

**Digital European Backbone
Performance:
A 12-Month Summary
for the Frankfurt North Segment**

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PREFACE

Certain commercial equipment, instruments, or materials are identified in this report to adequately specify the experimental process. 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 this application.

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DIGITAL EUROPEAN BACKBONE PERFORMANCE:

A 12-MONTH SUMMARY FOR THE FRANKFURT NORTH SEGMENT

J. A. Hoffmeyer and T. J. Riley*

This report describes the interim results of an 18-month digital microwave transmission network performance and propagation measurement project that was conducted on a portion of the Defense Communications System (DCS) in West Germany. Only the first 12 months of data are summarized in this report. More than 3 gigabytes of data were collected between April 1988 and March 1989. The report provides the results of bit error rate measurements made at the 56-kb/s user level on one long (99-km) line-of-sight (LOS) link and at the 64-kb/s user level on two end-to-end channels consisting of multiple LOS and/or troposcatter radio links. The report also provides summaries of 12 months of received-signal-level (rsl) measurements on five LOS links and one troposcatter link.

Key words: DEB; digital radio performance; DRAMA; LOS propagation; military standard (MIL-STD); multipath fading; propagation measurements; radio outages; transmission system performance standards; troposcatter

1. INTRODUCTION

This report describes the interim results of a digital transmission network performance and propagation measurement program on the Frankfurt North Phase I (FKT-N1) segment of 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)
- Schwarzenborn-Feldberg Link Performance Characterization (LPC)

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

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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 equipment performance on tandem LOS links (see Thomas et al., 1979, for a description of the DRAMA equipment). There is no existing data base on long-term DRAMA performance. The data also will be used to determine if improvements to the DRAMA radio are required.

The DEB 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 LOS microwave radio links that utilize DRAMA radios and multiplexers. Two of the links are troposcatter radio links. Figure 1 depicts the FKT-N1 Segment of DEB.

The NPC measurements consist of end-to-end digital 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 LOS microwave links. The second channel, from Linderhofe to Feldberg (LDF-FEL), consists of four tandem LOS links. As can be seen in Figure 1, three of the LOS links are common to both the BLN-FEL and LDF-FEL channels.

The LPC error performance and propagation measurements are made on the Schwarzenborn-to-Feldberg (SBN-FEL) LOS microwave link. The LPC data are 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 FKT-N1 segment of DEB and to compare this performance with that specified by draft MIL-STD-188-323 (DCEC, 1985; Smith and Cybrowski, 1985).

This measurement program was not conducted as a retest of the FKT-N1 segment of DEB. Instead, the joint measurement program is considered to be a characterization of actual 64 and 56-kb/s user performance achieved on a portion of the DCS. A major purpose of this characterization is to determine the adequacy of draft MIL-STD-188-323 for the performance specification of transmission networks within the DCS. The criteria and allocations contained in draft MIL-STD-188-323 require validation with performance data from actual 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 multi-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 that may be found in the Defense Communications Agency Circulars such as DCAC-300-175-9 entitled DCS Operating-Maintenance Electrical Performance Standards (DCA, 1986).

A second major purpose of the measurement program is to quantify the DRAMA radio performance on an actual link within the DCS rather than on a test link such as the one at

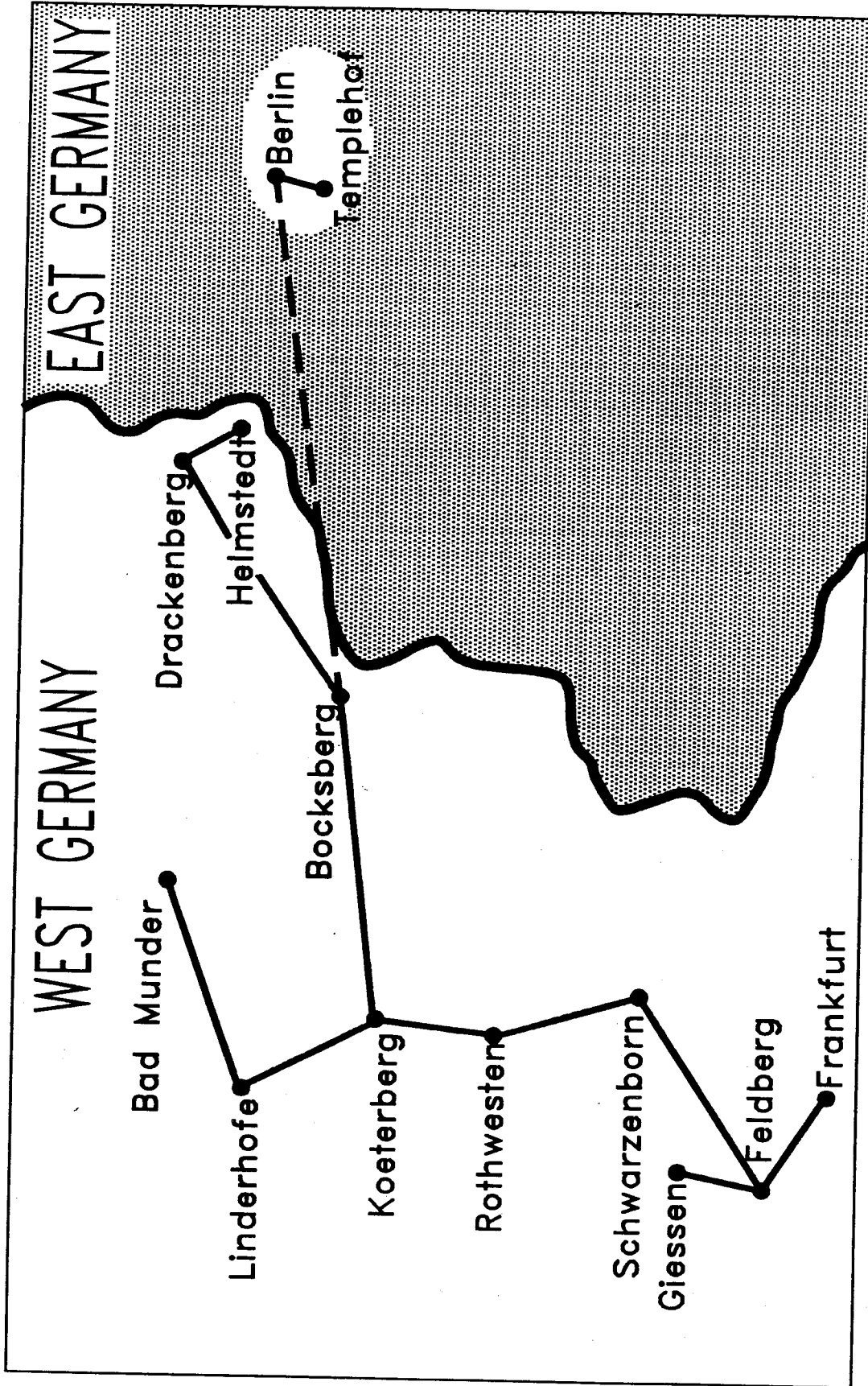


Figure 1. Frankfurt north Phase I Segment of DEB.

Pt. Mugu (Hubbard, 1983). Both the NPC and the LPC projects are long-term (18-month) measurement programs in contrast to the DEB link tests, which are 72-hour tests.

The general objectives of the NPC/LPC Program are 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, the Institute for Telecommunication Sciences installed equipment at the following DEB sites: Berlin, Bocksberg, Linderhofe, Schwarzenborn, and Feldberg. The following section provides a summary of the data acquisition system.

2. NPC/LPC DATA ACQUISITION SYSTEM

Figure 2 depicts all of the inputs to the NPC/LPC data acquisition system, which is located at the DEB site at Feldberg, GE. In addition to bit-error-rate test-set (BERTS) information, data collected on the NPC/LPC projects include data obtained from two monitor systems: the Transmission Monitor and Control (TRAMCON) System and the Berlin-Bocksberg (BLN-BBG) Link Performance Monitor System (LPMS). (See Farrow and Skerjanec, 1986 for a description of TRAMCON. The LPMS system is described in the manual, "Link performance monitoring system program manual" prepared for U.S. Air Force Systems Command, Electronic Systems Division by the developer, REL, Inc. under contract no. F19628-86-C-0037 (March 1987).)

The data summarized in this report includes the following:

- BER data sampled five times per second
- SBN-FEL rsl data sampled five times per second
- TRAMCON rsl data on five links (sampled once every 100 seconds)
- LPMS rsl data on the BLN-BBG troposcatter link based on an average of 48 samples per second for each of the four receiver/antenna configurations

The BERTS are placed on the two end-to-end channels (BLN-FEL and LDF-FEL) and on the SBN-FEL link. The two end-to-end channel measurements are made on 64-kb/s mission channels, while the SBN-FEL link performance measurement is made on a 56-kb/s service channel. The BERTS transmitters interface with the FCC-98 multiplexer through multirate, digital data cards at Berlin, Linderhofe, and Schwarzenborn. The BERTS receivers interface with the FCC-98 multiplexer data cards at Feldberg.

The TRAMCON data for the entire FKT-N1 segment of DEB are integrated into the NPC/LPC data base. This report will summarize the rsl portion of the TRAMCON data only. The five links for which TRAMCON rsl data are summarized in this report are

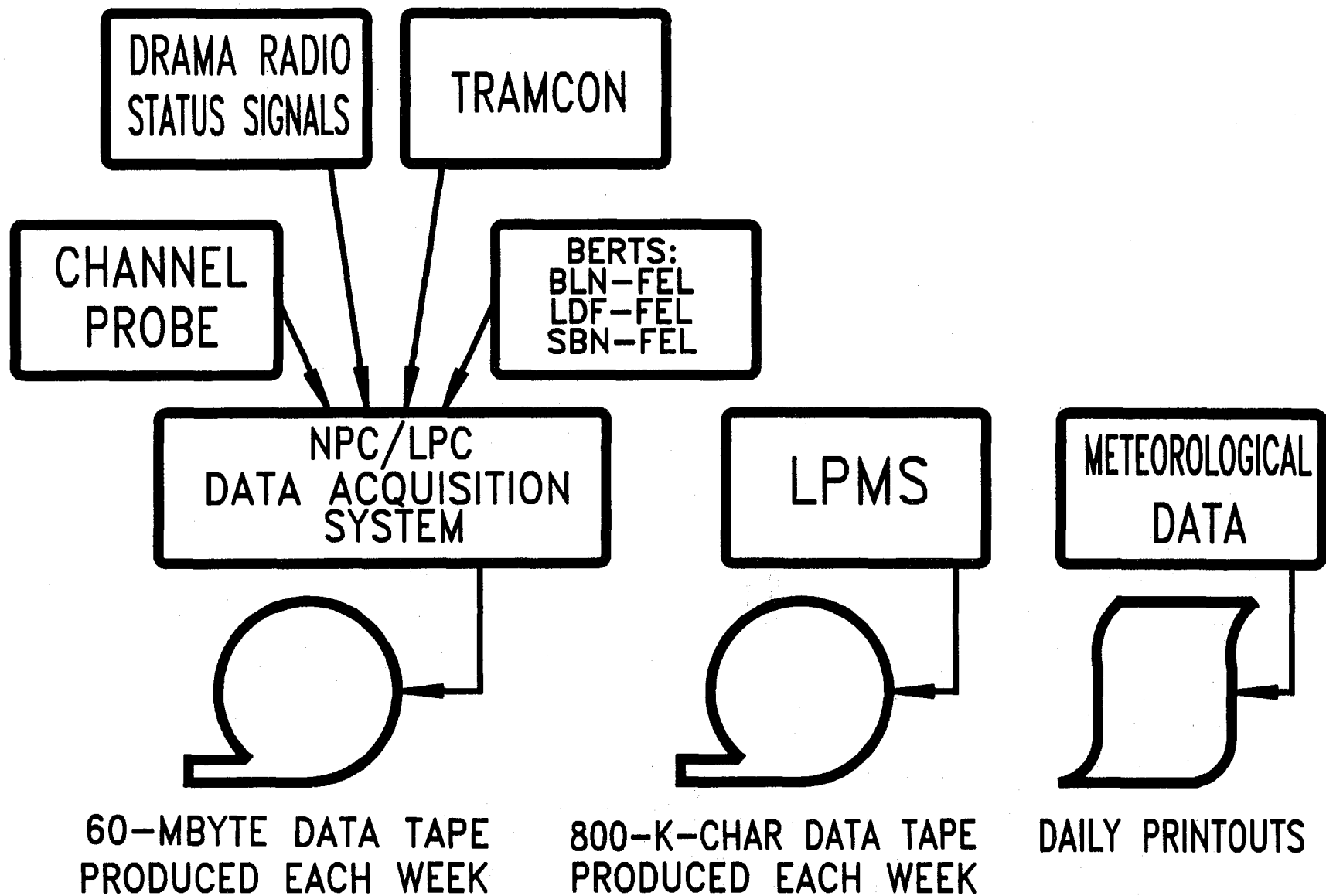


Figure 2. NPC/LPC data acquisition system inputs and outputs.

- Bocksberg to Koeterberg (BBG-KBG)
- Koeterberg to Rothwesten (KBG-RWN)
- Rothwesten to Schwarzenborn (RWN-SBN)
- Schwarzenborn to Feldberg (SBN-FEL)
- Linderhofe to Koeterberg (LDF-KBG)

Normally, the TRAMCON rsl data are saved in histogram form for a period of 24 hours only. For the NPC/LPC program, a special modification was made to the TRAMCON software that permits the transfer of data from the TRAMCON Master computer at Feldberg to the NPC/LPC data acquisition system, allowing the NPC/LPC system to archive the TRAMCON data for the entire data collection period (April 1988 through September 1989).

The LPMS System is a special monitoring system that was designed to provide rsl measurements on each of the four receivers on the BLN-BBG troposcatter link and estimates of the following:

- signal-to-noise ratio (SNR)
- bit-error-ratio (BER) performance of mission bit-stream
- number of errored seconds
- multipath dispersion
- multipath fade rate
- multipath fade duration
- intersymbol interference (ISI)

Only the rsl data from the LPMS system will be described in this report. This system, which was not designed by ITS, suffered a number of failures during the course of this program, resulting in incomplete LPMS data.

This interim report does not summarize the multipath fading data on the SBN-FEL link obtained from the channel probe and spectrum analyzers or the meteorological data, which are useful in the detailed analysis of specific multipath fading periods. The DRAMA radio signals (signal quality monitor voltages, samples of the DRAMA radio receiver spectrum, and measures of the spectral amplitude distortion) and space-diversity improvement information are not described in this report. These data will be summarized in the final report.

3. DRAFT MIL-STD-188-323 PERFORMANCE OBJECTIVES

The draft MIL-STD-188-323, entitled "System Design and Engineering Standards for Long Haul Digital Transmission System Performance," provides individual and tandem link performance objectives for unavailability (UA) time, errored seconds, transmission delay, jitter, and mean-time-to-loss-of bit count integrity. Data relevant to all of these parameters were recorded during the NPC/LPC program. Only the UA time and errored seconds design objectives and measured data are reported in this interim report. It should be emphasized that

draft MIL-STD-188-323 contains design objectives that are more stringent than the operational specifications found in Defense Communications Agency Circulars such as DCAC-300-175-9, entitled "DCS Operating-Maintenance Electrical Performance Standards" (DCA, 1986).

The CCITT (International Consultative Committee for Telephone and Telegraph) has standards that are somewhat similar to draft MIL-STD-188-323. Comparisons with this international standard will not be made in this report. However, it should be noted that the CCITT performance standards (CCITT, 1980) and draft MIL-STD-188-323 are equally demanding.

UA time is defined in draft MIL-STD-188-323 as "any loss of continuity or excessive channel degradation (average BER greater than 10^{-4}) on the 64 kb/s voice and data user channel, which occurs for a period of 60 consecutive seconds (one minute) or greater ...". The errored seconds that fall into the UA time category are subtracted from the total number of recorded errored seconds to find the errored seconds (ES) performance quality parameter, i.e.:

ES quality parameter = total errored seconds - unavailability time errored seconds.

As shown in Table 1, the design objectives for UA time and errored seconds (ES) are

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

D = 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

$$(2.47 \times 10^{-4}) \times (24 \text{ hours/day}) \times (365 \text{ days/year}) = 2.1 \text{ hours per year.}$$

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

Table 1 applies the draft MIL-STD-188-323 UA and ES allocation design objectives summarized above to the LOS and troposcatter link data from the FKT-N1 segment of DEB. A comparison of these UA and ES design objectives with the 12 months of NPC/LPC measured data is provided in the next section.

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)	467.4	One tropo and four LOS links	16.14	52,466 (14.57 hours)	9,792	62,258 (17.29 hours)	64 kb/s user channel between Berlin and Feldberg
Linderhofe-Feldberg (LDF-FEL)	214.4	Four LOS tandem links	8.65	4,226	7,364	11,590 (3.22 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)	31.0	LOS	2.16	611	1,841	2,452	
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 = 2.47×10^{-4}

Propagation ES = $6.25 \times 10^{-7} \times D$

Equipment ES = $[(1-0.999533)/8.0]$

TROPO: Unavailability = 8.54×10^{-4}

Propagation ES = $7.1875 \times 10^{-4} \times D$

Equipment ES = $[(1.0-0.999456)-(1.0-0.999533)]$
 $= 7.7 \times 10^{-6}$

D = distance in km

4. SUMMARY OF MEASUREMENT RESULTS AND COMPARISON WITH MIL-STD OBJECTIVES

This section summarizes 12 months of rsl and error-performance data. This is done first for the individual links in the FKT-N1 segment of DEB and then for the two end-to-end channels (LDF-FEL and BLN-FEL). The rsl data include TRAMCON and LPMS data as well as direct measurements from the NPC/LPC system for the SBN-FEL link.

During the period from April 1988 through March 1989, the NPC/LPC data acquisition system recorded 7,866 hours of data. The total number of hours during a year is 8,760, so the 7,866 hours of recorded data represent 89.8% of the maximum hours possible in a year. The NPC/LPC data acquisition system has proven to be a very reliable system.

4.1 Analyses of Individual Links

Data were collected on one troposcatter link and five LOS links in the FKT-N1 segment of DEB. The troposcatter link is from Berlin to Bocksberg, West Germany. The LOS links are BBG-KBG, KBG-RWN, RWN-SBN, SBN-FEL, and LDF-KBG. Rsl data in the reverse direction (e.g., KBG-LDF) from the TRAMCON and LPMS systems are available but are not analyzed in this report.

The only individual link for which link-error-performance measurements were made is the SBN-FEL link. Ideally, one would like to make error-performance measurements on each individual link comprising the end-to-end channel. This would have been a difficult and expensive undertaking for this segment of DEB because there are no "breakouts" to 64-kb/s user channels at several of the nodes (Bocksberg, Koeterberg, Rothwesten, and Schwarzenborn). Measurements on each individual link would require the installation of FCC-99 and FCC-98 multiplexers at those sites. Additional data acquisition equipment also would be required.

4.1.1 Schwarzenborn-to-Feldberg (SBN-FEL) Link Analysis

The DRAMA radio performed well on the SBN-FEL link. Figure 3 is a plot of the total errored seconds and UA time for each month from April 1988 through March 1989. The left vertical axis provides the scale for errored seconds, while the right vertical axis provides the scale for UA time.

Only 2,347 errored seconds were recorded during the year. Of the 2,347 total errored seconds, only 788 seconds (0.22 hours) were identified as being unavailable (60 consecutive seconds each having a 1-second average BER of 1×10^{-4} or worse). As Figure 3 shows, periods

of unavailability occurred in April 1988 and February 1989 only. 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 (see Table 1 for application of the draft MIL-STD-188-323 to the SBN-FEL link).

There were 1,559 errored seconds remaining after subtracting the unavailable seconds. The long-term (annual) ratio of seconds that are errored to the 7,866 hours of recorded data is 5.5×10^{-5} . Since the MIL-STD design objective is 3,800 errored seconds for this link (see Table 1), the measured data fall well within both the UA time and errored seconds criteria for this link.

In Figure 3, it is of interest to note the months in which significant errored seconds occurred. January was the worst month with 955 errored seconds, followed by September with 212 errored seconds. This reduced performance is due to multipath fading on this link as seen from plots of rsl data from TRAMCON and the NPC/LPC system.

Figure 4 is a dual plot of errored-second data and rsl data. The errored-second bars represent seconds in which at least one error occurred. One error in one second for the 56-kb/s service channel corresponds to a BER of 1.79×10^{-9} . The rsl bars represent the number of seconds in which the DRAMA radio receiver-on-line (ROL) is below the rsl minimum threshold and an error occurred on the ROL. The rsl threshold is -73 dBm for a 1×10^{-2} BER for a 26-Mb/s quadrature partial response (QPR) DRAMA radio (CECOM, 1984, p. 1-6).

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. Figure 4 shows that the months with the greatest number of errored seconds (January and September) also have the largest number of seconds in which the ROL rsl is below the 10^{-2} threshold. The difference between the two numbers for any given month is most likely due to the different BER thresholds (10^{-2} for the rsl data and 10^{-5} for the errored-second data). For a particular month, the difference between the number of errored seconds and the number of seconds below the 10^{-2} threshold also could be due to either frequency-selective fading or short (less than 60 seconds) equipment-caused error events. Frequency-selective fading results in signal distortions causing errors in digital radios even though the rsl is well above the minimum required signal level. (The effects of selective fading on a DRAMA radio performance are described in "Evaluation of DRAMA radio performance in a simulated fading environment" (Hoffmeyer, J. A., and L. E. Pratt (1987), NTIA Tech. Mem. 87-120).)

Figure 5 is a 12-month summary of

- the number of errored seconds that occurred in each receiver (ROL, Rx A, and Rx B)
- the number of seconds that ROL, Rx A, and Rx B rsl's are individually below the minimum signal level, and an error occurred in that receiver.

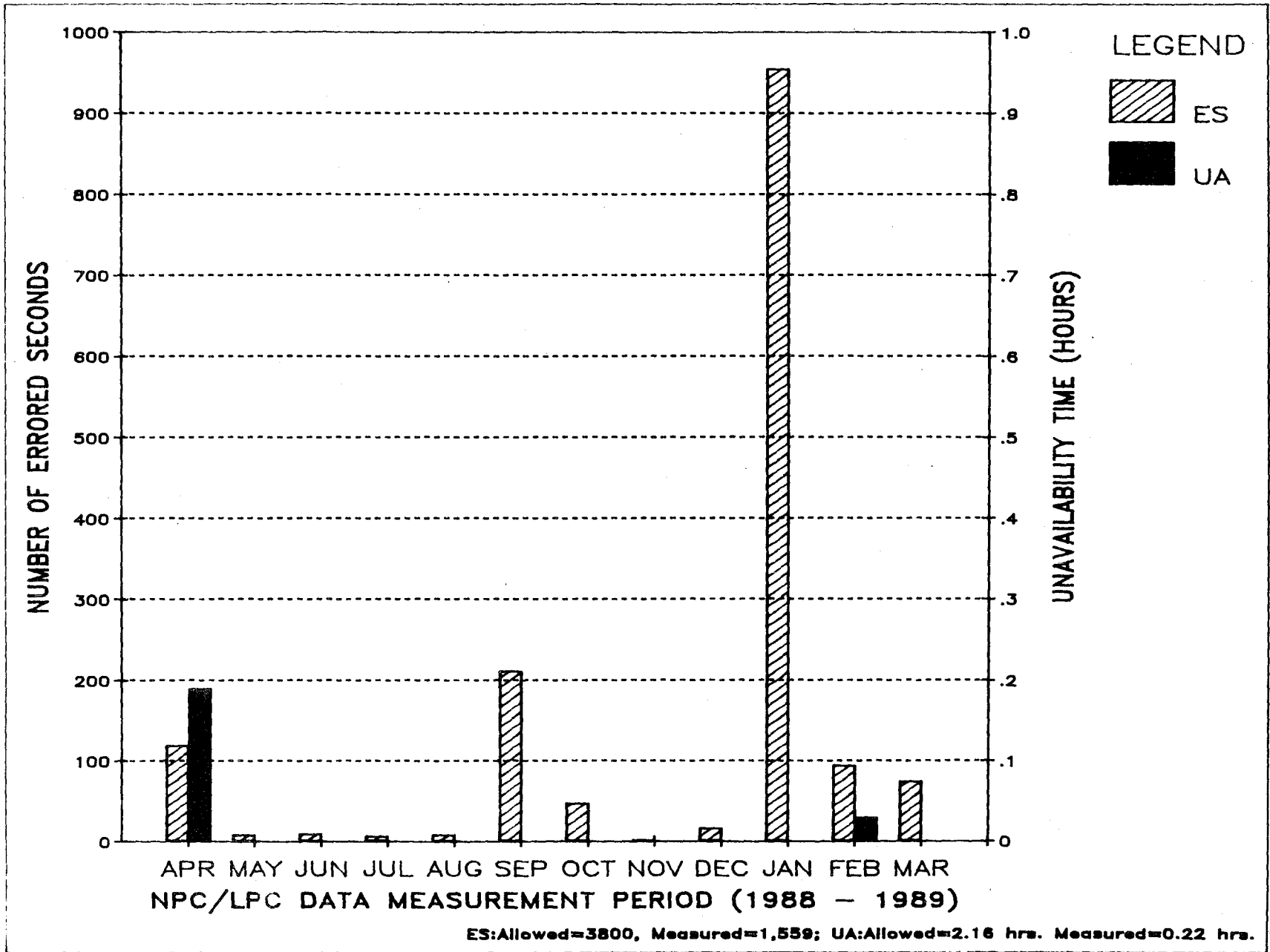


Figure 3. Schwarzenborn-Feldberg errored seconds and unavailability time.

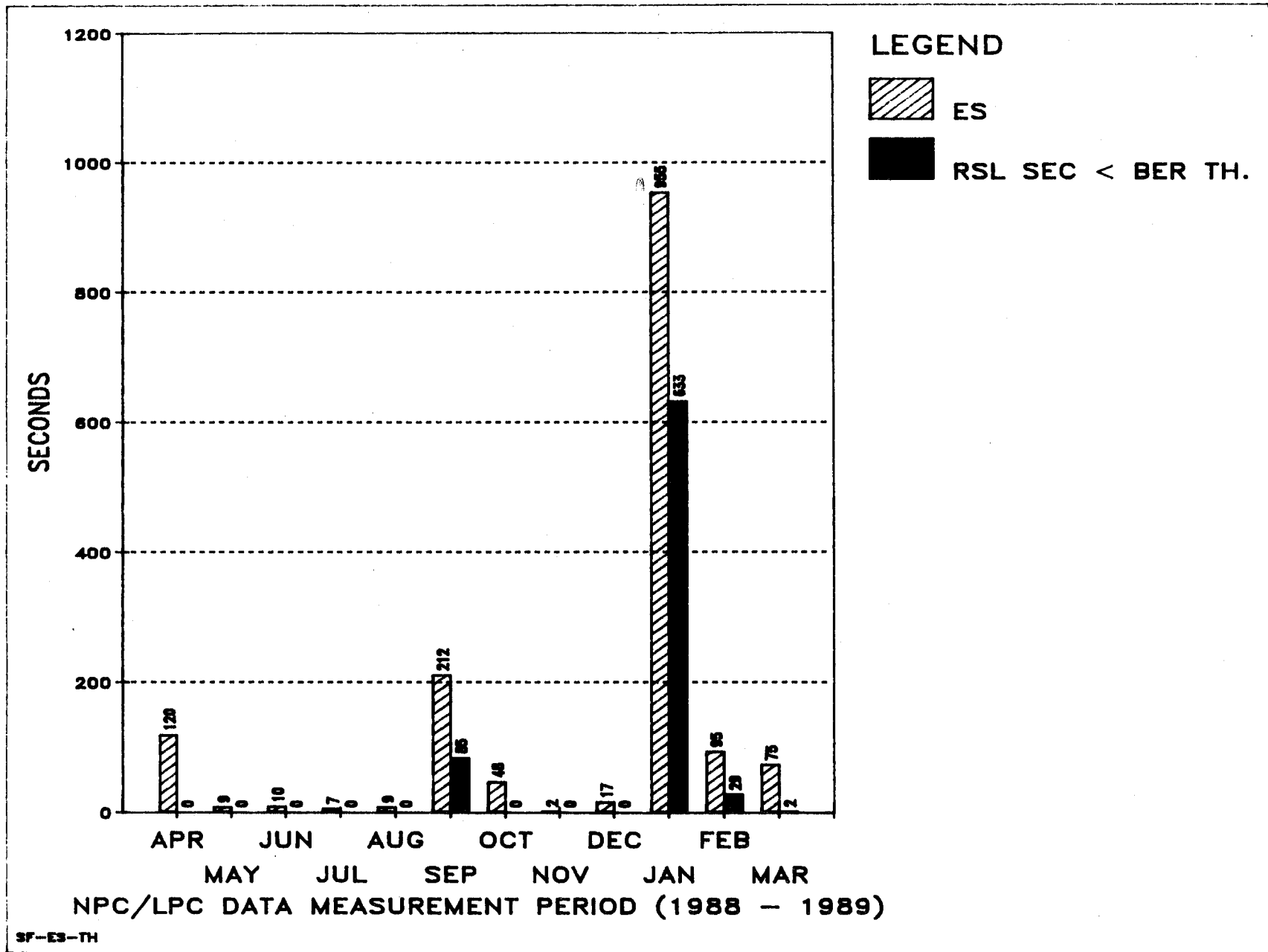


Figure 4. Schwarzenborn-Feldberg errored second performance and number of seconds that the received signal level is below the rsl threshold for DRAMA radios.

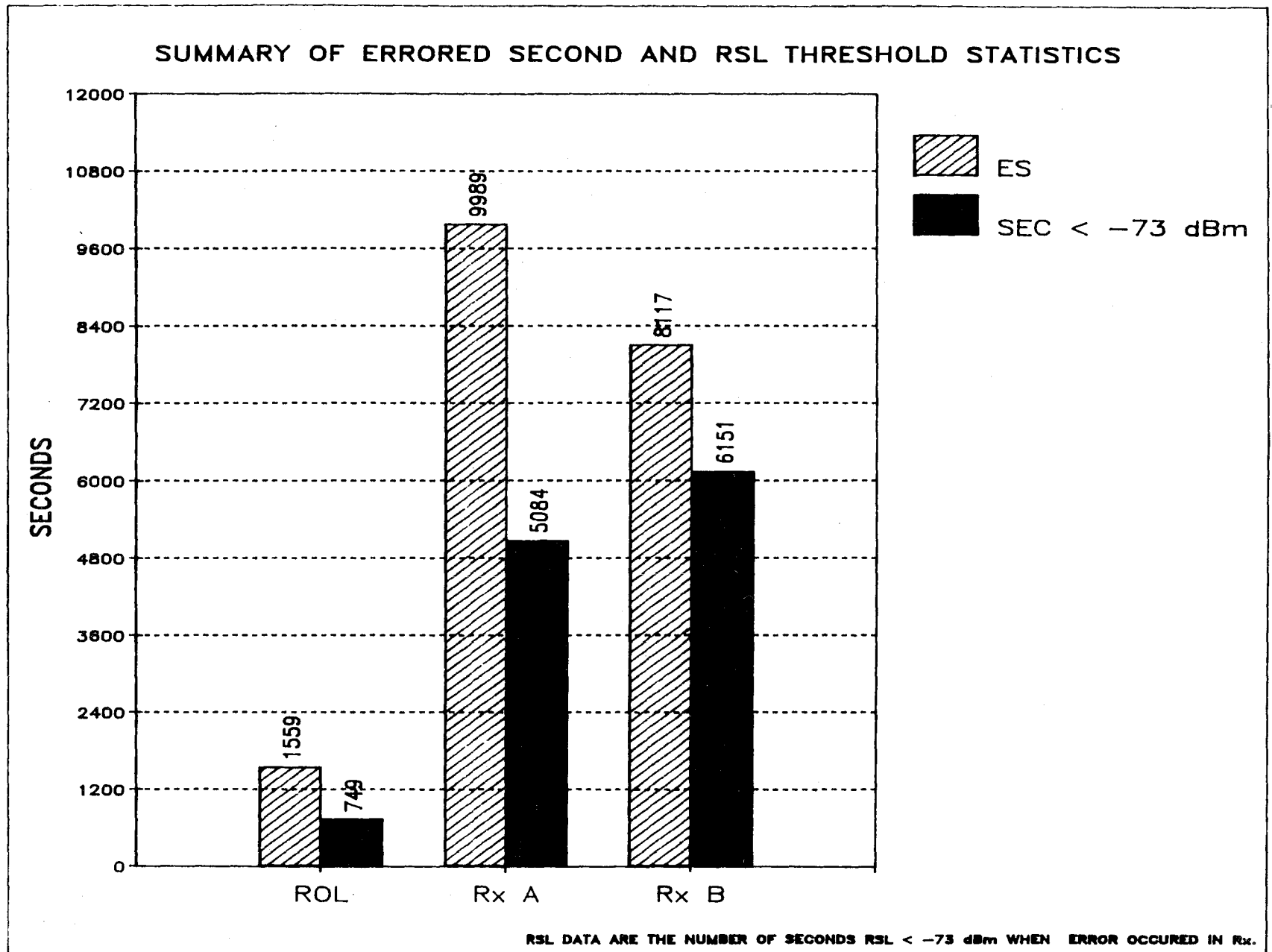


Figure 5. Summary of the number of errored seconds and the number of seconds the rsl is less than the 1×10^{-2} BER threshold.

Each receiver is treated independently. The errored-second ROL bar is the sum of the monthly errored-second data provided in Figure 4.

In Figure 5, each bar for the rsl-below-threshold data represent the number of seconds that a receiver's rsl was less than the minimum signal threshold when an error occurred in that receiver. For example, there were 6,151 seconds during the year in which an error occurred in Rx B and the signal level for Rx B was below the minimum threshold. Obviously, errors also can occur when the rsl is above the 10^{-2} BER threshold. The ROL bar for rsl less than -73 dBm is the sum of the 12 rsl bars shown on the previous figure.

The data provided by this figure can be used to calculate the space-diversity improvement factor since there are many more errors in either Rx A or Rx B than in the ROL. For example, the ratio of the number of errors for Rx A to the number of errors for the on-line receiver (9,989/1,559) is 6.4:1. The ratio for Rx B to ROL (8,117/1,559) is 5.2:1. Other measures of the space-diversity improvement factor could be calculated. However, these data suggest that a space-diversity improvement factor of approximately 6 can be used as a rule of thumb for the DRAMA radio. The System Engineering Plan for the FKT-N1 Digital Upgrade Project calculates a diversity improvement factor of 2,109 (CEEIA, 1981). 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 a 90-Mb/s radio.

Figure 6 displays a 12-month summary of the rsl's recorded by TRAMCON on the SBN-FEL link. Five curves are shown – two for each of the DRAMA radio's two space-diversity receivers and a horizontal line that shows the predicted unfaded threshold. The latter was taken from the Systems Engineering Plan for FKT-N1 (CEEIA, 1981). The curves labeled 50% depict the monthly median rsl's, i.e., 50% of the rsl samples were greater than the monthly value plotted and 50% of the rsl samples were less than the monthly value plotted. The 99.9% data point indicates the monthly value at which 99.9% of the received signals were above and 0.1% of the received signals were below that level.

There are several points of interest regarding Figure 6. First, the rsl curves for Rx A and Rx B are fairly close, indicating the antennas are properly aligned at both ends of the link. Second, there is very little variation in the median (50%) values from month to month since signal fading occurs a relatively small fraction of the time. Third, the worst fading months of September, January and February were also the months with the worst error performance on the SBN-FEL link (see Figure 4). Fourth, the median (50%) rsl is about 8 dB less than the unfaded rsl predicted in the Systems Engineering Plan (CEEIA, 1981, p. 47).

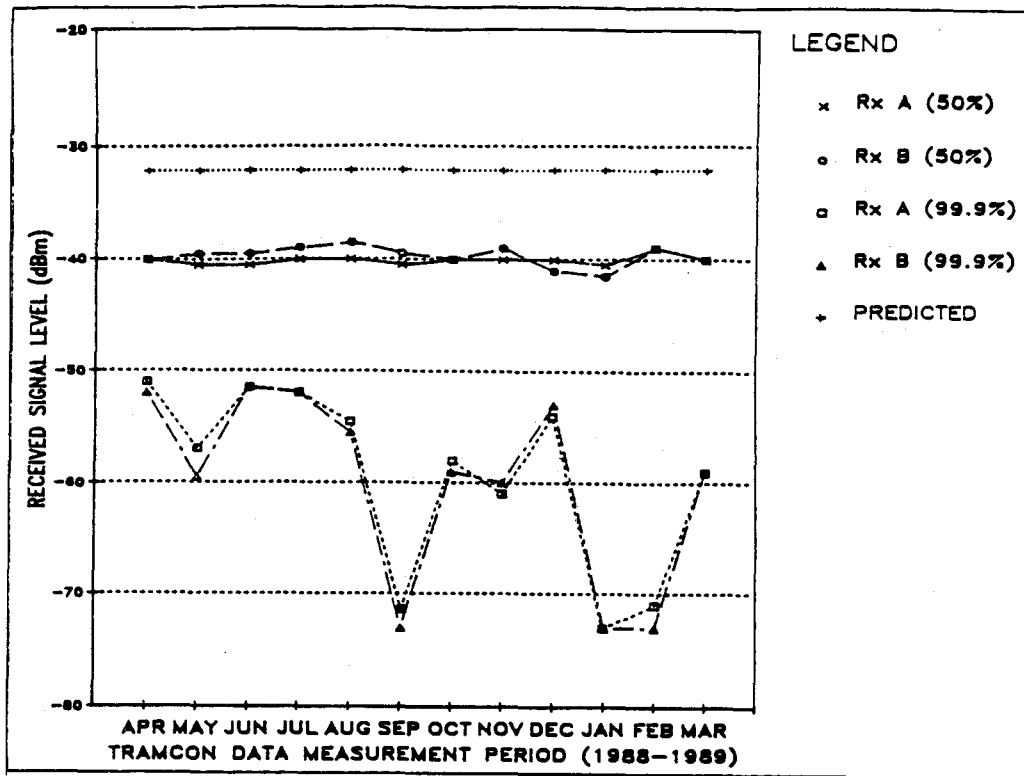


Figure 6. Schwarzenborn-Feldberg received signal levels recorded by TRAMCON.

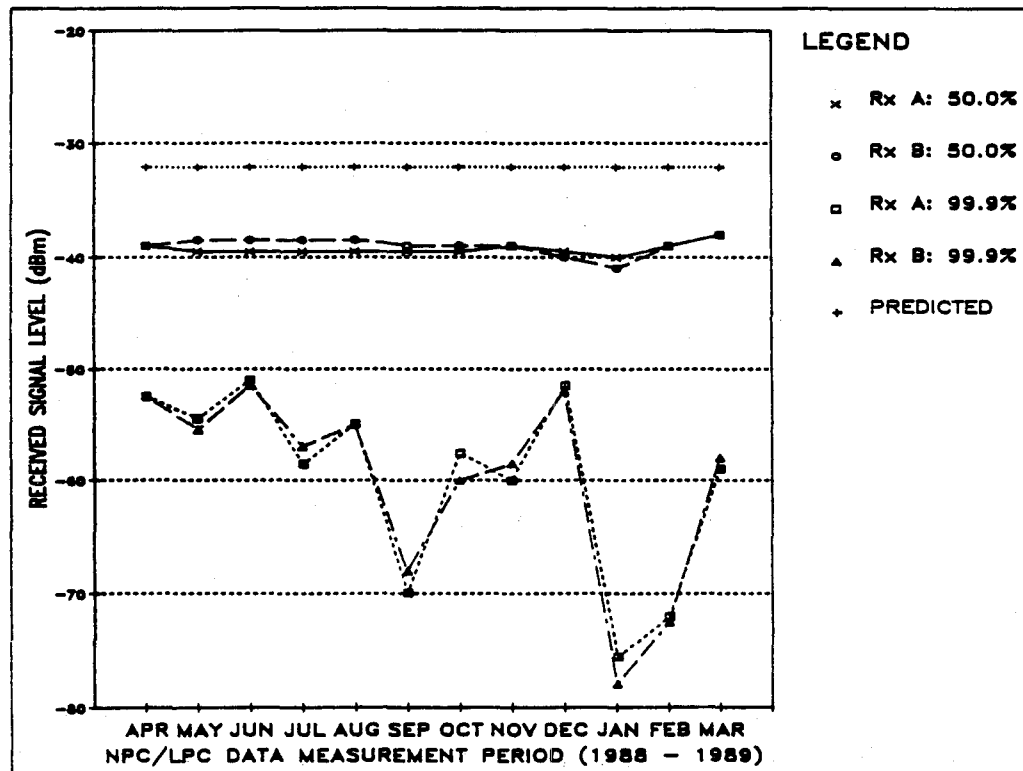


Figure 7. Schwarzenborn-Feldberg received signal levels recorded by NPC/LPC data acquisition equipment.

Figures 6 and 7 are similar except that the former is a plot of rsl data measured by TRAMCON while the latter is a plot of rsl data measured by the NPC/LPC system. 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. For the FKT-N1 segment, the TRAMCON polling cycle is approximately 100 seconds long and the resolution of the TRAMCON rsl measurement is 1 dB. The NPC/LPC rsl measurement equipment samples the rsl every 200 ms with a resolution of less than 0.1 dB. This higher resolution and sample rate is required for the special objectives of the NPC/LPC Program. As a result of the differences in the sampling rate between TRAMCON and the NPC/LPC rsl measurement equipment, TRAMCON may miss a small number of fading events that the NPC/LPC system would detect.

It should be noted that the rsl's recorded by TRAMCON (Figure 6) were about the same for January and February but the number of errored seconds were 955 and 95, respectively (see Figure 4). There is a possible explanation for this 10:1 errored-second ratio despite the similarities in rsl's between the 2 months. Careful examination of Figures 6 and 7 for the TRAMCON data and the NPC/LPC data for the 2 months shows slight differences between the results from the two measurement systems. The TRAMCON rsl's are approximately -72.5 dBm for both months, above the 10^{-2} BER threshold of -73 dBm. The NPC/LPC rsl's are approximately -78 dBm at the 99.9% level for January (below the threshold) and -72 dBm for February (above the threshold). The NPC/LPC system's measured rsl appears to be a more accurate indicator of error performance than TRAMCON's measured rsl when dynamic fading is a factor.

Figure 8 displays the SBN-FEL link's rsl for the ROL. The rsl's for Rx A and Rx B are sampled five times per second; however, the rsl for the ROL can be determined only when the DRAMA radio status data are available. Status signals, which include an indication of which DRAMA receiver is on-line, are recorded once every 60 seconds or if an error occurred on either Rx A, Rx B, or ROL. Because of this difference in the data base for the rsl data, caution should be exercised in comparing Figures 7 and 8.

4.1.2 Berlin-to-Bocksberg (BLN-BBG) Link Analysis

Figure 9 is a plot of errored seconds and UA time for the 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 comprise 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

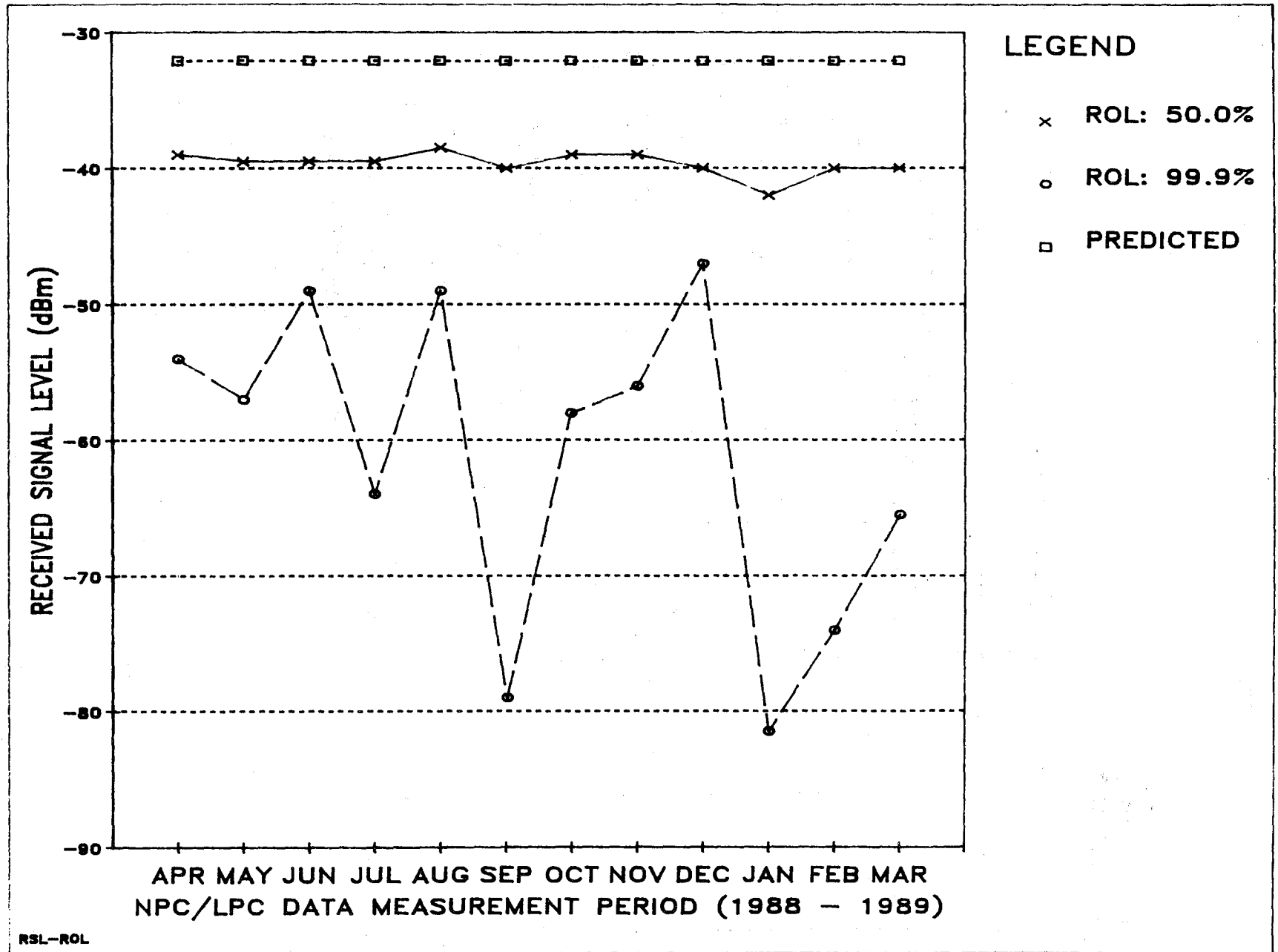


Figure 8. Schwarzenborn-Feldberg rsl's for the receiver on line.

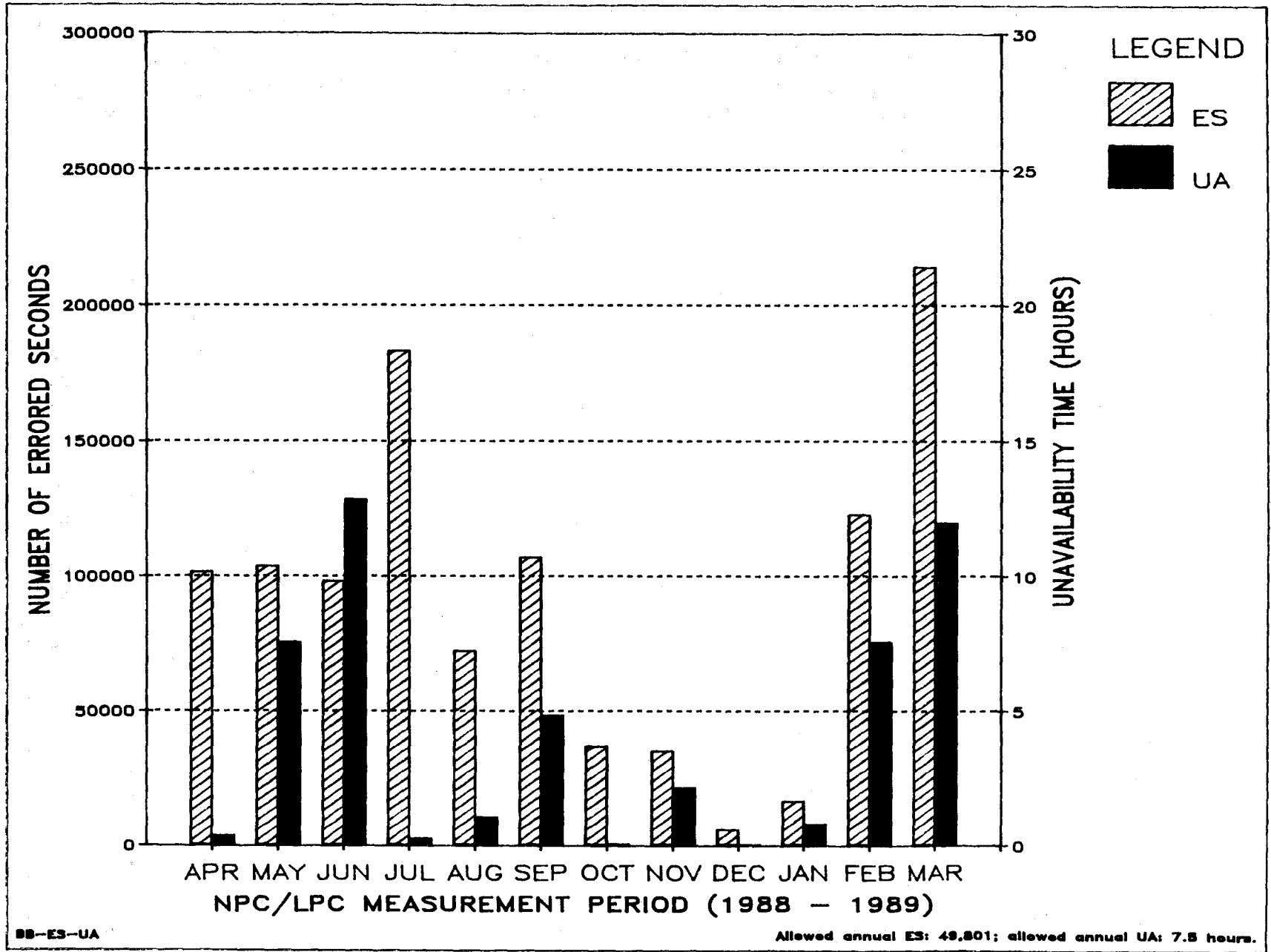


Figure 9. Berlin-Bocksberg errored seconds and unavailability time.

(KBG-RWN, RWN-SBN, and SBN-FEL) are common to both end-to-end channels and would cause errors to occur on both channels. TRAMCON data were further utilized to allocate the errors between these two links.

Application of draft MIL-STD-188-323 to the BLN-BBG troposcatter link result in a design objective of 7.48 hours UA time and 49,801 errored seconds on an annual basis. The total UA time estimate was 49.81 hours. The total errored seconds estimate was 1,101,551 seconds. Figure 9 shows the distribution of these numbers for each month from April 1988 through March 1989.

Due to the lack of a calibration procedure, the TRAMCON rsl data for the BLN-BBG link were unreliable and could not be used. As a result, the rsl data for this link were taken from the LPMS. Figure 10 presents the rsl's recorded by the LPMS at Bocksberg. The LPMS rsl is a 1 second average of the outputs of each space-diversity receiver sampled at 48 times per second. Two curves representing the 50% and 99.9% levels are displayed for each of the four quad-space diversity receivers. The data are incomplete for the 12-month period of this report because of failures with the LPMS. As stated earlier, ITS was not responsible for the design, development, installation, operation, or maintenance of the LPMS.

There appears to be a difference of several decibels between the rsl's of the four receivers at Bocksberg. Because the maximum rsl difference is not always between the same two receiver pairs, it is possible that the rsl differences between the receivers are due to inaccurate calibration curves in the LPMS. The differences may also be due to differences in length of waveguide runs to the receivers or misalignment of the antennas.

Note that the median and 99.9% rsl's are well below corresponding levels predicted in the FKT-N1 System Engineering Plan (CEEIA, 1981, p. 90). Reasons for these differences are under investigation.

It should be noted that the BLN-BBG link was not designed using the draft MIL-STD-188-323 performance criteria objectives but rather the current fade outage probability criteria (DEB MEP, 1980). The fade outage criteria was met during the link acceptance testing.

4.1.3 Bocksberg-to-Koeterberg (BBG-KBG) Link Analysis

Figure 11 presents the rsl's for the BBG-KBG link obtained from TRAMCON. Two curves (50% and 99.9%) are provided for each DRAMA radio receiver (Rx A and Rx B). With the exception of the 99.9% data points for June 1988, the two receiver rsl's are very close, indicating good antenna alignment. The Rx B 99.9% data point for June is an anomaly and is due to a statistical artifact. As noted in Section 4.1.1, the worst rsl fading months for the SBN-FEL link were September, January and February. The worst rsl fading months for the

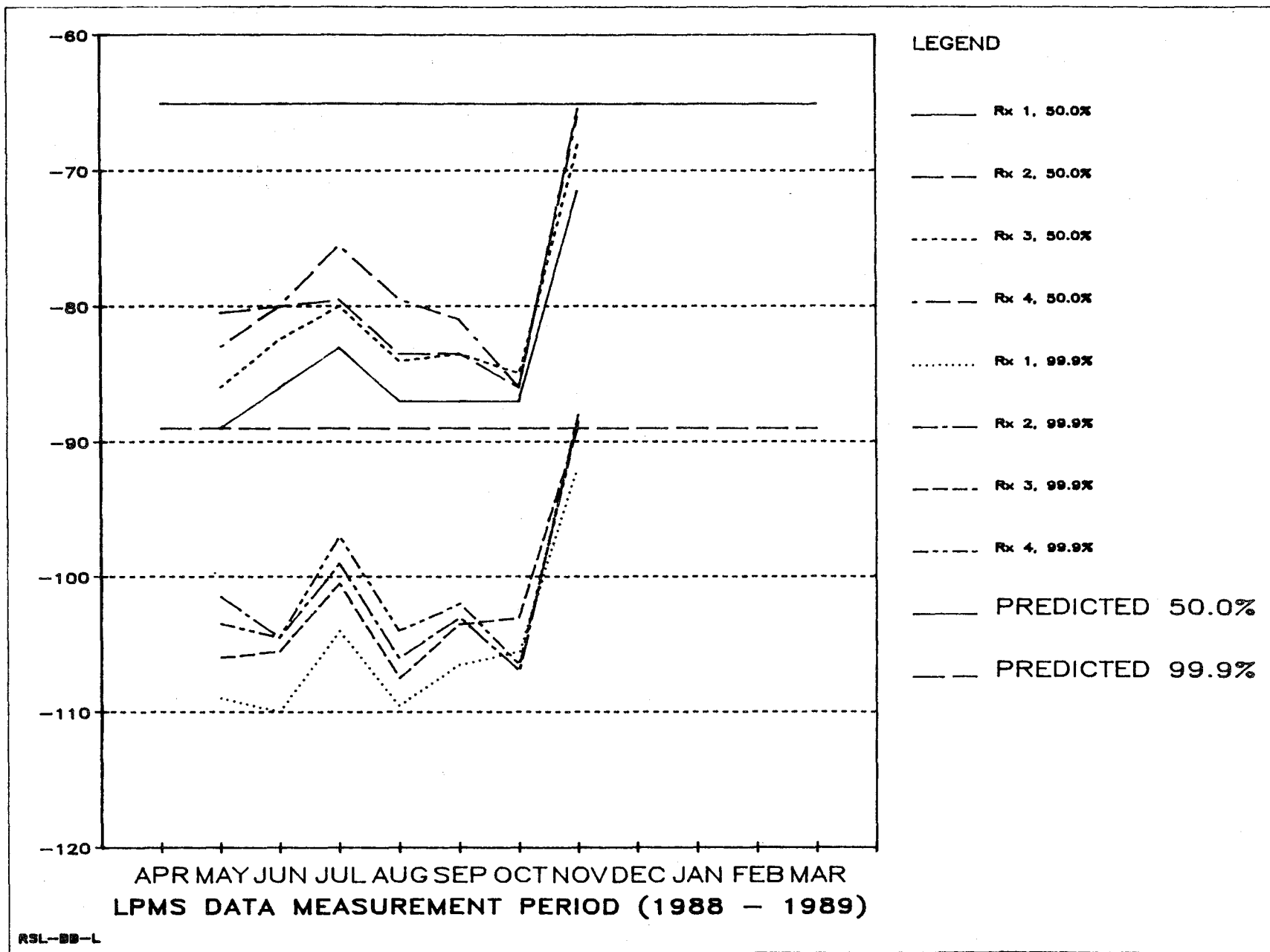


Figure 10. Berlin-Bocksberg rsl's recorded by LPMS system.

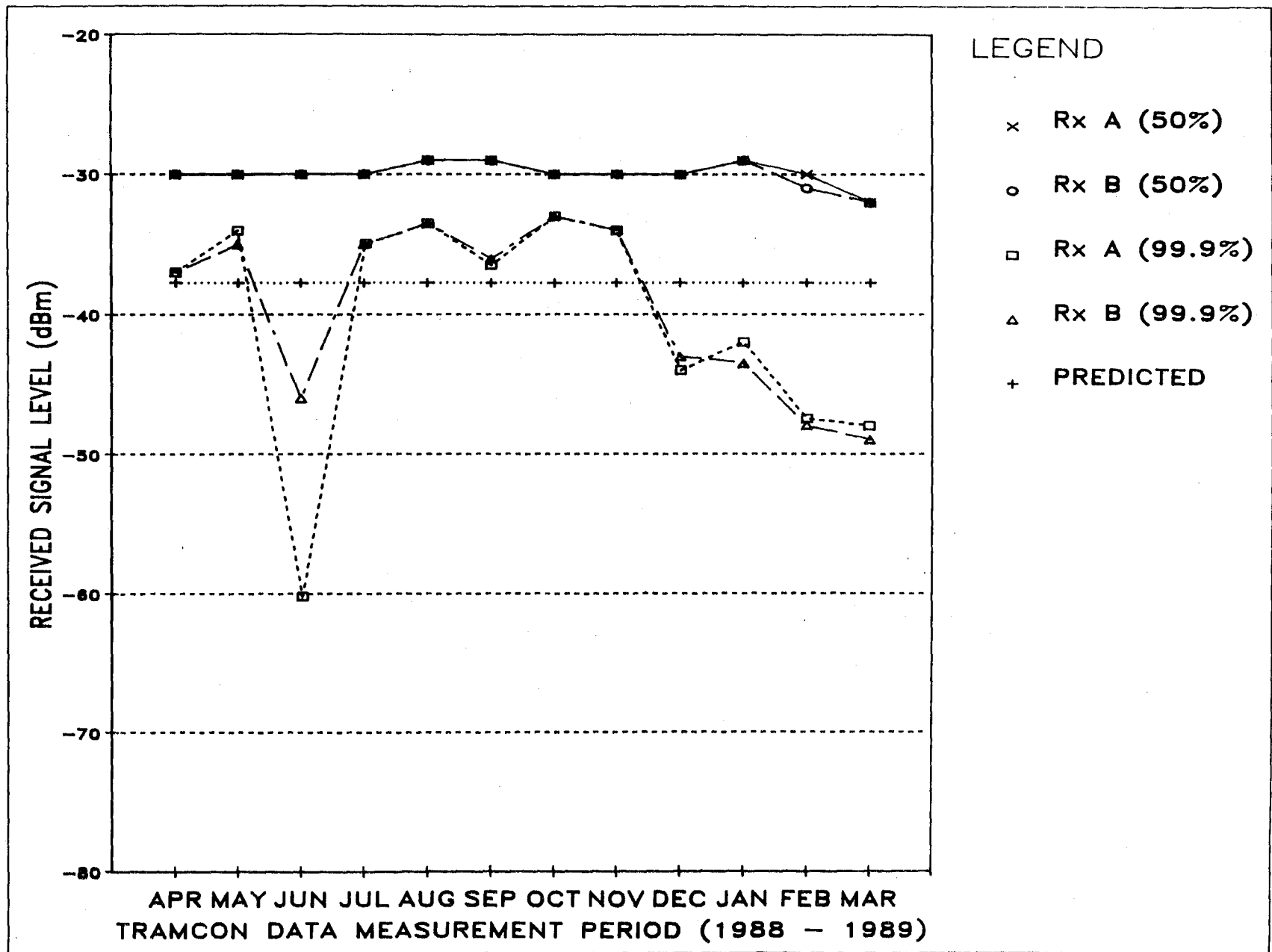


Figure 11. Bocksberg-Koeterberg rsl's recorded by TRAMCON.

BBG-KBG link were June, February and March. 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).

4.1.4 Koeterberg-to-Rothwesten Link (KBG-RWN) Analysis

Figure 12 is a plot of TRAMCON rsl data for the KBG-RWN link. The two DRAMA space-diversity receivers appear to track very well, as indicated by the closeness of the rsl's. The worst signal fading month was December, but even during this month the Rx A and Rx B rsl's were well above the DRAMA radio flat fade threshold. The median rsl's were slightly below the unfaded rsl provided by the FKT-N1 System Engineering Plan (CEEIA, 1981, p. 56).

4.1.5 Rothwesten-to-Schwarzenborn Link (RWN-SBN) Analysis

Figure 13 is a plot of TRAMCON rsl data for the RWN-SBN link. Rsl's on the two diversity receivers were nearly identical. January was the only month that appeared to have any multipath fading activity. Even during this month the Rx A and Rx B rsl's at the 99.9% level were well above the DRAMA radio flat fade threshold. The median rsl's were slightly below the unfaded rsl provided by the FKT-N1 System Engineering Plan (CEEIA, 1981, p. 51).

4.1.6 Linderhofe-to-Koeterberg (LDF-KBG) Link Analysis

Figure 14 is a plot of TRAMCON rsl data for the LDF-KBG link. In contrast to the TRAMCON rsl data for other links, the Rx A and Rx B rsl's for the LDF-KBG link differ significantly. There appears to be a consistent difference of about 4 or 5 dB between the rsl's for the two receivers. The rsl differences 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 DRAMA radio flat fade threshold. The median rsl's were slightly below the predicted unfaded rsl provided by the FKT-N1 System Engineering Plan (CEEIA, 1981, p. 61).

4.2 End-To-End Channel Analyses

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 a 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.

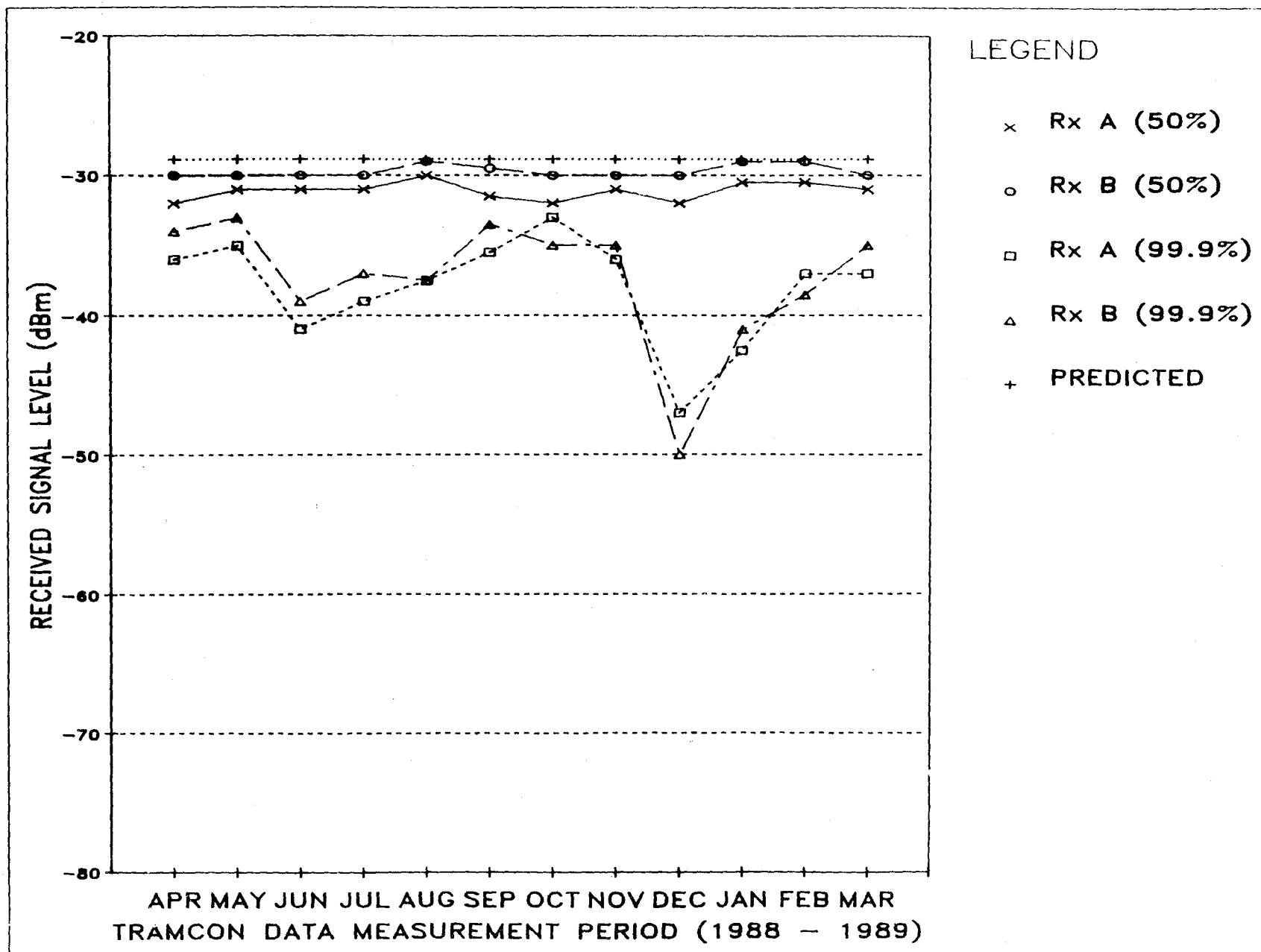


Figure 12. Koeterberg-Rothwesten rsl's recorded by TRAMCON.

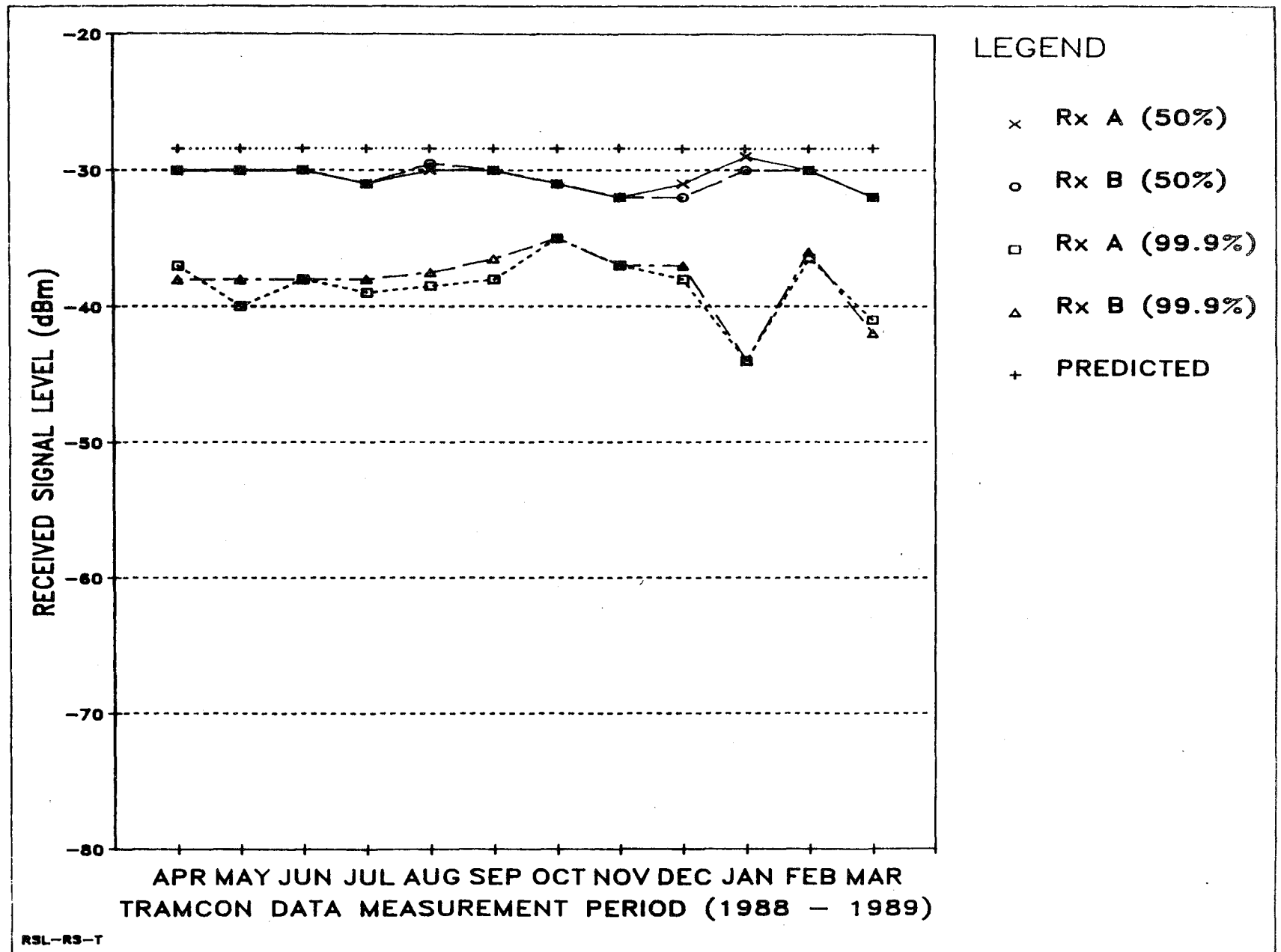


Figure 13. Rothwesten-Schwarzenborn rsl's recorded by TRAMCON.

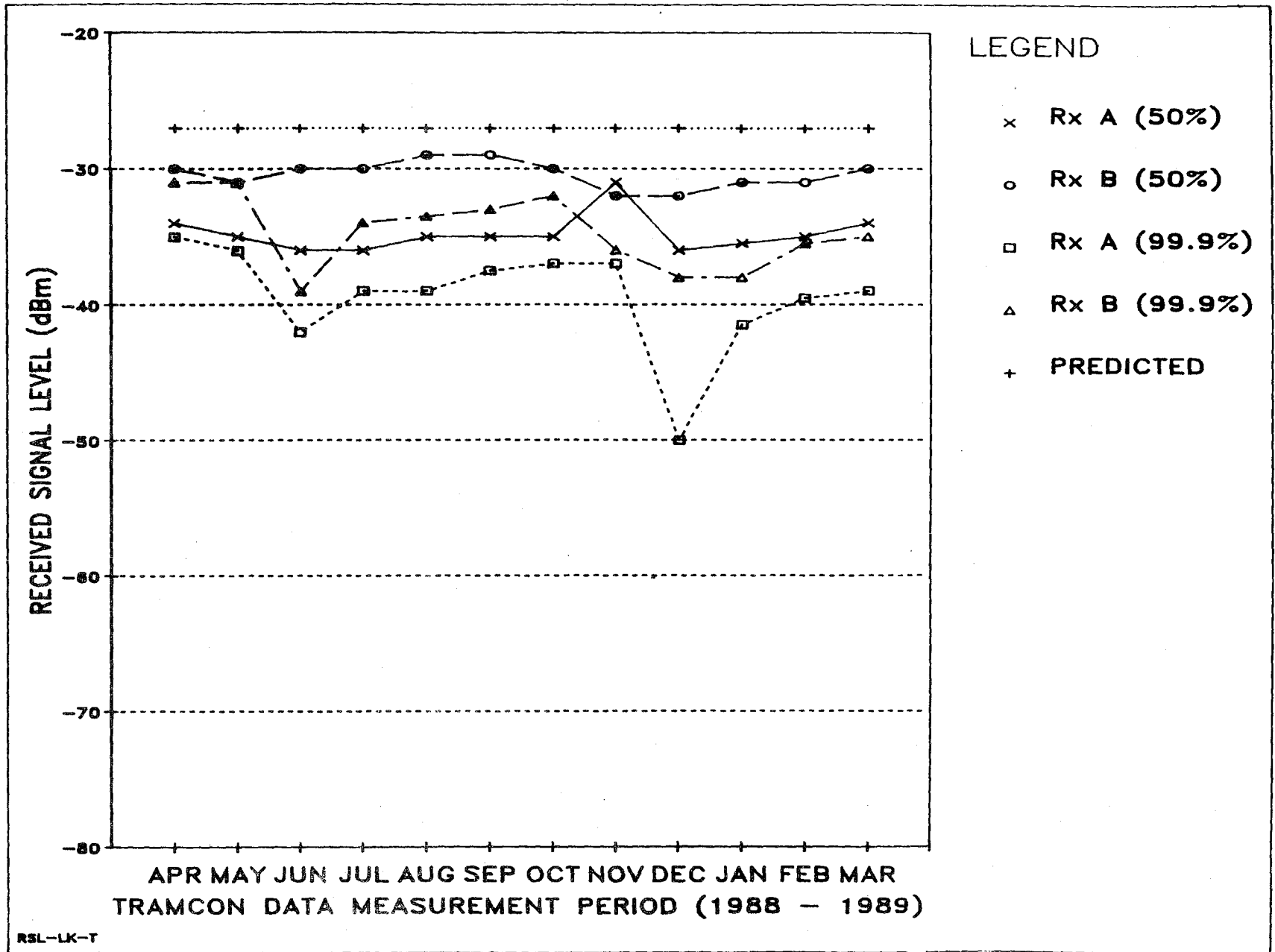


Figure 14. Linderhofe-Koeterberg rsl's recorded by TRAMCON.

4.2.1 Linderhofe-to-Feldberg (LDF-FEL) Channel

Figure 15 provides a summary of the monthly errored seconds and UA time for the LDF-FEL channel. This end-to-end circuit does not meet draft MIL-STD-188-323 design objectives. Application of the MIL-STD to this circuit results in design objectives of 11,590 errored seconds and 8.64 hours for UA time annually (see Table 1).

The errored seconds for each of three months (June, October, and November) individually exceed the objective for the entire year. The total errored seconds for the year are 81,412 seconds. This errored seconds total is seven times the design objective. The 81,412 errored seconds represents a long-term (annual) errored seconds ratio of 2.87×10^{-3} for the 7,866 hours of recorded data.

The total UA time for the year is 11.07 hours. This total exceeds the design objective of 8.64 hours.

It does not appear likely that the effects of propagation (i.e., multipath fading) were the primary cause of the degradation of performance on this end-to-end channel. One would expect that the SBN-FEL link would make the largest contribution to outages due to fading because it is by far the longest link of the four LOS links that comprise the LDF-FEL channel. One would also expect the contribution to outage time due to equipment failures would be approximately the same for each of the four links. As noted in Section 4.1.1, the performance of the SBN-FEL link does meet the MIL-STD design objectives for both errored seconds and unavailability.

It is interesting to compare Figure 15 with Figure 3 on a month-by-month basis. In making this comparison, note that the vertical scales are not the same. The largest number of errored seconds for the LDF-FEL channel is November (22,611 seconds). The same month has the smallest number of errored seconds for the SBN-FEL link (2 seconds). The reason for the large number of errored seconds on the end-to-end LDF-FEL channel is currently under investigation.

4.2.2 Berlin-to-Feldberg (BLN-FEL) Channel

Figure 16 provides a summary of the monthly errored seconds and UA time for the BLN-FEL channel. The figure shows this end-to-end circuit does not meet draft MIL-STD-188-323 design objectives. Application of the MIL-STD to this circuit results in design objectives of 62,258 seconds and an UA time of 16.12 hours annually. The errored seconds for each month of the year individually exceeds the annual errored-second design objective. The total number of errored seconds for the BLN-FEL channel is 1,905,530 seconds. This is 31 times the design objective. The 1.9 million errored seconds represent a long-term (annual)

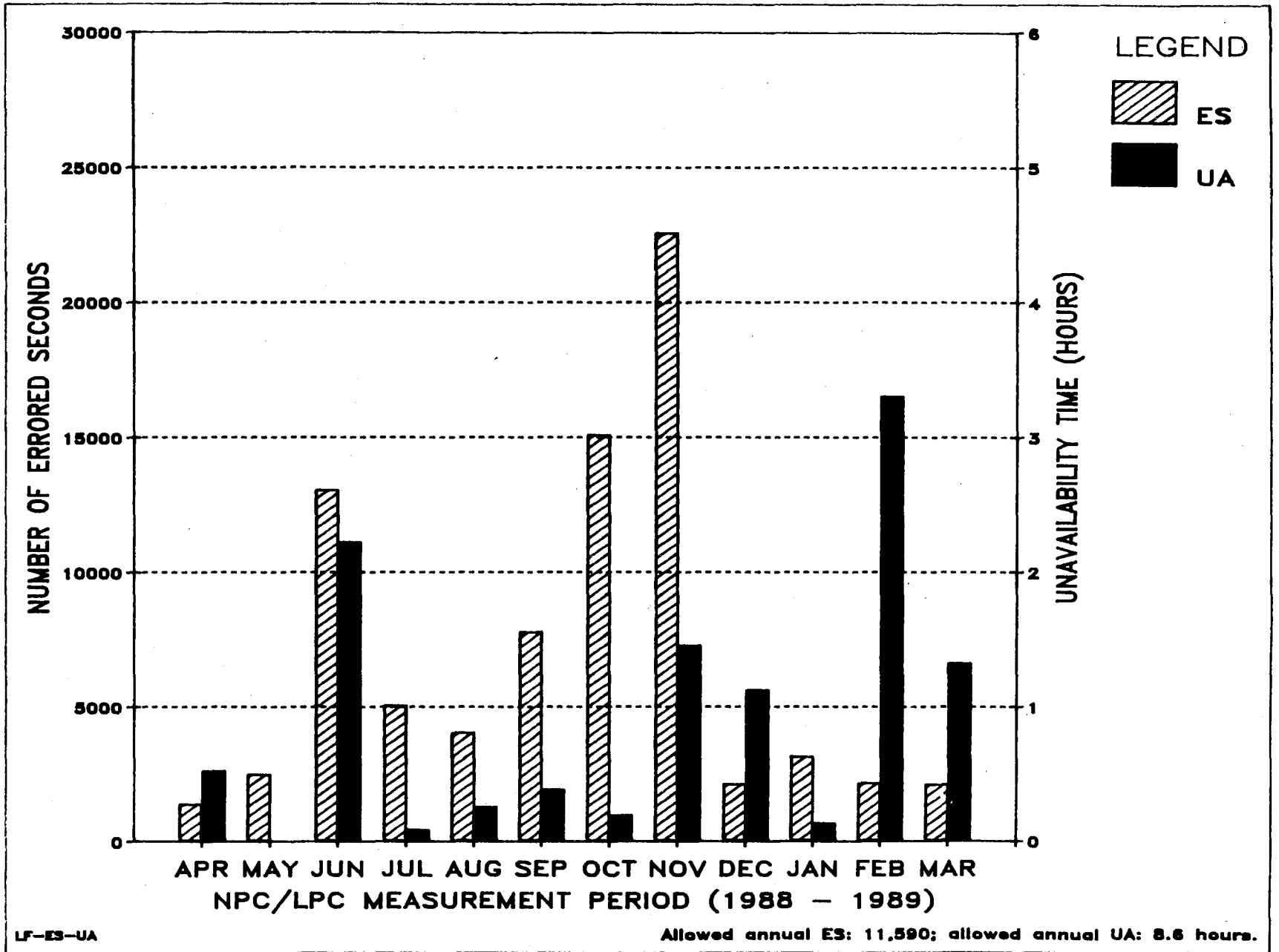


Figure 15. Linderhofe-Feldberg errored seconds and unavailability time

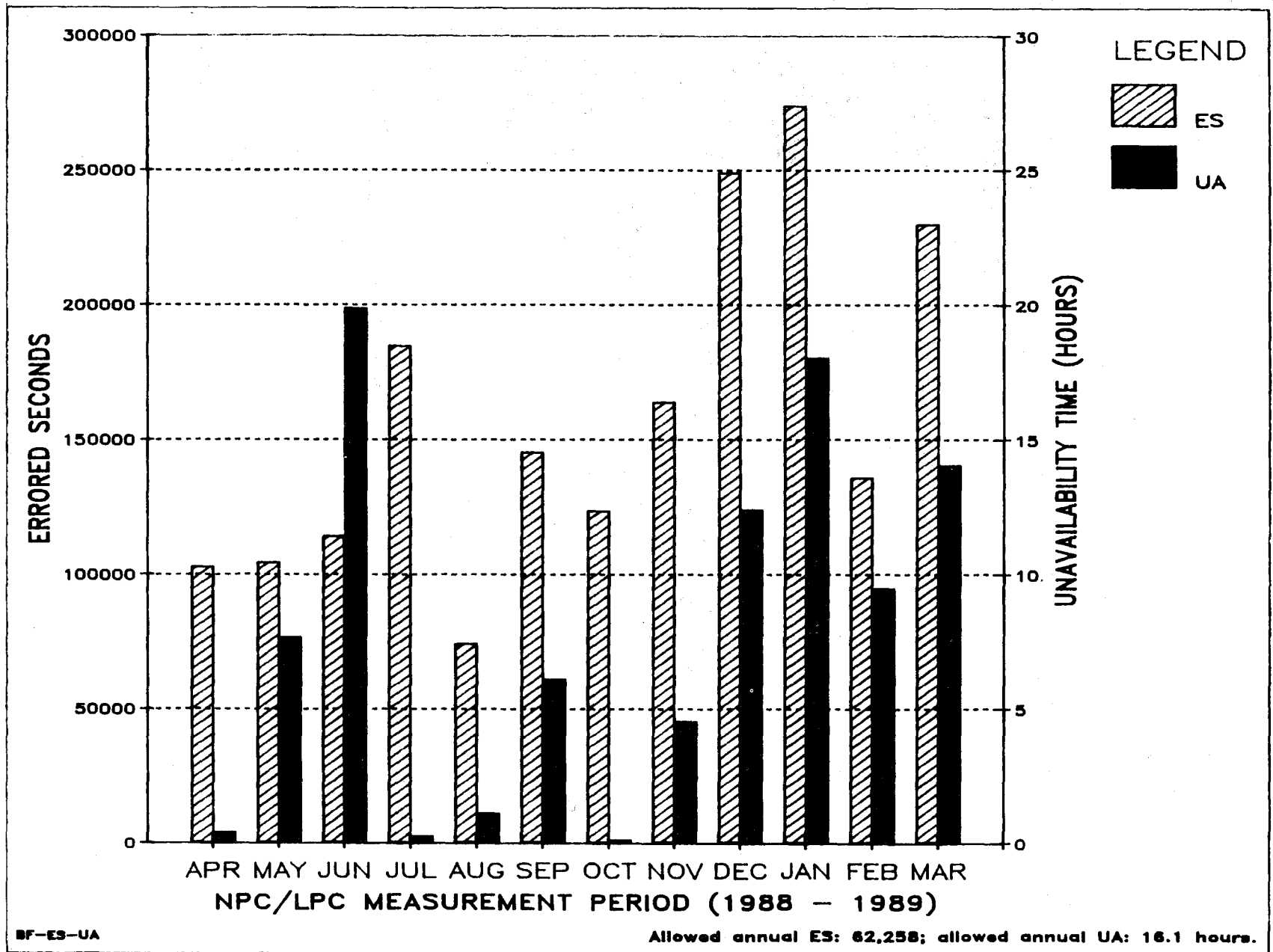


Figure 16. Berlin-Feldberg errored seconds and unavailability time.

errored-second ratio of 6.04×10^{-2} . The total UA time for the year for the BLN-FEL channel is 94.39 hours. Since the design objective for this channel is 16.12 hours, the measured unavailability exceeds the design objective unavailability by a factor of 5.8. There is no explanation at this time for the excessive unavailability time on this channel or the large month-to-month difference in unavailability time. The cause is currently under investigation.

Several statements regarding the performance of the BLN-FEL channel should be made. First, it was apparent from field observations that the quality of the BLN-BBG troposcatter link was greatly enhanced by the switchover from analog to digital equipment. Subjective evaluations of the voice quality were made by both operational personnel and ITS field personnel. There is a consensus that the quality of the order-wire circuit is adequate for carrying voice traffic and that the quality is much improved over the original analog system. However, the error performance noted above suggests the use of channel coding techniques (such as forward error correction) to improve performance for data traffic. Channel coding results in reduced throughput, but enhanced accuracy of the received data.

Second, performance of the BLN-FEL troposcatter link is likely to improve when new, low-noise amplifiers are installed. This is expected to improve the signal-to-noise ratio by about 3 to 6 dB and will result in improved digital error performance.

Finally, the current digital modem is a modified engineering development model and will be replaced by newly designed production modems in the near future. Improvements in digital error performance may result from the upgrade to the production modems.

5. CONCLUSIONS

Table 2 presents a summary of the error performance data that have been discussed in this report. Clearly, the DRAMA radio performance on the long (99.4-km) SBN-FEL link met the design objectives of draft MIL-STD-188-323 for this link during the measurement period. The performance of the two end-to-end channels (LDF-FEL and BLN-FEL) did not meet the MIL-STD design objectives. However, it should be emphasized that draft MIL-STD-188-323 contains design objectives that are more stringent than the operational specifications that are found in the Defense Communications Agency Circulars such as DCAC-300-175-9, entitled "DCS Operating-Maintenance Electrical Performance Standards" (DCA, 1986).

Table 2. Summary of Error Performance

	SBN-FEL <u>LINK</u>	LDF-FEL <u>CHANNEL</u>	BLN-FEL <u>CHANNEL</u>
<u>Annual unavailability time (hours)</u>			
Design objective	2.16	8.64	16.12
Measured	0.22	11.07	94.39
<u>Annual total errored seconds</u>			
Design objective	3,800	11,590	62,258
	(1.21×10^{-4})	(3.68×10^{-4})	(1.97×10^{-3})
Measured	1,559	81,412	1,905,530
	(5.51×10^{-5})	(2.87×10^{-3})	(6.73×10^{-2})

Note: The measured fraction, shown in parenthesis, is the fraction of errored seconds based on the total hours of data recorded (7,866).

At this time it is unclear what caused the excessive errors on the LDF-FEL channel. The performance is particularly unexpected since the performance of the SBN-FEL link, which is the longest of the four tandem LOS links comprising this channel, was well within MIL-STD criteria. Investigation of this issue is continuing and will be described further in the final report on this project. It should be noted, however, that the measured performance was only slightly under the design objectives obtained by the application of draft MIL-STD-188-323 to this channel.

The performance of the BLN-FEL channel was significantly worse than the design objectives of the MIL-STD. The measured UA time was 6.7 times worse than the design objective, and the measured number of errored seconds was 31 times greater than the design objective.

It has been reported that year-to-year variability of outage is considerable and that the measured outage (or errored seconds) can change by a factor of 5 to 6 from year to year (AT&T/Harris, 1988).

Comparisons can be made between the two end-to-end channels. Each of these two channels contain four LOS links. Three of the LOS links are common to each channel. The LDF-FEL channel includes the LDF-KBG link (28.0 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 contribution 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 (it would be expected to be slightly greater because the BBG-KBG LOS link is longer than the LDF-KBG LOS link). A logical conclusion is that most of the difference between performance of the two end-to-end channels probably is due to the troposcatter link that is part of the BLN-FEL channel, but not the LDF-FEL channel.

The following observations are made about the BLN-BBG troposcatter link:

- the modem being used on this link is an engineering development model that will be replaced in the near future; performance may improve when the new modem is installed.
- the low-noise tunnel-diode amplifiers in the modified Army Tactical AN/GRC-143 radio receivers will be replaced, which will result in about a 3 dB signal-to-noise ratio improvement; this will result in improved digital error performance.
- users of the troposcatter link have noted a significant improvement in voice quality as the result of the replacement of the analog system with the digital system.
- channel coding (e.g., forward error correction) may be required to obtain satisfactory performance for data communications traffic that is 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 LOS rsl's recorded during the first 12 months of this project show that multipath fading occurred only during a few months of the year. Fading caused some degradation of DRAMA radio performance on the SBN-FEL link, but not enough to cause the link to exceed MIL-STD design objectives. The space-diversity improvement factor (DIF) for the DRAMA radio was found to be between 5.2 and 6.4. This is slightly lower than the DIF that has been reported on other systems; DRAMA diversity performance may be explained by the type of combiner used (selective combining theoretically is worse than IF combining) and the algorithm used for selection of Rx A or Rx B.

The TRAMCON system has proven to be a valuable source of rsl data. Normally, TRAMCON rsl and other data are not kept beyond 24 hours. It is recommended that the TRAMCON software be modified to permit the creation of monthly summaries of rsl and other data.

Additional analyses of the data collected as part of the NPC/LPC project are in progress. A final report will provide the results of these analyses and will provide final conclusions and recommendations. The measurements made during this project and the analysis of the resultant data do not in any way negate the results obtained during the cutover testing of any links in FKT-N1.

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* Mr. Francis Cheng is now with the Defense Communications Engineering Center.

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<p>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.)</p> <p>This report describes the interim results of an 18-month digital microwave transmission network performance and propagation measurement project that was conducted on a portion of the Defense Communications System (DCS) in West Germany. Only the first 12 months of data are summarized in this report. More than 3 gigabytes of data were collected between April 1988 and March 1989. The report provides the results of bit error rate measurements made at the 56-kb/s user level on one long (99-km) line-of-sight (LOS) link and at the 64-kb/s user level on two end-to-end channels consisting of multiple LOS and/or troposcatter radio links. The report also provides summaries of 12 months of received-signal-level (rsl) measurements on five LOS links and one troposcatter link.</p>			
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