A High Resolution Statistical Characterization of Fading on Meteor Communication Channels

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)
This document describes the second part of a statistical study of fading on meteor communication channels based on data obtained from the Geophysics Laboratory's High Latitude Meteor Scatter Test Bed. In this experiment the sampling rate is increased from 100 Hz to 2000 Hz to provide resolution of 0.5 ms. Trails at 45 MHz from both the Sondrestrom Thule, and Sondrestrom Narsarsuaq links are considered. Trails are classified as underdense or overdense using a modified version of the GL automatic classification routine. Trails are then analyzed for fades with depths exceeding 3, 6, and 9 dB relative to a 10 dB Signal-to-Noise threshold. Signal-to-noise ratios are considered relative to bandwidths which vary from 4.8 kHz to 128 kHz. Statistics are computed as a function of frequency, time of day, and trail type for the first D seconds of a trail, where D = 50, 100, 200, 400, and 600 ms. The experiment considers fades with 1 ms minimum duration with a resolution of 0.5 ms.

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1.0 INTRODUCTION

Phase I of the meteor scatter fading study [Weitzen et al., 1990a] considered the effects of fading events (minimum duration 20 ms with a 10 ms resolution) on meteor scatter communication. Data showed that for the most part the effect of fading was not significant (less than 10-15 percent of the trails exhibited fading) at trail durations less than 200 ms.

The objective of Phase II of the experimental program is to improve the resolution by increasing the sampling rate from 100 to 2000 Hz to observe whether the trends remain the same. The Phase I report has a detailed description of the equipment and the theory of the fading mechanisms observed on the meteor channel.

2.0 STATISTICAL CHARACTERIZATION OF FADING ON METEOR CHANNELS

2.1 Experiment Description

The objective of this effort in contrast to previous channel characterization efforts is to accept the fact that there are a number of mechanisms which can cause fading and to statistically characterize the probability of fade occurrence. Data were collected at 45 MHz on the 1210 km Sondrestrom-Thule link during April 1990 and on the 690 km Sondrestrom-Narsarsuaq link during July 1990. Both links are operated as part of the Air Force Geophysics Laboratory High Latitude Meteor Scatter Test Bed. In this experiment, the sampling rate was increased from 100 Hz to 2000 Hz and the system bandwidth was increased from 50 Hz to 1000 Hz.

Data from the links are returned to the Geophysics Laboratory for automatic analysis. Special versions of the automatic classification routine and the automated data analysis routines were developed to analyze the larger data records. Four second data records consisting of 8000 data points are computer classified as either sporadic-E propagation or meteor propagation and each meteor trail identified is further classified as underdense or overdense using the technique described in the BMO Criteria Report [1990] and other documents [Weitzen and Tolman, 1986; Weitzen, 1990].

As with the previous study, fading is defined according to the following methodology illustrated in Figure 1.

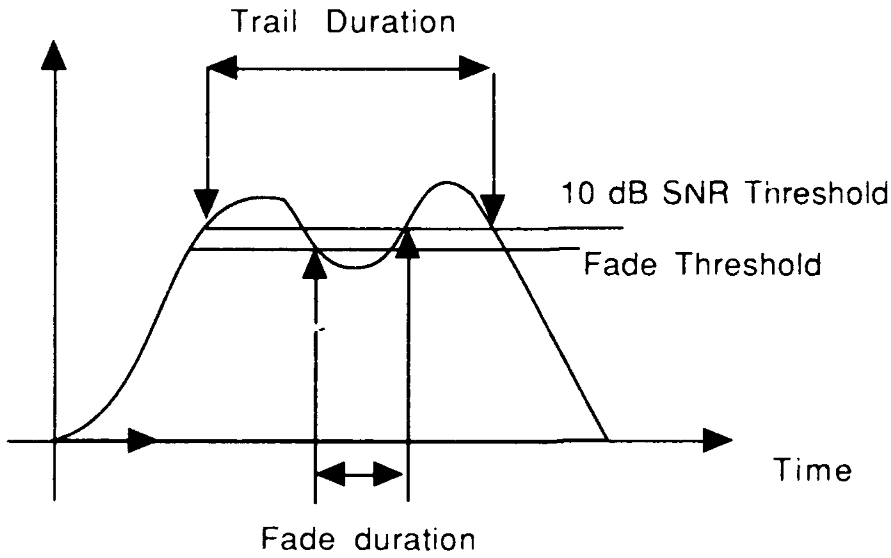


Figure 1. Meteor Trail Fade Methodology

A trail event begins when the received signal to noise ratio first exceeds 10 dB (s + n/n = 10.4 dB) relative to the defined bandwidth. The effective system bandwidth is 1000 Hz. Bandwidths considered for analysis are: 4.8, 8.0, 9.6, 19.2, 32.0, 64.0, 128.0 kHz. For example 10 dB SNR relative to a 8000 Hz bandwidth corresponds to a 19 dB SNR relative to the 1000 Hz system bandwidth.

Care must be exercised when interpreting the data from the higher resolution experiment because the system bandwidth has increased relative to the Phase I study. To illustrate the effect of increasing system bandwidth, consider the following example. In the Phase I study, at 8000 Hz effective bandwidth with 10 dB SNR in this bandwidth, the actual signal-to-noise ratio in the 50 Hz system bandwidth was on the order of 32 dB. Because of the high signal-to-noise ratio, it could be inferred with a high degree of certainty that a fade was due to a decrease in the channel gain rather than an increase in the noise level. In the Phase II program, the bandwidth is increased by a factor of 20 so that the signal-to-noise ratio at a given effective bandwidth is reduced by 13 dB relative to the Phase I experiment. For the 8000 Hz data rate considered as the baseline for analysis, the signal-to-noise ratio is on the order of 19 dB relative to the 1000 Hz system bandwidth. Assuming additive white Gaussian noise, independent from point to point, with a minimum 19 dB SNR, the probability that there will be a 3 dB or greater fade due to noise alone is on the order of 4.0×10^{-6} for each point. For a 50 ms trail the probability of a noise induced fade is on the order of 1 percent. For a 200 ms trail, the probability of a noise induced fade is on the order of 3 percent.

One other factor must be considered. It is well known that during the formation of a meteor trail, as the meteor transits the higher order Fresnel zones, alternating zones of constructive and destructive interference will be observed. With a resolution of 10 ms or less, this phenomenon may not be observed, however with the increased system bandwidth, it will be observed. To insure that noise induced fades are not considered, we will consider 6 and 9 dB fades in the analysis.

2.1.1 Definition of a Fade

When the trail event begins, the duration clock is started. For a trail to be counted towards the number of trails exceeding the signal level for the required duration, the signal must be above the required signal threshold D seconds after the trail event begins. For the given analysis trail durations of D = 50, 100, 200, 400, and 600 ms are considered.

A fade occurs when the signal-to-noise ratio drops below (10 - fade depth) dB and then the signal returns above the original 10 dB SNR threshold, all within the first D seconds from the beginning of the trail event. Fade depths considered are are 3, 6, or 9 dB. A fade must be 1 ms or greater (2 or more data points) for it to be counted as a fade. This is done to minimize the effect of single point noise bursts. The definition of fading used in the analysis provides a data set in which the number of samples is independent of the depth of the fade. Other definitions would not have this desirable characteristic.

The duration of a fade is measured from the time the signal threshold drops below the 3, 6, or 9 dB threshold to the time that it exceeds the original 10 dB SNR threshold. This is illustrated in Figure 1. Using this methodology, there can be more than one fade during the duration of a trail.

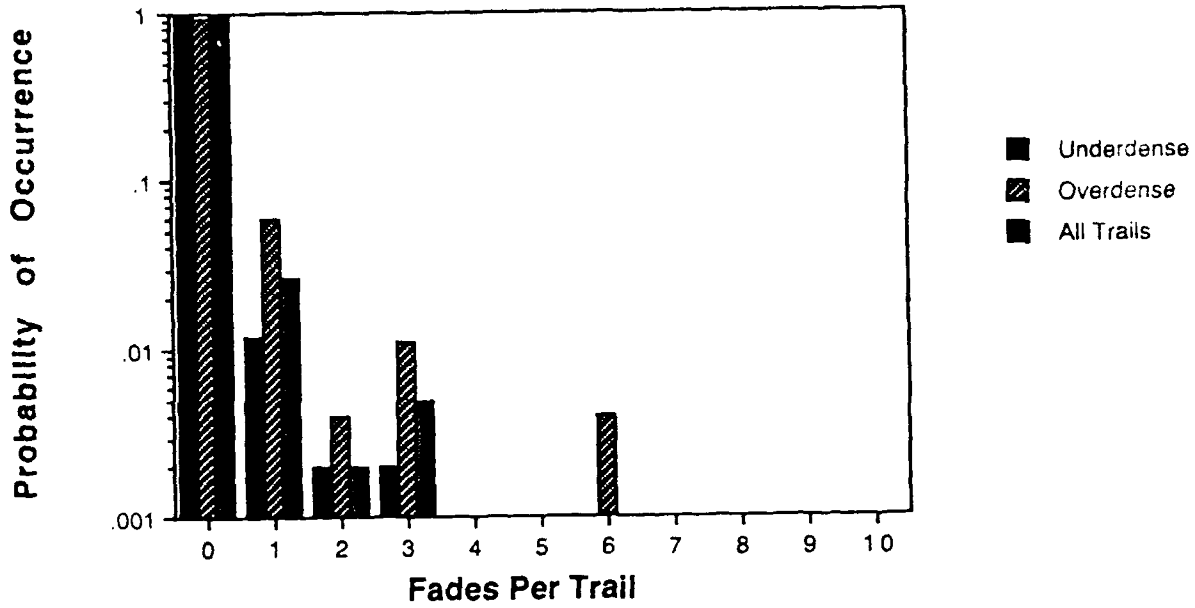
For each fade which is observed in the first D seconds of the trail, the duration is measured and recorded. For each trail the number of fades in the first D seconds (D = 50, 100, 200, 400, 600 ms) and their durations are recorded. For this experiment data were collected at 45 MHz and analyzed as a function of trail type (underdense and overdense) and time of day. Figure 1 illustrates the definition of a fade used in the analysis.

2.2 Data Analysis

Data from the Sondrestrom-Thule link (1210 km) for the month of April 1990 and from the Sondrestrom-Narsarsuaq link (690) km for the month of July 1990 were selected for detailed analysis. In table form, statistics of fades at all bandwidths, durations, and fade depths are computed for each trail type. Since the number of tables exceeds 1000, we have selected for analysis in this report a data set which closely approximates the proposed SICBM scenario. Consider a data rate of 8000 bps. We consider the fading observed at depths of 6 and 9 dB. A 6 dB fade (SNR dropping below 4 dB) is assumed to be adequate to cause an outage.

We first consider the case of trails with 50 ms minimum duration and 10 dB SNR relative to the 8 kHz bandwidth. In the first plots, Figures 2 and 3, we present normalized histograms of the number of fades observed per trail versus the probability. For the case of 50 ms duration, with minimum resolution of 1 ms, less than 2 percent of all the trails for each data set show fading. On each plot, the size of the data sample, (U = underdense, O

Month: July; BW: 8000 Hz; Duration: 50 ms;
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km
Sample Size: U:584 O:269 A:853



Month: July; BW: 8000 Hz; Duration: 50 ms;
Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 690 km
Sample Size: U: 584 O: 269 A:853

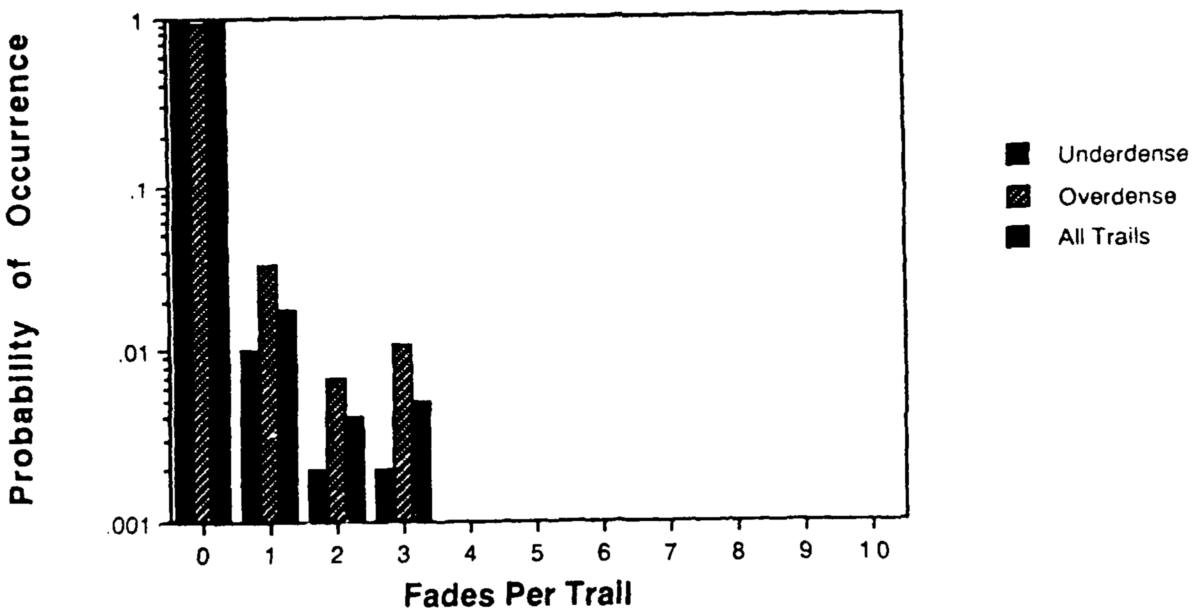
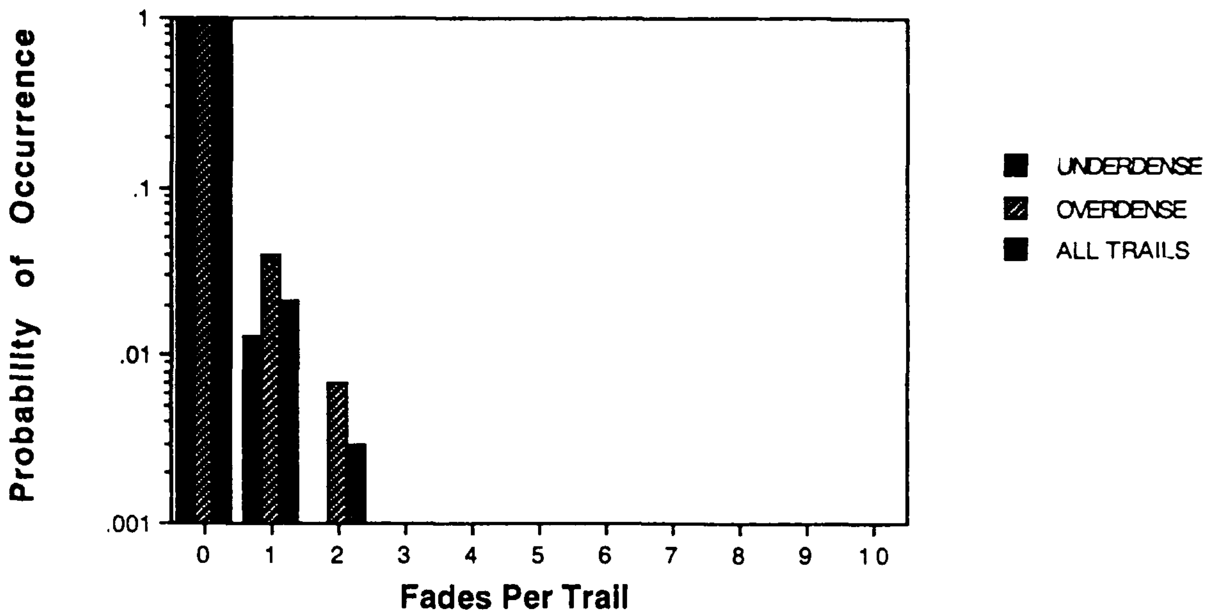


Figure 2. Sondrestrom-Narsarsuaq Link; 50 ms Duration

Month: April; BW: 8000 Hz; Duration: 50 ms;
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km
Sample Size: U:4037 O:1970 A:6007



Month: April; BW: 8000 Hz; Duration: 50 ms;
Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km
Sample Size: U: 4037 O:1970 A: 6007

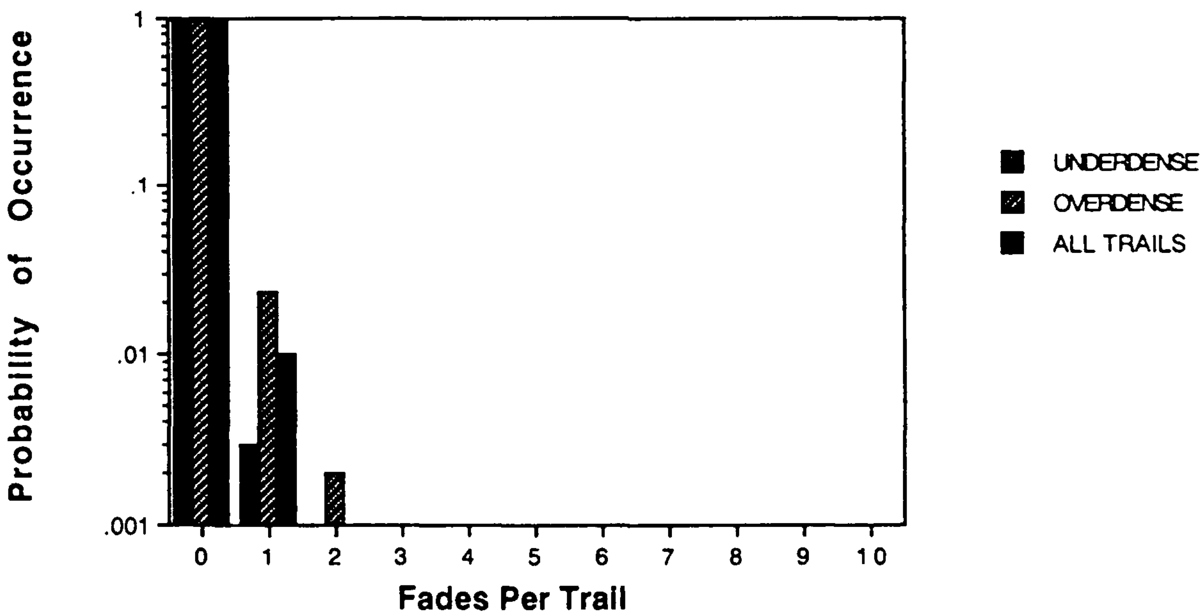


Figure 3. Sondrestrom-Thule Link; 50 ms Duration

= overdense, A = all trails) is included in the header. Data from both the 1210 and 690 km links are considered.

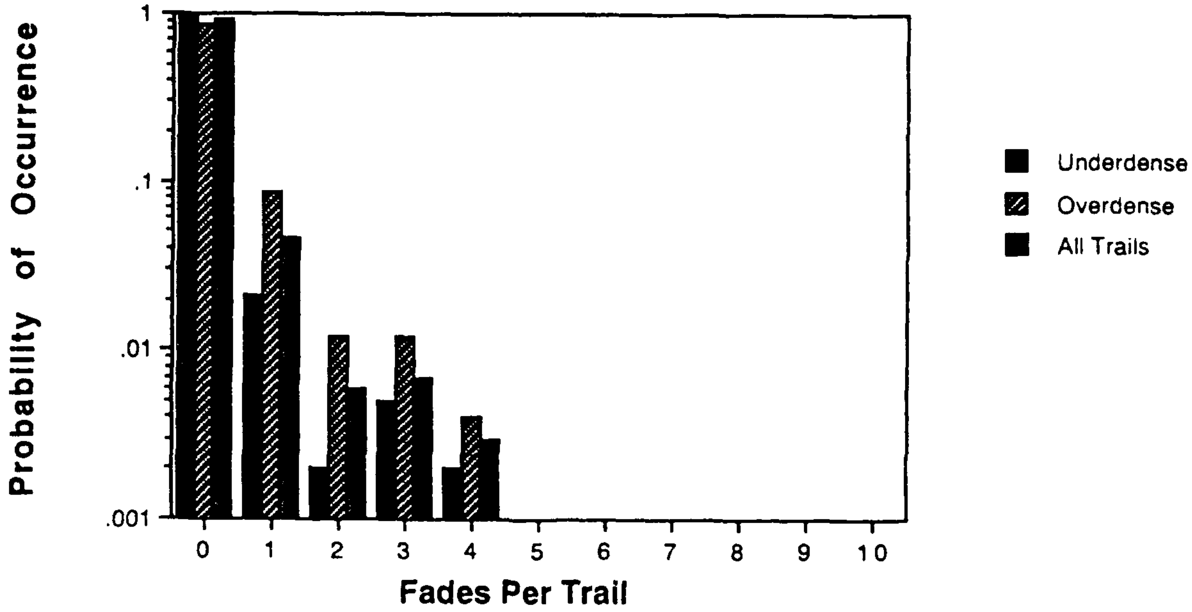
The next set of plots, Figures 4 and 5, consider the case of 100 ms trail durations. A trend emerges in the data which is consistent over the entire data set. Underdense trails tend to show less fading than overdense trails. At 100 ms duration, approximately 3-4 percent of all the trails examined have fades with a maximum depth exceeding 6 dB below the 10 dB threshold. As expected, fewer fades are observed at 9 dB than at 6 dB peak depth.

The next set of plots, Figures 6 and 7, cover the 200 ms trail durations. As the duration increases, the percentage of trails which show fading increases. The trend for the duration of fades to increase with depth continues. Two effects tend to influence the percentage of trails which are showing fading: 1) the percent of the data sample which is underdense is decreasing and 2) the percent of overdense trails which are fading is also increasing. At 200 ms, approximately 7 % of the trails are showing fades of depth 6 dB or greater.

At 400 ms trail duration, high altitude winds have had time to warp trails as described in Section 1 of the Phase 1 report. The percentage of trails which show fading increases. The percentage of trails which are also overdense increases. As the duration increases, the variation in the percentage of trails which are fading is around 15-20% at 45 MHz. Then plots are shown in Figures 8 and 9.

At 600 ms duration, the percentage of trails with fades is approaching 30%. At this long duration, wind induced warping will be common. Interleaving combined with error correcting coding would be very useful at the longer trail duration. Then plots are shown in Figures 10 and 11.

Month: July; BW: 8000 Hz; Duration: 100 ms;
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km
Sample Size: U: 424 O:245 A: 669



Month: July; BW: 8000 Hz; Duration: 100 ms;
Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 690 km
Sample Size: U: 424 O:245 A:669

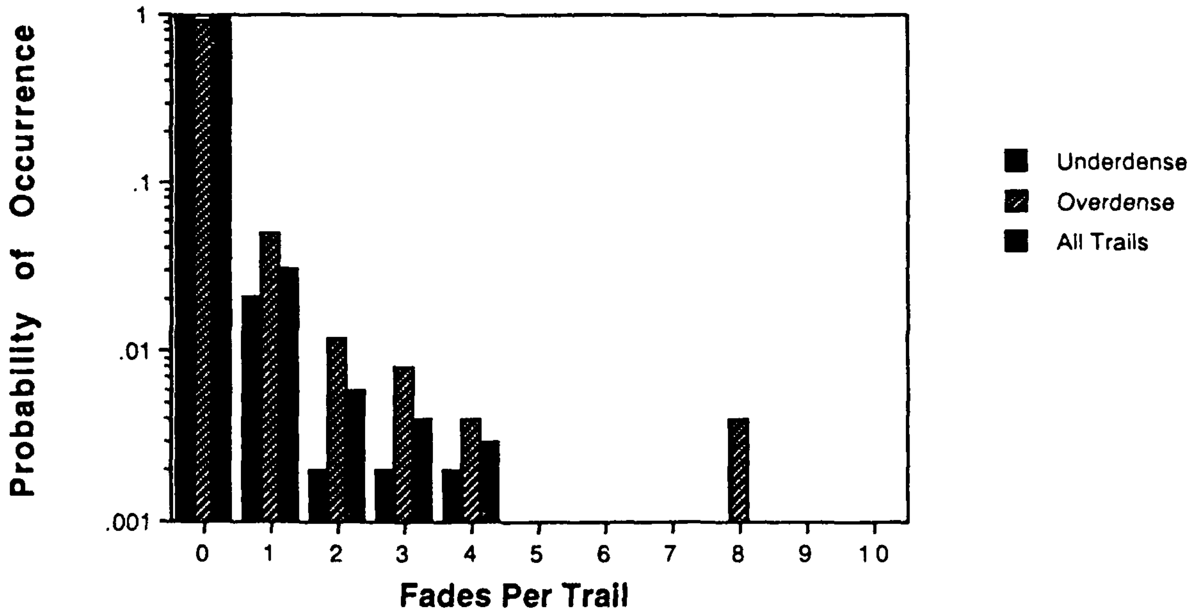


Figure 4. Sondrestrom-Narsarsuaq Link; 100 ms Duration

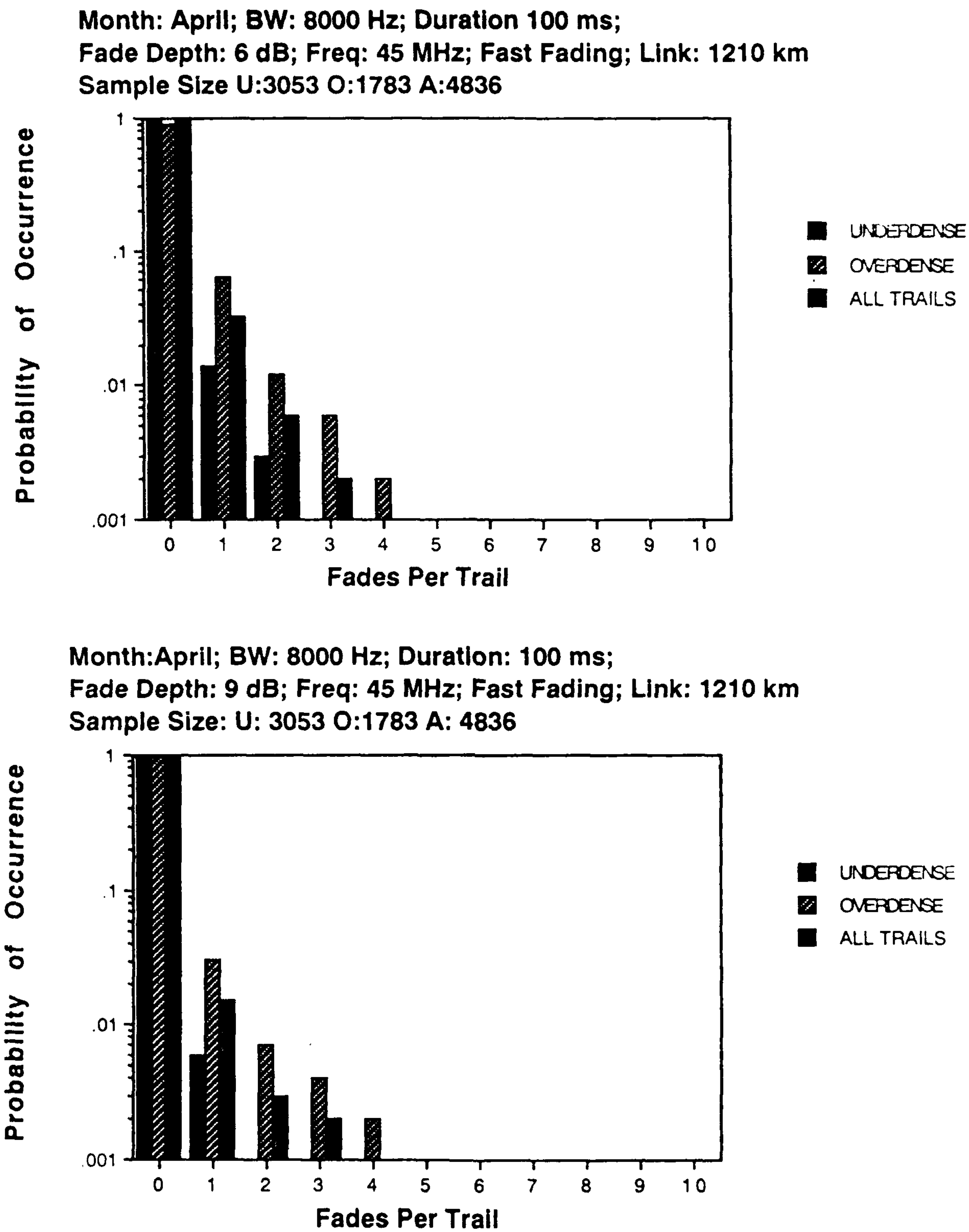


Figure 5. Sondrestrom-Thule Link; 100 ms Duration

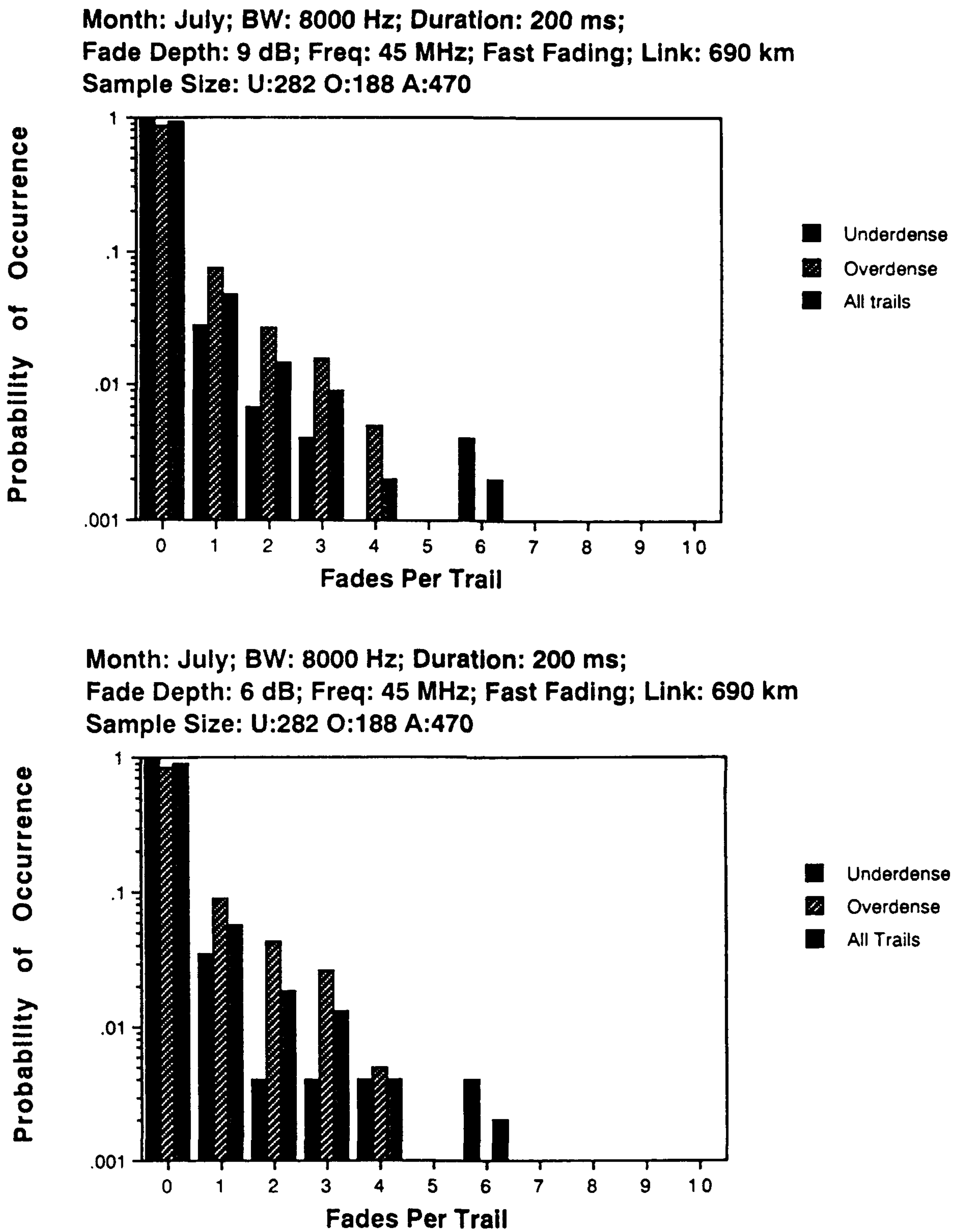


Figure 6. Sondrestrom-Narsarsuaq Link; 200 ms Duration

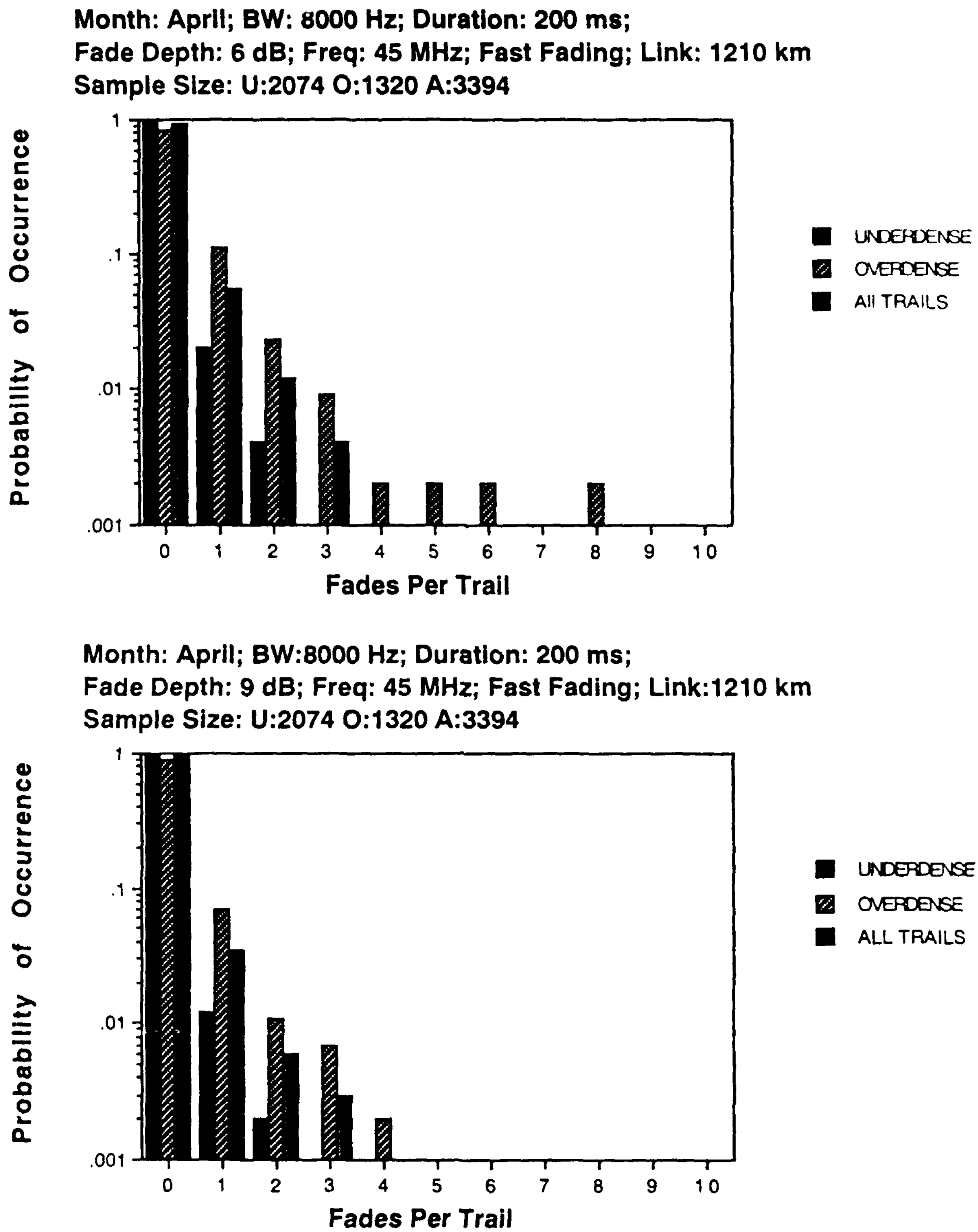
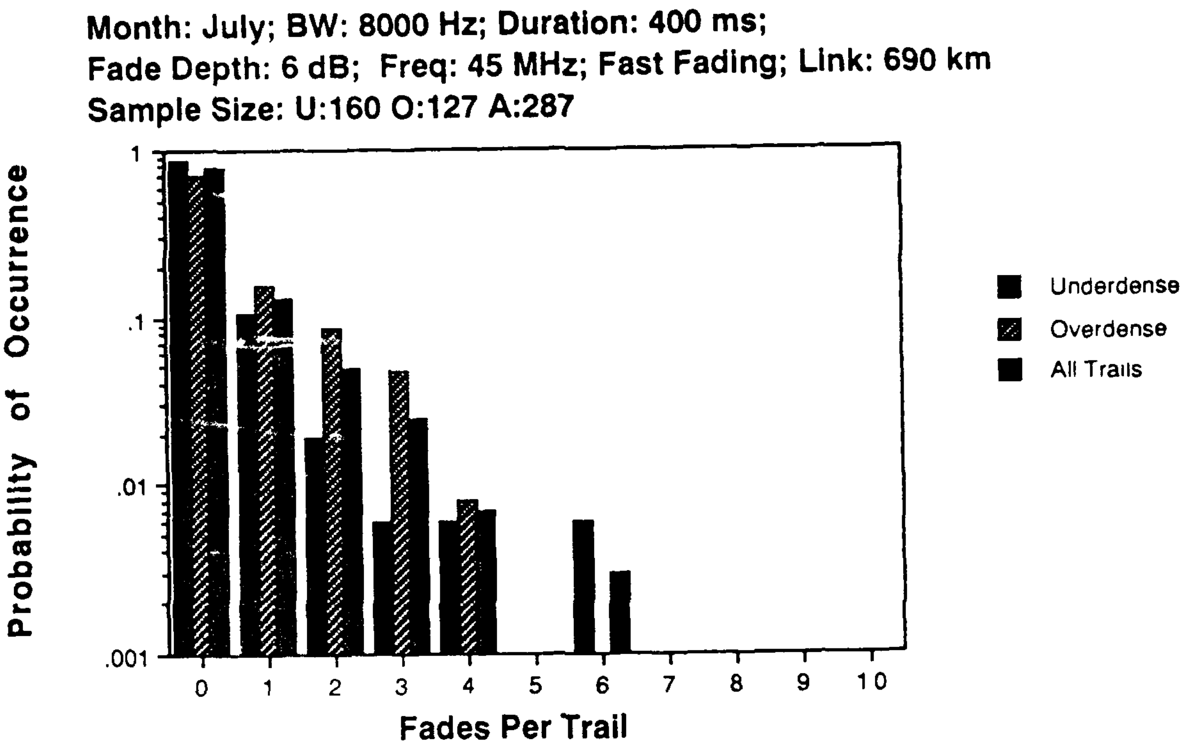


Figure 7. Sondrestrom-Thule Link; 200 ms Duration



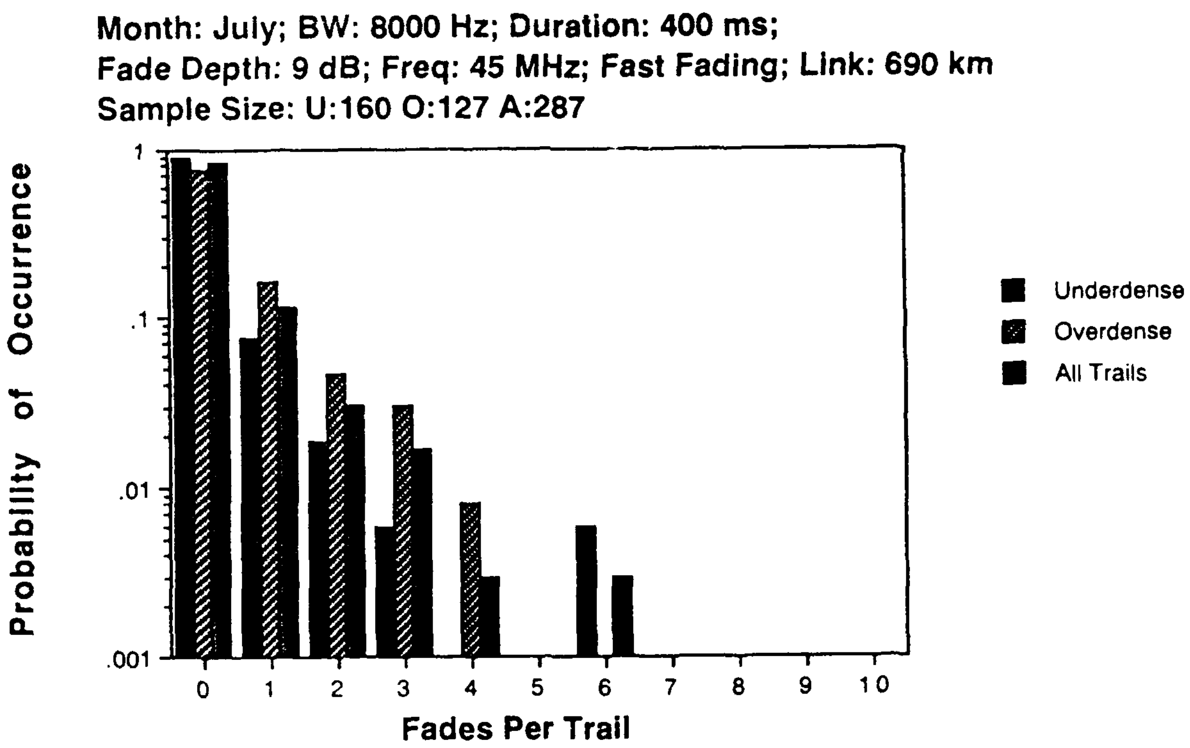


Figure 8. Sondrestrom-Narsarsuaq Link; 400 ms Duration

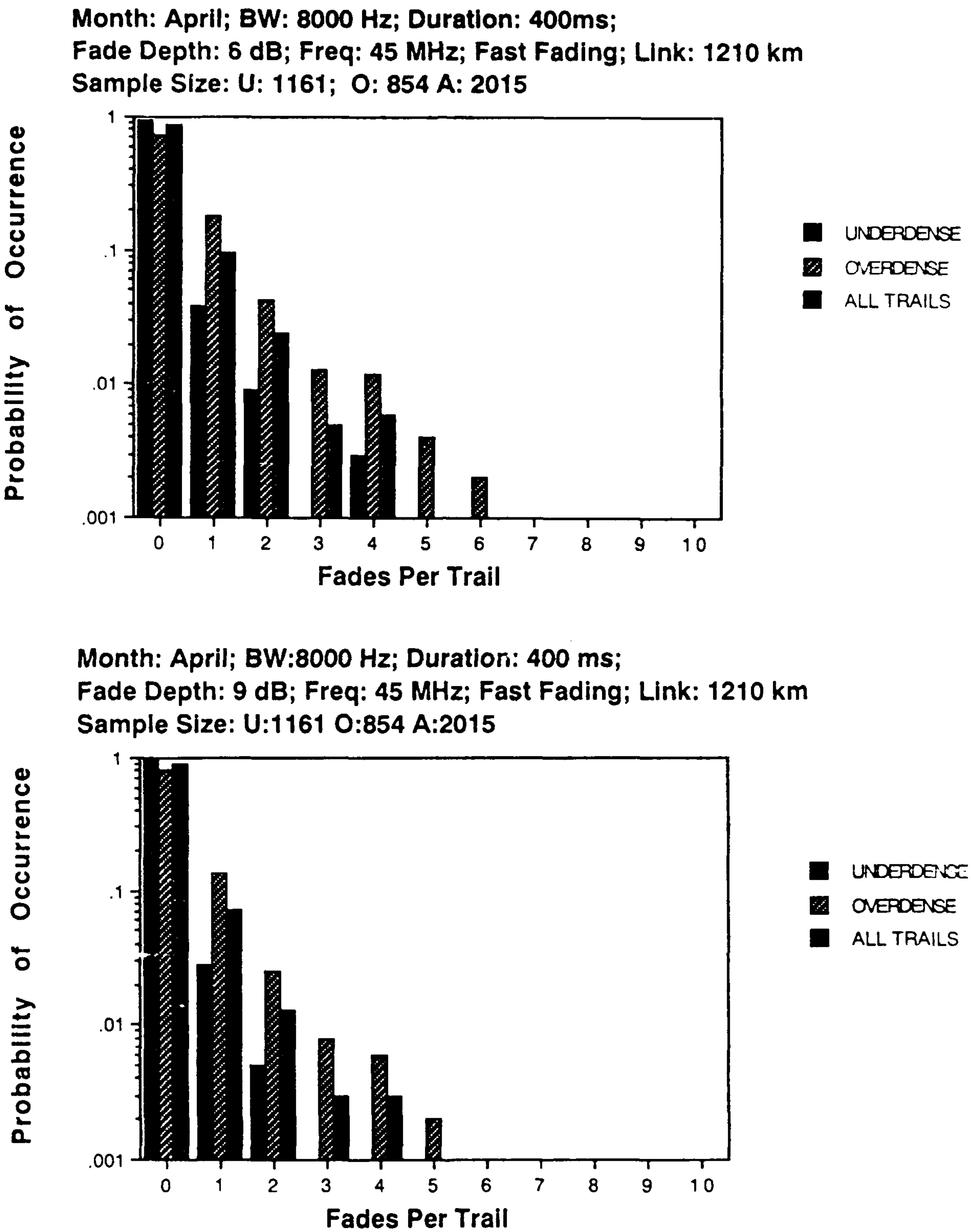
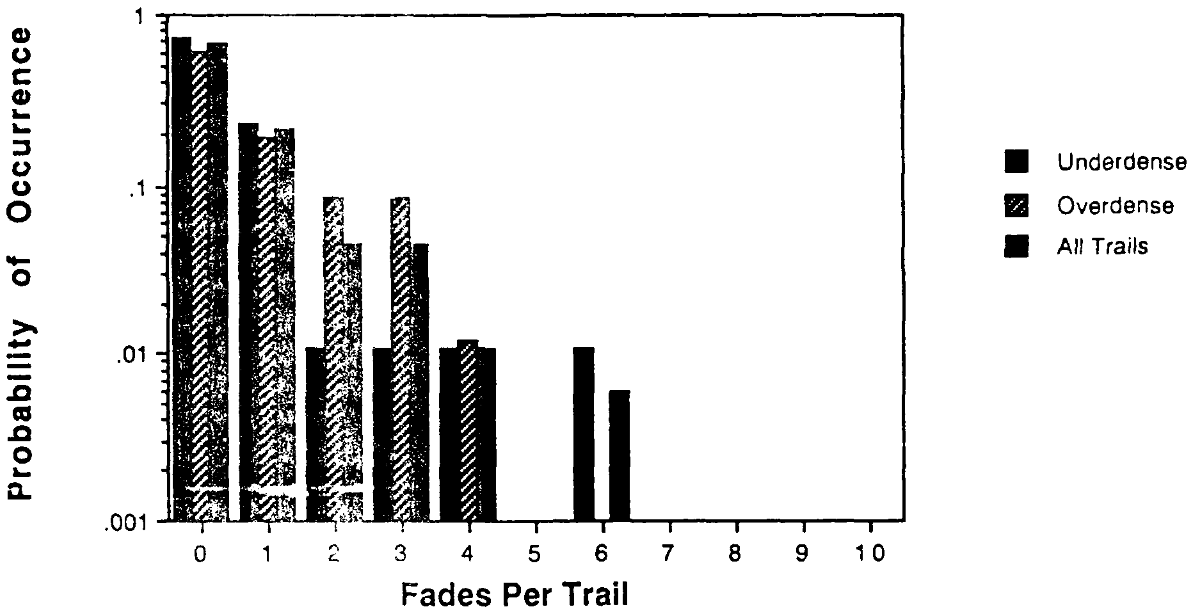


Figure 9. Sondrestrom-Thule Link; 400 ms Duration

Month: July; BW: 8000 Hz; Duration: 600 ms;
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fade; Link: 690 km
Sample Size; U:93 O:82 A:175



Month: July; BW: 3000 Hz; Duration: 600 ms;
Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 690 km
Sample Size: U:93 O:82 A: 175

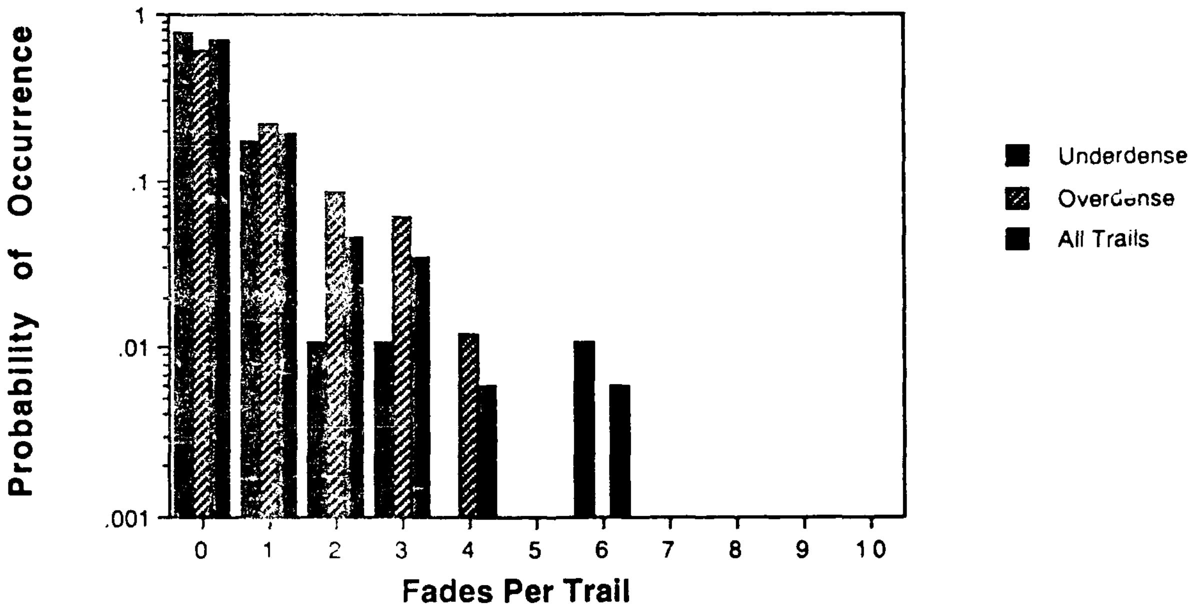
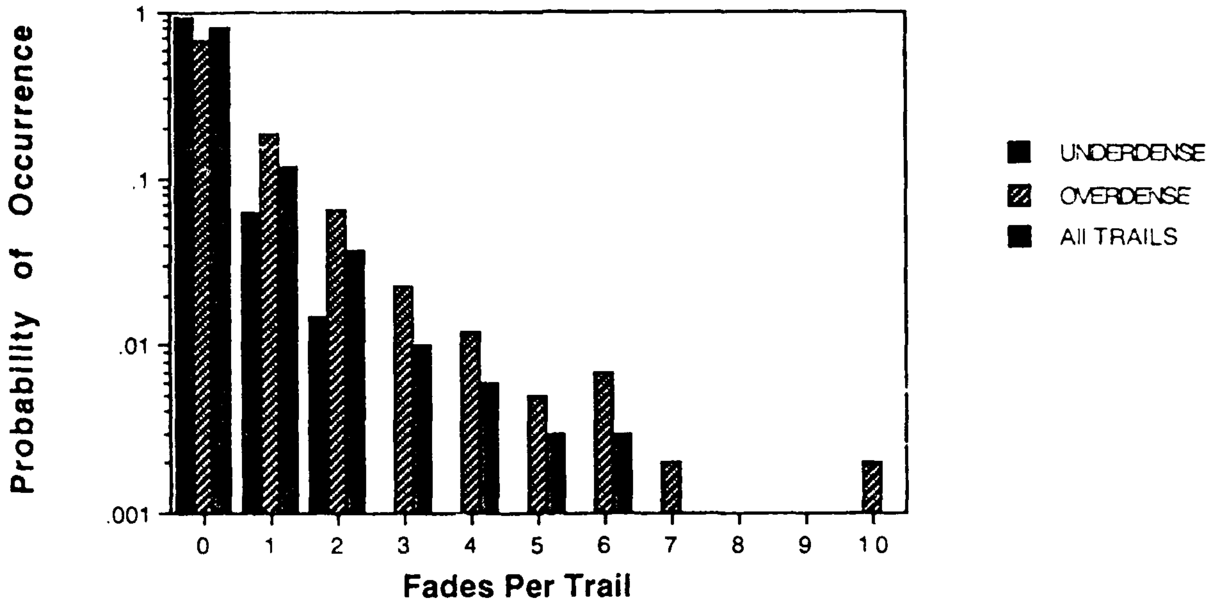


Figure 10. Sondrestrom-Narsarsuaq Link; 600 ms Duration

Month: April; BW:8000 Hz; Duration: 600ms;
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fade; Link: 1210 km
Sample Size: U:735 O:575 A:1310



Month: April; BW:8000 Hz; Duration: 600 ms;
Fade Depth: 9 dB; Freq: 45 MHz; Fast Fade; Link: 1210 km
Sample Size: U:735 O:575 A:1310

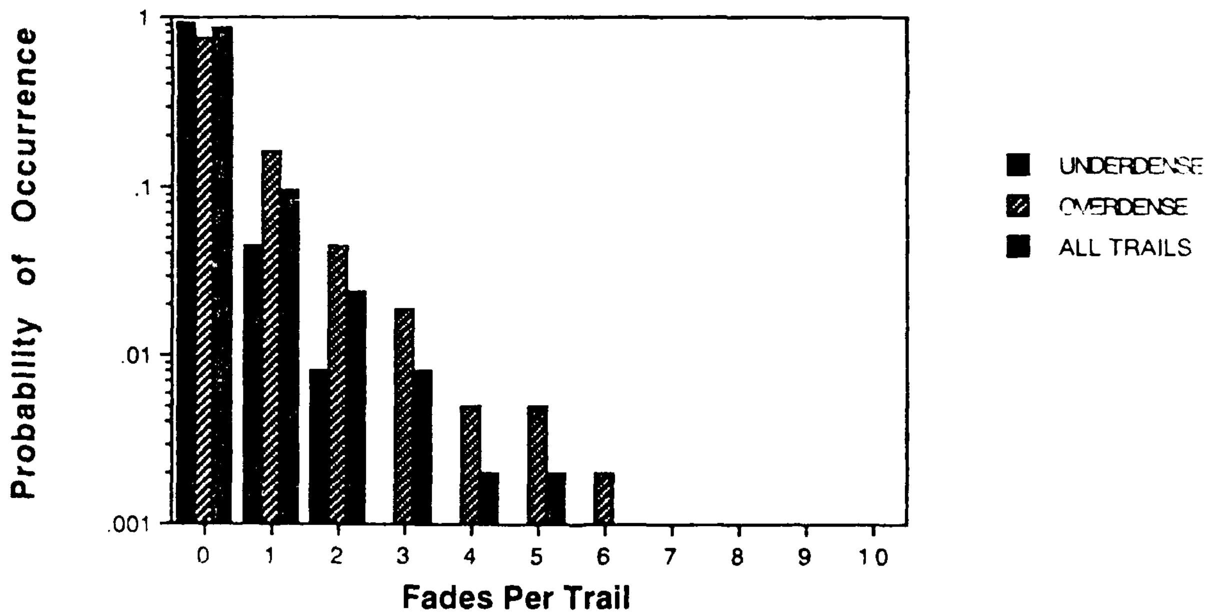


Figure 11. Sondrestrom-Thule Link; 600 ms Duration

Tables 1 and 2 summarize the results in terms of the percentage of trails which are underdense or overdense, the percentage of underdense trails exhibiting fading, the percentage of overdense trails exhibiting fading, and the percentage of all trails exhibiting fading. Statistics are computed for fade depths of 6 and 9 dB and are computed for both links.

Table 1. Summary of Results for July 1990: Sondrestrom-Narsarsuaq Link

6 dB Fades

Duration	%und	%ovd	%und-fad	%ovd-fad	%all fad
50	69	31	1	7	3
100	63	37	3	12	6
200	60	40	5	17	10
400	56	44	14	30	21
600	53	47	27	38	32

9 dB Fades

Duration	%und	%ovd	%und-fad	%ovd-fad	%all fad
50	69	31	1	5	2
100	63	37	2	8	4
200	60	40	4	12	7
400	56	44	10	25	17
600	53	47	20	28	29

Table 2. Summary of Results for April 1990: Sondrestrom-Thule Link

6 dB Fades

Duration	%und	%ovd	%und-fad	%ovd-fad	%all fad
50	67	33	1	5	2
100	63	37	1	8	4
200	61	39	2	15	7
400	57	43	5	215	14
600	55	45	8	31	28

9 dB Fades

Duration	%und	%ovd	%und-fad	%ovd-fad	%all fad
50	67	61	0	3	1
100	63	63	0	4	2
200	61	39	3	8	5
400	57	43	3	18	10
600	55	45	5	24	14

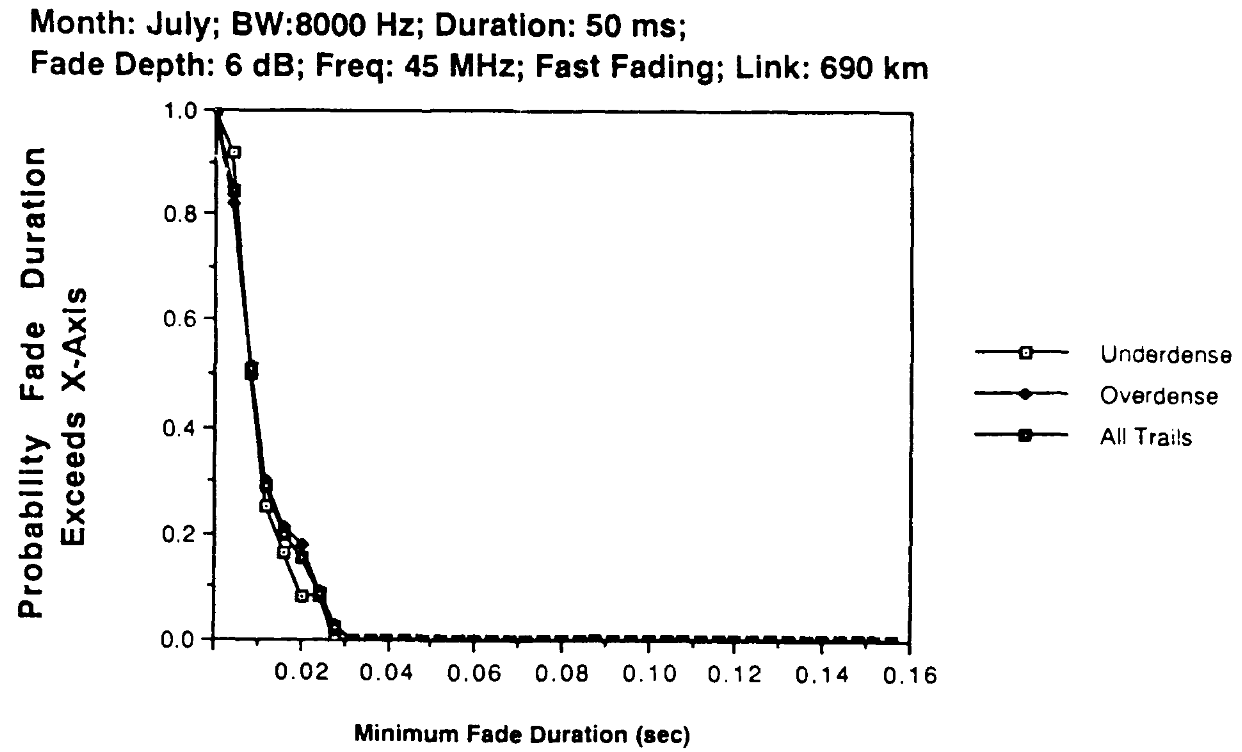
Table 3 summarizes the results for the low resolution experiment for trails of 100 ms duration for the Sondrestrom-Thule line and we see that the results are consistent with Table 2.

Month(1989)	% und	%ovr	%und-fad	%ovr-fad	%all-fad
Mar	51	49	1	2	1
Jun	37	63	1	4	3
Sep	50	50	1	4	2
Dec	48	52	1	4	2

Table 3. Summary of Results for Low Resolution Experiment

For both links, a second set of plots has been generated, as presented in Figures 12 through 16. This set plots the cumulative probability distribution function of each fade observed in the set. Recall that there can be more than one fade per trail. The X-axis plots the duration of the fade and the Y axis plots the probability that the duration of the fade exceeds the x-axis.

As expected, the duration of fades increases as the depth of the fade is increased.



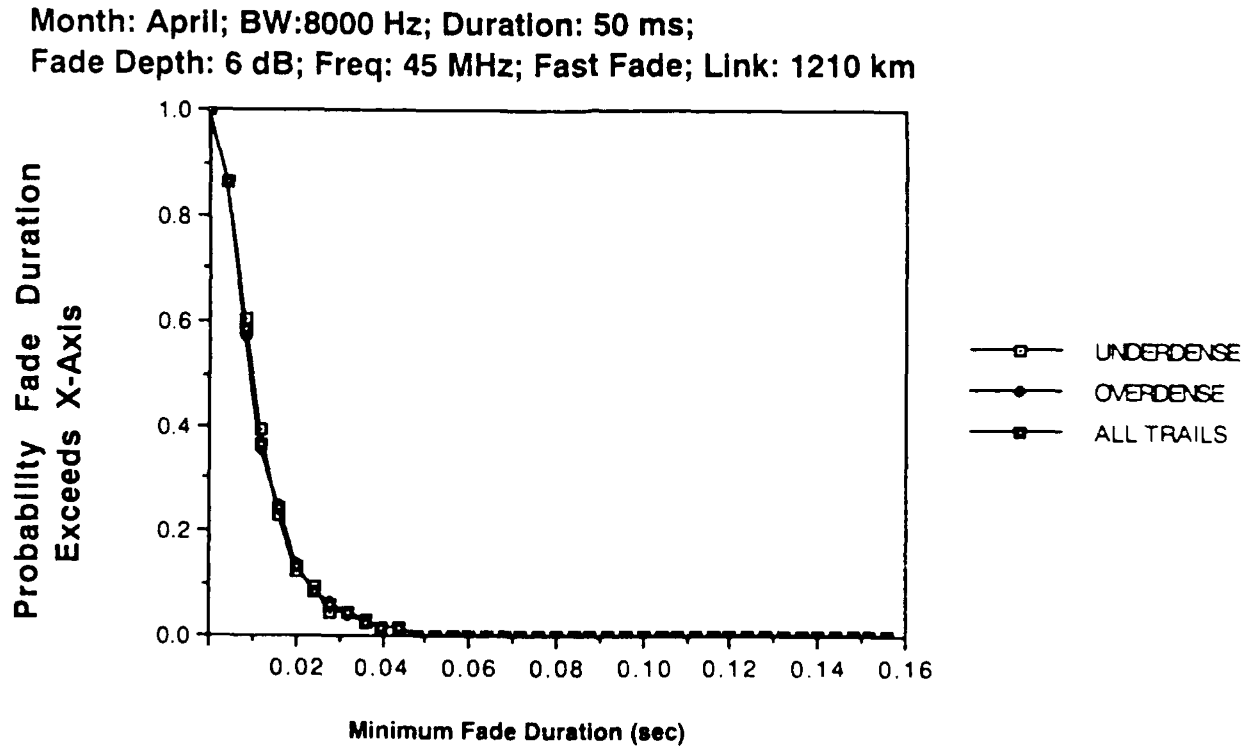
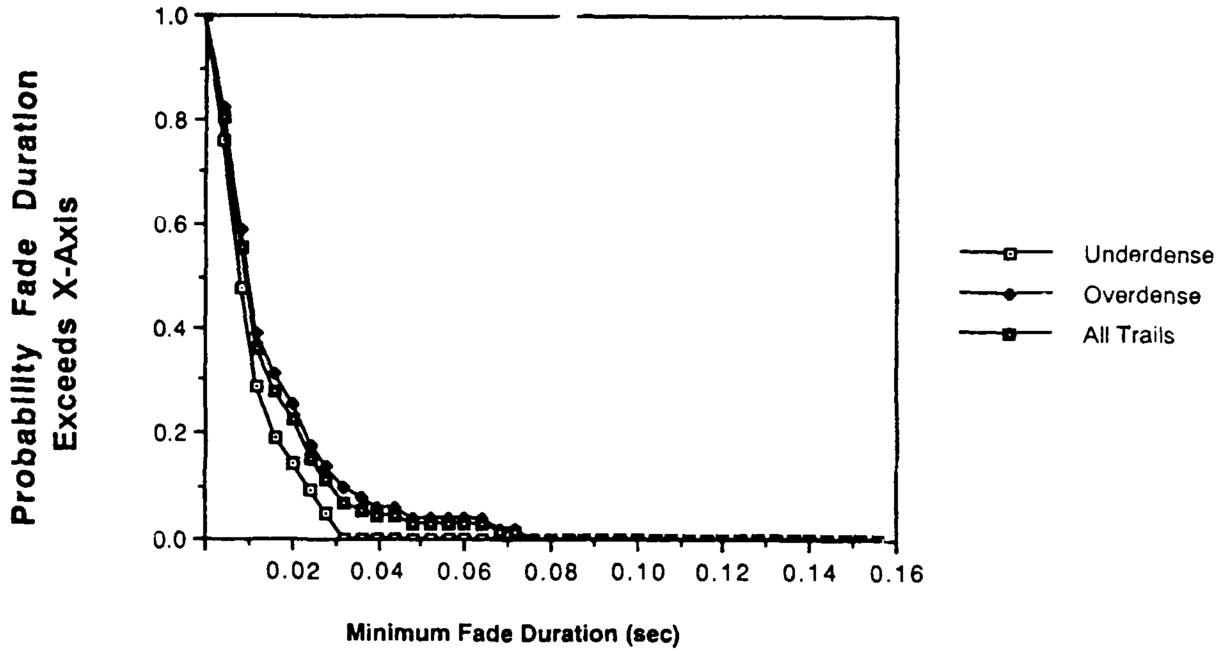


Figure 12. Cumulative Probability Distribution Function; 50 ms Duration

**Month: July; BW: 8000 Hz; Duration: 100 ms;
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**



**Month: April; BW: 8000 Hz; Duration 100 ms;
Fade Depth 6 dB; Freq: 45 MHz; Fast Fade; Link:1210 km**

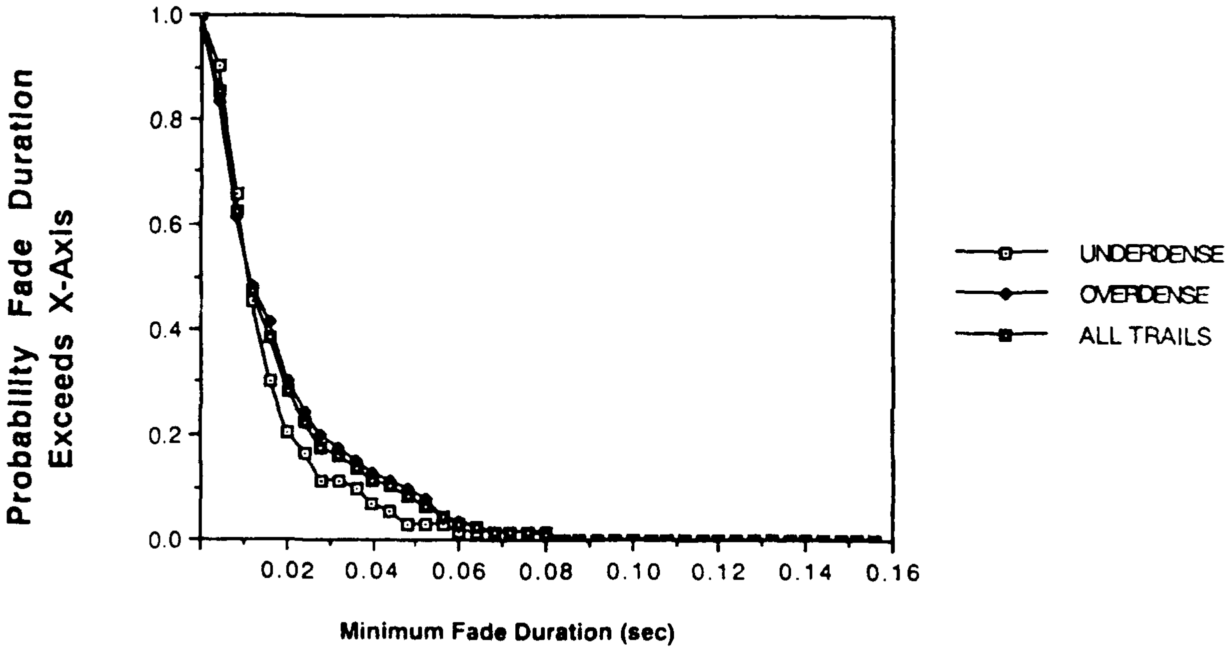
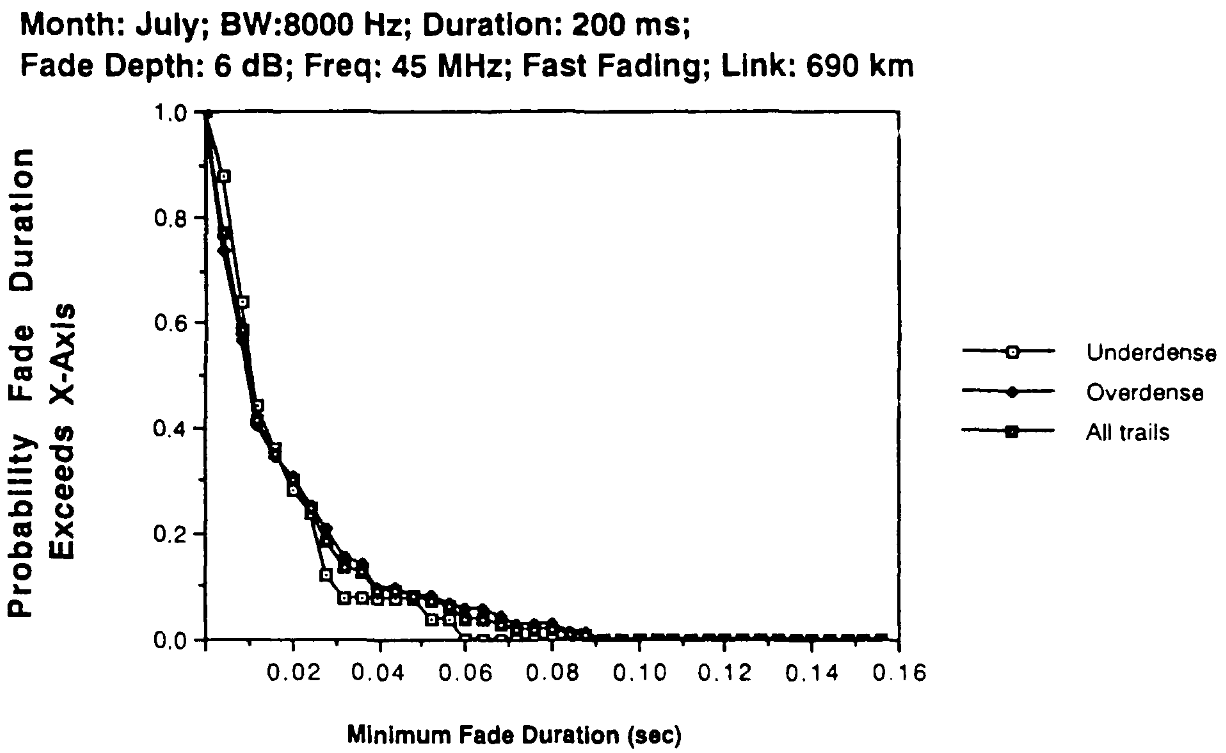


Figure 13. Cumulative Probability Distribution Function; 100 ms Duration



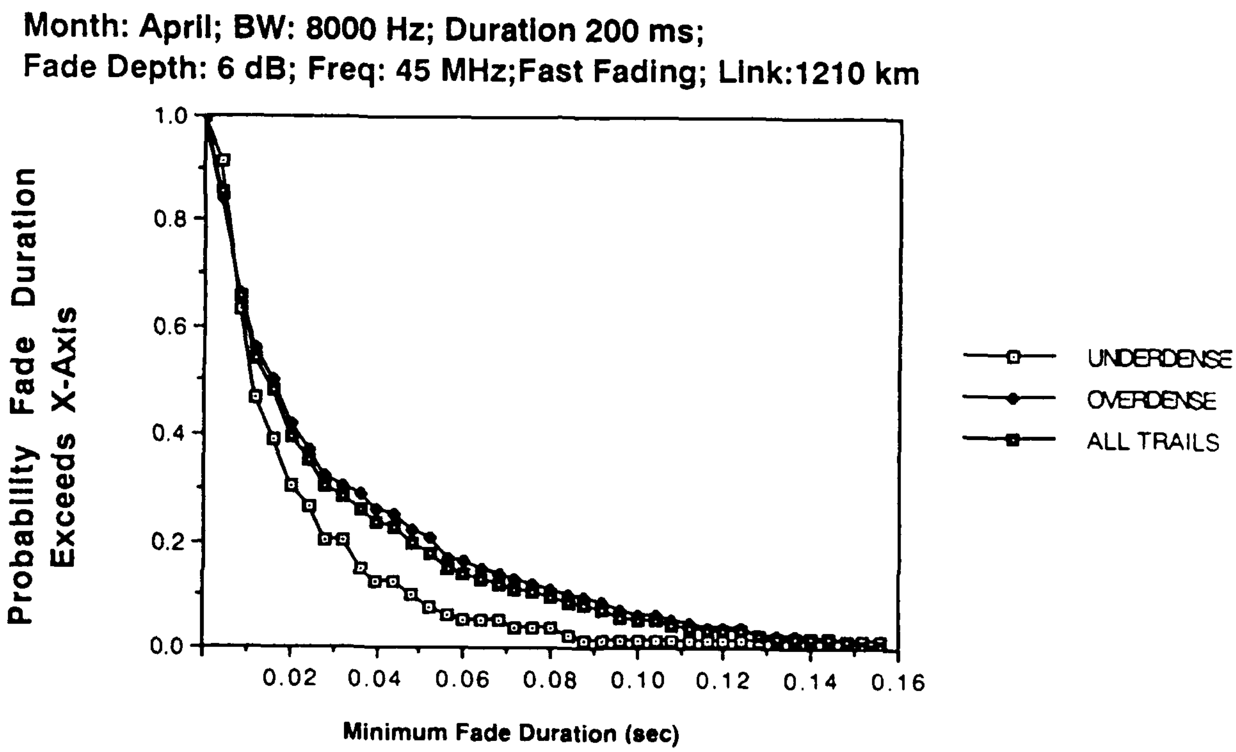
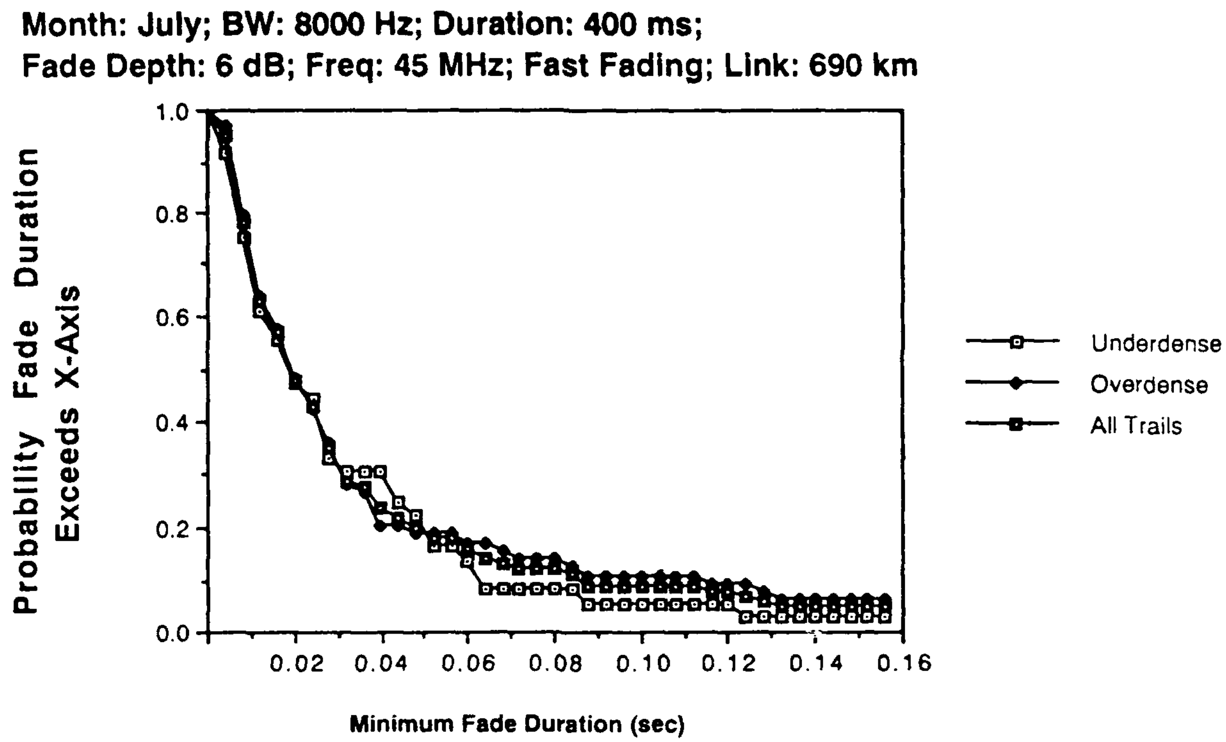


Figure 14. Cumulative Probability Distribution Function; 200 ms Duration



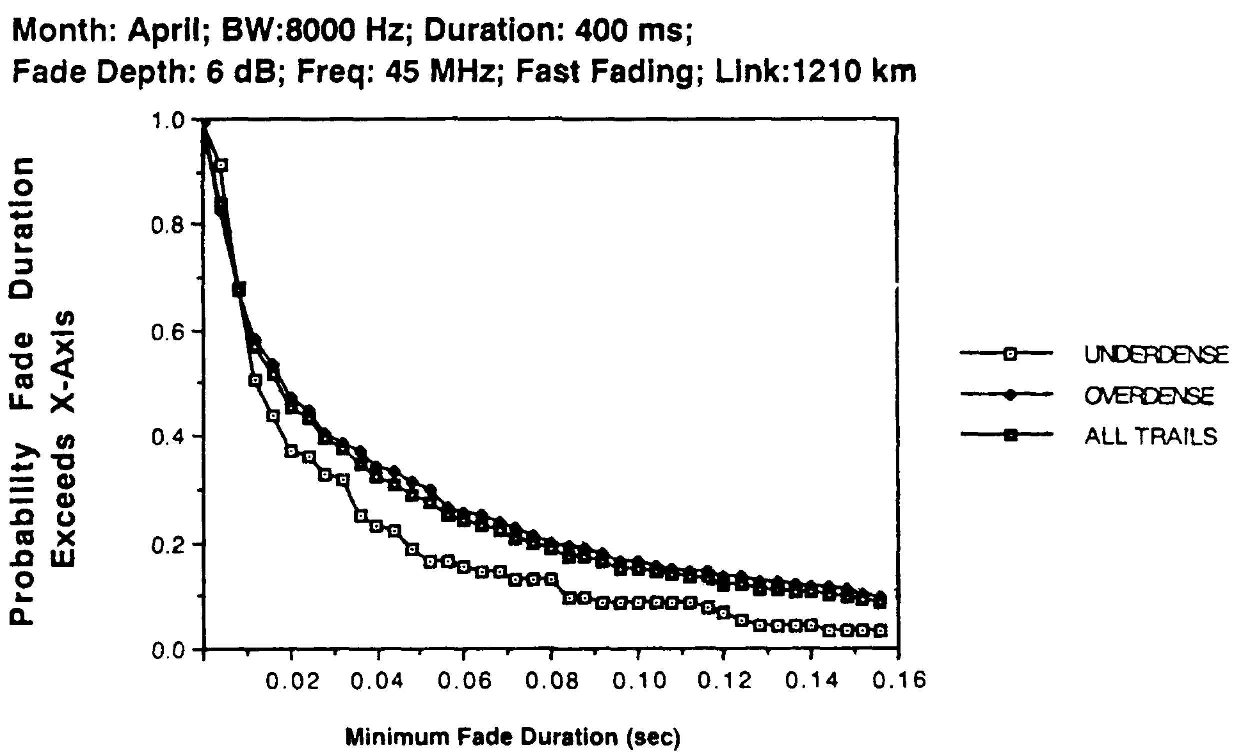
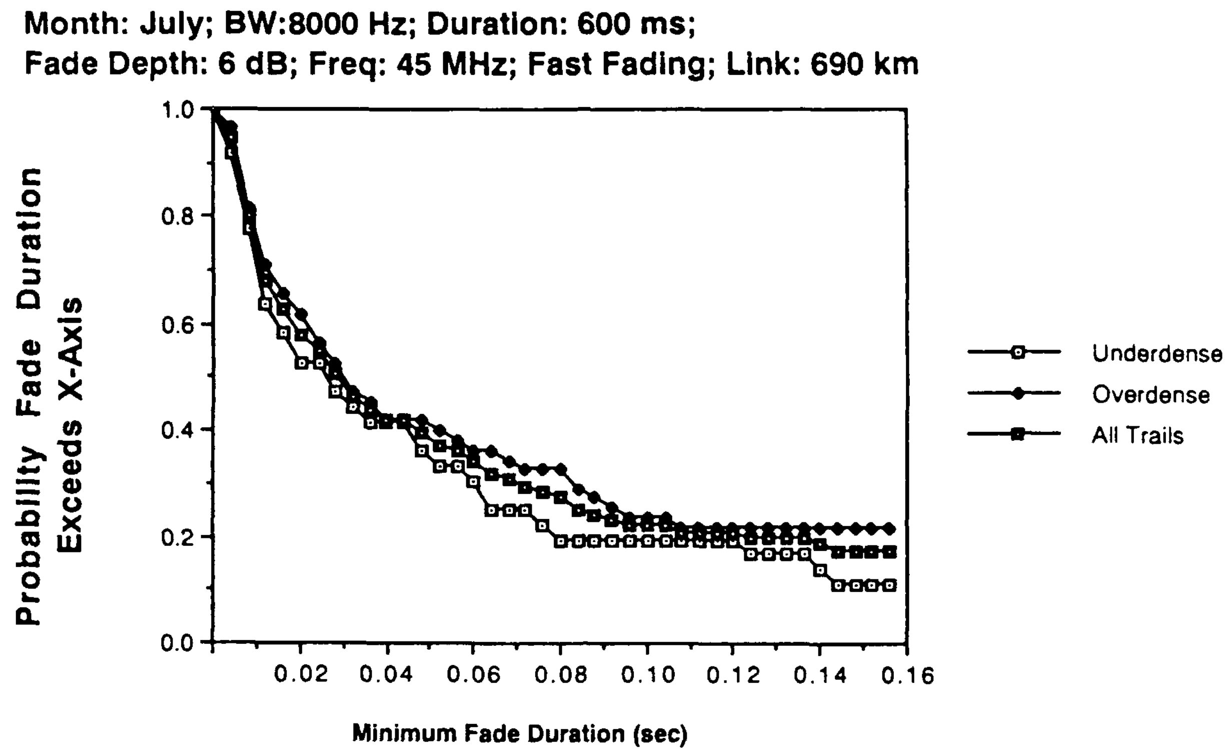


Figure 15. Cumulative Probability Distribution Function; 400 ms Duration



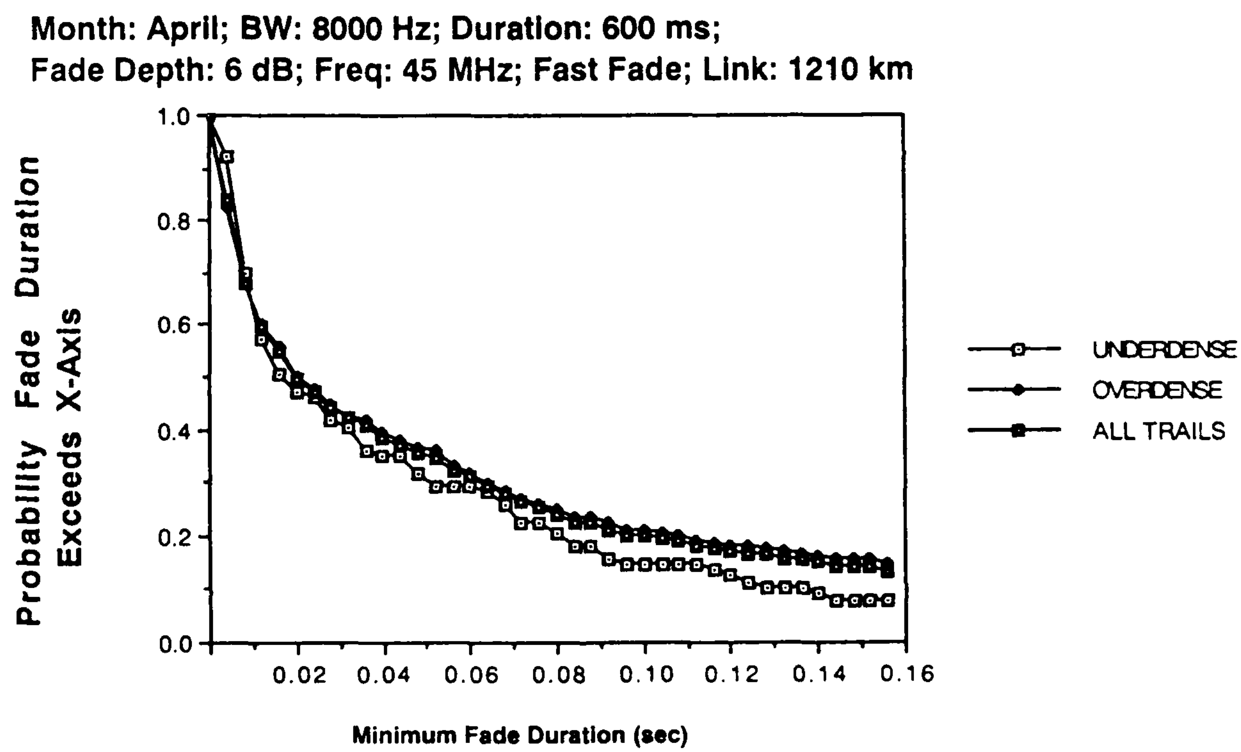


Figure 16. Cumulative Probability Distribution Function; 600 ms Duration

3.0 DISCUSSION

In the two high resolution data sets, the trends were for the most part consistent with the previous lower resolution experiment. The primary difference observed was in the percentage of trails classified as underdense and overdense. Data from the fast fade experiment tended to show more underdense trails as opposed to the slow fade data.

In terms of percentages of trails showing fading, the results were very consistent between the two different data sets. As expected due to the lower noise margin and the ability to resolve the fine structure of the trails, the percent of trails showing fading was slightly higher for the higher resolution experiment. At trail durations less than 200 ms, the conclusion from the first experiment that the effect of fading is minimal is confirmed.

Consider 100 ms trails at 45 MHz with 6 dB fade depths. For the most part the percentage of underdense trails in which fading was observed was on the order of 1 percent for both the high and low resolution experiments. For the entire trail set between 1 and 4 percent of the trails at 45 MHz showed 6 dB or greater fades. See Table 4.

Table 4. Comparison of High Resolution and Low Resolution Data for 100 ms Duration Trails.

Month(1989)	% und	%ovr	%und-fad	%ovr-fad	%all-fad
Mar	51	49	1	2	1
Jun	37	63	1	4	3
Sep	50	50	1	4	2
Dec	48	52	1	4	2
Apr*	63	37	1	8	4

* denotes high resolution data

At 200 ms duration the results were similarly consistent. Approximately 2 percent of the underdense trails exhibited fading and approximately 8 percent of all the trails showed fading. See Table 5.

Table 5. Summary of High and Low Resolution Measurements for Trails of 200 ms Duration.

Month (1989)	% und	%ovr	%und-fad	%ovr-fad	%all-fad
Mar	49	51	1	6	3
Jun	35	65	2	7	5
Sep	46	54	2	10	7
Dec	43	57	3	11	7
Apr*	61	39	2	15	7

In the analysis of the data several definite trends emerge. Underdense trails tend to show less fading than overdense trails. This was consistent between the two experiments. As the trail duration increases, the probability of fading increases. As expected, as the trail duration increases, the percentage of underdense trails decreases. As signal level increases, the percentage of underdense trails decreases so the percent of trails with fading will increase. As expected from the analysis of Manning, wind induced effects become apparent at about 400 ms trail duration at which the percentage and depth of fades increases. For long duration trails (defined as those exceeding approximately 250 ms), model predictions must be made more pessimistic to take into account the effects of fading.

Analysis showed that approximately 50% of the fade durations were less than 20 ms. Given the distribution of fades, techniques such as interleaving combined with forward error correction coding can be very effective in combatting the effect of the fades.

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