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Long-Term Performance and Propagation Measurements on Single and Tandem Digital Microwave Transmission Links

Volume I: Analysis of Measurement Data

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PREFACE

Certain commercial equipment, instruments, or materials are identified in this paper to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

Because of the length of this report, it is divided into three volumes. The first volume is the main body of the report and provides a summary of the propagation and digital radio performance data collected during an 18-month data collection period. The second volume contains appendixes which contain supplementary information. The third volume contains tables and graphs for the first twelve months of data collected on this project. The beginning of the third volume gives an overview of the types of tables and graphs presented within that volume.

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EXECUTIVE SUMMARY

This three-volume report is the result of a project jointly sponsored by the Defense Communications Engineering Center (DCEC) and the U.S. Air Force Electronic Systems Division (ESD). The report provides a summary of the performance and propagation data collected between April 1, 1988 and September 30, 1989. Performance data were collected on a 64-kb/s mission channel from Berlin to Feldberg, Germany, a 64-kb/s mission channel from Linderhofe to Feldberg, and a 56-kb/s service channel between Schwarzenborn and Feldberg. A variety of propagation data were collected on the Schwarzenborn-to-Feldberg link. In addition, received signal level (rsl) data from the Transmission Monitor and Control (TRAMCON) System were collected on all of the line-of-sight (LOS) links in the Frankfurt North Phase I (FKT-N1) Segment of the Digital European Backbone (DEB). Some propagation data were also collected on the Berlin-Bocksberg troposcatter link by the Link Performance Monitoring System. During the 18-month measurement period, over 6 Gbytes of data were collected and analyzed. Data were processed on a monthly basis and provided to the sponsoring organizations.

The objectives of this project were

- to obtain data needed to verify existing Defense Communications System (DCS) link design methods, models, and criteria,
- to compare measured performance with Draft MIL-STD-188-323 link and network design objectives,
- to compare measured performance with network performance objectives contained in CCITT Recommendation G.821 and related CCIR Reports and Recommendations, and
- to quantify Digital Radio and Multiplex Acquisition (DRAMA) radio performance on long LOS links and investigate alternative methods of DRAMA radio space diversity switching.

These objectives are described in further detail in the statements of work, which were part of the agreements between the Institute of Telecommunication Sciences (ITS), DCEC, and ESD.

This report is the final report for the project and is divided into three volumes. The first volume contains a summary and analysis of the measured data. The most important results of this project are presented and discussed in this volume. The second volume contains appendixes that describe details of the data acquisition and data analysis software, the testing of the Network Performance Characterization/Link Performance Characterization (NPC/LPC) hardware and software, and other information needed for the full understanding of the objectives and execution of this comprehensive data acquisition and data analysis program. The third volume contains 14 tables and 124 graphs (figures), which summarize the measured data for the first 12 months of this program.

Table 1 - Executive Summary provides a summary of the measured data. The table contains ratios of the measured value to the stated objective for each parameter. In examining this table, it should be noted that the Draft MIL-STD-188-323 is a design standard rather than an operational standard. The CCITT/CCIR Reports and Recommendations discussed in Section 2 and referenced in Section 7 provide network performance objectives. Although one may expect a lower level of measured operational performance than the design objectives, it is, nonetheless, instructive to make the comparisons of the measured data to the objectives. These comparisons are shown as the ratios provided in the table. The table provides errored second (ES) and unavailability (UA) data for both the MIL-STD-188-323 and CCITT standards. As explained in Section 2, the definitions for these two quantities are different in the two standards. The table also provides severely errored second (SES) and degraded minute (DM) information, which are parameters defined in CCITT Recommendations (see Section 2 of this report).

The first observation is that the long (99-km) Schwarzenborn-Feldberg (SBN-FEL) link performed quite well. On the other hand, the Linderhofe-Feldberg (LDF-FEL) channel performance was worse than either the MIL-STD-188-323 design objectives or the CCITT/CCIR network performance objectives. This is surprising because the LDF-FEL channel includes only four links, the longest of which is the SBN-FEL link. The next observation that can be made from the table is that the LDF-FEL channel came closer to meeting the Draft MIL-STD-188-323 objectives than it did to meeting the CCITT/CCIR objectives. From this one may conclude that the CCITT/CCIR objectives are more stringent than the MIL-STD-188-323 objectives. As noted in Section 5.1.2 of the report,

Table 1 - Executive Summary. Ratio of Measured Annual Performance Values to Specified Objectives

Parameter	SBN-FEL	LDF-FEL	BLN-FEL
MIL-STD-188-323 UA	0.1	1.3	5.9
MIL-STD-188-323 ES	0.4	6.8	30.4
CCITT/CCIR UA	0.2	7.4	5.6
CCITT/CCIR ES	0.4	6.9	109.3
CCITT/CCIR SES	1.0	19.1	16.1
CCITT/CCIR DM	2.3	68.2	720.9

Notes:
1) SBN-FEL meets all MIL-STD-188-323 recommended limits
2) LDF-FEL and BLN-FEL do not meet any MIL-STD-188-323 recommended limits for any of the specified performance parameters

commercial terrestrial transmission networks have met the objectives stated in the CCITT/CCIR Recommendations and Reports. Thus, we conclude that the performance of the Frankfurt North Segment of the Digital European Backbone is lower than that of similar commercial networks.

The major results, conclusions, and recommendations are provided in Section 6 of Volume I. They are summarized in an abbreviated form below. The technical results are factual summaries of the measured results. The conclusions and recommendations are those of the authors and are based on the major technical results of this extensive measurement program. These conclusions and recommendations do not necessarily reflect the official position of the Defense Communications Agency or the U.S. Air Force Electronic Systems Division.

Summary of Major Technical Results

1. Measured performance on the long, line-of-sight SBN-FEL link was better than all MIL-STD-188-323 design objectives and better than most CCITT/CCIR network performance objectives.
2. Except for one month (January 1989), multipath was not a significant factor affecting performance on the SBN-FEL links.
3. DRAMA Radio space diversity performance was satisfactory on the SBN-FEL link.
4. The current space diversity switching algorithm performed better than any of the hypothetical space diversity switching algorithms suggested as possible improvements for the DRAMA radio.
5. The measured space diversity improvement factor was much less than that predicted by space diversity improvement (SDI) prediction algorithms.
6. The median rsl's for four of the five LOS links were several decibels (dB) below those predicted but were generally well above the flat fade threshold for the DRAMA radio (this does have the net effect of reducing the expected fade margin, however).
7. LDF-FEL and BLN-FEL channels were substantially worse than MIL-STD-188-323 design objectives and CCITT/CCIR network performance objectives.

8. The performance of LDF-FEL channel was significantly worse than the performance of comparable commercial LOS microwave channels.

9. Unavailability time on the LDF-FEL channel (17.0 hours) was very high in comparison with the unavailability time on the SBN-FEL link (0.22 hours).

10. The total errored seconds for twelve months on the LDF-FEL channel (121,255 errored seconds) was very high in comparison with the total errored seconds for the SBN-FEL link (2,347 errored seconds).

11. The 15-minute average bit error ratio (BER) for the SBN-FEL link was worse than $1x10^{-3}$ only 0.2% of the time and worse than $1x10^{-6}$ only 0.6% of the time.

12. The 15-minute average BER for the LDF-FEL channel was worse than $1x10^{-3}$ 1.2% of the time and worse than $1x10^{-6}$ 32% of the time.

13. The 15-minute average BER for the BLN-FEL channel was worse than $1x10^{-3}$ 0.5% of the time and worse than $1x10^{-6}$ 98% of the time.

Conclusions

1. The DRAMA radio performed well on the long SBN-FEL link--no modifications to the space diversity switching algorithm should be made.

2. If 1×10^{-6} and 1×10^{-3} are considered BER thresholds for acceptable performance for data and voice service respectively, then the BLN-FEL channel will provide poor service to data communications users 98% of the time and poor service to voice users 3.5% of the time.

3. The LDF-FEL channel would provide poor service to data communications users 34% of the time and poor service to voice users 1% of the time.

4. Based on measured errored seconds and BER performance, data users on the Berlin-Bocksberg troposcatter link would benefit from channel coding to ensure adequate performance.

5. TRAMCON is capable of providing rsl and pseudo-error performance data that are potentially valuable to both the operational and R&D communities.

6. The NPC/LPC data base contains valuable propagation data applicable to the refinement of the outage prediction techniques used for LOS microwave transmission networks.

Recommendations

1. The cause of high errored seconds and unavailability on DEB FKT-N1 line-of-sight microwave links should be further investigated.
2. TRAMCON software should be modified to provide historical archives of rsl, errored seconds, and BER.
3. No changes to the DRAMA radio space diversity switching algorithm should be made.
4. Further analysis of channel probe and other propagation data should be made and applied to outage prediction for LOS transmission systems.
5. Further analysis of the channel error statistics should be made and applied to development of channel coding requirements, channel modeling, and outage prediction.
6. NPC/LPC data should be applied to standards for operational performance objectives.

LONG-TERM PERFORMANCE AND PROPAGATION MEASUREMENTS ON SINGLE AND TANDEM DIGITAL MICROWAVE TRANSMISSION LINKS

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This report describes the results of an 18-month digital microwave radio performance and propagation measurement project that was conducted on a portion of the Defense Communications System in Germany. More than 6 gigabytes of data were collected between April 1988 and October 1989.

The collected data include end-to-end (user-to-user) performance data, radio performance and propagation data on one line-of-sight and one troposcatter link, and meteorological data. The end-to-end measurements are referred to as the Network Performance Characterization (NPC) data, and consist of error performance measurements on two separate 64-kb/s channels consisting of tandem terrestrial microwave links. The radio performance and propagation measurements are referred to as the Link Performance Characterization (LPC) data. These data consist of digital radio performance and propagation measurements made on a long (99-km) line-of-sight microwave link. The propagation measurements on this link include multipath delay spread, in-band power difference (IBPD), and receive signal level (rsl) measurements.

The report provides summaries of the long-term statistics of both radio performance and propagation data. The performance data are compared with both CCITT and Military Standard (MIL-STD) performance criteria. The propagation data are used in the assessment of the causes of digital radio outages. The propagation data are also useful for a variety of modeling purposes. These applications of the propagation data are described in the report.

Key words: CCITT; DEB; Digital European Backbone; digital microwave radio; digital radio performance; DRAMA; IBPD; in-band dispersion; linear amplitude difference; LOS propagation; MIL-STD; multipath fading; propagation measurements; radio outages; transmission system performance standards; troposcatter

1. INTRODUCTION

This report describes the results of an 18-month digital radio performance and propagation measurement program on the Frankfurt North Phase I (FKT-N1) segment of

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the Digital European Backbone (DEB). The report provides the results of two separate, but highly interrelated, projects:

- Defense Communications System (DCS) Network Performance Characterization (NPC) Project
- Schwarzenborn-Feldberg Link Performance Characterization (LPC) Project

The goals of the Network Performance Characterization project were to obtain long-term (18-month) end-to-end performance data on two 64-kb/s channels, and to measure or to estimate the contributions to error performance from each of the individual links in the end-to-end channel. The goals of the Link Performance Characterization (LPC) project were to characterize Digital Radio and Multiplexer Acquisition (DRAMA) radio performance on a long line-of-sight link, and to provide specific measurements in support of the NPC project.

The data resulting from the NPC/LPC measurements will be used to refine DCS digital transmission criteria, link modeling and design methods, and to quantify DRAMA radio performance on tandem line-of-sight links (see Appendix I and Thomas et al., 1979, for descriptions of DRAMA equipment). There is no existing data base on long-term DRAMA performance. The data will also be used to determine if improvements to the DRAMA radio are required.

The Digital European Backbone is a U.S.-owned and operated digital transmission network that stretches across the European Theater from the United Kingdom to Italy. The majority of the links are line-of-sight (LOS) microwave radio links that utilize the Digital Radio and Multiplexer Acquisition (DRAMA) Equipment. Two of the links are troposcatter radio links. Figure 1 depicts the Frankfurt North Phase I (FKT-N1) Segment of DEB. A description of DEB may be found in the DEB Management Engineering Plan (DCA, 1980) and a description of the DRAMA transmission equipment may be found in Thomas et al. (1979).

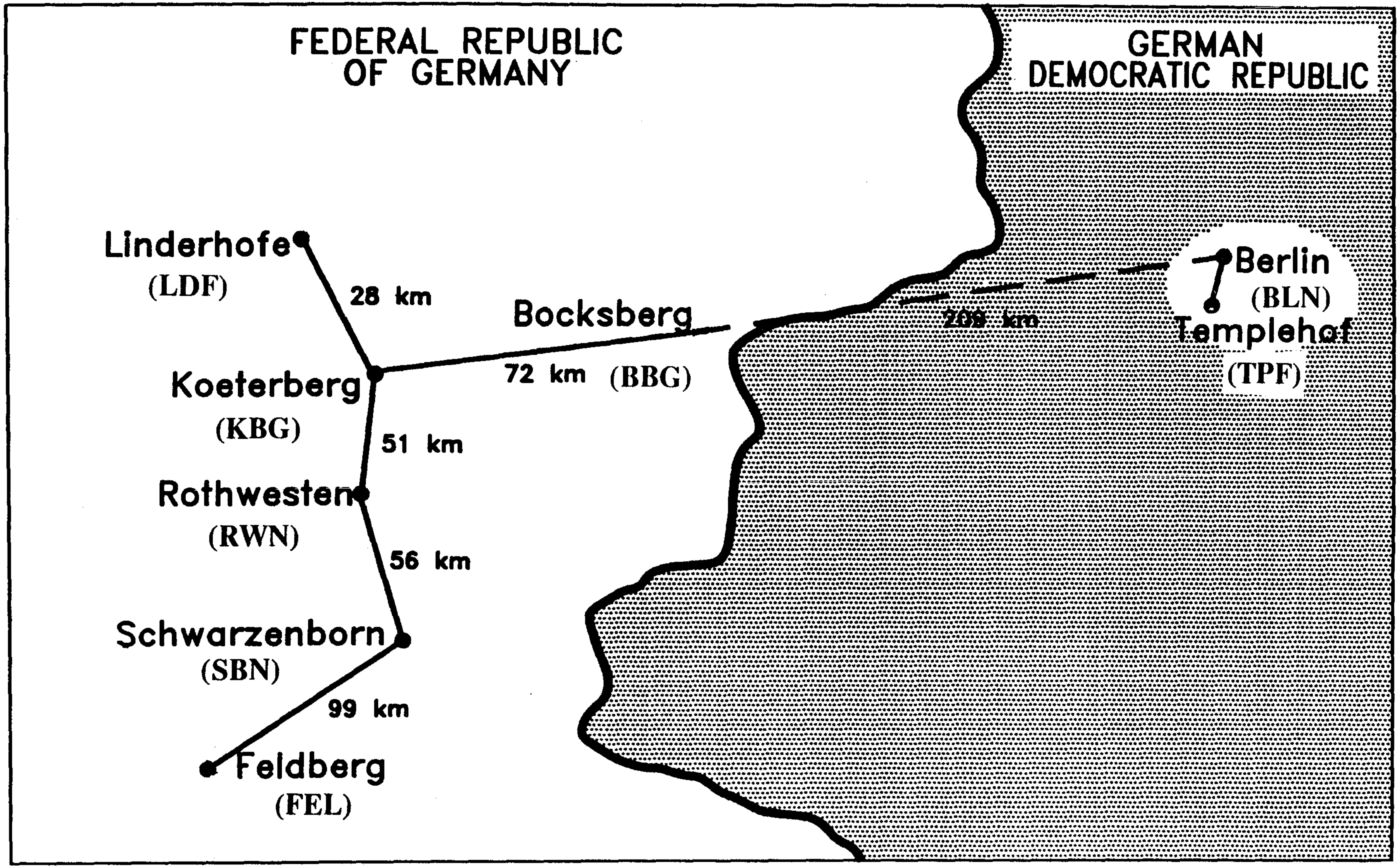

Figure 1. Frankfurt North Phase I Segment of DEB.

The NPC measurements consisted of end-to-end digital error performance measurements on two 64 kb/s channels. The first channel, from Berlin to Feldberg (BLN-FEL), consists of one troposcatter link in tandem with four line-of-sight (LOS) microwave links. The second channel, from Linderhofe to Feldberg (LDF-FEL) consists of four tandem LOS links. As can be seen in the figure, three of the LOS links are common to both the BLN-FEL and LDF-FEL channels. Jitter and end-to-end delay measurements were also made on these two channels.

The LPC measurements were made on the Schwarzenborn to Feldberg LOS microwave link. The LPC data were integrated with the NPC data in a common data base. Both parts of this integrated data set are needed to characterize the system performance of the Frankfurt North Segment of DEB and to compare this performance with that specified by draft MIL-STD-188-323 (DCEC, 1985; Smith and Cybrowski, 1985) and CCITT Recommendation G.821 (CCITT, 1984).

This measurement program was not conducted as a retest of the Frankfurt North Phase I Segment of DEB. Instead, the joint measurement program was considered to be a characterization of actual 64- and 56-kb/s user performance achieved on a portion of the Defense Communications System (DCS). A major purpose of this characterization was to determine the adequacy of draft MIL-STD-188-323 and CCITT Recommendation G.821 for the performance specification for transmission networks within the DCS. The criteria and allocations contained in draft MIL-STD-188-323 required validation with performance data from operational tandem links. Prior to this effort, there was no existing data base on long-term 64- and 56-kb/s user end-to-end performance in a tandem digital link network.

It should be emphasized that draft MIL-STD-188-323 contains design objectives that may be more stringent than the operational specifications found in the Defense Communications Agency Circulares such as DCAC-300-175-9 (DCS Operating-Maintenance Electrical Performance Standards; DCA, 1986). The CCITT also distinguishes between Equipment Design Objectives (EDO), Network Performance Objectives (NPO), and Prompt Maintenance Limits (PMA) (CCITT, 1986d; Ivanek, 1989, pp. 56-59).

A second major purpose of the measurement program was to quantify DRAMA radio performance on an actual link within the DCS rather than on a test link such as the one at Pt. Mugu (Hubbard, 1983). Both the Network Performance Characterization and the Link Performance Characterization projects were long-term (18-month) measurement programs in contrast to the DEB link tests which were 72 hours in length.

The general objectives of the NPC/LPC Program were to:

- verify existing DCS link design methods, models and criteria
- compare measured performance with draft MIL-STD-188-323
- compare measured performance with CCITT Recommendation G.821
- quantify DRAMA radio performance on long LOS links and investigate alternative methods of DRAMA radio space diversity switching

To achieve these objectives, bit error rate test sets (BERTS) were placed on the two end-to-end channels (BLN-FEL and LDF-FEL) and on the Schwarzenborn-Feldberg (SBN-FEL) link. Data were also obtained from two monitor systems: the Transmission Monitor and Control (TRAMCON) System and the Berlin-Bocksberg Link Performance Monitor System (LPMS). The integrated data base contains additional data on the SBN-FEL link including: DRAMA radio signals (received signal level and signal quality monitor voltages, samples of the DRAMA radio receiver signal spectrum, and measures of the spectral amplitude distortion) and multipath fading data obtained from the ITS line-of-sight channel probe. Meteorological data were also obtained, but were not integrated into the combined data base.

The objectives of this combined measurement program are discussed in more detail in Section 2 of this report. For the measurements that were made, the data acquisition system, and the data analysis system (hardware and software), are described in Section 3. Details of these data acquisition and analyses systems are contained in the appendixes (Volume II). Section 4 contains a data summary and analysis of data obtained from the end-to-end channel measurements (Network Performance Characterization). Section 5 contains a data summary and analysis of data obtained from the Link Performance Characterization. Conclusions and recommendations may be found in Section 6. References are in Section 7.

2. MEASUREMENT PROGRAM OBJECTIVES

As stated in the introduction, the general objectives of the network and link performance characterization project were to obtain data necessary to:

- verify DCS link design methods, models, and criteria
- compare measured performance with draft MIL-STD-188-323
- compare measured performance with CCITT Recommendation G.821
- obtain long-term DRAMA radio performance data on tandem LOS links and
- investigate alternative methods of DRAMA radio space diversity switching.

These four objectives are discussed in detail in Sections 2.1, 2.2, 2.3, and 2.4 respectively. Section 2.5 describes some secondary objectives that could be met by additional analysis of the data. No additional data collection is required to meet these secondary objectives, only additional analysis.

The data that were collected included error performance, availability, loss of synchronization, transmission delay, Transmission Monitor and Control (TRAMCON) data, Berlin-Bocksberg troposcatter Link Performance Monitoring System data, channel propagation data, and meteorological data. The data will be used by the Defense Communications Agency (DCA), the Defense Communications Engineering Center (DCEC), and the Military Departments (MilDeps) to verify and modify, if needed, current digital transmission link and system performance criteria as stated in Management Engineering Plans (MEP's), DCAC 300-175-9, DCAC 300-70-57, and draft MIL-STD-188-323 (DCEC, 1985; Smith and Cybrowski, 1985). The data will also be used for verifying LOS and troposcatter link error performance modeling and radio frequency (rf) link design methods.

2.1 Verification of DCS Link Design Methods, Models, and Criteria

The design of digital transmission systems requires the development of accurate models of the propagation channel and of the digital system performance. These models must be based upon empirical data. Model accuracy and completeness is dependent upon a data collection period sufficiently long to ensure statistical correctness. Although there has been a significant amount of activity in both the private and public sectors in the area of channel modeling and link design methodology, the procedures are incomplete. Examples are the modeling of frequency selective fading and digital radio performance prediction for fading channels.

Smith and Cormack (1984) discuss one approach for outage prediction for digital radio. It is based on the work of Serizawa and Takeshita (1983). Other approaches have been proposed. Rummler has provided a summary of the various outage prediction techniques which have been proposed for digital radio (Ivanek, 1989, Chapter 4). There is current interest in the development of methods which account for the dynamics of multipath fading, and hysteresis in the radio (Elkhouri, et al. 1988). (Hysteresis in digital radios is due to the difference in the amount of signal distortion at which synchronization is lost and the amount of signal distortion at which synchronization is reestablished. Generally, the resynchronization level is higher than the loss-of-synchronization level.) Many of the outage prediction techniques require the use of radio signatures or "m-curves." Hoffmeyer et al. (1986) provide examples of such signatures for the DRAMA radio. One objective of this project was to obtain data needed to validate and compare these models. Specific models that require data for validation include:

- Serizawa and Takeshita simplified method for prediction of multipath fading outage of digital radio
- "M-curve" approach for prediction of multipath fading outage of digital radio (Jakes, 1979)
- multipath occurrence factor model
- space diversity improvement model
- amplitude dispersion model (Vigants, 1981, 1982, 1983, 1984)

It was not the objective of this project to perform all of the analysis needed for model validation. The objective was to collect the appropriate data in the needed format that will allow DCA and the MilDeps later to validate those models currently being developed.

2.2 MIL-STD-188-323 Performance Specifications

Draft MIL-STD-188-323 (DCEC, 1985; Smith and Cybrowski, 1985) provides end-to-end system configuration functions and performance and design standards for long-haul DCS digital transmission. The standards encompass both Government-owned and leased transmission segments composed of LOS microwave, troposcatter, cable, and satellite media (DCEC, 1985). The combined NPC/LPC program provides a data base useful in determining final LOS and troposcatter link specifications contained in draft MIL-STD-188-323. Appendix A provides a summary of the portions of this draft standard that apply to the LOS and troposcatter media. A brief discussion of the draft MIL-STD-188-323 objectives as applied to the Frankfurt North Phase I Segment of DEB is provided below.

The process of performance allocation for digital transmission systems is depicted in Figure 2. Specific objectives are dependent upon the media type, circuit length, type of service provided by the circuit (e.g., voice, bulk data, interactive data, etc.), and multiplex hierarchy. The objectives are divided into two major categories: availability and quality. The inverse of availability, i.e., unavailability, is a measure of long term outages. Unavailability is defined as any loss of continuity or excessive channel degradation (1-s average BER greater than 1×10^{-4}) on the 64-kb/s voice and data user channel if the degradation occurs for a period of 60 consecutive seconds or longer. Disturbances with durations shorter than 60-seconds are covered by the error quality measure. The threshold time of 60 consecutive seconds was chosen to separate propagation effects from equipment failure. However, propagation effects may cause the 60-second threshold to be met on satellite and troposcatter channels (Smith and Cybrowski, 1985). Rain attenuation on LOS links may also cause a propagation-related outage greater than 60 seconds.

Error free seconds (EFS), bit count integrity (BCI), jitter, and delay are measures of the quality of a circuit. The quality of a circuit is considered only when the circuit is available. All of these parameters, except BCI, were measured during the NPC/LPC program. Error free seconds, or its inverse, errored seconds (ES), are further divided into propagation-related and equipment-related service degradations (see draft MIL-STD-188-323 (DCEC, 1985) summary in Appendix A, and Smith and Cybrowski, 1985).

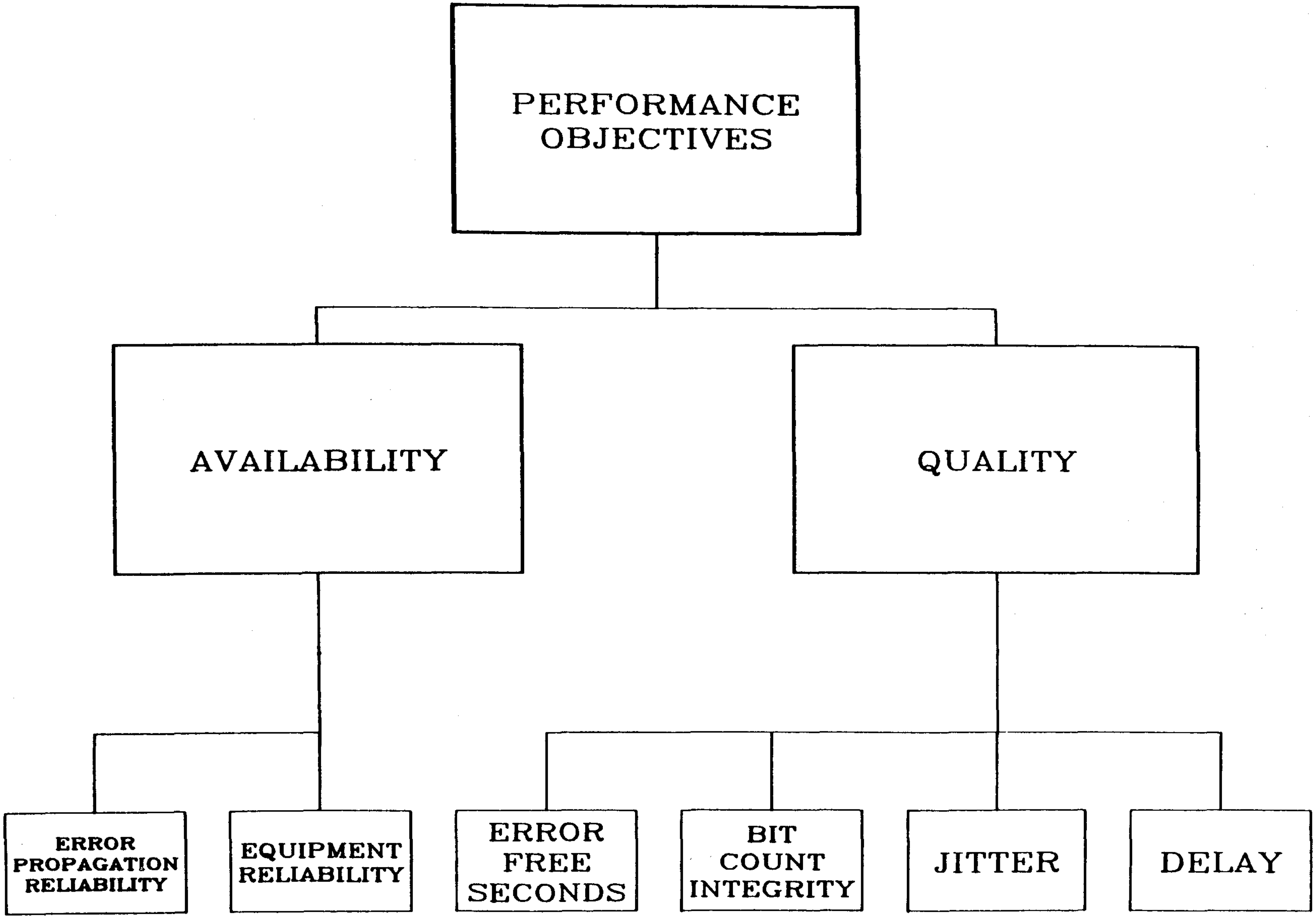

Figure 2. Performance allocation process for digital transmission systems (from draft Military Standard MIL-STD-188-323, System Design and Engineering Standards for Long Haul Digital Transmission System Performance, 30 July 1985).

The MIL-STD-188-323 design objectives for unavailability (UA) and errored seconds (ES) are:

	LOS	Tropo
Unavailability:	2.47×10^{-4}	8.54×10^{-4}
Propagation ES:	$(6.25 \times 10^{-7}) \cdot L$	$(7.1875 \times 10^{-6}) \cdot L$
Equipment ES:	5.8375×10^{-5}	7.7×10^{-5}

L = link distance in km

The above numbers represent the fraction of time that a user channel on a link is allowed to contain errors. For example, the unavailability design objective for an LOS link for 1 year is:

$$(2.47 \times 10^{-4}) \times (24 \text{ hours/day}) \times (365 \text{ days/year}) = 2.2 \text{ hours per year.}$$

The errored-second design objective for propagation is distance-dependent as a result of the "L" parameter in the above ES allocations.

Table 1 applies the LOS and troposcatter availability and EFS quality specifications provided in draft MIL-STD-188-323 (Smith and Cybrowski, 1985) to the individual links and two end-to-end circuits (BLN-FEL and LDF-FEL) of the Frankfurt North Phase I Segment of DEB. As can be seen in the table, the proposed link design objectives are quite stringent. For the Schwarzenborn-Feldberg link for example, all but 3800 seconds in an entire year must be error free excluding the errored seconds that are lumped into unavailability time.

To compare actual link performance with the link design performance required by the proposed MIL-STD, ideally one would make performance measurements on each individual link that comprises the two end-to-end channels as well as end-to-end performance measurements. It was not practical to do this due to cost considerations. The only link on which exact performance measurements were made was the Schwarzenborn-to-Feldberg LOS link. The Link Performance Monitor System was used to make estimates of error performance on the Berlin-to-Bocksberg troposcatter link. For the

Table 1. Proposed MIL-STD-188-323 Unavailability and Quality (ES) Objectives for FKT-N1

Path	Path Length (km)	Type of link	Unavailability Objective (hours)	Quality (ES per year)			Comments
				Propagation Objective	Equipment Objective	End-to-End Objective	
Berlin–Feldberg (BLN–FEL)	487.4	One tropo and four LOS links	16.14	52,860 (14.68 hours)	9,792	62,652 (17.40 hours)	64 kb/s user channel between Berlin and Feldberg
Linderhofe–Feldberg (LDF–FEL)	234.4	Four LOS tandem links	8.65	4,620	7,364	11,984 (3.32 hours)	64 kb/s user channel between Linderhofe and Feldberg
Berlin–Bocksberg (BLN–BBG)	209.0	Tropo	7.48	47,373 (13.16 hours)	2,428	49,801 (13.83 hours)	
Bocksberg–Koeterberg (BBG–KBG)	72.0	LOS	2.16	1,419	1,841	3,260	
Koeterberg–Rothwesten (KBG–RWN)	51.0	LOS	2.16	1,005	1,841	2,846	
Rothwesten–Schwarzenborn (RWN–SBN)	56.0	LOS	2.16	1,104	1,841	2,945	
Schwarzenborn–Feldberg (SBN–FEL)	99.4	LOS	2.16	1,959	1,841	3,800	56 kb/s service channel between Schwarzenborn and Feldberg
Linderhofe–Koeterberg (LDF–KBG)	28.0	LOS	2.16	552	1,841	2,393	

LOS: Unavailability $= 2.47 \times 10^{-4}$
Propagation ES $= 6.25 \times 10^{-7} \times D$

TROPO: Unavailability $= 8.54 \times 10^{-4}$
Propagation ES $= 7.1875 \times 10^{-6} \times D$

other links, a complex algorithm was developed to allocate the end-to-end errors to individual links. Section 3.3 provides an overview of this allocation algorithm, Appendix D provides a detailed description, and the results are presented in Section 5.

Table 2 applies the draft MIL-STD-188-323 mean-time-to-loss-of-bit-count integrity (MTTLBCI) and delay to the links and two end-to-end circuits being measured in the NPC/LPC program.

The draft MIL-STD-188-323 objectives for jitter are the same as those specified by CCITT Recommendation O.171 (CCITT, 1984a). These jitter objectives are summarized in Appendix A. The jitter objectives must be met regardless of the amount of equipment preceding the interface at which the jitter is being measured (DCEC, 1985; p. 23). The jitter measurements were made at Feldberg at both low-speed (64 kb/s) and high-speed (1.544 Mb/s) transmission rates. The low-speed jitter measurements were made on both the Linderhofe-Feldberg channel and the Berlin-Feldberg channel. The high-speed jitter measurements were made on only the Linderhofe-Feldberg channel. As noted in draft MIL-STD-188-323, some of the values for jitter on a 64 kb/s data stream are still under study by the CCITT. These measurements could result in a contribution to the CCITT study group which is responsible for the recommendation on jitter.

It should be emphasized that draft MIL-STD-188-323 contains design objectives that are more stringent than the operational performance specifications found in Defense Communications Agency Circulares such as DCAC-300-175-9 (DCA, 1986). In addition, the Frankfurt North DEB links whose performance was characterized by this effort were not designed to the draft MIL-STD-188-323 objectives.

2.3 CCITT and CCIR Performance Specifications

The CCITT Recommendation G.821 is a specification for Error Performance of an International Digital Connection Forming Part of an Integrated Services Digital Network (CCITT, 1984b). The entire recommendation is provided in Appendix B. The CCITT performance objectives are specified for a 27,500-km Hypothetical Reference Connection (HRX) and then apportioned to local, medium, and high grade circuits which comprise the HRX. Figure 3 depicts the HRX as defined in CCITT Recommendation G.821. The HRX

Table 2. Proposed MIL-STD-188-323 MTTLBCI and Delay Objectives

	Los Link	Troposcatter Segment	320-km Segment	640-km Segment	Berlin-Feldberg	Linderhofe-Feldberg
MTTLBC	113 days	14 days	14 days	7 days	---	---
Delay (One-Way)	---	---	Minimum: 4.176 ms Expected: 4.211 ms Maximum: 4.246 ms	Minimum: 5.253 ms Expected: 5.484 ms Maximum: 5.706 ms	Expected: 7.68 ms (1) (3)	Expected: 6.83 ms (2) (3)

(1) Based on 2 FCC-98's, 6 FCC-99's, 8 LOS Radios, and 2 Tropo Radios in the circuit, and a path length of 467.4 km.

(2) Based on 2 FCC-98's, 6 FCC-99's, 8 LOS Radios, and 2 Tropo Radios in the circuit, and a path length of 214.4 km.

(3) First level multiplexer delay = 3.0 ms
Second level multiplexer delay = 0.0104 ms
LOS Radio delay = 0.0072 ms
Troposcatter Radio delay = 0.0001 ms

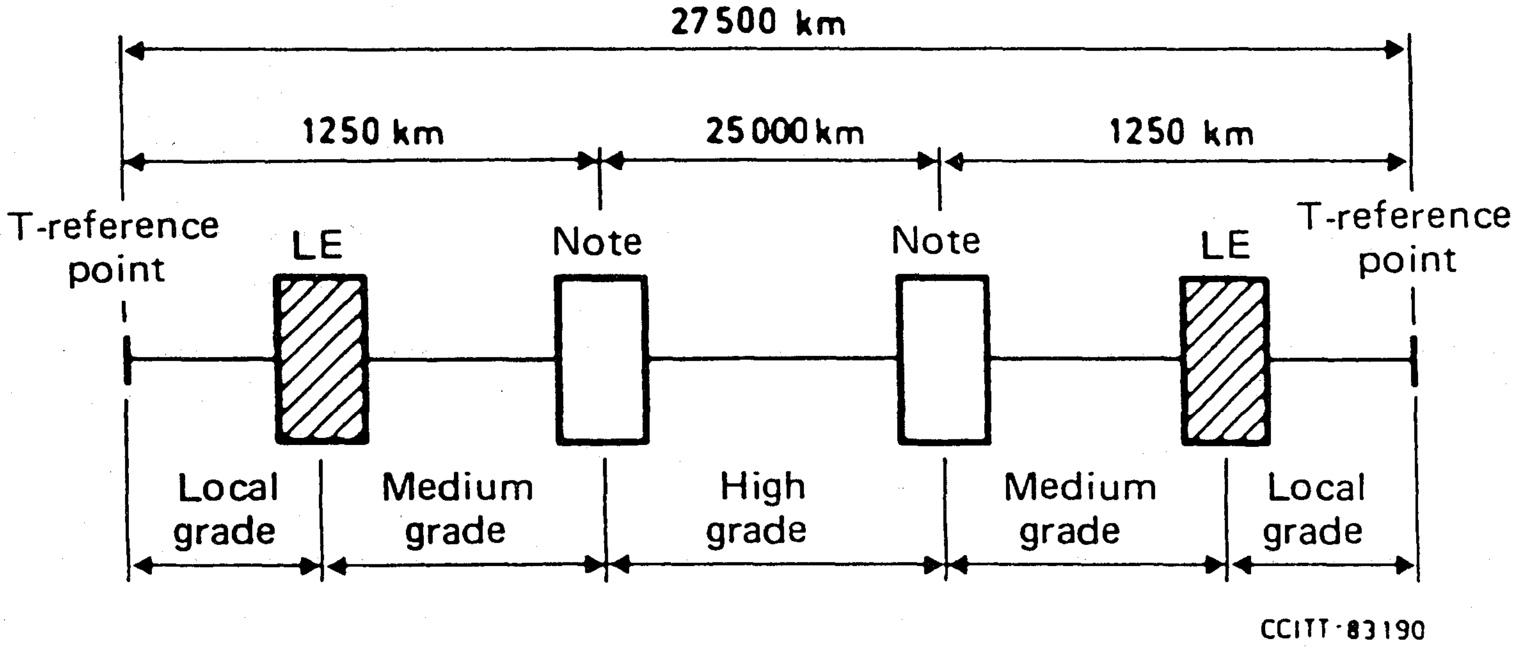

Figure 3. CCITT hypothetical reference circuit (CCITT G.821, Geneva, 1985, Red Book).

is further divided into a 2500-km international circuit as defined in CCITT Recommendation G.104 (CCITT, 1984c) and CCIR Report 556 (CCIR, 1986a).

CCITT Recommendation G.102 provides explanations of the differences between performance and design objectives (CCITT, 1984d). Design objectives are more stringent than performance objectives. The CCITT Recommendation G.821 is an example of a performance objective.

In assessing performance according to CCITT Recommendation G.821, available time is first determined. A 64 kb/s channel is considered unavailable if 64 or more errors occur in each second (BER greater than or equal to 1 x 10^{-3}) for 10 or more consecutive seconds. Unavailable time is first determined before calculating the following three error performance parameters:

- severely errored seconds (SES): the number of seconds in which the BER is worse than or equal to 1 x 10^{-3} (64 or more errors in a second); SES is computed only for the periods in which the system is considered available, i.e., errored seconds meeting the unavailability criterion are first subtracted from the total seconds in which one or more errors occur

- degraded minutes (DM): a minute is considered to be degraded for a 64-kb/s channel if 4 or more errors occur within the minute (corresponds to a BER of 1.04 x 10^{-6}); DM is computed after first subtracting out both unavailability time and SES time from the total seconds in which one or more errors occur

- errored seconds: all seconds that contain errors after unavailability time has been subtracted from the total seconds in which one or more errors occur

The rationale for the definition for severely errored seconds is that 1 x 10^{-3} is the BER threshold beyond which degradation becomes unacceptable to most services and some systems such as multiplexers may lose frame alignment (Ivanek, 1989, p 35). The degraded minute BER threshold (1 x 10^{-6}) was chosen because this is the BER at which degradations to PCM (pulse code modulation) telephony first become perceptible.

The CCIR Hypothetical Reference Digital Path (CCIR, 1986a) and the allowable bit error ratios (CCIR, 1986b) are compatible with the CCITT G.821 Recommendation. The CCIR defines an additional parameter called the residual bit error ratio (RBER). The

RBER is the error ratio in the absence of fading and includes allowance for system-inherent errors, environmental and ageing effects and long-term interference.

CCIR Recommendations 634, 1052, and 1053 allocate performance objectives to high-, medium-, and local-grade portions of an ISDN circuit respectively (CCIR 1986c, 1986d, and 1986e). The performance objective allocations for high-grade circuits are as follows (CCIR, 1986c):

- Severely Errored Seconds:
  BER $> 1 \times 10^{-3}$ for ($2.16 \times 10^{-7} \times L$) seconds of any month
  (L is the path length in km)
- Degraded Minutes:
  BER $> 1 \times 10^{-6}$ for ($1.60 \times 10^{-6} \times L$) minutes of any month
- Errored Seconds:
  Errored seconds for no more than ($1.28 \times 10^{-6} \times L$) of any month
- Residual Bit Error Ratio:
  RBER $< (2 \times 10^{-12}) \times L$

Where L is the path length in km; the above performance objectives apply to real digital radio links between 280 and 2500 km long.

Table 3 is an application of the objectives of CCITT Recommendation G.821 and CCIR Recommendation 634 to the links and two end-to-end channels in FKT-N1. Note that the CCITT and CCIR do not provide different standards for different transmission media. Thus, the LDF-FEL end-to-end channel, which is comprised of only LOS links, has errored seconds, severely errored seconds, and degraded minute requirements nearly as severe as the BLN-FEL end-to-end channel which includes one troposcatter link as well as four LOS links. The only difference in the CCITT-required performance for these two links is due to path length. Thus, the MIL-STD, which does have different unavailability and errored second requirements for troposcatter and LOS, is more realistic for military transmission systems.

Table 3. CCITT G.821 Objectives Applied to FKT-N1

Path	Path Length (km)	Errored Seconds Per Year (1)	Severely Errored Seconds Per Year (2)	Degraded Minutes Per Year (3)
Berlin-Feldberg (BLN-FEL)	487.4	19,672 (5.4 hours)	3319	411
Linderhofe-Feldberg (LDF-FEL)	234.4	9,460 (2.6 hours)	1596	198
Berlin-Bocksberg (BLN-BBG)	209.0	8,436 (2.3 hours)	1424	176
Bocksberg-Koeterberg (BBG-KBG)	72.0	2,906 (0.8 hours)	490	61
Koeterberg-Rothwesten (KBG-RWN)	51.0	2,058 (0.6 hours)	347	43
Rothwesten-Schwarzenborn (RWN-SBN)	56.0	2,260 (0.6 hours)	381	47
Schwarzenborn-Feldberg (SBN-FEL)	99.4	4,012 (1.1 hours)	677	84
Linderhofe-Koeterberg (LDF-KBG)	28.0	1,130 (0.3 hours)	191	24

(1) Fraction of errored seconds is 1.28×10^{-6}per km (CCITT Rec. G. 821 allocation for high grade circuits.)

(2) CCITT Rec. G.821 states that each 2500 km high grade portion may contribute not more than 0.004% of the severely errored seconds. CCIR recommends that the fraction of seconds which are severely errored must be 2.16×10^{-7}per km or better.

(3) Fraction of degraded minutes is 1.6×10^{-6}per km (CCITT Rec. G.821 allocation for high grade circuits.)

There are a number of differences between the way CCITT Recommendation G.821 and draft MIL-STD-188-323 state error performance objectives for digital systems. The differences include:

- draft MIL-STD-188-323 differentiates between equipment and propagation related outages for both availability and quality; CCITT G.821 does not
- draft MIL-STD-188-323 differentiates between types of media (e.g., LOS and troposcatter); CCITT G.821 does not
- draft MIL-STD-188-323 uses only errored seconds; CCITT G.821 uses errored seconds, severely errored seconds, and degraded minutes
- draft MIL-STD-188-323, being a design standard, does not specify whether the errored second measurement be made synchronously or asynchronously; CCITT G.821 specifies that the measurement should be made at fixed time intervals (i.e., asynchronously)
- draft MIL-STD-188-323 states that a channel is unavailable if the one-second average BER is greater than or equal to 1×10^{-4} for 60 consecutive seconds; CCITT G.821 states that a channel is unavailable if the 1-second average BER is greater than or equal to 1×10^{-3} for 10 consecutive seconds

The differences cited above make it difficult to compare Tables 1 and 3. However, one objective of the NPC/LPC program was to collect data that are consistent with the requirements of both standards. This could be done because both standards are based on the errored-second measurement parameter. The errored second measurements were made asynchronously.

It is possible to make a limited comparison of the MIL-STD and CCITT/CCIR errored-second criteria. The MIL-STD requires that fewer than $6.25 \times 10^{-7} \times L$ seconds in a month contain errors. The CCITT/CCIR standards require that fewer than $1.28 \times 10^{-6} \times L$ seconds in any month contain errors. One must be cautious in making this comparison, however. Both standards require that unavailable seconds be deleted prior to adding up the number of errored seconds. As noted above, the definitions for unavailability differ for the two standards.

2.4 DRAMA Radio Performance Measurement Objectives

The objectives stated in the statement-of-work with the U.S. Air Force Electronic Systems Division (ESD) for the Feldberg-Schwarzenborn measurements were to:

- measure DRAMA radio performance on one actual link in DEB and correlate this performance with channel propagation and meteorological measurements
- determine if improvements to the radio are required

These objectives result from questions regarding DRAMA radio performance on long links during periods of multipath fading. In meeting these measurement objectives, data were collected which were also needed in meeting the objectives described in the three previous sections. The data collected on the SBN-FEL link included:

- bit error ratio test set (BERTS) data on a 64 kb/s service channel
- multipath delay spread using the ITS channel probe
- DRAMA radio rsl and signal quality monitor (SQM)
- DRAMA radio spectrum distortion due to multipath
- DRAMA radio status signals
- meteorological data

The BERTS data were used both to evaluate DRAMA radio performance on the long Feldberg-Schwarzenborn link and to validate draft MIL-STD-188-323 performance criteria for LOS links. The multipath data are needed for link design models being developed by DCA and the MilDeps, as well as for the correlation of DRAMA radio performance with fading conditions. The meteorological data were required for detailed analyses of propagation conditions during periods of multipath fading.

The objective of collecting these data was to determine if the DRAMA radio meets performance objectives during periods of fading. The data were used to evaluate the current space diversity switching algorithm, and to determine if other space diversity switching algorithms would provide an improvement. The other switching algorithms that were investigated were ones based on the SQM voltage and on measures of the spectral distortion.

Previous investigations (see Hoffmeyer and Pratt, 1987 and Hubbard, 1983) have indicated that the DRAMA radio may not perform adequately in a frequency-selective fading environment. However, the tests conducted by Hubbard were on a link which has an abnormal amount of fading. The type of fading is the same as that found in Europe; the frequency of occurrence is not. The experiments reported by Hoffmeyer and Pratt were conducted in the laboratory using the ITS line-of-sight simulator. These tests indicated that the DRAMA radio space diversity switching algorithm was not optimal. However, measurements of DRAMA radio performance on an actual link in the DCS were required to determine if propagation-related service degradation occurs frequently enough to warrant an engineering change to the DRAMA radio. The addition of an adaptive equalizer has been proposed and partially evaluated on a link within the continental United States. The data collected on the SBN-FEL link were used to address the need for an adaptive equalizer on an operational DCS link as well as the need for changes to the space diversity switching algorithm.

2.5 Secondary Measurement Objectives

The data collected under the NPC/LPC program are useful for validation of models not previously discussed under Section 2.1. One example is the channel bit error distribution model being developed by ITS (Vogler, 1986a, b). The data collected under this program can be used to validate the Vogler bit error statistical model. The model will be useful for future link design and for simulation of digital transmission networks.

The multipath delay spread data collected on the Schwarzenborn-Feldberg link using the ITS channel probe will be useful in the validation and extension of the model of fading on LOS microwave links. The ITS has constructed a LOS channel simulator based on the Rummler channel model (rummler, 1982) which has been modified to include variable delay spread. This dual-channel simulator has proven useful in the investigation of DRAMA radio performance in a fading environment. Distributions of delay spread and the correlation of fading on the two space diversity channels are needed to permit an evaluation of the diversity improvement factor of space diversity radios. As noted by Greenstein and Shafi (1987), the general treatment of diversity in estimating digital radio outage remains an open issue. The data measurements on the Feldberg-Schwarzenborn link required to meet primary objectives can also be useful in meeting this secondary objective. No additional data collection will be required; only additional data analysis.

The data collected may provide useful inputs to various CCITT/CCIR standardization activities. The availability, error performance, jitter, and propagation data which support channel modeling and simulation are examples of data of interest to various CCITT/CCIR study groups.

3. DATA ACQUISITION AND DATA ANALYSIS SYSTEMS

Figure 4 depicts the inputs and outputs of the NPC/LPC measurement program. These are the NPC-LPC program objectives discussed in the previous section. The bit-error-ratio test set (BERTS) data, the radio performance measurement data, the multipath fading data, and TRAMCON data are recorded by a high-speed data acquisition system on magnetic tape as an integrated data base. A tape containing 60 Mbytes of data was filled approximately every 5 days during the entire 18-month period. The other measurement program inputs shown in the figure are not recorded on the integrated NPC-LPC database.

The Link Performance Monitoring System (LPMS) is a system that was previously developed by another agency. It provides estimates of troposcatter radio performance and propagation measurements on the Berlin-Bocksberg link. These data are recorded on magnetic tape but are not integrated with the remainder of the NPC-LPC database. The LPMS data tapes have been made available to the Institute for Telecommunication Sciences for analysis as part of our effort to characterize the performance of the Frankfurt North I (FKT-N1) Segment of DEB.

The meteorological data and the jitter and delay measurement data were not recorded on magnetic media. Hard copy of meteorological data for several weather stations in Germany was collected and is available for detailed analyses for periods of significant multipath fading.

3.1 Description of Measurement Requirements

The types of data recorded during the 18-month measurement program are:

- bit error performance data on a Berlin-to-Feldberg (BLN-FEL) 64-kb/s mission channel
- bit error performance data on a Linderhofe-to-Feldberg (LDF-FEL) 64-kb/s mission channel

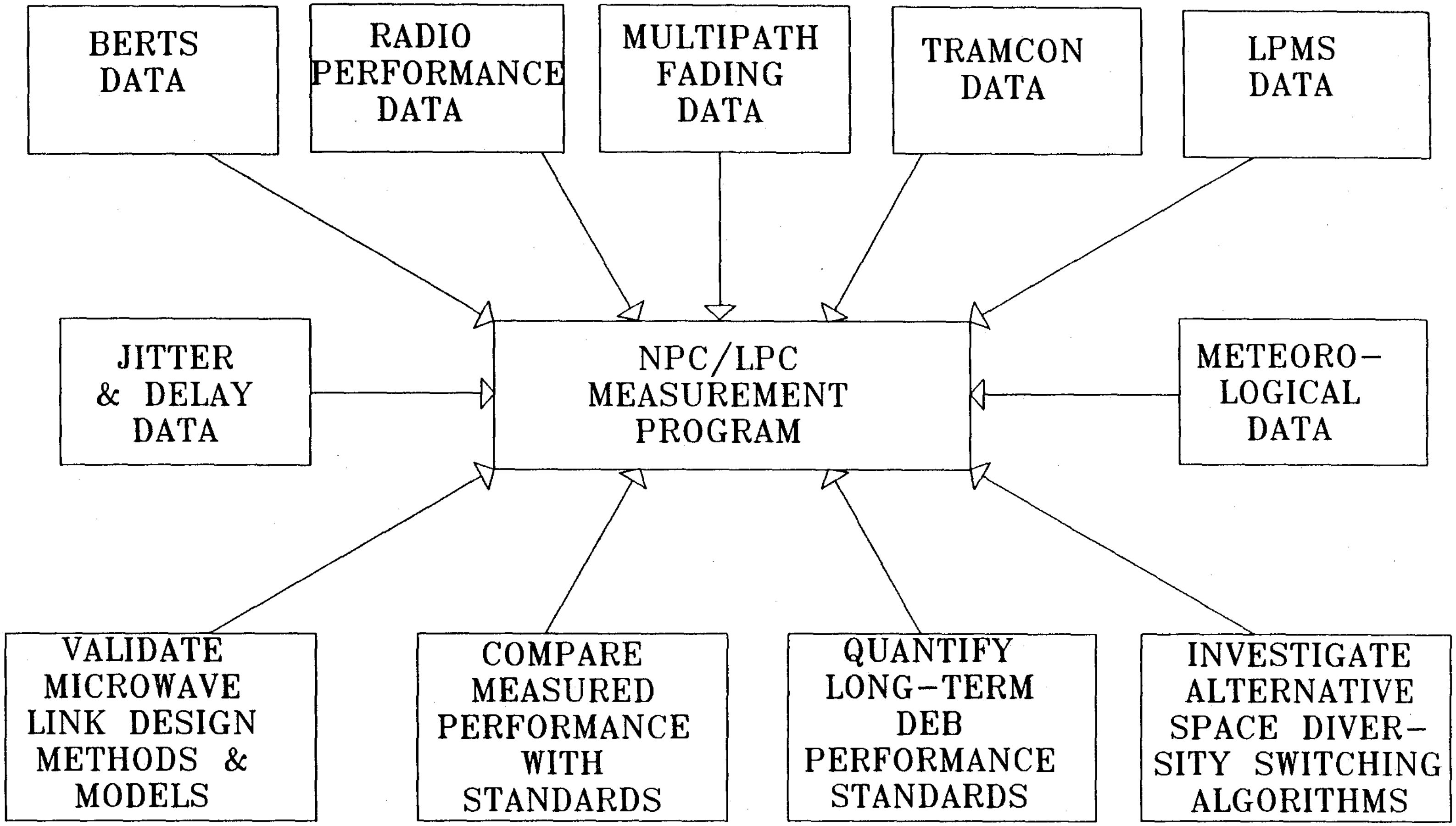

Figure 4. NPC/LPC data input requirements and program objectives.

- bit error performance data on a Schwarzenborn-to-Feldberg (SBN-FEL) 56-kb/s service channel
- measurement of the DRAMA radio receiver at Feldberg (including rsl, SQM, spectrum, and slope distortion voltages)
- line-of-sight channel probe impulse response data on the (SBN-FEL) link
- TRAMCON data
- LPMS data
- meteorological data (hard copy)
- jitter and delay data

A description of how these data were used is provided in the remainder of this section.

3.1.1 Error Performance Measurement Requirements

Table 4 is a list of the user-to-user performance parameters that were measured. The basic unit of measurement used for error rate and availability was the errored second. An errored second is any second that contains one or more errors. One error in one second corresponds to a BER of 1.56 x 10^{-5} for a 64-kb/s channel and 1.78 x 10^{-5} for a 56-kb/s channel. The number of errors that occur in each second, number of consecutive error seconds, and number of consecutive error free seconds are data needed for modeling the burstiness of single and tandem channels (Vogler, 1986a, b). The measurement results for all of the parameters listed in Table 4 are described in Section 5.

Table 5 lists the statistical data derived from the measured data. Data analysis techniques described briefly in Section 3.3 and in detail in Appendix D were applied to the raw data listed in Table 4 to obtain the statistics of Table 5. The collected data permit comparison of measured performance with both the proposed MIL-STD-188-323 and CCITT Recommendation G.821. Measured statistical results for all of the parameters listed in Table 5 are provided in Section 5.

Table 4. User-to-User (64 kb/s) Performance Parameters Measured

a. Errored seconds.

b. Number of errors in each errored second.

c. Length of consecutive errored second occurrence.

d. Length of consecutive error free second occurrence.

e. 15-minute average BER.

f. Troposcatter link rsl, rsl fade rates, modem frame error rate, estimate of multipath dispersion, estimate of mission bit stream error rate*.

g. Individual tandem LOS link rsl's, time below the rsl corresponding to the BER threshold for errored second occurrences to include MIL-STD-188-323 unavailability, radio frame error ratio, radio multiplex loss of frame, space diversity switch occurrences, and estimate of mission bit stream error rate.

h. Delay measured at 64 kb/s.

i. Jitter measured at both 64 kb/s and 1.544 Mb/s.

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*Obtained from the U.S. Army Berlin Command Link Performance Monitor System.

Table 5. Statistics Derived From Measured Data*

a. User-to-User (64 kb/s) errored seconds.

b. Estimate of each individual link contribution to the total errored seconds.

c. Estimate of the errored seconds correlation on tandem links.

d. Distribution of consecutive errored second occurrences.

e. Distribution of consecutive error free second occurrences.

f. Distribution of consecutive fixed 15-minute interval average BER's.

g. Correlation between percent errored free seconds and average BER in consecutive 15 minute intervals.

h. Estimate of errored second contribution due to the single troposcatter link to the total tandem system.**

i. Estimate of errored second contribution due to the tandem LOS links to the total tandem system.

j. Distribution of the number of errors occurring in errored seconds.

k. Fraction of total time where the 1-s BER is worse than $1\text{x}10^{-4}$ for equal to or greater than 60 s (MIL-STD-188-323 unavailability threshold).

l. Correlation of measured data with atmospheric data from other sources (design objective).

* All of these statistics were derived for each consecutive 30-day measurement interval and the overall statistics were derived for the entire measurement period.

**Obtained from U.S. Army Berlin Command Link Performance Monitor System.

The measurements provide exact error performance and unavailability data for the two end-to-end channels (BLN-FEL and LDF-FEL) and one line-of-sight (LOS) link (SBN-FEL). Only estimates of error performance were obtained for the remainder of the links which make up the two end-to-end channels. This is due, in part, to the fact that the nodes on the tandem links are sites with no 64-kb/s channel breakout. It would have been difficult to make exact measurements on each individual link on the two end-to-end channels. Additional multiplexer equipment would have had to have been added to several sites to permit measurements on the 64-kb/s user channel at each node in the circuit and would have been a prohibitively expensive approach. As an alternative, estimates of error performance were made using available sources of data other than direct measurements. For links other than the SBN-FEL link, the TRAMCON system was used to obtain estimates of error performance on individual links as will be described in Section 3.2.4. The TRAMCON system was also used to obtain rsl data on all of the links in the FKT-N1 segment of DEB. The LPMS system was used to make both performance and propagation estimates on the Berlin-Bocksberg troposcatter link as will be described in Section 3.2.5.

3.1.2 DRAMA Radio Performance Measurement Requirements

The DRAMA radio performance measurements were made on one of the three Schwarzenborn to Feldberg 56-kb/s service channels. These data were needed for two reasons. First, they were needed to determine the contribution of one link to the overall end-to-end error performance described in Section 3.1.1. Second, they were required to quantify DRAMA Radio performance over a long measurement period. These data will be used to determine if engineering changes to the DRAMA Radio are required. It is emphasized that the existing operational system was not affected in any way by the measurement system that was installed for this program. No changes were made to the DRAMA radio or to any FCC-98 first-level multiplexer. The switching algorithm in the DRAMA radio was not changed.

Sufficient data were collected to quantify the space diversity improvement factor for each of the following:

the present switching algorithm

- a switching algorithm based on signal quality monitor (SQM) voltage
- a switching algorithm based on amplitude slope distortion

The objective of the slope distortion measurement was to evaluate slope detection circuitry as a possible method for space-diversity switching. Collection of these data on an operational link permitted a realistic evaluation of the technique. The result is compared with performance of both the present switching algorithm, and an SQM-voltage-based switching algorithm described in Section 4.

3.1.3 LOS Propagation Measurement Requirements

Bit error data are insufficient by themselves for the characterization of either network or link performance. One needs to know the environmental, i.e., propagation, conditions in which the performance data were collected. It is important to quantify the amount of multipath fading and to correlate these fading data with the radio performance. The LOS channel probe developed by ITS has been utilized for many years for the measurement of multipath on links similar to the SBN-FEL link. The data obtained from the channel probe provide the following information:

- multipath delay and rate of change of delay on both diversity antennas
- phase and rate of change of phase of the multipath signal relative to the direct signal
- ratio of the signal amplitude of the delayed (multipath) signal relative to the amplitude of the direct signal and the rate of change of these ratios
- occurrence of a second multipath component

These data, combined with spectral and meteorological data and existing ray-tracing and channel probe impulse response analysis programs provide a complete picture of the propagation conditions during those periods in which the performance of the digital radios was degraded. The reports by Kolton (1986), Hubbard (1983), and Hubbard and Riley (1989) provide examples of the manner in which channel probe data are analyzed.

The channel probe delay spread data are used for purposes other than the correlation of DRAMA performance with propagation conditions. They are needed for modeling purposes (e.g., the channel transfer model used in LOS channel simulators) and they also are useful for specification of performance requirements for future adaptive equalizers.

3.1.4 Meteorological Measurement Requirements

Certain atmospheric conditions can cause refractive propagation phenomena conducive to radio multipath. It often is desirable to obtain meteorological data to help in the understanding of propagation conditions extant at the time there is a degradation in digital radio performance. Specifically, radiosonde data consisting of temperature, wet bulb temperature, or dewpoint depression, and atmospheric pressure at several altitudes are required. Ideally, the data would be available on an hourly basis, and at height intervals of about 100 m from the Earth's surface up to about 2000 km. Practically, most meteorological measurements are made once or twice a day, and have much coarser resolution than the desired 100-m resolution. It is desirable to obtain meteorological data from sites near both ends of the communications link, and near the path midpoint. This frequently is not possible.

For the NPC/LPC Program, meteorological data were obtained from the following sites:

• St. Hubert, Belgium	5 24’E	50 02’N
• Hannover, FRG:	9 42’E	52 28’N
• Berlin Templehof, FRG:	13 25’E	52 29’N
• Fritzlar-Kasseler, FRG:	9 17’E	51 08’N
• Kassel, FRG:	9 29’E	51 19’N
• Giessen, FRG:	8 44’E	50 36’N

The Frankfurt and Kassel are the closest meteorological measurement sites to Feldberg and Schwarzenborn respectively. The Giessen site is near midpath on the SBN-FEL link.

3.1.5 End-to-End Channel Delay Measurement Requirements

Proposed MIL-STD-188-323 describes delay limits for the various types of transmission links (LOS, troposcatter and satellite), equipment configurations, and segments. Delay measurements were made on the two end-to-end channels (BLN-FEL) and (LDF-FEL).

3.1.6 Jitter Measurement Requirements

Jitter measurements were made at Feldberg on a 1.544 Mb/s channel from Linderhofe. This channel is composed of four tandem microwave LOS links. No jitter measurements were made at the 1.544-Mb/s rate on the end-to-end channel from Berlin because a bi-polar interface was not available for this channel at Berlin. Low-speed measurements (64 kb/s) were made on both the BLN-FEL channel (which includes one troposcatter link and four tandem LOS links) and on the LDF-FEL channel.

3.2 Overview of the NPC/LPC Data Acquisition System

This section provides an overview of the data-acquisition system that was developed by ITS to meet the data measurement requirements described in Section 3.1. A more detailed description of the data-acquisition system software may be found in Appendix C. Some data-acquisition hardware, such as the channel probe, bit error ratio test sets (BERTS), and slope distortion measurement circuitry, were developed by ITS engineers. All of the data-acquisition real-time applications software was developed by ITS computer systems engineers.

Figure 5 depicts the real-time data-acquisition system that was located at Feldberg. Table 6 lists the specific equipment used in the data-acquisition system, and Table 7 lists the sampling rates used for each of the measurement parameters. The figure and tables provide an overview of the total data-acquisition system. Each of the various components of the system will be described in the following sections.

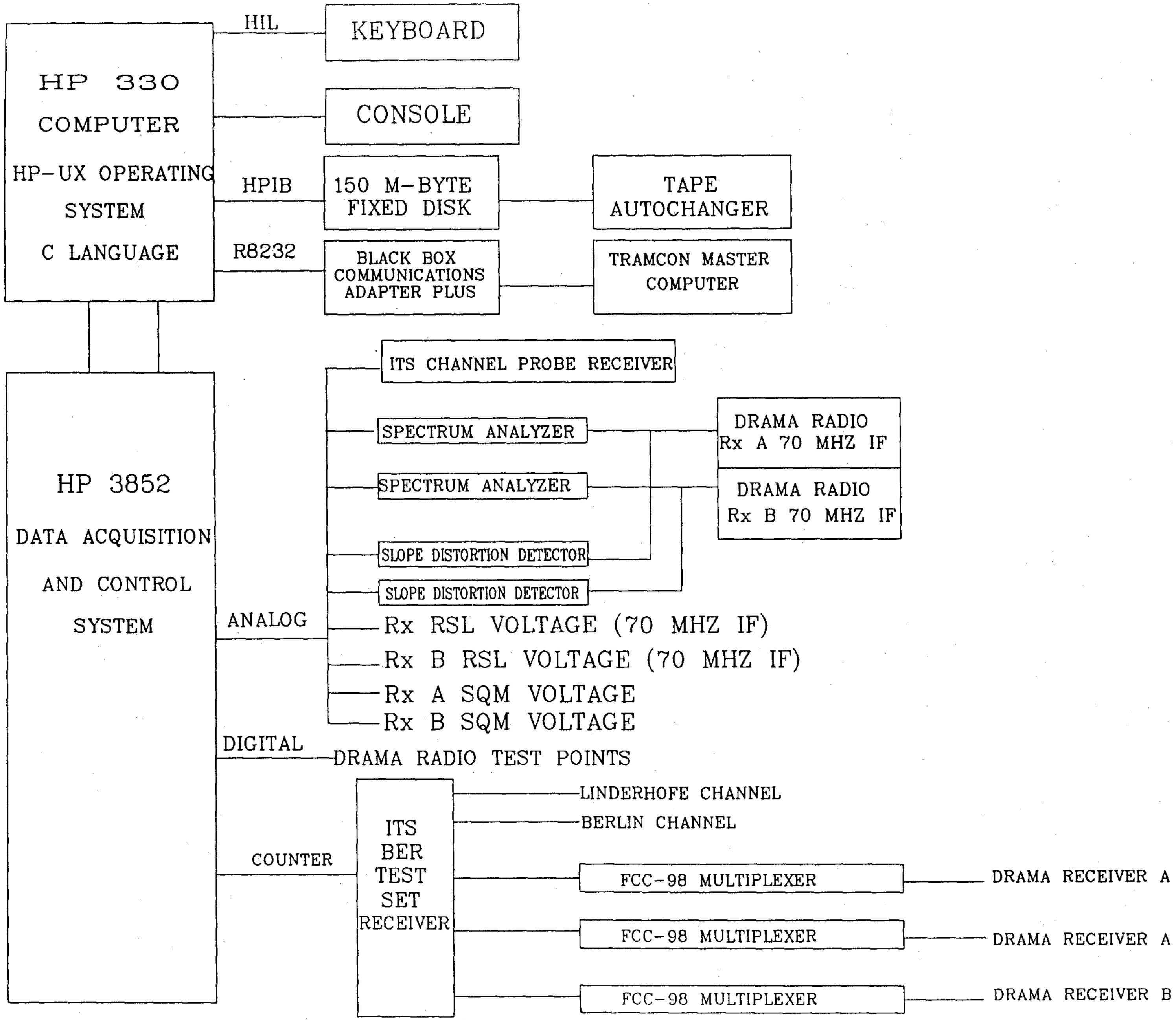


Figure 5. NPC/LPC data acquisition system functional block diagram.

Table 6. List of Measurement System Equipment

HP 98582 M	Computer Model 330M with 2-slot Digital Input/Output Backplane
HP 7958A	Disk Drive (131 Mb)
HP 35401	1/4-inch Tape Autochanger
HP 98622A	GPIO Interface
HP 98517A	HP-UX Programming Environment (1 User)
HP 2225	HP Thinkjet Printer
HP 3852	Data Acquisition and Control System with 1 Mb Extended Memory
HP 44702B	2 X 13 Bit High-Speed Voltmeter
HP 44711A	2 X 24 Channel High-Speed Multiplexer
HP 44715A	5-Channel Counter/Totalizer
HP 44721A	16-Channel Digital Input

Black Box Communication Adapter Plus
2 Phoenix 501 BER Test Sets
ITS 5-channel BER Test Set
ITS Channel Probe
2 ITS Slope Distortion Analyzers
2 Spectrum Analyzers
2 Marker Signal Generators
Uninterruptible Power Supply
2 Omega Time Dissemination Systems

Table 7. Data Acquisition System Sampling Rates and Sample Sizes

Signal	Sample Rate	#Samples
1. Co-phase Probe Ch A	1/s	80
2. Co-phase Probe Ch B	1/s	80
3. Quad-phase Probe Ch A	1/s	80
4. Quad-phase Probe Ch B	1/s	80
5. Signal Spectrum Radio Ch A	5/s	250
6. Signal Spectrum Radio Ch B	5/s	250
7. rsl Radio Ch A	5/s	5
8. rsl Radio Ch B	5/s	5
9. SQM Radio Ch A	5/s	5
10. SQM Radio Ch B	5/s	5
11. Slope Detection A	5/s	5
12. Slope Detection B	5/s	5
13. Slope Detection C	5/s	5
14. Slope Detection D	5/s	5
15. Slope Detection E	5/s	5
16. Slope Detection F	5/s	5
17. Digital Status #1	5/s	5
18. BERTS #1	5/s	5
19. BERTS #2	5/s	5
20. BERTS #3	5/s	5
21. BERTS #4	5/s	5
22. BERTS #5	5/s	5
Total	980 words = 1960 bytes	

All samples are one 16-bit word in length.

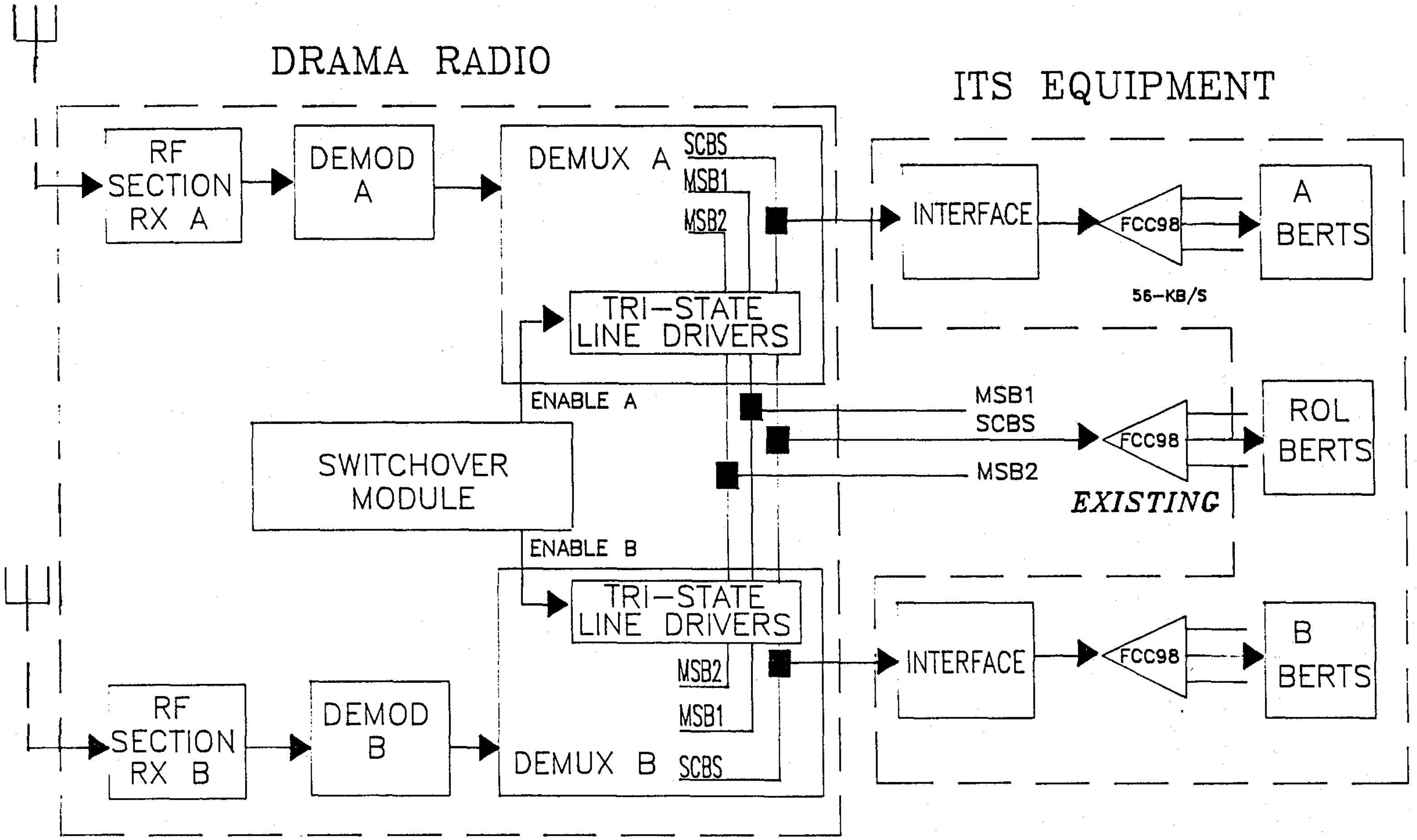
Signals 5-16 are on analog card 1.
Signals 1-4 are on analog card 2.
Signal 17 is on the digital card.
Signals 18-22 are on the counter card.
Signals 1-4 comprise the Channel Probe.
Signals 5-10 and 17 comprise the DRAMA Performance and Status Data.
Signals 11-16 comprise the Spectrum Slope Detection.
Signals 18-22 comprise the BERTS.

3.2.1 Error Performance and Unavailability Measurements

As shown in Figure 5, there are five BERTS receivers that are monitored by the HP-3852 Data Acquisition and Control System (DACS). As noted in Table 7, the number of errors detected by each of the BERTS receivers was sampled five times per second. The ITS built and tested bit error test sets for measuring error seconds and the number of errors which occurred within any given errored second. These test sets were utilized to measure the long-term error performance of a BLN-FEL 64 kb/s mission channel, a LDF-FEL 64-kb/s mission channel, and a SBN-FEL 56 kb/s service channel. The BERTS transmitters were installed by ITS at Berlin, Linderhofe, and Schwarzenborn. The corresponding BERTS receivers were installed at Feldberg.

Normal access to a 56-kb/s service channel can be obtained for the DRAMA radio only after demultiplexing, which occurs after the diversity switch. Performance measurements for each side of the radio, i.e., Receivers A and B, could be accomplished only by gaining access to both the A and B 192-kb/s channels before the diversity switch and demultiplexing each to the 56-kb/s channel that carried the test digital bit stream injected at Schwarzenborn. The objectives of the link performance characterization program included evaluating the present space diversity switching algorithm, and investigating the use of SQM or slope distortion for diversity switching. This could be done only by collecting performance data on both diversity receivers. The way that this was accomplished can be seen in Figure 6, and is explained below.

The DRAMA radio contains an internal multiplexer/demultiplexer that is used to multiplex two 12.928-Mb/s mission bit streams (MBS) with a 192-kb/s service channel bit stream (SCBS). Each MBS carries 192 64-kb/s voice or data channels. The SCBS consists of three 56-kb/s service channels plus framing bits. Because there was no breakout to 64-kb/s user channels at Schwarzenborn, a 56-kb/s service channel was utilized for the error performance measurement on the SBN-FEL LOS link. A BERTS transmitter injected a 56-kb/s data stream into the 3-channel FCC-98 multiplexer at Schwarzenborn. The 192-kb/s aggregate rate from the FCC-98 was then sent to the DRAMA radio at Schwarzenborn. At the receive end at Feldberg, two additional FCC-98's were installed for making error measurements on both diversity receivers that are part of the FCC-171 space



MBS -- Mission Bit Stream (12.928 Mb/s)
SCBS -- Service Channel Bit Stream (56 kb/s)
ROL -- Receiver-on-line

Figure 6. DRAMA radio performance measurement configuration at Feldberg.

diversity DRAMA radio. Measurements also were made on the selected (i.e., receiver-on-line) 56-kb/s channel, as depicted in Figure 6. Thus, simultaneous error measurements were made on the DRAMA receiver A, DRAMA receiver B, and the selected receiver. These data were necessary to compute the space diversity improvement factor.

3.2.2 Radio Performance and LOS Propagation Measurements

As shown in Figure 5, the radio performance measurement inputs to the HP-3852 Data Acquisition and Control System included both analog and digital input signals:

- ITS channel probe
- two spectrum analyzers for the two DRAMA receiver intermediate frequency (IF) signals
- two slope-distortion detectors
- received-signal-level (rsl) IF voltages
- signal quality monitor (SQM) voltages
- DRAMA radio test points.

The ITS channel probe, described in more detail in Appendix H, is an instrument which is used to measure multipath on LOS microwave links. It is a dual-channel instrument capable of simultaneous measurements on each of two space diversity channels. The system operates at 8.6 GHz which is slightly above the 7.8-GHz frequency used on the SBN-FEL link. The channel probe transmitter output signal was multiplexed onto the existing waveguide which carries DRAMA Radio signals at the Schwarzenborn site. The rf signals arriving at the space diversity antennas at Feldberg were input to the dual-channel probe receiver. Channel probe complex (I & Q) signals were digitized by the HP-3852 DACS using a 13-bit analog-to-digital (A/D) converter. These data provide multipath fading information in the time domain.

The two 70-MHz IF space diversity signals from the DRAMA radio were also sampled through the use of two spectrum analyzers. Five times per second, each of the two spectra were sampled 50 times as the spectrum analyzer swept across the 14-MHz passband of the DRAMA receivers, resulting in a sample every 280 kHz.

Figure 7 depicts the circuitry for measuring slope distortion. The circuitry shown in the figure is replicated for each of the two radio receivers. The basic concept is to determine which receiver signal has the least amount of amplitude distortion across the passband of the radio. The slope across the passband is measured through the use of two filters, each of which covers half the passband. After amplification and detection, a differential amplifier was used to measure the slope's magnitude and sense (positive or negative). The differential amplifier's output was recorded for both receivers. These data were used as a measure of multipath fading in the frequency domain (the channel probe provides a measure of fading in the time domain). The data also were used to compute a theoretical space diversity improvement factor assuming that the diversity switching algorithm was based upon the greatest amount of slope distortion in the passbands of the two diversity receivers.

As shown in Figure 5, the analog inputs to the HP-3852 DACS included rsl and signal quality monitor (SQM) voltages. The rsl data provide a measure of power fading. The data were also used to compute a theoretical space diversity improvement factor, assuming that the diversity switching algorithm was based upon the highest received signal level.

The SQM voltage is a measure of the eye closure of the baseband signal. It also has been shown to be a measure of the amount of frequency selective fading in the channel. The SQM voltages for the two diversity receivers were recorded primarily to investigate the use of these voltages as the basis for a space diversity switching algorithm. Section 5 and Volume III provide results of several theoretical space diversity switching algorithms.

3.2.3 Transmission Monitor and Control (TRAMCON)

The TRAMCON system is an integral part of the entire DEB and is used to remotely monitor and control the transmission assets of DEB including the digital radios, multiplexers, and encryption equipment. It is used to monitor a variety of different types of equipment including LOS, troposcatter, and fiber-optics equipment. The TRAMCON System consists of 20 Master Terminals (HP-1000 Computer Systems) used to monitor

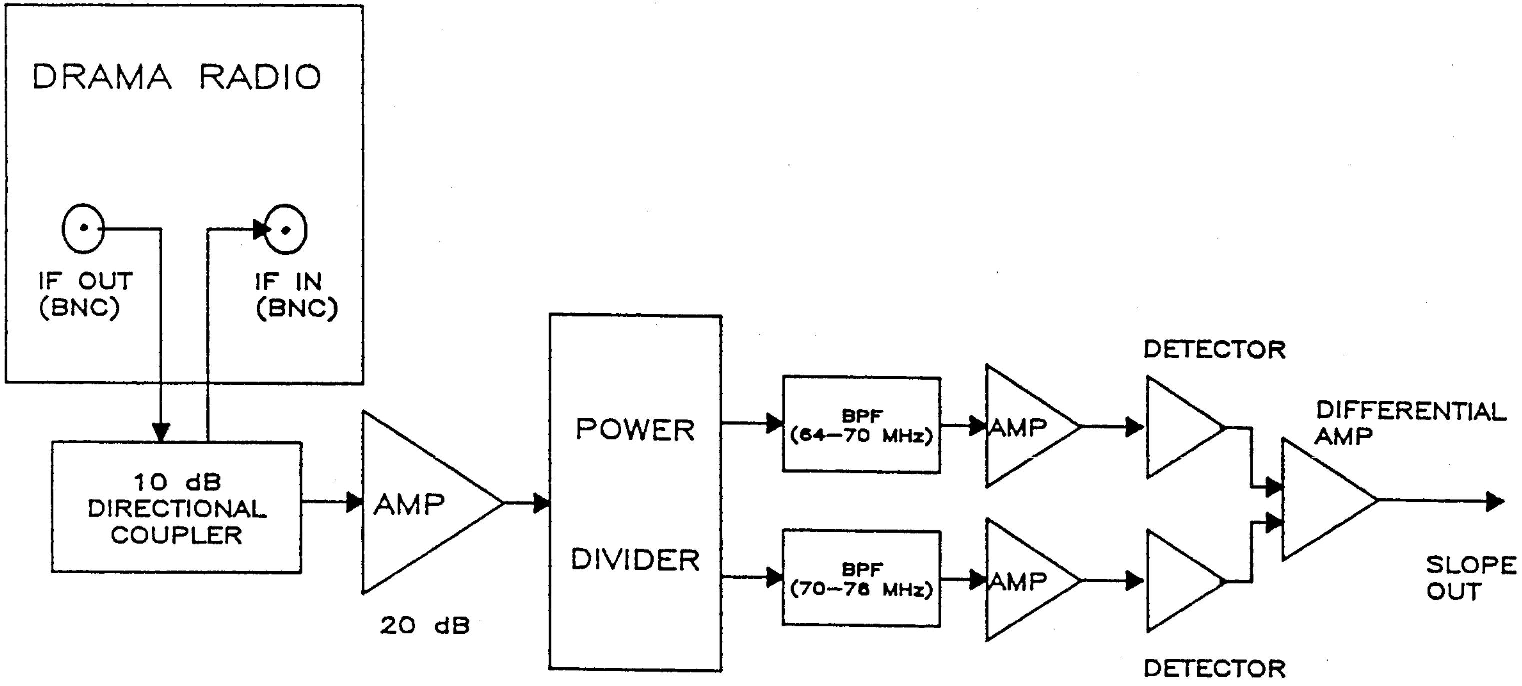


Figure 7. Slope distortion detection measurement subsystem functional block diagram.

transmission equipment at 250 sites in DEB. Figure 8 is a functional block diagram of the TRAMCON System. Appendix F provides a more detailed description of TRAMCON.

A TRAMCON Master Terminal (TMT) obtains information from each node within its segment of responsibility by sequentially polling each node and waiting for a response. The poll cycle time can vary slightly, depending upon whether each node is operational and whether each sends a response (a timeout is generated if a response is not received by the TMT within a specified time interval). For FKT-N1, the TRAMCON polling cycle is about once every 100 seconds.

Because a TMT had previously been installed at Feldberg to monitor the FKT-N1 Segment of DEB, it was logical to incorporate selected TRAMCON data into the NPC/LPC data base. An interface was installed to provide a communications path between the TMT HP-1000 Computer and NPC/LPC HP-9000/330 computer. Special software changes were made to the TRAMCON applications software to accommodate this data communications interface.

The TRAMCON data received by the HP-9000/330 computer consist of the following: status and alarm indicators from the transmission equipment and analog and digital parameters. Tables 8 through 11 list all of the alarms, status indicators, performance parameters, and analog signals sampled by TRAMCON. All of these data were incorporated into the 18-month archive data base. The alarms and status indicators listed in Tables 8 and 9 are latch (high or low) signals. The parameters listed in Tables 10 and 11 consist of both digital data obtained from digital counters and analog signals which are sampled by an A/D converter.

The analog signals include rsl samples. One sample is sent from each node every poll cycle. Because of the length of the poll cycle (about 100 seconds), it is possible that some multipath fading events are missed by TRAMCON. However, the long-term rsl statistics from TRAMCON and a system having more frequent sampling can be expected to be approximately the same. Data provided in Section 4 show that this was the case for the NPC/LPC measurement program.

The TRAMCON data also include estimates of errored seconds and the number of bit errors that occurred at each node during each polling interval. Framing bits are used

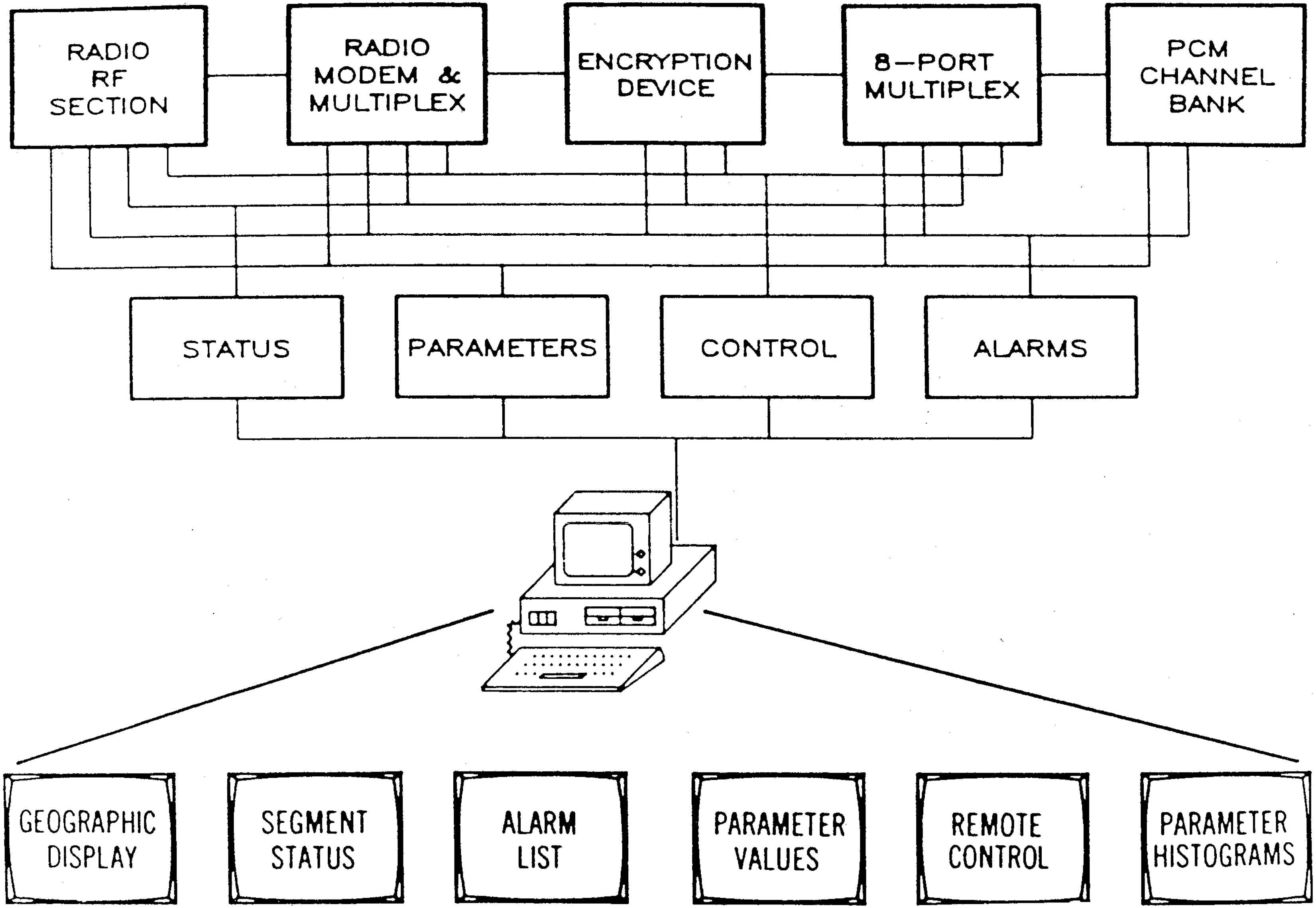


Figure 8. TRAMCON functional block diagram.

Table 8. DRAMA Radio and Multiplex Alarms and Status Indicators Monitored by TRAMCON

0	Radio Power Supply Failed [A or B]
1	Radio A Side Failure
2	Radio B Side Failure
3	Radio Transmitter Freq. Drift [A or B]
4	Radio Modulator Failed [A or B]
5	Radio MBS 1 XMT Failed [A or B]
6	Radio MBS 2 XMT Failed [A or B]
7	Radio SCBS XMT Failed [A or B]
8	Radio MBS 1 RCV Failed [A or B]
9	Radio MBS 2 RCV Failed [A or B]
10	Radio SCBS RCV Failed [A or B]
11	Radio Demodulator Failed [A or B]
12	Radio Frame Sync Loss [A or B]
13	Radio Transmitter Power Failed [A or B]
14	Crypto 1 Failed
15	Crypto 2 Failed
16	Crypto 1 Bypassed
17	Crypto 2 Bypassed
18	TDM 1 Power Supply Failed
19	TDM 1 Frame Loss
20	TDM 1 RCV MBS Data Loss
21	TDM 1 XMT MBS Data Loss
22	TDM 1 Input Port Loss - A Side
23	TDM 1 Input Port Loss - B Side
24	TDM 1 Output Port Loss - A Side
25	TDM 1 Output Port Loss - B Side
27	TDM 2 Power Supply Failed
28	TDM 2 Frame Loss
29	TDM 2 RCV MBS Data Loss
30	TDM 2 XMT MBS Data Loss
31	TDM 2 Input Port Loss - A Side
32	TDM 2 Input Port Loss - B Side
33	TDM 2 Output Port Loss - A Side
35	Service Channel Mux Failed
36	Digroup #1 MBS 1 Failed
37	Digroup #2 MBS 1 Failed
38	Digroup #3 MBS 1 Failed
39	Digroup #4 MBS 1 Failed
40	Digroup #5 MBS 1 Failed
41	Digroup #6 MBS 1 Failed
42	Digroup #7 MBS 1 Failed
43	Digroup #8 MBS 1 Failed
44	Digroup #1 MBS 2 Failed
45	Digroup #2 MBS 2 Failed
46	Digroup #3 MBS 2 Failed
47	Digroup #4 MBS 2 Failed
48	Digroup #5 MBS 2 Failed
49	Digroup #6 MBS 2 Failed
50	Digroup #7 MBS 2 Failed
51	Digroup #8 MBS 2 Failed
52	Radio Transmitter A On Line (Status)
53	Radio Transmitter B On Line (Status)
54	Radio Receiver A On Line (Status)
55	Radio Receiver B On Line (Status)
56	TDM 1 A Side On Line (Status)
57	TDM 1 B Side On Line (Status)
58	TDM 2 A Side On Line (Status)
59	TDM 2 B Side On Line (Status)
60	TDM 1 Manual Switchover Achieved (Status)
61	TDM 1 Auto Switchover Achieved (Status)
62	TDM 2 Manual Switchover Achieved (Status)
63	TDM 2 Auto Switchover Achieved (Status)
66	Radio Transmitter in Manual Mode (Status)
67	Radio Receiver in Manual Mode (Status)

Table 9. Troposcatter Radio and Multiplex Alarms and Status Indicators Monitored by TRAMCON

0	Radio Power Ampl Summary Alarm No A
1	Radio Power Ampl Summary Alarm No B
2	Radio Transmitter RF Output Loss No A
3	Radio Transmitter RF Output Loss No B
4	Radio Transmitter LO Output Loss No A
5	Radio Transmitter LO Output Loss No B
6	Radio Receiver LO Output Loss No A
7	Radio Receiver LO Output Loss No B
14	Crypto 1 Failed
16	Crypto 1 Bypassed
18	TDM 1 Power Supply Failed
19	TDM 1 Frame Loss
20	TDM 1 RCV MBS Data Loss
21	TDM 1 XMT MBS Data Loss
22	TDM 1 Input Port Loss A Side
23	TDM 1 Input Port Loss B Side
24	TDM 1 Output Port Loss - Side A
25	TDM 1 Output Port Loss - Side B
35	Service Channel Mux Failed
36	Digroup #1 MBS 1 Failed
37	Digroup #2 MBS 1 Failed
38	Digroup #3 MBS 1 Failed
39	Digroup #4 MBS 1 Failed
40	Digroup #5 MBS 1 Failed
41	Digroup #6 MBS 1 Failed
56	TDM 1 A Side On Line (Status)
57	TDM 1 B Side On Line (Status)
60	TDM 1 Manual Switchover Achieved (Status)
61	TDM 1 Auto Switchover Achieved (Status)
64	MD-918 On Line No 1 (Status)
65	MD-918 On Line No 2 (Status)

Table 10. DRAMA Radio and Multiplex Parameters Sampled by TRAMCON

0	Radio Receiver A RSL (Analog)
1	Radio Receiver B RSL (Analog)
2	Radio Receiver A Signal Quality (Analog)
3	Radio Receiver B Signal Quality (Analog)
6	Radio Receiver A Frame Error Seconds (Digital)
7	Radio Receiver A Frame Error Count (Digital)
8	Radio Receiver B Frame Error Seconds (Digital)
9	Radio Receiver B Frame Error Count (Digital)
10	TDM 1 Frame Error Seconds (Digital)
11	TDM 1 Frame Error Count (Digital)
12	TDM 2 Frame Error Seconds (Digital)
13	TDM 2 Frame Error Count (Digital)

Table 11. Troposcatter Radio and Multiplex Parameters Sampled by TRAMCON

2	Composite RSL A (Analog)
3	Composite RSL B (Analog)
10	TDM 1 Frame Error Seconds (Digital)
11	TDM 1 Frame Error Count (Digital)
14	MD-918 Number 1 Error Rate (Digital)
15	MD-918 Number 2 Error Rate (Digital)

to determine both of these estimates of digital transmission performance. These error performance estimates from TRAMCON are made for both diversity receivers of the DRAMA radio and for both mission bit streams of the FCC-99 second level multiplexer (see Appendix I for a description of the DRAMA radio/multiplexer configuration).

Examination of TRAMCON estimated error performance data showed that many more errored seconds occurred on either of the mission bit streams than on either of the diversity radios. Each of the diversity receivers carries the 26.112 Mb/s aggregate bit stream (ABS). The diversity switching algorithm will cause the output of the selected receiver to be switched to the output of the DRAMA radio. The FCC-99 will demultiplex the 26.112 Mb/s DRAMA radio output data stream into two mission bit streams (MBS), each of which has a data rate of 12.928 Mb/s. One might expect that the sum of the number of errored seconds of the two MBSs (as measured by the FCC-99 Multiplexer) would be less than the number of errored seconds of either of the diversity receivers because of the diversity improvement factor. This was found to not be the case, however. The TRAMCON data show that the opposite is true, i.e., there were many more errors on the two FCC-99 MBSs than the ABS in either of the diversity receivers. There may be a problem caused by the cryptographic equipment between the DRAMA radio and the FCC-99. This problem will be investigated further. None of the TRAMCON estimates of error performance is included in this report because of this problem.

3.2.4 Jitter and Delay Measurement Equipment

Jitter measurements were made at Feldberg using a Phoenix Microsystems 5501 Data Communications Analyzer. Measurements were made on both 64-kb/s and 1.544-Mb/s bit streams using the J01 and J02 options available with this instrument. These measurements were made on digital bit streams containing operational traffic and did not affect normal system operation. The measurements were made on the aggregate-bit-stream side (1.544 Mb/s) of one of the FCC-98 multiplexers at Feldberg. The 1.544-Mb/s jitter measurement was made only on a T1 channel from Linderhofe. A jitter measurement was not made on the 1.544-Mb/s channel from Berlin because the DRAMA multiplexer for that channel had NRZ (non-return-to-zero) coding output as opposed to the bi-polar coding required by the measurement instrument.

Delay measurements were made on the LDF-FEL Feldberg channel. Delay measurements were made through the use of a loopback arrangement at Linderhofe. Two channels from Linderhofe to Feldberg were made available to this measurement program. The delay measurement on the LDF-FEL channel was made by injecting a signal at Feldberg on one channel, and looping this signal back at Linderhofe on the second channel. The round-trip-delay time was determined by measuring the time-of-arrival at Feldberg on the second channel.

3.3 Data Analysis System

This section provides an overview of the data analysis system developed by ITS to meet the data measurement requirements described in Section 3.1. The data analysis was performed off-line using as input the 60-Mbyte tape cartridges created by the data acquisition system. The data analysis hardware was also used to analyze tapes created by the Link Performance Monitoring System (LPMS). Figure 9 depicts the data analysis hardware system. Specific components of that system are listed in Table 12.

Table 12. List of Data Analysis System Equipment

HP-98583L	Model 330C Computer
HP-7958A	Disk Drive (131Mb)
HP-9144A	Two 1/4 inch Tape Cartridge Drives
HP-10833B	Two 2m HPIB Cables
HP-7550A	Plotter
HP-33440A	Laserjet Series II
HP-33444A	Memory (2 Mbyte)

number of errored seconds of the two MBSs (as measured by the FCC-99 Multiplexer) would be less than the number of errored seconds of either of the diversity receivers because of the diversity improvement factor. This was found to not be the case, however. The TRAMCON data show that the opposite is true, i.e., there were many more errors on the two FCC-99 MBSs than the ABS in either of the diversity receivers. There may be a problem caused by the cryptographic equipment between the DRAMA radio and the FCC-99. This problem will be investigated further. None of the TRAMCON estimates of error performance is included in this report because of this problem.

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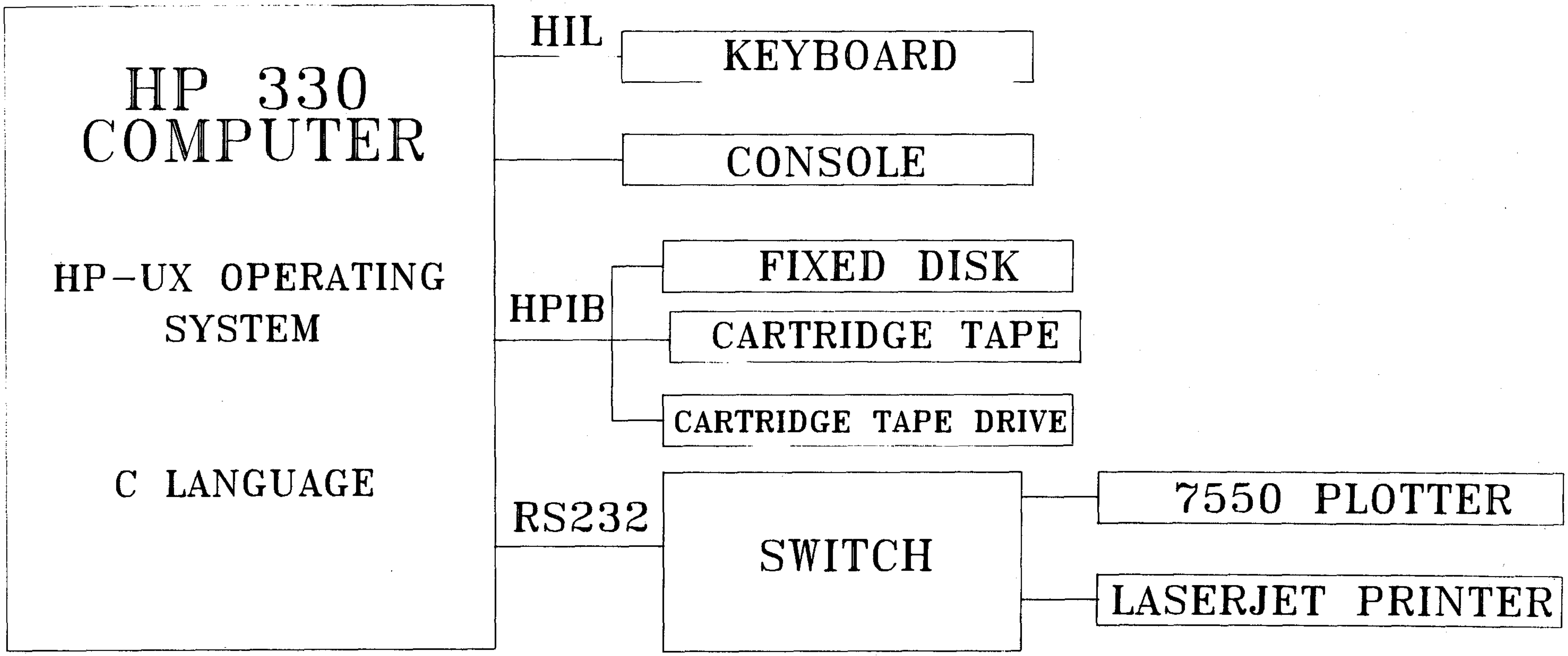


Figure 9. Functional diagram of the data analysis systems.

Most of the data analysis software was developed prior to fielding the data acquisition system in March 1988. The software was tested as extensively as possible using test facilities at ITS, which include DRAMA equipment, TRAMCON equipment, and a microwave channel simulator. Appendix E describes the system evaluation which included testing both the data acquisition and data analysis systems.

The data were analyzed on a monthly basis. The output from this analysis was a looseleaf binder (one for each month) containing 124 figures and 14 tables. Volume III of this report is the summary of the data for the first 12 months of this data-collection effort. The same figures and tables used in the monthly reports are contained in the 12-month summary (Volume III). The figures provide statistical distributions of the following:

- contiguous errored seconds
- contiguous error free seconds
- 15-minute average bit error ratio
- correlation between fraction of errored seconds and average BER
- number of errors in errored seconds
- received signal levels
- DRAMA radio IF amplitude distortion
- signal-quality-monitor (SQM) voltage
- space diversity improvement factor
- multipath fading data obtained from the ITS channel probe

The error information contained in the first five items was summarized for both of the two end-to-end channels and for each individual link within the FKT-N1 segment of DEB. This was done by allocating the end-to-end errors in each individual link using a complex error allocation algorithm (Appendix D). The TRAMCON data listed in Tables 8 through 11 were used to allocate these errors to individual links. After the errors were allocated to individual links, they were further allocated to a specific cause of the digital error. The causes identified were multipath fading and equipment.

As a simple example of this allocation process, refer back to Figure 1. The two end-to-end channels were from Berlin to Feldberg and Linderhofe to Feldberg. If an error occurred on the LDF-FEL channel and not the BLN-FEL channel, it was assumed that the source link was the LDF-KBG link since this is the only link in the LDF-FEL channel that is not also in the BLN-FEL link for the entire 18-month measurement period was 0.75 hours, while the UA time for the same period for the LDF-FEL channel was 17.03 hours. Thus, there are system-wide effects that cause the end-to-end errors to be greater than those measured on the individual links of the end-to-end channel. The possible sources of these errors are crypto resynchronization, system timing in a plesiochronous network, upfading which might cause the rsl to be slightly too high for the DRAMA radio, and human error. As noted earlier, it was not the objective of this program to test the network, or to identify problems in the network.

To ensure that the LDF-FEL performance results were not due to problems in the measurement system itself, several tests were conducted. These are described briefly in Appendix E. Two 64-kb/s channels from Linderhofe to Feldberg were available to ITS for this program. For a short time, the measurements were made on the second channel to see if there were any differences in the level of error performances of the two channels. The number of errored seconds occurring on the second channel was noticeably higher than on the first channel. The reason for this is not clear. However, this brief test did eliminate the bit error ratio test sets and FCC-98 interface cards as a potential source of the unexpectedly high errors on the LDF-FEL channel.

In making the comparisons of errored seconds and unavailability of the SBN-FEL link and the LDF-FEL channel, one must remember the differences between how the two measurements were made. The SBN-FEL measurements were made on a 56-kb/s service channel, while the LDF-FEL measurements were made on a 64-kb/s mission channel. The latter includes the KG-81 cryptographic equipment as part of the circuit equipment while the former does not.

Jitter

Figure 50 depicts the test configuration that was used to make jitter measurements on a T1 channel from Linderhofe to Feldberg. The jitter measurements were made on the same SBN-FEL channel. If the error occurred in the BLN-FEL channel and not the LDF-FEL channel, the source link could be either the BLN-BBG troposcatter link or the BBG-KBG LOS link. TRAMCON status information was then used to attempt further to allocate the errors to one of those links and to determine the cause. If errors occurred on both channels, the allocation algorithm became more complicated. Appendix D contains a more detailed description of the algorithms used in this allocation process.

The channel probe data were used to compute the following multipath fading statistics: multipath delay and rate of change of delay, relative phase and amplitude of the multipath signal relative to the direct signal, and the rate of change of these relative amplitudes and phases, and the occurrence of a third multipath component. Examples of these output data are provided in Section 4 and Volume III of this report.

The primary objective of the data analysis was to summarize the measured data and to derive the statistics described in Tables 4 and 5. An additional objective was to obtain the statistics describing the performance of the DRAMA radio. To describe the analysis scheme, certain terminology must be defined before additional explanation is attempted. In some cases, these definitions are limited in their scope. They should only be used to understand better the NPC/LPC data analysis.

3.3.1 Definitions Applicable to Analysis of NPC/LPC Data

Errored second: An errored second is a second in which at least one error occurs in a 64-kb/s or 56-kb/s channel. The second is an asynchronous clock second. An errored second does not begin at the occurrence of the first error following an error-free period of more than a second. Rather, the second is determined by a time base locked to an Omega clock receiver.

Error event: An error event is a set of contiguous errored seconds in a single channel.

Fifteen-minute data block: A 15-minute data block is a block of data recorded that starts at the hour or at whole 15-minute intervals past the hour.

Amplitude distortion (based on spectrum analyzer output): Amplitude distortion values are derived from the spectrum analyzer output which is linear in decibels. The IF spectrum is sampled at intervals of 280 kHz. The 21 samples closest to 70 MHz (the center of the IF band) are converted to decibels and saved for analysis. These samples represent the part of the band from 66 to 74 MHz (approximately the 3-dB points of the band). A running-average set of these samples is obtained during nonfading (no distortion) periods as a reference spectrum. During periods of multipath fading, a set of samples is collected five times per second representing the multipath distorted spectra. A set of 21 difference values is obtained by subtracting corresponding values of the distorted spectrum from the reference spectrum. The difference value corresponding to 66 MHz is subtracted from the difference value corresponding to 74 MHz and the resulting value is divided by 8 MHz to obtain the distortion across the band in dB/MHz for each spectrum sweep. Also the difference value corresponding to each frequency point is subtracted from the difference value corresponding to the next highest point, and the resulting value is divided by 0.4 MHz to obtain the distortion between adjacent points. The difference having the largest magnitude is saved to obtain the maximum distortion in dB/MHz for each sweep.

Equipment outage event: An equipment outage event is an error event in which either or both of the following conditions prevailed:

1) A complete outage occurred within one second of the start of the event and lasted for more than 10 seconds.
2) An alarm was observed that could not have been caused by the propagation media.

Multipath fading time (on the SBN-FEL link): Multipath fading time is defined as a period between errors when the following conditions were observed:

1) The spacing between errors was less than 1 minute.

2) Within the minute, an amplitude distortion value was measured having a value greater than 0.1 dB/MHz, or an rsl value on either receiver was measured that was more than 6 dB below the median on either receiver and the rsl values on the two receivers differed by at least 3 dB at some time within the period.

3) There was no transmitter-end alarm or switchover at SBN.

Power fading outage event: A power fading outage event is an error event in which the following conditions prevailed within 1 minute of the event:

1) An rsl value on either receiver was more than 6 dB below the median on either receiver, but the rsl values on the two receivers never differed by more than 3 dB at any time within the period.
2) There was no transmitter-end alarm or switchover at SBN.

Space diversity improvement: If receivers are switched based on the value of some parameter or some combination of parameters, space diversity improvement (SDI) is the ratio of A to B where A and B are as follows:

A) The number of 0.2-second intervals having a BER greater than a particular BER (in this case BER > 1/64000) measured for a single receiver.

B) The number of 0.2-second intervals having a BER greater than a particular BER (in this case BER > 1/64000) measured for the receiver on line.

Because there are two receivers, there are two sets of SDI values, one for the first receiver and the other for the second.

Flat fade margin: Flat fade margin (in decibels) is 10 times the log (base 10) of the ratio of the median rsl to the rsl at which flat fading causes the BER to increase above a specified threshold value (for this analysis, BER = 1/64000).

3.3.2 Overview of the Data Analysis Software

The data analysis consisted of five operations:

- conditioning
- categorization
- calculations
- accumulation
- presentation

These five operations generally took place in the order in which they were listed above, but calculations and categorization were often interspersed with the other operations. The raw Feldberg data were pre-processed to make analysis efficient. This operation included removing blocks of data that were obtained when the test system had failed or was out of calibration. Pre-processing was done after transferring the raw data from tape to disk.

After pre-processing, the raw data were taken from a file and processed in 15-minute blocks. To do the analysis, intermediate data arrays were used to process the raw data. Three blocks were held in memory at one time to provide smooth transitions at block edges for overlapping error events. The three 15-minute blocks are called "LAST", "CURRENT", and "NEXT". "LAST" refers to the previously analyzed block. "CURRENT" refers to the block currently being analyzed. "NEXT" refers to the next block to be analyzed. If the "CURRENT" data block was found to be valid (the test system was working properly), the 15-minute blocks were analyzed further. Using positive integers to identify particular error events, errored seconds were assigned to specific error-events in the "NEXT" section. For the error events in the "CURRENT" data block, source-link and cause flags were assigned. If a 15-minute data block was not complete, it was not counted as part of the 1-month test period. When the 1-month test period was analyzed, all data analysis accumulation files were archived on tape.

From the 15-minute intermediate data arrays, analysis software performed additional calculations and organized the data into accumulation arrays that were compatible with the data output routines. In general, the accumulation arrays correspond to sets of graphs and tables.

The output routines were designed to automatically prepare a report from the accumulation arrays. Graphs and tables for each monthly report were produced for each 1-month test period. A separate program that does final data preparation produced all of the graphs within a specified range. The plotter used in the data analysis system had an automatic sheet feeder feature; thus, no further action was required once the program was started. Another program produced the tables. The entire complement of plots and tables could be generated within a few hours. Use of the autochanger for cartridge tape handling facilitated the monthly data analysis and report generation.

A chronological summary of data analysis flow for a new increment of test period (one raw data tape block) from the current 1-month test period is as follows:

1) Raw data were transferred from tape to a disk file on the analysis computer system.
2) A pass was made through the raw data on disk. Brief data summaries and all operator log entries were placed in a disk file which was subsequently printed.
3) Based on this output, the operator determined the start and end times of all potentially valid data periods.
4) Data-accumulation arrays were loaded from data-accumulation files.
5) Intermediate arrays were loaded from the intermediate files.
6) The raw data were analyzed in 15-minute increments.
7) At the end of a tape, intermediate arrays and accumulation arrays were saved to disk.

After a month's worth of data blocks had been analyzed, data from the accumulation arrays were processed by the output routines and suitable hard copy output was generated.

3.4 Link Performance Monitoring System

The Link Performance Monitoring System was developed by another agency to provide real-time monitoring of the BLN-BBG troposcatter channel. It was designed to provide a) rsl measurements on each of the four receivers on the BLN-BBG link and b) estimates of error performance and multipath fading (dispersion) parameters. Table 13 is a summary of LPMS measured and computed parameters, measurement accuracies, and input interfaces.

Hardware problems with the LPMS system prevented collection of all of the LPMS data (particularly certain parameters such as dispersion) during the 18-month data collection effort in Germany. The data that were collected are summarized in Section 4.2, and graphs are provided in Volume III. Appendix G provides a more complete description of the LPMS system.

Table 13. LPMS CAPABILITIES

LPMS INPUT INTERFACES

- AN/FRC-177 Radio Set interface: 70-MHz IF (rsl measurement)
- MD-918/GRC Digital Data Modem interfaces:
    - backward equalizer--three 8-bit digital words
    - symbol clock (sampled at 1/2 the bit rate)
    - eye pattern (sampled at 1/2 the bit rate)

LPMS MEASUREMENT ACCURACIES

rsl:	±0.5 dB accuracy, 0.1 dB resolution	
BER:	0.5 to 10^{-10} :	one order of magnitude
	10^{-10} to 10^{-12} :	two orders of magnitude
SDR:	±1 dB	
ISI:	±2 dB	
dispersion:	±1 symbol interval	

LPMS COMPUTED PARAMETERS

- received signal level
- bit error ratio (BER)
- errored seconds
- error free seconds
- dispersion
- fade rate
- fade duration
- fade outage probability
- signal-to-noise ratio (SNR)
- signal-to-distortion ratio (SDR)
- intersymbol interference

4.0 SUMMARY AND ANALYSIS OF LINK PERFORMANCE CHARACTERIZATION DATA

The 18 months of DRAMA performance and propagation data that were collected on this project are summarized in this section and Section 5. As required by the DCEC statement of work, 14 tables and 124 graphs were generated for each month in the data collection period (April 1988 through September 1989). In addition, 12-month and 18-month summaries of these same graphs and tables were created. Volume III of this report is the 12-month summary. It was more meaningful to include the 12-month summary rather than the 18-month summary because certain fading phenomena are seasonal. The 18-month summary may be biased because 6 months are covered twice (April through September). The additional 6 months of data are useful, however, for investigation of the issue of the year-to-year variability of both propagation and digital radio performance. The data presented in this section and in Section 5 summarize some of the key results for both the 12-month and 18-month periods.

Table 14 lists the number of hours of data recorded and analyzed for each month during the entire data collection period. Some 15-minute blocks of data were rejected from the monthly summaries because of hardware failures in the NPC/LPC data acquisition system or because of operational problems associated with this data collection effort. During the first 12 months of the data collection effort, the data acquisition system was monitored by an ITS individual assigned full-time to the Feldberg site. During that period, automated logs were created that document the reason for periods during which data were not recorded. During the last 6 months the system was not monitored by an ITS engineer, and the automated log was not used. The problems which resulted in so few hours of data being recorded in September 1989 are, therefore, not known. As shown in the table, data from over 90% of the total number of hours from April 1988 through September 1989 were recorded and analyzed. This percentage is quite good considering the complexity of the data acquisition system that was fielded at 5 sites in the FKT-N1 Segment of DEB.

The link performance characterization, which resulted from the analysis of the 18-month data base, is now described. The emphasis will be on the Schwarzenborn-Feldberg link because of the large amount of data collected on that link. However, data are also presented that characterize the performance on the other LOS links of the Frankfurt North Phase I Segment of DEB. Performance and propagation data for the Berlin-Bocksberg troposcatter link are also described.

Table 14. Summary of Monthly Hours of Recorded Data

	HOURS RECORDED	TOTAL HOURS IN MONTH	% OF TOTAL HOURS DATA COLLECTED		HOURS RECORDED	TOTAL HOURS IN MONTH	% OF TOTAL HOURS DATA COLLECTED
Apr. 1988	671.00	720	93.2%	Jan. 1989	696.75	744	93.6%
May 1988	566.75	744	76.2%	Feb. 1989	537.00	672	79.9%
Jun. 1988	664.25	720	92.3%	Mar. 1989	738.25	744	99.2%
Jul. 1988	707.50	744	95.1%	Apr. 1989	718.00	720	99.7%
Aug. 1988	698.75	744	93.9%	May 1989	618.50	744	83.1%
Sep. 1988	613.75	720	85.2%	Jun. 1989	716.25	720	99.4%
Oct. 1988	691.25	744	92.9%	Jul. 1989	738.25	744	99.2%
Nov. 1988	579.50	720	80.5%	Aug. 1989	740.50	744	99.5%
Dec. 1988	701.25	744	94.3%	Sep. 1989	491.75	720	68.2%

Total average hours data collected - 90.4%
Total hours in 18-month period - 13,152
Total hours recorded - 11,889.25

4.1 Schwarzenborn-Feldberg Link Analysis

This section provides both performance and propagation data summaries for the Schwarzenborn-Feldberg link. The performance data analysis for the SBN-FEL link includes comparisons of measured data with both MIL-STD-188-323 and CCITT/CCIR standards. The propagation data analysis for this link includes summaries of the rsl, SQM, slope distortion, and channel probe data. Comparisons are made of several hypothetical space diversity improvement factors calculated using different space diversity switching algorithms.

4.1.1 SBN-FEL Performance Comparisons with DRAFT MIL-STD-188-323 Specifications

As described in Section 3, the basic performance measure for both the end-to-end 64-kb/s channels and the Schwarzenborn-Feldberg 56-kb/s link was the number of errors within a 200-ms interval. From this basic measure, a number of performance indicators can be derived. The basic derived parameter, for the purposes of comparisons with both MIL-STD and CCITT/CCIR standards, is the ES. The definitions for ES and unavailability provided in the Draft MIL-STD-188-323 (see Section 2.2 of this report) were used to categorize the performance data collected on the Schwarzenborn-Feldberg link.

The results of the MIL-STD-188-323 ES analysis are provided in Figure 10. The left vertical axis provides the scale for ESs, while the right vertical axis provides the scale for UA time. Note that the measured link performance meets the MIL-STD-188-323 performance specifications for both ESs (3800 seconds) and UA time (2.16 hours) for the 12-month period beginning in April 1988. Allocating the MIL-STD requirements on a monthly basis results in a requirement of 316 ESs and 0.18 hours of unavailability. Only the performance in January 1989 fails to meet the monthly specification for ESs. Only the months of April 1988 and August 1989 fail to meet the monthly allocation of UA. The UA time for April 1988 narrowly misses the monthly UA objective, while the August 1989 measured performance misses the monthly UA objective by a factor of 2.4.

Only 2,347 ESs (including those allocated to unavailability) were recorded during the first 12 months. In the year, the fraction of seconds that contained an error is, therefore, 7.4×10^{-5}. Of these ESs, only 788 seconds (0.22 hours) could be categorized as unavailable time (60 consecutive seconds each having a 1-s BER of 1×10^{-4} or worse). The 0.22 hours of UA time are well within the draft MIL-STD-188-323 design criteria of 2.16 hours for this link. There were 1,559 ESs remaining after subtracting the unavailable seconds. Since the MIL-STD objective for this link was 3,800 ESs for this link, the measured performance fell within the ES quality objective as well as the unavailability time for the SBN-FEL link.

The worst month for ESs was January 1989. In later sections we show that rsl and other propagation measures indicate that significant multipath fading occurred in January. The analysis algorithms described in Appendix D were used for the allocation of ES to the cause of the errors: equipment, multipath fading (frequency selective fading) and power

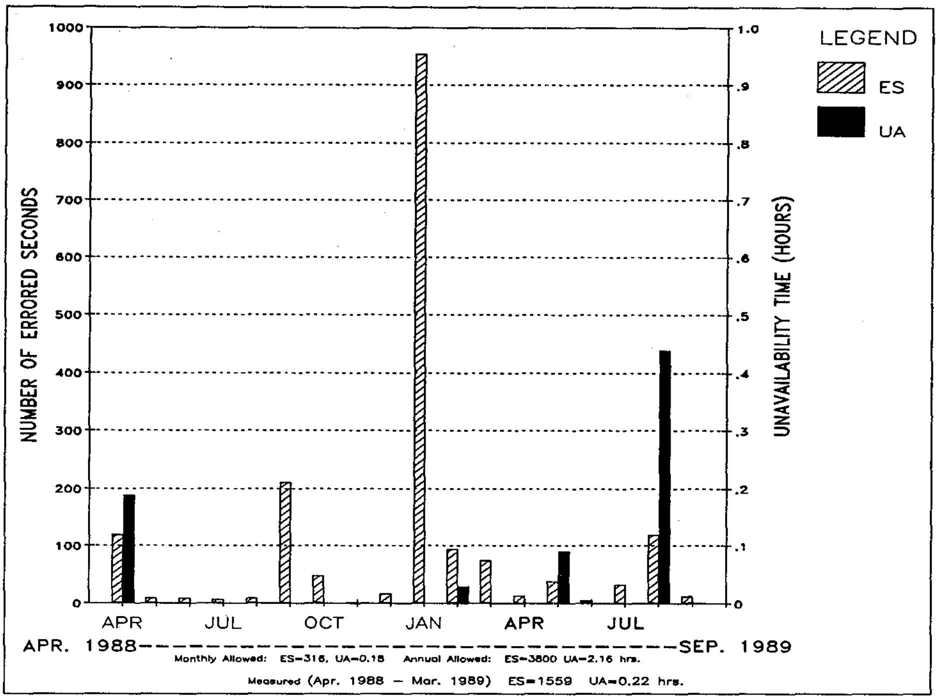


Figure 10. Schwarzenborn-Feldberg errored seconds and unavailability.

fading. For the January 1989 data, all of the ESs were allocated to multipath.

As can be seen in Figure 10, there was significant yearly performance variability (e.g., compare August 1989 with August 1988). The ES and UA numbers for August 1988 were 9 seconds and 0 hours respectively, while the same numbers for August 1989 were 120 seconds and 0.44 hours. Note that the deterioration of errored-second performance for September 1988 (which from other NPC/LPC data was found to be due to multipath) did not repeat itself in September 1989. Without several years of data, it is difficult to determine which month is the worst fading month on this link. However, January appears to be a strong candidate based on analysis of both propagation and performance data (see Section 4.8).

Figure 11 is a plot of the ESs for the receiver on line (ROL), receiver A (Rx A) and receiver B (Rx B). The DRAMA radio is a space diversity radio. For purposes of discussion, we refer to the two diversity receivers as Rx A and Rx B. The ROL is the receiver (A or B) that has been selected by the DRAMA space-diversity switching algorithm. The figure dramatically illustrates the improvement achieved by the DRAMA radio space diversity receivers. One measure of space diversity improvement (SDI) is the ratio of the number of ESs in Rx A (or Rx B) to the number of ESs in the ROL. For Rx

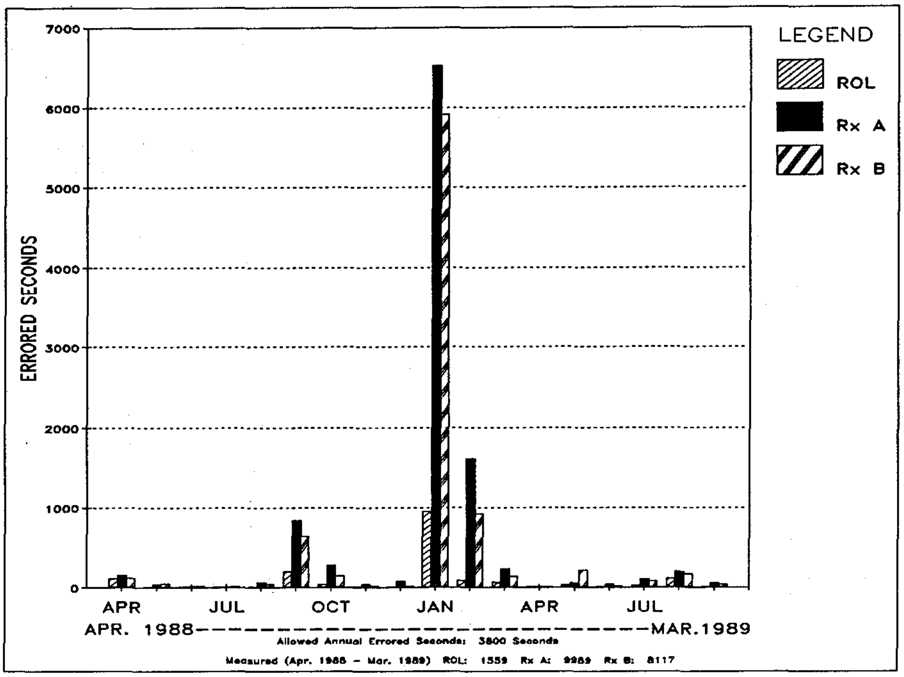


Figure 11. Schwarzenborn-Feldberg errored seconds for the receiver on line, receiver A, and receiver B.

A, the SDI is found to be 5.0 (11,813 / 2347). For Rx B, the SDI is found to be 4.2 (9829 / 2347). Other measures of SDI can be calculated (see Section 4.1.7).

Figures 12 and 13 are plots of ESs and the number of seconds in which the receiver rsl is below the 1 x 10^{-2} BER threshold. Figure 12 provides data for the receiver on line for each month of the 18-month measurement period. Figure 13 provides 12-month summary data for the period from April 1, 1988, through March 31, 1989, for the receiver on line, Rx A and Rx B. As was the case for Figures 10 and 11, the errored-second bars in Figures 12 and 13 represent seconds in which at least one error occurred. The errored-second data for the latter two figures differ from the former two figures in that the previous plots contained the ESs remaining after the unavailability time was removed. Figures 12 and 13 contain all ESs. Note that one error in 1 second for the 56-kb/s service channel corresponds to a BER of 1.79 x 10^{-5}.

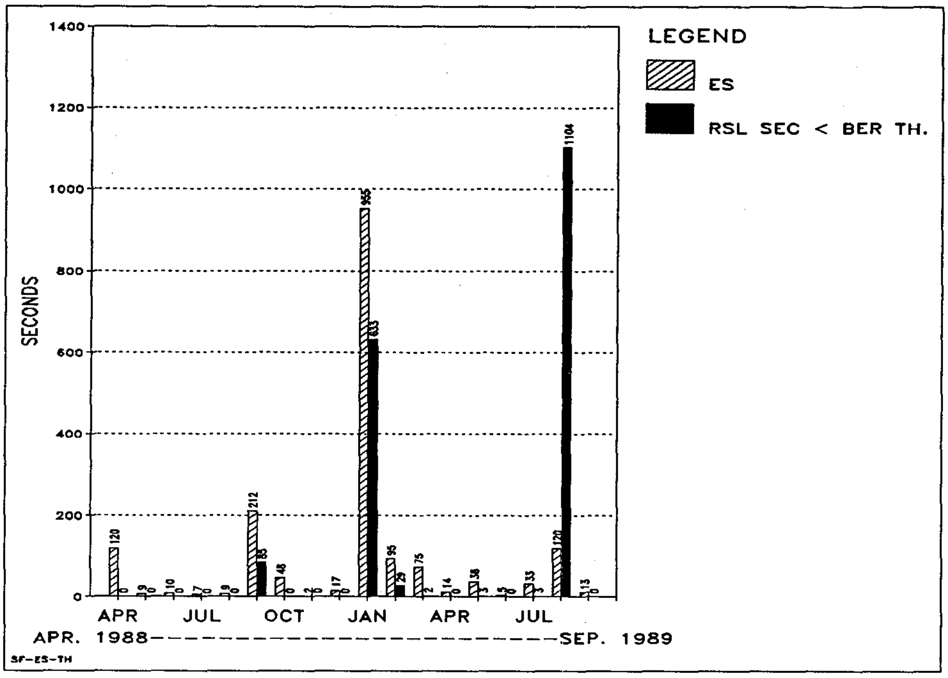


Figure 12. Schwarzenborn-Feldberg receiver-on-line monthly errored second performance and the number of seconds that the rsl is less than the 1×10^{-2} BER threshold.

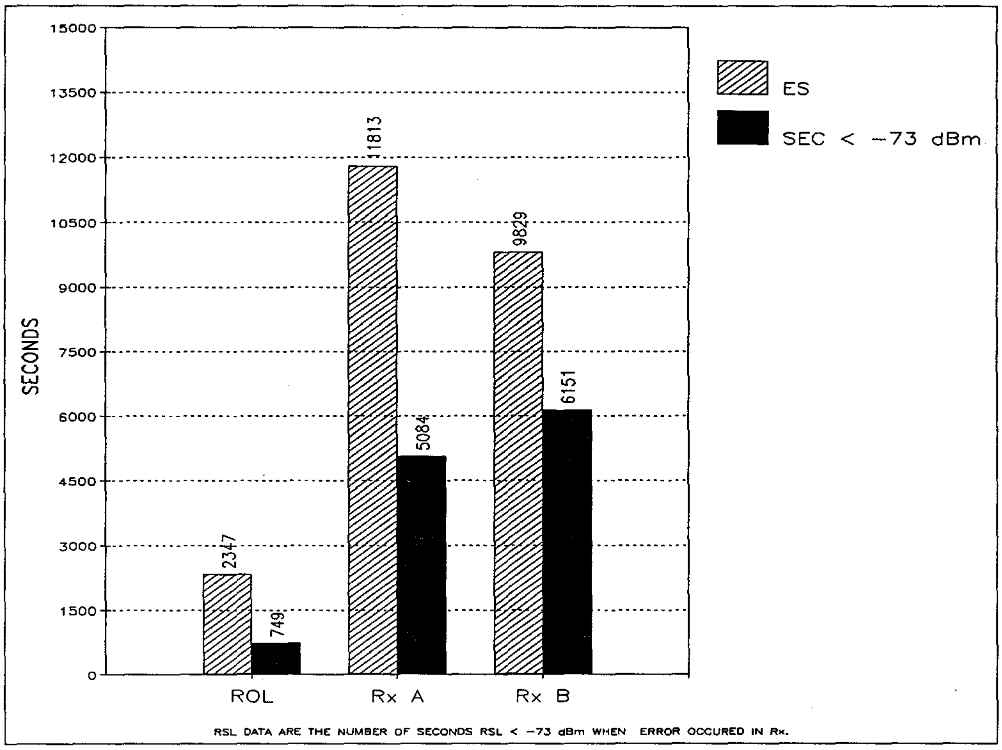


Figure 13. Twelve-month summary of the number of errored seconds and the number of seconds that the rsl is less than 1×10^{-2} BER threshold.

The rsl bars in Figures 12 and 13 represent the number of seconds in which the DRAMA radio receiver-on-line (ROL) is below the rsl minimum threshold and an error occurred. The rsl threshold is -73 dBm for a 1 x 10^{-2} BER for a 26-Mb/s quadrature partial response DRAMA radio (CECOM, 1984, pp. 1-6). Note that the -73 dBm threshold is the level at which the probability of an error is 0.01. At a data rate of 56 kb/s, it is highly likely that an error will occur within 1 second if the fading level reaches -73 dBm.

Figure 12 shows that the months with the most ESs (January and August 1989) are also the months with the most number of seconds in which the ROL rsl is below the 1 x 10^{-2} threshold. It should be noted that the two BER thresholds are different (10^{-5} for the errored second data and 10^{-2} for the rsl data), and that there are other contributions to the total ESs in addition to power fading (e.g., multipath fading and equipment).

The August 1989 data presented in Figures 10 and 12 invite further examination. The figures present the following statistics for that month:

Total number of ESs including unavailability time:	1720
Number of ESs not including unavailability time:	120
Number of seconds in which rsl was less than -73 dBm:	1104

These data show that there were periods in which the link BER was of the order of 1 x 10^{-4} or less for periods of 60 seconds or longer. The UA time was unusually high (0.44 hours). The algorithms described in Appendix D were used to categorize, by cause, both ES and UA. All of the unavailability time for August 1989 was allocated to equipment problems. Specific identification of the equipment problem is beyond the objectives of this program. The 120 ESs for August 1989 were allocated as follows: 52 seconds to equipment, 59 seconds to multipath, and 9 ESs were caused by unknown problems.

4.1.2 SBN-FEL Performance Comparisons with CCITT/CCIR Recommendations

Table 15 is a summary of the SBN-FEL performance in each of the performance categories specified by the CCITT and CCIR as discussed in Section 2.3. The table shows that the SBN-FEL link meets some, but not all, of the performance criteria. The unavailability and errored-second objectives are met by wide margins. The severely

Table 15. Schwarzenborn-Feldberg Summary of Error Performance and Comparison with CCITT G.821 Objectives (12-Month Summary)

	SBN-FEL Link	
Unavailability Time	Actual Time	Fraction
Design Objective	1.04	1.19×10^{-4}
Measured	0.17	1.94×10^{-4}
Severely Errored Sec.		
Design Objectives	678	2.15×10^{-5}
Measured	696	2.21×10^{-5}
Degraded Min.		
Design Objectives	84	1.59×10^{-4}
Measured	192	3.65×10^{-4}
Errored Sec.		
Design Objectives	4012	1.27×10^{-4}
Measured	1746	5.54×10^{-5}

errored-second measured performance narrowly missed the objective, while the measured degraded-minute performance missed the objective by a factor of more than two. The intent of the CCITT performance specifications is that the severely errored-second parameter is a measure of the amount of time in which the service becomes unacceptable to all users including voice channel users. The degraded-minutes parameter quantifies the amount of time that performance degradations first become perceptible to users of voice channels (Ivanek, 1989; p. 35). Strictly speaking, the CCITT/CCIR objectives are applicable to circuits whose lengths are between 280 km and 2500 km (CCIR, 1986c). However, the objectives are often applied to circuits outside these limits since the CCIR gives no guidance on how to derive objectives for high-grade routes for other circuit lengths (Ivanek, 1989; p. 47).

Figures 14, 15, and 16 provide the monthly performance for ESs, SESs, and DMs respectively. The figures clearly indicate that the CCITT performance parameters were the worst during January 1989. This is consistent with the MIL-STD-188-323 errored-second measure which also indicated that January was the worst month for the SBN-FEL performance (see Figure 10). The characteristics of fading in January and early February 1989 are discussed in more detail in Section 4.8.

4.1.3 SBN-FEL BER Performance Data

Figure 17 provides distributions of 15-minute average BER's for the Schwarzenborn-Feldberg LOS link. The data are for the 12-month period beginning April 1, 1988. The 7866 hours of recorded data were broken into 15-minute periods for analysis purposes. The average BER was calculated for each of the 31,464 fifteen-minute blocks. Each of the three distributions contains three curves; one for errors caused by multipath, one for errors caused by equipment, and one for all causes. Average BER's of 1×10^{-3} and 1×10^{-6} are of interest because they are error ratios at which voice quality and data quality, respectively, deteriorate to a point of unacceptable performance. The following data were obtained directly from the three distributions for the "all causes" curves:

	% of the samples worse than 1×10^{-6}	% of the samples worse than 1×10^{-3}
ROL	0.6 %	0.2 %
RX A	2.0 %	1.0 %
RX B	0.8 %	0.7 %

Thus, the average BER for the 15-minute blocks is poor for data transmission only 0.6% of the time, and is poor for voice transmission only 0.2% of the time.

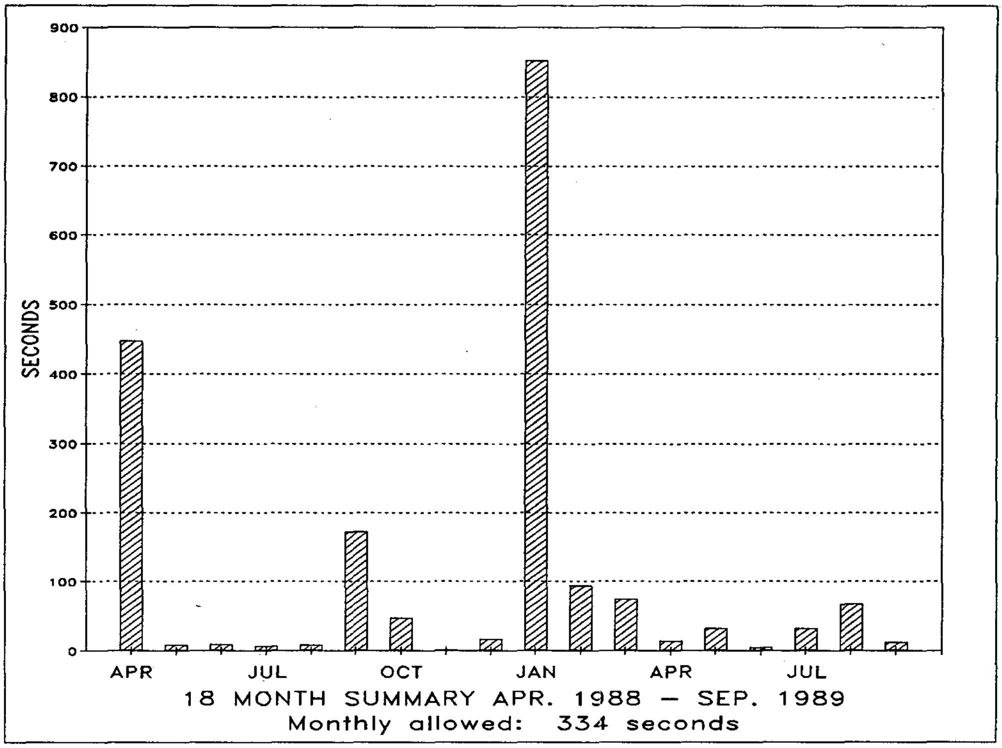


Figure 14. CCITT errored seconds for SBN-FEL.

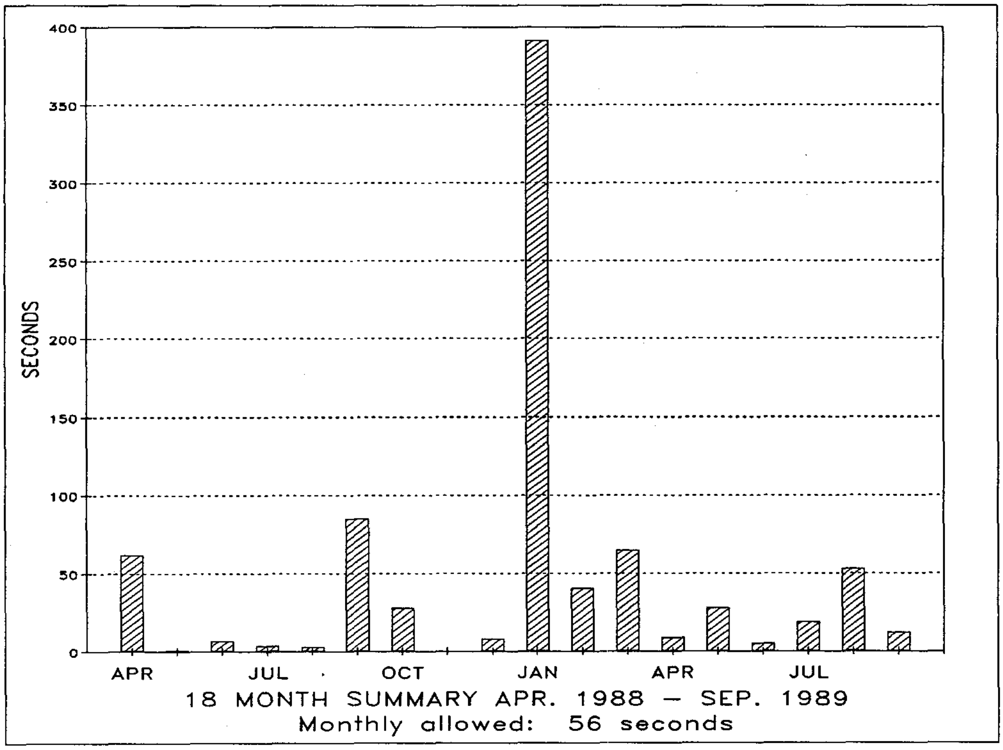


Figure 15. CCITT severely errored seconds for SBN-FEL.

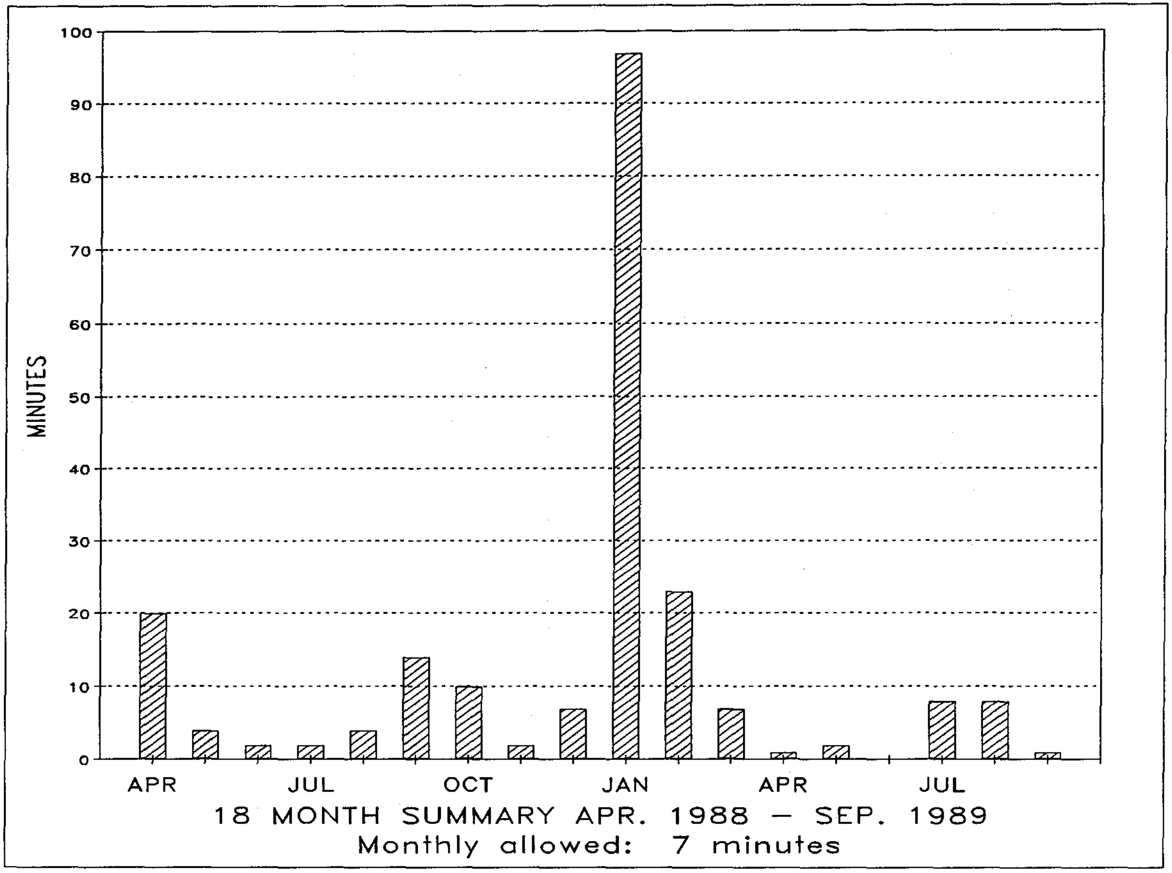
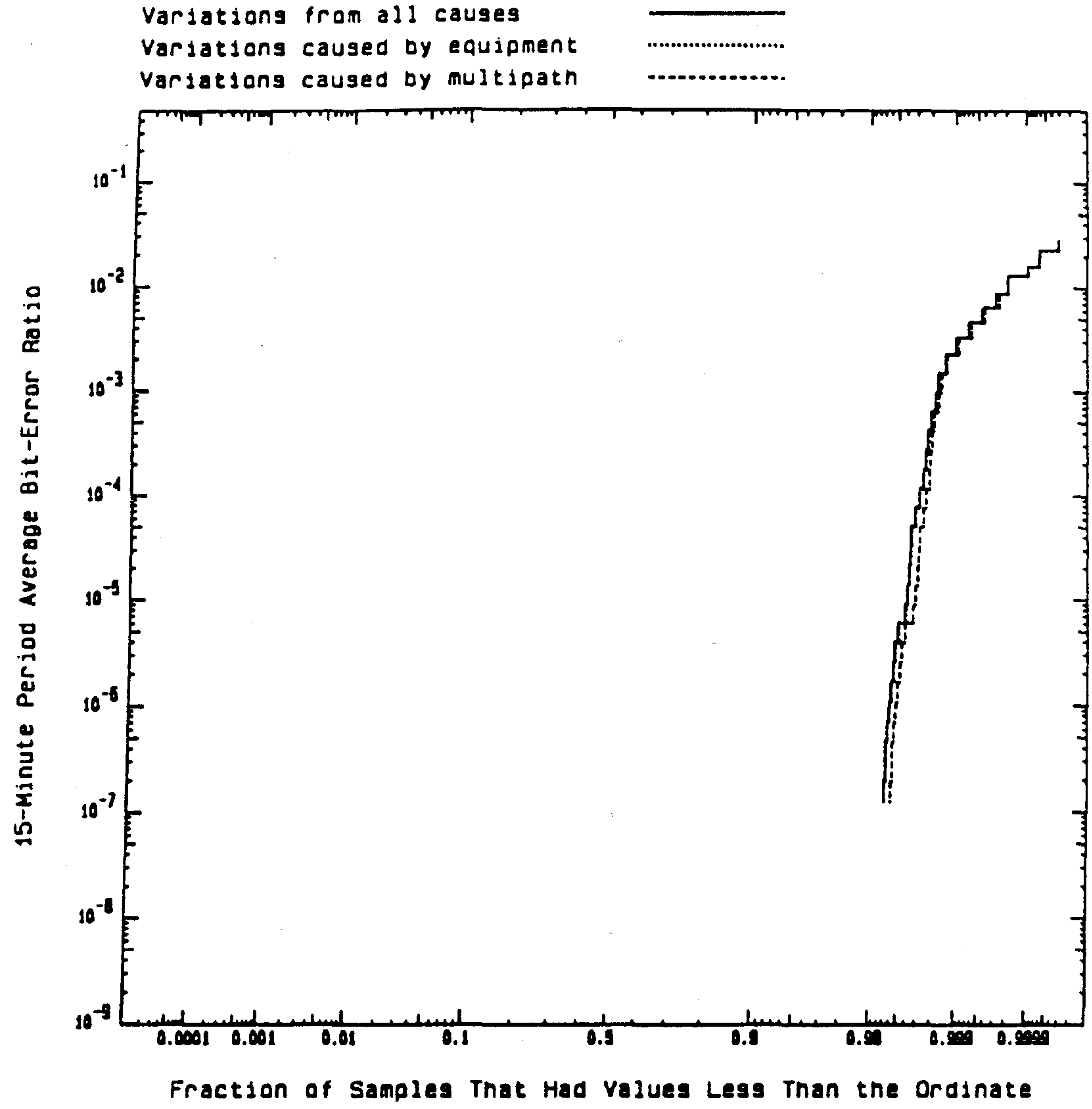


Figure 16. CCITT degraded minutes for SBN-FEL.

4.1.4 SBN-FEL Received-Signal-Level Data

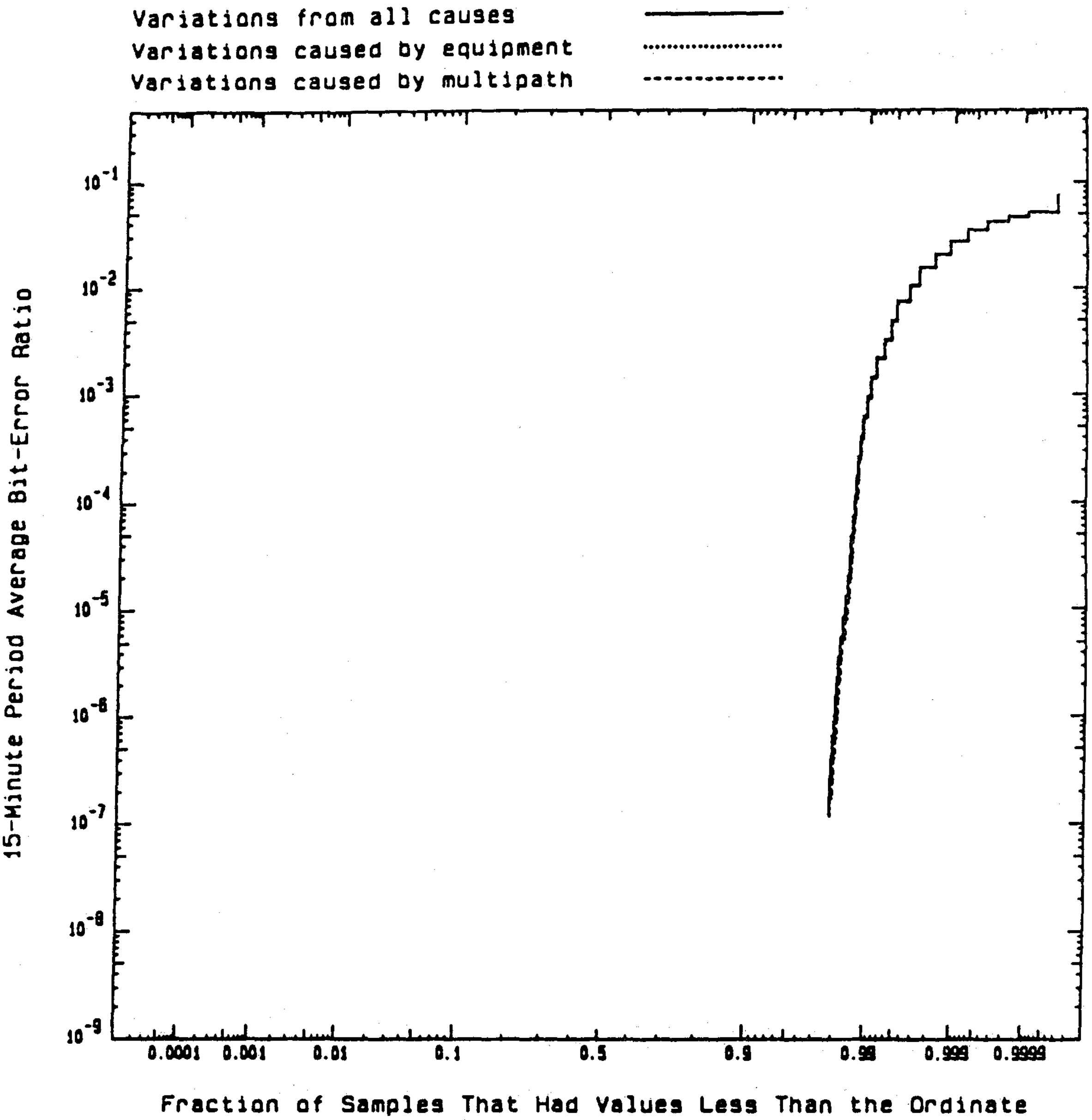
Figure 18 provides plots of the cumulative probability distributions of rsl for the Schwarzenborn-Feldberg link for the 12-month period starting April 1, 1988. Five rsl samples per second were made during the entire measurement period. Figure 18a is a cumulative probability distribution of the rsl samples for the entire 7866 hours which resulted in over 141 million samples. Figure 18b is a cumulative probability distribution of rsl samples for those periods in which multipath fading was detected and an error occurred in either of the receivers. Thus, the data in Figure 18b are a subset of the data in Figure 18a.



Notes: 1) Sample sizes for all curves are 31,464 15-minute blocks.
2) Data are for the 12-month measurements period starting April 1, 1988.

a) On-line receiver

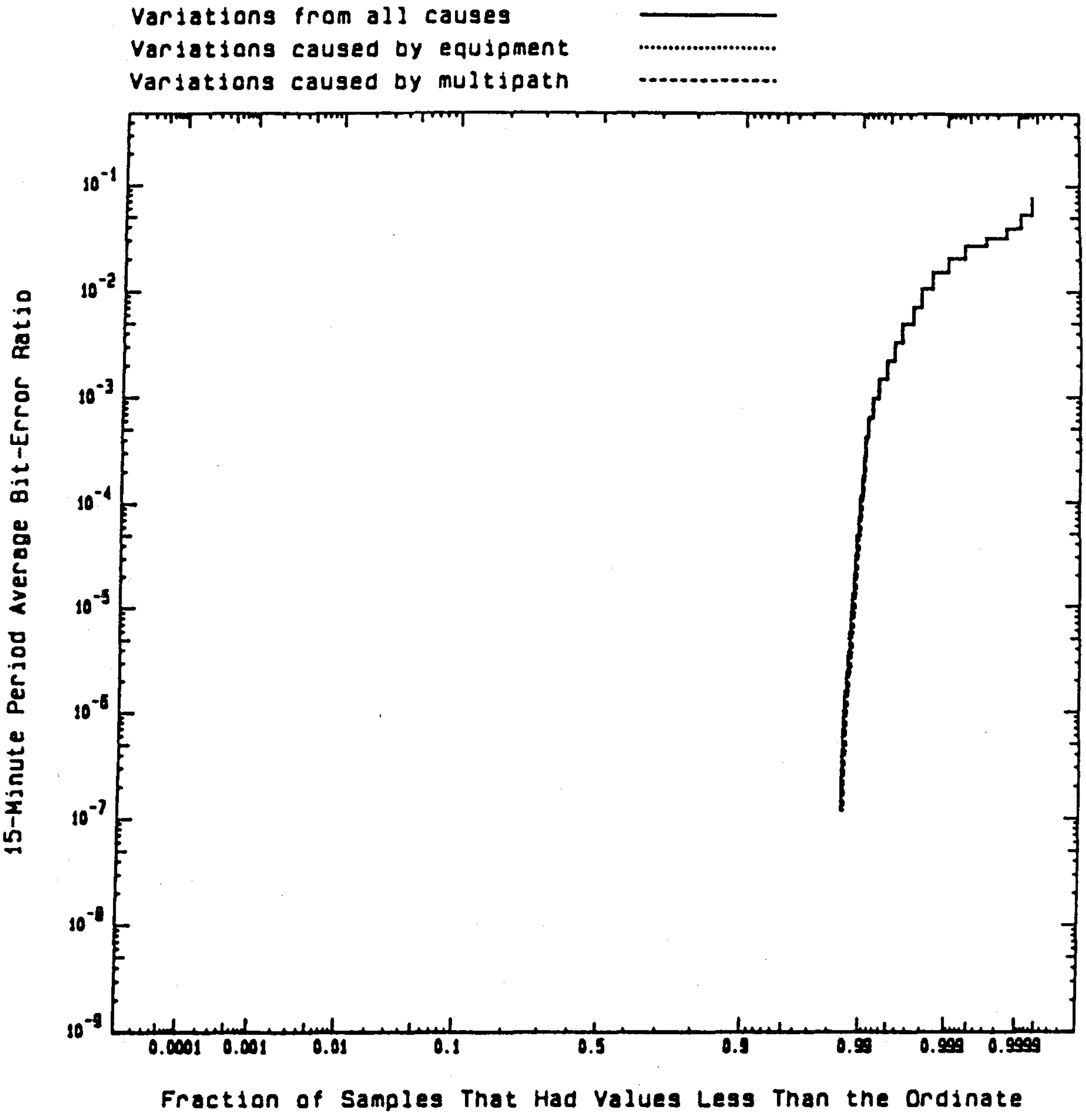
Figure 17. Distributions of 15-minute average BER for SBN-FEL link.



Notes: 1) Sample sizes for all curves are 31,464 15-minute blocks.
2) Data are for the 12-month measurements period starting April 1, 1988.

b) Receiver A

Figure 17 (cont). Distributions of 15-minute average BER for SBN-FEL link.



Notes: 1) Sample sizes for all curves are 31,464 15-minute blocks.
2) Data are for the 12-month measurements period starting April 1, 1988.

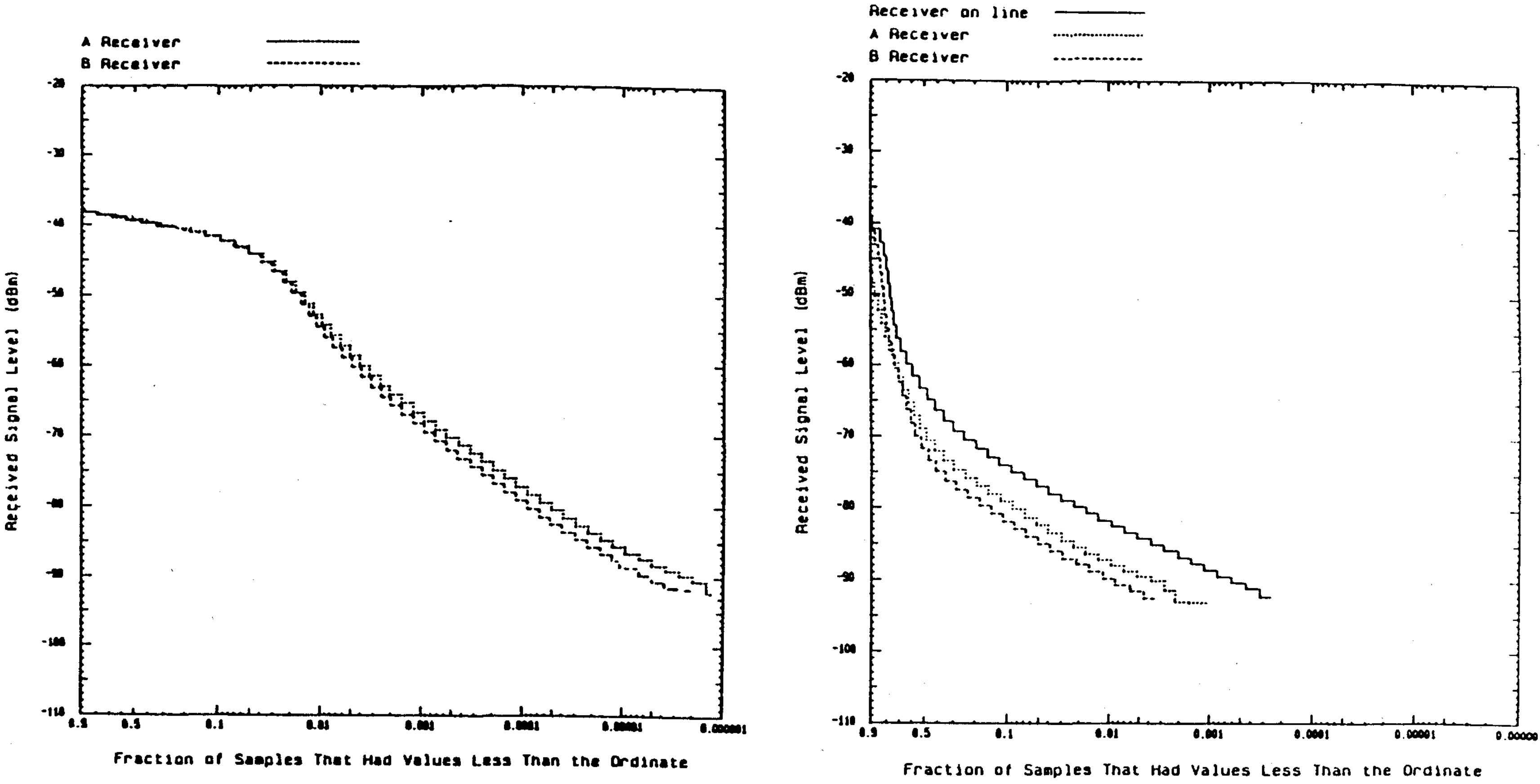
c) Receiver B

Figure 17 (cont). Distributions of 15-minute average BER for SBN-FEL link.

resulted in over 141 million samples. Figure 18b is a cumulative probability distribution of rsl samples for those periods in which multipath fading was detected <u>and</u> an error occurred in eithr of the receivers. Thus, the data in Figure 18b are a subset of the data in Figure 18a. Note that the rsl's are significantly lower for the distributions in Figure 18b than they are in Figure 18a. In Figure 18a, the median rsl for either receiver is about -39.5 dBm. In Figure 18b, the median rsl is about -63 dBm for the receiver on line. Note that the receiver-on-line rsl curve is higher than the rsl for either Rx A or Rx B, as expected.

Figure 19 is a plot of the rsl's recorded by TRAMCON for the entire 18-month measurement period. The data were obtained from the cumulative probability distributions that were plotted each month for the rsl data obtained from TRAMCON. The data plotted are the median and 99.9% points obtained from the cumulative distributions. The 99.9% curves depict the rsl levels for which 99.9% of the rsl samples recorded for the month are greater than the point plotted. The predicted line is the rsl level predicted in the Systems Engineering Plan (CEEIA, 1981).

Figure 20 is a plot very similar to Figure 19. The difference between the two figures is that Figure 19 is a plot of TRAMCON rsl data, while Figure 20 is a plot of rsl data obtained from a measurement system unique to the NPC/LPC program. The closeness the data from the two sources provides <u>a high level of confidence in the reliability of the TRAMCON data</u>. The small differences between the data in the two figures are due to differences in the sampling intervals of the two systems and in the accuracy of the measurements. The TRAMCON system samples rsl on every link once every polling cycle. The length of the polling cycle varies depending on the number of nodes in the DEB segment being monitored by the TRAMCON master computer. For the FKT-N1 Segment, the TRAMCON polling cycle is approximately 100 seconds long. The resolution of the TRAMCON rsl measurement is 1 decibels. The NPC/LPC measurement system samples the rsl every 200 ms with a resolution of less than 0.1 decibels. This higher resolution and sample rate are required for the special objectives of the NPC/LPC program. As a result



a) RSL's for all of valid test period; 141,588,000 samples for each curve.

b) RSL's for periods of multipath fading in which errors occurred; 109,520 samples for each curve.

Notes: 1) RSL was sampled 5 times per second.
2) Data are from 12-month measurements.

Figure 18. Distributions of rsl's for SBN-FEL link.

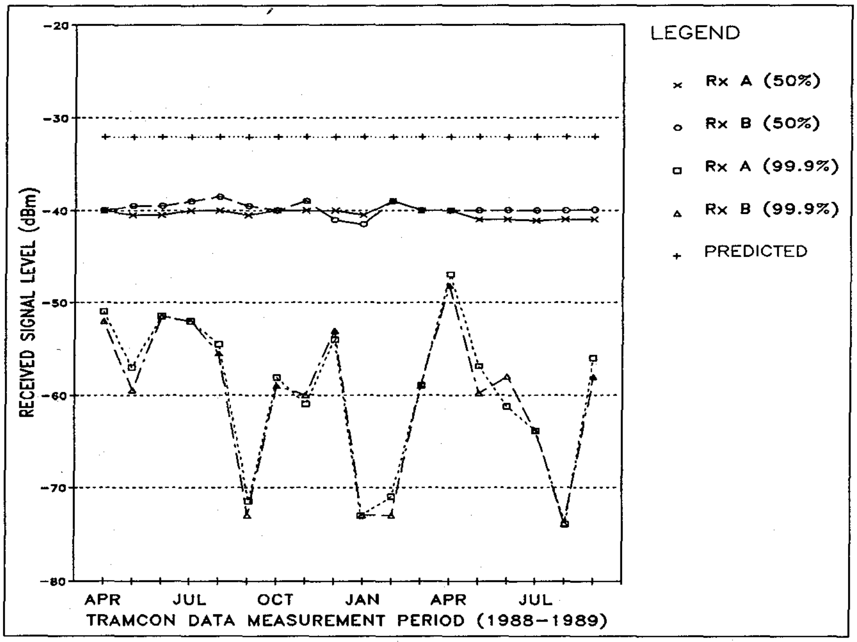


Figure 19. Schwarzenborn-Feldberg rsl's recorded by TRAMCON.

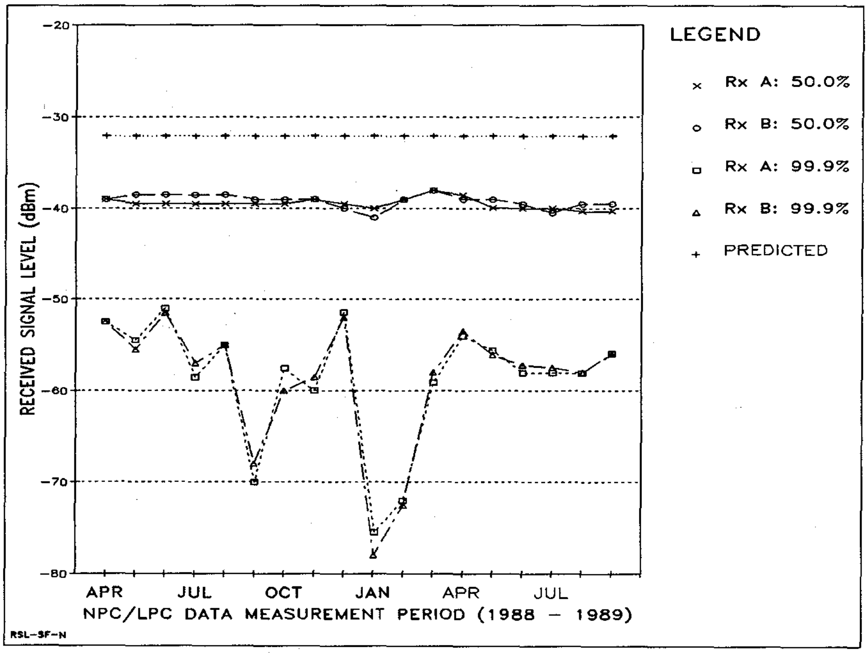


Figure 20. Schwarzenborn-Feldberg rsl's recorded by NPC/LPC data acquisition system.

of the differences in the sampling rate between TRAMCON and the NPC/LPC measurement system, TRAMCON may miss a small number of fading events that the NPC/LPC system would detect.

Several observations can be made from the examination of Figures 19 and 20. First, note that the median rsl's are about 8 decibels below that predicted in the Systems Engineering Plan. The second observation is that rsl's for the two receivers are very close, which indicates that the antennas are properly aligned. The third observation is that the worst fading months are September 1988, and January, February, and August 1989. Comparisons of Figures 10 and 19 (or 20) show the correlation between the worst fading months and the worst errored-second performance months. Clearly, January 1989 was the worst fading and performance month during this measurement period. Data for this period will be examined more closely in Section 4.8.

Figure 21 is a plot of the monthly median and 99.9% rsl's obtained from monthly cumulative probability distributions. The reason for this is as follows. The rsl's for Rx A These data were obtained from a much smaller number of samples than the data for Rx A and Rx B which were presented in Figures 19and 20. and Rx B were sampled every 200 ms for the entire duration of the measurement period. Some other parameters and status indicators were sampled only when a) an error occurred in either receiver and for a period of 1 minute after that error occurred, and b) once every minute on the minute. This sampling strategy was used to limit the size of the NPC/LPC data base which would have assumed unmanageable proportions without such a strategy. The status indicator that indicates which receiver is the receiver on line was one of the parameters that had a limited sampling rate. This is not a problem, however, because the data of primary interest are the parameters and indicators at the time errors are occurring on the radio. Because of the differences in sample sizes, Figure 21 should not be compared with either Figure 19 or Figure 20.

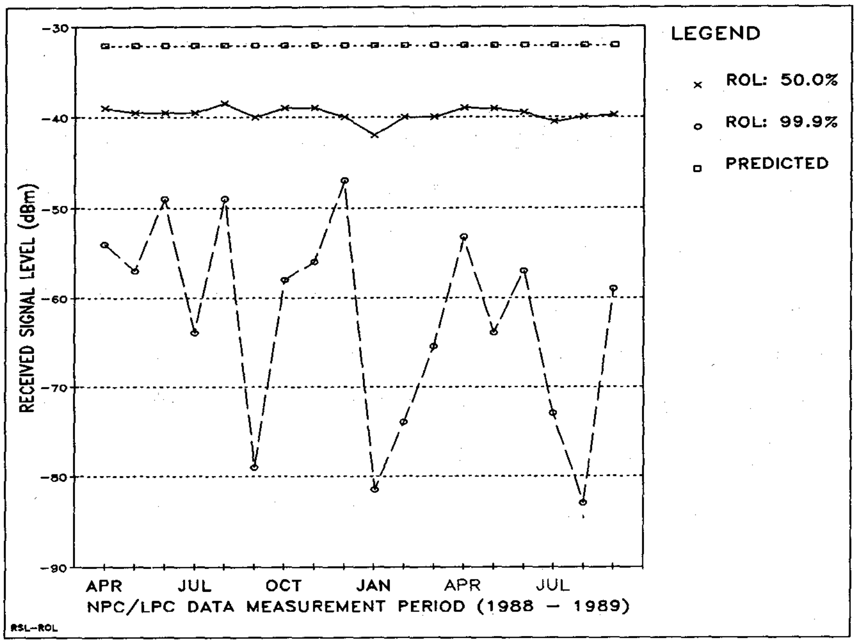
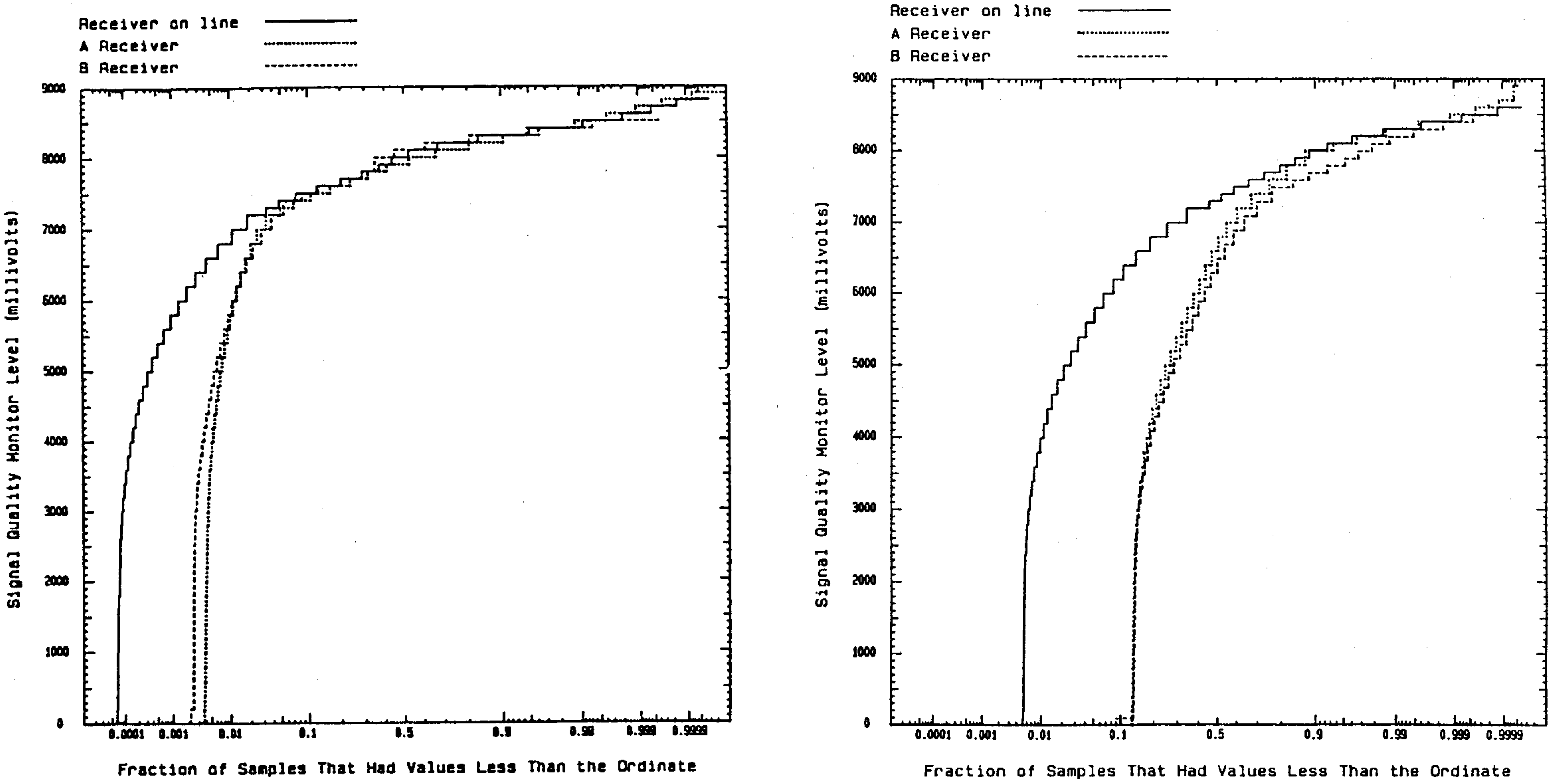


Figure 21. Schwarzenborn-Feldberg rsl's for the receiver on line.

4.1.5 SBN-FEL Signal Quality Monitor Data

Figure 22 is a plot of distributions of the voltages on the signal quality monitor. The SQM voltages were recorded during the following periods: a) whenever an errored second occurred and for a period of 1 minute after that errored second occurred, and b) once every minute on the minute. Figure 22a provides cumulative probability distributions for all of the SQM data collected. Figure 22b provides cumulative probability distributions of multipath fading periods in which an error occurred. Thus, Figure 22b is a subset of Figure 22a. Note that the median values for two receivers are significantly less for the periods in which multipath occurred (Part b of the figure). Note also that the median values for the receiver on line are significantly higher than the values for the individual receivers. These data show that SQM is a good indicator of multipath and the resulting digital radio performance. This assessment is further verified by the plots of hypothetical space diversity improvement which would result from a diversity switching algorithm based on the SQM voltage (see Section 4.1.7).



a) All of valid test period (12 months); sample sizes are all 3,941,820.

b) Periods of multipath fading; sample sizes are all 109,520.

Note: Data are from 12-month measurements.

Figure 22. Distributions of DRAMA radio SQM voltages.

4.1.6 Amplitude Distortion Multipath Data for the SBN-FEL Link

The literature on the effects of multipath fading on digital LOS microwave radio performance includes a large number of papers that describe in-band power difference (IBPD) as a measure of the amount of fading that occurs on a particular channel (see Vigants, 1984; Gardina and Vigants, 1984; Greenfield, 1984; Ranade, 1985, for example). The IBPD is a measure of the amount of amplitude distortion in the passband of the receiver. Barnett (1979) states that as little as 0.2-dB/MHz distortion is sufficient to cause performance degradation to a BER of 1 x 10^{-3} for a digital radio without a slope adaptive equalizer.

Because of the interest in this particular parameter and the need to investigate alternative space diversity switching algorithms for the DRAMA radio, three different measures of the IF amplitude distortion were included in the NPC/LPC program. Two of the measures were based on data from a spectrum analyzer that was used to monitor the IF spectrum of each of the two DRAMA diversity receivers. These measures were the distortion across the band (3-decibels points) and the maximum slope as defined in Section 3.3.1. The third measure was the output from two filters that were installed as part of the NPC-LPC measurement system. The test configuration was previously described in Section 3.2.2 and shown in Figure 7.

The results of the IF amplitude distortion measurements are depicted in Figure 23. Distributions of the three different measures of the IF amplitude distortion are provided in the figure. Part (a) of the figure contains the distributions for all of the time in which multipath fading occurred. Part (b) contains the distributions for the time in which multipath was detected and an error occurred in the receiver on line. Thus, the data set for Figure 23b is a subset of the data set for Figure 23a. Note that the two tails of each of the three distributions are worse for the curves in Figure 23b than they are for the curves in Figure 23a. To illustrate this point the following values were obtained directly from the figure at the 0.001 probability level:

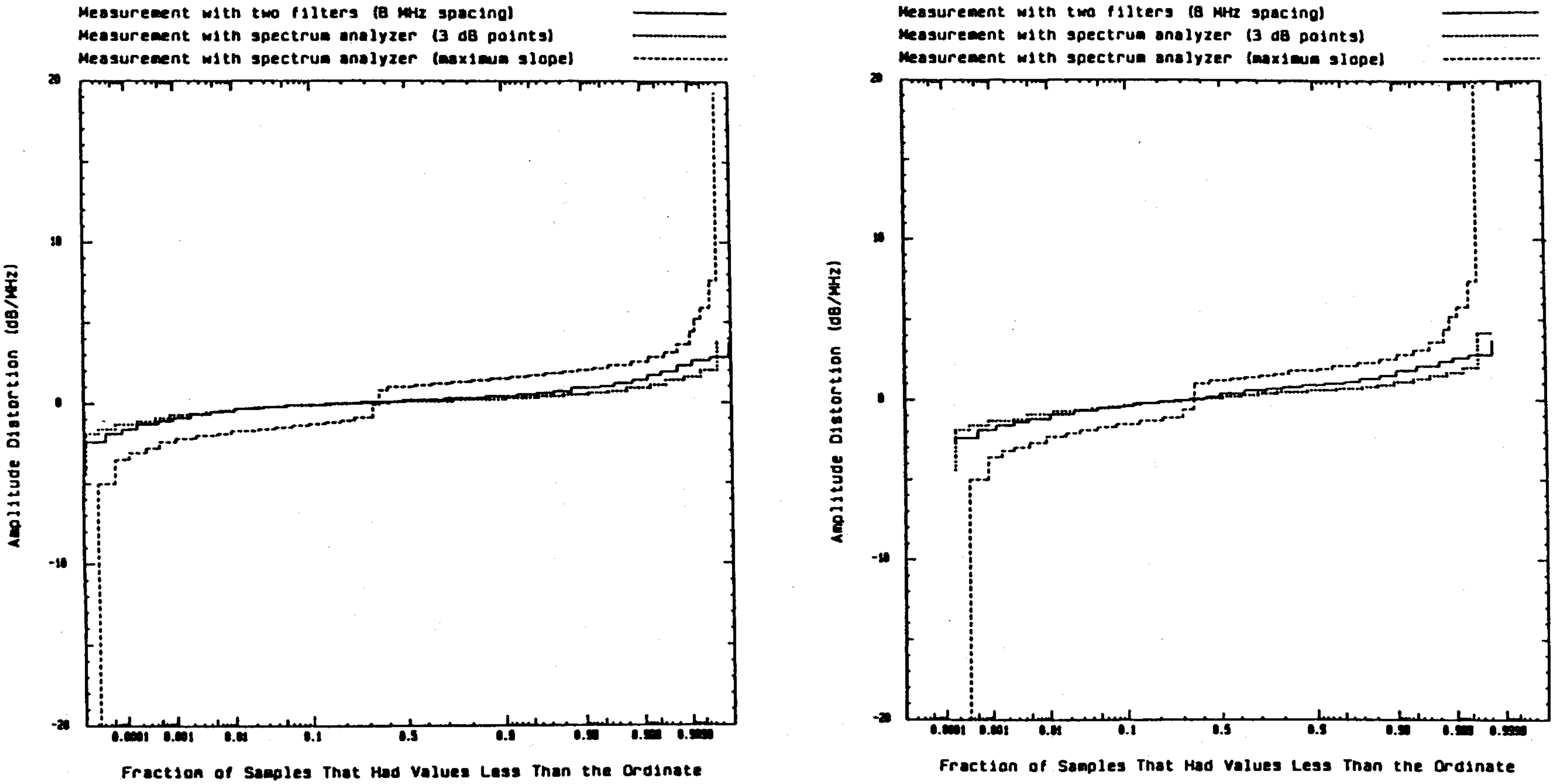
	Periods of Multipath Fading	Periods of Multipath Fading In Which Errors Occurred
Two filter measurement:	-1.2 dB	-1.8 dB
Spectrum analyzer 3-dB measurement:	-0.8 dB	-1.0 dB
Spectrum analyzer maximum slope measurement:	-2.4 dB	-3.5 dB

This demonstrates that errors are more likely to occur on the DRAMA radio during times in which the IF amplitude distortion has deteriorated due to multipath fading.

4.1.7 DRAMA Radio Space Diversity Improvement.

Figure 24 provides the hypothetical space diversity improvement which could be obtained with each of the following diversity switching algorithms:

- current DRAMA radio diversity algorithm
- switching based on IF amplitude slope distortion using two 8-MHz filters (see Figure 7)
- switching based on IF amplitude slope distortion using spectrum analyzer output at the 3-decibels points of the DRAMA radio passband
- switching based on IF amplitude slope distortion for the maximum slope for any two adjacent points separated by 400 kHz within the passband
- switching based on signal quality monitor (SQM) voltage
- switching based on received signal level

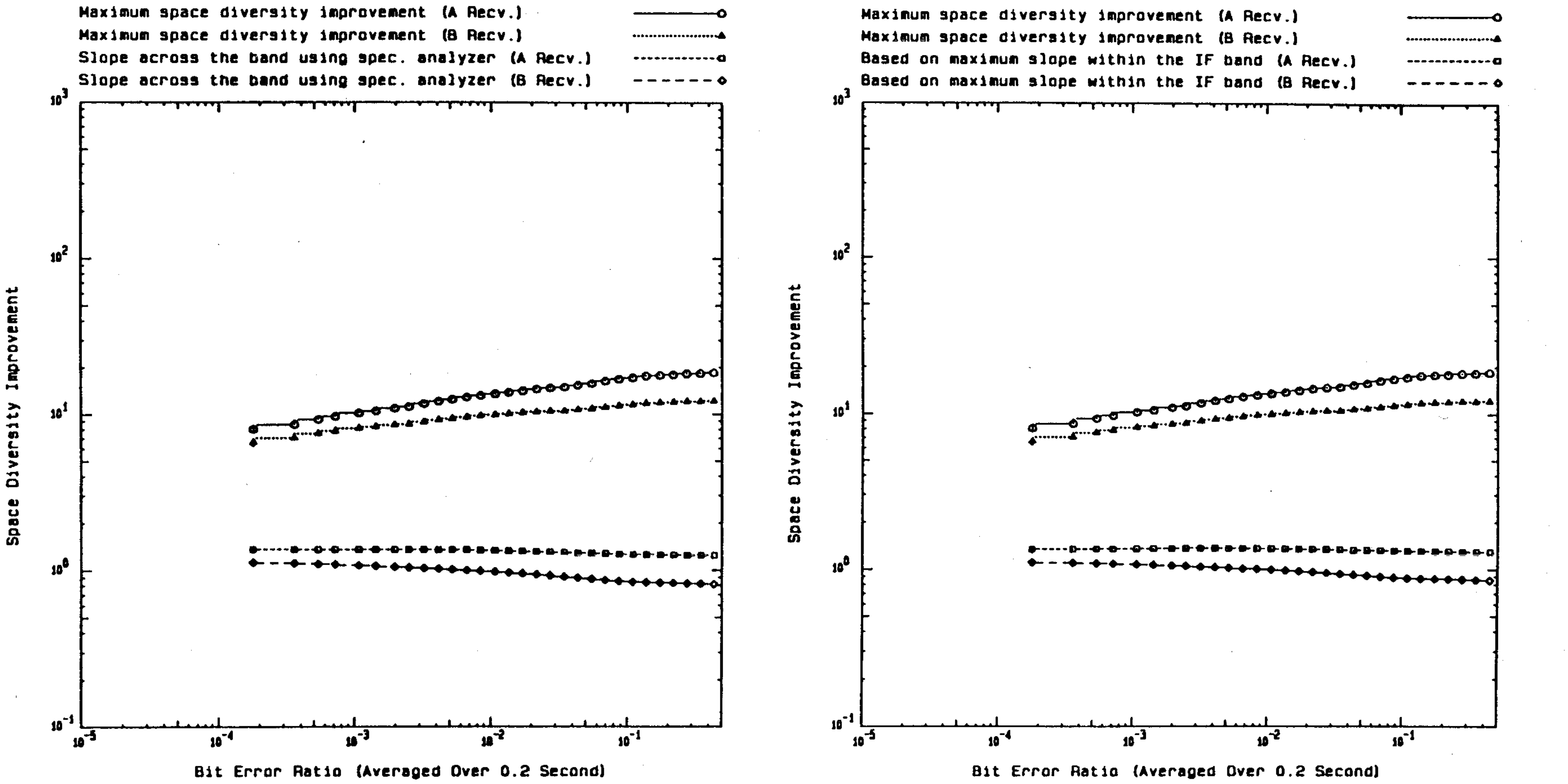


a) Periods of multipath fading; sample sizes are all 87,470.

b) Periods of multipath fading in which an error occurred in at least one receiver; sample sizes are all 5,900.

Note: Data are from 12-month measurements.

Figure 23. Distributions of DRAMA radio IF amplitude distortion.

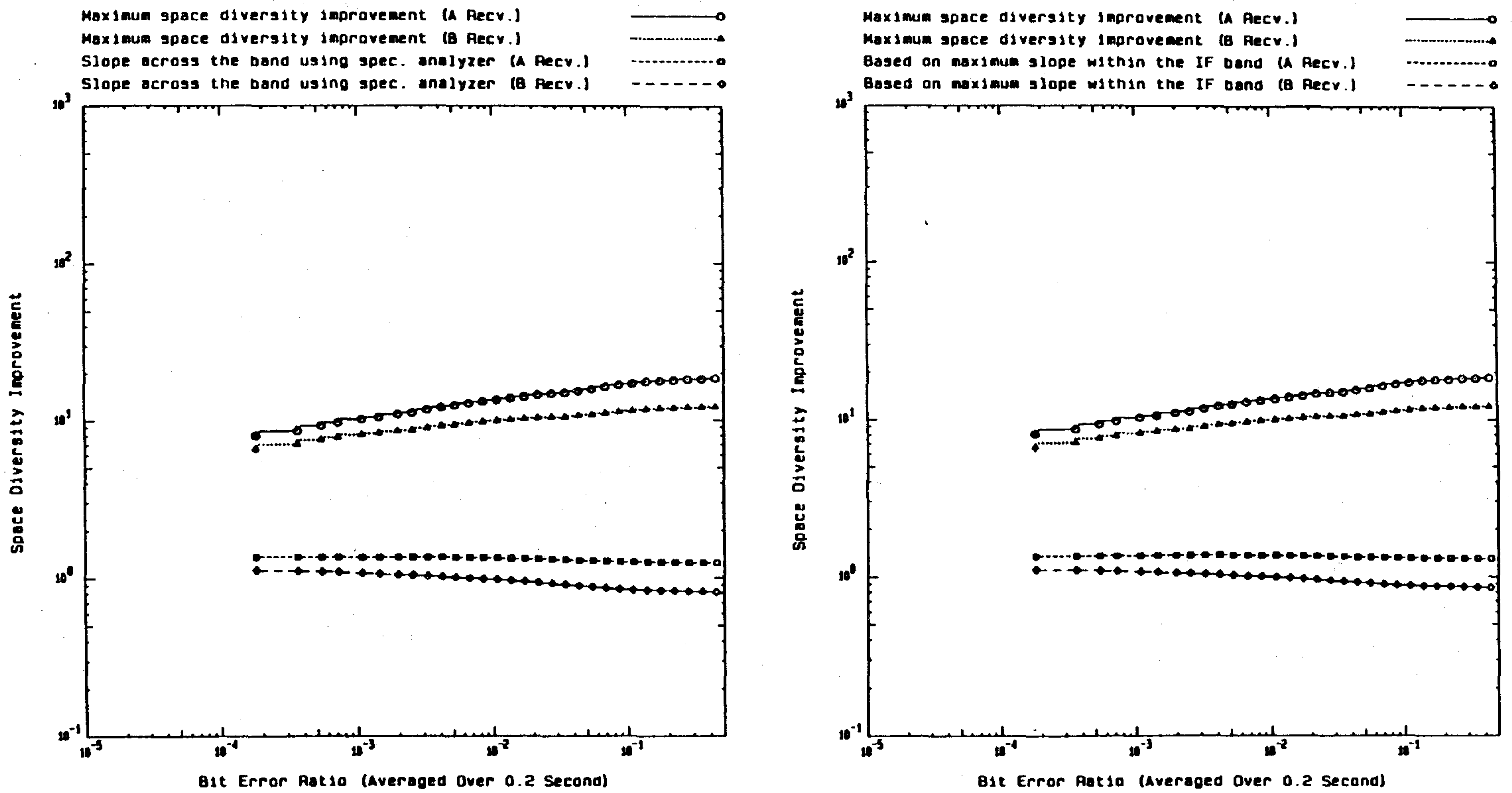


a) Comparison of current system SDI with hypothetical maximum SDI; sample sizes are all 69,652.

b) Comparison of IF slope using filters SDI with hypothetical maximum SDI; sample sizes are all 69,652.

Note: Data are from 12-month measurements.

Figure 24. Space diversity improvement for various hypothetical diversity switching algorithms.

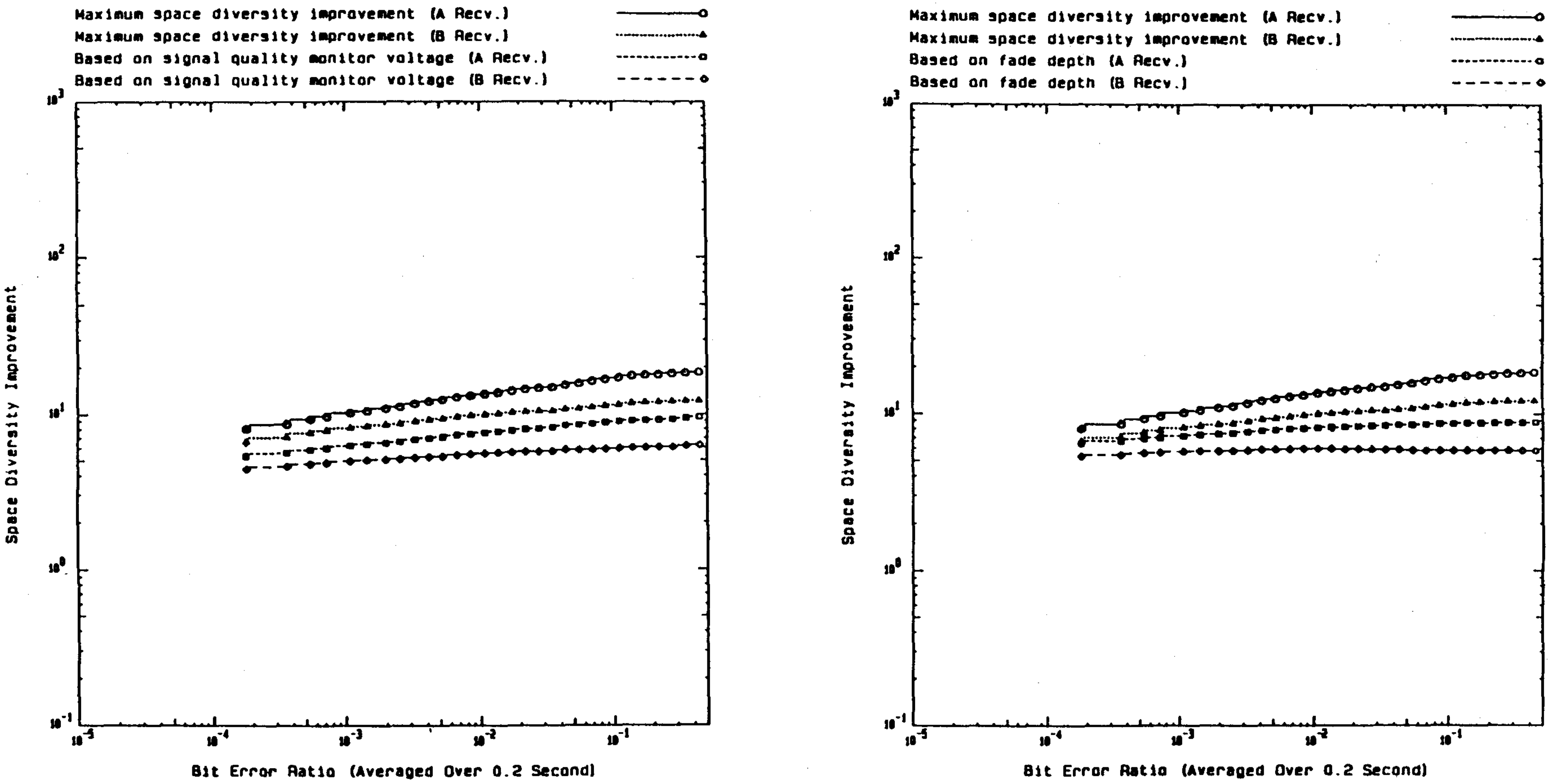


c) Comparison of slope distortion SDI with hypothetical maximum SDI; sample sizes are all 69,652.

d) Comparison of maximum slope SDI with hypothetical maximum SDI; sample sizes are all 69,652.

Note: Data are from 12-month measurements.

Figure 24. (cont.)



e) Comparison of SQM SDI with hypothetical maximum SDI; sample sizes are all 69,652.

f) Comparison of rsl SDI with hypothetical maximum SDI; sample sizes are all 69,652.

Note: Data are from 12-month measurements.

Figure 24. (cont.)

The space diversity improvement (SDI) for each of the above algorithms is plotted in Figure 24 parts (a) through (f) respectively. The maximum theoretically obtainable SDI is plotted in each figure for comparison purposes. The methodology used for the calculation of the SDI factor was provided in Section 3.1.1.

It is clear from Figure 24 that the current space diversity switching algorithm (Figure 24a) performs better than any of the alternative algorithms that have been suggested (Figure 24b through 24f). The current switching algorithm is based on a combination of the received signal level and status alarms (e.g., loss of frame synchronization). Careful comparison of Figures 24a and 24e reveals that switching based on the SQM voltage performs nearly as well as the current switching algorithm. Switching based only on rsl also performs nearly as well as the current switching algorithm.

Depending on the BER threshold chosen, the SDI factors plotted in Figure 24 vary from about 1 to 20. The SDI calculated in Section 4.1.1 based on error second measurements was 5 and 4 for Rx A and Rx B respectively. The Systems Engineering Plan for FKT-N1 (CEEIA, 1981) calculates a diversity improvement factor of 2,109 for the SBN-FEL link. However, Smith (1985, p. 403) reports space diversity improvement factors for other systems range from 6 to 38. Smith and Cormack (1984) report a diversity improvement factor of 14.2 for 90-Mb/s radio. Thus, the measured and hypothetical SDI factors calculated from the NPC/LPC data are consistent with the SDI factors reported by other researchers. The improvement factor found in the Systems Engineering Plan for FKT-N1 seems unrealistic.

Other models for predicting the SDI factor also appear to be overly optimistic. The equation for space diversity improvement (I_o) given by Shafi and Rummler (Ivanek, 1989; p. 323) is:

$$I_o = 1.2 \times 10^{-3} v^2 S^2 f/d L^2 \quad (S < 15) \qquad (1)$$

where: v = relative gain parameter (gain of secondary antenna relative to main antenna is 20 log v)
S = center-to-center vertical separation of receiving antenna in meters
f = frequency in GHz
d = path length in kilometers
L = $10^{-(\text{depth of fade} / 20)}$

Some authors (Lin et al., 1988; Ivanek, 1989, p. 323) state that (1), which was developed for analog space diversity radios, is pessimistic when used for predicting the SDI factor.

This was not the case for the space diversity measurements made on the DRAMA radio on the SBN-FEL link.

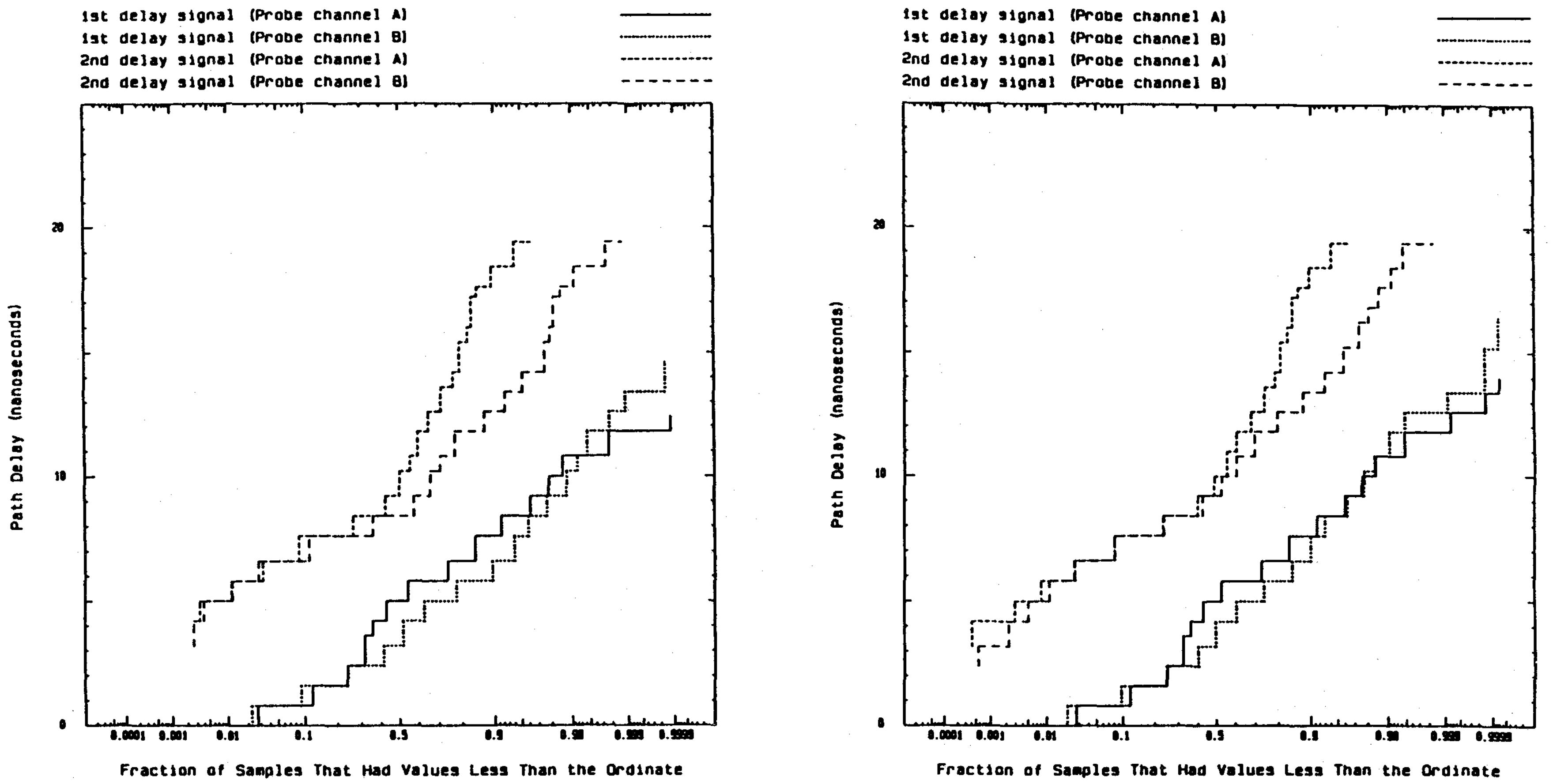
For the SBN-FEL link we use the following values in (1): v = 1, S = 12.3 m, f = 8.2 Ghz, d = 99.4 km, and 20 log L = 39 decibels. Using these numbers in equation (1), we calculate a space diversity improvement factor of 119, which is more than an order of magnitude greater than was actually measured on the SBN-FEL link. These results are useful for the refinement of outage prediction models that incorporate space diversity improvement factors.

4.1.8 Channel Probe Propagation Data.

Figures 25 through 30 provide data obtained from the ITS line-of-sight channel probe which is described in Appendix H. Distributions of multipath delay, rate of change of multipath delay, relative phase between the direct and indirect signal, rate of change of phase, relative amplitude of the indirect signal to the direct signal, and rate of change of the relative amplitudes are provided in Figures 25 through 30 respectively. Part (a) in each of these figures provides distributions in which multipath was detected and an error occurred in one or both of the DRAMA receivers. Part (b) in each of these figures provides distributions for all recorded samples in which multipath was detected. Channel probe data were recorded once every minute and any time in which an error occurred. Thus, part (a) in each of the figures is a subset of the data presented in part (b). The data in each of the figures are from the 12-month period that began in April 1988. Each of the figures contains data from the probe Channel A and probe Channel B which were connected to the main and diversity antennas respectively. Figures 25 and 29 contain data for both the first multipath signal and the second multipath signal.

The following observations are made regarding the data presented in Figures 25 through 30:

1. There are no apparent differences in the distributions in part (a) and part (b) of any of the figures except for Figure 29. In that figure, the median values of the ratio of the multipath signal to the direct signal are higher in part (a) in which errors occurred during multipath than they are in part (b), which includes multipath in which errors did not occur. From this one can conclude that the amount of path delay, relative phase, and fading dynamics (rate of change of delay, phase, and amplitude) are not important parameters in characterizing the effects of multipath fading on the DRAMA radio.

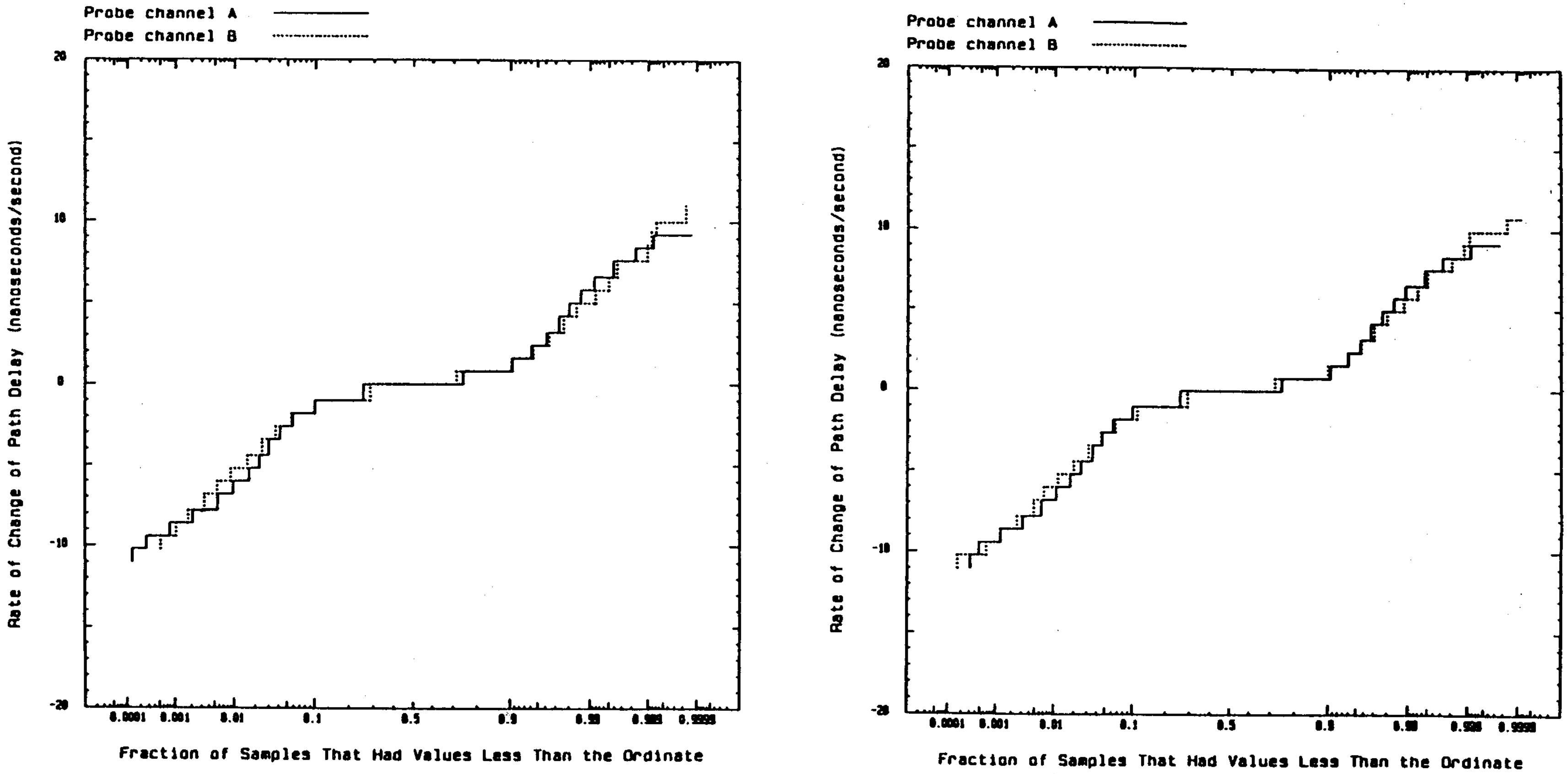


a) Multipath fading periods in which an error occurred on at least one receiver; sample sizes are 8223, 6203, 1502, and 763.

b) All multipath fading periods; sample sizes are 14235, 13596, 2452, and 1812.

Notes: 1) Second signal delay consists of distinct multipath only.
2) Data from 12-month measurements.

Figure 25. Distributions of multipath delay.

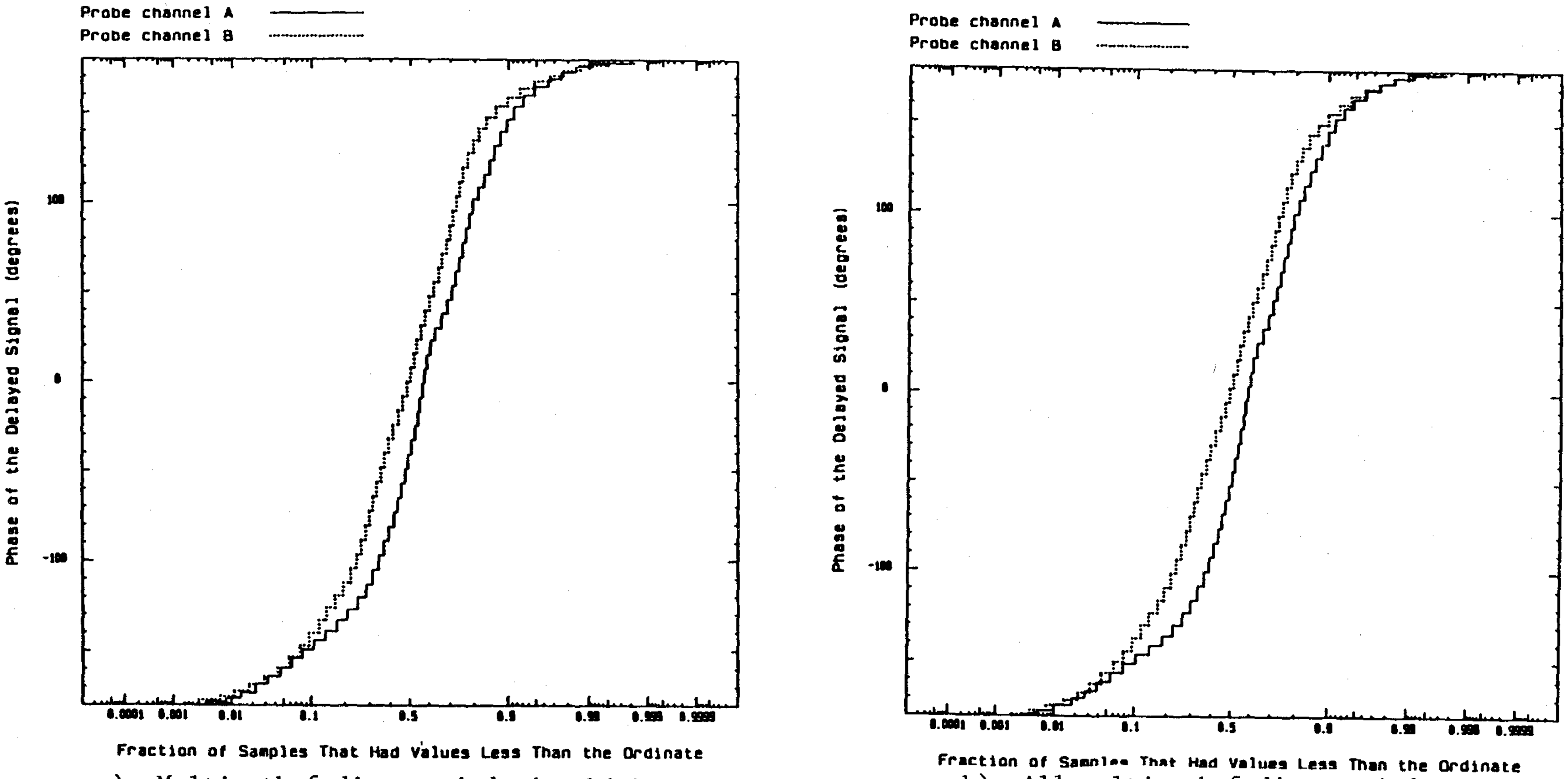


a) Multipath fading periods in which an error occurred on at least receiver; sample sizes are 7517 and 5694.

b) All multipath fading periods; sample sizes are 13039 and 12381.

Note: Data from 12-month measurements.

Figure 26. Distributions of rate of change of path delay.

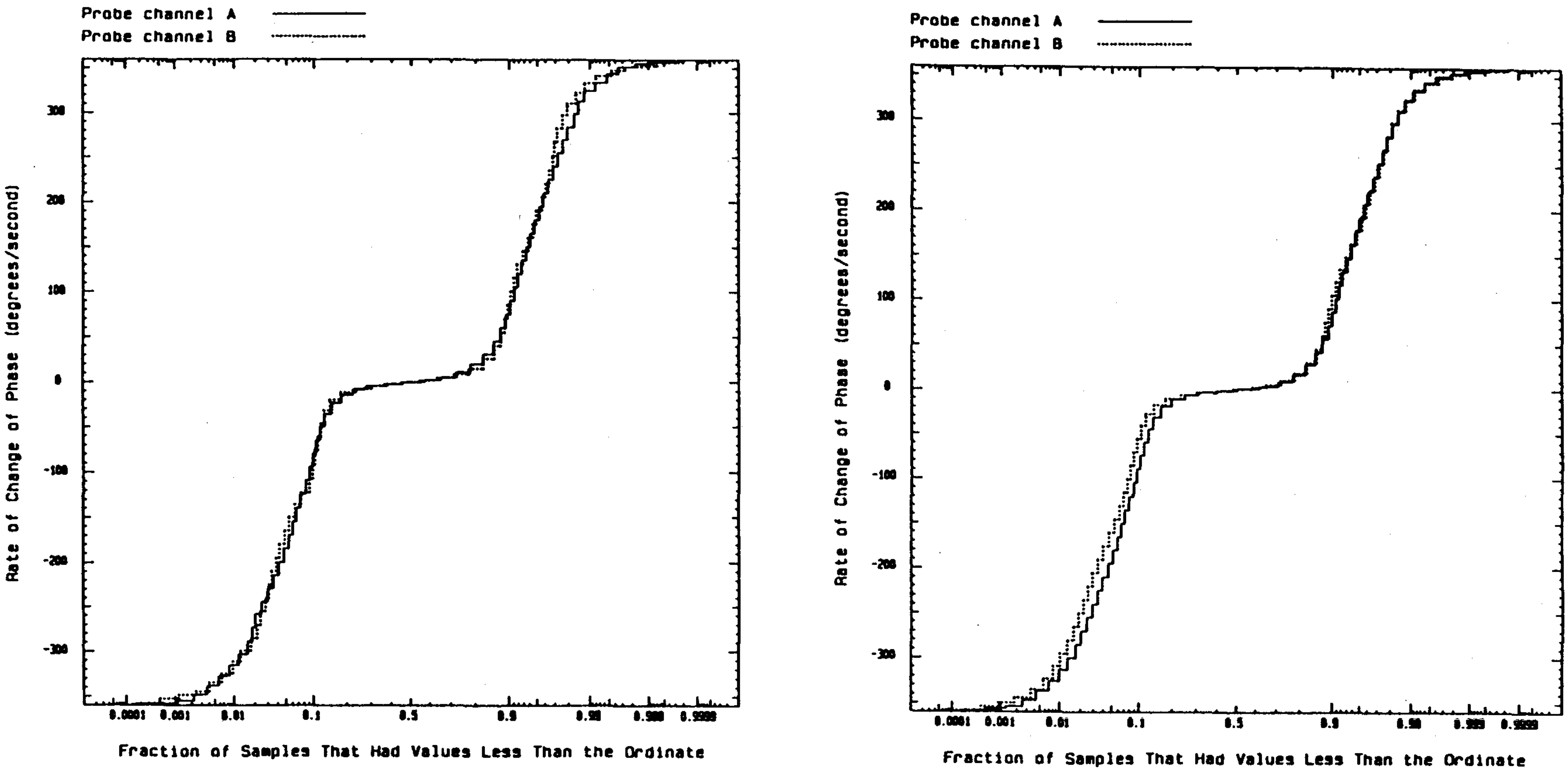


a) Multipath fading periods in which an error occurred in at least one receiver; sample sizes are 7999 and 6071.

b) All multipath fading periods; sample sizes are 13972 and 13338.

Note: Data from 12-month measurements.

Figure 27. Distributions of the phase of the delayed signal.

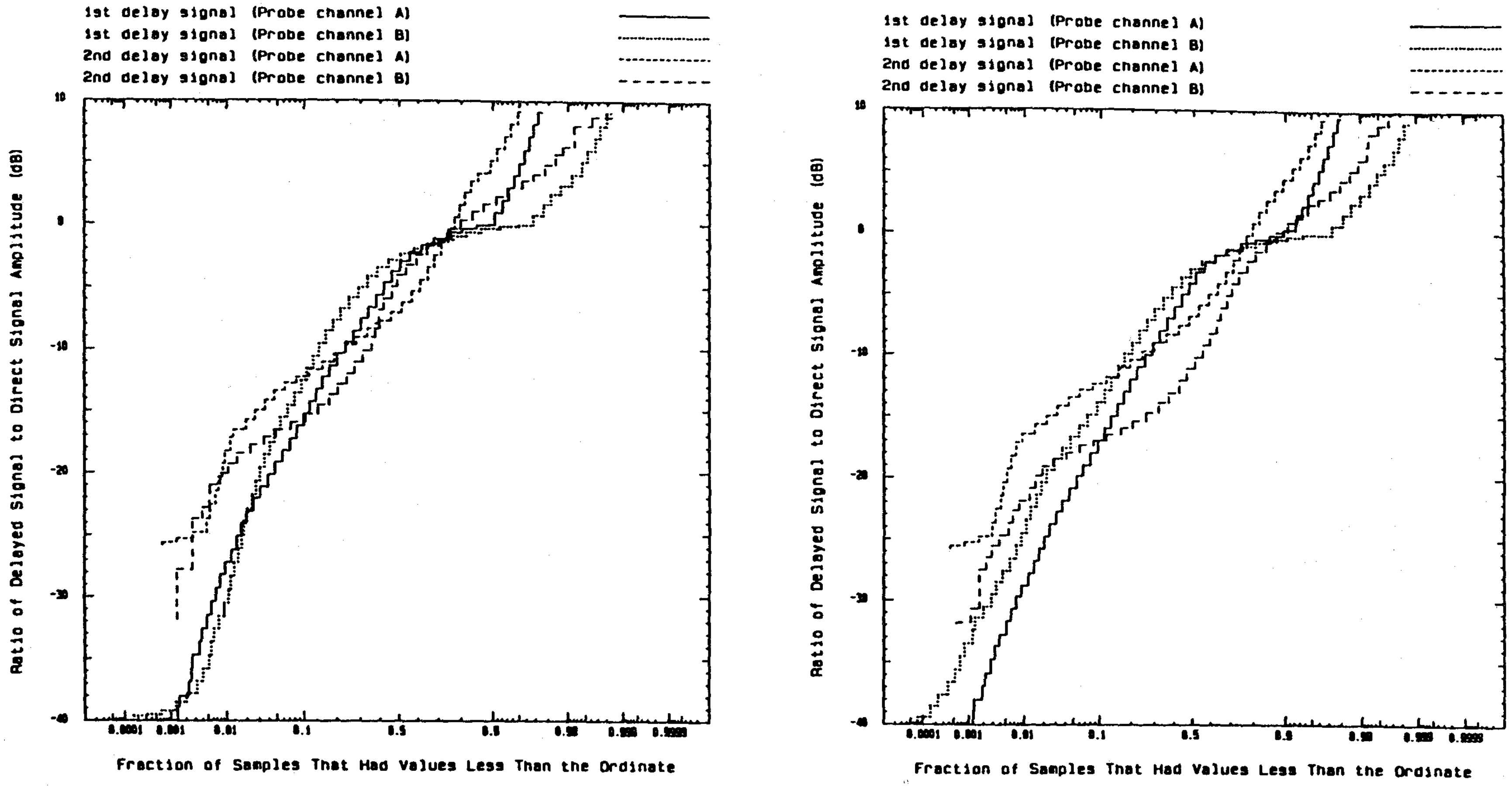


a) Multipath fading periods in which errors occurred in at least one receiver; sample sizes are 7328 and 5895.

b) All multipath fading periods; sample sizes are 12806 and 12260.

Note: Data from 12-month measurements.

Figure 28. Distributions of rate of change of phase.

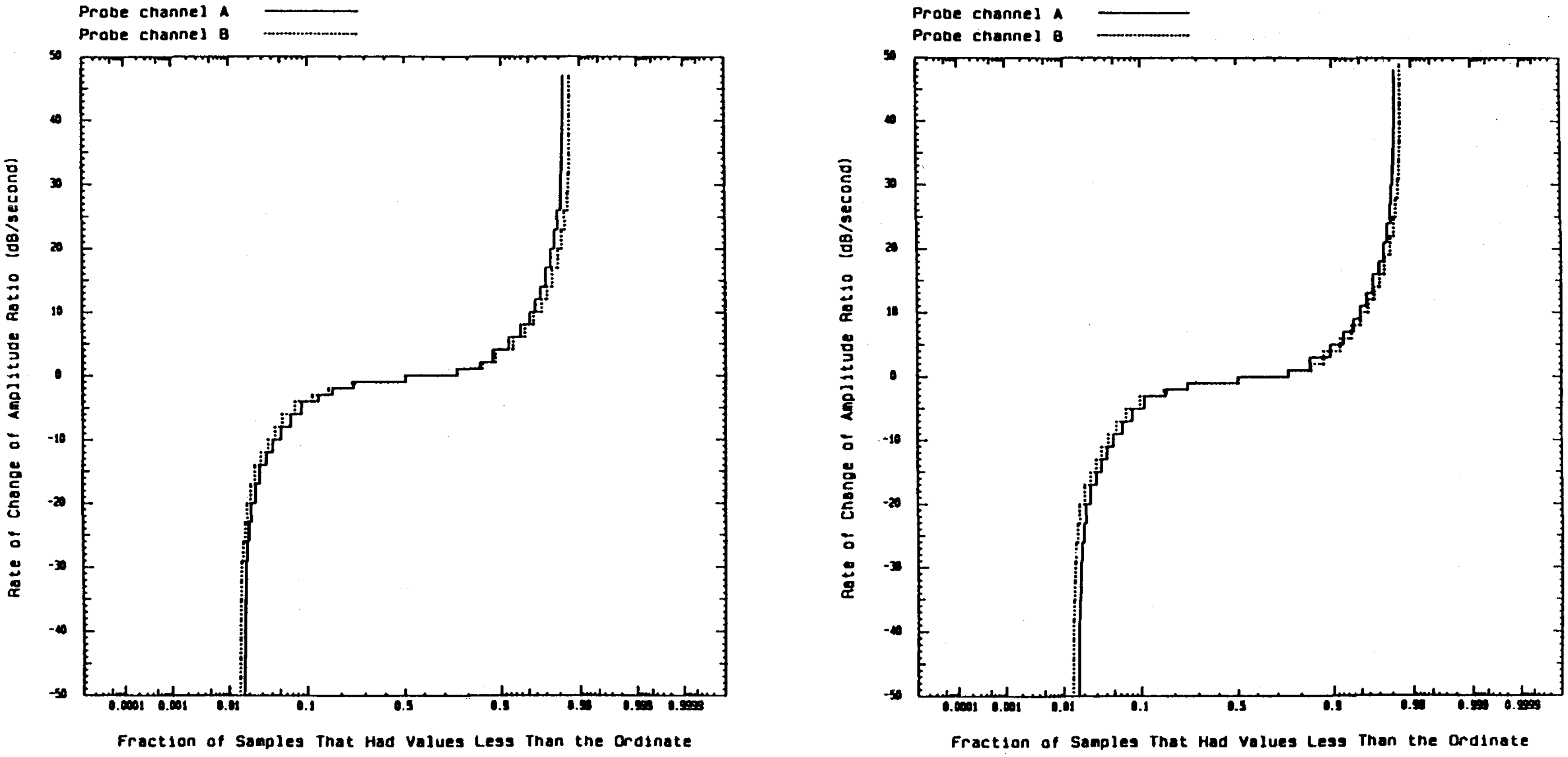


a) Multipath fading periods in which an error occurred in at least one receiver; sample sizes are 8045, 6214, 1502, and 763.

b) All multipath fading periods; sample sizes are 13849, 13320, 2452, and 1812.

Notes:
1) Second delay signal data consists of distinct multipath only.
2) Data from 12-month measurements.

Figure 29. Distributions of ratio of delayed signal to direct signal amplitudes.



a) Multipath fading periods in which an error occurred in at least one receiver; sample sizes are 7517 and 5694.

b) All multipath fading periods; sample sizes are 13039 and 12381.

Note: Data are from 12-month measurements.

Figure 30. Distributions of the rate of change of the ratio of delayed signal to direct signal amplitudes.

2. The delay spreads observed would cause minimal intersymbol interference (ISI) for the DRAMA radio. The intersymbol period for the 26-Mb/s, QPR DRAMA radio is about 73 ns. Multipath delay did not exceed the 38-ns symbol interval of the DRAMA radio (see Figure 25).

3. Whenever multipath fading occurs, a second component of multipath can be detected a significant part of the time. From the sample sizes provided in Figure 25b, one can determine that, for probe Channel A, the second multipath component can be detected 17.2% of the time and that, for probe Channel B, the second multipath component can be detected 13.3% of the time.

4. Careful examination of Figure 29 shows that for probe Channel A, approximately 9% of the multipath fading samples were of the nonminimum-phase variety, i.e., the multipath ray is stronger than the direct ray. For probe Channel B, approximately 6% of the multipath fading samples were nonminimum phase.

Additional analyses of the channel probe and other propagation data should be performed. The results of these analyses should be applied to the refinement of outage prediction models for LOS microwave transmission systems.

4.2 Berlin-Bocksberg Troposcatter Link Analysis

This section provides estimates of error performance and measurement results for the rsl's of the four diversity receivers obtained for the Berlin-to-Bocksberg link.

4.2.1 Errored Second and Unavailability Data

Figure 31 is a plot of ESs and unavailability time for the Berlin-to-Bocksberg (BLN-BBG) troposcatter link. The data for this plot were obtained through a process of allocating end-to-end channel errors to individual links which make up the channel. For example, if an error occurred on the BLN-FEL channel and not on the LDF-FEL channel, it is assumed that the source of the error was either the BLN-BBG troposcatter link, or the BBG-KBG LOS link since the other links (KBG-RWN, RWN-SBN, and SBN-FEL) are common to both end-to-end channels and would cause errors to occur on both channels. The TRAMCON data were used to isolate further the errors between these two links. This allocation process is described in detail in Appendix D.

Application of draft MIL-STD-188-323 to the BLN-BBG troposcatter link results in a design objective of 7.48 hours of UA time and 49,801 ESs on an annual basis. The total UA time estimate was 49.81 hours. The total ESs estimate was 1,101,551 seconds. Thus, the Berlin-to-Bocksberg troposcatter link ES and UA time measured performance does not meet the link design specifications of the Draft MIL-STD-188-323. Figure 31 shows the number of ESs and UA time for each month from March 1988 through September 1989.

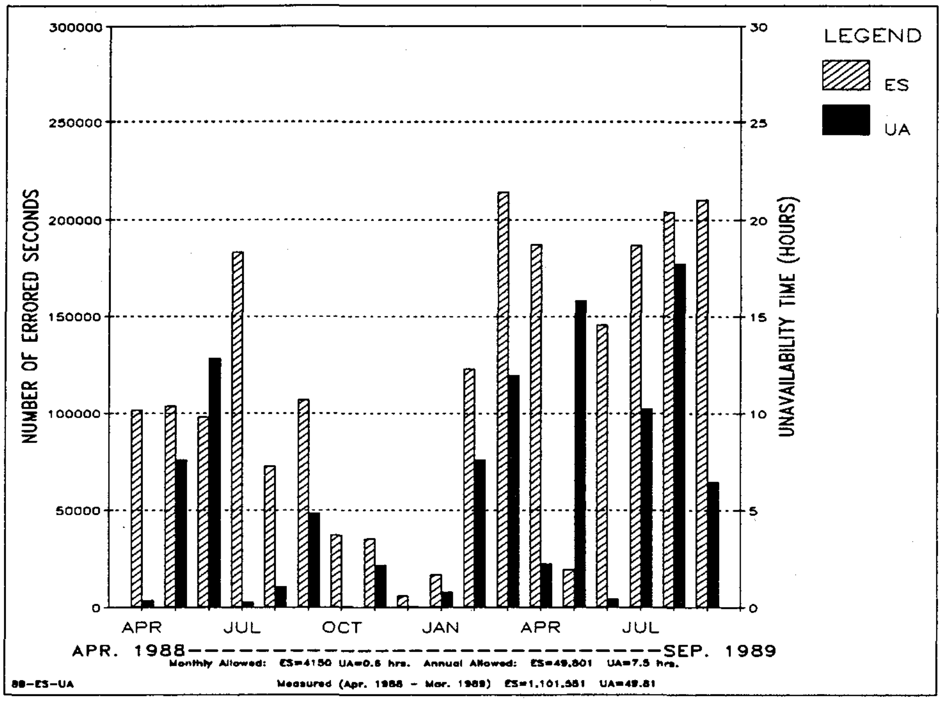


Figure 31. **Estimated Berlin to Bocksberg link errored seconds and unavailability.**

4.2.1 RSL Data for Berlin-Bocksberg Troposcatter Link

As briefly described in Section 3.4, data were collected from the Link Performance Monitor System on the Berlin-Bocksberg troposcatter link. The data were collected at both the Berlin and the Bocksberg sites. The LPMS equipment was developed by a private company for the U.S. Army Berlin Command. The original purpose of the system was to provide a real-time monitor of both troposcatter propagation conditions and estimated error performance in both directions on the Berlin-Bocksberg link. The equipment was installed and initial operations were begun prior to the start of the NPC/LPC data collection effort.

The data collected by this system are potentially very valuable for verification of system engineering design models for troposcatter links as well as for estimates of operational performance. The data collected by the LPMS system potentially would have provided very useful information for the NPC/LPC program. Unfortunately, the LPMS equipment at both ends of the link was found to be very unreliable for a variety of reasons.

The ITS obtained copies of LPMS tapes collected at both Bocksberg and Berlin by site operations personnel. The original emphasis was on analyzing only the LPMS tapes from Bocksberg because the performance measurements were being made for the Berlin-to-Bocksberg direction on this link. Because of hardware reliability problems and incompleteness of the LPMS data at Bocksberg, the ITS decided to analyze LPMS data from the Berlin site even though this was not part of the tasking in the statement of work. Analysis of the Berlin LPMS data also appeared to be very questionable for most of the measured or estimated parameters such as dispersion, fade rates, and estimated BER performance. Although numerous plots of these data were made, they are not published in this report because of the questions on their reliability and accuracy.

The LPMS equipment at both Bocksberg and Berlin provided useful rsl data part of the time. Figures 32 and 33 are examples of rsl distributions from data obtained at the Bocksberg and Feldberg sites respectively.

Figure 34 is a plot of LPMS rsl data at Bocksberg obtained for several months during the NPC/LPC data collection program. The data were obtained by picking the median and 99.9% values off of the cumulative probability distributions. Unfortunately, the Bocksberg LPMS system was down for several months beginning in December 1988. Some data are available after the system was repaired but the data are incomplete and, therefore, are not plotted. Figure 34 also shows the predicted median and 99.9% rsl values obtained from the DEB Systems Engineering Plan for Frankfurt North Phase I (CEEIA, 1981). Note that the measured rsl values are significantly lower than the predicted rsl values.

A monthly plot of LPMS rsl data from Berlin (similar to Figure 34 for Bocksberg) is not provided because of the unreliability of much of the Berlin rsl data.

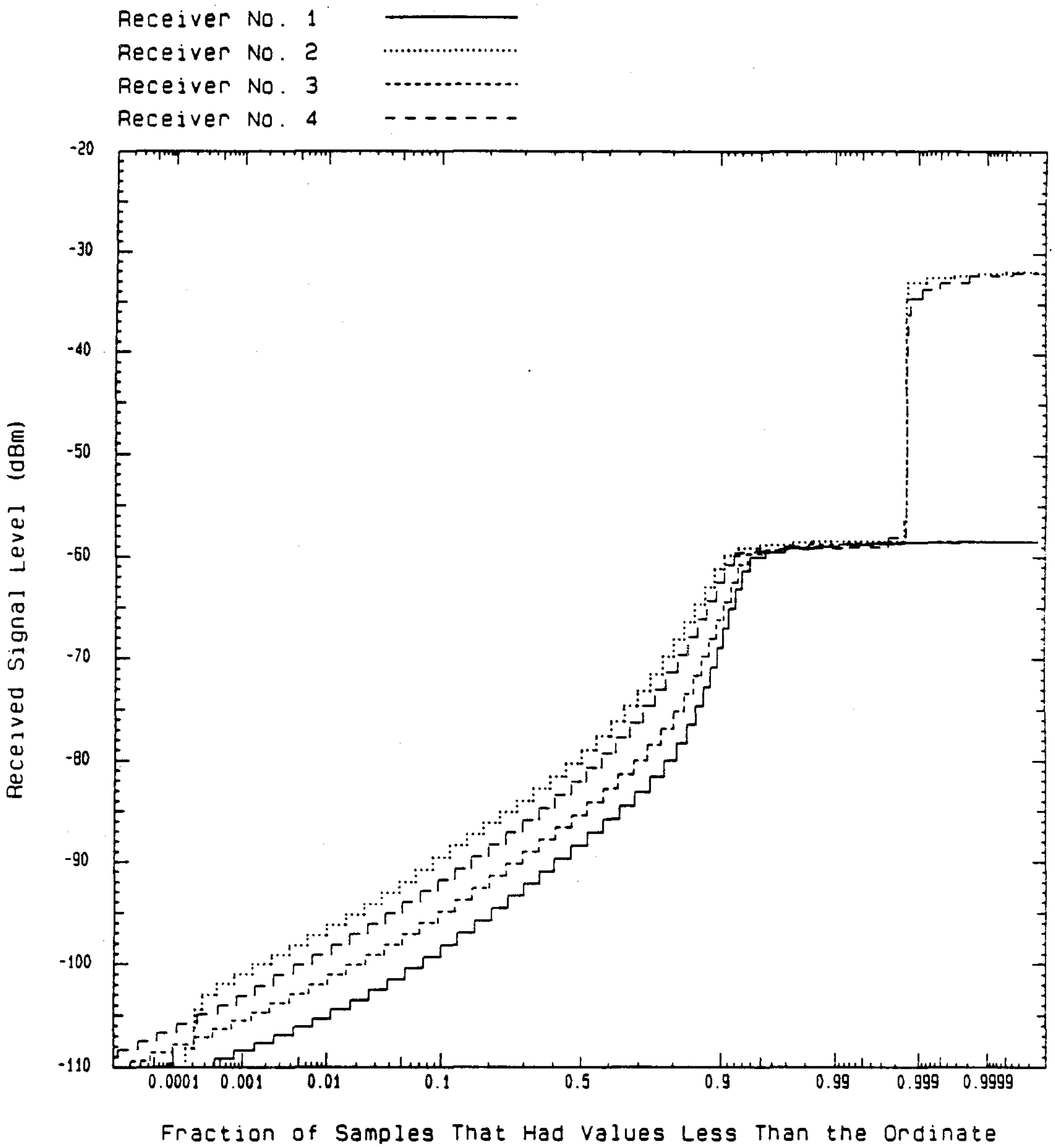


Figure 32. Distributions of rsl's obtained from the LPMS at Bocksberg from 5/1/88 to 5/26/88.

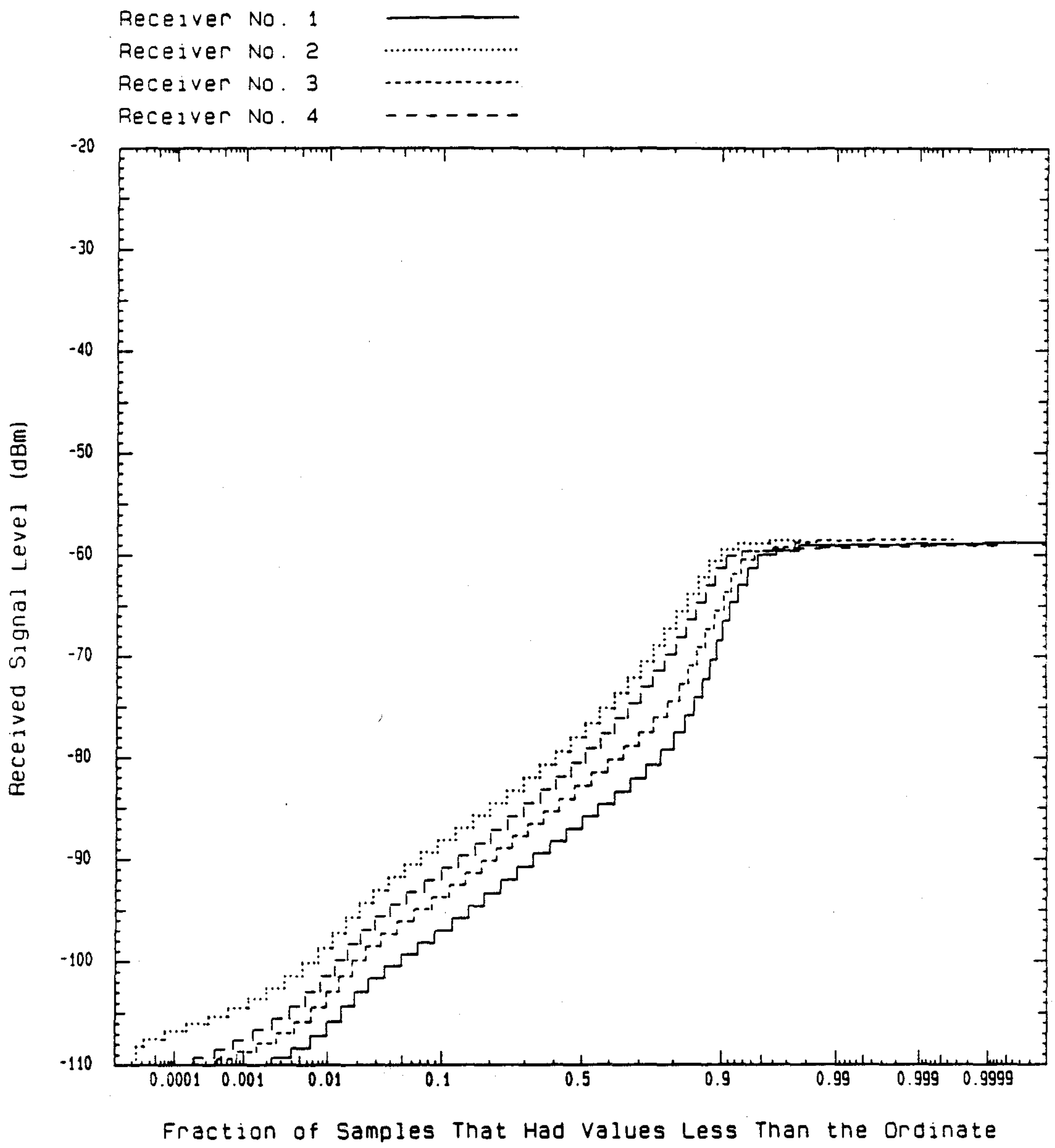


Figure 33. Distributions of rsl's obtained from the LPMS at Berlin from 4/18/88 to 4/25/88.

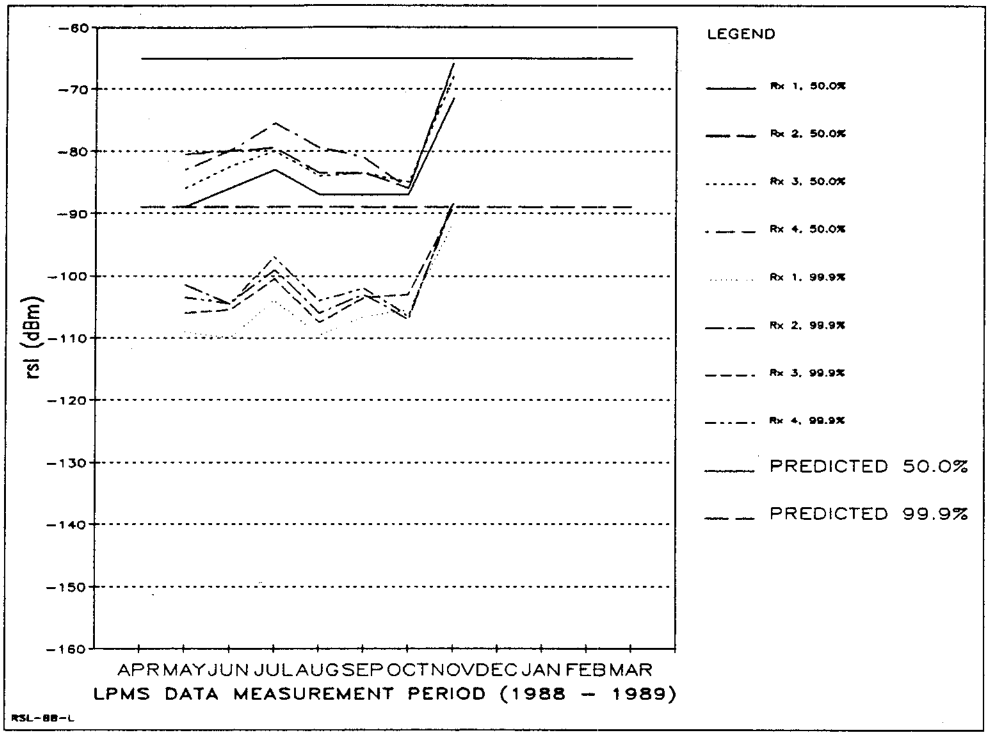


Figure 34. Monthly rsl's recorded at Bocksberg by the LPMS.

4.3 Bocksberg-to-Koeterberg Link Analysis

Figure 35 presents the rsl's for the BBG-KBG link obtained from TRAMCON. Two curves (50% and 99.9%) are shown for each DRAMA radio receiver (Rx A and Rx B). The data for the curves were obtained from cumulative distributions of rsl's that were created monthly. Except for June 1988 and July 1989, the rsl's for the two receivers are very close which indicates that the antennas are well aligned. The June 1988 and July 1989 rsl differences are due to sharp changes in the cumulative distribution at the 99.9% level. The worst fading months were June 1988, February 1989, and March 1989, which differ from the worst fading months for the SBN-FEL link. Note that the median rsl's were well above the 10^{-2} BER threshold provided in the FKT-N1 System Engineering Plan (CEEIA, 1981; p. 71). Note also that the 99.9% monthly values are well above the 10^{-2} BER threshold for this version of the DRAMA radio (-73 dBm).

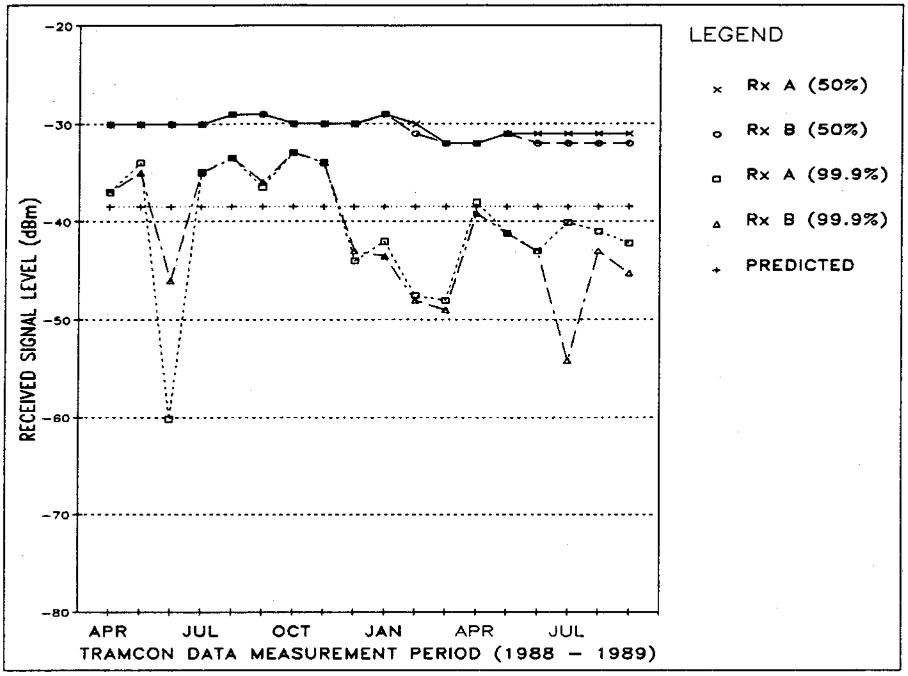


Figure 35. Bocksberg-to-Koeterberg rsl's recorded by TRAMCON.

4.4 Koeterberg-to-Rothwesten Link Analysis

Figure 36 is a plot of rsl's for the Koeterberg-to-Rothwesten link as recorded by TRAMCON. With the exception of May 1989, the rsl's for the two receivers track very closely indicating good antenna alignment. The low data point for Rx B for May 89 is due to the sharp drop-off in the cumulative probability distribution from which these data were extracted. The worst fading months for this link were December 1988 and May 1989. The median rsl's for each of the receivers are about [illegible] to 5 decibels below that predicted in the Systems Engineering Plan (CEEIA, 1981; p. 56). However, the 99.9% values are well above the flat fade threshold (-73 dBm). The only exception to this is the 99.9% value for May 1989 for Rx B. Because of the space diversity capability of the DRAMA radio, the receiver-on-line rsl would be expected to be above the flat-fade threshold most of the time. Therefore, the effect of the fading on Rx B for May 1989 would be expected to have a minimal impact on overall performance.

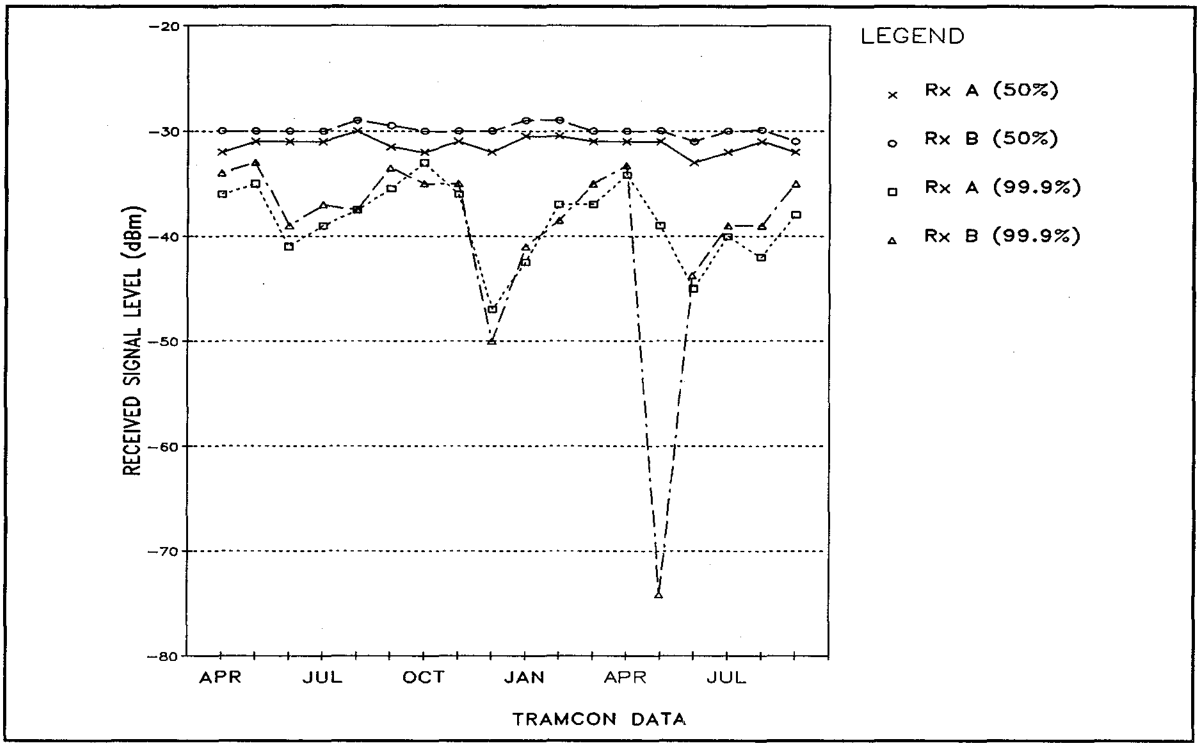


Figure 36. Koeterberg-to-Rothwesten rsl's recorded by TRAMCON.

4.5 Rothwesten-to-Schwarzenborn Link Analysis

Figure 37 is a plot of monthly rsl's for the Rothwesten-to-Schwarzenborn link as recorded by TRAMCON. The rsl's for the two receivers track very closely for the entire 18-month measurement period. The median rsl's were about 2 to 3 decibels below the expected rsl predicted in the Systems Engineering Plan (CEEIA, 1981; p. 51). The worst fading month was May 1989. The 99.9% values for all other months within the measurement period were well above the -73 dBM flat-fade threshold. Even though the measured rsl was less than the flat-fade threshold more than 0.1% of the time in May 1989 on both receivers, it should not be assumed that the fading on the two receivers occurred simultaneously.

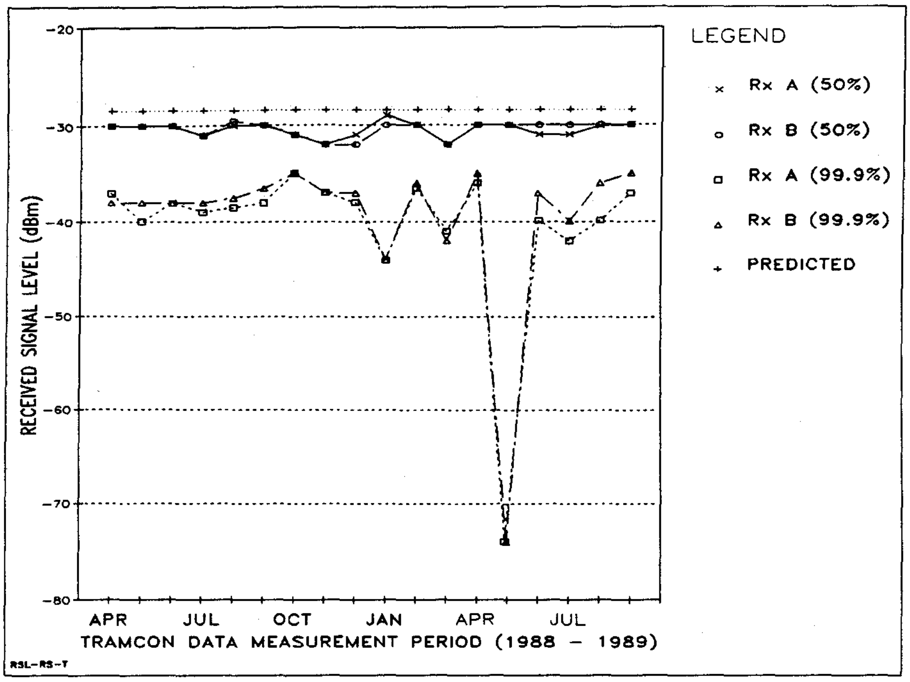


Figure 37. Rothwesten-to-Schwarzenborn rsl's recorded by TRAMCON

4.6 Linderhofe-to-Koeterberg Link Analysis

Figure 38 is a plot of monthly rsl's for the Linderhofe-to-Koeterberg link as recorded by TRAMCON. In contrast to the TRAMCON rsl data for the other links, the Rx A and Rx B rsl's for the LDF-KBG link differ significantly. There appears to be a constant difference of about 4 or 5 decibels between the rsl's for the two receivers. The rsl difference may be due to antenna misalignment. This does not appear to be a problem for this short (28-km) link because the rsl's remain well above the flat-fade threshold. The only exception to this is the May 1989 Rx B 99.9% value. The median rsl's are 3 to 8 decibels below the rsl's predicted in the Systems Engineering Plan (CEEIA, 1981; p. 61).

4.7 Summary of RSL Data for LOS Links in FKT-N1

Figure 39 is a plot that contains rsl data for the SBN-FEL, BBG-KBG, KBG-RWN, RWN-SBN, and LDF-KBG links previously given in Figures 19, 35, 36, 37, and 38 respectively. Only the Rx A data are plotted. The data were extracted from 90 cumulative probability distributions (each of the five links has an rsl distribution for each of the 18

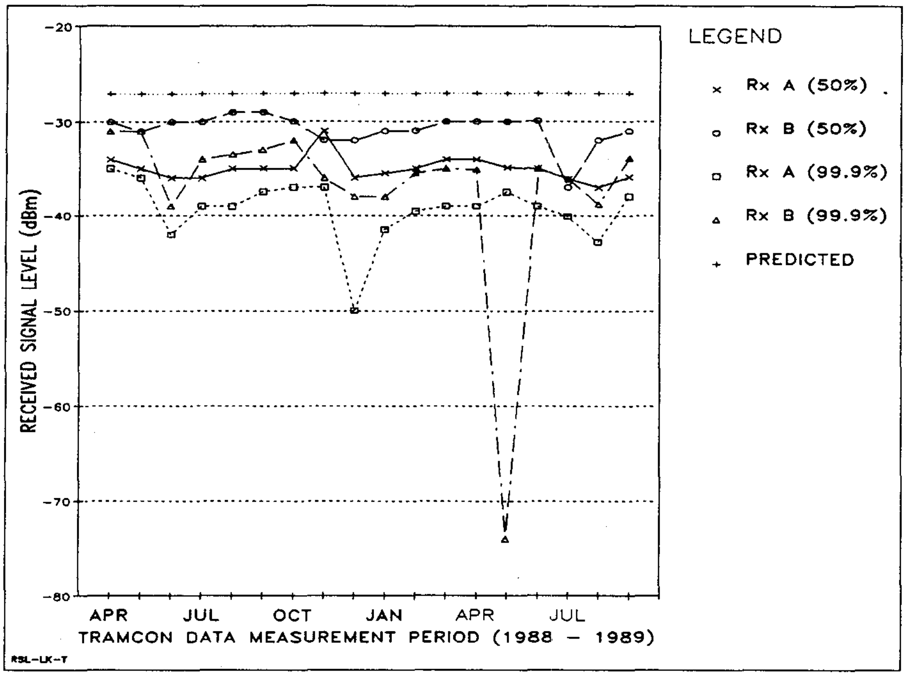


Figure 38. Linderhofe-to-Koeterberg rsl's recorded by TRAMCON.

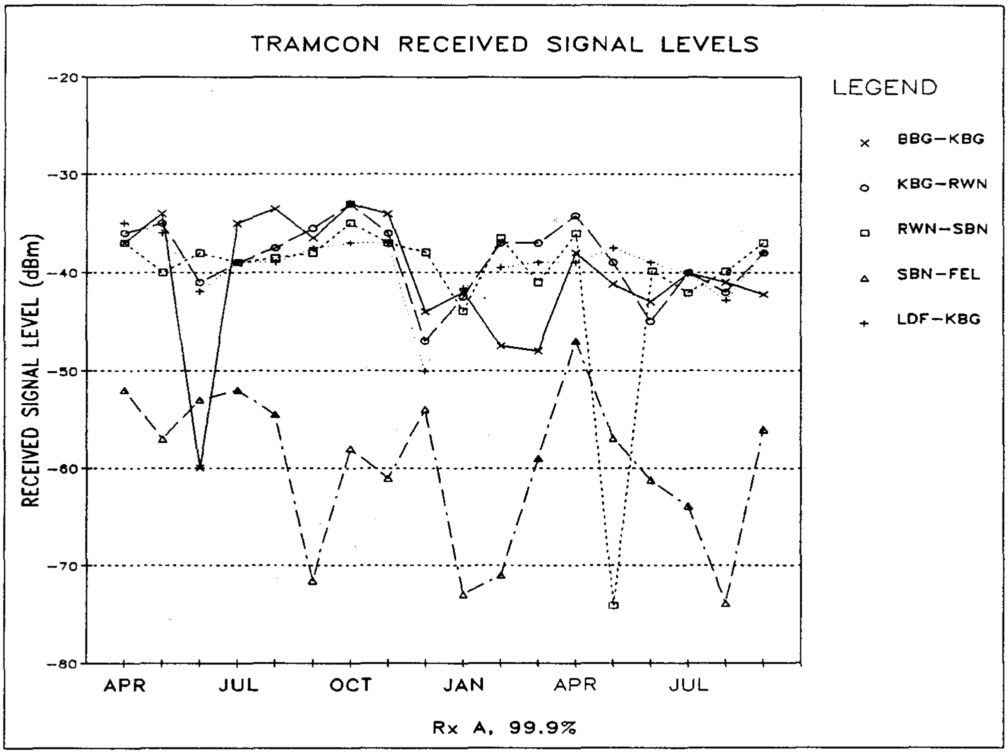


Figure 39. Summary of rsl data for five LOS links in FKT-N1.

months). The data used were the rsl values corresponding to the 99.9% level in the monthly cumulative probability distributions for each of the five links. Thus, only 0.1% of the rsl values measured for each link were less than the value plotted in Figure 39.

The two points that appear to be anomalies in Figure 39 are the June 1988 rsl for the BBG-KBG link and the May 1989 rsl for the RWN-SBN link. As can be seen from Figure 35 given previously, the Rx B value for June 1988 for the BBG-KBG link was much greater than the Rx A value at the 99.9% level. Referring to Figure 37, both Rx A and Rx B had low rsl's for May 1989 at the 99.9% level. The two data points that appear to be anomalies in Figure 38 are believed to be valid data. It is simply a case that the distributions fell off sharply, as can be seen from Figures 40 and 41, which are the original cumulative probability distributions that were among the 90 cumulative distributions used to obtain the data for Figure 39.

Figure 39 also shows that the worst fading month does not appear to be the same month for all of the five LOS links in FKT-N1. The LDF-KBG, KBG-RWN, and RWN-SBN links appear to fade consistently from month to month. The fading pattern for the BBG-KBG link is somewhat different from the fading patterns of those three links, and the SBN-FEL fading pattern is significantly different from the fading patterns of any of the other links. For example, December 1989 was one of the most significant fading months for every link other than SBN-FEL. December 1989 was one of the months having the least fading for the SBN-FEL link.

The differences of the fading patterns on the five links have ramifications for outage prediction modeling. In particular, the differences affect the model commonly used for the occurrence of multipath fading which includes a climate factor (see, for example, Ivanek, 1989; p. 296). It does not appear to be valid to use a single climate factor to cover a large region of the world, which is what is usually done by system designers.

The data presented in Figure 39 also have implications regarding the applicability of meteorological data in the analysis of fading on a specific link. Typically meteorological data are not available for the end points or mid-point of a particular link. Rather, the data may be from some meteorological station which is located some distance away from the link. The different fading patterns depicted in Figure 39 imply that different meteorological conditions may exist on links that are a fairly short distance away from one another. Terrain may also have a significant influence.

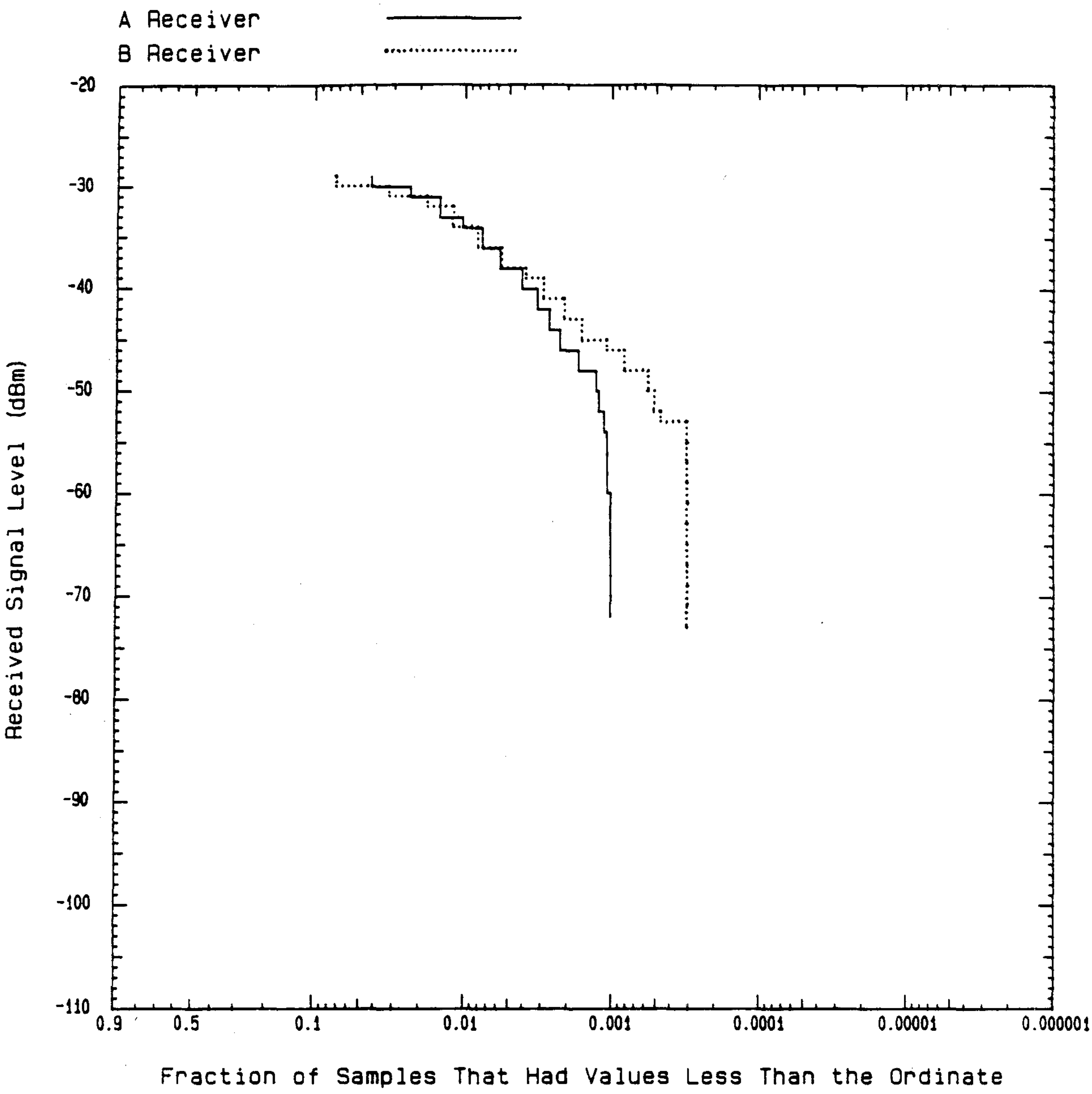


Figure 40. Cummulative probability distributions of rsl's for the BBG-KBG link for June 1988 obtained from TRAMCON data.

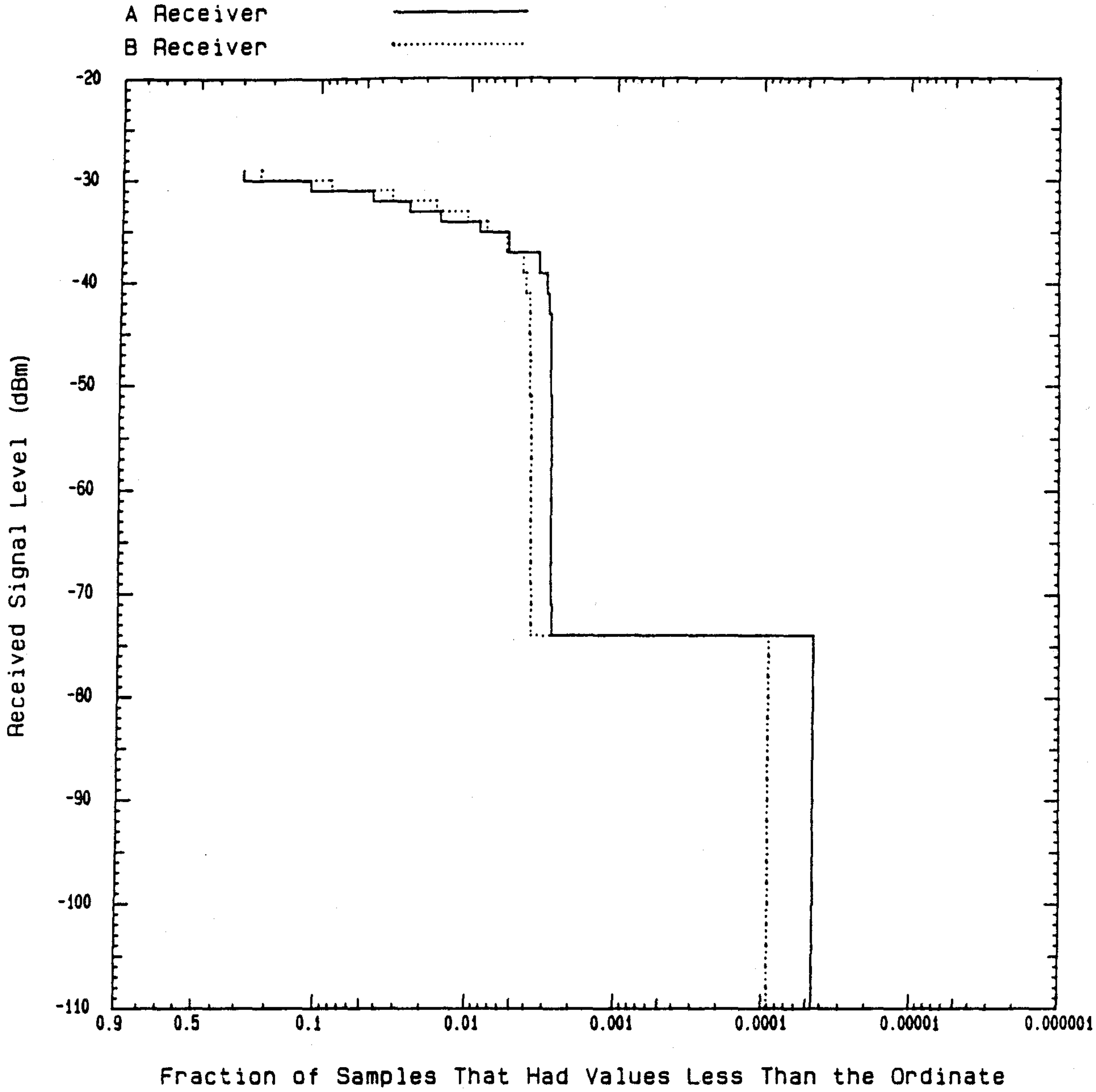


Figure 41. Cummulative probability distributions of rsl's for the RWN-SBN link for May 1989 obtained from TRAMCON data.

4.8 Analysis of Worst Fading Month Data

Figure 10 clearly shows that January 1989 was the worst errored-second performance month for the SBN-FEL link during the 18-month measurement period that began April 1, 1989. Figures 19 through 21 show that the rsl's for this link were also among the worst monthly rsl's. Other propagation data such as the channel probe data and in-band power distortion measurement data also show that January was the worst fading month. Because of the large number of ESs for this month, it is of interest to examine the propagation data, radio performance data, and meteorological data in more detail.

There were several periods during January and early February 1989 where DRAMA radio performance was severely degraded due to propagation. The specific periods of interest are:

- 14:15 hrs. on January 19th through 01:45 hrs. on January 20th
- 07:45 hrs. on January 26th through 11:30 hrs. on January 27th
- 05:00 hrs. on January 28th through 22:15 hrs. on January 28th
- 06:45 hrs. on February 1st through 10:00 hrs. on February 1st

DRAMA radio performance, rsl propagation, and meteorological data for each of the above periods is now presented.

Figure 42 is a map of Northern Germany, showing the locations of the Feldberg-Schwarzenborn sites and the locations of sites from which meteorological data were collected. As noted in Section 3.1.4, meteorological data were collected from six sites for the NPC-LPC program. However, for the purposes of the present analysis, only the data from the Giessen and Fritzlar-Kassel meteorological sites are analyzed. The data from the

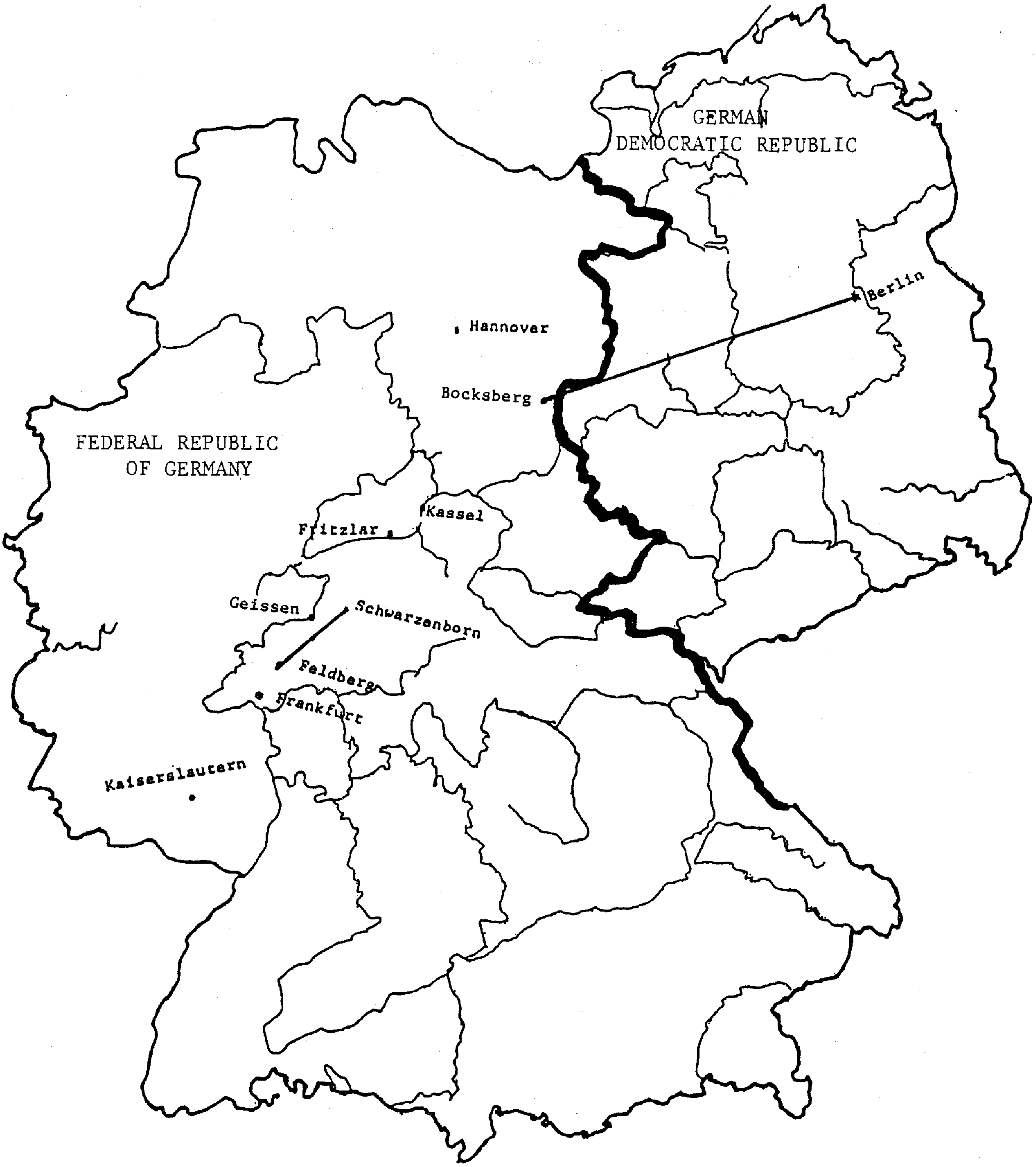


Figure 42. Map of the Federal Republic of Germany and the Germany Democratic Republic.

other sites are of lesser value because of greater distances from those sites to the Schwarzenborn-Feldberg link. The data from the Giessen site are of particular value because of its location near midpath on the SBN-FEL link.

Figure 43 is a plot of the SBN-FEL path profile that was plotted using the Digital Line of Sight (DLOS) software developed by ITS under sponsorship of the U.S. Army Information Systems Engineering Command (Farrow and Rothschild, 1989). This figure shows the elevation of the SBN-FEL sites, and is provided for reference purposes during the examination of the refractivity profiles discussed in the next several paragraphs.

The first fading period to be discussed is the period from 14:15 hrs. on January 19th through 01:45 hrs. on January 20th. Table 16 is a data scan from 15:15 hrs. on January 19th until 01:45 hrs. on January 20th. The data scan provides a one-line summary for each 15-minute block of data. The columns of the table are explained below.

The first two columns contain the date and time of the 15-minute summary line. The date is in the year-month-day format. The time is local time. The "RECORD" column contains information used internally by ITS to determine the types of records recorded and is not germane to the present discussion. The next five columns (under ROL status) provide the number of occurrences (sampled every 200 ms) that neither receiver was selected, the number of samples that Rx A was selected, the number of samples that Rx B was selected, and the number of samples in which both receivers were selected. To explain further, there are two indicator lights (one for each diversity receiver) which indicate if that receiver has been selected as the receiver on line. On rare occasions, neither light is energized and on other rare occasions both are energized. Normally only the Rx A <u>or</u> Rx B light is energized. The columns of primary interest, therefore, are the "A" and "B" columns. High numbers in these columns indicates that there was considerable switching back and forth between the two diversity receivers. The maximum number that can occur in these columns is 4500 (15 minutes x 60 seconds/minute x 5 samples/second).

The "man" column indicates whether the DRAMA radio has been placed under manual control by maintenance personnel. When in the manual mode, the space diversity switch is not operational, and one or the other of the two diversity receivers is selected manually.

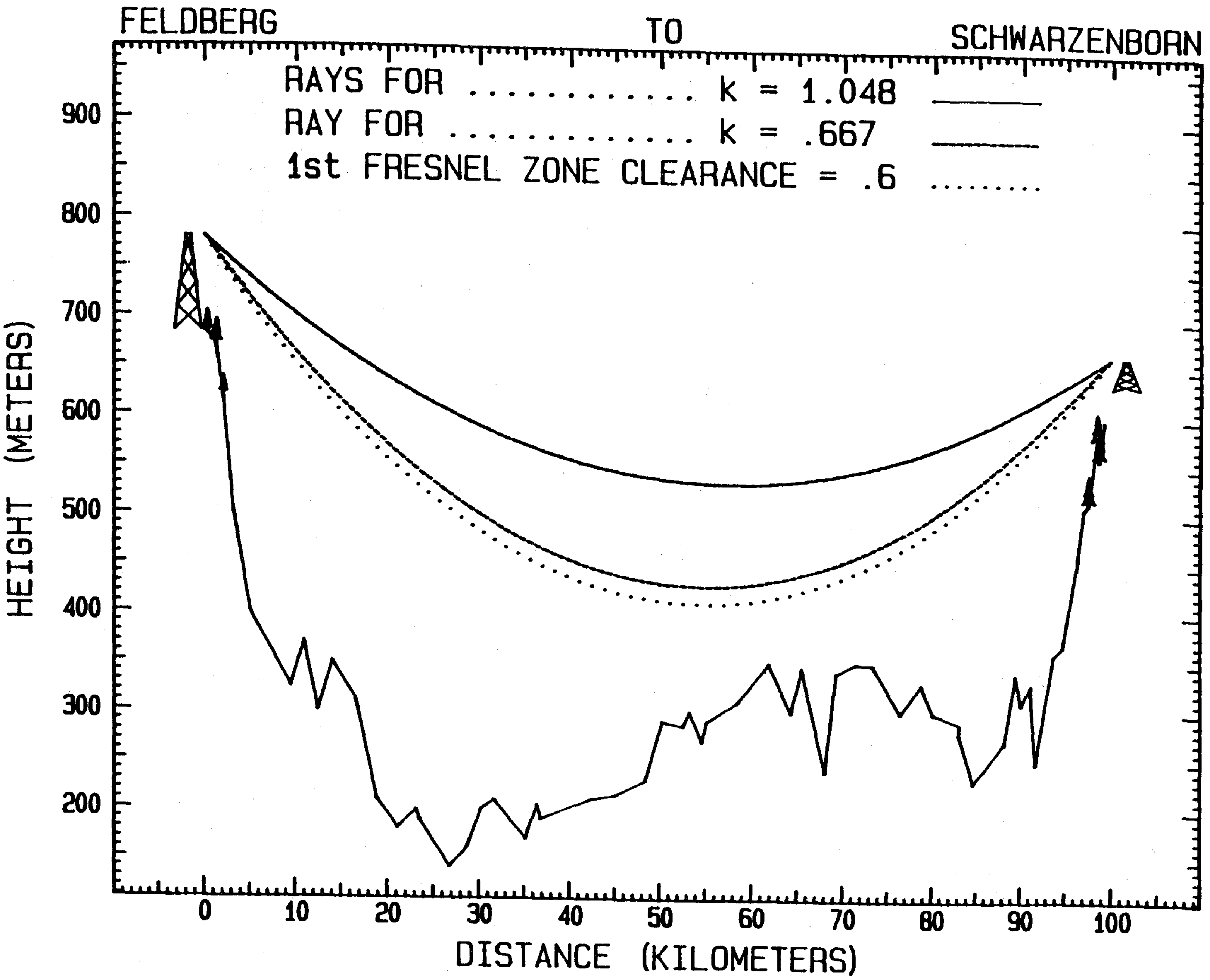


Figure 43. SBN-FEL path profile.

Table 16. NPC/LPC Data Scan From 15:15 Hrs. on January 19th Until 01:45 Hrs. on January 20th

15 minute		record			ROL status - (0.2secs)					Errored seconds					Ave RSL(dB)	
date	time	lng	sht	TRM	0	A	B	bth	man	BLN	LDF	A	ROL	B	A	B
890119	1515	680	220	108	0	2310	1075	15	0	65	21	49	14	88	-63.0	-66.0
890119	1530	530	370	119	1	1518	1131	0	0	10	3	32	3	68	-59.6	-63.5
890119	1545	691	209	116	0	935	2512	8	0	21	12	127	8	16	-62.9	-58.7
890119	1600	473	427	116	0	1292	1073	0	0	28	5	58	3	11	-57.2	-57.8
890119	1615	512	388	124	0	954	1606	0	0	23	0	49	0	13	-58.3	-59.5
890119	1630	592	308	114	0	1780	1180	0	0	34	15	121	13	127	-62.8	-64.4
890119	1645	155	745	113	0	390	385	0	0	12	0	7	0	13	-56.9	-54.4
890119	1700	413	487	108	0	997	1063	5	0	62	69	78	34	63	-61.8	-63.2
890119	1715	143	757	108	0	375	340	0	0	82	10	3	4	10	-56.7	-59.5
890119	1730	176	724	109	0	330	550	0	0	44	0	26	0	1	-60.2	-60.5
890119	1745	141	759	110	1	441	263	0	0	36	0	7	0	13	-54.8	-57.1
890119	1800	401	499	98	0	1078	927	0	0	49	9	6	2	44	-61.7	-64.3
890119	1815	101	799	105	0	148	357	0	0	388	0	10	0	0	-59.5	-59.7

```
Message time=890119 183917
Probe is really low (B channel is almost non-existant).
Message time=890119 183944
Radio RSL's are really low.
Message time=890119 184002
Receiver A is taking a lot of hits.
Message time=890119 184013
```

890119	1830	337	563	119	0	1014	671	0	0	177	0	73	0	22	-63.7	-65.3
890119	1845	128	772	107	0	434	206	0	0	18	0	0	0	4	-54.0	-58.9
890119	1900	74	59	12	0	205	165	0	0	2	0	5	0	14	-60.4	-66.5
890119	1915	305	595	104	0	1295	230	0	0	22	0	0	0	81	-57.4	-63.2
890119	1930	284	616	100	0	1343	77	0	0	98	20	12	12	62	-62.7	-65.1
890119	1945	719	181	102	0	2295	1236	64	0	175	166	220	124	272	-68.8	-72.3
890119	2000	603	297	108	0	1125	1885	5	0	333	38	198	40	99	-69.6	-69.9
890119	2015	408	492	97	0	1731	309	0	0	290	3	26	1	155	-64.1	-71.0
890119	2030	15	885	110	0	65	10	0	0	297	0	0	0	0	-58.7	-62.7
890119	2045	115	785	104	0	575	0	0	0	296	0	0	0	34	-57.5	-61.8
890119	2100	15	885	105	0	65	10	0	0	55	0	0	0	0	-53.4	-57.1
890119	2115	184	716	104	0	731	189	0	0	83	36	20	20	57	-57.5	-64.7
890119	2130	15	885	108	0	65	10	0	0	80	1	0	0	0	-56.4	-59.3
890119	2145	473	427	116	0	1462	903	0	0	434	0	35	0	62	-60.8	-65.0
890119	2200	361	539	111	0	1489	316	0	0	66	4	21	0	51	-58.6	-62.4
890119	2215	261	639	109	0	753	552	0	0	16	0	25	0	11	-57.9	-62.2
890119	2230	437	463	109	0	1324	861	0	0	18	0	71	0	14	-62.2	-65.1
890119	2245	562	338	116	0	1405	1405	0	0	30	18	85	10	97	-65.1	-66.4
890119	2300	279	621	111	1	993	401	0	0	17	15	38	13	66	-63.4	-65.6
890119	2315	40	860	108	0	200	0	0	0	5	0	0	0	0	-58.9	-64.1
890119	2330	329	571	111	0	1599	41	5	0	28	26	23	22	138	-64.7	-69.0
890119	2345	672	228	111	0	2448	912	0	0	89	56	98	39	186	-70.0	-72.8
890120	0000	748	152	103	1	2108	1631	0	0	140	69	143	52	122	-68.2	-70.0
890120	0015	371	529	108	0	962	893	0	0	158	31	79	7	27	-64.6	-66.4
890120	0030	265	635	113	0	728	597	0	0	110	16	55	13	54	-65.5	-66.9
890120	0045	350	550	111	0	1142	603	5	0	487	57	66	39	133	-65.6	-68.3
890120	0100	175	725	108	0	25	850	0	0	529	0	44	0	0	-62.6	-62.1
890120	0115	15	885	113	0	70	5	0	0	572	0	0	0	0	-55.6	-58.8
890120	0130	15	885	114	0	75	0	0	0	653	0	0	0	0	-53.8	-56.4
890120	0145	12	738	88	0	60	0	0	0	532	0	0	0	0	-48.8	-53.5

The four columns under the "Errored Seconds" heading provide the number of ESs that occurred during this 15-minute period for the Berlin-to-Feldberg 64-kb/s channel, the Linderhofe-to-Feldberg (LDF-FEL) 64-kb/s channel, the SBN-FEL diversity receiver A, the SBN-FEL receiver on line (ROL), and the SBN-FEL diversity receiver B. The latter three measurements are on the 56-kb/s service channel.

The final two columns of Table 16 provide the 15-minute average received signal level for each of the space diversity receivers. For comparison purposes, the median rsl for the SBN-FEL link is -32 dBm and the 1 x 10^{-2} BER threshold is -7 dBm.

Of particular relevance to our analysis in this section are the rsl and ESs columns for the Rx A, Rx B and the receiver on line (ROL). Note that the 15-minute average rsl's were of the order of -65 dBm, whereas the median monthly rsl's given previously in Figures 19 and 20 are about -39 dBm. The ESs columns show the large number of ESs that occurred in each receiver. The lower numbers of ESs in the ROL column show the space diversity improvement. Despite the diversity improvement, up to 14% of the 900 seconds in some 15-minute blocks contained errors. The 15-minute period starting at 23:45 hrs. was particularly bad in both the rsl and errored-second measured data.

Figures 44 and 45 show the refractivity profiles obtained from radiosonde data taken at Giessen on the mornings of January 19th and 20th. Also plotted on the figures are refractivity profiles that correspond to both normal and ducting conditions. A "normal" atmosphere is one in which the refractive gradient is -39 units/km, and which results in the 4/3 Earth radius approximation. Ducting occurs for refractive gradient values less than -157 units/km. In both Figures 44 and 45, note the ducting that is present at about the same height as both the Feldberg and Schwarzenborn sites. Thus, the meteorological data clearly show the causative mechanism for the degradation of the DRAMA radio performance during this period. Since the meteorological data for the two figures were taken 24 hours apart, it is clear that a stagnant ducting condition was in effect during that entire period of time. Channel-probe and in-band power difference (IBPD) data (not shown here) also show the effects of the multipath that occurred during this period.

Table 17 provides a summary of NPC/LPC data from 11:30 to 23:00 hrs. on January 26, 1989. Figures 46 and 47 provide refractivity profiles of meteorological data collected at Giessen on January 26th and 27th respectively. Note that there is again a ducting layer at about the same height as for the previous example. However, the ducting was not so severe as the previous example. This is reflected in the DRAMA radio performance data

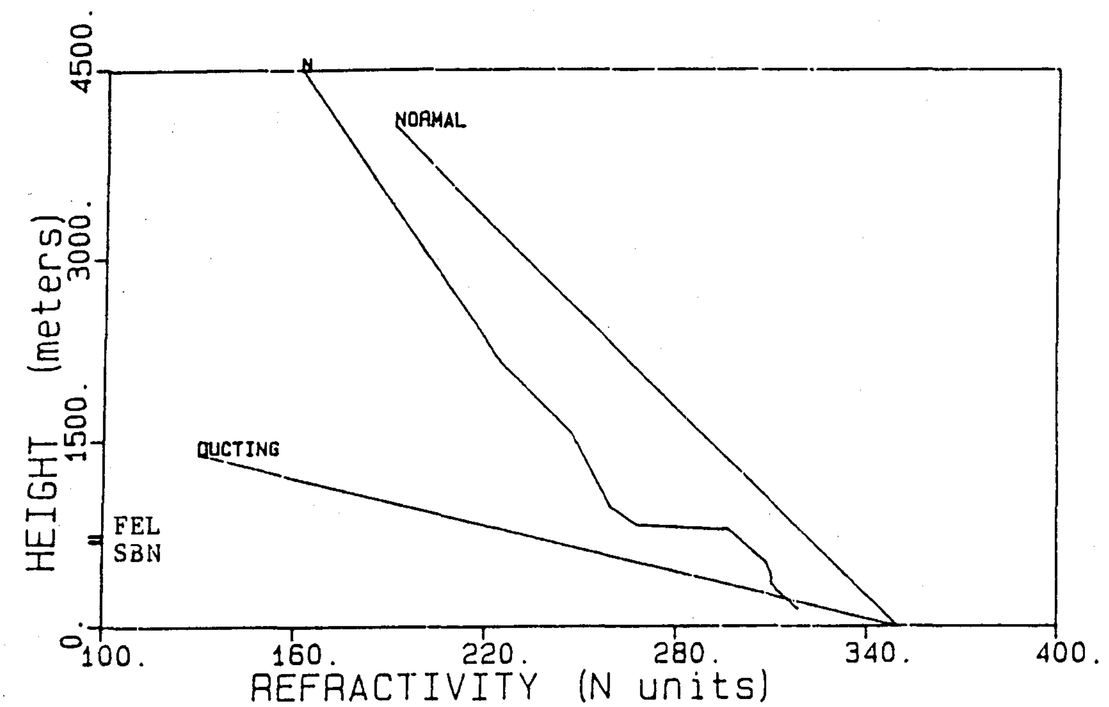


Figure 44. Refractivity profile at Giessen at 06:50 on January 19, 1989.

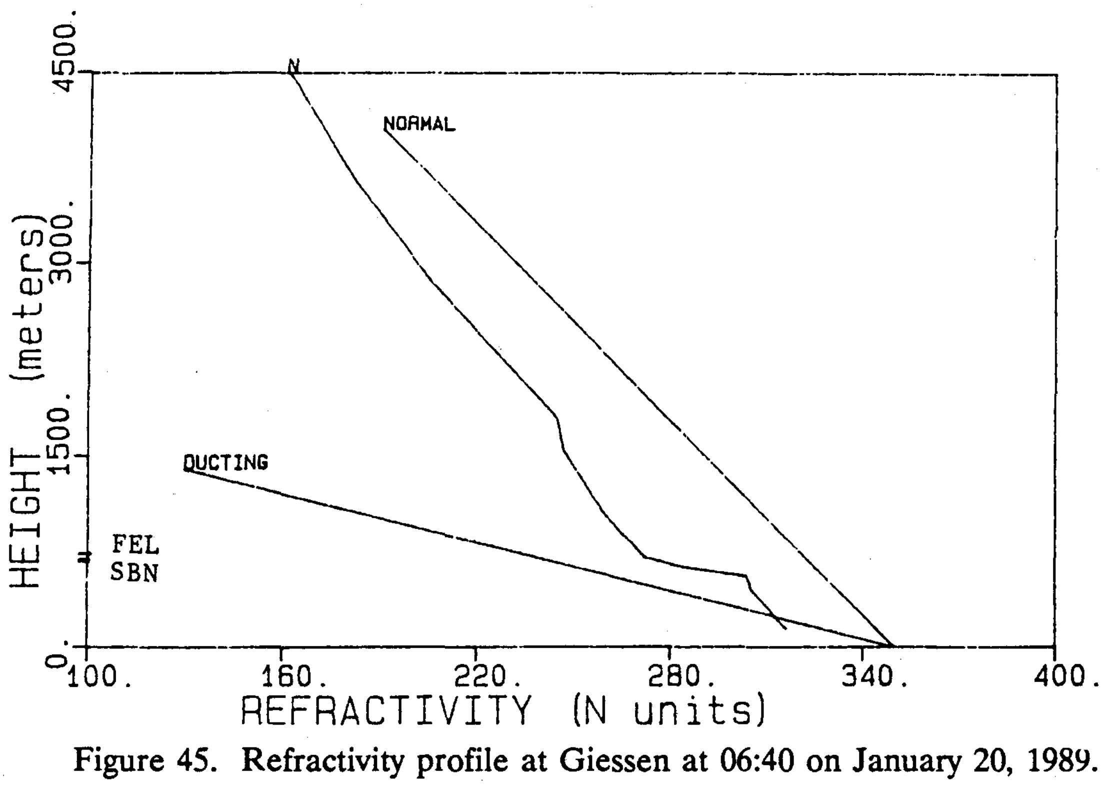


Figure 45. Refractivity profile at Giessen at 06:40 on January 20, 1989.

Table 17. NPC/LPC Data Scan From 11:30 to 23:00 Hrs. on January 26, 1989

15 minute		record			ROL status - (0.2secs)					Errored seconds					Ave RSL(dB)	
date	time	lng	sht	TRM	0	A	B	bth	man	BLN	LDF	A	ROL	B	A	B
890126	1130	146	754	109	0	505	225	0	0	900	11	0	0	14	-56.4	-58.9
890126	1145	15	885	106	0	70	5	0	0	900	0	0	0	0	-50.2	-55.8
890126	1200	15	885	107	0	40	35	0	0	900	0	0	0	0	-52.6	-54.3
890126	1215	15	885	108	0	65	10	0	0	900	0	0	0	0	-53.2	-58.2
890126	1230	236	664	121	0	1118	62	0	0	900	0	0	0	59	-56.3	-60.7
890126	1245	157	743	109	0	780	5	0	0	900	0	0	0	18	-54.7	-59.1
890126	1300	316	584	98	0	1126	454	0	0	867	2	7	0	56	-57.2	-60.5
890126	1315	368	532	101	0	1762	78	0	0	279	15	4	4	81	-58.3	-63.8
890126	1330	416	484	107	0	890	1190	0	0	834	0	43	0	40	-61.5	-62.4
890126	1345	147	753	103	0	345	390	0	0	801	0	1	0	3	-55.3	-54.3
890126	1400	15	885	108	0	70	5	0	0	739	0	0	0	0	-47.7	-50.5
890126	1415	15	885	108	0	40	35	0	0	736	0	0	0	0	-51.3	-51.9
890126	1430	358	542	106	0	1237	553	0	0	844	8	66	8	25	-60.9	-63.8
890126	1445	601	299	106	0	1875	1130	0	0	878	0	132	0	68	-62.4	-64.9
890126	1500	297	603	107	0	1015	470	0	0	861	0	32	0	63	-56.7	-64.5
890126	1515	378	522	105	0	1208	682	0	0	834	0	19	0	132	-56.4	-61.2
890126	1530	374	526	108	0	1006	864	0	0	433	5	99	4	75	-62.0	-62.2
890126	1545	228	672	106	0	949	191	0	0	33	0	13	0	11	-61.2	-65.6
890126	1600	15	885	106	0	75	0	0	0	35	0	0	0	0	-58.9	-63.8
890126	1615	75	825	108	0	55	320	0	0	34	2	1	0	0	-62.2	-64.7
890126	1630	75	825	107	0	40	335	0	0	37	0	1	0	0	-59.3	-61.1
890126	1645	15	885	120	0	75	0	0	0	37	0	0	0	0	-56.9	-59.5
890126	1700	15	885	108	0	45	30	0	0	35	0	0	0	0	-59.4	-61.1
890126	1715	15	885	107	0	65	10	0	0	37	0	0	0	0	-56.0	-58.9
890126	1730	15	885	109	0	75	0	0	0	44	0	0	0	0	-55.4	-59.0
890126	1745	15	885	108	0	75	0	0	0	195	0	0	0	0	-50.1	-57.3
890126	1800	15	885	108	0	75	0	0	0	203	0	0	0	0	-49.8	-54.2
890126	1815	15	885	106	0	75	0	0	0	207	0	0	0	0	-50.9	-52.1
890126	1830	15	885	107	0	55	20	0	0	201	0	0	0	0	-54.4	-55.5
890126	1845	15	885	106	0	45	30	0	0	115	0	0	0	0	-54.0	-54.7
890126	1900	15	885	104	0	60	15	0	0	56	0	0	0	0	-46.7	-50.7
890126	1915	15	885	107	0	45	30	0	0	46	0	0	0	0	-44.8	-46.0
890126	1930	15	885	107	0	65	10	0	0	45	0	0	0	0	-49.8	-53.8
890126	1945	15	885	104	0	75	0	0	0	120	0	0	0	0	-49.8	-51.8
890126	2000	15	885	108	0	75	0	0	0	215	0	0	0	0	-50.4	-54.0
890126	2015	15	885	107	0	50	25	0	0	302	0	0	0	0	-55.2	-57.2
890126	2030	15	885	108	0	75	0	0	0	316	0	0	0	0	-54.8	-58.8
890126	2045	15	885	108	0	75	0	0	0	101	0	0	0	0	-55.4	-58.9
890126	2100	15	885	108	0	60	15	0	0	96	0	0	0	0	-57.9	-61.1
890126	2115	120	780	108	0	62	538	0	0	62	0	35	0	0	-57.6	-57.1
890126	2130	420	480	109	0	1995	105	0	0	50	0	5	0	168	-58.6	-63.4
890126	2145	248	652	108	0	696	544	0	0	57	0	29	0	23	-61.2	-60.4
890126	2200	396	504	108	0	472	1508	0	0	65	2	79	1	13	-57.6	-55.9
890126	2215	129	771	108	0	50	595	0	0	59	0	6	0	0	-56.5	-57.9
890126	2230	15	885	108	0	30	45	0	0	115	0	0	0	0	-53.2	-53.6
890126	2245	75	825	107	0	45	330	0	0	118	0	1	0	0	-52.8	-54.7
890126	2300	15	885	108	0	61	14	0	0	55	0	0	0	0	-47.6	-52.1

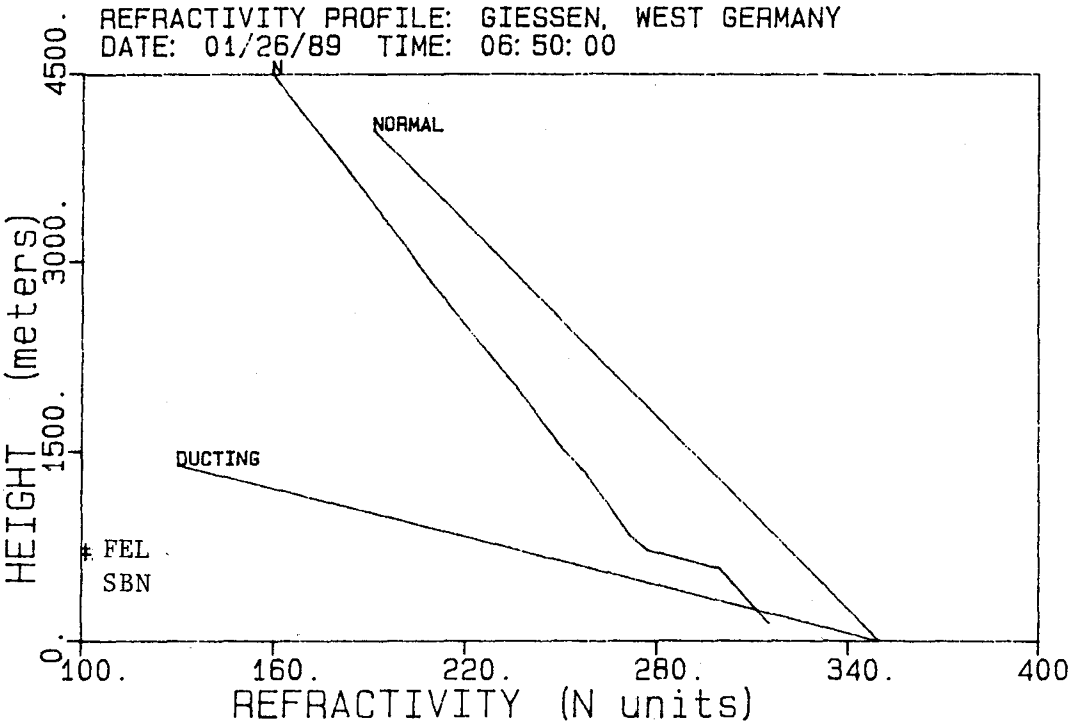


Figure 46. Refractivity profile at Giessen at 06.50 on January 26, 1989.

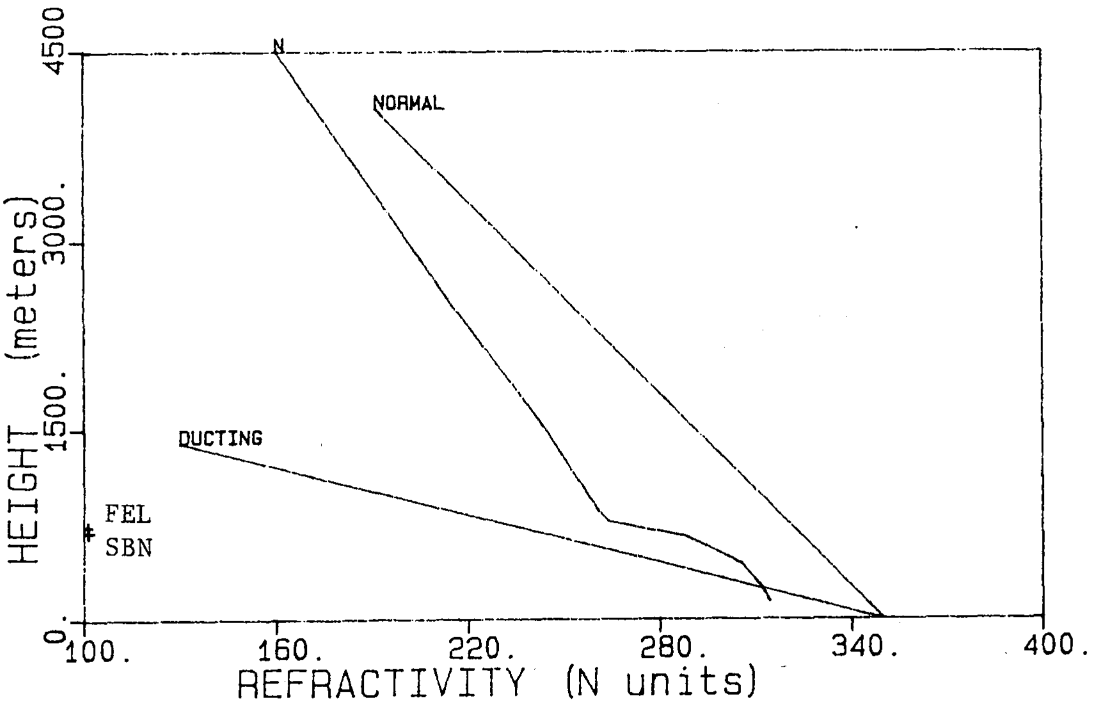


Figure 47. Refractivity profile at Giessen at 06:50 on January 27, 1989.

in Table 17. Although the two diversity receivers (Rx A and Rx B) individually had a significant number of ESs during this period, the selected receiver on line had few ESs. This again demonstrates the performance gain of the DRAMA radio.

Table 18 is a data scan for the NPC/LPC data from 05:30 to 16:45 hrs. on January 28, 1989. No meteorological data were available from Giessen for this period. However, it is clear from the data scan that the propagation conditions were changing during this period. The received signal levels were poor at about 05:00 until 06:45 hrs., resulting in a significant number of ESs. During the remainder of the day, the average rsl's varied up and down by 5 to 10 decibels between adjacent 15-minute blocks of data. This demonstrates how rapidly the propagation conditions can change. Meteorological measurements typically are scheduled at either 12-hour or 24-hour intervals, and, therefore, may not depict the conditions that are extant only a few hours later.

Table 19 is a scan of NPC/LPC data from 06:45 until 11:30 hrs. on February 1, 1989. The data show the significant deterioration of the DRAMA radio performance resulting from the severe reduction of the received signal levels. No meteorological data from Giessen were available for this period. Figure 49 is a plot of the refractive gradient from meteorological data obtained at Fritzlar-Kassel at 11:50 hrs. Note that the refractivity profile depicts a normal atmosphere. This, again, demonstrates the need for meteorological data for sites close to the path whose performance is being evaluated, and for the timely collection of that data during the period that multipath fading is affecting radio performance.

Table 18. NPC/LPC Data Scan From 05:30 to 1:45 Hrs. on January 28, 1989

```
  15 minute  |   record    | ROL status - (0.2secs)     |  Errored seconds    |Ave RSL(dB)
 date   time |lng sht TRM  |  0     A     B  bth    man |BLN LDF   A ROL    B|   A     B
 ----------- | ----------- | -------------------------- | ------------------- | ----------
890128 0530|502 365 148|  0 1333 1162   15    0|169  22 116  18  73|-66.6 -67.3
890128 0545|405 495 126|  0 1031  984   10    0| 86  31 128  25 122|-66.9 -70.4
890128 0600|272 628 108|  0  575  785    0    0| 13   0  32   0   3|-65.0 -65.1
890128 0615|750 150  93|  0 2730  987   33    0|216 186 246 152 333|-71.9 -74.8
890128 0630|296 604 104|  0 1336  136    8    0|100  51  44  45  97|-65.3 -69.2
890128 0645|291 609 105|  1  116 1338    0    0| 44   0  42   0   0|-66.2 -66.6
890128 0700|333 567 108|  0  643 1022    0    0| 12   7  38   2   9|-63.1 -63.9
890128 0715|139 761 109|  0  690    5    0    0| 17   0   0   0  19|-54.7 -59.9
890128 0730| 87 813 105|  0  425   10    0    0| 11   0   0   0   4|-56.5 -60.4
890128 0745|217 683 108|  0  367  718    0    0|167   7  15   3   3|-61.1 -62.7
890128 0800| 15 885 108|  0   60   15    0    0|307   0   0   0   0|-56.2 -59.1
890128 0815| 15 885 109|  0   75    0    0    0| 67   0   0   0   0|-51.1 -57.2
890128 0830| 15 885 108|  0   75    0    0    0| 17   0   0   0   0|-53.2 -58.4
890128 0845| 32 868 108|  0   60  100    0    0| 19   0  12   0   0|-55.3 -58.3
890128 0900|133 767 108|  0  479  186    0    0| 18   1   1   1   0|-52.3 -56.8
890128 0915| 15 885 108|  0   75    0    0    0| 18   0   0   0   0|-56.2 -61.0
890128 0930|217 683 105|  0  516  569    0    0| 22   5  71   6   8|-59.9 -63.2
890128 0945|116 784  98|  0  210  370    0    0|112  15  22   8   8|-55.9 -57.4
890128 1000|179 721 108|  1  362  532    0    0| 56   0   7   0  12|-54.6 -56.4
890128 1015|460 440 108|  0  995 1305    0    0| 13   1  29   0   4|-58.3 -59.5
890128 1030| 81 819 108|  0  385   20    0    0| 13   0   0   0   2|-46.5 -50.2
890128 1045|222 678 108|  0   79 1031    0    0| 12   0  28   0   0|-57.0 -56.3
Message time=890128 111141
Tape is off line
890128 1100|140 760 108|  0  538  162    0    0| 13   0   0   0   7|-53.0 -57.2
Message time=890128 111707
Tape is on line
890128 1115|123 777 108|  0  615    0    0    0| 13   1   0   0   3|-49.3 -57.1
890128 1130|491 409 108|  0  790 1665    0    0| 18   4  85   5  16|-55.7 -57.7
890128 1145|707 193 107|  0 1790 1745    0    0| 20   6  58   7  22|-61.0 -62.3
890128 1200|859  41 100|  0 2433 1862    0    0|134  12  96  11  49|-62.7 -64.9
890128 1215|850  50 106|  1 2630 1614    5    0| 61  39 124  25  86|-64.9 -67.4
890128 1230|674 226 107|  0 2667  703    0    0| 78   3  41   3  53|-59.2 -62.2
890128 1245|543 357 102|  0 1171 1544    0    0| 91  13  36   6  17|-55.3 -56.1
890128 1300|329 571 106|  0  782  863    0    0|103   1   8   0   4|-52.9 -52.6
890128 1315|213 687 102|  0  180  885    0    0|104   1   9   0   1|-47.9 -48.3
890128 1330|138 762 108|  0  530  160    0    0|109   1   0   0   5|-45.7 -50.2
890128 1345|263 637 108|  0  484  831    0    0|104   1  12   0   1|-50.5 -50.9
890128 1400| 15 885 107|  0   40   35    0    0|108   0   0   0   0|-40.1 -41.5
890128 1415| 15 885 103|  0   45   30    0    0|112   1   0   0   0|-41.4 -42.7
890128 1430| 15 885 105|  0   55   20    0    0|115   0   0   0   0|-40.8 -42.2
890128 1445| 78 822 108|  0  350   40    0    0|115   0   0   0   4|-43.0 -43.5
890128 1500| 15 885 108|  0   40   35    0    0|122   3   0   0   0|-37.0 -42.2
890128 1515| 76 824 108|  0   30  350    0    0|101   3   2   0   0|-48.3 -45.9
890128 1530|300 600 108|  0  746  754    0    0|272   0   9   0   3|-55.6 -51.6
890128 1545|311 589 109|  0  519 1036    0    0|214   1  36   0  17|-53.6 -54.2
890128 1600|308 592 108|  0  461 1079    0    0|237   8  46   3   2|-53.2 -50.7
890128 1615|373 527 108|  0 1374  491    0    0|237  14  33   7  38|-60.4 -60.4
890128 1630|712 188 105|  0 1657 1903    0    0|281  36 126  20  41|-63.9 -63.5
890128 1645|164 736 108|  0  532  288    0    0| 34   0  10   0   6|-54.3 -57.8
```

Table 19. NPC/LPC Data Scan From 06:45 to 11:30 Hrs. on February 1, 1989

15 minute		record			ROL status - (0.2secs)					Errored seconds					Ave RSL(dB)	
date	time	lng	sht	TRM	0	A	B	bth	man	BLN	LDF	A	ROL	B	A	B
890201	0645	2	88	9	0	5	5	0	0	1	0	0	0	0	-42.0	-41.1
890201	0700	109	791	109	0	175	370	0	0	6	0	6	0	0	-50.7	-52.6
890201	0715	476	424	147	0	1422	953	5	0	31	34	71	17	44	-60.2	-62.5
890201	0730	148	752	104	0	730	10	0	0	7	0	0	0	12	-55.5	-57.7
890201	0745	742	158	105	0	2400	1295	15	0	166	153	232	129	237	-66.7	-70.1
890201	0800	689	211	131	0	2377	1053	15	0	91	53	131	45	136	-66.8	-70.4
890201	0815	743	157	98	0	2094	1610	11	0	175	92	213	84	236	-69.9	-71.9
890201	0830	871	29	85	1	2711	1596	47	0	174	175	266	166	356	-72.1	-75.2
890201	0845	837	63	94	0	3298	821	66	0	221	177	184	159	404	-69.1	-75.2
890201	0900	832	68	103	0	1053	3071	36	0	82	83	309	73	82	-71.4	-70.3
890201	0915	863	37	93	1	3325	941	48	0	197	186	206	167	422	-70.3	-75.4
890201	0930	885	15	96	0	2697	1713	15	0	152	151	222	97	324	-70.4	-72.0
890201	0945	745	155	95	0	688	3037	0	0	44	20	74	6	28	-63.3	-58.0
890201	1000	204	696	108	0	10	1010	0	0	11	0	10	0	0	-51.5	-41.6
890201	1015	15	885	108	0	0	75	0	0	10	0	0	0	0	-42.2	-37.5
890201	1030	75	825	108	0	55	320	0	0	24	0	1	0	0	-38.3	-41.0
890201	1045	166	734	108	0	87	743	0	0	44	0	12	0	0	-42.5	-43.0
890201	1100	153	747	108	0	308	457	0	0	40	0	7	0	0	-40.3	-41.7
890201	1115	15	885	105	0	25	50	0	0	69	0	0	0	0	-41.2	-40.3
890201	1130	92	808	105	0	345	115	0	0	68	0	4	0	5	-40.4	-40.9

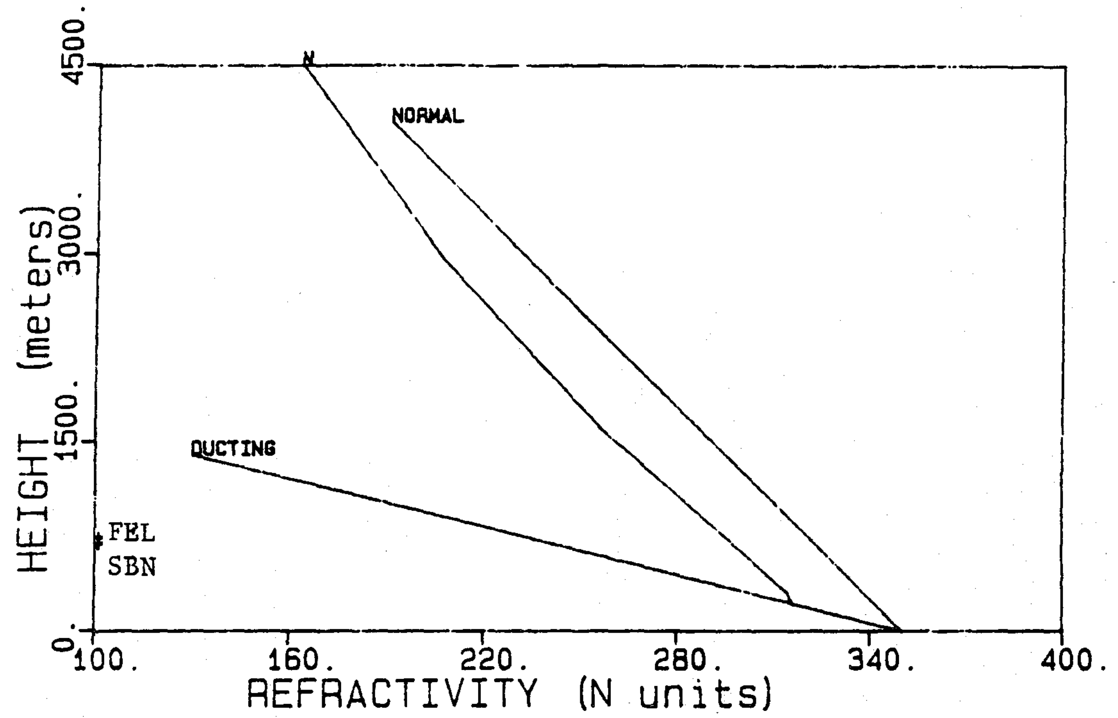


Figure 48. Refractivity profile at Fritzlar-Kassler at 11:50 on Feb. 1, 1989.

5. SUMMARY AND ANALYSIS OF NETWORK PERFORMANCE CHARACTERIZATION DATA

As described in Section 1, channel measurements were made on two 64-kb/s mission channels--one from Linderhofe to Feldberg (LDF-FEL), and one from Berlin to Feldberg (BLN-FEL). The reason for the choice of the latter channel is that it provided an unique opportunity to make end-to-end performance measurements on tandem LOS and troposcatter links. The LDF-FEL channel is comprised of only LOS links, and can be used as a comparison between end-to-end channels with and without a troposcatter link.

5.1 Linderhofe-to-Feldberg Channel Analysis

The Linderhofe-Feldberg channel consists of four tandem LOS links. The longest of the four links is the SBN-FEL link whose performance was analyzed in Section 4.1. The performance measurements on the LDF-FEL channel were made by placing a BERTS data generator at Linderhofe and a BERTS data receiver at Feldberg. The resulting error data were analyzed and compared with both the draft MIL-STD-188-323 and CCITT/CCIR Recommendations. The results of these analyses are presented in the following sections.

5.1.1 LDF-FEL Performance comparisons with Draft MIL-STD-188-323 Specifications

Errored seconds and unavailability

Figure 49 provides a summary of the monthly errored seconds and unavailability time for the LDF-FEL channel. This end-to-end circuit does not meet Draft MIL-STD-188-323 design objectives for either ES or UA. Application of the MIL-STD to this circuit results in design objectives of 11,984 errored seconds and 8.65 hours for UA time annually (see Table 1). The total errored seconds for the 12-month period beginning April 1, 1988, was 81,412 seconds. For the same period, the UA time was 11.07 hours. Thus, the measured annual errored-second performance was worse than the design objective by a factor of 6.8. The measured annual UA time was worse than the design objective by a factor of 1.3.

Allocation of the errored-second objectives and UA time on a monthly rather than a yearly basis results in an errored-second objective of 999 seconds and an UA time objective of 0.72 hours per month. The monthly errored-second objective was not met for any of the 18 months in the measurement period of April 1988 through September 1989. The monthly UA time objective was not met for 7 of the months during this 18-month period.

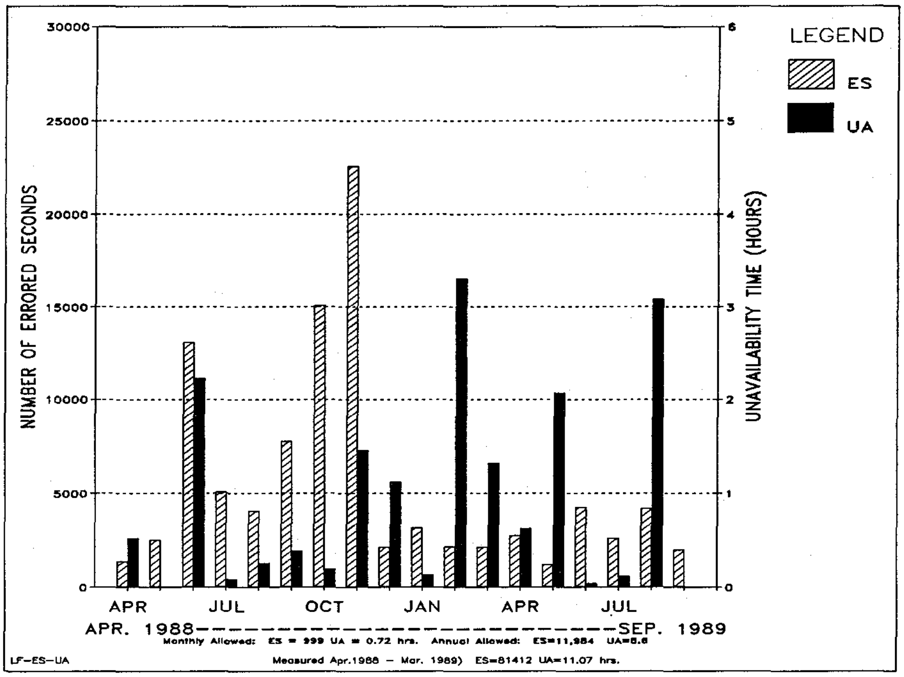


Figure 49. Errored seconds and unavailability for the LDF-FEL channel.

The total number of errored seconds including the errored seconds allocated to unavailability time was 121,255 seconds for the 12-month period beginning in April 1988. This represents a long-term errored-second ratio of 4.28×10^{-3} for the 7866 hours of recorded data.

Comparison of Figure 49 with Figure 10 reveals the following:

- The greatest number of errored seconds for the LDF-FEL channel occurred in November 1988 (22,611 errored seconds); the SBN-FEL link had only 2 errored seconds for that month.

- The greatest number of errored seconds for the SBN-FEL link occurred in January 1989 (955 errored seconds); the LDF-FEL channel had a total of 3,184 errored seconds for that month which is low compared to several months during the test period.

- Unavailability time was very high in August 1989 for both the SBN-FEL link and the LDF-FEL channel. Even for this month however, the SBN-FEL link contributed only 0.44 hours (14%) of the total UA time (3.1 hours) measured for the end-to-end channel which includes the SBN-FEL link.

From the above observations, it would appear that propagation is probably not the major cause of the degradation of end-to-end channel performance observed on the LDF-FEL channel. One would expect that the longest link (SBN-FEL) in the LDF-FEL circuit would contribute more to performance degradation from propagation than would the other three LOS links in the circuit. The fact that there were few errored seconds on the SBN-FEL link and many errored seconds on the LDF-FEL channel in November 1988 leads one to speculate that the predominant cause of errors on the channel was some factor other than propagation. It is recognized that propagation phenomenon can cause fading outages on short links. However, all of the links in DEB are engineered to have adequate terrain clearance. The fact that the links comprising the LDF-FEL channel are in close proximity means that they are subjected to the same climatic conditions. This rationale led to the conclusion that propagation is not the likely cause of the unexpectedly high number of errored seconds on the LDF-FEL channel. However, the data collected during this project did not permit the full resolution of this question because testing and troubleshooting the network was not a program objective.

The MIL-STD-188-323 definition of unavailability time was designed to separate performance degradation due to equipment from performance degradation due to propagation on LOS microwave links. The 60-second time specification for the UA time criterion will eliminate multipath fading from inclusion in the UA time because multipath fading typically is of a much shorter duration. It is possible that power fading due to rainfall could be greater than 60 seconds in length, but the rainfall would need to be very heavy to cause fading at the 8-GHz frequencies used in DEB. Thus, one could expect that the UA time (which is primarily due to equipment failures) should be about the same on the four links that compose the LDF-FEL channel, because each of the four links has essentially the same amount of equipment. Comparison of the data plotted in Figures 10 and 49 shows that this is not the case. The UA time for the SBN-FEL link for the entire 18-month measurement period was 0.75 hours, while the UA time for the same period for the LDF-FEL channel was 17.03 hours. Thus, there are system-wide effects that cause the end-to-end errors to be greater than those measured on the individual links of the end-to-end channel. The possible sources of these errors are cryptographic equipment resynchronization, system timing in a plesiochronous network, upfading which might cause the rsl to be slightly too high for the DRAMA radio, and human error. As noted earlier, it was not the objective of this program to test the network, or to identify problems in the network.

To ensure that the LDF-FEL performance results were not due to problems in the measurement system itself, several tests were conducted. These are described briefly in Appendix E. Two 64-kb/s channels from Linderhofe to Feldberg were available to ITS for this program. For a short time, the measurements were made on the second channel to see if there were any differences in the level of error performances of the two channels. The number of errored seconds occurring on the second channel was noticeably higher than on the first channel. The reason for this is not clear. However, this brief test did eliminate the bit error ratio test sets and FCC-98 interface cards as a potential source of the unexpectedly high errors on the LDF-FEL channel.

In making the comparisons of errored seconds and unavailability of the SBN-FEL link and the LDF-FEL channel, one must remember the differences between how the two measurements were made. The SBN-FEL measurements were made on a 56-kb/s service channel, while the LDF-FEL measurements were made on a 64-kb/s mission channel. The latter includes the KG-81 cryptographic equipment as part of the circuit equipment while the former does not.

Jitter

Figure 50 depicts the test configuration that was used to make jitter measurements on a T1 channel from Linderhofe to Feldberg. The jitter measurements were made on the same operational channel that carries the 64-kb/s subchannel used for the error performance measurements between Linderhofe and Feldberg. The jitter that was measured was the "input jitter", which is defined as the limit on the amount of jitter that can be applied to digital equipment input without causing errors or loss in bit count

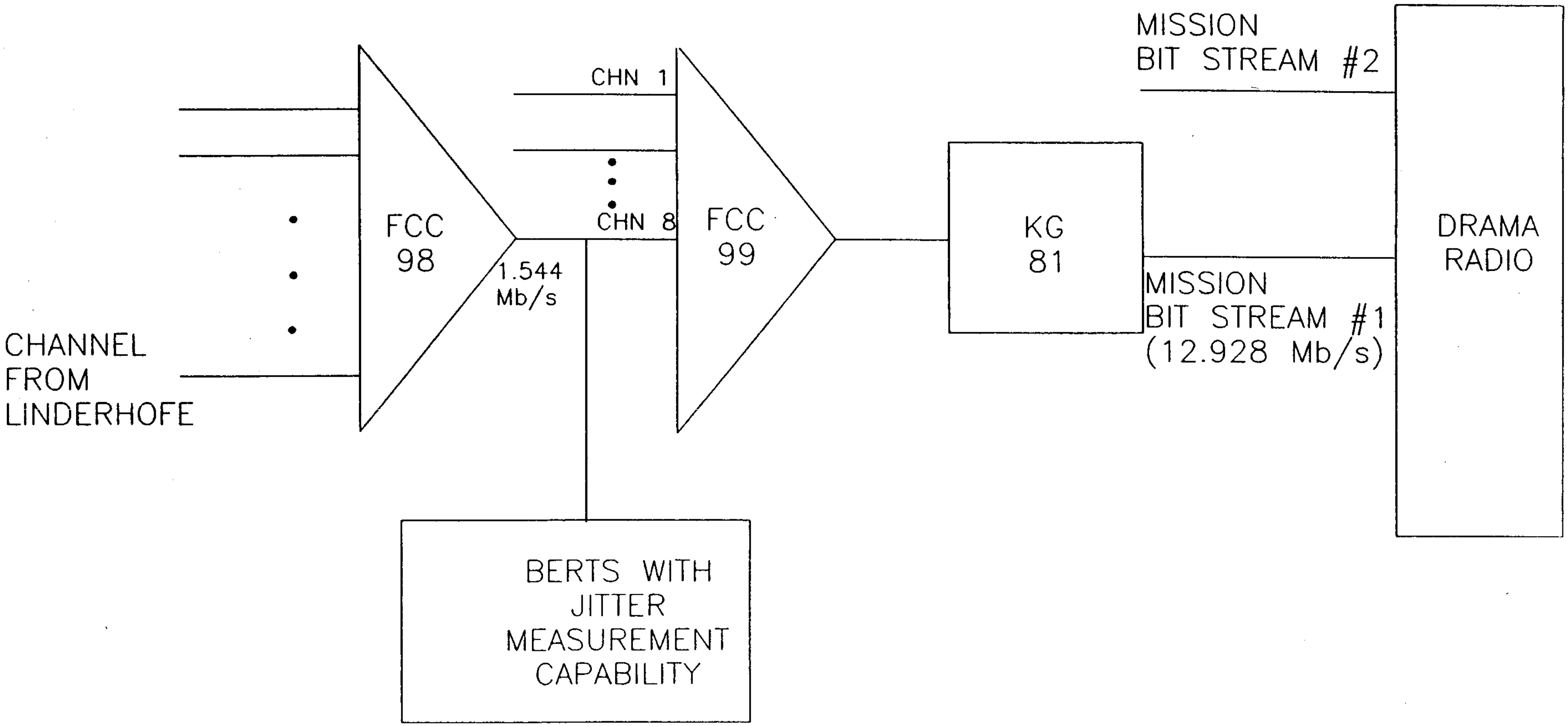


Figure 50. Jitter measurement configuration.

integrity. The CCITT provides a mask which specifies upper limits in terms of peak-to-peak sinusoidal jitter amplitude versus jitter frequency (CCITT, 1984a).

Figure 51 presents the results of the high-speed (1.544-Mb/s) jitter measurements. The figure shows both the CCITT mask and the jitter that was measured on this channel. As can be seen, the measured jitter is well within the mask specified by the CCITT. MIL-STD-188-323 specifies the same mask as that specified by the CCITT. The measurements were made using a commercial BERTS instrument which also has a capability for making jitter measurements. The high-speed jitter measurements were made on two separate occasions with similar results.

Jitter measurements were also made on a low-speed (64-kb/s) user channel using the same test instrument used for the high-speed measurements. With few exceptions, the peak-peak jitter was zero.

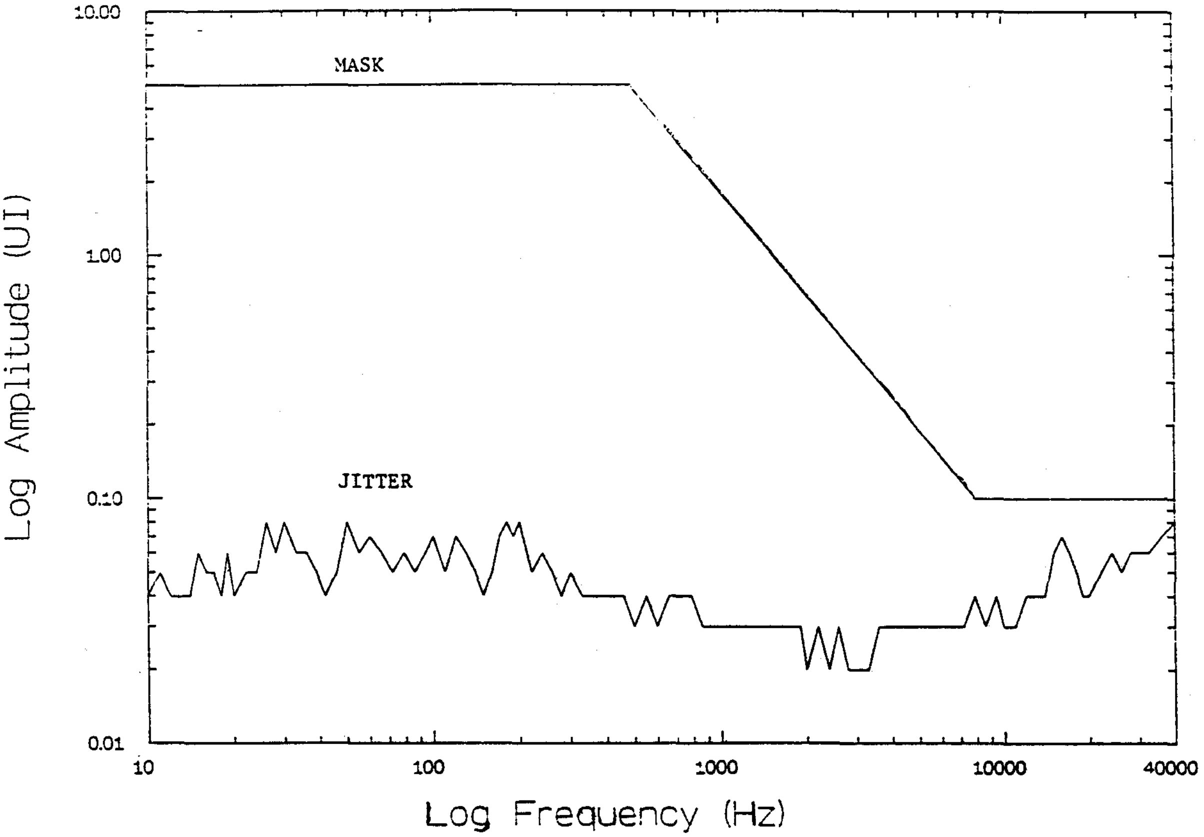


Figure 51. Jitter measurement results on LDF-FEL channel at 1.544 Mb/s rsl's.

Delay

Delay measurements were made on the LDF-FEL channel by making use of the two channels between the Linderhofe and Feldberg nodes which were made available for theNPC/LPC program. The error performance measurements were not made during the brief period in which the delay measurements were made. A test signal was injected at Feldberg, and a loop-back connection was made at Linderhofe. The time delay between the injection of the signal at Feldberg and its return to the Feldberg receiving site was measured. From Table 2, we see that application of the draft MIL-STD-188-323 delay criteria to the LDF-FEL link results in a maximum allowed delay of 6.8 ms. The measured one-way delay was less than 2.5 ms. Thus, the measured delay was well within the delay specified by the military standard. One does not normally expect delay to be a technical issue on terrestrial circuits.

5.1.2 LDF-FEL performance comparisons with CCITT/CCIR Recommendations

Table 20 provides a comparison of the measured error performance of the LDF-FEL channel with the CCITT/CCIR 12-month design objectives. The measured time is for the 12-month period beginning on April 1, 1988. As can be seen in the table, the LDF-FEL channel does not meet the design objectives for any of the parameters specified by the CCITT/CCIR. The measured unavailability time is 7.3 times the design objective, the measured number of severely errored seconds is 19.1 times the design objective, the measured number of degraded minutes is 68.2 times the design objective, and the measured number of errored seconds is 6.9 times the measured objective.

The time period over which the CCITT/CCIR objectives apply has not been specified (Ivanek, 1989; p. 39). Since the objectives are specified as fractions of time, they can be applied to either yearly or monthly time periods. It can be argued that the application over a 12-month period is less severe than application over a 1-month period because of propagation considerations. For example, a given link could meet the 12-month objectives, but not meet the 1-month objectives during the worst fading month.

Application of the CCITT/CCIR Recommendations to the LDF-FEL channel results in the following 1-month objectives:

- Unavailability time: 0.19 hours
- Errored seconds: 788 seconds
- Severely errored seconds: 133 seconds
- Degraded minutes: 16 minutes

Table 20. Berlin-Feldberg Summary of Error Performance and Comparison with CCITT G.821 Objectives (12-Month Summary)

	BLN-FEL Link	
Unavailability Time	Actual Time	Fraction
Design Objective	4.91 hrs.	5.61×10^{-4}
Measured	27.26 hrs.	3.11×10^{-3}
Errored Sec.		
Design Objective	19,672 s	6.23×10^{-4}
Measured	2,150,214 s	6.82×10^{-2}
Severely Errored Sec.		
Design Objective	3,319 min.	1.05×10^{-4}
Measured	53,598 min.	1.70×10^{-3}
Degraded Minutes		
Design Objective	411 s	7.82×10^{-4}
Measured	295,304 s	5.63×10^{-1}

Figures 52-55 can be used to compare the monthly measured UA, ES, SES, and DM with the above limits. Only May 1988, June 1989, and September 1989 met the CCITT/CCIR unavailability criteria. No month met the criteria for severely errored seconds, degraded minutes, or errored seconds.

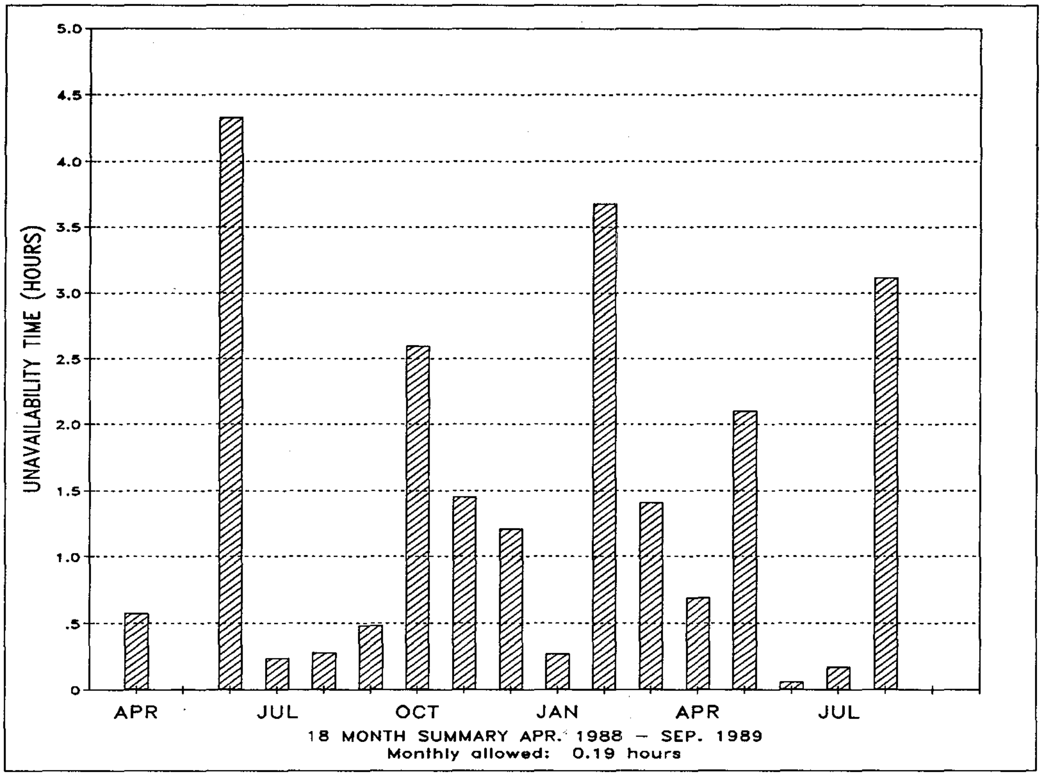


Figure 52. Eighteen-month summary of CCITT/CCIR unavailability time for LDF-FEL channel.

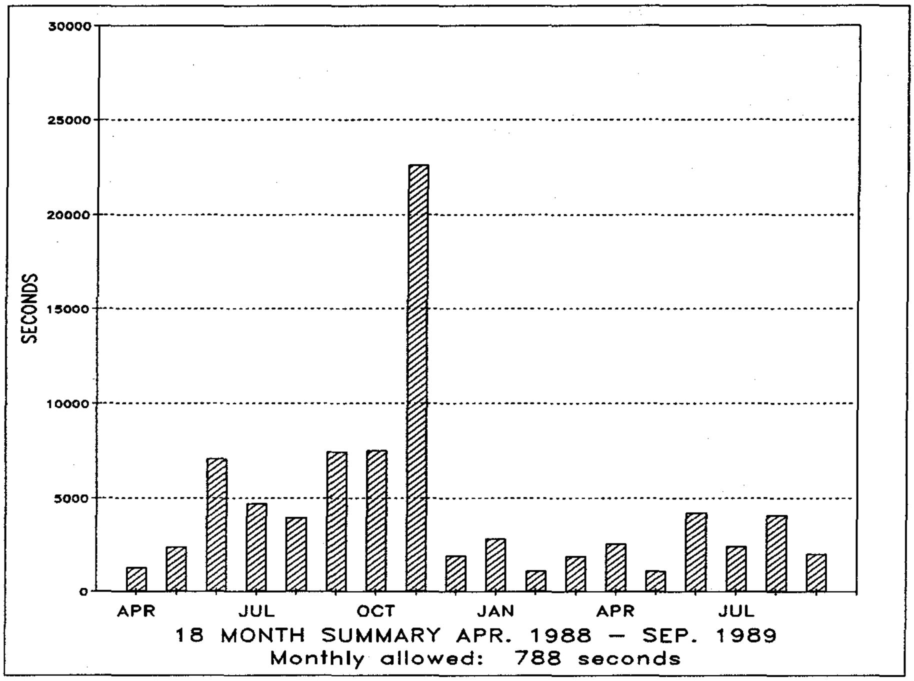


Figure 53. Eighteen-month summary of CCITT errored seconds for the LDF-FEL channel.

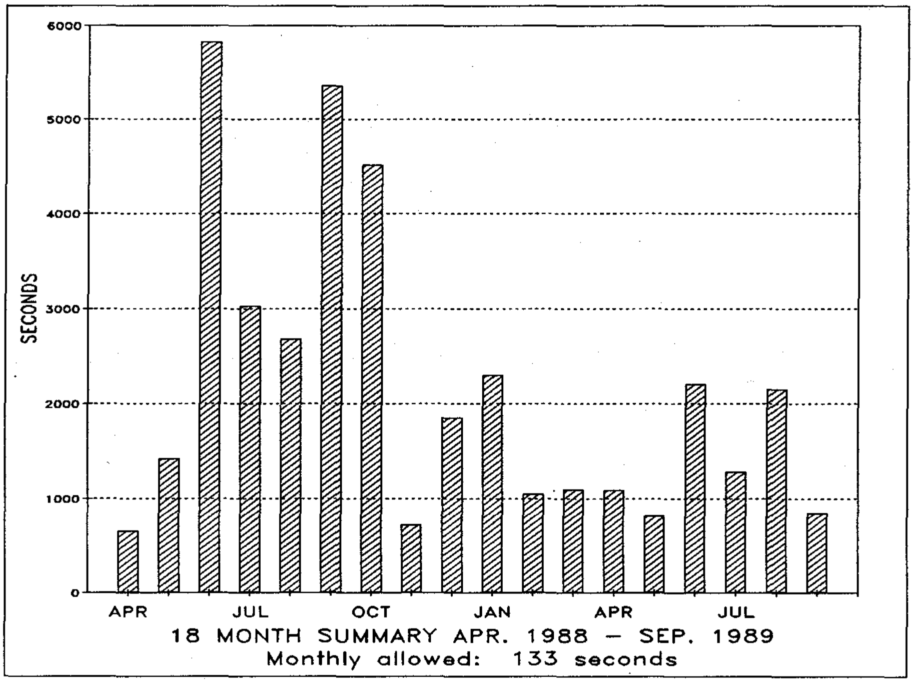


Figure 54. Eighteen-month summary of severely errored seconds for the LDF-FEL channel.

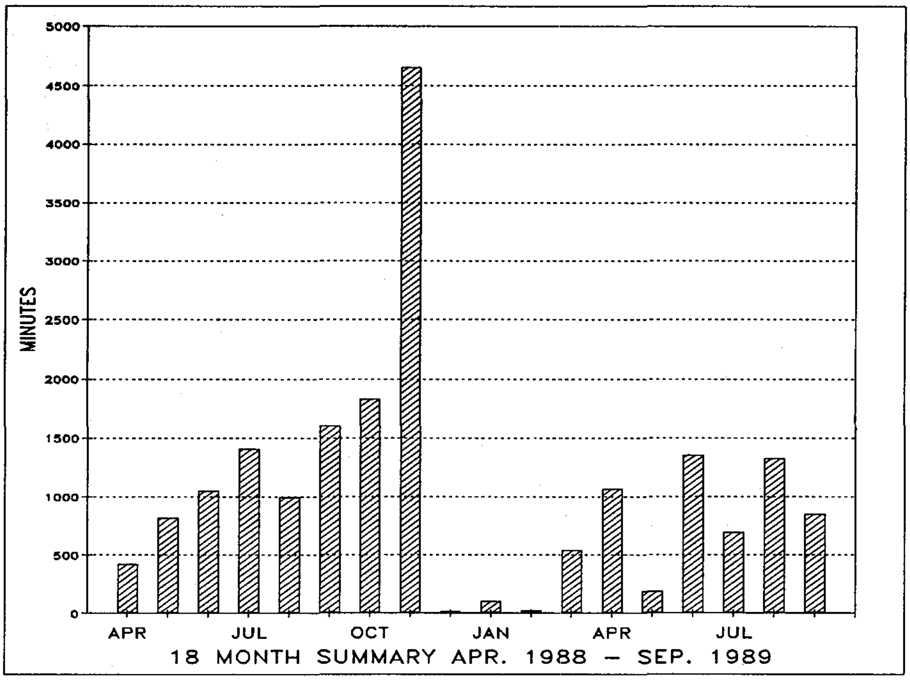
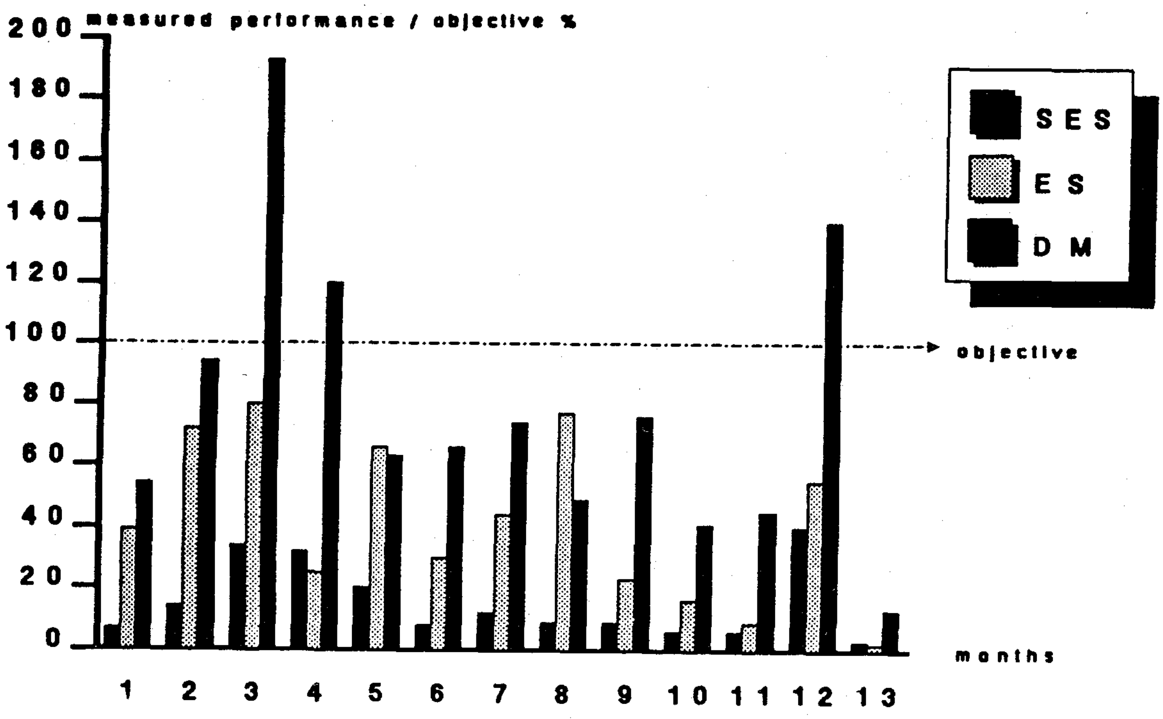


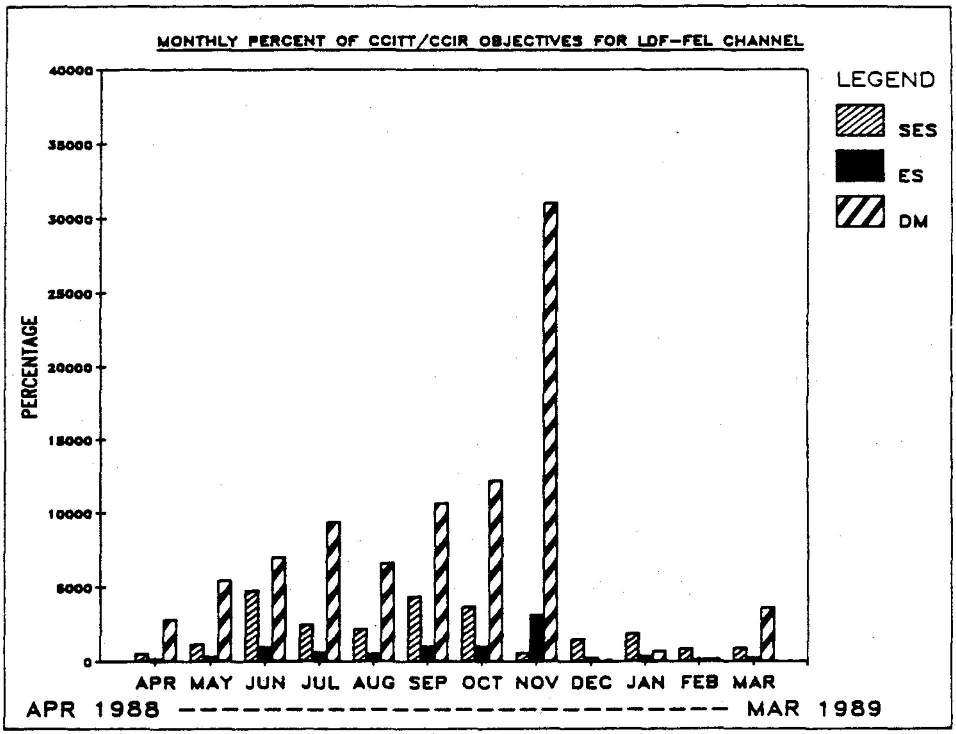
Figure 55. Eighteen-month summary of degraded minutes for the LDF-FEL channel.

Ivanek (1989, pp. 59-68) presents 13-month measurements that have been made on digital radio-relay circuits in Australia and the United Kingdom. The results of these measurements show that the CCITT/CCIR limits were met on both of these links the vast majority of the time. Figure 56 provides measured SES, ES, and DM data as ratios of the measured values to the monthly objectives for each of the three parameters. Part (a) of the figure is the result of measurements made on one 2628-km route in Australia (Ivanek, 1989; pp. 59-60). The route utilized a 140 Mb/s 16-QAM radio system. Part (b) of the figure is the result of the NPC/LPC measurements on the LDF-FEL channel. It is apparent that the commercial system outperformed the DEB system by almost two orders of magnitude (note that the scale on part (a) of the figure is more than two orders of magnitude greater than the scale on part (b)).

The conclusion that one can draw from the above is that the CCITT/CCIR recommended performance limits are not too stringent for application to LOS microwave circuits. The fact that the LDF-FEL channel did not meet the CCITT/CCIR objectives



a) Commercial microwave channel in Australia (from Terrestrial Digital Microwave Communications, F. Ivanek, editor, 1989; Courtesy of Artech House, Inc., Norwood, MA).



b) LDF-FEL channel.

Figure 56. Comparison of results of measurements with CCITT/CCIR objectives.

leads to the further conclusion that the performance of the Digital European Backbone is significantly less than that of commercial microwave networks.

The implications of the failure to meet the CCITT/CCIR recommended performance limits are as follows. The SES parameter is a measure of the 10^{-3} BER for all of the time that the system is considered to be available. Failure to meet the SES criterion implies that the channel will provide inadequate performance for either voice or data users (see Ivanek, 1989; pp. 34-36). The degraded minutes parameter is useful to quantify the amount of time that the performance of the channel deteriorates to the point that degradation of circuit quality is noticeable to voice users. The errored second is a method of quantifying error performance that is especially appropriate to data communications users (Ivanek, 1989; p. 36). Failure to meet the ES criterion implies inadequate service provision to data communications users.

5.2 Berlin-to-Feldberg Channel Analysis

The BLN-FEL channel, as was shown in Figure 1, consists of 5 tandem links: 1 troposcatter link and 4 LOS links. Three of the LOS links are also part of the Linderhofe-to-Feldberg channel. In this section we compare measured performance with both MIL-STD-188-323 and CCITT/CCIR objectives.

5.2.1 BLN-FEL Performance comparisons with MIL-STD-188-323 Specifications

Errored seconds and unavailability

Figure 57 is a plot of the measured errored seconds and UA time for each month of the entire 18-month period for the BLN-FEL channel. This end-to-end circuit does not meet Draft MIL-STD-188-323 design objectives for either ES or UA. Application of the MIL-STD to this circuit results in design objectives of 62,652 errored seconds and 16.14 hours for UA time annually (see Table 1). The total errored seconds for the 12-month period beginning April 1, 1988 was 1,905,530 seconds. For the same period, the UA time was 94.39 hours. Thus, the measured annual errored-second performance was worse than the ES design objective by a factor of 30.4. The measured annual UA time was worse than the UA design objective by a factor of 5.9.

Allocation of the errored second objectives and UA time on a monthly rather than a yearly basis results in an errored-second objective of 5221 seconds and an UA time objective of 1.35 hours per month. The monthly errored second objective was not met for any of the 18 months in the measurement period of April 1988 through September 1989. The monthly UA-time objective was not met for 14 of the months during this 18-month period.

The total number of errored seconds, including the errored seconds allocated to unavailability time, was 2,245,346 seconds for the 12-month period beginning in April 1988. This represents a long-term errored-second ratio of 7.9 x 10^{-2} for the 7866 hours of recorded data.

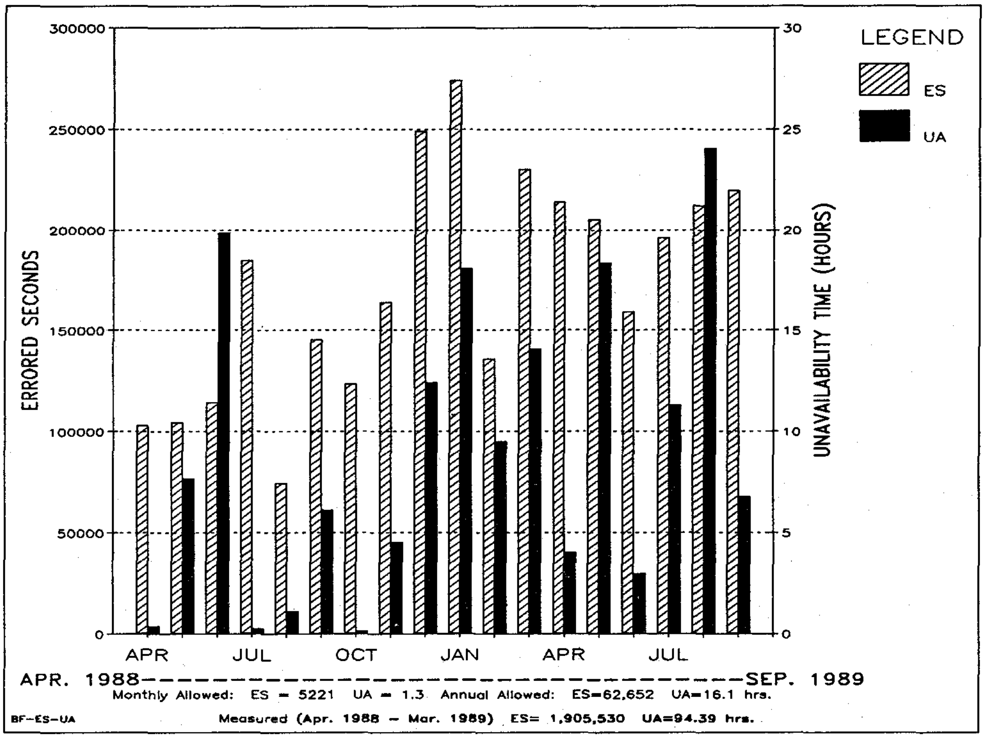


Figure 57. Errored seconds and unavailability for the BLN-FEL channel.

Jitter

High-speed (1.544-Mb/s) jitter measurements could not be made on the BLN-FEL channel because the test instrument required an NRZ (non-return-to-zero) interface. The only interface available for the BLN-FEL channel was a bipolar interface. Low-speed (64-kb/s) measurements were made on the BLN-FEL channel. With few exceptions, the peak-to-peak jitter was zero.

Delay

Delay measurements were attempted on the BLN-FEL channel. The same method described in the delay measurements for the LDF-FEL channel was used for the BLN-FEL channel. However, the signal returned to Feldberg after loop-back at Berlin was too noisy for the test instrument at Feldberg to archive lock-on. The test instrument generated a 64-kb/s PN (pseudonoise) data stream that was injected into the same FCC-98 digital interface that was normally used for the error performance measurements for the NPC-LPC program. The returned signal, viewed on an oscilloscope, did not appear to be a clean signal. The cause of this noise is not known. Although the delay measurements on this channel were not made, we do not believe that delay on the channel is of any significant consequence.

5.2.2 BLN-FEL Performance Comparisons with CCITT/CCIR Recommendations

Table 21 provides a comparison of the measured error performance of the BLN-FEL channel with the CCITT/CCIR 12-month design objectives. The measured time is for the 12-month period beginning on April 1, 1988. As can be seen in the table, the BLN-FEL channel does not meet the design objectives for any of the parameters specified by the CCITT/CCIR. The measured unavailability time is 5.6 times the design objective, the measured number of severely errored seconds is 16.1 times the design objective, the measured number of degraded minutes is 720.9 times the design objective, and the measured number of errored seconds is 109.3 times the measured objective.

Application of the CCITT/CCIR Recommendations to the BLN-FEL channel result in the following 1-month objectives:

• Unavailability time:	0.41 hours
• Severely errored seconds:	277 seconds

- Degraded minutes: 34 minutes
- Errored seconds: 1639 seconds

Figures 58-61 can be used to compare the monthly measured UA, ES, SES, and DM with the above limits. Only May 1988 and July 1988 met the CCITT/CCIR unavailability criteria. No month met the severely errored seconds, degraded minutes, or errored seconds criteria.

Table 21. Berlin-Feldberg Summary of Error Performance and Comparison with CCITT G.821 Objectives (12-Month Summary)

	BLN-FEL Link		
Unavailability Time	Actual Time		Fraction
Design Objective	4.91	hrs.	5.61×10^{-4}
Measured	27.26	hrs.	3.11×10^{-3}
Errored Sec.			
Design Objective	19,672	s	6.23×10^{-4}
Measured	2,150,214	s	6.82×10^{-2}
Severely Errored Sec.			
Design Objective	3,319	min.	1.05×10^{-4}
Measured	53,598	min.	1.70×10^{-3}
Degraded Minutes			
Design Objective	411	s	7.82×10^{-4}
Measured	295,304	s	5.63×10^{-1}

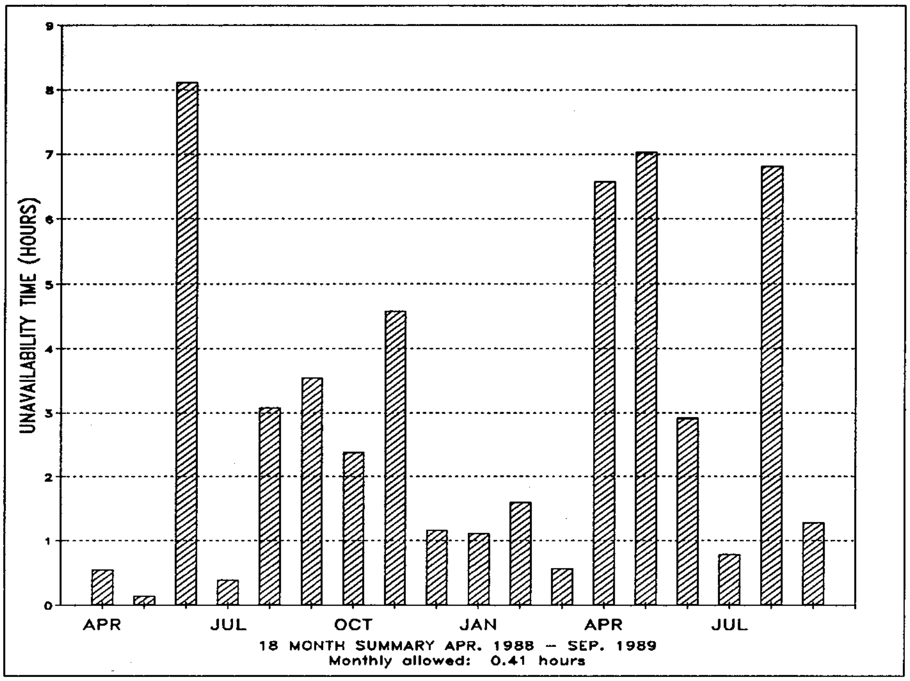


Figure 58. Eighteen-month summary of CCITT/CCIR unavailability time for BLN-FEL channel.

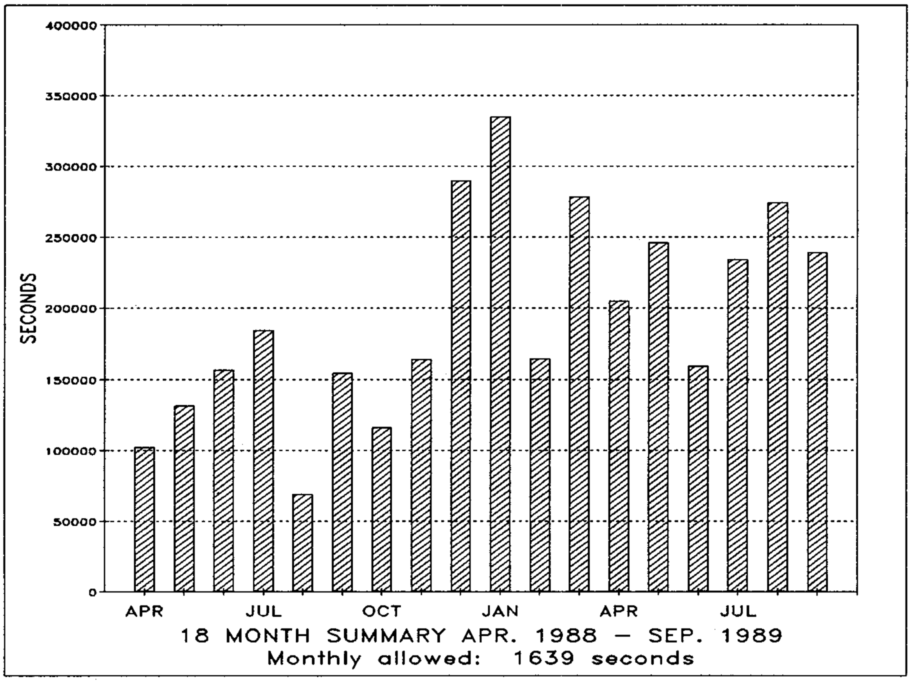


Figure 59. Eighteen-month summary of CCITT errored seconds for the BLN-FEL channel.

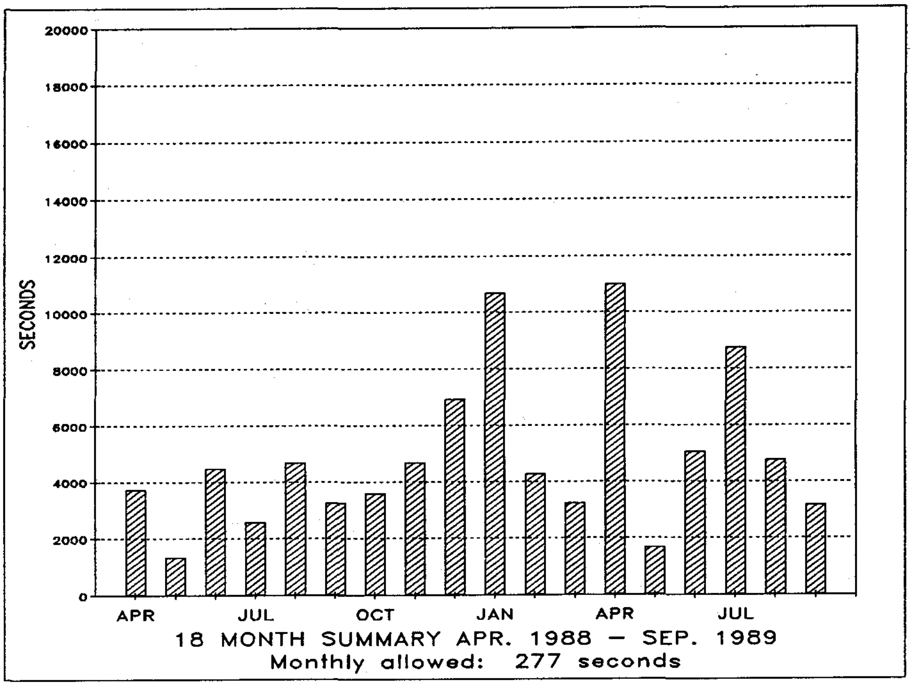


Figure 60. Eighteen-month summary of severely errored seconds for BLN-FEL channel.

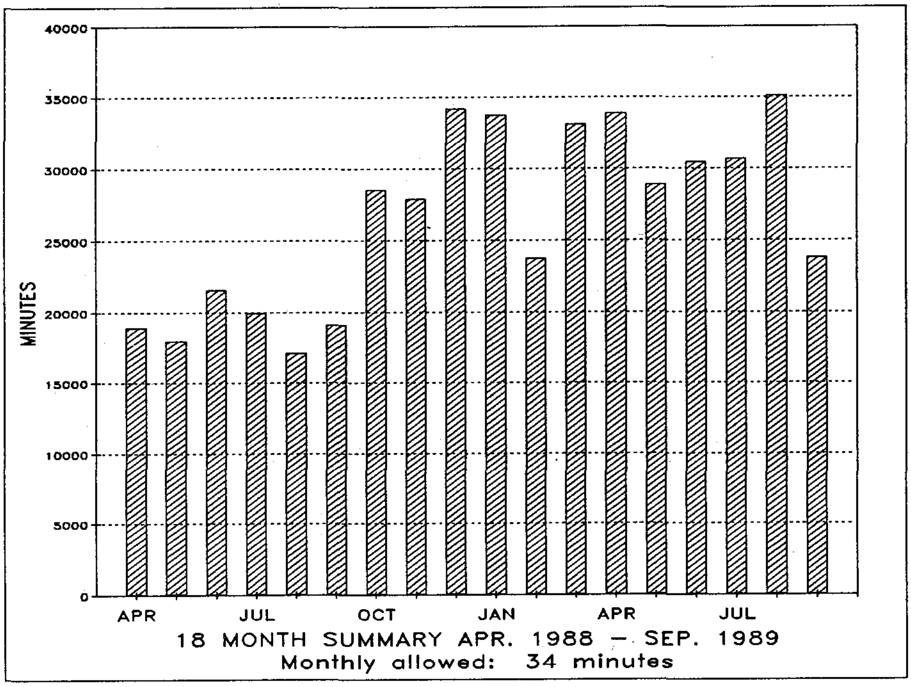


Figure 61. Eighteen-month summary of degraded minutes for the BLN-FEL channel.

5.2.3 Discussion of the Performance of the BLN-FEL Channel

Comparisons can be made of the two end-to-end channels. Each of these two channels contains four LOS links. Three of the LOS links are common to each channel. The LDF-FEL channel includes the LDF-KBG link (28 km), which is not part of the BLN-FEL channel. The BLN-FEL channel includes the BBG-KBG link (72 km), which is not part of the LDF-FEL channel. From this, one might intuitively expect that the contributions to digital errors from the LOS portion of the BLN-FEL channel would be approximately the same as the digital errors measured on the end-to-end LDF-FEL channel (the errors would be expected to be slightly greater because the BBG-KBG LOS link is longer than the LDF-KBG LOS links). A logical conclusion is that most of the difference between performances of the two end-to-end channels is probably due to the troposcatter link that is part of the BLN-FEL channel, but not the LDF-FEL channel.

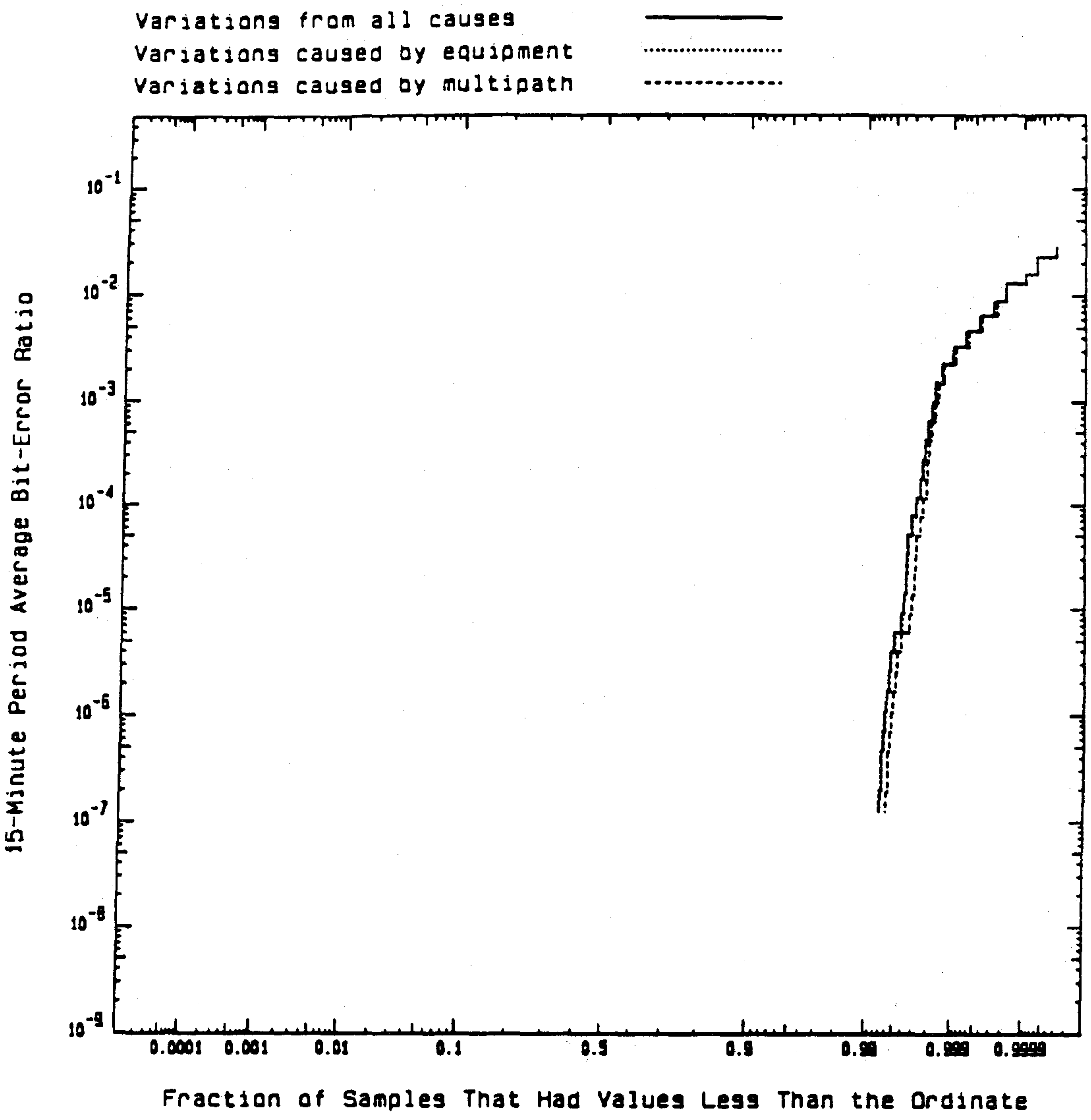
The implications of the measured BLN-FEL channel performance are as follows. Channel coding may be required to obtain satisfactory performance for data communications that are passed over troposcatter links. Channel coding will cause some loss of throughput because of the overhead bits associated with such coding. However, the accuracy of the received data would be enhanced. Further analysis of the need for channel coding and its impact on system performance is recommended. The implications of BLN-FEL performance for voice users will be discussed in the next section.

5.3 Other Network Performance Characterization Statistics

This section presents additional network performance characterization statistics that were required by the statement of work with the Defense Communications System Engineering Center, as delineated in Tables 4 and 5. The data presented will be for the 12-month measurement period that started on April 1, 1988.

5.3.1 Fifteen-Minute average BER distributions

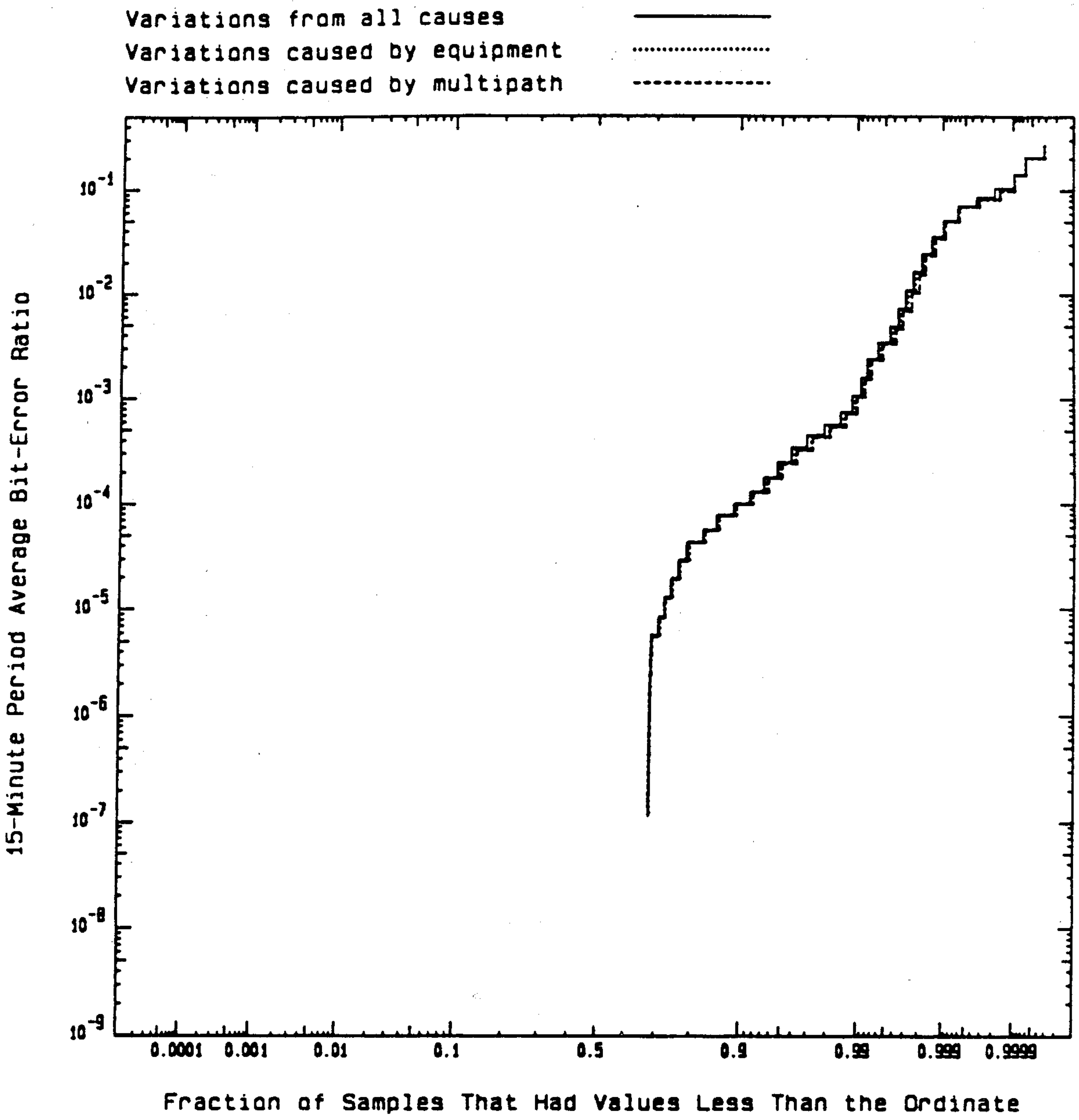
Figure 62 presents 15-minute average BER distributions for the BLN-FEL channel, the LDF-FEL channel and the SBN-FEL link. Each part of the figure contains several distributions--one curve for each potential cause of errors and one curve for all causes.



Notes: 1) Errored seconds allocated to unavailability time are included.
2) Data are from 12-month measurements.

a) BLN-FEL tandem tropo and LOS channel; 2% of 15-minute BER samples are worse than 1 x 10^{-3}; 98.4% are worse than 1 x 10^{-7}; sample sizes are all 31,464.

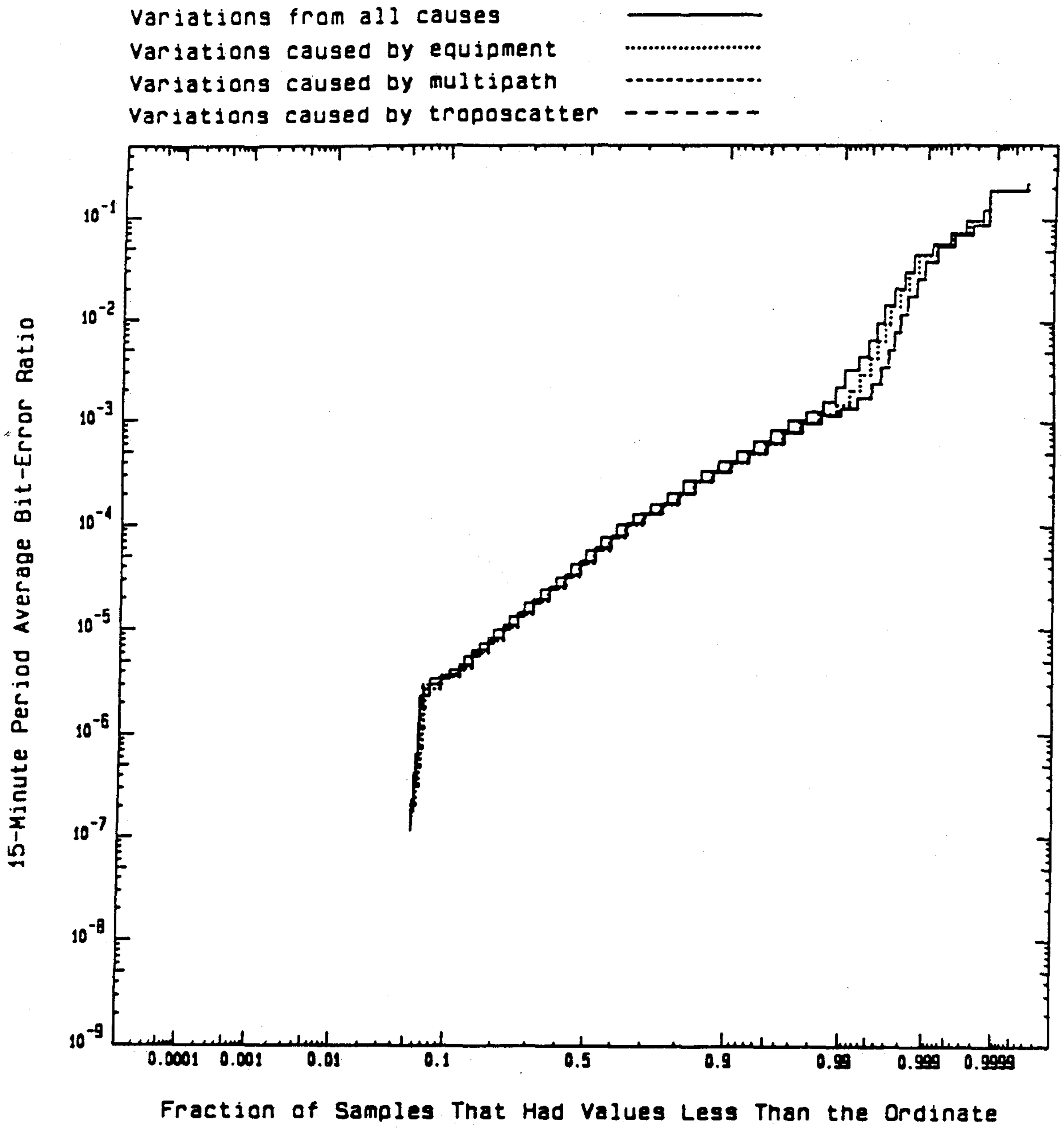
Figure 62. Fifteen-minute average BER distributions.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

b) LDF-FEL tandem LOS channel; 1% of 15-minute BER samples are worse than 1×10^{-3}; 32% are worse than 1×10^{-7}; sample sizes are all 31,464.

Figure 62 (cont). Fifteen-minute average BER distributions.



Notes: 1) Errored seconds allocated to unavailability time are included.
2) Data are from 12-month measurements.

c) BLN-FEL tandem tropo and LOS channel; 2% of 15-minute BER samples are worse than $1X10^{-3}$; 98.4% are worse than $1X10^{-7}$; sample sizes are all 31,464.

Figure 62 (cont). Fifteen-minute average BER distributions.

For the purpose of discussion, we selected the data points for the 1 x 10^{-3} and the 1 x 10^{-6} 15-minute average BER for each of the three circuits. Voice quality is seriously degraded on PCM digital voice circuits at the 1 x 10^{-3} BER threshold. A BER of 1 x 10^{-6} is the BER threshold at which degradations to voice quality first become perceptible for PCM-encoded speech. It is also the level of minimum acceptable performance for some data communications users. Use of these thresholds results in the following observations: 3.5% of the time the BLN-FEL channel would provide poor performance to voice communications users, and 98% of the time it would provide poor service to data communications users; 1% of the time the LDF-FEL channel would provide poor performance to voice users, and 32% of the time it would provide poor performance to data communication users.

Figure 63 depicts the monthly plot of the median values from each of the monthly cumulative probability distributions of the 15-minute average BER for the BLN-FEL channel. Several of the months have a median average 15-minute BER of the order of 1 x 10^{-4}. The BER's at this level are quite noticeable to PCM voice users of the channel. Figure 64 shows a similar plot for the LDF-FEL channel, except that the data points are the 0.9 levels of the monthly cumulative probability distributions of the 15-minute average BER.

5.3.2 Statistics of error bursts in the channel

Figures 65 and 66 are plots of contiguous errored seconds and contiguous error-free seconds respectively. The data in Figure 65 show that 99% of the BLN-FEL consecutive error-second samples contained 6 or fewer errored seconds. The corresponding data for the LDF-FEL channel and the SBN-FEL link are 13 and 17 errored seconds respectively. The data in Figure 66 show that 1% of the gaps between error events were greater than 210 seconds for the BLN-FEL channel, 10,000 seconds for the LDF-FEL channel, and 700,000 seconds for the SBN-FEL channel.

Figure 67 provides distributions of the number of errors that occurred in errored seconds for the BLN-FEL channel, the LDF-FEL channel, and the SBN-FEL channel. Note that the median number of errors in an errored second was 22, 250, and 110 for the BLN-FEL, LDF-FEL, and SBN-FEL circuits respectively. This indicates that the LOS

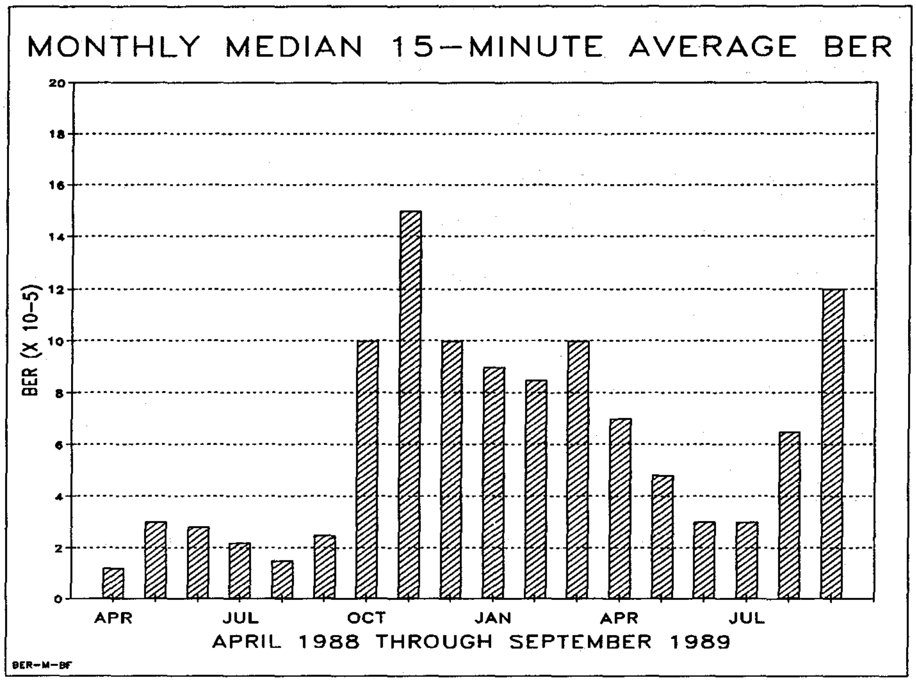


Figure 63. Monthly median 15-minute average BER for BLN-FEL channel.

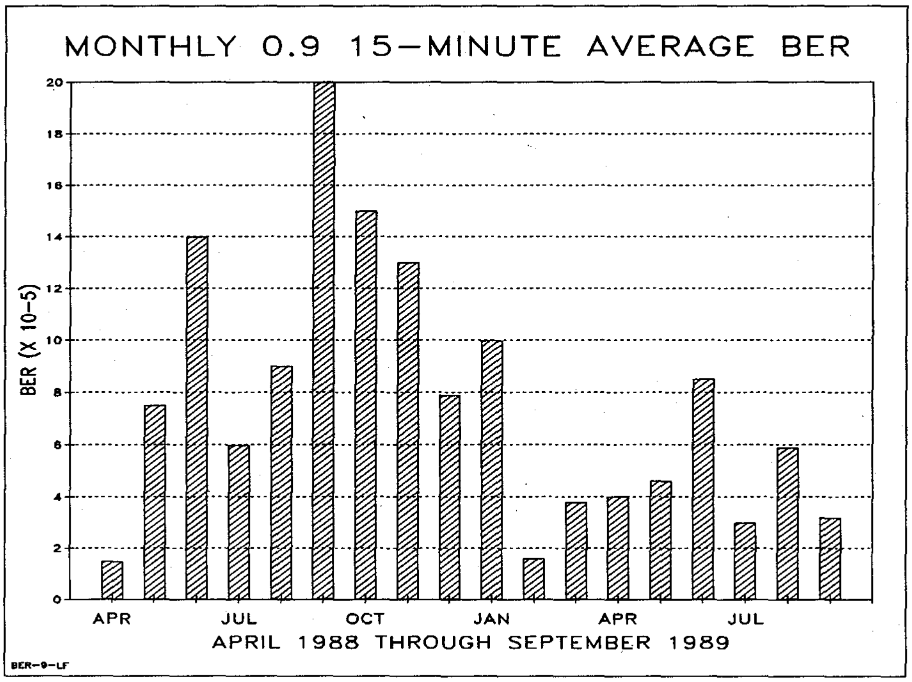
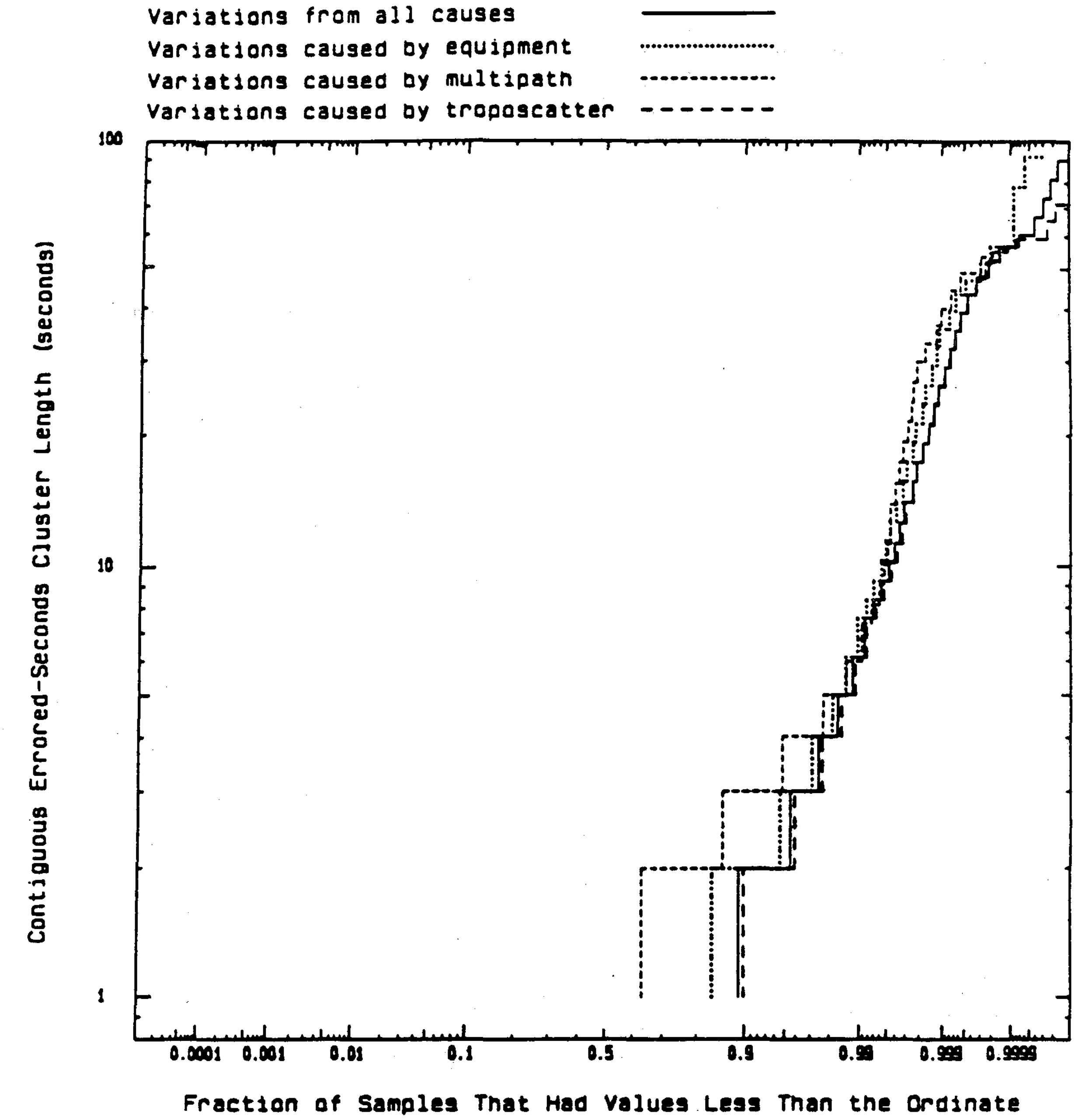


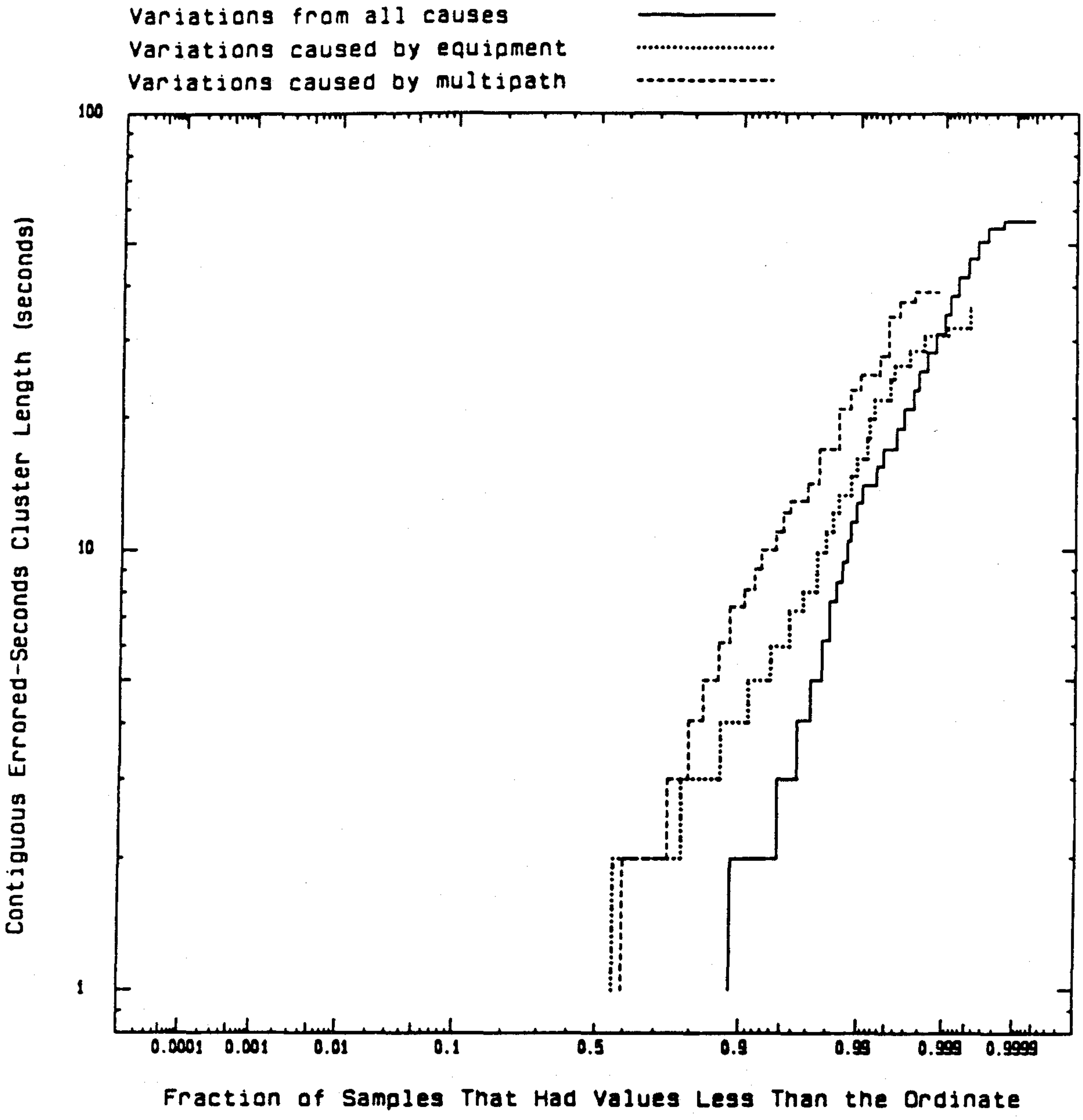
Figure 64. Monthly 15-minute average BER at 0.9% level for LDF-FEL channel.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

a) BLN-FEL tandem tropo and LOS channel; 1% of error events contained six or more errored seconds; median error event had only one errored second, sample sizes are 1,485,371, 33,696, 10,584, and 855,897.

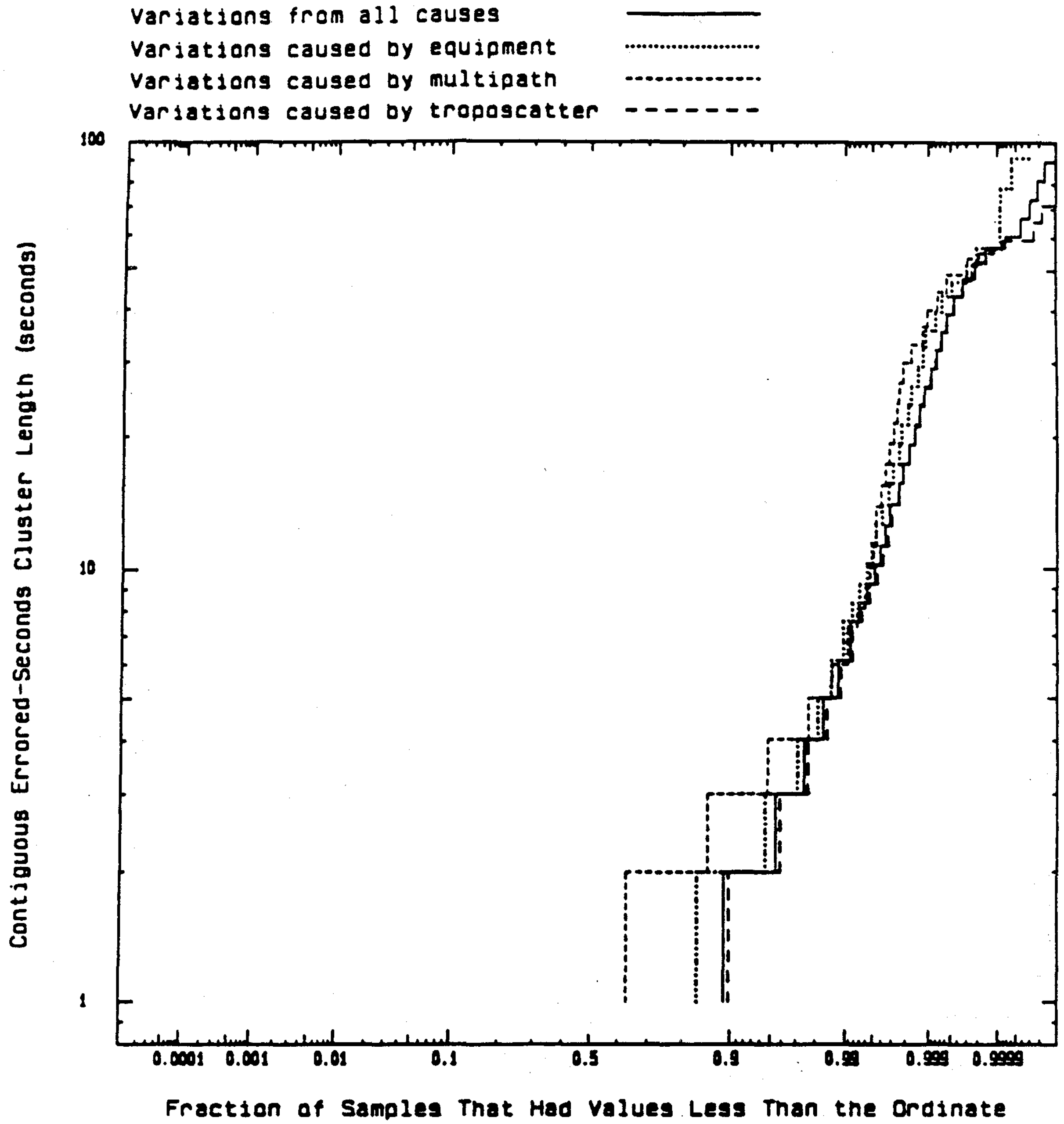
Figure 65. Distributions of contiguous errored-second cluster length.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

b) LDF-FEL tandem LOS channel; 1% of error events contained 13 or more errored seconds; median error event had only one errored second; sample sizes are 57,142, 2145, and 813.

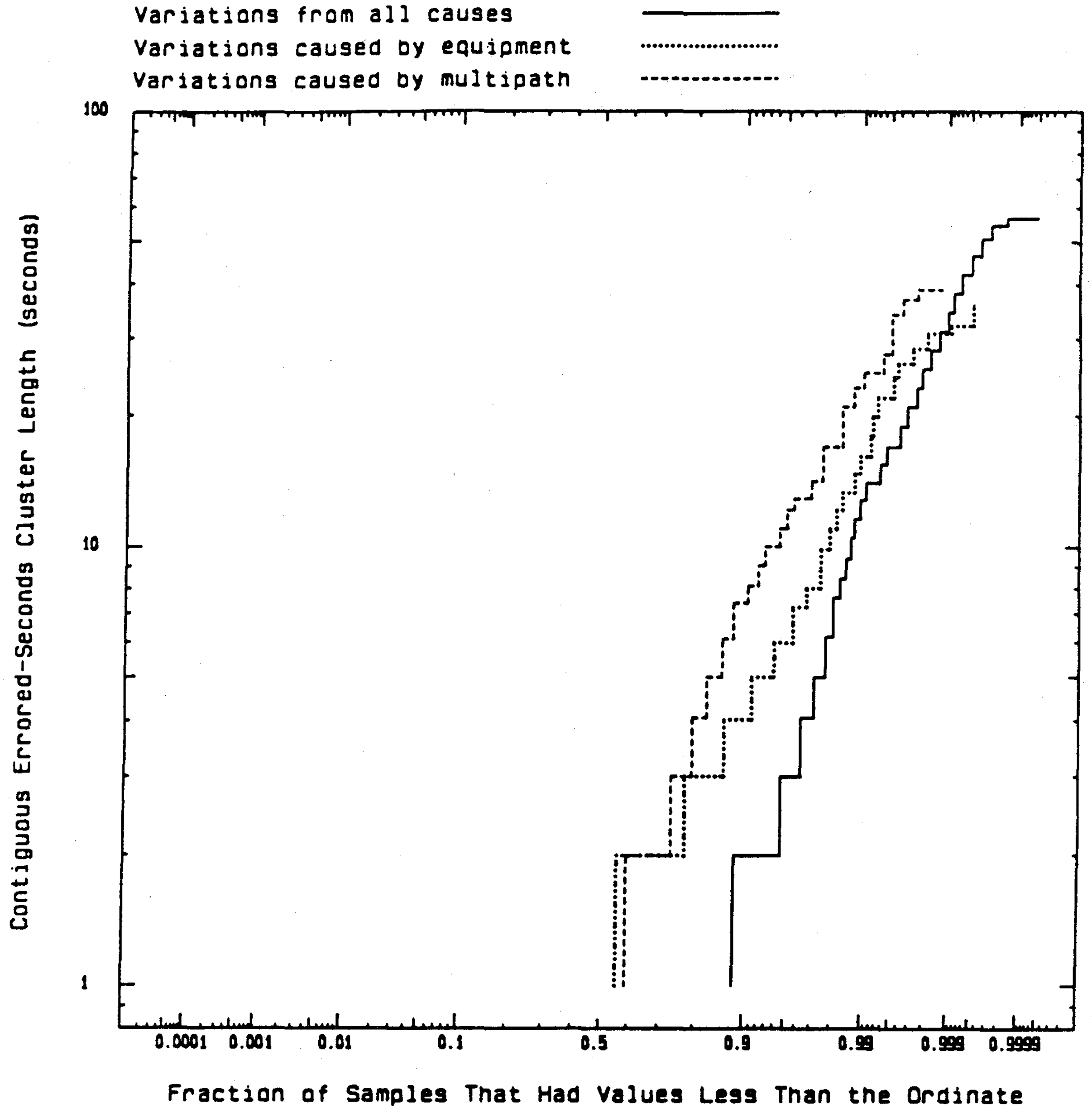
Figure 65 (cont). Distributions of contiguous errored-second cluster length.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

a) BLN-FEL tandem tropo and LOS channel; 1% of error events contained six or more errored seconds; median error event had only one errored second, sample sizes are 1,485,371, 33,696, 10,584, and 855,897.

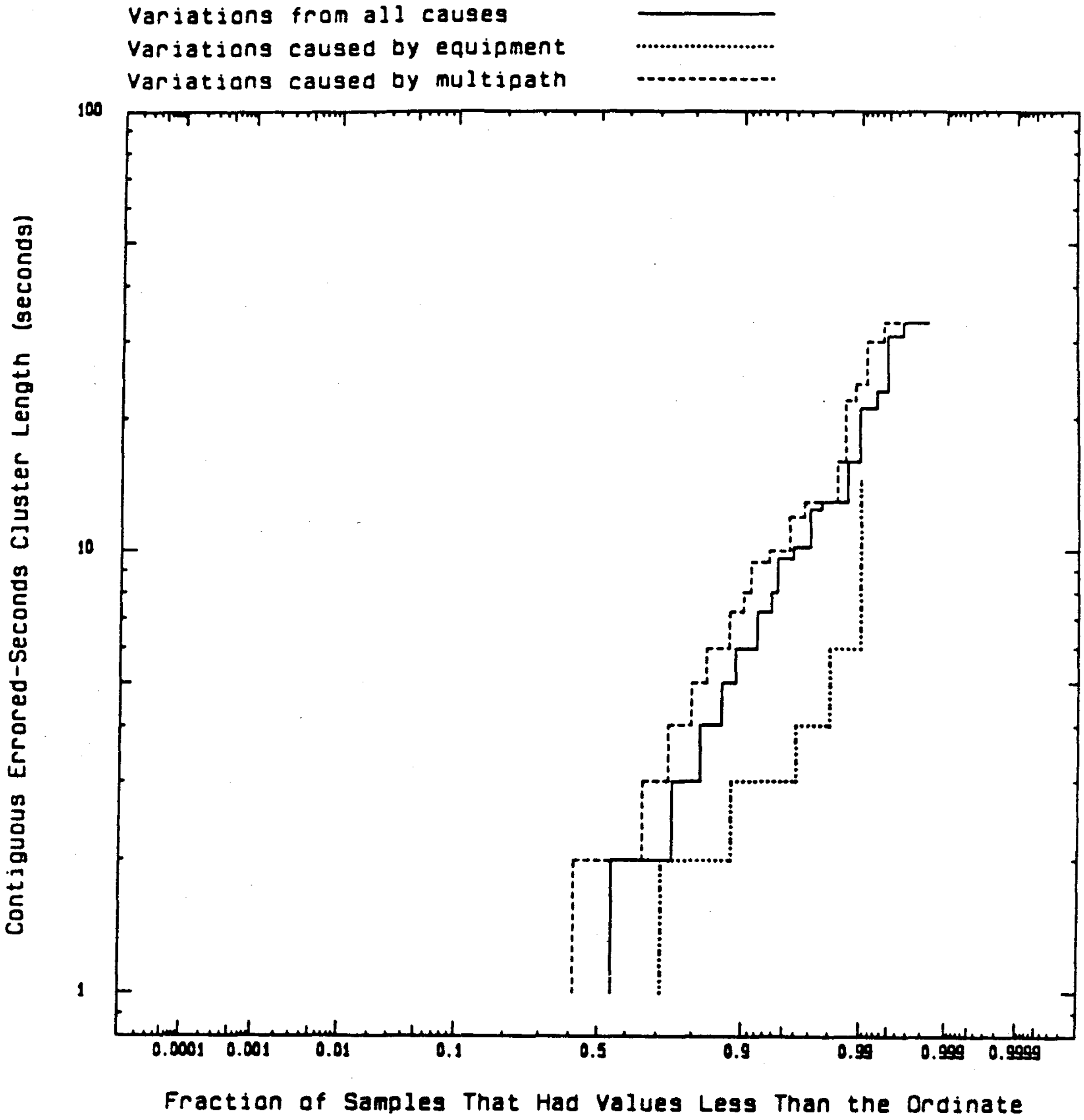
Figure 65. Distributions of contiguous errored-second cluster length.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

b) LDF-FEL tandem LOS channel; 1% of error events contained 13 or more errored seconds; median error event had only one errored second; sample sizes are 57,142, 2145, and 813.

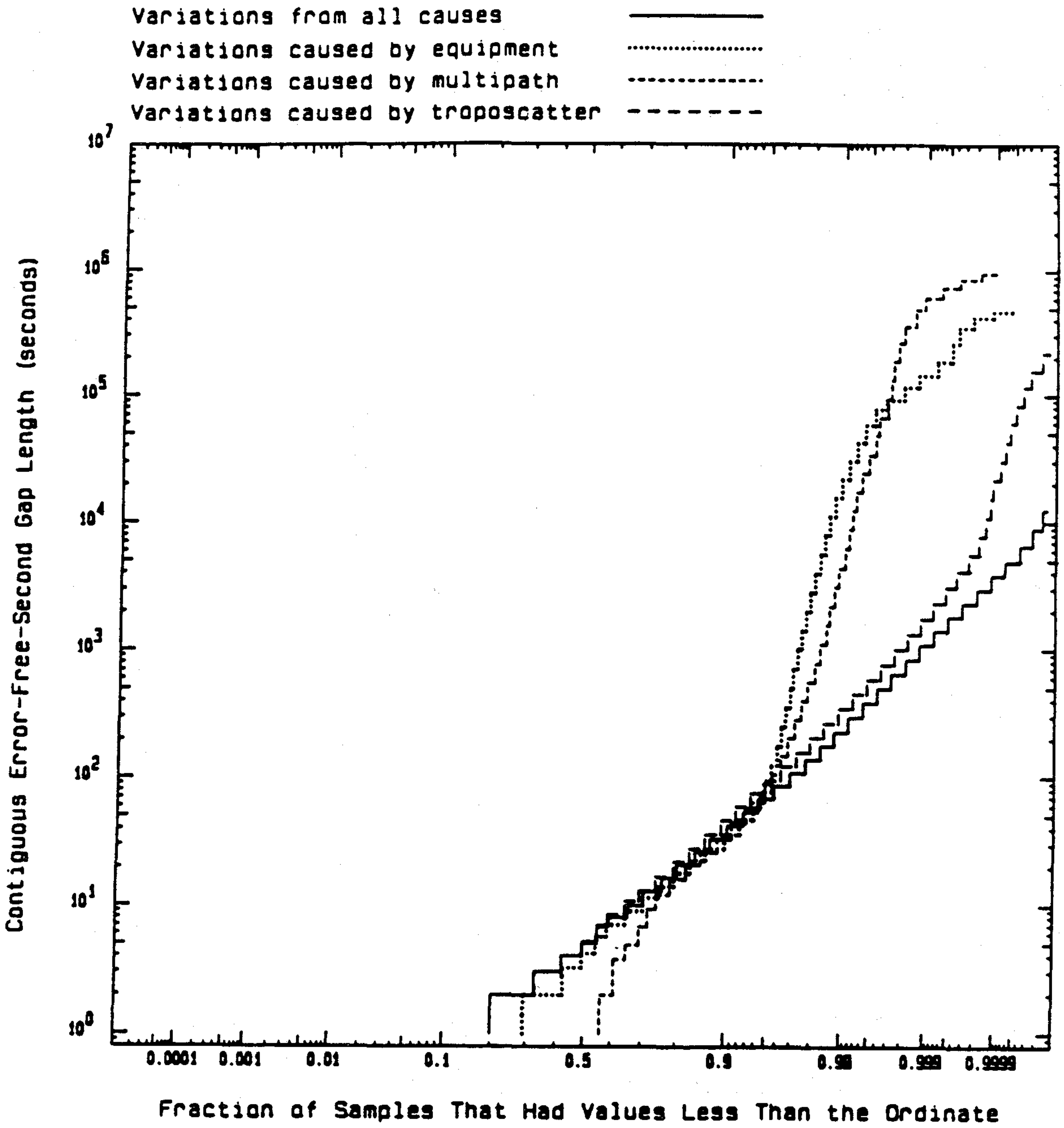
Figure 65 (cont). Distributions of contiguous errored-second cluster length.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

c) SBN-FEL link; 1% of error events contained 17 or more errored seconds; median error event had only one errored second; sample sizes are 587,100 and 349.

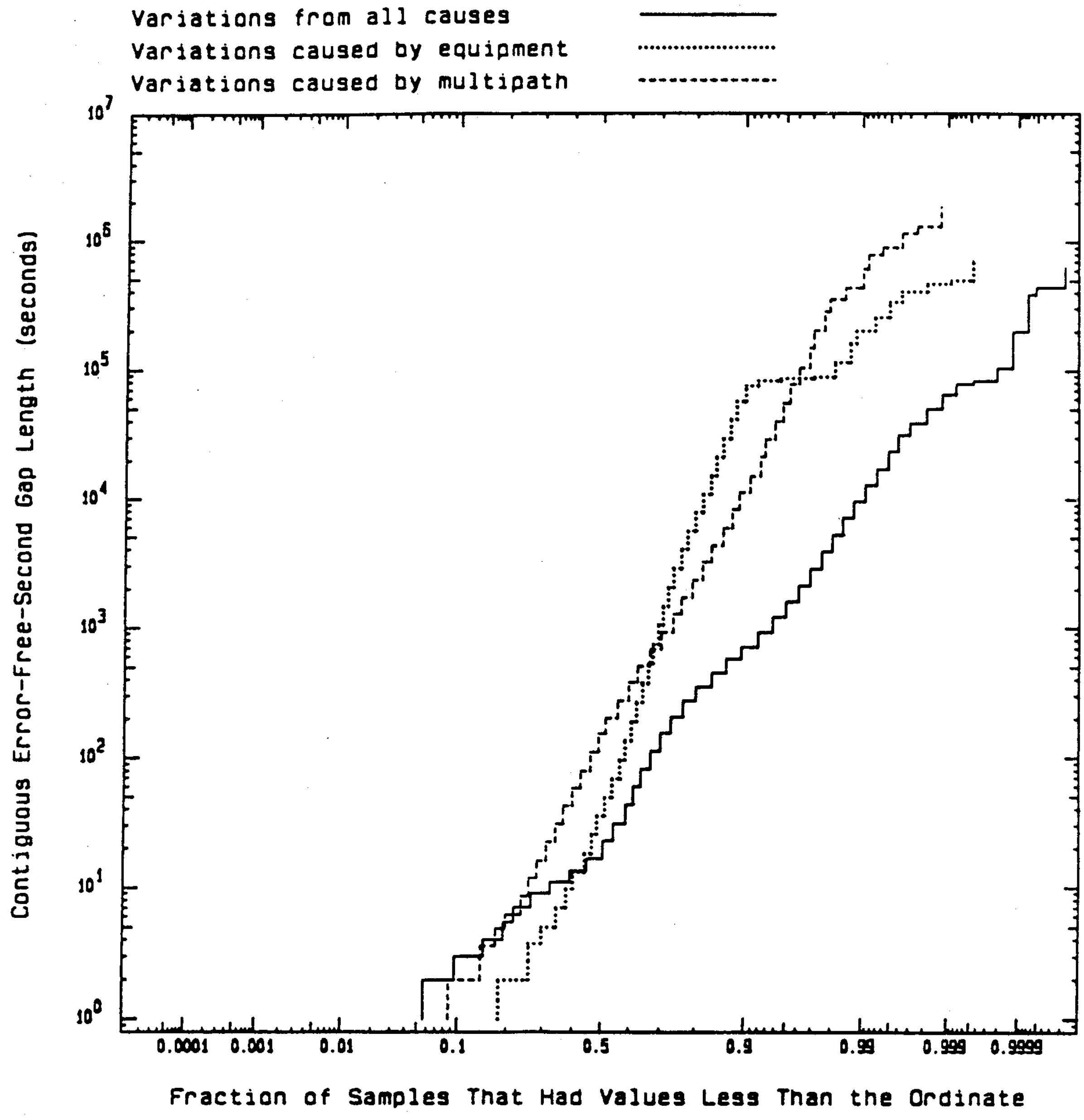
Figure 65 (cont). Distributions of contiguous errored-second cluster length.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

a) BLN-FEL tandem tropo and LOS channel; 1% of the gaps between error events were greater than 210 seconds; median gap between error events was 5.0 seconds; sample sizes are 1,486,386, 33,738, 10,518, and 856,532.

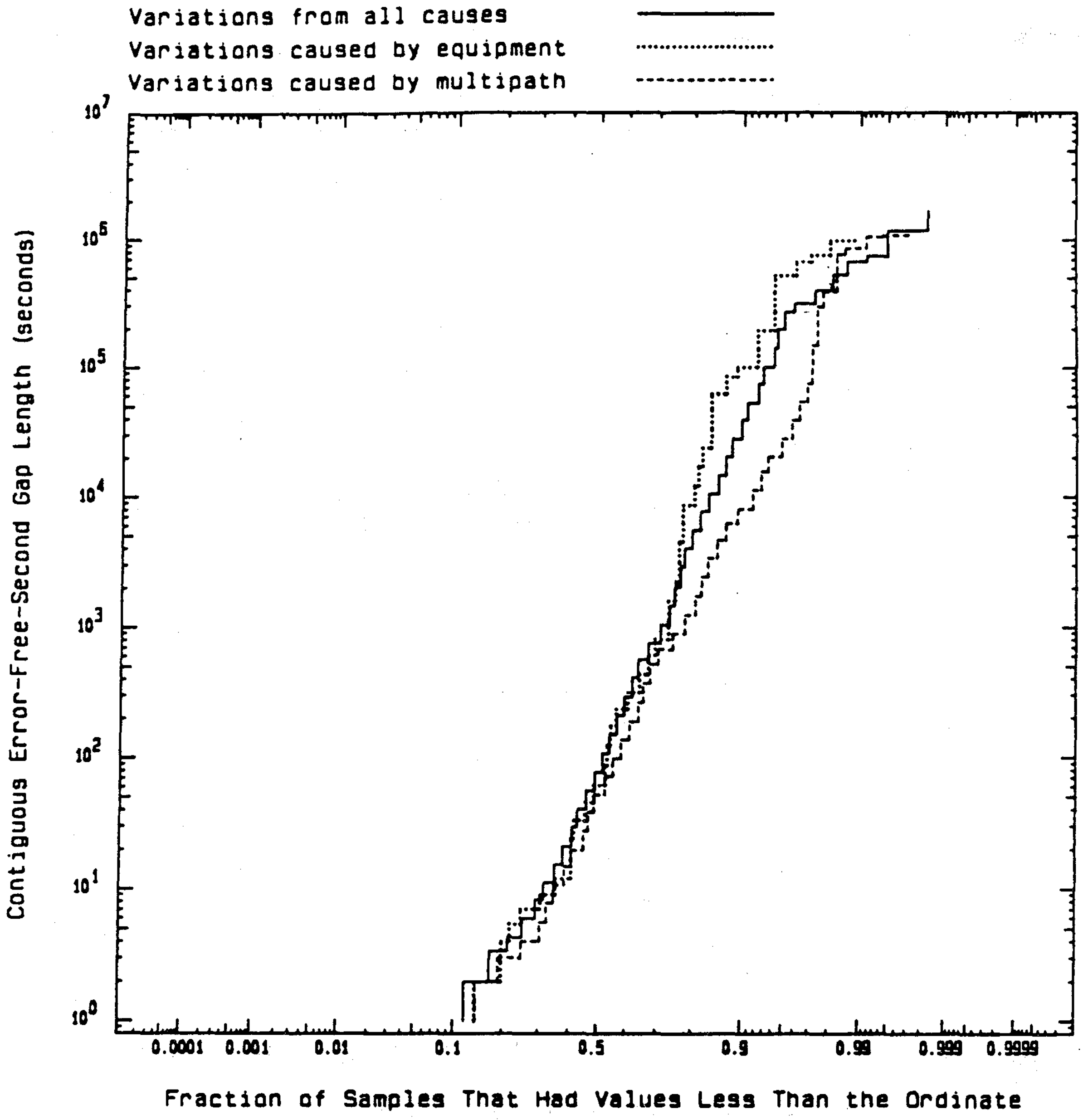
Figure 66. Distributions of contiguous error-free second gap length.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

b) LDF-FEL tandem LOS channel; 1% of the gaps between error events were greater than 10,000 seconds; median gap between error events was 18 seconds; sample sizes are 57,208, 2167, and 813.

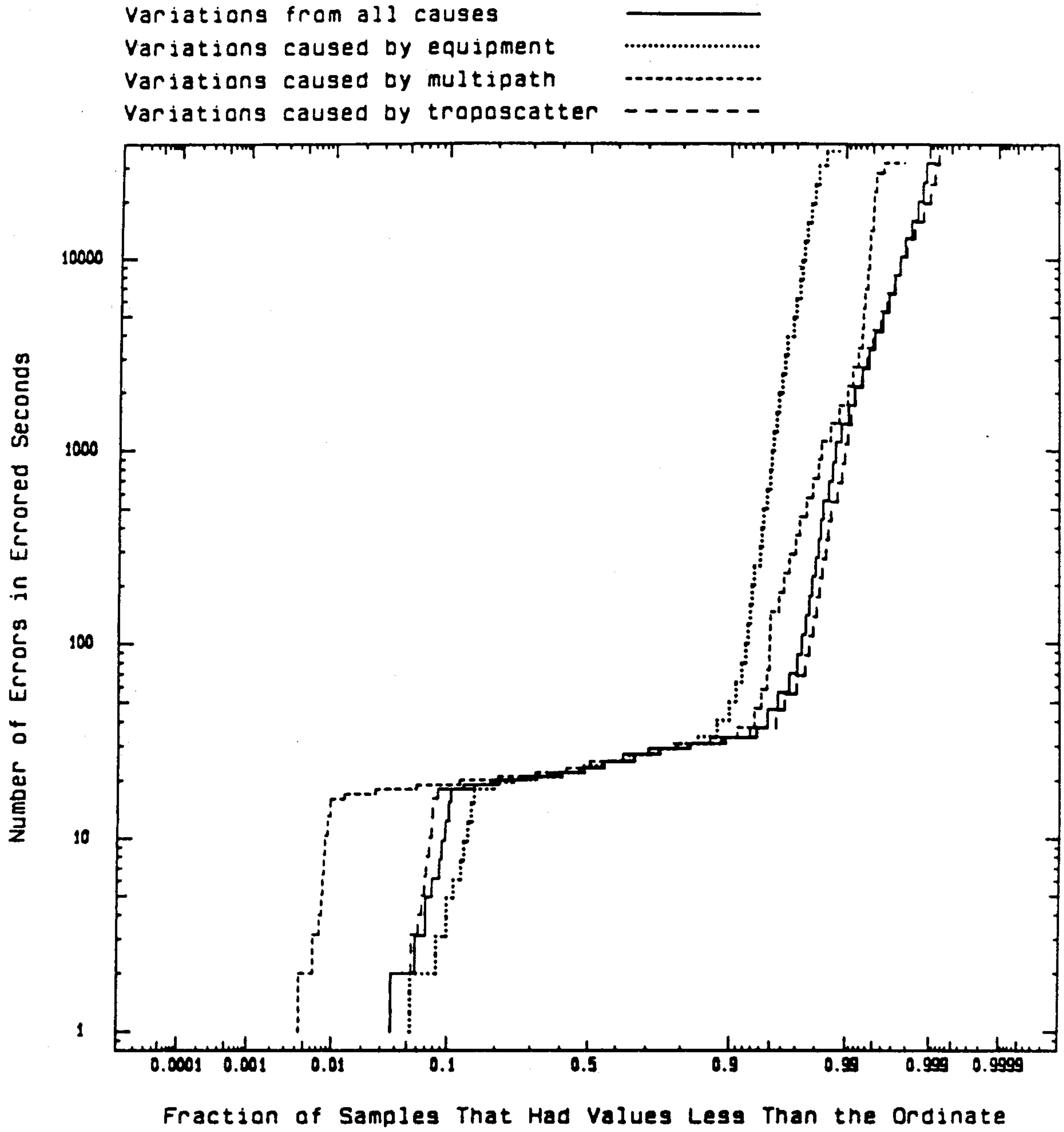
Figure 66 (cont). Distributions of contiguous error-free second gap length.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

c) SBN-FEL LOS link; 1% of the gaps between error events were greater than 700,000 seconds (ight days); median gap between error events was 80 seconds; sample sizes are 589, 101, and 349.

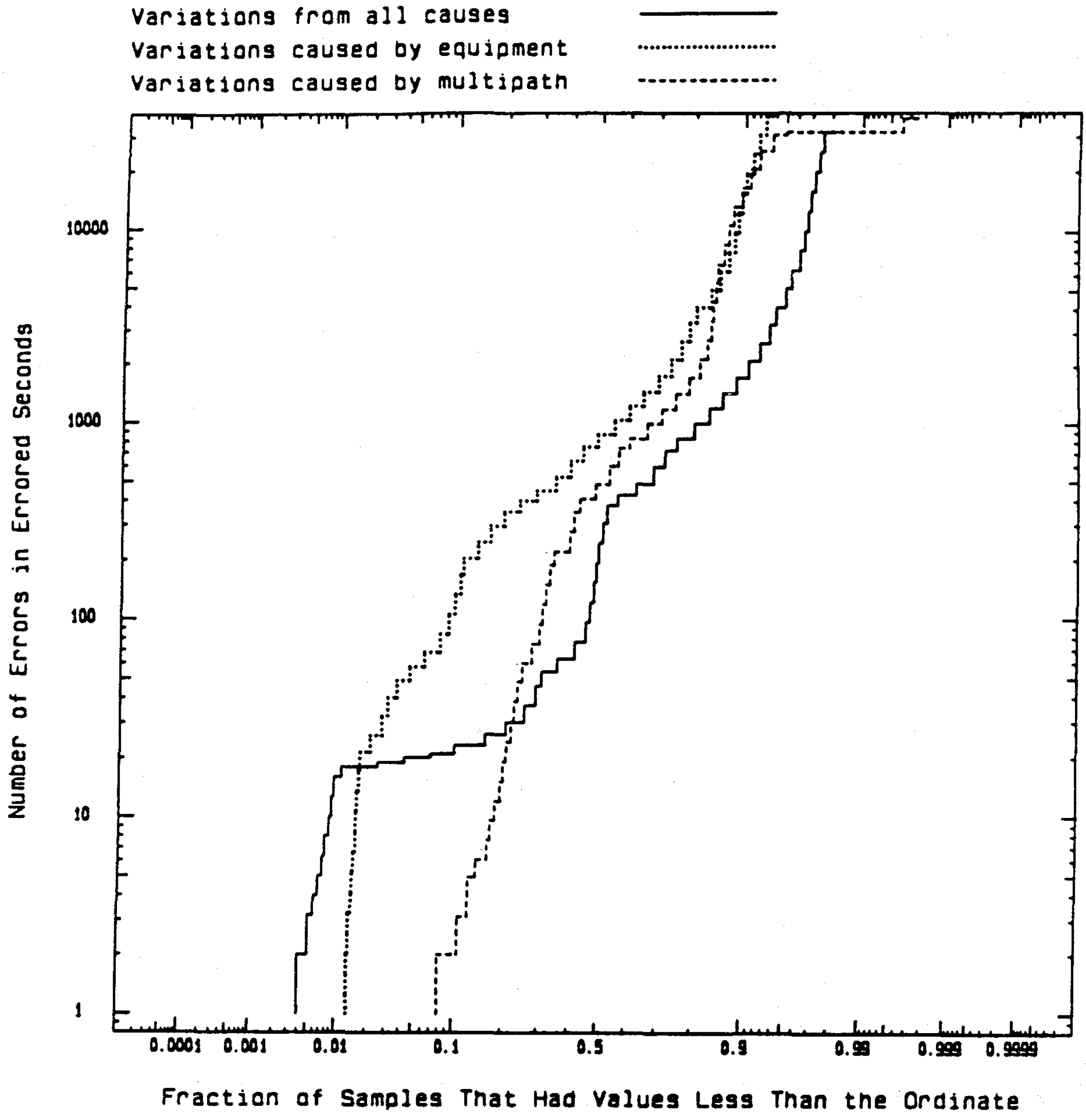
Figure 66 (cont). Distributions of contiguous error-free second gap length.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

a) BLN-FEL tandem tropo and LOS channel; 1% of errored seconds contained more than 2000 errors; median number of errors in an errored second was 22; sample sizes are 1,905,530, 46,590, 18,100, and 1,081,814.

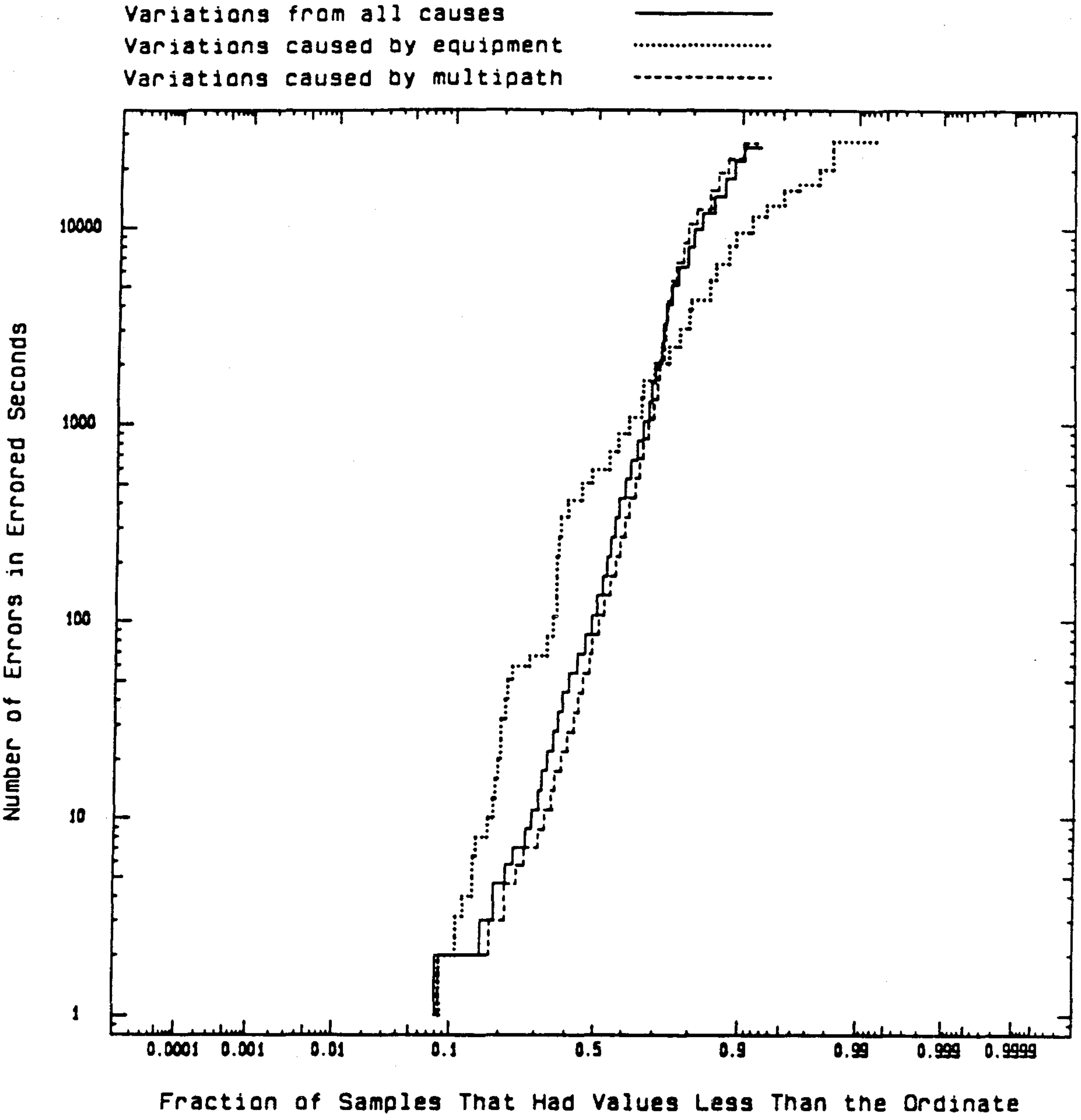
Figure 67. Distributions of the number of errors within errored seconds.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

b) LDF-FEL tandem LOS channel; 1% of errored seconds contained more than 3000 errors; median number of errors in an errored second was 250; sample sizes are 81,412, 4836, 2432.

Figure 67 (cont). Distributions of the number of errors within errored seconds.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

c) SBN-FEL links; 1% of errored seconds contained more than 2800 errors; median number of errors i an errored second was 110; sample sizes are 1559, 165, and 1180.

Figure 67 (cont). Distributions of the number of errors within errored seconds.

channel is more bursty than the troposcatter channel, i.e., the errors occur in larger bursts on the LOS channel than on the troposcatter channel. The data presented in Figures 65 and 67 are useful for channel modeling and simulation purposes.

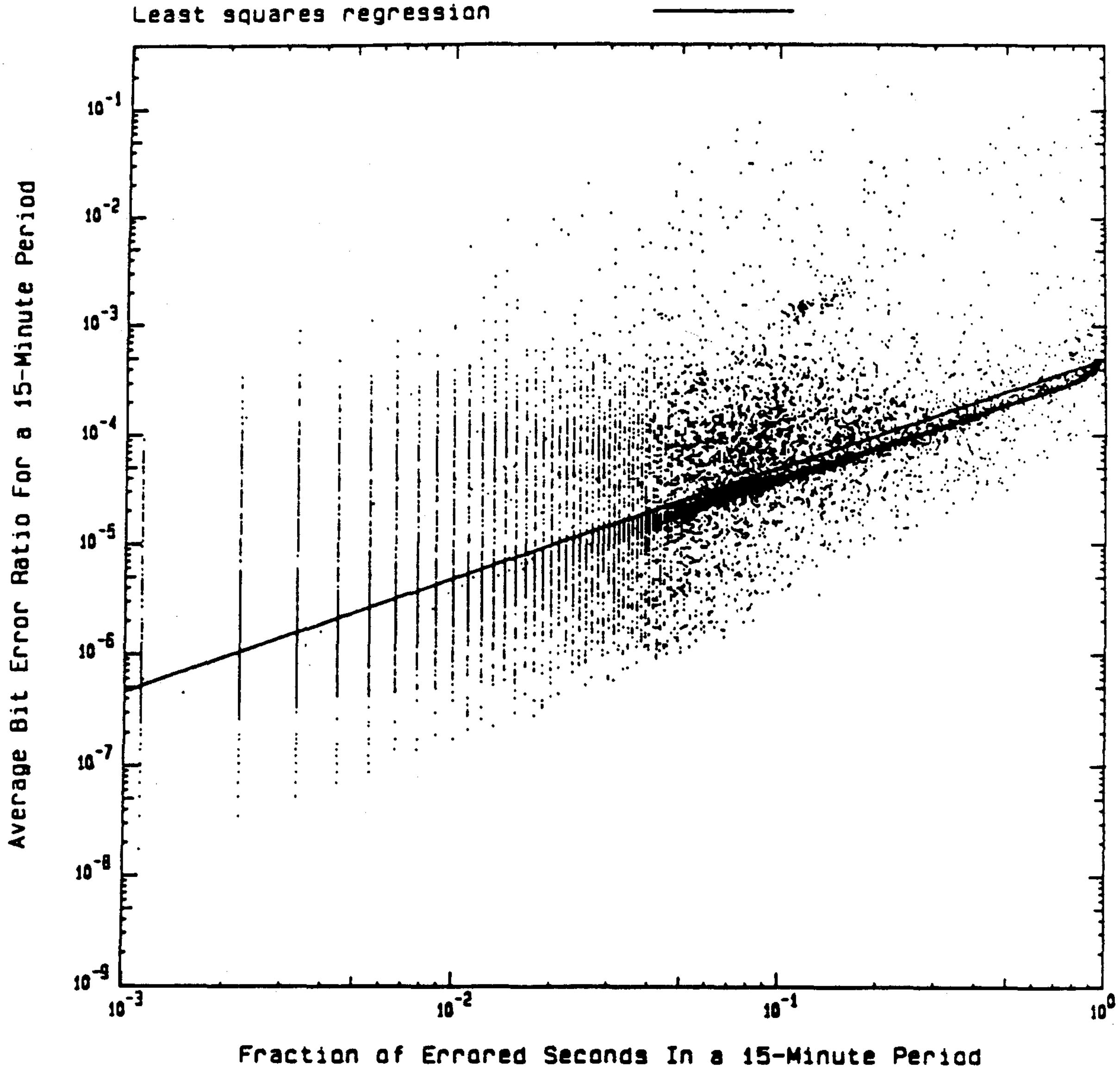
5.3.3 Correlation of average BER and fraction of errored seconds

Figure 68 is a scatter plot of the 15-minute average BER and the fraction of the seconds in the 15-minute period that contains errors. The figure provides data for the BLN-FEL channel, the LDF-FEL channel, and the SBN-FEL link. The data show that the correlation for these two parameters is low for the BLN-FEL channel. The parameters are moderately correlated for the LDF-FEL channel, and fairly well correlated for the SBN-FEL link. These data are in agreement with the statement in CCIR Report 930-1 that in general there is no simple relationship between bit-error-rate performance and the long-term error-free-second performance during periods of multipath fading (CCIR, 1986f).

5.4 Allocation of End-to-End Channel Errors to Individual Links

One of the objectives of this program, as listed in Table 5, was to estimate the contribution of each tandem LOS link and of the BLN-BBG tropo link to the total errors measured on the two end-to-end channels. Ideally, one should make exact performance measurements on each link in addition to the end-to-end performance measurements. By doing so, one could compare the total of the individual link errored seconds to the errored seconds made by a direct measurement of the end-to-end channel.

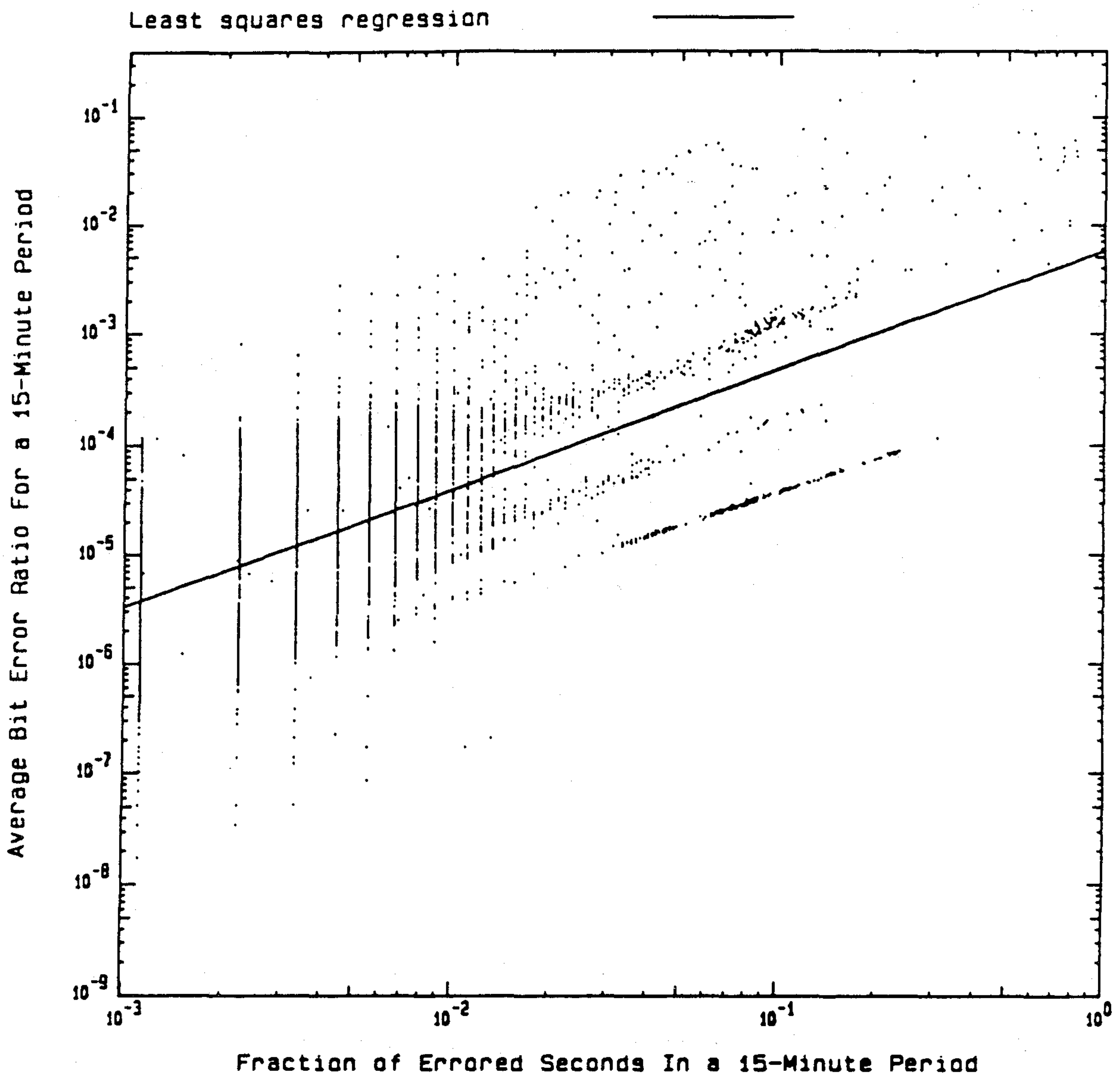
At the start of this program, considerable effort was made in investigating alternative approaches for obtaining the required data. Direct measurements of each individual link's performance was discarded because of the cost and extensive equipment that would be involved. Two of the nodes (Schwarzenborn and Rothwesten) are repeater sites, and two other nodes (Koeterberg and Bocksberg) did not have the FCC-98's needed to permit a breakout to a 64-kb/s mission channel. Thus, performance of 64-kb/s mission channels on each individual link would have required reconfiguration of the FKT-N1 segment through the addition of several multiplexers. Even a 56-kb/s channel on some links was not available for use in the NPC/LPC Program (because of previous commitments for these channels).



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

a) BLN-FEL tandem tropo and LOS channel; correlation coefficient is 0.1046; sample size is 29,714.

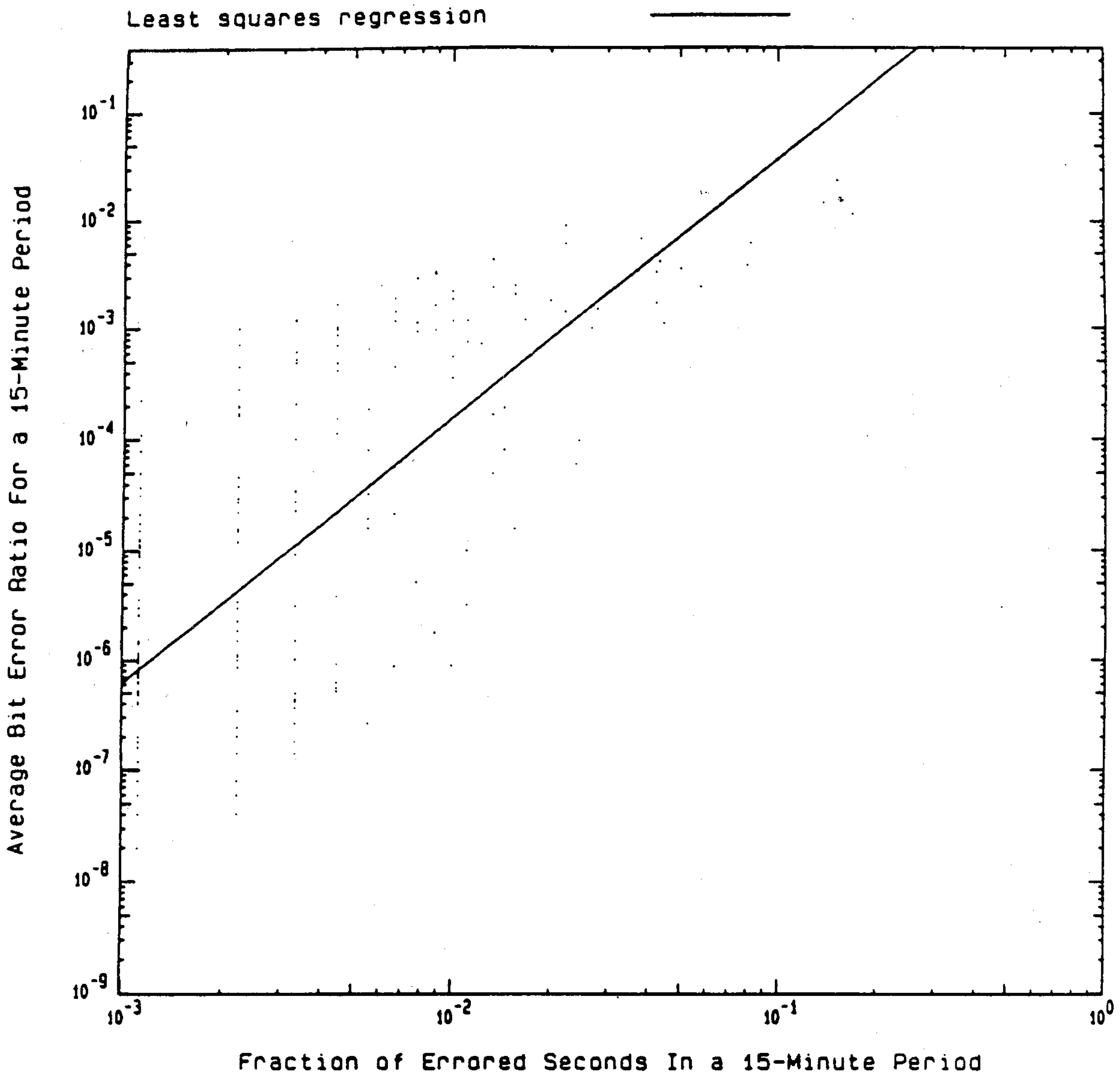
Figure 68. Scatter plot of average bit error ratios vs. fraction of errored seconds in a 15-minute block.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

b) LDF-FEL tandem LOS channel; correlation coefficient is 0.5111; sample size is 10,037.

Figure 68 (cont). Scatter plot of average bit error ratios vs. fraction of errored seconds in a 15-minute block.



Notes: 1) Errored seconds allocated to unavailability time are not included.
2) Data are from 12-month measurements.

c) SBN-FEL LOS link; correlation coefficient is 0.8582; sample size is 225.

Figure 68 (cont). Scatter plot of average bit error ratios vs. fraction of errored seconds in a 15-minute block.

Because of the above, we decided a) to make exact measurements on one LOS link (SBN-FEL), b) to obtain estimates of the error performance on the BLN-BBG troposcatter link from the LPMS system, and c) to estimate the errors for the remaining links through an allocation process. The approach used was to allocate the end-to-end channel errors to each individual link in the channel through the use of a complicated algorithm that made use of all of the NPC/LPC measurement data plus information from TRAMCON and the LPMS systems. This algorithm is described in detail in Appendix D. The development, testing, and modification of this complicated algorithm required significant effort.

The first part of the algorithm was to allocate errors to the source link. The second part of the algorithm was to allocate errors for each link to the cause of the error (power fading, multipath fading, equipment, and cause). Results of this allocation process may be found in the tables and graphs provided in Volume III.

The allocation algorithm did not work as well as expected for several reasons. First, many of the error events were of a duration that was much shorter than the TRAMCON polling cycle, thereby making it difficult to correlate the TRAMCON data with the error event. The TRAMCON polling-cycle time, or revisit time to a particular site, is about 100 seconds for this segment of DEB. The lengths of the error events, as provided previously in Figure 65, were typically much shorter than the TRAMCON polling cycle. For example, the median length of contiguous errored seconds for the LDF-FEL link was only 1 errored second. This made it impossible to utilize the TRAMCON data for allocation of the end-to-end errored seconds to one of the four links in the LDF-FEL channel.

The second reason that the allocation algorithm was not fully successful relates to the statistics of the data. A very short burst of errors could statistically result in an errored-second occurrence on the mission channel, but not in the pseudo-error detection scheme used by the DRAMA equipment and reported by TRAMCON.

The third reason for difficulties in the error allocation process is that the LPMS system, which was developed under another program, did not prove to be reliable. Although some useful data were obtained (see Section 4.2), the data could not be used in the algorithm for the allocation of end-to-end channel errors to individual links.

The allocation of link errors to the cause was quite successful, however. For the Schwarzenborn-Feldberg link the allocation of the measured errored seconds (including unavailability time) for the 12-month period which started in April 1988 is as follows:

- total number of errored seconds: 2347
- number of errored seconds allocated to fading: 1180
- number of errored seconds allocated to equipment: 953

Thus, 91% of the SBN-FEL errored seconds were allocated to the cause of equipment failure.

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS.

Table 22 provides a comparison of measured performance data with the performance objectives obtained from the application of both the Draft MIL-STD-188-323 and appropriate CCITT/CCIR Recommendations to the Schwarzenborn-Feldberg link and the Berlin-Feldberg and Linderhofe-Feldberg end-to-end channels. As can be seen from the table, the SBN-FEL link meets both of the MIL-STD error-performance objectives and nearly meets all of the CCITT/CCIR objectives. The BLN-FEL channel and the LDF-FEL channel do not meet any of the objectives of either MIL-STD-188-323 or CCITT/CCIR Recommendations. As described in Section 2, the definitions for errored seconds and unavailability are different in Draft MIL-STD-188-323 from those in the CCITT/CCIR Recommendations.

In making these comparisons, it should be recognized that Draft MIL-STD-188-323 contains design objectives that are more stringent than the operational specifications found in the Defense Communications Agency Circulares such as DCAC-300-175-9, entitled "DCS Operating-Maintenance Electrical Performance Standards" (DCA, 1986). The difference between the MIL-STD-188 and the DCA Circular is that the former is a design standard, while the latter is an operational standard. Also, the links whose performance was characterized in this study were not designed using the draft MIL-STD-188-323 or CCITT criteria.

Table 22. Summary of Error Performance

A. Draft MIL-STD-188-323 Parameters	SBN-FEL Link	LDF-FEL Channel	BLN-FEL Channel
1. Unavailability time (hours)			
Design objective	2.16	8.64	16.12
Measured	0.22	11.07	94.39
2. Errored seconds			
Design objective	3,800	11,984	62,652
Measured	1,559	81,412	1,905,530
B. CCITT/CCIR Parameters			
1. Unavailability time (hours)			
Design objective	1.04	2.25	4.91
Measured	0.17	16.60	27.26
2. Errored Seconds			
Design objective	4,012	9,460	19,672
Measured	1,746	64,845	2,150,214
3. Severely errored seconds			
Design objective	678	1,596	3,319
Measured	696	30,543	53,598
4. Degraded minutes			
Design objective	84	198	411
Measured	192	13511	296,304

The CCIR also recognizes the need to differentiate between different levels of performance objectives. The CCITT/CCIR objectives discussed in this report are known as network performance objectives. Operational CCITT/CCIR objectives are known as maintenance-limit and prompt-maintenance-alarm performance objectives (Ivanek, 1989; pp. 56-59), and are less stringent than the network performance objectives. However, the exact numerical ratio of the actual network performance (of a real circuit) to the network performance objective is not specified by the CCITT/CCIR.

Failure of the BLN-FEL and LDF-FEL channels to meet either MIL-STD-188-323 or CCITT/CCIR objectives raises the following questions:

1) Are the differences between the measured performance and the design objectives simply the result of operational considerations such as equipment ageing?

2) Are the MIL-STD-188-323 and CCITT/CCIR objectives too stringent?

We believe that the answer to the first question is no. The differences between measured performance values and objectives for the LDF-FEL and BLN-FEL channels are too large to be attributed to operational considerations.

For line-of-sight links, we do not believe that the objectives are overly stringent for the following reasons. The LDF-FEL link came closer to meeting the MIL-STD-188-323 unavailability objective than to meeting the CCITT/CCIR unavailability objective. It came equally close to meeting the errored-second objectives of MIL-STD-188-323 and the CCITT/CCIR Recommendations. It can be argued, therefore, that the CCITT/CCIR objectives are more stringent than the MIL-STD objectives. Commercial systems comparable to the LDF-FEL channel have met the CCITT/CCIR objectives during 13-month performance measurement programs (Ivanek, 1989; pp. 59-68). One can, therefore, conclude that the LDF-FEL channel should have met the errored second and unavailability time objectives of the less stringent MIL-STD-188-323.

For troposcatter links and end-to-end channels that contain an embedded troposcatter link such as the BLN-FEL channel, we believe that the design objectives of the MIL-STD-188-323 may be too stringent, and may not be attainable. The following observations are made regarding the performance of the Berlin-Bocksberg troposcatter link and the BLN-FEL channel:

- the modem being used on this link is an engineering development model that will be replaced in the near future;
- the low-noise tunnel-diode amplifiers in the radio receivers will be replaced, which will result in about a 3-dB signal-to-noise ratio improvement.

A significant improvement in the digital error performance may result from these equipment changes.

Table 23 provides the ratio of the measured value to the design objective for each performance parameter. All of the ratios for the LDF-FEL and BLN-FEL channels are greater than unity, indicating that none of the objectives for either the MIL-STD or CCITT/CCIR Recommendations was met. Some objectives, such as the degraded minute objective, were not met by wide margins. Because commercial systems have met the more stringent CCITT/CCIR objectives, it appears that the performance of the DEB network is significantly worse than that of commercial networks. These comparisons can be made only for the LDF-FEL channel because commercial networks do not typically employ troposcatter radio systems such as those embedded in the BLN-FEL link. From the numbers in Table 23, one can conclude that the performance of the LDF-FEL channel is from one to two orders of magnitude worse than that of commercial networks. However, it should be noted that the LDF-FEL links were not designed using the same criteria as commercial network links.

The following section summarizes the major measurement results obtained from the NPC/LPC measurement program. This is followed by the conclusions that we have reached as the result of these measurements, and by our recommendations resulting from these findings.

6.1 Summary of Measurement Results

The following list delineates the major results of the 18-month Network Performance Characterization and Link Performance Characterization Program.

1. The DRAMA equipment met MIL-STD-188-323 design objectives for both errored seconds and unavailability time on the Schwarzenborn-Feldberg link.

Table 23. Ratio of Measured Annual Performance Values to Specified Objectives

Parameter	SBN-FEL	LDF-FEL	BLN-FEL
MIL-STD-188-323 UA	0.1	1.3	5.9
MIL-STD-188-323 ES	0.4	6.8	30.4
CCITT/CCIR UA	0.2	7.4	5.6
CCITT/CCIR ES	0.4	6.9	109.3
CCITT/CCIR SES	1.0	19.1	16.1
CCITT/CCIR DM	2.3	68.2	720.9

Notes:
1) SBN-FEL meets all MIL-STD-188-323 recommended limits
2) LDF-FEL and BLN-FEL do not meet any MIL-STD-188-323 recommended limits for any of the specified performance parameters.

2. The DRAMA equipment met some, but not all, of the CCITT/CCIR network performance objectives as applied to the Schwarzenborn-Feldberg link.

3. The Berlin-Bocksberg troposcatter errored-second and unavailability estimated performance does not meet the Draft MIL-STD-188-323 design objectives.

4. The LDF-FEL channel did not meet the MIL-STD-188-323 annual errored-second or unavailability design objectives. No month of the 18-month measurement period met the monthly errored-second objectives. The monthly unavailability time objective was not met for 7 months of the 18-month measurement period.

5. The MIL-STD-188-323 unavailability time on the LDF-FEL channel (17.0 hours) was very high in comparison with the UA time measured on one of the four links that comprise the channel (UA time on the SBN-FEL link was 0.75 hours).

6. The LDF-FEL channel did not meet any of the CCITT network performance parameter objectives (unavailability time, severely errored seconds, degraded minutes or errored seconds) on an annual basis. When performance was compared to objectives for each month of the 18-month measurement period, we found that monthly objectives for severely errored seconds, degraded minutes, and errored seconds were not met for any month. The monthly unavailability-time objective was only met for 3 months of the 18-month period.

7. The BLN-FEL channel did not meet the MIL-STD-188-323 errored seconds and unavailability objectives. No month of the 18-month measurement period met the monthly errored second objectives. The monthly unavailability-time objective was not met for 14 months of the 18-month measurement period.

8. The BLN-FEL channel did not meet any of the CCITT/CCIR performance objectives on an annual basis. When performance was compared to objectives for each month of the 18-month measurement period, we found that severely errored-seconds, degraded-minutes, and errored-seconds monthly objectives were not met for any month. The monthly unavailability objective was only met for 2 months of the 18-month period.

9. The 15-minute average BER for the SBN-FEL link was worse than 1 x 10^{-3} only 0.2% of the time and worse than 1 x 10^{-6} only 0.6% of the time. The 10^{-6} threshold is considered the threshold at which the degradation to a PCM voice channel is first noticeable, and is the minimal acceptable performance level for some data communications users. The 10^{-3} threshold is considered the threshold at which performance for PCM voice is unacceptable.

10. The 15-minute average BER for the LDF-FEL channel was worse than 1 x 10^{-3} only 1.2% of the time and worse than 1 x 10^{-6} 32% of the time.

11. The 15-minute average BER for the BLN-FEL channel was worse than 1 x 10^{-3} 3.5% of the time and worse than 1 x 10^{-6} 98% of the time.

12. The current space diversity switching algorithm performed better than any other switching algorithm tested on the SBN-FEL link. A hypothetical switching algorithm based on signal quality monitor voltage performed only slightly worse than the current switching algorithm.

13. The space diversity improvement for SBN-FEL link was much less than that predicted in the FKT-N1 Systems Engineering Plan (CEEIA, 1981), and less than that predicted by other space diversity improvement models (e.g., Ivanek, 1989; p. 323).

14. The median rsl's for 4 of the 5 LOS links were several decibels below the rsl's predicted in the Systems Engineering Plan for the Frankfurt North Phase I Segment of DEB (CEEIA, 1981).

15. The worst fading months were not all the same months on the five line-of-sight links even though the links are all in the same general geographic area. This has strong implications for general equations widely used in outage-prediction techniques for LOS microwave transmission systems.

16. Jitter and delay are well within the limits specified by MIL-STD-188-323.

17. A second multipath ray can be detected 15% to 20% of the time on the SBN-FEL LOS link. This has implications for channel modeling, channel simulation, and outage prediction, because a second multipath ray is not currently included in present models, simulators, or outage prediction techniques.

6.2 Conclusions

The measurement results from the NPC/LPC Program lead to a number of conclusions and recommendations. These conclusions and recommendations are solely those of the authors of this report, and do not necessarily reflect the opinions of personnel from the U.S. Air Force Electronic Systems Division or from the Defense Communications Agency.

1. The LDF-FEL errored-second and availability performance did not meet specified objectives of either Draft MIL-STD-188-323 or CCITT/CCIR Recommendations. The implication of the measured performance on the LDF-FEL channel is that the service provided to either voice or data communications users is marginal compared to commercial standards.

2. Based on the 15-minute average BER distributions, it is estimated that 3.5% of the time the BLN-FEL channel would provide poor performance to voice

communications users, and 98% of the time it would provide poor service to data communications users; 1% of the time the LDF-FEL channel would provide poor performance to voice users, and 32% of the time it would provide poor performance to data communications users. Data communications performance estimates assume that no channel encoding is employed. As explained in Section 5.3.1, these percentages are based on the 15-minute average BER distributions for the 12-month measurement period which began on April 1, 1988. It was assumed that a BER of 1×10^{-3} is the minimal acceptable level of performance for voice service, and a BER of 1×10^{-6} is the minimal level of performance for data communication service.

3. Errored-second and BER performance of the Berlin-Bocksberg troposcatter link is adequate for voice communications most of the time, but is not adequate for most data communications without some form of channel coding (either forward error correction or automatic repeat request).

4. The errored second and unavailability time on end-to-end channels is greater than the errored seconds and unavailability time of each of the component links which compose the end-to-end circuit.

5. The primary cause of both errored seconds and unavailability of circuits--which are made up of tandem LOS links that utilize DRAMA equipment (such as the LDF-FEL channel)--is neither multipath fading nor power fading. The unexpectedly poor performance of the LDF-FEL link also does not appear to be caused by problems with individual hardware subsystems (radios, multiplexers, etc.). Adequate performance was achieved on the SBN-FEL 56-kb/s service channel but was not achieved on a 64-kb/s mission channel from Linderhofe-to-Feldberg, which includes the long SBN-FEL link. Unlike the mission channels, the 56-kb/s service channel is not encrypted and does not go through an FCC-99 second-level multiplexer. This leads one to suspect that system timing problems, loss of synchronization in the cryptographic equipment, or possibly a ripple effect of digital errors in tandem links may have been causes of the unexpectedly poor performance of the LDF-FEL link. Electromagnetic interference (EMI) anywhere along the circuit could be another contributing mechanism. Human error and acts of nature are other possible causes. Since testing and troubleshooting of the FKT-N1 Segment of DEB was not an objective of this program, the system performance characterization effort was not designed to address these technical issues. The choice of the FKT-N1 Segment of DEB made it impossible to make precise measurements on each individual link comprising the LDF-FEL channel because two of the nodes are repeater sites. In any future examination of the performance of end-to-end channels, the measurements should be made on channels that would permit measurements on individual links as well as on the end-to-end channel. Operational differences between military microwave communications networks and commercial communications networks should also be reviewed because the latter have been proven to meet technical standards more stringent than those in the draft MIL-STD-188-323.

6. TRAMCON is capable of providing long-term (monthly or annual) summaries of rsl and estimated errored-second performance on every link within the Digital European Backbone. These data would be useful to the R&D community, to transmission network system designers, and to the DCS operational community. The estimated errored-second data would be of particular value in addressing issues regarding performance on individual links compared to performance on end-to-end channels.

7. The DRAMA radio performed well on the long SBN-FEL link. Although the space diversity improvement factor was significantly less than that predicted in widely used LOS microwave design equations, the space diversity improvement of the DRAMA radio is adequate for the majority of time on the SBN-FEL link. There were some brief periods during January and early February 1989 when fading was a significant problem on this link. During those periods, DRAMA radio performance was greatly degraded. A slope adaptive equalizer would have improved performance during those periods. However, this multipath fading occurrence was not frequent enough to warrant the expenditures of large amounts of money to retrofit the DRAMA radio with an adaptive equalizer. This conclusion should be reexamined if other data show that fading occurs much more frequently on DEB links other than on the SBN-FEL link.

8. Algorithms used in the FKT-N1 Systems Engineering Plan (CEEIA, 1981) to predict rsl and space diversity improvement factors are inadequate.

9. The amount of path delay, relative phase, and fading dynamics (rate of change of delay, phase, and amplitude) are <u>not</u> important parameters in characterizing the effects of multipath fading on the DRAMA radio. This is not likely to be true for other radios that utilized more advanced modulation techniques and adaptive equalizers.

10. Line-of-sight channel models and channel simulators should include a second multipath ray component as well as the direct ray and the first multipath ray currently used in LOS channel models and simulators.

11. Outage prediction models should <u>not</u> assume that minimum and nonminimum phase fading events are equally likely to occur.

6.3 Recommendations

1. The cause of errors on channels having tandem LOS links should be further investigated. This investigation should consist of both laboratory testing and a short (1- or 2- month) field test on a portion of DEB that would permit measurements on each link making up the end-to-end channel. Three phases of this testing are envisioned:

   Phase I: Laboratory testing at the DRAMA/TRAMCON Test Facility at ITS to investigate a) the effect of high received signal levels on DRAMA radio performance, and b) the pseudo-error data available from the DRAMA radio (derived from framing bits).

   Phase II: Laboratory testing at the Transmission Systems Engineering Evaluation Facility (TSEEF) at Ft. Huachuca, which contains DRAMA and TRAMCON equipment interconnected in a three-link configuration. This configuration would permit comparisons of performance of each of the three tandem links and of the end-to-end channel. It also would permit comparisons of the performance of the unencrypted 56-kb/s service channel with the encrypted 64-kb/s mission channel.

   Phase III: Short tests (1 to 2 months) on a segment of the DEB that contains tandem links where the 64-kb/s mission channel is available at the intervening nodes of the end-to-end channel. This would permit performance evaluation of each individual link as well as of the end-to-end channel, and would permit comparisons between the performance of the unencrypted 56-kb/s service channel and the encrypted 64-kb/s mission channel.

2. The TRAMCON software should be modified to provide a historical archive of selected DRAMA performance parameters such as rsl and estimated BER, and to create monthly and yearly summaries of these data. This is a relatively small change to the TRAMCON software and would be helpful to both the R&D community and the operational community. For example, it would be helpful for the examination of performance of tandem LOS links.

3. No changes to the DRAMA radio space diversity switching algorithm should be made. A retrofit of the DRAMA radio to include an adaptive equalizer is not required.

4. The large quantity of performance and propagation data (approximately 6 G-bytes) should be used to verify existing DCS O&M standards.

5. Additional analyses should be performed of channel probe data and of other propagation data. The results of these analyses should be applied to outage-prediction models for LOS microwave transmission systems.

6. Further analysis of the statistics (error burst length and burst gaps) of the Berlin-Feldberg data should be performed. The results of this analysis should be applied to the determination of the type of channel coding needed for data communications users of digital troposcatter links.

The results provided in this report are the result of several person years of effort. The measured results are believed to be highly accurate and reliable. As described briefly in Appendix E, we performed extensive laboratory and field testing of both the data acquisition system software and the data analysis software to ensure accuracy and reliability. The errored-second data were further verified by comparisons of our data with those obtained from a Berlin-to-Feldberg mission channel user. The compatibility of these measurement results obtained from independent measurement systems on different mission channels leads to a high level of confidence in the measured results provided herein.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes the results of an 18-month digital microwave radio performance and propagation measurement project that was conducted on a portion of the Defense Communications System in Germany. More than 6 gigabytes of data were collected between April 1988 and October 1989.

The collected data include end-to-end (user-to-user) performance data, radio performance and propagation data on one line-of-sight and one troposcatter link, and meteorological data. The end-to-end measurements are referred to as the Network Performance Characterization (NPC) data, and consist of error performance measurements on two separate 64 kb/s channels consisting of tandem terrestrial microwave links. The radio performance and propagation measurements are referred to as the Link Performance Characterization (LPC) data. These data consist of digital radio performance and propagation measurements made on a long)99-km) line-of-sight microwave link. The propagation measurements on this link include

16. Key Words *(Alphabetical order, separated by semicolons)*

Key words: CCITT;DEB; Digital European Backbone; digital microwave radio; digital radio performance; DRAMA; IBPD; in-band dispersion; linear amplitude difference; LOS propagation; MIL-STD; multipath fading; propagation measurements; radio outages; transmission system performance standards; troposcatter.

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multipath delay spread, in-band power difference (IBPD), and receive signal level (rsl) measurements.

The report provides summaries of the long-term statistics of both radio performance and propagation data. The performance data are compared with both CCITT and Military Standard (MIL-STD) performance criteria. The propagation data are used in the assessment of the causes of digital radio outages. The propagation data re also useful for a variety of modeling purposes. These applications of the propagation data are described in the report.