INTO BUILDING FADING AT L- AND S-BAND FOR SATELLITE PCS

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Abstract - Selected results from L- and S-Band slant-path fade measurements into six different buildings employing a tower-mounted transmitter and dual-frequency receiver are presented. The objective of the measurements was to provide information for personal communications satellite design on the correlation of fading inside buildings between frequencies near 1620 and 2500 MHz. Fades were measured along horizontal directions with 5 cm spacing. Fade differences between L- and S-Band exhibited a normal distribution with means usually near 0 dB and standard deviations from 7.2 to 8.2 dB. After spatial averaging over a few wavelenghts, the correlation between L- and S-Band was significantly improved. Simultaneous swept measurements over 160 MHz spans showed that the standard deviation of the power levels as function of frequency increased linearly with average fade depth from a minimum of about 1.3 dB and increased by .2 dB per 1 dB of fade. Fade slopes were also a function of fade level, with LMSS-Band averages in the range of 1 to 2 dB/MHz for 10 dB fades and increasing to about 3 to 4 dB/MHz at a 30 dB fade.

I. INTRODUCTION

While voice service into buildings may demand more link margin than can be provided economically from a satellite, other services, such as call-alert or paging with lower data rates and, therefore, higher fade margin, might be feasible. To characterize the penetration of satellite signals into buildings on slant paths, it is necessary to measure and understand the typical power level structure in the time, space, and frequency domains.

Propagation measurements for slant-path into-building fading have previously been reported for the frequency range from 700 to 1800 MHz [1]. Those measurements were targeted towards the application of broadcasting from geostationary satellites, however, and used a relatively directive receiving antenna. It is expected that the azimuthally omni-directional antennas used in this experiment interact more fully with the multipath environment inside buildings and produce somewhat different fade results. This experiment used one wideband transmit antenna and two separate receiving antennas, which were mounted 5 cm apart in the direction of the receiver motion. Because of this, L-Band and S-Band data were obtained at the same receiver location consecutively, with a time interval of about 2 seconds. Data were generated 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. We present the results from our "simultaneous" L- and S-Band into-building measurements in terms of the observed temporal, spatial, and frequency characteristics and draw some conclusions.

II. Experimental Details

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 remote receiving antenna, filter, and preamplifier mounted on a linear positioner. The system has been described previously [3]. To maintain the same signal structure for the consecutive L- and S-Band observations performed at the same location, the tower was tethered and measurements were obtained only on days with (at most) very light winds.

The receiving antennas are quadrifilar helixes mounted with 5 cm spacing in direction of motion of the linear positioner; either a pair of left- or right-hand polarized antenna can be used. The receiving antennas are narrow-band, azimuthally omni-directional, and have peak gain at about 30° elevation.

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. The axis of motion is horizontal, 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.

Measurements were made into six different buildings during the Fall of 1994. The names of these buildings, pertinent construction details, and the path elevation angle are given in Table 1. The transceiver-van was parked on one side of the building under test with the transmitter tower fully extended to 20 m. The antenna positioner was placed inside the building on the first floor and moved along a horizontal direction. The building was in the far-field of the transmitting antenna in all cases.

Table 1: Building Names, Construction Details, and Elevation Angle.

Building name	Approx. year of constr.	Construction type	No. of stories	Roof type	Average elevation (°)	Distance measured (m)
Commons	1987	concrete tilt wall	1	tar	16	16
EERL Office	1944	block brick	1	tar	30	8.8
Farmhouse	1880	wood frame	2	wood shingle	57	19.2
House	1958	wood frame	1	composition	40	12
Motel	1980	brick	2	composition	26	8
Store	1967	steel frame	1	tar	37	16

All L- and S-Band levels, $P_{L\text{-}Band}$ and $P_{S\text{-}Band}$, have been implicitly adjusted relative to the co-polarized clear-path level and all results are presented relative to the co-polarized clear-path level.

III. RESULTS

A. Time Variability

Time series were obtained to support the assumption that variations observed during the 2 s separated consecutive frequency sweeps are due to changes with frequency as opposed to time. As an example, data are shown in Fig. 1 as the tower was being retracted. One can observe that motion of the transmitter has a dramatic impact on the received signal level and that guying of the tower for the measurements was necessary.

Comparing the standard deviations of the timeseries data with those of the spatial and frequency variations to be presented in the following sections (typically 0.5 dB vs. 8 dB), one can say that the system's data acquisition rate of L-Band and S-Band signal levels at the same location taken within 2 seconds of each other and the frequency sweep rate of 2000 MHz/s was sufficiently fast to ensure that space or frequency variability as opposed to time variability was measured during frequency sweeps.

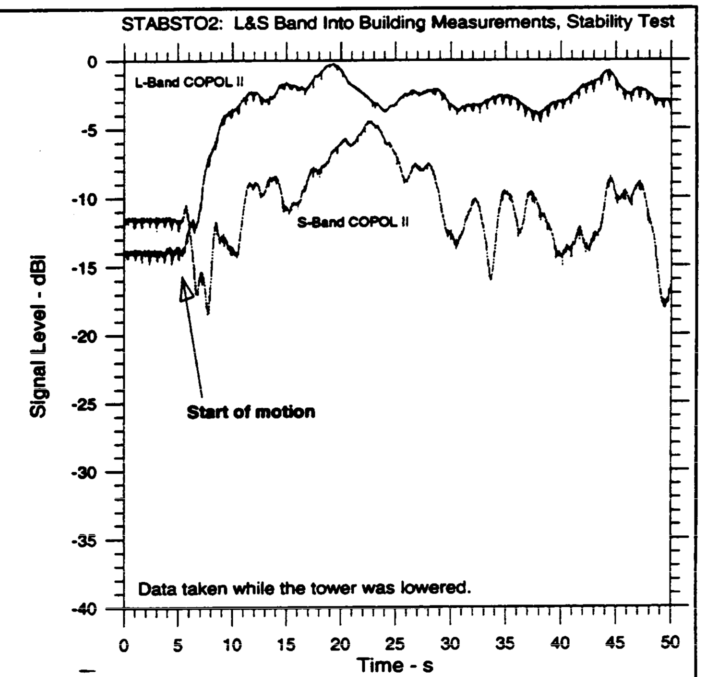

Fig. 1: Time variations without and with transmitter motion.

B. Space Variability

Figure 2 illustrates the typical spatial variation of power levels received at 1618 and 2492 MHz with co-polarized antennas as a function of position inside a building. Some general observations can be made while 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 structures, with 10 to 20 dB being typical values. The fades at the two frequencies often overlap in the graphs. On a finer distance scale, however, there are many deviations from equality which will be quantified below.

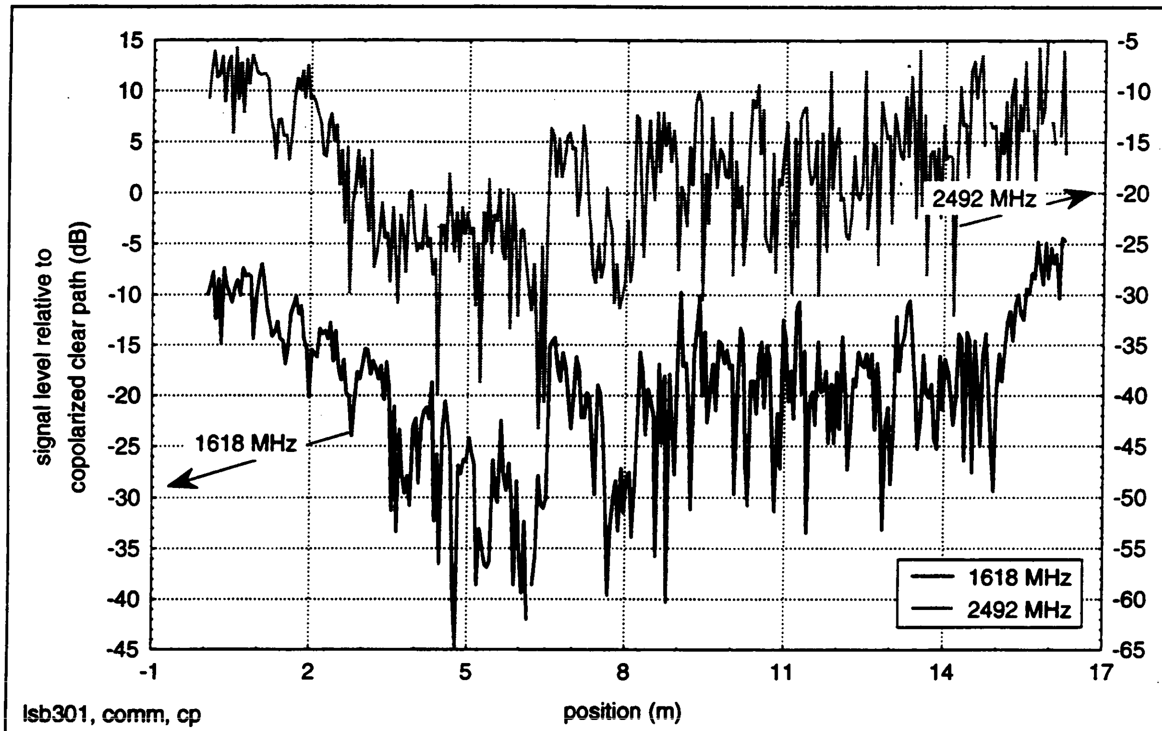

Fig. 2: The L-Band (left scale) and S-Band (right scale) signal levels vs. position in the Commons building.

The mean and standard deviation for each building and frequency band are summarized in Table 2 and some of the results are plotted in Figure 3. Also given in Table 2 are the differences between the received power levels at 1618 and 2492 MHz. One would expect that the building attenuation at S-Band on average exceeds that at L-Band, as for instance in the Store location, where the mean S-Band fades were 4.8 dB higher than the mean L-Band fades. At four other locations, however, the absolute difference was only 1 dB or less, which is about the accuracy of the measurement and at another location, the Commons, the average L-Band fades were about 2 dB greater than those at S-Band. Considering that fading into buildings depends on both the absorption by building materials and the reflection and scattering properties of the building skeleton, it is not entirely surprising to observe counter-intuitive results. A window, for instance, represents a larger opening at S-Band than at L-Band, but its attenuation may primarily depend on its frequency-independent metallic reflective coating. Similarly, steel mesh embedded in concrete may be less transmissive at the longer wavelength. In [1], median fades increased significantly over the frequency range from 700 to 1800 MHz. It is not clear, however, whether or not the fades tend to level off above about 1500 MHz. Preliminary results from wideband swept measurements into buildings from 500 to above 3000 MHz indicate at best a weak frequency dependence of the fading.

Table 2: Summary of Spatial Variation Results for Scans Inside Buildings

	L-Band		S-Band			Difference Power	
Building	**Mean (dB)**	**Std (dB)**	**Mean (dB)**	**Std (dB)**	**corre-lation**	**S-Band - L-Band Mean (dB)**	**Std (dB)**
Commons	-19.9	8.1	-18.0	7.2	0.56	1.9	7.2
EERL	-15.0	6.9	-15.6	6.9	0.34	-0.6	7.9
Farmhouse	-7.4	6.1	-7.9	7.1	0.28	-0.5	7.9
House	-10.6	5.7	-9.6	5.1	0.13	1.0	7.2
Motel	-19.8	6.3	-20.1	5.6	0.05	-0.3	8.2
Store	-14.7	6.2	-19.5	7.3	0.34	-4.8	7.8

Spatial moving averages were found for the scans in the six buildings, with an averaging interval of 60 cm or 12 positions, i.e., 3.2λ and 5λ at L- and S-Band, respectively. The correlation of the slowly-varying, low-pass filtered signal levels is larger than that of the unfiltered levels, ranging from a high 0.89 for the Commons to a low of 0.21 for the Motel. As an example, unfiltered L-Band and S-Band levels in the Commons are correlated by 0.54, increasing to 0.89 after low-pass filtering. The high-frequency variations, however, have consistently low correlations, in this case about zero (-0.02).

C. Frequency Variability

Similar to spatial variability, rapid changes with frequency occur only when the average power level vs. frequency is comparable to the diffusely scattered power. Inside buildings the multipath power is assumed to be about 10 dB or more below the clear path power level. A close-up view of the typical frequency selectivity of into-building fading has been plotted for EERL's laboratory building in Fig. 3. Four cases were selected from all positions, namely frequency scans with mean received power vs. frequency of 20, 15, 10, and 5 dB below the clear-path level. The graph illustrates that at high signal levels only limited frequency selectivity is exhibited over a narrow bandwidth but that the variability increases with decreasing mean in a scan, exhibiting deep and relatively sharp nulls for the -15 and -20 dB mean scans. The 16.5 MHz LMSS up- and

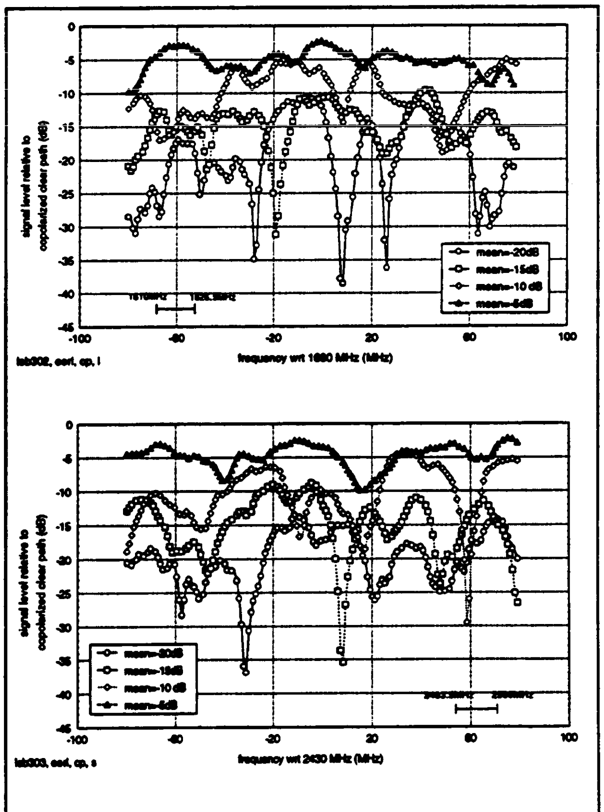

Fig 3: Fading vs. frequency at 4 positions.

down-link bands are marked in these graphs by horizontal bars. Another indicator for frequency variability is the fade slope vs. frequency, defined by

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

where dS is the change in received co-polarized power over the measurement frequency resolution dF, i.e., 1.0 MHz. Figure 4 presents an overview of the fade slopes observed at L- and S-Band in the six buildings.

The fade slope has been determined for all co-polarized signals within the MSS bands and regression coefficients for the standard deviation of the fade slope as a function of the mean signal level have been derived using

$$\sigma_{fs} = a + b\mu_{sl} + c\mu_{sl}^{2}, \tag{8}$$

where σ_{fs} is the standard deviation of the fade slope and μ_{sl} is the mean signal level over the frequency span. Scatter plots of average fade slope as a function of average co-polarized signal level are shown in Figures 39 to 44, and the polynomial fit coefficients of (8) are summarized in Table 3.

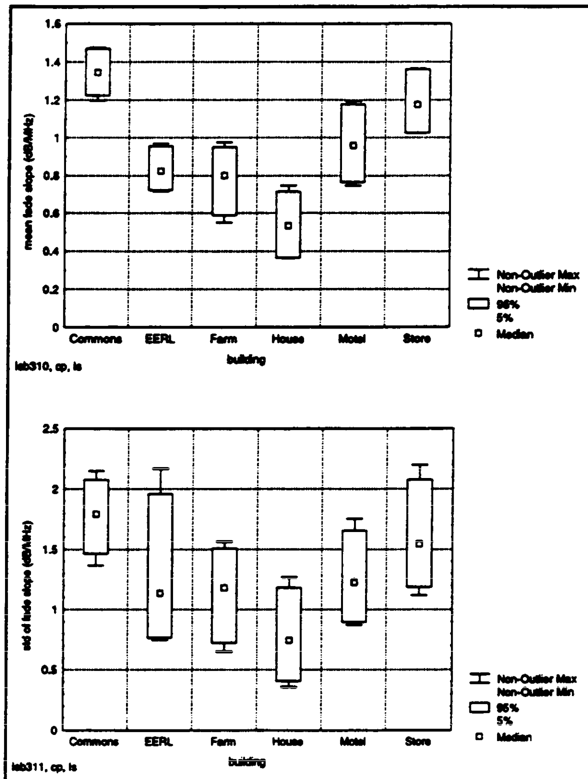

Fig. 4: Mean and std of the fade slope.

Table 3: Fit Parameters for the Fade Slope in the LEO Bands

LOCATION	L-Band a	L-Band b	L-Band c	S-Band a	S-Band b	S-Band c
Commons	-0.589	-0.11	0.000	-0.52	-0.123	-0.001
EERL	0.323	0.038	0.004	0.296	0.027	0.003
Farm	0.298	-0.047	0.003	0.196	-0.014	0.003
House	0.169	-0.015	0.002	0.237	0.026	0.004
Motel	0.531	0.063	0.004	0.342	0.047	0.004
Store	0.379	0.008	0.004	0.549	0.057	0.004

IV. CONCLUSIONS

We have observed the time, space, and frequency domain structures of L- and S-Band simulated satellite signals propagated into six buildings on a slant path. Our findings are:

1. Power level variations at L-Band are not correlated with those measured in the same location at S-Band. By forming spatial averages of power levels over a few wavelengths, the correlations increase.
2. Time variations are small if there is little wind and the receiver and transmitter are stationary. This means that for satellite communications systems with fade margins less than about 15 dB, time variations of mobile terminal power at the satellite will be spatial variations converted to time variations primarily by user motion and secondarily by satellite motion.
3. Power level variability in the space and frequency domains increases with increasing attenuation, because as the direct signal is reduced, multipath scattering has a greater effect.
4. Simultaneous swept measurements over 160 MHz spans showed that the standard deviation of the power level variation with frequency increased linearly with average fade depth from a minimum of about 1.3 dB and increased by 0.2 dB per 1 dB of fade.
5. Fade slopes were also a function of fade level, with LMSS-Band averages in the range of 1 to 2 dB/MHz for 10 dB fades and increasing to about 3 to 4 dB/MHz at a 30 dB fade.

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