NTIA Report 90-265

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

## Volume II: Appendixes

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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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VOLUME I: MEASUREMENT SYSTEM DESCRIPTION AND SUMMARY OF RESULTS

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# APPENDIX A: MILITARY STANDARD

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NOTE: This draft document, dated 1 June 1989, prepared by DCA/DCEC Code R220, has not been approved and is subject to modification. DO NOT USE PRIOR TO APPROVAL. (Project No. SLHC-3230). This document replaces draft Military Standard MIL-STD-188-323, 15 May 1986.

MILITARY STANDARD

# SYSTEM DESIGN AND ENGINEERING STANDARDS FOR LONG HAUL DIGITAL TRANSMISSION SYSTEM PERFORMANCE

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5.5 DCS terrestrial reference link and segment performance.

5.5.1 Overall characteristics.

Background, tutorial, and rationale in the allocation of all performance criteria contained in this standard are provided in Appendix D.

5.5.2 LOS link performance. A LOS link is defined as the user-to-user connection between 64 kb/s ports on the Level 1 multiplexer, over a LOS radio path of distance D(km), and includes the equipment as shown in figure 1 on both ends of the link.

5.5.2.1 LOS link error free second allocation. The 40 km LOS link in the Global, Overseas and Intracontinental HRC's shall be designed to provide 0.999975 error free second (EFS) performance, during periods when link availability is met (see 4.4.1) and due to propagation effects only, at the 64 kb/s voice and data user port of the first level (PCM) multiplexer. This link design level of performance shall be over any continuous 30 day* interval during the worst propagation period of the year for the geographic location of the link. The following relationships give the minimum EFS and maximum errored second (ES) performance criteria for a LOS link as a function of path length, D(km):

$$EFS = 1 - 6.250 \times 10^{-7}/km \times D(km) \text{ and } ES = 6.25 \times 10^{-7}/km \times D(km).$$

5.5.2.2 LOS link availability. The availability of the line-of-sight (LOS) link for voice and data users at the 64 kb/s channel shall be at least 0.999753 (Appendix D, paragraph 3.3). This availability criteria is based on equipment failures and long-term propagation outages.

5.5.2.3 Mean time to acquire synchronization. For a received signal-to-noise (S/N) ratio corresponding to an average BER of 10(-3), the LOS radio, bulk encryption device, digital patch and access (DPAS) and multiplexers down to the 64 kb/s channel interface shall acquire synchronization within a mean (average) time of 150 msec.

5.5.2.4 Mean time to loss of bit count integrity. The mean (average) time to loss of BCI on the LOS link shall not be less than 2,712 hours.

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*The 30 day time period stated here for LOS, also used for satellite and cable link performance, and the 365 day period for TROPO, is a link design parameter needed in determining fade margin requirements during the worst case propagation period where the link is located. It is not intended to imply a link performance measurement time period. Appendix D contains a further discussion.

5.5.2.5 RF bandwidth. The radiated signal of the reference LOS RF link (for $f_0 \leq 15GHz$), including all RF frequency uncertainties, shall contain no energy in any 4 kHz band outside the authorized bandwidth at the operating nominal throughput bit rate, in excess of 50 dB below the desired signal or in excess of that specified by the following relationship (see Appendix C):

$$A = [10 \log_{10} (B) + 0.8(P-50) + 35]dBc$$

A = Attenuation below the mean transmitted spectrum power output level (dBc).

P = Percent of the authorized bandwidth of which the center frequency of the 4 kHz power measurement bandwidth is removed from the carrier frequency.

B = Authorized transmitted bandwidth (MHz).

A minimum attenuation (A) of 50 dBc is required and attenuation of greater than 80 dBc is not required.

The radiated signal of the reference LOS RF link (for $f_0 > 15GHz$), including all RF frequency uncertainties, shall contain no energy in any 1 MHz band outside the authorized bandwidth at the operating nominal throughput bit rate, in excess of 11 dB below the desired signal or in excess of that specified by the following relationship (see Appendix C):

$$A = [10 \log_{10} (B) + 0.4(P-50) + 11]dBc$$

A = Attenuation below the mean transmitted spectrum power output level (dBc).

P = Percent of the authorized bandwidth of which the center frequency of the 1 MHz power measurement bandwidth is removed from the carrier frequency.

B = Authorized transmitted bandwidth (MHz).

A minimum attenuation (A) of 11 dBc is required and attenuation of greater than 56 dBc is not required.

5.5.3 TROPO link performance. A TROPO link is defined as the user-to-user connection between 64 kb/s ports on the Level 1 multiplexer, over a tropospheric scatter radio path of distance D(km), and includes the equipment as shown in figure 1 on both ends of the link.

5.5.3.1 TROPO link error free second allocation. The 320 km Overseas HRC TROPO link shall be designed to provide 0.9977 error free second (EFS) performance, during periods when link availability is met (see paragraph 4.4.1) and due to propagation effects only, at the 64 kb/s voice and data user port of the first level (PCM) multiplexer. This link design level of performance shall be over any continuous 365 day interval using the worst case climate type for the geographic location of the link. The following relationships give the minimum EFS and maximum ES performance criteria for a TROPO link as a function of path length, D(km);

$EFS = 1 - 7.1875 \times 10^{-6}/km \times D(km)$ and $ES = 7.1875 \times 10^{-6}/km \times D(km)$.

5.5.3.2 TROPO link availability. The availability of the troposcatter link for voice and data users at the 64 kb/s channel shall be at least 0.999146 (Appendix D, paragraph 3.3). This availability criteria is based on equipment failures and propagation.

5.5.3.3 Mean time to acquire synchronization. For a signal to noise (S/N) ratio corresponding to an average BER of $10^{-3}$, the TROPO radio, bulk encryption device, DPAS and multiplexers down to the 64 kb/s channel interface shall acquire synchronization within a mean time of 600 msec.

5.5.3.4 Mean time to loss of bit count integrity. The mean time to loss of BCI on the TROPO RF link shall not be less than 316 hours.

5.5.3.5 RF bandwidth. The radiated signal of the TROPO RF link, including all RF frequency uncertainties, shall contain no energy in any 4 kHz band outside the authorized bandwidth at the operating nominal throughput bit rate in excess of 40 dB below the desired signal or in excess of that specified by the following relationship (see Appendix C):

$$A = [10 \log_{10}(B) + 0.6(P-50) + 15]\text{dBc}$$

A = Attenuation below the mean transmitted spectrum power output level (dBc).

P = Percent of the authorized bandwidth of which the center frequency of the 4 kHz power measurement bandwidth is removed from the carrier frequency.

B = Authorized transmitted bandwidth (MHz).

A minimum attenuation (A) of 40 dBc is required and attenuation of and greater than 80 dBc is not required.

5.5.4 Cable link performance. A cable link is defined as the user-to-user connection between 64 kb/s ports on the Level 1 multiplexer, over a metallic or fiber optic cable path of distance D(km), and includes the equipment as shown in figure 1 on both ends of the link. (This definition excludes repeaters; repeaters are included in the segments and HRS.)

5.5.4.1 Cable link error free second allocation. The nominal 40 km cable link in the global HRC shall be designed to provide 0.999974 error free second (EFS) performance, during periods when link availability is met (see 4.4.1) and due to transmission effects only, at the 64 kb/s voice and data user port of the first level (PCM) multiplexer. This link design level of performance shall be over any continuous 30 day interval. To account for longer or shorter cable links a distance dependence relationship is given for minimum EFS and maximum ES performance as a function of link length, D(km);

$$EFS = 1 - (6.4 \times 10^{-7}/km \times D(km))$$

and

$$ES = 6.4 \times 10^{-7}/km \times D(km)$$

5.5.4.2 Cable link availability. The cable link shall provide an availability of at least 0.999785 (Appendix D, paragraph 3.3) down to the 64 kb/s channel. Sufficient cable and repeater redundancy shall be engineered into the system to meet this requirement. This availability criteria is based on equipment failures only.

5.5.4.3 Mean time to acquire synchronization. With a bit error rate of $10^{-3}$ due to randomly distributed errors on the cable link, the cable terminal bulk encryption device, DPAS, and multiplexers down to the 64 kb/s channel interface shall acquire synchronization within a mean time of 150 msec.

5.5.4.4 Mean time to loss of bit count integrity. The mean time to loss of BCI shall not be less than 4,800 hours.

5.5.5 DCS terrestrial reference segment performance. The 320 km and 640 km terrestrial reference segments and the 320 km tail reference segment were defined in section 4.2.5. This section gives detailed performance criteria for each segment.

5.5.5.1 Tail reference segment performance. Performance characteristics of the reference tail segment shall be measured from one 64 kb/s voice and data user input port of the first level multiplexer to the corresponding 64 kb/s output port at the opposite end of the segment except for the jitter component which shall be measured at any point.

5.5.5.1.1 Error free second allocation. Each tail reference segment (320 km) in the global, overseas and intracontinental HRC's shall provide 0.9997 EFS performance, during periods of availability (see 4.4.1) and due to the combined effects of propagation and inherent (back-to-back) equipment errors (Appendix D, paragraph 2.3).

5.5.5.1.2 Availability allocation. Each tail reference segment (320 km) in the global, overseas and intracontinental HRC's shall provide an availability (one minus unavailability) of 0.999370 (table I, 4.4.1 and Appendix D, paragraph 3.3). This availability criterion is based on equipment failures and long-term propagation outages.

5.5.5.1.3 Mean time to loss of bit count integrity allocation. Each tail reference segment (320 km) in the global, overseas and intracontinental HRC's shall provide a mean time to loss of BCI (MTTLBCI) of not less than 339 hours (table III).

5.5.5.1.4 Delay. Each tail reference segment (320 km) in the global, overseas and intracontinental HRC's shall not exceed the combined transmission and propagation maximum delay values in table IV, for the VF and data users.

5.5.5.1.5 Jitter. At any point in the tail reference segment (320 km) of the global, overseas and intracontinental HRC's the jitter specifications given in 4.4.5 shall be met.

5.5.5.2 Three hundred and twenty (320) km reference segment performance. Performance characteristics of the reference 320 km segment shall be measured from one 64 kb/s voice and data user input port of the first level (PCM) multiplexer to the corresponding 64 kb/s output port at the opposite end of the segment except for the jitter component which shall be measured at any point.

5.5.5.2.1 Error free second allocation. Each 320 km reference segment in the global and intracontinental HRC's shall provide 0.9993 EFS performance, during periods of availability (see 4.4.1) and due to the combined effects of propagation and inherent (back-to-back) equipment errors, (table II).

5.5.5.2.2 Availability allocation. Each 320 km reference segment in the global and intracontinental HRC's shall provide an availability (one minus unavailability) of 0.99932 (table I, para 4.4.1 and Appendix D, paragraph 3.3). This availability criterion is based on equipment failures and propagation.

5.5.5.2.3 Mean time to loss of bit count integrity allocation. Each 320 km reference segment in the global and intracontinental HRC's shall provide a MTTLBCI of not less than 339 hours (table III).

5.5.5.2.4 Delay. Each 320 km reference segment in the global and intracontinental HRC's shall not exceed the combined transmission and propagation maximum delay values in table IV for the VF and data users.

5.5.5.2.5 Jitter. At any point in the 320 km reference segment of the global and intracontinental HRC's the jitter specifications given in 4.3.6 shall be met.

5.5.5.3 Six hundred and forty (640) km reference segment performance. Performance characteristics of the reference 640 km segment shall be measured from one 64 kb/s voice and data user input port of the first level multiplexer to the corresponding 64 kb/s output port at the opposite end of the segment except for the jitter component which shall be measured at any point in the segment.

5.5.5.3.1 Error free second allocation. Each 640 km reference segment in the global and overseas HRC's shall provide 0.9970 EFS performance, during periods of availability (see 4.4.1) and due to the combined effects of propagation and inherent (back-to-back) equipment errors (table II).

5.5.5.3.2 Availability allocation. Each 640 km reference segment in the global and overseas HRC's shall provide an availability (one minus unavailability) of 0.99830 (table I para 4.4.1 and Appendix D, paragraph 3.3). This availability criterion is based on equipment failures and propagation. (TROPO link propagation contribution only).

5.5.5.3.3 Mean time to loss of bit count integrity allocation. Each 640 km reference segment in the global and overseas HRC's shall provide a MTTLBCI of not less than 164 hours (table III).

5.5.5.3.4 Delay. Each 640 km reference segment in the global and overseas HRC's shall not exceed the combined transmission and propagation maximum delay value in table IV for the VF and data user.

5.5.5.3.5 Jitter. At any point in the 640 km reference segment of the global and overseas HRC's, the jitter specifications given in 4.3.6 shall be met.

# APPENDIX B: ERROR PERFORMANCE OF AN INTERNATIONAL DIGITAL CONNECTION FORMING PART OF AN INTEGRATED SERVICES DIGITAL NETWORK

(Copied verbatim from CCITT G.821, Geneva, 1985, Red Book)

# ERROR PERFORMANCE OF AN INTERNATIONAL DIGITAL CONNECTION FORMING PART OF AN INTEGRATED SERVICES DIGITAL NETWORK

*(Geneva, 1980: further amended)*

The CCITT,

*considering*

(a) that services in the future may expect to be based on the concept of an Integrated Services Digital Network (ISDN);

(b) that errors are a major source of degradation in that they affect voice services in terms of distortion of voice, and data type services in terms of lost or inaccurate information or reduced throughout;

(c) that while voice services are likely to predominate, the ISDN is required to transport a wide range of service types and it is therefore desirable to have a unified specification;

(d) that an explanation of network performance objectives and their relationship with design objectives is given in Recommendation G.102,

*recommends*

that within the following scope and definitions the requirements set out in Table 1/G.821 and subsequent paragraphs should be met.

## 1 Scope and definitions

1.1 The performance objectives are stated for each direction of a 64 kbit/s circuit-switched connection used for voice traffic or as a "Bearer Channel" for data-type services.

1.2 The 64 kbit/s circuit-switched connection referred to is an all digital Hypothetical Reference Connection (HRX) and is given in Figure 1/G.821. It encompasses a total length of 27 500 km and is a derivative of the Standard Hypothetical Reference Connection given in Figure 1/G.801.

1.3 The performance objective is stated in terms of **error performance parameters** each of which is defined as follows:

"The percentage of averaging periods each of time interval $T_0$ during which the bit error ratio (BER) exceeds a threshold value. The percentage is assessed over a much longer time interval $T_L$" (see Note 3 to Table 1/G.821).

It should be noted that total time ($T_L$) is split into two parts, namely, time for which the connection is deemed to be available and that time when it is unavailable (see Annex A).

Requirements relating to the permissible percentage of unavailable time will be the subject of a separate Recommendation.

1.4 The following BERs and intervals are used in the statement of objectives:

a) a BER of less than $1 \cdot 10^{-6}$ for $T_0 = 1$ minute;

b) a BER of less than $1 \cdot 10^{-3}$ for $T_0 = 1$ second;

c) zero errors for $T_0 = 1$ second (equivalent to the concept of error free seconds EFS).

These categories equate to those of Table 1/G.821. In assessing these objectives periods of unavailability are excluded (see Annexes A and B.

1.5 The performance objectives aim to serve two main functions:

a) to give the user of future national and international digital networks an indication as to the expected error performance under real operating conditions, thus facilitating service planning and terminal equipment design;

b) to form the basis upon which performance standards are derived for transmission equipment and systems in an ISDN connection.

1.6 The performance objectives represent a compromise between a desire to meet service needs and a need to realize transmission systems taking into account economic and technical constraints. The performance objectives, although expressed to suit the needs of different services are intended to represent a single level of transmission quality.

The performance objective for degraded minutes (Table 1/G.821 a)) as stated, is based on an averaging period of one minute. This averaging period and the exclusion of errors occurring within severely errored seconds which occur during this one minute period (see Table 1/G.821, Note 2), may allow connections with frequent burst errors to meet this particular part of the overall objective, but such events will be controlled to a certain extent by the severely errored seconds objective (Table 1/G.821 b)). However, there is some doubt as to whether the objectives are adequate for proper operation of real-time video services with relatively long holding times, and this is the subject of further study.

1.7 Since the performance objectives are intended to satisfy the needs of the future digital network it must be recognized that such objectives cannot be readily achieved by all of today's digital equipment and systems. The intent, however, is to establish equipment design objectives that are compatible with the objectives in this Recommendation. These aspects are currently the subject of discussion within the CCITT and CCIR.

It is further urged that all technologies, wherever they appear in the network, should preferably be designed to better standards than those indicated here in order to minimize the possibility of exceeding the end-to-end objectives on significant numbers of real connections.

1.8 The objectives relate to a very long connection and recognizing that a large proportion of real international connections will be shorter, it is expected that a significant proportion of real connections will offer a better performance than the limiting value given in § 2. On the other hand, a small percentage of the connections will be longer and in this case may exceed the allowances outlined in this Recommendation.

## 2 Performance objectives

The performance objectives for an international ISDN connection as identified in §§ 1.1 and 1.2 are shown in Table 1/G.821. It is intended that international ISDN connections should meet all of the requirements of Table 1/G.821 concurrently. The connection fails to satisfy the objective if any one of the requirements is not met.

TABLE 1/G.821

**Error performance objectives for international ISDN connections**

| Performance classification | Objective |
|---|---|
| (a) (Degraded minutes) (Notes 1, 2) | Fewer than 10% of one-minute intervals to have a bit error ratio worse than $1 \cdot 10^{-6}$ (Note 4) |
| (b) (Severely errored seconds) (Note 1) | Fewer than 0.2% of one-second intervals to have a bit error ratio worse than $1 \cdot 10^{-3}$ |
| (c) (Errored seconds) (Note 1) | Fewer than 8% of one-second intervals to have any errors (equivalent to 92% error-free seconds) |

*Note 1* – The terms "degraded minutes", "severely errored seconds" and "errored seconds" are used as a convenient and concise performance objective "identifier". Their usage is not intended to imply the acceptability, or otherwise, of this level of performance.

*Note 2* – The one-minute intervals mentioned in Table 1/G.821 and in the notes are derived by removing unavailable time and severely errored seconds from the total time and then consecutively grouping the remaining seconds into blocks of 60. The basic one-second intervals are derived from a fixed time pattern.

*Note 3* – The time interval $T_L$, over which the percentages are to be assessed has not been specified since the period may depend upon the application. A period of the order of any one month is suggested as a reference.

*Note 4* – For practical reasons, at 64 kbit/s, a minute containing four errors (equivalent to an error ratio of $1.04 \times 10^{-6}$) is not considered degraded. However, this does not imply relaxation of the error ratio objective of $1 \cdot 10^{-6}$.

*Note 5* – Annex B illustrates how the overall performance should be assessed.

## 3 Allocation of overall objectives

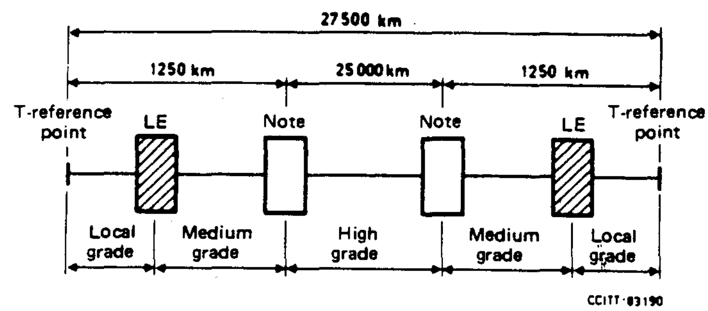
Since the objectives given in § 2 relate to an overall connection it is necessary to sub-divide this to constituent parts. This paragraph outlines the basic principles and strategy for apportioning the performance objectives.

The overall apportionment philosophy involves the use of two slightly different strategies, one applicable to the degraded minutes requirement and the errored seconds requirement (see classifications (a), (c)) and the other applicable to the severely errored seconds requirement (see classification (b)).

### 3.1 *Basic apportionment principles*

Apportionment is based on the assumed use of transmission systems having qualities falling into one of a limited number of different classifications.

Three distinct quality classifications have been identified representative of practical digital transmission circuits and are independent of the transmission systems used. These classifications are termed local grade, medium grade and high grade and their usage generally tends to be dependent on their location within a network (see Figure 1/G.821).




*Note* — It is not possible to provide a definition of the location of the boundary between the medium and high grade portions of the HRX. Note 4 to Table 2/G.821 provides further clarification of this point.

FIGURE 1/G.821

**Circuit quality demarcation of longest HRX**

The following general assumptions apply to the apportionment strategy that follows:

- in apportioning the objectives to the constituent elements of a connection it is the "% of time" that is subdivided;
- an equal apportionment of the objectives applies for both the degraded minutes and errored seconds requirements (classifications (a), (c));
- the error ratio threshold is not sub-divided. The rationale for this is based on the assumption that the performance of real circuits forming the parts of the HRX (Figure 1/G.821) will normally be significantly better than the degraded minute threshold (see Note to § 3.1);
- no account is taken of the error contribution from either digital switching elements or digital multiplex equipments on the basis that it is negligible in comparison with the contribution from transmission systems.

These quality classifications for different parts of the connection are considered to represent the situation for a large proportion of real international connections. Administrations are free to use whatever transmission systems they wish within their own networks and these other arrangements are considered as being completely acceptable provided that the overall performance of the national portion is no worse than it would have been if the standard CCITT arrangements had been employed.

It should be noted that a small percentage of connections will be longer than the 27 500 km HRX. By definition the extra connection length will be carried over high-grade circuits and hence the amount by which such connections exceed the total allowance envisaged in this Recommendation will be proportional to the amount by which the 25 000 km section is exceeded. Administrations should note that if the performance limits in the various classifications could be improved in practical implementations, the occurrence of these situations could be significantly reduced.

*Note* — For terrestrial systems the apportionment of the "degraded minute" performance classification to smaller entities (e.g. Hypothetical Reference Digital Section) may require sub-division of the error ratio objective, as well as the sub-division of "% of time", with distance. This is the subject of further study.

3.2 *Apportionment strategy for the degraded minutes and errored seconds requirements*

The apportionment of the permitted degradation, i.e. 10% degraded minutes and 8% errored seconds, is given in Table 2/G.821. The derived network performance objectives are given in Annex C.

TABLE 2/G.821

**Allocation of the degraded minutes and errored seconds objectives for the three circuit classifications**

| Circuit classification | Allocation of the degraded minutes and errored seconds objectives given in Table 1/G.821 |
|---|---|
| Local grade (2 ends) | 15% block allowance to each end (Notes 1, 4 and 5) |
| Medium grade (2 ends) | 15% block allowance to each end (Notes 2, 4 and 5) |
| High grade | 40% (equivalent to conceptual quality of 0.0016% per km for 25 000 km, but see Note to § 3.1) (Notes 3, 6 and 7) |

*Note 1* – The local grade apportionment is considered to be a block allowance, i.e. an allowance to that part of the connection regardless of length.

*Note 2* – The medium grade apportionment is considered to be a block allowance, i.e. an allowance to that part of the connection regardless of length. The actual length covered by the medium grade part of the connection will vary considerably from one country to another. Transmission systems in this classification exhibit a variation in quality falling between the other classifications.

*Note 3* – The high grade apportionment is divided on the basis of length resulting in a conceptual per kilometre allocation which can be used to derive a block allowance for a defined network model (e.g. Hypothetical Reference Digital Link).

*Note 4* – The local grade and medium grade portions are permitted to cover up the first 1250 km of the circuit from the T-reference point (see Figure 1/I.411) extending into the network. For example, in large countries this portion of the circuit may only reach the Primary Centre whilst in small countries it may go as far as the Secondary Centre, Tertiary Centre or the International Switching Centre (see Figure 1/G.821).

*Note 5* – Administrations may allocate the block allowances for the local and medium grade portions of the connection as necessary within the total allowance of 30% for any one end of the connection. This philosophy also applies to the objectives given for local and medium grades in Table 3/G.821.

*Note 6* – Based on the understanding that satellite error performance is largely independent of distance, a block allowance of 20% of the permitted degraded minutes and errored second objectives is allocated to a single satellite HRDP employed in the high-grade portion of the HRX.

*Note 7* – If the high-grade portion of a connection includes a satellite system and the remaining distance included in this category exceeds 12 500 km or if the high-grade portion of a non-satellite connection exceeds 25 000 km, then the objectives of this Recommendation may be exceeded. The occurrence of such connections is thought to be relatively rare and studies are continuing in order to investigate this. The concept of satellite equivalent distance (the length of an equivalent terrestrial path) is useful in this respect and it has been noted that a value in the range 10 000 to 13 000 km might be expected.

3.3 *Apportionment strategy for severely errored seconds*

The total allocation of 0.2% severely errored seconds is subdivided into each circuit classification (i.e. local, medium, high grades) in the following manner:

a) 0.1% is divided between the three circuit classifications in the same proportions as adopted for the other two objectives. This results in the allocation as shown in Table 3/G.821.

TABLE 3/G.821

**Allocation of severely errored seconds**

| Circuit classification | Allocation of severely errored seconds objectives |
|---|---|
| Local grade | 0.015% block allowance to each end (Note 5 to Table 2/G.821) |
| Medium grade | 0.015% block allowance to each end (Note 5 to Table 2/G.821) |
| High grade | 0.04% (Note 1) |

*Note 1* – For transmission systems covered by the high grade classification each 2500 km portion may contribute not more than 0.004%.

*Note 2* – For a satellite HRDP operating in the high grade portion there is a block allowance of 0.02% severely errored seconds (see also Note 6 to Table 2/G.821).

b) The remaining 0.1% is a block allowance to the medium and high grade classifications to accommodate the occurrence of adverse network conditions occasionally experienced (intended to mean the worst month of the year) on transmission systems. Because of the statistical nature of the occurrence of worst month effects in a world-wide connection, it is considered that the following allowances are consistent with the total 0.1% figure:

- 0.05% to a 2500 km HRDP for radio relay systems which can be used in the high grade and the medium grade portion of the connection;
- 0.01% to a satellite HRDP (the CCIR are continuing studies on severely errored seconds performance for satellite systems and this value may eventually need to be increased).

ANNEX A

(to Recommendation G.821)

**Available and unavailable time**

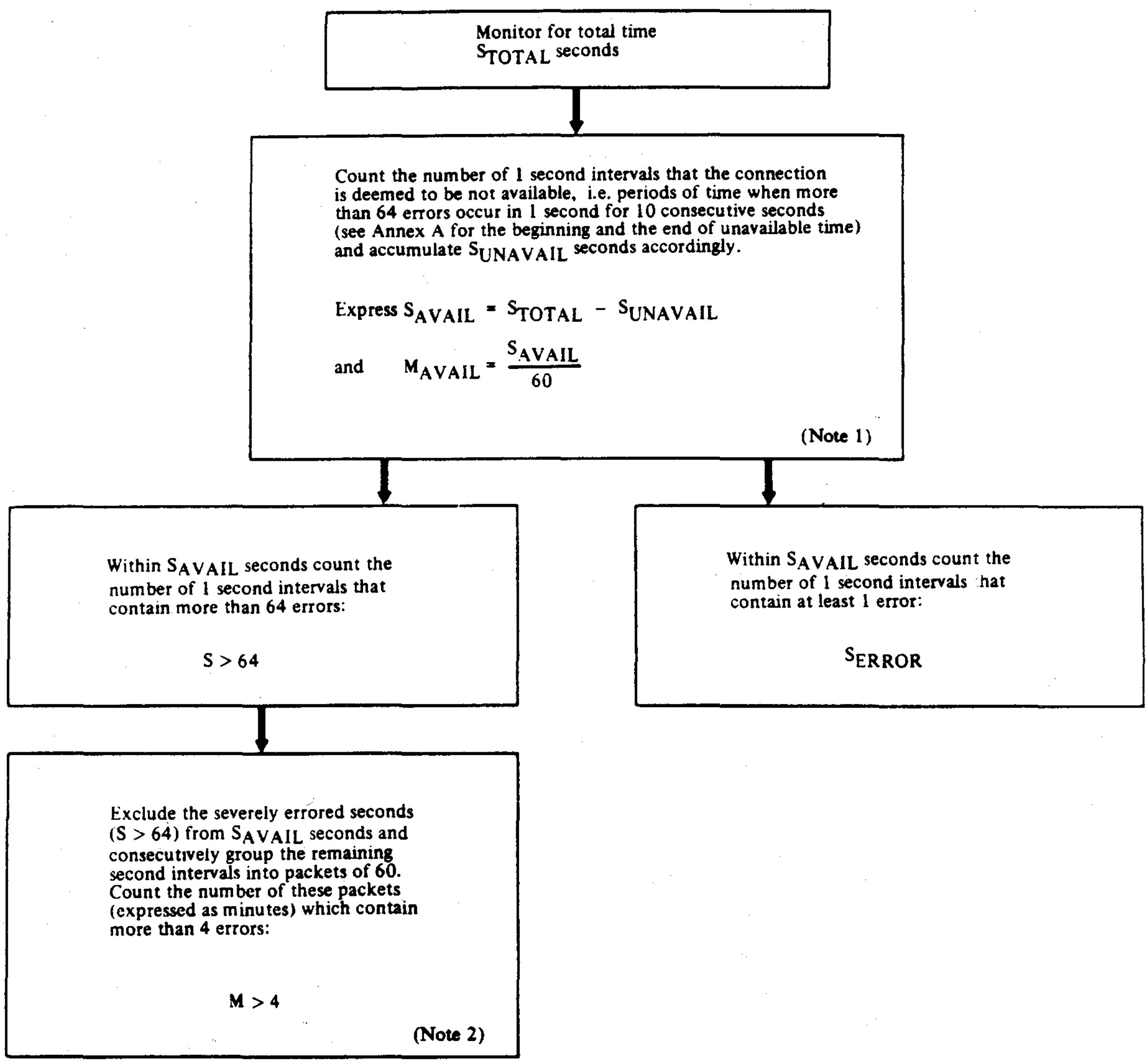
A period of unavailable time begins when the bit error ratio (BER) in each second is worse than $1 \cdot 10^{-}$ for a period of ten consecutive seconds. These ten seconds are considered to be unavailable time. The period of unavailable time terminates when the BER in each second is better than $1 \cdot 10^{-3}$ for a period of ten consecutive seconds. These ten seconds are considered to be available time.

Definitions concerning availability can be found in Recommendation G.106.

## ANNEX B

(to Recommendation G.821)

**Guidelines concerning the interpretation of Table 1/G.821**




*Note 1* — **The result is rounded off to the next higher integer.**

*Note 2* — **The last packet which may be incomplete is treated as if it were a complete packet with the same rules being applied.**

| Performance classification (see Table 1/G.821) | Objective |
|---|---|
| (a) | $\frac{M > 4}{M_{AVAIL}} < 10\%$ |
| (b) | $\frac{S > 64}{S_{AVAIL}} < 0.2\%$ |
| (c) | $\frac{S_{ERROR}}{S_{AVAIL}} < 8\%$ |

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## ANNEX C

(to Recommendation G.821)

**Allocation of objectives to constituent parts**

TABLE C-1/G.821

**Allocation of % degraded minute intervals and errored seconds objectives**

| Circuit classification (see Figure 2/G.821) | Network performance objectives at 64 kbit/s | |
|---|---|---|
| | % degraded minutes | % errored seconds |
| Local grade | 1.5 | 1.2 |
| Medium grade | 1.5 | 1.2 |
| High grade | 4.0 | 3.2 |


**Reference**

[1] CCITT Recommendation *Transmission performance objectives and recommendations*, Vol. III, Rec. G.102.

## APPENDIX C: DESCRIPTION OF DATA ACQUISITION SYSTEM SOFTWARE

The measurement system consists of six programs running simultaneously under the HP Windows System, which in turn, runs under UNIX on an HP 9000/330 system. A seventh program loads and initializes the programs before it terminates and allows the programs to run until interrupted by the operator. All interprocess communication is handled by messages sent and received by the individual processes. These messages contain operational information in addition to actual data collected. The data are accumulated and stored by one program in a disk file. When the file reaches a predetermined size, another program transfers the data file to tape. One program handles operator input. The remaining three programs collect data from the TRAMCON system, the channel probe, and the HP Data Acquisition System (HP-DAS).

**start.c:**

This is the main start-up program for the NPC/LPC measurement system. Two message queues are set up to allow the independent processes to communicate with each other. The tape handler process is started followed by a 2 second pause to assure that the process has reset properly. The program then starts the disk handler, TRAMCON data collector, channel probe data collector, and HP-DAS collector processes to run simultaneously. Finally, it starts the operator request handler, which then replaces the start program as the main controller program.

**tapehan.c:**

This program controls the cartridge tape changer for the NPC/LPC measurement system. It initially creates a window on the screen to display the status of the tape drive and current activity regarding writing data files to the tape. It then initializes the GPIB interface and commands the tape changer to load the first tape. After the tape is loaded, it waits for a message from either the disk handler indicating that a disk data file is full or the operator input program commanding it to take the tape off-line or put the tape on-line. If a data file is to be written to the tape, the program determines if there is enough room on the tape for another data file. If there is not, the current tape is first unloaded and the next tape is loaded (assuming that there is another tape. If not, an error is generated and the program exits). The data file is then written to the tape while the disk handler writes collected data to a new data file. Once the data file is written to the tape, it is deleted, and the tape handler program then waits for a new message (see Figures C-1 through C-3).

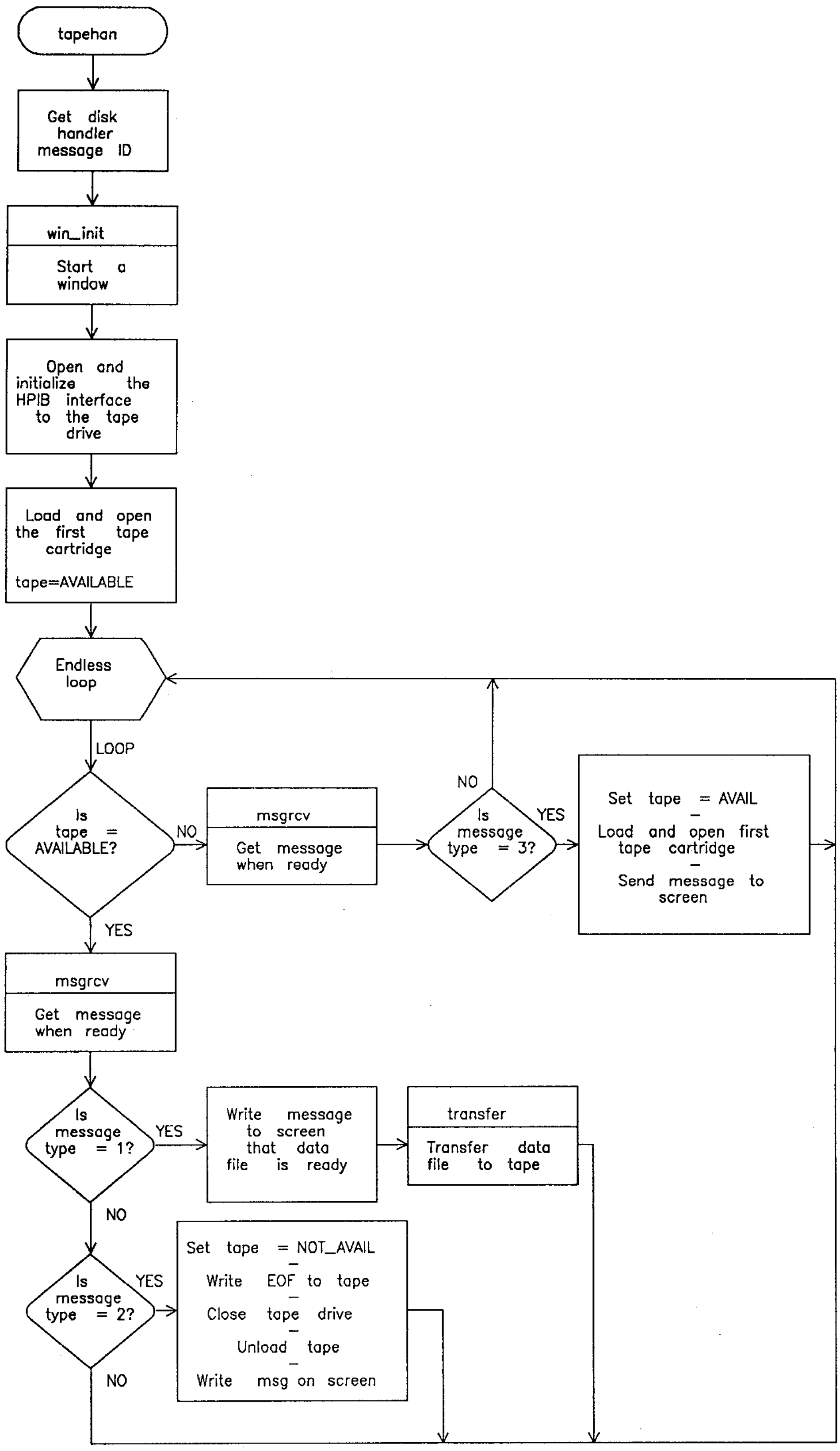


Figure C-1. Flow diagram for program TAPEHAN.

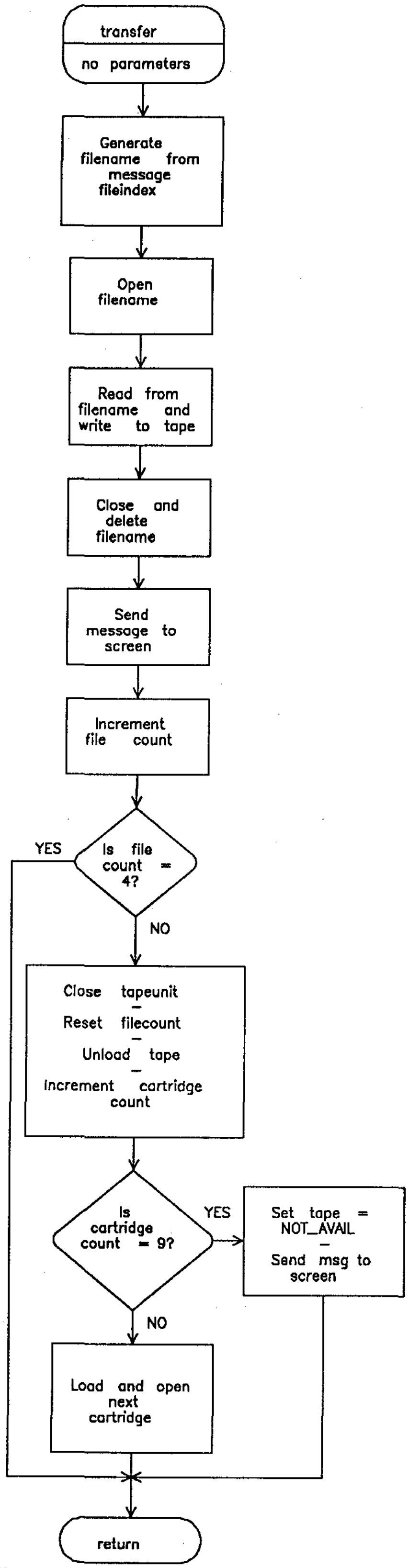


Figure C-2. Flow diagram for subroutine TRANSFER.

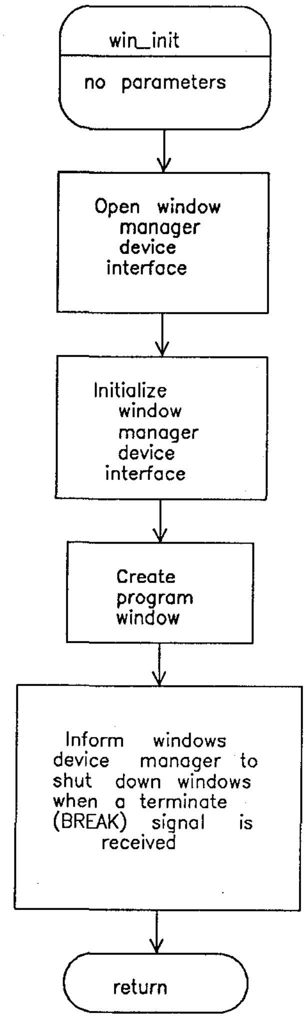


Figure C-3. Flow diagram for subroutine WIN_INIT.

**diskhan.c:**

This program controls the disk for the NPC/LPC system. It first opens two windows to display collected data. One, a graphics window, alternately plots the four channel probe signals and the two spectrum analyzer waveforms. The second window is a text window, which displays RSL, SQM, status and error information. The program then searches the disk for existing data

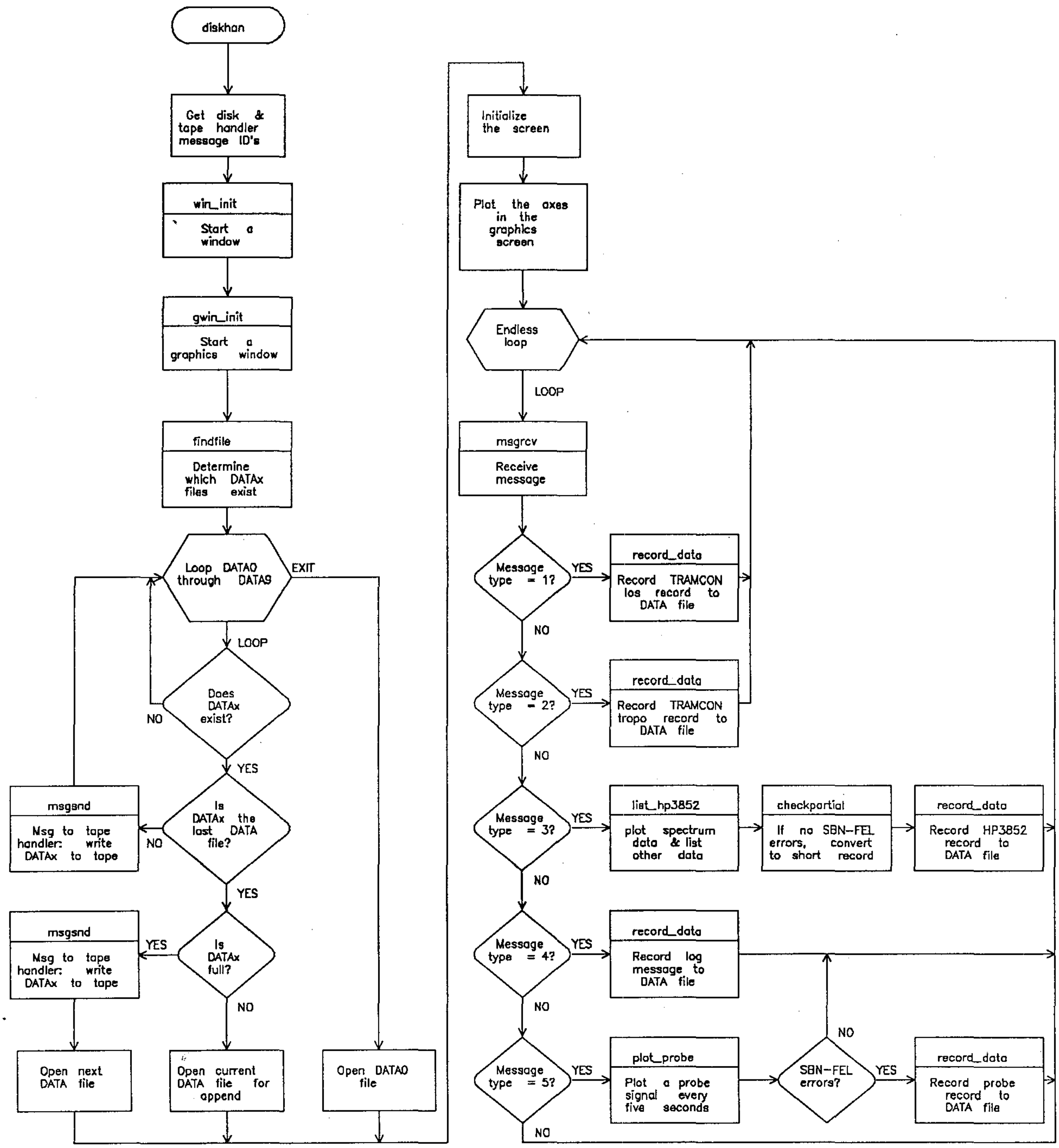


Figure C-4. Flow diagram for program DISKHAN.

files. For any full data files it finds, it sends a message to the tape handler program to write them to tape. While these files are being written the disk handler opens a new file and begins recording data. Any time the disk becomes full (for whatever reason), the handler displays an error message and discards data until space becomes available. Once the old data files have been taken care of and a new data file has been opened, the program then waits for messages from the three collection programs and stores each message in a disk file. These messages contain the data collected by these programs. All messages received from the TRAMCON program are stored in the data file. All messages received from the HP-DAS (RSL, SQM, radio status, error performance, and spectral

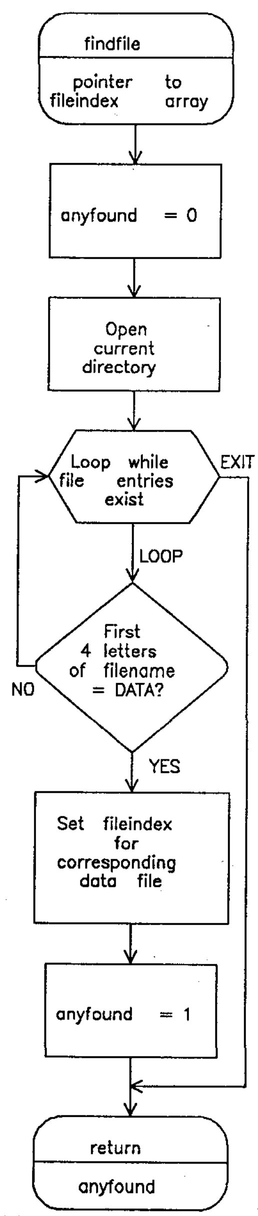


Figure C-5. Flow diagram for subroutine FINDFILE.

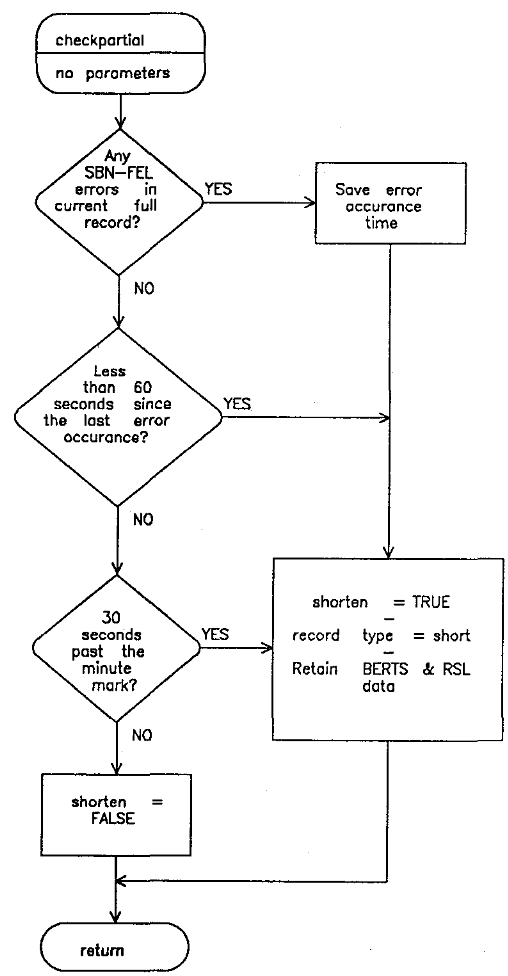


Figure C-6. Flow diagram for subroutine CHECKPARTIAL.

waveforms) are examined. If an error occurred on the Schwarzenborn to Feldberg 56-kb/s channel, an "error occurred" flag is set and the full record is written to the disk file. This flag then remains set for 60 seconds following the last occurrence of an error. Thus, for every second in a 60-second period following the last occurrence of an error, a full record is written to the disk. At any other time, the record is stripped to contain only RSL and error performance data. The exception is that once per minute (at 30 seconds after the minute), a full record is written to allow for monitoring of system conditions during error-free periods. When channel probe data are received, the "error occurred" and "1 minute" flags are examined. When set, the probe data are recorded. Otherwise, the data are discarded. Every time a full data record is recorded, a probe record is recorded as well. The disk handler also updates the text window every time a HP-DAS message is received. Every

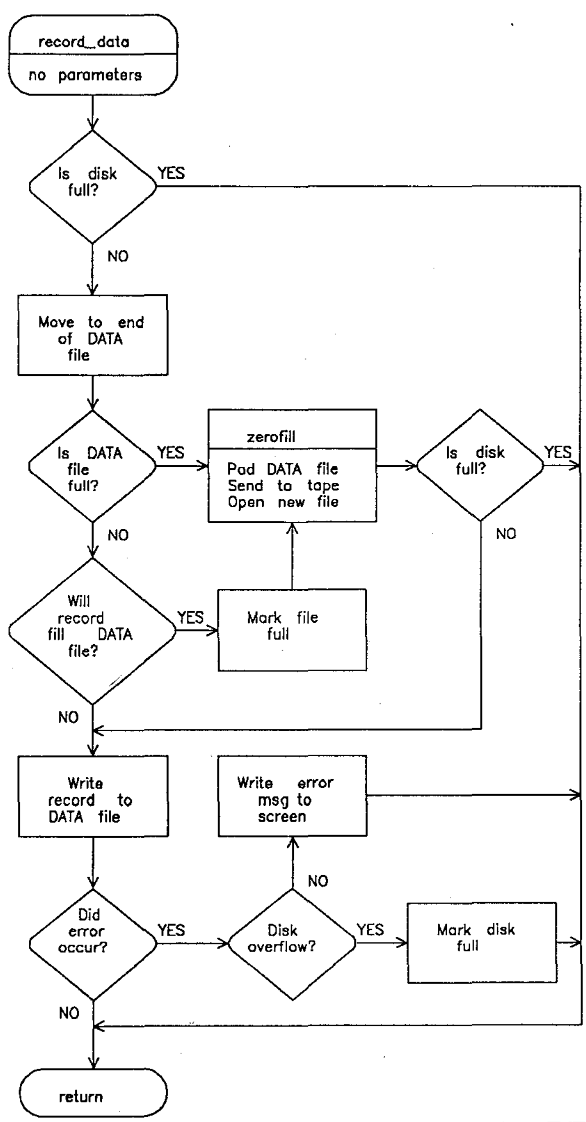


Figure C-7. Flow diagram for subroutine RECORD_DATA.

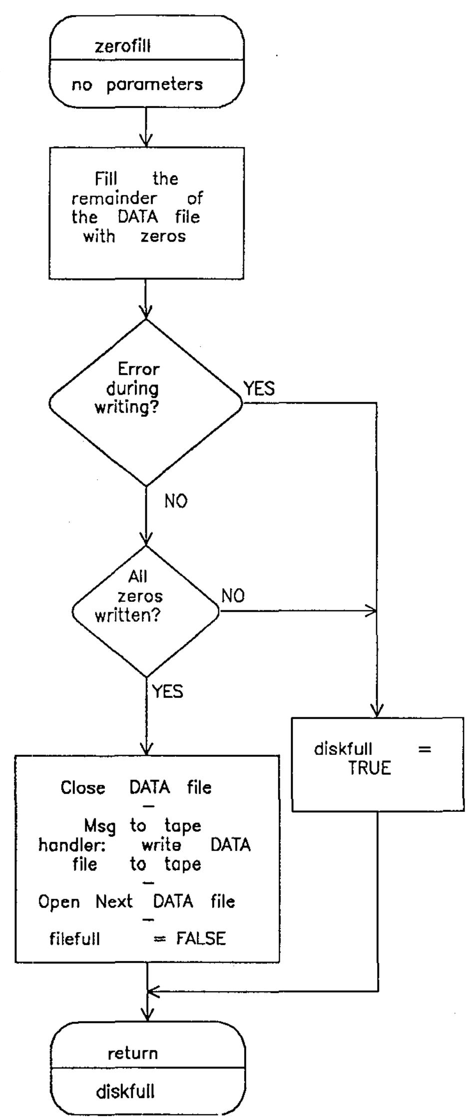


Figure C-8. Flow diagram for subroutine ZEROFILL.

five seconds, it displays a plot of the most recent probe and spectrum analyzer waveforms, cycling through the six waveforms twice per minute.

Finally, log messages may be received from the operator input program "reqhan." The log messages are time tagged and written to the disk data file to inform future data users of unusual situations encountered during data collection (see Figures C-4 through C-10).

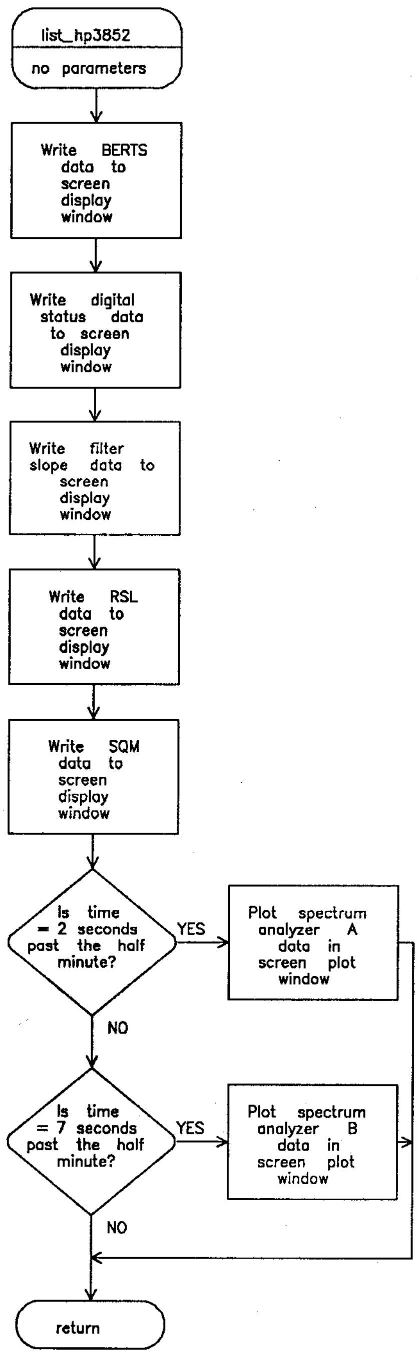


Figure C-9. Flow diagram for subroutine LIST_HP3852.

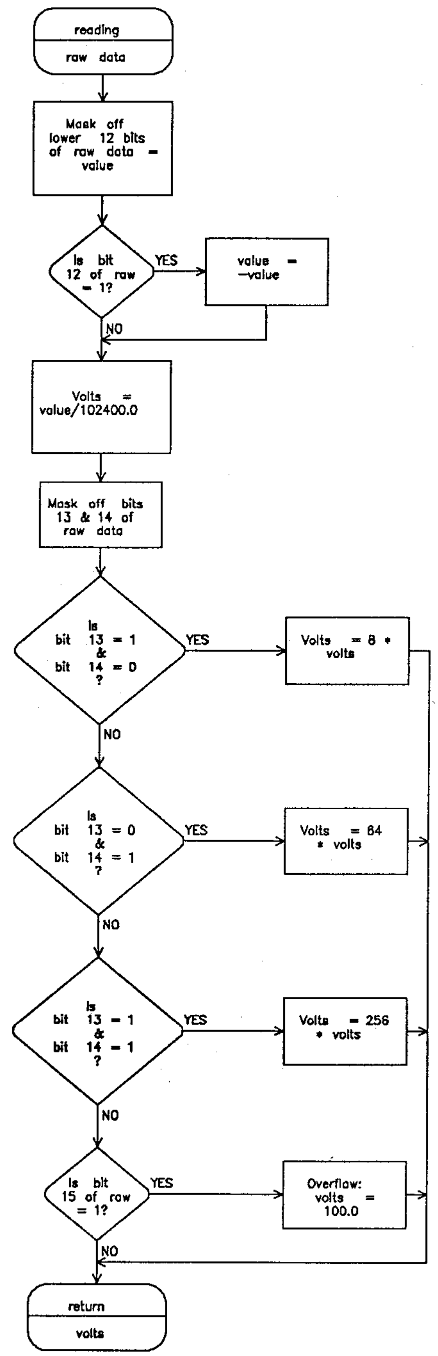


Figure C10. Flow diagram for subroutine READING.

**hp1000:**

This program handles the communication with the TRAMCON master computer (an HP1000). It first obtains the message ID for communication with the disk handler. It then opens a screen window to display the received TRAMCON messages. After opening the communication channel with the HP1000, it initializes the channel with the proper baud rate, parity, time-out values, etc. The screen window is then initialized with the appropriate column and row headings. Once this is complete, the program loops waiting for data from the HP1000. The HP1000 sends its data in 33-byte blocks, followed by an ENQ (ASCII 5). After an ACK (ASCII 6) is returned, the cycle continues until the entire record is received. At the end of the record, a series of three ENQ-ACK handshakes is required. If the record length is 39 bytes, it is declared to be a line-of-sight (LOS) record. Otherwise, it is a troposcatter record. The record, containing a byte identifying its type, is sent to the disk handler to be written to the disk data file. The record information (link id, time and date, alarms, and parameters) is written to the screen window as well (see Figures C-11 and C-12).

**probe:**

Even though the channel probe is read in through the HP3852 Data Acquisition System (DAS), it is handled separately from the rest of the measured parameters due to the speed at which it is collected and the manner in which it is transferred to the HP9000/330 computer. Unlike the other data, which are read over a GPIB interface, the probe data are read by a high-speed A/D converter and transferred to the computer over a high-speed GPIO (general-purpose I/O) interface.

This program first obtains the message ID to communicate with the disk handler. It then opens, resets, and initializes the GPIO channel, which communicates with the DAS. The DAS is initially programmed by the program "hp3852" (see the following section). It then waits in an endless loop for data from the probe. When the probe data are received (eighty samples each for the co- and quad-phases for the two probe channels, interleaved), they are sent to the disk handler, which then determines whether or not the data should be saved to the disk data file, depending on the status of the error-occurrence flag (see the preceding description of "diskhan"—see Figure C-13).

**m3852:**

The HP 3852 is a Data Acquisition System (DAS) that can be configured with various I/O modules to collect, measure, and control various external processes. In addition to a backplane, which can accept up to eight I/O modules, the DAS possesses a front panel keyboard (for optional operator input) and LCD display and an internal processor, allowing the DAS to perform off-line processing and collecting of data without requiring the intervention of the main computer. This

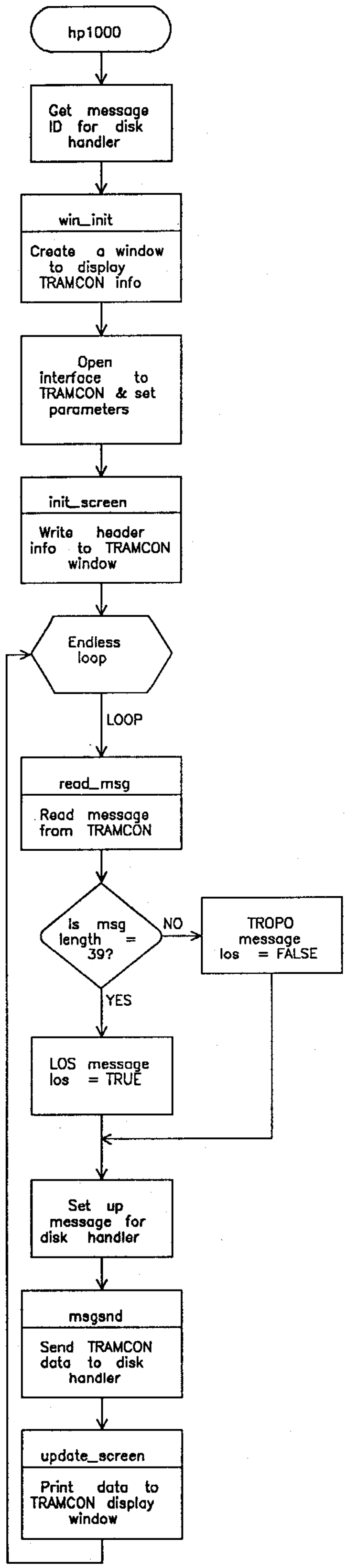


Figure C-11. Flow diagram for program HP1000.

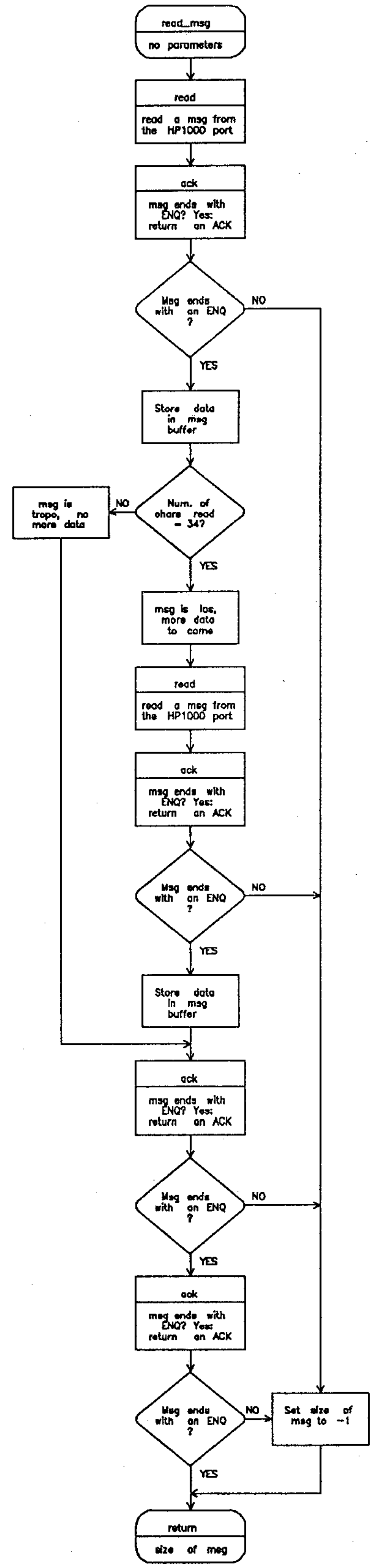


Figure C-12. Flow diagram for subroutine READ_MSG.

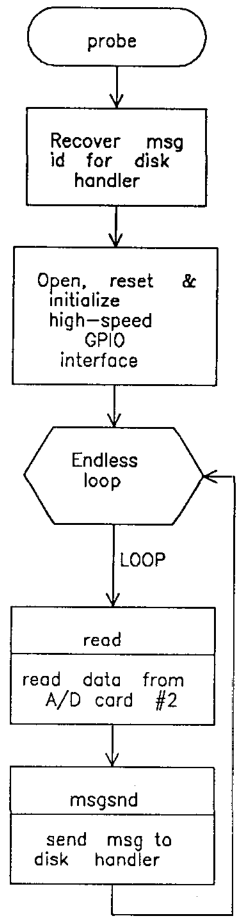


Figure C-13. Flow diagram for program PROBE.

allows the acquisition system to perform all of its independent processes simultaneously. The HP9000/330 communicates with the DAS over a GPIB interface. All low-speed data are also transferred over this interface. These data are collected with a counter/timer module (error performance), a parallel input module (digital status), and a high-speed A/D converter (RSL, SQM, and slope voltages and spectrum analysis curves). A second high-speed A/D converter collects the probe data and communicates with the main computer through a GPIO (high-speed parallel) interface. The DAS is synced with a signal received from an Omega global time standard receiver. The Omega receiver also sets the time of the main computer for time-tagging the received data, and syncs the sweep of the spectrum analyzers. The probe generates its own 1-second sweep signal, necessitating its own, independently synced A/D converter.

The program first recovers the message ID to communicate with the disk handler program. It then opens the GPIB interface channel, the HP3852 communications channel and the GPIO channel for communicating with the first (low-speed) A/D converter. Finally, it opens and initializes the RS-232 interface with the Omega clock. It then proceeds to program the HP3852.

It first resets the I/O modules and sends measurement set-up instructions, so that the DAS bases its timing on the pulses received from the Omega clock. The counter card's parameters are set up, followed by those for the first A/D card. The channel list for the first A/D card, which controls the input multiplexer, is initialized. The same is done for the second (high-speed) A/D card. However, its timing is controlled by the pulse from the channel probe. The DAS's pacer, which triggers the start of a measurement cycle, is set to start on the 1 second (the signal received from the Omega clock is at a 100-Hz rate). The counters reading the error performance data are set up to provide a reading five times per second for each of the five channels. The parallel input card is set up and the first GPIO channel is set up to read the data from the first A/D card. Finally, the date and time are read from the Omega clock and are used to reset the main computer's clock.

The program starts the DAS measurements and enters a loop, waiting for data. The first second's data are ignored to clear out any potentially erroneous data. Each time a block of data is received, it is assembled in the proper order. Every 60 seconds (on the minute) the main computer's clock is synced to avoid any drift with respect to the Omega's time. Finally, the data are sent to the disk handler program. Depending on the status of the error occurrence flag, either the full data record is written to the disk data file, or an abbreviated version containing only the error and RSL data (see Figure C-14).

**reqhan:**

This program accepts operator input to place the tape drive on- or off-line, or to input a log entry to the disk data file, should any unusual conditions occur warranting notification during subsequent analysis. The program first recovers the message ID's for the disk and tape handlers. It then opens a window listing the operator input options (1 to take the tape unit off-line, 2 to put it on-line and 3 to enter a log message). To begin with, the program writes a message to the status window that the data collection system has started. It then enters a loop waiting for input from the keyboard. If a "1" is received, it sends a log message stating, "Tape is off line," to the disk handler. A message is sent to the tape handler instructing it to place the tape drive off-line. If a "2" is received, it sends a log message stating, "Tape is on line," to the disk handler. A message is sent to the tape handler instructing it to place the tape drive on-line. If a "3" is received, input is collected from the keyboard and the log entry is sent to the disk handler (see Figure C-15).

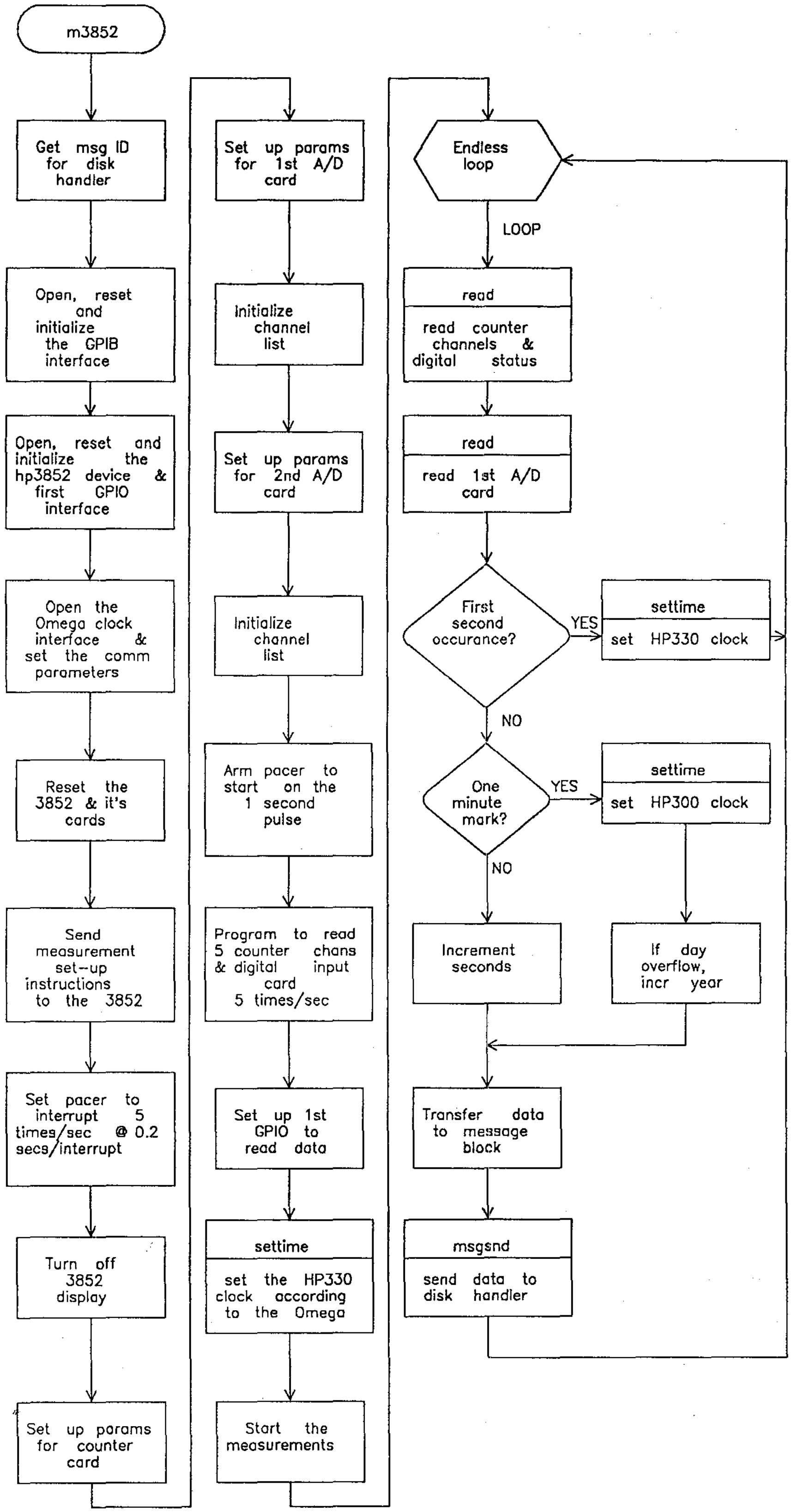


Figure C-14. Flow diagram for program M3852.

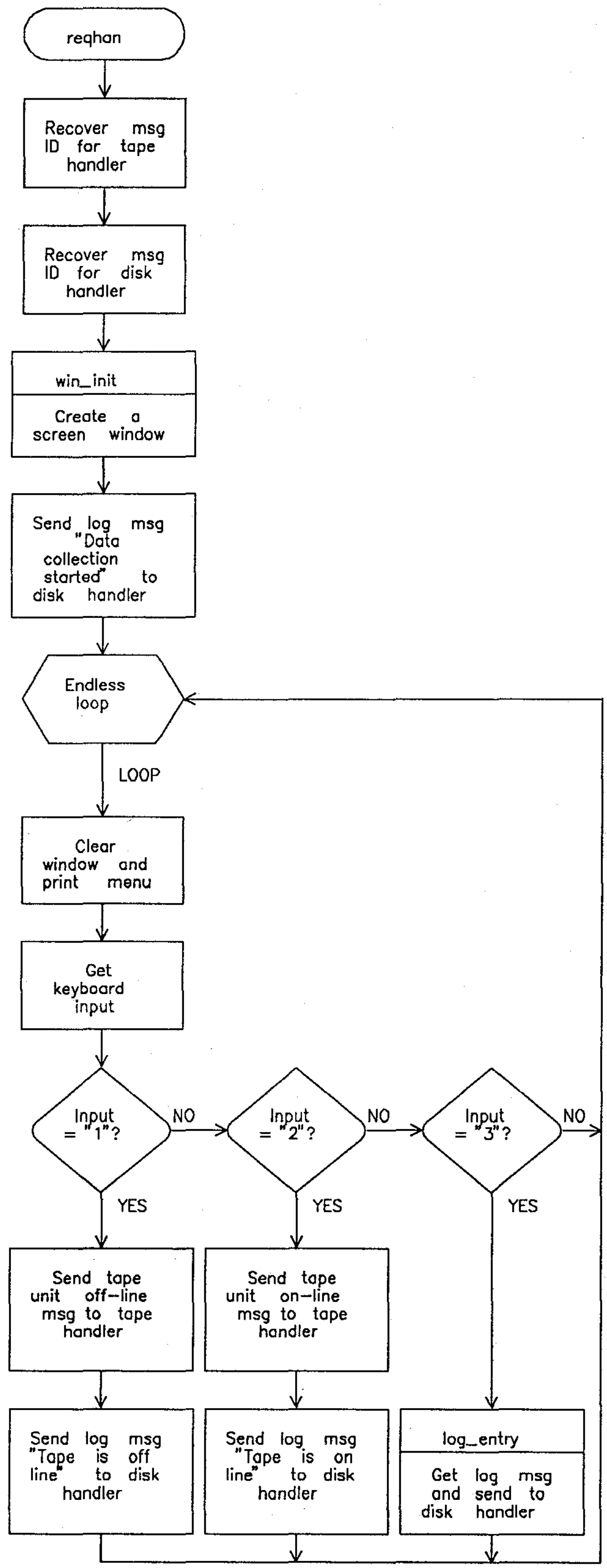


Figure C-15. Flow diagram for program REQHAN.

# APPENDIX D: DESCRIPTION OF DATA ANALYSIS ALGORITHMS AND SOFTWARE

## D.1 Introduction to data analysis

It is the primary objective of data analysis to measure (or derive from measured data) the statistics described in Tables 1 and 2 of the statement of work for DCS Network Performance Characterization and to obtain the statistics describing the performance of the DRAMA radio described in the statement of work for Feldberg-Schwarzenborn Link-Performance Characterization. It is also an objective to present these statistics in the clearest possible way as quickly as possible after they are obtained. To describe the analysis scheme, certain concepts are used that need to be defined before additional explanation is attempted.

### D.1.1 Definitions

In some cases, these definitions are limited in their scope. They should only to be applied to understanding this ITS data analysis. The definitions are as follows:

Errored second

An errored second is a clock second in which at least one error occurs in a 64-kb/s or 56-kb/s channel. The second is a clock second (the error does not start an errored second when the first error occurs after a period of more than a second without errors).

Error event

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

A 15-minute data block

A 15-minute data block is a block of data recorded by ITS that starts on the hour or on whole 15-minute intervals past the hour.

Unavailability time (Draft MIL-STD-188-323)

According to draft MIL-STD-188-323: "Unavailability is defined 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 (1 minute) or greater."

Unavailability time (Recommendation G.821)

The definition from CCITT Recommendation G.821 is: "A period of unavailable time begins when the bit error ratio (BER) in each second is worse than $1 \times 10^{-3}$ for a period of 10 consecutive seconds. These 10 seconds are considered to be unavailable time. The period of unavailable time terminates when the BER in each second is better than $1 \times 10^{-3}$ for a period of 10 consecutive seconds. These 10 seconds are considered to be available time."

Amplitude distortion (based on spectrum analyzer output)

Amplitude distortion values are derived from the spectrum analyzer output, which is linear in dB. The IF spectrum is sampled at intervals of 400 KHz. The 21 samples closest to 70 MHz (the center of the IF band) are converted to dB 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 5 times per second, representing the multipath distorted spectrums. 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 that point plus 400 KHz, and the resulting value is divided by 0.4 MHz to obtain the distortion between adjacent points from these 20 distortion values; the one 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 60 seconds.
2) Any alarm occurred that could not be caused by the observed 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 is 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 but the RSL values on the two receivers were different 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 within 1 minute of the event the following conditions prevailed:

1) An RSL value on either receiver was measured that was more than 6 dB below the median on either receiver, but the RSL values on the two receivers were never different 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 (for an LOS path using vertically spaced antennas)

If receivers are switched based on the values 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 at 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 at 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 dB) is 10 times the log to the base 10 of the ratio of the median received signal level (RSL) to the RSL at which flat fading causes the BER to increase above a specified threshold value (for this analysis, BER = 1/64000).

Composite-fade margin (see the calculations section on composite and dispersive fade margins from measured data)

Dispersive-fade margin (see the calculations section on composite and dispersive fade margins from measured data)

### D.1.2 Organization of data analysis

The data analysis consists of five types of operations:

- Conditioning
- Categorizing
- Calculating
- Accumulating
- Presenting

These five general types of operations generally take place in the order in which they are listed but calculations and categorizations are often interspersed with the other operations. The raw FEL data are pre-processed to make analysis efficient. This operation includes removing blocks of data that were obtained when the test system had failed or was out of calibration. Pre-processing also includes transferring the raw data from tape to disk.

After pre-processing, the raw data are taken from a file and processed in 15-minute blocks.To do the analysis, intermediate data arrays are used to hold and process the raw data. Three of these blocks are held in memory at one time to provide smooth transitions at block edges for overlapping error events. A 45-minute period of data is held in three 15-minute blocks. The three 15-minute blocks are called "LAST", "CURRENT", and "NEXT". "LAST" means last to be analyzed. "CURRENT" means currently being analyzed. "NEXT" means next to be analyzed. If the "CURRENT" data block is valid (the test system was working properly), the 15-minute blocks are analyzed further. Errored seconds are assigned to particular error-events in the "NEXT" section. For the error events in the "CURRENT" data block, source-link and cause flags are assigned for each error event. If a 15-minute data block is missing more than 10 seconds of data, it is not counted as part of the test period. At the end of the test period, all data-analysis-accumulation files are achieved on tape.

From the 15-minute intermediate data arrays, analysis software performs additional calculations and organizes the data into accumulation arrays that are compatible with the data output programs. In general, the accumulation arrays correspond to sets of graphs and tables. In arrays corresponding to distributions, the data are held as counts of samples at particular values. For correlations, the data are held as value pairs corresponding to time increments. For ordinary functions and tables, the processed data are held as value pairs. The accumulated results of each test period are archived so that 12- and 18-month analyses can be made at the end of the project.

The formatting software modules automatically prepare a report from the accumulation arrays, to the degree that this is possible. Graphs and tables for the report are produced for each test period. To draw graphs, a separate program does final data preparation and makes the graphs. The program calculates labeling and scale constants for the first graph. A separate program processes the data from the accumulation file and transfers the data into a file compatible with data plotting. The main program then continues drawing scales, labeling, and plotting the curves from the graph files just created. The program repeats this cycle for each graph. A similar program is used to print the tables.

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

1) The program SCAN is run. It reads the data from an individual tape and creates a printable output that summarizes record (long, short and TRAMCON) count, receiver status (receiver-on-line, manual mode) count, errored second count and average rsl's for each 15-minute block.
2) Using the SCAN output, the operator enters the start and end times of all valid data periods.
3) Raw data are transferred from tape to a disk file on the analysis computer system.
4) Data accumulation arrays are loaded from data accumulation files.
5) The intermediate arrays are loaded from the intermediate files.
6) The tape block is cycled through in 15-minute increments.
7) At the end of the tape, intermediate arrays are saved to intermediate files and accumulation arrays are saved to accumulation files.

After all of the data collected over the test period have been analyzed, data from the accumulation arrays are processed by the data-formatting software modules and converted into suitable hard-copy output.

To categorize data, the concept of an error event is used. An error event is a contiguous set of errored seconds on a data channel. To show how the data acquired by the HP3852 data acquisition and control system at Feldberg are categorized, an outline of that data classification is presented as follows:

A) Information for each **errored second** for each of the 64-kb/s channels, from Berlin to Feldberg and from Linderhofe to Feldberg, is obtained as follows:
   1) Errored-Second Occurrence Time
   2) Number of Errors

3) Error-event Number
4) Performance Flags
   1) For this second, is BER worse than $10^{-3}$?
   2) For this second, is BER worse than $10^{-4}$?
   3) Is this second MIL-STD-188-323 unavailability time?
   4) Is this second Recommendation G.821 unavailability time?

B) Information for each **error event** for each of the 64-kb/s channels, from Berlin to Feldberg and from Linderhofe to Feldberg, is obtained as follows:
1) Error-event Number
2) Error-event start time
3) Duration of the error event in seconds
4) Source-link flags
   1) Source link is BLN-BBG
   2) Source link is BBG-KBG
   3) Source link is LDF-KBG
   4) Source link is KBG-RWN
   5) Source link is RWN-SBN
   6) Source link is SBN-FEL
   7) Source link is unidentified
5) Error-cause flags
   1) Cause is troposcatter propagation
   2) Cause is rain attenuation
   3) Cause is multipath
   4) Cause is equipment
   5) Cause is unidentified
6) Performance Flags
   1) During the event, was frame lost?
   2) Did this event contain MIL-STD-188-323 unavailability time?
   3) Did this event contain Recommendation G.821 unavailability time?
   4) Was the number of errors for the first second of the event greater than 16000?

C) Information for each **15-minute period** for each of the 64-kb/s channels, from Berlin to Feldberg and from Linderhofe to Feldberg, is obtained as follows:
1) The 15-minute-period start time
2) What is the valid-15-minute-test-period sum in the current test period for the 64-kb/s channels?
3) Number of both errors and errored seconds from all causes (not including unavail-ability time) for:
   1) BLN-BBG (Berlin to Feldberg channel)
   2) BBG-KBG (Berlin to Feldberg channel)
   3) KBG-RWN (Berlin to Feldberg channel)
   4) RWN-SBN (Berlin to Feldberg channel)
   5) SBN-FEL (Berlin to Feldberg channel)
   6) BLN-FEL (Berlin to Feldberg channel)
   7) LDF-KBG (Linderhofe to Feldberg channel)
   8) KBG-RWN (Linderhofe to Feldberg channel)
   9) RWN-SBN (Linderhofe to Feldberg channel)
   10) SBN-FEL (Linderhofe to Feldberg channel)
   11) LDF-FEL (Linderhofe to Feldberg channel)
   12) Link Unidentified (Berlin to Feldberg channel)

13) Link Unidentified (Linderhofe to Feldberg channel)

4) Number of both errors and errored seconds caused by equipment (not including unavailability time) for:
   1) BLN-BBG (Berlin to Feldberg channel)
   2) BBG-KBG (Berlin to Feldberg channel)
   3) KBG-RWN (Berlin to Feldberg channel)
   4) RWN-SBN (Berlin to Feldberg channel)
   5) SBN-FEL (Berlin to Feldberg channel)
   6) BLN-FEL (Berlin to Feldberg channel)
   7) LDF-KBG (Linderhofe to Feldberg channel)
   8) KBG-RWN (Linderhofe to Feldberg channel)
   9) RWN-SBN (Linderhofe to Feldberg channel)
   10) SBN-FEL (Linderhofe to Feldberg channel)
   11) LDF-FEL (Linderhofe to Feldberg channel)

5) Number of both errors and errored seconds caused by multipath (not including unavailability time) for:
   1) BBG-KBG (Berlin to Feldberg channel)
   2) KBG-RWN (Berlin to Feldberg channel)
   3) RWN-SBN (Berlin to Feldberg channel)
   4) SBN-FEL (Berlin to Feldberg channel)
   5) BLN-FEL (Berlin to Feldberg channel)
   6) LDF-KBG (Linderhofe to Feldberg channel)
   7) KBG-RWN (Linderhofe to Feldberg channel)
   8) RWN-SBN (Linderhofe to Feldberg channel)
   9) SBN-FEL (Linderhofe to Feldberg channel)
   10) LDF-FEL (Linderhofe to Feldberg channel)

6) Number of both errors and errored seconds caused by troposcatter (not including unavailability time) for:
   1) BLN-BBG (Berlin to Feldberg channel)
   2) BLN-FEL (Berlin to Feldberg channel)

7) Current quiet running average RSL for both the A and B receivers in both the North to South and South to North directions for:
   1) BBG-KBG
   2) KBG-RWN
   3) RWN-SBN
   4) SBN-FEL
   5) LDF-KBG

D) Information for each **errored second** or **multipath-fading second** for the 56 kb/s channel (Feldberg-Schwarzenborn link) for each receiver (A and B) is obtained as follows:

1) Errored-second Occurrence Time
2) Number of Errors in the second
3) Error-event Number
4) Performance Flags
   1) For this second, is BER worse than $10^{-3}$?
   2) For this second, is BER worse than $10^{-4}$?
   3) Is this second MIL-STD-188-323 unavailability time?
   4) Is this second Recommendation G.821 unavailability time?
   5) Is the frame-loss alarm on?
   6) Is this second a multipath fading second?
   7) During the second was there a notch in the IF band?
5) Period that rsl is less than BER threshold in fifth-seconds
6) Number of errors during each of the five 0.2-second periods

7) rsl during each of the five 0.2-second periods
8) Signal-quality monitor value during each of the five 0.2 second periods
9) Slope distortion from distortion monitor (from two IF filters) during each of the five 0.2-second periods
10) Slope distortion from the spectrum analyzer (across the band) during each of the five 0.2-second periods
11) Slope distortion from the spectrum analyzer (slope between adjacent points) during each of the five 0.2 second periods
12) Indication of the receiver on line (A Recv = 1 and B Recv = 2) during each of the five 0.2-second periods

E) Information for each **errored second** or **multipath-fading second** for the 56-kb/s channel (Feldberg-Schwarzenborn link) for the receiver-on-line is obtained as follows:
1) Errored-second Occurrence Time
2) Number of Errors in the second
3) Error Event Number
4) Performance Flags
    1) For this second, is BER worse than $10^{-3}$?
    2) For this second, is BER worse than $10^{-4}$?
    3) Is this second MIL-STD-188-323 unavailability time?
    4) Is this second Recommendation G.821 unavailability time?
    5) Is the frame-loss alarm on?
    6) Is this second a multipath-fading second?
    7) During the second was there a notch in the IF band?
5) Period that rsl is less than BER threshold in fifth-seconds
6) Number of errors during each of the five 0.2-second periods
7) rsl during each of the five 0.2-second periods

F) Information from both the A and B channels of the Probe for each **errored second** or **multipath-fading second** for the Feldberg-Schwarzenborn link is obtained as follows:
1) Ratio of direct to 1st and 2nd delayed signal amplitudes (dB)
2) Delay between direct and 1st and 2nd delayed signals (nanoseconds)
3) Phase of the delayed signal (degrees)
4) Rate of change of amplitude ratio (dB/s)
5) Rate of change of delay (ns/s)
6) Rate of change of phase (degrees/s)

G) Information for each **error event** for the 56-kb/s channel (Feldberg-Schwarzenborn link) for each receiver (A, B, and the receiver-on-line) is obtained as follows:
1) Error Event Number
2) Error event start time
3) Duration of the error event in seconds
4) Second at which the radio frame-loss alarm came on
5) Error-cause flag
    1) Cause is troposcatter propagation
    2) Cause is power fading
    3) Cause is multipath
    4) Cause is equipment
    5) Cause is unidentified
6) Performance Flags
    1) During the event, was frame lost?
    2) Did this event contain MIL-STD-188-323 unavailability time?

from the special monitoring equipment on the SBN-FEL link to help further in the allocation of errors to individual links. Figures D1 through D6 trace these allocation procedures. After errors are assigned to individual links, the cause of errors can be allocated based on the TRAMCON data and data from the other monitoring systems (Figure D7). A clarification of the meaning of certain TRAMCON alarms is provided in Figure D8 and Table D1. The allocation processes are based on certain assumptions, which are listed as follows:

1) Outages are so infrequent that any error event should be allocated to no more than two links. In other words, all errored seconds in an error event have the same error-event source link or links.
2) Outages are so infrequent that there is only one cause of an error event. In other words, all errored seconds in an error event have the same cause.
3) If there are more than five errors in one 64-kb/s channel, there will be at least one error in any other particular channel if a digroup has not failed. If there are more than five errors in one 64-kb/s channel, the probability of an error in any other particular channel is greater than 99 percent if the applicable digroup has not failed. This conclusion is based on the assumption that the errors are randomly distributed in the whole radio mission bit stream.
4) If there is a complete outage of a radio mission bit stream, there is only one error-event-source link and it is the link just beyond the farthest terminal end from FEL that shows a TRAMCON indication of outage at the FEL TRAMCON terminal.
5) If there are several indicators of an error-event source link and the indicators have different priorities of indicating an event, the priorities are those shown in Figure D6 and the source link or links are only those whose indicators are "on" with the same and highest priority.
6) Except for rsl values, the TRAMCON alarms and values that are applicable to the analysis of an error event are ones observed immediately before, during, or immediately after the start of an error event.

**Table D1. TRAMCON alarms for the DRAMA radio equipment**

| ALARM NO. | ALARM NAME | ALARM NO. | ALARM NAME |
|---|---|---|---|
| 0 | Radio Power Supply Failed [A or B] | 34 | TDM 2 Output Port Loss - B Side |
| 1 | Radio A Side Failure | 35 | Service Channel Mux Failed |
| 2 | Radio B Side Failure | 36 | Digroup #1 MBS 1 Failed |
| 3 | Radio Xmit Freq. Drift [A or B] | 37 | Digroup #2 MBS 1 Failed |
| 4 | Radio Modulator Failed [A or B] | 38 | Digroup #3 MBS 1 Failed |
| 5 | Radio MBS 1 XMT Failed [A or B] | 39 | Digroup #4 MBS 1 Failed |
| 6 | Radio MBS 2 XMT Failed [A or B] | 40 | Digroup #5 MBS 1 Failed |
| 7 | Radio SCBS XMT Failed [A or B] | 41 | Digroup #6 MBS 1 Failed |
| 8 | Radio MBS 1 RCV Failed [A or B] | 42 | Digroup #7 MBS 2 Failed |
| 9 | Radio MBS 2 RCV Failed [A or B] | 43 | Digroup #8 MBS 2 Failed |
| 10 | Radio SCBS RCV Failed [A or B] | 44 | Digroup #1 MBS 2 Failed |
| 11 | Radio Demodulator Failed [A or B] | 45 | Digroup #2 MBS 2 Failed |
| 12 | Radio Frame Sync Loss [A or B] | 46 | Digroup #3 MBS 2 Failed |
| 13 | Radio Xmit Power Failed [A or B] | 47 | Digroup #4 MBS 2 Failed |
| 14 | Crypto 1 Failed | 48 | Digroup #5 MBS 2 Failed |
| 15 | Crypto 2 Failed | 49 | Digroup #6 MBS 2 Failed |
| 16 | Crypto 1 Bypassed | 50 | Digroup #7 MBS 2 Failed |

| | | | |
|---|---|---|---|
| 17 | Crypto 2 Bypassed | 51 | Digroup #8 MBS 2 Failed |
| 18 | TDM 1 Power Supply Failed | 52 | Radio Transmitter A On Line |
| 19 | TDM 1 Frame Loss | 53 | Radio Transmitter B On Line |
| 20 | TDM 1 RCV MBS Data Loss | 54 | Radio Receiver A On Line |
| 21 | TDM 1 XMT MBS Data Loss | 55 | Radio Receiver B On Line |
| 22 | TDM 1 Input Port Loss - A Side | 56 | TDM 1 A Side On-Line |
| 23 | TDM 1 Input Port Loss - B Side | 57 | TDM 1 B Side On-Line |
| 24 | TDM 1 Output Port Loss - A Side | 58 | TDM 2 A Side On-Line |
| 25 | TDM 1 Output Port Loss - B Side | 59 | TDM 2 B Side On-Line |
| 27 | TDM 2 Power Supply Failed | 60 | TDM 1 Manual Switchover Achieved |
| 28 | TDM 2 Frame Loss | 61 | TDM 1 Auto Switchover Achieved |
| 29 | TDM 2 RCV MBS Data Loss | 62 | TDM 2 Manual Switchover Achieved |
| 30 | TDM 2 XMT MBS Data Loss | 63 | TDM 2 Auto Switchover Achieved |
| 31 | TDM 2 Input Port Loss - A Side | 66 | Radio Transmitter in Manual Mode |
| 32 | TDM 2 Input Port Loss - B Side | 67 | Radio Receiver in Manual Mode |
| 33 | TDM 2 Output Port Loss - A Side | | |

**TRAMCON link end designations**

| REMOTE | SITE | END NO. | PATH | LINKEND ID | TYPE OF LINK END |
|---|---|---|---|---|---|
| 1) | FEL | 0 | SBN-FEL | 3 | RECV, NEAR END, LOS |
| 3) | SBN | 0 | SBN-FEL | 9 | XMIT, FAR END, LOS |
| | SBN | 1 | RWN-SBN | 10 | RECV, NEAR END, LOS |
| 4) | RWN | 0 | KBG-RWN | 12 | RECV, NEAR END, LOS |
| | RWN | 1 | RWN-SBN | 13 | XMIT, FAR END, LOS |
| 5) | KBG | 0 | KBG-RWN | 15 | XMIT, FAR END, LOS |
| | KBG | 1 | LDF-KBG | 16 | RECV, NEAR END, LOS |
| 6) | KBG | 2 | BBG-KBG | 17 | RECV, NEAR END, LOS |
| 7) | LDF | 1 | LDF-KBG | 19 | XMIT, FAR END, LOS |
| | BBG | 0 | BLN-BBG | 21 | RECV, NEAR END, TROPO |
| 10) | BBG | 2 | BBG-KBG | 23 | XMIT, FAR END, LOS |
| | BLN | 0 | BLN-BBG | 30 | XMIT, FAR END, TROPO |

## D.5.1 Error-event source link identification

In this section, the algorithms shown on Figures D1 through D6 are examined in detail with points of discussion in direct correspondence with the numbering of the blocks in the figures.

### D.5.1.1 Examination of Figure D1

In this figure, the process of allocating the error-event-source links to the individual links is started.

1) At the start, we assume that the error events have been numbered sequentially for each of the two channels and that the channels are properly identified. Each error event for both channels is examined, in turn, starting at this point.
2) If the error event is identified with the BLN-FEL/64 channel, we move to block 3. If it is identified with LDF-FEL/64, we move to block 5.

3) This block tests if this digroup (alarm 51) and not more than 2 digroups from BLN (more than 1 of alarms 48, 49, and 50) show an alarm at FEL. Consider that for the channel from BLN to FEL, the mission bit stream is broken down into digroups only at sites with FCC-99 port cards, with most of the digroup equipment at BLN and at FEL. That consideration means that if only the digroup (which supports the test channel bit stream) alarm is "on" at FEL, then either one of the port cards at sites with FCC-99s, an FCC-98 digroup transmitter at BLN, or the digroup receiver at FEL has failed. If the decision is no, then the algorithm prepares to examine the source links on the basis of coincidental error events (entry point B, Figure D3).

4) This block recognizes the consideration described in block 3 and prepares to examine all links with port electronics on the basis of their port-alarm states (entry point A, Figure D2).

5) This block tests if this digroup (alarm 36 or 37 but not both) and not more than 2 digroups (not more than 1 of alarms 38, 39, 40, 41, and 42) show an alarm at FEL. Consider that for the channel from LDF to FEL, the mission bit stream is broken down into digroups only at sites with FCC-99 port cards, with most of the digroup equipment at LDF and at FEL. That consideration means that if only the digroup (which supports the test channel bit stream) alarm is "on" at FEL, then either one of the port cards at sites with FCC-99s, an FCC-98 digroup transmitter at LDF, or the digroup receiver at FEL has failed. If the decision is no, then the algorithm prepares to examine the source links on the basis of coincidental error events (entry point E, Figure D5).

6) Block 6 recognizes the consideration described in block 5 and prepares to examine all links with port electronics on the basis of their port-alarm states (entry point D, Figure D4).

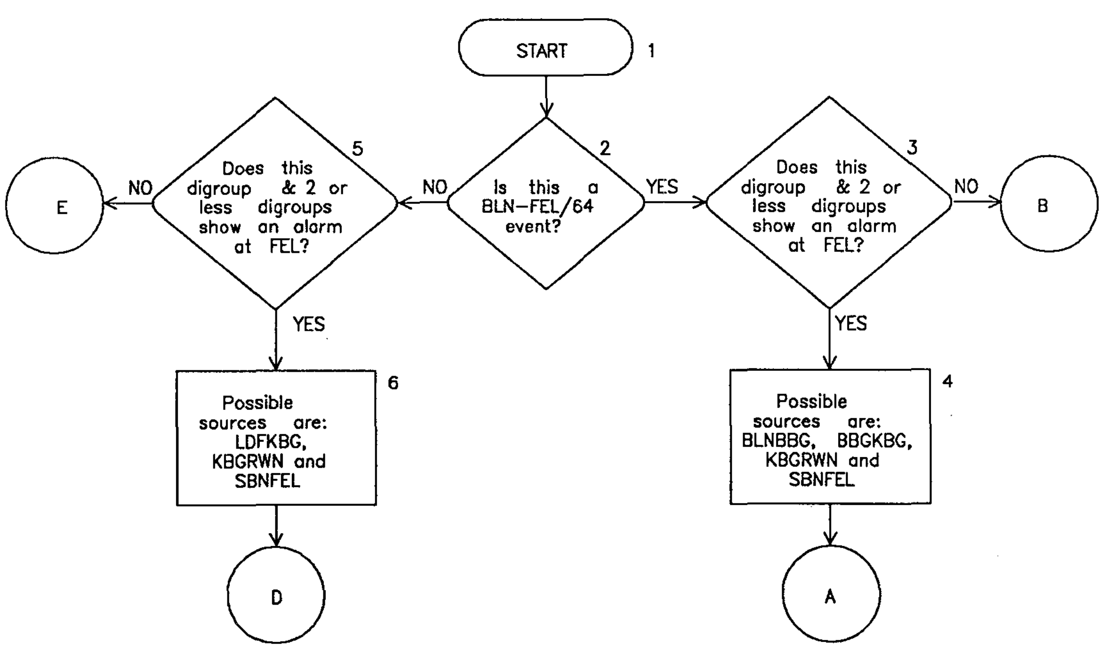


Figure D-1. Locating error-event source links.

### D.5.1.2 Examination of Figure D2

In Figure D1, if TRAMCON alarms are unique to one BLN-FEL digroup at FEL, the algorithm branches to "A." The further isolation of the error event source link is then based upon FCC-99 port alarms. These alarms propagate from link to link from the up-stream position of the outage source. Two sites (RWN and SBN) do not have FCC-99s and, therefore, they have no port alarms. Since it is possible to have port alarms propagating from sites branching off of the test link set, this algorithm is designed to ignore such port alarms. For all link ends, FCC-99 input port alarms are TRAMCON alarms 22, 23, 31, and 32. For all link ends, FCC-99 output port alarms are TRAMCON alarms 24, 25, 33, and 34.

7) This block recognizes that candidate error-event-source links remain that may be further isolated as to which are the actual error-event source link or links.

8) Each of these candidate source links is to be examined in turn, and this block increments the examination of these links.

9) After each link is examined, it is accepted or rejected as a source link. If it is accepted, it receives a priority value (of being the source link). The accepted links with their priority values are accumulated with their priority values until all candidate links have been evaluated.

10) This block decides to examine the next link if the current one is not the last one in the set. If it is the last one, it branches to the final selection process.

11) This block examines the remaining list of candidate source links and their priorities. It first selects the links with highest priority numbers. If there are more than two links with this priority number or no remaining candidates, it records that the source link is unidentified. If one or two links remain, it flags the error event with source-link identification and continues with the cause allocation algorithm.

12) If there are no port alarms on the FCC-99 at either link end of the current link, the link can not be a source link. For this block, only the input port alarms at the link end farthest from FEL (far link end) should be examined, and only the output port alarms at the link end nearest to FEL (near link end) should be examined.

13) Since BLN-BBG is the farthest link and it is terminated in an FCC-98, if there is an output port alarm (any one of 24, 25, 33, and 34) at the near end of the link then BLN-BBG is a source link.

14) If there is an output port alarm at the near link end of BBG-KBG and there is not an output port alarm at the near link end of BLN-BBG, then BBG-KBG is a source link.

15) There is no FCC-99 at RWN. If there is an input-port alarm at the far link end of KBG-RWN and there is no output-port alarm at the near link end of BBG-KBG, then KBG-RWN is a source link.

16) If there is an FCC-99 input-mux-port alarm at the far link end of KBG-RWN, then SBN-FEL is not a source link since there are no FCC-99s at RWN or SBN. Otherwise SBN-FEL is a source link.

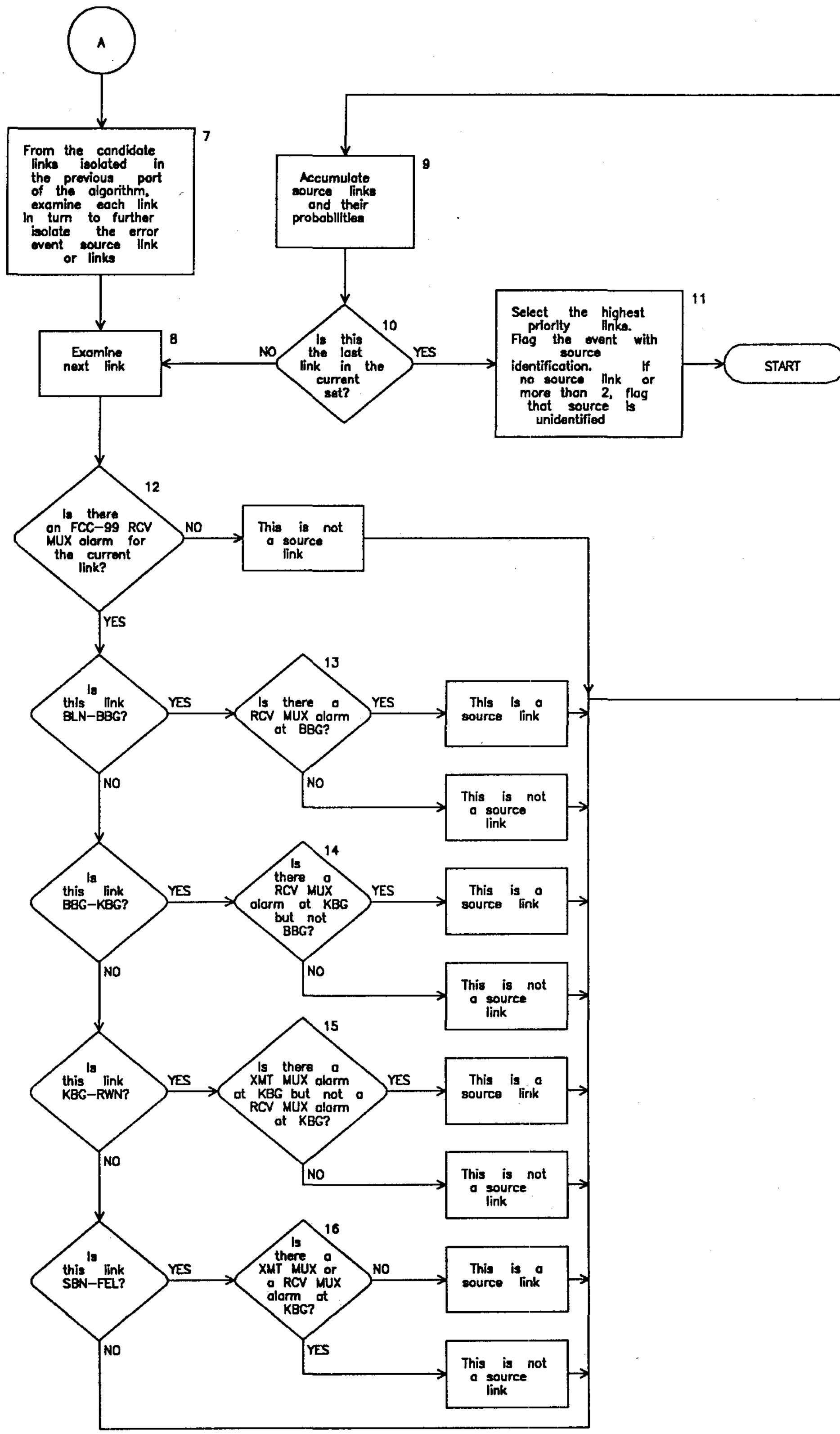


Figure D-2. Source-link selection based on digroup and FCC-99 port alarms for the BLN-FEL/64 channel.

### D.5.1.3 Examination of Figure D3

This figure bases isolation of error-event source links on the coincidence of error events in the two 64 kb/s channels and only deals with events on the 64-kb/s channel from BLN to FEL. Error events are considered coincident when an event or events on the LDF-FEL/64 channel have time in common with the BLN-FEL/64 event being examined.

17) This block tests if there were there errors on LDF-FEL/64 during the event. If yes, then there were errors on both channels during this BLN-FEL/64 error event. If not, then there were only errors on the BLN-FEL/64 channel during this error event.

18) This block tests if the ratio of the errors in the two channels greater than 10. By the "ratio" we mean the greater of the two ratios of the errors in one channel to the errors in the other. If the ratio of errors is greater than 10, it is unlikely that the errors were either randomly distributed or that they resulted from one cause. For all but a digroup failure, random distribution of errors is a good assumption. We therefore draw the conclusion that there is more than one cause and that it is very likely that more than one link is involved.

19) Because of the conclusion from block 18, none of the links is eliminated as candidate error-event source links.

20) Since there were errors on both links and the frequency of occurrence of errors is very unusual, we assume that the error-event-source link is one of the links common to the two 64-kb/s channels.

21) This block tests if there were there more than five errors. If yes, then the probability is very high (greater than 99 percent) that the error-event-source link is either one or both of the two links not common to both channels. If not, then no links associated with this channel have been eliminated.

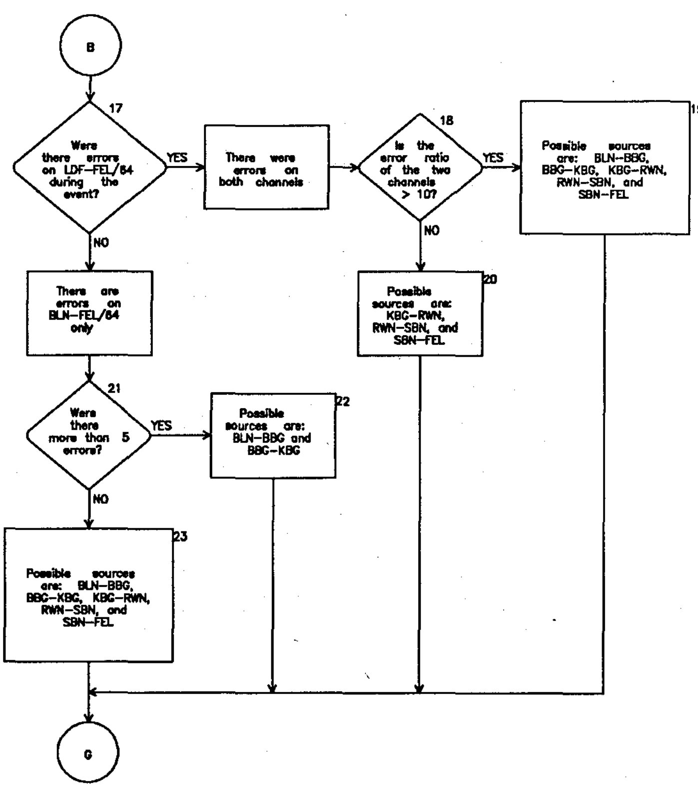


Figure D-3. Source-link selection based on coincidence of error events in the two 64-kb/s channels for the BLN-FEL/64 channel.

22) Because of the conclusion from block 21, only BLN-BBG and BBG-KBG remain as candidate error-event-source links.

23) Because of the conclusion from block 21, all of the links associated with this channel remain as candidate error-event-source links.

### D.5.1.4 Examination of Figure D4

This figure is a link-source-isolation algorithm for the LDF-FEL/64 channel based on FCC-98 digroup alarms at FEL and the propagating port alarms of the FCC-99s. In Figure D1 if TRAMCON alarms are unique to one LDF-FEL digroup at FEL, the algorithm branches to "D". The further isolation of the error-event-source link is then based upon FCC-99 port alarms. These alarms propagate from link to link from the up-stream position of the outage source. Two sites (RWN and SBN) do not have FCC-99s and, therefore, have no port alarms. It is possible to have port alarms being propagated from sites beyond or branching off of the test link set. This algorithm is designed to ignore such port alarms. For all link ends, FCC-99 input port alarms are TRAMCON alarms 22, 23, 31, and 32. For all link ends, FCC-99 output port alarms are TRAMCON alarms 24, 25, 33, and 34.

24) This block recognizes that candidate error-event-source links remain which may be further isolated as to which are the actual error-event-source link or links.

25) Each of these candidate source links is to be examined in turn, and this block increments the examination of these links.

26) After each link is examined, it is accepted or rejected as a source link. If it is accepted, it receives a priority value (of being the source link). The accepted links with their priority values are accumulated with their priority values until all candidate links have been evaluated.

27) This block decides to examine the next link if the current one is not the last one in the set. If it is the last one, it branches to the final selection process.

28) This block examines the remaining list of candidate source-links and their priorities. It first selects the links with highest priority numbers. If there are more than two links with this priority number or no remaining candidates, it records that the source link is unidentified. If one or two links remain, it flags the error event with source link identification. It then continues with the cause-allocation algorithm.

29) If there are no port alarms on the FCC-99 at either link end of the current link, the link can not be a source link. For this block, only the input port alarms at the current-link end farthest from FEL (far-link end) should be examined and only the output-port alarms at the current-link end nearest to FEL (near-link end) should be examined.

30) Since LDF-KBG is the farthest link and it is terminated in an FCC-98, if there is an output-port alarm (any one of 24, 25, 33, and 34) at the near end of the link, then LDF-KBG is a source link.

31) There is no FCC-99 at RWN. If there is an input-port alarm at the far-link end of KBG-RWN and there is no output port alarm at the near link end of LDF-KBG, then KBG-RWN is a source link.

32) If there is an FCC-99 input-mux-port alarm at the far link end of KBG-RWN, then SBN-FEL is not a source link since there are no FCC-99s at RWN or SBN. Otherwise SBN-FEL is a source link.

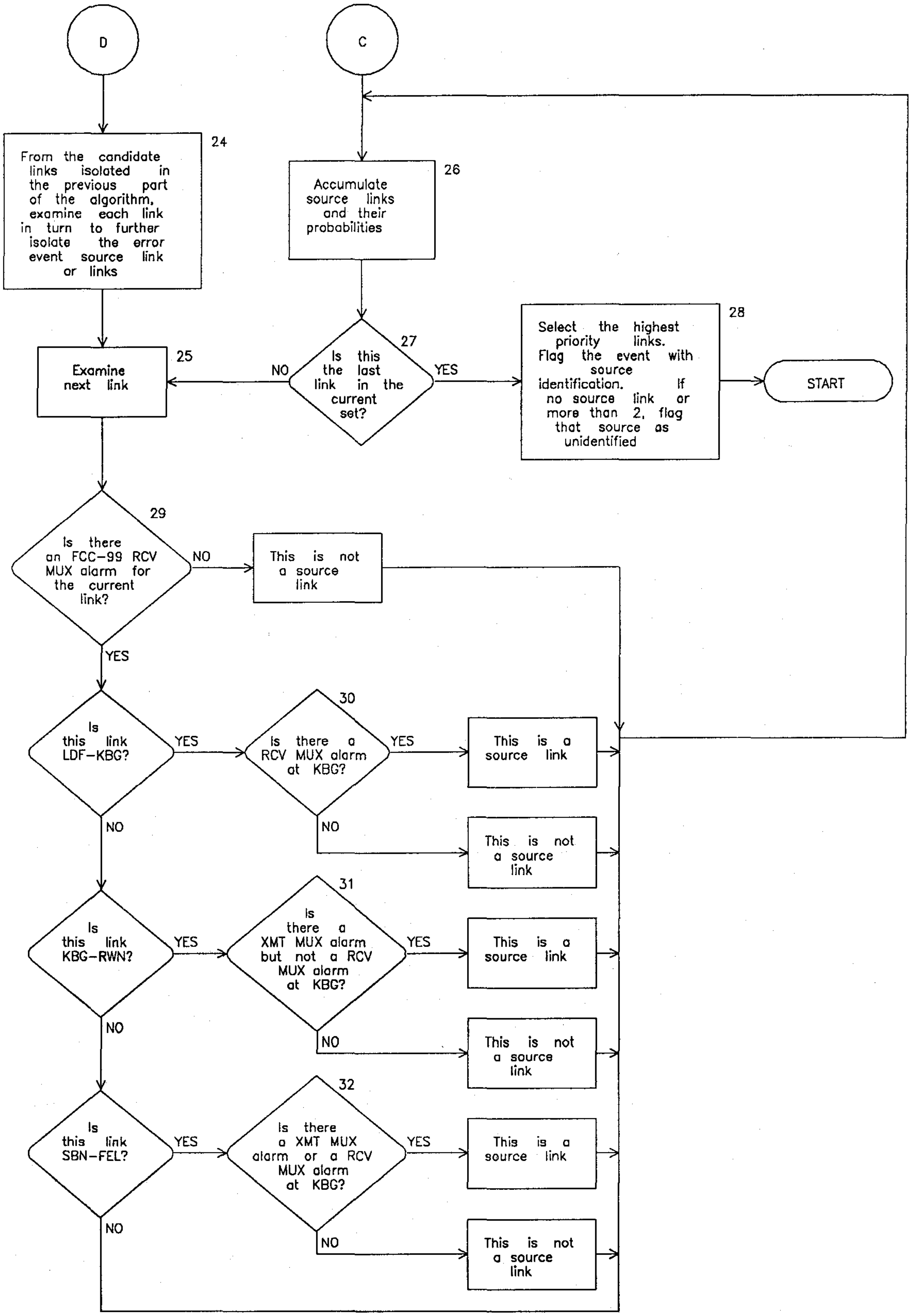


Figure D-4. Source-link selection based on digroup and FCC-99 port alarms for the LDF-FEL/64 channel.

### D.5.1.5 Examination of Figure D5

This figure bases isolation of error-event-source links on the coincidence of error events in the two 64 kb/s channels, and only deals with events on the 64-kb/s channel from LDF to FEL. Error events are considered coincident when an event or events on the BLN-FEL/64 channel have time in common with the LDF-FEL/64 event being examined.

33) This block tests if there were there errors on BLN-FEL/64 during the event. If yes, then there were errors on both channels during this LDF-FEL/64 error event. If not, then there were only errors on the LDF-FEL/64 channel during this error event.

34) This block tests if the ratio of the errors in the two channels is >10. By the "ratio" we mean the greater of the two ratios of the errors in one channel to the errors in the other. If the ratio of errors is greater than 10, it is unlikely that the errors were either randomly distributed or that they resulted from one cause. For all but a digroup failure, random distribution of errors is a good assumption. We, therefore, draw the conclusion that there is more than one cause and, therefore, that it is very likely that more than one link is involved.

35) Because of the conclusion from block 34, none of the links is eliminated as a candidate error-event-source link.

36) Since there were errors on both links and the frequency of occurrence of errors is very unusual, we assume that the error-event-source link is one of the links common to the two 64-kb/s channels.

37) This block tests if there were there more than five errors. If yes, then the probability is very high (greater than 99 percent) that the error-event-source link is the link not common to both channels (LDF-KBG). If not, then no links associated with this channel have been eliminated.

38) Because of the conclusion from block 37, LDF-KBG is picked as the error-event source link.

39) Because of the conclusion from block 37, all of the links associated with this channel remain as candidate error-event-source links.

### D.5.7 Examination of Figure D6

This figure presents the algorithm for completing the allocation of error-event-source links that were not eliminated as candidates by the previous procedures. Nonpropagating TRAMCON alarms (alarms that are not propagated from link to link) are used in this algorithm. TRAMCON alarm identification of signal blockage is shown using Figure D8 and Table D1.

40) This block recognizes that candidate error-event source links remain that may be further isolated as to which are the actual error-event source link or links.

41) Each of these candidate source links is to be examined in turn and this block increments the examination of these links.

42) After each link is examined, it is accepted or rejected as a source link. If it is accepted, it receives a priority value (of being the source link). The accepted links with their priority values are accumulated with their priority values until all candidate links have been evaluated.

43) This block decides to examine the next link if the current one is not the last one in the set. If it is the last one, it branches to the final selection process.

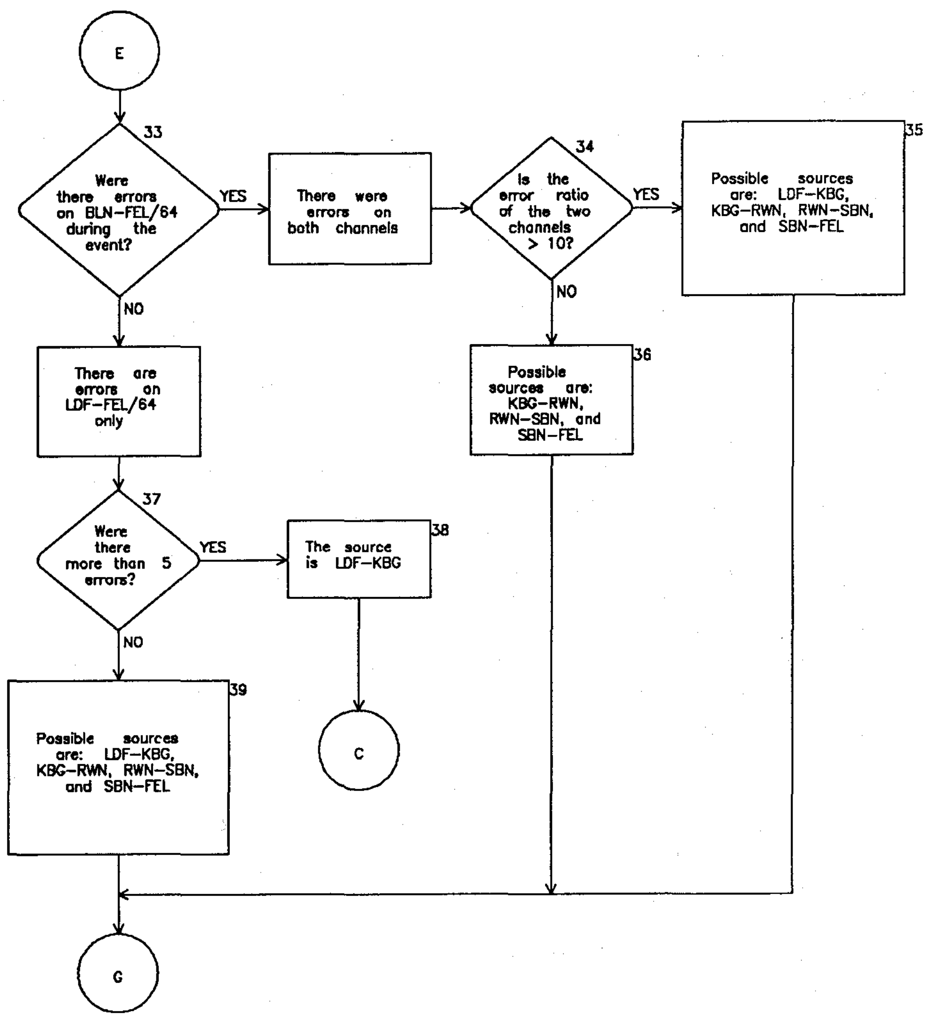


Figure D-5. Source-link selection based on coincidence of error events in the two 64-kb/s channels for the LDF-FEL/64 channel.

44) This block examines the remaining list of candidate-source links and their priorities. It first selects the links with highest priority numbers. If there are more than two links with this priority number or no remaining candidates, it records that the source link is unidentified. If one or two links remain, it flags the error event with source-link identification. It then continues with the cause-allocation algorithm.

45) This block tests if this link is SBN-FEL. If it is, then a special test is required since additional information is available for this link because it is being monitored separately.

46) This block tests if there were there errors on the link test channels. The most sensitive indicator that there have been errors on the SBN-FEL link in one of the applicable end-to-end 64-kb/s channels is the indication that there have been errors in the service-channel test channels that are constantly monitored on this link. If there are such errors during the error event, the probability is very high that SBN-FEL is an error-event-source link.

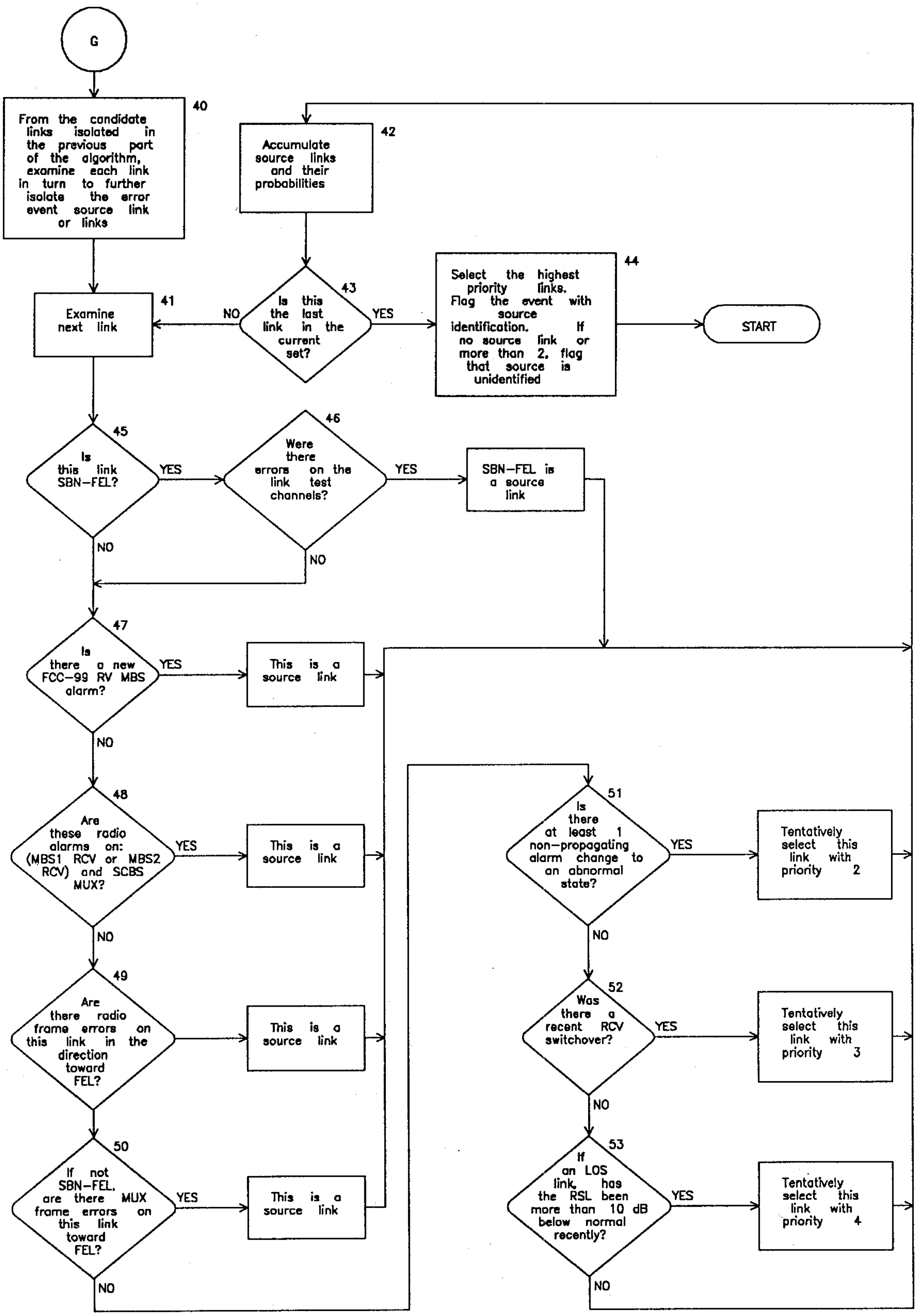


Figure D-6. Isolation of source links using nonpropagating TRAMCON alarms and status information.

47) This block tests if there is a new FCC-99 recv MBS alarm. Such an alarm (TRAMCON alarms 20 or 29), if fresh, indicates that the mission bit stream was at least momentarily lost and that whatever link is being examined is an error-event-source link. Not all sites have an FCC-99.

48) This block tests if either of the following alarms is on:

    8 Radio MBS 1 receiver failed (A or B)
    9 Radio MBS 2 receiver failed (A or B).

and if the alarm, 35 Service-channel-mux failed, is on. Not all sites have multiplex alarms referred to in block 47. It is necessary to find out whether the mission bit stream has been blocked at a point that includes as much of the link equipment as possible. At sites where there are no mux alarms, this combination of alarms indicates such a blockage.

49) This block tests if there radio frame errors on this link in the direction toward FEL. If there are frame errors, the TRAMCON system reports their number for each link. These frame errors, which are part of the same mission bit stream as the test channel, are sensitive indicators of errors in the test channel. It follows that if there are radio frame errors, then the current link is very probably an error-event-source link since the frame errors are not propagated from link to link.

50) This block tests if there are mux frame errors on the link in the direction toward FEL if the link is not SBN-FEL. Not all sites have FCC-99 mux equipment but for the ones that do have it, if there are mux frame errors, the TRAMCON system reports the number of errors for each link. These mux frame errors, which are part of the same mission bit stream as the test channel, are sensitive indicators of errors in the test channel. It follows that if there are mux frame errors, then the current link is very probably an error-event-source link except for SBN-FEL since the frame errors are not propagated from link to link except for the three links: KBG-RWN, RWN-SBN, and SBN-FEL.

51) This block tests if there is at least one nonpropagating alarm change to an abnormal condition. It should be added that this includes the transmit alarms at the far-link end (alarms for LOS links are 0, 3, 4, 5, 6, 13, 18, 21, 27, and 30) and the receive alarms at the near-link end (alarms for DRAMA radio are 0, 8, 9, 11, 12, 18, 19, 20, 27, 28, and 29) and no others. For the troposcatter link, the transmit alarms at the far-link end are 0, 1, 2, 3, 4, 5, 18, and 21, and the receive alarms at the near-link end are 6, 7, 18, 19, and 20. This condition is a second priority indication that a link is an error-event-source link. If such alarms occur at the start of an error event, there is a high probability that there is a relationship between the errors and the alarm information. If so, the candidate link will be held in memory for further consideration.

52) This block tests if there was there a recent receiver switchover. This block is only valid for LOS links. The condition is detected by observing a fresh change in the near end TRAMCON status alarms 54 and 55. This is a third-priority indication that a link is an error-event-source link. If such a switchover occurs at the start of an error event, there is a strong probability that there is a relationship between the errors and the switchover information. If so, the candidate link is held in memory for further consideration.

53) This block tests if the rsl (either A or B) on an LOS link has been more than 10 dB below normal recently (within 15 minutes). This is a fourth priority indication that a link is an error-event-source link. If such a decrease in RSL occurs within 15 minutes of the start of the error event, there is a reasonable probability that a relationship between the errors and the rsl information exists. If so, the candidate link is held in memory with its priority for further consideration.

### D.5.2 Identification of cause of an error event

An assumption is made that there is only one cause, associated with each source link, for each error event for a particular path. The cause categories are:

1) Multipath
2) Tropospheric scatter propagation
3) Equipment
4) Power fading
5) Cause unidentified

To identify the cause of each error event, we examine a number of conditions associated with the error-event-source links isolated in algorithms outlined in Figures D1 through D6.

#### D.5.2.1 Examination of Figure D7

This figure presents the algorithm for allocating the cause of an error event. If the source link for an error event is unidentified, then the cause is unidentified. Since there may be two source links identified, each link is examined in turn until a cause is identified. The cause identified is assumed to apply to both links.

54) This block starts by recalling the identity of the error event and the one or two error-event-source links previously isolated.
55) This block starts the cause identification process for the current source link.
56) This block branches on the basis of whether this is the last of two possible source links.
57) This block initially sets the flag as "cause unidentified." As the algorithm increments through the source links, the flag takes on the value of the first cause identified.
58) BLN-BBG is a tropospheric scatter link and uses different radios than do the LOS links, and should be analyzed for error-event cause differently than the other links.
59) This block tests if a complete outage occurred suddenly (in 1 second or less) and lasted for more than 60 seconds. Atmospheric fading on LOS paths usually exhibits a slow transition into high bit-error rates and for the few occasions of fast transitions the outage duration is only a few seconds. Equipment outage, on the other hand, is typically sudden, and in many cases, requires minutes to fix.
60) This block tests if this channel's digroup but not more than two digroups show an alarm at FEL. This is true if certain alarm conditions exist. For the BLN-FEL/64 channel, the condition is fulfilled if alarm 51 is on and not more than one of alarms 48, 49, and 50 are on at FEL. For the LDF-FEL/64 channel, this condition is fulfilled if alarm 36 or 37 but not both are on and not more than one of alarms 38, 38, 40, 41, and 42 are on at FEL. Consider that for the channel from BLN to FEL, the mission bit stream is broken down to FCC-98 inputs only at BLN and at FEL. That consideration means that if only the digroup (which supports the test channel bit stream) alarm is "on", then either the digroup transmitter at BLN, the FCC-99 port mux cards at intermediate sites, or the digroup receiver at FEL has failed.
61) This block tests if rsl levels were >10 dB below normal without a transmit alarm or transmit switchover within 15 minutes of the start of the event. The transmit alarms are 3, 4, 5, 6, 13, 21, and 30 at the far end of the link. The switchover is detected by noting a change in 52 and 53 from the previous TRAMCON poll for the far link end. There can be two causes of low rsl on a LOS path: radio transmitter malfunction and propagation abnormalities. We must first eliminate the transmitter

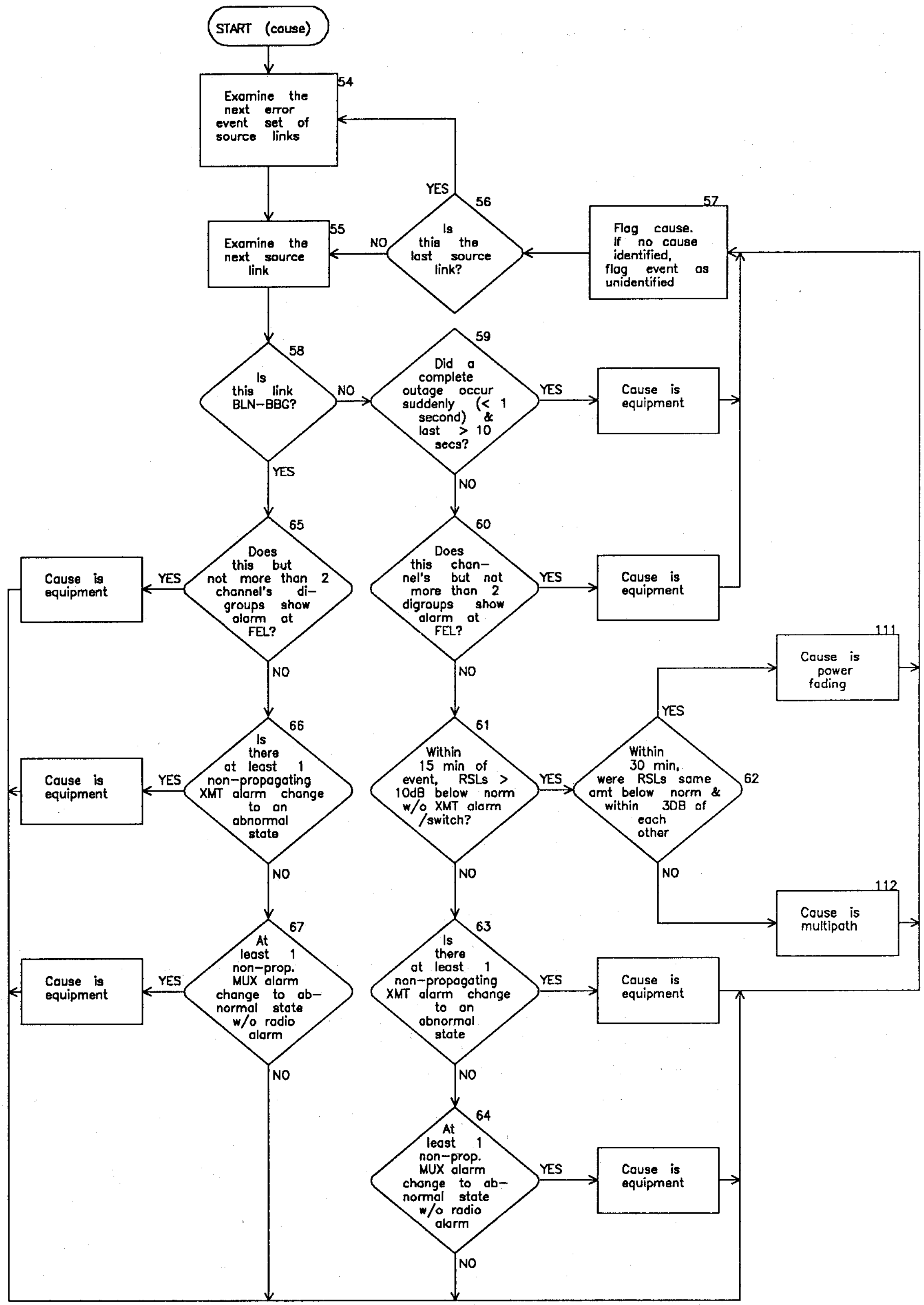


Figure D-7. Identification of the cause of an error event for each source link.

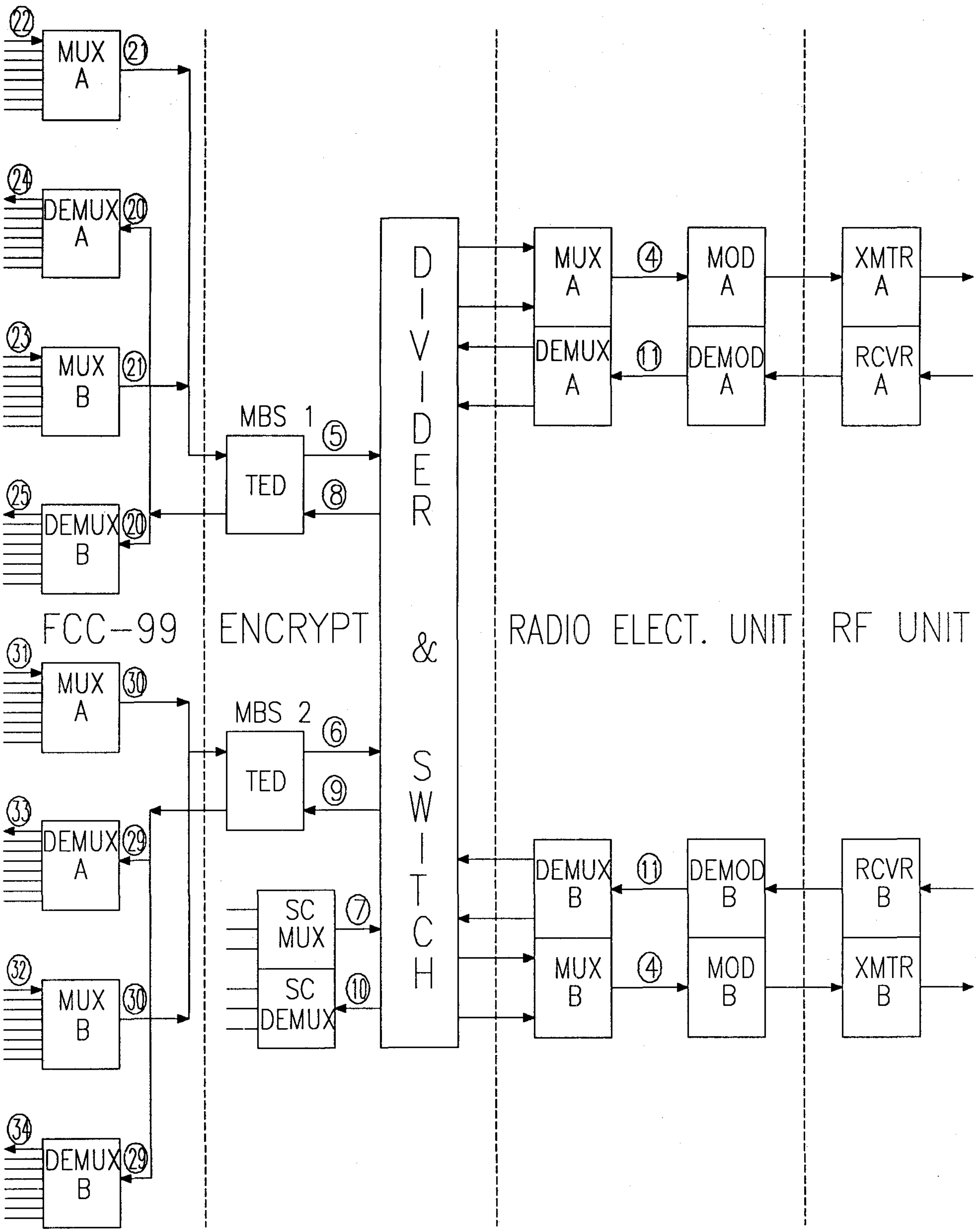


Figure D-8. TRAMCON alarm identification of signal blockage (circled numbers correspond to TRAMCON alarms).

malfunction possibility by observing that there were no transmitter alarms or transmitter switchovers. The TRAMCON system reports rsl values at intervals of about 45 seconds and will often miss minimum values. By looking at the values for a 30-minute period, we can see whether conditions existed for a propagation-related error event.

62) This block tests if the rsl values on both receivers were approximately the same amount below normal (within 3 dB) within the half-hour period. If on the basis of block 61 it is decided that the cause is propagation, then it must be further decided whether it was power fading or multipath. Power fading can be differentiated from multipath by the fact that with power fading all frequencies are attenuated by the same amount. In other words, the rsl values in both directions on the path will be faded the same amount.

63) This block tests if there was at least one nonpropagating transmit-alarm change to an abnormal condition. The transmit alarms are 3, 4, 5, 6, 13, 21, and 30 at the far end of the link. Since a radio transmit alarm can not be caused by propagation, we may assume that the cause is equipment related if this condition is true.

64) This block tests if there was at least one nonpropagating FCC-99 or crypto-alarm change to an abnormal condition without a radio alarm. The radio alarms are 0 through 13 and the other nonpropagating alarms are the groups 14 through 21 and 27 through 30. Since this set of conditions can only occur with equipment malfunction, we may assume that the errored second cause is equipment related if the condition is true.

65) This block tests if this channel's digroup but not more than two digroups show an alarm at FEL. This is true if certain alarm conditions exist. For the BLN-FEL/64 channel, this condition is fulfilled if alarm 51 is on and not more than one of alarms 48, 49, and 50 are on at FEL. Consider that for the channel from BLN to FEL, the mission bit stream is broken down to FCC-98 inputs only at BLN and at FEL. That consideration means that if only the digroup (which supports the test channel bit stream) alarm is "on", then either the digroup transmitter at BLN, the FCC-99 port-mux cards at intermediate sites, or the digroup receiver at FEL has failed.

66) This block tests if there was at least one nonpropagating transmit-alarm change to an abnormal condition. These alarms are 0 through 5, 18, and 21. Since these alarms can not be caused by propagation, we may assume that the cause is equipment related.

67) This block tests if there was at least one nonpropagating FCC-99 alarm change to an abnormal condition without a radio alarm. The radio alarms are 0 through 7; the nonpropagating FCC-99 alarms are 14 and 18 through 21. Since these alarms cannot be caused by propagation if there are no radio alarms, we may assume that the cause is equipment related.

### D.5.3 Assignment of errors to individual links

When there is a complete outage on a channel, 16,000 or more errors will be assigned to that second to indicate the outage. If one link is selected as the error-event-source link, the errors in the errored second are assigned to that link. If two or more links are selected as the error-event-source links, then the number of errors per link is considered unknown. Each of the error-event-source links is recorded as being a source of the errored seconds that occurred during the error event.

## D.6 Measuring system unavailability using TRAMCON

There are two definitions of unavailability which are of concern, one from Draft MIL-STD-188-323 and the other from CCITT Recommendation G.821 (see definitions). TRAMCON measures some parameters from the radio that may be useful in providing an estimate of unavailability. The FRC-171 provides a Frame-word Error which is counted by TRAMCON. TRAMCON keeps a count of the number of errors and the number of seconds that contain errors. Because there is a 16-bit frame word every 250 microseconds the number of frame bits is 64 kb/s. Because this is the same rate as a 64-kb/s user channel, using the Frame-word Errors to estimate unavailability on a 64-kb/s user channel would appear to be valid. ITS conducted preliminary laboratory experiments to verify this relationship. However, TRAMCON has a major fault when trying to measure unavailability. TRAMCON works by polling each site in turn and receiving the information from that site. The time it takes completely to poll the Frankfurt North segment depends on the number of sites. Currently with 18 sites, the polling cycle requires about 2 minutes. The values that are measured by TRAMCON are the number of seconds (during the polling cycle) that contain frame errors and the total number of frame errors during the polling cycle. These two numbers are available for both the A and B receivers on each end of every link in Frankfurt North.

Because the distribution of the errors within the 2-minute period is not known, it is not possible to tell whether the error rate for any second is above or below any BER threshold. This means that it is impossible to calculate accurately the unavailability time using only TRAMCON data. For example a poll may show that all 120 seconds since the previous poll have errors and also that the total number of errors is high, say 1000. However, it may be possible that spaced in that 120 seconds are seconds that have only one error, which would be a low enough error rate that the time should not be counted as unavailable.

Even though TRAMCON does not have sufficient data accurately to determine the unavailability time, it may be possible to estimate the unavailability time. The simple method proposed here is based on the draft MIL-STD-188-323 definition of unavailability. The method used will be as follows:

> When a TRAMCON poll shows all seconds since the last poll to have errors in them and the average BER for the time period to exceed $10^{-4}$, then the time period since the last poll will be counted as unavailable. It is possible that the $10^{-4}$ BER rate may not be the best choice; however, the proper level is not known, and $10^{-4}$ BER was arbitrarily chosen for simplicity.

This method, of course, is only an estimate of the actual unavailability. Some examples of limitations of this method exist. Figure D9 shows three TRAMCON polls with every second in the poll cycles being severely errored except for the 2 seconds in the figure that have no errors. By our method of estimating unavailability, each poll cycle would have 1 second that did not contain an error, so no unavailability time would be counted. In actuality there should be 230 seconds of unavailability time counted because 230 consecutive seconds were severely errored.

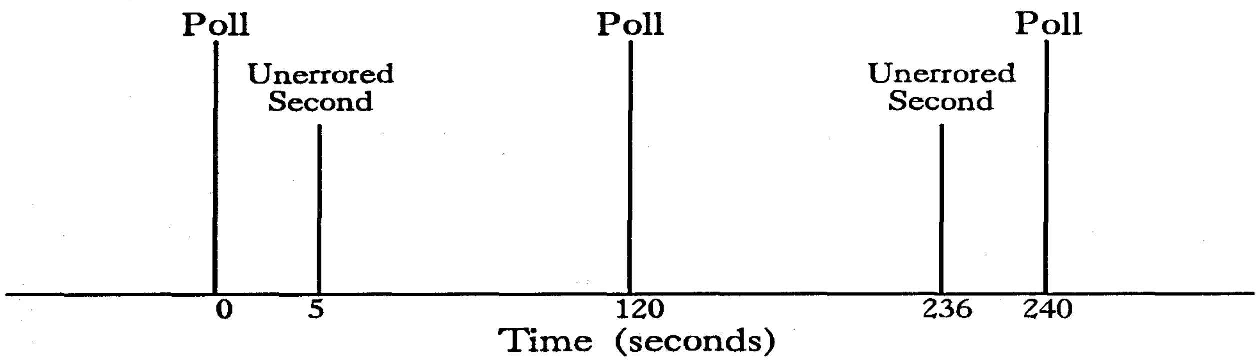


Figure D-9. TRAMCON polling cycle, case 1.

Figure D10 illustrates the case where another possibility of error can occur when a 120-second poll cycle has all severely errored seconds and is counted as unavailable, but because there are unerrored seconds just outside the poll cycle, the time would not be accounted as unavailable by the draft MIL-STD definition. Two TRAMCON polls are shown. Every second in the diagram is severely errored except for the 2 seconds shown.

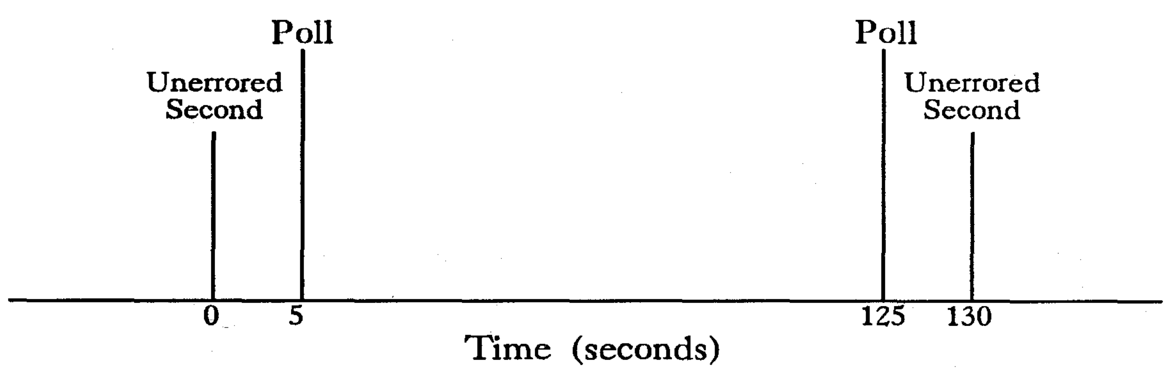


Figure D-10. TRAMCON polling cycle, case 2.

Figure D11 shows that a third source of errors occurs because TRAMCON does not measure the distribution of the errors in each second. It is possible to have a high average rate of errors in the poll cycle and have every second in error, but yet have 1 second in which the error rate is low. Using only the data available from TRAMCON, we will count the 120-second poll cycle as unavailable time but, by the draft MIL-STD definition, the time should not be unavailable as there were not 60 seconds of consecutive severely errored seconds. With a 64-kb/s data rate, 10 errors would be above the $10^{-4}$ threshold. The total number of errors in this poll cycle would be

119 seconds at 10 errors and 1 second at 1 error for a total of 1191 errors. The data bits would be 64K times 120 seconds for 7680K bits. This number of errors gives an average error rate greater than the $10^{-4}$ standard, so the time by our algorithm would be erroneously counted as unavailable.

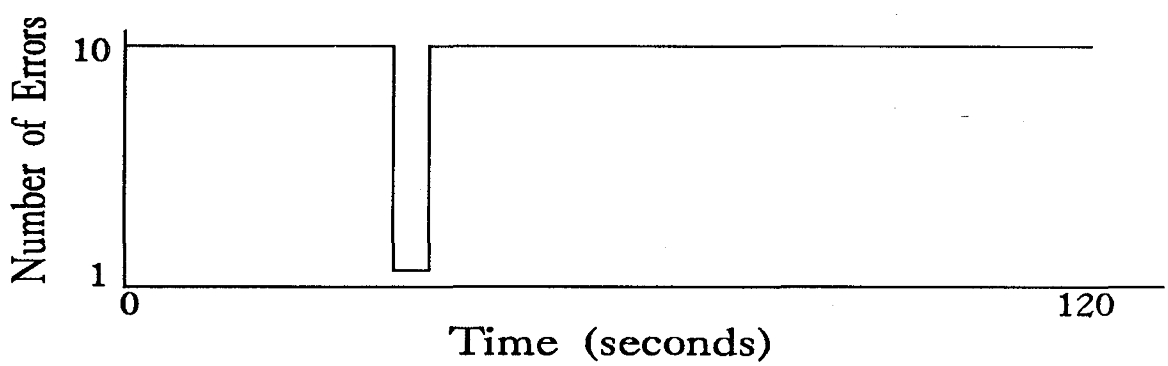


Figure D-11. TRAMCON polling cycle, case 3.

Even with these various sources of errors, there is reason to believe that this method of estimating unavailability using only the TRAMCON data will give a reasonable estimate. It is believed that most unavailable time comes in long blocks with very high error rates. In this usual case, the TRAMCON method will give the correct answer.

## D.7 Calculations

### D.7.1 Correlation coefficients

For each 15-minute period, with more than 1 error, a number pair (x,y) should be formed where x = fraction of errored seconds and y = average BER. From these pairs, the correlation coefficient, r, will be found. The equation for the correlation coefficient is:

$$r^2 = \frac{(n\sum xy - \sum x \sum y)^2}{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}$$

### D.7.2 Least squares regression line

The least squares regression line, y = mx + b, is plotted for these scatter plots. The value of m is given by the equation:

$$m = \frac{\sum x_i y_i - n\overline{xy}}{\sum x_i^2 - n\overline{x}^2} \quad \text{and} \quad b = y - m\,x.$$

### D.7.3 Amplitude distortion

(see definitions section)

### D.7.4 Diversity improvement

Current space-diversity improvement (SDI) is calculated for the Schwarzenborn-Feldberg (SBNFEL) link. In addition, various hypothetical SDI sets of values are calculated for this link based on single-receiver Average BER and hypothetical receiver-on-line average BER. The BER averaging time is 0.2 seconds. Only periods that have been designated as multipath fading time are included in the analysis. Unavailability time is not included. Besides the current switching algorithm, the hypothetical switching algorithms are as follows:

1) Receiver selection based on minimum BER (maximum SDI, it is used as a reference)
2) Receiver selection based on minimum absolute value of IF amplitude distortion calculated from the outputs of two band filters (amplitude distortion = $K \log [V_1/V_2]$)
3) Receiver selection based on minimum absolute value of spectrum-analyzer-measured amplitude distortion across the band (only the center 8 MHz of the IF band is used to reduce distortion in low-signal-level periods)
4) Receiver selection based on minimum absolute value of spectrum-analyzer-measured maximum amplitude distortion (between adjacent power spectrum points, which are spaced 400 KHz apart)
5) Receiver selection based on signal-quality-monitor (SQM) voltage
6) Receiver selection based on minimum fade depth

The equation for SDI is as follows:

$$SDI = \frac{\text{No. of 0.2 sec. at BER} \geq \text{a particular BER for a single receiver}}{\text{No. of 0.2 sec. at BER} \geq \text{a particular BER for receiver–on–line}}$$

Because there are two received signals, there are two sets of SDI values, one for receiver A, and the other for receiver B.

### D.7.5 Composite and Dispersive Fade Margins From Measured Data

Composite fade margin (CFM), dispersive fade margin (DFM), and flat fade margin (FFM) are defined in terms of the bit error ratio (BER) and rsl statistics for a particular test path during periods of multipath fading and interference. To simplify these calculations, we have assumed that there is no significant interference on this test path. The value of these fade margins will depend upon the BER threshold selected, which for this analysis is 1/64000. The corresponding flat-fading BER threshold for the DRAMA radio used in these tests is -73 dBm. The following equations define the relationships between these parameters.

$$P_{mf} = \frac{\text{Number of seconds BER > Threshold}}{\text{Number of seconds of valid multipath data}} \qquad (1)$$

$$P_{mf} = k_0 \cdot 10^{-CMF/10} \qquad (2)$$

$$P_0 = \frac{\text{Number of seconds RSL < RSL Threshold}}{\text{Number of seconds of valid multipath data}} \quad (3)$$

$$P_0 = k_0 \cdot 10^{-FFM/10} \quad (4)$$

$$FFM = \text{Median RSL} - \text{RSL Threshold} \quad (5)$$

$P_0$ is the measured fraction of time that the fade margin is exceeded.

$$\frac{P_{mf}}{P_0} = \frac{k_0 \cdot 10^{-CFM/10}}{k_0 \cdot 10^{-FFM/10}} = 10^{-FFM/10 - CFM/10} \quad \text{(from eq. 2 and 3)}$$

$$\log\frac{P_{mf}}{P_0} = \frac{FFM - CFM}{10} \quad (6)$$

$$10 \cdot \log\frac{P_{mf}}{P_0} = FFM - CFM \quad (7)$$

$$CFM = FFM - 10 \cdot \log\frac{P_{mf}}{P_0} \quad (8)$$

$$CFM = FFM - 10 \cdot \log\left[\frac{\text{Number of seconds that BER > Threshold}}{\text{Number of seconds that RSL < RSL Threshold}}\right] \quad (9)$$

$$CFM = -10 \cdot \log\left[10^{-FFM/10} + 10^{-DFM/10}\right] \quad \text{(definition of DFM)} \quad (10)$$

$$10^{-CFM/10} = 10^{-FFM/10} + 10^{-DFM/10}$$

$$DFM = 10 \cdot \log\left[10^{-CFM/10} - 10^{-FFM/10}\right] \quad (11)$$

## D.8 Description of analysis programs and subroutines

The analysis program consists of a main analysis routine and several output routines. With each description, a reference is made to the specific blocks of the allocation-algorithm flowcharts (Figures D1 through D6) where applicable.

### D.8.1 ANALYSIS: analyze the HP3852 data collected on tape

**analysis**

Description: analysis reads the file "time_period.da" (subroutine: time_period) and returns with the period name and two arrays containing the start and end times (in cumulative seconds from January 1, 1970) of all defined time periods. These are used to create an array of the start times of all valid 15 minute blocks (subroutine: build_15_minute). The operator is then prompted for the source of the data to be analyzed (disk or tape) or whether all files should be initialized for the beginning of an analysis period. If initialization is specified, all cumulative disk files are deleted and all cumulative arrays and structures are cleared (subroutine: initialize). If tape is specified, the tape drive unit is opened and a 16-Mbyte block is read and written to the disk in the file DATA0 (subroutine: tape_read). If disk is specified, the appropriate disk file is opened. All cumulative data is read in from the disk. All of the cumulative analysis files are then opened and the file containing the running data arrays and structures is read (subroutine: GS_DATA_get). At the beginning of a new 15 minute block all counters are cleared. A block is then read in from the raw data file (subroutine: read_NEXT) and the date and time of the beginning of the block is converted to character strings (subroutine: datetime). Missing seconds are then filled (subroutine: fill_missing). If more than 10 were missing, then the block is discarded (subroutine: cast_off). The data block is then scanned to convert errored seconds to error events (subroutine: pass2) for each of the five channels (BLN-FEL, LDF-FEL, SBN-FEL/A, SBN-FEL/B and SBN-FEL/ROL). If it is determined that there is no data in the current block, or that the radio was in manual mode at all during this block, the block is discarded. The average RSL's for the two sides of the SBN-FEL receiver are calculated (subroutine: RSL_ave). If there were no errors in this block, it is included in the running averages as well as the spectral data. If there were errors and this is the first block of the analysis, the block is discarded. The first block of an analysis period must be error-free to produce basic value upon which the subsequent analysis is based. An event summary of the block is sent to the operator file (TTY.prt). Next, the MILSTD unavailability flags for the block are calculated (subroutine: set_unavail) for each of the 5 channels. The TRAMCON statistics are calculated (subroutine: TRAMCON_stats) using the unavailability information. The source links and causes are then determined (subroutine: pass3). The results of the current block analysis are saved (subroutine: pass4) and the next block is analyzed. If this is the last block of the data file and a tape is being analyzed, a new tape record is read. If the end of tape has been reached, or a disk file is being analyzed, cumulative totals are calculated, the cumulative files are closed, the data arrays and structures are saved to disk (subroutine: GS_DATA_put) and a plot file for the average spectrums is created.

**castoff**

Arguments received: none.
Description: Moves the current data block to the last data block and the next data block to the current data block. Likewise, all pointers, event arrays and spectrum samples are moved.
Arguments returned: none.

**fill_missing**

Arguments received: none.
Description: Fills in any missing data seconds in the next block. If a second of data is missing, it's data is arbitrarily set to the data of the following second.
Arguments returned: number of missing seconds.

**RSL_ave**

Arguments received: pointer to raw data structure, pointer to 56-kb/s channel extra raw data structure, pointer to RSL average variable.
Description: Calculates the average RSL over the block for the SBN-FEL/A or /B 56-kb/s channels.
Arguments returned: number of errored seconds in the block.

**GS_DATA_put**

Arguments received: none.
Description: Saves the current data statistics in the disk file GS_DATA.
Arguments returned: none.

**TRAMCON_stats**

Arguments received: amount of MILSTD unavailability time found in this block.
Description: Scans the TRAMCON polls in the current block and totals all of the TRAMCON statistics. First, the link indices for TRAMCON unavailability time are obtained (subroutine: unav_idx). The number of seconds the errors reported by TRAMCON exceed the $10^{-4}$ threshold are counted. The indices for the RSL distribution

graphs are calculated (subroutine: idx69_80) and the TRAMCON RSL distribution arrays are updated. If there was no MILSTD unavailability time in this block, a running average of the TRAMCON RSL's for the two receivers is updated.
Arguments returned: none.

**build_15_minute**

Arguments received: pointer to array of start elapsed times specified in the file "time_period.da," pointer to array of end elapsed times specified in the file "time_period.da," number of valid data periods, pointer to array containing starting time of valid 15 minute blocks.
Description: Using the arrays of start and end times created by the subroutine "time_period," build an array containing the start times of valid 15 minute blocks.
Arguments returned: number of valid 15 minute blocks.

**spec_plot**

Arguments received: none.
Description: Create the file "plot.spec," containing information needed by the program "plot" to plot the average (over the current analysis; tape or disk file) spectrums of each of the two receivers.
Arguments returned: none.

**initialize**

Arguments received: none.
Description: Clears counters, initializes data files and arrays, and clears all cumulative data files at the beginning of the new analysis period.
Arguments returned: none.

**pass2**

Arguments received: pointer to raw data structure, pointer to event structure, pointer to array containing the number of error events in each time block.
Description: Scans next 15 minute block and sets the $10^{-3}$ and $10^{-4}$ BER thresholds, determines error event length, start time and total errors. Does not take into account 15 minute block overlap.
Arguments returned: none.

**unav_idx**

Arguments received: TRAMCON link ID, pointer to array of link indices, pointer to number of links.
Description: Gets the link indices for use with TRAMCON unavailability time given a TRAMCON linkend.
Arguments returned: link index.

**set_unavail**

Arguments received: pointer to raw data structure, pointer to event structure, pointer to array containing number of events.
Description: Scans the current 15 minute block, checks for G.821 unavailability (subroutine: set_G821), sets MILSTD (subroutine: MILSTD_unavail) and G.821 (subroutine: G821_unavail) unavailability flags, and sets the IS_16000 flag if there are more than 16000 errors (total outage) in either of the first two seconds of an error event. Also checks for error event continuity over 15 minute block boundaries.
Arguments returned: flag indicating existance of MILSTD unavailability.

**julian**

Arguments received: number of year, number of month, number of day.
Description: Calculates the Julian day [1-365] for a given date. Takes leap years into account (subroutine: leapyr).
Arguments returned: julian day.

**leapyr**

Arguments received: number of year.
Description: Checks if a given year is a leap year.
Arguments returned: flag set if the year is a leap year.

**ndays_yr**

Arguments received: number of year.
Description: Calculates the number of elapsed days between the BASEYEAR (1970) and the year previous to the given year. Leap years are taken into account (subroutine: leapyr).
Arguments returned: number of elapsed days.

**elapsed**

Arguments received: pointer to date string, pointer to time string.
Description: Calculates the elapsed time (in seconds) since BASEYEAR (1970) for a given date and time (subroutines: i2, julian, ndays_yr).
Arguments returned: seconds of elapsed time.

**i2**

Arguments received: pointer to a 2 character string.
Description: Converts a 2 character string to an integer.
Arguments returned: integer value.

**datetime**

Arguments received: number of elapsed seconds, pointer to date string, pointer to time string.
Description: Converts elapsed seconds (since BASEYEAR) to date and time strings (subroutines: ndays_yr, juldat).
Arguments returned: none.

**juldat**

Arguments received: julian day number, number of year.
Description: Convert Julian days to a month and day number for a given year (subroutine: leapyr).
Arguments returned: number of month * 100 + number of day.

**scale_occurance**

Arguments received: pointer to maximum value, pointer to label increment value, pointer to tic increment value.
Description: Calculates the maximum scale value, label increment and tic increment for axis labeling given a maximum data value.
Arguments returned: none.

**time_period**

Arguments received: pointer to file name string, pointer to start time array, pointer to end time array.

Description: Reads the file "time_period.da" and generates arrays of start and end times for each of the valid periods found.
Arguments returned: number of periods found.

**path_link**

Arguments received: value specifying one of the 5 channels, 6 bit source link flag, pointer to array of link indices, pointer to number of source links assigned.
Description: Converts source link flags into an array of link indices.
Arguments returned: number of links assigned.

**path_link56**

Arguments received: value specifying one of the 3 56-kb/s channels.
Description: Converts a path name to a numeric value.
Arguments returned: 0 for 'r', 1 for 'a', 2 for 'b'.

**get_link**

Arguments received: link index.
Description: Converts a link index to a link name.
Arguments returned: a pointer to a character string.

**idx69_80**

Arguments received: TRAMCON linkend.
Description: Converts a TRAMCON linkend to an index number for the TRAMCON RSL plots.
Arguments returned: the GS69_80 index or a -1 if the linkend was not valid.

**time_period_name**

Arguments received: pointer to a character string.
Description: Reads the "name" from the "time_period.da" file.
Arguments returned: none.

**tape_read**

Arguments received: device unit number, file number.
Description: Reads a file from the tape and stores it in the disk file DATA0. Check the first 4 bytes of the file to determine if the end of tape was encountered.
Arguments returned: 1 if the read was successful, 0 if not (end-of-tape, read error, tried to read more than 4 files).

**pass3**

Arguments received: pointer to raw data structure, pointer to events structure, pointer to array containing number of events in each 15 minute block, path identifier, file pointer to events file.
Description: Scans events of current 15 minute block and assigns source links (subroutine: Source_Link, source_link_pack) and causes (subroutine: Cause). Also checks to see if the frame-lost flag was set during an event (subroutine: frame_lost56, frame_lost64). Converts the link flags to link names (subroutine: get_links) and writes the event infoemation to the event file.
Arguments returned: none.

**source_link_pack**

Arguments received: pointer to array containg source link character strings, number of links.

Description: Packs source link list into a 6 bit number.
Arguments returned: the 6 bit number.

**frame_lost56**

Arguments received: pointer to raw data structure, event start time, event duration.
Description: Checks if a "frame loss" flag was set during a 56-kb/s event's duration.
Arguments returned: A flag, set if there was a frame loss during the event, cleared if not.

**frame_lost64**

Arguments received: pointer to raw data structure, event start time, event duration, pointer to the array of source links, number of source links.
Description: Checks if a "frame loss" flag was set during a 64-kb/s event's duration. On the 64-kb/s channels, which are made up of multiple tandem links, the following conditions must be met for a "frame loss" flag to be valid: the cause must be one link (not multiple or undefined); the error event must contain a second with a BER less than $10^{-2}$; within the error event or 2 minutes after, the TRAMCON record for the troposcatter link must show both MD918's BERs to be less than $10^{-3}$, or for a LOS link, both receiver's frame error counts must be non-zero and the radio frame sync loss flag must be set (subroutine: TRAMCON_linkID, get_TRAMCON).
Arguments returned: A flag, set if there was a frame loss during the event and all of the conditions were met, cleared if not.

**get_links**

Arguments received: channel flag, 6 bit link flag, pointer to link string.
Description: Returns up to two link names given the link flag (subroutine: path_link, get_link).
Arguments returned: number of links.

**get_cause**

Arguments received: cause number.
Description: Returns the cause name given the cause index.
Arguments returned: pointer to cause string.

**get_LDFFEL64**

Arguments received: event time, event duration.
Description: Finds a LDF-FEL/64 event occurring during an event defined by time and duration.
Arguments returned: number of errors found in the LDF-FEL/64 event, zero if no concurrent events were found.

**get_BLNFEL64**

Arguments received: event time, event duration.
Description: Finds a BLN-FEL/64 event occurring during an event defined by time and duration.
Arguments returned: number of errors found in the BLN-FEL/64 event, zero if no concurrent events were found.

**get_ARECV**

Arguments received: event time, event duration.
Description: Finds a SBN-FEL/56 ARECV event occurring during an event defined by time and duration.

Arguments returned: number of errors found in the SBN-FEL/56 ARECV event, zero if no concurrent events were found.

**get_BRECV**

Arguments received: event time, event duration.
Description: Finds a SBN-FEL/56 BRECV event occurring during an event defined by time and duration.
Arguments returned: number of errors found in the SBN-FEL/56 BRECV event, zero if no concurrent events were found.

**Source_link**

Arguments received: path identifier, event time, event duration, number of errors during the event, pointer to returned source link error paths.
Description: Given an event of time and duration, determine which source links caused the error event (Figure D1, block 1).

- For the event path BLN-BBG/64 (Figure D1, block 3), check for the SBN-FEL digroup errors (subroutine: TRAMCON_linkID, box3). If digroup 8 MBS2 and one or less of digroups 5-7 MBS2 failed (Figure D2, block 7), then check the FCC-99 receive mux port alarms of the links BLN-BBG, BBG-KBG, KBG-RWN and SBN-FEL (Figure D2, block 12) in that order (subroutine: FCC99_recv_mux_port). The first one to exhibit an alarm is the cause. If no alarms were found, no cause was found. Otherwise, if there were no simultaneous errors on the LDF-FEL/64 channel (subroutine: get_LDFFEL64; Figure D3, block 17), the possible causes are the links not common to both channels (BLN-BBG and BBG-KBG). If there were simultaneous error of equal magnitude (Figure D3, block 18), the possible causes are those links common to both channels (Figure D3, block 18; KBG-RWN, RWN-SBN and SBN-FEL). If there were simulatneous errors of differing magnitude, then all BLN-FEL links (BLN-BBG, BBG-KBG, KBG-RWN, RWN-SBN and SBN-FEL) are possible causes (Figure D3, block 20).
- For the event path LDF-FEL/64 (Figure D1, block 5), check for the SBN-FEL digroup errors (subroutine: TRAMCON_linkID, box5). If either digroup 1 or 2 MBS1 and one or less of digroups 3-7 MBS1 failed, then check the FCC99 receive mux port alarms (Figure D4, block 29) of the links LDF-KBG, KBG-RWN and SBN-FEL in that order (subroutine: FCC99_recv_mux_port). The first one to exhibit an alarm is the cause. If no alarms were found, no cause was found. Otherwise, if there were no simultaneous errors on the BLN-FEL/64 channel (Figure D5, block 33; subroutine: get_BLNFEL64), the possible cause is the link not common to both channels (LDF-KBG; Figure D5, block 38). If there were simultaneous error of equal magnitude (Figure D5, block 35), the possible causes are those links common to both channels (KBG-RWN, RWN-SBN and SBN-FEL). If there were simulatneous errors of differing magnitude (Figure D5, block 36), then all LDF-FEL links (LDF-KBG, KBG-RWN, RWN-SBN and SBN-FEL) are possible causes.
- For the event path SBN-FEL/56: the cause is the SBN-FEL link.
- Finally, for each of the suspected cause links, assign a priority (subroutine: final_select). Then arrange the cause links according to priority. If one or two links of the highest priority were found, return them. If no links, or more than two were assigned the highest priority, then no specific cause links were found (Figure D6, block 44).

Arguments returned: number of cause links found.

**final_select**

Arguments received: pointer to link name, event time, event duration.
Description: Determines if candidate link caused error during an event. Returns a priority assigned to the link. If this is the SBN-FEL link and an ARECV or BRECV event occurred

(subroutine: get_ARECV, get_BRECV), priority = 1. Otherwise, check TRAMCON data for the link. If there was a new TDM MBS data loss alarm (subroutine: TRAMCON_link-ID, get_TRAMCON; Figure D6, block 47), check further. If there was a service channel MUX failed alarm (subroutine: get_TRAMCON; Figure D6, block 48), priority = 1. Otherwise, if the link is not a troposcatter link, and there were radio frame errors (subroutine: get_TRAMCON; Figure D1, block 49), priority = 1. Otherwise, if this is not the SBN-FEL link, and there were MUX frame errors on this link in the direction of FEL (subroutine: get_TRAMCON; Figure D6, block 50), priority = 1. Otherwise, if there was at least 1 nonpropagating alarm (LOS radio: transmitter frequency drift, modulator failed, MBS XMT failed, MBS RCV failed, demodulator failed, frame sync loss, transmitter power failed; troposcatter radio: power amplifier summary alarm, transmitter RF or LO output loss, receiver LO output loss; TDM: power supply failed, frame loss, MBS RCV data loss, MBS XMT data loss) change to abnormal conditions (subroutine: TRAMCON_linkID, get_TRAMCON, alarm_count; Figure D6, block 51), priority = 2. Otherwise, if this link is BLN-BBG, priority = 5. Otherwise, if there was a receint receiver switchover (subroutine: get_TRAMCON; Figure D6, block 52) priority = 3. Otherwise, if this is an LOS link and the RSL has been more than 10 dB below normal recently (subroutine: box84; Figure D6, block 53), priority = 4. Otherwise, cannot determine the source of the error, priority = 0.
Arguments returned: the priority assigned to the link (0=not a link, 1=highest priority, 5=lowest priority).

**FCC99_rcv_mux**

Arguments received: pointer to path string, event time, event duration.
Description: For a given path, check the TRAMCON record for this event (subroutine: TRAMCON_linkID, get_TRAMCON) for TDM 1 and 2 input port loss alarms (subroutine:alarm_count).
Arguments returned: 1 if alarm condition met, 0 if not.

**Cause**

Arguments received: path identifier, pointer to source link strings, number of cause links, event time, event duration, total outage flag.
Description: For a given event and time, determine the cause of the error event (subroutine: cause56, cause_TROPO, cause_LOS; Figure D7, block 54). Assuming there is only one cause, the first cause found is considered the correct cause. If no source link was found, no cause be found.
Arguments returned: cause identifier (unidentified, troposcatter propagation, power fading, multipath or equipment).

**cause_TROPO**

Arguments received: pointer to source link string (should be "BLNBBG"), event time, event duration.
Description: Determine the cause for the troposcatter link. Check the TRAMCON alarms (subroutine: TRAMCON_linkID, box3). If digroup 8 MBS2 alarm and one or less of digroup 5-7 MBS2 alarms were on, then the cause is equipment (Figure D7, block 65). If any nonpropagating transmit alarms (radio: power amplifier summary alarm, transmitter RF and LO output loss; TDM: power supply failed, XMT MBS data loss) were set, cause is equipment (Figure D7, block 66). If any nonpropagating mux alarms (crypto failed; TDM: power supply failed, frame loss, MBS RCV data loss, MBS XMT data loss) were set without a radio alarm (power amplifier summary alarm, transmitter RF and LO output loss, receiver LO output loss), cause is equipment (Figure D7, block 67). Otherwise, cause is unknown.
Arguments returned: cause identifier.

**cause_LOS**

Arguments received: path code, pointer to source link string, event time, event duration, total outage flag.
Description: Determine the cause for an LOS link on BLN-FEL or LDF-FEL. If a complete outage occurred suddenly and lasted for more than 60 seconds, cause is equipment (Figure D7, block 59). If the channel's digroup (BLN-FEL: digroup 8 MBS2 and one or less of digroups 5-7 MBS2; LDF-FEL: digroups 1 and 2 MBS1 and one or less of digroups 3-7 MBS1) show an alarm at FEL (subroutine: TRAMCON_linkID, box3, box5), cause is equipment (Figure D7, block 60). If there was at least one nonpropagating transmit alarm (radio: transmitter frequency drift, modulator failed, MBS XMT failed, transmitter power failed; TDM XMT MBS data loss), cause is equipment (Figure D7, block 63). If, within 15 minutes of the start of an event, there was no transmitter switchover (subroutine: get_TRAMCON) and either receiver's TRAMCON RSL level was more than 10 dB below normal (subroutine: TRAMCON_linkID, box84; Figure D7, block 61) and the two receiver's TRAMCON RSLs were within 3 dB of each other (subroutine: box110; Figure D7, block 62), power fading was the cause. If the two TRAMCON RSLs were greater than 3 dB of each other, multipath was the cause. If there was at least 1 nonpropagating mux alarm (cryptos: failed, bypassed; TDM: power supply failed, frame loss, MBS RCV data loss, MBS XMT data loss) change to an abnormal condition without a radio alarm (power supply failed, A or B side failed, transmitter frequency drift, modulator failed, MBS XMT failed, SCBS XMT failed, MBS RCV failed, SCBS RCV failed, demodulator failed, frame sync loss, transmitter power failed), cause was equipment (subroutine: get_TRAMCON, alarm_count; (Figure D7, block 64).
Arguments returned: cause identifier.

**cause56**

Arguments received: path code, event time, event duration, total outage flag.
Description: Determine the cause for the SBN-FEL/56 link. If a complete outage occurred suddenly and lasted for more than 60 seconds, cause is equipment. If there is more than 0.1 dB of slope distortion measured by the IF filters, cause is multipath. If, within 15 minutes of the start of an event, there was a transmitter switchover (subroutine: TRAMCON_linkID), cause was equipment. If a transmit alarm (transmitter frequency drift, modulator failed, MBS XMT failed, transmitter power failed) was on, cause was equipment. If, within 15 minutes of the start of an event, either of the receiver's RSLs were more than 6 dB below average and, for one minute before and one minute after the event, the two RSLs were within 3 dB of each other, the cause was power fading. If the difference was greater than 3 dB, the cause was multipath. If there were nonpropagating mux alarms (cryptos: failed, bypassed; TDM: power supply failed, frame loss, MBS RCV data loss, MBS XMT data loss, SCBS mux failed) but no radio alarms (power supply failed, A or B side failed, transmitter frequency drift, modulator failed, MBS XMT failed, SCBS XMT failed, MBS RCV failed, SCBS RCV failed, demodulator failed, frame sync loss, transmitter power failed), cause was equipment (subroutine: get_TRAMCON, alarm_count). If, by this point, a cause was not found and the path being examined is either receiver A or B, then the cause is undetermined. If the path is the receiver-on-line, check to see if there is a concurrent event for either receiver A or B that has a cause assigned. If there is, assign the same cause to the receiver-on-line.
Arguments returned: cause identifier.

**box110**

Arguments received: TRAMCON linkend.
Description: Compare the TRAMCON RSLs for the two receivers (Figure D7, block 62) for the current, previous and following 15 minute periods (subroutine: idx69_80). If the

RSL fading differences of the two receivers were within 3 dB of each other, then the probable cause is power fading. Otherwise, the cause is multipath.
Arguments returned: flag indicating power fading or multipath.

**get_TRAMCON**

Arguments received: TRAMCON linkend, event time, event duration, search flag.
Description: Get TRAMCON alarms and parameters associated with an event given a link ID. Because of the TRAMCON polling procedure, the alarms may not be set during the first poll, so the next two TRAMCON polls sould be available for examination. The actual poll examined is controlled by the search flag. Matching TRAMCON records occurring up to 230 seconds following the end of the event is searched to allow for a full polling cycle. If the appropriate TRAMCON record is found, store the parameters and unpacked alarms in global array for use in calling routines.
Arguments returned: Flag indicating if a TRAMCON record was found.

**TRAMCON_linkID**

Arguments received: pointer to path six character string, pointer to mode character string.
Description: Given a path string and a mode string ("recv" or "xmit"), return TRAMCON linkend ID.
Arguments returned: TRAMCON linkend.

**box5**

Arguments received: TRAMCON linkend, event time, event duration.
Description: Determine BOX5 digroup alarm test at FEL (Figure D1, block 5). For the first two matching TRAMCON records after the start of the event (subroutine: get_TRAMCON), check to see if one or the other of digroup 1 or 2 MBS1 failed alarms are set and one or less of digroups 3-7 MBS1 alarms are set (subroutine: alarm_count).
Arguments returned: flag set if criteria was met.

**box84**

Arguments received: TRAMCON linkend.
Description: Examine the TRAMCON RSLs for the two receivers (Figure D6, block 53) for the current, previous and following 15 minute periods (subroutine: idx69_80) to see if the RSL of either receiver was more than 10 dB below the average.
Arguments returned: flag set if criteria was met.

**alarm_count**

Arguments received: pointer to array of alarm numbers.
Description: Counts the number of alarms in the alarm array that are set.
Arguments returned: number of alarms set.

**box3**

Arguments received: TRAMCON linkend, event time, event duration.
Description: Determine BOX3 digroup alarm test at FEL (Figure D1, block 3). For the first two matching TRAMCON records after the start of the event (subroutine: get_TRAMCON), check to see if the digroup 8 MBS2 failed alarm is set and one or less of digroups 5-7 MBS2 alarms are set (subroutine: alarm_count).
Arguments returned: flag set if criteria was met.

**pass4**

Arguments received: none.

Description: Scans the current 15 minute block and generates the intermediate arrays used by the graph and table programs. First, perform the operation on the BLN-FEL/64 and LDF-FEL/64 channels (subroutine: PASS_4_3a). Then set the multipath flags for the current 15 minute block (subroutine: set_multipath), after which perform the operation on the three SBN-FEL/56 channels (subroutine: PASS_4_4a). Update the receiver-on-line flags for the current block. Create the Table 16 entries (subroutine: table16), make the space diversity improvement calculations (subroutine: SDI), then finish updating the average BER and fraction-errored-seconds graphset storage structure (GS35_57) and append it to the disk file.
Arguments returned: none

**PASS_4_3a**

Arguments received: pointer to raw data structure, pointer to event structure, pointer to array containing the number of error events in each time block, path identifier.
Description: Generate the intermediate arrays used by the graph and table programs for the BLN-FEL/64 and LDF-FEL/64 channels. Get the error information for G.821 availability time (subroutine: get_G821) then generate G.821 parameter (unavailabilty time, severly errored seconds, degraded minutes, errored seconds) totals for all causes. Scan the events in the current 15 minute block and count the number of frame losses during MIL-STD availability time for each of the five causes: unidentified, troposcatter propagation, equipment, power fading and multipath (subroutine: path_link). Scan each second in the current block (subroutine: path_link) and sum the total MIL-STD available time, and for each cause, total errored seconds, total errored seconds caused by two links, error event statistics (subroutine: dist_3a); MIL-STD available time total errored seconds, total errored seconds caused by two links, total number of errors and total unavailable time. Total the statistics for each cause to obtain the values for all causes. Finally, calculate the average BER and fraction of errored seconds for the 15 minute block foe each of the causes.
Arguments returned: total MIL-STD available time.

**dist_3a**

Arguments received: cause index, link index, second index (in current 15 minute block), number of errors in this second, MIL-STD error flag.
Description: Creates the error event statistic histograms for the current second. Bin the number of errors for MIL-STD available time (subroutine: store_idx), duration of event, error free seconds, and availability duration.
Arguments returned: none.

**get_G821**

Arguments received: pointer to raw data structure, pointer to G.821 unavailability time counter, pointer to severly errored seconds counter, pointer to degraded minutes counter, pointer to errored seconds counter.
Description: Generate the G.821 unavailability statistics for the current 15 minute block. Scan the current block. If the G.821 flag is set, increment the unavailability time counter. If the flag is not set (available time), and the number of errors is greater than 64, increment the severly errored seconds counter. If there are any errors at all, increment the errored second counter. Counting the number of errors during a one minute period (and ignoring a second if it is not available or is severly errored), if the total is greater than four, then increment the degraded minute counter.
Arguments returned: none.

**PASS4_4a**

Arguments received: pointer to raw data structure, pointer to 56-kb/s channel extra raw data structure, pointer to event data structure, pointer to array containing the number of error events in each 15 minute block, path identifier.

Description: Generate the intermediate arrays used by the graph and table programs for the SBN-FEL/56 A, B and receiver-on-line channels. Get the error information for G.821 availability time (subroutine: get_G821) then generate G.821 parameter (unavailabilty time, severly errored seconds, degraded minutes, errored seconds) totals for all causes. Scan the events in the current 15 minute block and count the number of frame losses during MIL-STD availability time for each of the five causes: unidentified, troposcatter propagation, equipment, power fading and multipath (subroutine: path_link). Scan each second in the current block (subroutine: path_link), update the histograms for receiver RSLs (at 0.1 dB increments), slope distortion at the 3 dB points (from the spectrum analyzer data), and receive SQM voltages. Sum the total MIL-STD available time, and for each cause, total errored seconds, time the receiver's RSL is less than the BER threshold, error event statistics (subroutine: dist_3a); MIL-STD available time total errored seconds, total errored seconds caused by two links, total number of errors and total unavailable time. Total the statistics for each cause to obtain the values for all causes. Finally, calculate the average BER and fraction of errored seconds for the 15 minute block foe each of the causes.

Arguments returned: total MIL-STD available time.

**multi_dist**

Arguments received: pointer to 56-kb/s channel extra raw data structure, fading identifier, link index.

Description: Update the histograms for errored second or multipath fading periods data (slope distortion measured by filters, 3 dB slope distortion measured by the spectrum analyzers, adjacent point slope distortion measured by the spectrum analyzers, receiver SQM voltage, receiver RSL, and probe data for the individual receivers: delay, rate-of-change of delay, phase, rate-of-change of phase, amplitude ratio and rate-of-change of amplitude ratio) for the current second.

Arguments returned: none.

**idx_minmax**

Arguments received: index, maximum value.

Description: Limit the index to the range [0-max].

Arguments returned: corrected index.

**set_multipath**

Arguments received: none.

Description: Scan the current 15 minute block and set the receiver-on-line multipath fading flag if required by examining each of the two receivers. A second is defined to be in multipath fading if it is part of an error event caused by multipath, within a 60 second period between multipath events, or between a multipath event and within 60 seconds of the start or end of the 15 minute block.

Arguments returned: none.

**SDI**

Arguments received: none.

Description: Calculate the space diversity improvement values for each fifth of second of the current 15 minute block. Also count the number of multipath fading period seconds and receiver-on-line MIL-STD unavailability seconds. All calculations are done only for those seconds labelled as being in a multipath fading period. Errors are tabulated for 9

different receivers: the hypothetically best receiver (minimum errors of A or B), actual A receiver, actual B receiver, actual receiver-on-line, receiver having the least slope distortion as measured by the filters, receiver having the least 3 dB slope distortion as measured by the spectrum analyzer, receiver having the least adjacent point slope distortion as measured by the spectrum analyzer, receiver having the greatest SQM voltage (subroutine: pick_ROL), and the receiver having the minimum fade depth (difference between average RSL and current RSL). Count the total time, errors and errored seconds for each possibility.
Arguments returned: none.

**pick_ROL**

Arguments received: receiver A value, receiver B value, receiver-on-line flag, receiver-on-line default flag.
Description: Determine the hypothetical ROL based on the minimum of the receiver A and B values. If the values are equal, the selection returned is the actual receiver-on-line.
Arguments returned: receiver-on-line selection.

**table16**

Arguments received: none.
Description: Scans the SBN-FEL/56 receiver A and B events for the current 15 minute block (subroutine: get_next_err) and creates the Table 16 output file GS_DATA.T16 (subroutine: dump_table16).
Arguments returned: none.

**get_next_err**

Arguments received: pointer to next receiver A exent index counter, pointer to next receiver B exent index counter, pointer to event start time, pointer to event end time, pointer to cause of error event.
Description: Obtains the date, time and cause of next error event in the current 15 minute block for receivers A and B.
Arguments returned: flag set if events were found.

**dump_table16**

Arguments received: none.
Description: Dumps a TABLE 16 line of data to the GS_DATA.T16 file. Calculates the event duration and ignores any events less than 60 seconds in length. Otherwise, convert the event's elapsed time to a date and time character string (subroutine: real_datetime), converts the cause index to a character string (subroutine: table16_cause) and appends the resultant text line to the disk file.
Arguments returned: none.

**table16_cause**

Arguments received: cause index.
Description: Returns a cause name character string given a cause index.
Arguments returned: pointer to cause character string.

**real_datetime**

Arguments received: elapsed time, pointer to date character string, pointer to time character string.
Description: Returns date and time character strings in the form: mm/dd/yy and hh:mm:ss given an elapsed time (subroutine: datetime).
Arguments returned: none.

**store_idx**

Arguments received: initial value.

Description: Given an initial value, return the storage index s = 100 * log(v) + 0.5, where s = [0-1599].

Arguments returned: storage index.

**read_NEXT**

Arguments received: file pointer to raw data file.

Description: Reads the next 15 minute time block and performs preliminary calculations and data conversions. When first called, it checks to see if there is a 15 minute block fragment to be continued. If not, it assumes that a new 15 minute block is beginning and the event and error counters are reset. The raw data is read from the disk file one record at a time (subroutine: next_rec). If the record type is zero, indicating the end of the file, the next data block is read from the tape (subroutine: tape_read). If the end of the tape is sensed, the program returns with an end-of-tape flag to signal the main analysis program to exit. Otherwise, the time counter is updated. If, according to the record's time stamp, the data occurs earlier than the current block limits, it is discarded, and data is read until it is time-valid. Data is read until the end of either the block or the data file is reached. When a valid record is read, it can be one of five types: long record (BERTS, digital status, slope filter, RSL, SQM and spectrum analysis data), short record (BERTS and RSL data), operator (log) message, probe data and TRAMCON records.

- For a long record: various counters are initialized, as well as the probe variables (the probe record following a long record are considered time linked). The error information is checked for negative values (overflow) and set to a maximum value if they are. Errors for the five fifth-seconds are summed for the BLN-FEL and LDF-FEL channels. The errors for the 3 SBN-FEL channels are checked for invalid values. If receivers A and B show errors but the receiver-on-line does not, or if the receiver-on-line shows errors but neither A or B show any, the error data is ignored (this is to correct for hardware problems discovered after the data was collected). All valid data is summed over the five fifth-second periods. The RSL and SQM values are converted to voltages and then to dB (for RSL) (subroutine: reading, volts_to_dB) and stored. Periods that the RSL is less than the BER threshold are counted. The digital status byte is examined and the manual mode, sync loss and receiver-on-line flags are stored. The filter data is converted to first to voltages and then to slope distortion. The spectrum analyzer data is read and decoded (subroutine: read_spec). Based on the receiver-on-line flag, the individual receiver data is assigned to the receiver-on-line variables. At the end of the second's initial reduction, the error totals and flags are stored in the appropriate channel's structures.
- For a short record: various counters are initialized, as well as the probe variables. The error information is checked for negative values (overflow) and set to a maximum value if they are. Errors for the five fifth-seconds are summed for the BLN-FEL and LDF-FEL channels. The errors for the 3 SBN-FEL channels are zero (the condition of a short record). The RSL values are converted to voltages and then to dB (subroutine: reading, volts_to_dB) and stored. Periods that the RSL is less than the BER threshold are counted. No digital status is recorded, so the receiver-on-line flag is set to "don't care". At the end of the second's initial reduction, the error totals and flags are stored in the appropriate channel's structures.
- For a TRAMCON record: the record is first tested to eliminate any bad records. The conditions used to determine a bad record are: if the linkend is invalid; if the number of parameters is wrong (6 for troposcatter, 12 for line-of-sight); the previous record's linkend was 0 or the same as the current record's and the two times are the same; any error parameters are negative. If the record is valid, the TRAMCON statistics (record count, total errors, total errored seconds) are accumulated and the record is stored in the block's TRAMCON array.

- Operator (log) messages are ignored during the analysis.
- Probe records containing co-phase and quad-phase information for the two channels are converted to delay, phase and amplitude ratio values (subroutine: probe).

Arguments returned: a negative value if the end-of-tape was detected, otherwise, the number of records processed.

**read_spec**

Arguments received: second index, fifth-second index, pointer to array containing notch count for the two channels.
Description: Reads and decodes spectrum analyzer data. The individual readings are converted to volts and then dB (subroutine: reading). The middle of the spectrum is found and then the middle 21 points are added to the running average for the next 15 minute block. The middle of the spectrum is then compared to the current average. The two endpoint differences are subtracted and converted to a dB/Mhz slope distortion value. The occurrence of notches in this spectrum is determined (subroutine: is_notch) and added to the second's fifth count. Out of the middle spectrum data points, the largest adjacent point slope distortion is found and converted to dB/Mhz.
Arguments returned: none.

**maxval**

Arguments received: pointer to array of floating point values.
Description: Finds the index of the maximum value of an array of floating point numbers.
Arguments returned: array index.

**is_notch**

Arguments received: array of values representing the middle of the spectrum.
Description: Determines if there is a notch in the spectrum. If a point is surrounded by two points of higher values, a notch exists. This test is performed for all of the 19 data points (excluding the endpoints).
Arguments returned: flag set if one or more notches were found.

**next_rec**

Arguments received: pointer to raw data file.
Description: Reads a record from the data file. The record is of variable length, depending on the type of record. If it is a TRAMCON record, the TRAMCON time tag is set to the last record time since the TRAMCON clock was not synced to the NPC/LPC clock and there was a discrepency between the two. The record time is set everytime a long (time-tagged) record is read and incremented every time a short (non-time-tagged) record is read.
Arguments returned: record type.

**reading**

Arguments received: raw data.
Description: Converts the output of the HP3852 data acquisition system A/D converter to a voltage.
Arguments returned: voltage.

**volts_to_dB**

Arguments received: voltage.
Description: Converts an RSL voltage to dB using a known conversion slope.
Arguments returned: dB

**probe**

Arguments received: pointer to raw probe data, pointer to receiver A's probe data array, pointer to receiver B's probe data array.

Description: Converts raw probe data to delay, phase, power and rate-of-change values. The scaled time between samples is calculated. The two probe channels are handled one at a time. First, the delay and peak arrays are cleared. Then the co- and quad-phase values are converted to voltages (subroutine: reading) and the sum-of-squares (SOS) curve is generated. The baseline of the SOS is chosen by averaging the first two readings and adding a noise floor (chosen to be 0.2 volts). The highest SOS point is located. Then the waveform is scanned from this point in both directions to where it falls below the baseline. This defines the baseline of the SOS and the range which will be considered. If the signal never rises above the baseline, then no further work is done on the channel. Once the signal range is defined, a search for up to three peaks within this range in the co- and quad-phase signals is performed. If a peak is found that lies over two points of equal value, the first point is chosen to be the peak. Once peaks in both phases have been found, the type of calculation is based on the following possibilities:

- No peaks were found in one or more channels: there are problems with this data. Further calculations are terminated.
- Two or more peaks were found in the SOS signal: If two peaks exist, the delay is the time difference between the two peaks. If three peaks exist, the first delay is the time difference between the first and second peaks. The second delay is the time difference between the first and third peaks. If no or one distinct delays were found in the SOS signal, continue to search for indistinct delay in the co- and quad-phases:
- One peak is found in each of the co- and quad-phases: the delay is the time difference between the two peaks. If the difference is less than 2 sample times, the delay is the SOS basewidth - 16 sample times.
- Either co- or quad-phases have three peaks: discard the one farthest from the highest SOS peak. Then:
- Both the co- and quad-phases have two peaks each: if the SOS basewidth is >16 sample times, then the delay is the time difference between the largest amplitude co-phase peak and the largest magnitude quad-phase peak. If the SOS basewidth is <16 sample times, then discard the smallest amplitude peak of the four co/quad peaks. Then:
- One phase has two peaks, the other has one: the delay is the time difference between the peak of the phase with one peak and the furthest peak of the phase with two peaks.
- If one distinct and one indistinct delay value were found, the second delay is the indistinct value only if it is more than two sample times different from the distinct value.
- If one distinct and two indistinct delay value were found, the second delay is the indistinct value that is more than two sample times different from the distinct value (the second indistinct value will be within two sample times of the distinct value).

Once multipath delay times and positions have been found (the maximum SOS peak is considered to be the direct path occurance), the amplitude ratios and phases are calculated (phase = arctangent(quad-phase/co-phase)). If a probe measurement was recorded in the previous second, the rate-of-change of delay, amplitude ratio, and phase for the first multipath component is calculated.

Arguments returned: none.

### D.8.2 GRAPHSETS: Creates all "GS_FILE.nnn" & "TB_FILE.nnn" files

**main**

main routine for "graphsets"

**dump_GS****
Description: create the individual graph files.

**dump_TB***
Description: create the individual table files.

**correlation_coef**
Description: calculate the curve fit r rot the scatter plots.

**fade_margins**
Description: calculate the fade margins for Table 15.

**SDI_calc**
Description: perform the SDI calculations.

### D.8.3 BLDGRAPHFILE: Used by "makegraph" to create the file "graphfile" which contains data for the graph being plotted

**main**
main routine for "bldgraphfile"

**data_for_graph_***
Description: generate data for the figures.

**read_time**
Description: read the start and end times of the test period.

### D.8.4 MAKEGRAPH: Plots the graphs

**main**
main routine for "makegraph"

**draw**
Description: initialize the plotter and draw the plot.

**load_fixed_data**
Description: load label strings and constant data.

**load_curve_data**
Description: run "bldgraphfile" & read in data from "graphfile".

**load_variable_data**
Description: load the appropriate labels for each graph.

**test_period**
Description: convert start & end times to date & time.

**load_labels**

Description: load the labelling strings in the control arrays.

**axis_max_min**

Description: define the axis boundries.

**labels**

Description: plot the labels.

**plot_curves**

Description: plot the curves.

**scatter_plot**

Description: plot a scatter plot.

**line_curves_graph**

Description: plot line curves.

**PltCon**

Description: define constants to control plot size and location.

**TicLbl**

Description: label the tickmarks with the proper number formats.

**TicPlt**

Description: draw the frame edge and tickmarks.

**POS**

Description: transform a value to a plotter pen position.

**Tran**

Description: perform a linear, log or log normal transformation.

**TV**

Description: calculate consecutive tickmark values.

**LogNormal**

Description: calculate a value's log normal.

**ftoa**

Description: convert a (float) to an alphanumeric string.

**cstr**

Description: plot string centered or right justified.

**interval**

Description: check if a value lies within an interval.

**circle**

Description: plot a circle.

**pltcv**

Description: plot a graph with a symbol around the data points.

**clipit**

Description: clip the data so the plot lies within the frame.

**intersect**

Description: determine where a line intersects the frame.

### D.8.5 PRINTTABLES: Print the tables

**main**

main routine for "printtables"

**set_up_tables**

Description: determine which report style to use.

**load_fixed_data**

Description: load label data.

**read_table_data**

Description: determine which table data format to use.

**table_data_***

Description: read the data for the table.

**LPMS_events_data**

Description: read the data for Table 17.

**load_variable_data**

Description: put together the table pieces.

**main_title**

Description: generate the table's main title.

**test_period**

Description: convert start & end times to date & time.

**report_style_***

Description: send everything to the printer.

**table10**

Description: generate the data for Table 10.

**table10_sub**

Description: determine if a frame error occured.

**frame_err_read**

Description: check to see if the frame sync error flag is set.

### D.8.6 LPMS: Analyze a LPMS data tape

**main**

main routine for "lpms"

**endevent**

Description: end an lpms event.

**process**

Description: process any saved records.

**add1**

Description: add 1 to a histogram array.

**tp_check**

Description: check to see if "time" falls within a valid period.

**histwrt**

Description: write all the histogram info to a disk file.

**lpmsopen**

Description: open the LPMS cartridge tape.

**nextrec**

Description: read the next data record from the tape.

**prtber**

Description: print out a ber histogram.

**prtrate**

Description: print out the min and max fade rates.

**prtrsl**

Description: print out the min and max RSL values.

### D.8.7 LPMS_PLOT: Plot any of the LPMS data and combines PLMS events into one file for use by the "analysis" program

**main**

main routine for "lpms_plot"

**rdsum**

Description: read a ".s" lpms summary file.

**fileindex**

Description: get a file index number.

**suml**

Description: summation of a (long int) array.

**bercvt**

Description: convert BER histogram data into (x,y) array.

**dispcvt**

Description: convert dispersion histogram data into (x,y) array.

**histread**

Description: read all the histogram info from a disk file.

### D.8.8 SCAN: Scans a data tape for a quick summary

**main**

main routine for "scan"

**print_block**

Description: print out the last block's results to "scan.prt".

**print_head**

Description: print the heading to the "scan.prt" file.

**next_rec**

Description: read a record from the data file.

**reading**

Description: convert integer to volts.

**volts_to_dB**

Description: convert volts to dBm.

**tape_read**

Description: read a file from the tape & save it as file DATA0.

**leapyr**

Description: return 0 if it isn't a leap year and 1 if it is.

**ndays_yr**

Description: calc number of days between BASEYEAR and year-1.

**datetime**

Description: convert elapsed time to two strings (date & time).

**juldat**

Description: convert Julian days to month/day.

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## APPENDIX E: TESTING THE NPC/LPC MEASUREMENT SYSTEM

The objectives of the Network-Performance Characterization and Link-Performance Characterization Program required the collection of 18-months of digital transmission performance and propagation data. A large amount of manpower was expended in the system design and development of the hardware and software data acquisition subsystems and in the collection of data for a long period of time. To check the validity of the data prior to the end of the long data-collection period, ITS decided that the majority of the data-analysis software would be developed prior to the start of the data collection effort. System tests were required to validate the entire data collection and analysis systems. Initial testing was conducted in the Transmissions System Test Facility at ITS. Later testing was conducted in Germany after installation of the NPC/LPC equipment but prior to the commencement of the 18-month data collection period. The lab and field testing of the NPC/LPC data acquisition and data analysis system are described in the next two subsections.

### E.1 Laboratory Testing of the NPC/LPC Data Acquisition and Data Analysis Systems

Figure E-1 depicts the ITS test facility used to test the NPC/LPC data acquisition and data analysis systems prior to shipment of the equipment to Germany. The test facility can be viewed as a simulation of the Schwarzenborn-Feldberg (SBN-FEL) line-of-sight link. A LOS channel simulator developed by ITS (Hoffmeyer, et al., 1986) was used to simulate fading on the actual SBN-FEL link. Connections were made between the NPC/LPC data-acquisition computer and the test-facility TRAMCON computer. This test configuration was similar to the configuration later installed at Feldberg. The TRAMCON computer was connected to the laboratory DRAMA radio and multiplexer equipment to replicate the interface between TRAMCON and DRAMA equipment in DEB. Because it was not feasible, or even logical, to obtain DRAMA equipment to simulate the entire Frankfurt North Phase I (FKT-N1) Segment of DEB, the TRAMCON segment simulator was used

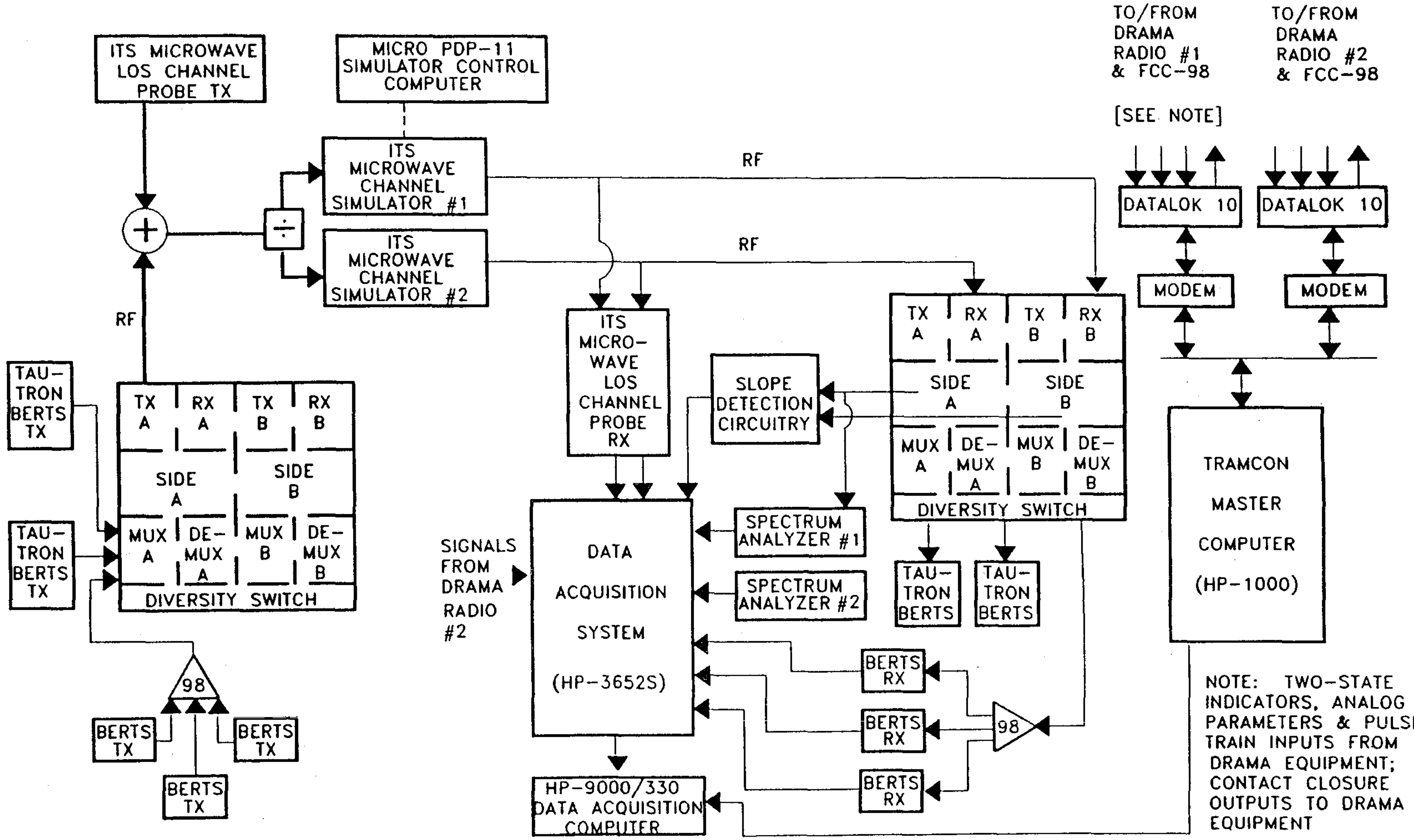



Figure E-1. NPC/LPC system test configuration.

to simulate polling responses from nodes in FKT-N1 other than the Schwarzenborn and Feldberg nodes. All of the other hardware (such as the spectrum analyzers and spectral slope distortion detection circuitry) that was later installed at Feldberg was also integrated into the ITS Transmission Test Facility.

Because of the completeness of the test facility, very realistic tests could be conducted on the NPC/LPC system. The test facility was also a necessary and useful tool during the development phase of both the data acquisition system software and the data analysis system software. The specific tests which were run to test the latter are now briefly described.

A series of five tests was conducted to test the accuracy of the data analysis software in developing summaries of the digital radio performance and propagation data. The experiments included tests to validate both the MIL-STD-188-323 and CCITT output error data. They also included tests to validate the received signal level (rsl), signal-quality monitor (SQM), slope distortion, and space diversity probability distributions.

The tests were conducted by the computer-controlled variation of the parameters of the channel simulator for precise periods of time. Because of the a priori knowledge of the total test time and the time the simulator was in a fixed state, it was possible to compare the predicted distribution with the measured distribution. In testing the rsl-distribution-analysis software, for example, fading on a single DRAMA radio channel was held constant for a fixed period prior to increasing the fading for another fixed period of time. To test the distribution software, the periods of time that the fading was held constant were changed for each fading level. Similar procedures were used in testing the SQM, amplitude distortion, and space diversity improvement distributions. Table E-1 provides a summary of these tests.

Detailed numerical test results and actual plots of the appropriate SBN-FEL propagation and error-performance distributions and tables were obtained, but are not provided herein. The importance of these tests, coupled with the field testing of the NPC/LPC measurement system described in the next section, is that one has a good deal of confidence in the actual measurement results from this project.

In addition to the above tests, several other tests were conducted. These included rsl calibration tests, and tests of the error-allocation algorithm. The latter tests were conducted using the TRAMCON Segment Simulator.

Table E-1. Laboratory Tests of NPC/LPC Data Acquisition and Data Analysis Systems

| Test No. | Test Conditions | | Output Tested |
|---|---|---|---|
| | Channel A | Channel B | |
| 1 | flat fading | no fading | RSL distributions<br>SQM distributions<br>error performance |
| 2 | strong selective fading | no fading | slope distortion distributions<br>SQM distribution |
| 3 | weak selective fading | strong flat fading | RSL distributions<br>slope distortion distributions<br>SQM distributions<br>space diversity improvement distributions |
| 4 | weak selective fading | weak selective fading | error performance tables |
| 5 | random selective fading of varying degrees of intensity | random selective fading of varying degrees of intensity | error performance tables<br>error free second distributions<br>15-minute average BER distributions<br>EFS vs. 15-minute BER scatter plots<br>number of errors in errored second distributions<br>slope distortion distributions<br>SQM distributions<br>space diversity improvement distributions<br>RSL distributions |

## E.2 Field Testing of the NPC/LPC Data Acquisition and Data Analysis System

The final testing of the NPC/LPC data acquisition and data analysis system was conducted in Germany in March 1988 prior to the start of the 18-month data collection effort. The emphasis of these field tests was to ensure that the error-performance data on the SBN-FEL link and the two end-to-end channels (Linderhofe-to-Feldberg and Berlin-to-Feldberg) were not only recorded properly, but also were accurately summarized in the tables created by the NPC/LPC data analysis software. Specific tests were designed to ensure that the errored second data were properly analyzed according to both MIL-STD-188-323 and CCITT definitions for errored second and unavailability. The experiments also tested the analysis-software allocation of errored seconds according to the CCITT definitions for severely errored seconds and degraded minutes.

The SBN-FEL tests were conducted by manually causing errored seconds to occur by disruption (at Schwarzenborn) of the bit stream generated by the transmitter portion of the ITS-developed bit-error-ratio test set (BERTS). The tests of the Linderhofe-Feldberg and Berlin-Feldberg channels were conducted by a loop-back arrangement at Feldberg. The statistics on errored seconds, unavailability, severely errored seconds, and degraded minutes were tested in this manner. Tables that are part of the data-analysis software were produced for the test period. Detailed numerical results were obtained, but are not reprinted herein. The numerical outputs for the errored seconds statistics agreed with those predicted at the time the tests were designed.

In addition to the above, tests of the two end-to-end channels (LDF-FEL and BLN-FEL) were conducted by manually pushing a button on the BERTS transmitters at Linderhofe and at Berlin. It was verified that the errors were detected by the NPC/LPC data-acquisition system by observing the real-time display at Feldberg.

Further verification of the NPC/LPC data-collection system occurred during the actual measurement program. A network user tested a channel from Berlin to Feldberg using errored second instrumentation that was completely independent of the NPC/LPC instrumentation. Identical errored second measurement results were obtained. Quantitative results from both measurement systems are available, but are not presented in this report.

## E.3 References for Appendix E

Hoffmeyer, J. A., L. E. Pratt, and T. J. Riley (1986), Performance evaluation of LOS microwave radios, Military Commun. Conf., paper no. 4.3, Monterey.

# APPENDIX F: TRANSMISSION MONITORING AND CONTROL SYSTEM OVERVIEW

(Copied verbatim with permission from "Transmission Monitoring and Control of Strategic Communication Systems", by J.E. Farrow and R.E. Skerjanec, ITS/NTIA, U.S. Dept. of Commerce, Boulder, CO.)

This paper discusses a minicomputer-based communications system monitor used by the U.S. Department of Defense to improve the service availability and reduce the operating costs of the new multichannel digital transmission systems. A brief history of the development of the monitor and a general description of the present-generation hardware and software are included.

## INTRODUCTION

As plans for the upgrade of the long-haul U.S. military communications network in Europe were being made, the advantages of digital transmission became more and more apparent. Long-haul voice channel quality could be improved, integrated medium-speed data transmission could be made more efficient, and bulk encryption of wide-band transmission could be made more efficient, and bulk encryption of wide-band transmission could improve communication security. For these reasons, military communication planners decided to emphasize digital transmission techniques for all future main-line communication facility upgrades to be a part of the Digital European Backbone.

The conversion of the Defense Communications System's European wide-band communication system to an all-digital communication scheme started with the installation in 1975 of the Frankfurt-Koenigstuhl-Vaihingen (FKV) microwave links that carried a digital baseband signal on frequency-modulated analog radio equipment. The next step in the conversion was the installation of the Digital European Backbone, Phase I (DEB-I), that used the same technology. Current plans are to convert the entire European wide-band system to digital transmission over the next several years.

The planning and development of these first two digital microwave systems indicated that an improvement in system effectiveness and a decrease in operating costs could be realized by reexamining the traditional methods of communication system control. In the past, each radio site in a system had a number of people assigned to operate the site 24 ours a day. This practice was recognized as being wasteful of both money and trained personnel. furthermore, modern communication equipment is reliable enough that continuity of service can be assured by installing redundant electronic equipment with automatic switching. This makes reduction or complete elimination of the personnel at repeater sites practical. As a consequence, both the FKV and DEB-I systems were commissioned with certain relay sites that were not staffed. Maintenance and restoral at these sites were to be performed by dispatch of trained, skilled maintenance operators to know the status of the equipment at these unstaffed sites, and alarm monitoring system was installed to report site conditions to the location of the responsible system operator.

The initial alarm remoting equipment was a wired-logic, poll response type system. a master unit requested information from the remote sensing unit and displayed the conditions of the remote radio site as an array of alarm and status indicator lights at the master location.

In order to make the remote site information more complete and accessible to the human operators, the Air Force system engineers decided to use a minicomputer to do some data processing and put the information in a more useful format for presentation to the operators. The development of this improved alarm remoting system, called the Enhanced Fault Alarm System, or EFAS, was begun in 1977.

The EFAS development consisted of preparing hardware and software to allow the minicomputer to replace a master fault alarm terminal. The computer sent poll messages to the remote units and received and decoded the responses. the information in the responses was analyzed and used to generate displays on a CRT terminal. These displays presented the alarm, status, and parameter data gathered from the remote sites in English text designed to show site and entire system conditions on easily understood displays.

The deployment of the minicomputer master units of the Enhanced fault Alarm System was done in parallel with the DEB-I installations in southern Germany and northern Italy during early 1979. The DEB-I EFAS consisted of 13 remote data acquisition units and 3 minicomputer-based master units. Each communication site, even those where a master unit was located, was equipped with one of the remote data acquisition units.

The next major development in the Transmission Monitoring and Control (TRAMCON) concept was the decision to deploy a second-generation minicomputer with a fully revised software package in support of the next two stages of the Digital European Backbone, namely, the DEB-IIA segment and the Frankfurt North-Berlin troposcatter segment. This was an opportune time for a change since these later DEB stages will use a completely new digital multiples, a new digital line-of-sight link radio, and a new digital tropscatter link radio.

The most important changes in TRAMCON system will not affect the display of information, but rather the way information is stored in the computer. The changes will enable TRAMCON to monitor any type of communication link, either terrestrial radio, satellite, fiber optic, or metallic cable technology, carrying traffic in either analog or digital form.

This paper deals primarily with the development of the second-generation system and includes a description of both hardware and software.

## OBJECTIVES

The basic reason for the establishment and continuation of the system monitoring project is to reduce the per-channel-mile cost of communication services by increasing the productivity of the communication operation and maintenance personnel. The increase in productivity is expected to occur as a result of requiring fewer operation and maintenance workers to provide the increased communication capacity being provided by the installation of the Digital European Backbone. To make this improvement in productivity possible, the communication system operators need new tools and techniques to permit them to monitor and control entire segments of a communication network and to isolate problems at any site quickly and accurately so that remedial action can be taken before total communication outage or failure occurs. The TRAMCON system is seen as the tool that will make the improvement possible and support the development of new operation and maintenance doctrines and techniques.

The intent of TRAMCON is not to displace or reduce the responsibility of human operators, but rather to increase their span of control by placing information of a more refined quality at their disposal to allow them to make better control and troubleshooting decisions.

The success of the transmission monitoring and control systems up to this time can be ascribed in no small part to the fact that a well-defined objective was set out and that a system was designed to move in evolutionary steps toward that objective.

## TRAMCON SYSTEM CAPABILITIES

The basic purpose of the transmission monitoring and control system is to gather information on communication equipment status from a number of sites and present this information in a useful format to a communication system operator. The information is presented to the operator in the form of displays on a CRT terminal. These displays report the functioning of the communication system in English text and can present data from a single communication terminal within a station or can present an overview of the operation of an entire transmission segment.

The monitoring process starts when the controlling master unit sends an addressed poll message to each of its remote units in turn. The remote unit replies with a formatted message that contains all of the alarm, status, and parameter information about its communication site. The master unit disassembles this message and places the information in local data files. The CRT terminal displays are generated form these data files at the request of the operator. Some of the data are processed for long-term archival storage. Examples are received signal level measurements, other parameter measurements, and the occurrence of alarms of major significance.

Another function the TRAMCON equipment performs is remote control switching of certain equipment at the remote sites. To perform a remote switching function, the system operator enters the request on the CRT terminal keyboard.

In addition, the master unit performs a number of other functions that support the TRAMCON mission. These involve maintaining information on communication system configuration, information on the status of communication system elements, and the necessary calibration and threshold tables for processing the input data from the remote communication sites. These databases are established specifically for operation of the TRAMCON system, but such data can be obtained form the computer so that other analyses scan be performed.

A new capability of the TRAMCON system is for the connection of a number of CRT terminals in addition to the system console. These extra terminals, called remote displays or maintenance dispatch terminals, will be used to provide communication system monitor information to other than the system operator.

The TRAMCON system includes both master and remote units. To improve the reliability of the monitoring system, at least two master units are able to monitor each segment or group of communication sites. The polling master will actually control the remote units on a segment while any other masters will operate in a listen-only mode. The polling line is broken at segment boundaries so that only polling messages intended for a particular segment's remote units appear on the segment poll line.

Fig. 1 is a functional block diagram that shows some of the capabilities of a TRAMCON master unit. The master software includes a real-time operating system, file-handling utilities, various language compilers, and communication handlers and drivers for the various input/output devices. The TRAMCON data acquisition, manipulation, storage, and display programs that were written at ITS will be described in detail in a forthcoming NTIA report.

All data acquisition performed by the TRAMCON system is handled through the wired-logic remote units, which also implement the remote switching mentioned previously. Fig. 2 is a functional block diagram of a remote unit. As shown, three types of input can be accommodated, namely, two-state status or alarm indications, continuously varying voltages that correspond to analog parameters, and pulse train or random pulse occurrences. In addition, the remote unit provides for contact closures, either momentary or latching as required, to perform the remote switching functions. As the TRAMCON remote units are now designed, all of the functions they drive or monitor are those that are built into the communication equipment at status and alarm indicators and remote switching points.

One type of signal monitored-- the two-state indicators-- are the status and alarm conditions used by an operator or maintenance person to assist in diagnosing problems with the communication equipment.

A second type of signal the remote unit is equipped to monitor is a slowly varying dc voltage. The communication equipment generates these voltages as analogs of parameters of interest to the operators, such as radio received signal level and mission traffic signal-to-noise ratio. The remote unit samples and measures the voltage and sends the measurement to the TRAMCON master for conversion to a value in the units of the parameter being monitored for display and for further a analysis or archiving.

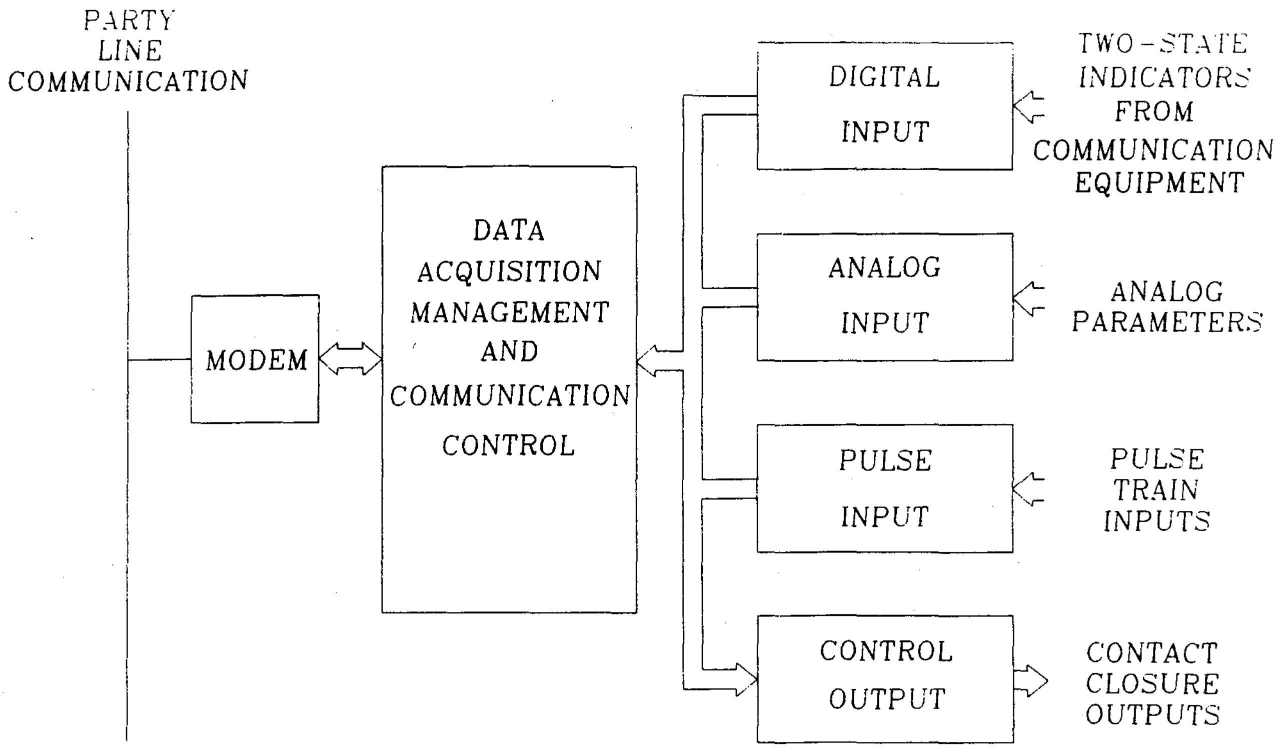



Figure 1. Functional block diagram of a TRAMCON master.

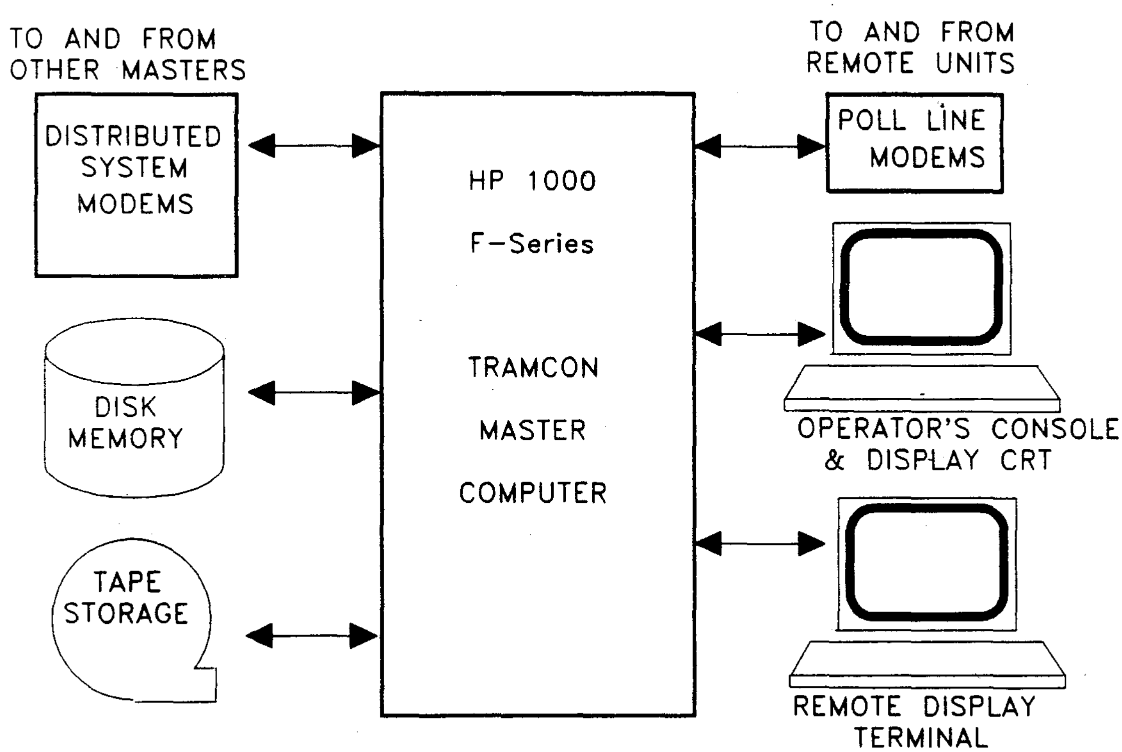



Figure 2. Functional block diagram of a TRAMCON remote.

A third type of signal monitored by the remote unit is the pulse or pulse train. The remote unit collects these data in two ways. The first is simply to count the number of pulses during the interval between poll messages from the master and to report the number in the poll response (up to the maximum count capability of the remote). The second way is to count the number of seconds between poll messages during which one or more pulses were detected. This second measure, called the number of "errored seconds," is also sent to the master unit for processing and display.

The control outputs of the remote unit that will be used to control the communication equipment are metallic relay contacts, both normally open and normally closed, without any voltage on the contacts that originates in the remote unit. Either latching or momentary contact closure is available so these outputs are able to handle a wide variety of external switch functions.

## TRAMCON MASTER SOFTWARE

The master unit is a general-purpose minicomputer with a number of peripheral devices for large-scale data storage, information display, and communication. The computer operating system, which is the software that controls the basic functioning of the computer and allows other programs to be run, was purchased from the manufacturer. In addition, high-level language compilers for Fortran and Pascal and a number of other useful software utilities were obtained. Manufacturer-provided software was used to develop application software for polling, data collection, analyses, storage, and display.

Since the TRAMCON system is intended for worldwide application to the Defense Communications System, the communication and data storage programs must be easily adaptable to many different types of communication equipment. This is implemented as a technique for easy field entry of a communication system configuration database. These configuration data will include such segment-peculiar items as segment identifier, number of sites, site names, communication equipment configuration, communication equipment type, trunk identifiers, and any other information needed to define the operational status of the communication system.

As TRAMCON is more widely used, there will be further evolution of the software and displays to enhance the usefulness of the system. To make trend analysis easier for the operator, display software is planned that will summarize system performance on an hourly and daily basis. This summary will be updated each hour and the oldest hour's data will be deleted. The software will also provide for displaying any of the data on more than one terminal and for making any data available for use by other elements of network control.

The primary device for providing assistance to the communication system operator is the CRT terminal and hard-copy device. For this reason, a great deal of planning and testing has been done to make the formatted data displayed on the CRT terminal informative and understandable. The data displays were provided to system operators with the request that any suggestions for improvement or simplification to make the data display more easily understood be sent to programmers for consideration. Most of the displays have been revised a number of times, and the current formats are the result of considerable operating experience. In subsequent sections of this paper, the formatted data presentations will be referred to simply as displays.

The menu has a list of 37 commands, most of which evoke the various displays. Some of these commands, however, perform a specific action without regard to what display is on the screen. Table 1 shows which commands call up displays and which commands do not.

The commands can also be divided into five categories, depending on the purpose and effect of the command. The first category includes those commands that are intended to assist the operator in using the TRAMCON system. The MENU and HELP commands fit this description. The next category includes those commands that directly show or influence communication system operation. These commands would include the map, the segment status, the remote unit status alarm, and the switch commands, among others. The third category comprises a set of utility commands that support the communication system operation commands. Examples of this category are the calibration curve and operator identification commands. The fourth category includes those that request information about the communication system or TRAMCON configuration, such as list or CRT status. The fifth (andfinal) category includes all other commands. These are commands to set the clock and to run the diagnostic and simulator functions. Details of each display and commands are given in NTIA Technical Report 84-147.

Table 1. List of Control Commands for Displays

| | |
|---|---|
| DISPLAY COMMANDS | |
| AL | ALARM/STATUS DISPLAY FOR ONE OR MORE REMOTES |
| AR | ARCHIVE RECORD REVIEW FOR SINGLE REMOTE |
| CC | CALIBRATION CURVE ENTRY FOR SINGLE LINK END |
| CN | COUNTED TWO-STATE ALARM OR STATUS OCCURRENCE |
| CO | CONFIGURATION DATA BASE CHANGE FOR SEGMENT |
| CR | CRT STATUS FOR THIS TRAMCON MASTER UNIT |
| DI | DIAGNOSTIC ROUTINE, TURN ON OR OFF |
| DT | DATA TRANSFER TO ANOTHER REMOTE |
| HE | HELP WITH TRAMCON OPERATING PROCEDURES |
| HI | HISTOGRAMS OF A/D AND COUNT DATA FOR ONE REMOTE |
| LS | LIST ALARMS/STATUS DEFINITIONS FOR SINGLE REMOTE |
| MA | MAP DISPLAY OR SEGMENT STATUS, ALL REMOTES |
| ME | MENU OR OPERATOR COMMANDS |
| MS | MESSAGE ENTRY, FOR ANOTHER TRAMCON OPERATOR |
| NM | NETWORK MAP SHOWING MANY SEGMENTS |
| PA | PARAMETER DISPLAY OF A/D AND COUNT DATA |
| PC | PCM ALARM SUMMARY |
| PM | POLLER/MONITOR/INACTIVE SELECTION FOR THIS MASTER |
| SC | SCENARIO MODE START FOR TRAINING |
| SD | SITE DIAGRAM OF COMMUNICATION SIGNAL FLOW |
| SE | SEGMENT NAMES IN SHORT FORM FOR COMMAND ENTRY |
| SS | SEGMENT STATUS TABULAR DISPLAY, ALL REMOTES |
| SW | SWITCHING DISPLAY FOR REMOTE RELAYS FOR ONE REMOTE |
| TH | THRESHOLD SET FOR A/D AND COUNT ALARM LEVELS |
| TR | T - 1 DIGROUP FAULT MAP FOR SEGMENT |
| TS | SEGMENT ALARM HISTORY, SHORT TERM |
| NONDISPLAY COMMANDS | |
| AC | ACKNOWLEDGE ALARMS FOR ONE OR MORE REMOTES |
| DE | DEFAULT DISPLAY SELECTION |
| EN | ENABLE ALARM NOTIFICATION FOR SINGLE REMOTE |
| IN | INHIBIT ALARM NOTIFICATION FOR SINGLE REMOTE |
| OL | ON-LINE/OFF-LINE TOGGLE COMMAND, THIS TERMINAL |
| OP | OPERATOR IDENTIFICATION ENTRY, THIS TERMINAL |
| PO | POLLING SEQUENCE CHANGE ON SEGMENT |
| PR | PRINT CONTENTS OF CURRENT CRT DISPLAY |
| SI | SIMULATOR COMMAND ENTRY FOR TRAINING |
| SR | SYNCHRONIZE CLOCK WITH NETWORK TIME |
| ST | STOP TRAMCON PROGRAMS AT THIS MASTER UNIT |

## OPERATIONAL EXPERIENCE

The initial EFAS (now TRAMCON) installations were made in 1978, so some experience with the system has been gained. The primary users of the DEB-I TRAMCON have been the technical control personnel on the sites where the master units are located. In late 1981, a maintenance dispatch terminal was added to a site with no master unit, but from which maintenance teams are dispatched to several unstaffed sites in the area. The purpose of this installation was to learn some of the problems and possibilities of a remote terminal and to permit the maintenance dispatch personnel to use the remote terminal to develop operating procedures. As the TRAMCON program has developed, the military personnel who are and will be using the system have had a definite formal channel to assist in the design and development of the displays, the operator input commands, and the operating doctrines and procedures.

The TRAMCON concept emerged from the realization that first, the type of communication equipment now being installed, particularly for line-of-sight links, does not require constant attention and, second, that providing full staffing at all sites, including relay sites with no voice break-outs, was inexpensive and inefficient use of trained operators. The opportunity for centralized control and maintenance dispatch over limited segments of the system was recognized. However, a prerequisite for taking advantage of the opportunity was a means for gathering information quickly from each site in the segment and presenting the information to a technical controller in a format that would allow one segment operator to monitor, control, and dispatch maintenance for all sites in a segment. The technique developed has allowed reduced staffing at many sites, particularly those difficult to reach in winter or collocated with other United States or NATO military functions. Maintenance teams are dispatched from central locations at the request of the segment operator to sites from which reports of faults or failures have been collected by the TRAMCON system. While this system has been in operation on the DEB-I segment, no observed decrease in communication channel availability has accompanied the reduced levels of operation and maintenance personnel. That is a testimonial to the equipment selection, link design, and installation, as well as a justification for the faith the military departments placed in the idea.

The introduction of computers into the operation and management of military wide-band strategic communication systems permits a new alignment of resources to perform the primary task of the communicator-- namely, to provide the best quality of communication service to the customer user at the lowest cost consistent with the established constraints of required service availability and existing physical plant.

As the field experience with the DEB-I TRAMCON developed, it became apparent that the computer could provide a degree of fault isolation. The alarm data were already being collected, the fairly simple fault isolation algorithms could be developed to isolate equipment faults to major modules. This function will be part of the final TRAMCON software.

The original DEB-I CRT terminals were simple alphanumeric screens and all information was shown in that format. Suggestions were received from the users to the effect that graphic presentations might make the information easier for operators to grasp at a glance. An initial effort in this direction was a map display showing the segment status that was made up of ASCII characters such as hyphens, dashes, and slashes. This was so well received that the new TRAMCON terminals have full graphic capability and new displays that present information in either text or graphic format at the choice of the operator.

The fact that each computer has available complete and current data on the segment it is monitoring suggests that such data could be gathered for many segments and collated to provide status information on communication system operation on a much wider geographical basis than a single segment. This would allow a network control technique to be developed that could permit much more rapid restoral of critical communications and improved operating procedures. The new TRAMCON computers will have a dedicated data port to which such a network monitoring system could be connected if this is desired.

Another enhancement of the TRAMCON system under consideration is the replacement of the wired-logic data-acquisition equipment by a microprocessor-controlled unit that would permit some data processing to be done at each site to reduce the volume of information sent to the TRAMCON master during each poll cycle.

The TRAMCON project started in a small way with limited objectives. As these were met, other desirable features were added, but only in an orderly way so that adding some new feature would not cause TRAMCON system failure. During the development, the users were consulted frequently to get their reactions to the steady development is a monitoring scheme that is easy to use and has permitted savings in personnel costs.

## REFERENCES

[1] J.E. Farrow and R.E. Skerjanec "A Computer-Based Transmission Monitor and Control System," NTIA Rep. 84-147, 1984.

[2] R.D. Rosner, "An Integrated Distributed Control Structure for Global Communications," IEEE Trans. Commun., Vol. COM-28, Sept. 1980.

## APPENDIX G: LINK-PERFORMANCE MONITORING SYSTEM (LPMS) OVERVIEW.

(Copied verbatim from Publication No. 86-010, Part 1 of 2, Operation and Maintenance Manual with Parts Identification).

### GENERAL INFORMATION

**DESCRIPTION AND PURPOSE**

a. The Link Performance Monitoring System (LPMS) (Figure G-1) is a computer-based system used for monitoring troposcatter-path parameters and digital modem performance. The LPMS uses an advanced, scientifically oriented computer, associated computer peripherals, and interface circuits to accomplish its monitoring function.

b. Specifically, the LPMS monitors and records performance of a quadruple diversity troposcatter link employing AN/FRC-177 Digital Radio Sets and MD-918/GRC Digital Data modems. Data rates on the order of 10 Mb/s can be monitored. Monitoring is done without interfering with normal operational performance of the troposcatter link.

c. As shown in Figure G-2, the LPMS (less two interface assemblies and power system) is mounted on a computer workstation desk (7). The power system (6) is located at the rear of the workstation desk and functions to prevent line voltage fluctuations (or losses) from interfering with sensitive computer components. Power supply, mounted on the rear of desk (7, Figure G-2), provides dc power for all LPMS interface circuits. Power strip (12) provides convenient outlets for connecting LPMS workstation-mounted equipment to 220 Vac, 50 Hz, single-phase primary power source.

d. The remaining two interface assemblies (not shown on Figure 2) are the LPMS IF interface and MD-918 modification kit. The LPMS IF interface is mounted within the AN/FRC-177 radio set. The MD-918 modification kit is mounted within the primary MD-918/GRC digital modem.

e. A simplified functional block diagram of the LPMS is shown in Figure 3. Received signal level (RSL) samples from AN/FRC-177 radio set are applied to an analog-to-digital converter (ADC). The ADC changes the RSL analog sample signals to a digital format that is readable by the main computer.

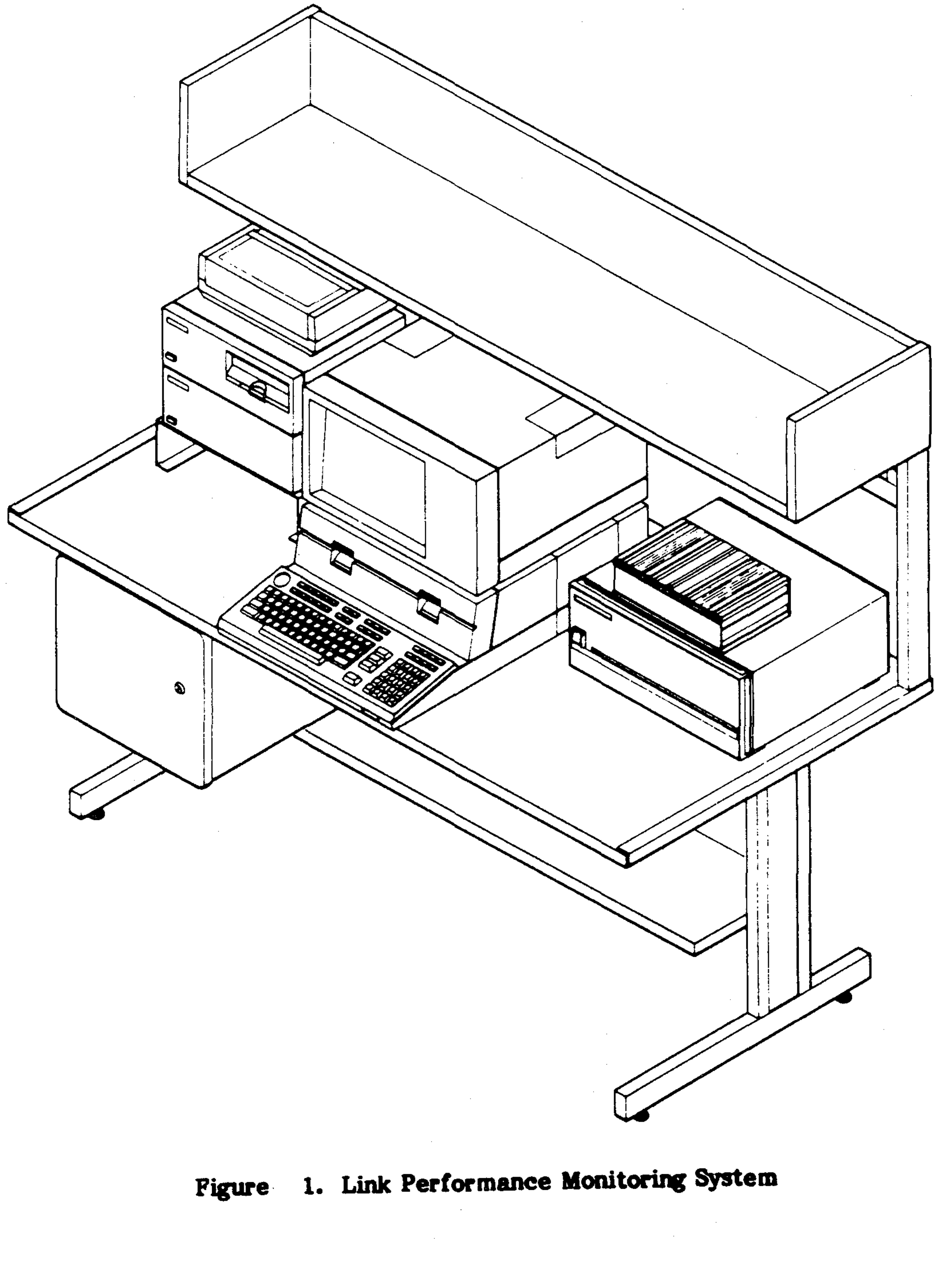


**Figure 1. Link Performance Monitoring System**

## LPMS PROGRAM THEORY OF OPERATION

The LPMS program is an interrupt-driven routine that collects, processes, logs, and displays data at a rate of once per second. The program listing contains sufficient comment statements to provide explanations for all procedures and variables. The following paragraphs will provide further details on the LPMS program operation.

When in operation, the LPMS program is controlled primarily by the TIMER_HOOK and the SYSTEM_MONITOR procedures (sub-routines). The TIMER_HOOK divides each second into 25 intervals, and collects and processes data during each interval. The three primary input data types are: (1) IF Input levels, (2) Eye (Pattern) voltage, and (3) Backward Equalizer (BEQ) tap values. This data is collected in the following manner:

a. IF Input levels: sampled twice per diversity each interval.

b. Eye voltage: sampled 100 times every odd interval.

c. BEQ taps: sampled 50 times per tap in interval 6.

d. No data collected in interval 25 (reserved for processing).

The TIMER_HOOK processes most of the data collected and provides updated variable values each second.

The SYSTEM_MONITOR controls the Input/Output (I/O) functions of the LPMS program as well as processing certain data into a usable form. The SYSTEM_MONITOR controls operator interactions, display data, logged data, printer data, and many other functions.

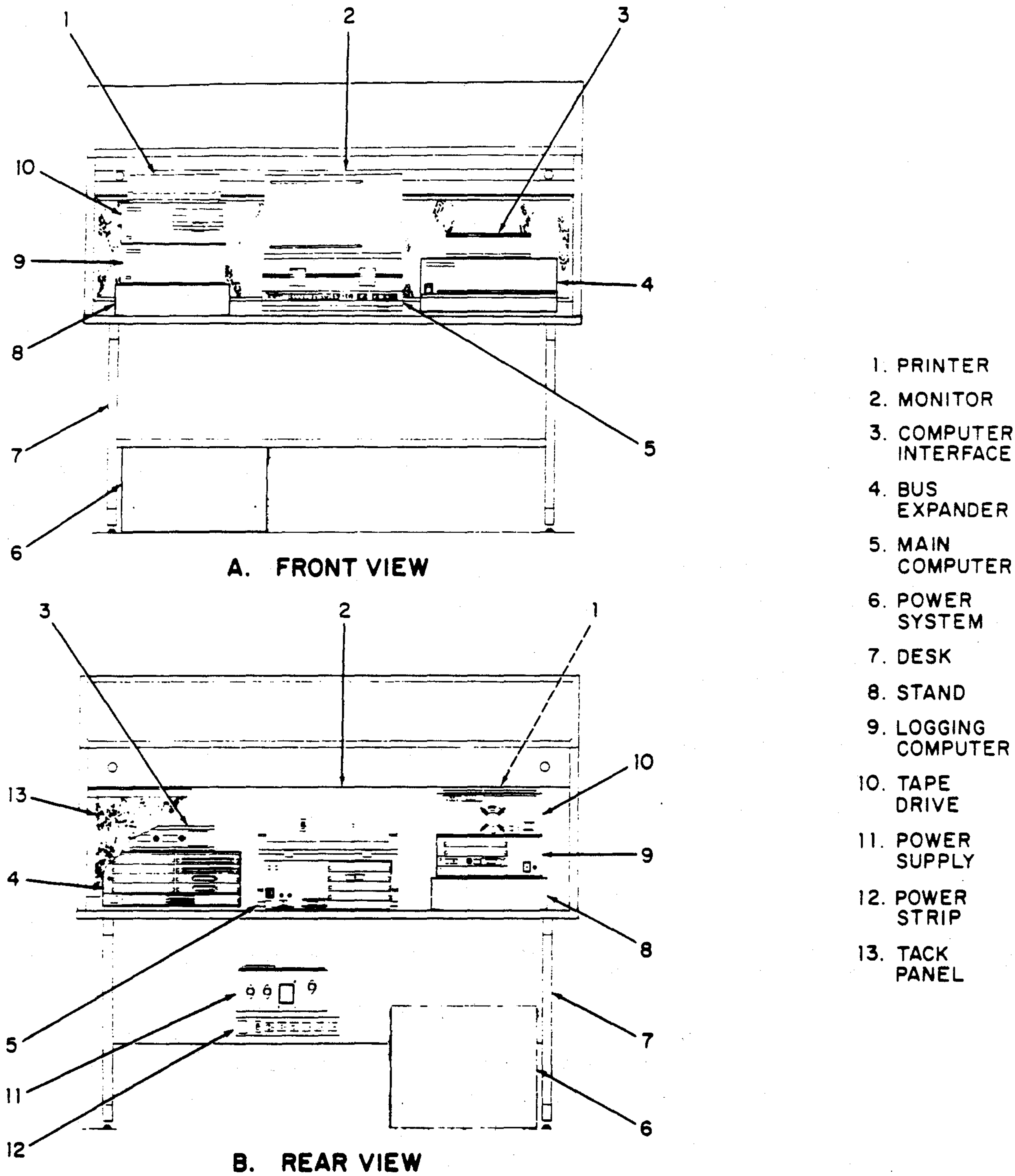



**Figure 2. Workstation Equipment Identification**

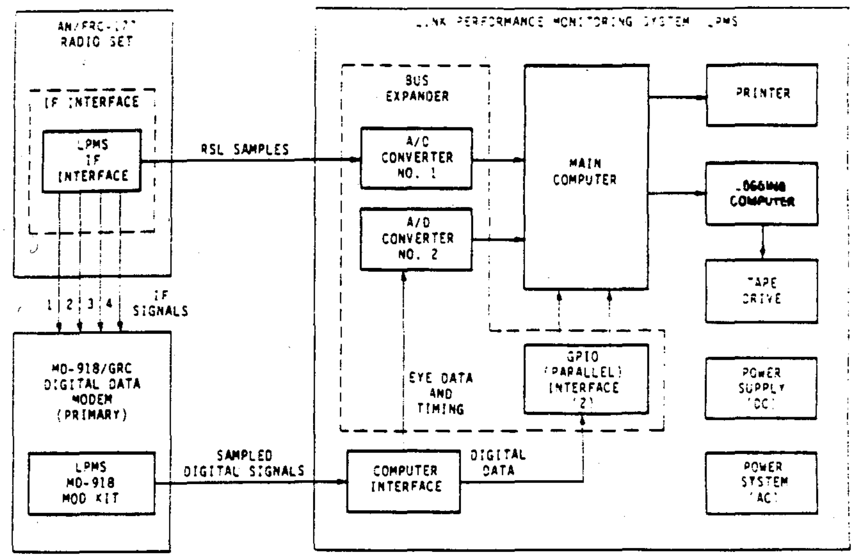



**Figure 3. Link Performance Monitoring System, Simplified Functional Block Diagram**

g. The main computer samples outputs from the two analog-to-digital (A/D) converters and GPIO interface, and computes the various required link performance parameters. The results are constantly displayed on the computer's monitor screen and periodically applied to the printer for a hard-copy recording. All data is applied to the logging computer, which uses the tape drive to permanently record the data on tape for later evaluation.

h. Power for LPMS interface circuits is provided by the dc power supply. The power system prevents line voltage fluctuations (or losses) from interfering with LPMS monitoring functions.

## LEADING PARTICULARS.

Leading particulars for the LPMS are listed in table 1.

**Table 1. Leading Particulars**

| Item | Characteristic |
|---|---|
| Primary power requirement | 220 Vac ± 10%, 50 Hz, single-phase, 3 amperes (maximum) |
| Physical characteristics | |
| Height | 54 inches (145 cm) |
| Width | 61 inches (155 cm) |
| Depth | 31 inches (79 cm) |
| Weight (estimated) | 500 pounds (227 kg) |

## CAPABILITIES AND LIMITATIONS.

Capabilities and limitations for the LPMS are listed in table 2.

**Table 2. Capabilities and Limitations**

| Item | Characteristic |
|---|---|
| LPMS INPUT INTERFACES | |
| AN/FRC-177 Radio Set Interface | |
| IF input frequency | 70 MHz nominal |
| IF input range | -10 to -80 dBm |
| IF input/output impedance | 50 ohms nominal |
| Number of IF inputs | Four |
| MD-918/GRC Digital Data Modem (Primary) Interface | |
| Backward equalizer | |
| Samples | Three 8-bit digital words |
| Signal levels | TTL levels |
| Symbol clock | |
| Sample | One |
| Rate | 1/2 bit rate (4.9898 MHz nominal) |
| Level | TTL |
| Eye pattern | |
| Sample | One |
| Rate | 1/2 bit rate (4.9898 MHz nominal) |
| Level | ±1.5V nominal, ±6.0V maximum |
| LPMS MEASUREMENT ACCURACY | |
| RSL | ±0.5 dB accuracy, 0.1 dB resolution |
| BER | |
| 0.5 to $10^{-10}$ | 1 order of magnitude (10) |
| $10^{-10}$ to $10^{-12}$ | 2 orders of magnitude (100) |
| SNR | ±1 dB |

**Table 2. Capabilities and Limitations - Continued**

| Item | Characteristic |
|---|---|
| SDR | ±1 dB |
| ISI | ±2 dB |
| Dispersion | ±1 symbol interval |
| LPMS Computed Parameters | Received signal level (RSL)<br>Bit error rate (BER)<br>Errored seconds<br>Fade rate<br>Fade duration<br>Fade outage probability<br>Error free seconds<br>Signal-to-noise ratio (SNR)<br>Signal-to-distortion ratio (SDR)<br>Disperson<br>Intersymbol interference (ISI)<br>2 Sigma/Tau |
| LPMS Operator Entries | Clock and calendar<br>Receiver gain<br>Fade threshold<br>Print intervals<br>Errored second interval<br>Fade rate interval<br>Fade outage interval<br>Log linear amplifier calibration<br>Directional coupler loss |

The Main Computer communicates with the Logging Computer via a Hewlett-Packard data communications interface in a quasi RS-232 type serial format. The Logging Computer is programmed in BASIC. The main purpose of the Logging Computer is to control a tape drive in real time. Data is passed to the Logging Computer once per second for recording. The Logging Computer is booted using a special program tape with a BASIC operating system and the LPMS_LOG program.

## SAMPLING ALGORITHMS

### RECEIVED SIGNAL LEVELS (RSLs)

The RSLs are derived from the dc outputs from the four log/linear amplifiers (located in the IF Interface). The dc output signals are passed to analog-to-digital (A/D) converter no. 1, where they are sampled. The LPMS program samples each of the four RSLs twice per interval (except interval 25), for a total of 48 samples/sec/diversity.

The TIMER_HOOK procedure controls the processing of the RSL readings. The A/D converter samples are read in as If_input_1 through If_input_8. If_input_1 through If_input_4 are the first set of readings of the four channels; If_input_5 through If_input_8 are the second set of readings. The A/D converter readings are then referred to the same time mark by using the following algorithm:

```
If_signal_level_1 = 0.125 * If_input_1 + 0.875 * If_input_5
If_signal_level_2 = 0.375 * If_input_2 + 0.625 * If_input_6
If_signal_level_3 = 0.625 * If_input_3 + 0.375 * If_input_7
If_signal_level_4 = 0.875 * If_input_4 + 0.125 * If_input_8
```

The four resultant RSLs are then converted from voltage to dB values. The System Initialization procedure reads in the log/linear amplifier calibration data and generates a lookup table (array) of volts to dBm (Lℓ_v_to_dB) for each amplifier. The dB value for each channel is then converted to power (using another lookup table — Db_to_power) and added to a running sum: If_power_sum. At the end of interval 25, an average is computed (If_power_average), converted to dBm (by the DB function), and combined with If_gain and If_loss values to determine the RSL.

### SIGNAL-TO-NOISE RATIO (SNR)

The SNR is calculated from the reconstructed EYE voltage signals measured in the modem by the MD-918 mod kit and sampled by A/D converter no. 2. The EYE voltages are sampled 100 times in each of the odd intervals (except interval 25). The sampling is controlled by the TIMER_HOOK procedure in the following manner.

The Eye samples are read by A/D converter no. 2. The sign bit is ignored, and the resultant absolute values are stored in an array named Eye_input. After all the samples are collected, the readings are converted to a summation of the readings (Sum_eye) and a summation of the square of the readings (Sum_eye_sqr). The average of these two summations is found (Avg_eye, Avg_eye_sqr), and then the square of the average is found (Sq_avg_eye). The variance can now be determined as:

Sigma_2 = Ave_eye_sqr - Sq_avg_eye - Eye_noise_corr

where Eye_noise_corr is an empirically determined constant used to compensate for extraneous noise.

The SNR can now be approximated as:

Snr_1 = Sq_avg_eye/Sigma_2

This value of SNR assumes that the noise amplitude for a specific reading is the absolute value minus the average absolute value for the 100 sample group. If a bit error has been made, then this assumption is incorrect because the correct noise amplitude is the absolute value plus the average absolute value.

The decibel value of the SNR can be found (using natural logarithms) as:

Snr_1_dB = 10.0/Ln_10p0 * LN(Snr_1)

where:

Ln_10p0 = 2.302... (i.e., LN(10.0))

and:

LN = natural log function

In order to correct for the effect of bit errors, an empirical correction term, Snr_corr, based upon a statistical analysis, is subtracted from Snr_1_dB, to give the best estimate for the true value Snr_dB.

This correction term is generated using a linear approximation as follows:

| Snr_1_dB Value (X) | Correction (Snr_corr) |
|---|---|
| X < 4.0 | 9.9 - 2.0 * Snr_1_dB |
| 4.0 < X < 5.0 | 5.9 - Snr_1_dB |
| 5.0 < X < 6.0 | 3.65 - .55 * Snr_1_dB |
| 6.0 < X < 7.0 | 1.55 - 0.2 * Snr_1_dB |
| 7.0 < X < 8.0 | 1.2 - 0.15 * Snr_1_dB |
| X > 8.0 | 0 |

The resulting SNR values are then limited to a maximum of +30.0 dB and a minimum of 0 dB. This value (Snr_dB) is summed over the 12 odd intervals and then averaged during interval 25 processing.

**BIT ERROR RATE (BER)**

The BER is calculated using the SNR value (Snr_dB) for each of the 12 measurement intervals during each second, and is based upon the theoretical SNR and BER relationships. In order to speed up the time required to determine the BER value, a lookup table (from SNR to BER) is generated during the start-up procedure. The Snr_to_ber array is calculated in the Main Context, COLD START procedure. The array is 300 elements long and corresponds to SNR values from 0.0 to 30.0 dB.

The algorithm used to generate the SNR to BER table is shown below. The counter I represents 0.1 dB increments and runs from 0 to 300.

```
V_snr = EXP((0.5 * (I/10.0)) * Ln_10p0_dp1)
BER = 0.5 * Compl_err_f(V_snr * Sqrt_p5)
BER = 2 * BER * (1.0 - BER)
Snr_to_ber[I] = BER
```

where:

The third equation represents the effect of differential encoding.

EXP = exponential function ($10^X$)

Ln_10p0_dp1 = 0.230258... (i.e., LN(10.0)*0.1)

Sqrt_p5 = 0.7071... (square root of 2)

Compl_err_f = Complementary error function (erfc)

The erfc is generated by means of Taylor series expressions.

where SQR = squaring function and Avg_eye_sqr and Sq_avg_eye are defined during SNR calculations.

The SDR can now be determined as:

Sdr = Sq_avg_eye/Distortion
Sdr_dB = DB(Sdr)

This value is then limited to a range of +5 to +25 dB.

## ERRORED SECOND COUNT

The determination as to whether an errored second has occurred is controlled by the average BER for that second. If this average BER is such that the probability of error during that second is greater than 0.5, then that second is determined to be an errored second. The Errored Second Count is simply the number of errored seconds that occurred during the ERRSEC Interval (set by the operator). Note that the value displayed is determined by the previous interval; it is not a running count.

## ERROR FREE SECONDS

The Error Free Seconds, expressed in percent, is the number of error-free seconds divided by the number of seconds in the interval.

## FADE RATE

A fade is determined to occur when the interval BER is larger than the Fade Threshold value set by the operator. The Fade Rate is simply found as the number of crossings from below-threshold to above-threshold divided by the number of seconds in the interval.

## FADE DURATION

When a fade occurs, the LPMS program begins timing the fade. At the end of each second, the duration of the fade is displayed. For example, consider a 3.0-second fade starting midway through the first second. The FADE DURATION would display 0.5, 1.5, 2.5, 3.0, 0 for successive seconds.

## FADE OUTAGE

The Fade Outage is defined as the outage probability. The probability is determined by the number of fade intervals divided by the total number of intervals during the specified time period.

## INTERSYMBOL INTERFERENCE (ISI)

The Intersymbol Interference is a measure of the disturbing effect of the presence of symbols other than the one for which the decision is being made. ISI arises from the signal passing through a dispersive medium and encountering the effects of multipath propagation. The LPMS monitors the internal functions of an MD-918/GRC Digital Troposcatter Modem and derives a measure of ISI from the sampled signals.

In the MD-918, the Adaptive Forward Equalizer (AFE) and the Adaptive Backward Equalizer (ABE) circuits work to combat the effect of ISI. The ABE generates delayed replicas of decisions previously made. Weighted amounts of these delayed decisions are then combined with the signal derived from the AFE to form a composite signal with reduced ISI.

The LPMS monitors the three taps in the ABE (refer to REL Publication No. 86-010, LPMS O&M Manual for hardware configuration). The Backward Equalizer (BEQ) taps are spaced at 1 symbol length and are weighted using an 8-bit (two's complement) scheme. The individual weight of each tap determines the amount of delayed signal power present at that tap. The LPMS program collects 50 samples of the BEQ data once per second during interval 6 in the TIMER_HOOK procedure. The data is stored in three arrays (Beq_input_N, N = 1, 2, 3) for later processing by the background procedure.

The System Monitor procedure is the background procedure that calculates the ISI from the BEQ data. The total power of each tap is summed over the 50 samples taken using the following:

```
Isi_power_N = Isi_power_N + SQR(Beq_input_N[I])
Isi_avg_power_N = Isi_power_N/Beq_input_max * SQR(Beq_scale)
```

where:

N = 1, 2, 3
I = 1 to 50
Beq_input_max = 50
Beq_scale = .00698

where Beq_scale represents the effect of 1 LSB change in the BEQ output upon the Eye Output, referenced to the nominal Eye output.

The ISI is then calculated by simply summing the average powers of the three taps and converting to decibels as follows:

Isi_total_power = Isi_avg_power_1 + Isi_avg_power_2 + Isi_avg_power_3
Isi_dB = DB (Isi_total_power) + 3.0

The ISI expressed in dB form represents a ratio of total delayed signal power to the undelayed signal power (assumed as unity). The ABE compensates ISI only for symbols preceding the one for which a decision is being made. The action of the AFE is such that the ISI power from following symbols is equal to the ISI power from preceding symbols; therefore, the total amount of ISI power is twice that indicated by the BEQ taps. The 3.0 dB in the last expression represents this effect.

## DISPERSION AND 2 SIGMA/TAU

Dispersion and 2 Sigma/Tau are equivalent terms used to express a measure of the delay power spectrum which arises from multipath signal propagation. The Dispersion is calculated from the BEQ data as shown in the following paragraphs.

The delay variance ($\sigma^2$), based upon power measurements at discrete points $t_1$ through $t_n$, is given by:

$$\sigma^2 = \frac{\Sigma (t_n)^2 P_n}{\Sigma P_n} - \left[\frac{\Sigma t_n P_n}{\Sigma P_n}\right]^2$$

Where $\Sigma$ represents the summation over n values.

If the points $t_1$ through $t_n$ are separated by identical time intervals (1 symbol interval, T), then, mathematically:

$$\left(\frac{\sigma}{T}\right)^2 = \frac{\Sigma n^2 P_n}{\Sigma P_n} - \left[\frac{\Sigma n P_n}{\Sigma P_n}\right]^2$$

If the last mathematical formula is applied to the LPMS program quantities, one can generate the proper dispersion (2 Sigma/Tau) formulas in the following manner. The total signal power ($P_n$) is defined as:

Dspr_sum_p = 1.0 + Isi_total_power

where:

1.0 = power of undelayed signal

$\Sigma n P_n$ in the above expression becomes:

Dspr_sum_p_n = Isi_avg_power_1 + (Isi_avg_power_2 * 2.0) + (Isi_avg_power_3 * 3.0)

and $\Sigma n^2 P_n$ in the above expression becomes:

Dspr_sum_p_nn = Isi_avg_power_1 + (Isi_avg_power_2 * 4.0) + (Isi_avg_power_3 * 9.0)

The first term in the previous mathematical formula can be expressed as:

Dspr_avg_nn = Dspr_sum_p_nn/Dspr_sum_p

and the term inside the square bracket becomes:

Dspr_avg_n = Dspr_sum_p_n/Dspr_sum_p

Solving for dispersion expressed as 2 Sigma/Tau:

Dispersion = 2.0 * SQRT(Dspr_avg_nn - SQR(Dspr_avg_n))

Actual tests indicated that this value was different than the dispersion set on a troposcatter simulator. This difference is due to the fact that measurements are being taken only on the ABE. Experimentally, the following correction curve was found to give optimum correlation between the indicated values and those set on the simulator:

Dispersion' = 2.778 * Dispersion - 0.194

In order to convert the 2 Sigma/Tau value to a dispersion value in nanoseconds, the following formula is used:

Dispersion_nsec = 2.0 * (Dispersion' * 1.0E9)/(1.0208 * 9.696E6)

where:

9.696E6 = mission bit rate in bps
1.0208 = effect of overhead bits

## APPENDIX H: DESCRIPTION OF ITS CHANNEL PROBE

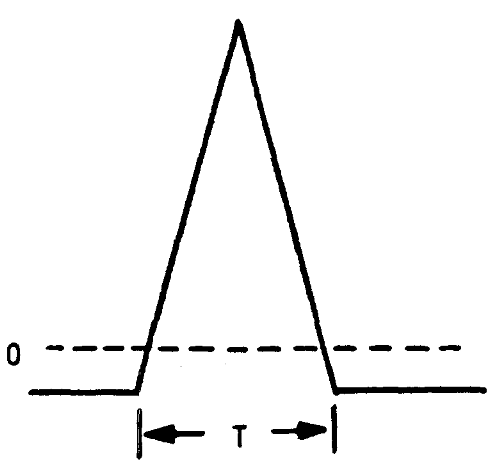
Multipath in LOS microwave circuits has long been a problem of concern to communication engineers. Multipath effects in digital communication systems has been found to be more detrimental to system performance then was anticipated. Some of the earlier results of digital performance measurements in LOS circuits were reported in a number of papers at the International Communications Conference, Toronto, Ontario, Canada, in June 1978 (Anderson, et al., 1978; Barnett, 1978; Emshwiller, 1978). One rather surprising result of these tests was a high bit error ratio (BER) observed under conditions of relatively low degrees of distortion (tilt) caused by multipath effects in the digital signal passband. These results were typical of nondiversity path.

The Institute for Telecommunication Sciences (ITS) has been investigating multipath in microwave circuits for some time, using an instrument developed at ITS to measure the multipath structure of the transmission channel directly in the time domain. This instrument, known as a pseudo random Noise (PN) Channel Probe, has been used in a variety of microwave circuits in the past several years, in tests and experiments designed to characterize the transmission channels.

Multipath in a radio transmission channel can be most readily measured in the time domain from the impulse response function. The basic techniques for such a measurement have been given by many authors; an excellent summary of the theory is given by Gallager (1964) , and instrumentation approaches have been discussed by Bellow et al. (1973), and Linfield, et al. (1976).

The objective of this appendix is to present only a rudimentary description of the ITS Channel Probe instrumentation, and a few of the basic characteristics of the impulse-response measurement. The impulse response of the measured channel is developed from the correlation properties of a pseudo random noise (PN) test signal, developed as a binary bit-stream. The correlation function of this signal resembles an impulse in the time domain. It has a triangular shape, with a base width that is proportional to the reciprocal of the rate at which the PN sequence is clocked. In the ITS system, the clock rate that is normally used is 150 MHz, which yields a correlation function with a base width of 13.33 ns. This function is sketched in Figure H-1, showing the relationship of the base width to the frequency of the clock source. The base level of this function is actually a negative value, dependent on the reciprocal of the number of stages used in the sift register that generates the code. Details such as these do not impact directly on the measurements of interest here. Thus, we leave them to the cited references for further discussion.

The correlation method of measuring an impulse response function is a time-bandwidth tradeoff technique. For example, the impulse response of a radio circuit could be measured by using a very sharp (unit type) impulse of rf energy and detecting the response of that pulse in the receiver. However, this requires a wide bandwidth for both the transmitter and receiver, as well as high power in order to achieve a good signal-to-noise ratio. The primary advantage of the rf approach is the rapidity of the measurement. However, most propagation channels will change in response at a relatively slow rate, and thus we may effectively trade the high-power large-bandwidth measurement for the slower correlation process. In addition, the correlation techniques has the inherent advantage of process (detection) gain in the receiver which reduces the effects of additive noise.




$$T = \frac{2}{f_c} = 2\tau$$

where $f_c$ = clock frequency used for the pseudo-random sequence generator, and $\tau = 1/f_c$ = signalling pulse width.

Figure H-1. The autocorrelation function for a pseudorandom binary sequence.

The method chosen by ITS for implementing a PN Channel Probe has been defined as a multiplex system (Bello, 1973), in which the delay time in the correlation process is developed in a pseudoanalog fashion. This is accomplished by clocking the replica of the PN test sequence in the receiver at a slightly slower rate than the 150-MHz rate used at the transmitter. The receiver clock is controlled by a synthesizer, and several clock rates are selectable to change the impulse response data rate. For example, a data rate ranging from 1 to 50 impulse responses/s is selectable by the operator at the receiver. In most LOS circuit measurements, we have found that a rate of 1 or 2 impulses/s is adequate to register the dynamic changes in the transmission channel. All of the data presented in this report have been measured at these rates.

The data rate of the instrument is important to consider so that the results are better understood.

The following factors will serve to convey the details of the methodology:

- Data Frame: Total length in time of the PN sequence.
  511 bits x 6.666 ns/bit = 3/4066 μs
- Data Frame Rate: Time selected by operator for impulse response display rate.
  Example: 2 impulses/s
- Time Correspondence:
  With a frame rate of 2/s, one complete correlation function is developed in 500 ms.
  Therefore, 500 ms in frame-rate corresponds to 3.4066 μs in real time data.
  Or, 1 ms corresponds to 6.183 ns.

For this example, it can be seen that the data rate is based on a ms time scale in display, but represents slightly over 6 ns in actual measurement time. Thus a clear channel (no multipath) response in this example would have displayed a pulse width on the order of 2 ms (1.957 ms). The real time width is 13.33 ns; a data ratio of nearly $15 \times 10^4$. This ratio indicated the number of code sequences that are processed in developing one output correlation function at the 2 impulse/s data rate. This is a slip-rate (rate of change in delay time) of approximately $2.3 \times 10^{-2}$ ns/code sequence in the correlator. These factors of course change with different data rates, but those given are typical and serve to illustrate the operation of the probe system.

The hardware implementation of the probe is illustrated in the block diagrams of Figure H-2(a) and (b). Figure H-2(a) shows the probe transmitter, where it can be seen that the transmitted test signal is developed as the upper sideband of a bi-phase modulation. The modulation takes place at a subcarrier (IF) frequency of 600 MHz, which is then mixed with 8.0 GHz up to the rf transmission frequency of 8.6 GHz. The lower sideband (7.46 GHz) is filtered out in the power amplifier output stage. The transmitted spectrum has the envelope of a $[\sin x/s]^2$ function, with the primary (first) nulls at a frequency of $\pm$150 MHz from the center frequency. The receiver diagram is shown in Figure H-2(b). Two correlation detectors are employed in a quadrature signals are developed from the preserved in the data. The two quadrature signals are developed from the 600-MHz IF local oscillator. This signal is split in a quadrature divider. Each half is then biphase modulated with the PN code test signal and correlated with the received 600-MHz IF signal. The complex low-pass equivalent impulse function is then displayed and recorded as the real and imaginary part [$h_r(\tau)$ and $h_i(\tau)$]. The power impulse function is also displayed and recorded from the output of a circuit that produces the sum of the squares of the above two signals.

The receiver is configured in two identical channels for application in diversity arrangements. Only one receiver channel is depicted in Figure H-2(b). The PN generators, frequency synthesizer, and the reference oscillator are common to both channels. The reference oscillator is controlled by a phase-locked-loop (not shown in the diagram) from the 600-MHz IF signal. This loop establishes a coherent detection process between the transmitter and receiver. Another feature of the receiver (not shown in the simplified diagram) is a data detector, which recovers the PN sequence from one of the received signals. The sequence can then be used to monitor the bi-phase error performance using the same test signal that is used to measure the impulse response function.

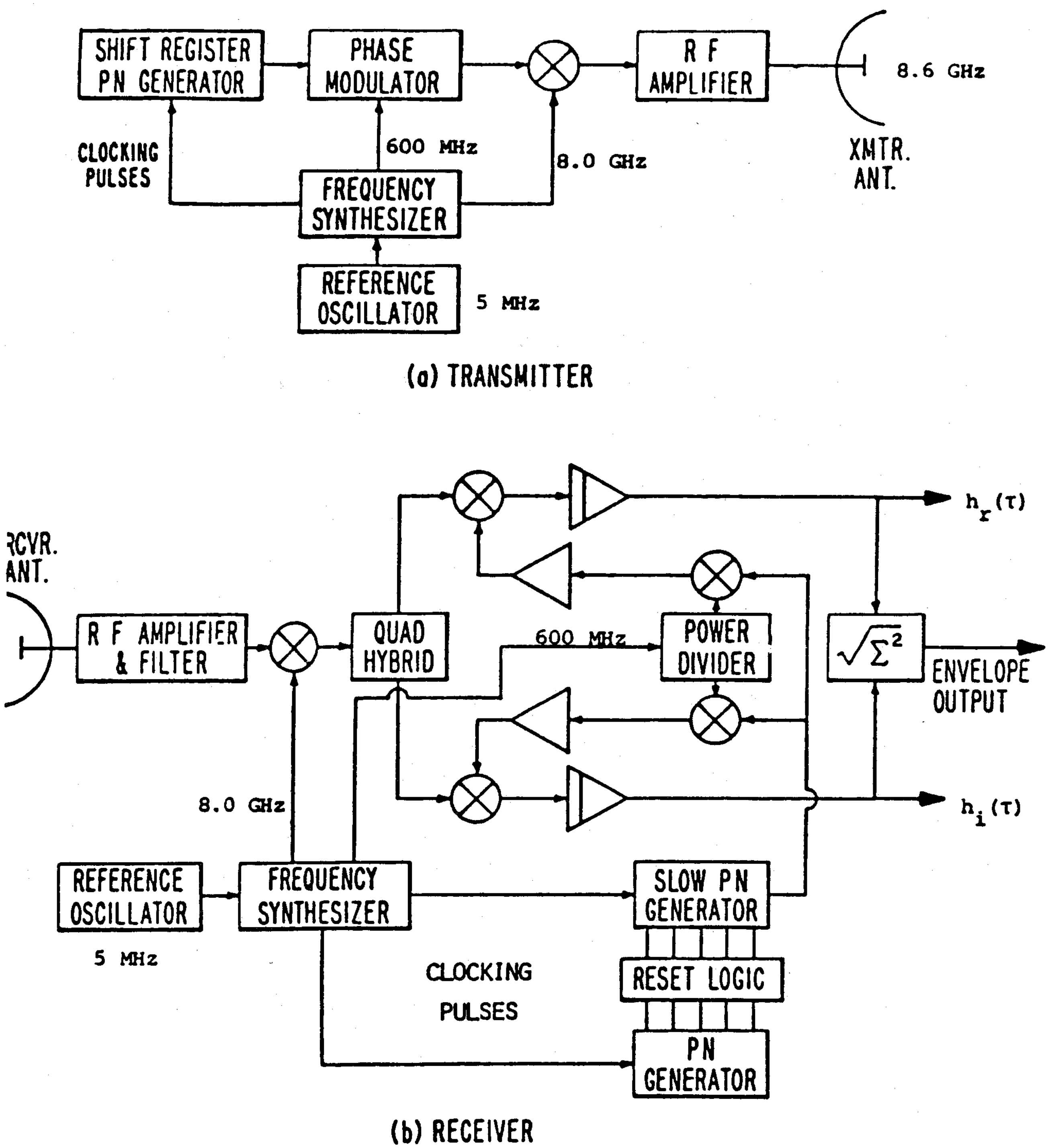
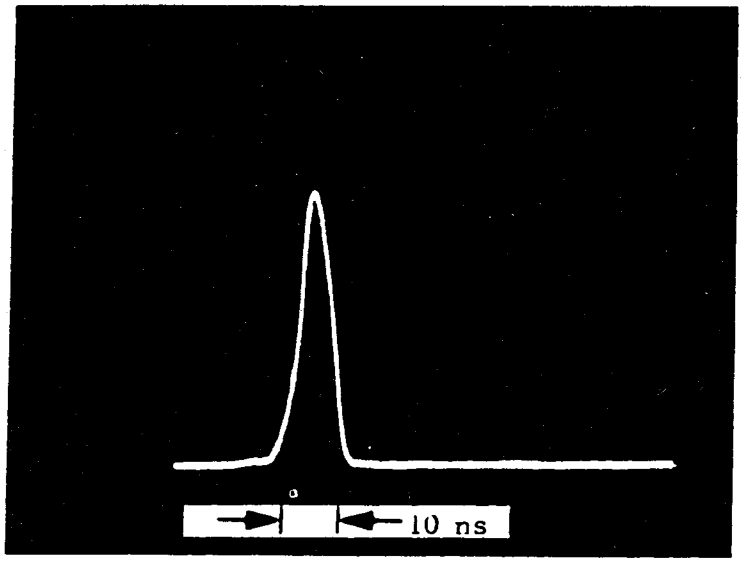



Figure H-2. Simplied block diagram of the PN channel probe. The receiver is dual-channel; only one channel is shown.

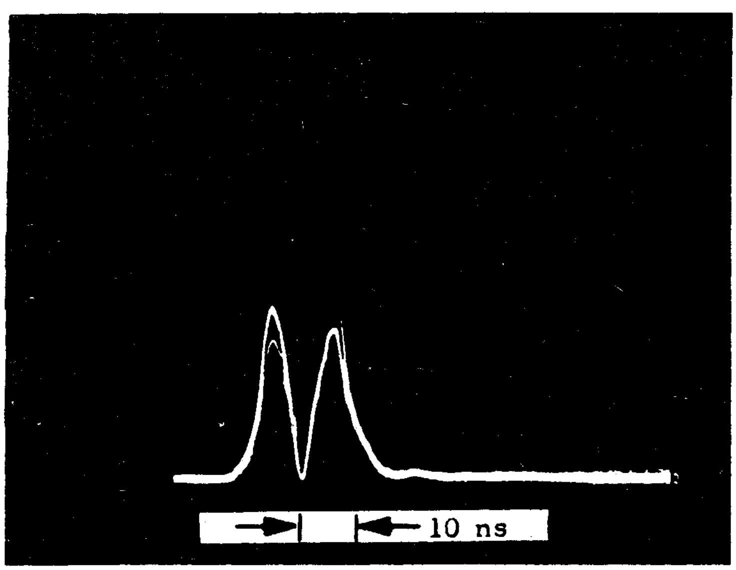
Figure H-3 shows two examples of the measured power impulse response of a microwave LOS channel at two instances of time. A clear-channel (no multipath) condition results in the power impulse provided in Figure H-3(a). The base width of the response for a clear channel would be approximately 13.3 ms (for a clock rate of 150 MHz).

A power impulse response containing a strong multipath component with a delay of about 10 ms is shown in Figure H-3(b). In general, the delay time can be measured as the difference between the two (or more) peaks in the response.

This difference, however, can be misleading for delays shorter than the resolution due to the relative phase of the direct and indirect signals. In these cases, the base width of the response will indicate the delay difference when compared with the clear width.




(a) Clear channel response; impulse width is 13.3 ns.




(b) Response with a multipath component delayed 10 ns.

Figure H-3. Example outputs from the ITS line-of-sight channel probe.

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## APPENDIX I: DESCRIPTION OF DRAMA EQUIPMENT

The Digital European Backbone (DEB) is a U.S.-owned-and-operated transmission network that utilizes a variety of digital transmission equipment including line-of-sight (LOS) microwave radio, troposcatter radio, and fiber optics equipment. The vast majority of the DEB links utilize the Digital Radio and Multiplexer Acquisition (DRAMA) Equipment. The measurements described in this report were on one segment of DEB known as the Frankfurt North Phase I Segment (FKT-N1) which utilizes DRAMA equipment on all links with the exception of the troposcatter link from Berlin to Bocksberg.

The DRAMA system configuration is depicted in Figure I-1. The DRAMA family includes first- and second-level multiplexers and several versions of a LOS digital radio. As shown in Figure I-1, KG-81 encryption equipment, which is not specifically part of the DRAMA family, typically is included in actual installations in DEB. The following paragraphs will provide a brief overview of the DRAMA equipment. More detailed descriptions may be found in the references found at the end of this Appendix.

The first level multiplexer (FCC-98) has several configurations as summarized in Table I-1. The two configurations most commonly used in DEB are the first and last configurations listed in the table. The three-input port version is used to provide three service channels. Typically, one channel is used for voice orderwire, one channel is used for carrying TRAMCON polling messages and responses (see Appendix F) and the remaining channel is available for other uses. There are a number of analog and digital interfaces available for the FCC-98. In the service-channel version of the FCC-98 multiplexer, three 56-kb/s channels are multiplexed with framing bits to achieve an aggregate 192 kb/s service channel bit stream (SCBS), which is input directly to the DRAMA radio as shown in Figure I-1.

The other version of the FCC-98 widely used in DEB is the 24-channel version. This version is compatible with the North American standard for a T-1 carrier. The 24 input channels, which may be either voice or data, are multiplexed with standard framing bits to achieve an aggregate 1.544 Mb/s data stream for input to the second level multiplexer (FCC-99), as shown in Figure I-1.

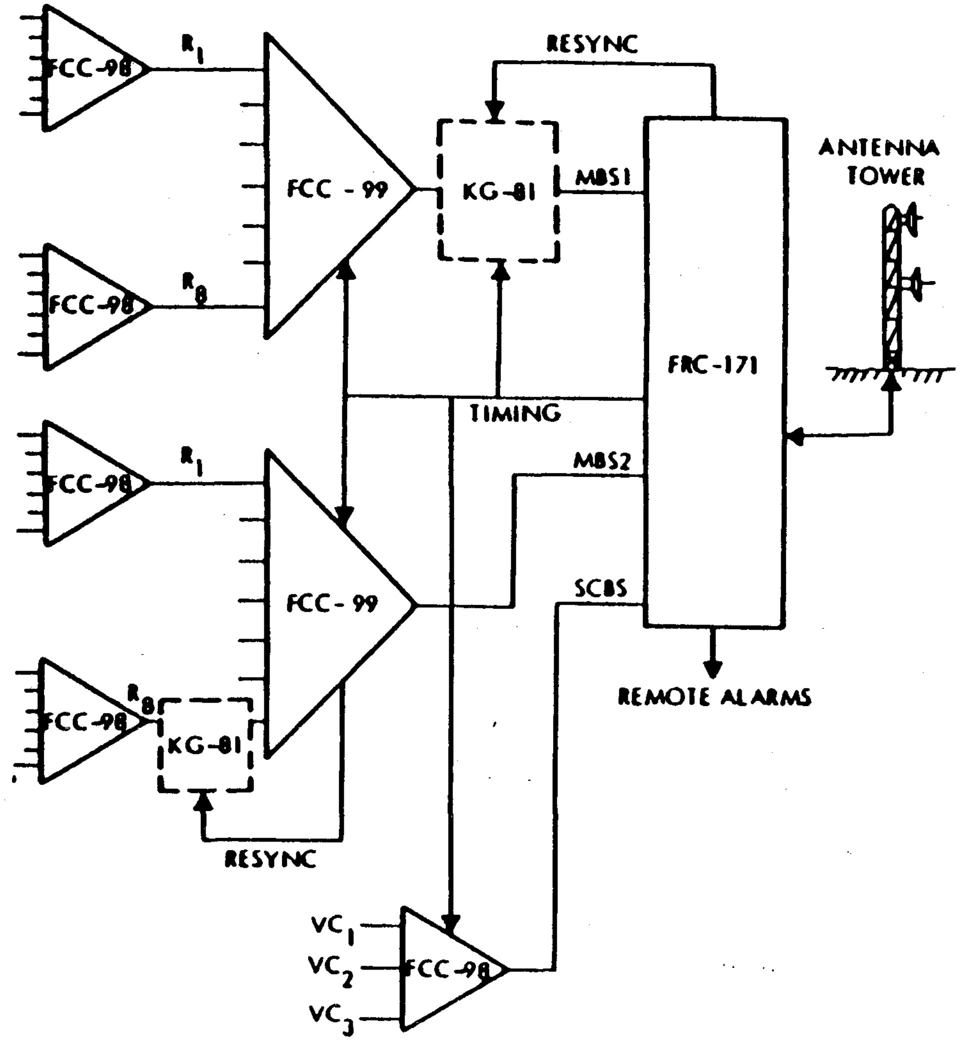


Figure I-1. DRAMA system configuration.

## Table I-1. FCC-98 Multiplexer Versions and Characteristics

| Input Ports (nominally 64 kHz each) | Output Data Rate (kb/s) | Major Use |
|---|---|---|
| 3 | 192 | Orderwire |
| 6 | 384 | Satellite |
| 12 | 768 | Satellite |
| 24 | 1544 | To 2nd Level Multiplexer |

Input Impedance: 600 ohms ± 10%
Output Impedance: 100 ohms ± 10% , balanced
Maximum Input Level: 3 dBmO
Idle Channel Noise: 23 dBmCO maximum
Output Jitter: 2% of nominal, maximum
MTBF: 3500 hours minimum
MTTR: 10 minutes, 30 minutes maximum for 95% of the time

## Table I-2. FCC-98 Multiplexer Versions and Characteristics

| Input Channels (Nominally 64 KHz each) | Input Ports* (Nominally 1.544 Mb/s each) | Output Data Rate (Mb/s) |
|---|---|---|
| 48 | 2 | 3.232 |
| 96 | 4 | 6.464 |
| 144 | 6 | 9.696 |
| 192 | 8 | 12.928 |

Input/Output Impedance: 100 ohms ± 10%, balanced
Output Jitter: 4% of nominal, maximum
MTBF: 1600 hours minimum
MTTR: 15 minutes, 45 minutes maximum for 95% of the time

*Inputs may be synchronous or asynchronous. If asynchronous, bit stuffing or bit extraction is used to yield the appropriate synchronous output rate.

The FCC-99 second-level multiplexer also has several versions as shown in Table I-2. The version most widely used in DEB is the version with eight-input ports. This version multiplexes eight 1.544-T-1 channels from the FCC-98 along with additional framing bits to achieve and aggregate 12.928-Mb/s mission bit stream (MBS) for input into the DRAMA radio, as shown in Figure I-1. Each mission bit stream typically carries 192 voice or data user channels.

In a typical DEB installation, two 12.928 -Mb/s mission bit streams (MBS1 and MBS2) and one 192-kb/s service-channel bit stream are input to the DRAMA radio, which contains an internal 3rd-level multiplexer. The aggregate DRAMA digital data rate from this internal multiplexer in this typical configuration is 26.112 Mb/s (additional framing bits are added in the third-level multiplexer).

There are a number of different versions of the DRAMA radio, as can be seen in Tables I-3 and I-4. Space- and frequency-diversity versions are available for operation in either the 4-Ghz or 8-Ghz bands. The 8-GHz space diversity radio is the most widely used version in DEB. In addition to the basic version options, there are other options available depending upon the mission bit stream requirements and the choice of modulation desired. Both quadrature phase shift keying (QPSK) and quadrature partial response (QPR) radios are available. The DRAMA radio version most commonly used in DEB is the 26.112-Mb/s, 8-Ghz, space diversity, QPR version (FRC-171, V-10). All of the DRAMA radios on the LOS links that were part of this measurement program were this version.

Table I-5 list the specifications for the DRAMA radio. Figure I-2 is a functional block diagram of the space diversity version of this radio. Figure I-3 is a sketch of the physical layout of the radio.

## Table I-3. Drama Radio Versions and Characteristics

| Nomenclature | Frequency Band* | Diversity |
|---|---|---|
| AN/FRC-170 | 4 GHz | Space |
| AN/FRC-171 | 8 GHz | Space |
| AN/FRC-172 | 4 GHz | Frequency |
| AN/FRC-173 | 8 GHz | Frequency |

Transmitter Frequency Stability: $\pm 5$ parts in $10^6$ over any 60 day period
MTBF: 1600 hours minimum
MTTR: 30 minutes, 90 minutes maximum for 95% of the time

*4 GHz nominal: 4400 GHz to 5000GHz.
8 GHz nominal: 7125 GHz to 8400 GHz.

## Table I-4: Bit Rate and Modulation Versions of the DRAMA Radio

| Radio (V) Number | MBS Ports | MBS Rate (MHz) | Aggregate bit rate (Mb/s) | Modulation (Note 1) | Bandwidth (MHz) | Power Out (dBm) | Threshold (dBm) (Note 2) | Threshold (dBm) (Note 3) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 6.464 | 6.720 | QPSK | 7 | 30 | -86 | -79 |
| 2 | 2 | 3.232 | 6.720 | QPSK | 7 | 30 | -86 | -79 |
| 3 | 1 | 9.696 | 9.952 | QPR | 7 | 30 | -78 | -71 |
| 4 | 1 | 12.928 | 13.184 | QPR | 7 | 30 | -77 | -70 |
| 5 | 2 | 6.464 | 13.184 | QPR | 7 | 30 | -77 | -70 |
| 6 | 1 | 9.696 | 9.952 | QPSK | 10.5 | 32 | -84 | -77 |
| 7 | 2 | 9.696 | 19.648 | QPR | 10.5 | 32 | -75 | -68 |
| 8 | 1 | 12.928 | 13.184 | QPSK | 14 | 33 | -83 | -76 |
| 9 | 2 | 6.464 | 13.184 | QPSK | 14 | 33 | -83 | -76 |
| 10 | 2 | 12.928 | 26.112 | QPR | 14 | 33 | -74 | -67 |
| 11 | 2 | 9.696 | 19.648 | QPSK | 20 | 26 | -81 | -74 |
| 12 | 2 | 12.928 | 26.112 | QPSK | 20 | 26 | -80 | -73 |

NOTES

1 QPSK: Quadrature Phase Shift Keying

QPSK: Quadrature Partial Response

2 Threshold is received signal level where the ratio performs with a bit error rate of $5 \times 10^{-2}$.

3 Threshold is received signal level where the radio performs with a bit error rate of $5 \times 10^{-9}$.

## Table I-5. DRAMA Radio Specifications

| | | |
|---|---|---|
| **System** | | |
| Transmission Band | 4.4 to 5.0 GHz<br>7.125 to 8.4 GHz | |
| Diversity | Space and Frequency | |
| Bandwidth Efficiency | 1.0 and 1.9 bits/sec/Hz | |
| Number of Mission Bit Streams (MBS) | 1 or 2 | |
| Mission Bit Stream Rate | 3.232 to 12.928 Mb/s | |
| Service Channel Rate | 192 kb/s | |
| Power | -42 to -54 Vdc | |
| Mean-Time-To-Failure | 1600 hrs. | |
| Mean-Time-To-Repair | 30 min. | |
| **Transmitter** | | |
| Output Power | 0.1 to 2.0 W | |
| Transmission Bandwidths | 3.5 to 20 MHz | |
| Emission Requirements | FCC Mask | |
| Frequency Stability | ±5 ppm | |
| **Receiver** | QPSK | QPR |
| Signal Level for $5x10^{-9}$ BER with Maximum Input Data Rate | -73 dBm | -67 dBm |
| Signal-to-Interference Ratio for 2 dB Degradation: | | |
| Co-channel | 20 dB | 25 dB |
| Adjacent Channel (noncontiguous) | -50 dB | -50 dB |
| Frequency Stability | ± 5 ppm | ± 5 ppm |

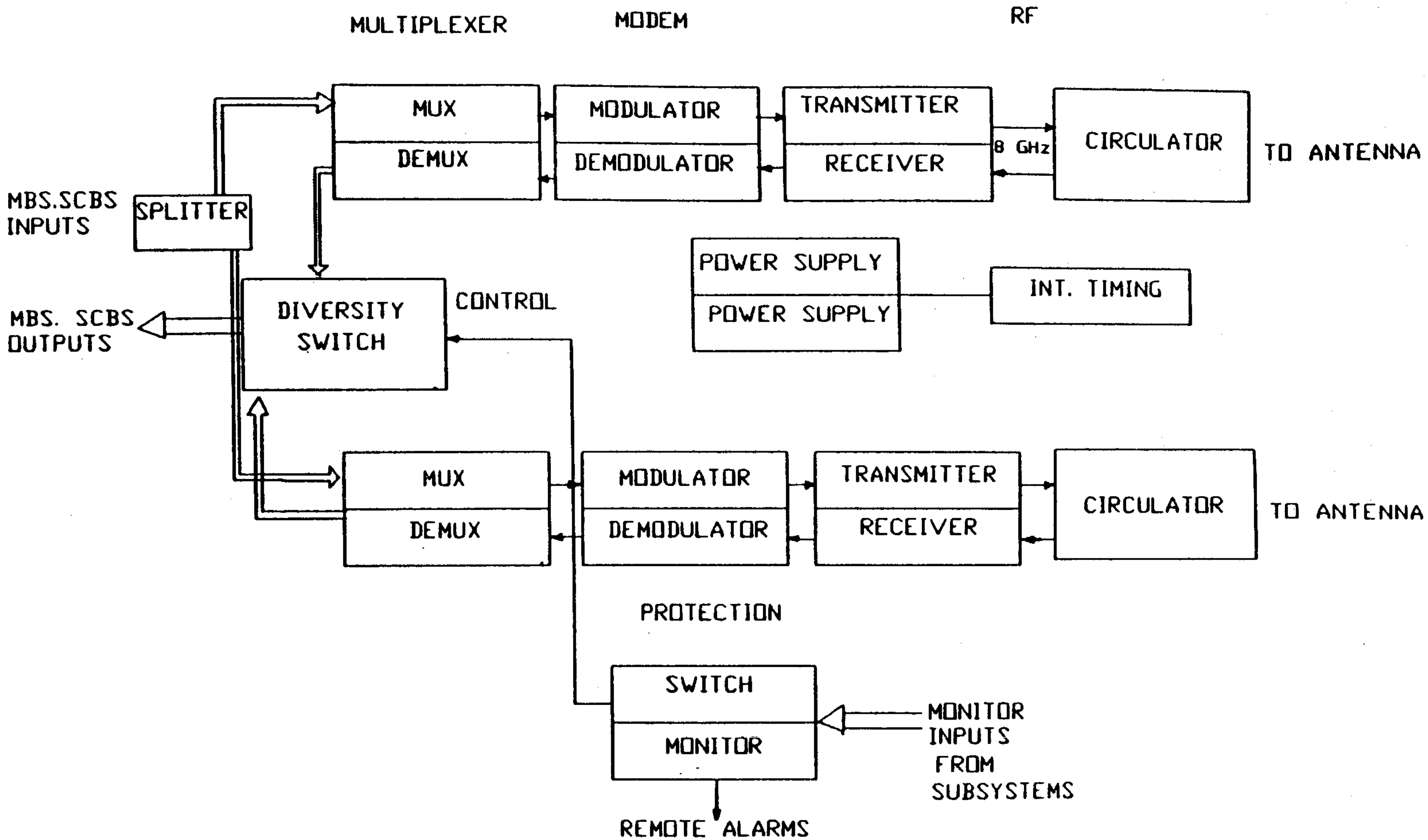


Figure I-2. Block diagram of space diversity version of DRAMA radio.

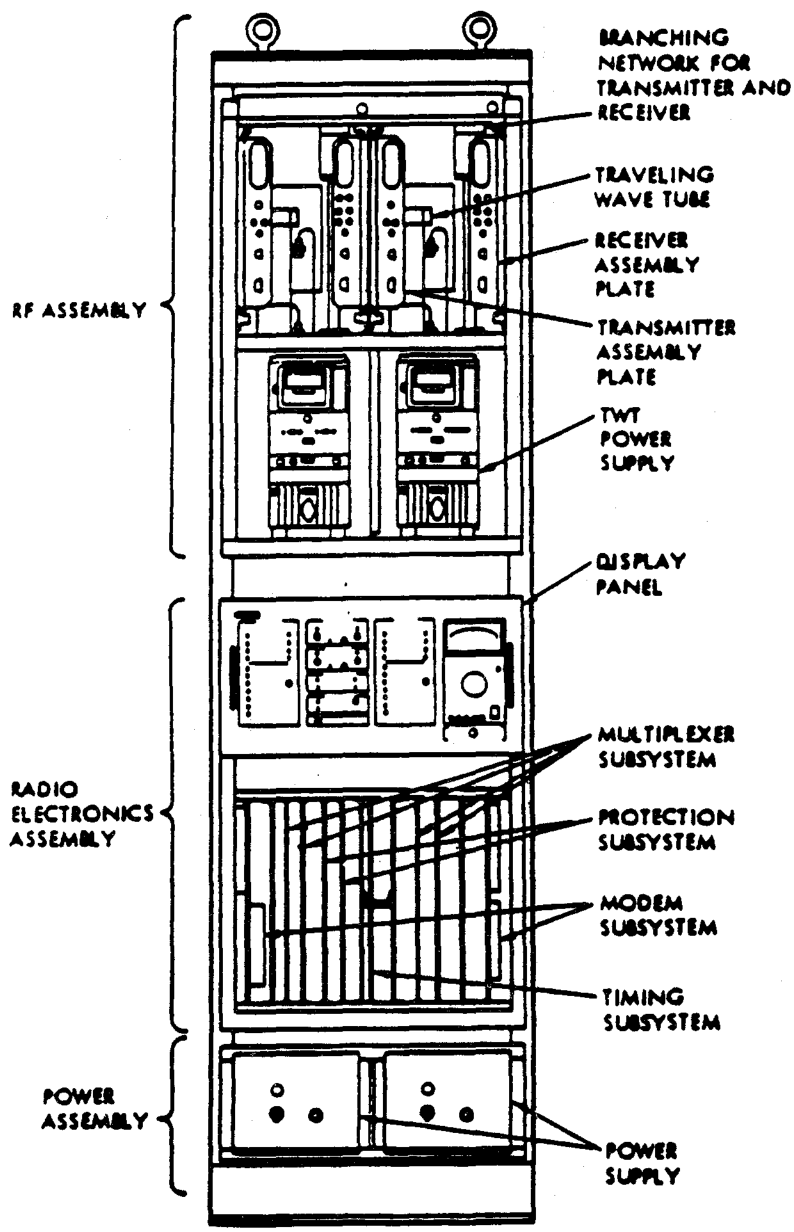


Figure I-3. DRAMA radio physical layout (U.S. Communications Command, 1987).

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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


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 are also useful for a variety of modeling purposes. These applications of the propagation data are described in the report.