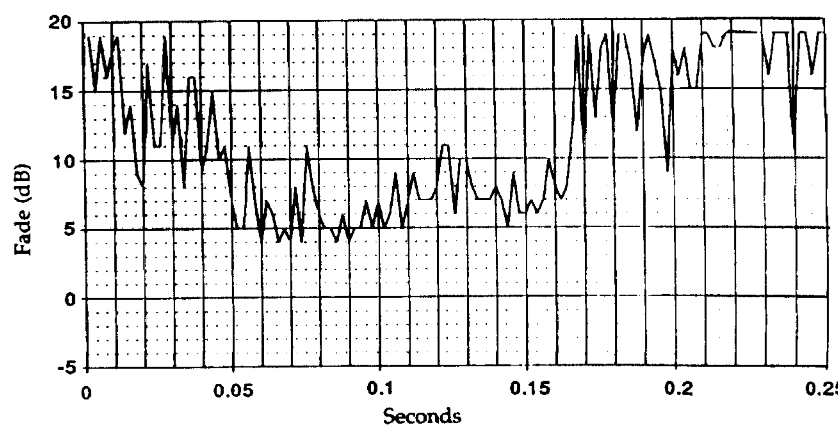


Figure 6. Run 343 Time-Series Waveform 0-25 Sec

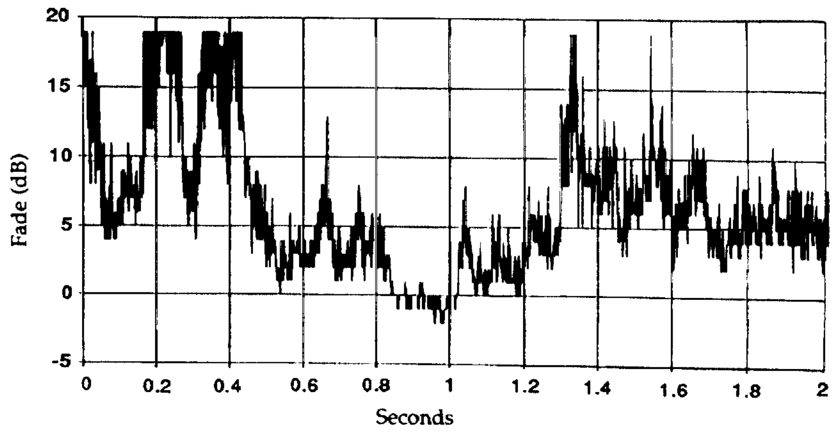


Figure 7. Run 343 Time-Series Waveform 0-2 Sec

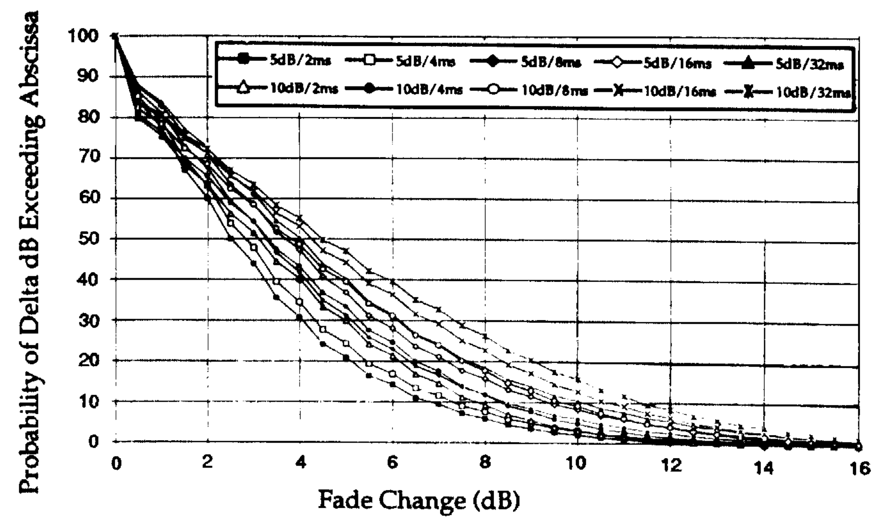


Figure 8. Run 343 Cumulative Probability Distribution of Fade Change

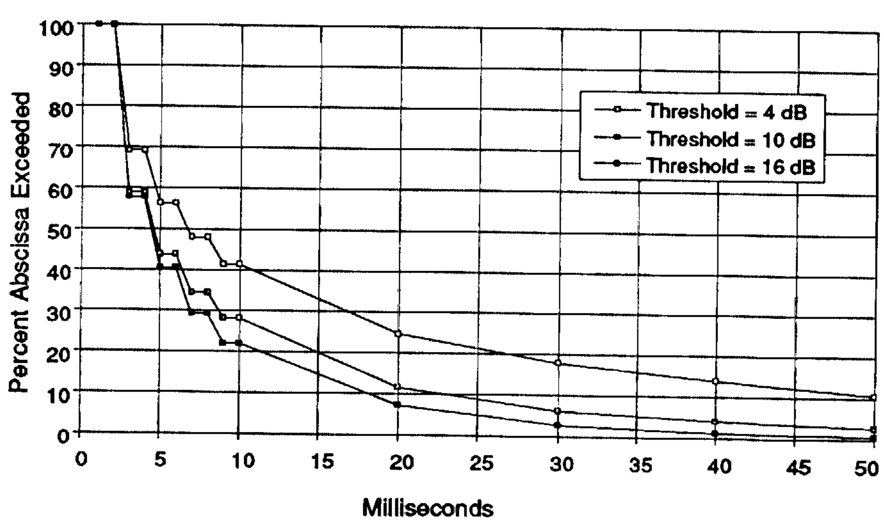


Figure 9. Run 343 Duration Statistics (25 MPH)

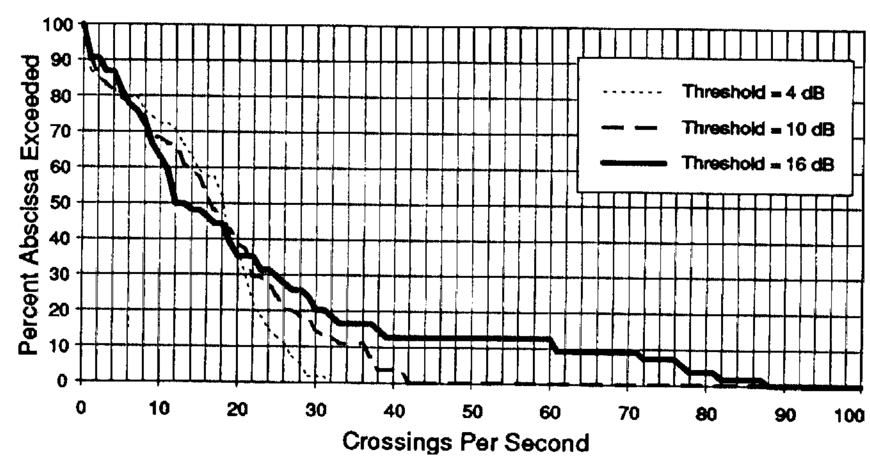


Figure 10. Run 343 Level Crossing Rate

## Session 9
## Mobile Terminal Technology

Session Chair—Russell Fang, COMSAT, U.S.A.
Session Organizer—Martin Agan, Jet Propulsion Laboratory, U.S.A.



***(continued)***