SLANT PATH L- AND S-BAND TREE SHADOWING MEASUREMENTS

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Abstract - This contribution presents selected results from simultaneous L- and S-Band slant-path fade measurements through a Pecan, a Cottonwood, and a Pine tree employing a tower-mounted transmitter and dual-frequency receiver. A single, circularly-polarized antenna was used at each end of the link. The objective was to provide information for personal communications satellite design on the correlation of tree shadowing between frequencies near 1620 and 2500 MHz. Fades were measured along 10 m lateral distance with 5 cm spacing. Instantaneous fade differences between L- and S-Band exhibited normal distribution with means usually near 0 dB and standard deviations from 5.2 to 7.5 dB. The Cottonwood tree was an exception, with 5.4 dB higher average fading at S- than at L-Band. The spatial autororrelation reduced to near zero with lags of about 10 λ. The fade slope in dB/MHz is normally distributed with zero mean and standard deviation increasing with fade level.

I. INTRODUCTION

Several proposed personal satellite communications systems in the 1610-1626.5 and 2483.5-2500 MHz bands envision employing CDMA modulation, for which high system efficiency requires keeping every user's signal power in the transponder at a similar level. Propagation effects such as tree shadowing, terrain multipath, and obstacle blockage, however, impose variations on each user's power level and therefore may require mitigation. One way of achieving this is through active transmitter power control, which could be most conveniently implementated by setting the power to be transmitted using the known received signal level. This method also has the benefit of not requiring hub-station feed-back with its inherent round-trip delay of at least several tens of milliseconds.

Multi-frequency propagation measurements of roadside tree fading have previously been reported for UHF and L-Band [1,2] and at UHF, L-Band and S-Band [3]. In these measurements, however, spatially separated receiving antennas were used for each band, allowing only statistical comparisons between the power levels observed at each frequency. Also, the propagation data were obtained at just a single frequency in each band. This experiment differs in two key aspects. It used a single aperture at both ends of the dual-frequency transmission link and it generated data in either fixed- or swept-cw modes, thus permitting a deterministic comparative assessment of the temporal, spatial, and frequency structure of the received power levels at L- and S-Band. In addition, data were obtained for co-polarized and cross-polarized reception, although at separate times.

II. EXPERIMENTAL SETUP

The measurement system consists of a dual-frequency sweeping transceiver located in a van, a 20 m crank-up transmitter tower mounted to the van, and a wired remote receiving antenna, filter, and preamplifier mounted on a linear positioner. A simplified block diagram of the transmitter and receiver is shown in Figure 1. The signals at L- and S-Band are generated as the upper and lower sidebands mixing products of a stable 2055 MHz oscillator combined with a tracking generator. After the mixing stage, the two signals are separated and leveled to account for differences in system and spreading losses at the two frequencies, with the objective of achieving approximately equal powers in the final receiver stage. Before transmission through a single, wideband, cavity-backed conical spiral antenna on top of the tower, the signals are recombined and amplified. The system can be operated in two modes: (1) constant cw-tone mode for measuring time series data and (2) swept cw-tone mode for measuring the frequency variability of the channel. In Mode 1, the tracking generator frequency is set to 437 MHz, resulting in test frequencies of 1618 and 2492 MHz. These frequencies are approximately centered in the up- and down-link LEO bands. In Mode 2, the tracking generator frequency sweeps ±100 MHz centered on 375 MHz, resulting in simultaneous sweeps over the 1580-1780 MHz and 2330-2530 MHz ranges. All frequencies in the transmitter are phase-coherent with a stable 10 MHz reference oscillator.

The receiving antenna is of the same type as the transmitting antenna, but alternately a left- or right-hand polarized antenna can be used. All antennas have a 3 dB beamwidth of about 90° at both frequency bands. The received signals are high-pass filtered, low-noise amplified, and returned through a 100 m long cable to the equipment in the measurement van. The processed Mode 1 output is a power level time series with a 0.01 s sampling rate. Mode 2 processing results in frequency spectra over 160 MHz with about 1 MHz resolution obtained in 0.1 s sweep duration. The outer 20 MHz regions of each spectrum are not used to eliminate edge effects due to the digital signal processing. The advantage of this dual-frequency system implementation is that it allows making simultaneous dual-band measurements through shared antennas with a single-channel receiver.

The receiver positioner holds the receiving antenna on a computer-controlled linear motion arm. The motion can be along any direction and over a range of 80 cm. When the axis of motion is vertical, as during the clear-path calibrations, the antenna moves from 1.8 to 2.6 m above the ground, when it is horizontal, the axis is 1.4 m above ground. To take data over a wider range of receiver positions, the entire positioner has to be moved in 80 cm increments.

III. Measurement Details

Measurements were made through three different trees, a Pecan (*carya illinoensis*), a Cottonwood (*populus deltoides*), and a Loblolly Pine (*pinus taeda*) during the Fall of 1993, while the deciduous trees were still in leaf. Photographs of the test trees are shown in Figure 2, in which the deciduous trees have been pictured without foliage to make the limb-structure visible. All trees had heights in the range from 9 to 12 m, maximum crown diameters of 6 to 10 m, and trunk diameters of 0.25 to 0.38 m. The transceiver-van was parked on one side of the tree under test with the transmitter tower fully extended. The receiver positioner was placed on the opposite side of the tree and moved along a horizontal arc centered on the tower base such that the propagation path would initially be clear of obstructions and subsequently, after moving laterally, pass through the tree crown. With each tree about 1/3 of the way from the receiver to the transmitter tower, the foliage was in the far-field of both antennas in all cases. Only the Pine was entirely free-standing, the other two trees had neighbors of the same species on one side. At the end of the measurement arc, therefore, only the signal in the Pine tree case returned to the clear-path level. In that case, the projected shadow zone from the part of the crown intercepted by the transmission was nearly 10 m wide at the receiver. The path elevation angle was 30° for the Pecan, 23° for the Cottonwood, and 20° for the Pine tree.

The two deciduous trees stand on lawns at the J. J. Pickle Research Campus in Austin, Texas, and have buildings, roads, and chain-link fences in their vicinity; the coniferous tree grows on a park-road median in the `Lost Pines' area of Bastrop, Texas, and has no adjacent buildings or fencing. Mode 2 (swept-cw; frequency spectrum) data were obtained in 5 cm steps over 13 m for the Pecan and Pine and over 10.5 m for the Cottonwood. Mode 1 (fixed-cw; time series) data were taken at every sixteenth Mode 2 position (every 80 cm), when the receive antenna positioner was moved. Although the antennas have large beamwidths, the transmitter antenna was repointed repeatedly (by remote control) to track the moving receiver direction to within ±10°. The measurements were performed in dry weather with variable light to gusty winds. After completing a measurement set with one receiving antenna, the set was repeated with the opposite receiving polarization.

The measurements also included a calibration procedure. During calibration, the co-polarized receiver antenna was scanned vertically while measuring the power levels at 16 points. This was repeated at four horizontal positions separated by 0.3 m along the beginning of the measurement arc with clear path conditions. At each frequency, the clear-path co-polarized power level was obtained as the (linear) mean over the 64 (16x4) measurements, thus averaging out the effects of specular ground reflections and diffuse multipath reflections from the nearby trees and/or buildings. All results are presented relative to the co-polarized clear-path level.

IV. Results

A. Spatial Variability

Figure 3 shows the spatial variation of power levels received at 1618 and 2492 MHz with co-polarized and cross-polarized antennas as a function of position in the shadow of the Pecan, Cottonwood, and Pine trees. As mentioned, the Pine was the only free-standing tree, allowing the power levels at both ends of the horizontal scan to return to the clear-path value. For the Pecan and Cottonwood, the crowns of other trees were intercepted by the line-of-sight path towards the end of each scan. Some general observations can be made from inspecting the plots. As expected, there is a macroscopic correlation between power levels at the two frequencies, i.e., both L- and S-Band are attenuated by the intervening tree, with 5 to 20 dB being typical values. On a finer distance scale, however, there are many deviations from equality which will be quantified below. Co-polar fades at the two frequencies occupy a similar range for the Pecan and Pine, but fades for the Cottonwood tend to be deeper at S-Band than at L-Band. Cross-polar power levels do not show as much dependence as the co-polar levels on how much tree crown is intercepted at each position, they range from -10 to -25 dB relative to the co-polar clear-path level and this indicates a relatively constant illumination intensity with scattered, depolarized power at locations both to the side and behind each tree. Considering that data for RHC and LHC polarizations were obtained successively, the cross-polar isolation, i.e. difference of co-polar and cross-polar levels, was not derived. The mean, median, minimum, maximum and standard deviation for each tree, polarization, and frequency band are summarized in Table 2. Also given in the table are the differences between the received power levels at 1618 and 2492 MHz.

Figure 4 summarizes the difference between the two frequencies for co-polarization, in the form of normal probability plots. The straight line in the graph represents a best fit normal approximations. The data show the Cottonwood difference and overall somewhat normal behavior.

To assess the sensitivity of received power to horizontal motion, the L-Band spatial autocorrelation functions for each tree have been plotted in Figures 5. The autocorrelation decreases from near 0.9 at the measurement increment to near 0 at a lag of about 10 wavelengths. Similarly, the S-Band autocorrelation was found to decrease to near 0 with a lag of about 20 to 30 wavelengths. The difference between the two frequency bands may be due to the dominant effect of the size of the tree branches as opposed the wavelengths on the scattering patterns.

B. Frequency Variability

Variations of the received power levels were measured at L- and S-Band frequencies over a 160 MHz span for all trees and polarizations. Both co- and cross-polarization show similar characteristics. A close-up analysis of the frequency selectivity of tree fading (Pine) for the allocated mobile satellite service bands from 1600 to 1626.5 (upper panel) and 2483.5 to 1500 MHz (lower panel) revealed that at low fade levels only limited frequency selectivity is exhibited.

An indicator for frequency variability is the fade slope vs. frequency, defined by

$$fadeslope = \frac{dS}{dF} \qquad \text{(dB/MHz)} \qquad (1)$$

where dS is the change in received co-polarized power over the measurement frequency resolution dF, i.e. 1.55 MHz for the Pecan and 1.0 MHz for the Cottonwood and Pine trees. The fade slope was found to depend on the mean signal level. Regression coefficients for the standard deviation of the fade slope as a function of the mean signal level have been derived using

$$\sigma_{fs} = a + b\mu + c\mu^2 \qquad (2)$$

where σ_{fs} is the standard deviation of the fade slope and μ is the mean signal level over the frequency span. The mean fade slope is very nearly equal to zero in all cases. The coefficients for the standard deviation are given in Table 1.

Table 1: Regression Coefficients for the Standard Deviation of the Fade Slope as a Function of the Mean Signal Strength.

	L-Band			S-Band		
	a	b	c	a	b	c
Cottonwood	0.137	-0.006	0.002	0.113	-0.041	0.003
Pecan	0.253	0.027	0.004	0.230	-0.082	0.003
Pine	0.253	0.046	0.005	0.231	-0.063	0.003

For a 5 dB faded signal at L-Band the central 90% of the fade slopes (±1.96 Std. Dev.) are within a 0.7 dB/MHz range, compared to a 1.9 dB/MHz range at S-Band. All fade slope distributions were tested for normality using the Kolmogorov-Smirnov procedure and for most the hypothesis of normality could not be rejected. Probability plots of L- and S-Band fade slopes for selected Pine tree measurements with mean signal levels of -5, -10, -15, and -20 dB are shown in Figure 6 to illustrate the approximately normal fade slope distribution.

V. Conclusions

We have observed the space and frequency domain structures of L- and S-Band simulated satellite power levels in both circular polarizations after slant-angle propagation through three representative trees. Our findings are:

- Power level variations at L-Band are not correlated with those measured simultaneously at S-Band in any of the domains. Spatial means of power levels are weakly correlated, however.
- Power level variability in the three domains increases with increasing attenuation, because as the direct signal is reduced, multipath scattering has a greater effect.
- Power levels as a function of space measured with a cross-polarized receiving antenna were in the mean 15 to 20 dB below the co-polarized clear-path level and more variable than the co-polarized signal. These characteristics were independent of position with respect to the tree.
- The fade slope with frequency, measured in dB/MHz, was found to be normally distributed with zero mean and standard deviation increasing with fade level.

Acknowledgment

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References

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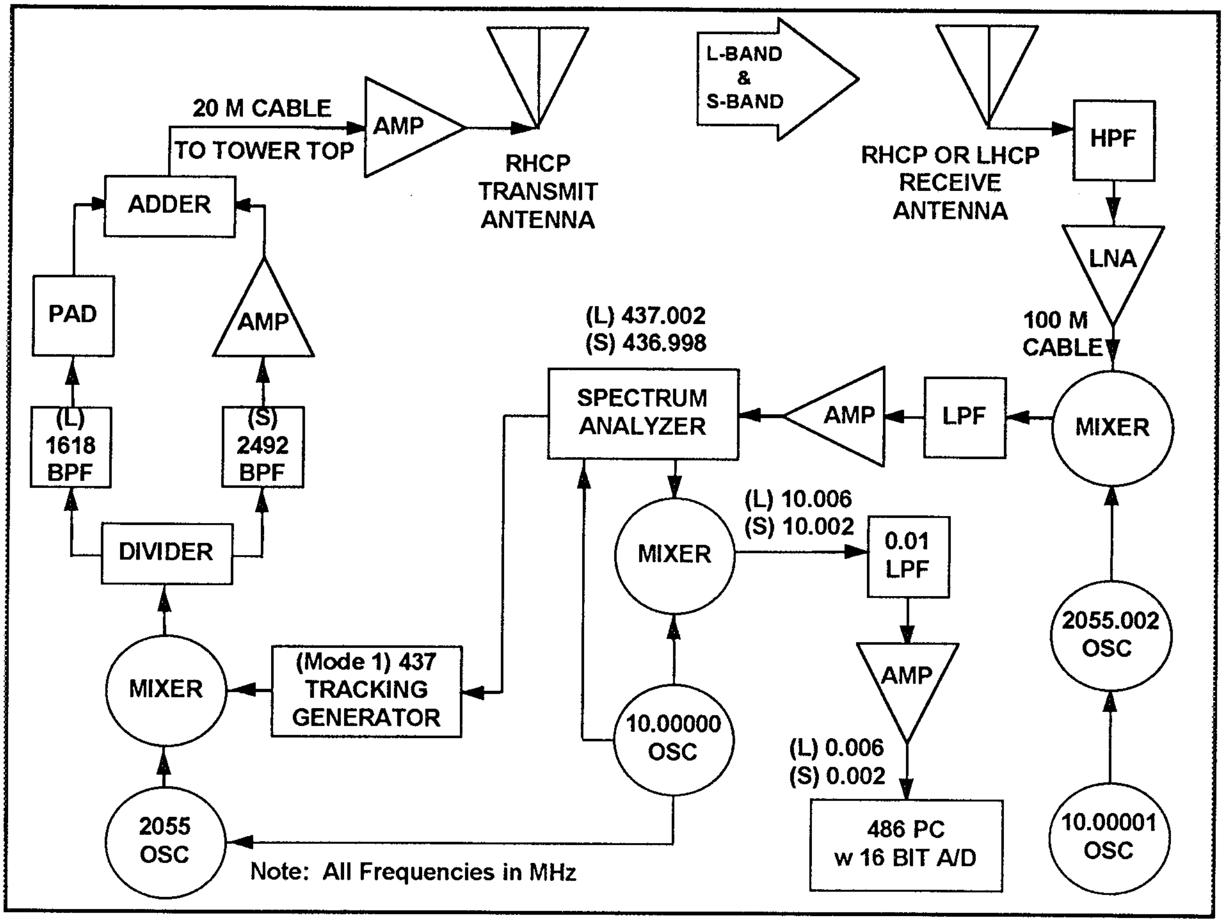

Fig. 1 Simplified blockdiagram of the dual-frequency measurement system.

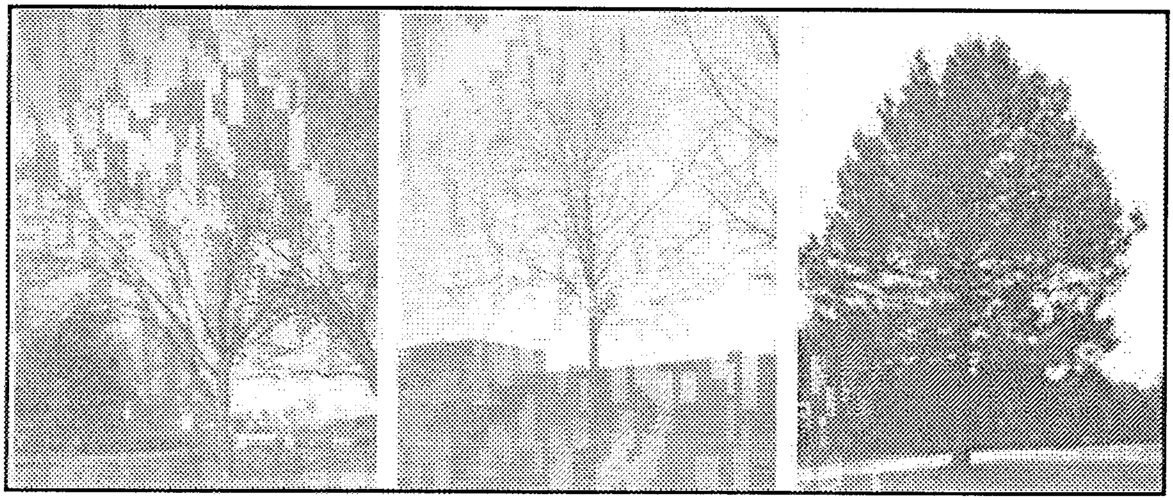

Fig. 2 Photographs of the Cottonwood, Pecan, and Pine trees (left to right). Although bare deciduous trees are shown, the data were taken while they were still I n leaf.

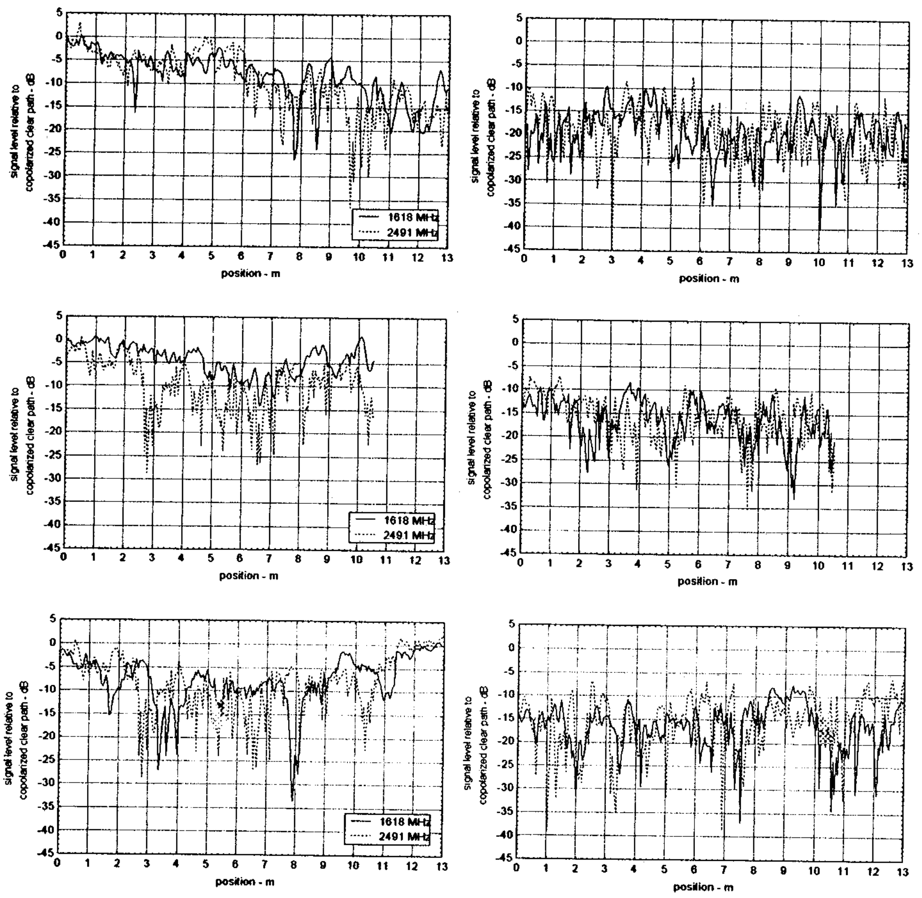

Fig. 3 Signal Levels received at 1618 Mhz (solid line) and 2491 Mhz (dashed line) with a co-polarized (left panels) and a cross-polarized (right panels) antenna versus position in the shadow of a Pecan (top), Cottonwood (middle), and Pine (bottom) tree .

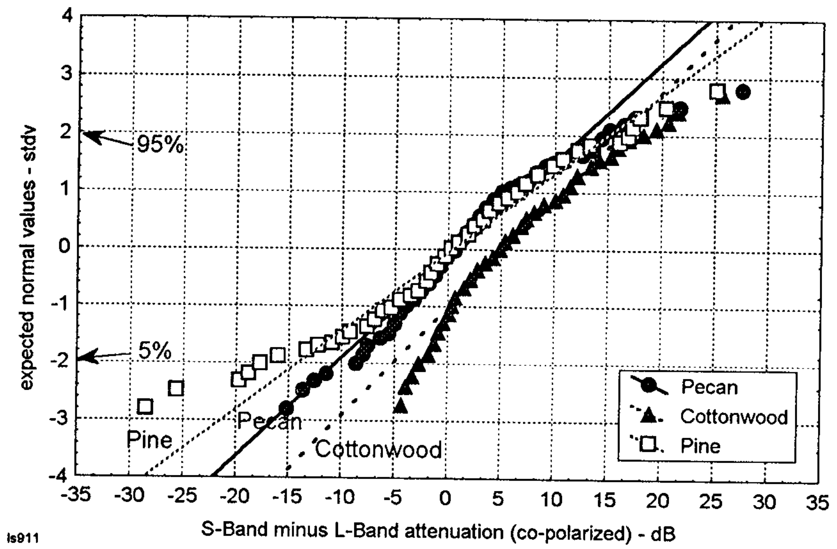

Fig. 4 Probability plot of the difference between S-Band and L-Band co-polarized attenuation for the three trees.

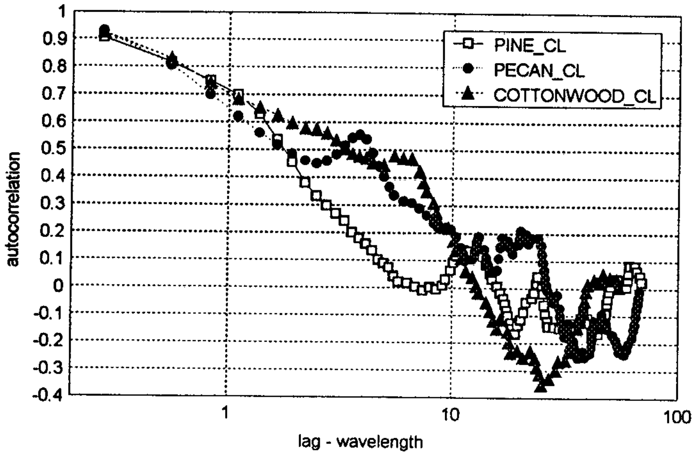

Fig. 5 The autocorrelation of the spatial data as a function of lag (in wavelenghts) for the co-polarization case at L-Band.

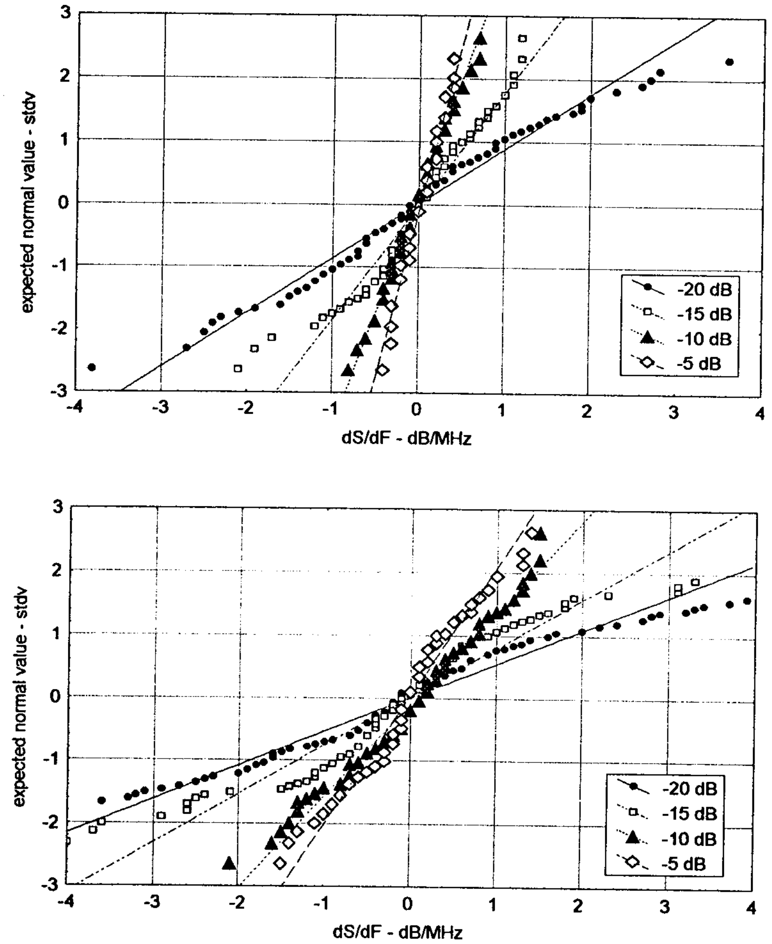

Fig. 6 Probability plot of co-polarized fade slopes for the Pine tree exhibit near-normal behavior at L-Band (top) and S-BAnd (bottom).