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July 8, 1993

BY CERTIFIED MAIL

Frequency Liaison Branch
Federal Communications Commission
Room 7326
2025 M Street, N.W.
Washington, D.C. 20554

Re: Experimental Radio Station Licenses KK2XBA and KK2XBB
Six Month Progress Report

Dear Sir/Madam:

Enclosed for your files is the six month progress report required under Special Condition #2 of each of the above-referenced licenses. If you have any technical questions relating to this report, you may contact Eric Barnhart at (404) 894-8248. Please give me a call at (404) 894-4812 for any administrative questions.

Sincerely,

Gail Gunnells

E. Gail Gunnells
Attorney

EGG/vc
Enclosure
cc: Eric Barnhart

INTERIM TECHNICAL REPORT NUMBER 3: EXPERIMENTAL LICENSES: KK2XBA and KK2XBB

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July 2, 1993

Communications Laboratory
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1.0 INTRODUCTION

On January 3, 1992 the Federal Communications Commission granted experimental licenses KK2XBA and KK2XBB to the Georgia Tech Research Instate (GTRI). The license was requested for the purpose of taking measurements to characterize the in-building propagation channel to support development of indoor wireless communications technology. Specifically, the objectives of the program are as follows:

(1) Advancing the body of knowledge in indoor propagation as applied to wireless, digital communications;

(2) To establish a technology basis for development of indoor wireless communications technology and services.

To meet these objectives, GTRI is conducting an ongoing effort to collect, assess and document data related to indoor propagation for indoor wireless applications. This report documents the following key sub tasks of the effort: Normalization and preliminary assessment of the data collected.

This is the third interim report generated under these experimental licenses. The first two reports documented how and where measurements were taken, as well as explaining the rational behind the measurement program. Some preliminary results were also provided in these reports.

In this reporting period, efforts have focused on further processing of the data obtained under these licenses. This interim report presents the results of processing the raw channel transfer function data to obtain mean delay and multipath spread data. Specific results generated from these interim licenses appear in section 3.2. For completeness, this data is being processed in parallel with similar data taken in previous studies. This data is discussed in section 3.1.

1.1 Overview

In recent years multipath has been recognized as an extremely important physical mechanism degrading urban mobile communications and, even more recently, degrading wireless indoor communications. The primary physical reason for this is that there is not often a clear, unobstructed propagation path on such channels and, even when a direct path does exist, there is an abundance of reflective surfaces that can contribute to a multiplicity of ray paths.

As a consequence of the multipath, wireless personal communication services on the indoor communication channel must cope with a seriously degraded and distorted channel. A parameter of primary importance in characterizing such channels is the RMS multipath spread [1][2][3].

Below, we report on results obtained by statistically processing measurements made in two quite different work places in the Atlanta area. One of these was a high-rise office building in downtown Atlanta (the BellSouth building at 1100 Peachtree) and the other was a single-story office/workplace (Hitachi Telecom, Norcross, Georgia). The measurements are distinguished by virtue of the fact that they were made in the frequency domain. At the onset of the measurement program that led to the results described here there were no extant, published results displaying frequency domain measurements. During the measurement program, [4] appeared.

2. EXPERIMENTAL PROCEDURES

The frequency domain measurements of the channel transfer function were made using test equipment arranged and interconnected as described in [6]. An HP8510 Network Analyzer was the centerpiece of this experimental test set and provided the means whereby the complex samples of the channel transfer function could be taken in just a matter of minutes. The measurements were made by cycling through the 1600 and 4000 frequencies spanning the lower and higher test bandwidths of 140 MHz and 350 MHz respectively, and by simultaneously measuring and recording the amplitude and phase shift induced on each. A fiber optic link served as a virtually non-distorting channel, providing the clean reference against which the amplitude and phase of each received tone arriving over the propagation channel could be measured.

The precautions taken to remove the two major sources of potential error in the experiment are described in [5]. The antennas used in the test configuration were essentially omnidirectional. This choice was made so that multipath components arriving at angles off-boresight would not be discriminated against. Proceeding in such a way as to avoid time variations of the communication channel, the measurements obtained with the apparatus described above provide the magnitude and phase of the channel transfer function $H(f)$ in a variety of situations, e.g. for a variety of pairwise placements of the transmit and receive antennas. This transfer function, in turn, yields the impulse response $h(\tau)$ via straightforward inverse Fourier transformation.

For the transformation, a Hanning window was applied to the frequency domain data. Of several of the common windows that are popular for this type of application, the Hanning was found to add the least amount of multipath spread to the inverse Fourier transform of a perfectly flat (ramp phase) spectrum. This, of course, is the $H(f)$ that would result from a measurement made on a perfect non-reflecting channel. On such an ideal channel, the impulse response tends to become a perfect impulse as the bandwidth tends to infinity.

For the mean delays and multipath spreads presented in this paper, the impulse response was used to form $p(\tau_i) = |h(\tau_i)|^2 \Big/ \sum_{j=0}^{j=N-1} |h(\tau_j)|^2$ which was then used in much the same fashion as a probability density function to compute the mean delay $\bar{\tau} = \sum_{i=0}^{i=N-1} \tau_i p(\tau_i)$ and the variance $\sigma^2 = \sum_{i=0}^{i=N-1} (\tau_i - \bar{\tau})^2 p(\tau_i)$. In these expressions, $\tau_i = i \cdot \Delta\tau$. For measurements made at BellSouth, $\Delta\tau$=7.14ns. Although some of the measurements made at Hitachi were of the same resolution, several measurements made at that facility are characterized by considerably higher time domain resolution ($\Delta\tau$=2.86ns).

3. MULTIPATH SPREAD MEASUREMENTS

This section presents measurements made at the sites described in previous sections. The high-rise and low-rise office building sites are discussed separately below.

3.1. High Rise Office Building

In this section, measurements made on three different types of paths are presented. These consist of line-of-sight, fully obstructed, and semi-obstructed tracks in a high-rise.

Line-of-Sight (LOS) Track Although a wide range of data in different locations was collected, the statistical data described in this section have been obtained by processing of raw channel data taken at eighty positions along the track shown in Figure 1.

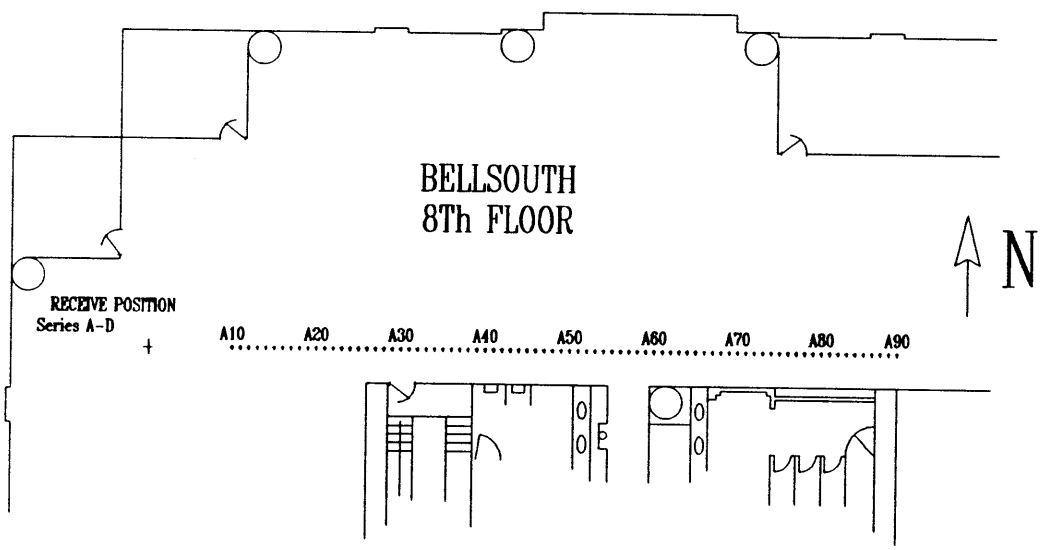

Figure 1 The "A" track in high-rise office building.

The raw data in a complete channel characterization (referred to as a "record") at any point along the track of Figure 1 consists of the 1600 measurements of amplitude and phase corresponding to that point. The mean delay plotted as a function of position along the track is illustrated in Figure 2. This figure displays the rough linear dependence of delay on distance that one expects to see as the transmitter (on track) is moved away from the fixed receiver. For the same track, the RMS multipath spread is shown in Figure 3. Quite unlike the mean delay, this figure shows a saturation and leveling off roughly half way along the track. The RMS delay spread reaches its maximum value of approximately 70 ns and then gets no higher. This behavior seems to be reasonable in view of the fact that there are no new sources of reflections beyond the middle of the track.

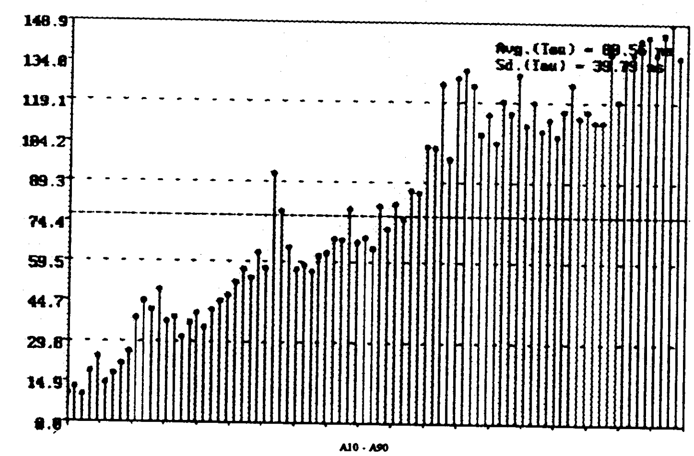

Figure 2 Mean Delay on "A" track.

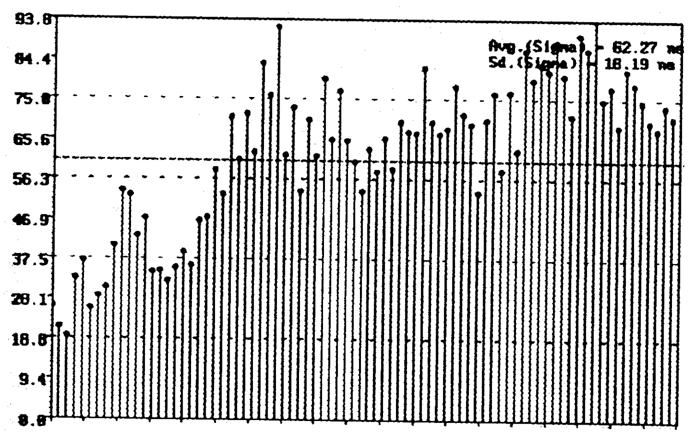

Figure 3 RMS Spread on "A" Track.

Obstructed (OBS) Track In the high-rise, one of the three tracks (referred to as the "C" track and located just to the right of A90 and down from it in Figure 1) was distinguished by virtue of the fact that the paths between the receiver and the transmitter locations were heavily obstructed. The sample points on this track were only eight in number and had the same spacing as on the "A" track. Because of the obstructions and the closeness of the samples, both the mean delay and the RMS multipath spread show no clear trends in their dependence on distance along the track, and hence are not plotted here. The numerical values are generally consistent along the track. The mean delay samples more or less randomly fluctuate around an average of 153.3 ns with a small standard deviation of 9.92 ns. The RMS delay spread varies similarly, fluctuating about an average of 122.8 ns with a standard deviation of 19.2 ns.

LOS/OBS Track The "B" track, illustrated in Figure 4, wherein it can be seen that the receiver is located at the same position used for the "A" track measurements, is the most interesting of the tracks in the high-rise office building. As one proceeds along the "B" track away from the receiver, the first few samples are all line-of-sight. After the first seven sample points, however, the track becomes obstructed. As one passes along the track through this area of mild obstruction, one passes into a region of heavy obstruction. Thus, the "B" track can be viewed as passing through the full range of possibilities ... LOS at first, then mild obstruction, then heavy obstruction. The mean delay along the "B" track, just as in Figure 2, shows a rough linear dependence. Because of space restrictions, the mean delay on the "B" track is not presented here.

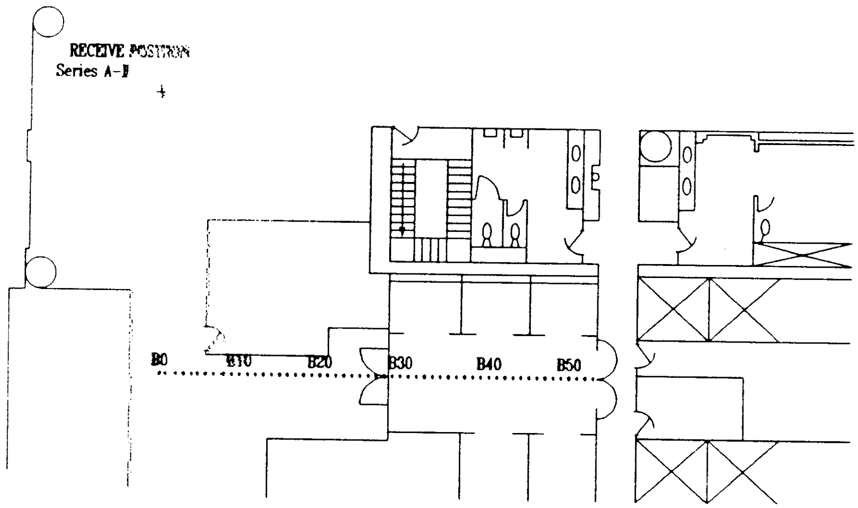

Figure 4 The "B" track in high-rise.

The average RMS spread along the path is given in Figure 5. This figure, in much the same manner as the multipath spread on the "A" track (see Figure 3), shows little change just before the path becomes obstructed at the seventh sample point. At this point, where the moving transmitter finds that the fixed receiver is obscured by thin intervening partitions, the spread begins to rise slightly. At 30 ft the track goes through a door into a region where the points are severely obstructed, and the delay spread then begins an even more pronounced rise. It is not known whether or at what value this new trend will saturate, but the trend is quite dramatic, and the spread rises to values that are commensurate with those of the severely obscured "C" track.

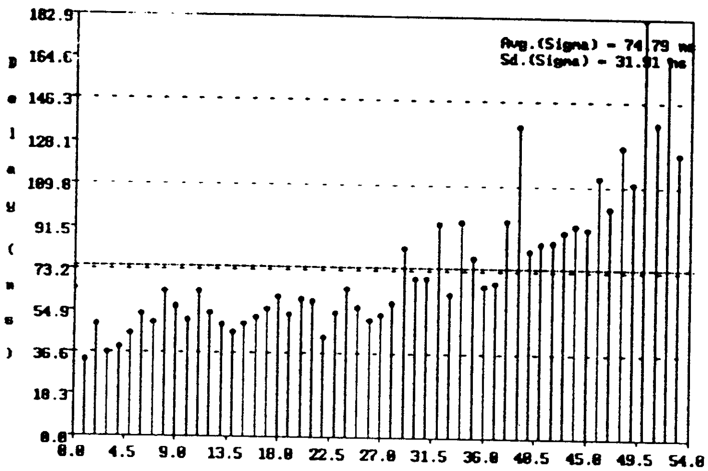

Figure 5 RMS Delay Spread on "B" Track.

3.2 Low-Rise Office Building

An extensive set of transfer function measurements were also made in a single-story office building at the Hitachi Telecom facility in Norcross, Georgia. Measurements made in one area, an assembly area, at a number of locations on a series of four grids, are of particular interest. The area containing the grids is shown in Figure 6. The measurements were made in this fashion, so that the transmitter-to-receiver distance dependence would not distort the data over the points on the grid. This approach, for each grid, provides a statistically valid number of samples to average over, since each grid point is roughly the same distance from the receiver. (In a subsequent numerical analysis, the approach has been validated with best-fit algorithms and quality-of-fit indicators.)

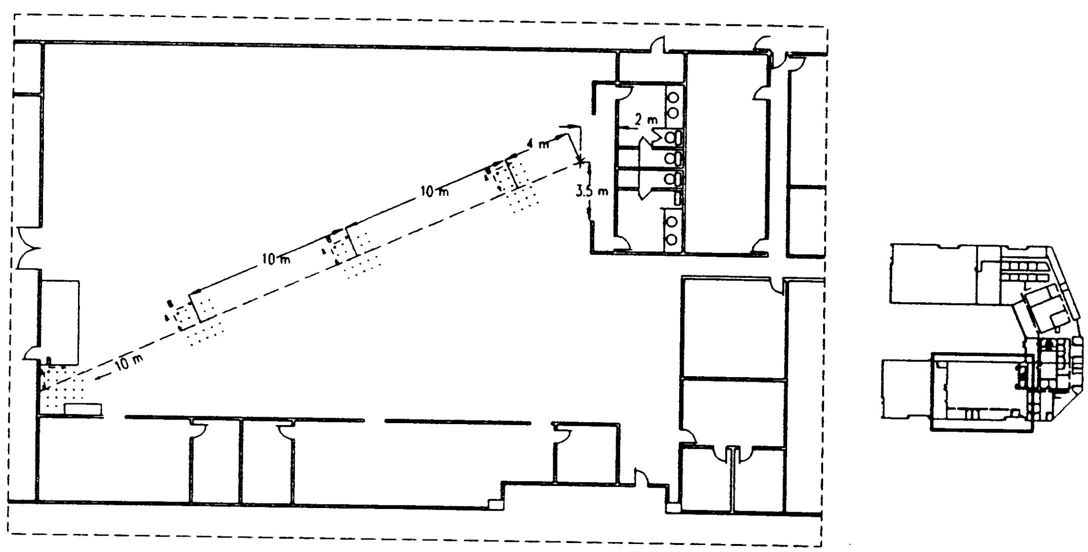

Figure 6 Measurement Grids in Assembly Area.

To convey some of the character of the measurements, we point out that the RMS delay spread over the 24 points of Grid 1 (the grid closest to the receiver in the upper right corner) had an average value of 39.50 ns with a standard deviation of 6.00 ns. The average values for each of the four grids are displayed in Figure 7. An important trend to note in this data is that the multipath spread tends to reach a saturation level, just as in the case of the line-of-sight paths characterizing Track "A" of Figure 2. In the assembly area the saturation level is slightly higher, 80-90 ns as opposed to 60-70 ns on the "A" track.

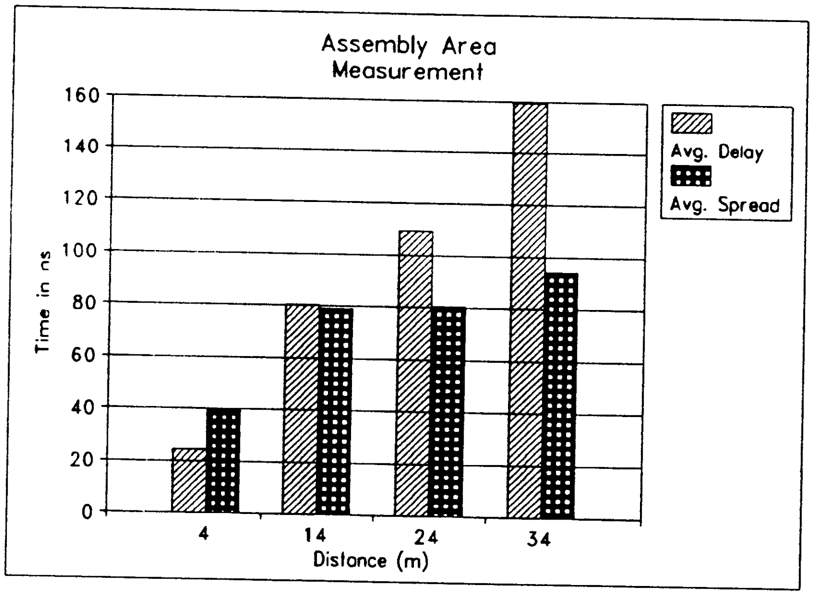

Figure 7 Delay and Spread in Assembly Area.

4. SUMMARY

Results depicted here indicate that statistical processing of the raw transfer function data on the indoor radio channel can yield multipath spread data that provides important indicators of dependence on different configurations (and levels of obstruction) characterizing the indoor propagation path. Efforts continue in the analysis of the comprehensive set of data collected at both the high-rise and low-rise locations, with special focus on generalizing saturation levels, points of onset of saturation and other factors that can be used to make more general predictions about the performance of communication systems on the wireless indoor channel.

5. REFERENCES

[1] Devasirvatham, D.M.J., "A Comparison of Time Delay Spread and Signal Level Measurements Within Two Dissimilar Office Buildings," IEEE Transactions on Antennas and Propagation, Vol. AP-35, No. 3, March 1987.

[2] Rappaport T., "Delay Spread and Time Delay Jitter in Manufacturing Environments," 1988 IEEE Veh. Tech. Conf. Record, Philadelphia, PA, pp. 186-189, June 15, 1988.

[3] Devasirvatham Daniel M. J., "Multipath Time Delay Spread in the Digital Portable Radio Environment", IEEE Communications Magazine, Vol. 25, No. 6, June 1987.

[4] Howard S.J. and Pahlavan K., "Measurement and analysis of the Indoor Radio Channel in the frequency Domain", IEEE Transactions on Instrumentation and Measurement, Vol. 39, No. 5, pp. 751-755, October 1990.

[5] Pickering, L.W., Barnhart, E.H., Witten M.L., Hightower, N.H., and Frerking, M.D., "Characterization of Indoor Propagation for Personal Communications Services," IEEE Southcon 91 Conference Record, March 1991.

[6] Pickering, L.W., Barnhart, E.N., and Witten, M.L., "Statistical Data from Frequency Domain Measurements of Indoor PCN Communication Channel," International Symposium on Personal, Indoor and Mobile Radio Communications, Symposium Proceedings, London, September 23-25, 1991.