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EIA-CEG / DAR Subcommittee, WG-B / Laboratory Testing and SG-1 / VHF Channel Characterization Test Final Report
July, 1995

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FOREWORD

NRSC-R56, EIA-CEG / DAR Subcommittee, WG-B / Laboratory Testing and SG-1 / VHF Channel Characterization Test – Final Report, documents the results of a test program conducted by the DAR Subcommittee of the Electronics Industries Association (EIA, precursor to CEA) to establish the characteristics of multipath fading at VHF frequencies for a variety of reception environments including urban, suburban, rural, and terrain obstructed.

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DAR6

EIA-CEG / DAR SUBCOMMITTEE, WG-B / LABORATORY TESTING AND SG-1 / VHF CHANNEL CHARACTERIZATION TEST

FINAL REPORT OF THE CHANNEL CHARACTERIZATION TASK GROUP; THE DERIVATION AND RATIONAL FOR MULTIPATH SIMULATION PARAMETERS FOR THE EIA-DAR LABORATORY TESTING

Robert D. Culver, Lohnes and Culver, Chairman
EIA-DAR Channel Characterization Task Group
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Prepared by
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July, 1995

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FINAL REPORT OF THE CHANNEL CHARACTERIZATION TASK GROUP; THE DERIVATION AND RATIONAL FOR MULTIPATH SIMULATION PARAMETERS FOR THE EIA-DAR LABORATORY TESTING

1. CHANNEL SIMULATION BACKGROUND

At the October 18, 1991 DAR Subcommittee meeting at the EIA, Working Groups A and B were established to begin describing and then testing DAR systems. By the next meeting in November a draft outline of WG-A and WG-B tasks had been prepared. The WG-B outline began the listing of channel problems to be evaluated relative to DAB system performance. At the January 22, 1992 meeting the "Digital Audio Radio Technical Performance and Service Objectives" were discussed and adopted. Item 2 of that document listed Immunity to Multipath. This item was carried forward into the second WG-A task outline regarding, Channel coding effectiveness - Multipath Fades. Thus the requirement for multipath performance testing was set.

2. EARLY CHANNEL SIMULATION ASSUMPTIONS & PLANS

Having decided to employ multipath conditions as part of the lab testing, the question was asked regarding simulating those conditions and the multipath parameters that would be used for the testing. General discussions revealed that the parameters could be specified in a variety of ways, including the channel delay spread, Frequency Domain characteristics or Direct Time Domain characteristics. The candidates for a channel simulator are all directly programmed using time domain values for each channel; including the attenuations, doppler frequencies (or relative phases) and time delays. Searching the literature for channel characteristics in the time domain for direct application to the simulator revealed very little information. If such information were not available, the time domain values would have to be estimated from other values for simulator programming. A source of direct information on time domain parameters was sought.

3. CHANNEL SIMULATION CONTROL; SIMULATION AND DIRECT MODES

At the May 23, 1992 WG-A meeting the topic of VHF/UHF multipath characteristics was discussed. Both the NTIA digital mobile propagation tests and the Hewlett Packard digital mobile testing seminar were mentioned. At the July 16, 1992 meeting, Tom Keller was confirmed as the Chairman of WG-B (testing) and a draft strawman of the test plan (version 1.0) was circulated. It described tests for system performance under multipath conditions, with and without added noise. At the November 5, 1992 DAR WG-B meeting the Hewlett Packard R.F. Channel Simulator, HP Model No. 11759C, was discussed as a candidate laboratory multipath simulator. Subsequent discussions revealed the HP Simulator operating modes, including those described as Doppler simulation, Rayleigh simulation and Direct control. These modes later were lumped into two main categories and came to be referred to as Sim mode (doppler and Rayleigh) and Direct mode. At a May 4, 1993 WG-B meeting, Jim McVey from Hewlett Packard was present to discuss the simulator. By September 1993, the NASA Lewis Laboratory was being offered as the DAR testing laboratory and the proposed equipment list included the Hewlett Packard simulator.

4. CHANNEL TEST BACKGROUND; EARLY INPUT AND THE DELCO PLAN

The Hewlett Packard Channel Simulator was chosen for laboratory testing, and its operating modes became clear. So did the need to program its operation directly with the time domain values of magnitude, time delay and doppler frequency (or phase) of the R.F. signal on each of its operating channels. The source of such time domain parameters was discussed and it was discovered that while considerable information exists on the VHF channel delay spread and other qualitative factors, very little information is available on actual individual reflection quantitative parameters. Measurement of those parameters was discussed and the NTIA television measurement system and a new proposed Delco Electronics test plan were explored.

In early 1993 the Delco channel test plan system was disclosed and a thorough discussion of it was held during a WG-B, Sub Group-1 (channel characterization) conference call on February 19, 1993. The Delco system is based on a design built and used by others and described in a published paper. A preliminary memorandum was provided by Brian Warren of Delco on February 23, 1993 describing the system. To meet the needs of our group, and Delco, and because this would be one of very few such systems ever built, it was a totally custom built experimental system, not depending on any "off the shelf" hardware. The Delco system description evolved over a number of months as detailed in the attached **Appendix A**, a series of memoranda and reports.

Following the channel characterization measurements the data that was to be collected would be processed over a period of months to extract the time domain parameters that would then be applied to the laboratory channel simulation. The data formatting, processing and parameter extraction process is described in the attached **Appendix B**.

5. RECONCILING SIMULATION AND TEST PLANS; THE DIRECT CONTROL SIMULATION CHOICE

The Hewlett Packard simulator can be programmed in the direct mode with the individual channel amplitudes, time delays and signal Doppler frequencies or phases to simulate a multipath condition. At any one simulator setting the channel simulation represents a snapshot of the channel at that time or at a particular location for a changing channel. This simulation technique can achieve a dynamic simulation at fixed sequential steps along a path (sequential snapshots). This "Direct" control simulation method was discussed. The simulator control data update rate would allow for significant simulated velocities with sufficient accuracy if a reasonably small step size is used. A step size of about 1/10 wavelength would present an accurate simulation of the VHF channel and such a step size could be easily accomplished in the VHF Characterization measurements while allowing a reasonable data collection speed and manageable amount of total data. The direct control of the simulator based on the actual measured channel characteristics was pursued.

6. CHANNEL TEST NEEDS; EQUIPMENT, VENUE, ETC.

The channel test program is summarized in **Appendix C**, a paper presented at the Toronto DAR symposium in March, 1994. The test signal occupies a wide bandwidth and therefore a wide bandwidth R.F. channel must be used. An unused VHF television channel rather than an FM band channel is required. The FM band is immediately adjacent to TV Channel 6, making that the preferred test band. The received digital signal must be recorded in computer data files and a suitable instrument van is necessary to carry the receivers, computers and associated equipment along the test paths. A General Motors minivan was available to Delco. The purpose of laboratory testing with simulated multipath is to present difficult but controlled propagation tests to the DAR systems. Therefore, benign environments were not desired and the difficult paths, or difficult portions along a path, in various surroundings were measured. Only one city could reasonably be used for channel characteristic testing because of cost and time limits, therefore it should contain many areas that represent as many "difficult" environments as possible. Finally the city and transmission facility must be available and easily accessible.

7. CHANNEL TEST IMPLEMENTATION; CHARLOTTE, SEATTLE, SALT LAKE CITY

Advanced Television (ATV) testing was being conducted in Charlotte at the time the VHF channel characterization testing was planned and the ATV test hosts offered the Charlotte site for testing. The environment at Charlotte presented a modest central city urban area, sufficient surrounding sub-urban and rural areas, modestly rolling terrain with some low hills and mountains at some distance away. It was not the all encompassing significant multipath environment but it was available and easily accessible.

By May 1993, plans were underway for conducting a channel characterization test in Charlotte, N.C. The test would use the existing ATV test tower and TV Channel 6 transmitter with a separate Circularly polarized transmission antenna. Those early tests revealed system and operational limitations in conducting such tests. They are detailed in the July Subcommittee meeting and in a report attached as **Appendix D**. The early test equipment was subject to internal and external noise interference and the Channel 6 testing interfered with cable television operations in the area immediately around the test transmitter site, so testing could only be done at night. That initial test data proved useless for channel simulation, though it provided the basis for equipment and measurement procedure improvements. Plans were made to revise the equipment and test at another venue where daytime testing could proceed. A new test venue was sought.

Bonneville Broadcasting, a long time participant in the EIA-DAR test program offered its transmitter site in Seattle, nearly an ideal test environment with a large central city developed area, hilly terrain, much vegetation, over water paths, and much more. The site was investigated and scheduled for testing in August of 1993. However, problems arose with tower availability which prohibited testing there. The Bonneville Salt Lake City transmitter site on Farnsworth Mountain was then offered and investigated. An FCC experimental application was filed in September and by early fall the site was approved for testing. The equipment was delivered and set up at the site with testing beginning in late September and continuing to early October of 1993. Equipment removal was accomplished in a relatively short time thereafter, well before the winter snows, fortunately delayed that year, closed the mountain to further work.

8. CHANNEL TEST DATA COLLECTED; FINDINGS; ENVIRONMENTS, SPEED, DATA VOLUME COLLECTED, PROCESSING TIME, ETC.

In early October 1993 the actual Salt Lake City channel characterization test data was collected over approximately one week. Attached as **Appendix E** is a description of the measurements and the data collected. The first section describes the data collection, defines some terms and generally indicates the data structure; the second section details the data analysis and presentation; the third explains the areas over which data was measured and the derivation of the four "environment" classifications into which the data was divided; the fourth and last section discusses the application of the data to the laboratory multipath simulation.

Approximately 126 kilometers of paths were examined and measurements were made every 1/10 wavelength (0.35 meters) at over 361,000 points along the paths. At each point the signal parameters (the time delay, magnitude and phase) for the six most significant signals was measured for both the vertical and horizontal polarizations, yielding about 4.3 million path parameter values. A briefing on the channel test program with preliminary results extracted from the data was presented at the November 17, 1993 DAR Subcommittee meeting.

By March of 1994 the preliminary raw data reduction had been completed, delivering samples of data in a form now suitable for building control files for the channel simulator. Testing the simulator with sample files revealed some of the physical limitations of the equipment as explained below. The sample files were also used to refine the computer methods to expeditiously review all of the collected test data and extract the files which have significant multipath impact. During this time the hardware used for the channel characterization measurements and methodology of data collection and analysis was tested to confirm that it correctly measured the channel characteristics. The findings indicated that this channel characteristic data represented the best (and only) available directly measured time domain data from which to extract control values for the H.P. channel simulator. Attached as **Appendix F** is a March 7, 1994 memorandum discussing this aspect.

The algorithm used to extract the channel parameters for the reflections was initially designed to extract those time domain parameters which presented the largest frequency domain effect. That strategy was subsequently studied and modified from this initial version to one which selected reflections based on time domain values in order of the strongest reflections with their accompanying delay and relative phases.

9. DATA PROCESSING AND INTEGRATION TO SIMULATOR(S)

By April the VHF Channel Characterization data had been analyzed to the point of developing the overall range of reflection magnitudes verses time delay for the four significant environments in Salt Lake City. Attached as **Appendix G** is a memorandum report on this aspect. Further analysis then extracted the reflection vs. time information on a file by file basis (with 160 sample points in each file) as explained in the memorandum report dated April 17, 1994 attached as **Appendix H.** The measured VHF reflection time vs. magnitude information was studied to arrive at the range of data appropriate to simulate challenging multipath Environments for all systems under test.

Information from other sources was also compared to the measured VHF channel data so that the simulation could include the 1.4 GHz UHF channel DAR system as well. The Canadian CRC investigation relating to L-Band characterization lead to the exchange of several documents, samples of which are attached as **Appendix I**. The "Proposed Channel Simulation Procedures", outlined various tests at different velocities, time delays, and amplitudes for the UHF environments which had been characterized. A proposal to adopt unified VHF-UHF simulation parameters was discussed. Subsequent documents compared the UHF and VHF data and unified test scenarios were subsequently developed. Additional documents in **Appendix I**, trace the development of the use of the three (of four original) unique environments with two speeds for the Urban environment, thus still maintaining four tests. The use of nine active simulator channels (of a total of 12), leaving three channels for simulating multipath on later interference/compatibility testing, also is adopted. This was made possible after the shift from the Direct simulation mode which made only six simulator channels available. The resulting three unified VHF-UHF environments and ranges of parameters is listed in a July 29, 1994 memorandum.

As a result of the now unified VHF-UHF simulation parameters a memo was sent to the EIA-DAR test laboratory listing those parameters to be used and the laboratory provided a document confirming the values actually programmed into the simulator. Those listings of time delays and magnitudes with appropriate doppler velocities and Rayleigh file parameters for each of the three environments (four tests) is attached as **Appendix J**. By June and July benchmark testing of the laboratory simulator had been completed and some anomalous simulation conditions were encountered.

10. SIMULATOR LIMITATIONS; ATTENUATOR RATE OF CHANGE LIMIT, TWO SIMULATOR MODE.

As the Channel Characterization data was processed in early 1994, samples were sent to the lab to test the direct control operation of the simulator. The plan had been to use the point-by-point amplitude, delay and relative phase to directly control the six channel simulator. This method, described in the Simulator Operating Manual, was tested and limitations quickly appeared. The simulator attenuator control circuits have a significantly slow time constant which will allow only slow changes in the simulation channels, far slower than were measured. The Hewlett Packard simulator was on loan and therefore, modification of the circuits to alter the time constant was not possible and another remedy was sought. By operating TWO simulators in parallel the relative phase between the two parallel channels can be changed rapidly, thus generating the required rapid level changes. This was implemented and found to function properly.

11. SIMULATOR LIMITATION; STEP FUNCTION DATA INTRODUCES "ARTIFACTS"

When more file data became available for the multipath "significant" paths, tests were run using a relatively wide band FM modulated signal. An FM modulator was driven by a sine wave tone at approximately 1khz modulation to generate a 1.5 mHz wide R.F. spectrum. This was monitored on a spectrum analyzer with a 1 mHz bandwidth display. The resulting "flat top" display easily shows the radio frequency nulls introduced by the multipath simulation. Upon close observation, especially by slow motion or frame-by-frame playback of a video recording of the analyzer, it could be seen that frequency domain artifacts were being generated.

Attached as **Appendix K** is a memorandum and report of July 12, 1994 describing the findings. The report and attachments indicate that the frequency domain artifacts are generated by the step changes in the simulator channels. Dummy data tests with controlled uniform step sizes indicates worsening artifacts with larger step size. An attempt to smooth the direct control data was made.

12. ATTEMPTED DATA SMOOTHING;

In an attempt to resolve the Frequency Domain artifacts the data was "smoothed", as indicated in **Appendix K**, by limiting the rate of change of some of the parameters and approximating missing data between data files. The artifacts decreased but still remained. Further testing with artificially created test files with controlled step sizes revealed that the simulator is very sensitive to even relatively small but rapid steps in the control values. The decision is reached that, not knowing the impact of the artifacts on the systems under test, the direct control of the simulator is not possible. The fall-back plan of using the "simulation" mode of operation, with Doppler and Rayleigh faded Doppler channel variations, was followed.

13. IMPLEMENTING SIMULATION MODE; MAINTAINING VARIABILITY WITH RAYLEIGH FADING

The Simulation or "sim" mode of operation allows for two variations. The first is the "Doppler" mode, described in the Hewlett Packard Manual as simulating a "static" Doppler effect, where each channel can be assigned a doppler frequency to represent relative velocity between the transmitter, reflectors and receiver due to actual motion of the receiver. The relative Doppler frequency can range from 0 to full actual velocity frequency equivalent and for both positive (approaching) and negative (receding) frequencies. This simulates velocity by phase change but <u>without</u> any variation of other parameters that would also be changing with motion, for example the amplitude and time delay parameters. It is like simulating velocity without motion. The second simulation mode, employing a Rayleigh variation characteristic on the control parameters, will restore some of this variability.

The Rayleigh fading characteristic is imparted on the simulator action by a control file that is generated by the HP program IQMAKE. The basic attenuation and Doppler control values for each channel of the simulator are modified by the computer algorithm to create a control value file which is used to rapidly update the simulator channels. This dynamically controls the channel parameters, simulating the multipath environment for a finite time depending on the size of the file made. The Rayleigh fading values created by IQMAKE are oriented about the basic channel parameters, those which were measured in Salt Lake City, not any other parameters associated with any standard Cellular or Land Mobile System. The resulting simulation has the overall characteristic of the measured control values but with the Rayleigh characteristics specific for the frequency and velocity of interest for the test impressed on each of the control channels. This effect on each of the individual channels then generates a combined effect on the overall variation of the combined R.F. six-channel output.

What would be a uniform and repeated R.F. channel fading with the Doppler simulation, determined by the beat frequency of the various Doppler frequencies, becomes a significantly random fading channel, similar to what is expected when driving along a path with changing parameters. With this simulation none of the direct control artifacts are evident. The IQMAKE program is specified for the Radio Frequency of interest and the Doppler frequencies (based on the anticipated vehicle velocities) for all simulator channels. This makes it specific for the R.F. frequency and measured channel characteristics with only the Rayleigh fading impressed on the control parameters.

14. DISCUSSION OF APPROPRIATENESS OF DOPPLER VS. RAYLEIGH CHANNEL CHARACTERISTICS

Much discussion centered about the proper use of the Doppler or Rayleigh simulation modes. Objections were raised citing the HP instruction manual with various references to the Rayleigh model defined for mobile cellular radio. Concerns were expressed relative to whether or not a Rayleigh faded channel was appropriate for the proposed laboratory testing of the mobile environment. The use of particular sections of the Salt Lake City measured channel characteristics and the use of only that one venue was questioned.

Use of the IQMAKE program to generate a Rayleigh fading file supplies control data specific to the actual measured channel characteristics, the radio frequencies in question and the anticipated Doppler frequencies (velocities) under test. This yields a Rayleigh characteristic representative of VHF propagation, not specific to cellular 900mHz frequencies or cellular frequency channel characteristics. The fading characteristic is generated and applied separately for each channel in the simulator and the overall R.F. channel response is the composite addition of all the channels. That overall response will have much variation but not a strictly single channel Rayleigh characteristic. Many individual experts in mobile communications reviewed the questions and concerns and have supported this simulation concept as appropriate for the laboratory testing. Attached as **Appendix L** are several of the observations, comments and responses regarding the Rayleigh and Doppler simulations.

15. PARALLEL DOPPLER AND RAYLEIGH TESTING; COMPARISON OF RESULTS

As a result of the questions regarding the use of Rayleigh simulation a decision was made to incorporate both Doppler and Rayleigh simulations in an expanded laboratory test. To characterize the effects of both simulations on a familiar medium, an FM modulated signal carrying audio test segments was passed through the simulator and then detected and recorded. The resulting audio clearly illustrated the repetitive nature of the Doppler simulation and the random fading nature of the Rayleigh simulation. That audio tape is available upon request.

16. CHANNEL TEST AND SIMULATION; LESSONS LEARNED

This channel characterization project and the channel simulation in the laboratory has again confirmed the immense variability that exists in an R.F. propagation path which can not be carried to and totally duplicated in laboratory simulation. For laboratory purposes, however, capturing all that variability would be counter-productive. For example, in an average environment, much of the time the R.F. channel may be quite benign with few if any interesting and stressful multipath conditions. The laboratory testing is meant to be a critical test of the systems. It is the relatively rare but stressful conditions that need to be reliably and rapidly repeated in the laboratory. This goal guided the extraction of "significant" multipath segments from the four environments to concentrate on those areas that generally would yield harsh tests.

Ideally, the original laboratory test would have used the actual channel parameters measured in the field, complete with their variability along the measurement path, to control the channel simulator as if driving along that same path. Having collected the data at uniform distances along the path, various and changing velocities could be simulated by changing the update rate of the simulator. When hardware limitations prohibited this, the same general channel characteristics for the difficult path segments were used but with the parameter variability now supplied by the Rayleigh fading profile applied to those characteristics.

The channel simulation testing has been applied uniformly to all of the proponent systems, even to the extent of testing in both Rayleigh and Doppler modes. The systems individual relative performances will be determined by the systems themselves, not by the design of the testing. If the testing were designed so that all systems were to fail the test, or where all were to easily pass the simulation test, the results would be useless. The only valid test is one that spans the range of performance from perfect to failed for all systems under test and hence determines a threshold of actual performance. The laboratory simulation provides such a test.

APPENDIX A

APPENDIX A - CHANNEL TEST BACKGROUND; EARLY INPUT

A-1 E. Moriyama, et.all "Development of Multipath Measurement and Simulation Equipment for Wideband Mobile Radio"

A-2 FAX memo from B. Warren, DELCO, to DAR Subcommittee, WG-B, Channel Characterization Task Group (hereafter "CCTG"), "PN Sequence Test Setup"

A-3 FAX memo from B. Warren, DELCO, to "CCTG", "Meeting Summary of 2/18"

A-4 FAX memo 03/05/93 from B. Warren, DELCO, to "CCTG", "PN Test System"

A-5 FAX memo from B. Warren, DELCO, to "CCTG", "Main Points from Charlotte Meeting -- 3/3/93"

DEVELOPMENT OF MULTIPATH MEASUREMENT AND SIMULATION EQUIPMENT FOR WIDEBAND MOBILE RADIO

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Abstract An equipment which has the capabilities for multipath measurement and also for wideband (10 MHz) digital simulation of a land mobile radio channel is described. Since, the equipment has the capability for reproducing measured multipath, we propose to use measured data (successive impulse response sequences) to make a standard propagation model. This can then be used as an alternative to the conventional simplified model for developing and evaluating radio equipment operating in the land mobile multipath environment.

In the multipath measurement mode, the equipment has the capability to store signals from multiple receiving antennas. We can use 3-dimensional antenna array on vertical and horizontal polarizations simultaneously. Consequently, we can measure arbitrary incoming path directions. This capability is useful for developing and evaluating adaptive arrays and space diversity antennas as countermeasures to channel distortion in the multipath propagation environment.

1 Introduction

In land mobile digital radio communications, irreducible bit errors occur due to fading [1][2]. It is well known that as data rate increases, irreducible bit errors due to multipath distortion also increase.

As for multipath propagation characteristics themselves, they just like narrow-band field strength characteristics, are severely affected by radio obstructive objects such as buildings and hills. Therefore, to realize high bit rate digital communication systems a deterministic multipath estimation model is indispensable. By using the model with a geographical and / or building database, the cell configuration design principle for high bit rate communication system can be established. However, a very detailed database is needed for predicting multipath propagation data and since this is not usually available, measurement of multipath is very important for clarifying the influence of obstacles and reflective objects.

In general, for developing anti-multipath techniques, computer simulation based upon some idealized multipath model is used. However, since multipath models used by different groups differ, immediate comparison between these techniques is not easy. Indeed, comparison on the basis of some idealized model is artificial. For such a purpose, measured multipath data must be correct and extensive enough to provide a standard measure. For example, spatially varying real multipath data should be used for evaluating an equalizer's tracking capability under time variant multipath condition using computer simulation or laboratory test. However, currently, a two ray model or other simplified multipath model is used instead.

What is needed to solve this problem is a model based on a comprehensive database of real multipath data. Considering these above situations, test equipment was developed. The equipment has both the capability for multipath measurement and also for wideband (10 MHz) digital simulation of a land mobile radio channel.

In this memorandum, we describe the configuration and basic performance of the newly developed equipment and briefly show laboratory test results of simulated multipath and a field test result of measured multipath.

2 Multipath measurement

There are many wideband radio propagation measuring methods. These are classified according to the type of transmitting signal, for example, impulse [3-5], frequency sweeping, multi-carrier and pseudo-noise (PN) [6-11]. However, of these methods, the PN method has an advantage in S/N and the capability of phase measurement, and is used frequently for land mobile radio propagation measurements. This section consists several of these methods and explains why we adopted a PN based technique in which calculation of impulse response is not perform in real time but by off-line correlation in laboratory. The equipment for receiving a transmitted PN signal, is classified by correlation technique, for example, real time sliding analog correlator [6-8], matched filter correlation using for example, CCD (charge coupled device), SAW (surface acoustic wave) device [9], digital signal processing correlator, or received signal storing for off-line signal processing [10-12]. Since real time sliding analog correlation equipment has the capability of real time delay profile monitoring, which is convenient for field measurements, it has been used frequently. Correlation is performed by a double-balanced mixer acting as multiplier and a low pass filter as integrator, accordingly it is difficult to acquire a wide correlation dynamic range. In contrast, in the received signal storing type method, correlation is performed by off-line digital signal processing and its correlation dynamic-range, which is chiefly restricted by the correlator, is superior to the analog sliding type. Measurement period of real-time sliding correlation is given by

$$R = (L/C)*(W/S)$$

where

L: Spectrum spreading code length [chip]
C: Code rate (chip rate) [chip/sec]
W: Correlation width [chip]
= correlation time*C
S: Sliding step size [chip]

For example, for a code length of $1023 = 2^{10}-1$, code rate of 5 M-chips/sec, sliding step size of 1/2chip and correlation width of 20 μs, the correlation width W is $W = 20 \times 10^{-6} (5 \times 10^{6}) = 100$ chip and measurement period R is $R = (1023/(5 \times 10^{6})) (100/(1/2)) = 41$ ms. For exact recording of multipath spatial variation, from sampling theory, the measurement interval must be less than half wave length. (we assume no components have a shift frequency larger than maximum Doppler frequency.) For instance, in 1.5 GHz band, the minimum interval is $3 \times 10^{8}/(1.5 \times 10^{9})/2 = 0.1$ m. For this case, vehicular speed must be less than 0.1 m/41 ms = 2.4 m/s = 8.64 km/h. This restriction is unfavorable for smooth field measurement. For example, even if measuring vehicle speed is kept less than this maximum speed, the speed of other vehicles surrounding the measuring vehicle cannot be limited when measuring on a highway. In this case, reflected waves from surrounding vehicles are observed as components with frequency shift larger than the maximum Doppler shift. This phenomena causes errors in the estimation of the delay Doppler scattering function. The use of techniques with a fast response time allows greater test vehicle velocity to be used thus a reduction in this kind of is to be expected. Matched filter correlation techniques, described above, have a capability for prompt measurement, by which the correct delay Doppler scattering function can be obtained. However, devices such as CCD or SAW correlators have the following limitations.

(1) narrow bandwidth
(2) small dynamic range
(3) short code length

Thus these devices are seldom used for multipath measurement.

As for real-time digital signal processing correlation, this can only be accomplished using many DSP's (digital signal processor) or MACC's (multiplying accumulator) for correlators. These make such equipment unrealistically expensive for land mobile field measurement. However, if we abandon the calculation of the correlation in real time and choose just to store the data during the measurement, then the above limitation of expense can be avoided. This type of measurement, correlation is not performed in field but performed laboratory. Using this method we can afford to compensate for distortion introduced by measurement equipment during data processing in laboratory. Since calculation is performed off-line, the time taken to perform correlation does not affect the effective response time of the correlation equipment. As the measurement equipment just has to store the received signal, the effective measurement period is given by L/C. If the same example system parameters previously assumed for the case of sliding correlation are used, this measurement period becomes $1023/(5\times10^{6})=0.2$ ms. As described before, measuring period of real-time analog sliding equipment is 41 ms, this value of 0.2 ms is about 200 times shorter.

3 Features of the measurement equipment

3.1 RF/IF signal record function

RF signals with bandwidth up to 10 MHz with center frequencies in the range 1.5 GHz to 3 GHz can be recorded. Once received signal has been recorded, it can be analyzed and edited as required. The recorded signal is correlated with a PN sequence on a laboratory computer and we can obtain delay profiles (these cannot be monitored in real-time). Input to the equipment can be in the form of RF, IF, analog or digital signals. Similarly, output can be in the form of IF, analog or digital signals can be synthesized from recorded data. The delay spread value calculated from the measured average power delay profile is susceptible to noise. In the real-time correlation scheme, the S/N is enhanced by using a slower sliding speed. However, the analog of this technique for the off-line correlation scheme requires a huge amount of memory. Instead, the equipment performs averaging in real time. The PN signal transmitted for channel sounding is periodic with frame length of L, but noise is not periodic. The signal after addition $S(t)$ is given by

$$S(t)=\sum_{k=0}^{2^m-1}[PN(t+kL)+n(t+kL)]\exp[2\pi j(ft-fr)(t+kL)+j\theta]\ \ldots\ldots(1)$$

where, $PN(t)$ is transmitted signal having a power of 1, $n(t)$ is complex Gaussian noise with power of σ^2 and ft and fr are respectively the transmitted and receiving frequencies. In general, to avoid a clock slip during measurement, very high stable master oscillators are used. Thus, ft-fr is very close to 0 during the averaging period. Since, $PN(t)=PN(t+kL)$ (1) become

$$S(t)=[2^mPN(t)+\sum_{k=0}^{2^m-1}n(t+kL)]\exp[j\theta]\ \ldots\ldots(2)$$

and the S/N becomes

$$S/N=\frac{[2^m]^2}{2^m\sigma^2}=\frac{2^m}{\sigma^2}\ \ldots\ldots(3)$$

Thus S/N is enhanced by a factor of 2^m by addition.

3.2 Multipath fading simulating function

There are many obstacles and reflective objects in the land mobile radio environment. Transmitted signal travels by many different paths as a result of various obstructions, scattering, and reflections. In general, each path has a different propagation delay time. Thus the received signal can be expressed by the super position of many transmitted signal. The transmitted signal is expressed as $\mathrm{Re}[u(t)\exp(j2\pi f_c t)]$, where $u(t)$ has bandwidth B. After transmission, the output of the propagation channel can be expressed in terms of the equivalent tapped delay line as

$$r(t)=\sum_{k=0}^{\infty}h_k(t)u(t-k/B)\ \ldots\ldots(4)$$

where $h_k(t)$ is the complex amplitude of kth tap.

By successively setting tap weights of a digital transversal filter, multipath fading can simulated. The equivalent tap weights are recorded in the main memory before starting a fading simulation and thus no device like a DSP, that restricts the speed of tap weight change, is required and the equipment has the capability for simulating multipath at relatively greater vehicular speeds. Tap weight can be set in a very flexible manner using measured multipath data or, as with conventional simulators, or idealized model such as GSM or some future model may be used.

3.3 Antenna switching control

With the help of antenna switching controller, we can simultaneously store data measured by multiple antennas on vertical and horizontal polarizations. Using this capability, polarization change due to scattering can be observed on each delayed path. Alternatively, if a linear array of receive antennas is oriented to traverse to the direction of the test route, we can obtain 2 dimensional data as the measurement vehicle travels along the road. By off-line processing of this data, we can synthesize different receiver antenna directions. An initial measurement using dual antenna array is reported in separate paper in this conference [13].

This capability should prove useful for developing and evaluating adaptive arrays and space diversity antennas as countermeasures to channel distortion in the multipath propagation environment.

4 Structures and configuration of the measurement equipment

4.1 The measurement equipment

The simplified block diagram of the equipment is shown in Fig. 1. The equipment consists of an analog block and a digital block. The detailed schematic diagram of digital block is shown in Fig. 2. Configuration of each block are described as follows.

For field measurement convenience, functions such as wheel axle pulse counter and an event marker are included.

4.1.1 RF section

This section consist of tunable band pass filter, low noise amplifier, AGC module (consisting of pin diode switches and fixed value attenuators), and a mixer for down conversion. By using fixed value attenuators for AGC the equipment can achieve a wide dynamic range without losing amplitude and phase accuracy. The fixed attenuator value is chosen from 0 to 36 dB in multiples of 12dB. Two 10 bits A/D converters (SONY CX20220-1) having a maximum sampling clock frequency of 10 MHz are used. The output data format resembles binary firsting point format with 2 bits format of data word, consists of 2 bit AGC data and 10 bit AGC data and 10 bit A/D data.

4.1.2 Signal processing section

This section consists of two parts, an averaging part for enhancing the S/N, and a tapped delay line for simulating multipath. Averaging time is selected such the number of bit period is given by 2m. This allows an m bit shift operation, by barrel shifter, to be used instead of division. This averaging is valid on the assumption that vehicle is stationary. At high vehicle speed, the Doppler shift in ft results in imperfect averaging which impair the accuracy of the multipath measurement. Averaging is implemented using high speed memory by an address generator which can be adjusted for an arbitrary Tx. frame length. The tapped delay line for multipath simulation is implemented using eight ZORAN ZR33891 chips per channel. These are connected in cascade to expand the maximum delay time, and tap weight and controlled by an 8 bit data word. The main memory of the equipment has a capacity of 8 M-word/channel and is used for data collection during multipath measurement, and for tap weight storage during multipath simulation. Since the number of tap is 8tap/chip*8chip/channel=64 tap/channel, number of profiles stored in the equipment is 8 M-word/64=125 k-profile. If the maximum Doppler frequency (fd) is 10 Hz and spatial sampling frequency for simulation is assumed to be 20*fd, thus regenerating time length is 125 k-profiles/10/20=625 second. This is about 10 minutes and is sufficient for most equipment tests conducted in the laboratory. The choice of a digital tapped delay line for multipath simulation avoids the influence of phase changes due to temperature change which occurs, for example, with SAW devices

4.1.3 Main memory section

Since the access time of the 1 Mbit dynamic RAM used for measurement storage is somewhat slower than maximum A/D converting period of 100 ns, two way interleaving is employed to reduce the effective data transfer rate. Memory capacity is 8 M-word/channel where each words is 12 bits long, of 2 bits AGC data and 10 bits A/D data, thus the main memory capacity is 8*12*2/8=24 MByte. During multipath simulation tap weight data having a 8 bit/word is stored in memory

4.1.4 D/A section

Two 10 bits D/A converters(SONY CX20202A-1) having a maximum clock frequency of 10MHz are used for generating base band signals.

4.1.5 Measurement control section

This section consists of three parts. The first part controls triggering. Triggering can be initiated on, for example, a time varying signal such TDMA burst signal or vehicle distance pulse. Triggering control is implemented by digital comparator and other devices. The second part controls antenna switching. This selects receive antennas synchronously with the frame cycle of the transmitted PN sequence. The number of receiving antennas can be up to 256. This part is implemented by counters and pin diode switch drivers. The third part controls AGC during field measurements. If the maximum received signal level during one measurement cycle is larger than upper threshold level, then a larger attenuator value is selected for the next PN frame cycle by pin diode switch. Conversely, if the maximum received signal level of one measurement cycle is less than lower limit threshold level, then a smaller attenuator value is selected for the next PN frame cycle. With the help of the AGC controller, given that both lower and upper threshold levels are appropriate, the A/D converter input is controlled to a proper value.

A Z80A processor controls most of this section. However the processor only sets the measurement conditions simulation parameters before starting a measurement. Therefore, neither data recording nor transfer speed are restricted by the processor.

4.2 Peripherals

4.2.1 Data transfer and storing

All received data is stored temporary in the main memory of the measurement equipment. When measurement of one course is finished the data on the main memory is transferred to PC expansion memory. For this purpose 32 MByte of commercially available expansion memory for NEC PC's is installed to enhance a memory size.

Data is stored on MO disk (Sony NWP-539S) having a one side capacity of 256 M-Byte. After this measurement cycle is finished, measurement on another course can begin.

4.2.2 delay profile monitoring

The equipment does not show delay profiles in real time. However a monitoring capacity is preferable for smooth field measurement. Therefore, instead of real-time monitoring, a vector signal processor(VSP; ZORAN ZR34161DC-20) board is installed in the controlling PC for obtain delay profiles from recorded data for multipath monitoring and equipment check in the field. The board employs FFT algorithm using the following relationship to obtain a delay profile.

$$R(\tau)=\frac{1}{2L}\int_{-L}^{L} u^*(t)\, v(t+\tau)\,dt \quad \text{..................................(5)}$$

$$R(\tau) \Leftrightarrow \frac{1}{2L} W(f)=U^*(f)V(f) \quad \text{..................................(6)}$$

where

$R(\tau)$=delay profile

$u(t)$=receiver input

$v(t)$=PN replica stored on VSP

$U(f) \Leftrightarrow u(t)$ and,

$V(f) \Leftrightarrow v(t)$ are Fourier transform pairs

4.2.3 Operating software description

The operation of the equipment is controlled by a menu driven computer program which can select 10 sub programs. These program are written in BASIC except for the data transfer part which is written in machine language for speed.

5 Measurement Results

Laboratory tests and field measurement test were carried out to confirm the equipment performance. Fig. 3 shows an example of the multipath data generated by this equipment in multipath simulation mode. This figure was obtained by feeding the output of the simulator into conventional sliding correlator. Transversal filter tap weights, with 0.4 micro-second step size, were set with a linearly decreasing amplitude out to a maximum delay of 4.4 micro second. As shown in Fig. 3, delay profile is consistent with the tap weights. Fig. 4 shows the delay profile resulting from direct coupling of Tx. and Rx. at IF which shows that the direct path level, which is observed near 100 micro second delay, is at least 40 dB larger than the level of false echo. We carried out a multipath measurement to confirm the field operation of the equipment. Fig. 5 shows an example delay profile measured in a railroad crossing. Measurement frequency is 2.3 GHz and base station antenna height is 30 m. As shown in Fig. 5, signal peak exceeds noise floor by 40 dB under field conditions.

6 Conclusion

In this work the development of equipment for the dual purpose of multipath analysis and synthesis is described. Major advantages of this equipment are

(1) Measurement of each delayed path amplitude and phase with high accuracy.

(2) Can be used with multiple receiving antenna.

(3) Enhancement of S/N by coherent addition.

(4) Reproduction of measured multipath in the laboratory.

EIA Multipath Test Data Subcommittee

PN Sequence Test Setup [Brian]

Objectives:
Compile time-domain multipath data for characterization of FM-band proponent DAB systems.

Strategy:
For a range of multipath environments, we will gather data for extracting the time delay spread and compile the statistical parameters for the Rayleigh distribution of received power. The primary site is intended to be Charlottesville, North Carolina (NTIA sponsored). We will use continuous PN transmission. If time permits and equipment for horizontal interval transmission is available we may test a secondary site. Data will be recorded in a mobile receiver in a test van.

System Description:
To allow independent observation of both the I and Q channels without frequency lock, two (orthogonal) PN sequences drive the modulator. The PN sequences have length 127 to allow for 21 dB dynamic range, slightly greater than needed for the Viterbi recovery width of 3 bits. The sequences are transmitted continuously in order to maintain the high dynamic range. The chip rate is 2 MHz, generating a 4 MHz main lobe in the band. This width is constrained by the TV mask, and limited by a filter in the TV transmitter. Preserving both sides of the main lobe allows for linear recovery at the receiver. These parameters will allow a time spectral resolution of 500 nsec and an observation window of 63.5 usec. Forthcoming Matlab simulations show typical results of measurements using this method. The dynamic range is limited by the autocorrelation of PN sequences (ratio of desired-to-undesired) and the cross-correlation between PN sequences. The sources of error are the residual phase front in the base-band signal and the bit-averaging algorithm, both described in the receiver section.

The modulator mixes the drive signals to a level of ____ [need interface specs] and a frequency of 40? MHz to drive the TV exciter. The sequences are pre-filtered with a 5-pole elliptic filter to limit sidelobe emissions to greater than 40 dB below the level of the main lobe. The broadcast setup and antennas have been described by Tom.

The RF demodulator recovers I and Q from the 85 MHz carrier. A slow AGC maintains optimal levels to the A/D converter. The receiver operates with non-coherent sampling by using two generators with less than 1 ppm short-term frequency drift as the LO's in each of the transmitter and receiver sections. Once the receiver is adjusted for frequency, the maximum frequency delta will be 280 Hz. This corresponds to a phase roll across the PN sequence of 6.3 degrees, which has an acceptably small effect on the data, as the Matlab simulations will show. The receiver will be set up to store raw data: 4 bits for each of the I and Q channels will recover the dynamic range determined by the PN length. A correlator for one of the PN sequences (implemented with a pair of Stanford

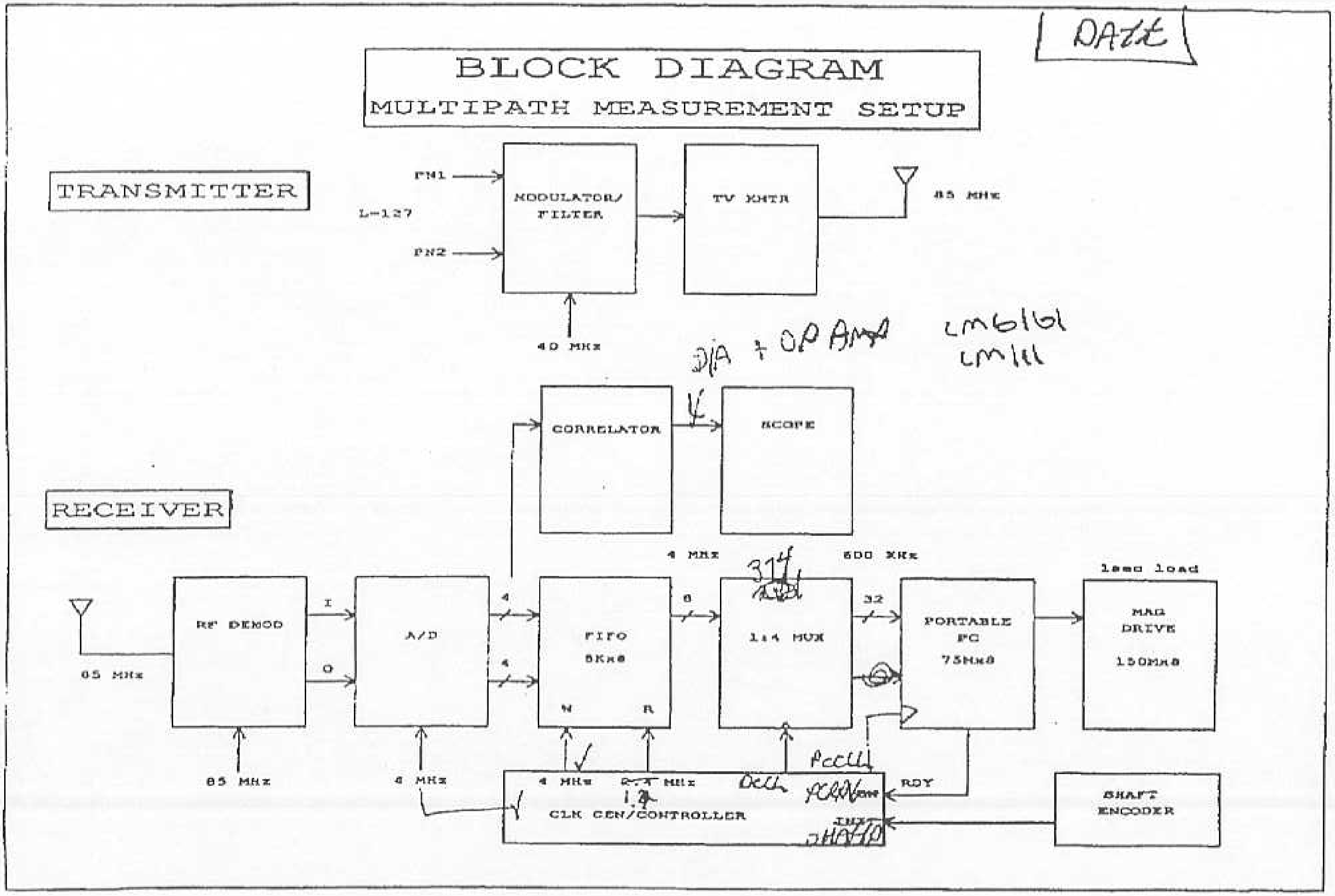
Telecom 3310's -- data sheet forthcoming) is connected to allow observing the data in real time.

The sample rate is twice the chip rate, and each pair of bits is averaged during analysis, relieving the need for synchronized sampling.

Data is buffered through a FIFO for the maximum clock rate of the card. The clock generator/controller counts pulses from a shaft encoder to initiate data taking. At that point it collects from 2 to 32 continuous PN instances (254 to 8192 bytes) in the FIFO which it downloads to the PC. The data is multiplexed into 32-bit words to prepare for storage into the PC through the National Instruments interface card. This is repeated after uniform distances until the PC inactivates the ready signal indicating it has filled the 75 M x 8 free section of the hard drive (storing 590 instances), at which time the PC will dump the data to the magnetic tape drive. At 7 Mbytes/min this will take 11 minutes and can be dumped two times per tape. We estimate filling twenty tapes. By spreading groups of instances, a reasonable distance can be characterized with a single tape. For example, if 4 instances are gathered every 36 ft, a mile of data can be gathered with a 11 minute stop after each half mile.

The raw data can then be processed by decorrelating against each of the original PN sequences. The direct reflections can be identified, allowing generation of the time spectral density graphs. Then, the received power levels may be filtered and statistically analyzed for distribution parameters.

Brian Warren



DAZE
BLOCK DIAGRAM
MULTIPATH MEASUREMENT SETUP
TRANSMITTER
PN1
L-127
PN2
MODULATOR/ FILTER
TV XMTR
85 MHz
40 MHz
D/A + OP AMP
LM6161
LM111
CORRELATOR
SCOPE
RECEIVER
4 MHz
600 KHz
1msc load
I
Q
4
4
8
32
RF DEMOD
A/D
FIFO 8Kx8
W
R
1:4 MUX
PORTABLE PC 75Mx8
MAG DRIVE 150Mx8
85 MHz
85 MHz
4 MHz
4 MHz
1.2
PCCLK
RDY
SHAFT ENCODER
CLK GEN/CONTROLLER

EIA Multipath Test Data Subcommittee

Meeting Summary of 2/18

1) Tom Keller explained that the North Carolina facility is our best first choice and our only significant point of interest is the interference measurements, which may require us to test early morning. The in-face meeting with NTIA's Ed Creedy will be attended by Tom, Ralph, and myself, arriving at various times from Tuesday to Wednesday, March 2/3.

2) Primary system was decided to be the Delco continuous PN system with open issues concerning bit-width of recorded data and length of PN sequence. These will be resolved based on simulations by Bill. Bob will receive system description by fax on Monday the 22nd. All comments on major system changes needed by Friday the 26th. Backup system will possibly be NTIA equipment, transmitting in the horizontal interval. This equipment may be available for a possible secondary site and can be used to confirm the data measured with the continuous system. The data, intended to be taken and analyzed in the time domain, should be transformed to the frequency domain to provide the fade parameter information (depth, repetition) that some members will be looking for.

3) Responsibilities were claimed to take the lead for the remaining parts of the test process. Responsibility for test procedure is jointly held by Tom and Brian, to be defended in Ottawa on March 3rd. Tests may begin soon after. Responsibility for data analysis was taken by Bill. Responsibility for the final report was taken by Bob.

4) The next teleconference, hosted by Ralph Justus, is planned for Friday, 2/5, 3:00-4:00.

EIA Multipath Test Data Subcommittee

PN Test System

Changes -- 3/5

1) Take data in both horizontal- and vertical-polarization (two consecutive runs).

2) Take two types of data (variations on when data is recorded). For statistical measurements and time-correlation data (which would exercise adaptive equalizers) take consecutive data, perhaps at two speeds: 30 mph and 60 mph. To maintain distance, data can be taken at 1/8 rate (256ksamples/sec), matching the channel and removing the need for the FIFO. Even at 60 mph (7.60wavelengths/sec) this rate of data will give well-correlated data. The computer will down-load every 2.44 minutes, storing over a mile of data at 30 mph. A tape will store twice that amount. In place of correlation, squaring or forth-ing the data and rooting will remove modulation. For time-delay spread (frequency-correlation) data, we may use the original method (data bursts over a longer distance). A switch at the receiver changes from one mode to the other.

3) Changes to extend range: lower-noise front-end, FM notch-filter front-end (make system noise-limited).

4) Decide during shake-down for single vs. dual PN. Dual PN increases phase resolution but limits dynamic range to 22 dB due to cross-correlation.

Objectives:

Compile time-domain multipath data for characterization of FM-band proponent DAB systems.

Description:

For a range of multipath environments, we will gather data for extracting the time delay spread and compile the statistical parameters for the Rayleigh distribution of received power. The primary site is intended to be Charlotte, North Carolina (NTIA sponsored). We will use continuous PN transmission. If time permits and equipment for horizontal interval transmission is available we may test a secondary site. Data will be recorded in a mobile receiver from a mobile test van.

System Description:

To allow independent observation of both the I and Q channels without frequency lock, two (orthogonal) PN sequences drive the modulator. The PN sequences have length 255 to allow for 48 dB dynamic range. The sequences are transmitted continuously in order to maintain the high dynamic range. The chip rate is 2 MHz, generating a 4 MHz main lobe in the band. This width is constrained by the TV mask, and limited by filters in both the test generator and the TV transmitter. Preserving both sides of the main lobe allows for linear recovery at the receiver. These parameters will allow a time spectral resolution of 500 nsec and an observation window of 127.5 usec. The dynamic range is limited by the cross-correlation between PN sequences, which is 22 dB worst-case. Minor sources of error include the residual phase front in the base-band signal and the bit-averaging algorithm.

The modulator mixes the drive signals to a level of 0 dBm and a frequency of 43 MHz to drive the TV exciter. The sequences are pre-filtered with a 5-pole elliptic filter to limit sidelobe emissions to greater than 40 dB below the level of the main lobe. The overall level of the sidelobe at transmission will be at most -60 dBc. The broadcast setup and antennas have been described by Tom.

The RF demodulator recovers I and Q from the 85 MHz carrier. A slow AGC maintains optimal levels to the A/D converter. The receiver operates with non-coherent sampling by using two generators with less than 1 ppm short-term frequency drift as the LO's in each of the transmitter and receiver sections. Once the receiver is adjusted for frequency, the maximum frequency delta will be 280 Hz. This corresponds to a phase roll across the PN sequence of 12.9 degrees, which has little effect on the data. The receiver will be set up to store raw data: 8 bits for each of the I and Q channels will recover the dynamic range determined by the PN length. A correlator for one of the PN sequences (implemented with 4 Stanford Telecom 3310's) is connected to allow data observation in real time.

The sample rate is twice the chip rate, and each pair of bits is averaged during analysis, relieving the need for synchronized sampling.

Data is buffered through a FIFO for the maximum clock rate of the card. The clock generator/controller counts pulses from a shaft encoder to initiate data taking. At that point it collects from 2 to 16 continuous PN instance pairs (254 to 8192 bytes) in the FIFO. The data is multiplexed into 32-bit words to prepare for storage into the PC through the National Instruments interface card. This is repeated after uniform distances until the PC inactivates the ready signal indicating it has filled the 75 M x 8 free section of the hard drive (storing 295 instance pairs), at which time the PC will dump the data to the magnetic tape drive. At 7 Mbytes/min this will take 11 minutes and can be dumped two times per tape. We estimate filling twenty tapes. By spreading groups of instances, a reasonable distance can be characterized with a single tape. For example, if 4 instances are gathered every 72 ft, a mile of data can be gathered with a 11 minute stop after each half mile.

The raw data can then be processed by decorrelating against each of the original PN sequences. The direct reflections can be identified, allowing generation of the time spectral density graphs. Then, the received power levels may be filtered and statistically analyzed for distribution parameters.

Brian Warren

Main Points from Charlotte Meeting -- 3/3/93

Attendees

Ralph Justus
Tom Kellar
Bernard
[Peyton]
John Goodwin
Ed Williams
Bob Culver
Brian Warren

Equipment

The NTIA equipment was being debugged on the bench, prior to installation into a test van for a Thursday test run. As best I understood it, the system uses two overlapping PN sequences of length 127 (for an overlapped length of 228), transmitted in the horizontal interval. Bit and carrier synchronization is provided by the TV synchronizer. The system has been successfully used for data measurements in San Francisco and Boulder at UHF. The system gathers 8-bits each of I and Q data (although the direct path is always received at 0 degrees) at a 30 Hz rate.

The main strengths of the equipment include its test-readiness, its reliability, and its appearance to station broadcasters who are positively-influenced by TV-intended equipment. Some of the drawbacks are its inability to lock in high-multipath areas, the low recording speed of the data, and the non-continuous nature of the PN modulation transmission. Some of these problems may be corrected by additional equipment: an independent frame synchronizer for lock problems, and a high-speed recorder for data gathering.

So far, it looks like the primary path is to continue with a modified Delco system and use the NTIA system as a back up. Tests could be taken with two people in the test van and a third person at the test site, communicating by cellular telephone.

Location

The Charlotte terrain is well-wooded with gently rolling elevation. The urban center is modest with some half dozen sky-scrapers. Some small hills are located 15-30 miles west of the broadcast tower, a river valley 15 miles east of the tower, and mountains 60 miles west of the tower. On the existing stations 90.7 and 104.7, a listener can hear multipath interference in both the urban and hilly areas. Depending on the ability to extend our measurement range, the mountains may be out of reach.

If we want to include mountainous terrain, giving us the longer, albeit low-level multipath reflections, we may want to consider a second site. Since Boulder is the NTIA's background, it may be a good idea to quickly investigate the possibility of some backup data from this location, using either the NTIA or the EIA equipment.

Range of Measurements -- Charlotte

The following pages show a more careful determination of link margin for the Charlotte site. Using the FCC field strength chart Figure 9 of 73.699, pg. 221 gave a more favorable estimate than using 4th law.

The first parameter in the chart is the transmitter height of 450 ft. The power is 4kW eirp. The antenna factor of a vertical whip is 5.25. The IF bandwidth is 2 MHz. kTB noise is used assuming the receiver is noise-, not interference-limited. The digital signal-to-noise ratio, equal to the required detector signal-to-noise ratio for this 1Hz/Hz system is 10 dB. For a PN sequence length of 255, the processing gain is 24.1 dB.

The table is generated by tabulating the field strengths from the FCC chart for the proper antenna height at distances ranging to the 60 mile mountains. The fourth column adjusts for the transmitter power. The fifth column adjusts for the whip antenna gain at the receiver. The sixth restates the fifth column in dBm. The seventh calculates margin as the distance to the kTB noise floor, less the noise figure and the required SNR. This is the dynamic range of the receiver for the time domain measurements, and will not be a full 40 dB at 60 miles.

The last column shows the final link margin after processing through the correlator. This indicates a good chance of recovering the time-delay spread at a 40 dB dynamic range.

Until these measurements are confirmed on-site, we should consider using the transmitting antenna director. Is changing this easy? We also need to ensure that the receiver can indeed notch out interference.

Brian Warren

APPENDIX B

APPENDIX B - INPUT THE DELCO CHANNEL CHARACTERIZATION PLAN

B-1 FAX from B. Warren, DELCO, to "CCTG", "Algorithm Development"

B-2 FAX from B. Warren, DELCO, to "CCTG", "Data Reduction and Multipath Parameter Selection"

B-3 Letter (L&C), to B. Warren, DELCO, "Crunching Charlotte Data" -- 6/10/93

B-4 FAX from B. Warren, DELCO, "Multipath: Conversion of Data to Parameters"

B-5 Letter, (L&C), to B. Warren, DELCO, "Data Analysis" -- 2/25/94

EIA Multipath Test Data Subcommittee

Algorithm Development

With the completion of the tests of the Charlotte, North Carolina site and in preparation for the Seattle tests, we are ready to "crunch" our multipath data and to firm up the algorithms for doing so. To accomplish this, an ad hoc team is coming together:

A. J. Vigil	Comlinear Corp	(217) 367-2600
Barry McLarnon	CRC	(613) 998-5005
Roger McDanell	Delco	(317) 451-1050
Brian Warren	Delco	(317) 451-1591

Afterwards, we plan to deliver the software and data to Lyn Robertson at Seiko for processing. (Note: Barry is participating as part of a sharing effort: his team has gathered data using a similar system.)

At this point, we have selected the media (1.35 Gbyte SCSI driven mag tape), the processing software platform (Matlab), and have written the preprocessing software to extract the time-domain data from the raw data. A set of papers and information have been gathered by the working group to assist in designing the remainder of the analysis software. Although many aspects have become firm, everything is fair game for this new group.

The goals of the analysis are:

- o Extract time-domain data in the form of delay-spread graphs (perhaps the means of the population for each terrain type)
- o Assist in determining settings for AT&T multipath simulator, which can simulate six reflectors of varying delay and magnitude
- o Derive frequency-domain data from the time-domain data: analyze frequency of nulls by depth and width

Along with the multipath papers is included a description of the data-gathering system and a disk containing the software we've written so far plus some sample data. The raw data processor (Proc5) begins by reading the raw data into MatrixA. Each cycle processes one "instance" of multipath data. An instance consists of 6120 8-bit bytes, the amount of data gathered each time the shaft encoder indicates the passage of a tenth-wavelength. The first half of the points contains vertical antenna data, the second half contains the horizontal. In each 3060-byte half, the points are organized as I/Q pairs, oversampled by twice the chip rate (2 MHz) and containing three consecutive PN sequences of length 255. (2 I/Q x 2 oversampling x 3 PN sequences x 255 PN length = 3060 bytes total.

Each instance is analyzed for phase roll, then corrected for that roll. Then decorrelation takes place to give one full frame of complex impulse-response data. The complete frame is detected (need to figure out how) and the data stored as part of initial processing. This is a storage reduction of 6120 bytes to 1020 bytes and completes the initial processing.

The post-processing is the focus of our efforts to fulfill the above goals. The papers contain several directions on how to do this. We can decide the direction and the detail of the data we report.

As a last consideration, our schedule for the EIA portion of the processing is a bit tight. We should plan to have our Charlotte data crunched by the first week in July, a week prior to the Seattle tests. In turn, the Seattle data, taken the last two weeks in July should be processed within a week from those tests, the first week in August.

We can discuss these issues more and get started with our impressions of the papers during next Tuesday's teleconference.

Thank you very much for your help!

Brian Warren

EIA Multipath Test Data Subcommittee

Data Reduction and Multipath Parameter Selection

Data Reduction

Original raw data (i.e., 1.chn, 2.chn, etc.) files are gathered according to the description in the paper. The files are then processed in two steps. The first step, performed by the Matlab file process.m, correlates the data and performs bit averaging and frame synchronization, relieving the need for a high-speed processor in the receiver. One raw file in produces one processed file out. The data stored in the processed (.prc) files has not been reduced: it contains complete time-domain snapshots provided by the raw data. The program extract.m contains the Matlab format for reading the data. Individual data may be examined by executing process.m, option 2: process(2).

The second processing step, performed by extract.m, compiles the data into three salient components: (.tda) the time-domain average for the file????, (.sta) the statistical parameters of the frequency-domain for each of the 160 instances, vertical and horizontal, and (.ext) the extracted multipath delays, with associated magnitude and phase, for each of the instances, vertical and horizontal. Therefore, one processed file in produces three data files out. The format for each of the files is contained, respectively, in readtda.m, readsta.m, and readext.m; these files may be executed to examine the data in the files.

A special set of .tda files exist which are not associated with individual files, for example, urban.tda. These contain the averaged time-domains for a set of .chn files and may be used to examine data for a particular environment. They have an associated set of .ext files, which are the estimated delays for the environment composite.

An important consideration for .ext files is that the data is ordered from shortest to longest delay and that, in the case that fewer than six dominant delays are stored, the valid data is followed by filler zeros.

Parameter Selection

The philosophies of parameter selection are:

1) That the parameters be a set of delays that can be programmed into an HP multipath simulator for field-like testing.

2) That the sets of delays be chosen to represent each of the expected environments. This would be done by choosing an actual multipath progression whose statistics reasonably matched those of the average, for each environment. This would allow each proponent access to the statistics of each environment in which it would expect to

operate, and to know the frequency and time profiles that would indicate the type of fading the receiver must deal with.

Along these lines, the files used for the multipath simulator are selected. First the .tda time-domain files are examined for each environment:

urban	(short delays - flat fading)
wooded suburban	(los plus longer delay multipath)
clear field	(los dominant)
*wooded fringe	(los and multipath at same level - strong ISI)

* although this is an important environment, it is obviously less typical than the other three

The parameters are selected to compose a total of eight test vectors, are programmed for consecutive execution into the multipath simulator. Each lasts a minute. Any portion of these eight may be selected for execution, depending on the test involved. These eight vectors cover each of the four environments, run "stationary", then repeated "at speed".

The stationary tests use the extracted parameters from the composite .ext file for each environment, which do not change over the time of a minute.

Added to these are the parameters representing mobile conditions. First, individual .tda files are examined to find one approximating the average for each entire environment. Then, three of the associated .ext files can be appended for a minute's worth of data approximating 50 mph. The four sets of data can be entered with the appropriate doppler shift for a consecutive run "at speed".

[Bob, I don't like the description for the stationary tests, which is based on what Ken said yesterday. I think we are still averaging results. (His argument of averaging and then producing 3 sigma extremes will not produce representative multipath data, which, as you know, has a definite pattern which statistical analysis could muddy.) I would rather see a slowly changing pattern of real data, with individual frames taken from real files, which would represent a real set of stationary conditions.]

This plan completes our recommendations for multipath test parameters in a timely manner. It provides a significant data base available for future study. One remaining issue is the timing of the partial or total release of this data for public proponent use.

Brian Warren

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GEORGE M. LOHNES, P.E. (1991)
RONALD H. CULVER, P.E.
ELIZABETH L. DAHLBERG, P.E.

June 10, 1993

Brian Warren
Delco Electronics
One Corporate Center, Mail stop E-110
Kokomo, In. 46904-9005

Dear Brian:

In response to your fax today about "crunching" the Charlotte data, I have the following comments.

I assume the AT&T multipath simulator is really the H.P. simulator. Programming that simulator is the main goal of the channel testing and I assume that the simulated multipath tests will be done with the simulator operating in the path mode. Fixed reflectors will be programmed into the simulator and a "path" will be "driven" around them. This will dynamically change the reflection level and the time delay from each reflector. The minimum path spacing relative to each reflector will define the minimum time delay for a reflector. The maximum delay will be defined by the relative spacing from a reflector to the end (or start) of a drive path. Since signal strength will be proportional to spacing from a reflector, the maximum delay positions will be at a very low relative level unless some of the distant reflectors are very strong to start with.

The time domain data you refer to includes, I presume, both reflection time difference from the main signal and reflection relative level. Delay spread may be the proper statistical parameter to describe multipath reflections but the actual time delay and signal levels may be more useful. The system designer will have to deal with intra symbol interference (time delay) and the frequency response of the channel. The ultimate data for the latter is going to be the frequency-domain data you describe; the center frequency, depth and width (at various depths) of the nulls. Just as important will be the short distance variation of those nulls: how long do they last, how do they change over that time/distance, and how often do they repeat? We have the problem of presenting several items of data with several degrees of freedom. Producing information on the null characteristics as described above and then quantifying them as "null spread", if you will, for different families of nulls may be better understood.

Returning to programming the simulator, and having thought about this problem long enough to type out the first page, it appears that we must first define the minimum delay times encountered and then group them by relative reflection level. That should be easy. Next we should attempt to see what happens to the relative reflection level from those close reflectors as the path is traversed. How does the reflection decay with distance. This is actually a two way problem, the approach side of the path counts too.

Then, by defining longer and longer delays, a family of reflection decays vs. path vs. delay time will be built. At some point the relative reflection levels will always be so low that they cause no significant interference, either in the frequency or time response of the channel. This may all be derivable from the delay spread of the channel but I find it better to talk it through to really understand what is happening to the signal in the channel.

Continuing on to the description of extracting the one complete frame for further study, I was not aware that you were troubled by that. Since the direct signal, if any, in each instance will recur at regular intervals (shifted in absolute time only by the relatively constant Doppler shift of the vehicle), and the reflections will shift in relative time faster (due to the geometry change over relatively short reflection paths) and will <u>probably</u> be at lower levels, the direct signal, and hence the frames, should just stand out in the time/magnitude data.

As you know I will be out of town from 6/12 to 6/27. I can be reached at 307-733-6281 with the best times between 7-9 AM MDT and after 6PM. From 6/17 to 6/19 I will be in meetings at Snow King hotel at 307-733-5200. In an emergency you can leave a message with the neighbors at 307-733-6097.

Sincerely,

Bob

Robert D. Culver

Multipath: Conversion of Data to Parameters

Philosophy and Limitations

Although the multipath parameters of the HP simulator may be varied at a 2.3 kHz rate, the attenuation has a switching delay of 400 msec typical. In addition, the manual says that changes in the phase settings are "not instantaneous" and that they are limited by the "DAC and the bandwidth of the IQ modulator", but no specifications are indicated. The following measurements should be made to get values of performance for the simulator:

1) Speed change of phase, measurable as a frequency shift of null

2) Speed of attenuation change: faster for small changes? Make sure that it is not a functionof update rate.

The hardware is more suited for quick delay changes, particularly in the CLOCK delay mode, than attenuation or phase changes. For high velocity files, having the six reflectors track the dominant values should restrict the size of attenuation changes. Hopefully, small changes will be made more quickly. For the low velocity files, changes could be made by attenuating the reflections (leaving the LOS intact) first, waiting the 400 usecs, then activating the new reflections.

Note: The .txt files control which instances are compiled into the simulator file. This text file, created with any word processor, should carry the same name as the simulator file created by GENSIM. For instance, the operator would create a file called run1.txt. By running GENSIM, and entering the name "run1", the file run1.asc will be created. Finally, this file is copied to the CHANSIM subdirectory with the multipath simulator software. She then runs ASCI2DAT RUN1.ASC RUN1.DAT to generate the .dat file for the simulator.

Run1.txt has the format of five alpha fields followed by lines of numbers. The first alpha field is either "FAST" or "SLOW", representing simulator files pertaining to the two velocities. "FAST" will cause GENSIM to create a file containing a frame for each instance, at the update rate corresponding to a certain vehicle velocity set as the variable VELOCITY under the GENERAL PARAMETERS section. "SLOW" causes the update rate to become its slowest value of 1 Hz, and each instance is repeated to maintain the frame for the duration of the variable HOLDTIME.

The next four alpha fields are headers for the following numbers, and are ignored. Each of the following lines contain the instances for each file to be included. For example, a 10 in the first column extracts instances from 10.ext, a 1 in the second column specifies horizontal polarizations (as opposed to a 2 for vertical), and the third and fourth numbers show the beginning and ending instances. Bad instances as specified in the .use are ignored. If two polarizations from the same file are desired, two lines are required. Two lines must also be used for disjointed segments of instances.

Note: Although the manual indicates that phase changes may be used to control Rayleigh delay changes, this only appears appropriate when employing fast-changing, statistically-determined profiles and cannot be used for our relatively static, exactly-determined environments.

Note: One concern has been that the environment set by the simulator could be changed so rapidly that abrupt transitions would play unreasonable havoc on the devices under test. Obviously, we have the opposite problem: changes are too slow!

Note: To verify real-time operation, run SYST:ERR? at sim conclusion. See page 3-39.

Brian Warren

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GEORGE M. LOHNES, P.E. (1991)
RONALD H. CULVER, P.E.
ELIZABETH L. DAHLBERG, P.E.

February 25, 1994

Brian Warren - DELCO

by; FedExp

Dear Brian:

The enclosed disc and hard copy are of the program called "density" (density.m and den2.m) that produced the samples of the Post Script plot files also on the disc. File 16103.exa is the data file that has non-integer bin numbers in it. I haven't the slightest idea where they came from. Using our original program "tmenvelo" produces the same results. Viewing the data shows the 6 bins and corresponding magnitudes. The bin numbers would typically be 1, 3, 14, .5, .7, .9 with corresponding magnitudes typically 0, 7.7, 12.3, 0, 0, 0. I guess it's a data translation problem.

Plot file 16allh_v.ps is an example of one plot with all of the 16000's data, both horizontal and vertical, representing "Environment D" along Wasatch Blvd. The data errors were trapped during execution and bins less than zero were arbitrarily changed to zero, a mistake in this case.

Plot file 18all.ps, for Environment A in the wearhouse area south of the airport,is similar except the format is two separate plots for H & V rather than all data on one. Plot file 18all2.ps is the same except the title, axis and color have been changed.

These graphical representations of the data show the method I planned to use to first define the envelope of an environment and then search for paths, parts of paths or groups of files to cover the envelope. I'm beginning to think we may have to produce simulated delays and magnitudes rather than use actual data. I haven't seen a part of a path that moves quickly over the envelopes produced so far. But I can't make that decision till I see all the data. I'm looking forward to working with you to get to that point.

Sincerely,

Robert D. Culver

APPENDIX C

APPENDIX C - CHANNEL TEST NEEDS; EQUIPMENT, VENUE, ETC.

C-1 Memo Report (L&C), "N.A.B. \ NRSC-DAR (Multipath Propagation Tests) Presentation - May 19, 1993

C-2 Report (L&C), Toronto DAR Symposium March 1994, EIA Digital Audio Subcommittee, The VHF Channel Characterization Test

C-3 Memo Report (L&C), to EIA DAR Subcommittee, "VHF Channel Characteristics Measurement Procedures"

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N.A.B. \ NRSC-DAR "MULTIPATH PROPAGATION TESTS" PRESENTATION - MAY 19, 1993
ver. 5/17/93

INTRODUCTION

The EIA VHF channel test program is a recent addition to the EIA-DAR system tests for the purpose of quantifying VHF propagation characteristics.

I. THE NEED FOR "CHANNEL CHARACTERIZATION" TESTS

The EIA-DAR System Test Program, was begun in October 1991 as an effort to test all potential systems in a uniform and impartial forum. It, in conjunction with the NRSC IBOC-DAR program, will test several proponents systems designed to operate in the VHF radio spectrum. Laboratory testing will employ a multi-channel multipath simulator, operating over the range of multipath propagation delays and reflections expected in the real world. Unfortunately, the current literature does not clearly define the multipath characteristics to be found at FM frequencies. Because of the proponents questions regarding the limits of multipath testing, the EIA-DAR test program will conduct a channel characterization test. The first test will be conducted at the ATV test site in Charlotte, N.C. Other tests may be conducted elsewhere to expand the data obtained relative to differing terrain and metropolitan areas. The channel test program will use a wideband digital pulse delay test system implemented by Delco Electronics. The NTIA multipath test system may also be used if needed.

II. **THE CHARLOTTE, N.C. TEST SITE;** WITH ITS 1200 FOOT LOADSTAR TOWER, is home to the PBS experimental ATV test. The proposed DAR test signal falls within the PBS television channel 6 experimental authorization and FCC notification has been made and their concurrence with the proposed test has been requested. The terrain around the site is generally rural with gently rolling topography. The city of Charlotte is located approximately 8 miles west southwest of the transmitter site, with low hills approximately 30 miles to the west and higher mountains 50 to 60 miles west northwest of the transmitter. It is expected that measurements can be made over the entire area west of the test site and including the mountains.

III. THE TEST SITE TRANSMISSION SYSTEM

The horizontally polarized antenna used by the PBS ATV test, located at 1200 feet AGL on the Loadstar tower, will not be used. Instead, an individual DAR circularly polarized test antenna, supplied by the Alan Dick Company, will be supported at 470 feet above ground level. This height, also approximately 470 feet above average terrain, simulates approximate Class B FM operation. The antenna, a Spearhead type circularly polarized panel antenna, will be arrayed as a single layer consisting of two panels splayed at approximately 120 degrees. Oriented south and northwest, the two panels will generate a relatively uniform signal over the 180 degree span centered on an azimuth of 240 degrees true.

The PBS ATV test transmitter will be used for the EIA-DAR tests. It is a Larcan solid state transmitter of nominal 30kW television power. It is capable of more than 30kW peak power but for these tests will be operated well below that level to provide the linear amplification necessary for digital testing. Since the DAR test signal occupies most of the channel 6 spectrum, testing will only be done when the ATV system is off the air. The test signal will be generated and delivered to the transmitter input from equipment specially designed and built by Delco Electronics.

IV. THE TEST SIGNAL AND RECEIVER

Delco Electronics has been investigating radio reception issues for years and has been planning this type of channel characterization test for some time. Lack of a suitable test site and FCC authorization for a test transmitter had been a major roadblock for them. The need for the EIA-DAR channel test program, the availability of the PBS ATV Test Program and the Delco built test equipment, together, allow the test to be conducted.

VIEWGRAPH #1 PRESENTS A REPRESENTATION OF THE DELCO TEST SYSTEM. The test signal consists of a string of Pseudo Random Noise pulses, structured into sequences (PN sequences), typically 255 pulses (bits) long, and driving the transmitter modulator. Use of high stability reference oscillators in both the transmitter and receiver allows for demodulation without frequency lock. The pulses will be generated at a rate of 2MHz, generating a 4mHz wide radio frequency signal, fitting within the television 6MHz bandwidth. A 5-pole elliptic filter will be used to limit the out of band emissions.

Data will be received in a mobile van driven along a desired route. The uniform spacing of measuring points will be assured by use of a trigger counter, driven by a shaft encoder on the van drive train. At each data collection point, the on-board computer will collect data over a span of from 2 to 16 continuous PN sequences. The received wave form will be digitized to 8 bit resolution, generating from 512 to 4k Bytes of data at each point. The data is two times oversampled, for both the Horizontal and Vertical polarizations resulting in from 2kB to 16kB of data per sample point. Data

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collection is continued along a path until the computer indicates its hard drive is full and halts collection. At that point the data is transferred to tape and measurements can be resumed. The spacing between sample points and size of each sample (number of PN sequences) are variable, trading resolution for path length covered before the computer storage disc is full and a data transfer to tape is necessary. At 2 PN sequences per sample point, each 0.2 wavelength along a path, approximately 13 kilometers of data can be collected before data transfer to tape is necessary.

V. THE TEST VAN SYSTEM

A. VAN & EQUIPMENT

SLIDE 1- SHOWS a standard "mini-van" with suitable modifications that will be used to receive the test signal and record data. The van must accommodate the receiver, the computer and associated equipment, other real time monitoring equipment, operators and observers. A roof rack on the van is fitted with a ground screen, covering practically the entire roof area, over which the test receive antenna will be supported.

B. "STANDARD" RECEIVE ANTENNA

Several discussions within the EIA-DAR testing group, regarding the type of antenna to be used for reception testing led to the conclusion that some type of "standard" antenna must be used. Considering the many types of vehicles and antennas available, literally thousands of possible combinations exist. Each vehicle and antenna combination defines a different antenna system with its own characteristics; no one of which could be considered "standard". Choosing a well defined "standard" antenna should make it possible for anyone wanting to apply the information resulting form these measurements to a particular vehicle, to "correct" the data to fit a particular vehicle and antenna combination.

SLIDE 2- SHOWS A PRELIMINARY STANDARD ANTENNA DESIGN. The basic antenna requirements were chosen to provide omnidirectional horizontal plane reception with good bandwidth. Furthermore, the antenna must provide dual and independent outputs for the horizontal and vertical polarization components. A monopole of approximately 1/4 wavelength will be supported over the ground plane described above. The monopole length and diameter will be designed to provide reasonable impedance and wide band performance. The monopole antenna will be surrounded by a dielectric support tube which will support the top mounted horizontally polarized antenna. That antenna will be designed to provide a nearly circular horizontal plane pattern with minimum interaction with the vertical monopole or the ground screen. The entire antenna and ground plane assembly will be constructed at the Delco facility in Kokomo, Indiana, and will then be taken to the Harris antenna facility at Palmyra, Mo. for final adjustment and testing. Testing will include impedance bandwidth and horizontal pattern measurements for both polarizations.

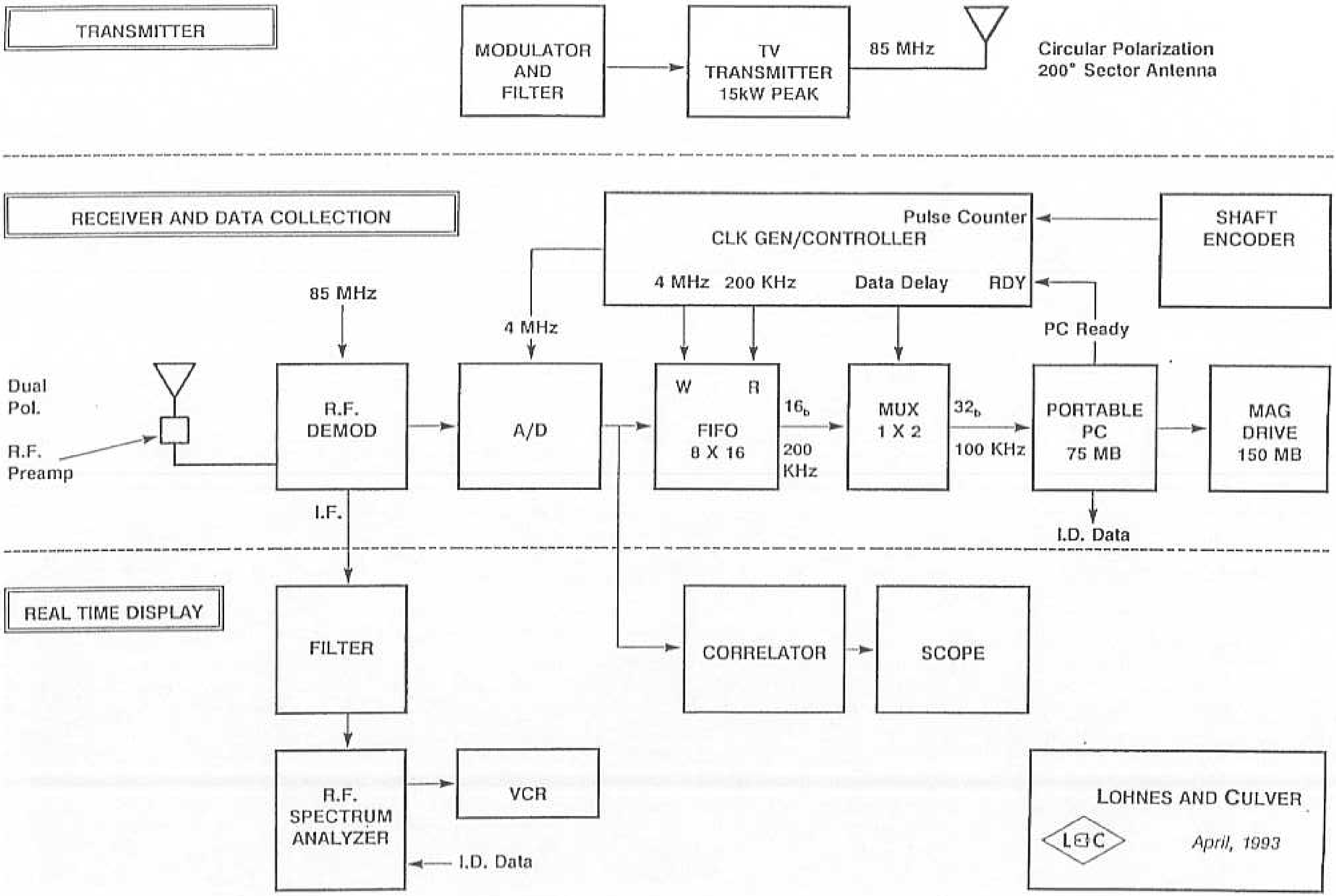
VI. DATA ANALYSIS AND RESULTS

Some instrumentation will be available in the van for real time observation of the test in progress. For the digital data, an on-board correlator will be used to recover the channel delay information for display on an oscilloscope. The Radio Frequency signal will be monitored at I.F. on a spectrum analyzer. The analyzer will then display a "Gaussian Noise" shaped frequency response over the approximate 4mHz wide test spectrum. Observation and recording this output will provide a visual representation of the depth, width and positional frequency of radio frequency fades.

The raw data contained on the data tapes will be remotely analyzed by de-correlation against the original PN sequence. The direct and reflected signals can then be identified, allowing generation of time spectral density graphs. Power levels present at the receiver may then be derived and statistically analyzed for spacial distribution parameters.

Measurements will have been made over the variety of terrain around the Charlotte test site. It will include the central city area, the rolling terrain in the rural area and the mountainous area to the north west. The typical range of time delay and magnitude of the reflections will be identified with the different areas. The upper and lower bound of the range of reflections will determine the limits for the laboratory simulation of multipath. Testing in other cities with different urban structure and surrounding terrain may be done to add to the multipath characterization data base. The data that is collected will be of value to the proponents and others interested in the multipath characteristics of the VHF channel.

EIA would like to acknowledge the assistance of all parties who have contributed to this ongoing program. Individuals include; the EIA WG-B Channel test Sub-Group, Brian Warren, Tom Keller, Bill Spurlin and Bob Culver and proponent member Carl Erik Sundberg form AT&T. Corporate assistance has been provided by; PBS for the use of the Charlotte ATV test site, tower site manager Loadstar, Larcan transmitters, Alan Dick Company, Cablewave, Passive Power Products, Delco Electronics and a host of others.



TRANSMITTER
MODULATOR AND FILTER
TV TRANSMITTER 15kW PEAK
85 MHz
Circular Polarization
200° Sector Antenna
RECEIVER AND DATA COLLECTION
CLK GEN/CONTROLLER
Pulse Counter
4 MHz
200 KHz
Data Delay
RDY
SHAFT ENCODER
85 MHz
4 MHz
PC Ready
Dual Pol.
R.F. Preamp
R.F. DEMOD
A/D
W
R
FIFO 8 X 16
16b
200 KHz
MUX 1 X 2
32b
100 KHz
PORTABLE PC 75 MB
MAG DRIVE 150 MB
I.F.
I.D. Data
REAL TIME DISPLAY
FILTER
CORRELATOR
SCOPE
R.F. SPECTRUM ANALYZER
VCR
I.D. Data
LOHNES AND CULVER
L&C
April, 1993

THE EIA DIGITAL AUDIO SUB-COMMITTEE VHF CHANNEL CHARACTERIZATION TEST

A Preliminary report on VHF Channel Characterization Testing and Plans for Proponent System Laboratory Testing

Robert D. Culver, P.E., Lohnes and Culver
Consulting Engineers, 8309 Cherry Lane
Laurel, Maryland 20707-4830

ABSTRACT

The Electronic Industries Association (EIA) DAR Subcommittee is evaluating proposed Digital Audio Radio (DAR) systems for the United States. As a part of that process, the Subcommittee is conducting a "VHF Radio Channel Characterization Test". The results of the test will be applied directly to the laboratory testing of the DAR systems and will also find general use within the radio communications industry.

INTRODUCTION

The EIA DAR Subcommittee was organized in October 1991 for the purpose of documenting and testing all potential United States DAR systems in a uniform and impartial forum. The testing will take place in both a laboratory and the field. The VHF channel characterization test program is a recent addition to the EIA-DAR system tests for the purpose of quantifying VHF multipath propagation characteristics for the FM channel proponent laboratory tests.

The test system consists of a wide band pulse transmitter, a mobile data collection van with receiver and off-line data processing. The test signal consists of a series of pseudo-random pulses, transmitted at a pulse rate of 2 MHz, yielding a 4 MHz wide test signal centered in the television band at Channel 6, 85 MHz. Transmission is made with a circularly polarized antenna for reception on a specially designed and built dual-independent polarized antenna. Data collection is triggered at fixed intervals along a path, for this test every 1/10 wavelength. By choosing the path to cover a representative sample of an area, the channel characteristics of that type of area can be reported.

The data is analyzed to reveal the delay times and magnitudes of the transmitted reflected signal, relative to the direct signal. This data is used in simulating the multipath environment for laboratory testing. From that information the frequency domain channel characteristics are then calculated and presented. The data can be analyzed in a variety of formats for presentation to specific users relative to their particular needs. A sample of the analyzed data is presented in this report supported by a series of tables, charts, graphs and photographs.

The Need for "Characterization Tests"

Laboratory testing will employ a multi-channel multipath simulator, operating over the full range of multipath propagation delays and reflections expected in the real world. Unfortunately, the current literature does not clearly define the multipath characteristics in relative time delay and reflected signal level to be found at FM frequencies. As a result of the proponent's questions regarding the range of multipath testing, the EIA-DAR test program was expanded to conduct a channel characterization test. The Advanced Television (ATV) test being conducted by PBS in Charlotte, N.C. had an existing FCC authorization to conduct experimental ATV broadcast tests which presented an opportunity to experiment with the DAR Channel test system. Data collection was later conducted in Salt Lake City. This paper describes the progress of the

EIA-DAR Channel Test as conducted to date and the forthcoming data reduction and reporting.

THE CHANNEL TEST SYSTEM

The system used for the EIA DAR Channel test, much like that described by Herman[1] and Moriyama [2], was built by engineers at the DELCO Electronics Audio Advanced Development Laboratory at Kokomo, Indiana. It consists of a pseudo-random pulse generator driving a wide band (television) transmitter as shown in the system block diagram in Figure 1. A pseudo random pulse string, 255 pulses (bits or chips) long, is generated at the pulse repetition rate (chip rate) of 2MHz. The string of pulses is random in time over the 255 pulse string which is then repeated continuously, hence the pseudo-random nature of the pulses. The repeated 255 pulse string, called an "instance", is long enough to allow for calculation of over 40dB of level resolution but short enough to assure identification and capturing of one complete string in a relatively short time with a reasonable amount of data. The 2MHz pulse rate and the method of computer analysis used, allows resolution of signal reflection delay times as short as 250 nanoseconds with a finite probability of error, and as long as 127.5 microseconds delay time.

Transmission

The transmitter begins with a pulsegenerator providing a single-bit, shift register based, Pseudo-random Number (PN) sequence, with accuracy derived from a 25ppm crystal oscillator. The natural frequency side lobes of the sequence decay in level with frequency and they are subject to an additional attenuation of 20 dB by filtering in the signal generator to achieve 30 dB or more attenuation with respect to the main lobe. The PN sequence is 255 pulses long over which its timing is random. The sequence is continuously repeated, hence the pseudo-random nature of the signal. This pulse train phase modulates a high stability (1ppm) oscillator, resulting in the BPSK (suppressed carrier) signal at approximately 44 MHz. The actual frequency is adjustable over a moderate range, within the range acceptable to most television transmitter exciters. The transmitter exciter provides additional filtering of the sidelobe out-of-band components in a Surface Acoustic Wave (SAW) filter, and provides a constant amplitude signal to drive the transmitter power amplifier. The power amplifier is capable of a significant television peak of sync power but it is driven only to an output power of a few dB below the power compression point to maintain good amplitude linearity.

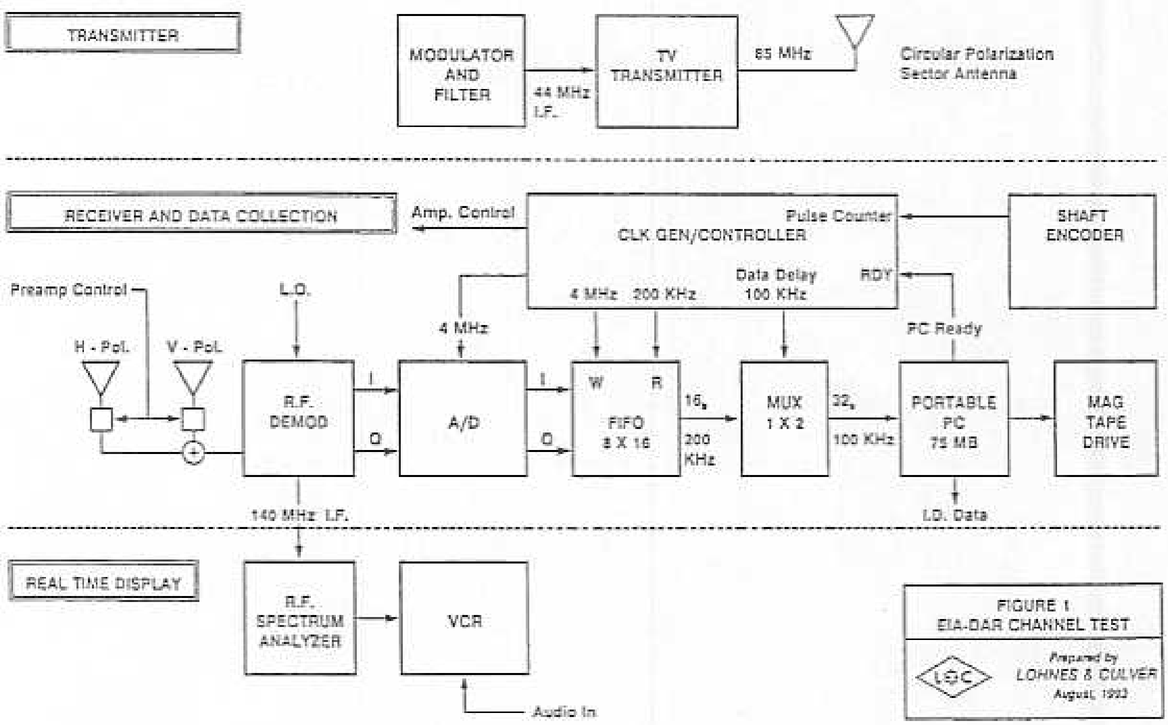
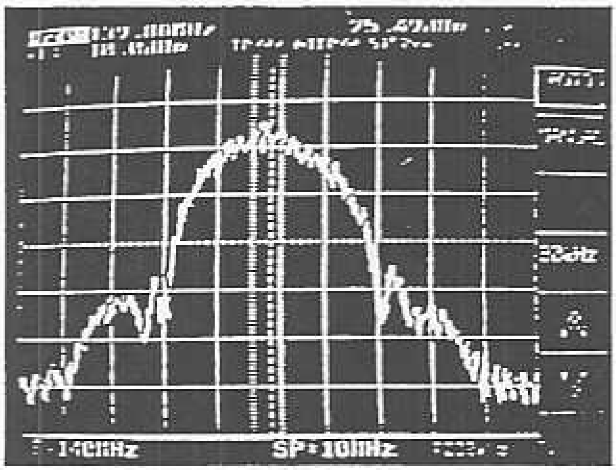


FIGURE 1
EIA-DAR CHANNEL TEST

The 2MHz pulse rate and BPSK (suppressed carrier) modulation generates a 4 MHz wide R.F. spectrum with its first frequency nulls at ±2 MHz and decreasing side lobes, each 2 MHz wide. The output is filtered as described above so that the transmitted signal appears as a 4MHz wide Gaussian distributed noise signal with rapidly decreasing side lobes as shown in the photograph of Figure 2.

FIGURE 2
Channel Characterization Test Signal



This spectrograph of the receiver I.F. output was taken with the test transmitter signal connected directly to the receiver antenna input. The horizontal span is 10 MHz, a scale of 1 MHz per division, with a vertical span of 80 dB, a scale of 10 dB per division. The test signal was transmitted with a center frequency of 85 MHz, the center of the television Channel 6 band, a relatively accessible frequency where ever a television Channel 6 station is not operating. This frequency is also sufficiently close to the FM band to accurately characterize it. Use of high stability reference oscillators (1 part per million) in both the transmitter and receiver allows for demodulation without frequency lock.

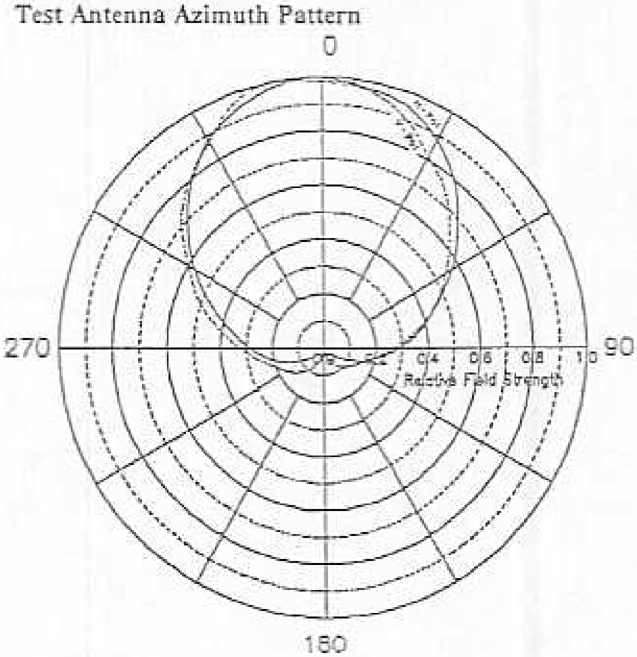
In Salt Lake City, a 6 kW Larcan transmitter was used with a two element LDL Spearhead Panel antenna configured with two elements stacked vertically and splayed ±30 degrees to provide a narrow azimuth pattern oriented east over the city and toward the mountains beyond. The resulting horizontal plane relative field patterns are shown in Figure 3.

The antenna was mounted at approximately 9100 feet AMSL or 4500 feet above the valley floor at the Bonneville Broadcasting KSL(TV) transmitter site on Farnsworth Peak, 18 miles west of Salt Lake City. The resulting ERP of 7.6 kW average power is sufficient to cover the city and surrounding area including the mountains up to 25 miles away.

Receiver

The receiver, using Superheterodyne radio frequency design, was also built by Delco. It was carried in a mini-van along with other associated equipment including a specially built "reference" antenna. Each of the two independently polarized antennas feed modular amplifiers and each amplifier output is combined in a power coupler into the single channel receiver. Under control of the test computer the antenna amplifiers are alternately turned on, completing one path and rejecting the other by over 40dB. In this combined R.F. output channel several tunable notch filters are available to remove strong out-of-band components without perturbing the pass band signal. The filtered signal is then mixed with a 140 MHz Local Oscillator (LO) to generate the 140 MHz I.F. and further filtered by a Surface Acoustic Wave (SAW) filter to provide up to an additional 40dB of out-of-band rejection.

FIGURE 3
Test Antenna Azimuth Pattern



At this point the signal is sampled for several monitoring functions. First, the IF is sampled to display the RF component on a spectrum analyzer with that display recorded on a video recorder. The IF is also mixed to baseband for monitoring by an oscilloscope to facilitate tuning the LO to zero frequency offset with the transmitter. In practice, approximately a 100 Hz drift occurs during one measurement run which has no significant effect on the data that is recorded.

Next, both the I and Q signal components are sampled by an 8-bit A/D converter. The resulting half-Least Significant Bit (LSB) uncertainty error is more than 40 dB below full level, limiting the dynamic range of the A/D conversion to approximately 40dB. A manual attenuator with a 50 dB range is adjusted on each data collection run to set the signal in the optimum digitizing range. The system has an effective sensitivity of better than -69 dBm in the presence of anticipated interference from strong nearby adjacent channel stations.

The received waveform is sampled at 4 MHz, twice the transmitted pulse rate (two times oversampled). The need for bit synchronization circuitry is eliminated by averaging every pair of data points. Data acquisition is controlled by an enable signal from the computer for each sample point. At each sample point the first polarization waveform is digitized and loaded into First-In-First-Out (FIFO) memory. Then the antenna amplifiers are switched and after a 1 microsecond settling time, the opposite polarization signal is digitized and transferred to FIFO. The antenna amplifiers are then switched back to their normal state to wait for the next sample point. The system remains in this position for at least 14 milliseconds while data in FIFO is multiplexed and loaded into the computer memory. This measurement cycle is dependent on the basic data transfer rate of 100kHz, from data acquisition board to computer, setting the maximum speed of data collection. That, in turn, sets the minimum computer cycle time which determines the maximum vehicle speed at the minimum sample point spacing chosen for this test. After collection of one data file, 1 M byte of data, the system pauses briefly to save the file to disc, clears the acquisition board and resumes collection.

Receiving Antenna

Several discussions within the EIA-DAR testing group, regarding the type of antenna to be used for reception testing, led to the conclusion that some type of "reference" antenna must be used. Considering the many types of vehicles and specific antennas available for each, literally thousands of possible combinations exist; no one of which could be considered standard.

The basic antenna requirements were chosen to provide omnidirectional horizontal plane reception with good bandwidth. Furthermore, the antenna must provide dual and independent outputs for the horizontal and vertical polarization components. The standard test antenna was designed in a joint effort by Delco, Lohnes and Culver and Harris. It is designed to receive both the horizontally and vertically transmitted components, but to receive them separately and independently with little interaction. Tests show that the antennas have a horizontal plane circularity of better than ±2.5 dB and a cross polarization self discrimination of at least 10 dB as shown in Figures 4 and 5 on the next page.

Figure 6 shows the test antenna mounted over a ground plane atop the van with its center approximately 3 meters above ground level. A monopole of approximately 1/4 wavelength is mounted over the ground plane described above. The precise monopole length and diameter was chosen to provide reasonable impedance and wide band performance. The vertical monopole antenna is surrounded by a dielectric structural tube which supports the top mounted horizontally polarized antenna. That antenna is designed to provide a nearly circular horizontal plane pattern with minimum interaction with the vertical monopole or the ground plane. The entire antenna and ground plane assembly was constructed and tested at the Delco facility in Kokomo, Indiana, with further testing at the Harris antenna facility at Palmyra, Mo.

The separate antenna lines were connected to medium gain amplifiers in the receiver, as described above, which could be biased on or off under control of the test computer, discussed below.

FIGURE 4
Standard Receive Antenna Horizontal Polarization

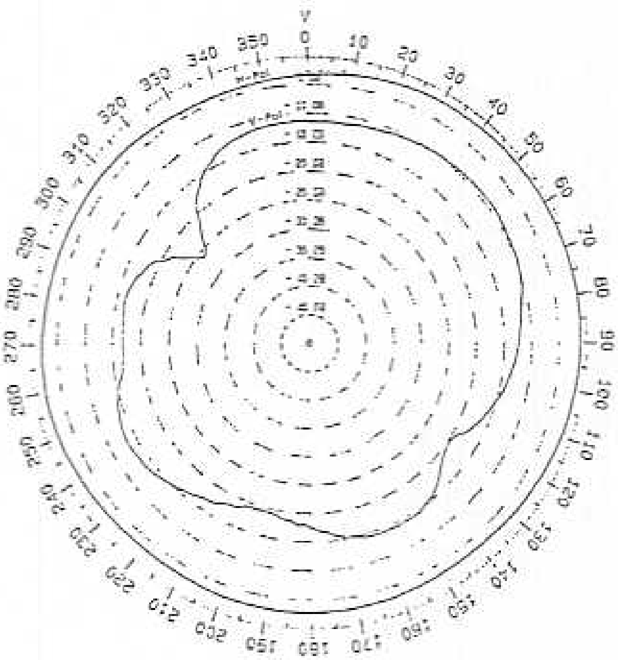


FIGURE 5
Standard Receive Antenna Vertical Polarization

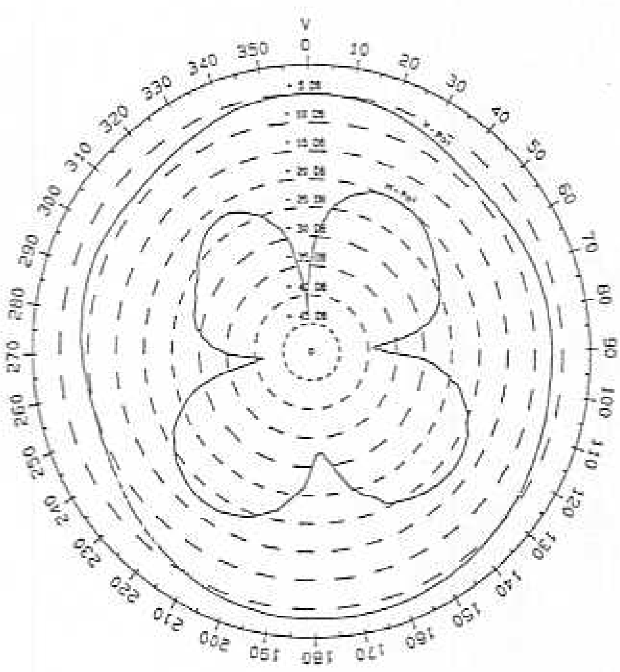


FIGURE 6
Test Van and Antenna

Computer

The test signal is received in the mobile van driven along a desired route. Uniform spacing of measuring points is assured by use of a trigger counter, driven by a shaft encoder on the van drive train. At the start of a measuring route the trigger counter and computer program automatically controls data collection. The crew in the van make notes of the run number, location and environment description, starting parameters such as attenuator setting and LO frequency, the time and date. The shaft encoder generates a string of pulses with vehicle motion and sends them to a programmable counter in the computer which, depending on its programming, sets the linear spacing of the data samples along a path. For this test, the sample interval was set at 0.35 meters or 1/10 wavelength at the 85 MHz center frequency, close enough to define the spacial distribution of multipath characteristics along the path and hence over an area.

At each data collection point, the on-board computer executes a routine which collects data over a span of 3 continuous PN sequences to ensure that after analysis at least one full instance is available. The received wave form is digitized to 8 bit resolution for the default polarization and then immediately repeated for the other polarization as described above. Data collection is continued along a path for up to 4.4 kilometers, 75 MB of data, until the computer hard drive is full and halts collection or when a convenient stopping landmark is reached prior to that.

At that point the 75MB data file is transferred to tape and ending parameters are noted such as; path end landmark, time, file length and LO frequency. After approximately 15 minutes required to transfer data to tpae storage, measurements can be resumed.

The collected data is grouped into 1 MB files each containing 160 samples of approximately 6KB each and covering 56 meters. A one kilometer path requires approximately 17 MB of data and a full 75 MB disk covers approximately 4.4 kilometers of path before data transfer to tape is required. The point spacing and the speed of the computer system allows for data to be collected at up to 60 KPH. However, slower speeds make data collection easier for the crew in the van.

At each sample point both the horizontal and vertical polarized signal were received and recorded. To do this the computer controlled the antenna amplifiers as described previously. The transition time between amplifiers is short enough to limit the distance moved between the horizontal and vertical samples to less than 1/100 wavelength at the maximum data collection speed. In reality, at lower speeds, the interval is less and the two samples are collected at nearly the same location.

Other System Equipment

As data was collected the computer displayed the 1 M byte sequential file number last written. At easily identified landmarks, such as cross streets, the file number, the landmark and other data, such as time, were written down by the van crew. Later, by plotting the measurement path and the file numbers on detailed topographic maps, the exact position at which data was recorded can be determined by linear distance interpolation along a path. Also on board were a spectrum analyzer and a video recorder. The analyzer, connected to the receiver I.F. output, displayed the signal spectrum after conversion to the 140 MHz I.F. The spectrographs attached as Figures 7A through 7D again show the reference signal and several typical multipath faded channels displayed by the analyzer.

The receiver sampled both the horizontal and vertical polarizations before conversion to I.F. but, because of the strong time bias toward one antenna, the predominant signal displayed is the default polarization. The spectrum analyzer has an update rate of less than five times per second which presents only a "snapshots" of the spectrum when vehicle speed is relatively high. At very slow speeds, however, even this slow update is fast enough to show a slowly changing spectrum.

FIGURE 7-A
Direct Input Test

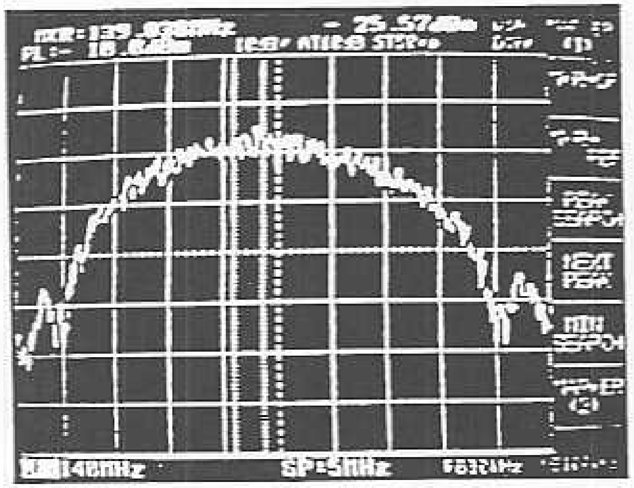


FIGURE 7-B
Sample Spectrograph

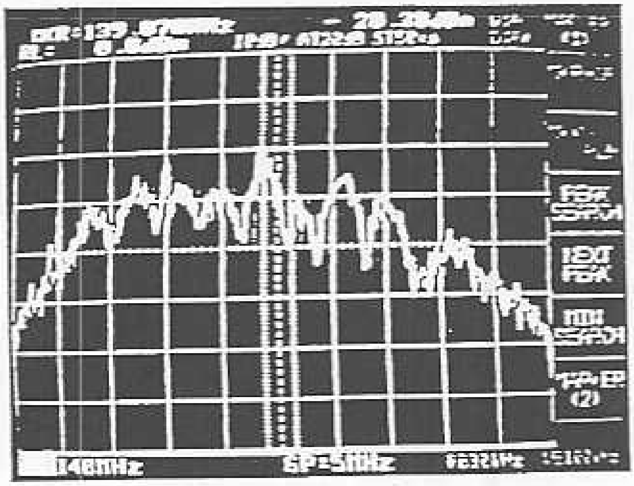


FIGURE 7-C
Sample Spectrograph

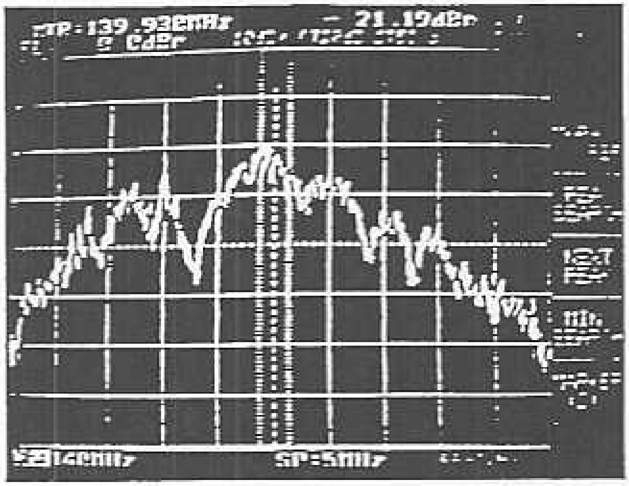
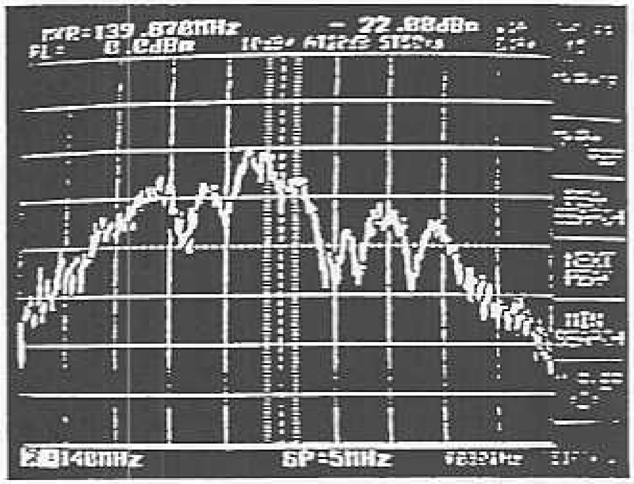


FIGURE 7-D
Sample Spectrograph



The recording of the spectrum analyzer display and the audio from a microphone in the van gives a continuous update on activities in the van. Thus, as each landmark was called out, the tape would contain narration describing the path and measurement positions.

DATA ANALYSIS AND REPORTING

The data that is generated by the test system is prodigious. At 17 M byte per kilometer, over 500 M bytes of data was collected in one day and nearly 3 Gigabytes of data was collected in one week. Data analysis requires identification of one full pulse instance and de-correlation of the data. Delco electronics and SEIKO Telecommunication Systems, Inc. of Beaverton, Oregon have contributed their time and computer facilities to perform the data reduction using the Math Works "MATLAB" software. The extensive matrix math operations involved in the data reduction require significant computer speed. The computers available included an IBM model RS/6000 and HP series 200 work station. Data analysis and presentation after bulk reduction is possible on a fast PC.

The data is processed in two logical sections. First, the data is averaged in a 2 bit moving window, decorrelated and frame synchronized to extract the single I/Q frames for the two polarizations at each sample point. This processed raw data is in a convenient format for further analysis. The second processing section analyzes the data for this study, extracting the parameters that will be used to program the multipath simulator and determining the statistics of the multipath fades in both time and frequency domains.

The first step in analyzing the processed data is to extract the relative time and magnitude of the five primary reflections in the channel. These delay values (plus the direct signal) will be programmed into the six channel multipath simulator. Knowing the time delay and the complex magnitude of the reflections allows the frequency domain effects to be calculated. This method of transforming the data from time to frequency is used to determine the significance of a reflection by assessing its frequency domain impact. Each of the significant reflections are shown by the cross tic-marks (+) on the time domain graphs. The corresponding frequency domain is shown as a "smooth" curve for the 6 or fewer significant points and as the "rough" curve for all reflection points in each of the 250 nanosecond bins.

The analysis is done by a complex algorithm based on linear programming, using the modified forward-backward linear prediction method described by Tufts [3] and suggested by Herman. It is a powerful algorithm for resolving reflectors spaced closer than the time between two transmitted pulses (chips), a single timing bin, in this case 500 nanoseconds, and in the presence of noise. With this method reflectors spaced less than half of a timing bin can be resolved at the minimum receiver SNR of 10 dB. In this method the channel is modeled as a Finite Impulse Response (FIR) filter with the number of filter elements is set at twenty. This allows the algorithm to perform nicely without using undue processing time that would be required for a larger filter order.

PRELIMINARY SALT LAKE CITY TEST RESULTS

The parameters of delay time and magnitude, over a set of instances that are grouped by physical environment, provide the path information to be programmed into the multipath simulator. Samples of this extracted data are shown on the following pages in Figures 8.A.1 & 2 through 8.D.1 & 2, presenting data for only one instance in each of the four chosen "environments" A,B,C and D described later. Samples of the time domain data transformed to frequency domain are also shown on those Figures.

A visual representation of time and magnitude data over one full set of 160 samples is shown on the waterfall graphs of Figures 8.A.3 through 8.D.3. Figures 8.A.4 through 8.D.4 show the resulting scattering function displays with Doppler shift vs. delay and magnitude. Mean and variance parameters are extracted to show a statistical profile of each environment as shown on Figures 8.A.5 through 8.D.5.

"Environment" Categorization

The test van was driven throughout Salt Lake City and the surrounding area collecting data along 21 paths ranging from 4.4 to 8.8 kilometers, zig-zaging across or encircling an area, for a total of approximately 140 kilometers of continuous data. The data was collected and numbered with a 5 digit identifier, two digits relating to the path number and three to the individual 1 M byte data files. Therefore, because each landmark was identified by the file being written at the time, the location along a path at which data was taken is known with the precision of each 1 M byte of data, 160 samples or 56 meters.

Each of the 21 paths was analyzed for the type of "environment" (buildings, vegetation, terrain, urbanization, etc.) that was predominant along the path or a significant portions of it. Preliminary review disclosed eight narrowly defined environments which were reduced to the four major environment categories listed below. Figures 8.A.1 through 8.D.5 correspond to environments A through D.

A. URBAN BUSINESS-INDUSTRIAL-COMMERCIAL:

This environment includes; the central city business district and surrounding area, approximately 6 blocks north-south by 8 blocks east-west; an industrial/warehouse area south west of the city center; and several moderately heavy commercial areas comprised of shopping centers and malls with multi story buildings.

The traffic paths are generally close to the buildings indicating that the expected reflections should be short in time delay and generally strong in level. The practical vehicle speed in the area ranges from stopped to approximately 40 KPH (25 MPH). Numerous stop lights and stop signs require stops from 0 to 45 seconds at frequent intervals. A simulation consisting of alternate stopped and moving data will be used.

B. SUBURBAN - RESIDENTIAL:

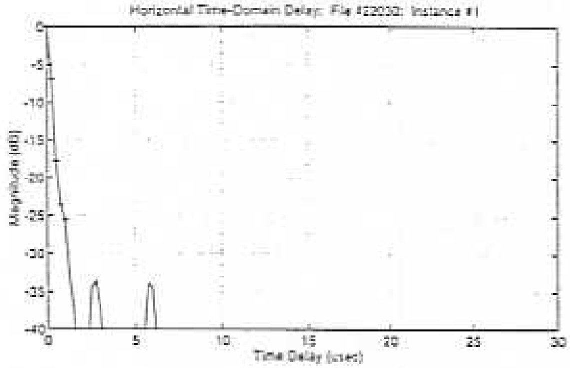
This environment includes many residential areas, scattered to the south of the city center. They range from single family large homes on large lots to duplex town houses and apartments. As a consequence, the neighborhood may include light commercial shopping areas, schools, libraries, college buildings, etc. Some of the typical older residential areas were heavily covered by mature trees of up to 25 meters in height.

The traffic paths are generally more open than for the urban environment but still relatively close to some structures. The expected reflections should be moderately short in time delay and moderately strong in level. In the more open areas in the environment, longer and weaker delays may predominate. The practical vehicle speeds still drop to zero on occasion but may increase to 70 KPH (45 MPH). A simulation with varying speed and few stops will be used.

C. RURAL - PARKWAY - HIGHWAY:

This environment includes generally open areas with a variety of roads ranging from; single lane country roads north west of the city, to divided

8.A.1



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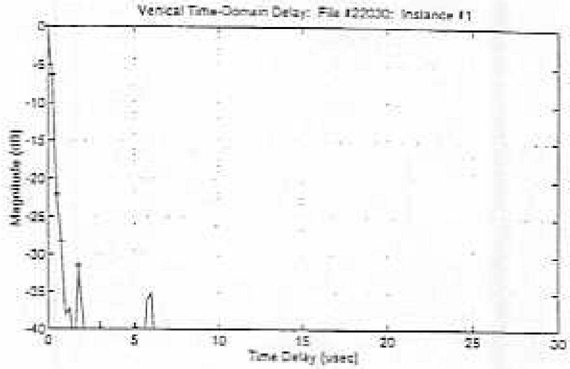

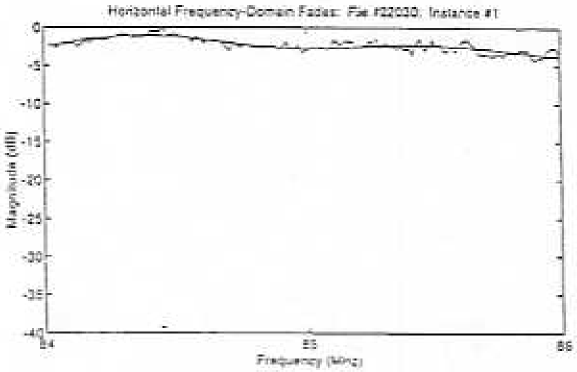

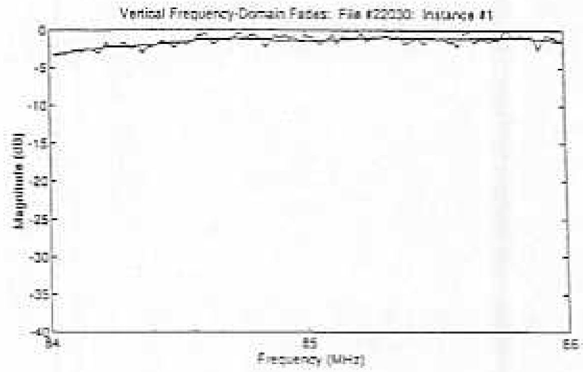

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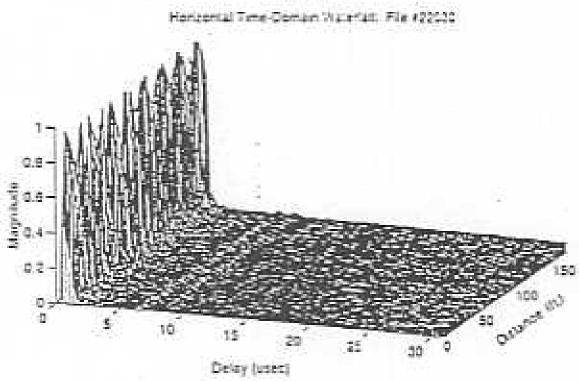

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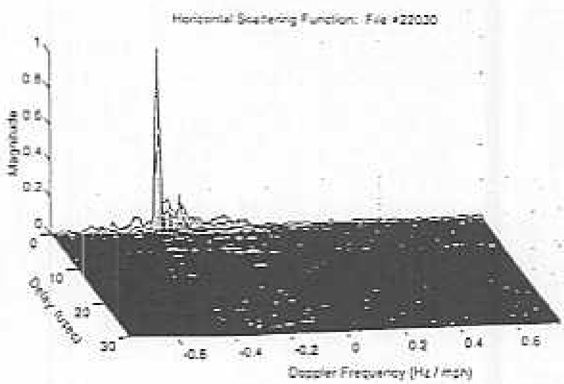

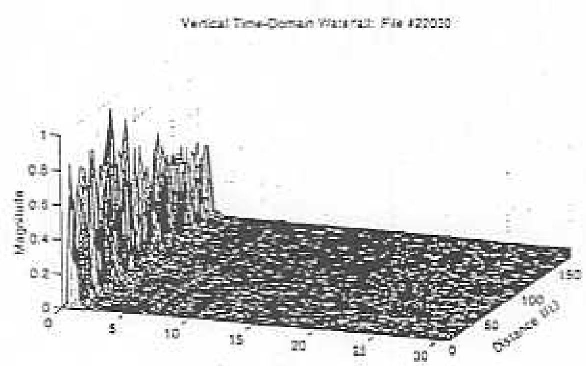

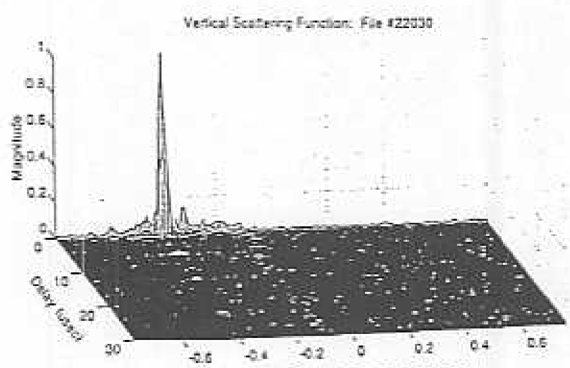

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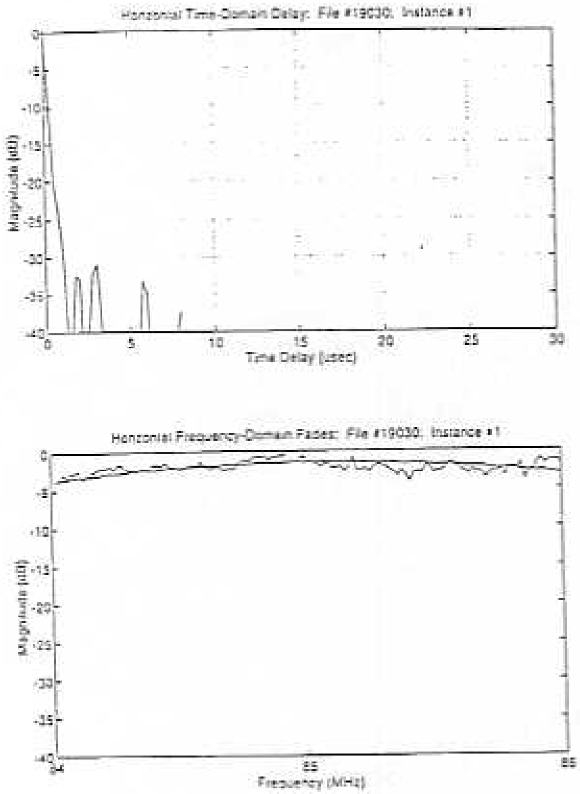

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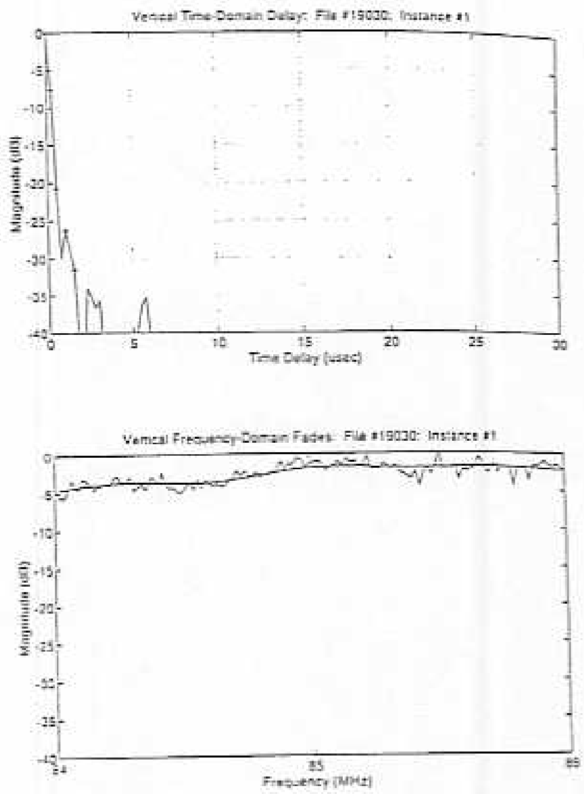

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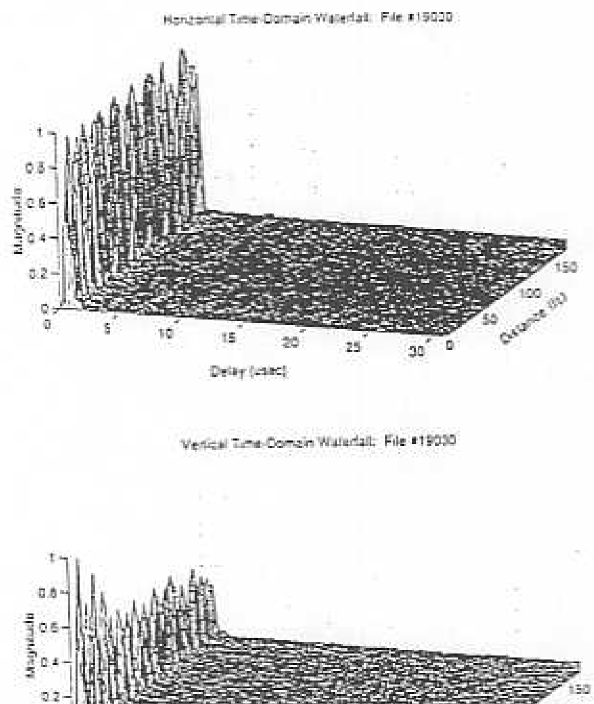

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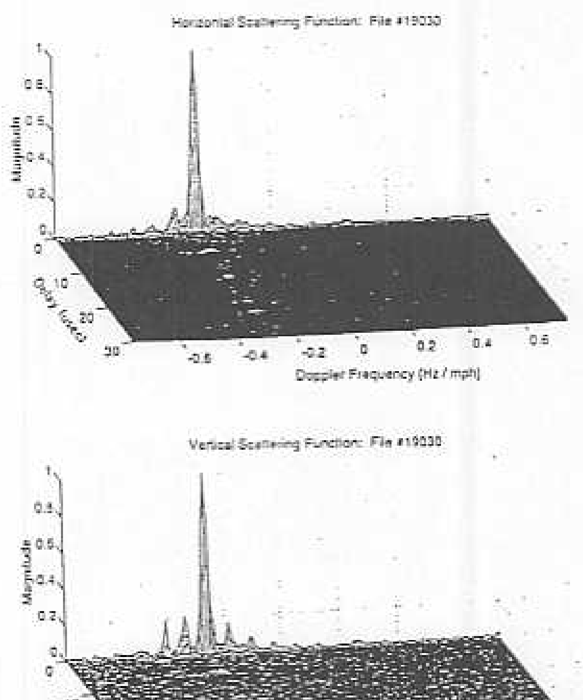
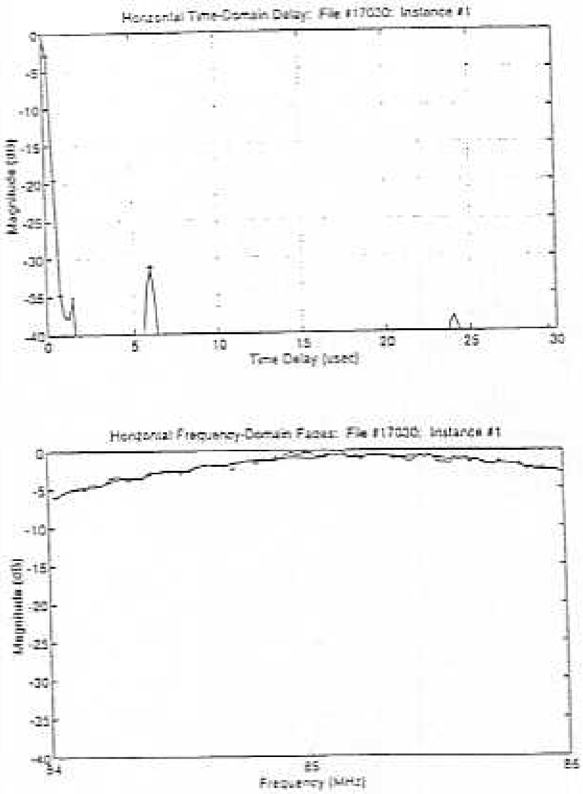


8.C.1.



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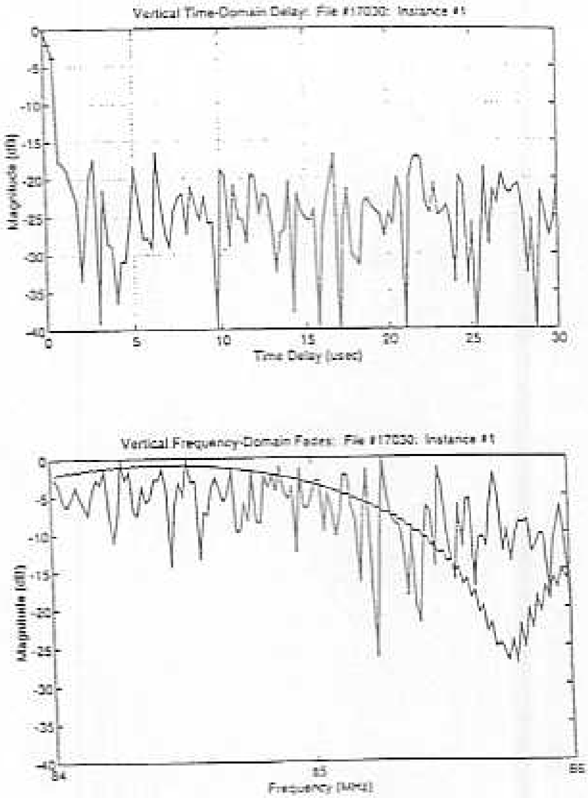

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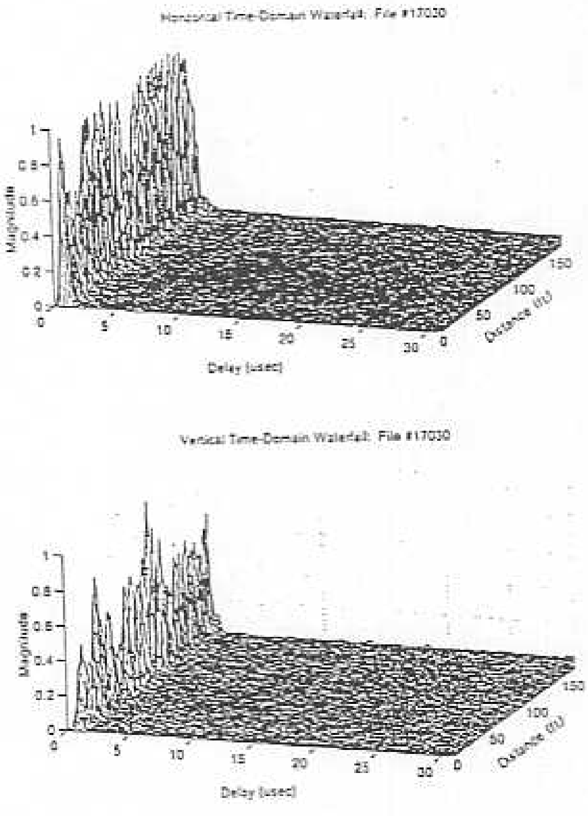

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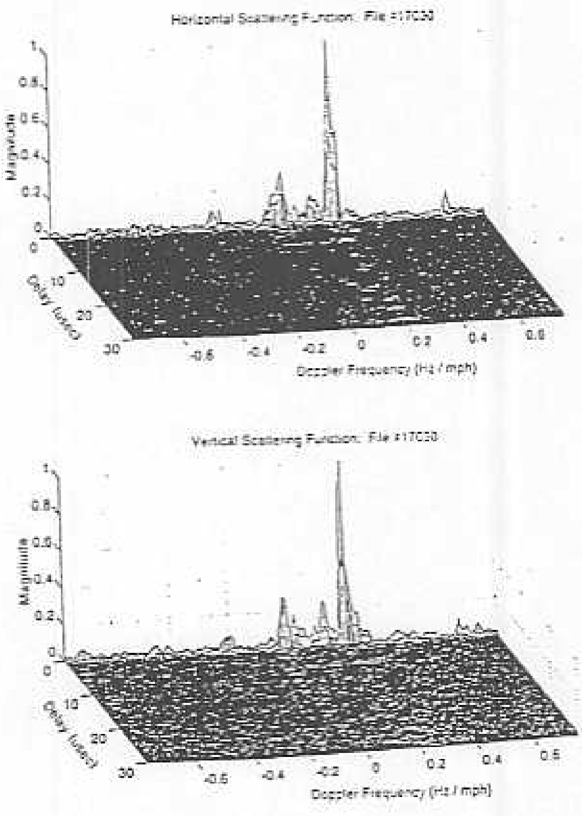
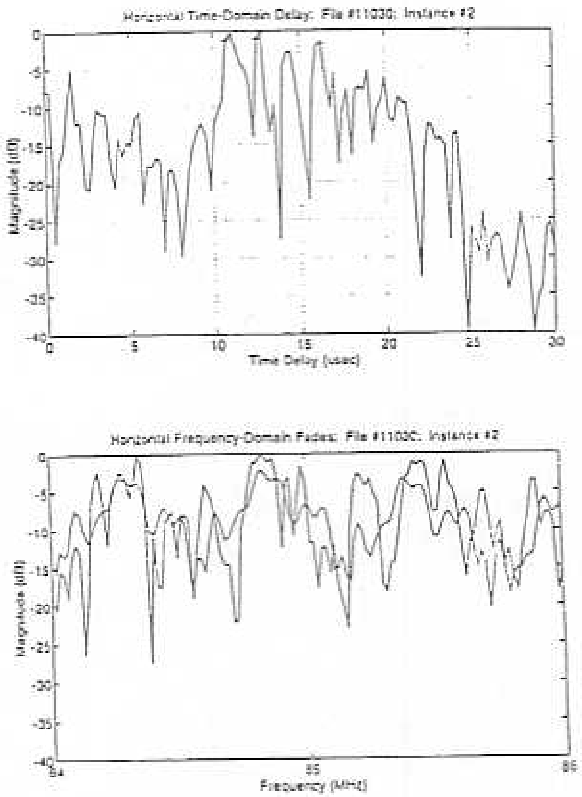
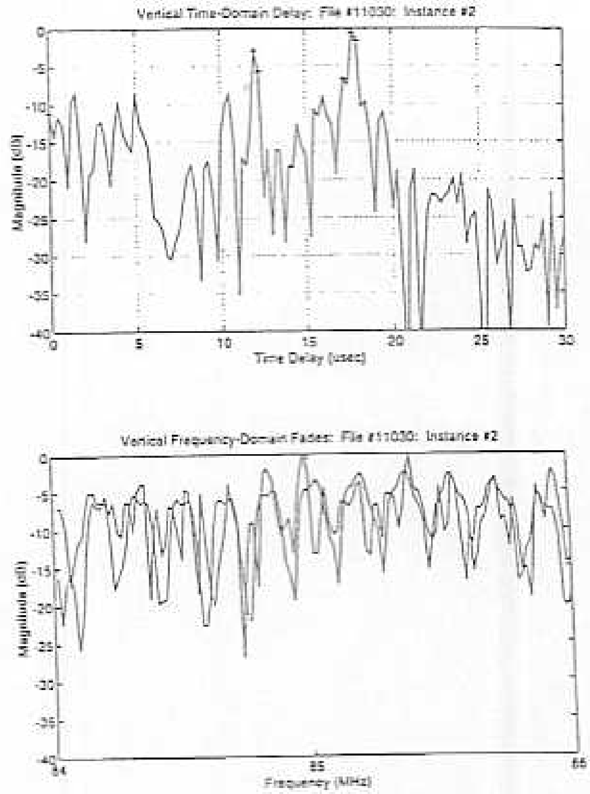


8.D.1.



8.D.2.



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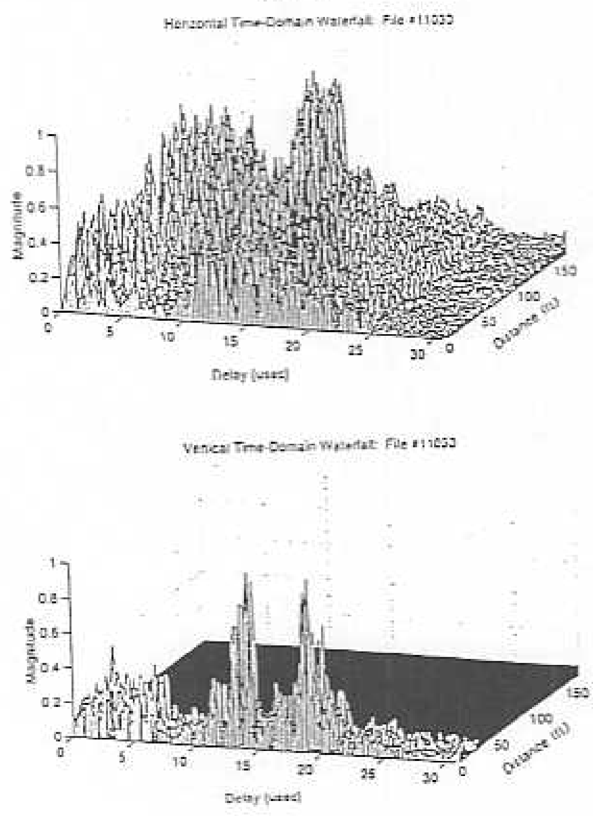
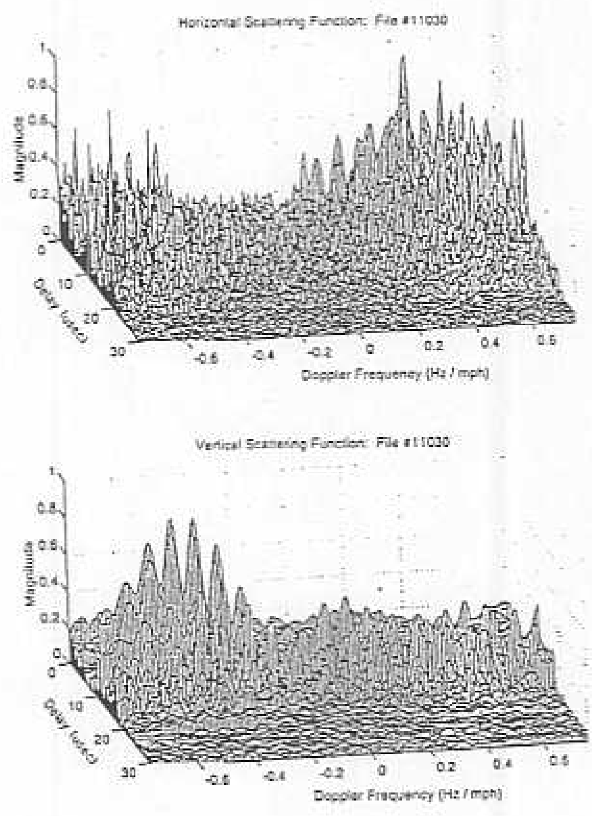


8.D.4.



highway parkways south of the city, to a commercial boulevard east of the city at the foothills of the mountains.

The open nature of the areas generally keeps the closest structures moderately far from the measurement path, with the structures themselves including all types from multistory office buildings to small residential buildings. The expected reflections should be moderate but cover a relatively wide range of time delays and magnitudes. The practical vehicle speeds should very rarely drop to zero. The range to be used is from 40 to 100 KPH (25 to 60 MPH) with one stop.

D. TERRAIN OBSTRUCTED PATHS:

This environment will include those paths which have a significant terrain involvement, including the Big and Little Cottonwood canyons and the few paths that followed river valleys in the area south and east of the city.

The terrain along these paths is the significant factor but some, particularly the river valley path, have some structures along the path. The expected reflections should be numerous and rapidly changing with moderate to long reflections over a wide range of magnitudes. The major feature of the signal path should be the frequent loss of a direct path with the dominant reflection becoming the substitute direct path, one which is subject to rapid change as reflection characteristics change. The practical vehicle speeds should rarely drop to zero but should also not be too high. The range to be used is from 25 to 70 KPH (15 to 45 MPH) with one stop.

LABORATORY TESTING - Multipath Simulation

The general parameters and operations of the DAR systems to be tested are well known but some of the system specific parameters that will affect testing are as yet unknown. The characteristics of multipath propagation which will affect those systems are also generally well known with the precise values of those characteristics being determined by this Channel test. The characteristics and application of the Hewlett Packard multipath simulator are generally understood but will become better known upon actually using the instrument with the data from the test.

As a result of these unknowns and variables, the actual fine structure of the tests will not be known until just before the start of actual testing. Several parameters which may be subject to change include the length of the test samples in each environment, speed and number of stops. The range over which the testing will be conducted, however, can be determined at this time from the channel test data.

This choice of four environments reduces the time burden on the laboratory testing, primarily in the audio listening tests. CRC, the audio test segment contractor, has stated that the test segments should be relatively short, preferably 30 seconds, and no more than 60 seconds. Within this constraint, a multipath test simulation must be devised which presents the full range of multipath conditions of an environment to each system under test. Some system parameters will define the minimum time in which an environment can be simulated. For example, environments which require zero velocity testing will be examining the system performance under fixed fade conditions, performance highly dependent on the length of data time interleaving in the system. Each simulation stop must be long enough to test all systems and short enough to test a sufficient number of stops without exceeding the maximum audio sample time. It is anticipated that a minimum of five stops would be necessary and exceeding the 30 second test time is likely.

If a segment of actual measured data, or several shorter segments for a "stopped" test, can be found which adequately represent the full range of multipath conditions in an environment, then there is no apparent reason that actual data should not be used to program the simulator. If, however, this is not the case, then it may be necessary to define the parameters over the maximum range and generate an artificial but representative segment. This choice can only be made after all of the channel data can be analyzed and the systems under test and simulator limitations are known. This will only affect the actual method of simulated testing while the general range and limits of testing will remain unchanged, being indicated by the data measured in Salt Lake City.

CONCLUSIONS

This procedure for data gathering and analysis will deliver results directly applicable to the laboratory multipath simulation testing.

Measurements will have been made over the variety of terrain around the test site. Data will include central city areas, hills and rolling terrain in suburban and rural areas and mountainous areas. The typical range of time delay and magnitude of the reflections will be identified with the different areas. The mean and variance of the reflection delay time and complex magnitude will be determined and used to guide the laboratory testing with the multipath simulator. From this information other parameters such as the channel frequency domain characteristics and statistical data will be computed. The data that is collected will be of direct value to the DAR proponents and others interested in the multipath characteristics of the VHF channel. In its processed form the data is well suited for further analysis ranging from frequency domain characterization to point-by-point generation of a multipath model.

The VHF channel characterization test is a joint effort of many parties who have contributed their time and materials. EIA would like to acknowledge the assistance of all parties who have contributed to this ongoing program, particularly the individuals in the EIA WG-B Channel Test Sub-Group; Brian Warren chairman, and other industry volunteers. Corporate assistance has been provided by; PBS for the use of the Charlotte ATV test site, tower site manager Loadstar, Larcan transmitters, Alan Dick antennas, Bird, Bonneville International Corp., Cablewave, Delco Electronics, Dielectric, Harris, Herritage Media Corp., Passive Power Products, SEIKO Telecommunication Systems, Inc., and a host of others.

REFERENCES

/1 Herman, S., et.al., "High Resolution Channel Measurements for Mobile Radio, Signal Processing V: Theories and Applications", L. Torres, E. Masgrau, and M.A. Lagunas (eds.) Elsevier Science Publishers B.V. 1990

/2 Moriyama, Eimatsu, et.al. "Development of Multipath Measurement and Simulation Equipment for Wideband Mobile Radio"; Communications Research Laboratory, Ministry of Posts and Telecommunications of Japan, Tokyo.

/3 Tufts, Donald W., "Estimation of Frequencies of Multiple Sinusoids: Making Linear Prediction Performance Like Maximum Likelihood", Proceedings of the IEEE, Vol.70, No.9, Sept. 1982

EIA DAR SUBCOMMITTEE
VHF CHANNEL CHARACTERISTICS
MEASUREMENT PROCEDURES

This test procedure is presented to document (and to provide sufficient information for a knowledgeable individual to obtain the necessary equipment and further expertise to recreate) the EIA-DAR Channel Characterization test. This procedure specifically describes the Channel Test conducted in Salt Lake City (SLC) in late 1993.

I. INTRODUCTION

A. NEED FOR TESTING; The EIA DAR Subcommittee was organized in October 1991 for the purpose of documenting and testing all potential United States DAR systems in a uniform and impartial forum. The testing will take place in both a laboratory and the field. The VHF channel characterization test program is a recent addition to the EIA-DAR system tests for the purpose of quantifying VHF multipath propagation characteristics for the FM channel proponent laboratory tests.

B. TEST SYSTEM DESCRIPTION; The test system consists of a wide band pulse transmitter, a mobile data collection van with receiver and off-line data processing. The test signal consists of a series of pseudo-random pulses, transmitted at a pulse rate of 2 MHz, yielding a 4 MHz wide test signal centered in the television band at Channel 6, 85 MHz. Transmission is made with a circularly polarized antenna for reception on a specially designed and built dual-independent polarized antenna. Data collection is triggered at fixed intervals along a path, for this test every 1/10 wavelength. By choosing the path to cover a representative sample of an area, the channel characteristics of that type of area can be reported.

C. THE NEED FOR "CHANNEL CHARACTERIZATION TESTS"; Laboratory testing will employ a multi-channel multipath simulator, operating over the full range of multipath propagation delays and reflections expected in actual broadcast conditions. Unfortunately, the current literature does not clearly define the FM Band multipath characteristics in terms of relative time delay and reflected signal level, the parameters needed for the multipath simulator. As a result of the proponent's questions regarding the range of multipath testing, the EIA-DAR test program was expanded to conduct a channel characterization test.

D. SALT LAKE CITY TEST VENUE; The channel test data was collected in September 1993 in Salt Lake City. The Salt Lake City area presented diverse terrain, well defined different "environments", a large "central city" type area and most importantly, a readily available and nearly ideal test transmitter site.

II. RADIO FREQUENCY SYSTEM; 85 MhZ TV Channel 6 band.

A. SYSTEM GENERAL DESCRIPTION; The system used for the EIA DAR Channel test, shown in the block diagram attached as Figure 1, is much like that described by Herman[1] and Moriyama[2], and was built by engineers at the DELCO Electronics Audio Advanced Development Laboratory at Kokomo, Indiana. It consists of a pseudo-random pulse generator driving a wide band (television) transmitter with a pulse string, 255 pulses (bits or chips) long, at the pulse repetition rate (chip rate) of 2MHz. The string of pulses is random in time over the 255 pulse string which is then repeated continuously, hence the pseudo-random nature of the pulses. The repeated 255 pulse string, called an "instance", is long enough to allow for calculation of over 40dB of level resolution but short enough to assure identification and capturing of one complete string in a relatively short time with a reasonable amount of data. The 2MHz pulse rate and the method of computer analysis used, allows resolution of signal reflection delay times as short as 250 nanoseconds with a finite probability of error, and as long as 127.5 microseconds delay time. Considering the custom nature of both the signal generator and receiver, they will be maintained in storage at Delco for future use.

B. BASIC FACILITIES; The ERP and height must be sufficient to cover the area of interest with a sufficient signal, ideally a 40 dB SNR, but useful data can be collected at lower levels even in the presence of interference. Antenna location and height must b sufficient to minimize local distortions (shadowing or reflections from objects near the antenna) so as to not mask the effects of the environment along the path and near the receiver. Circular polarization is required with H & V magnitudes as near as equal as practical over the arc of measurement to enable simultaneous but independent measurement of H & V pol signals.

C. R.F. TRANSMISSION EQUIPMENT list, SLC test source;
1. Transmitter, 6kW Solid State Ch.6 TV,
2. Modulator, modified tv modulator (change TV baseband filters for optimum response over 85mHz $\pm$2mHz)
3. Transmission line, 1-5/8 air flexible,
4. Transmission antenna, panel type, Circ.Pol., (optimize H & V polarization for as near as equal patterns).

D. SIGNAL SOURCE; The transmitter begins with a pulse generator providing a single-bit, shift register based, Pseudo-random Number (PN) sequence, with accuracy derived from a 25ppm crystal oscillator. The natural frequency side lobes of the sequence decay in level with frequency and they are subject to an additional

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1 Herman, S., et.al., "High Resolution Channel Measurements for Mobile Radio, Signal Processing V: Theories and Applications", L. Torres, E. Masgrau, and M.A. Lagunas (eds.) Elsevier Science Publishers B.V. 1990

2 Moriyama, Eimatsu, et.al. "Development of Multipath Measurement and Simulation Equipment for Wideband Mobile Radio"; Communications Research Laboratory, Ministry of Posts and Telecommunications of Japan, Tokyo.

attenuation of 20 dB by filtering in the signal generator to achieve 30 dB or more attenuation with respect to the main lobe. The PN sequence is 255 pulses long over which its timing is random. The sequence is continuously repeated, hence the pseudo-random nature of the signal. This pulse train phase modulates a high stability (1ppm) oscillator, resulting in the BPSK (suppressed carrier) signal at approximately 44 MHz. The actual frequency is adjustable over a moderate range, within the range acceptable to most television transmitter exciters. The transmitter exciter provides additional filtering of the sidelobe out-of-band components in a Surface Acoustic Wave (SAW) filter, and provides a constant amplitude signal to drive the transmitter power amplifier. The power amplifier is capable of a significant television peak of sync power but it is driven to a lesser output power of a few dB below the power compression point to maintain good amplitude linearity.

The 2MHz pulse rate and BPSK (suppressed carrier) modulation generates a 4 MHz wide R.F. spectrum with its first frequency nulls at ±2 MHz and decreasing side lobes, each 2 MHz wide. The output is filtered as described above so that the transmitted signal appears as a 4MHz wide Gaussian distributed noise signal with rapidly decreasing side lobes as shown in Figure 2.

This spectrograph of the receiver I.F. output was taken with the test transmitter signal connected directly to the receiver antenna input. The horizontal span is 10 MHz, a scale of 1 MHz per division, with a vertical span of 80 dB, a scale of 10 dB per division. The test signal was transmitted with a center frequency of 85 MHz, the center of the television Channel 6 band, a relatively accessible frequency where ever a television Channel 6 station is not operating. This frequency is also sufficiently close to the FM band to accurately characterize it. Use of high stability reference oscillators (1ppm) in both transmitter and receiver allows for demodulation without frequency lock.

In Salt Lake City, a 6 kW Larcan transmitter was used with a two element LDL Spearhead Panel antenna configured with two elements stacked vertically and splayed ±30 degrees to provide a narrow azimuth pattern oriented east over the city and toward the mountains beyond. The resulting horizontal plane relative field patterns are shown in Figure 3. The antenna was mounted at approximately 9100 feet AMSL or 4500 feet above the valley floor at the Bonneville Broadcasting KSL(TV) transmitter site on Farnsworth Peak, 18 miles west of Salt Lake City. The resulting ERP of 7.6 kW average power is sufficient to cover the city and surrounding area including the mountains up to 25 miles away.

E. RECEIVER SYSTEM; The receiver, using Superheterodyne radio frequency design, was also built by Delco. Its only automatic function is a <u>very</u> <u>slow</u> AGC. It was carried in a mini-van along with other associated equipment including a specially built "reference" antenna. Each of the two independently polarized antennas feed modular amplifiers and each amplifier output is combined in a power coupler into the single channel receiver. Under control of the test computer the antenna amplifiers are alternately turned on, completing one path and rejecting the other by over 40dB. In this combined R.F. output channel several tunabl notch filters are available to remove strong out-of-band component without perturbing the pass band signal. The filtered signal is then mixed with a 140 MHz Local Oscillator (LO) to generate the 140 MHz I.F. and further filtered by a Surface Acoustic Wave (SAW) filter to provide up to an additional 40dB of out-of-band rejection.

At this point the signal is sampled for several monitoring functions. First, the IF is sampled to display the RF component on a spectrum analyzer with that display recorded on a video recorder. The IF is also mixed to baseband for monitoring by an oscilloscope to facilitate tuning the LO to zero frequency offset with the transmitter. In practice, approximately a 100 Hz drift occurs during one measurement run which has no significant effect on the data that is recorded.

Next, both the I and Q signal components are sampled by an 8-bit A/D converter. The resulting half-Least Significant Bit (LSB) uncertainty error is more than 40 dB below full level, limiting the dynamic range of the A/D conversion to approximately 40dB. A manual attenuator with a 50 dB range is adjusted on each data collection run to set the signal in the optimum digitizing range. The system has an effective sensitivity of better than -69 dBm in the presence of anticipated interference from strong nearby adjacent channel stations.

The received waveform is sampled at 4 MHz, twice the transmitted pulse rate (two times oversampled). The need for bit synchronization circuitry is eliminated by averaging every pair of data points. Data acquisition is controlled by an enable signal from the computer for each sample point. At each sample point the first polarization waveform is digitized and loaded into First-In-First-Out (FIFO) memory. Then the antenna amplifiers are switched and after a 1 microsecond settling time, the opposite polarization signal is digitized and transferred to FIFO. The antenna amplifiers are then switched back to their normal state to wait for the next sample point. The system remains in this position for at least 14 milliseconds while data in FIFO is multiplexed and loaded into the computer memory. This measurement cycle is dependent on the basic data transfer rate of 100kHz, from data acquisition board to computer, setting the maximum speed of data collection. That, in turn, sets the minimum computer cycle time which determines the maximum vehicle speed at the minimum sample point spacing chosen for this test. After collection of one data file, 1 M byte of data, the system pauses briefly to save the file to disc, clears the acquisition board and resumes collection.

F. "STANDARD" RECEIVING ANTENNA; Several discussions within the EIA-DAR testing group, regarding the type of antenna to be used for reception testing, led to the conclusion that some type of "reference" antenna must be used. Considering the many types c vehicles and specific antennas available for each, literally thousands of possible combinations exist; no one of which could be considered standard. The basic antenna requirements were chosen to provide omnidirectional horizontal plane reception with good bandwidth. Furthermore, the antenna must provide dual and independent outputs for the horizontal and vertical polarization components. The standard test antenna was designed in a joint effort by Delco, Lohnes and Culver and Harris. It is designed to receive both the horizontally and vertically transmitted components, but to receive them separately and independently with little interaction. Tests show that the antennas have a horizontal plane circularity of better than ±2.5 dB and a cross polarization self discrimination of at least 10 dB as shown in Figures 4 and 5.

Figure 6 shows the test antenna mounted over a ground plane atop the van with its center approximately 3 meters above ground level. A monopole of approximately 1/4 wavelength is mounted over the ground plane described above. The monopole length and diameter was chosen to provide reasonable impedance and wide band performance. The vertical monopole antenna is surrounded by a dielectric structural tube which supports the top mounted horizontally polarized antenna. That antenna is designed to provide a nearly circular horizontal plane pattern with minimum interaction with the vertical monopole or the ground plane. The antenna and ground plane assembly was constructed and tested at the Delco facility in Kokomo, Indiana, with further testing at the Harris antenna facility at Palmyra, Mo.

The various components in the measuring system will be described individually in the following sections.

III. COMPUTER CONTROL SYSTEM GENERAL DESCRIPTION;

A. MANUAL START; The data reception process is started manually by the crew running the equipment. When a measuring point is selected and documented in a measurement log and all starting values are set (see below) the collection is begun by a manual computer command after the van begins motion along the measurement path and when the starting point is crossed.

B. AUTOMATIC COLLECTION; The data collection process is automatic once started and is described in more detail below. The computer collects data and reports the sequential number of the "file" (one megabyte each) being written so that the crew may observe progress and record the file number at various landmarks. The computer notifies the crew when hard disk capacity has been exceeded, approximately 75 files, thus ending a run if not manually ended by the crew. The only receiver control that is changed by the automated system is the biasing on and off of the two polarization amplifiers described previously.

C. MANUAL END OF RUN; At the end of a recording run the data is transferred from disc to tape by the crew manually initiating the process. Stopping parameters such as file number, time, location landmark, and receiver LO frequency and frequency drift from start to stop are written in the measurement logs.

IV. DAILY SETUP AND CALIBRATION

A. REFERENCE SITE; A reference setup site is established for dail system checks and calibration. In the Salt Lake City test it was located northeast of the downtown area on the side of a hill several hundred feet above the city with a very clear line-of-sight path to the transmitter site. The vehicle was positioned at this site and daily calibration measurements and tests were performed.

B. CALIBRATION PROCEDURE; A brief recording of the transmitted test signal, several files long, was made at this fixed location. The data was immediately processed and examined using the on board computer to make sure that the system was functioning normally. The data that was examined showed a point that was stable and free from any significant multipath. Occasionally, variable filters may be inserted into the RF system to remove strong nearby interferers. The filter tuning and lack of impact on the receiver was confirmed at this time. Each day the receiver frequency was synchronized to the transmitter and checked for short term drift. Frequency synchronization was gauged by the beat frequency between the I and Q channel data. At that point the receiver Local Oscillator frequency was recorded and the general weather conditions were noted. No other setup was required and at that poin the days measuring routine could begin.

V. MEASUREMENT RUN SETUP AND PROCEDURES

A. PRE RUN CHECKS; At each measuring location a similar frequency synchronization procedure was followed. In addition the route was "previewed" by driving and observing the signal strength. Based on this observation, a fixed attenuation of up to 40dB, in 10dB steps, was applied to the input signal so that the recorded signal level would be kept in its optimum range within the AGC control range. Information recorded at the start of each run included the time, date, local weather conditions, environment observations (type of terrain, traffic and local construction described below) and receiver LO frequency. Other tests were conducted as needed at measuring locations such as looking for strong interfering signals in adjacent bands. This was accomplished using the spectrum analyzer in the van. A strong adjacent frequency interferer would be attenuated by inserting tunable filters in the RF antenna path after preamps and combining. The filters were tuned for maximum undesired signal attenuation and minimum impact on the test signal channel band.

B. PROCEDURE DURING RUN; As the run progressed several bits of information were recorded. They were:

1. The path description and turns as they occurred,
2. land mark descriptions as they were crossed,
3. the file number of data being recorded at each,
4. the time of each landmark crossing,
5. the distance along the path at each,
6. comments regarding the local environment or path.

The audio channel of a video recorder in the van captured all of the voice announcements and commands during the course of a measurement run.

C. END OF RUN PROCEDURE; The end point of a run was manually selected at a convenient and easily identified location prior to the point at which the computer disc capacity would be exceeded. At that point the final entries were made in the path log and closing data regarding the receiver LO frequency was recorded.

D. DATA TRANSFER TO TAPE; The hard disc data was transferred to tape and when completed, another run could be started.

VI. AUTOMATIC DATA RECORDING PROCEDURE; The following description provides details of the automatic data measurement and recording collection process.

A. UNIFORM MEASUREMENT POINT SPACING; Measurement point spacing was set at 0.1 wavelength or 0.35 meters at the 85mHz channel test center frequency. Uniform spacing was controlled by use of a programmable pulse counter circuit and pulse generator attached to the vehicle drive train. The pulse generator generated several hundred pulses per revolution and a suitable divisor was programmed into the control system to yield a uniform measurement trigger spacing of 0.35 meters. The accuracy was confirmed by comparing file length per unit of distance traveled with the average yielding 0.35 meters per sample.

B. DATA COLLECTION SEQUENCE; When the pulse counter circuit triggered data collection, the sequence progressed as follows:
1. Start data collection for a time period equal to 3 times the pulse string length of 255, approximately 383 microseconds,
2. at the end of the first polarization data set, switch the antenna amplifiers from the default Vertical polarization to Horizontal and wait for a 1 microsecond "settling" time,
3. collect data for an equal time period for the second polarization,
4. return the antenna amplifiers to default and wait for the next trigger pulse.

C. DATA RECORDING; The receiver produced an analog wave shape of the received signal for both I and Q at an IF of 140 mHz. This signal was presented to a digital signal acquisition board in the computer and recorded as follows:
1. Digitize the I and Q channel analog signal to 8 bit resolution,
2. transfer the digitized signal to FIFO memory buffer at 2mHz,
3. block and transfer the data from FIFO to computer memory at 100kHz,
4. block the data into 160 consecutive recording points (approximately 1Mbyte) and transfer from computer memory to hard disc.

VII. **MEASUREMENT ROUTE AND LOCATION SELECTION;** The primary goal of the test procedure is to "categorize" multipath. At the start of the project it was known that all types of local "environments" should be included in the measurements. Generally these would include: central city, light commercial residential areas, open areas and terrain impacted areas. The test van was driven throughout Salt Lake City and the surrounding area collecting data along 21 paths ranging from 4.4 to 8.8 kilometers, zig-zaging across or encircling an area, for a total of approximately 140 kilometers of continuous data. The data was collected and numbered with a 5 digit identifier, two digits relating to the path number and three to the individual 1 M byte data files. Therefore, because each landmark was identified by the file being written at the time, the location along a path at which data was taken is known with the precision of each 1 M byte of data, 160 samples or 56 meters.

Each of the 21 paths was analyzed for the type of "environment" (buildings, vegetation, terrain, urbanization, etc.) that was predominant along the path or a significant portions of it. Preliminary review disclosed eight narrowly defined environments which were reduced to the four major environment categories listed below.

A. **URBAN: Business - Industrial - Commercial;** This environment includes; the central city business district and surrounding area, approximately 6 blocks north-south by 8 blocks east-west; an industrial/warehouse area south west of the city center; and several moderately heavy commercial areas comprised of shopping centers and malls with multi story buildings. The traffic paths are generally close to the buildings indicating that the expected reflections should be short in time delay and generally strong in level. The practical vehicle speed in the area ranges from stopped to approximately 40 KPH (25 MPH). Numerous stop lights and stop signs require stops from 0 to 45 seconds at frequent intervals. A simulation consisting of alternate stopped and moving data will be used.

B. **SUBURBAN: Residential;** This environment includes many residential areas, scattered to the south of the city center. They range from single family large homes on large lots to duplex town houses and apartments. As a consequence, the neighborhood may include light commercial shopping areas, schools, libraries, college buildings, etc. Some of the typical older residential areas were heavily covered by mature trees of up to 25 meters in height. The traffic paths are generally more open than for the urban environment but still relatively close to some structures. The expected reflections should be moderately short in time delay and moderately strong in level. In the more open areas in the environment, longer and weaker delays may predominate. The practical vehicle speeds still drop to zero on occasion but may increase to 70 KPH (45 MPH). A simulation with varying speed and few stops will be used.

C. **RURAL: Parkway - Highway;** This environment includes generally open areas with a variety of roads ranging from; single lane country roads north west of the city, to divided highway parkways south of the city, to a commercial boulevard east of the city at the foothills of the mountains. The open nature of the areas generally keeps the closest structures moderately far from the measurement path, with the structures themselves including all types from multistory office buildings to small residential buildings. The expected reflections should be moderate but cover a relatively wide range of time delays and magnitudes. The practical vehicle speeds should very rarely drop to zero. The range to be used is from 40 to 100 KPH (25 to 60 MPH) with one stop.

D. **TERRAIN OBSTRUCTED: Canyons - Valleys;** This environment will include those paths which have a significant terrain involvement, including the Big and Little Cottonwood canyons and the few paths that followed river valleys in the area south and east of the city. The terrain along these paths is the significant factor but some, particularly the river valley path, have some structures along the path. The expected reflections should be numerous and rapidly changing with moderate to long reflections over a wide range of magnitudes. The major feature of the signal path should be the frequent loss of a direct path with the dominant reflection becoming the substitute direct path, one which is subject to rapid change as reflection characteristics change. The practical vehicle speeds should rarely drop to zero but should also not be too high. The range to be used is from 25 to 70 KPH (15 to 45 MPH) with one stop.

VIII. **ANALYSIS AND PRESENTATION;** The data analysis is continuing. Presently the data has been converted from the raw collected data files to an intermediate form for further study. The reflection time delays and magnitudes are isolated and can be extracted for studied and assigning control parameters to the channel simulator. The final analysis and application to the laboratory testing will be presented in a written report.

The recorded data will be kept on file and will be made available to those wishing to further study it. The signal generator and receiver will be kept available for those wishing to conduct other channel characterization tests.

IX. **ACKNOWLEDGEMENTS;** The VHF channel characterization test is a joint effort of many parties who have contributed their time and materials. EIA would like to acknowledge the assistance of all parties who have contributed to this ongoing program, particularly the individuals in the EIA WG-B Channel Test Sub-Group and other industry volunteers. Corporate assistance has been provided by; PBS for the use of the Charlotte ATV test site, tower site manager Loadstar, Larcan transmitters, Alan Dick antennas, Bird, Bonneville International Corp., Cablewave, Delco Electronics, Dielectric, Harris, Herritage Media Corp., Passive Power Products, SEIKO Telecommunication Systems, Inc., and a host of others.

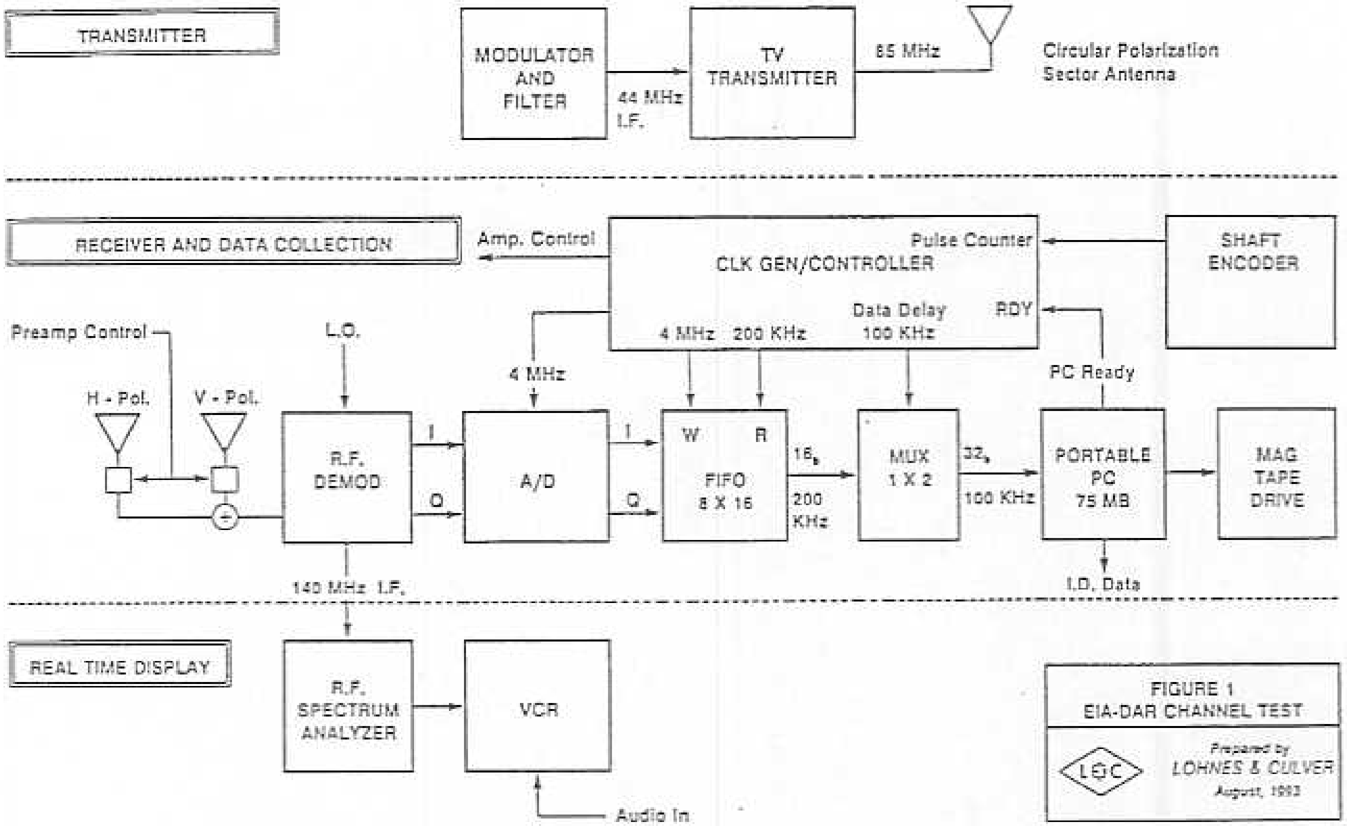


FIGURE 1
EIA-DAR CHANNEL TEST
Prepared by LOHNES & CULVER *August, 1993*

FIGURE 2
Channel Characterization Test Signal

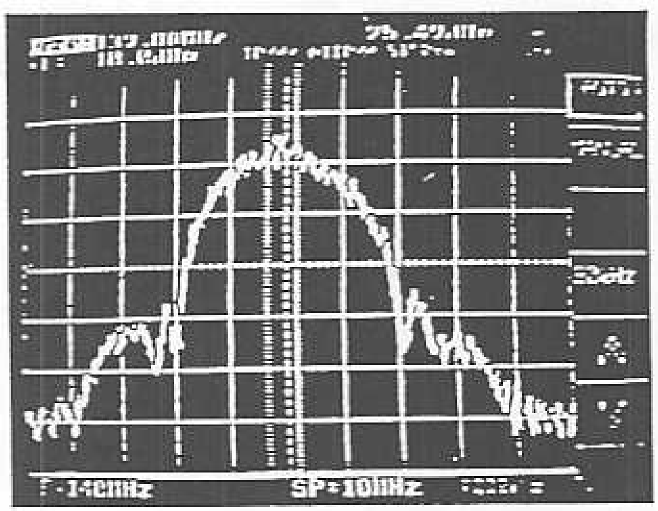


FIGURE 3
Test Antenna Azimuth Pattern

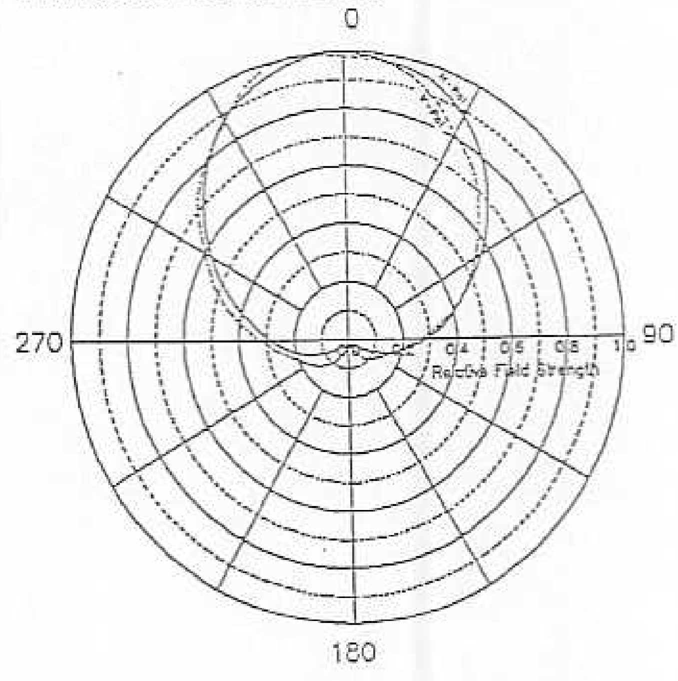


FIGURE 4
Standard Receive Antenna Horizontal Polarization

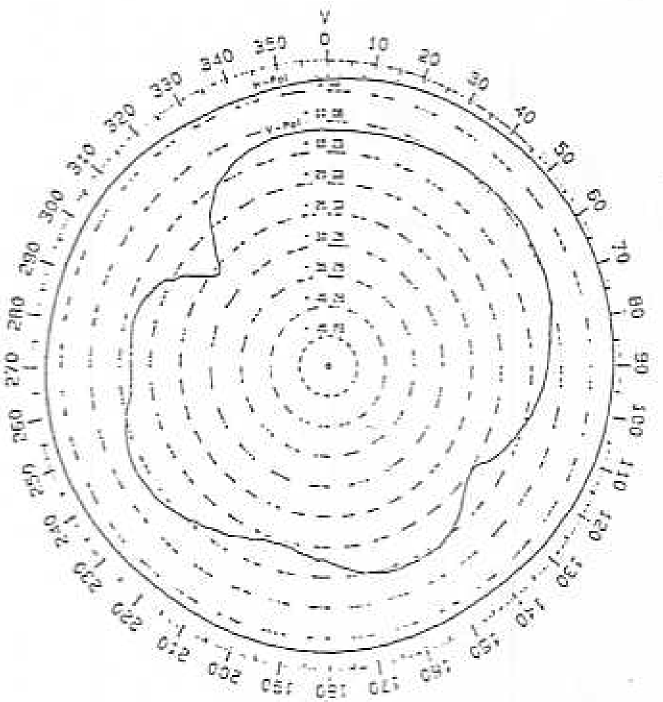


FIGURE 5
Standard Receive Antenna Vertical Polarization

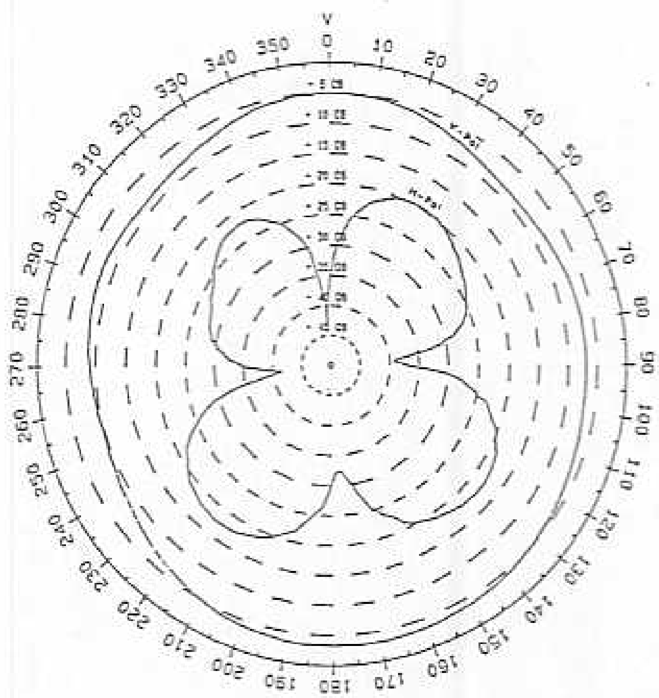


FIGURE 6
Test Van and Antenna

APPENDIX D

APPENDIX D - CHANNEL TEST IMPLEMENTATION; CHARLOTTE, SEATTLE, SALT LAKE CITY

D-1 Memo Report (L&C), to the NRSC and EIA DAR Subcommittee Meetings Wednesday and Thursday, July 28-29, 1993, "Charlotte Test Summary Report"

REPORT TO THE NRSC AND EIA DAR SUBCOMMITTEE MEETINGS
WEDNESDAY AND THURSDAY, JULY 28-29, 1993

CHARLOTTE TEST SUMMERY REPORT

The Charlotte initial measurements and follow-up tests revealed a condition of low sensitivity and susceptibility to interference with the receiver in the test van. The sensitivity was at least 20 dB lower than expected and interference was being encountered, generated both in the test equipment and occasionally from external sources. No useful data could be extracted form the Charlotte tapes and the Charlotte transmission system had to be dismantled, making a revisit impossible. The receiver has been redesigned to eliminate the self interference and to improve its sensitivity. Specific details will be provided by Brian Warren and his team from DELCO.

The operation of the test antenna and the van measuring system is acceptable in most respects. The shaft encoder and trigger appear to work well. Data collection with manual logging of the route and landmarks is easy. More rapid transfer from disc to tape would be desirable. The next generation of this system should probably include a full size 80486 PC with several disc drives and tape unit. I have been in vans with computers with hard drives and have seen no problems. To be on the safe side, shock mounting the PC in a remote location would be ideal.

One major problem remains the power supply in the van; when idling the inverter load causes the battery voltage to sag to the point that the inverter drops off line and the equipment will shutdown and then have to reset. I have suggested tackling this problem in one of two ways.

First, the inverter system should be improved by using a dual battery system with a proper diode isolator between the vehicle and the inverter battery. The inverter battery should be a <u>very</u> large (or two parallel) "high" voltage lead-acid battery with a nominal 12V minimum load voltage and a 14.5V+ charging voltage (talk to DELCO/GM about this). Most "maintenance free" batteries are now lead/calcium and have a slightly lower voltage. Adjust the alternator output for 15V+ output to deliver 14.5V+ at the inverter battery <u>after</u> the isolator. Insert series diodes in the vehicle battery charging line to drop the charge voltage to a safe continuous value for that battery. Attach a cutoff switch in the inverter battery charging line to avoid overcharging on a long road trip. Install an accurate volt <u>and</u> amp meter in the inverter battery line and install the battery in a plastic battery box in an <u>easily accessible</u> space under the counter cabinets.

Next, for those instruments operating from DC supplies, float rechargeable batteries across the supply lines with suitable charge limiting resistors and isolator diodes to carry the instruments (receiver, computer, etc.) through any voltage interruptions that still might occur.

The second alternative is to add or tow a generator behind the van. A 2.5kW± camper generator in a small trailer with auxiliary flashing lights for use in congested areas would solve the power problem and add to the observeability/safety of operating on highways at relatively slow speeds.

SEATTLE TEST PLANS

Early in the planning for the Seattle test an interference prediction to CHEK-TV channel 6, Victoria Canada, was conducted. Various interfering contours, down to 7dBu F(50,10), were predicted using the Tiger Mountain master FM antenna pattern. DELCO also supplied some preliminary d/u ratios for "just perceptible interference" against color bars. The result was that even at 40dB d/u, interference could still be seen and therefore the Tiger Mountain facility would not work. An alternative site was located using the KIRO FM & TV tower on Queen Anne Hill, 1 to 2 miles north of downtown Seattle. From an antenna mounted at approximately 430 feet AGL, 830 ft AMSL, the area up to approximately 20 miles south, including quite hilly terrain toward Cougar and Tiger mountains, should be accessible for testing. The "Charlotte" antenna will be reconfigured to give a narrow ±50 degree pattern oriented at 150 degrees true. The back side null will be oriented directly toward Victoria with less than 07dBu F(50,10) interfering signal strength over all of Canadian soil with the exception of a small area at approximately 12 degrees true. The Canadian concerns on interference have been addressed with additional showings of terrain shielding in addition to the directional antenna system.

As in Charlotte, the antenna will be fed by 1-5/8 inch Cablewave flexible transmission line from the Larcan solid state transmitter. The transmitter is a 6kW unit on loan prior to shipment to its final customer in Saskatchewan, Canada. The ATV Charlotte test transmitter exciter, a dual NTSC/ATV wideband exciter, will be loaned to the Seattle test project. Easy access and ample space at the KIRO transmitter site will make installation and operation convenient and simple.

The Seattle area will present an abundance of interesting sites to measure. Therefore, a map study and an on site pre-survey for potential sites is recommended. With the test transmitter operating, a spectrum analyzer can be taken to areas of expected multipath to pre-certify them as measurement candidates.

The FCC application has been filed and approved. The Seattle city approval is promised after filing for a building permit. Local coordination with Channel 5, FM broadcasters and the residents of the Queen Anne Hill area will be undertaken to assure minimum interference impact.

Respectfully Submitted,

Robert D. Culver

Robert D. Culver, WG-A Chairman

APPENDIX E

APPENDIX E - CHANNEL TEST DATA COLLECTED

E-1 Memo Report, "Salt Lake City Channel Characterization Measurements"

SALT LAKE CITY CHANNEL CHARACTERIZATION MEASUREMENTS

DATA COLLECTION AND STRUCTURE

The EIA-DAR Channel Characterization project has measured multipath delay data in and around Salt Lake City using the method and equipment previously described to the EIA and NRSC. Briefly the signal consisted of 255 random pulses, transmitted at a 2MHz rate and continuously repeated, hence generating a pseudo-random sequence. The signal was received in van equipped with a specialized antenna, receiver and data collection equipment. Several significant terms will be defined below.

CHIP - PULSE; In common digital sinal usage the transmitted pulses, described above, are often referred to as "chips". For consistency with past reports the term pulse will continue to be used.

BIN; Each transmitted pulse (chip) represents a time of 1/2e06 seconds or 500 nanoseconds. Upon analysis the minimum time resolution becomes 250 nanoseconds, therefore the reflections can be sorted into any of a series of sequential "bins", each representing a time progression of 250 nanoseconds.

INSTANCE; Each series of 255 pulses represents one "instance" of data.

SAMPLE; Three instances are captured for each polarization (horizontal and vertical) of the transmitted signal, making up one "sample". After data reduction each sample point will contain only one instance for each polarization.

FILE; Samples are collected at uniform spacing intervals until a 1 Megabyte "file" is written from core to hard disk. Because of the size of each sample a file contains 160 samples for each polarization. The samples are collected at 1/10 wavelength intervals, 0.35 meters at 85MHz, so a file also covers approximately 56 meters of continuous distance. The file writing process requires a brief halt in data collection, depending on the vehicle speed up to a few samples are missed.

PATH; Approximately 75 "files" or 75Mbyte of data can be stored on the computer hard disk at a time before transfer to tape backup is required. This limit yields approximately a calculated 4.2 KM path length, but the file writing delay cited above extends this slightly depending on vehicle speed. On several of the paths this distance was not sufficient to cover the area of interest and double length paths were run with a several minute pause between halves to transfer data to the tape backup. A "path" is either a single or double length run.

DATA ANALYSIS AND RESULT PRESENTATION

The data collected for each of the 21 paths is identifiable by file (160 samples), with each sample (eventually a single instance) and polarization identifiable in each file. The data is stored as "raw" data in a new file with the extension .chn (raw data files). It is then processed in two steps using the MatLab software. The first step, using MatLab software and a raw data processing routine.

This routine processes one instance of raw data at a time. First the data points are organized into I/Q pairs and oversampled by twice the transmission pulse rate of 2MHZ, generating twice the number of data points. The data is then decorrelated with the known pulse sequence. This process is repeated for the second polarization, the second half of the data in a sample point, and stored as one full frame of data for each instance in a sample set. At this point the data is in a form that is ready for further processing or for distribution to others.

After initial processing the data has now been refined to the point where significant results can be extracted. The data has been bit averaged and it has been through data decorrelation against the original pseudo-random bit sequence to identify the primary and following pulses. In this processing the result is a complete time domain "snapshot" of each sample point with the first pulse to arrive at the receiver normalized to 0dB. When viewing these files instance by instance the relative position of the main and trailing pulses and their magnitudes is evident. What is also evident is that the exact time of arrival of the main pulse can fall anywhere within the sample interval, 255 times 500 nanoseconds or 127.5 microseconds, since each sample is taken only at a specific spacing along a path and is completely time independent of the transmitted data. The data is frame synchronized to place the first pulse at relative time zero. The processed data is now stored in an array of files equal in number to the raw data files for a path, approximately 70 or 140 files depending on the path length. The data is now ready for reading into the final processing routines to extract relevant multipath statistics.

The next level of processing uses the "extract" MatLab routine to extract the multipath parameters and create three files. The time domain multipath delays, magnitudes and phases for each instance are extracted with the first pulse to arrive normalized to zero time and 0dB magnitude, with all of the significant trailing pulses placed into succeeding bins. In reality, very close spaced multipath echoes may well be averaged and placed into one bin at an equivalent magnitude. This process generates a file labeled with the extension .ext (extracted time delays). It contains the multipath delays, magnitudes and phases for each of the instances and polarizations that can be used for multipath simulation.

The average time domain data for the entire file, 160 instances of both vertical and horizontal polarization is generated in a file with the extension .tda (time domain analysis).

To determine which of the echoes is the most significant the next extraction routine computes the frequency domain fades for each of the 160 instances and creates a file with the extension .sta (frequency domain fade statistics). The time delay components, delay and magnitude, are examined to find the one with the most significant contribution to a frequency domain fade. Succeeding significant contributing echoes are identified, by their frequency domain effects, until a total of six (five plus the fixed direct pulse), equal to the number of programmable channels on the multipath simulator, have been identified. If less than five are found the remaining data array is filled with zeros. This generates the third file containing the statistical parameters of the frequency domain for each instance and polarization.

As a check for problems with the data collection or reduction, a count of usable instances in each file is kept in a file with the extension .use. Normally all 160 instances in a file are usable, but if the number of unusable instances becomes large, this will serve as a flag to examine the data or processing more closely.

Finally, the extracted data can be grouped together by files representing certain classifications of environments as appropriate. Some paths are contained entirely within an environment, while others may cross an environment and hence only part of each would be used for each environment. The division can be made on a file by file basis, each 160 instances or 56 meters long. Use of this time domain data for a particular environment is the basis of programming of the multipath simulator.

SALT LAKE CITY "ENVIRONMENTS" OVER WHICH CHANNEL CHARACTERIZATION DATA WAS MEASURED

The Salt Lake City propagation characterization measurement project measured time delay and reflection magnitude data along a total of 21 paths. Each path covered either approximately 5 or 10 kilometers, sometimes zig-zaging around a neighborhood, sometimes covering a loop or straight line path through an area. The area environments for each path were classified as to the types of structures, terrain, vegetation and roads and then placed in the four major "environment" categories listed below.

A URBAN BUSINESS - INDUSTRIAL - HEAVY COMMERCIAL:

This environment includes the central city business district and surrounding area, approximately 6 blocks north-south by 8 blocks east-west; an industrial/warehouse area south west of the city center; and several moderately heavy commercial areas comprised of shopping centers and malls with multi story buildings.

The traffic paths are generally close to the buildings indicating that the expected reflections should be short in time delay and generally strong in level.

The practical vehicle speed in the area ranges from stopped to approximately 40KPH (25MPH). Numerous stop lights and stop signs require stops from 0 to 45 seconds at frequent intervals. A simulation consisting of alternate stopped and moving data is recommended.

B SUBURBAN - RESIDENTIAL:

This environment includes many residential areas, scattered to the south of the city center, from single family large homes on large lots to duplex town houses to apartments. As a consequence the neighborhood may include light commercial shopping areas, schools, libraries, college buildings and etc. Some of the typical older residential areas were heavily covered by mature trees of up to 25 meters in height.

The traffic paths are generally more open than for the urban environment but still relatively close to some structures. The expected reflections should be moderately short in time delay and moderately strong in level. In the more open areas in the environment, longer and weaker delays may predominate.

The practical vehicle speeds still drop to zero on occasion but may increase to 70KPH (45MPH). A simulation with varying speed and only one stop is recommended.

C RURAL - PARKWAY - HIGHWAY:

This environment includes generally open areas with a variety of roads ranging from; single lane country roads north west of the city, to divided highway parkways south of the city, to a commercial boulevard east of the city at the foothills of the mountains.

The open nature of the areas generally keep the closest structures moderately far from the measurement path, with the structures themselves including all types from multistory office buildings to small residential buildings. The expected reflections should be moderate but cover a relatively wide range of time delays and magnitudes.

The practical vehicle speeds should very rarely drop to zero. The recommended range is from 40 to 100 KPH (25 to 60 MPH) without stops.

D TERRAIN OBSTRUCTED PATHS:

This environment will include those paths which have a significant terrain involvement, including the Big and Little Cottonwood canyons and the few paths that followed river valleys in the area south of the city.

The terrain along the paths is the significant factor but some, particularly the river valley path, have some structures along the path. The expected reflections should be numerous and rapidly changing with moderate to long reflections over a wide range of magnitudes. The major feature of the signal path should be the frequent loss of a direct path with the dominant reflection becoming the substitute direct path, one which is subject to rapid change as reflection characteristics change.

The practical vehicle speeds should rarely drop to zero but should also not be to high. The suggested range is from 25 to 70 KPH (15 to 45 MPH) without stops

APPLICATION TO LABORATORY TESTING - MULTIPATH SIMULATION

The general parameters and operations of the DAR systems to be tested is well known but some of the system specific parameters that will affect testing are as yet not known. The characteristics of multipath propagation which will affect those systems is also well known with the precise values of those characteristics being determined by this Channel Characterization test. The characteristics and application of the Hewlett Packard multipath simulator are generally understood but will become better known upon actually using the instrument. The proposed tests have several parameters which are subject to changing, such as number of multipath environments chosen and the length of the testing in each environment.

As a result of these unknowns and variables, the actual fine structure of the tests will not be known until just before the start of actual testing. The range over which the testing will be conducted can be determined at this time however and the following discussion is offered to assist in setting that range and finalizing the test procedures.

Upon examination, the Salt Lake City environments for each of the 21 paths, could be classified into at most eight distance environments. Those eight, however, can be grouped into approximately four, based on the similarities of some of the original eight. For example, there were several distinct residential environments but they all shared the similar characteristic of moderately well distributed buildings of at most moderate size, rarely more than two stories in height, moderately spaced from roads and with relatively slow speed limits on those roads. Indeed, this major environment consists of the largest block of data and of them all would be the only one to lend itself to sub-classification, perhaps into low and high density residential. Therefore four and at most five environments are suggested for laboratory testing. The suggested environments can incorporate both stopped and moving tests in two (or three) and only tests "at speed" in the remaining two.

This choice of four (or five, not a total of eight, four each stopped and at speed) frees up some of the time burden on the laboratory testing, primarily in the audio listening tests. CRC, the audio test segment contractor, has stated that the test segments should be relatively short, preferably 30 seconds and no more than 60 seconds. Within this constraint, a multipath test simulation must be devised which presents the full range of multipath conditions of an environment to each proponent system. Some system parameters will define the minimum time in which an environment can be simulated. For example, environments which require zero velocity testing will be examining the system performance under fixed fade conditions, performance highly dependent on the length of data time interleaving in the system. Each simulation stop must be long enough to test all systems and short enough to test a sufficient number of stops without exceeding the maximum audio sample time. It is anticipated that a minimum of five stops would be necessary and exceeding the 30 second test time is likely.

If a segment of actual measured data, or several shorter segments for a "stopped" test, can be found which adequately represent the full range of multipath conditions in an environment, then there is no apparent reason that actual data should not be used to program the simulator. If, however, this is not the case, then it may be necessary to define the parameters over the maximum range and generate an artificial but representative segment. This choice can only be made after all of the data can be analyzed and the system and simulator limitations are known. This will only affect the actual method of simulated testing and the general range and limits of testing will remain unchanged, being indicated by the data measured in Salt Lake City.

APPENDIX F

APPENDIX F - CHANNEL TEST FINDINGS, ENVIRONMENTS, SPEED, DATA, VOLUME COLLECTED, PROCESSING TIME, ETC.

F-1 Memo Report (L&C), to EIA DAR WG-B, Report on "Calibration of Multipath Test System" -- 3/7/94

F-2 FAX memo from B. Warren, DELCO, "Time - Domain Algorithm for Multipath Parameter Selection"

REPORT TO EIA DAR WG-B (TESTING)
EIA-DAR Channel Characterization Task Force
MARCH 8, 1994 TELEPHONE CONFERENCE CALL

DATE: March 7, 1994
RE: Report on "Calibration of Multipath Test System"
TO: Test Task Force

	PHONE	FAX
Brian Warren, Delco	317-451-1591	-1340
Tom Keller, T. Keller Corp.	703-569-3135	-3370
Carl-Erik Sundberg, AT&T	908-582-3811	-7308
Ken Springer, NAB	202-429-5341	-775-4981
Mike Geil, Nova Engineering	513-860-3456	-3535
Ralph Justus, EIA-CEG	202-457-8716	-4985

FROM: Robert Culver RDC, 301-776-4488 -4499

Attached are three pages of text and nine graphs from Brian Warren of Delco Electronics. They present the results of an analysis conducted by engineers at Delco of the Multipath Channel Test System used by the EIA-DAR Channel Characterization Test. The analysis shows the system impulse response and reflections extracted by the algorithm used to analyze the measured data. This document explains several aspects of the system and algorithm and the resulting enhancements and limitations in the resulting data.

It is important when considering this report, and the channel test data in general, to be aware of the limited use to which the data will be applied. Specifically the data will be used to dynamically control a channel simulator for laboratory testing. That simulator is limited to six channels, only five of which can be used to simulate reflections. Significantly, the algorithm extracts significant data by monitoring the impact of the time and magnitude of the reflections as they translate to the frequency domain. This test is applied to each of the reflections recorded in each of the 250 nanosecond bins throughout the entire 128+ microsecond measurement window, approximately 500 total samples, extracting at most 5 reflections. This and past analyses demonstrate that despite the anticipated impact of some obvious reflections, many do not have additional significant impact relative to the dominant reflections already selected by the algorithm. Clearly, the contribution of expected significant reflections is masked by others. Hence the very limited improvement in performance by the "fix" discussed in the report.

In the course of this project the equipment, methodology and analysis of the data have been discussed and explained in detail. Several important questions have been asked and carefully answered. The final analysis is that the Channel Characterization Test provides information entirely sufficient to assess the total range and characteristics of VHF multipath reflections in various "environments". The result of the test provides data from which the laboratory simulation can be controlled based on the "real world" multipath reflections, measured directly in time and relative magnitude, not extrapolated from frequency, for the selected environments. Absent further data, also measured directly in time and magnitude, the data collected and now being reviewed and programmed for laboratory testing constitutes the best and only available time and magnitude data directly measured for any environment.

VIA Facsimile
March 7, 1994

CONFERENCE CALL NOTICE

TO: EIA - DAR CHANNEL CHARACTERIZATION TASK FORCE

	PHONE	FAX
Brian Warren, Delco	317-451-1591	-1340
Tom Keller, T. Keller Corp.	703-569-3135	-3370
Carl-Erik Sundberg, AT&T	908-582-3811	-7308
Ken Springer, NAB	202-429-5341	-775-4981
Mike Geil, Nova Engineering	513-860-3456	-3535
Ralph Justus, EIA-CEG	202-457-8716	-4985

FROM: Robert Culver 301-776-4488 -4499

RE: Teleconferences; Tuesday March 8, 1994 at 3:00PM EST.
AND Friday March 11, 1994 at 3:00PM EST.
PARTICIPANTS MUST CALL IN; SEE PHONE NUMBERS BELOW!

A description and results from the VHF Channel Test "Equipment Calibration", conducted by Delco Electronics, will be distributed by Fax on Monday, March 7. The participants in the conference call should review this material and organize their questions for discussion on Tuesday. Action items will be adopted requiring the participants to respond at a follow-up teleconference.

YOU MUST CALL IN FOR THE TUESDAY TELECONFERENCE AT 1-800-377-4346
The following agenda is proposed:

1. Overview presentation of the "Calibration" test (Warren)
2. Discussion of the test as it applies to channel simulation.
3. Adoption of action items regarding test and application.
4. Other business.
5. Confirm follow-up teleconference, adopt agenda.

The follow-up teleconference will be held on;
Friday March 11, 1994 at 3:00PM EST.

At that teleconference all questions remaining from the Tuesday call will be answered and the Tuesday action items will be resolved.

YOU MUST CALL IN FOR THE FRIDAY TELECONFERENCE AT 1-800-377-4273.

Calibration of Multipath System
and Notes

Introduction

In order to verify the entire system, data is presented which shows calibration measurments. It contains the impulse response as well as the algorithm actions to different multipath situations based on that response.

In addition, some of the properties of the algorithm are described to help answer some of the questions that have arisen. This includes a discussion of the correlation function and the use of zero insertion.

Correlation Function

The continuous autocorrelation of a PN sequence is a triangle. When this output is sampled at the chip rate under synchronized conditions, time samples fall on the peak and the bases of the triangle, resulting in a single impulse output. As our system samples at twice the chip rate, the shoulders of the triangle are captured as well at a voltage level of half the peak amplitude.

This is a minor problem for the processing algorithm as it sometimes identifies the triangle shoulders along with the main reflections. (This tendency is increased by the use of zero insertion, as described in the next section.) This will not hurt the result if these points are included though it does not significantly help it either. This would be a major problem if the algorithm, which is limited to choosing six reflectors, selected shoulders instead of significant reflections, but it does not do this. (Examples are described later.)

A fix for this is seen in later samples. It is a filter which empirically detects shoulders as opposed to real reflections riding on shoulders. It does this by examining the first derivative for slopes which exceed 6 dB per bin, and zeros the shoulders of those reflections that do. More work could be done on this filter but it works reasonably well in its present form. (Examples shown later.) However, the work to perfect this filter is not worth the incremental increase in performance that its actions perform.

Zero Insertion

Zero insertion was added to increase the algorithm's sensitivity to close reflections in the presence of diffuse multipath, such as that found in Environment D. This is done by putting three zeros between each sample in the time domain before the linear prediction is performed. It serves to separate and enhance the resulting sinusoids produced by each sample in the frequency domain, relative to the discrete frequencies available. Some examples of the algorithm's performance when zero insertion is not used is shown later.

Calibration and Examples

Graph 1 shows the impulse response, representing the calibration of the system. This is a graph simulated from our knowledge of the SNR levels and the location of the LOS and artifacts. It represents a direct coax measurement from transmitter to receiver. The noise is at a level of -48 dB below the peak signal. The line of sight is shown in the third bin. Three artifacts appear at 9.5 usec, 89.5 usec and 123 usec. (When reflections are present, these are replicated.)

Graph 2 is a zoomed version of Graph 1.

Graph 3 shows the algorithm's response to the data from Graph 1. In this graph we see that a bin is marked which is not a reflection but rather a shoulder of a reflection in the next bin. This selection is not harmful since the presence of extra points does not degrade the FIR response; this is seen in the frequency plot.

Graph 4 shows the results of one line of sight and one half-magnitude reflection at 1.25 usec. Again, reflections are falsely detected in the time domain, as the algorithm maximizes the match in the frequency domain.

Graph 5 shows the line of sight with five reflectors at approximately half magnitude. The algorithm again chooses the most significant reflectors which will contribute to the frequency domain match. No choices are made of reflector shoulders at the expense of reflectors. (Of course, an even better match would be achieved if the remaining reflectors were inserted.)

Graph 6 is the same as Graph 5 with the reflectors slightly attenuated. The shoulder is again detected. Although the frequency match is still good, an improvement could be made by ignoring the shoulders.

Graph 7 is the same as Graph 6, with no zero insertion. Note the shoulder is not selected in this case. (However, the performance of the algorithm in diffuse multipath such as Environment D will be degraded without zero insertion.)

Graph 8 is the same as Graph 6 with an enhancement filter applied to reduce the effects of the decorrelation triangle. (To upgrade the algorithm, some work would need to be done. It can be seen that some of the operations such as normalization have not been performed. For this reason, the apparant match shown in the frequency domain should be ignored since it was performed on the filtered data rather than the original data. In reality, the improvement on the frequency response is comparatively small.)

Graph 9 is the same as Graph 8 with the first reflector moved to one bin past the line of sight. The algorithm easily detects these close reflectors and will do so to an SNR of 12 dB. (Any files worse than 26 dB are rejected).

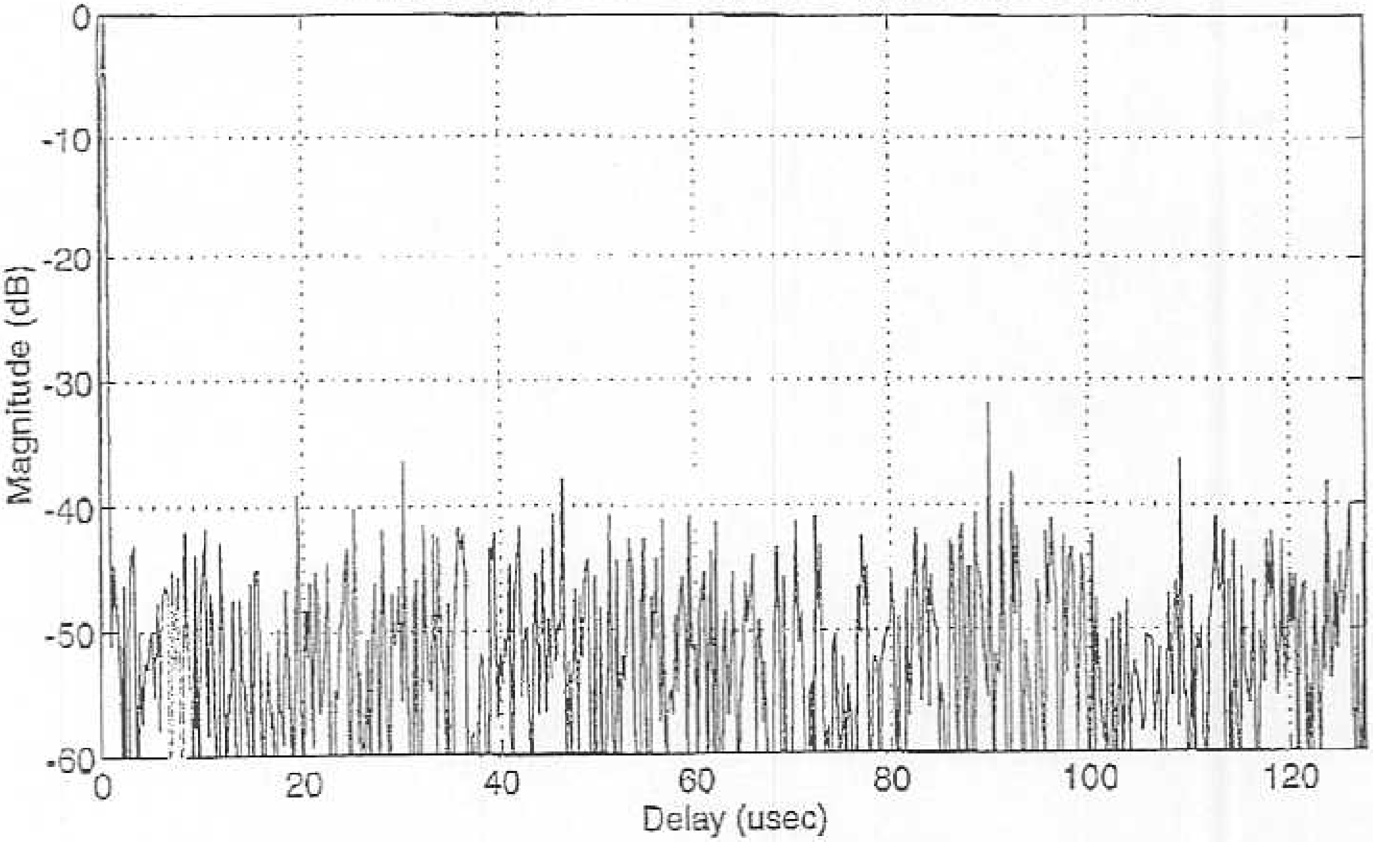
Conclusions

The system calibration is shown by presenting the receiver impulse response and then showing the algorithm detection to that response applied to a controlled FIR filter. One of the weaknesses of the algorithm, its tendency to select non-existent reflectors, is shown. However, since the algorithm performs its primary function which is to best match the frequency domain, that weakness is not material.

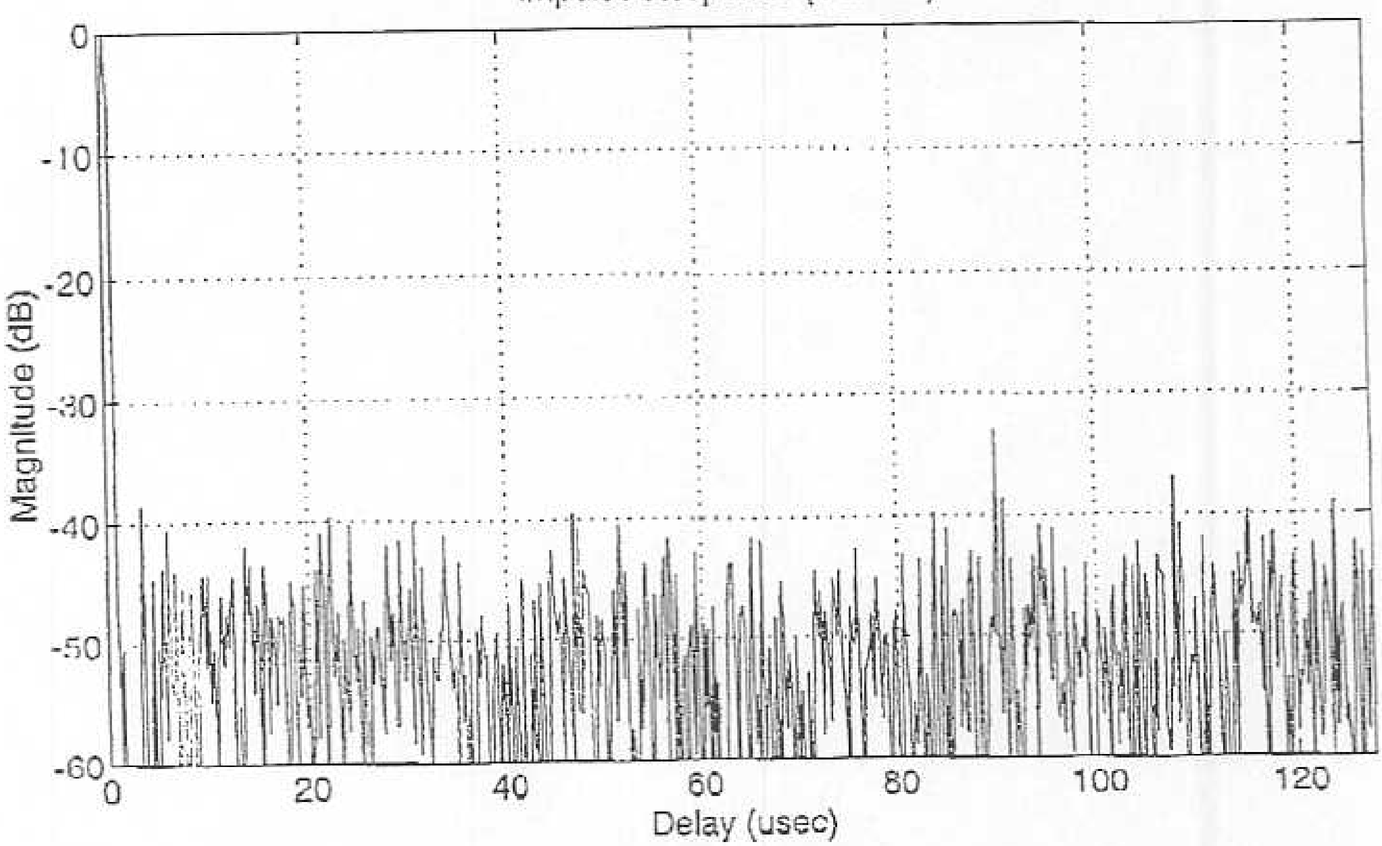
In addition, a filter is presented which will make minor enhancements to the algorithm. The work involved in developing the filter and rerunning the data is not justified by the small return.

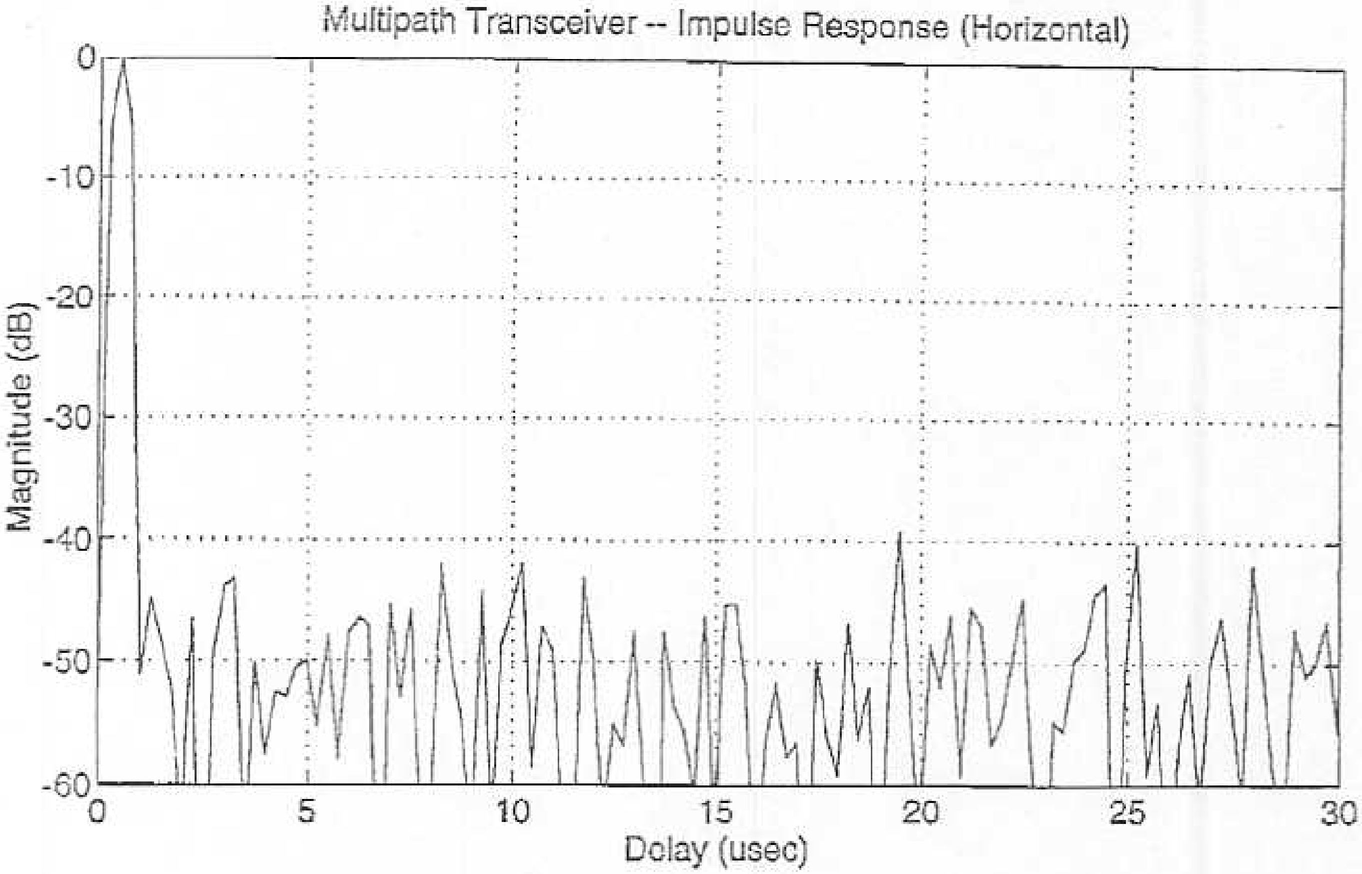
Brian Warren

Multipath Transceiver -- Impulse Response (Horizontal)



Impulse Response (Vertical)





Multipath Transceiver -- Impulse Response (Horizontal)
Magnitude (dB)
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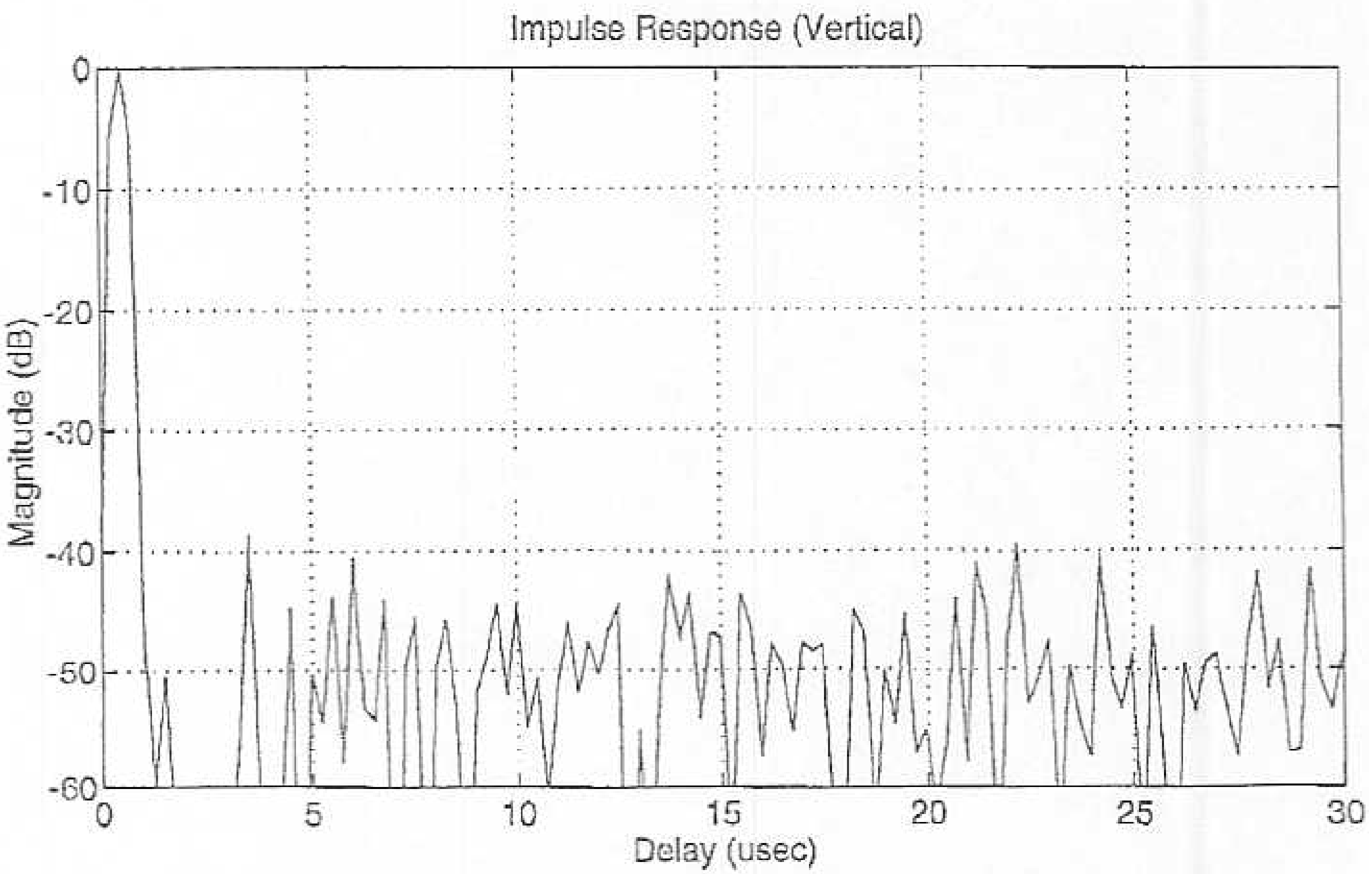
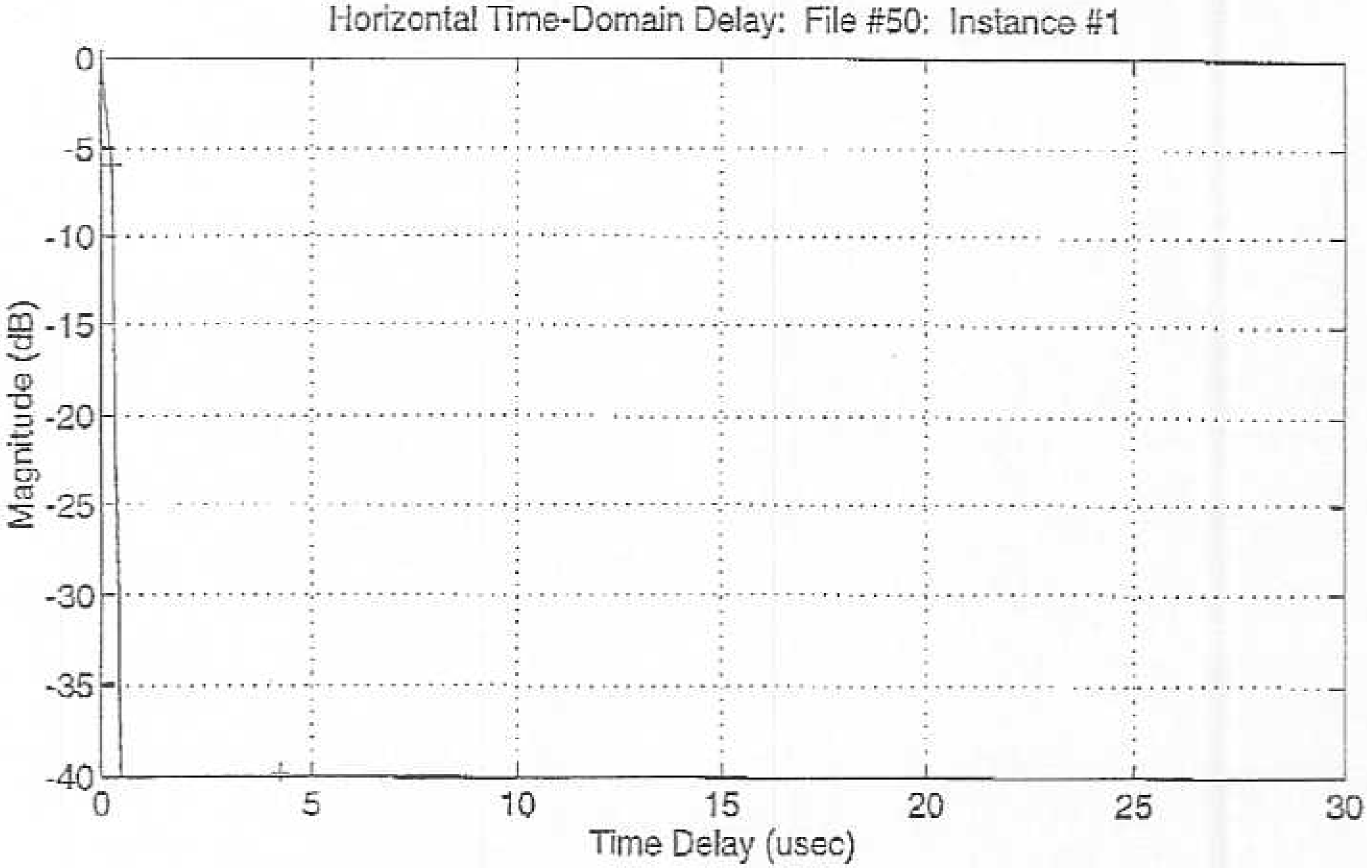
-20
-30
-40
-50
-60
0
5
10
15
20
25
30
Delay (usec)



Impulse Response (Vertical)
Magnitude (dB)
0
-10
-20
-30
-40
-50
-60
0
5
10
15
20
25
30
Delay (usec)

6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Magnitude (dB)
Time Delay (usec)
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-10
-15
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-25
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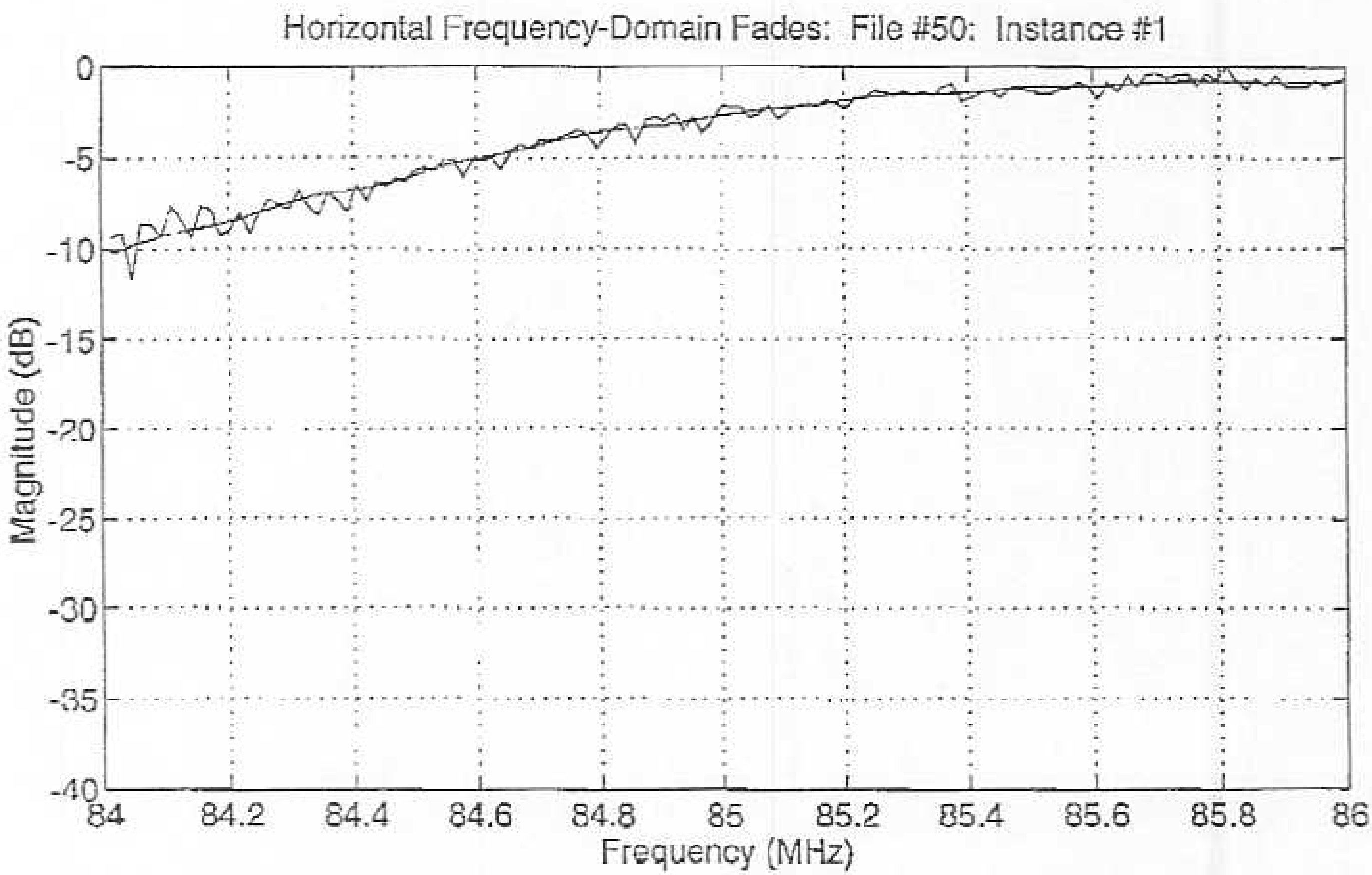
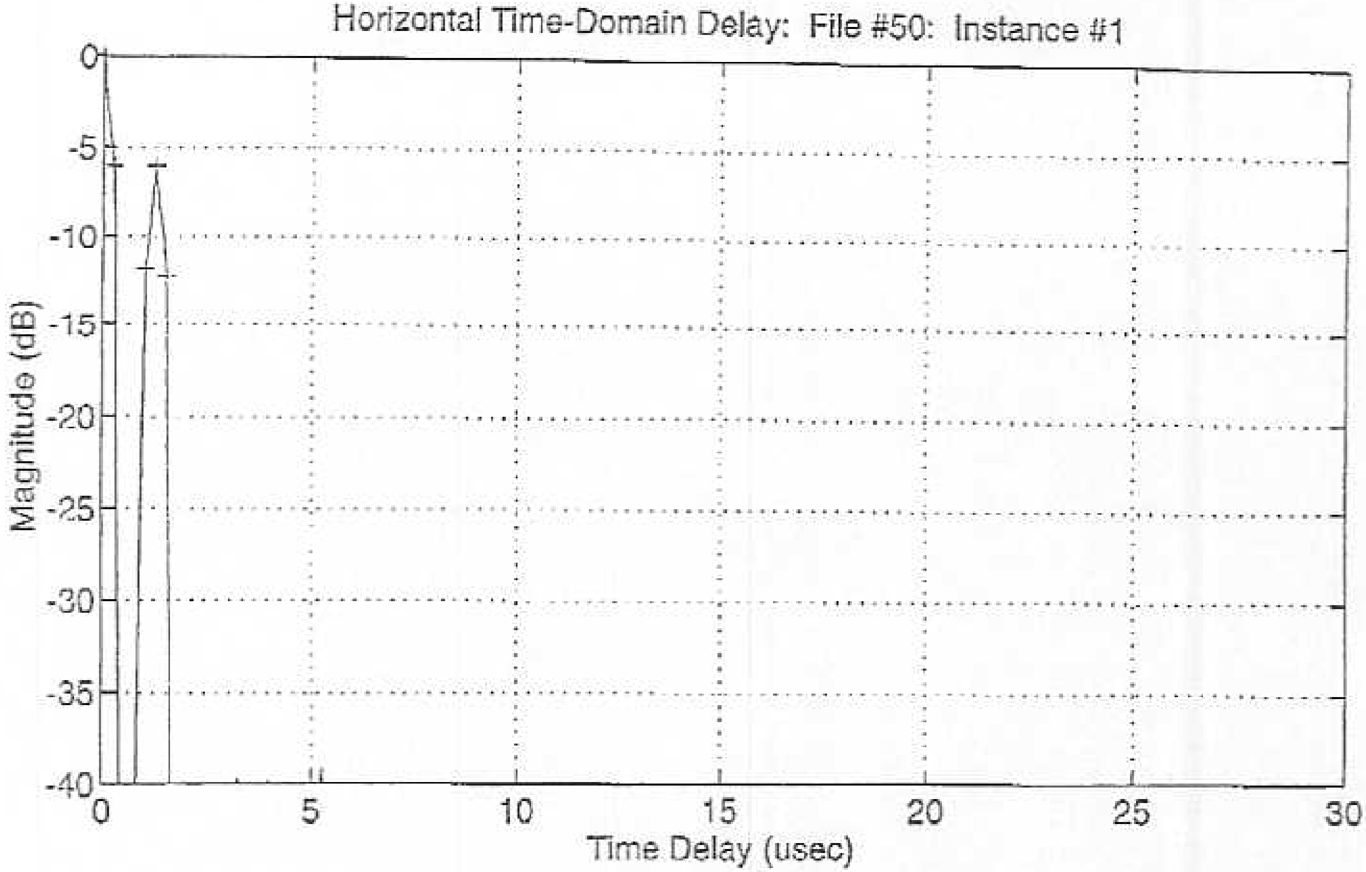
10
15
20
25
30


Horizontal Frequency-Domain Fades: File #50: Instance #1
Magnitude (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
84
84.2
84.4
84.6
84.8
85
85.2
85.4
85.6
85.8
86

(3)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Magnitude (dB)
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-20
-25
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-35
-40
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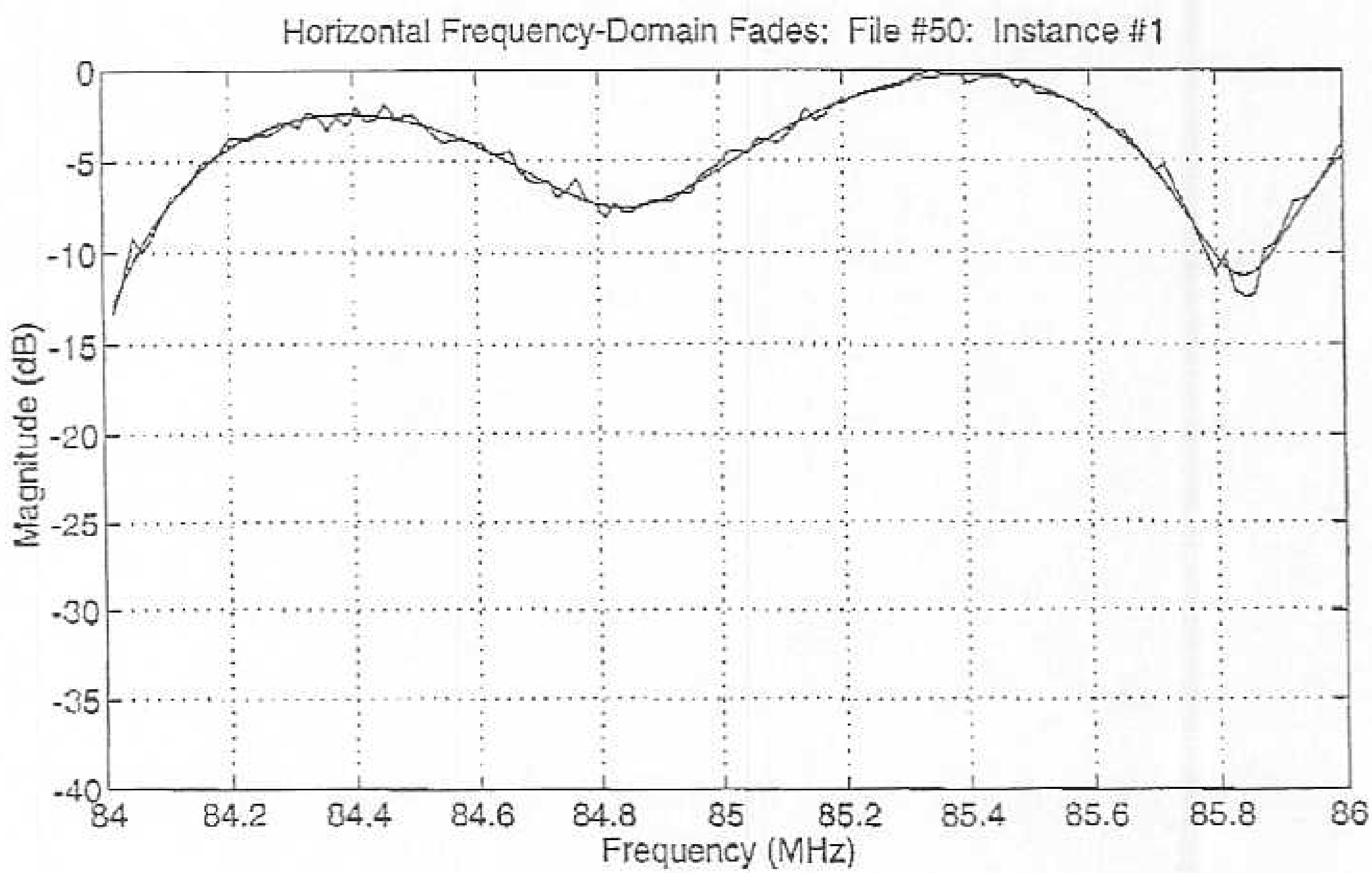
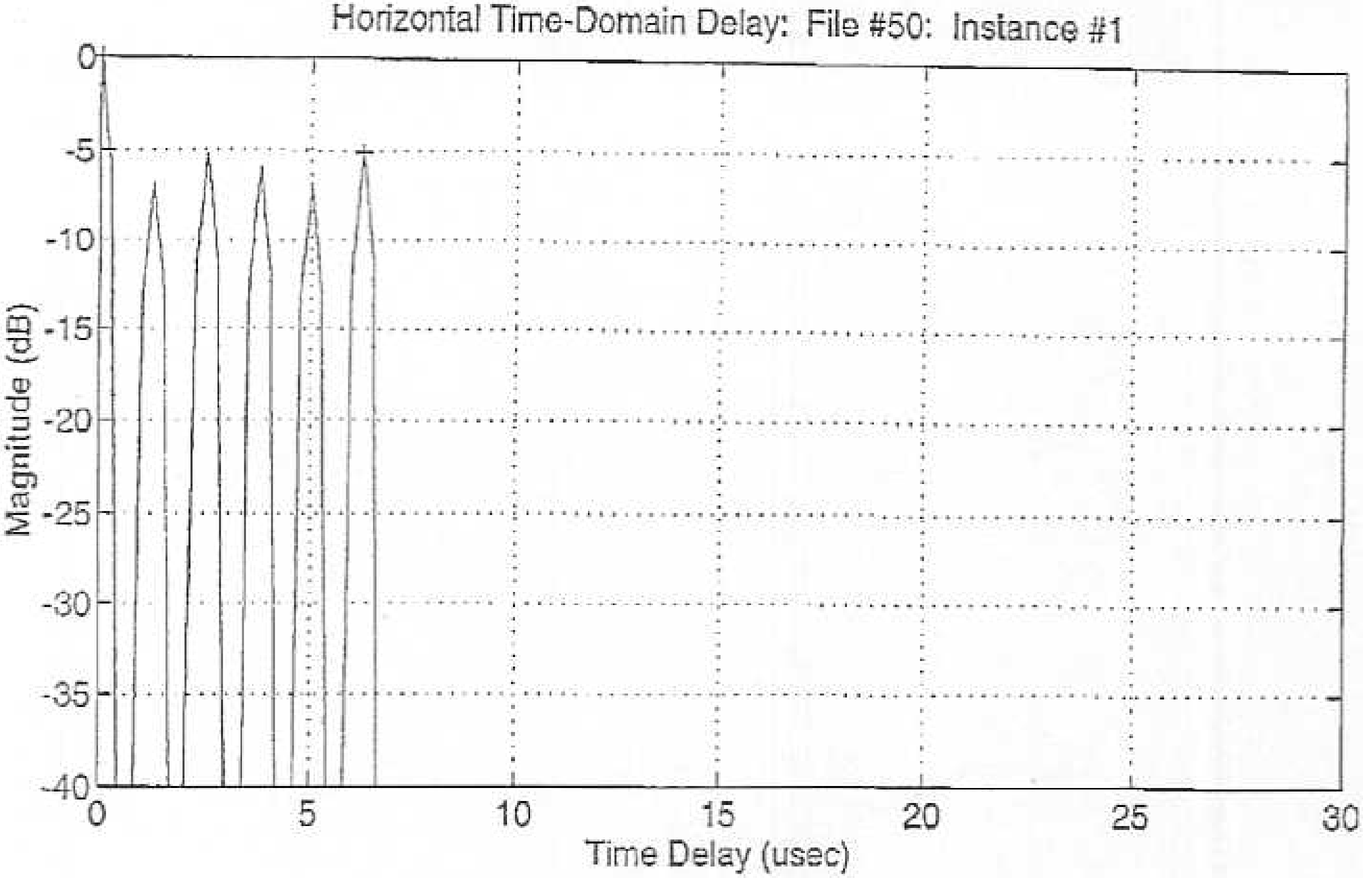
25
30
Time Delay (usec)


Horizontal Frequency-Domain Fades: File #50: Instance #1
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
84
84.2
84.4
84.6
84.8
85
85.2
85.4
85.6
85.8
86
Frequency (MHz)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Magnitude (dB)
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-40
0
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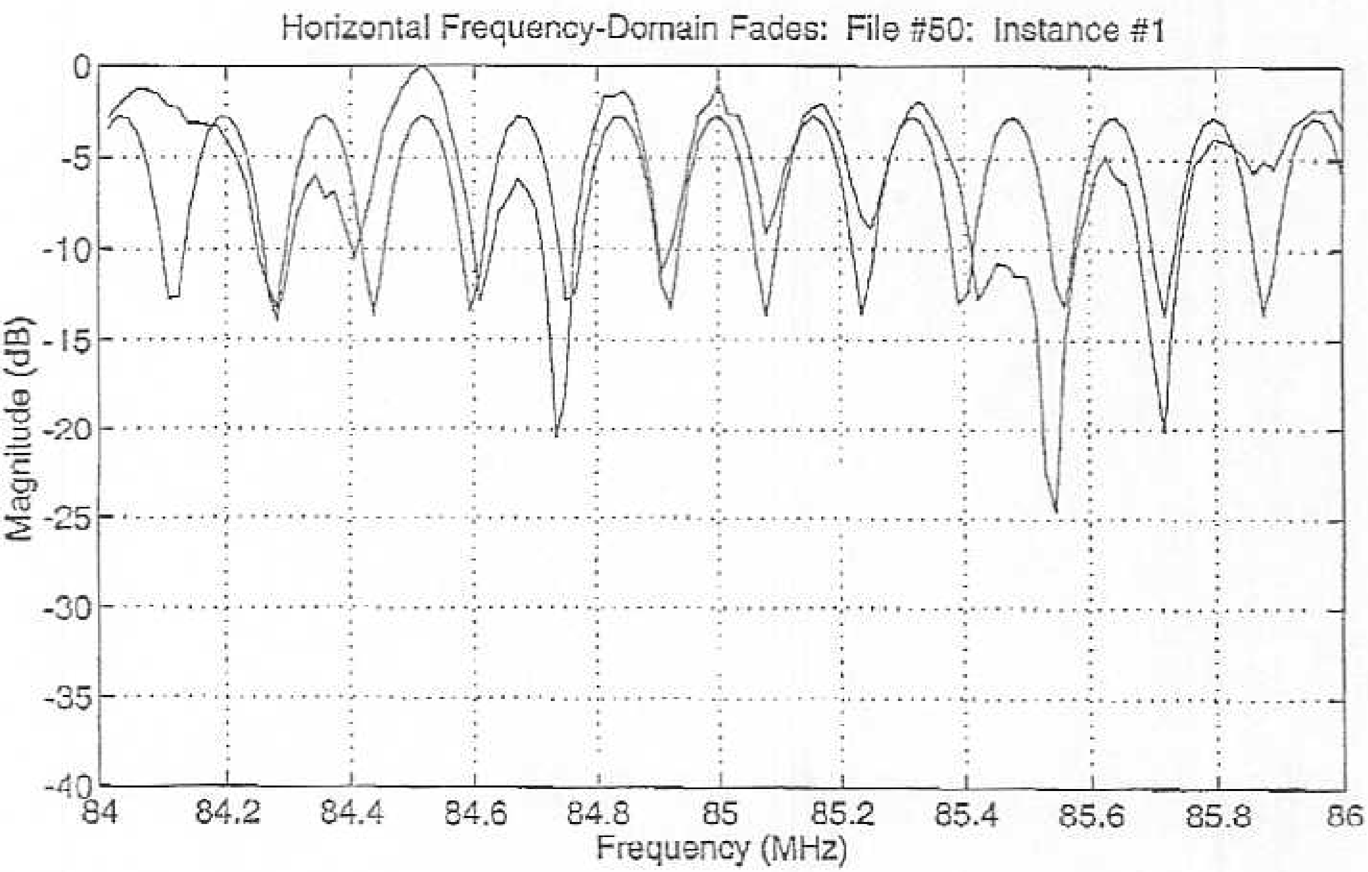
Time Delay (usec)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Magnitude (dB)
0
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84.6
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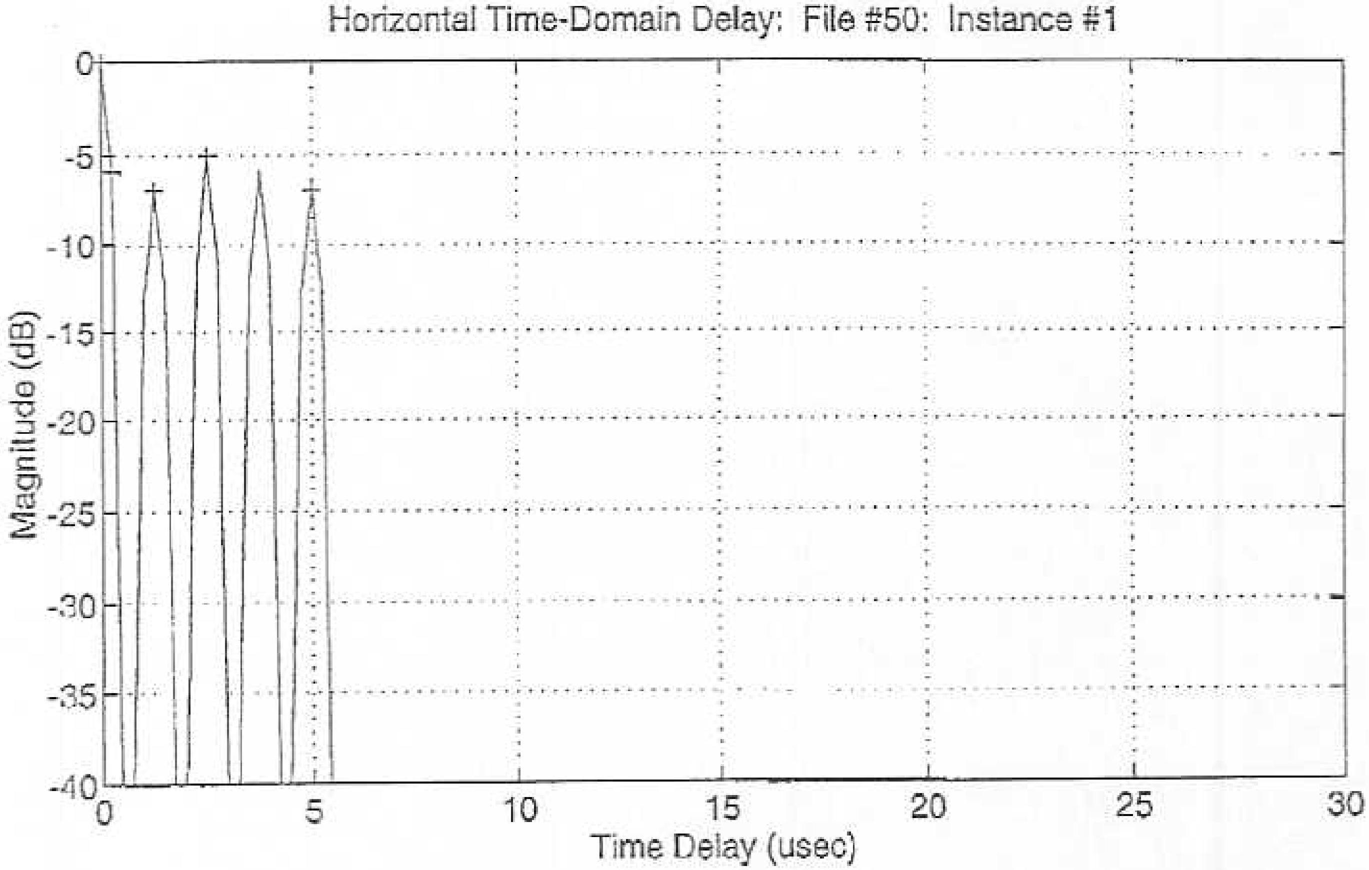
85.2
85.4
85.6
85.8
86
Frequency (MHz)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Magnitude (dB)
Time Delay (usec)
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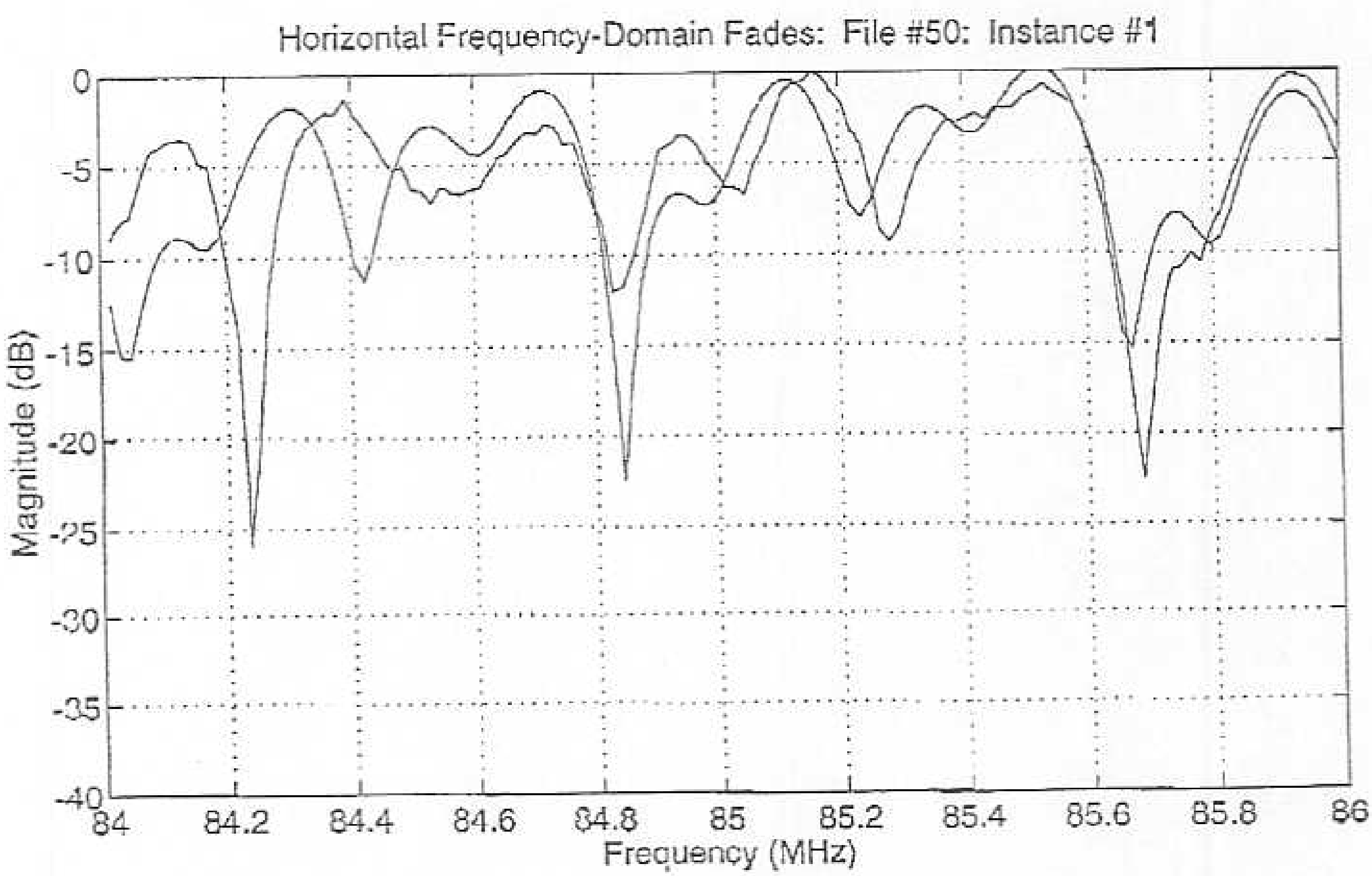
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Magnitude (dB)
Frequency (MHz)
0
-5
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-40
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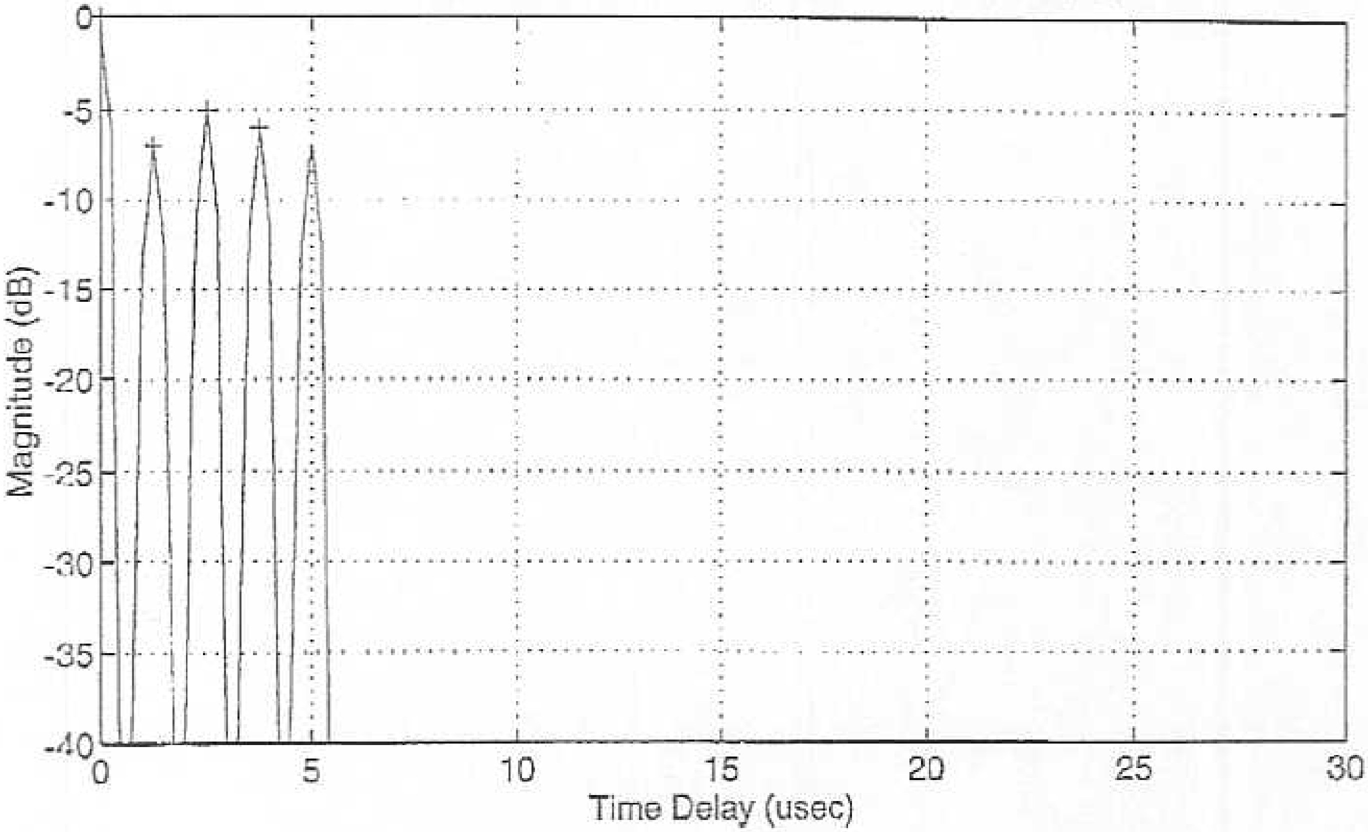
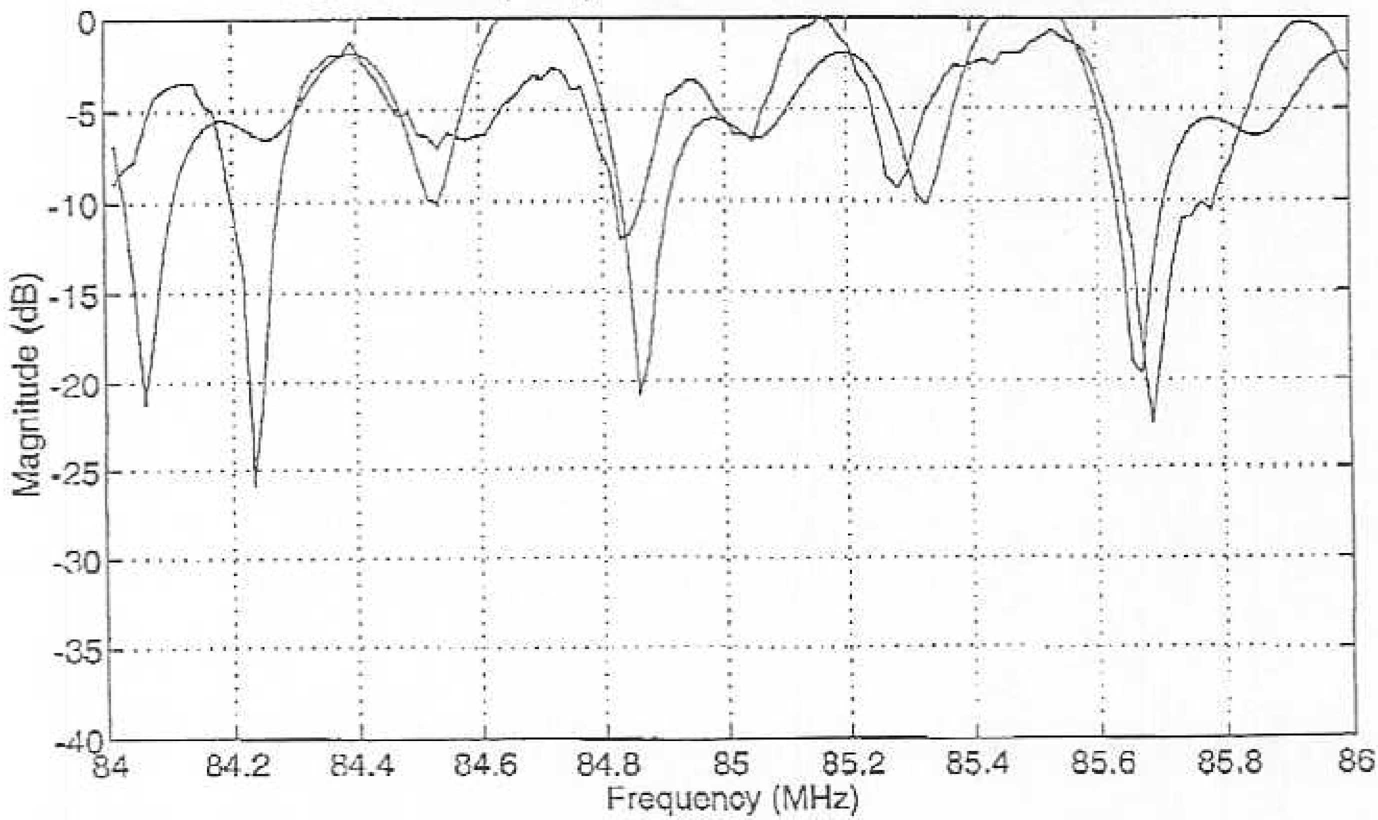
86

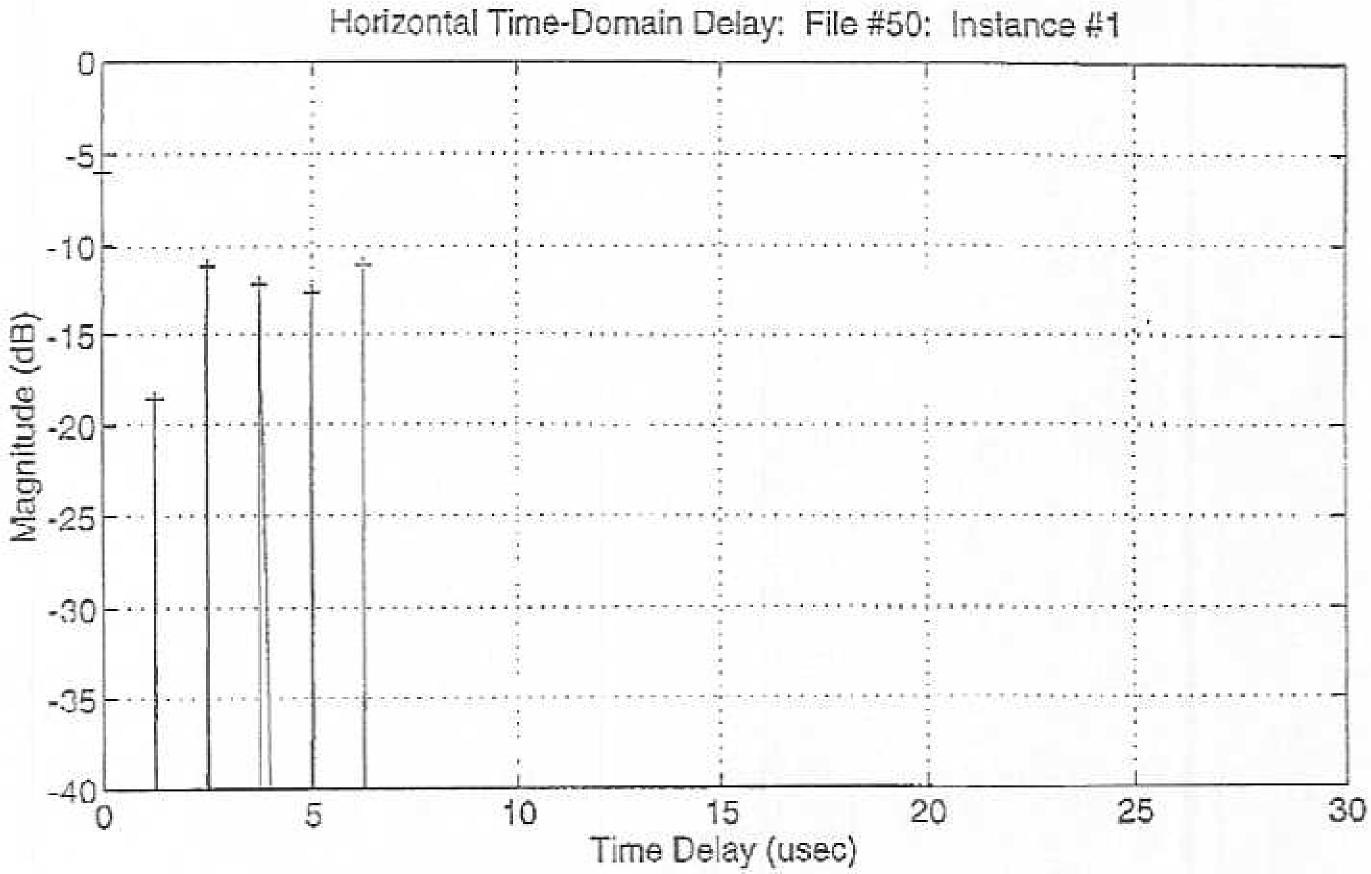
6

Horizontal Time-Domain Delay: File #50: Instance #1



Horizontal Frequency-Domain Fades: File #50: Instance #1





Horizontal Time-Domain Delay: File #50: Instance #1
Magnitude (dB)
0
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-35
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0
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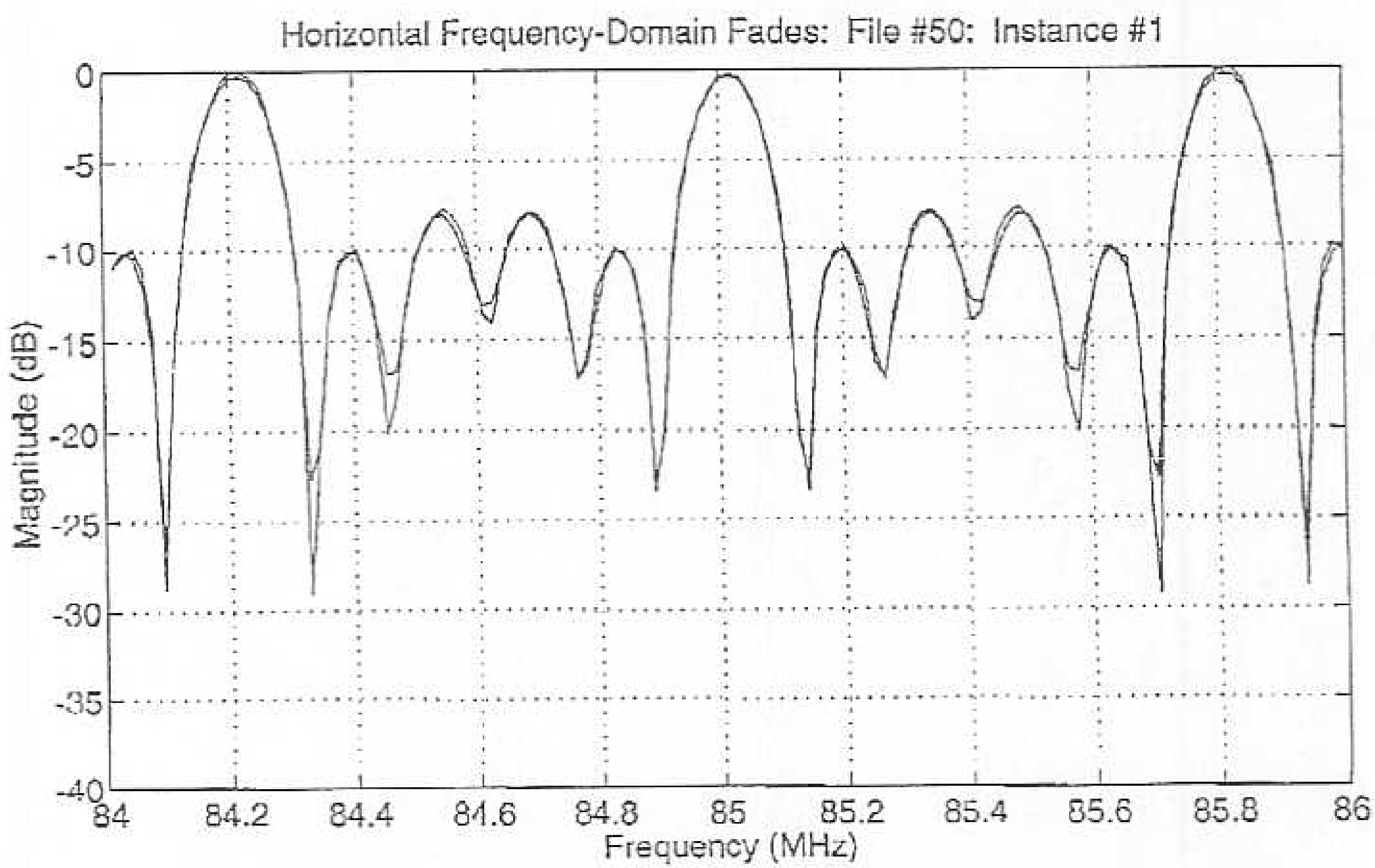
25
30
Time Delay (usec)



Horizontal Frequency-Domain Fades: File #50: Instance #1
Magnitude (dB)
0
-5
-10
-15
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-30
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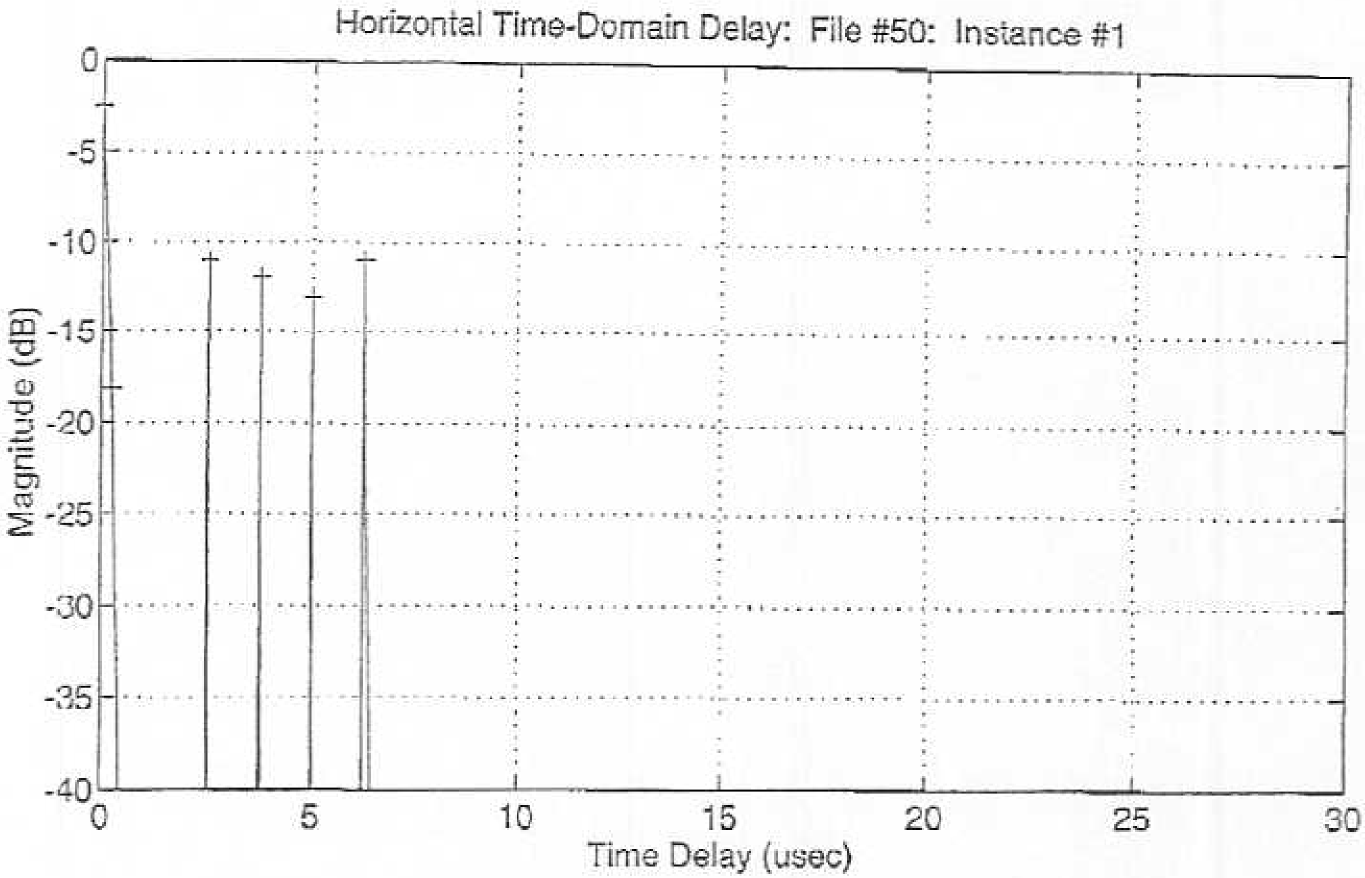
85.6
85.8
86
Frequency (MHz)


Horizontal Time-Domain Delay: File #50: Instance #1
Magnitude (dB)
Time Delay (usec)
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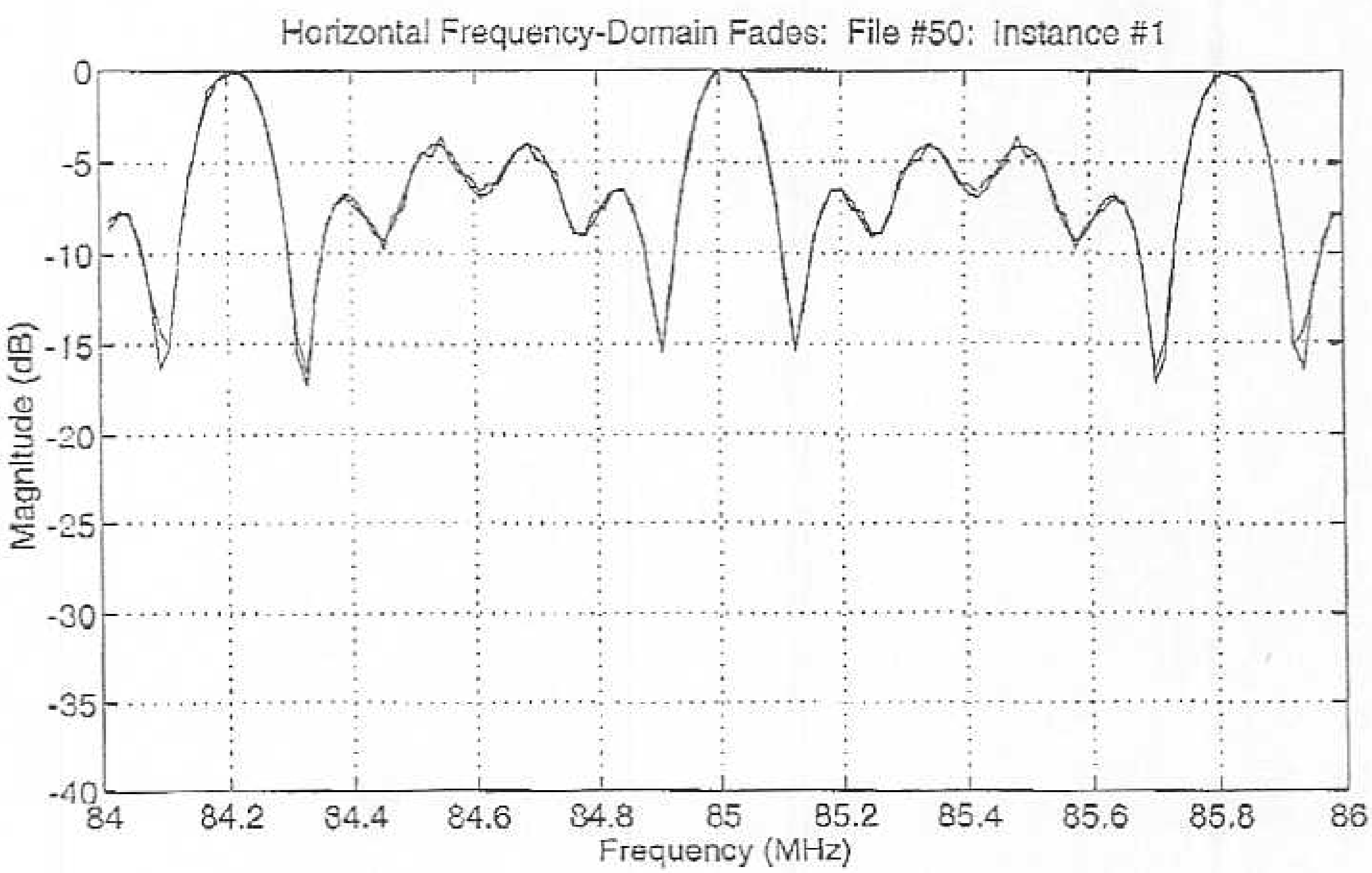
Horizontal Frequency-Domain Fades: File #50: Instance #1
Magnitude (dB)
Frequency (MHz)
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-35
-40
84
84.2
84.4
84.6
84.8
85
85.2
85.4
85.6
85.8
86

6

Time-Domain Algorithm
for Multipath Parameter Selection

Introduction

This memo shows the results of an alternate to the reflection parameter algorithm which is now being used. In place of the modified Prony's method, which matches response in the frequency-domain, the new algorithm selects parameters in the time domain.

Using four comparison files as examples, we see that the new algorithm chooses the six maximum time-domain peaks that are above the noise (a threshold set at -26 dBm.) No peaks are chosen within a single bin (250 nsec) of each other. The frequency matches do not seem very different from the desired. In fact, outliers are removed: the few cases where Prony's method fails to match the frequency domain, the new algorithm functions well. The new method looks like a viable alternative for processing our data.

Note: The original plots are extracted from the original data packets. The frequency plots of Graph 5 and Graph 7 have not been corrected for proper presentation. The arrows tell how to read these graphs.

New Algorithm

Mike Geile of Nova Engineering designed the new time-domain-based algorithm. It has the desirable qualities of the improvement filter discussed on March 8, but can also function when the environment is not in frame synchronization (which of course it is not).

The algorithm begins by generating a high-resolution basis matrix. The first row of the matrix is the triangle decorrelation function (the receiver impulse response without the noise or artifacts). Four more rows are generated as the original row delayed by the bin width (250 nsec) divided by 4.

The algorithm then follows an iterative process, six times for each of the desired reflectors. The process begins by determining the maximum magnitude of the waveform. The five data bins centered about that point in the waveform are examined. These points are convolved against the basis matrix to predict the reflector position, which is the largest value of the correlation; this delay value is recorded. Now the correlation magnitude is multiplied by the basis matrix to determine the contribution of the predicted reflector to the waveform. This contribution is subtracted from the original waveform, removing the reflector from the time-domain response, and the process is repeated by finding the next maximum magnitude.

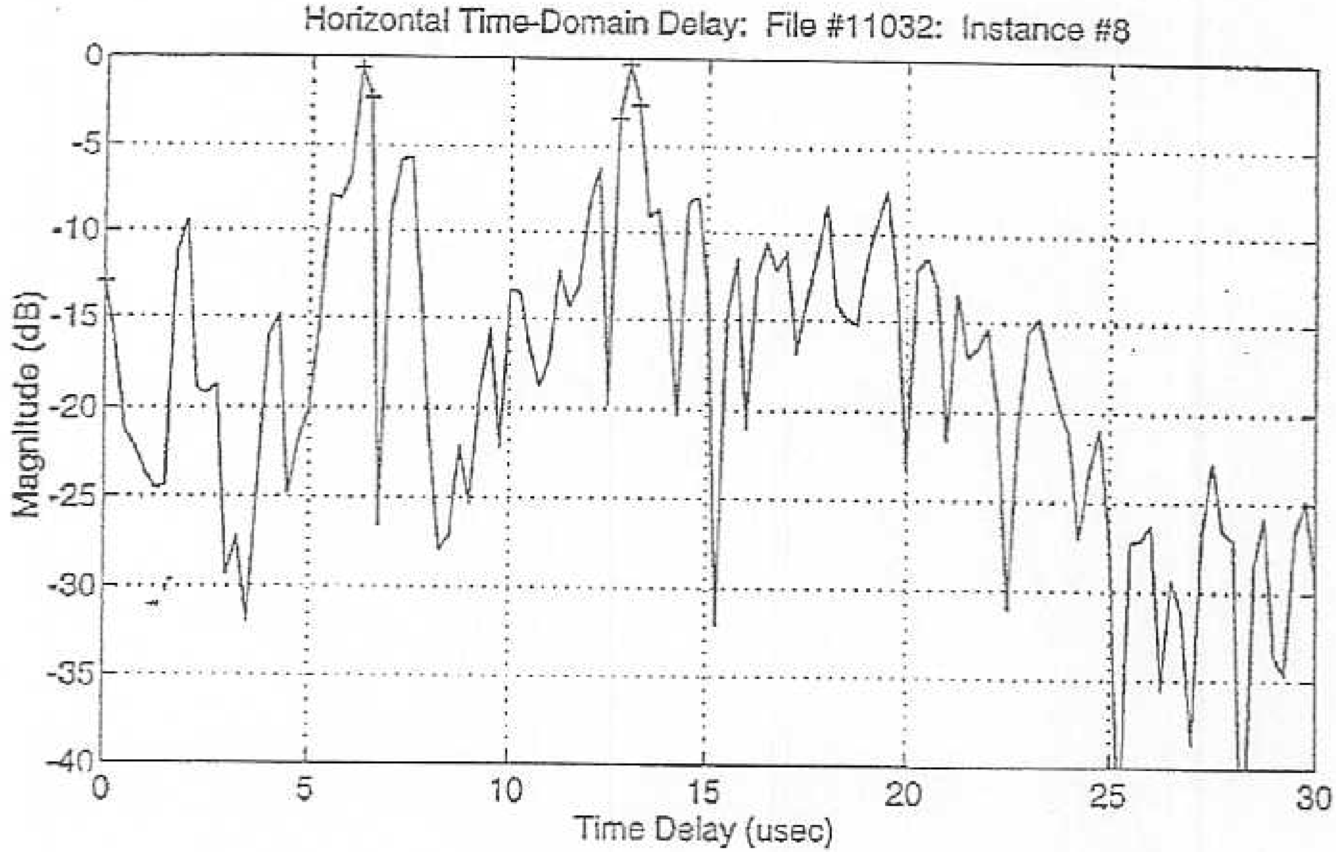
After six iterations, the algorithm has produced six delay values which are then rounded to the nearest bin and attached to the corresponding magnitude and phases.

Examples

Eight graphs are presented which represent the before (odd numbers) and after (even numbers) of four example files. These were used to draw the conclusions in the summary.

Note: The new algorithm (as well as the original) are ready to reprocess the selected set of files chosen by Bob Culver. The decorrelation has been updated to include the band-limited matched filter described in an earlier memo.

Brian Warren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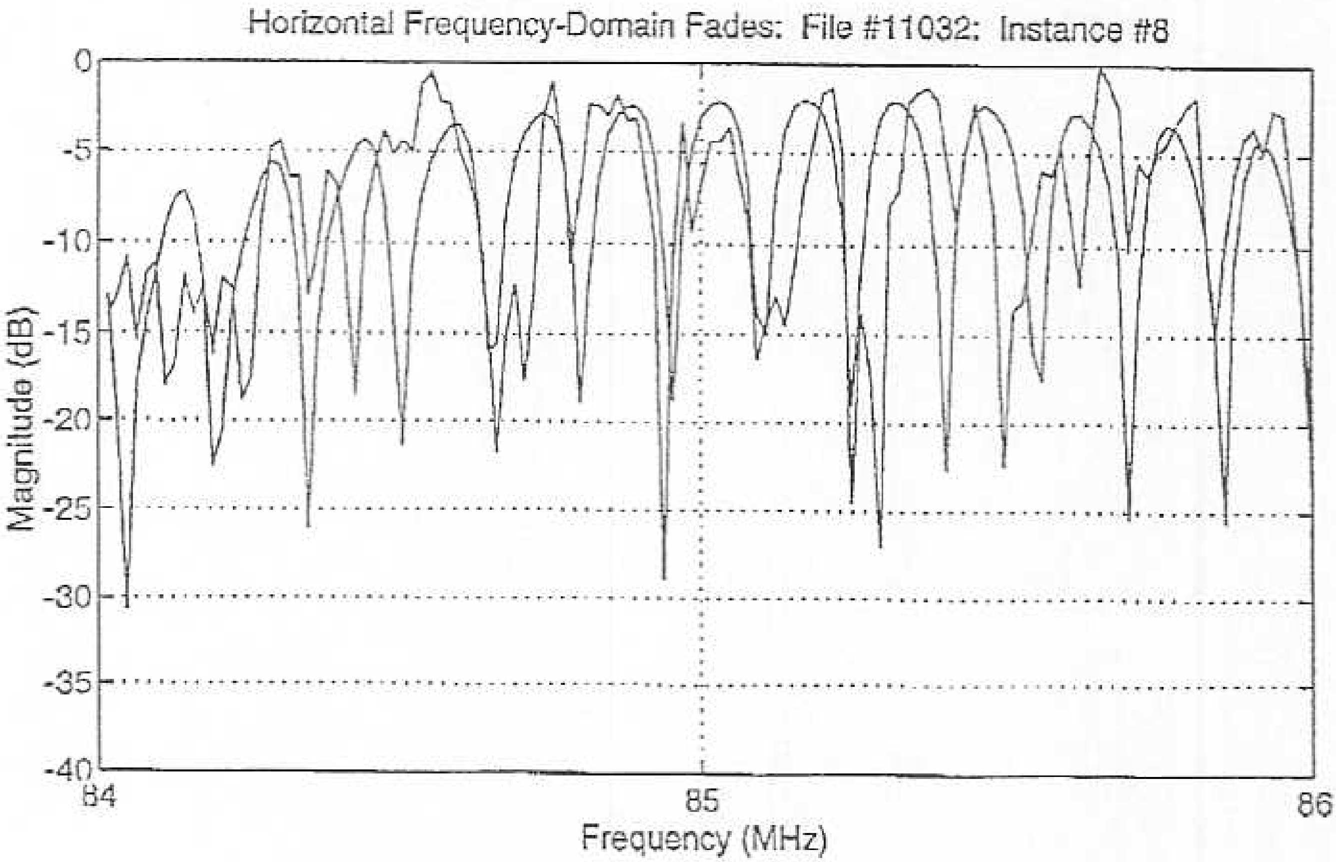
10
15
20
25
30
Time Delay (usec)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-15
-20
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-30
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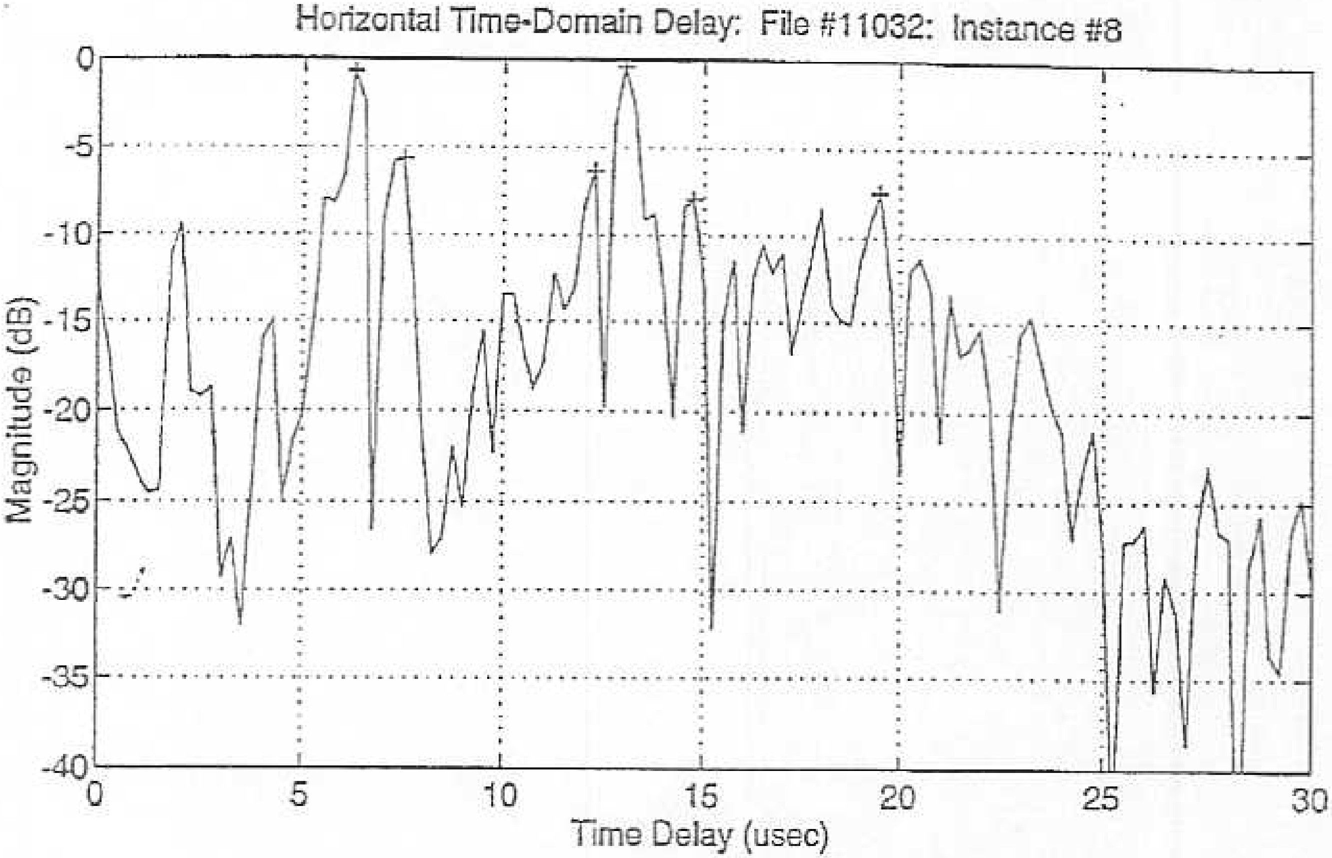
84
85
86
Frequency (MHz)

1



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Magnitude (dB)
Time Delay (usec)
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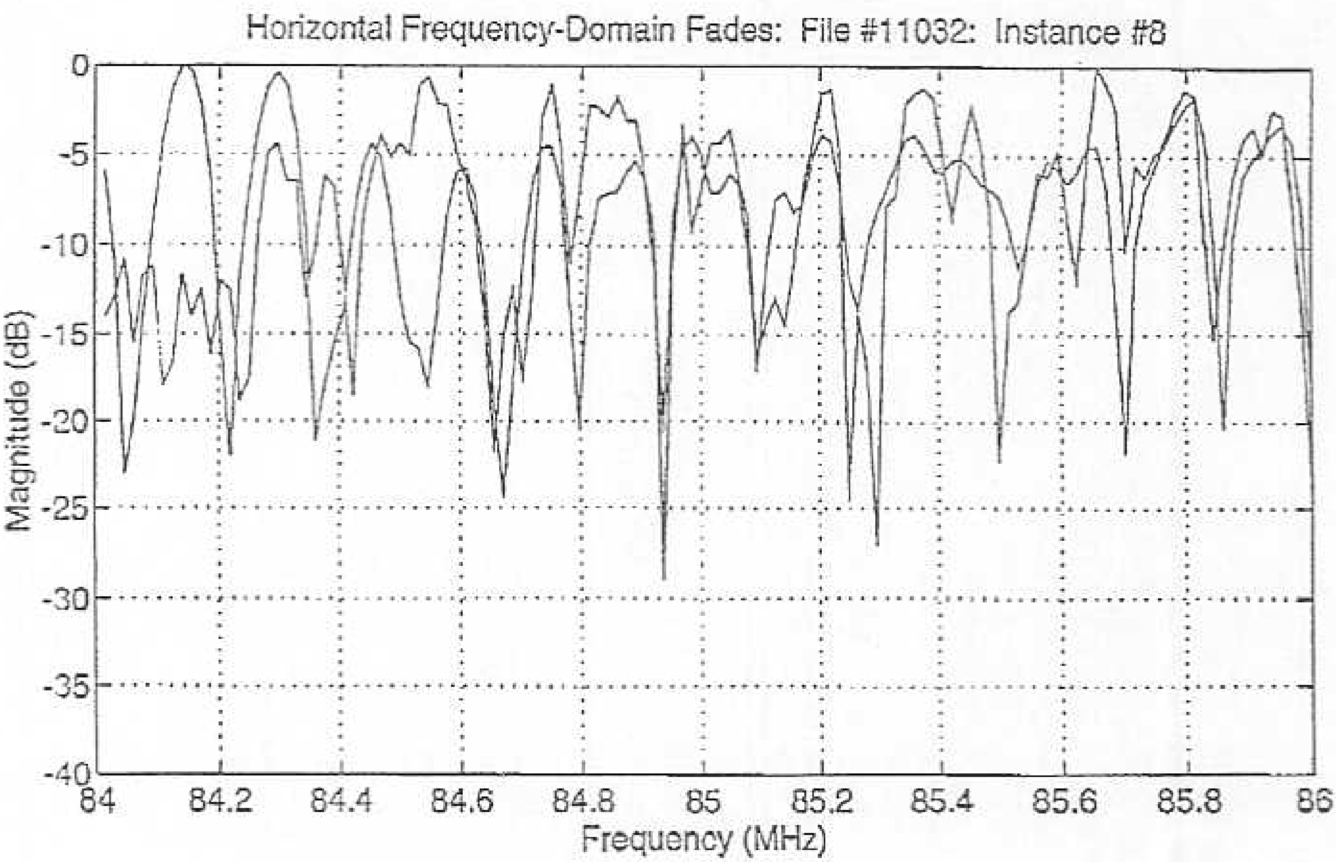

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Magnitude (dB)
Frequency (MHz)
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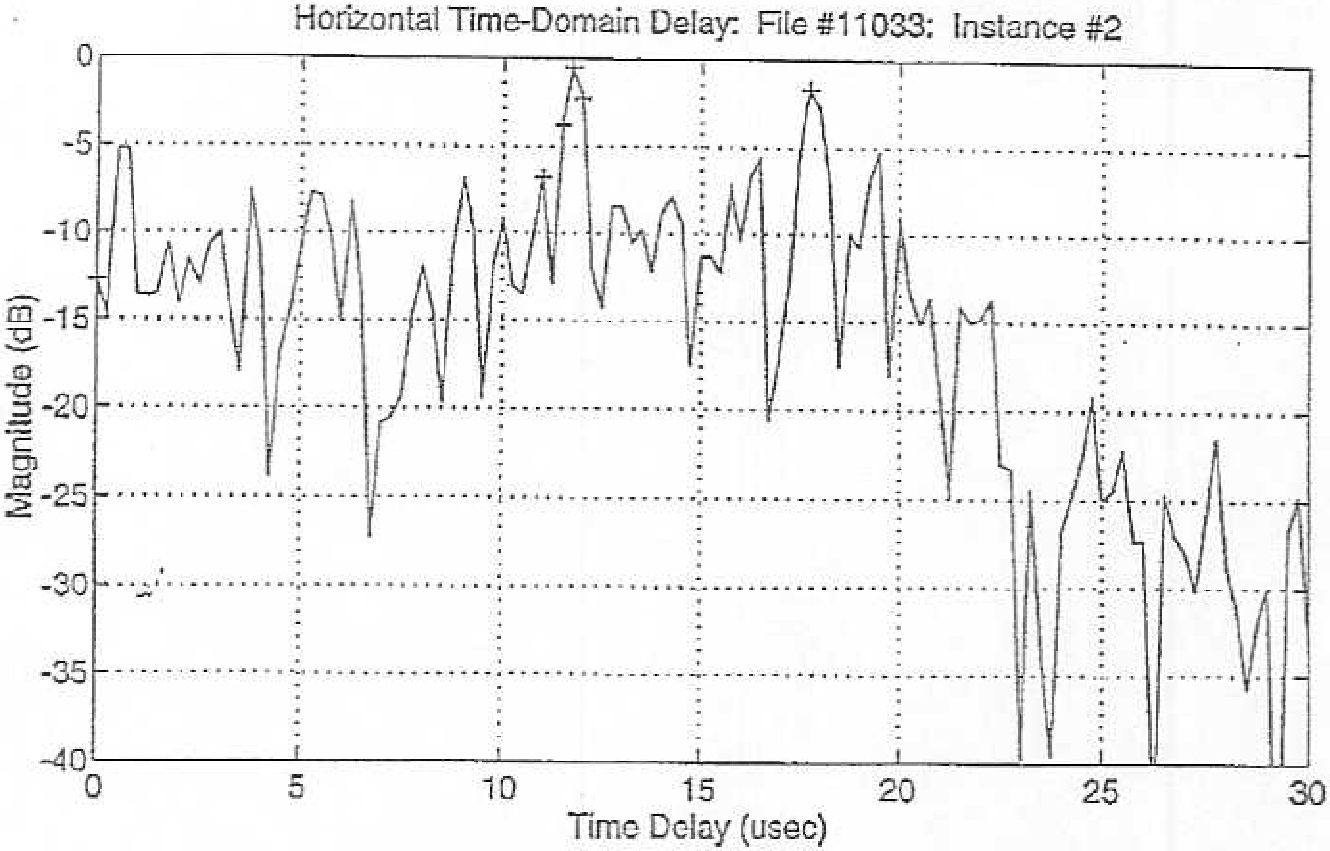
85.6
85.8
86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-25
-30
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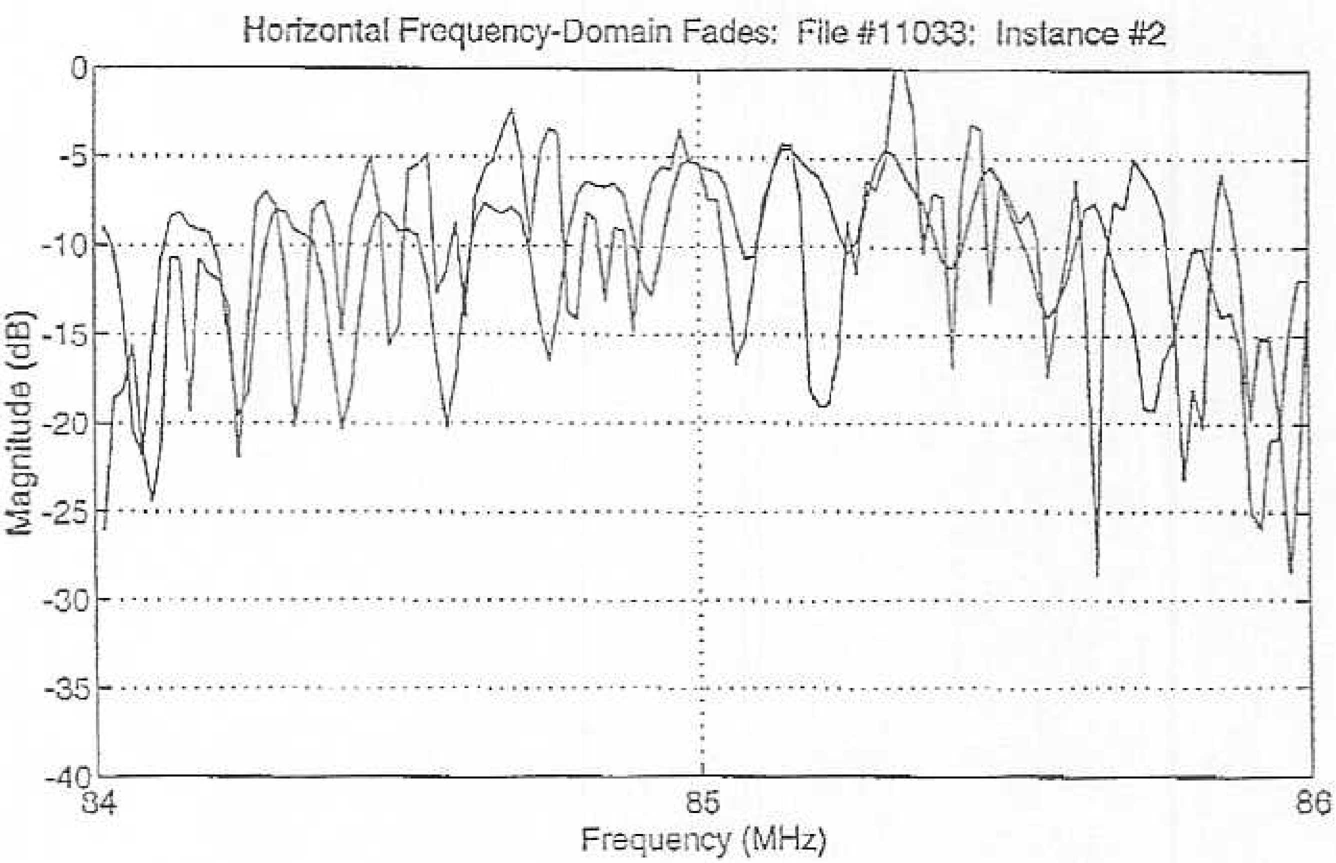
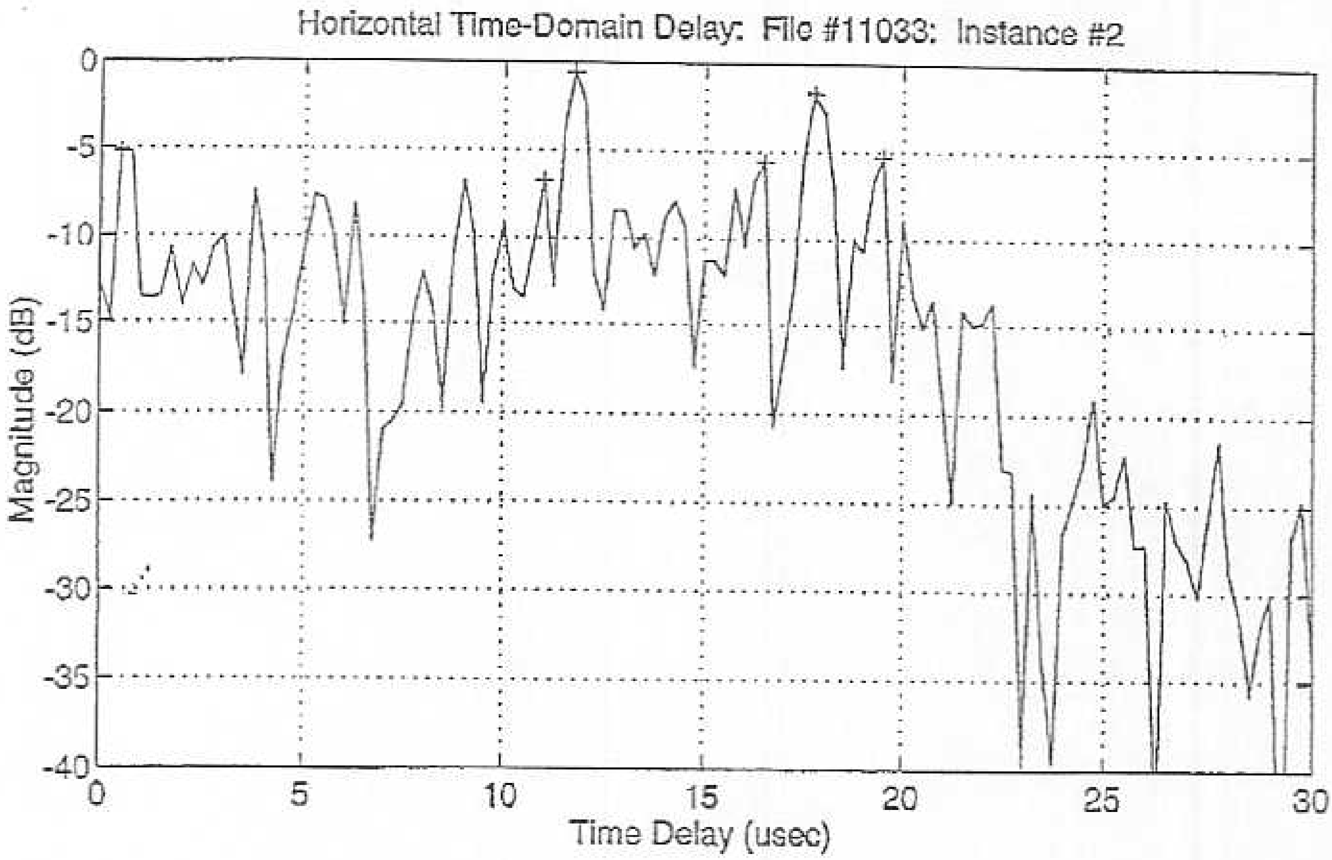
0
5
10
15
20
25
30
Time Delay (usec)


Horizontal Frequency-Domain Fades: File #11033: Instance #2
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
84
85
86
Frequency (MHz)


Horizontal Time-Domain Delay: File #11033: Instance #2
Magnitude (dB)
Time Delay (usec)
0
-5
-10
-15
-20
-25
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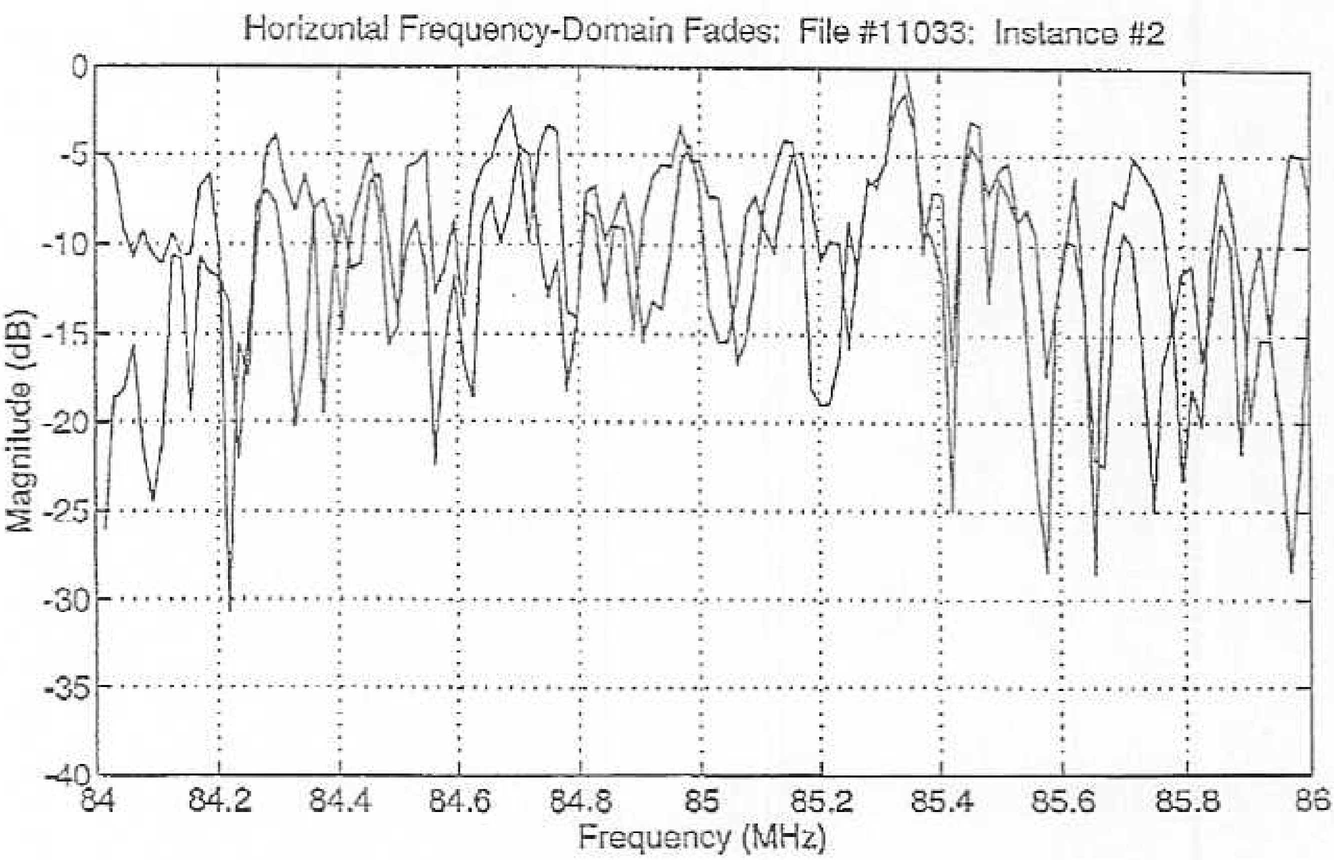
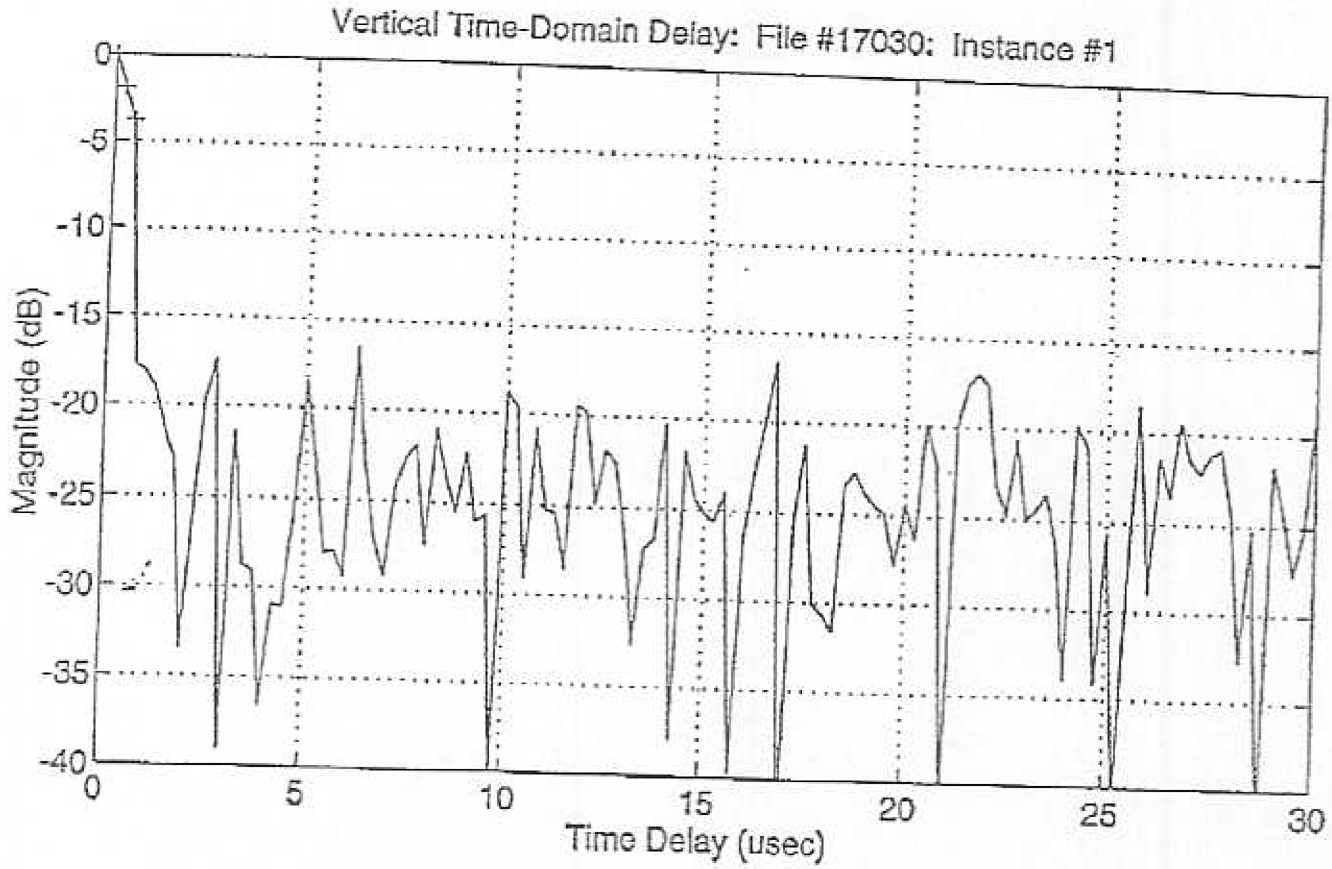
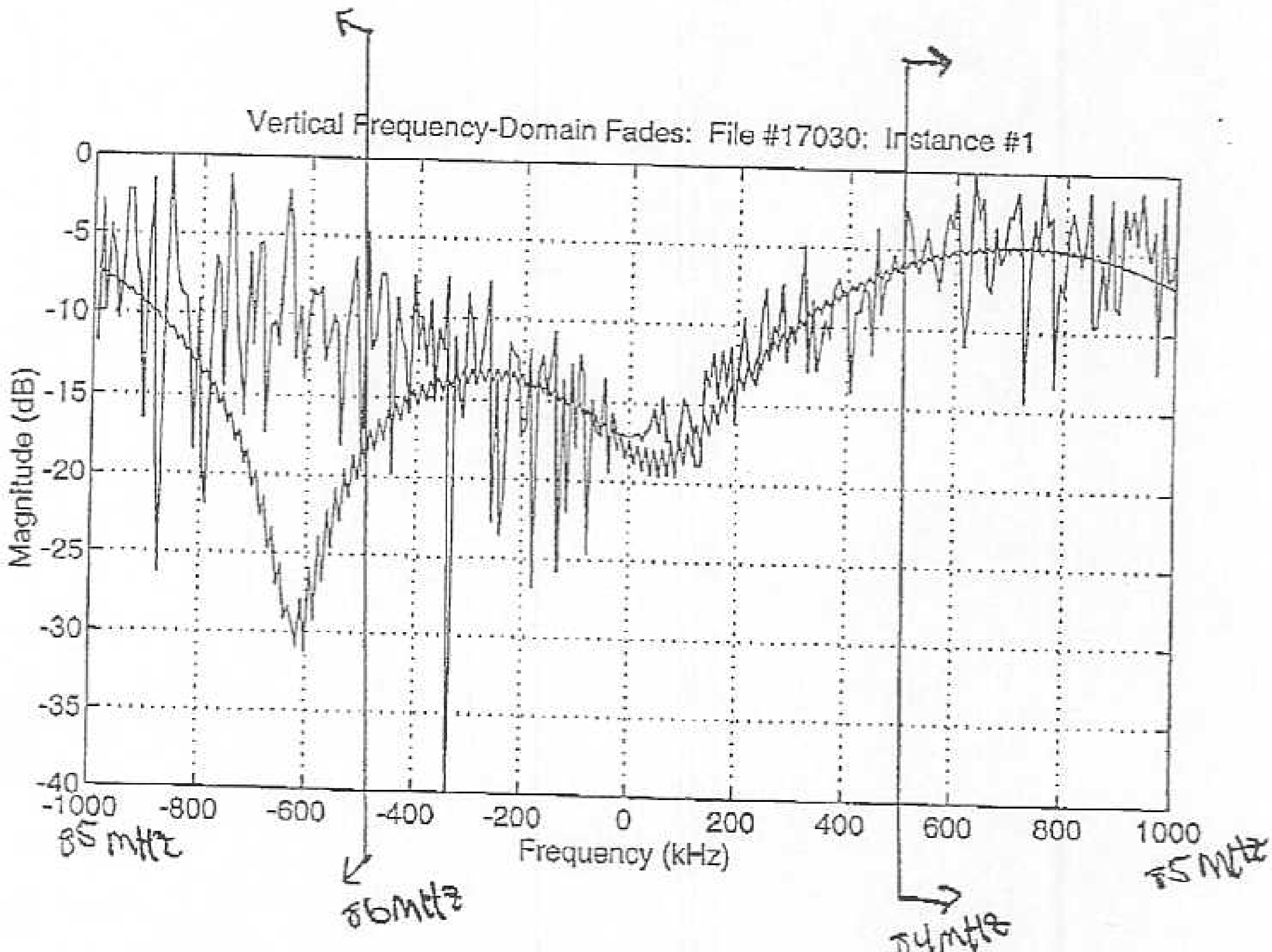
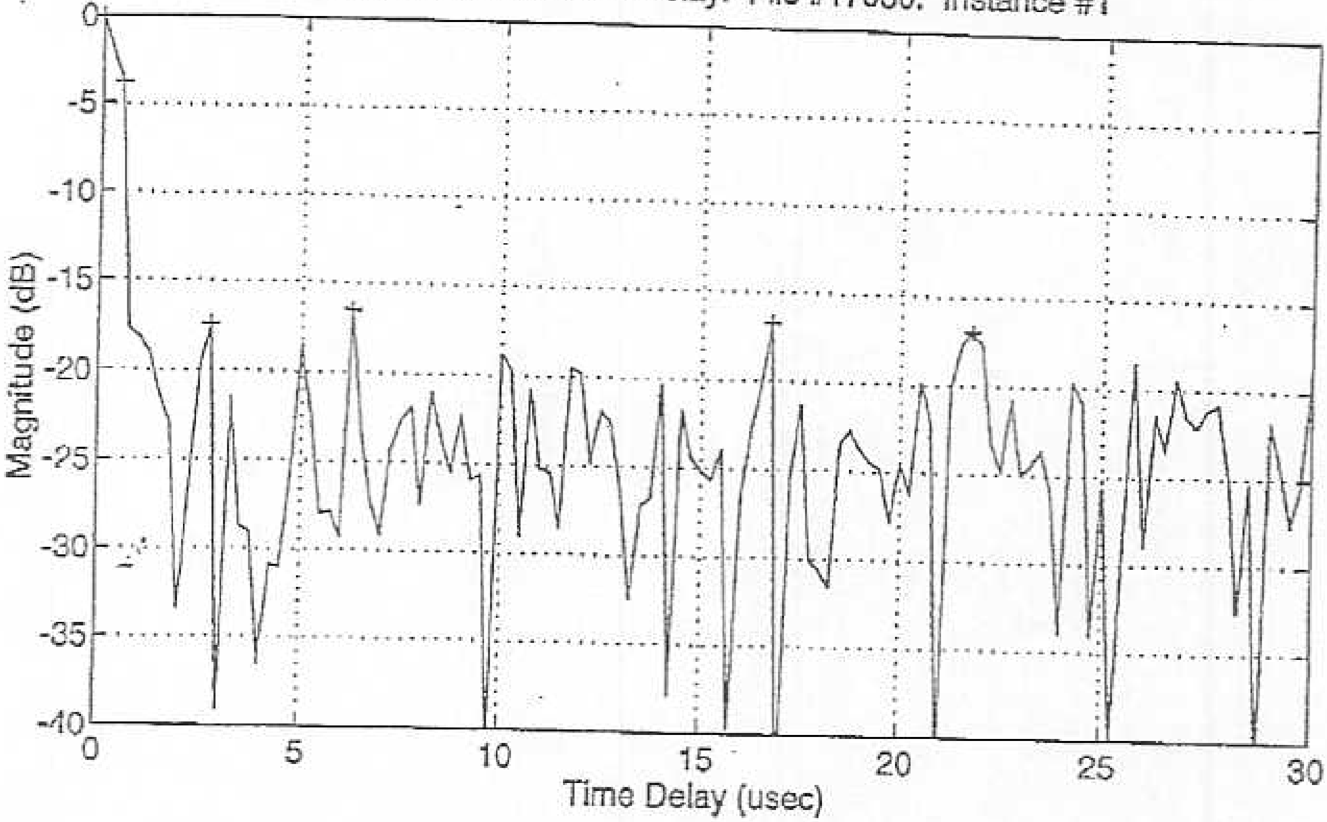
-35
-40
0
5
10
15
20
25
30


Horizontal Frequency-Domain Fades: File #11033: Instance #2
Magnitude (dB)
Frequency (MHz)
0
-5
-10
-15
-20
-25
-30
-35
-40
84
84.2
84.4
84.6
84.8
85
85.2
85.4
85.6
85.8
86

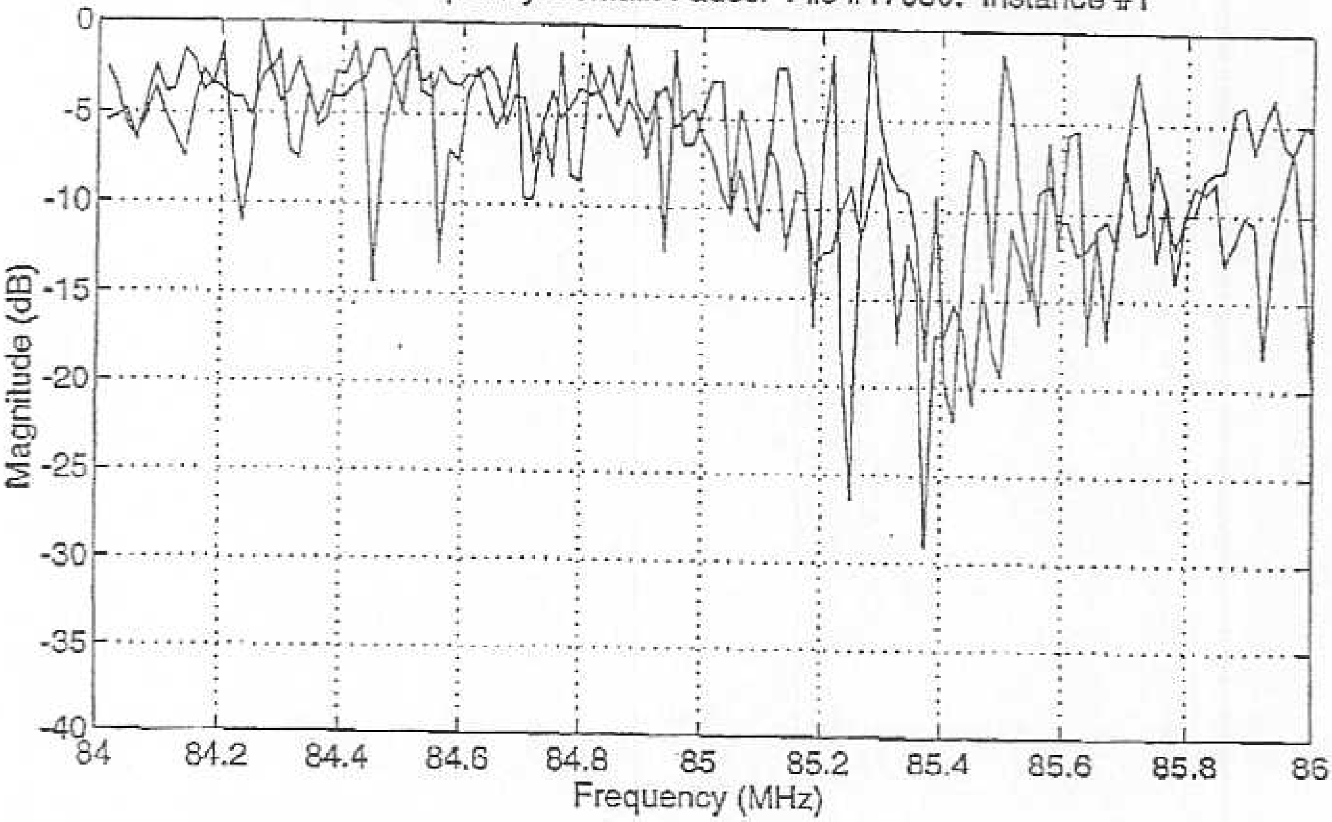

Vertical Time-Domain Delay: File #17030: Instance #1
Magnitude (dB)
Time Delay (usec)

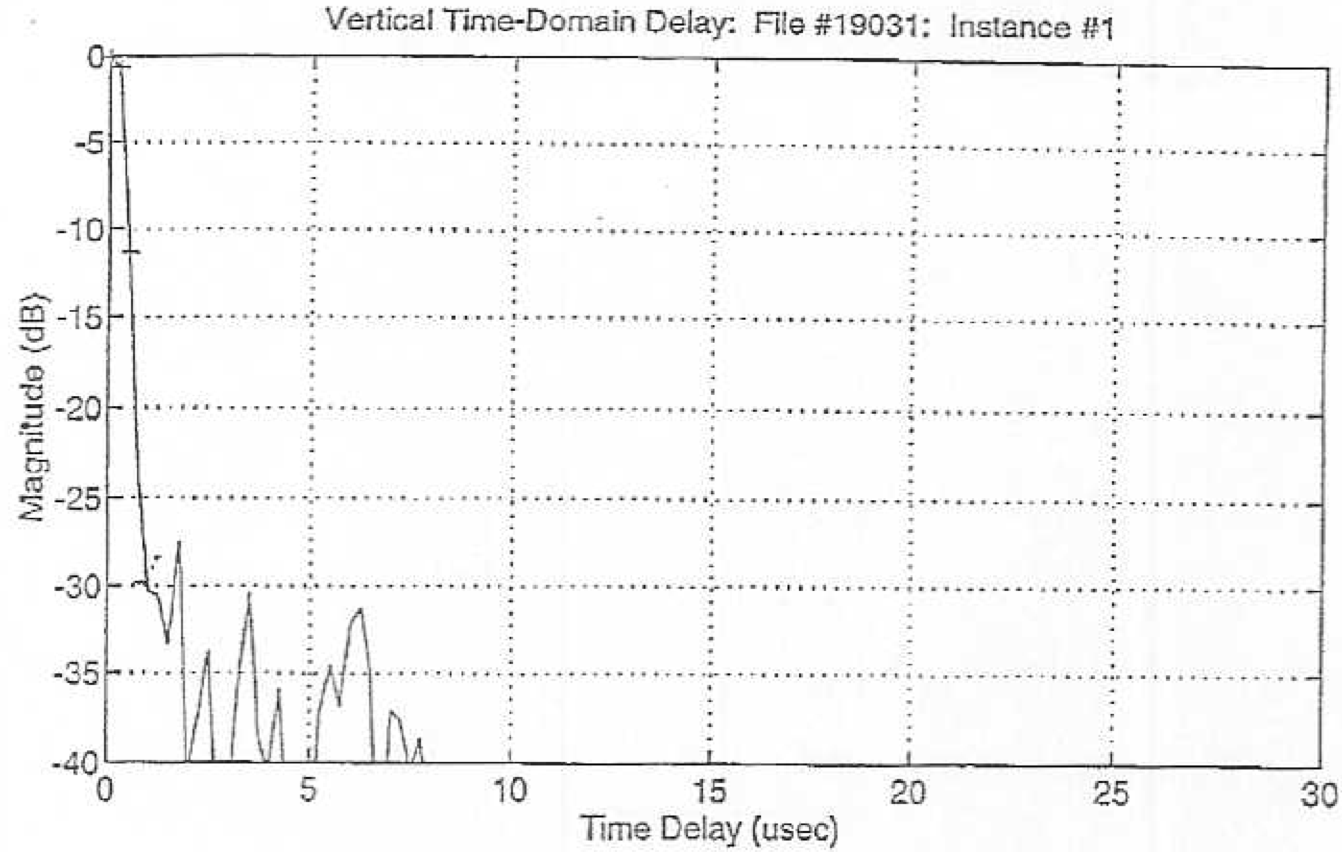

Vertical Frequency-Domain Fades: File #17030: Instance #1
Magnitude (dB)
Frequency (kHz)
85 MHz
86MHz
84MHz
85 MHz

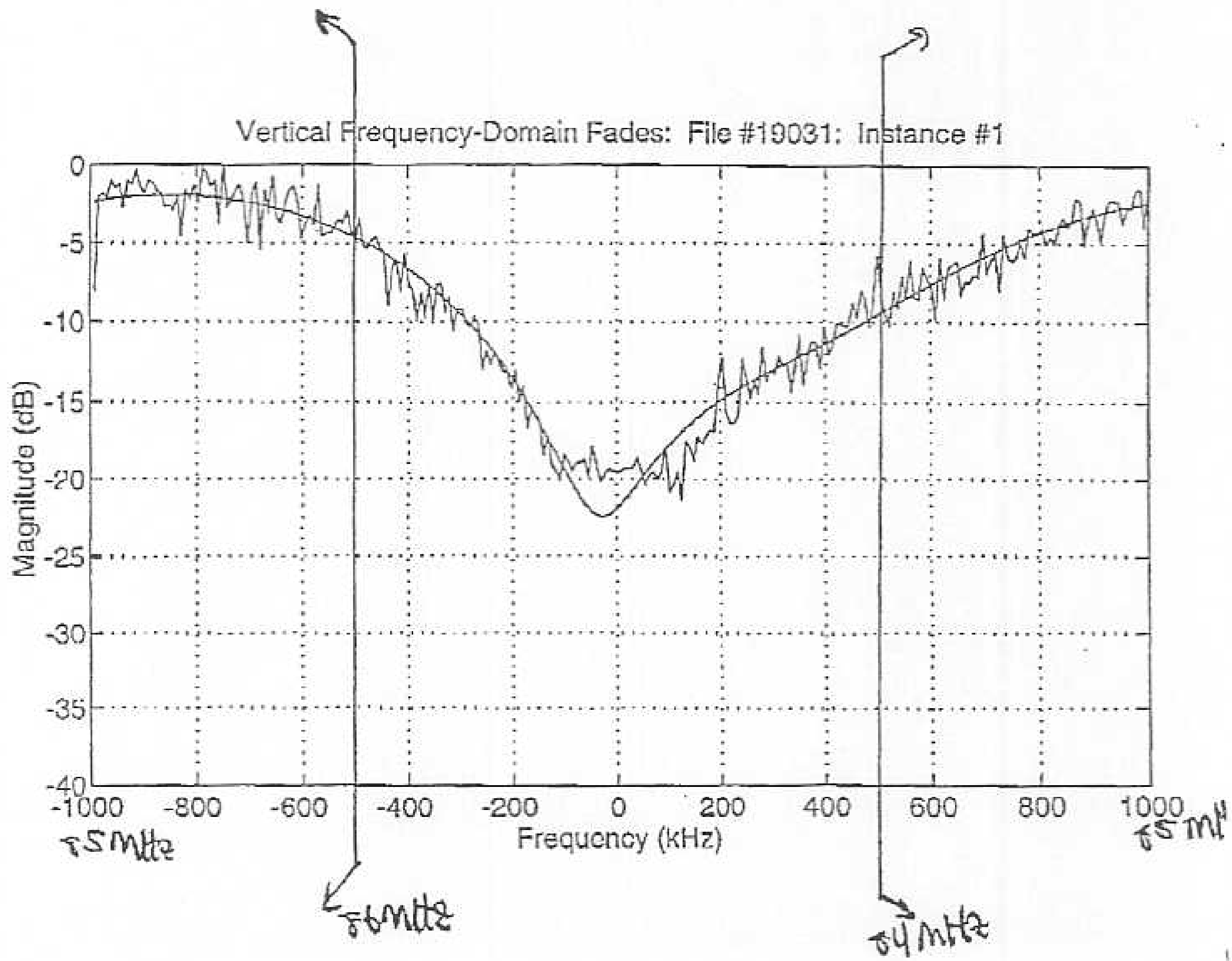
Vertical Time-Domain Delay: File #17030: Instance #1

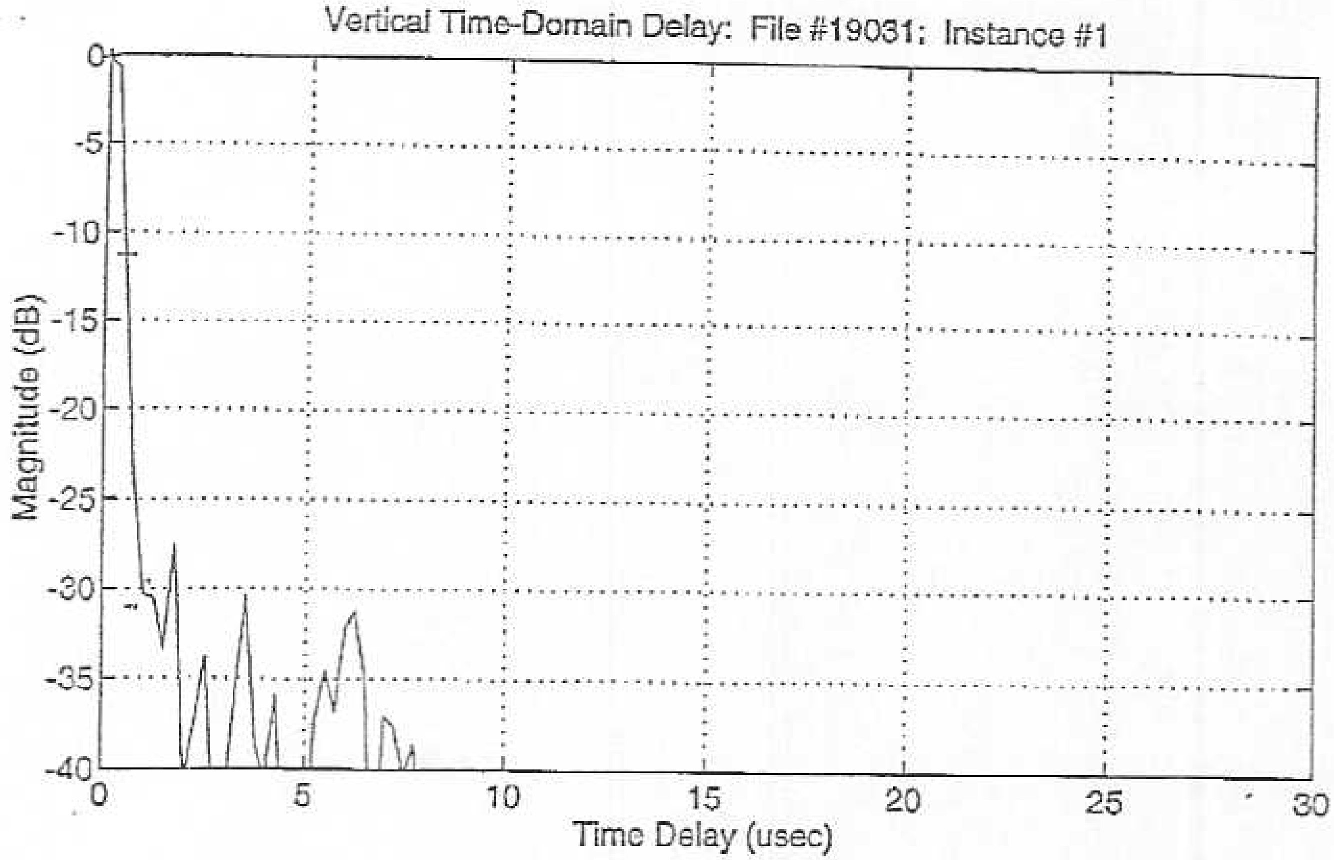


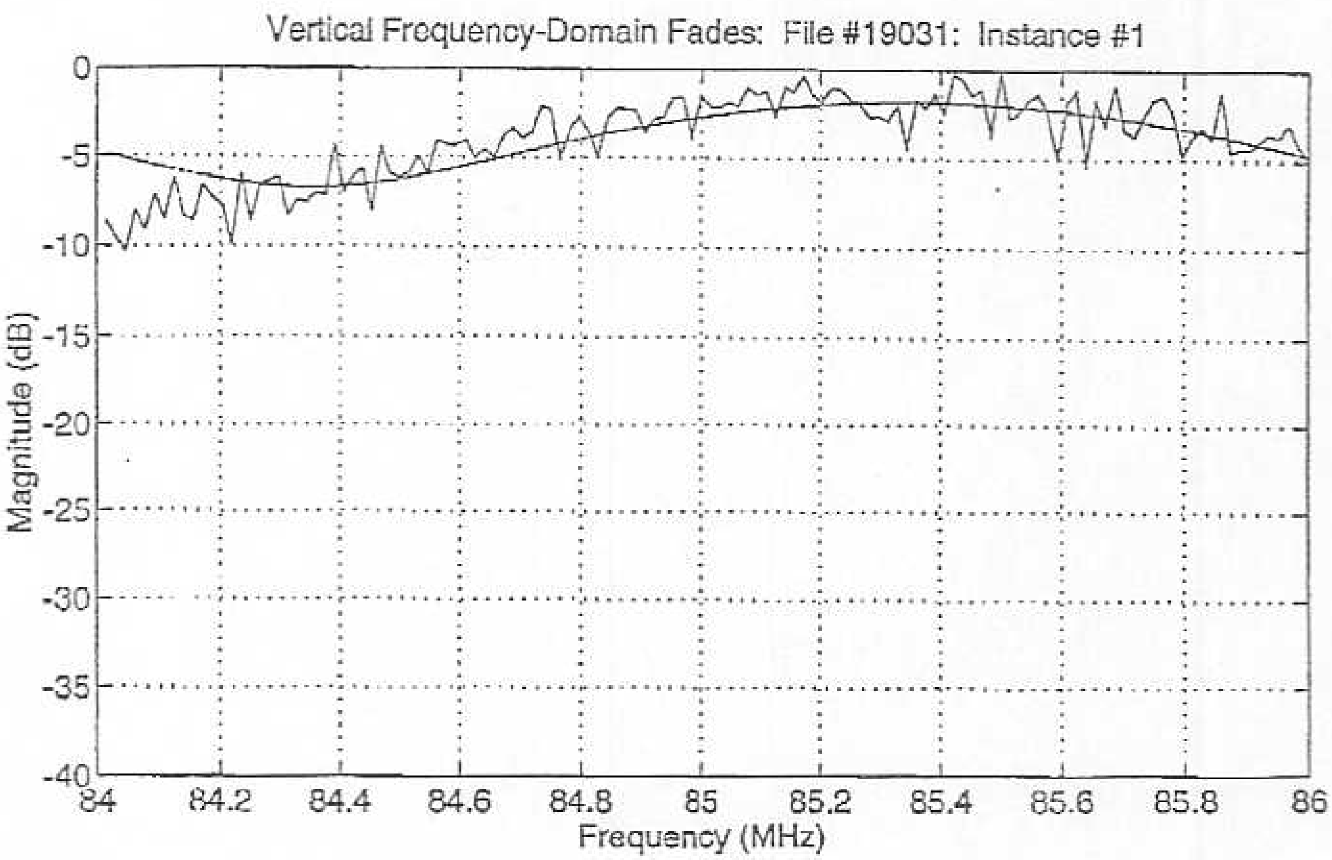
Vertical Frequency-Domain Fades: File #17030: Instance #1




Vertical Time-Domain Delay: File #19031: Instance #1
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
0
5
10
15
20
25
30
Time Delay (usec)


Vertical Frequency-Domain Fades: File #19031: Instance #1
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
Frequency (kHz)
75MHz
75 MH
76MHz
74MHz


Vertical Time-Domain Delay: File #19031: Instance #1
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
0
5
10
15
20
25
30
Time Delay (usec)


Vertical Frequency-Domain Fades: File #19031: Instance #1
Magnitude (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
84
84.2
84.4
84.6
84.8
85
85.2
85.4
85.6
85.8
86
Frequency (MHz)

8

APPENDIX G

APPENDIX G - DATA PROCESSING AND INTEGRATION TO SIMULATOR(S); RANGE OF DATA

G-1 Memo (L&C), to EIA-CEG DAR WG-B, "CCTG", "Determination of the "Envelope" of Magnitudes & Time Delays for Environments A through D" -- 4/8/94

G-2 FAX Memo from B. Warren, DELCO, "Multipath Simulator and Parameter Conversion: Issues and Status" -- 4/14/94

MEMORANDUM RE SALT LAKE CITY DATA ANALYSIS

RE: DETERMINATION OF THE "ENVELOPE" OF MAGNITUDES & TIME DELAYS FOR ENVIRONMENTS A THROUGH D.
TO: EIA-CEG DAR WG-B, CHANNEL TEST TASK FORCE
FROM: ROBERT D. CULVER
DATE: APRIL 08, 1994

	Phone	Fax
Randall Brunts & Brian Warren, Delco	317-451-7053	317-451-1340
David Londa, Consultant, NASA	216-433-3445	216-433-8705
James Hollansworth & David Londa, NASA	216-433-3458	216-433-8705
Thomas Keller, Consultant	703-569-3135	703-569-3370
Alford Resnick, Cap Cities/ABC	212-456-6457	212-456-~~6820~~ 3666
Milford Smith, Greater Media	908-247-6161X221	908-247-0215
Ken Springer, NAB	202-429-5341	202-775-4981\4901
Ralph Justus, EIA	202-457-8716	202-457-4985
Gerald Chouinard, CRC	613-998-2500	613-993-9950

The Salt lake data analysis is progressing along the planned route. The "envelope" of the maximum reflected signal levels at various time delays is now known. Plots of that data are attached and discussed below. The actual measurement segments which are significant contributors will now be investigated. It is hoped that a control sequence for the laboratory multipath simulation can be built from the actual measured values. This process has been long and laborious because of the intricacies of the Matlab software, the volume of data and P.C. hardware limitations.

Attached are sets of plots for the four "environments" of the Salt Lake City data; Urban (A), Suburban (B), Rural (C), and Terrain Obstructed (D). The first set of four plots are gray-scale renditions of the "density" function that was created to give a visual representation of the occurrence of particular reflection magnitudes vs. delay. The vertical scale is 0 to 40dB of attenuation in 1/10 dB steps. The horizontal scale is 0 to 80 bins (250nsec. each). The actual data values extend to approximately 60 dB and 130 bins. For this display 40dB approaches the noise floor of the measurement instrumentation and is well below any significant reflection magnitude. The significant reflections beyond 80 bins are non existent. The gray color in each of the 400 by 80 cells of the plot represents the number of occurrences of that magnitude and delay over the entire environment. The one, two and three occurrence cells are easily seen. The maximum gray scale limits the display to 8 or more occurrences. In the density populated central cells there are hundreds of occurrences in some cells. The primary information shown is the perimeter of the envelope, the scattered random "noise" data and some unusual artifacts.

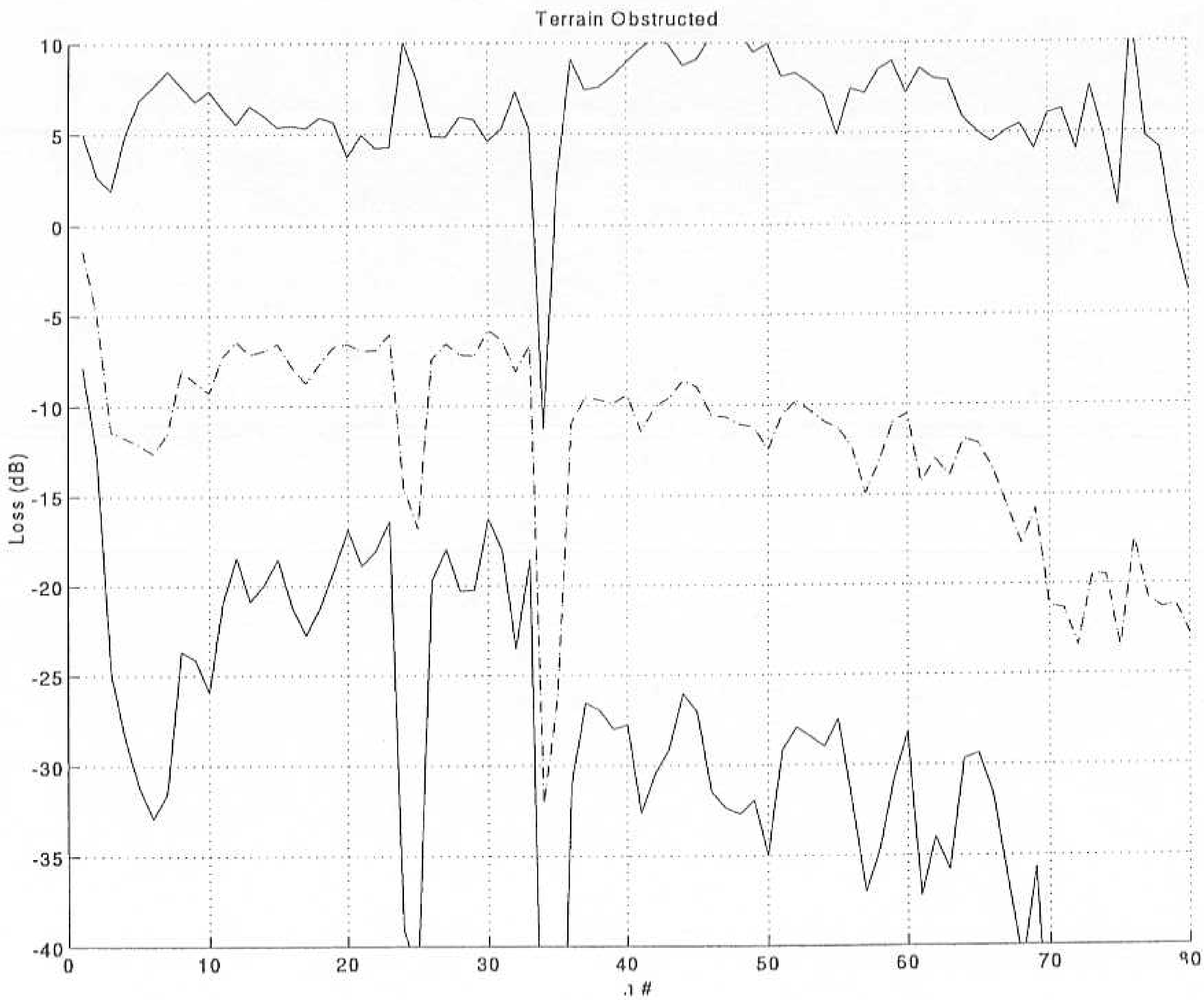
H 1383

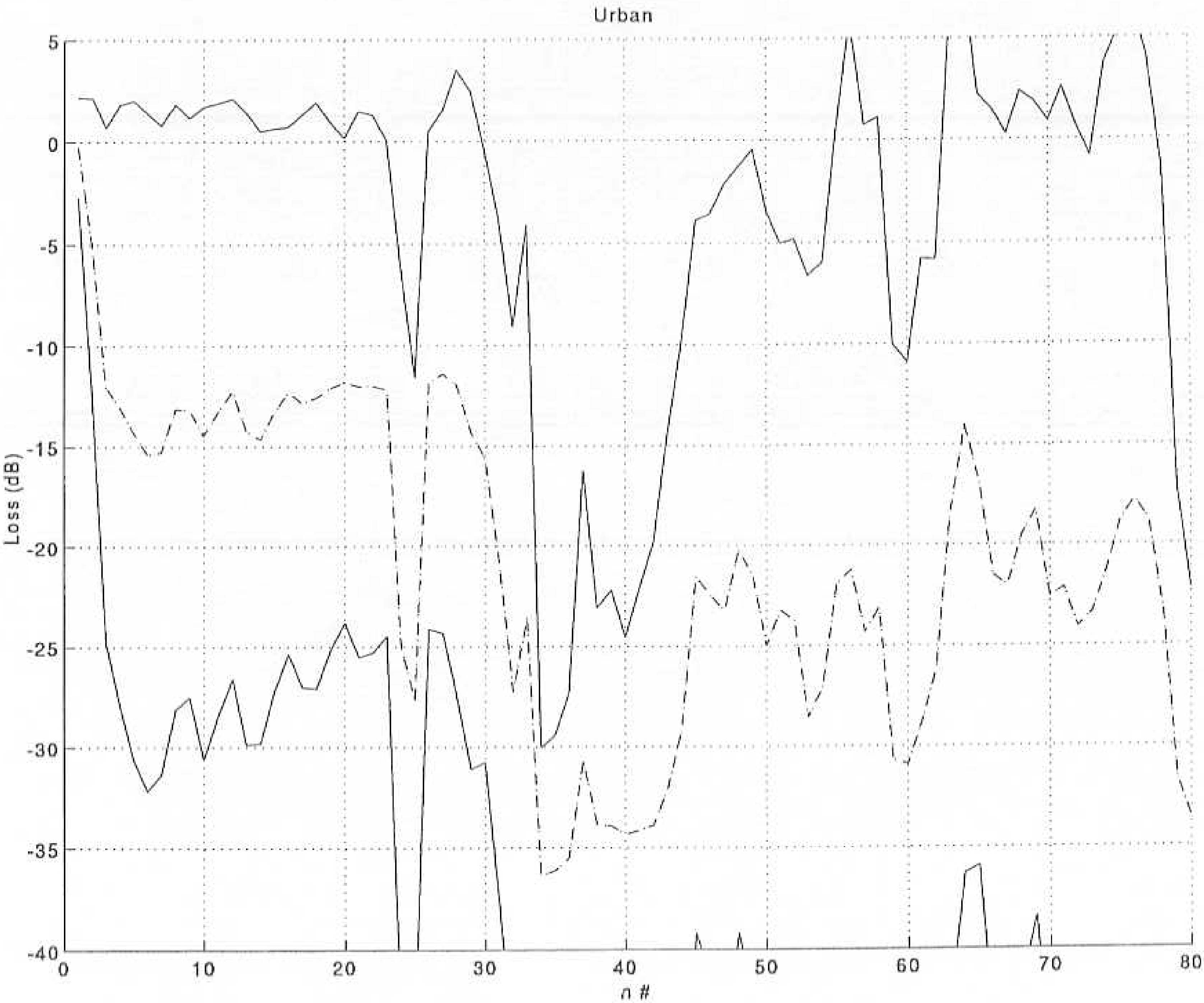
At bin 35 and bin 26, clusters of data can be seen. This same data appears in all measurement files. I believe this is false data possibly representing a signal leaking into the measurement system. That signal is at least 25dB below the normalized maximum and therefore not significant for channel simulation for this digital testing. That data also creates an artifact in the next set of graphs.

The next set of graphs show the mean reflection attenuation in each time bin for the entire data for environments A through D. Also shown are the $\pm$ 2sigma limits of the deviation of the data for each bin. The 1,2 and 3 sigma limits correspond to 67, 95 and 99% of the data values and a 95% limit probably is appropriate for the threshold of significant reflection probability. Any other limit desired can be used but since the actual magnitude delay values will be chosen by "eyeball interpolation" from this graph and the density plot, the 2sigma line is probably a good starting reference. Based on my quick scan of both these graphs I recommend the following starting values;

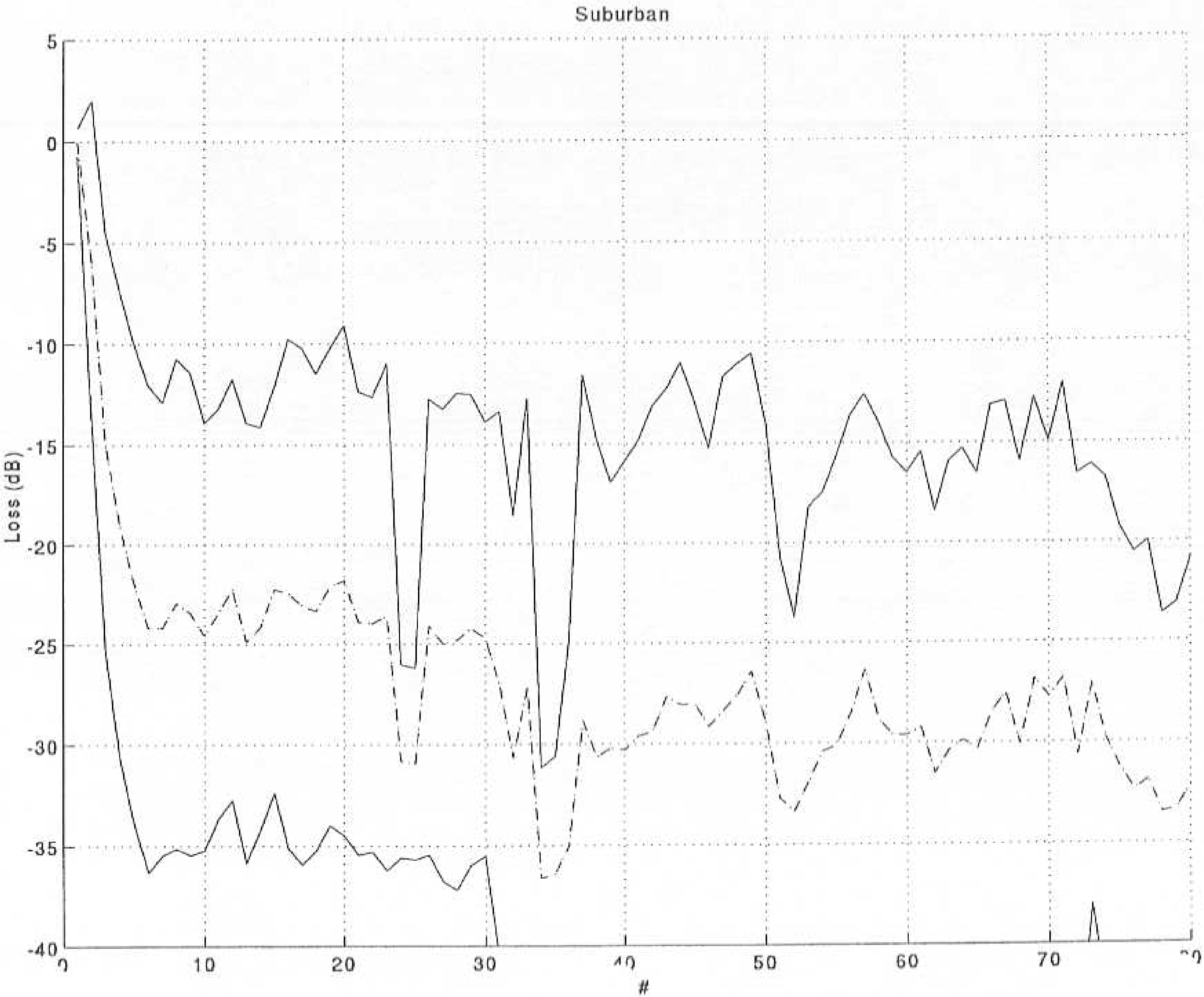
dB/bins	Env. A	Env. B	Env. C	Env. D
Ch. 0	-0/0-0	-0/0-0	-0/0-0	-0/0-0
Ch. 1	+2/1-8	-0/1-4	+2/1-2	+6/1-18
Ch. 2	+0/9-12	-5/5-7	+0/3-4	+0/13-18
Ch. 3	-5/13-17	-10/8-12	-6/5-6	-3/19-30
Ch. 4	-10/18-25	-15/13-20	-10/7-8	-6/31-45
Ch. 5	-15/26-35	-20/21-30	-12/9-35	-9/46-70

As discussed earlier it is an option to use the Salt Lake City test data magnitude and time delay envelope to program the simulator for the critical material selection test. I suggest we review this data and establish a conference call early next week to discuss the programming of the simulator for this first test. Brian Warren has some significant input to the simulator programming and should be part of the conference call.

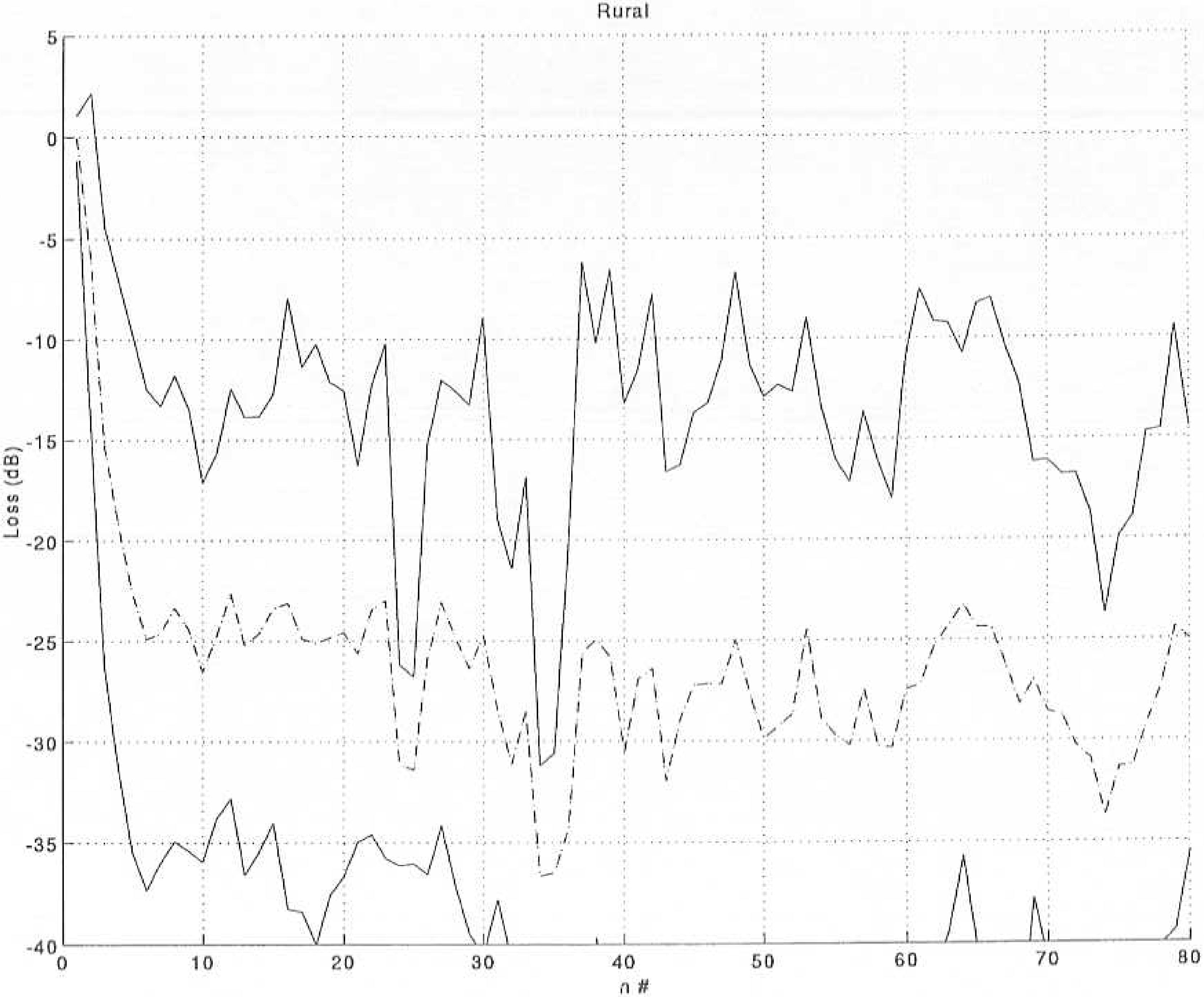

Terrain Obstructed
Loss (dB)
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80
.1 #



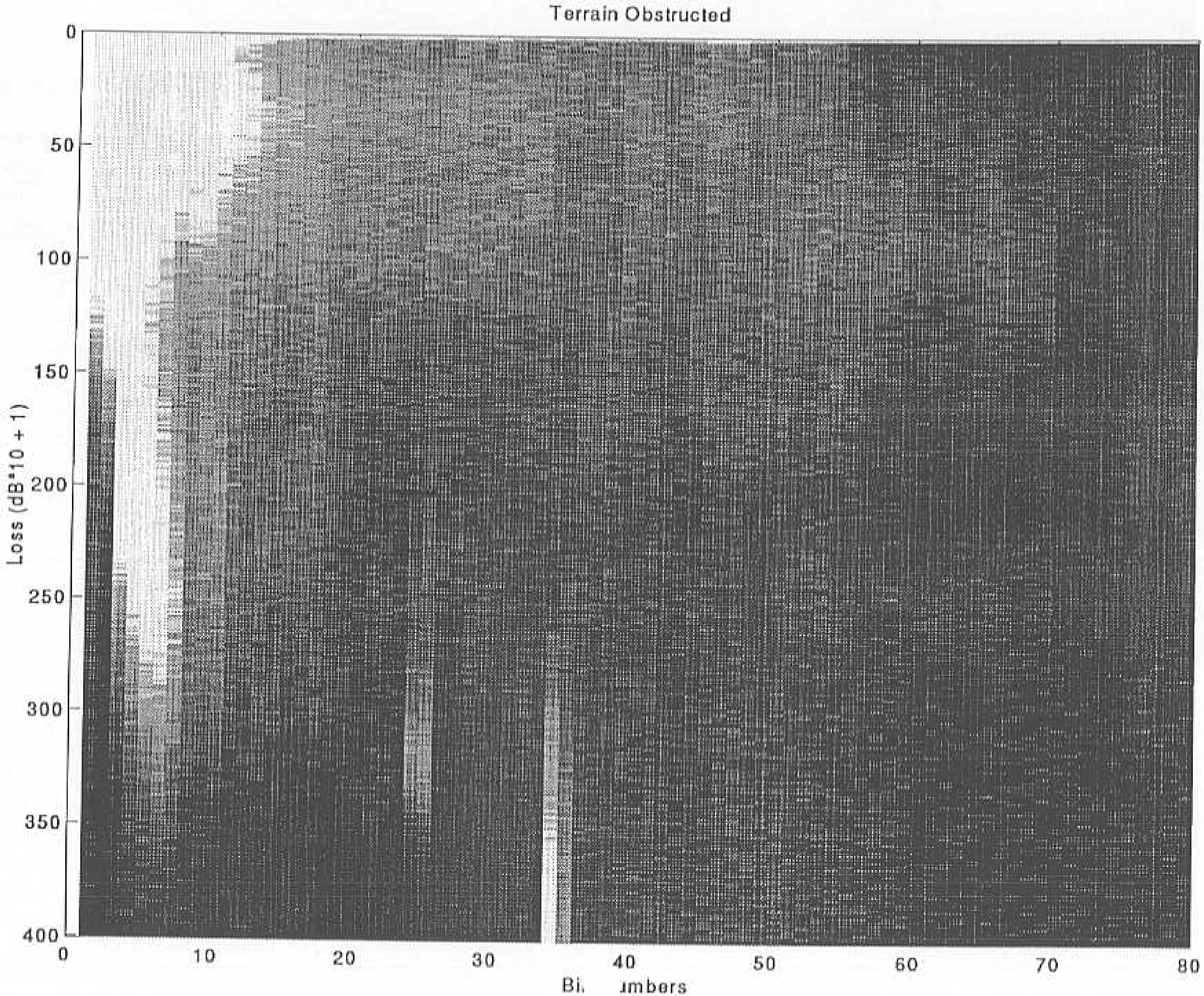
Urban
Loss (dB)
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80
n #

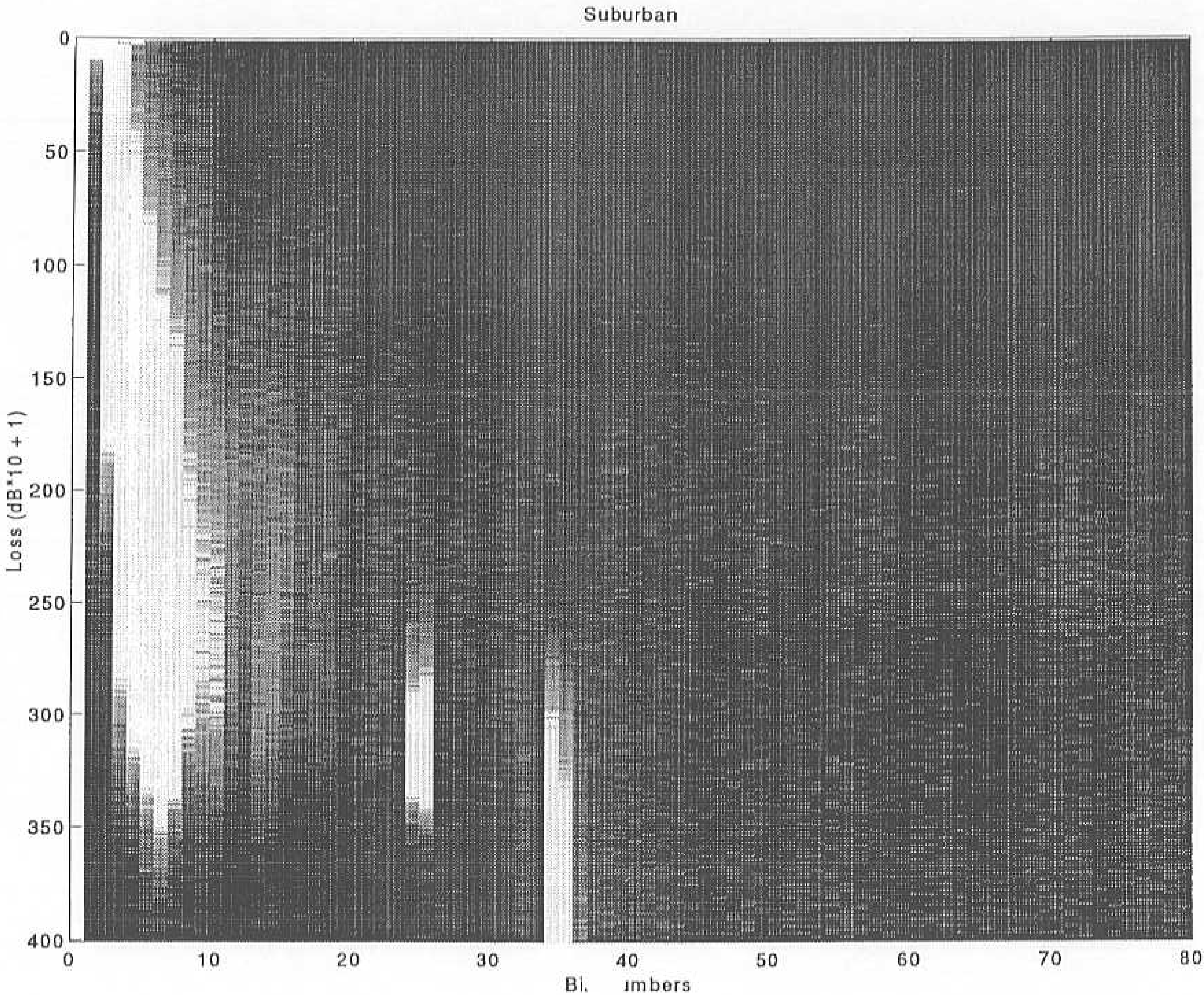


Suburban
Loss (dB)
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80
#

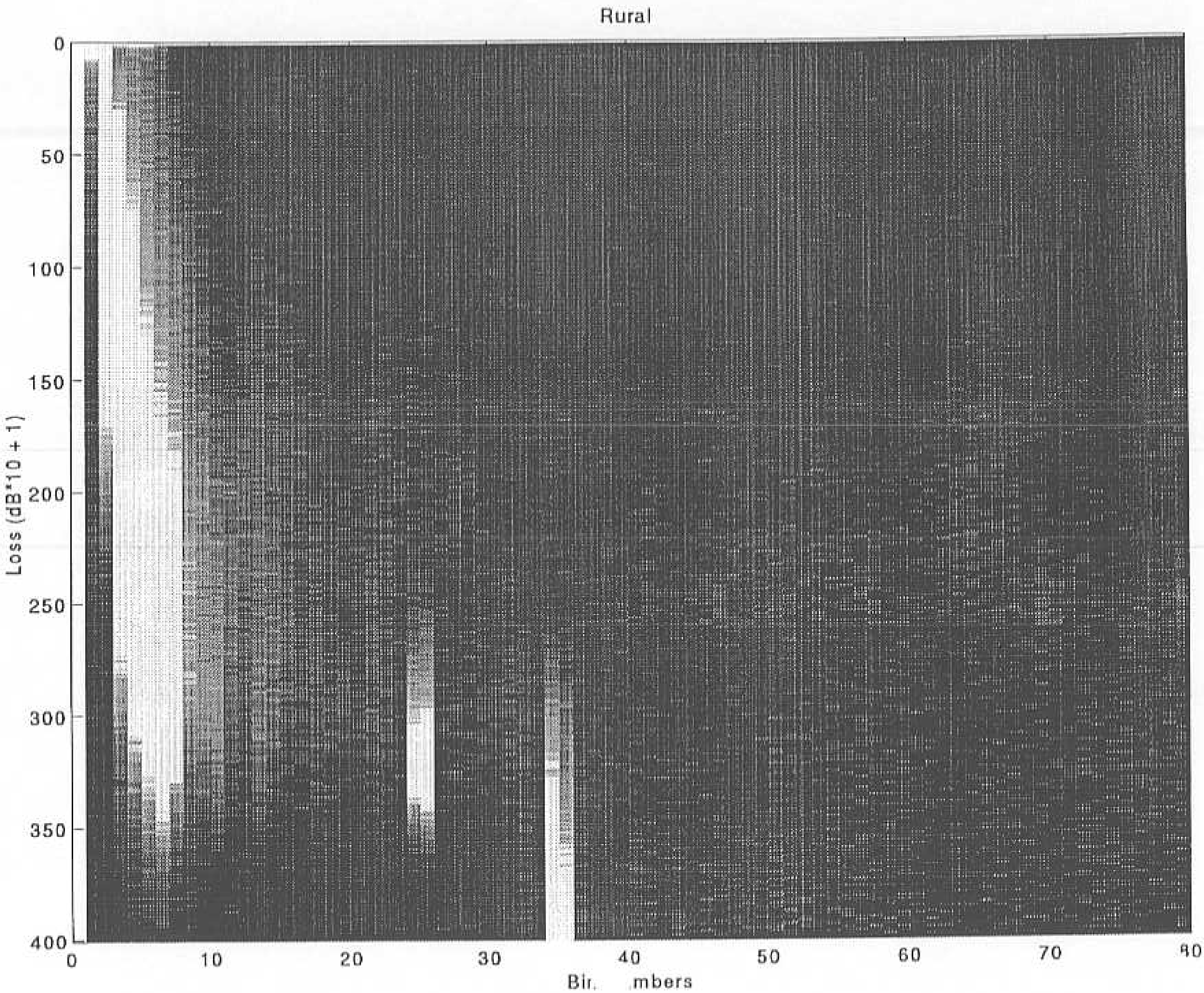


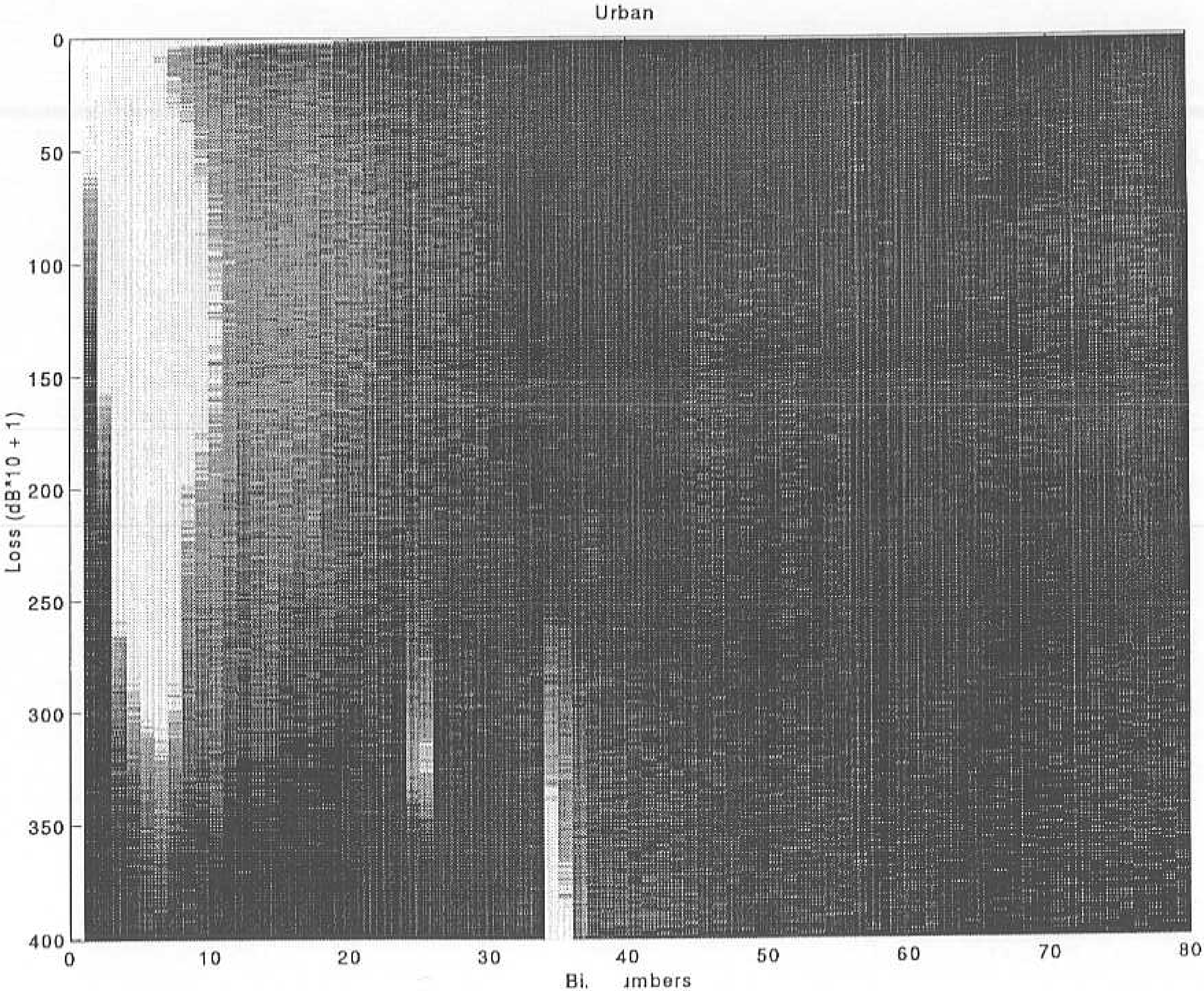
Rural
Loss (dB)
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80
n #


Terrain Obstructed
Loss (dB*10 + 1)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70
80
Bi. umbers



Suburban
Loss (dB*10 + 1)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70
80
Bi. ımbers


Rural
Loss (dB*10 + 1)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70
80
Bir.   mbers



Urban
Loss (dB*10 + 1)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70
80
Bi. umbers

To: Bob Culver

Copy: Ralph Justus

Subject: Multipath simulator and parameter conversion: issues and status

Bob, I made a little more progress on my part of the parameter conversion and have some information to share.

The two multipath simulators are connected to the computer and work well with our types of dynamic parameters (frozen amplitudes and one-minute segments) up to an update rate of 200 Hz. The computer was a 50 MHz model with standard TSR's, whose performance should at least be met by the computer Tom has procured for Ohio. An additional requirement to the equipment was discovered: the computer needs two parallel printer ports, one for each simulator. We added a second port to our computer by installing a card from Everex called a Magic I/O EV170A. This company is in California at (415) 498-1111. I left a message for Tom about this. In addition, I suggested that he send the computer here for us to test in the setup, configure, and generate the test files. However, this will not be necessary if we use a 70 Hz update rate. With each of the four one-minute segments requiring an hour of generation, the complete setup could be done in a day. I could spend a day in Ohio to do that, and bring the multipath simulator at that time.

Another issue I would like to discuss is the data smoothing. Our setup will support a smoothing factor of from 2 to over 4 times, depending on the programmed velocity. However, I think I have a simple scheme for smoothing that does not increase the update rate. From William C. Y. Lee's Book Mobile Communications Engineering I extracted the following graph:

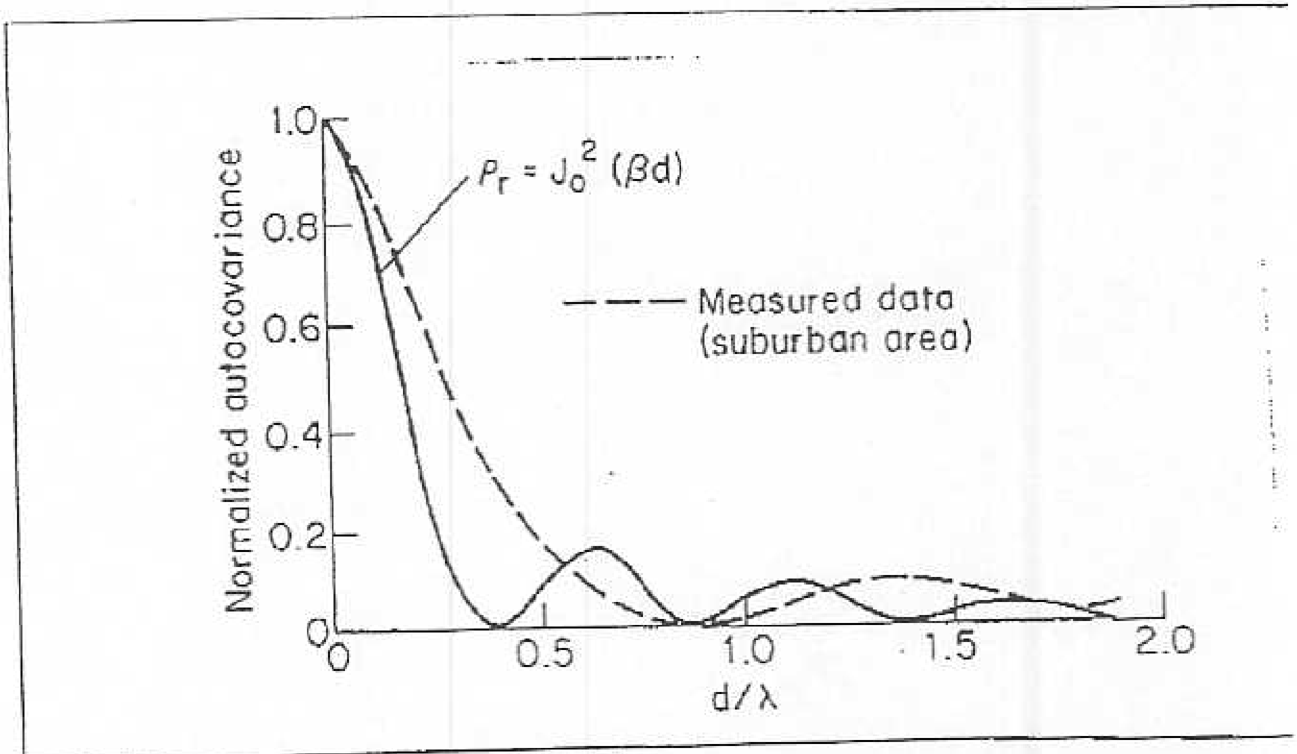


FIG 1

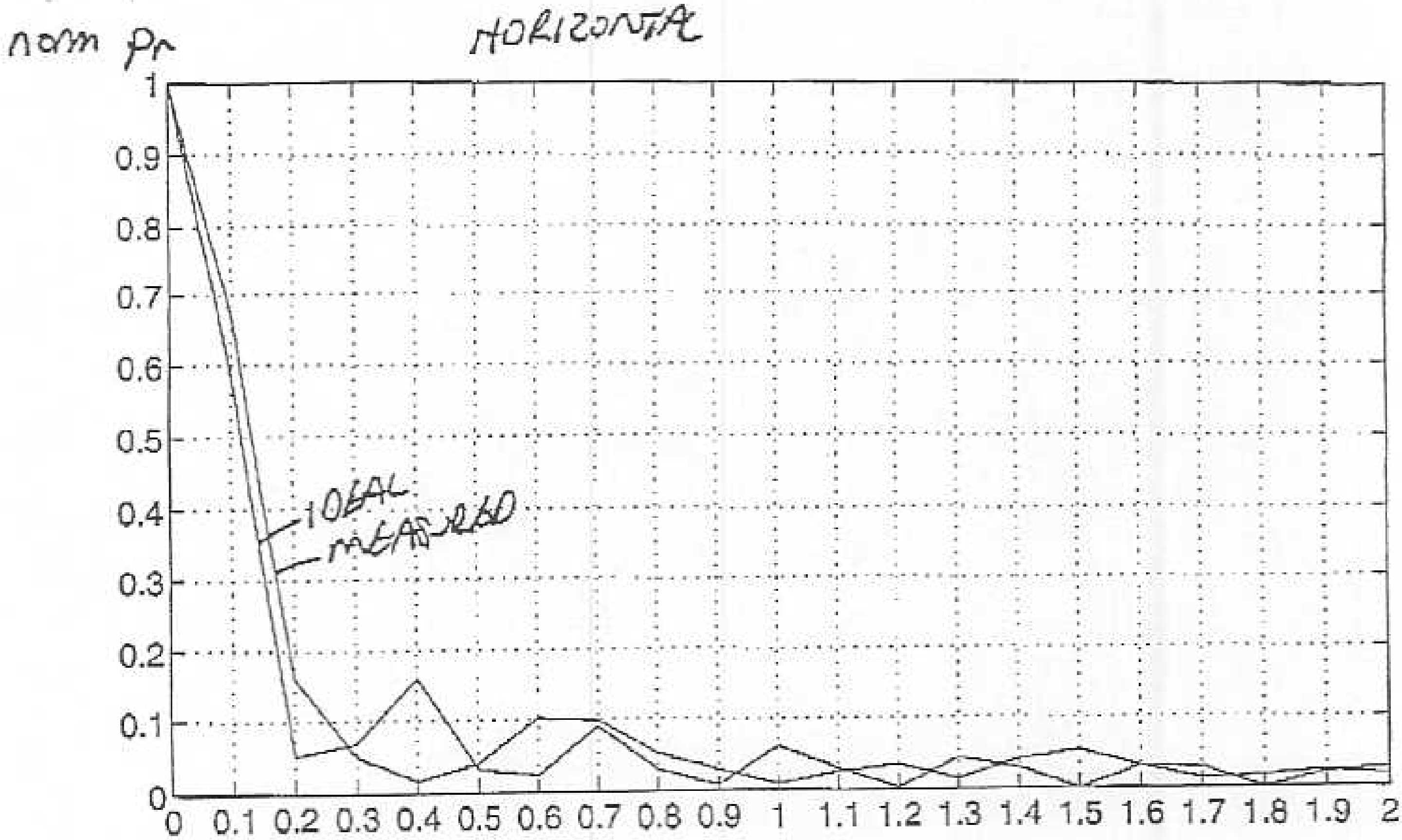
The high correlation between any two of our points within a file can be read at the tenth-lambda point. The calculated value is approximately 0.68. This value not only applies to overall magnitude, but also to magnitude at a given time delay and I and Q magnitudes taken individually. This was confirmed for a sample of our test data by taking the autocorrelation, lag 1 across the spatial values. There should be no problem for a receiver presented with sudden changes of magnitude that are small enough to lie within the correlation region. Examining the opposite constraint, our time constant of approximately 300 usec allows plenty of time to switch between each pair of correlated points.

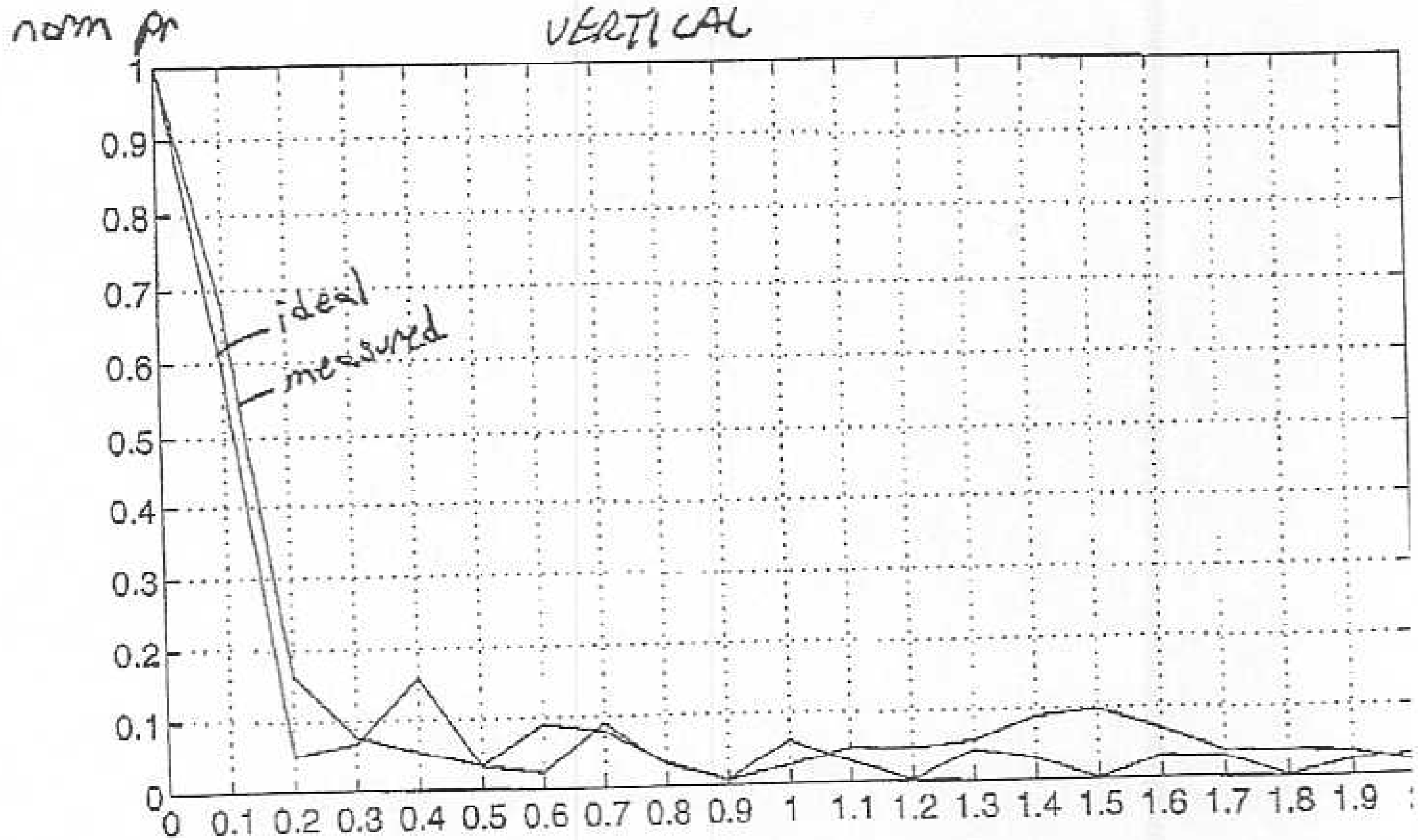
In addition, the low correlation can be seen between any two of our data points separated by at least two-tenths wavelength or equivalently, two sample points. The calculated values lie below 0.2 which is an accepted threshold for considering points as decorrelated. This was also confirmed by looking at some of the data. A sample of File #10 (taken in the downtown hotel parking lot, it represents Environment A, but is not included in the proponent packages) is shown in Figure 2. Like the ideal curve, the measured curve shows that our adjacent points are highly-correlated, but that our points separated by two or more are highly-decorrelated.

For the above reasons, we should have no problem with data in each of the given files, with the exception of delay changes, when different dominant reflectors change. Again, our high degree of correlation makes these changes "smooth" both for each reflector (reflectors stop being chosen as they shrink and start being chosen as they rise; typically, the same reflectors are chosen throughout a file, with the exception of Environment D), and for the aggregate signal.

This leaves us with the final problem of bridging data from different files. A simple method which would not require us to change the update rate would be to add a single "bridging" data point between the data streams of each pair of files. This point is derived by taking a linear combination of the two adjacent points. Practically, it is calculated as the mean of the adjacent points by averaging each of the I and Q values. An example of this is shown in Figure 3. A uniform random sequence was generate and the autocorrelation shown in Part A. The close-up to the right shows that adjacent points are decorrelated. In Part B, the technique described above is used to insert bridging points between each of the original sequence points, and the autocorrelation taken. (These steps nearly double the length of the sequence.) The close-up shows that adjacent points are now correlated approximately to the level we desire, and that points separated by two or more are decorrelated: this is a good match to the conditions of our data. I propose we use this algorithm when we convert our files to simulator format, and determine our update rate based on speed only (up to approximately 70 Hz).

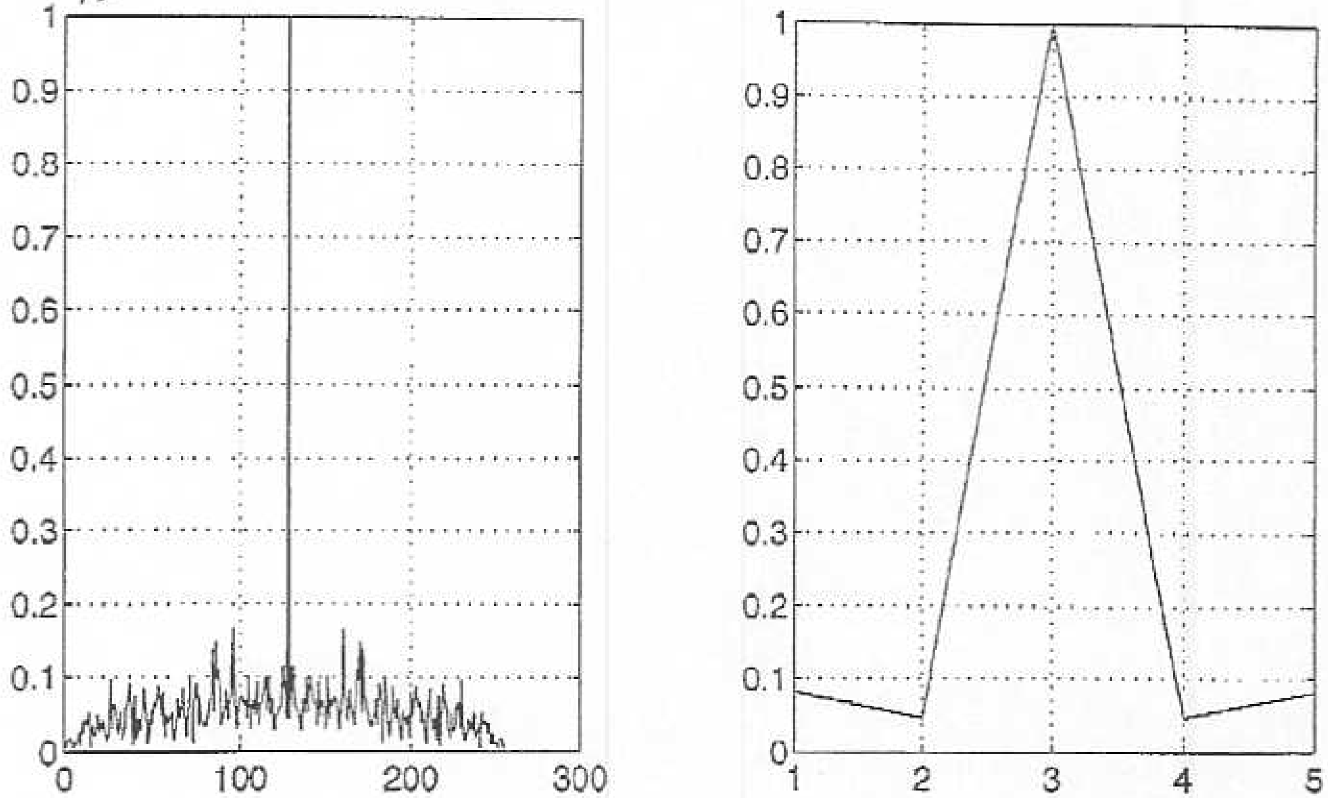
Finally, when you select the parameters, could you please store the appropriate files in their .chn format on floppies and bypass using the tape drive. I will be ready to do this on Monday. I would like to begin after all the data is selected and the team has agreed on the smoothing issues or anything else along those lines.


norm pr
HORIZONTAL
IDEAL
MEASURED
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2


norm pr
VERTICAL
ideal
measured
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9

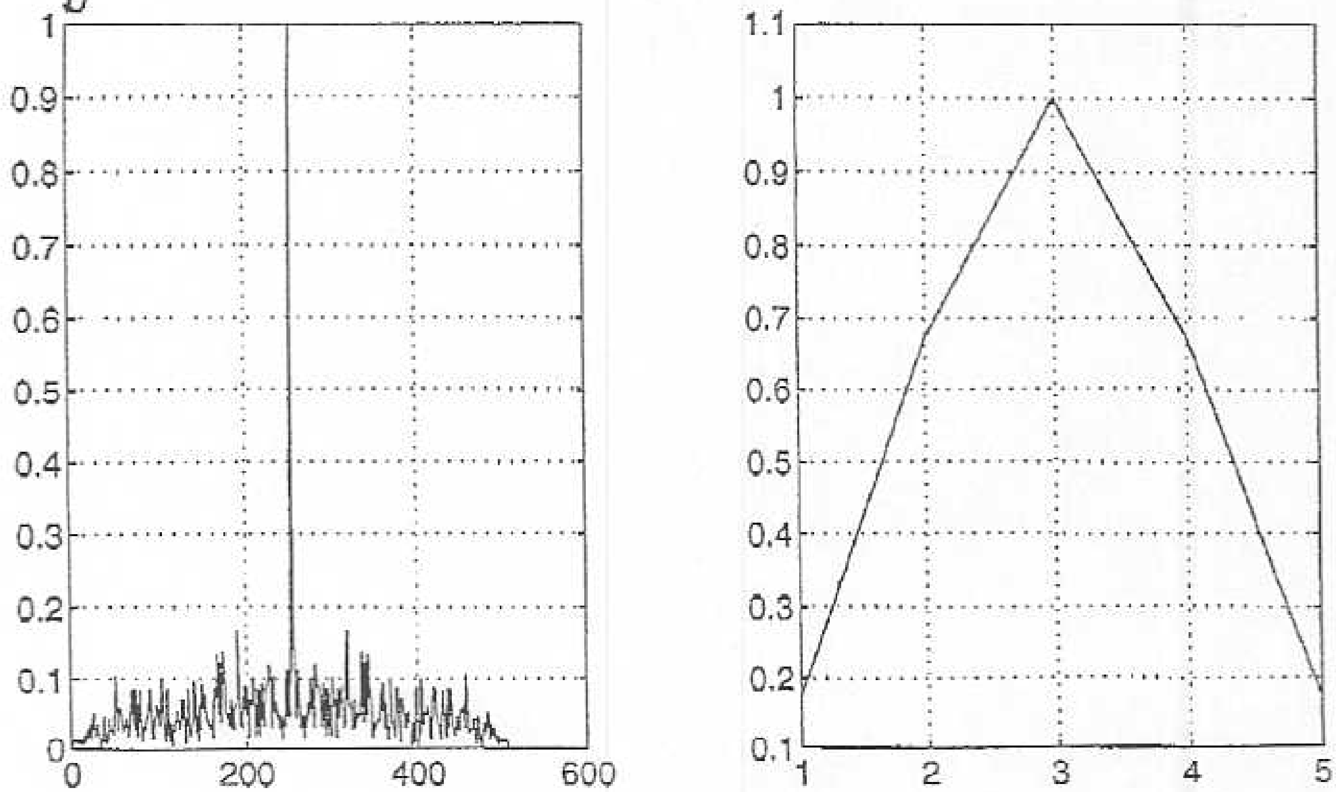
DECORRELATED POINTS

A



PAIRWISE-CORRELATED POINTS

B



APPENDIX H

APPENDIX H - DATA PROCESSING AND INTEGRATION TO SIMULATOR(S); CONTROL DATA

H-1 Memo (L&C), to EIA-CEG DAR WG-B, "CCTG", "Determination of the Files to be used for Multipath Simulation for Environments A-D" -- 4/17/95

CONFERENCE CALL ANNOUNCEMENT
THURSDAY APRIL 21, 1994 10:00 AM EDT

TO: EIA-CEG DAR WG-B, CHANNEL TEST TASK GROUP
FROM: ROBERT D. CULVER
RE: DETERMINATION OF THE FILES TO BE USED FOR MULTIPATH SIMULATION FOR ENVIRONMENTS A THROUGH D.
DATE: APRIL 17, 1994

	Phone	Fax
Brian Warren, Delco	317-451-7053	317-451-1340
Thomas Keller, Consultant	703-569-3135	703-569-3370
Ken Springer, NAB	202-429-5341	202-775-4981
Ralph Justus, EIA	202-457-8716	202-457-4985
Gerald Chouinard, CRC	613-998-2500	613-993-9950
Mike Geil, Nova Engineering	513-860-3456	513-860-3535
Carl-Erik Sundberg, AT&T	908-582-3811	908-582-7308

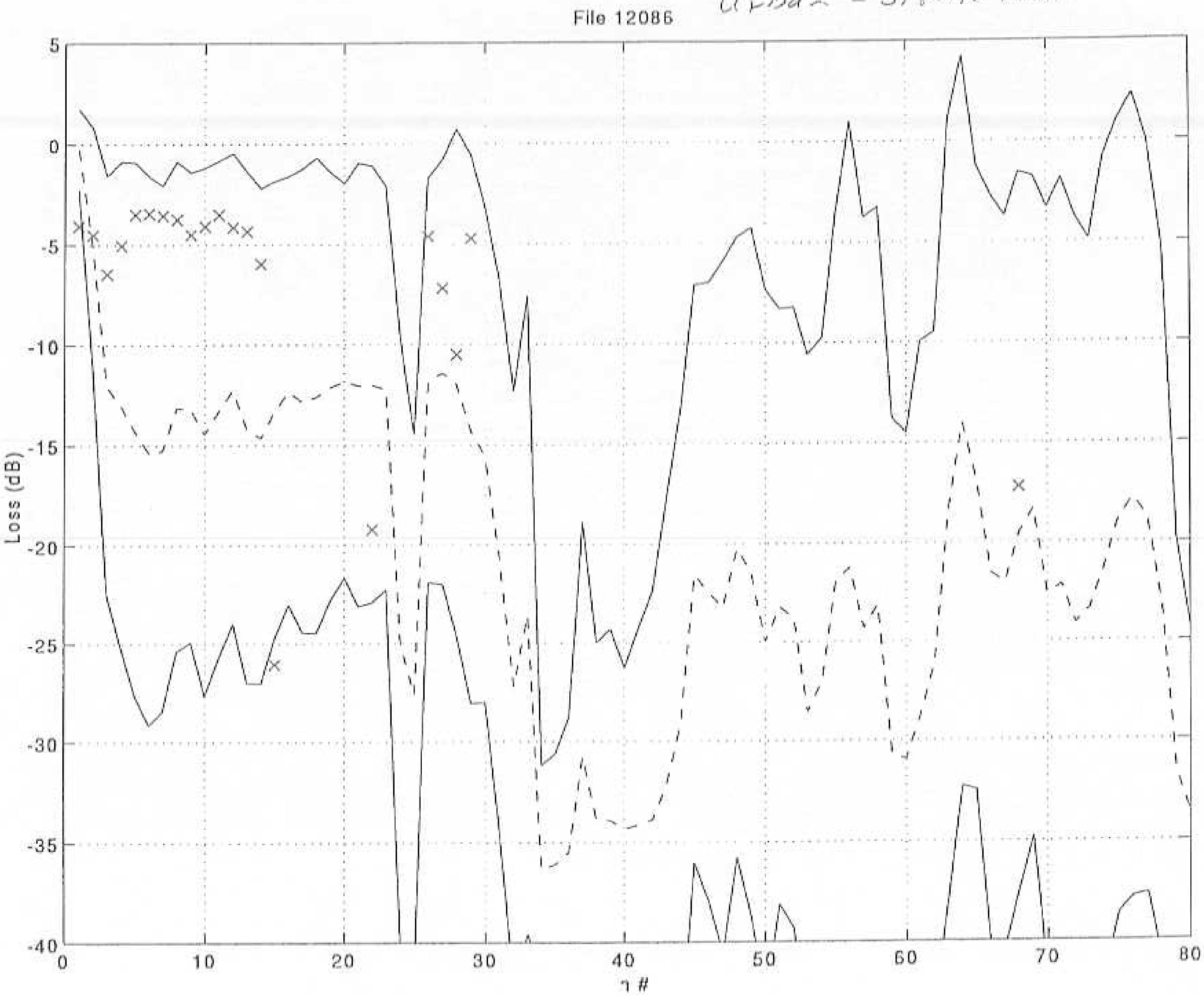
The Salt lake data analysis is progressing along the planned route. The "envelope" of the maximum reflected signal levels at various time delays is now known. The measured reflection magnitudes verses time delay have been examined on a file by file basis to determine which files should be used to control the multipath simulator in the test lab. Plots of samples of the environment envelopes with typical data from selected files are attached and discussed below.

The graphs show the median reflection attenuation in each time bin for the entire data for environments A through D. Also shown is the $\pm$ 1.64 sigma limits of the data for each bin. This corresponds to the 95 and 5% limits, probably an appropriate threshold of significant reflection probability. The median value for the data in the file of interest is shown by the X data points for each bin containing data in that file.

Attached are four sets of two plots each for the four "environments" of the Salt Lake City data; Urban (A), Suburban (B), Rural (C), and Terrain Obstructed (D). The first plot in each pair shows the data from what might be considered one of the significant files in an environment and therefore one of the files used to control the simulator. The second shows another file of less significance for comparison.

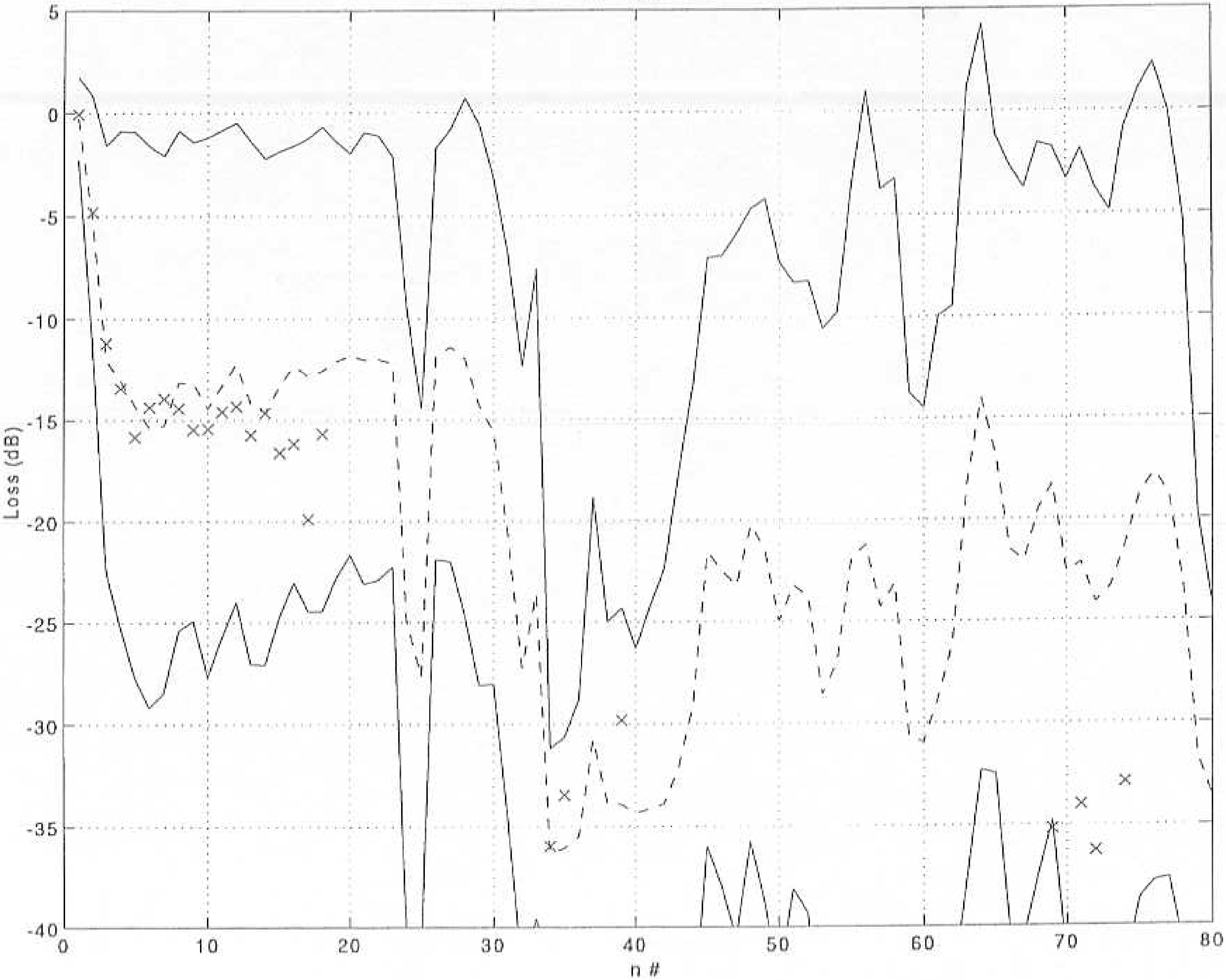
The data files required to control the channel simulator have been identified and will be available for programming into the computer controlling the simulator. The results of that work will be discussed in the conference call scheduled above.

urban - Significant

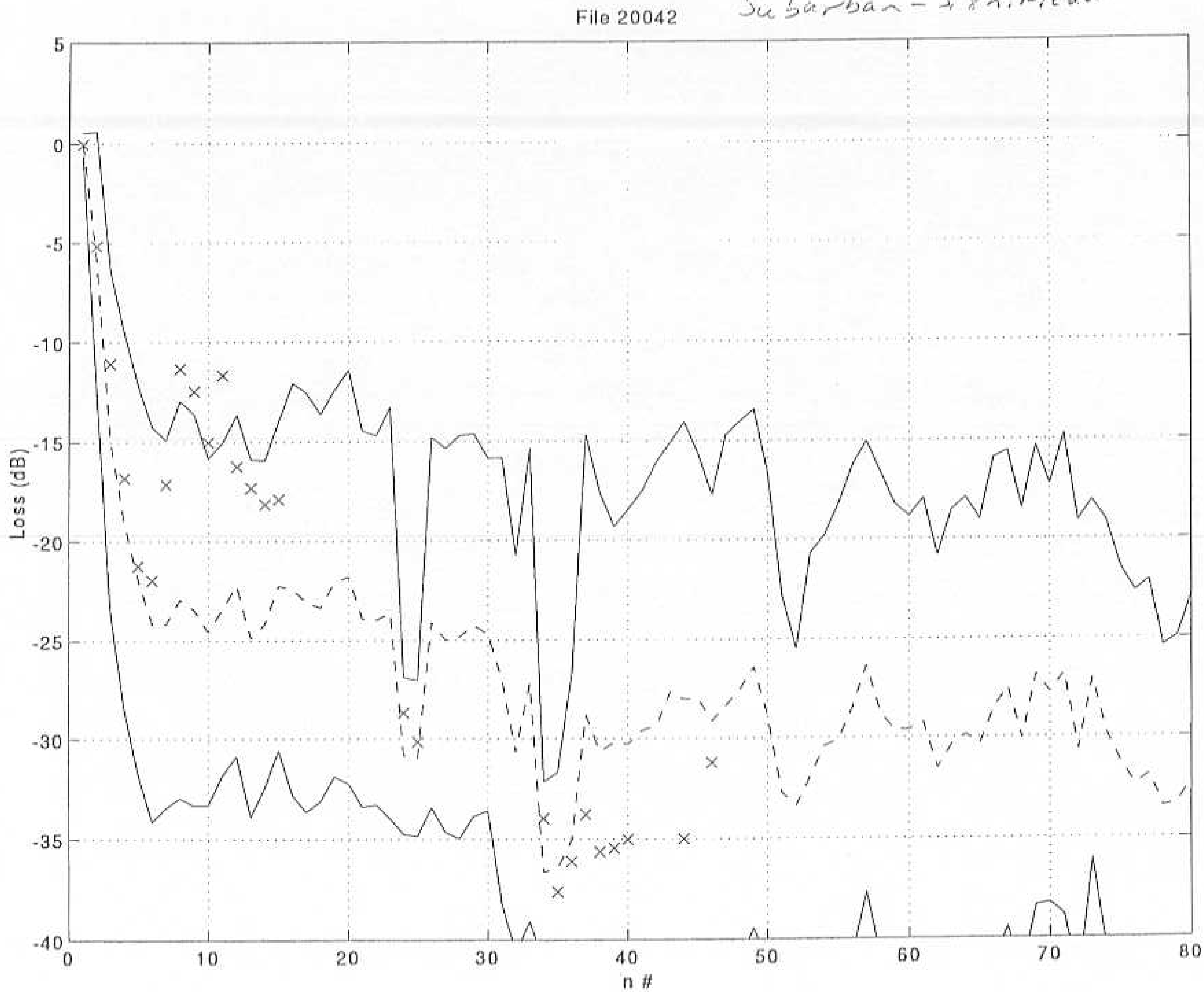


urban - nominal

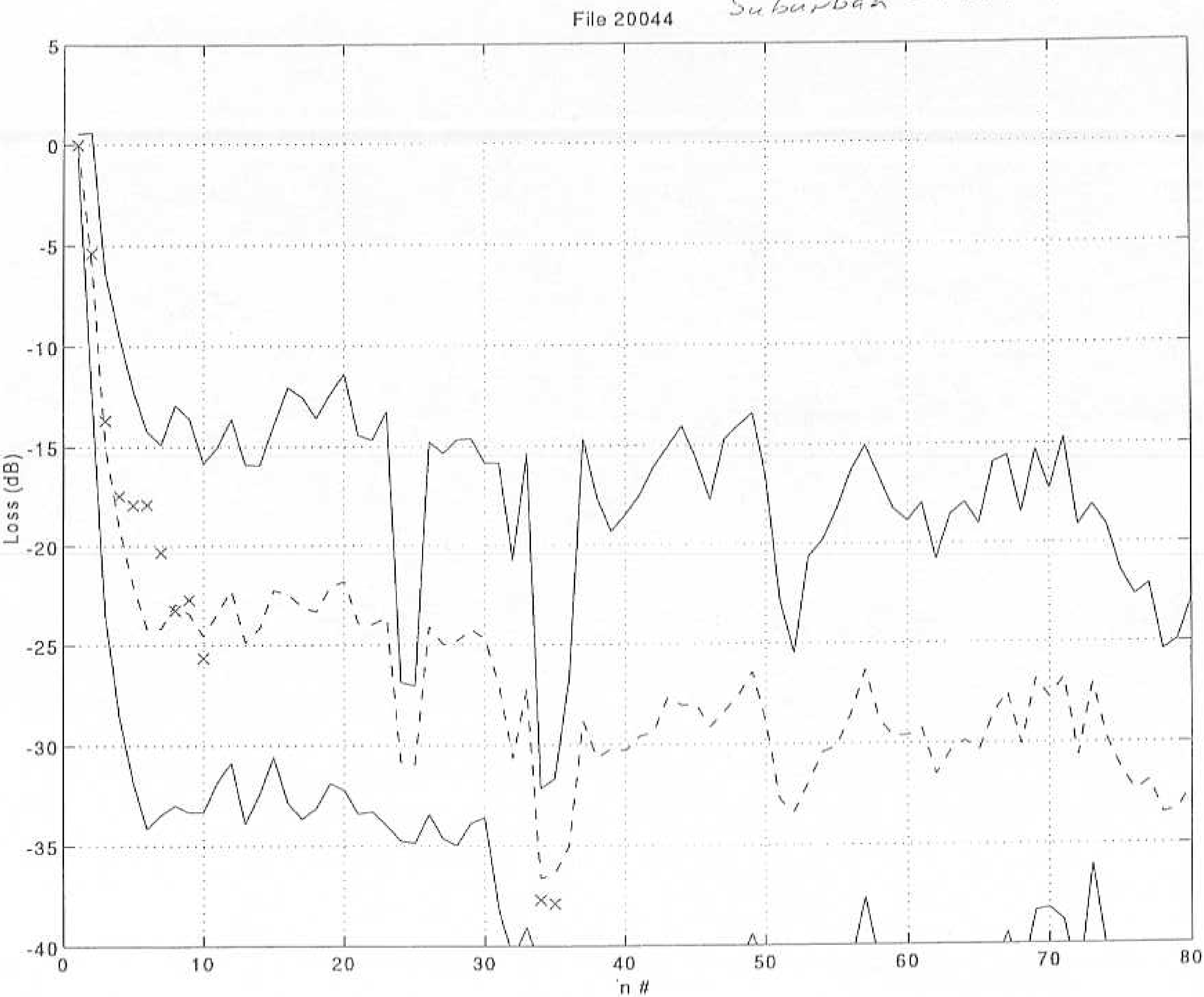
File 12088



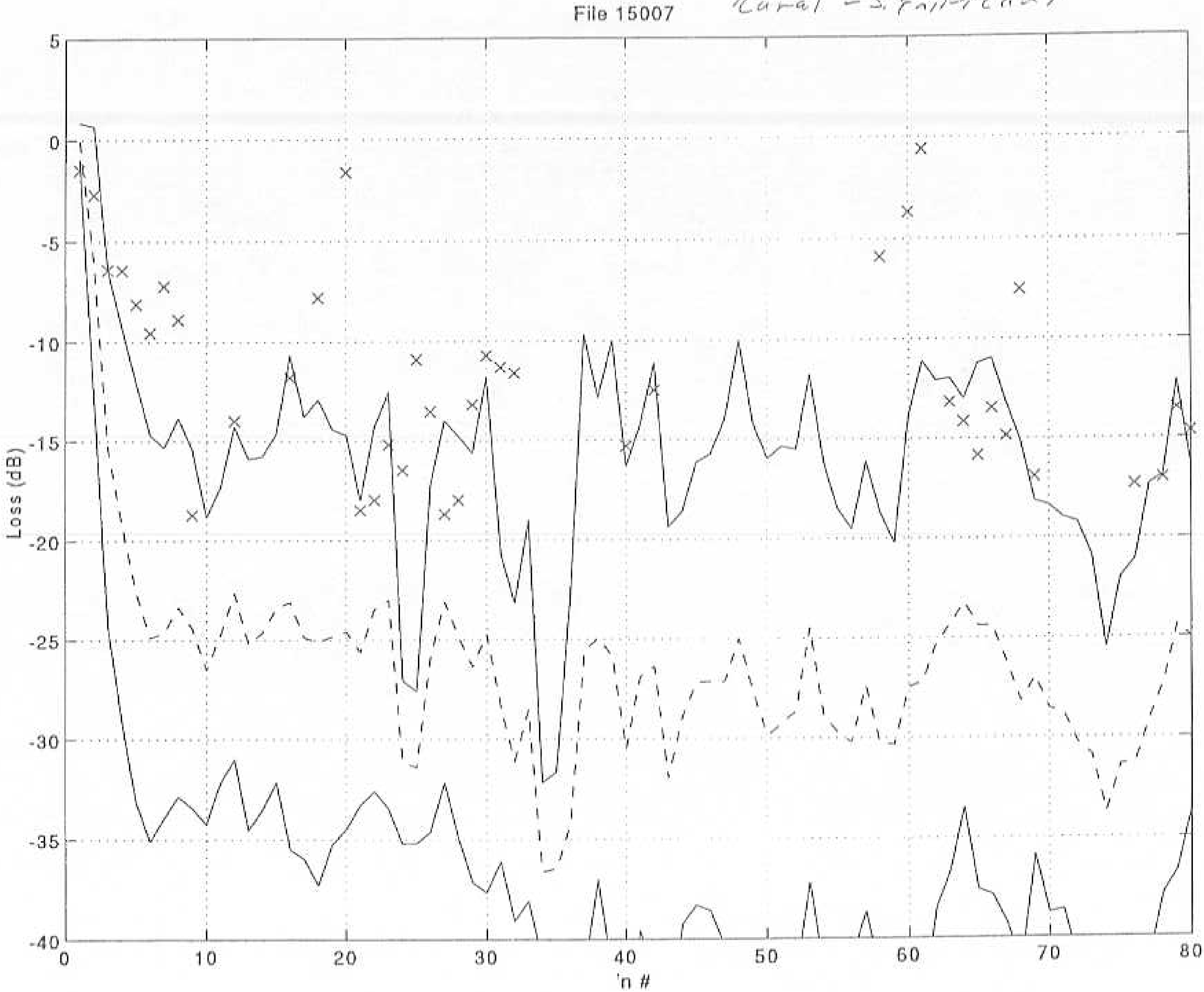
Suburban - significant



Suburban - Nominal

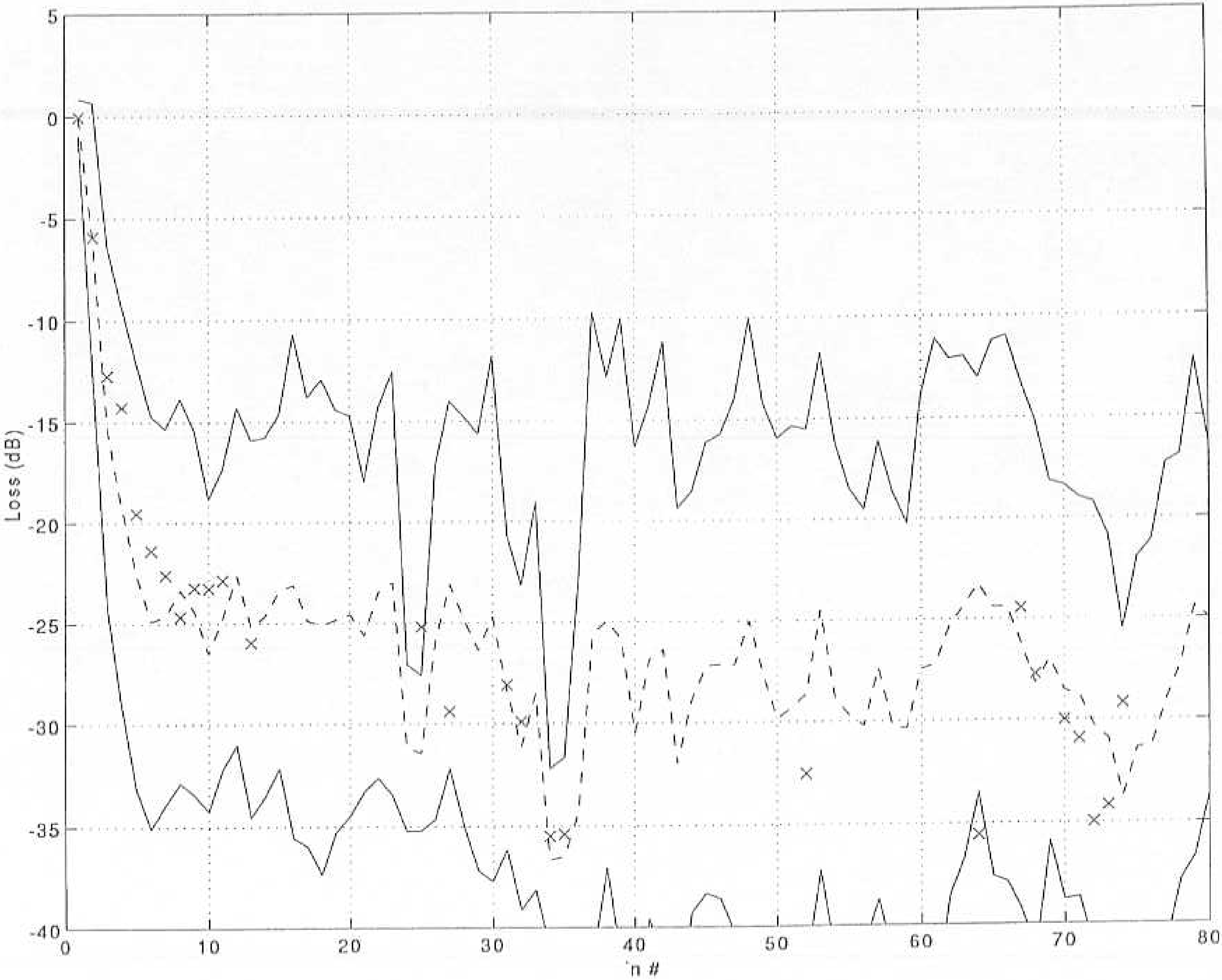


Rural - Significant

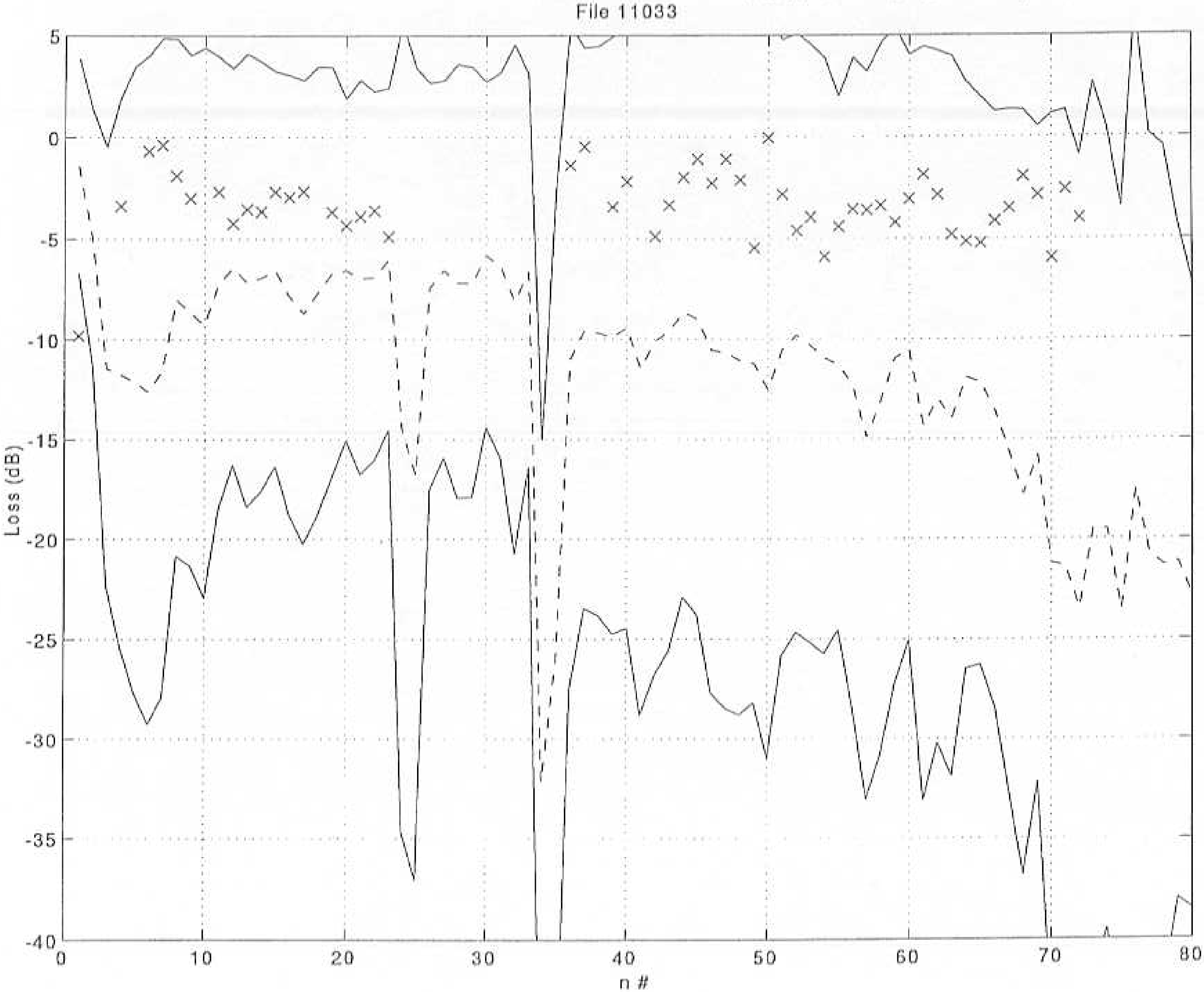


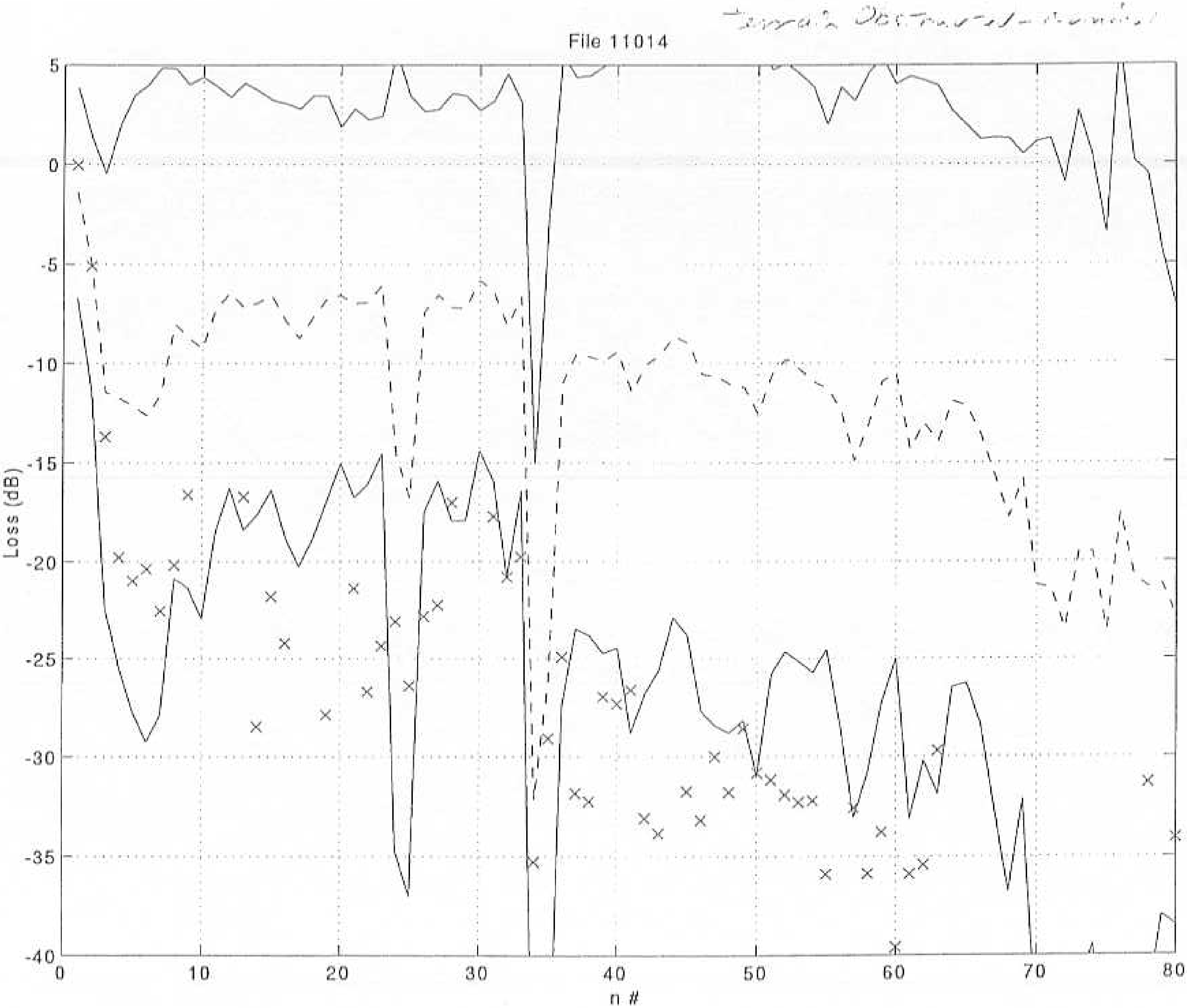
Rural - Nominal

File 15010



Tammi's Obstructed - Ste. [illegible]




File 11014
Loss (dB)
n #
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80

REPORT TO EIA CEG DAR-SUBCOMMITTEE
WG-B (TESTING) 5/10/94 WASHINGTON, D.C.

FROM; Robert Culver, Channel Characterization Test
DATE; April 29, 1994
SUBJECT; VHF Channel Test data selection and application to lab testing

CHANNEL TEST DATA

On Thursday April 27, 1994, the multipath simulator control computer and the second of the two simulators were delivered to the test lab and installation into the test bed was begun. The computer will provide for direct control of the simulators by the VHF Channel Test Data and for all other control. This memorandum presents the latest information regarding the analysis and use of the VHF Channel Test data.

The VHF Channel Test data has been studied as reported earlier. The overall time delay and reflection magnitudes for the four major environments have been determined as detailed in the April 8, 1994 memorandum presented in the conference call of the Channel Test Task Force of that date. The individual data files (from approximately 400 to 900 per environment) have now been examined and several have been selected as representing difficult segments of the environments, suitable for use in the laboratory testing simulations. That data is presented in the channel test task group conference call memorandum from April 21, 1994, a copy of which is attached.

MULTIPATH SIMULATION TEST PROFILE

The test duration suggested by CRC is from 30 to 60 seconds, with a strong preference for shorter tests. The four environments suggest particular simulated drive paths as described in earlier discussions of the environments. During discussions within the test task group and considering the environments, paths and test durations the following profiles are suggested.

A) Urban; Start at zero velocity, maintained for 3 seconds,
Accelerate to 60 KPH maximum in 3 seconds,
Cruise at 60 KPH for 1 second,
Decelerate to zero velocity in 3 seconds.

This completes one cycle in 10 seconds and therefore 6 full cycles can be completed in 60 seconds. The average velocity over the path is 24 KPH or 6.7 meters per second. The 10 second cycles will therefore cover 67 meters per cycle representing the distance covered by approximately 1.2 data files per cycle, or just over 7 data files for a 60 second test.

B) Suburban; Start at zero velocity, maintained for 3 seconds,
Accelerate to 70 KPH maximum in 5 seconds,
Cruise at 70 KPH for 7 seconds,
Decelerate to zero velocity in 5 seconds.

This completes one cycle in 20 seconds, 3 cycles per minute. The average velocity over the path is 42 KPH or 11.7 meters per second, covering 700 meters or approximately 12.5 files of data for a 60 second test.

C) Rural; Start at 100 KPH, maintained for 10 seconds,
Accelerate to 150 KPH in 10 seconds,
Cruise at 150 KPH for 20 seconds,
Decelerate to 100 KPH in 10 seconds,
Cruise at 100 KPH for 10 seconds.

The total cycle time is 60 seconds with an average velocity of 125 KPH or 34.72 meters per second, covering 2.1 kilometers or 37.2 files in 60 seconds.

D) Terrain Obstructed; Start at 25 KPH, maintained for 4 seconds,
Accelerate to 75 KPH in 2 seconds,
Cruise at 75 KPH for 4 seconds,
Decelerate to 25 KPH in 2 seconds.

The total cycle time is 12 seconds for 5 cycles per minute. The average velocity is 50 KPH or 13.9 meters per second, covering 833 meters or 14.9 files in 60 seconds.

LENGTH OF CRITICAL MATERIAL TEST SEGMENTS

As stated earlier the recommendation of the CRC staff is to use test segments shorter than 60 seconds. Attached is a memorandum from Louis Thibault which resulted at the request of Gerald Chouinard from discussions within the Channel Test Task Group. The suggested approximate 30 second test segments can be created from the four suggested test profiles outlined above. For example, a shorter test can be formulated by choosing fewer segments and possibly starting and/or stopping the test at different points in the sequence. Even for the Rural test a 30 second test sequence can be accommodated by using 10 seconds for each of the cruise at two different speeds and one acceleration segment.

Changing the test sequence is possible at the simulation phase but it appears to be much more convenient to do at the audio sample editing phase where the recorded test results are processed and loaded onto the CRC Listening Test audio work station. During the installation of the simulators the method by which the test segments would be recorded and synchronized with the multipath simulation was discussed. A method that appeared to have consensus support would be to start the audio sample and then place a start "mark" on the audio tape recording the output sample when the simulation was started. The precise method of doing this will have to be investigated. The Selection of Critical Audio Sequences, Test K-1, affords a good opportunity to resolve this prior to actual impairment and quality test recording.

MULTIPATH SIMULATION AT L-BAND AND ABOVE

The minimum acceptable data rate that is necessary for the computer and simulator to operate at is that needed to achieve 150 KPH test velocity. This requires approximately a 42 meter per second or 120 steps per second at 0.35 meters per step, the test point spacing. A rate of 4 or 5 times this will be used to provide an easy division method to provide lower speeds. At 1.5 GHz the VHF Channel Test data spacing is approximately 2 wavelengths, too wide a spacing to be used in this direct control method. Even with L-Band data measured at 1/4 wavelength intervals, like the Canadian test data was measured, the required repetition rate necessary to simulate a 150 KPH velocity would be over 800 steps per second. This appears to be in excess of the reliable capabilities of the computer and simulator combination. A method other than direct control for L-Band and S- Band testing will likely be required.

CONFERENCE CALL ANNOUNCEMENT
THURSDAY APRIL 21, 1994 10:00 AM EDT

TO: EIA-CEG DAR WG-B, CHANNEL TEST TASK GROUP
FROM: ROBERT D. CULVER
RE: DETERMINATION OF THE FILES TO BE USED FOR MULTIPATH SIMULATION FOR ENVIRONMENTS A THROUGH D.
DATE: APRIL 17, 1994

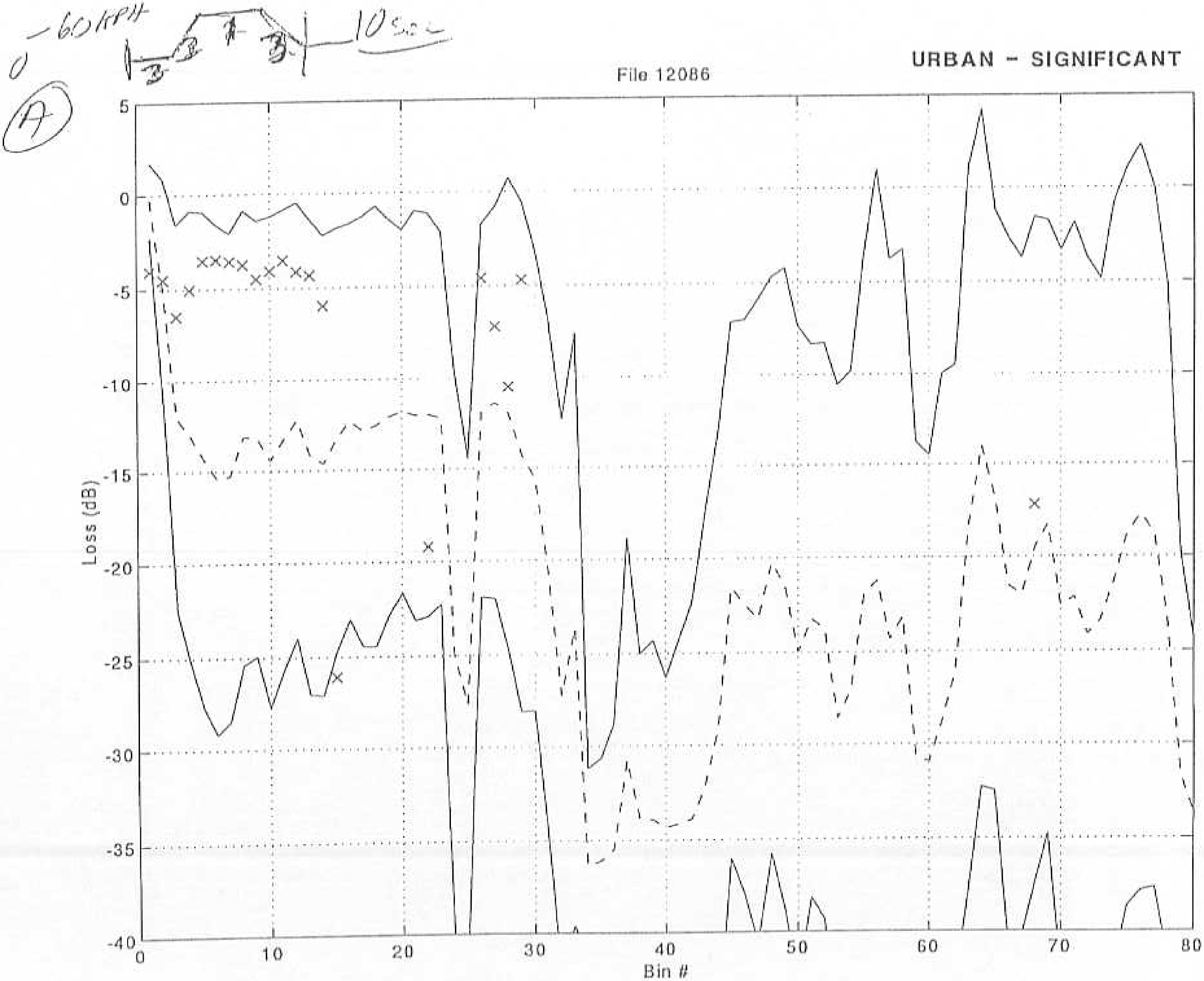
	Phone	Fax
Brian Warren, Delco	317-451-7053	317-451-1340
Thomas Keller, Consultant	703-569-3135	703-569-3370
Ken Springer, NAB	202-429-5341	202-775-4981
Ralph Justus, EIA	202-457-8716	202-457-4985
Gerald Chouinard, CRC	613-998-2500	613-993-9950
Mike Geil, Nova Engineering	513-860-3456	513-860-3535
Carl-Erik Sundberg, AT&T	908-582-3811	908-582-7308

The Salt lake data analysis is progressing along the planned route. The "envelope" of the maximum reflected signal levels at various time delays is now known. The measured reflection magnitudes verses time delay have been examined on a file by file basis to determine which files should be used to control the multipath simulator in the test lab. Plots of samples of the environment envelopes with typical data from selected files are attached and discussed below.

The graphs show the median reflection attenuation in each time bin for the entire data for environments A through D. Also shown is the $\pm$ 1.64 sigma limits of the data for each bin. This corresponds to the 95 and 5% limits, probably an appropriate threshold of significant reflection probability. The median value for the data in the file of interest is shown by the X data points for each bin containing data in that file.

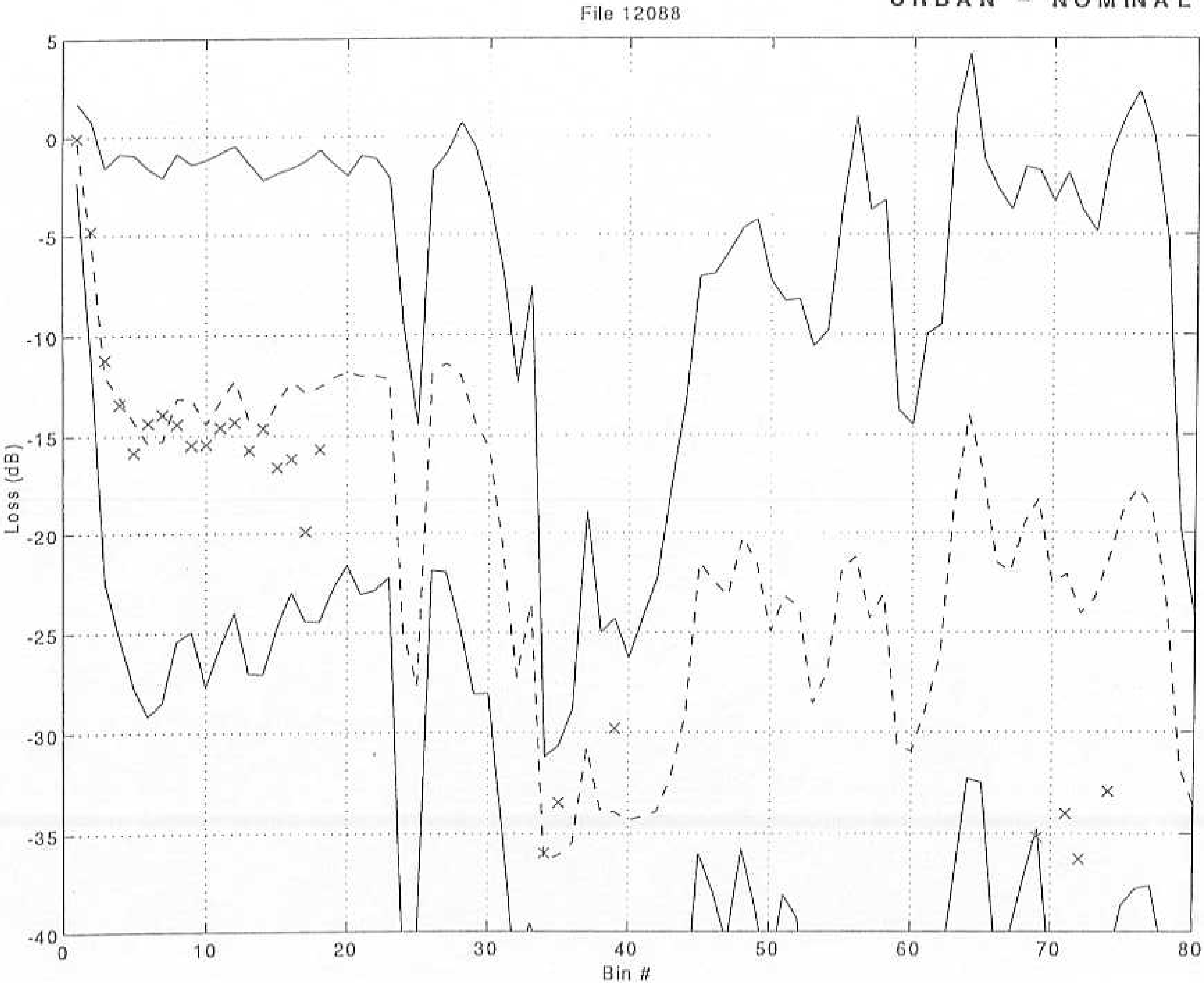
Attached are four sets of two plots each for the four "environments" of the Salt Lake City data; Urban (A), Suburban (B), Rural (C), and Terrain Obstructed (D). The first plot in each pair shows the data from what might be considered one of the significant files in an environment and therefore one of the files used to control the simulator. The second shows another file of less significance for comparison.

The data files required to control the channel simulator have been identified and will be available for programming into the computer controlling the simulator. The results of that work will be discussed in the conference call scheduled above.



0 - 60 KPH
10 sec
A
URBAN - SIGNIFICANT
File 12086
Loss (dB)
Bin #
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80

URBAN - NOMINAL



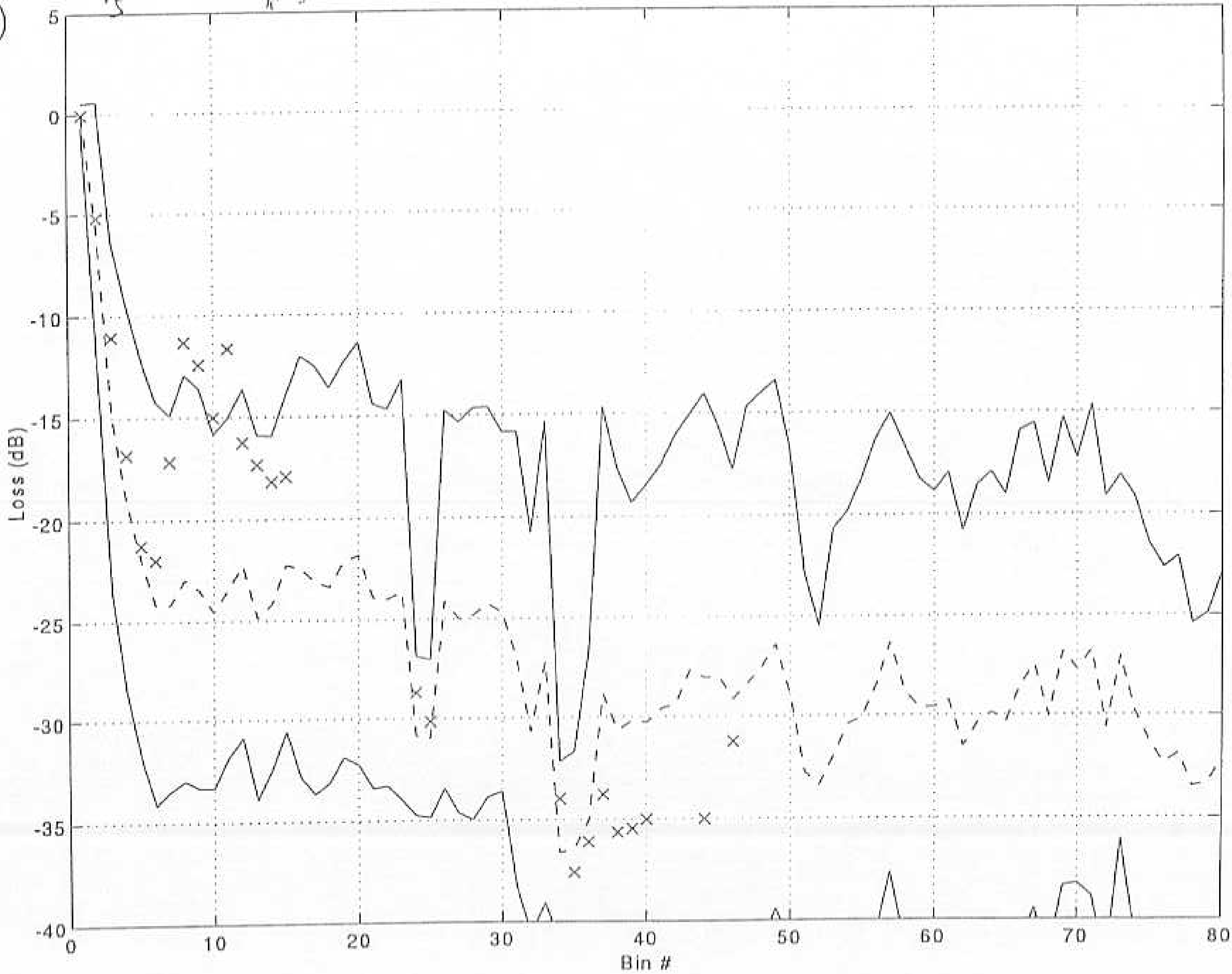
0-70 kpH

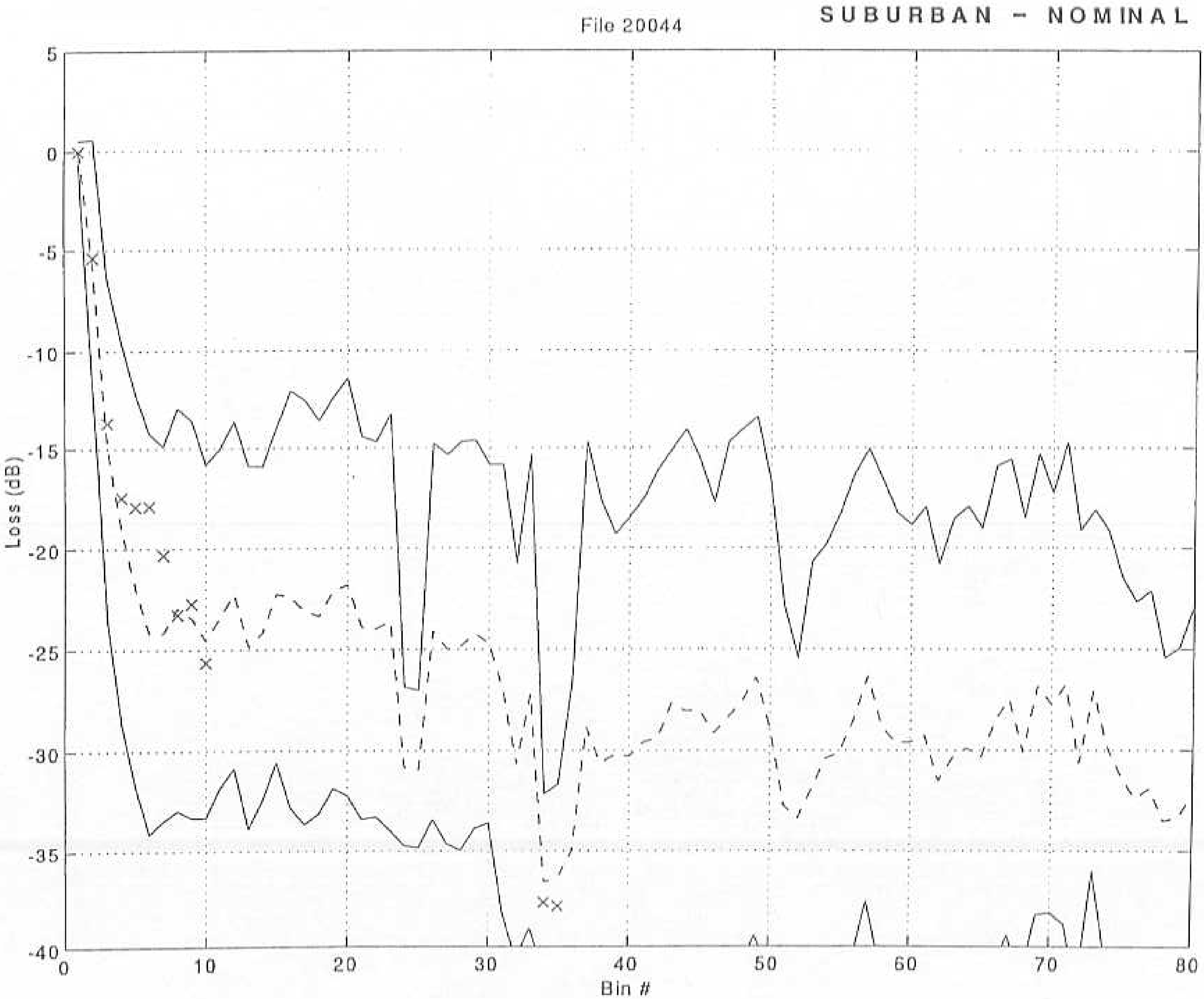
B

20 sec - 3 cycles

SUBURBAN - SIGNIFICANT

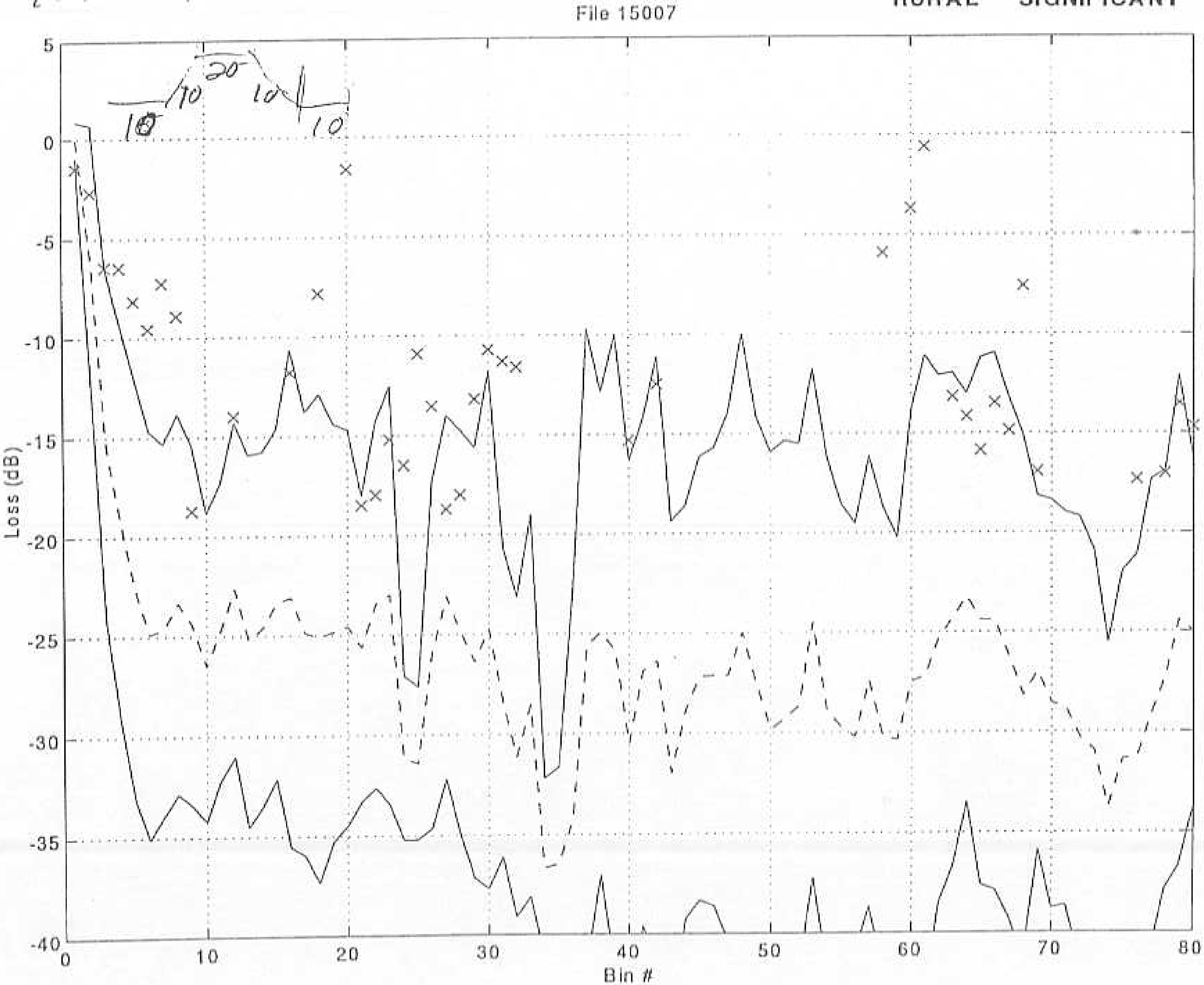
File 20042

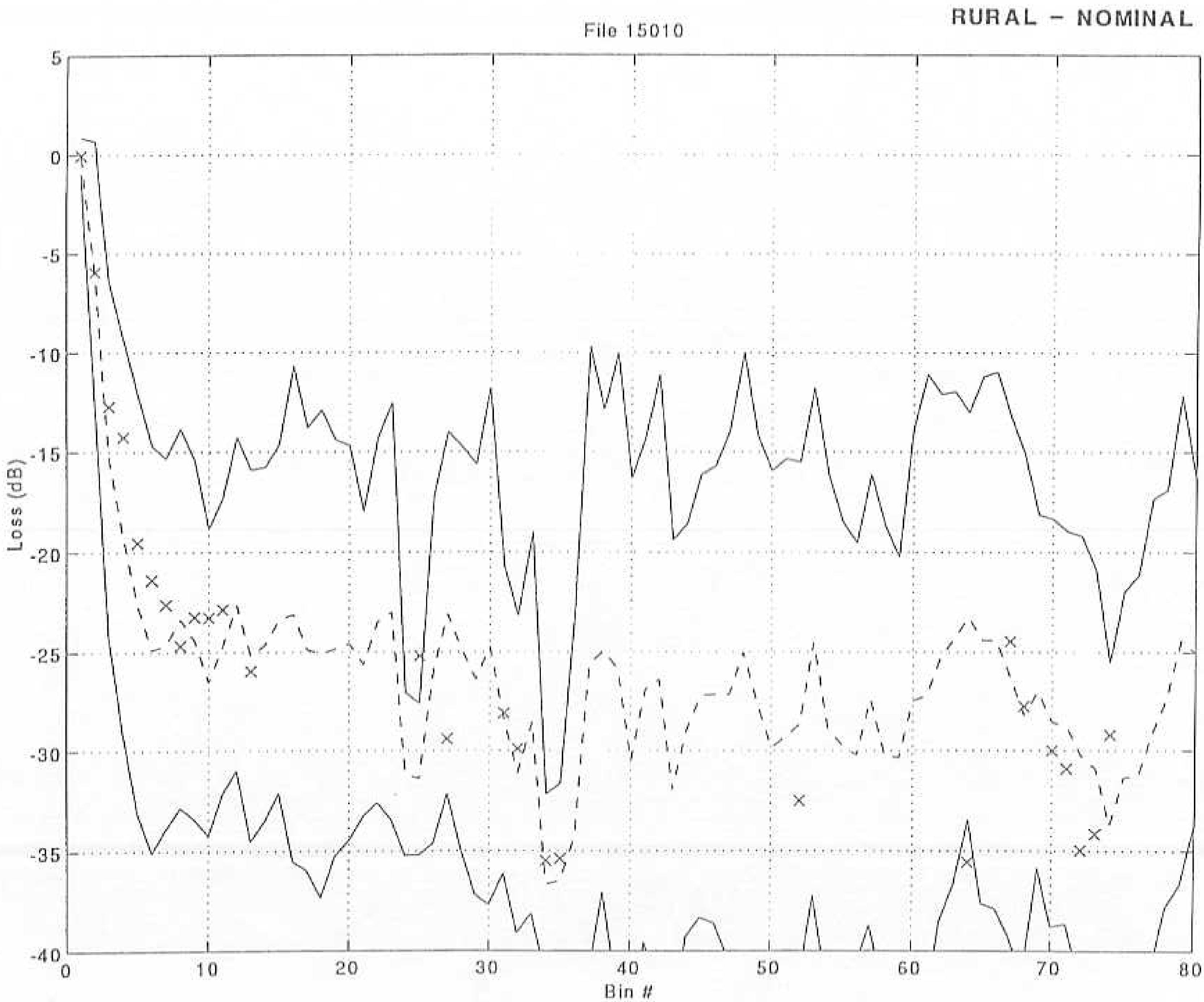



SUBURBAN - NOMINAL
File 20044
Loss (dB)
Bin #
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80

(C) 100 → 150 KpH Fixed 1Cycle

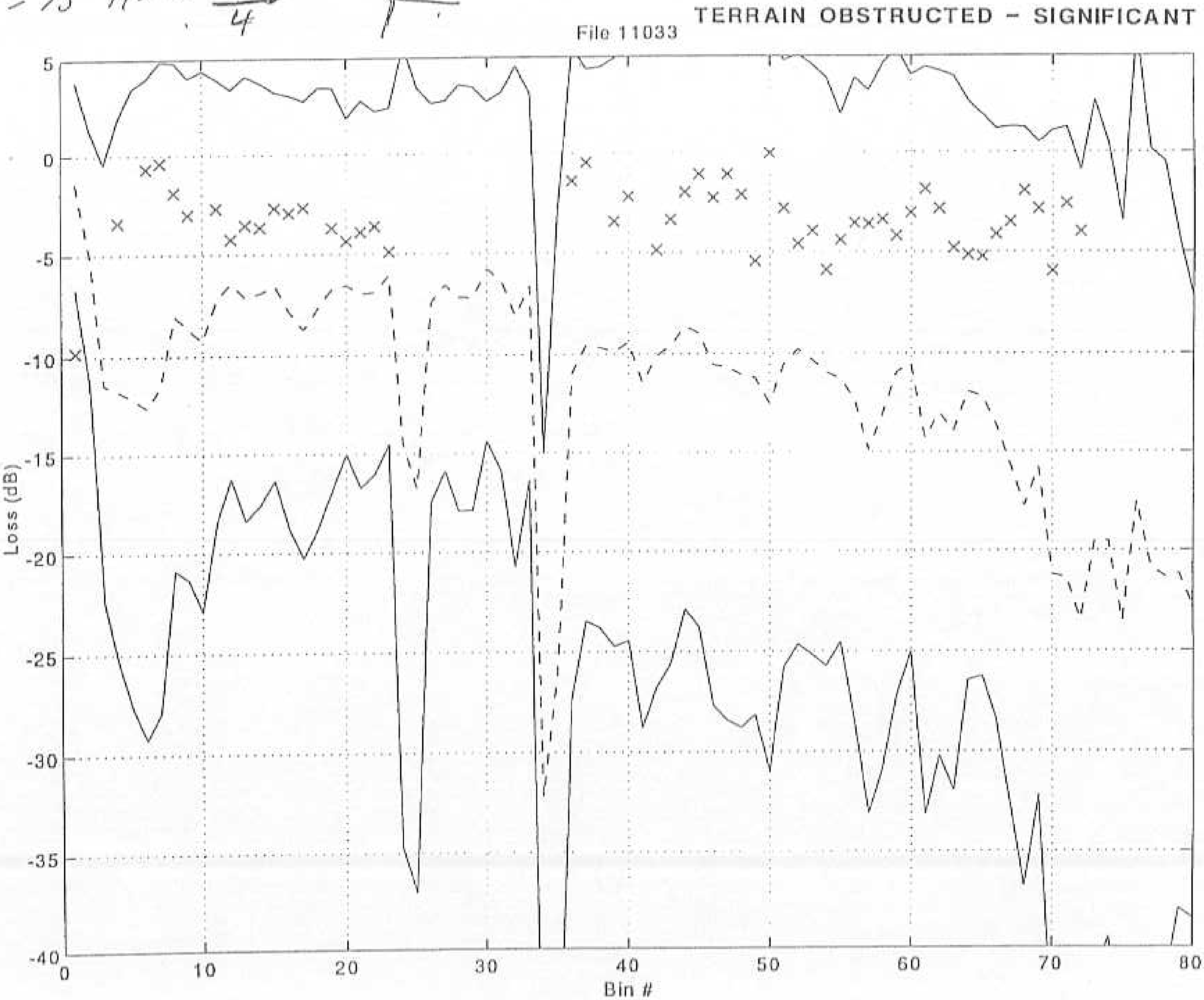
RURAL - SIGNIFICANT

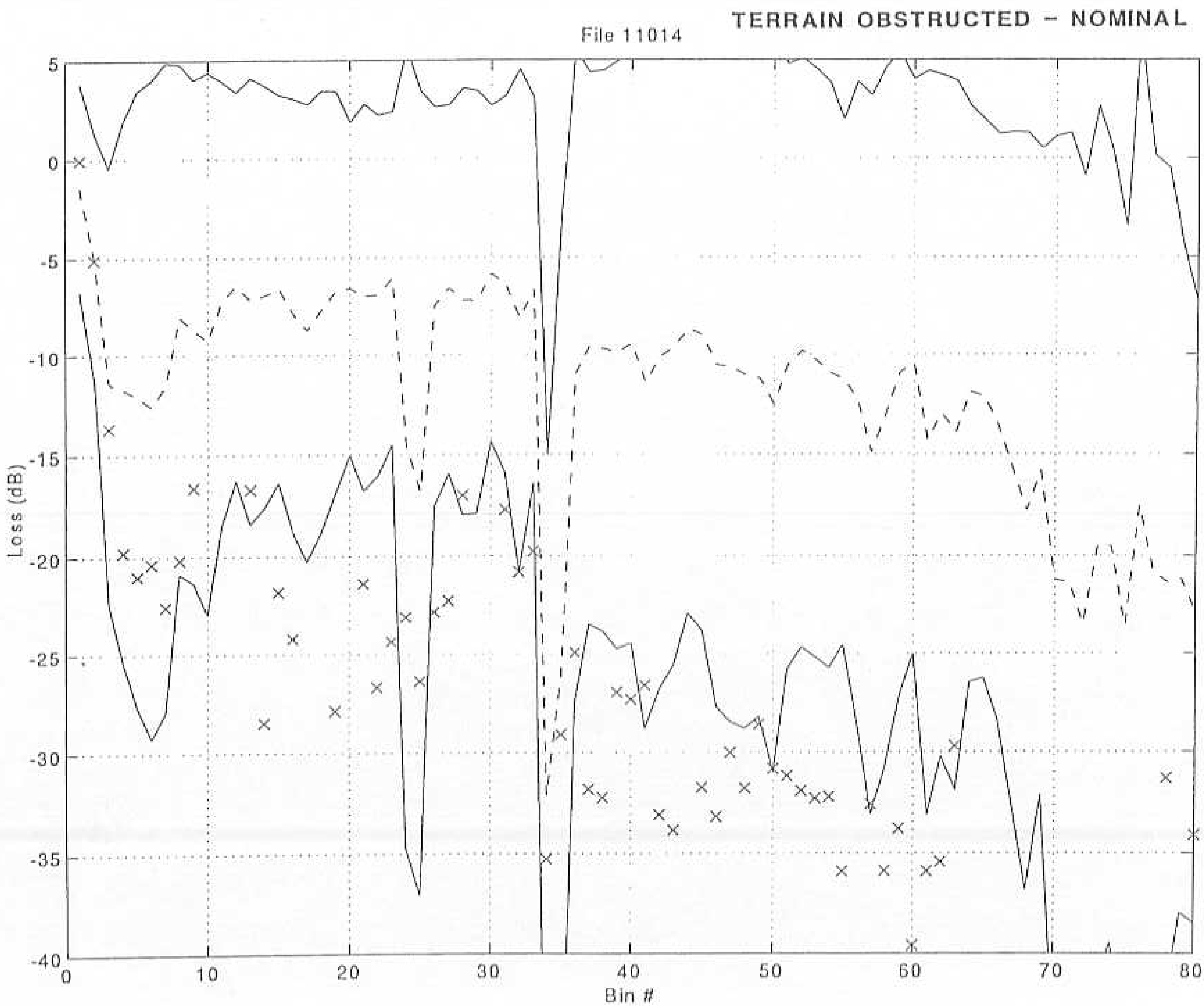



RURAL - NOMINAL
File 15010
Loss (dB)
Bin #
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80

25-75 KPH 4 2 4 2 12 sec = 5 cycles

(5)




TERRAIN OBSTRUCTED - NOMINAL
File 11014
Loss (dB)
Bin #
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
80

APPENDIX I

APPENDIX I - DATA PROCESSING AND INTEGRATION TO SIMULATOR(S); UNIFIED VHF-UHF SIMULATOR

I-1 Memo Report from Communications Research Center, "Proposed Channel Simulation Procedures for DAR Systems Tests of UHF"

I-2 Letter (L&C), to B. McLarnon, Communications Research Center, ""Proposed Channel Simulation Procedures"... and the "Multipath Stress Testing"" -- 7/20/94

I-3 FAX memo from B. McLarnon, Communications Research Center, "Three Suggested Multipath Profiles" -- 7/23/94

I-4 Letter (L&C), to B. McLarnon, Communications Research Center, "Salt Lake City Data" -- 7/25/94

I-5 Memo (L&C), "Derivation of Multipath Simulation Unified VHF-UHF Tests" -- 7/22/94

I-6 Memo (L&C), "Multipath Simulation Mode Unified VHF-UHF Tests" -- 7/29/94

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MICHAEL F. GRIMES
CECILY C. ORLANDO
D. SCOTT TURPIE

GEORGE M. LOHNES, P.E. (1991)
RONALD H. CULVER, P.E.
ELIZABETH L. DAHLBERG, P.E.

July 20, 1994

Mr. Barry McLarnon
Mr. Gerald Chouinard
CRC, Canada

by FAX 613-993-9950

Dear Barry and Gerald:

I have reviewed the "Proposed Channel Simulation Procedures..." and the "Multipath Stress Testing..." documents presented to me in the past few days. The proposal to adopt a uniform Simulation Mode test is quite logical now that the initial VHF tests must employ Simulation Mode. The incorporation of the Rayleigh files for doppler and attenuation variation also makes sense. I have reviewed the present VHF simulator settings for the four EIA test environments and have compared them to the settings suggested in your Procedures. While there are some differences there are many similarities and a common set can probably be reached. I will review all of the Direct Mode test files to see what parameters would actually be extracted from them for use in the Simulation Mode. In a general area let me make the following suggestions.

The EIA test plan proposes the use of four environments, distinct in some of their characteristics and therefore with distinct parameters. Your proposal calls for two environments run at two speeds each, one very slow and one at the practical upper limit for the environment. I propose that three environments be used and one of them tested at two speeds, thus still yielding four tests and not requiring any additional test time.

The EIA test plan also calls for testing co-channel interference with some multipath applied to the interfering signal as well as the signal for the system under test. Your procedure calls for up to 12 paths for Urban testing and 8 paths for Rural/Suburban. I suggest that we adopt a uniform 9 paths for all environments, leaving 3 paths available for co-channel interference multipath.

Now for some specifics as to which environments to test at which speed and what settings to use. The Urban environment should be tested at a very slow speed as you recommended. The 1 Kilometer Per Hour speed is easily slow enough to severely test the VHF systems time interleaving but may, as you suggested, be too slow to accurately represent all of the possible states the Rayleigh faded channel could assume. We should check 2 and 4 KPH speeds at our 94.1MHz test frequency to see if there is a significant difference. The Urban environment also needs to be tested at a more normal speed, as do all other environments. 60 KPH is appropriate.

At the other extreme the Rural environment is where speeds could reach a maximum which you suggest as 150 KPH. While the actual speeds could also be very low, in reality that has a much lower probability than for the Urban environment.

That leaves one test and two environments to go. I propose combining some of the settings for both our Suburban and Terrain Obstructed environments into one final environment and testing it at the intermediate 60 KPH speed, one appropriate for both the environments that were the basis for the resulting combined environment.

Now for the settings for the time delay and the attenuation for the 9 multipath simulator paths for the three environments. In the original 4 environments for our Simulation Mode testing we selected parameters based on the Salt Lake City measured data. The data was first screened on a file by file basis, with each file representing 160 consecutive measurement points for a total of approximately 56 meters of path. The screening was done by displaying the median value of the signal level in any one time delay bin on a graph verses time delay. A "density" display that indicated the relative probability of a reflection at a particular magnitude and delay was also consulted to determine when the limits of significant numbers of reflections had been reached. In the analysis I looked for files that had similar levels spread over a significant time. By similar I mean within at least 15 dB of the strongest signal, more often within a few dB, assuming that signals that are more than 15 dB below a reference level really did not pose any RF or time interference potential. I tried to find 150% of the data necessary to be able to "run" a one minute environment path at an assumed velocity profile, typically from 6 to 30 files. The Simulation Mode settings evolved from that data by choosing delays and attenuations that followed the profiles for those parameters in the direct mode data.

Your method I understand found one data file typical of an environment and then used selected points from the average delay spread graph for that file as the time delay and amplitude parameters. Although different in method the goal is the same, to try to find parameters that are typical of the more difficult parts of the environment that was measured. As you suggested I will examine my data to confirm that the VHF parameters are reflected in our average delay spread graphs. That analysis may well result in a revision in the parameters suggested here.

Let me suggest as a starting point the parameters for the three new environments shown in the table attached. Please review this and examine it in your simulator to see if it both reasonably matches the data from your UHF tests and is suitable for testing the UHF system. One factor to resolve is the minimum velocity. At 1500 MHz a 1 KPH velocity should be sufficient to allow full Rayleigh fading characteristics to be seen in a reasonably short test but perhaps not at our VHF test frequency of 94.1 MHz. We will have to pick some common velocity or doppler frequency to maintain a commonality of testing but one of the two parameters, velocity or frequency, will not be the same, just proportional.

Sincerely,

Robert D. Culver

cc Tom Keller
Ralph Justus
Brian Warren

SUGGESTED NINE PATH MULTIPATH SIMULATION SETTINGS

SIMULATOR SETTINGS - DELAY IN MICROSECONDS, ATTN IN dB

	URBAN SLOW-FAST		RURAL		SUBURBAN/TERRAIN	
PATH	DELAY	ATTN.	DELAY	ATTN.	DELAY	ATTN.
1	0.0	0	0.0	0	0.0	2
2	0.4	3	0.3	5	0.2	4
3	0.6	5	0.5	2	0.4	0
4	0.9	5	0.9	4	0.8	3
5	1.4	3	1.4	8	1.0	8
6	1.6	2	2.1	6	1.2	6
7	2.0	2	2.3	8	2.0	8
8	2.8	5	3.0	8	4.0	9
9	3.6	10	6.0	10	8.0	10

URBAN - SLOW; Use Rayleigh doppler path at 1 KPH at 94.1MHz RF test frequency. NOTE; this slow speed may not allow full development of all possible Rayleigh states. Be prepared to try 2 and 4 KPH to see if there is a difference.

URBAN - FAST; Use Rayleigh doppler at 60 KPH.

RURAL (FAST); Use Rayleigh doppler at 150 KPH.

SUBURBAN/TERRAIN (FAST); Use Rayleigh doppler at 60 KPH.

NOTE: The suggested settings above are based on a comparison of the original EIA SIM A - D files and the Canadian UHF suggested 12 path urban and 8 path rural settings. A thorough review of the Salt Lake City direct control files will be made to determine the average delays and magnitudes for the four environments to extract 9 path settings to be applied to this test. Those revised settings will be coordinated with Canada. The goal is a uniform Simulation Mode test for all bands.

Communications Research Centre
Centre de recherches sur les communications

Radio Broadcast Technologies Research
Communications Research Centre
P.O. Box 11490, Station H
3701 Carling Avenue
Ottawa, Ont., Canada K2H 8S2

FAX TRANSMISSION

Number of pages including this one: 2	Date: 23 July 94
To: Bob Culver FAX: 301-776-4499	From: Barry McLarnon Tel: 1-613-998-5005 Fax: 1-613-993-9950 Email: barry@dgbt.doc.ca

Subject: Dear Bob:

I have sketched out your three suggested multipath profiles, along with the two which we previously submitted for UHF system tests. The profiles for the urban environment are very similar, and I would have no qualms about using either one to simulate urban conditions. The "rural" profiles, on the other hand, are distinctly different, and they would result in quite different fading conditions. Moreover, the VHF rural profile is rather similar to the suburban/terrain obstructed profile. In fact, all three suggested profiles have similar characteristics, which I think indicates that perhaps too much emphasis has been placed on selecting only those cases from each environment which exhibit the largest delay spreads. In some respects, conditions with small delay spreads (typical of most "rural" environments) will present a more severe test for a system (particularly a wideband system) than the conditions with larger spreads. In any case, I don't think the three suggested profiles represent a sufficiently wide range of conditions for the tests.

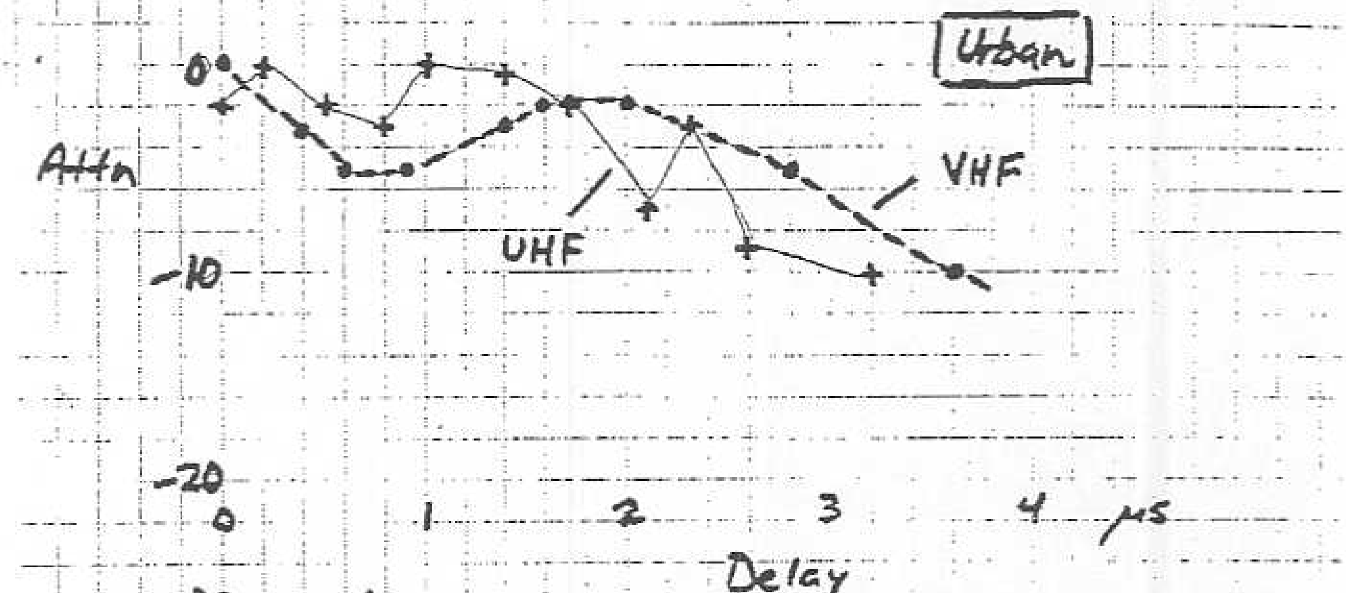
My suggestion therefore would be to merge your rural and suburban/terrain obstructed profiles into the latter category, and create a new rural profile which is based upon the UHF rural profile, or at least something close to it.

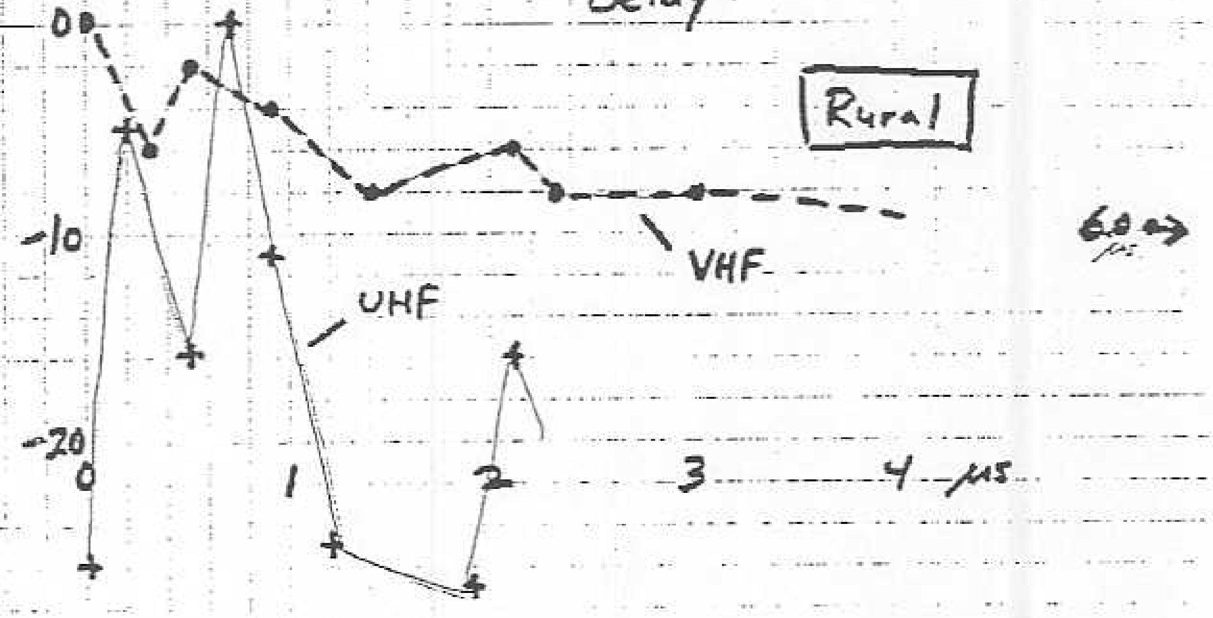
Your proposal to use 9 paths for the tests should present no problems. In fact, I ran some simulation tests last week comparing our 12-path urban profile with a reduced 9-path version obtained by removing the 3 weakest paths, and saw no significant difference in the resulting simulated channel.

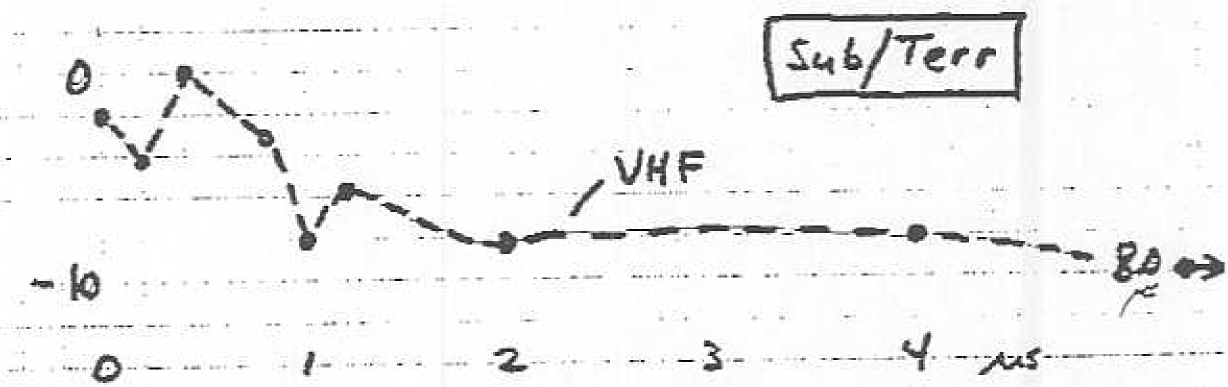
As I mentioned on the phone, we are certainly in agreement that it would be desirable to use a uniform set of tests for VHF and UHF systems, including the use of the same simulated vehicle speeds. The limiting factor is the slowest speed at VHF, where care must be taken to ensure that for the very small Doppler spread involved, the fading conditions still approximate Rayleigh. It looks like that potential problem has already been recognized and is being dealt with.

I will be available on Monday morning to discuss this further.

Regards,
Barry


Urban
Attn
0
-10
-20
0
1
2
3
4
μs
Delay
UHF
VHF


Rural
0
-10
-20
0
1
2
3
4
μs
UHF
VHF
6.0 μs →


Sub/Terr
0
-10
0
1
2
3
4
μs
VHF
8.0 μ →

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CECILY C. ORLANDO
D. SCOTT TURPIE

GEORGE M. LOHNES, P.E. (1991)
RONALD H. CULVER, P.E.
ELIZABETH L. DAHLBERG, P.E.

July 25, 1994

Mr. Barry McLarnon
Mr. Gerald Chouinard
CRC, Canada

by FAX 613-993-9950

Dear Barry and Gerald:

I have conducted a further study of our Salt Lake City data and offer the following. Attached are four plots of the measured signal levels verses delay bin (.25 microseconds) for the four original environments. Looking first at the "Urban" Simulator file there are nine total files that made up this computer control group, a selected worst case set of the hundreds of original files. The dashed line is a bin by bin median value for that limited data set and the upper and lower lines are the 95 and 5% limit lines. Some scattering of data is evident but a clear trend can be seen. One trend is for what I would describe as an "initial time delay gap", a term I've borrowed from audio analysis. Next, the occurrence of delayed signals fall dramatically beyond bin 16 or 4 microseconds. Looking at all the files that were collected in the Urban environment may show some signals out at great delays and relatively high levels but it was a very rare occurrence.

Next, the Suburban Simulator Files, plotted for a total of 39 files, shows extreme scattering of over 20 dB for any bin beyond bin 4. Generally a trend can be seen in those first bins with a rapid median signal decay to 10 dB below direct signal within 1 microsecond. A series of minor reflection bumps may be seen further out but these are 15 dB or more below the direct signal, below what I have adopted as my cut off level. Looking at the data on a file by file basis there are some trends for an initial time delay gap and some rare longer reflections.

The Rural Simulator Files, 36 total, show a rapid decay to about 2 microseconds and then a hint of stronger signals further out, but still well below the 15 dB cut off level. I do not see your short delay peak at 0.2 microseconds as a distinct peak, probably because our test was limited to a minimum delay resolution of 0.25 microseconds. Our bin 1 median signal is 5dB down, similar to your first peak, but the next peak at nearly 1 microsecond is not seen.

The last plot, for the 23 files in the Terrain Obstructed Simulator file, is dramatically different from any data you have. Please note that the horizontal time delay scale has been extended to show the long delay times in the environment. The main characteristic of this environment is the almost constant signal level for long delays. When looking at individual files you can see individual clusters of delays, often with sloping magnitudes vs. delay. That trend is faintly evident in this plot in the vicinity of bins 26-28, 32-32, 43-45, etc.

In conclusion, The overall VHF Urban data follows the VHF part of the graph you faxed to me on Saturday fairly well. The only differences were a uniform level shift of about 2dB and a slight drop in level at 2 microseconds and rise at 4 microseconds. I can still support a smooth channel setting following the trend through both the UHF and VHF data points.

The VHF data files for the Suburban and Rural environments are very similar. If a 15 dB signal cut off level were adopted they would be almost identical with only a minor variation of delay, 1.25 vs 1.0 microseconds, at the cutoff point. I can support a blending of these two environments, realizing that a few of the farther suburban reflections would artificially be associated with the rural file. I suggest you drop your first UHF data point at 25 dB down, it is far below any reasonable cut off point and adopt the second point at 5dB down as the first. The remaining points would be close to the delay time of those plotted with the main peak at 1us. The vertical attenuation scale could be compressed about 2:1 to yield 10 to 15 dB minimum levels so that significant reflections extend out to several microseconds. This is quite a bit different than both the VHF and UHF data but is a reasonable compromise of the data and approximation of the environment.

The VHF channel Terrain Obstructed data is unique. It is built up of many files and there was an easily noticed difference within the several parts of the file string. Indeed, this data was taken from parts of two runs up two canyons and such differences are expected. Simulating this variation may be impossible but if having characteristics from several areas blended into one test is acceptable I still propose my Terrain Obstructed test. The parameters can stay the same as was already supplied or be revised as shown. The overall effect of a rather long delay spread at nearly uniform signal level will be the same.

I have seen too much variation of data from file to file to pick the one "typical" file for extracting simulation parameters. I chose to look at what I thought would be "significant" difficult files on a file by file basis and then stringing them together for our simulation. I feel an average of these is appropriate for a test to challenge the systems.

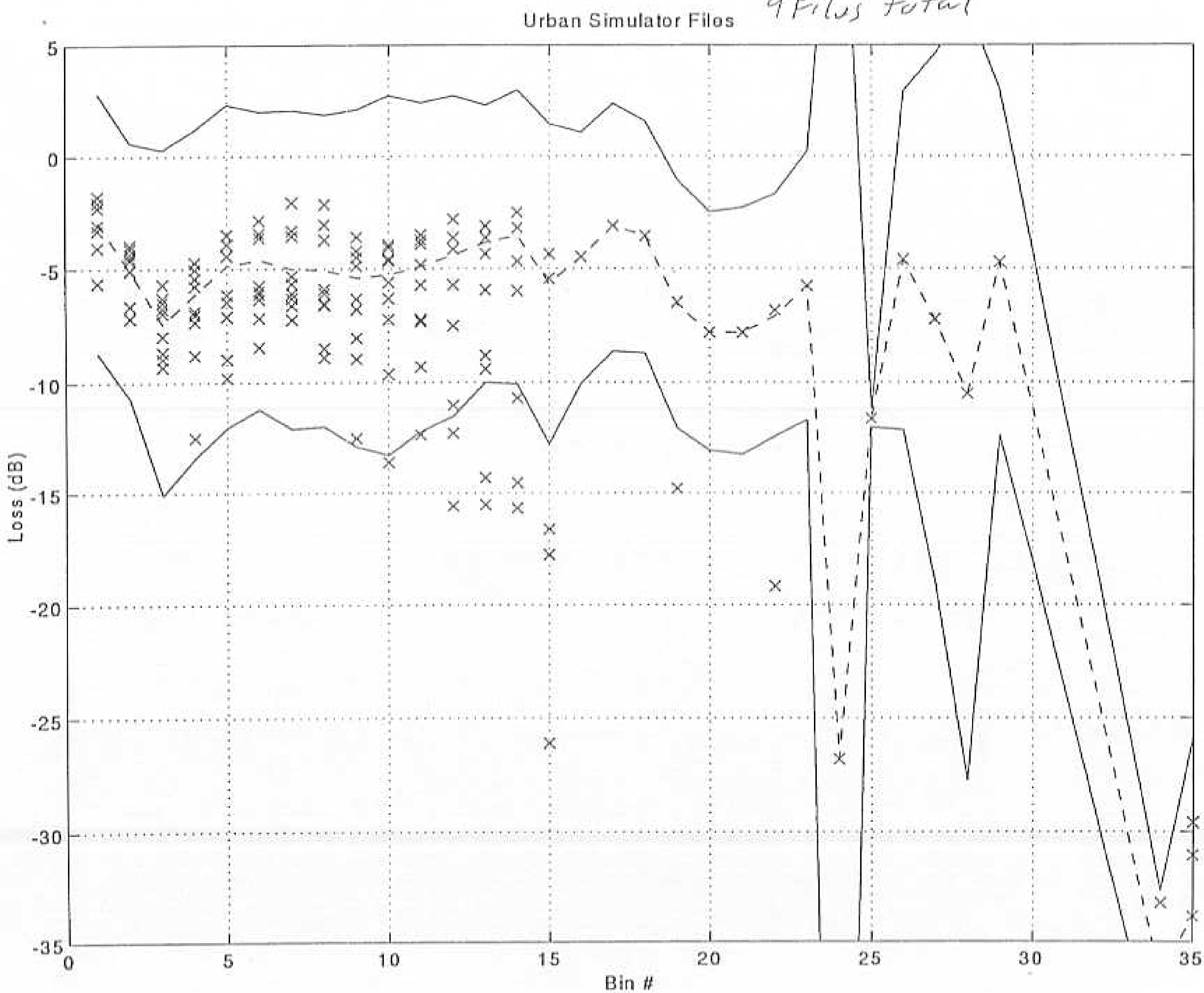
Please review this and call me as soon as you are able.

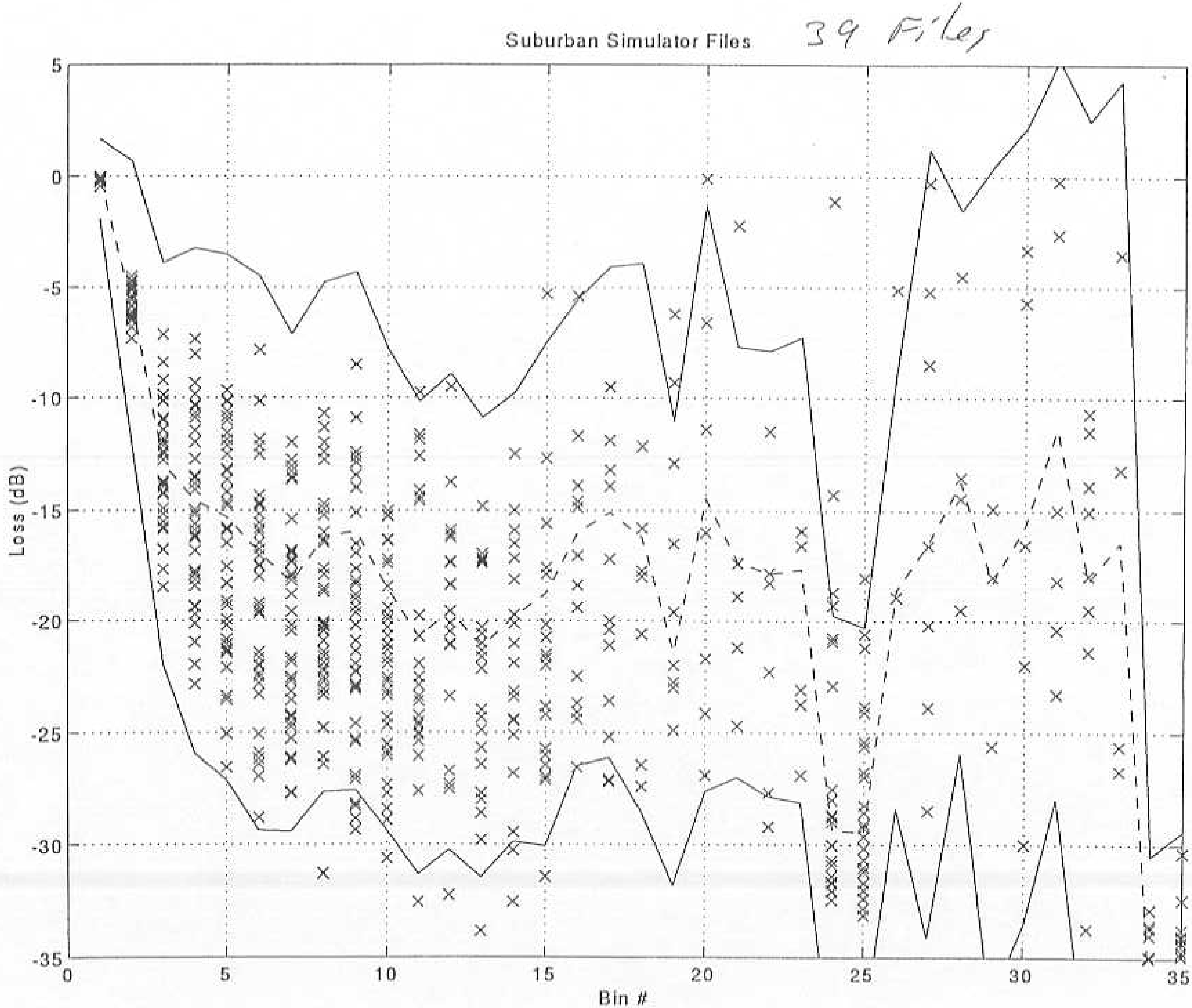
Sincerely,

Bob

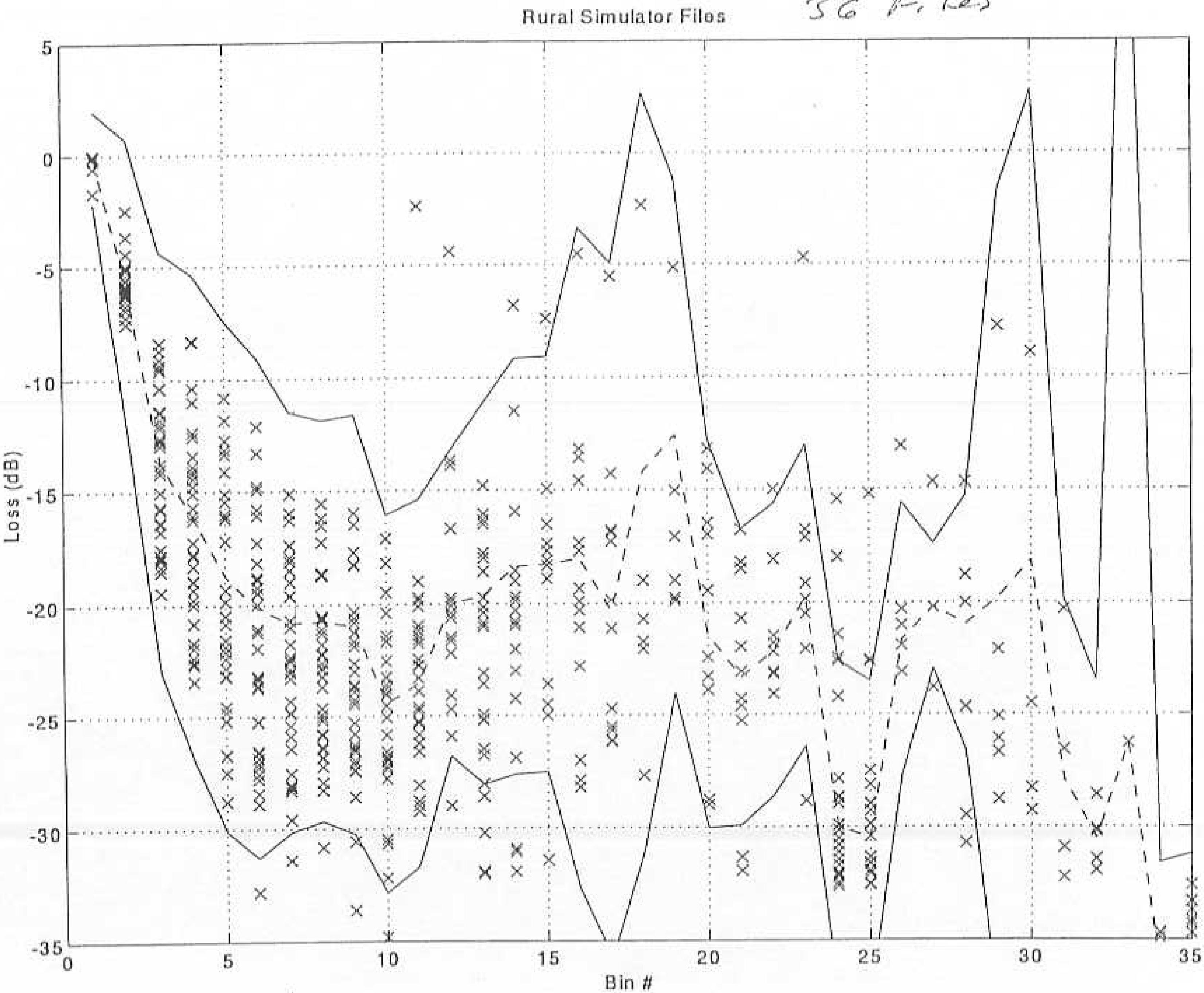
Robert D. Culver

9 Files total




Suburban Simulator Files
39 Files
Loss (dB)
Bin #
5
0
-5
-10
-15
-20
-25
-30
-35
0
5
10
15
20
25
30
35

36 Files



Rural Simulator Files
Loss (dB)
Bin #
5
0
-5
-10
-15
-20
-25
-30
-35
0
5
10
15
20
25
30
35

MEMO RE; DERIVATION OF MULTIPATH SIMULATION UNIFIED VHF-UHF TESTS
FROM; ROBERT D. CULVER, EIA-DAR VHF CHARACTERIZATION TASK FORCE
DATE; AUGUST 22, 1994

1) AT the July 19, 1994 EIA-NRSC DAR meetings a report was presented regarding the multipath simulations to be used at the DAR test lab at NASA Lewis in Cleveland. Artifacts generated in the Hewlett Packard Channel Simulator were described, their potential impact on the systems under test were discussed (see attachment A) and a decision was reached to employ the "simulation" mode of operation of the channel simulator for the upcoming initial tests. The resulting use of simulation mode for both the VHF and UHF system multipath testing was approved (UHF had always been scheduled to use simulation mode rather than direct mode). The logical use of a common test parameter set, also incorporating Rayleigh fading, was discussed and a consensus reached by the group to explore common parameters for testing and to implement them if possible. The parties directed to discuss this were the individuals directly involved with the multipath characterization data, Robert Culver for the VHF data and Gerald Chouinard with Barry McLarnon for the UHF data. (see attachments B and C)

2) At that meeting and over the following days the data representing the characteristics were examined and discussed, revealing the similarities and notable differences between them. (see attachment D) There was, of course, no similarity for the "Terrain Obstructed" environment because there was no UHF data for anything like that environment. The issue of at what signal level a reflection should no longer be considered significant was discussed. Both in practice and in using the Hewlett Packard simulation testing, reflections at 15dB or more below the highest signal were thought to not be a potential interferer. 15dB had been adopted as the initial reflection magnitude lower limit. However, with the incorporation of Rayleigh fading, magnitude variations would be added and a significant level of interference could be reached, even from a very low basic reflection level, on some occasions. 25dB was adopted as the lowest attenuation value to assign to any simulator channel. The maximum attenuation that can be achieved in any channel not assigned a reflection magnitude is approximately 50dB.

3) Which environments to test and the simulation of a "dynamic" test path was then considered. In the earlier proposed "direct" control testing, a dynamic test path would have been followed because the actual data would be used, impressing actual measured delay, attenuation and doppler changes on the test. The test was then to be conducted as if a vehicle were driven at variable speed over a path by changing the rate at which the simulator settings were updated from the direct data file. In the simulation mode, rather than the direct mode, this dynamic control is not possible and it was suggested that gross changes in vehicle velocity be simulated by individual tests at different velocities in each environment. It was decided at the July 19 meeting that the total time of laboratory testing could not be increased and thus a total of four tests, as anticipated in the past, should still be used. Considering the very real and frequent occurrence of very slow or stopped velocities in the urban environment, that environment should be tested at two speeds, very slow (set by the lower limits of the simulator) and medium, 60 KPH or approximately 40 MPH.

4) Leaving only two tests and three environments yet to be accommodated, an investigation was made to combine or drop one of the proposed environments. The suburban and rural VHF data were quite similar, therefore it was decided to adopt a combined "rural" as well as an "obstructed" environment. Each will be tested once at appropriate speeds. The obstructed medium speed was set at the same speed as the urban fast speed, 60 KPH, and the rural fast speed was set at 150 KPH, approximately 150% of the present highway speed limits, comparable with future highway and other present surface transportation speeds. Direct variation of speed within a simulation mode test is not possible but minor variations can be simulated by applying a Rayleigh doppler characteristic to the channel, a well accepted practice for multipath testing in other services. The Hewlett Packard simulators, when using a Rayleigh channel, also changes the attenuation of a channel, thus creating a variation around an "average" attenuation and Doppler, not fixed values. The Rayleigh channel would thus more accurately depict actual propagation conditions and more closely resemble the planned direct tests than if fixed parameters had been used.

5) The first major step to assign any of the channel simulator control values was to decide the method of data selection and then the limits for the data within environments. The Salt Lake City data had already been subject to much review for the direct control testing, to find those portions of the data that represented potentially stressful channels. In that review the approximately 2000 files of data from all environments was examined on a file by file basis with each file covering 160 sample points (instances) over a 56 meter path. Propagation paths which contained several reflections, each delayed by a different time but at approximately the same signal level, would clearly present a more difficult path than one with no reflections or with only low level reflections. This multisignal characteristic then set the criteria of focusing on files with nearly equal reflection magnitudes. The characteristic of reflections delayed in time then set the next criteria for difficult paths, those with delays greater than zero but within some upper limit.

6) In an effort to rapidly review the massive measurement data and to depict the selection methods and limits for others to see, a pair of visually oriented data analysis programs were written. The first displayed the "density" or number of data points for any given delay and magnitude level within a universe of data. This density display quickly painted in the area in which most magnitude and delay values fell, setting the upper bounds on both the reflection magnitude and time delays that should be chosen. For example, in the urban environment an area of high density of data (high probability) could be seen filling the area of higher level reflections at short delays, while progressively lower density of data (probability) is seen further out in delay and lower in magnitude. Conversely, in the rural environment, the reflections at significantly high levels extend much further out in time (see Example gray scale density plots "Urban" and "Rural") The next step involved selecting the individual significant data files from the entire universe of data, for example from one environment, to be used for the simulation. To do this the data was plotted using a second graphical routine on a file by file basis for a more detailed (and time consuming) review. To assist in selecting data files by magnitude of reflections two datum lines were plotted on each graph. They were the median and 95th percentile lines for all of the data for the particular environment under review. The area below these lines represent signal reflection magnitudes that occur for 50% or 95% of the time for any particular delay time. The original data analysis, described in paragraph 5 and above, chose up to 6

magnitude/delay pairs for each measurement instance, 160 instances per file and hundreds of files per environment. All other possible delay times in excess of the six chosen had no corresponding magnitude values assigned. Because of the large number of measurements made in each environment, tens of thousands of instances representing hundreds of thousands of data points, were collected and analyzed.

7) The measured data was then examined on a file by file basis in this graphical method. In each trial for each data file of 160 measurement instances the average of attenuation values for any of the measured time delays was plotted with the 50 and 95 percentile environment limits. Each plot then quickly indicated if a file contained significant reflection data. A comparatively small 10 to 30 significant files were extracted for each environment to control testing. Wherever possible contiguous files were sought, but in most cases the chosen files are not contiguous. Reviewing this group of files, originally chosen for the direct control mode testing, led to the magnitude and time delay parameters assigned for the three new simulation mode test environments. (see attachment E) The parameters chosen for each channel of the simulator thus represent the average attenuation and time delay, based on a larger group of individual measured values. When acted upon by the Rayleigh fading files the average settings are returned to individual control settings that are time varying around that average. Thus, the simulation process, creating individual control points from average channel settings, is the inverse of the channel setting selection process which created average settings from a group of files representing the average of individual measured reflection values.

8) As stated earlier, the VHF and UHF proposed simulator settings had some differences, and some remarkable similarities. For one, the original VHF simulation mode values proposed six channels as was the case for the direct control simulation, its predecessor. The UHF simulation mode values proposed 12 and 8 channels for their two proposed environments. The need for future addition of multipath to co-channel interfering signals argued for less than 12 channels and a compromise was struck for nine unified channels for all tests. An "initial time delay gap", that initial time in which low reflection levels are present, is evident in much of the VHF and UHF tests and is preserved in the unified parameters. The maximum VHF and UHF time delays and the individual attenuation and time delays differed slightly. For example, the maximum time delays for one of the environments was at one time proposed as 3.5 and 3.8 microseconds for the two frequency bands. Upon further review and reduction to a uniform nine channel test, the maximum delays became 2.7 and 3.5 microseconds. This was converged to 3.0 microseconds maximum delay. These differences were easily reconciled to common values, well within the range of parameters suggested by either test data set where comparable tests existed. Finally, the terrain obstructed data from the VHF tests was accepted and adopted for the UHF multipath simulation testing. The time delay/magnitude characteristics for urban UHF are very similar to the obstructed VHF data in its early time delays. The obstructed environment, however, continues that characteristic for up to four times the delay.

9) These unified VHF-UHF multipath simulations have been tested through the Hewlett Packard simulator with wide band test signals and displayed on a spectrum analyzer. The tests have been video recorded and presented to all of the proponents of systems under test.

MEMO RE; MULTIPATH SIMULATION MODE UNIFIED VHF-UHF TESTS

FROM; ROBERT D. CULVER, EIA-DAR VHF CHARACTERIZATION TASK FORCE

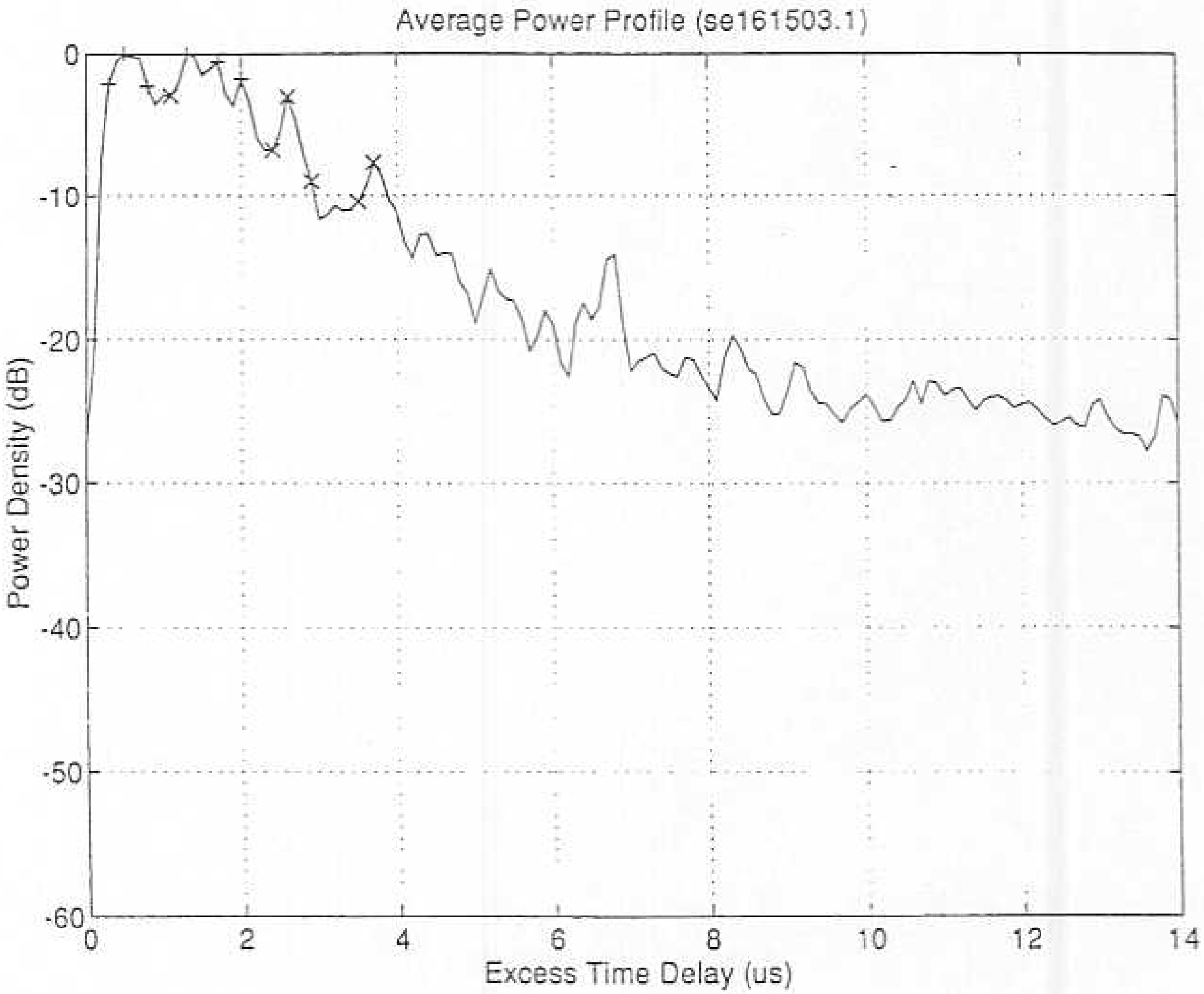
DATE; JULY 29, 1994

Three Simulation Mode Environment Parameter Sets are now available for laboratory testing. The three environments will still produce four tests, the Urban environment will be tested at slow (≤ 10 KPH) and fast 60 KPH speeds. The Rural environment will be tested at an average speed of 150 KPH ant the Obstructed environment at 60 KPH. All tests will incorporate Rayleigh fading keyed to these velocities. The fading will affect both the doppler frequency and the attenuation values. Nine paths will be used for each test, leaving 3 paths available for multipath on the co-channel interfering signal when called for in specific tests. The parameters were extracted from the VHF Channel data and coordinated with the Canadian CRC data for the UHF channel. The CRC concurs in the common use of these parameters for testing all systems. The parameters fall into the ranges tabulated below.

VHF-UHF CHANNEL SIMULATION ENVIRONMENT ESTIMATES

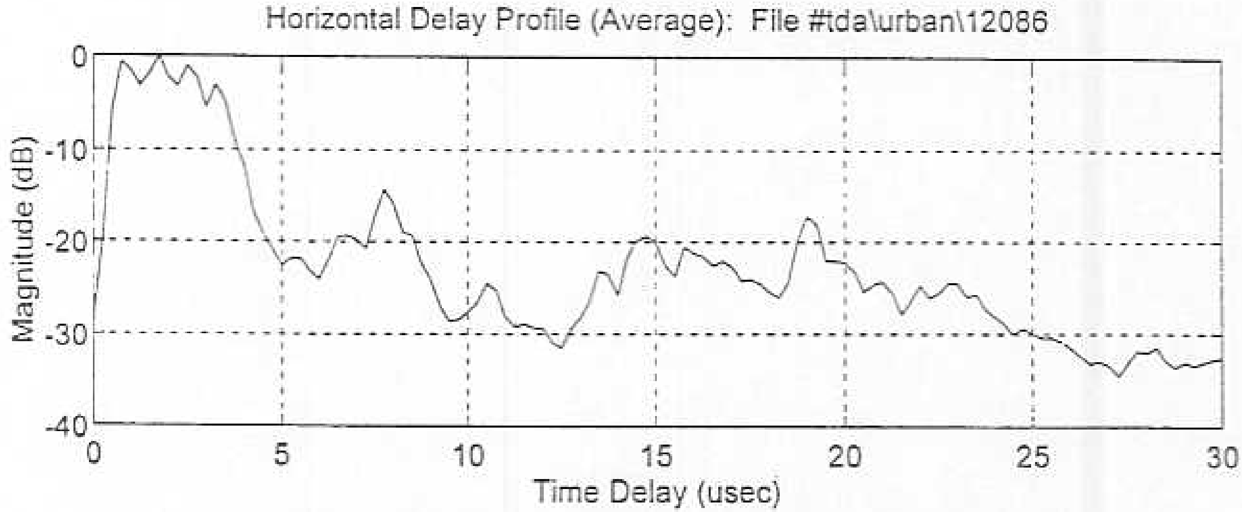
ENVIRONMENT	DELAY (us)	ATTN. (avg. dB)
A URBAN	0 - 3.0	0 - 10
B RURAL	0 - 3.0	0 - 25
D OBSTRUCTED	0 - 16.0	2.0 - 10

Fig 1

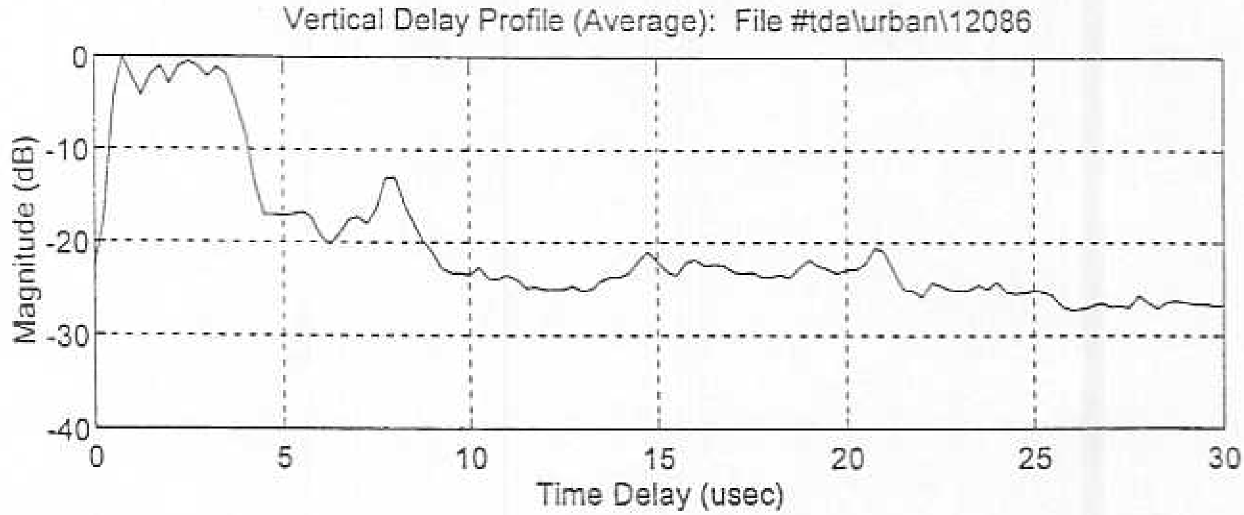


Average Power Profile (se161503.1)
Power Density (dB)
Excess Time Delay (us)
0
-10
-20
-30
-40
-50
-60
0
2
4
6
8
10
12
14

Fig 2

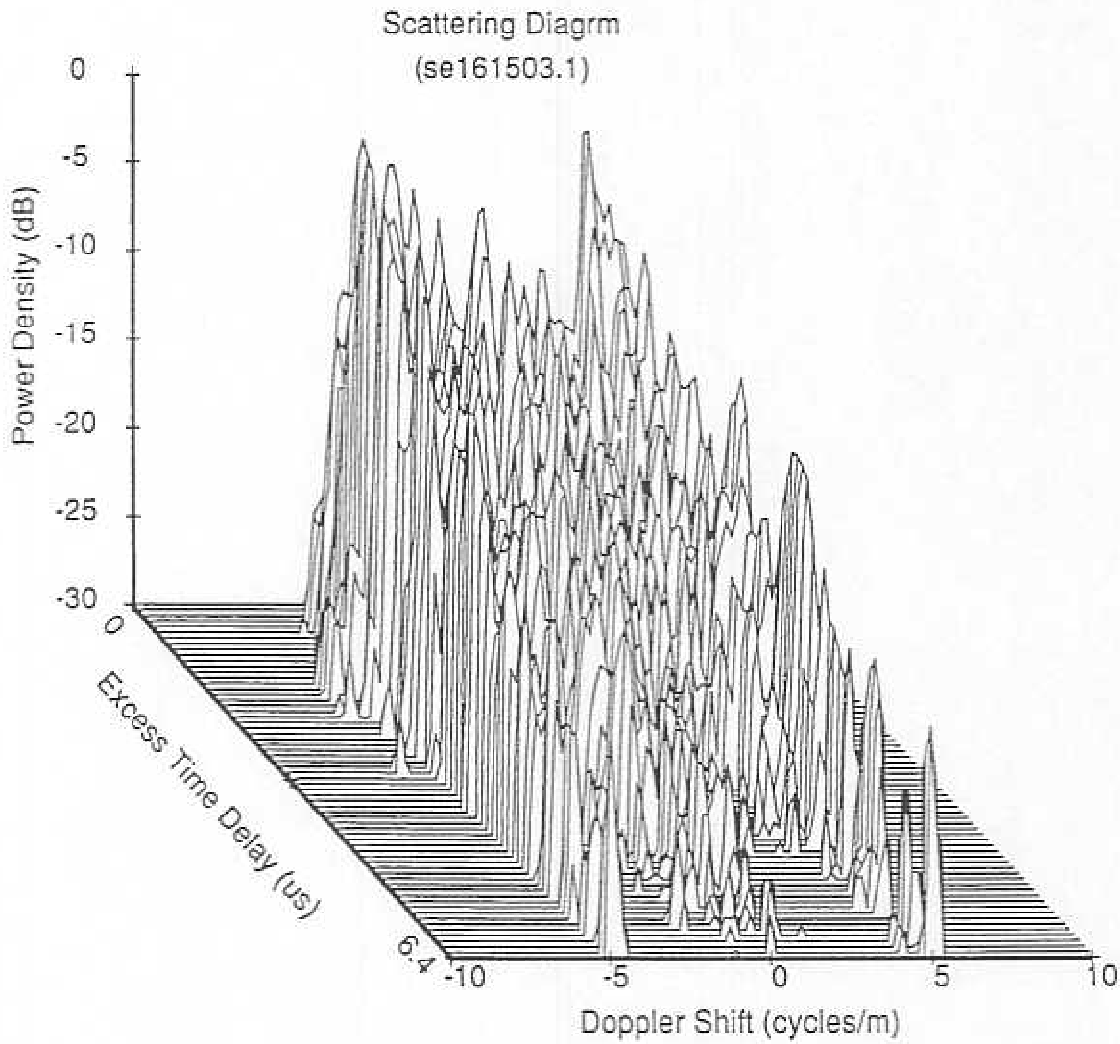


Horizontal Delay Profile (Average): File #tda\urban\12086
Magnitude (dB)
0
-10
-20
-30
-40
0
5
10
15
20
25
30
Time Delay (usec)



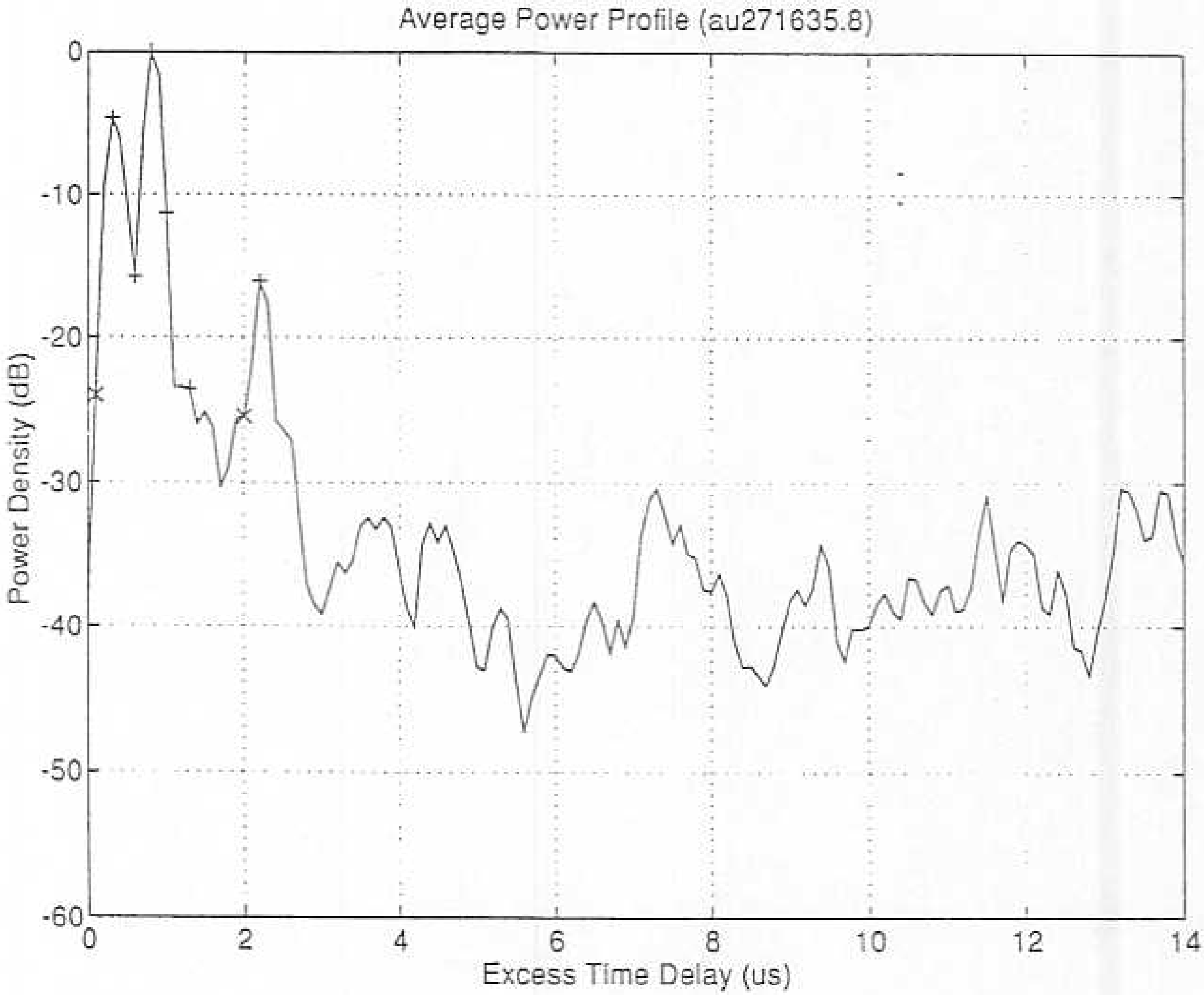
Vertical Delay Profile (Average): File #tda\urban\12086
Magnitude (dB)
0
-10
-20
-30
-40
0
5
10
15
20
25
30
Time Delay (usec)

Fig 3



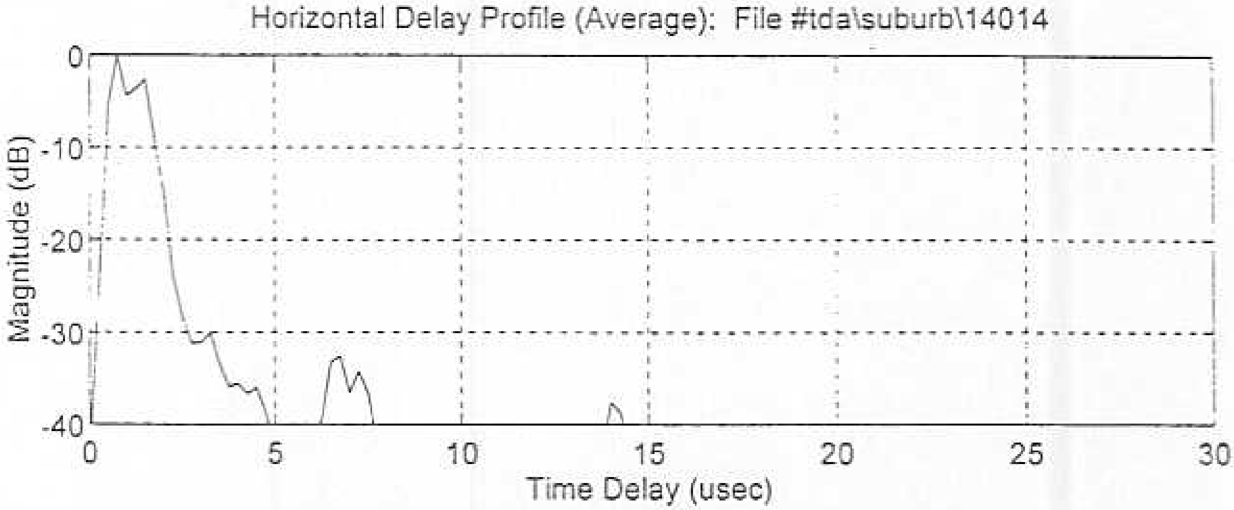
Scattering Diagrm
(se161503.1)
Power Density (dB)
0
-5
-10
-15
-20
-25
-30
Excess Time Delay (us)
0
6.4
-10
-5
0
5
10
Doppler Shift (cycles/m)

Fig 4

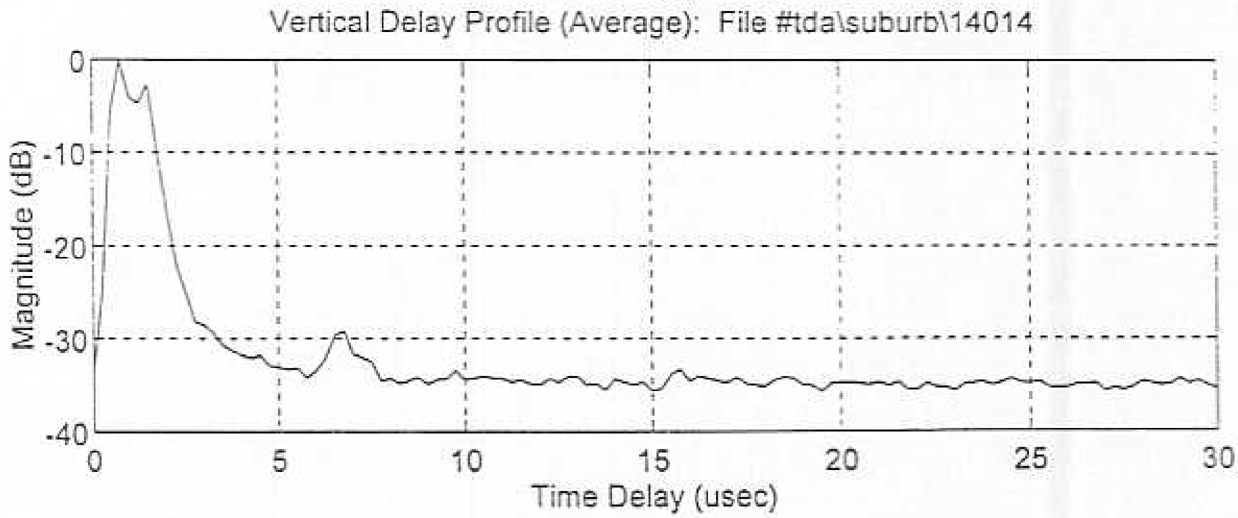


Average Power Profile (au271635.8)
Power Density (dB)
0
-10
-20
-30
-40
-50
-60
0
2
4
6
8
10
12
14
Excess Time Delay (us)

Fig 5

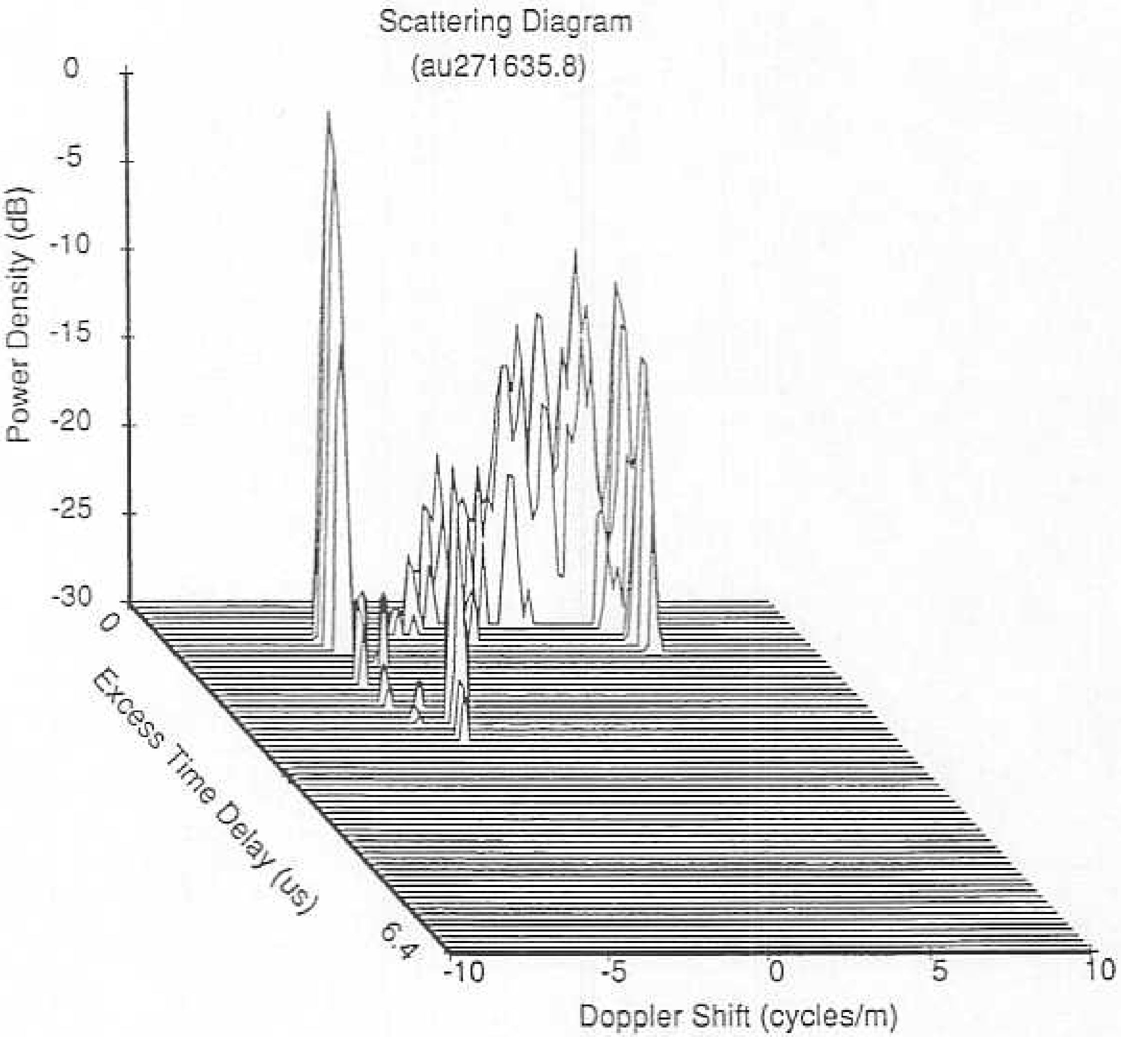


Horizontal Delay Profile (Average): File #tda\suburb\14014
Magnitude (dB)
0
-10
-20
-30
-40
0
5
10
15
20
25
30
Time Delay (usec)



Vertical Delay Profile (Average): File #tda\suburb\14014
Magnitude (dB)
0
-10
-20
-30
-40
0
5
10
15
20
25
30
Time Delay (usec)

Fig 6.



Scattering Diagram
(au271635.8)
Power Density (dB)
0
-5
-10
-15
-20
-25
-30
0
Excess Time Delay (us)
6.4
-10
-5
0
5
10
Doppler Shift (cycles/m)

Proposed Channel Simulation Procedures for DAR System Tests at UHF

Recent tests with the HP simulator indicate that it will not be feasible to use the Dynamic mode of the simulator for system tests at UHF, since the update rates required to simulate the same maximum vehicle speeds as used in the VHF tests cannot be attained. This document addresses the question of using the Simulation mode of the simulator to perform the UHF tests. As in the VHF tests, the objective is to ensure that these tests are effective in stressing the systems under test, but at the same time are based upon realistic multipath conditions that have been observed in field tests.

Since the standard Simulation mode involves fixed path delays and fixed maximum Doppler shift during a run, it is difficult to provide a wide range of test conditions with a small number of runs. One possible option is to use the Simulation mode which allows the use of user-specified IQ values rather than the Rayleigh fading simulation generated by the IQMAKE facility. This provides some of the flexibility of the Dynamic mode in that it could provide changing Doppler conditions during the simulation run. The major limitation of this mode is that the delay of the paths cannot be varied during the run. The IQ values therefore cannot be derived from individual impulse response records using the multipath extraction algorithm which is being used as the precursor to the Dynamic mode testing at VHF, since this generates changing path delays. An alternative could be to run the extraction algorithm on a long-term average power delay profile for a set of data files from a given environment. Then, having selected the 6 (or 12) delay bins with the most significant multipath over the long term, the IQ values from these bins could be extracted from the data files. However, multipath conditions can change considerably even during one measurement run, not to mention a large number of runs spliced together. Extracting the IQ data from only a few fixed delay bins would cause many significant multipath events to be missed. There may be ways of including the effects of a number of adjacent bins in this process, but this needs further study. At the moment, we feel that operation using the standard Rayleigh Simulation mode would be the more prudent approach to simulation with fixed delays, since it ensures that the contribution of each simulator path retains its significance throughout the run. This mode can provide effective system tests, as evidenced by its extensive use in the testing of mobile cellular systems.

If the number of simulation runs must be limited to four, we feel that the following conditions would provide the best scenario for tests of DAR systems at UHF, using the standard Simulation mode.

(1) A difficult urban multipath profile, with Doppler corresponding to the maximum vehicle speed to be simulated in the urban VHF test environment (60 kph).

(2) The same urban multipath profile, but with slow fading corresponding to very slow vehicle speed (say 1 kph).

(3) A difficult suburban/rural multipath profile, with Doppler corresponding to the maximum vehicle speed to be simulated in the rural VHF test environment (150 kph).

(4) The same suburban/rural multipath profile, but with slow fading corresponding to very slow vehicle speed (say 1 kph).

The definition of "difficult" depends on the system under test. In the context of the Eureka 147 system, this does not necessarily mean large multipath delay spreads. In all of our L-band channel characterization measurements, we have not encountered any instance of multipath with delays sufficent to cause problems for the current Eureka system design. This also applies to the severe multipath seen in some of the VHF measurements from the "terrain obstructed" environment. Channels with small delay spreads and multiple components with near-equal amplitudes are much more stressful, since they have the potential for causing deep fades over bandwidths which approach that of the wideband Eureka system. Very small Doppler shifts can be stressful by prolonging the duration of the fades; on the other hand, large Doppler shifts can cause problems such as intersymbol interference between the closely-spaced carriers in a COFDM system.

We have examined all of the L-band channel characterization data collected to date, and selected two segments which are expected to be among the most difficult, as discussed above. In each case, we have taken 128 successive impulse response snapshots, representing 6.4 meters of travel (one-quarter wavelength spacing at L-band). The snapshots were averaged to produce a short-term average multipath delay profile, and an extraction algorithm was run to select the six dominant components in each case. This algorithm is the same as that used for the VHF system tests. The only difference is that in this case, the extraction is performed on the ensemble average of 128 impulse response snapshots instead of a single one. The extraction process then provides the mean values of the contributions of what appear to be the six dominant multipath components in that small area. The impulse response data are normalized over the entire set of snapshots before averaging, so that the true relative amplitudes are reflected in the result. The average amplitudes of the six selected components become the baseline values for the Rayleigh fading which is generated in the simulation mode of the HP system. In the Simulation mode, only one simulator is required to generate six Rayleigh fading paths. Since two simulators will be available at the test facility, the possibility exists to generate 12 paths for the UHF tests. We have modified the extraction algorithm to produce the 12 most significant multipath components, so that this option can be exercised if it seems desirable to do so.

Preparation for the tests involves two steps:

(1) Use the HP IQMAKE program to generate the Rayleigh fading files for the necessary Doppler shifts. For L-band, the Doppler shifts needed are as follows:

1 kph:	1.4 Hz
60 kph:	83.3 Hz
150 kph:	208.3 Hz

(2) From the Simulation mode screen, enter the amplitude and delay values for the six paths, plus the appropriate Doppler values, for a given test scenario. Save the setup as a stored profile. Load the other Doppler values to be used for tests with those multipath conditions, and save that profile. Then load the other set of multipath delay/amplitude parameters, and save the remaining two profiles with the appropriate Doppler values.

Details about the Measurement Files

Urban

The multipath profile shown in Figure 1 is from L-band measurements taken in the downtown section of Ottawa. Also shown on the figure are the location of the delay bins selected by the extraction algorithm; the first set of six are shown with a '+', and the second set with a 'x'. This particular measurement is from a run near the intersection of Slater and O'Connor, which is in the downtown core of the city. There are a number of highrise buildings in the immediate vicinity, and we believe that conditions here are typical of large cities. This particular profile was selected because it contains more high-amplitude multipath components with small excess delays than usual. There is considerable similarity to Salt Lake City urban VHF measurements in these data; compare, for example, the profile shown in Figure 2, which is one of the data files selected as "significant" for use in the VHF tests. Both figures show average power-delay profiles, with the average taken over a number of successive impulse response "snapshots" (160 in the case of VHF, and 128 for L-band). Note that the L-band measurements were for vertical polarization only. The delay spread (averaged over the 128 snapshots) for this L-band measurement was 1.7 μsec, and the delay window for 90% of the power was 4.0 μsec. The profile is very similar to that given in the COST 207 recommendation for "typical urban" conditions, but the multipath spread from the L-band measurement is somewhat larger (the delay spread and 90% delay window for the COST 207 "typical urban" conditions are 1 μsec and 2.3 μsec, respectively). Figure 3 shows the scattering diagram for the L-band measurement. The complexity of the urban multipath environment is evident; moreover, it is apparent that the classical U-shaped Doppler spectrum generated by the Rayleigh fading files used by the simulator will be an excellent approximation to what was observed in the field.

Suburban/Rural

Most of the L-band measurement data for rural and suburban areas is characterized by small. delay spreads and a strong direct path component. In many cases, only slow (lognormal) fading is evident. The delay profile shown in Figure 4 was selected because of the presence of two (at least) multipath components of similar strength, separated by less than one microsecond. This can be expected to create fading which will be correlated over a relatively large bandwidth, and thus represents a difficult channel for both narrowband and wideband systems. In this case, there was no significant difference between the 6- and 12-parameter extraction routines, since the latter routine generated only two additional low-level points above the algorithm's threshold level. This profile comes from a rural area near Trois-Rivieres, Quebec. Similar conditions were encountered in the Salt Lake City VHF measurements in rural and suburban areas. Figure 5 shows one example (again, one which was selected for the VHF system tests). The scattering diagram for this L-band measurement is shown in Figure 6. It shows a much simpler environment than the urban case; nevertheless, there is significant Doppler spreading, especially at small excess delays.

	Urban Environment		Rural/Suburban Environment	
Path	Delay, µsec	Attenuation, dB	Delay, µsec	Attenuation, dB
1	0.4	2.1	0.4	4.7
2	0.6	0	0.7	15.8
3	0.9	2.3	0.9	0
4	1.4	0	1.1	11.3
5	1.8	0.6	1.4	23.5
6	2.1	1.8	2.3	16.1
7	1.2	3.0	0.2	24.0
8	2.5	6.7	2.1	25.4
9	2.7	3.1		
10	3.0	9.0		
11	3.6	10.4		
12	3.8	7.7		

Table 1 - Simulator Delay/Amplitude Values

Presented May '9
meeting

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VHF Also.

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(2) The same urban multipath profile, but with slow fading corresponding to very slow vehicle speed (say 1 kph).

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The multipath profile shown in Figure 1 is from L-band measurements taken in the downtown section of Ottawa. Also shown on the figure are the location of the delay bins selected by the extraction algorithm; the first set of six are shown with a '+', and the second set with a 'x'. This particular measurement is from a run near the intersection of Slater and O'Connor, which is in the downtown core of the city. There are a number of highrise buildings in the immediate vicinity, and we believe that conditions here are typical of large cities. This particular profile was selected because it contains more high-amplitude multipath components with small excess delays than usual. There is considerable similarity to Salt Lake City urban VHF measurements in these data; compare, for example, the profile shown in Figure 2, which is one of the data files selected as "significant" for use in the VHF tests. Both figures show average power-delay profiles, with the average taken over a number of successive impulse response "snapshots" (160 in the case of VHF, and 128 for L-band). Note that the L-band measurements were for vertical polarization only. The delay spread (averaged over the 128 snapshots) for this L-band measurement was 1.7 μsec, and the delay window for 90% of the power was 4.0 μsec. The profile is very similar to that given in the COST 207 recommendation for "typical urban" conditions, but the multipath spread from the L-band measurement is somewhat larger (the delay spread and 90% delay window for the COST 207 "typical urban" conditions are 1 μsec and 2.3 μsec, respectively). Figure 3 shows the scattering diagram for the L-band measurement. The complexity of the urban multipath environment is evident; moreover, it is apparent that the classical U-shaped Doppler spectrum generated by the Rayleigh fading files used by the simulator will be an excellent approximation to what was observed in the field.

Suburban/Rural

Most of the L-band measurement data for rural and suburban areas is characterized by small delay spreads and a strong direct path component. In many cases, only slow (lognormal) fading is evident. The delay profile shown in Figure 4 was selected because of the presence of two (at least) multipath components of similar strength, separated by less than one microsecond. This can be expected to create fading which will be correlated over a relatively large bandwidth, and thus represents a difficult channel for both narrowband and wideband systems. In this case, there was no significant difference between the 6- and 12-parameter extraction routines, since the latter routine generated only two additional low-level points above the algorithm's threshold level. This profile comes from a rural area near Trois-Rivieres, Quebec. Similar conditions were encountered in the Salt Lake City VHF measurements in rural and suburban areas. Figure 5 shows one example (again, one which was selected for the VHF system tests). The scattering diagram for this L-band measurement is shown in Figure 6. It shows a much simpler environment than the urban case; nevertheless, there is significant Doppler spreading, especially at small excess delays.

	Urban Environment		Rural/Suburban Environment	
Path	Delay, μsec	Attenuation, dB	Delay, μsec	Attenuation, dB
1	0.4	2.1	0.4	4.7
2	0.6	0	0.7	15.8
3	0.9	2.3	0.9	0
4	1.4	0	1.1	11.3
5	1.8	0.6	1.4	23.5
6	2.1	1.8	2.3	16.1
7	1.2	3.0	0.2	24.0
8	2.5	6.7	2.1	25.4
9	2.7	3.1		
10	3.0	9.0		
11	3.6	10.4		
12	3.8	7.7		

Table 1 - Simulator Delay/Amplitude Values

APPENDIX J

APPENDIX J - DATA PROCESSING AND INTEGRATION TO SIMULATOR(S); ACTUAL SIMULATION PARAMETERS

J-1 Memo Report (L&C), "Suggested Nine Path Multipath Simulation Settings" -- 7/26/94

J-2 Letter from D. Londa, EIA, "Channel Simulator Parameters" -- 8/16/94

SUGGESTED NINE PATH MULTIPATH SIMULATION SETTINGS 7/26/94

SIMULATOR SETTINGS - DELAY IN MICROSECONDS, ATTENUATION IN dB

	URBAN SLOW-FAST		RURAL		OBSTRUCTED	
PATH	DELAY	ATTN.	DELAY	ATTN.	DELAY	ATTN.
1	0.0	2	0.0	4	0.0	10
2	0.2	0	0.3	8	1.0	4
3	0.5	3	0.5	0	2.5	2
4	0.9	4	0.9	5	3.5	3
5	1.2	2	1.2	16	5.0	4
6	1.4	0	1.9	18	8.0	5
7	2.0	3	2.1	14	12	2
8	2.4	5	2.5	20	14	8
9	3.0	10	3.0	25	16	5

URBAN - SLOW; Use Rayleigh doppler path at 1 KPH at 94.1MHz RF test frequency. NOTE; this slow speed may not allow full development of all possible Rayleigh states. Be prepared to try 2 and 4 KPH to see if there is a difference.

URBAN - FAST; Use Rayleigh doppler at 60 KPH.

RURAL (FAST); Use Rayleigh doppler at 150 KPH.

SUBURBAN/TERRAIN (FAST); Use Rayleigh doppler at 60 KPH.

NOTE: The suggested settings above are based on a comparison of the original EIA SIM A - D files and the Canadian UHF suggested 12 path urban and 8 path rural settings. A thorough review of the Salt Lake City direct control files will be made to determine the average delays and magnitudes for the four environments to extract 9 path settings to be applied to this test. Those revised settings will be coordinated with Canada. The goal is a uniform Simulation Mode test for all bands.

NOTE: 7/26/94 The EIA VHF test data has been reviewed and coordinated with Canada. The above table represents consolidated Urban and Rural environment parameters for both VHF and UHF tests. The Obstructed file is based only on the VHF measurement further analysis.

EIA DAR Test Laboratory

August 16, 1994

Mr. Robert D. Culver
Lohnes & Culver
8309 Cherry Lane
Laurel, MD 20707-4830
Phone:(301) 776-4488 Fax:(301) 776-4499

Dear Bob,

Here is the multipath characterization video tape.

The channel simulator parameters used for the Urban environment are as follow:

PATH	DELAY (us)	DOPPLER (kmh)	ATTEN (dB)
1	0.0	2 or 60	2.0
2	0.2	2 or 60	0.0
3	0.5	2 or 60	3.0
4	0.9	2 or 60	4.0
5	1.2	2 or 60	2.0
6	1.4	2 or 60	0.0
7	2.0	2 or 60	3.0
8	2.4	2 or 60	5.0
9	3.0	2 or 60	10.0

The channel simulator parameters used for the Rural environment are as follow:

PATH	DELAY (us)	DOPPLER (kmh)	ATTEN (dB)
1	0.0	150	4.0
2	0.3	150	8.0
3	0.5	150	0.0
4	0.9	150	5.0
5	1.2	150	16.0
6	1.9	150	18.0
7	2.1	150	14.0
8	2.5	150	20.0
9	3.0	150	25.0

EIA Digital Audio Radio Test Laboratory
NASA Lewis Research Center
Communications System Branch
21000 Brookpark Road, MS 54-2
Cleveland, OH 44135
Telephone (216) 433-3445
Telefax (216) 433-8705

The channel simulator parameters used for the Suburban / Terrain Obstructed environment are as follow:

PATH	DELAY (us)	DOPPLER (kmh)	ATTEN (dB)
1	0.0	60	10.0
2	1.0	60	4.0
3	2.5	60	2.0
4	3.5	60	3.0
5	5.0	60	4.0
6	8.0	60	5.0
7	12.0	60	2.0
8	14.0	60	8.0
9	16.0	60	5.0

The IQMAKE.EXE utility was used twice to create the Rayleigh fading data. The command parameters used are as follow:
IQMAKE -R 94.1E6 2 60 150 and similarly
IQMAKE -R 1.47E9 2 60 150.

These command lines then created the Rayleigh fading data files and the appropriate filename was indicated in the simulation mode menu under the Spectrum filename heading. Simulation profiles were stored with the appropriate Raleigh fading data filenames, delay and attenuation and the profiles recalled and video taped.

The first four segments on the tape (00:00-05:42) are the VHF simulations and the last five segments (05:42-12:22) include a reference of the signal unimpaired followed by the simulations in L-Band.

Call me if you have any questions.

Best regards,

Dave

David M. Londa
RF Test Manager

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Cleveland, OH 44135

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APPENDIX K

APPENDIX K - SIMULATOR LIMITATION; STEP FUNCTION DATA INTRODUCES "ARTIFACTS"

K-1 Memo Report (L&C), to EIA-DAR Working Group B, "Report on the VHF Channel Simulation at the EIA-DAR Test Laboratory" -- 7/12/94

REPORT ON THE VHF CHANNEL SIMULATION AT THE EIA-DAR TEST LABORATORY

DATE: July 12, 1994
FROM: Robert D. Culver, EIA-DAR VHF Characterization Task Force
TO: EIA-DAR Working Group B

The data extracted form the EIA-DAR Channel Characterization test has been applied to the channel simulator at the test lab. The data was derived from the four environments identified in the Salt Lake City tests and contains sufficient data files to complete the simulations of approximately one minute each along a simulated mobile path. The data files were chosen from the "significant" files in an environment and do not represent contiguous files. In joining the files a data point was synthesized at the splice between files to smooth the transition.

Upon installation in the lab the data files were run through the simulator, using a wide band RF signal to observe the simulator output on a spectrum analyzer. The wide band signal was generated by frequency modulating a 94.1 MHz carrier with a 100Hz$\pm$ tone to more than 1MHz bandwidth. The data control and simulator response was checked for proper mobile test simulation, particularly those simulations which contained momentary stops. A short steady state unimpaired condition was added to the beginning of each simulation to allow all systems to reach stable operation prior to applying multipath simulation to the RF signal. During this testing several time and frequency domain artifacts of the simulation were noted and investigated.

Attached are several spectrum analyzer plots of the various tests. Each plot will be discussed in turn.

1) Plot No. 1 shows the output of the channel simulator in a steady state mode, using the VHF Channel data but with the dynamic simulation frozen (computer in pause mode). The radio frequency response is stable and smooth as expected.

2) Plot No. 2 shows the same conditions except with the dynamic simulation running. In this plot a series of switching transients are seen. The computer update rate of 400 samples per second matches the time interval of 25 milliseconds between transients. The path characteristics change from the first to the second simulator state. This simulator "snapshot" was captured by repeatedly viewing spectrum analyzer single sweep displays until one was seen with a transient. Such displays are not frequent, occurring less than 10% of the time.

The cause of the frequency response transients is an artifact of stepping the simulator from one state to the next. The transient was thought to be directly related to the magnitude of the step size and the greatest contributor to the transient was sought. Upon reviewing the structure of the data controlling the simulator it was felt that time delay jumps would cause the largest transients. An unmodulated carrier test was devised to explore this.

3) Plot No. 3 shows an unmodulated carrier after being processed by the channel simulator running in the Simulation (not direct) mode. The simulator had all 6 channels active with time delay, doppler and attenuation values sufficient to generate a significant RF domain multipath result. This and all the following plots were the result of an approximate 15 second peak hold sample. This plot shows that there are no artifacts generated within the 1MHz bandwidth and the 40 dB display range.

4) Plot No. 4 was recorded under the same analyzer conditions but the simulator was now being dynamically controlled by one of the direct simulation environments. Close examination of this condition over a wide frequency band could reveal no system artifact; such as L.O. leakage, computer clock frequencies, etc., that could account for the transients.

5) Plot No. 5 shows the results from a test with the same conditions a No. 4 but with the simulator being controlled by a test file with constant phase and amplitude but with a delay step of $\pm$10 microseconds for each successive point. The response is similar in nature to Plot No. 4.

6) Plot No. 6 is a similar test with a file that contains random steps of 1 microsecond over a limited total delay range.

7) Plot No. 7 is identical but with the steps limited to 0.5 microseconds.

8) Plot No. 8 is similar , using 1 microsecond steps, but with increased resolution on the spectrum analyzer (reduced from 30 to 3 kHz BW).

9) Plot No. 9 shows the same display for a 0.2 microsecond step size

At this point it was apparent that large delay steps caused significant artifacts. The data contained in one of the environment files was smoothed with respect to its time delay changes for further testing. The smoothing was accomplished by adding computer code to the program that creates the control files from the raw data so as to limit any one step to 0.1 microseconds. The resulting test file was run through the simulator for checking.

10) Plot No. 10 represents a test of the smoothed data with an analyzer resolution BW of 30 kHz.

11) Plot No. 11 shows the same test at increased resolution (3 kHz).

The improvement obtained by smoothing this one data parameter is substantial but more improvement is possible and desirable. Smoothing the two remaining parameters, phase and attenuation magnitude, should yield more improvement. It is clear that any direct control test with the simulator should use a high data rate with smoothing applied to the data. Also, tests must be applied to the data to make sure that any bad data points that were excluded from the control files do not in themselves introduce an unwanted step transition. The rational behind this is that the RF environment does not contain step changes, there may be a fast change or fade but there are no infinite rise time steps.

To accurately model the smoothly changing environment the step size should be as small as possible. The VHF Channel Characterization Test used measurements spaced at 1/10 wavelength, often enough to model the environment but not so often as to produce unnecessarily large amounts of data. At that spacing the data points are well correlated for statistical analysis, but even that step size, and potential missing points, are large enough to introduce step transition artifacts in the simulator. Further smoothing work on all parameters is needed so that direct environment simulations could be conducted in the future.

In the meantime, a Simulation Mode Environment Parameter Set was assembled for each of the four test environments. The VHF Channel test data supplied the range of all path settings for phases, delays and magnitudes associates with each environment.

The phases can change over the range from 0 to 360 degrees. This characteristic is simulated by the doppler frequency shift, the phase rotation parameter. In the Simulation Mode the rate of change is limited by the simulation "mobile path" speeds, and the resulting doppler frequency, adopted for each environment. Each of the six path doppler frequencies were adjusted to yield a simulation that was dynamic in its frequency response, one that changed null depth over a cycle of time and produced movement of the null frequencies throughout the frequency band.

The VHF Channel Test signal magnitudes ranged widely, with the most significant reflections being relatively close in level, for example within 5 or 10 dB of each other, rather than 30 or more dB different. The characteristic of moderately equal signal levels, and their associated time delays, was displayed in the level verses time delay computer analysis presented earlier, as part of the selection of the significant environment files.

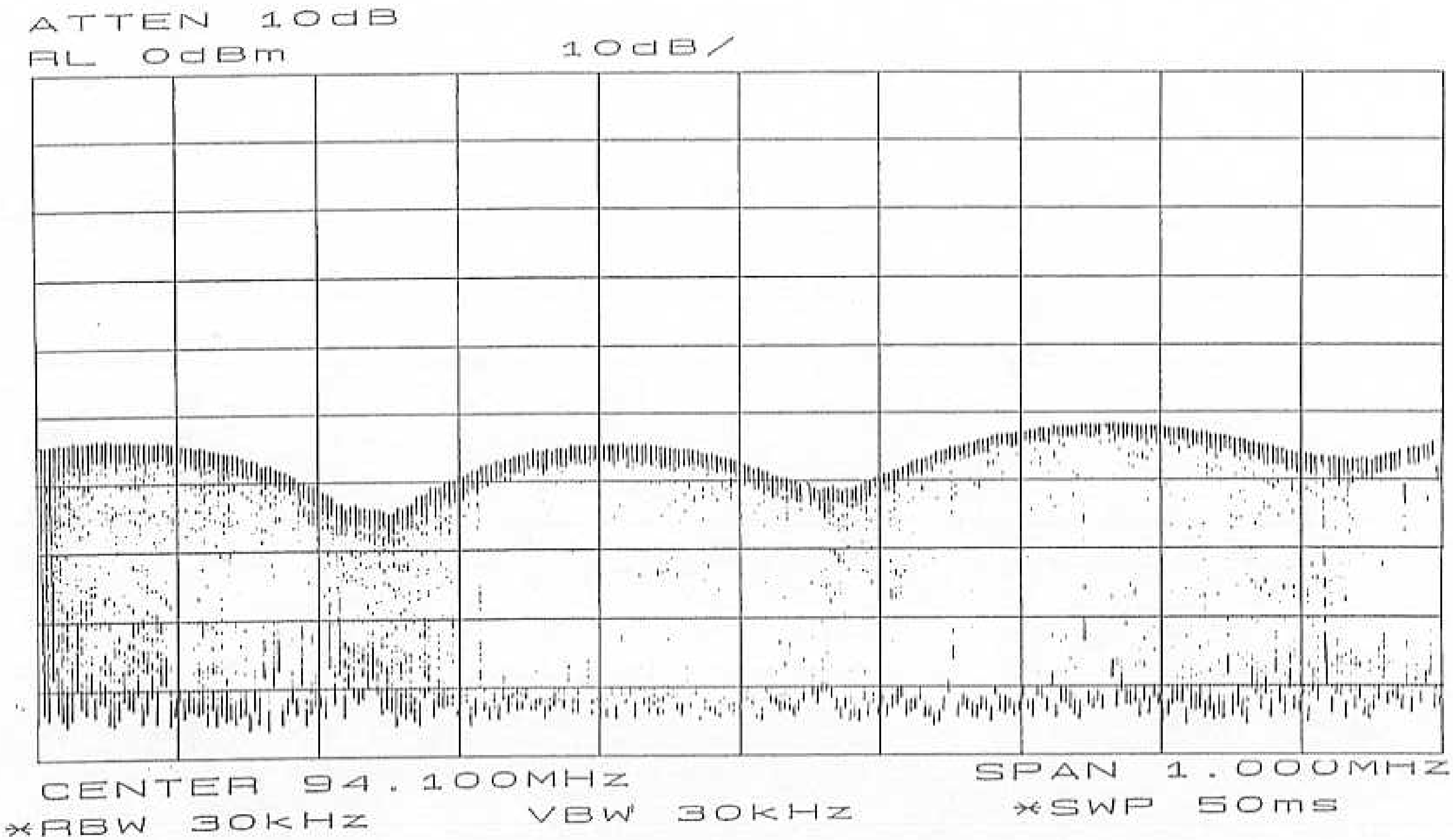
The time delays for an environment are directly displayed for each point in each environment file and the range of delays is easily extracted.

Four Simulation Mode Environment Parameter Sets are now available for laboratory testing. The parameters were extracted from the VHF Channel data as described above and fall into the ranges tabulated below.

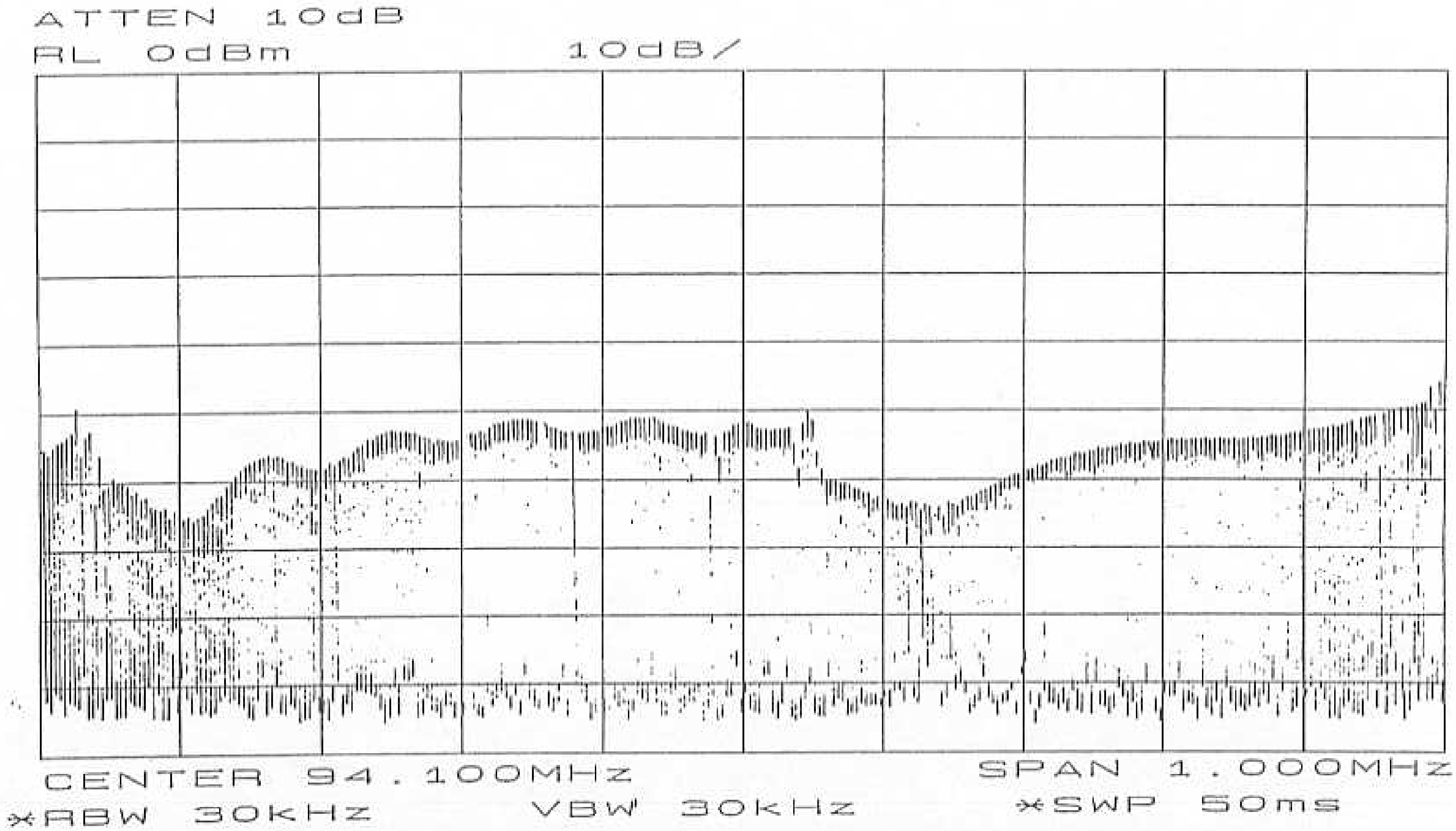
VHF CHANNEL SIMULATION ENVIRONMENT ESTIMATES

ENVIRONMENT	DELAY (us)	DOPPLER (Hz)	ATTENUATION (dB)
A URBAN	0 - 2.2	1.6 - 2.2	0 - 5.0
B SUBURBAN	0 - 6.0	1.3 - 3.5	0 - 8.0
C RURAL	0 - 15.0	7.2 - 12.0	0 - 15.0
D OBSTRUCTED	0 - 16.0	1.0 - 6.0	2.0 - 6.0

NO. 1


ATTEN 10dB
RL 0dBm
10dB/
CENTER 94.100MHz
SPAN 1.000MHz
*RBW 30kHz
VBW 30kHz
*SWP 50ms

NO. 2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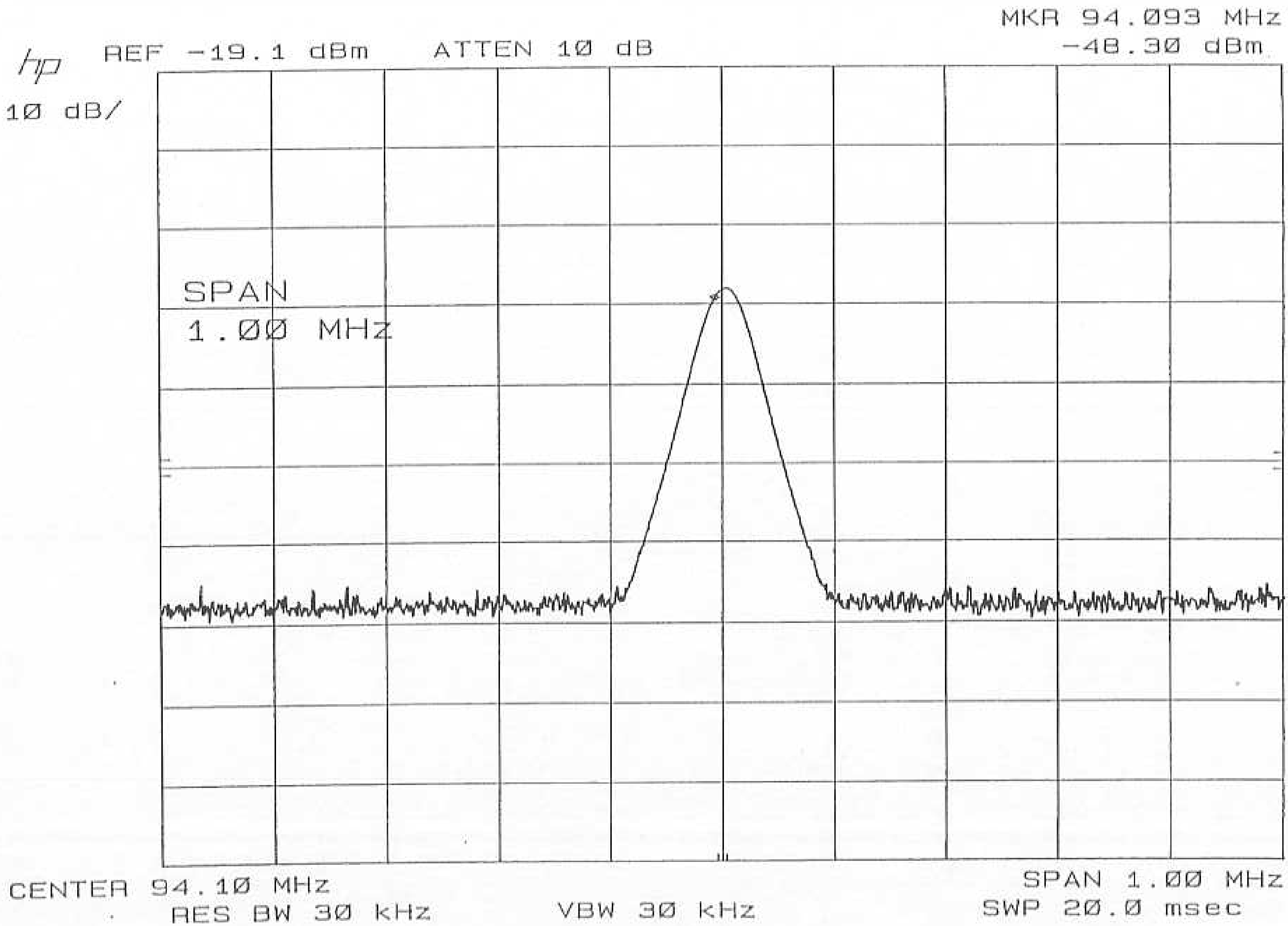
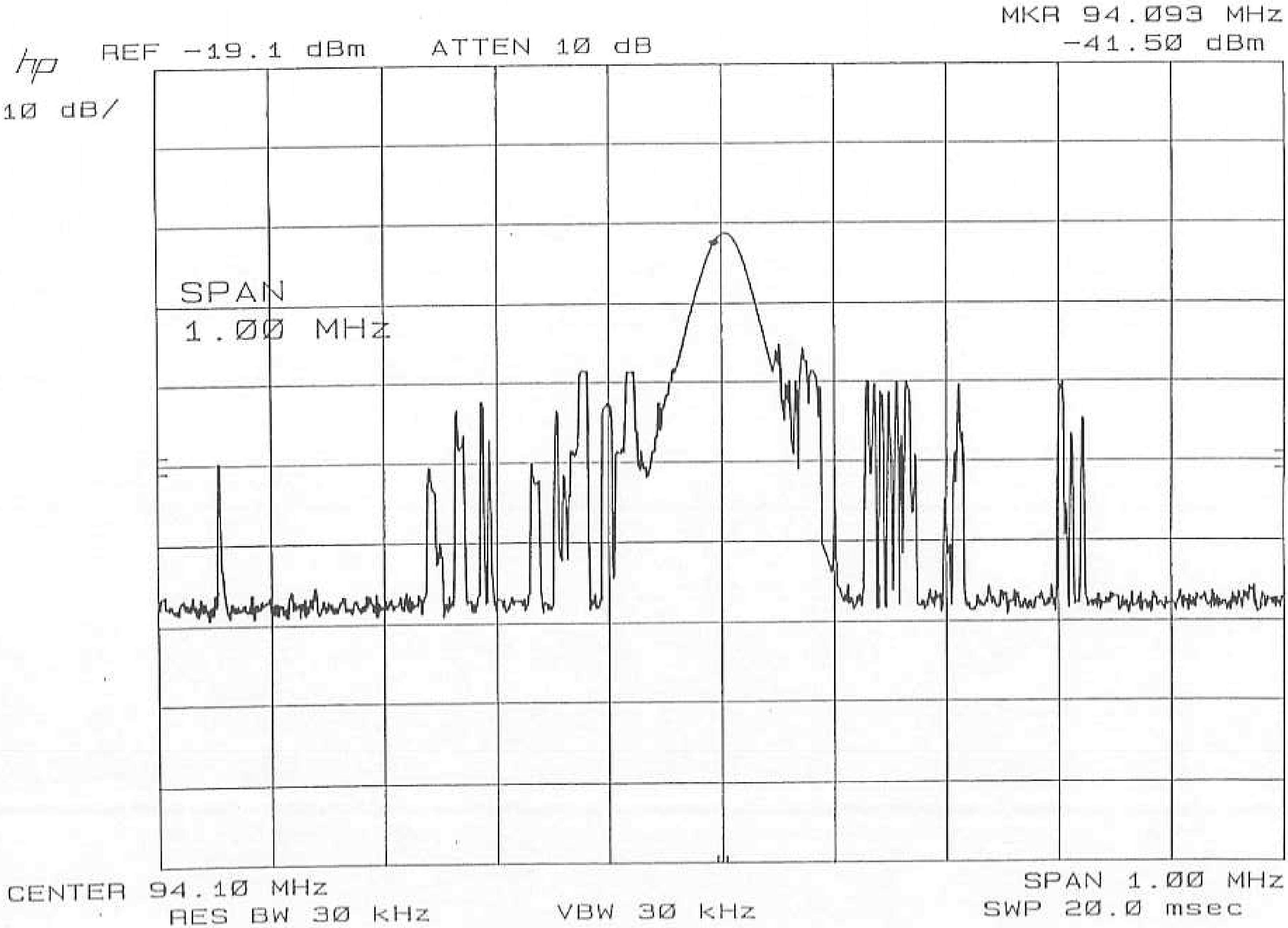
RL 0dBm
10dB/
CENTER 94.100MHz
SPAN 1.000MHz
*RBW 30kHz
VBW 30kHz
*SWP 50ms

NO. 3



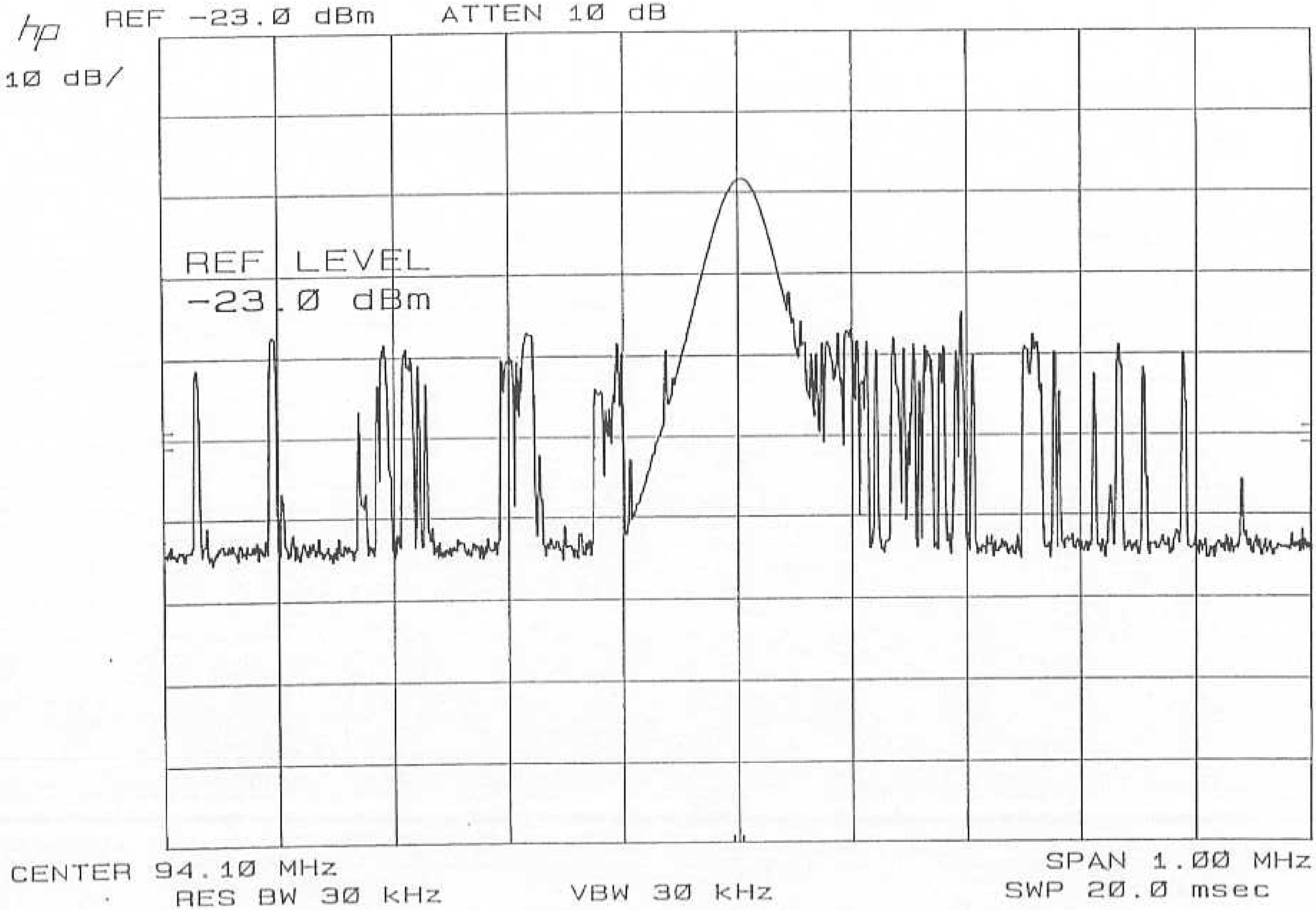
MKR 94.093 MHz
-48.30 dBm
hp REF -19.1 dBm ATTEN 10 dB
10 dB/
SPAN
1.00 MHz
CENTER 94.10 MHz
RES BW 30 kHz
VBW 30 kHz
SPAN 1.00 MHz
SWP 20.0 msec

NO. 4

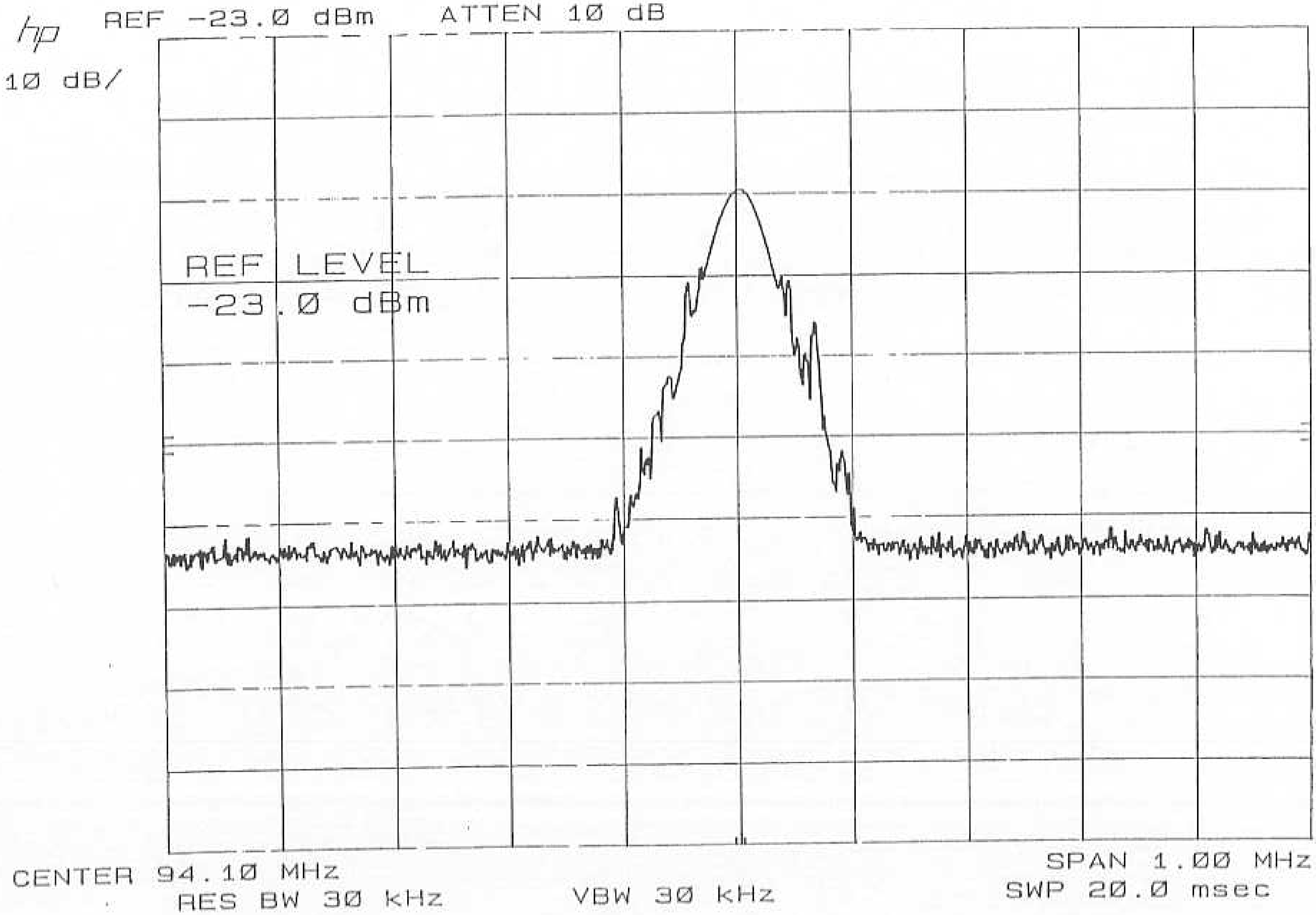


hp
REF -19.1 dBm
ATTEN 10 dB
MKR 94.093 MHz
-41.50 dBm
10 dB/
SPAN
1.00 MHz
CENTER 94.10 MHz
RES BW 30 kHz
VBW 30 kHz
SPAN 1.00 MHz
SWP 20.0 msec

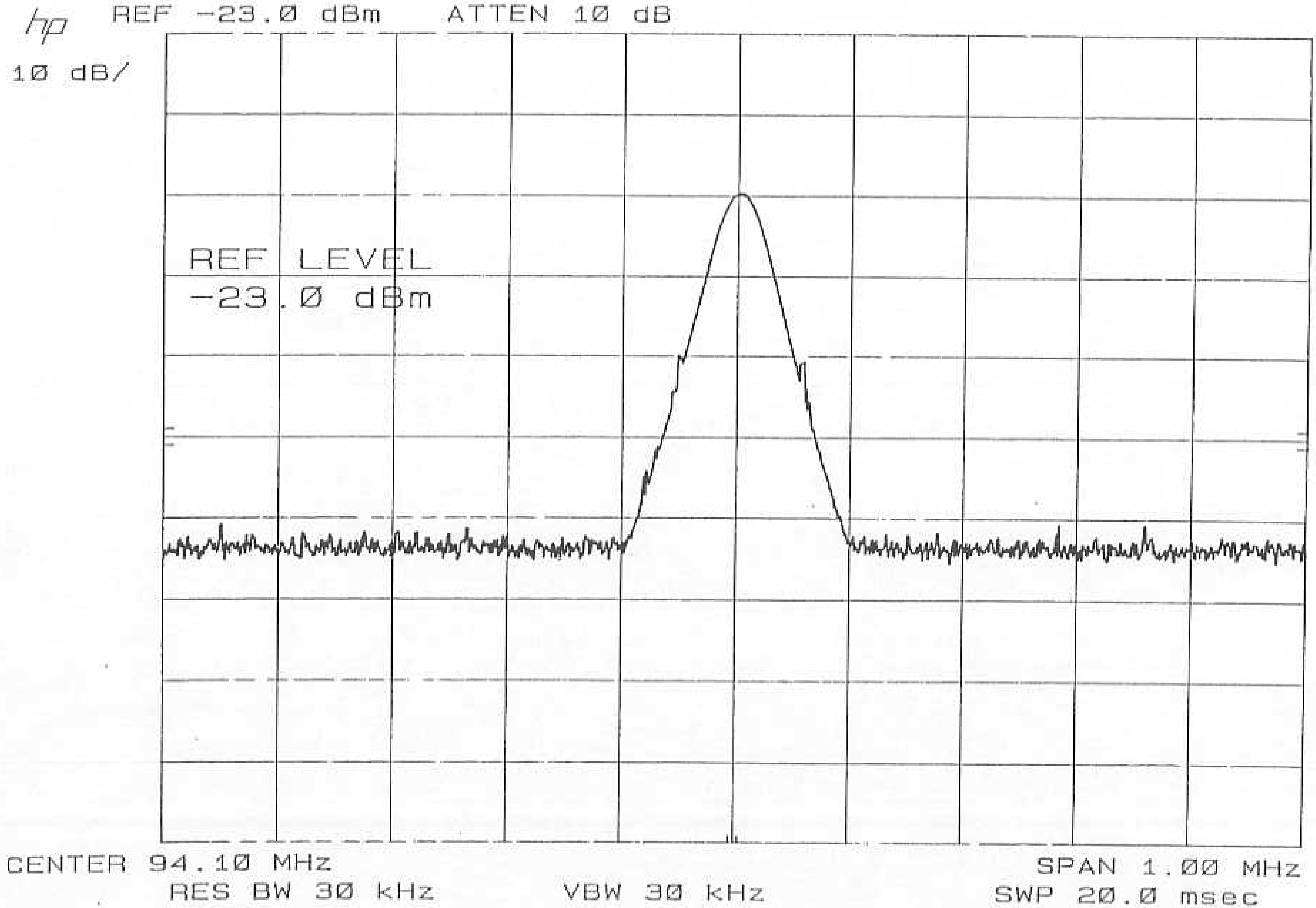
NO. 5


hp
REF -23.Ø dBm ATTEN 1Ø dB
1Ø dB/
REF LEVEL
-23.Ø dBm
CENTER 94.1Ø MHz
RES BW 3Ø kHz
VBW 3Ø kHz
SPAN 1.ØØ MHz
SWP 2Ø.Ø msec

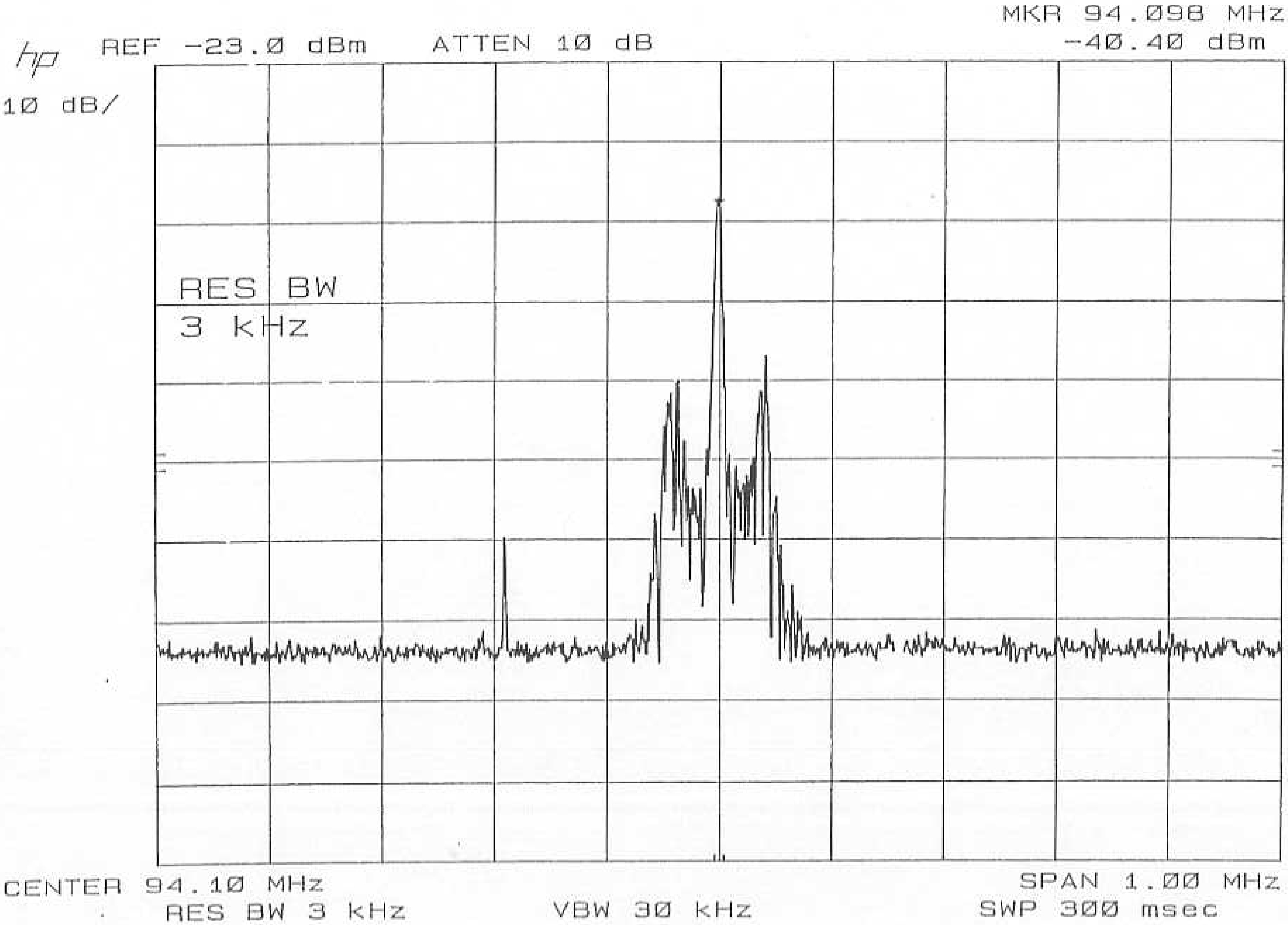
NO. 6


hp
REF -23.0 dBm ATTEN 10 dB
10 dB/
REF LEVEL
-23.0 dBm
CENTER 94.10 MHz
RES BW 30 kHz
VBW 30 kHz
SPAN 1.00 MHz
SWP 20.0 msec

NO. 7

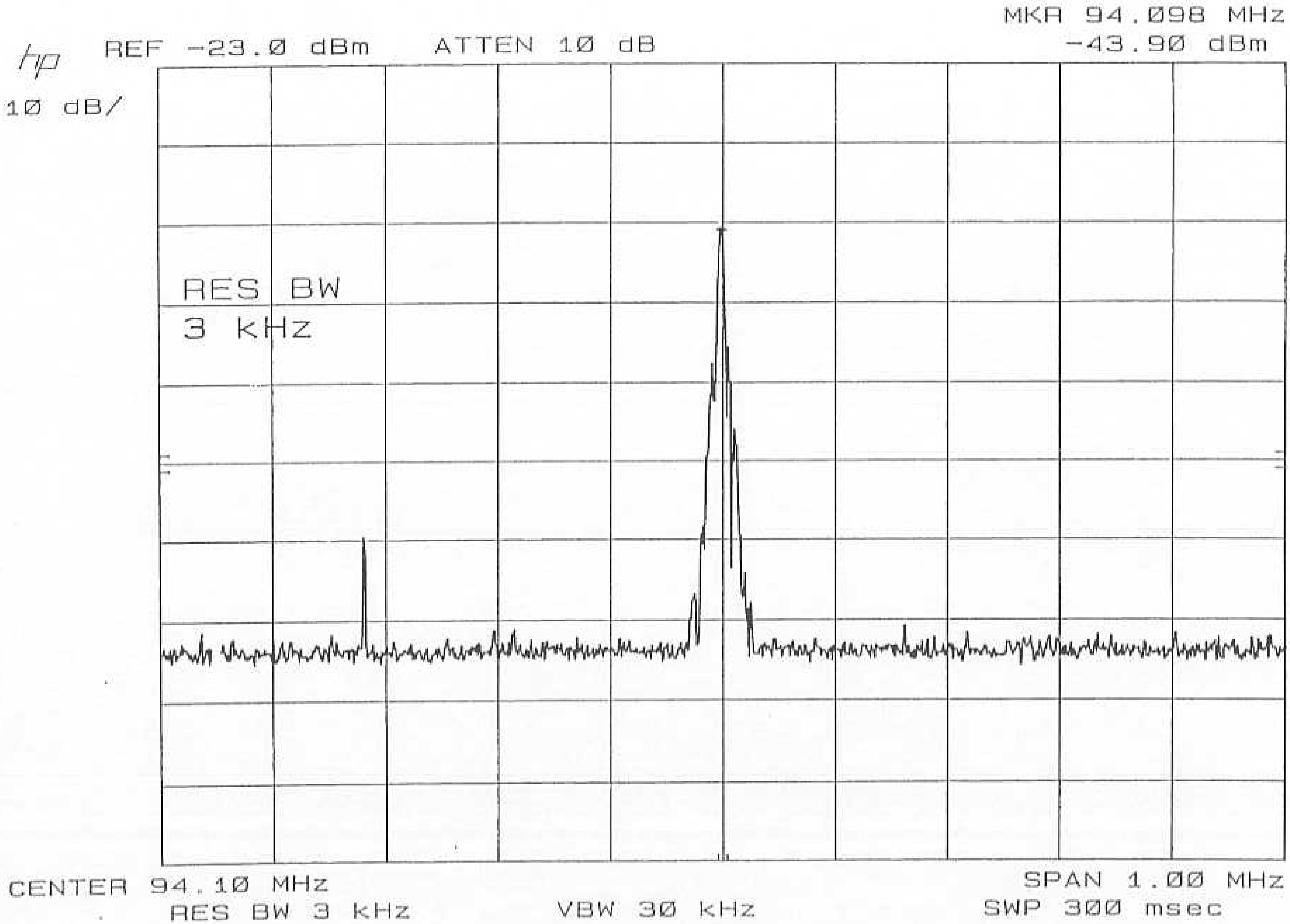

hp
REF -23.0 dBm ATTEN 10 dB
10 dB/
REF LEVEL
-23.0 dBm
CENTER 94.10 MHz
RES BW 30 kHz
VBW 30 kHz
SPAN 1.00 MHz
SWP 20.0 msec

NO. 8

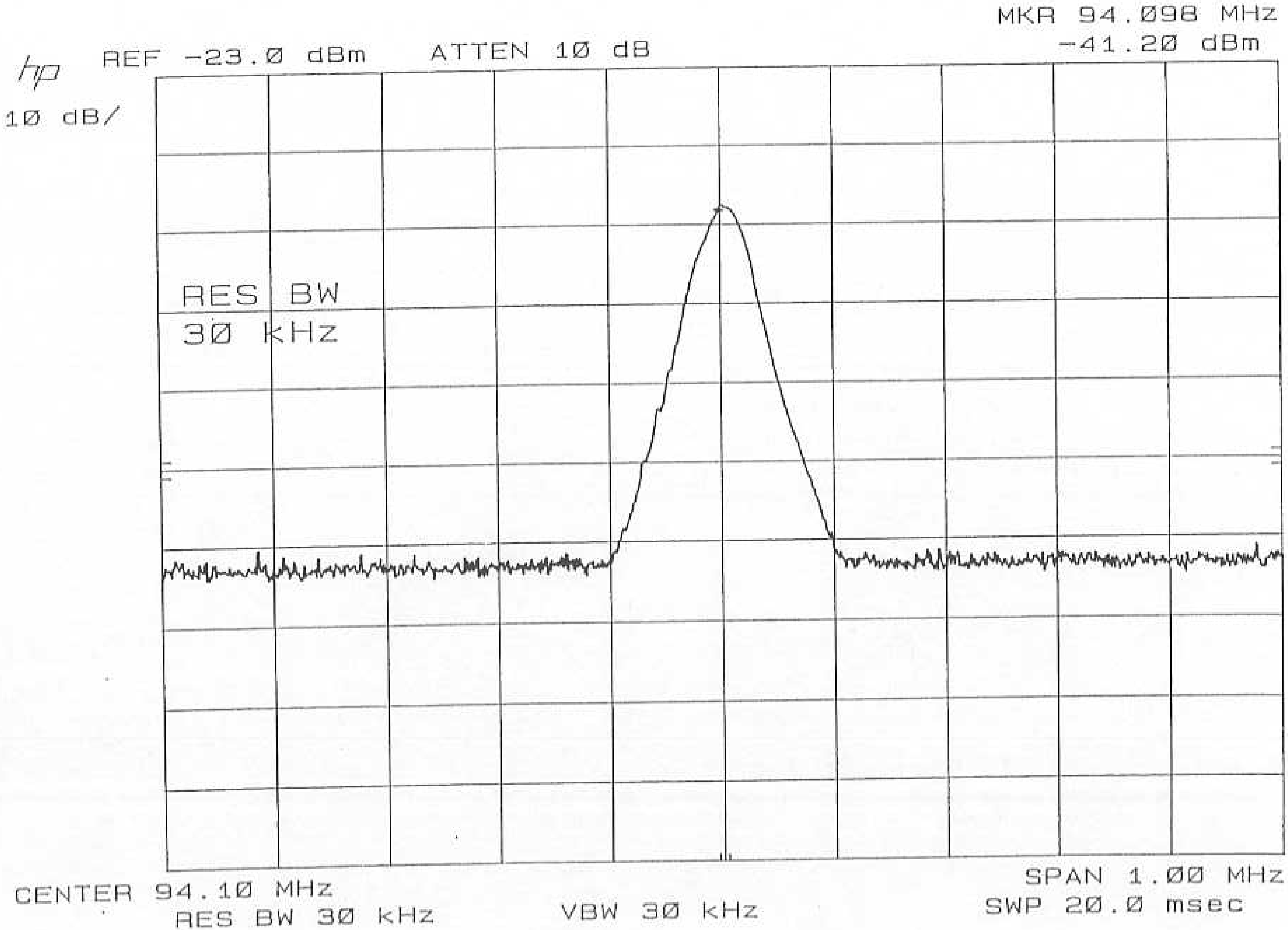


MKR 94.098 MHz
-40.40 dBm
hp REF -23.0 dBm ATTEN 10 dB
10 dB/
RES BW
3 kHz
CENTER 94.10 MHz
RES BW 3 kHz
VBW 30 kHz
SPAN 1.00 MHz
SWP 300 msec

NO 9

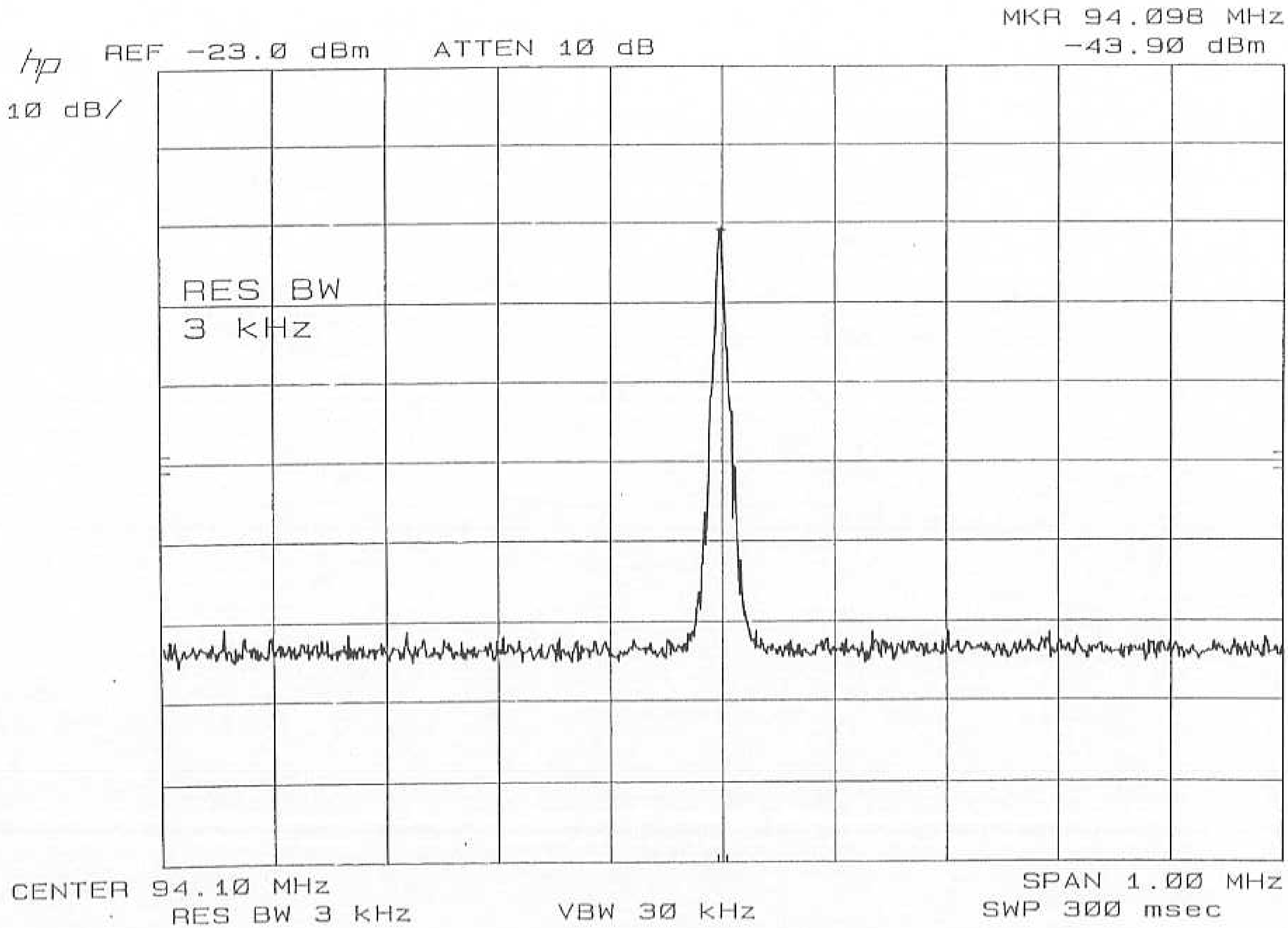

MKR 94.098 MHz
-43.90 dBm
REF -23.0 dBm
ATTEN 10 dB
10 dB/
RES BW
3 kHz
CENTER 94.10 MHz
RES BW 3 kHz
VBW 30 kHz
SPAN 1.00 MHz
SWP 300 msec

NO. 10



hp
REF -23.0 dBm
ATTEN 10 dB
MKR 94.098 MHz
-41.20 dBm
10 dB/
RES BW
30 kHz
CENTER 94.10 MHz
RES BW 30 kHz
VBW 30 kHz
SPAN 1.00 MHz
SWP 20.0 msec

NO 11


MKR 94.098 MHz
-43.90 dBm
hp
REF -23.0 dBm
ATTEN 10 dB
10 dB/
RES BW
3 kHz
CENTER 94.10 MHz
RES BW 3 kHz
VBW 30 kHz
SPAN 1.00 MHz
SWP 300 msec

APPENDIX L

APPENDIX L - DISCUSSION OF APPROPRIATENESS OF DOPPLER VS. RAYLEIGH CHANNEL CHARACTERISTICS

L-1 Letter from Jeffrey Andrew, USADR, Inquiry 9/6/94 Through Letter Ralph Justus, EIA Response 10/10/94 (6 Items)

L-2 Letter from Jeffrey Andrew, USADR, Further Inquiry 10/25/94 Through Letter Ralph Justus, EIA Response 11/12/94 (4 Items)

2313 Blackthorn Drive
Champaign, IL 61821

September 1, 1994

Mr. Jeffrey S. Andrew
USA Digital Radio
332 South Michigan Avenue
Suite 600
Chicago, Illinois 60604

Dear Mr. Andrew:

I am writing this letter to express my concerns regarding the proposed multipath evaluation of the FM-1 IBOC DAB system by the EIA at the Cleveland, Ohio test site. The scarcity of technical data on the characteristics of the VHF channel necessitates that an accurate VHF channel multipath simulation be used, which is based upon experimental data, not a mathematical model. In concept, the original plan submitted by the EIA fulfilled this goal by accurately mapping the channel impulse response over real terrain. However, there has apparently been limited success in replicating this data on the Hewlett Packard emulator. These difficulties have caused the EIA to abandon the previously agreed upon approach and adopt a significantly different methodology. The current proposed approach, as outlined in the July 29, 1994 memorandum of Robert Culver, is based in large part on Rayleigh model data, which has not yet been shown to be adequate or relevant to the mobile VHF channel. Furthermore, the characteristics of the GSM 900 MHz Rayleigh distribution have been essentially used unperturbed for the VHF model, other than being frequency translated. This action implies that path loss, scattering and other parameters are being considered as independent of frequency, which is unlikely.

During a phone conversation between myself and Tom Keller on August 31, I was informed that the multipath simulations are being conducted by choosing "averaged" reflector rays from specific groups of frames of the acquired terrain data. This data is being used in conjunction with arbitrary vehicle speeds to control the amplitude and delay of the channels in the Hewlett Packard emulator. Uncorrelated Rayleigh distributions are then being used to provide fading profiles, effecting both amplitude and differential Doppler. This is, at best, an ad hoc procedure, loosely based upon experimental data. Furthermore, the approach neglects to comprehend certain essential characteristics of physical multipath. Clusters of strong reflectors are prevalent in the EIA data, some of which are caused by apparent peak-splitting in the analysis algorithm. Close clusters of reflectors with little attenuation should show some correlation because the differential Doppler spread must also be limited. The proposed approach ignores this, using uncorrelated rays. As a direct result, the simulations exhibit extensive deep fades, which are illustrated in the videotape. These fades penalize IBOC systems as a whole, implying that the lack of sufficient field strength (shadowing) is responsible for most multipath impairment. The USADR field tests have not corroborated the existence of these fades, even in the intense multipath in Chicago, which is more pronounced than Salt Lake City. The rural highway data shown on the videotape is particularly compelling, showing many rapidly varying 30+ dB broad fades, which seems contrary to physical intuition.

It is not clear that it is possible to legitimize the proposed technique by introducing correlation between rays. It would appear that the choice of channel model is based not only on the channel characteristics, but the expected receiver implementation as well. Receivers which do not employ adaptive equalization cannot distinguish between specular and diffuse multipath. Multipath impairment in such systems tends to act as clutter of various amplitudes. However, in an equalized system, the adaptive equalizer can typically mitigate deterministic specular multipath, but achieves little gain over probabilistic clutter. Hence, the proposed channel model emulates specular multipath as simply large amplitude clutter, which is a direct consequence of using Rayleigh distributions on all rays. This will compromise the performance of a receiver which relies upon the adaptive equalizer. Probabilistic clutter can only be mitigated with wide bandwidth or heavy coding.

Without an accurate VHF channel representation, it is difficult to draw meaningful conclusions about the performance of the various systems in multipath, based on laboratory simulations. A proponent system may appear more robust simply because a higher level of coding, better RF sensitivity or increased interleaver depth was chosen. This does not imply that such a realization is optimal or even adequate in the dynamic mobile environment nor that it is suitable for economical integration. At this point, I believe that the burden of proof is on the EIA to demonstrate that the proposed approach will yield realistic multipath data. However, I am willing to provide what assistance I can. Specifically, I would be able to provide a more complete analysis if I had access to a specific set of multipath parameters that are identical or substantially similar to a set being used in the EIA tests. This would at least permit me to try and establish some relationship between the USADR field test results and the EIA data.

Regardless of the outcome, it seems likely that the deficiencies of the current procedure will make field testing of the proponent systems assume a role of primary importance in overall evaluation.

Sincerely,

Derek D. Kumar

Appendix 2

USA DIGITAL RADIO

S 1994

September 6, 1994

Mr. Ralph Justus
Director of Engineering
Electronic Industries Association
2001 Pennsylvania Ave. NW
Washington, DC 20006-1813

Dear Ralph,

This letter is to formally advise you of a grave concern which USADR has regarding the introduction of new unsubstantiated and arbitrary multipath data into the DAR testing process at this late a date.

From the onset of the data gathering, USADR, the EIA, and NRSC, along with all of the test proponents have always stressed the importance of using real world test data to be programmed in the HP Simulators. IBOC DAB Systems are designed to function in a real world, within existing spectrum. Now it seems once again we have discounted the "real world data" for some theoretical Rayleigh model which is inconsistent with our previous models. These new settings invalidate all of the months of previous data gathered by these committees and USADR, which decidedly clouds the viability of the entire EIA/NRSC DAR testing process.

Enclosed is a letter from Derek Kumar ,our new RF Project Manager, stating technically why we feel these arbitrary test parameters are invalid and will not stand up to any outside scrutiny. Also how this new test data is not only unsubstantiated and capricious, but it goes against everything we have striven to validate in our combined efforts up to now. Unfortunately, we somehow were omitted from receiving the meeting notice on July 19th, where all of these changes were apparently approved, or we would have objected sooner.

I realize that some of the testing is far behind schedule and we have been vacillating on this multipath data forever. The fact of the matter is that substantial resources have been spent by the EIA, the NRSC and proponents to gather valid data to be used in the multipath testing process. This data has been accepted by the testing process and is representative of real world conditions. To use anything else at this juncture would invalidate years of work and effort by the EIA, and NRSC, and I feel it would be very detrimental to the overall testing.

We would like to be of any help we can to help solve this situation in a manner that is fair to all the proponents as usual, and to keep the testing schedule somewhat on track. Please feel free to contact me with any further questions about our concerns.

Truly Yours,

Jeff Andrew

Jeff Andrew
Interim Managing Director

CC Dan Ehrman

L-1.3

TIA/EIA/IS-55-A

TIA/EIA
INTERIM STANDARD

Recommended Minimum Performance Standards of 800 MHz Dual-Mode Mobile Stations

TIA/EIA/IS-55-A

(Revision of EIA/TIA/IS-55)

SEPTEMBER 1993

TELECOMMUNICATIONS INDUSTRY ASSOCIATION

TELECOMMUNICATIONS INDUSTRY ASSOCIATION

Representing the telecommunications industry
in association with the Electronic Industries Association

6.6.2.6 Standard BER /WER Test Equipment

(a) Data Generation: It shall be capable of generating pseudo-random bit stream that is interleaved and built into time slots in accordance with IS-54 1.2.

(b) Data Reception: It shall be capable of receiving the data in time slot format. Data from the user channel will be de-interleaved for comparison to the original pseudo-random bit stream.

(c) BER shall be measured up to rates of 40%.

(d) WER shall be measured up to rates of 100% provided BER is less than 40%.

6.6.2.7 Reserved

6.6.2.8 Standard Protocol Test Equipment

The Standard Protocol Test Equipment shall have the necessary signallin and protocol capability to perform:

(a) Call origination and Mobile Station paging

(b) Handoffs within digital or analog modes and across mode boundries

(c) Time alignment tests

(d) Mobile Assisted Handoff tests

6.6.2.9 Standard Channel Simulator

Measurements requiring the Standard Channel Simulator will be performe at Channel 367, at a nominal Mobile Station receive center frequency ‹ 881.010 MHz and a nominal Base Station receive center frequency ‹ 836.010 MHz.

The maximum Doppler frequency referred to in this section is a function ‹ the receive center frequency of the unit under test and the simulated vehic speed, as follows

$$f_d = \left(\frac{v}{c}\right) f_c$$

where v is simulated vehicle speed, c is 2.997925×10^8 m/s, the speed light in vacuum, and f_c is 881.010 MHz for Mobile Stationtesting a 836.010 MHz for Base Station testing. The table below gives t corresponding values of v and f_d.

Vehicle speed (km/h)	MS f_d (Hz)	BS f_d (Hz)
8	6.531	6.197
50	40.816	38.731
100	81.631	77.462

The Standard Channel Simulator shall at a minimum be capable of the following:

(a) RF input and output center frequencies between 800 and1000 MHz.

(b) Simulate a flat fading channel for simulated vehicle speeds varying from 8 to 100 km/h. Specifically for 8, 50, and 100 km/h (nominally 5, 30 and 60 mph).

(c) Simulate two rays with independent fading statistics. Each Rayleigh faded ray shall have a time delay of up to 1 symbol (41.2 µsec) with delay resolution of 0.1 µsec.

(d) Have sufficient bandwidth to accommodate co-channel and adjacent channel measurements. The passband characteristics of the channel simulator shall not degrade the modulated signal as specified in 3.3.2.

Generation of the Rayleigh fading conditions shall conform to the following (all measurements shall hold for simulated vehicle speeds of 8km/h to 100km/h upon an unmodulated carrier):

(a) The measured Rayleigh Cumulative Probability Distribution Function (CPDF) shall be compared against a calculated CPDF. The calculated Rayleigh CPDF, F(P), is as follows:

For $P < 0$: $F(P) = 0$; For $P \geq 0$: $F(P) = 1 - \exp\{-P/P_{ave}\}$. where P is the signal power level and P_{ave} is the mean power level.

(1) Measured CPDF of power shall be within ±1 dB of the calculated CPDF of power for 10 dB above the mean power level to 20 dB below the mean power level.

(2) Measured CPDF of power shall be within ±5 dB of the calculated CPDF of power for 20 dB below the mean power level to 30 dB below the mean power level.

(b) The Level Crossing Rate (LCR) shall be compared against a calculated LCR. The calculated Rayleigh LCR, L(P), is as follows:

For $P<0$: $L(P) = 0$; For $P \geq 0$: $L(P) = (2\pi P/P_{ave})^{0.5} \cdot f_d \exp\{-P/P_{ave}\}$, where P is the signal power level, P_{ave} is the mean power level, and f_d is the Doppler frequency offset ssociated with the simulated vehicle speed.

(1) The measured LCR curve shall not deviate from the calculated LCR curve by more than ±10% of the simulated vehicle speed. This shall hold for 3 dB above the mean power level to 30 dB below the mean power level.

(c) The measured power spectral density, S(f), shall meet the requirements specified below. The power spectrum measurement shall be made on an unmodulated carrier (at frequency f_c) applied to the input of the channel simulator.

(1) The maximum power spectral density level, S_{max}, shall exceed $S(f_c)$ by at least 6 dB.

(2) The simulated Doppler frequency offset, f_d, shall be within ±5% of the theoretical Doppler frequency offset associated with the vehicle speed. The simulated Doppler frequency offset shall be calculated from the measured power spectral density as follows:
$f_d = (1/2\pi)\,(2b_2/b_0)^{0.5}$,

where $b_n = (2\pi)^n \int_0^{\infty} S(f)\, f^n\, df$.

b_n is the n^{th} moment of $S(f)$.

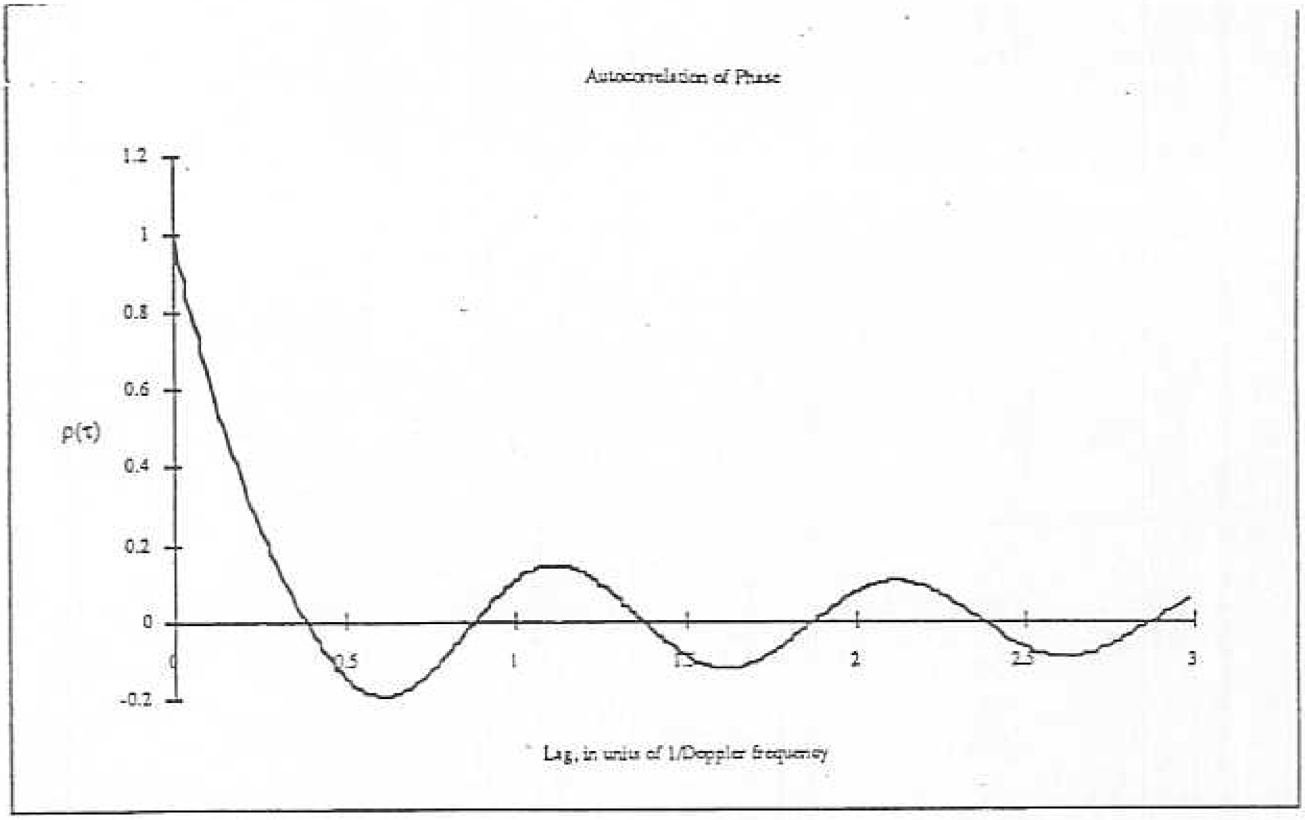
(3) $S(f)$ shall be at least 30 dB below $S(f_c)$ for $|f-f_c| > 2f_d$.

(d) The autocorrelation function of the unwrapped phase of the simulated, received signal shall be compared against the calculated theoretical autocorrelation function of the phase of a Rayleigh faded signal. The theoretical autocorrelation, $\rho(\tau)$, is well approximated by

$$\rho(\tau) = \frac{3}{2\pi}\sin^{-1}(J_0(2\pi f_d\tau)) + 6\left\{\frac{1}{2\pi}\sin^{-1}(J_0(2\pi f_d\tau))\right\}^2$$

$$-\frac{3}{4\pi^2}\sum_{n=1}^{\infty}\frac{(J_0(2\pi f_d\tau))^{2n}}{n^2}$$

(1) The measured autocorrelation function of the phase shall be 0.8 ±0.1 at a lag of $0.05/f_d$, and 0.5±0.1 at a lag of $0.15/f_d$. The theoretical curve is shown in the figure below.



6.7 Standard Duty Cycle

The Mobile Station equipment may be rated as either continuous or intermittent.

6.7.1 Continuous

The transmitter shall be capable of operating continuously at full rated power for a period of 24 hours. The equipment shall operate with all specified transmitter and receiver performance parameters being met during and after the 24 hour period.

6.7.2 Intermittent

Intermittent duty is full load (maximum transmitter output power) under the manufacturer's normal recommended loading conditions for this class of service using a cycle of ten minutes on and thirty minutes standby for a period of eight hours. The equipment shall operate with all specified transmitter and receiver performance parameters when continuous duty operation is attempted or the equipment shall shut itself off.

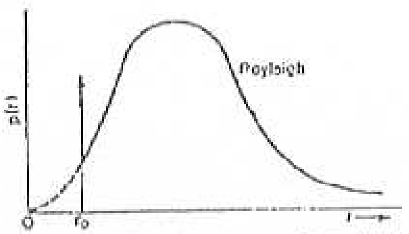


Fig. 7-10 Plot of a truncated Rayleigh curve at r_0.

Substituting Eq. (7-96) and Eq. (7-97) into Eq. (7-90) gives the following:

$$N_+ = N_- = \frac{\nu_a^2}{\sigma_n^2}\frac{1}{8\pi(\sigma^2/\sigma_n^2)}\left\{\operatorname{erfc}\left[\frac{1}{\sqrt{2}}\left(\frac{r_0}{\sigma}\right)\left(\frac{\sigma}{\sigma_n}\right)\right]\right.$$

$$\left. + \sqrt{\frac{2}{\pi}}\left(\frac{r_0}{\sigma}\right)\left(\frac{\sigma}{\sigma_n}\right)e^{(-1/2)(r_0/\sigma)^2(\sigma/\sigma_n)^2}\right\} \qquad (7\text{-}98)$$

where erfc ( ) is the complementary error function. Equation (7-98) involves σ^2/σ_n^2, which represents the carrier-to-noise ratio (cnr), defined:

$$\text{cnr} = \frac{\sigma^2}{\sigma_n^2} \qquad (7\text{-}99)$$

The relationship of Eq. (7-98) is plotted in Fig. 7-11 for specific values of r_0/σ.

7.5 SIMULATION MODELS

Many radio-propagation models have been proposed that can be used to predict the amplitude and phase of radio signals propagated within a mobile-radio environment [8–20]. These models can be classified into two general categories. The first category deals only with multipath-fading phenomena, whereas the second category deals with both multipath- and selective-fading phenomena. The following paragraphs describe some of the features associated with these two general categories of simulation models.

Rayleigh Multipath Fading Simulator

Based on analyses of the statistical nature of a mobile fading signal and its effects on envelope and phase, a fading simulator can be configured either from hardware or a combination of hardware and software. Figure 7-12 shows a simple hardware configuration for a Rayleigh multipath fading simulator that consists of two gaus-

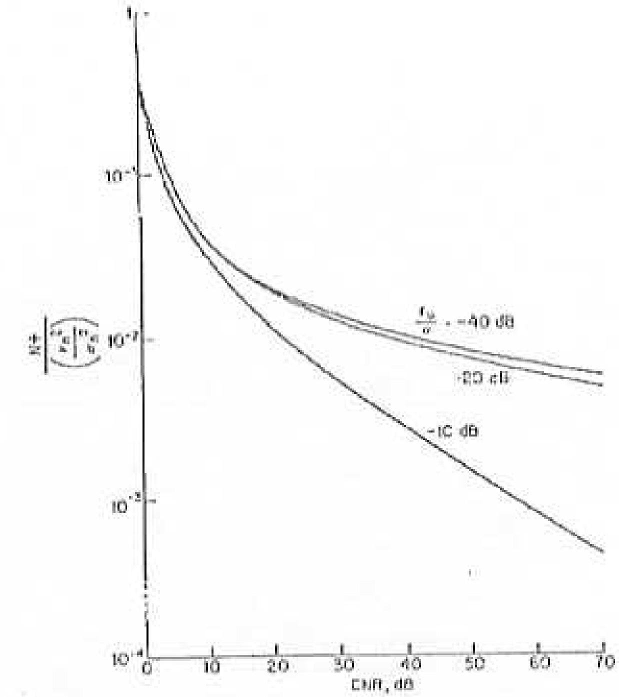


Fig. 7-11 Plot of average positive click rate N_+.

sian noise generators (GNG), two variable low-pass filters (VLPF), and two balanced mixers (BM). The cutoff frequency of the low-pass filter is selected on the basis of the frequency f_0 and the assumed average speed of the mobile vehicle V. The output of the simulator represents the envelope and phase of a Rayleigh-fading signal.

In a software-configured simulator [10], the model described in Sec. 6.2 is based upon, and Eqs. (6-10) through (6-13) are used to simulate, a Rayleigh-fading signal. In both Eq. (6-11) and Eq. (6-12), there are N gaussian random variables for R_i and S_i. Each of them has zero mean and variance one. Since a uniform angular distribution is assumed for N incoming waves, we let $\phi_i = 2\pi i/N$. The direction α of the moving vehicle can be set to $\alpha = 0°$ without loss generosity. The sampling interval $\Delta t = t_0/k$ can be set as small as $\Delta t = \lambda/(10V)$, i.e., 10 sampling points in every wavelength in space. On the basis of the preceding changes, Eq. (6-11) can be then expressed as

$$X_i = \sum_{i=1}^{N=n} \left[R_i \cos\left(k\frac{2\pi}{10}\cos\phi_i\right) + S_i \sin\left(k\frac{2\pi}{10}\cos\phi_i\right)\right] \qquad (7\text{-}100)$$

where the spacing between the samples is $\Delta t = \dfrac{\lambda}{10V}$, and

$$\phi_i = \frac{2\pi i}{N}$$

A similar formula for Y_k can be obtained from Eq. (6-12). With both X_k and Y_k calculated at any kth sample point, a Rayleigh envelope $r_i = (X_i^2 + Y_i^2)^{1/2}$ is simulated. For our demonstration, a frequency of 820 MHz and $V = 15$ mi/h are given, the sampling interval is $\Delta t = 0.00545$ s, and the simulated fading signal is shown in Fig. 1-17. Another similar software configuration simulation is shown by Smith [19]. The main advantage in a software-configured simulator is the ability to quickly change the operational parameters by merely making changes in the software program.

Multipath- and Selective-Fading Simulator

A simulator of multipath and selective fading can also be configured either from hardware or a combination of hardware and software. The hardware version uses an arrangement of components similar to those shown in Fig. 7-12; the components are duplicated several times, and a delay line is added to each assembly [21]. The number of assemblies and delay lines is determined by the kind of environment that is being studied. The several delayed output signals from the Rayleigh-

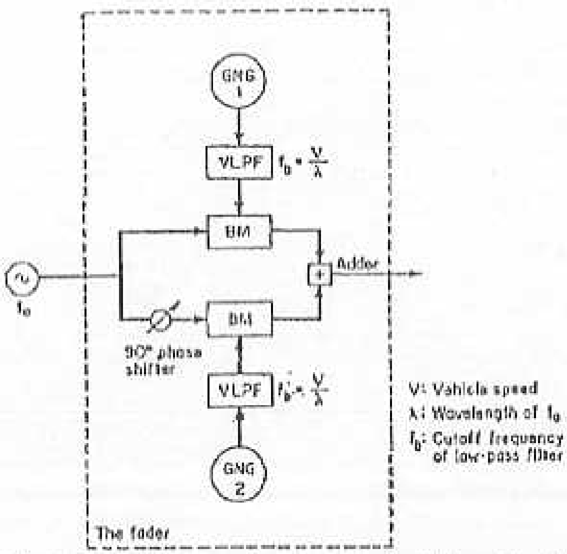


Fig. 7-12 Hardware configuration of a Rayleigh multipath-fading simulator.

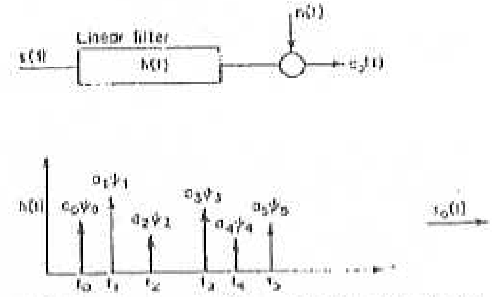


Fig. 7-13 Mathematical model for multipath- and selective-fading simulation.

fading simulators are summed together to form a multipath- and selective-fading signal.

The software version [13, 17] is based on a model developed by Turin [17], in which the mobile-radio channel is represented as a linear filter with a complex-valued impulse response expressed:

$$h(t) = \sum_{k=0}^{\infty} a_k \delta(t - t_k) e^{j\psi_k} \tag{7-101}$$

where $\delta(t - t_k)$ is the delta function at time t_k, and ψ_k and a_k are the phase and amplitude, respectively, of the kth wave arrival. The terms a_k, ψ_k, and t_k are all random variables. During transmission of a radio signal $s(t)$, the channel response convolves $s(t)$ with $h(t)$. Figure 7-13 shows the mathematical simulation generated by the software for this model [14]. The simulator enables evaluation of mobile-radio system performance without the need for actual road testing, since it simulates the propagation medium for mobile-radio transmissions.

PROBLEM EXERCISES

1. A mobile unit is traveling at a speed of 40 km/h while receiving a mobile-radio transmission at a frequency of 850 MHz. Assuming that the time-delay spread for the medium is 0.5 μs, what is the correlation coefficient for a frequency change from 850 MHz to 850.1 MHz in a time interval of 0.1 s?
2. If the time-delay spread is measured and found to be 3 μs and the required phase correlation coefficient is 0.5, what is the coherent bandwidth for a time delay of $\tau = 0$?
3. Which parameter has the greater effect on a random FM signal, velocity or audio band? If the upper limit of the audio band is increased from 10 to 20 times over the lower limit, how much of a reduction in vehicle speed is required to maintain the same random FM level?

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Via Overnight Delivery

October 11, 1994

TO: DAR System Proponents

FROM: Ralph Justus, Director of Engineering

RE: Decisions of Steering Committee Meeting of October 7, 1994

On Friday, October 7, 1994, the Joint Steering Committee of the DAR and DAB Subcommittees met by teleconference to consider the following matters: (1) USADR equipment changes; and, (2) multipath parameters. The following reports the results of its deliberations. Please inform me should you have any questions or comments.

(1) Responding to the laboratory staff's inquiries about the USADR FM inability to perform under intermittent weak signal conditions, USADR modified its FM-1 equipment as shown in the enclosed documentation from Jeffrey Andrew (Appendix 1), which improved the system's sensitivity. The Steering Committee met to consider this change and decided that this was not perceived to be a material change but, rather, a modification of the RF front end not necessarily coupled with improvements of the overall characterization of the system. However, they suggested that all other proponents be notified of this occurrence, and solicit their comments, if any.

(2) The "smoothing" of the Direct Control method of generating multipath has met obstacles. Accordingly, it is difficult to use that method for tests C-6 as decided at the September 20th Subcommittees meetings. Employment of multipath for tests C-6, E, I, J, and M-2 was imminent and a quick decision was needed on how best to proceed. Test B-3 had been completed on all systems except USADR FM-1 and FM-2 pending resolution of their weak signal performance problems. Those tests are now nearing completion.

Using the simulation mode with Rayleigh fading ("Sim+Ray") resulted in marginally useful data on the USADR FM-1 and FM-2 systems. Further, USADR continues to express concerns about the reasonableness of using Rayleigh fading in simulating multipath. See enclosed correspondence from Jeff Andrew (Appendix 2) and response from Ralph Justus (Appendix 3).

The Steering Committee considered these matters and decided to complete the Sim+Ray testing underway, and expand the multipath testing scenarios for tests C-6, E, I, J, L and M to use the simulation mode without Rayleigh fading ("Sim-Ray") for all systems, as appropriate (excluding second modes). See the enclosed chart from Tom Keller (Appendix 4) where Sim+Ray is designated "R" and Sim-Ray is designated "D." This was deemed the best course of action even though it may increase testing by approximately 2-1/2 weeks (which we will attempt to minimize). Should a potential challenge to the testing procedures occur about the appropriateness of incorporating Rayleigh fading into the simulation, Sim-Ray test results will be available on all appropriate systems for comparisons.

Should you have any questions, concerns or comments on these decisions, please inform me at your earliest convenience.

Enclosures (4)

cc: Joint Steering Committee

Appendix 4

Additional Multipath Tests with Doppler Spectrum Mode

	AT&T	Amati Mode 1	Amati Mode 2	FM-1	FM-2	E-147 Mode 1	E-147 Mode 2	VOA/JPL
C-6 Additional MP & Noise	D	D	D	D	D	D	D	NA
E-1,2,&3 DAR -> DAR with MP	D Added (Mode R is complete)	D Added (Mode R is complete)	No Added Mode	R/D (Mode D is added)	R/D (Mode D is added)	D Added (Mode R is complete)	No Added Mode	NA
I-1,2,3,4,& 5 Analog -> Digital with MP	D Added	D Added	No Added Mode	R/D (Mode D is added)	R/D (Mode D is added)	NA	No Added Mode	NA
J-2 Reacquisition with MP	D Added (Mode R is complete)	D Added (Mode R is complete)	No Added Mode	R/D (Mode D is added)	R/D (Mode D is added)	D Added (Mode R is complete)	No Added Mode	D Added (Mode R is complete)
L-4 IBOC -> Analog Host with MP	NA	D Added	No Added Mode	R/D (Mode D is added)	R/D (Mode D is added)	NA	No Added Mode	NA
M-2 Host analog -> to IBOC with MP	NA	D Added	No Added Mode	R/D (Mode D is added)	R/D (Mode D is added)	NA	No Added Mode	NA

Two and a half additional weeks

D - Multipath simulation will operate in the Doppler Spectrum Mode.

R - Multipath simulation will operate in the Rayleigh Spectrum Mode.

October 11, 1994

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Appendix 3

VIA Overnight Delivery and Facsimile (312) 427-7410

October 10, 1994

Mr. Jeffrey S. Andrew
Project Manager
USA Digital Radio
332 South Michigan
Suite 610
Chicago, IL 60604

Re: USADR letter of September 7, 1994

Dear Jeff,

I have conferred with members of the Channel Characterization Task Group about the concerns expressed in your letter of September 7, 1994 (with September 1, 1994 letter from Derek D. Kumar attached), and present below their analysis. In short, the critical multipath testing parameters are believed valid and representative of what occurs in the RF environment. Responding to your concerns, the DAR and DAB Subcommittees decided at their September 20 meetings to continue the "smoothing" process on the direct control data for simulation and, if possible, incorporate that into the C-6 (other multipath) tests.

Rayleigh Fading The present tests use the Rayleigh fading model to generate testing data. This is a standard and well-accepted method for testing. Other mathematical models, like Gaussian distribution which does not relate well to multipath characteristic distribution, could cause the simulator to generate situations not found in nature. The Rayleigh distribution does not cause unrealistic conditions, the results are a close match to real-life situations throughout the entire range of operation. This is because it is based on the random combinations of two reflectors - it is very intuitive. Its application to multiple reflectors in a variety of spectrums has been proven many times. In its general form, it is not frequency dependent, and will always determine the behavior limit. (Kenneth Bullington, Radio Propagation for Vehicular Communications, IEEE Transactions on Vehicular Technology, Vol. VT-26, No. 4 Nov. 1977) (For an excellent general discussion of the Rayleigh derivation, see William C.Y. Lee's book Mobile Communications Engineering, Chap 6.) Rayleigh fading is applied to the RF channel simulator control data but not at 900 MHz. The Rayleigh distribution is independent of frequency. It is applied to various simulator parameters, including attenuation and Doppler frequency. The average attenuation values are determined from the measured channel characteristics, not scaled from data at any other frequency. The Doppler must be set to a proper range of values to correspond to estimated vehicle speed and the RF frequency in use.

Kumar paragraph 2 The Memorandum from Robert Culver dated August 22, 1994 "Derivation of Multipath Simulation" shows the justification of the vehicle speeds chosen for each multipath environment. They have been carefully designed and chosen. Similarly, the simulation mode of the HP simulator has a significant history, as well as a strong following in the receiver industry. **[Ties to our experimental data?]** Peak-splitting, as we understand the term, no longer occurs with the new reflector-selection algorithm designed by Mike Guile this past Spring. Once a reflector is chosen, the two neighboring reflectors are set to zero, and are no longer considered for selection.

Correlation The Kumar letter at paragraph 3 provides a discussion of multipath from a receiver point of view. This is not relevant since the tests have been designed from a channel perspective. We have employed the most widely-accepted model in industry which will give an accurate predication of the kind of RF obstacles a receiver must overcome when presented with the harsh broadcast environment. This is the challenge of an IBOC system: to perform sufficiently well in the real RF environment without the advantages of "wide bandwidth or heavy coding." The laboratory tests are designed to examine system performance in this area. The channels of the multipath simulator are un-correlated; the reflection parameters change independent of each other since they represent separate reflectors. Hence, the Rayleigh fading characteristics impressed upon the parameters are not assigned a correlation factor - one of the options of the HP simulator. (The correlation capability of the HP simulator is intended to test situations where received signals are correlated, primarily by diversity receive systems. This use is specifically stated in the HP manual.) The chance of finding correlated reflectors in nature, at least ones which remain correlated over any significant area of a few meters or more, is extremely unlikely. One would have to envision an unlikely scenario, such as reflections from two adjacent mountain faces many kilometers distant which do not change much relative to each other (correlated) over a finite movement of a receiver. Generally, any very small movement of a receiver creates large differential changes in the path geometry and, hence, channel parameters, to the individual reflectors. The width of any multipath fade is controlled by the total path length difference between the direct and the reflected paths; short delays create wide fades, longer delays create narrower fades. The depth of fades is controlled by the relative amplitude and phase between the various signals. Individual fades can get deeper or shallower quickly with changing phase (i.e., small movements) or slowly with changing magnitudes or reflections. Fade width and the frequency of the center of the fade can change relatively slowly with total path delay, phase included. With changing parameters the fades will move in frequency, depth and slowly in width. Two or more fades, otherwise separate in frequency, will move in frequency (with changing receiver position and hence channel parameters) to eventually overlay each other. At any particular frequency the multipath signals previously generating two frequency separate fades, now come together to combine into one composite signal in the receiver generating one fade. The result is the sum of the various amplitudes at their respective phases and delays which generates a new fade of changed shape. The fade is different primarily in the amplitude of the signal with the width of the fade predominated by the wider of the two or more original fades (at this frequency). As the parameters continue to change the formerly independent fades will begin to reappear, first as a distorted fade, then as a double dip fade as they partly overlay each other, then as two or more separate fades.

I share your concerns that we not invalidate all the previous efforts to design system testing parameters. However, your characterizations that we have somehow embarked on an "unsubstantiated and capricious" path are without merit. The Subcommittees have labored long and hard, with extensive documentation, to arrive at appropriate multipath testing parameters and those deliberations have been opened to all (including system proponents) wishing to participate. Our intent has been to devise appropriate multipath test parameters that fairly stress DAR systems' performance which can then be used for comparative analysis. Experience is showing that we have achieved that goal. Further, our laboratory staff has provided Mr. Kumar with a specific similar parameter set for his analysis, as requested, and we look forward to discussing his findings with him. If any anomaly is suspected with the test program it should be investigated, thoroughly documented with explanation and example and presented to the appropriate DAR test group. With this procedure both the presenter and the group will be able to fully understand the effect and its cause. It would have been greatly appreciated if these highly specific discussions could have occurred in the Channel Characterization Task Group during its deliberations.

I hope this adequately responds to your concerns. Please contact me should you have any questions. As we agreed at the Subcommittee meetings, I will attach this and your letter in the meeting minutes for distribution.

Sincerely,

Ralph Justus

Ralph H. Justus
Director of Engineering

cc: Randall Brunts
Al Resnick
Tom Keller
Robert Culver

Notes on Channel Simulation for Digital Broadcast System Testing

B. McLarnon
Radio Broadcast Technologies Research
Communications Research Center
Ottawa, Ontario, Canada

Introduction

There have been some concerns expressed by one DAR system proponent about the validity of using a Rayleigh fading model in the 'simulation' mode of the HP simulator for testing DAR systems in a multipath environment. The following discussion addresses those concerns.

As part of the discussions that took place in the EIA-DAR Channel Characterization Task Group, and in order to assure a timely start of the multipath tests in Cleveland, CRC recommended that the 'simulation' mode of the HP simulator be used for system tests with multipath. This requires that a channel be modeled with 6 to 12 paths (more than 6 requires a two-simulator configuration). The final configuration in Cleveland uses 9 paths for the desired signal, and 3 are reserved for a co-channel interfering signal. Each path has a relative attenuation and time delay associated with it, and each can have either no fading or Rayleigh fading applied to it, with a Doppler shift corresponding to the desired vehicle speed and carrier frequency. The validity of a given multipath scenario then depends upon whether the amplitude, delay and fading (or lack of it) set for the individual paths represents a realistic approximation of conditions seen on actual mobile radio transmission channels. The set of conditions used for a simulation run is known as a 'profile'.

Correlation Between Paths

The HP simulator contains a number of stored profiles which are based on the COST 207 recommendations [1] for GSM digital cellular system tests. These recommendations were developed from inputs from a large number of researchers in Europe. They are based not just on theoretical scattering models, but on numerous measurements conducted in many different environments, so there is little doubt as to their validity for their intended purpose. It is worth noting at this point that in all of the recommended profiles, the fading on the different paths has *zero correlation*. The capability of between-path correlation is included in the HP simulator to allow simulation of two-antenna diversity receiver systems under conditions of less-than-optimal antenna spacing [2]. All of the standard propagation models make the reasonable assumption of uncorrelated fading between paths in a single-antenna receiver system, and there is no physical basis to expect otherwise.

Doppler Spectrum Shape

There is one departure from the standard GSM profiles in those used in the HP simulator. In the standard profiles, the paths with small excess delays (i.e. the first arrivals amongst the multipath components) are subjected to Rayleigh fading, and a 'classical U-shaped' Doppler spectrum. Physically, this can be interpreted to mean that the multipath signals are assumed to arrive from all angles, and are uniformly distributed in azimuth. For longer excess delays, a different Doppler spectrum is recommended; it consists of two Gaussian spectral distributions, one with negative frequency shift, and one with positive shift. The physical interpretation here is that the multipath components are clustered around two different angles of arrival rather than being uniformly distributed. Note that this does not necessarily imply fading that is non-Rayleigh. Rayleigh fading results when there are a number of independent component signals with similar amplitude and random phase. Uniform distribution of arrival angles is not required for these conditions to be met; however, tight clustering in the Doppler spectrum *may* indicate some dependence between the component waves and hence fading which is less severe than Raleigh. However, this typically happens only for the longer-delayed echoes which are also normally lower in amplitude than those which arrive earlier. The dominance of the early arrivals having a Doppler spectrum approximating the 'classical U-shape' will tend to cause fading statistics that are close to Rayleigh to prevail.

The COST 207 recommendations state that it is acceptable to use the 'classical' Doppler spectrum for all simulator paths (even in the case of the Rural Area profile, which, in the standard recommendation, contains a nonfading path so as to give the first signal arrival Rician rather than Rayleigh fading characteristics). This undoubtedly produces a somewhat more severe test, but it is clearly an acceptable practice, and the presence of all-classical standard profiles (and the absence of any capability to generate Gaussian Doppler spectra) in the HP simulator are a further indication that this type of test is accepted by industry for GSM and other mobile system testing.

Channel Characterization Measurement Results

We have accumulated an extensive database of channel characterization measurements at 1.5 GHz for various environments. Examination of the urban measurements confirm that the type of model implemented in the HP simulator is a very good approximation of what is seen in the field. As shown in Figure 1, the dominant multipath components tend to exhibit the classical U-shaped Doppler spectrum which is indicative of many scattering objects with an angular distribution which is approximately uniform. This is true in many cases even for the longer excess delays. Most of the measurements in rural areas show a dominant peak at or near the first arrival, indicating the presence of a direct path to the transmitter and fading statistics which are likely to be Rician. However, there are also many instances, particularly in suburban areas, where the direct path is highly attenuated and the Doppler spectra are indicative of a complex scattering environment. In these instances, assumption of Rayleigh fading characteristics does not appear to be unreasonable.

Applicability of the Channel Models to Different Frequency Bands

Since most of the measurement data available from the literaturehave been collected at UHF, the question remains whether the simulation models are valid at VHF, and in particular whether it is reasonable to use them for tests of systems operating in the FM broadcast band. There are certainly some physical reasons that would lead one to expect that the multipath characteristics of a channel would be different at widely differing wavelengths. One way of approaching this question is to examine the measurements of delay spread taken at different frequencies: if there was less multipath occurring at the longer wavelengths, for example, this should show up as reduced delay spreads. Conversely, similar delay spreads would tend to indicate similar multipath profiles, and very likely, similar Doppler spectrum characteristics arising from them. This question has been examined by Lee [3], who concludes that 'the data available show that the delay spread is independent of the operating frequency at frequencies above 30 MHz". The explanation for this is as follows: as the wavelength increases, the energy scattered off a given object tends to decrease (more absorption and diffraction), which would decrease the amplitude of the multipath reflections. On the other hand, path loss decreases with increasing wavelength, and these two effects tend to balance each other, making delay spread roughly independent of frequency. A similar conclusion is reached by Springer [4], who states that 'there is support for the proposition that most of the important statistical parameters are relatively constant across the VHF and UHF bands'. Further support for this proposition comes from the EIA VHF measurements in Salt Lake City, which show similar urban and rural multipath profiles to those seen in the CRC 1.5 GHz results and other UHF measurements. Indeed, the VHF results for the "terrain obstructed" environment show larger delay spreads than have yet been seen in our 1.5 GHz measurements. The limited Doppler data available from the Salt Lake City tests also lend credence to the claim that Rayleigh fading is frequently seen at VHF, except in flat rural areas.

Severity of Fading: Is Rayleigh an Unusual 'Worst Case'?

Despite the above, there may still be some apprehension that Rayleigh fading is uncommon, and the assumption of Rayleigh characteristics is too much of a 'worst case' for system testing. This is not so; in fact, it is entirely possible to have fading which is considerably worse than Rayleigh. One good example of this is in the measurements at 450 MHz in Denmark described by Eggers and Andersen [5] who found that "locations exist with envelope statistics more severe than a Rayleigh reference". An example is shown in which the incidence of deep fades was considerably more frequent than that predicted by Rayleigh statistics. The measurement location is described as "a major road in a suburban area leading to the city". Further investigation disclosed that the predominant multipath components were arriving from the front and rear of the moving vehicle giving rise to a situation "resembling a two-ray standing wave pattern, thus giving rapid deep fades and rapid phase shifts". At a second test site, described as "a 70 m stretch of a four-lane highway just before a tunnel", the fading statistics matched the Rayleigh model over a 40 dB range.

Conclusion

It can be concluded from the above that simulation using Rayleigh fading statistics, together with power delay profiles derived from measurements, is an appropriate and effective means of testing the performance of Digital Audio Radio broadcast systems under mobile reception conditions.

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[1] *Digital land mobile radio communications.* Final Report of COST Project 207, Commission of the European Communities, Brussels, 1989.

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[3] Lee, W.C.Y., *Mobile Communications Engineering*. New York: McGraw-Hill, 1982, p.43.

[4] Springer, K., "Multipath propagation and fading statistics for digital audio broadcasting in the VHF and UHF bands", *NAB Broadcast Engineering Conference Proceedings*, 1993.

[5] Eggers, P.C.F., and J.B. Andersen, "Measurements of complex envelopes of mobile scenarios at 450 MHz", *IEEE Trans. on Vehicular Technology*, vol. 38, no. 2, May 1989, pp. 37-42.

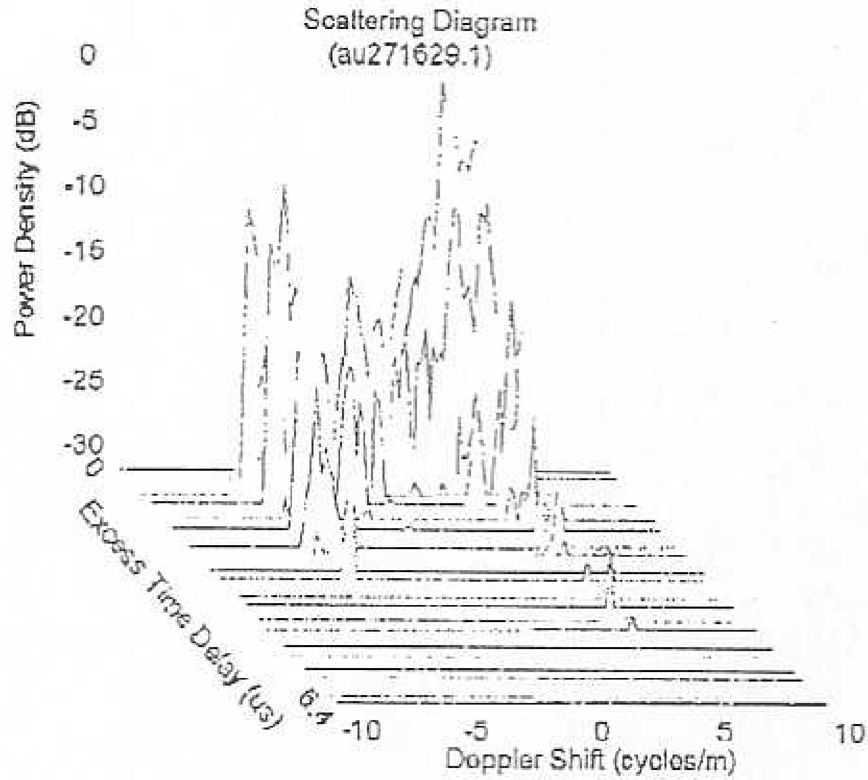

Figure 1: Typical scattering diagram for an urban environment

RECEIVED OCT 27 1994
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USA DIGITAL RADIO

October 25, 1994

Mr. Ralph Justus
Director of Engineering
Electronic Industries Association
2001 Pennsylvania Ave. NW
Washington, DC 20006-1813

Dear Ralph,

The response I received from you on Oct. 10th. was distributed to the USA Digital Radio Technical Advisory Committee. Apparently your response did not adequately satisfy our concerns. Attached is a further response from Derek Kumar, once again disputing your methods on Multipath Characterization for testing using the Rayleigh Fading model.

Also attached is another response from Mr. Kumar which address the IBOC Dab power level issue. Apparently this became an issue at the NAB Radio Show where USADR exhibited a mobile demonstration. I don't think this has become an issue in the lab, but I wanted to make you aware of it.

The reason I am bringing up these issues at this time is so they can be discussed and put on the agenda for the upcoming meetings on Nov. 3rd. I think that now these issues have become a matter of urgency as not to disrupt the structure of testing any more than has already been done. We plan to have a full compliment of representatives at the meetings to answer or defend any of your questions that might arise.

If you have any questions before the Nov. 3rd meetings, please feel free to contact me at the number below.

Sincerely,

Jeff Andrew
Project Manager

USA Digital Radio • 332 South Michigan • Suite 605 • Chicago, IL 60604
1(800)33USADR

October 21, 1994

Mr. Jeffrey S. Andrew
USA Digital Radio
332 South Michigan Avenue
Suite 600
Chicago, Illinois 60604

Dear Mr. Andrew:

I received a copy of the October 10 correspondence from Ralph Justus to you regarding the proposed EIA multipath testing procedure. Unfortunately, I believe that a number of the assertions made in his letter are incorrect or much more limited in scope than he is suggesting. I continue to oppose the SIM+RAY method of testing which utilizes Rayleigh fading. Furthermore, it is not acceptable to mix and match direction emulation and Rayleigh simulation testing, no matter what Paul Donahue is purported to have said. I appreciate the hard work of the characterization committee. However, it is a fact that the EIA has not gathered useful data from as many diverse sites as was originally expected. It is unclear whether or not the Salt Lake City data will adequately represent urban sites such as Chicago and New York. It appears that the EIA has experienced significant problems in reproducing the acquired multipath data on the HP emulator and that, at this time, no acceptable approach has been demonstrated. USA Digital Radio has demonstrated a viable FM IBOC solution in the field in an aggressive urban test environment, which no other proponent has yet accomplished. In the absence of an accurate emulation method at this time, the issue of the simulation is of great importance. Therefore, I am writing this letter to outline my arguments on the inadequacy of the Rayleigh model in some detail.

The principle of Rayleigh fading is based upon the observation of the envelope of a sinusoidal signal whose in-phase and quadrature components are independent and randomly distributed in phase. Cornerstone of this approach is the invocation of the well-known statistical Central Limit Theorem, by assuming that the RF channel can be characterized as having a large number of scattering reflectors of approximately equal magnitude [S. Stein and J. Jones, Modern Communication Principles. New York: McGraw Hill, 1967, pg. 355]. Hence, Rayleigh distributions are often used to model random background clutter in narrowband systems. It is widely known that the use

of the Rayleigh distribution is unacceptable where there is the presence of a significant direct path, such as microwave digital point-to-point links. This also applies to situations in which one or more of the scattering reflectors is much stronger than the others, which would again contradict the Central Limit Theorem. However, the proposed EIA approach utilizes Rayleigh distributions on all rays and in all scenarios, simply attenuating those reflectors which are considered less important. The net effect is that even the strong specular paths, which are physically generated by well-formed layer reflections, are modelled as diffuse clutter, which is clearly inaccurate. The proper distribution for a direct path is the Rician distribution.
I also question the suggestion that the Rayleigh model is independent of frequency. Propagation scattering is strongly frequency dependent because of the varying ratio between the carrier wavelength and the reflector (e.g., buildings, bridges) dimensions. Statistically, this is manifested in the variance of the distribution of the amplitudes of the reflected rays. This variance is directly effected by the Doppler shift, which is a simple function of velocity. An equally important component is the path loss factor, which is highly frequency dependent. However, the EIA is utilizing the 900 MHz Rayleigh model of the emulator and a frequency spread which is analytically determined by only vehicle speed (i.e., equating spread and shift). Therefore, frequency independent scattering is implicitly assumed.

I have examined the candidate Rayleigh settings supplied by the EIA and observed the resulting multipath impact on tones in the time domain. The resulting distortions do not accurately reflect what I have observed using time domain instrumentation during USA Digital Radio's extensive field trials in Chicago, particularly the rural highway rural settings. The Rayleigh carrier phase changes are much rapid than were observed, but the Rayleigh short-term envelope distortion is significantly less than observed. This implies that the Chicago multipath environment is much more specular (dispersive) than the corresponding urban EIA data.

I agree with Mr. Justus that the correlation model of the multipath emulator is not of particular use. However, that was not my point. My argument again pertains to the inadequacy of the Rayleigh model when widely disparate reflectors are present. Consider the simple scenario where there are three dominant rays, two strong, short reflectors in a city environment and a strong, long delay reflector due to a nearby mountainous region. In such an environment, the rays from the city reflectors will, in most cases, experience closely related Doppler shifts, when compared to the reflections from the mountains. Thus, in specular environments, it is critical to associate an appropriate Doppler spread with a specific ray delay and amplitude. In anything other than a pure clutter environment, it is capricious to characterize the full Doppler spread for all rays and then arbitrarily distribute the shifts among the rays.

Sincerely,

Derek D. Kumar

MEMORANDUM

RE: Response to further USADR inquiries on multipath simulation

TO: EIA-DAR Subcommittee and WG-B, testing

FROM: Robert D. Culver, VHF Channel Characterization

A letter dated October 25, 1994 from Jeff Andrew, accompanied by a letter dated October 20-21 from Derek Kumar, has been received and circulated. It raises questions that are the same or similar, to those that have been considered in previous meetings, correspondence and memos, relating to the character of multipath propagation and the proper application of multipath simulation. After consultation with Brian Warren of Delco Electronics, the principal investigator in the Multipath Characterization project, I offer the following responses to pertinent sections of the Derek Kumar letter.

Beginning in the second paragraph of the letter is a rather confused presentation of the nature of a fading R.F. channel. The essential points of multipath fading appear to be missing but would become clear upon reading any text with a good discussion of the subject, like Modern Communications Principals. Any general consideration of multipath propagation should also consider the environment, physical structures and geometries in which the proposed DAR systems will operate, the method by which the EIA Channel Characteristic measurements were made and the operation of the Hewlett Packard simulator. Those general multipath propagation points would be as follows.

The direct signal path, by itself without any additional path, is an AWGN (Additive White Gausian Noise) channel. This "direct path" could also be provided by a reflected path if it arrived without any other additional signal. In that case it would be modified by the reflector properties. The "direct" path has a log-normal probability distribution with a "slow" characteristic, meaning that it's fading events are generally widely separated (greater than 20 wavelengths). In this relatively benign channel, without multiple propagation paths, there is no challenge presented to a properly designed receiver with appropriate parameters, such as sensitivity and AGC.

The direct path signal is received at a certain "phase" at each instant in time. The phase reference can be arbitrarily chosen at some point along its propagation path, most likely at the transmission source. With no other path from any other source or reflection, the phase has no effect on the received signal amplitude. It does, however, have properties important to understanding the fading channel. If the receiver, the transmitter (and a reflector generating the one and only path) are all stationary, then the received signal is a constant amplitude phasor with a constant phase rotation representing the carrier frequency. At any given instant in time its phase (relative to the arbitrary reference cited above) will be between 0 and 360 degrees with an equal probability of any phase value within that interval. The first important property is that the signal phase has a uniform probability distribution.

When motion is added anywhere in the path, a Doppler component is added. If, for example, the receiver moves toward the signal source, the phasor appears to rotate faster. With movement away from the source the rotation is slower. This is the familiar Doppler frequency shift. If the motion is at any other angle, the shift is determined by the trigonometric relationship of the motion vector relative to the direction of signal arrival. For example if the motion is tangential there would be no shift. This presents the second important property, that the phase of the arriving signal, in a transmission path with motion, contains a Doppler component of the transmitted frequency. From this it follows that if the motion of a receiver relative to the propagation path is at an arbitrary angle and within an area of randomly located reflectors, a uniform probability distribution of possible angles of reflection arrival and relative velocities between receiver and reflectors results. Then the received Doppler shifted frequency will have a probability distribution based on the trigonometry to each individual reflector, but it will be randomly distributed and within the range equal to plus or minus the maximum possible Doppler frequency.

With the addition of a second propagation path, in addition to the properties cited above, the signal phase now begins to affect the recovered R.F. signal amplitude. Like the first path the reflected second path, in itself, follows an AWGN log-normal slow fading characteristic. In addition the sum of the two signals at a receiver also follows AWGN fading. However, when two delayed signals are combined (and they combine only in a receiver antenna or other conductor, not is space) a new property is generated. The relative phase of the two signals at the point of combining can change very rapidly, up to 360 degrees relative shift for 180 degrees of relative motion for one object (Double or more reflections of moving objects can cause faster shifts). This relative phase shift is much faster than the change of the AWGN fading signal and introduces the received signal reinforcements and cancellations found in multipath propagation. An interference pattern is set up in the reception area through which a receiver can move encountering fluctuating signals.

This concept is visually displayed on the graphs attached to this memorandum. One fundamental property is that the closer the two combined signals are in amplitude, the greater will be the fluctuation. With equal amplitudes the maximum increase is double voltage with a maximum cancellation to zero voltage. Both graphs were calculated for two signals of equal amplitude and with a frequency scale calculation interval of 100kHz. The first graph was calculated at points of total path delays of N+0.5 wavelengths (3.0+1.5 meters at 100 mhz with $C = 3.0 \times 10^{8}$ M/S). It illustrates the effect of increasing total path delay at the null centered on 100mHz. The initial broad null narrows with increasing delay and additional nulls are generated (the Comb Filter effect). The second graph is calculated with a delay interval of 0.1 meters, now revealing the alternate reinforcement and cancellation as delay is increased, and also revealing the change in null spacing at lower and higher frequencies. This visual representation should help in the understanding of the frequency domain consequences of adding time domain signals, the method by which the Hewlett Packard channel simulator operates and, I hope, display the difficulty of transforming from frequency domain back to time domain.

That difficulty arises because it only requires the combination of two signals, as illustrated, to create frequency domain effects over wide latitudes (really an infinite theoretical range). A frequency domain effect observed over a relatively narrow range will not disclose the unique time domain properties which created it. It is only possible to estimate the time domain values of relative signal level and delay based on null percentage width and depth, and then only when enough distance and frequency resolution precision is used to find and measure the center of the null.

At this point of studying multipath propagated signals, the Central Limit Theorem can be applied by adding more reflectors. As the number of reflectors approaches infinity, the Rayleigh probability distribution results. The mean and distribution of the Rayleigh statistics is determined by the amplitudes of the reflectors. The fast multipath Rayleigh distribution plus the slow "direct" or line-of-sight path log-normal distribution yields the Rician distribution. For many receivers the identification of a unique "direct path" separate from the reflectors is irrelevant and the composite Rician distribution is not always discussed.

For our multipath simulation task the important practical consideration when applying the Central Limit Theorem is that the number of samples need not be taken near infinity before the distribution function is valid. The Rayleigh distribution is well represented by an ensemble of six signals. In Mobile Communications Engineering Lee explains that a reasonable approximation of the Rayleigh distribution can actually be generated with only two reflectors (three paths total)! This is the reason that Hewlett Packard offers its multipath simulator with a total of six channels, in some models with two groups of three, to which Rayleigh distribution characteristics can be applied. The simulator creates the frequency domain simulation by using a relatively few fixed reflectors, with assigned amplitudes and delays.

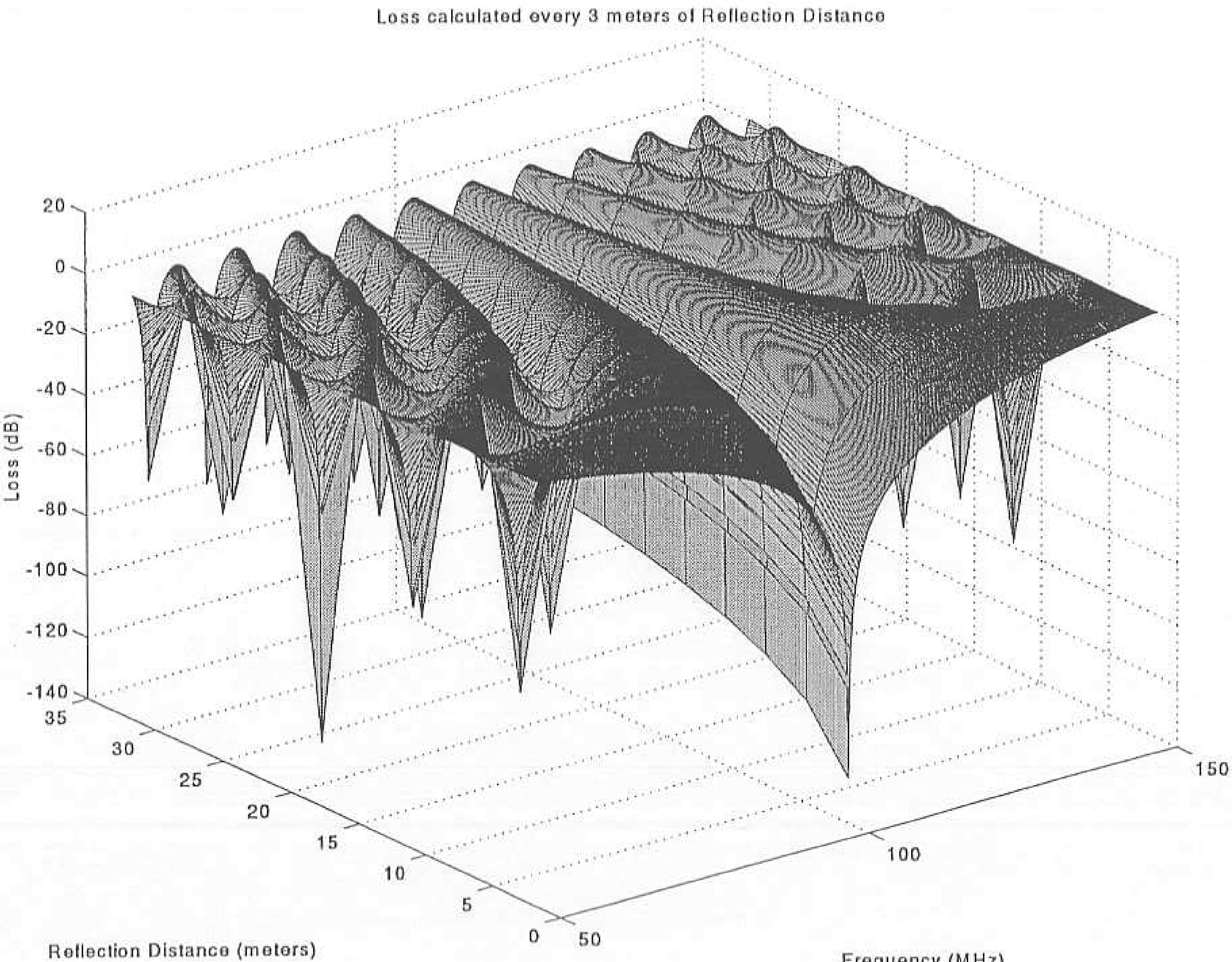
Without adding any variation these fixed reflectors would be, by definition, classified as "Specular", the reflected signal would remain constant with time (distance moved) or "coherent". Adding the Rayleigh distribution to the parameters "Diffuses" the reflections. Without using the Rayleigh distributions on the doppler and attenuation parameters of the simulator the resulting simulation would appear to be that of a receiver moving at the constant relative Doppler frequencies but without changes in reflection amplitude or delay that would accompany motion among reflectors. In other words the receiver would have velocity but no motion! The inclusion of Rayleigh distribution in the Doppler and attenuation parameters gives some variability to those parameters, moving the simulation further away from simulating a coaxial cable toward simulation of a moving receiver. Generally, the industry appears to widely support the use of Rayleigh distribution for this channel simulation by their support and use of this simulator. The attempt to deny the applicability of the Rayleigh distribution for this testing should be rejected. It has been accepted by this test group, and industry, as a good model for expected field conditions.

From the derivation of the Rayleigh distribution, it is evident that it is independent of frequency. The mean and variance of the distribution change with the amplitudes of the reflectors and they can change (slowly and continuously) with frequency. The GSM data is an appropriate approximation of that environment and the VHF Channel Test data from Salt Lake City determined the amplitude of the reflections in that general environment. The Rayleigh distribution files used in the laboratory DAR tests were generated based on the anticipated Doppler frequencies and applied to the measured VHF reflection amplitudes.

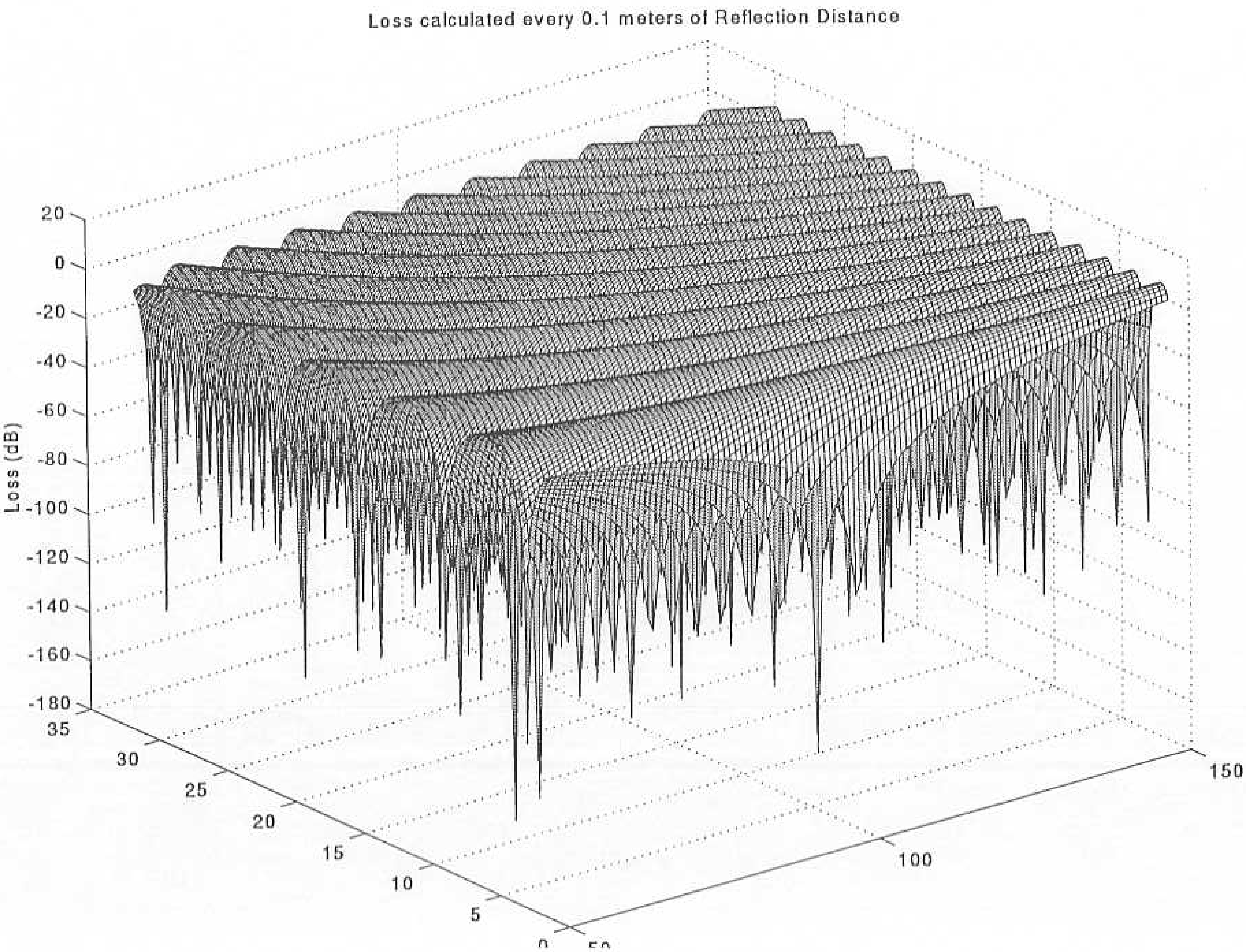
Another important point is that the reflectors are chosen to be completely specular. Two or more discrete reflectors could be perceived as a single diffuse component, but only if they are placed closer than the inverse of the receiver bandwidth. This is not the case. The Channel Characterization measurements could only resolve individual reflectors separated by a minimum reflection time and the Hewlett Packard simulator can only be programmed with six channels (reflectors). The Raleigh derivation also shows that the nature of the reflector profile, whether it is specular, diffuse or "widely disparate" is irrelevant.

The only remaining step is the choice of the proper Doppler frequencies. These must be applied to each reflector independently according to the uniform distribution of frequencies described above and dependent on apparent velocity. The frequencies are independent because they are related to independent reflectors at independent locations with independent path geometries. An interesting consequence is that, because the relative signal phases can change as fast as 360 degrees for 180 degrees of relative motion, the receiver can not differentiate the phase effect between two nearby and close spaced buildings, for example 20 wavelengths apart, and one nearby building and a mountain thousands of wavelengths away. The two close spaced buildings could have similar Doppler frequencies if the two path geometries are similar, but this does not add an unacceptable bias to the environment. I suggest using a mathematical modeling program such as MatLab to simulate and study this.

In summary, the single most important difference between the laboratory simulation and field operation is that the lab test has a bias toward the more difficult multipath environments, those that were isolated as difficult environments in the VHF Channel Characterization measurements. This is not to say that a multipath simulator makes impossible fading scenarios, but rather that it presents realistically difficult scenarios more often. This is appropriate for testing systems under a challenging condition. Systems that have a problem, even if it were to occur over a relatively small percentage of reception times or areas, will be readily identified in the relatively short lab test. The field tests conducted on the systems would have to be overly extensive and proportionately more costly to discover those serious but potentially infrequent difficulties. The field tests will be the final check but the lab tests are the controlled efficient performance testing environment.



Loss calculated every 3 meters of Reflection Distance
Loss (dB)
20
0
-20
-40
-60
-80
-100
-120
-140
Reflection Distance (meters)
35
30
25
20
15
10
5
0
Frequency (MHz)
50
100
150



Loss calculated every 0.1 meters of Reflection Distance
Loss (dB)
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
35
30
25
20
15
10
5
0
50
100
150

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November 18,, 1994

Mr. Jeffrey S. Andrew
Project Manager
USA Digital Radio
332 South Michigan
Suite 610
Chicago, IL 60604

Re: USADR letter of October 25, 1994

Dear Jeff,

Some of the technical issues you raised in your October 25, 1995 correspondence (Derek Kumar attached letter of October 21, 1994) are discussed further in the enclosed memorandum from Robert Culver. These matters received considerable discussions at the DAR & DAB Subcommittee meetings November 3rd. It appears that either mis-communications or misunderstandings are occurring or that there may be a fundamental lack of technical knowledge about VHF channel characterization as it applies to DAR system testing.

In any case, the Subcommittees would benefit from clear, concise and supportable technical discussions about channel characterization and the derivation and relevance of parameters used to simulate the multipath phenomena. The November 3 meetings charged the Channel Characterization Task Group to prepare a comprehensive report discussing its recommendations and to include that as an Appendix to the Test Data Report. A strawman draft report will circulate in the coming weeks for review prior to the next Task Group meeting. I encourage substantive technical participation in those meetings by representatives of USA Digital Radio. The reasons for your continued concerns might be better understood, discussed and addressed by experts in the field. If a consensus technical understanding cannot be attained, I suggest drafting a complementary technical report stating with particularity the facts, circumstances and supporting documentation that may justify alternative views. The intent would then be to provide the test report reader with adequate information to make their own informed judgments as to the relevance of test data. Please contact Bob Culver (301-776-4488) to ensure that the proper USADR representatives are included in meeting announcements.

On an administrative matter, should you wish to have topics included on meeting agendas in the future, it will greatly help if you could discuss their inclusion with staff and the Chairmen well in advance of the meetings. We generally strive to have meeting announcements and agendas mailed 3-4 weeks prior to meetings. Others (including yourselves) have expressed concerns that a subject was discussed that they would like to have participated in but did not attend the meeting based on the proposed (mailed) agenda subjects. I would like to accommodate requests for advanced mailing of material if enough lead time is available. In fairness, please help us plan ahead (4 weeks) to add subjects to the agenda.

If you have any other questions, please call me at (202) 457-8716.

Sincerely,

Ralph H. Justus
Director of Engineering

Enclosure

cc: Randall Brunts
Alfred Resnick
John Marino
Thomas Keller
Robert Culver
Brian Warren

NRSC Document Improvement Proposal

If in the review or use of this document a potential change appears needed for safety, health or technical reasons, please fill in the appropriate information below and email, mail or fax to:

National Radio Systems Committee
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