ITT COMMUNICATION SYSTEMS, INC.
PARAMUS, NEW JERSEY

FINAL REPORT

NORTH ATLANTIC TELETYPE ENGINEERING STUDY

VOLUME II

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
LAURENCE G. HANSCOM FIELD BEDFORD, MASSACHUSETTS

REPLY TO ATTN OF: ESNO

SUBJECT: Final Report - North Atlantic Teletype Engineering Study

TO: Distribution

1. Early study team research revealed the inadequacy of the data base available to engineers working on the problem of data/TTY transmission over marginal wideband media. Publication of findings thought to be of value to others in the engineering community has been an important secondary objective of this study effort.

2. A significant exception to the inadequate data base is the path intermodulation work of C. D. Beach and J. M. Trecker of Bell Telephone Laboratories. Since their tests were also USAF sponsored and included the DYE 4-5 link, our data permits supplementary comparisons. Additional conclusions regarding path intermodulation effects for the 300 KC to 60 KC range are contained herein. The Beach and Trecker formulation is advocated as being the best method available for estimating intermodulation noise. The correlation with test results of this study and other programs appear to contain no more uncertainty than current methods for estimating path loss. Also acknowledged is the work of M.I.T. Lincoln Laboratories in tropospheric scatter and data transmission. The loan of equipment by the Laboratory to the study is greatly appreciated.

3. Deserving recognition for a year of professional effort are Boris Dzula, A. J. Jurafsky, Anthony P. Baker, George F. Knights, and R. W. Rudmann. It is our hope that this work will result in the improvement of military communications and contribute to the resources of the professional community.

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30 JUNE 1964

FINAL REPORT

NORTH ATLANTIC TELETYPE ENGINEERING STUDY

VOLUME II

TASK 37

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PREPARED FOR

DEPUTY FOR COMMUNICATION SYSTEMS MANAGEMENT (ESN)
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FOREWORD

In July 1963, the Deputy for Communication Systems, ESD, requested an engineering study in support of the North Atlantic Teletype Program. This program is to provide TTY circuits between North American and Europe over the US-Government wholly owned and operated multi-channel communication system between Melville, Labrador (near Goose Bay) and Croughton, UK. The study involves two areas, namely:

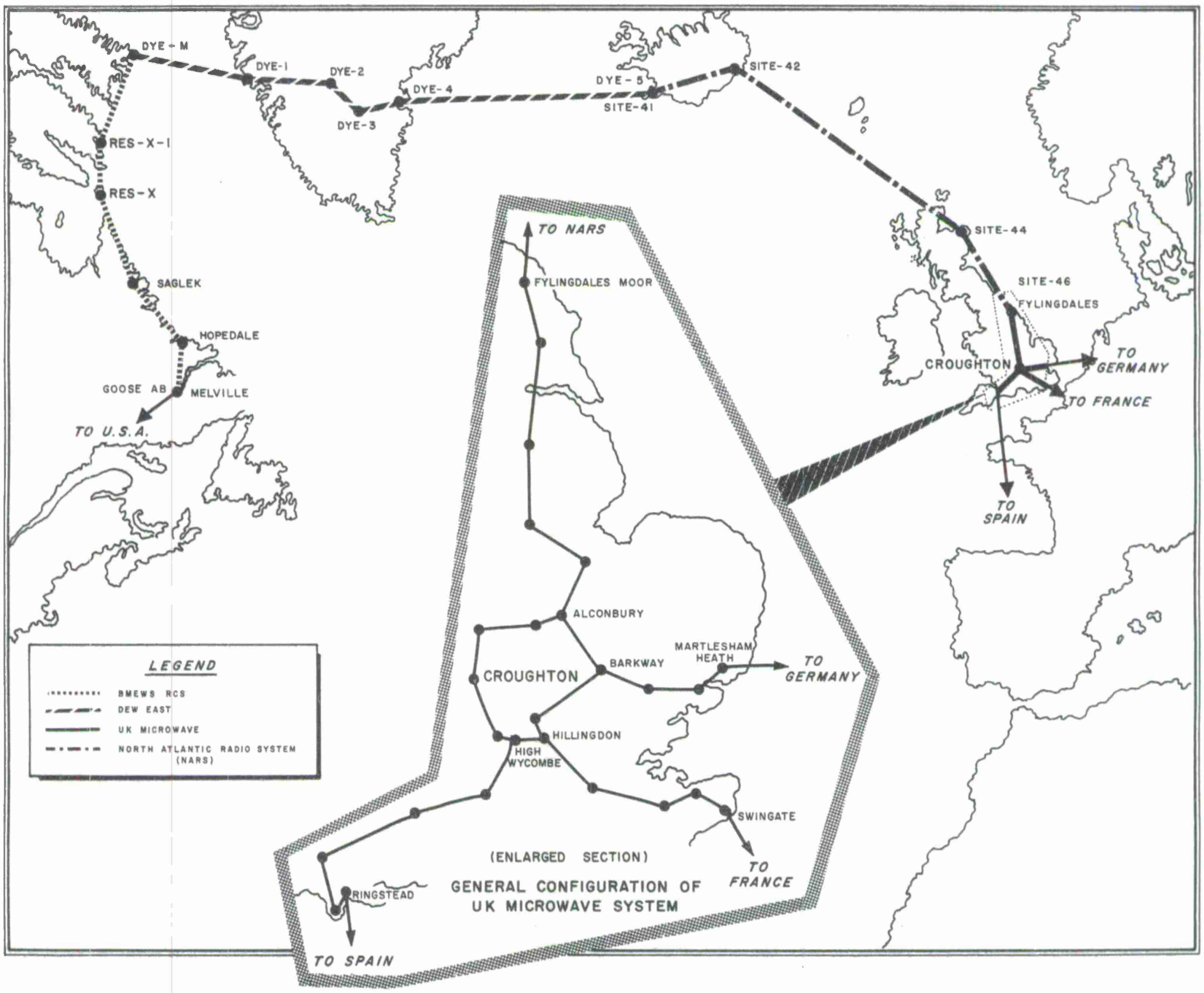
(a) An engineering study that will delineate the relative performance and procurement costs to be expected from a cross-section of teletype multiplex transmission techniques (Subtask 1).

(b) An engineering study of the performance of the transmission media between Melville and Croughton (Subtask 2).

The Melville-to-Croughton communication system is shown in Figure 1. It is composed of several older subsystems, all of which are now operating and carrying voice traffic. Deficiencies in the DEW East Subsystem and in the North Atlantic Radio System (NARS), however, have delayed the establishment of reliable TTY circuits between Melville and Croughton.

It was established in the Preliminary Report (ICS-63-TR-325) that, with the information then available, no estimate of the performance of TTY transmission equipments over the Melville-to-Croughton transmission system could be made. Therefore, on-site tests of representative TTY transmission techniques and actual measurements of the transmission media during the worst predictable propagation conditions were considered to be the best and most rigorous way of establishing the feasibility, cost, and performance of TTY communications over this system.

The Interim Report (ICS-64-TR-393) included the results of the NATTY tests. This final report contains the results of the RF studies which were made during the testing period, additional data from the NATTY tests, and the recommended course of action to implement a teletype network across the North Atlantic.



MELVILLE TO CROUGHTON COMMUNICATION SYSTEM

FIGURE 1

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

PART A

TELETYPE TESTS

1.0 GENERAL

A description of the four teletype transmission equipments tested during this study is included in the Preliminary Report, North Atlantic Teletype Study (ICS-63-TR-325) and Volume I of the Final Report (ICS-64-TR-440). A list of the equipment is included in paragraph 2.0.

Teletype transmission consisting of a repetitive 10 line message block from each of the four teletype equipments was transmitted from Goose Bay, Labrador to Croughton, UK. The number of errors in each message block were counted and tabulated with time-of-day notations every fifteen minutes. Summary tabulations were then prepared showing the number of message blocks and the number of errors for fifteen minute intervals. The data were then analyzed so that presentations could be made in the following ways:

(a) the cumulative distributions of character error per message interval and per fifteen minute interval (b) the occurrence of messages consisting of consecutive blocks having zero, two (or less), and four (or less) errors per block (c) comparisons of the error correcting equipment with standard fsk equipment.

For the purpose of this test, a circuit with a character error rate of 5×10^{-3} or better (equivalent to four errors per message block) is considered an operable circuit and this error rate was used as a basis of comparison for the four equipments. A brief discussion on the validity of this limiting error rate may be found in Section 3.1.3 of the Interim Report, North Atlantic Teletype Engineering Study (ICS-64-TR-393).

2.0 DESCRIPTION OF TELETYPE TRANSMISSION EQUIPMENTS TESTED

Four teletype transmission equipments were tested:

(a) Frequency shift keying, 16 channel teletype multiplex transmission equipment, represented by the Tele-Signal Corporation Model 2036, military nomenclature, AN/FCC-19, designed to DCA Specification DCAENSP-320-45.

(b) Phase shift keying, 32-channel, teletype multiplex transmission equipment, represented by the Robertshaw Controls Company Multilock 6000, military nomenclature AN/FGC-76(V).

(c) Replicate error correction represented by the Tele-Signal Corporation Proportional Error Protector Model 163; utilized in conjunction with AN/FCC-19 transmission equipment.

(d) Threshold error corrector, represented by the Codex Corporation Threshold Error Corrector Model T-1000, utilized in conjunction with Western Union Model 760 data transmission equipment. Codex equipment was modified to provide a 20 TTY channel parallel-to-serial converter at the transmitting terminal, and a 20 channel serial-to-parallel converter at the receiving terminal.

3.0 A SUMMARY OF PERFORMANCE OF ALL EQUIPMENTS

A detailed examination of the error rates found in testing all equipment was included in the Interim Report. However, a refinement in the method for counting the errors and calculating the error rates required minor changes to the results shown in the Interim Report. The error rates for all equipments are tabulated in Table I. The percentage of time a 10-line message was received with no errors, two or less errors, and four or less errors is tabulated in Table II. From Table I, it can be seen that the Codex T-1000 Error Corrector consistently provided the best performance. The median character error rate was at least an order of magnitude better than the standard fsk. The improved performance is further reflected in Table II, where it can be seen that the Codex T-1000 provided an operable (5×10^{-3}) circuit 91 percent of test period and errorless operation 77 percent of the test period.

4.0 CUMULATIVE DISTRIBUTION OF ERRORS

Cumulative distributions of errors for the four teletype equipments are shown in Figures A-1 through A-4. Figure A-1 was shown as Figure 5 in the Interim Report. The data used initially to determine Figure A-1 has been modified to exclude certain periods with high error rates, the causes of which were due to various reasons such as Transmitter Distributor (TD) failures at Goose Bay, erroneous patching, level checks, teleprinter trouble, etc. The justification for this modification of the data is based on the records kept in station log books at Goose Bay and at Croughton. A cursory investigation indicated that, although a slight change in the distributions did exist, the modification had a negligible effect for comparative purposes and, therefore, did not warrant retabulating and replotting the values for half-hour intervals.

A distribution showing the percent of time a ten line message had less than a given number of errors, up to a maximum of 40 errors per message, is shown in Figure A-2. The data base includes all ten line messages received by each of the four teletype equipments. The total number of messages received by each type of equipment are as follows:

TABLE I

COMPARISON OF ERROR RATES FOR ALL EQUIPMENTS
BASED ON 15 MINUTE INTERVALS

	Percent of Test Period Character Error Rate Equaled or Bettered			Test Period Median Character Error Rate	Improvement of Median Error Rate Over fsk Standard	Character Error Rate Not Exceeded 90% of the Time
	5×10^{-2}	5×10^{-3} (Note 1)	5×10^{-4}			
Codex Model T-1000 Threshold Error Corrector	96	90	61	1.7×10^{-4}	22.9	5×10^{-3}
Tele-Signal Model 163 Proportional Error Protector	91	70	34	1.5×10^{-3}	2.6	3×10^{-2}
Tele-Signal AN/FCC-19 FSK	94	56	12	3.9×10^{-3}	1.0	3×10^{-2}
Robertshaw AN/FGC-76(V) PSK	90	44	7	6.4×10^{-3}	0.6	5×10^{-2}

Notes:

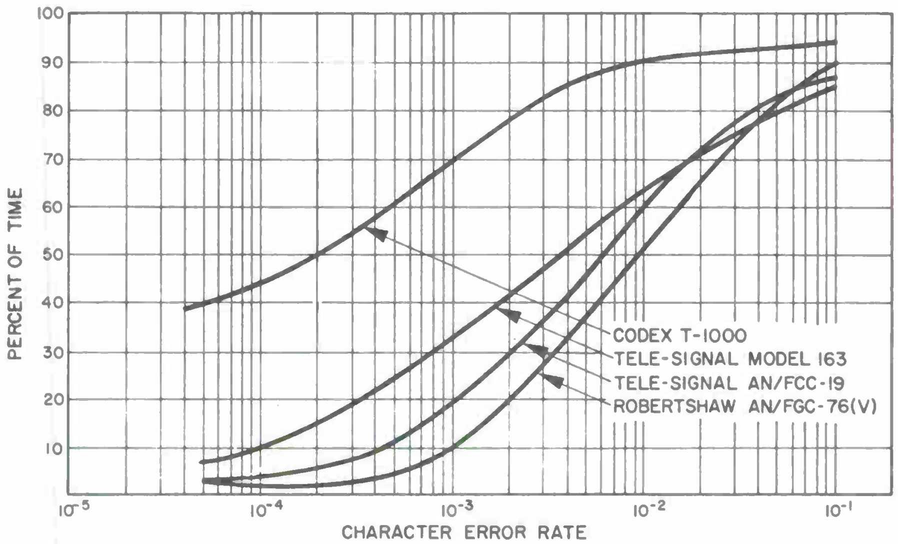
1. This error rate has been defined as the maximum error rate for an operable circuit.
2. This table is a summary of Figure A-4.

TABLE II

SUMMARY OF EQUIPMENT PERFORMANCE
ERRORS PER STANDARD 10 LINE MESSAGE

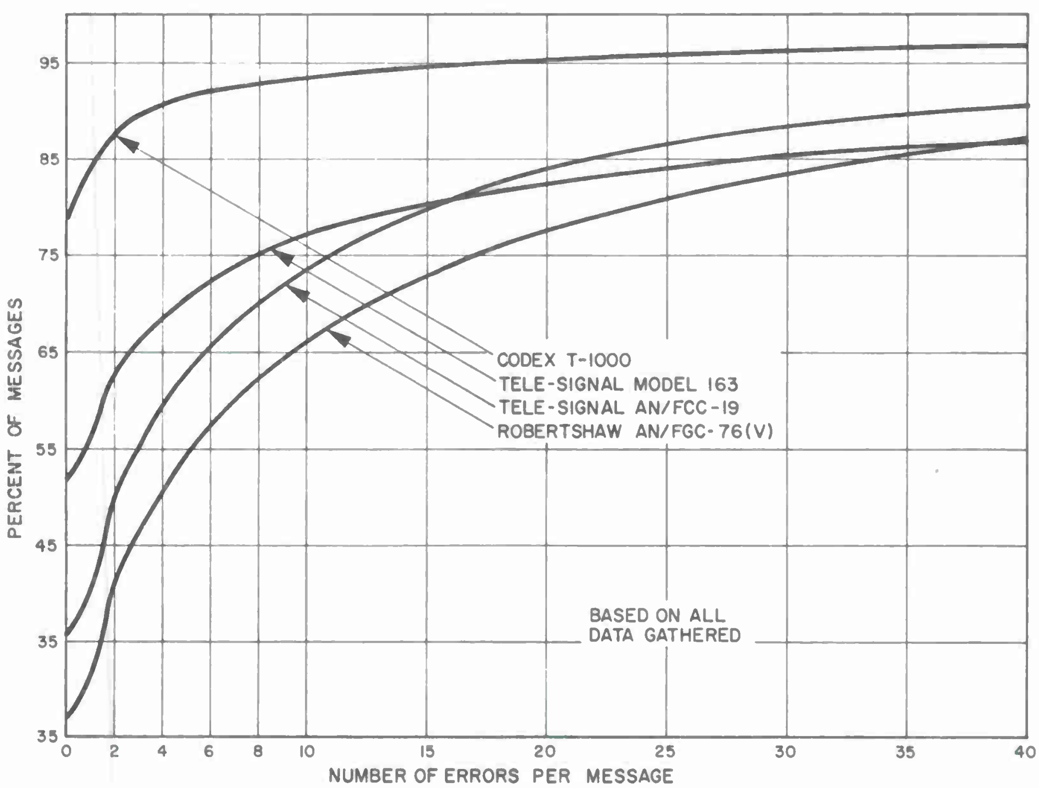
	Percent of Test Period A 10 Line Message Block Was Received With		
	No Errors	Two or Less Errors	Four or Less Errors (Note 1)
Codex T-1000	77	87.5	91
Tele-Signal 163	57	68	74
Tele-Signal AN/FCC-19	35	51.5	62
Robertshaw AN/FGC-76(V)	27	41	51

Notes:
1. This represents an error rate of 5×10^{-3} which has been defined as the maximum error rate for an operable circuit.
2. This table is a summary of Figure A-3.



CUMULATIVE CHARACTER ERROR RATE DISTRIBUTION

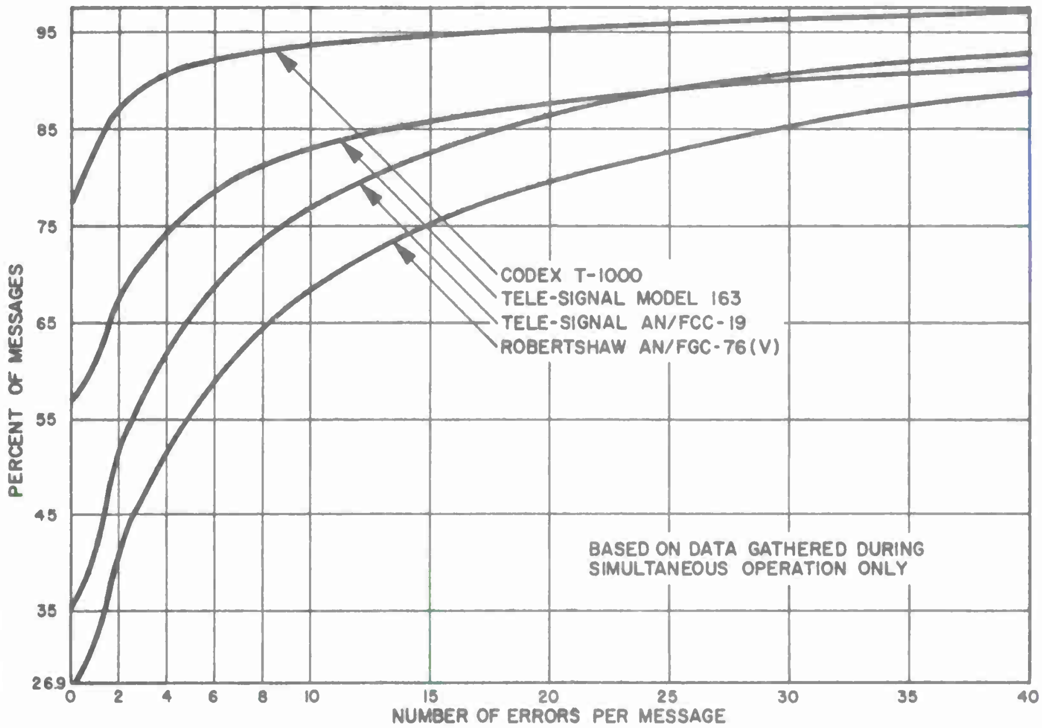
FIGURE A-1



CUMULATIVE ERROR DISTRIBUTION

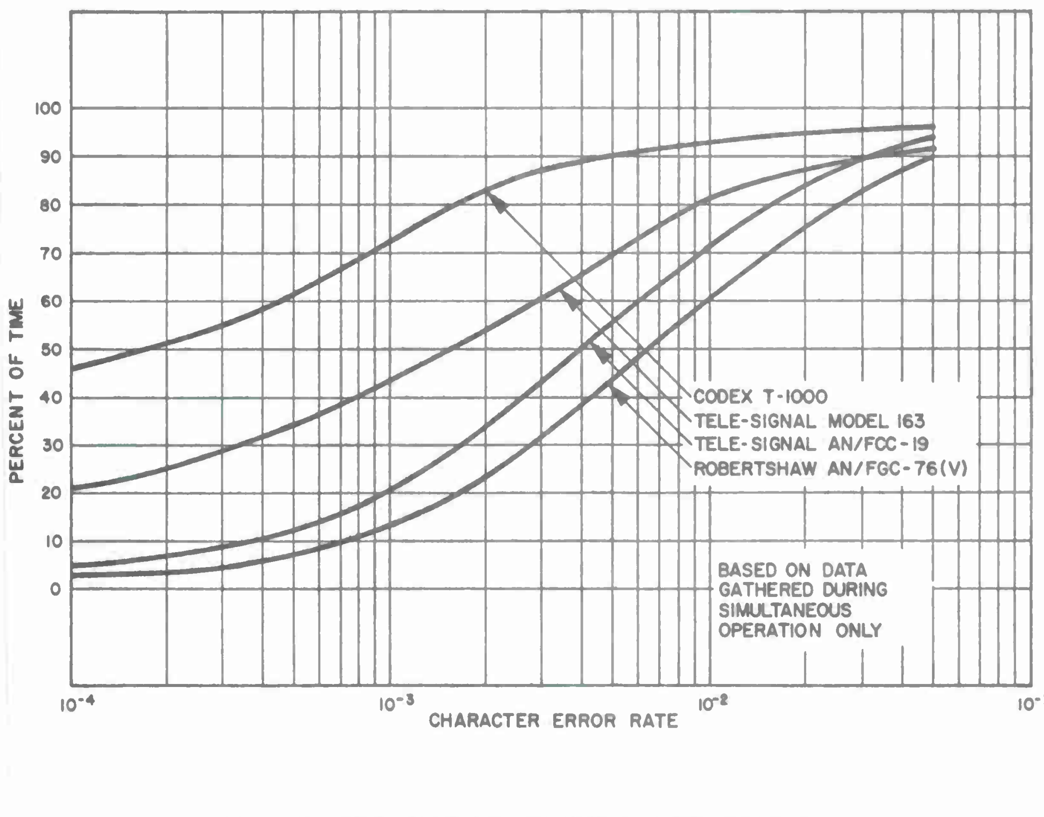
BASED ON ALL DATA GATHERED

FIGURE A-2



CUMULATIVE ERROR DISTRIBUTION

FIGURE A-3



15-MINUTE ERROR RATE DISTRIBUTION

FIGURE A-4

No. Messages	Equipment
9457	AN/FCC-19 (fsk)
9136	AN/FGC-76(V) (psk)
8171	Tele-Signal Model 163
8187	Codex Model T-1000

In order to provide an additional and more accurate basis of comparison of the various teletype equipments the data was restricted to periods when all four techniques were operating simultaneously. This amounted to an average reduction of almost 45 percent of the original data. There are a number of reasons for this reduction, including paper jams in the various teleprinters, circuit level checks, paper changes, equipment maintenance and repair, circuit outages, etc. A distribution of errors in a ten line message is shown in Figure A-3, for the simultaneous operation of all four equipments.

A cumulative distribution of character error rates of the four equipments is shown in Figure A-4. The character error is based on 15 minute intervals (approximately 9×10^3 characters) and includes only the periods when all equipments were operating simultaneously.

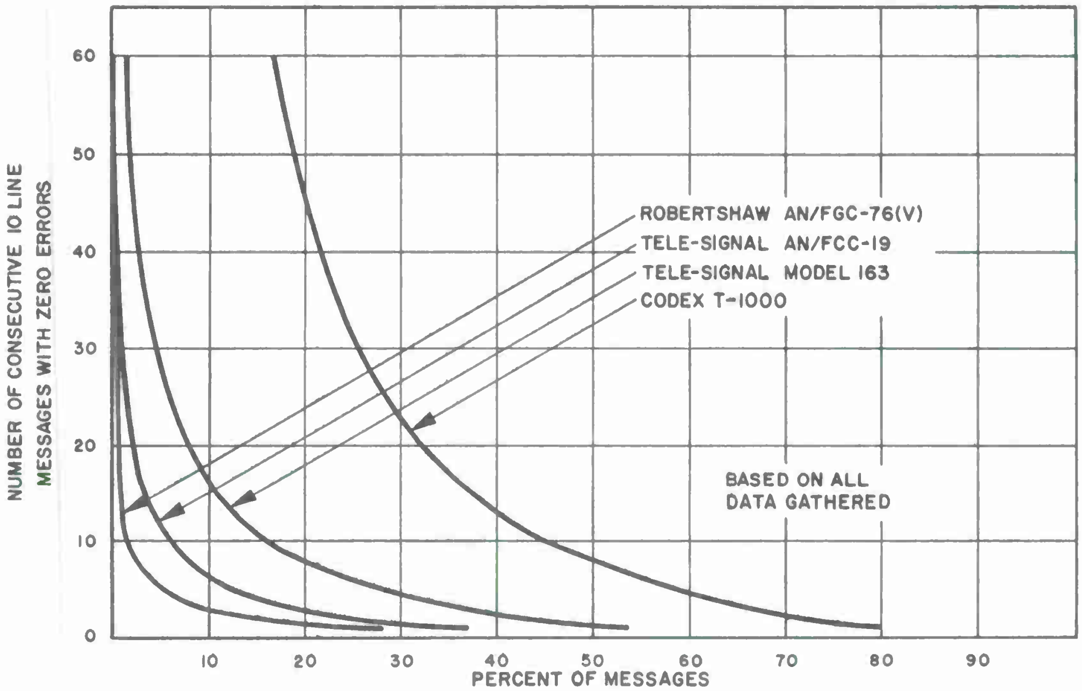
5.0 ERRORS PER STANDARD MESSAGE

An extension of the analysis reported on in the Interim Report (paragraph 3.1.2) to include all data shows a similar trend in the occurrence of messages of various lengths (consecutive ten line blocks) with zero, two or less, and four or less errors per 10 line block.

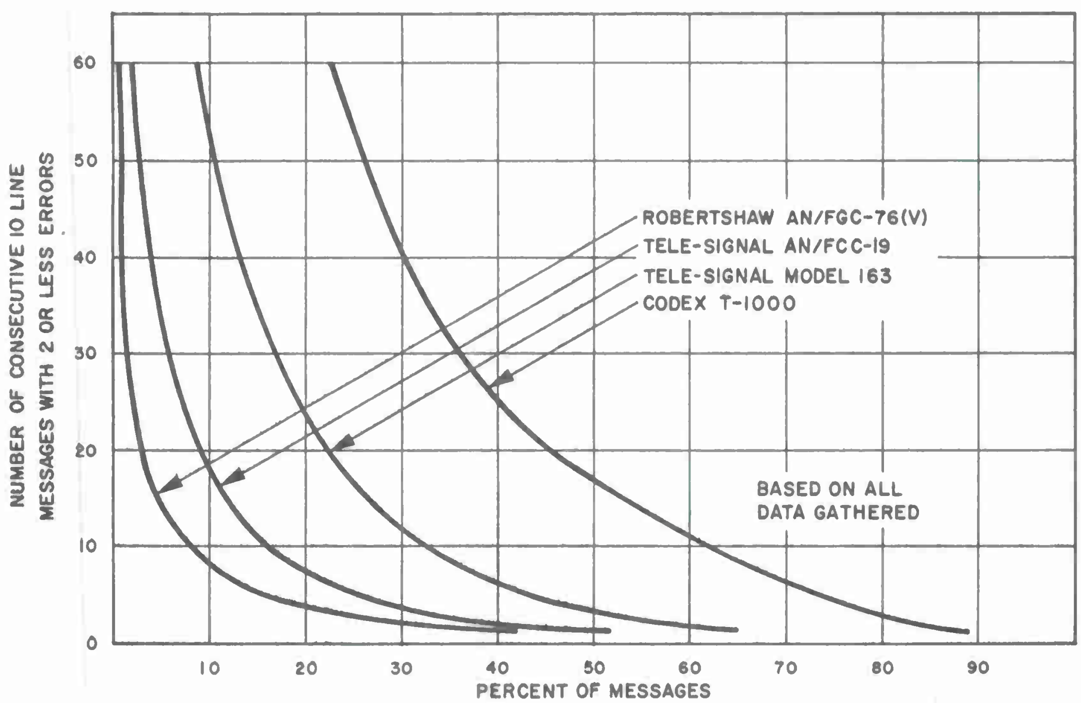
In Figures 5 and 6 of the Interim Report a crossover point existed between the Codex T-1000 and Tele-Signal Model 163 equipment. As expected, this did not occur when all data from the entire test were included.

Comparisons of the four teletype equipments are shown in Figures A-5 through A-7 respectively for zero errors, two or less errors and four or less errors per 10 line block for message lengths from one to sixty consecutive ten line blocks. Figures A-8 through A-11 show the same information for each of the individual teletype equipments.

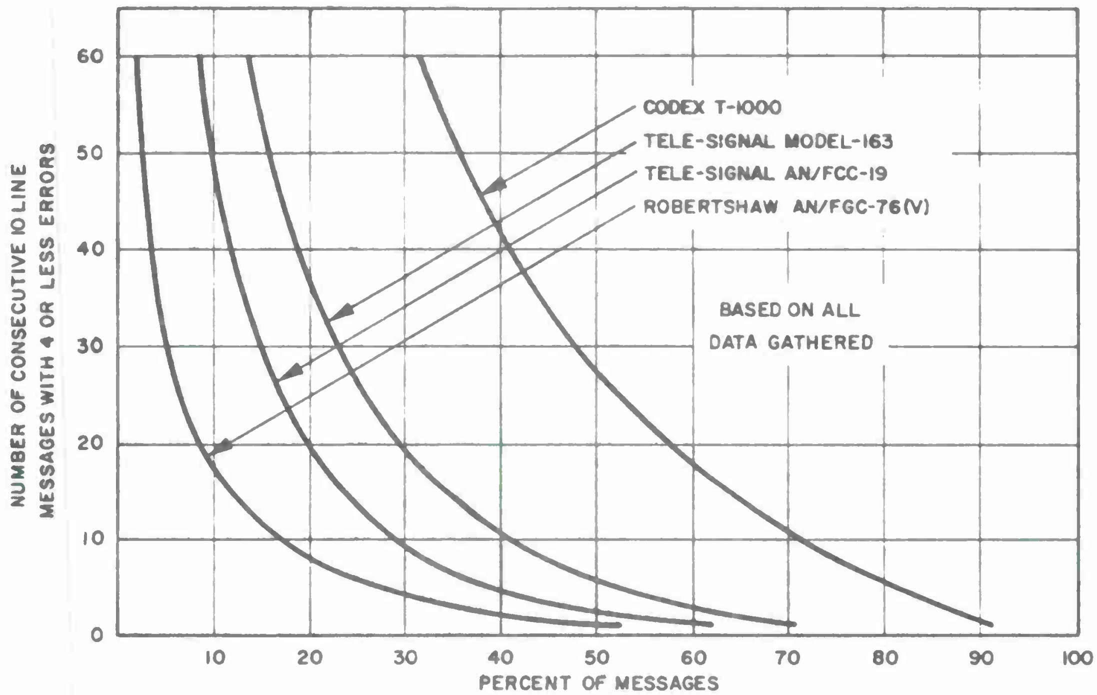
These curves are particularly useful since they indicate the percentage of time messages of various block lengths (1 block = 10 lines) were received with zero, two or less, and four or less errors per block during the test period. There was an even chance of receiving messages of 26, 5, 2, and 1 block lengths with four or less errors per block with the Codex



COMPARISON OF ALL EQUIPMENTS
(PERCENT OF MESSAGES
RECEIVED WITH ZERO ERRORS)
FIGURE A-5



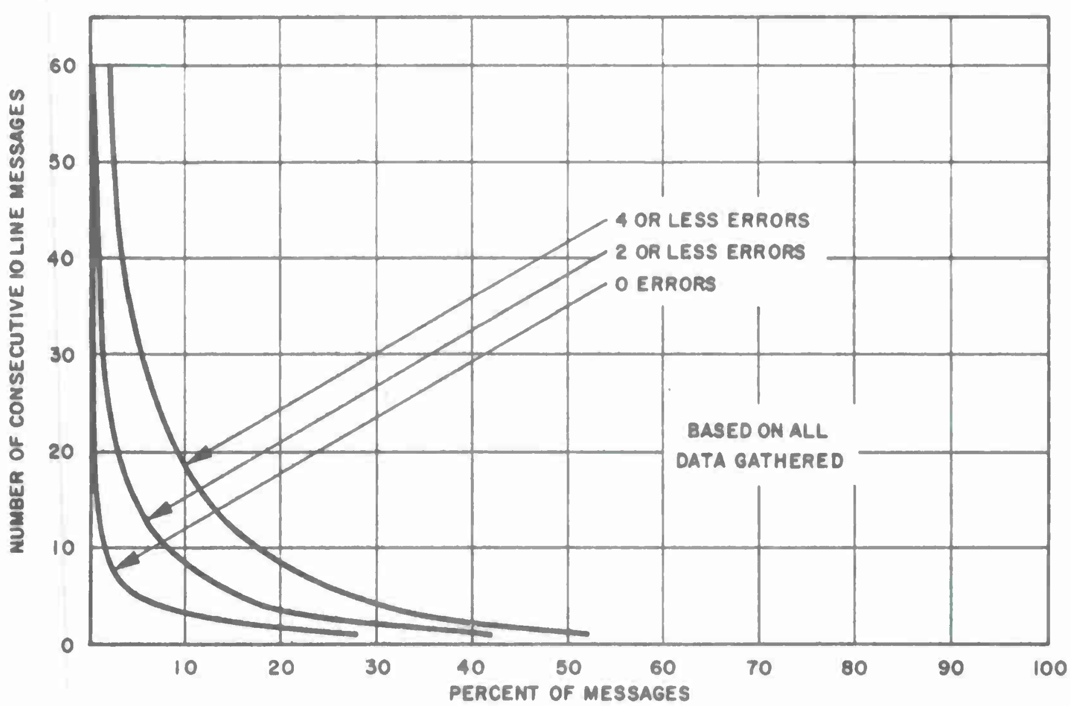
COMPARISON OF ALL EQUIPMENTS
(PERCENT OF MESSAGES
RECEIVED WITH 2 OR LESS ERRORS)
FIGURE A-6



COMPARISON OF ALL EQUIPMENTS

(PERCENT OF MESSAGES RECEIVED WITH 4 OR LESS ERRORS)

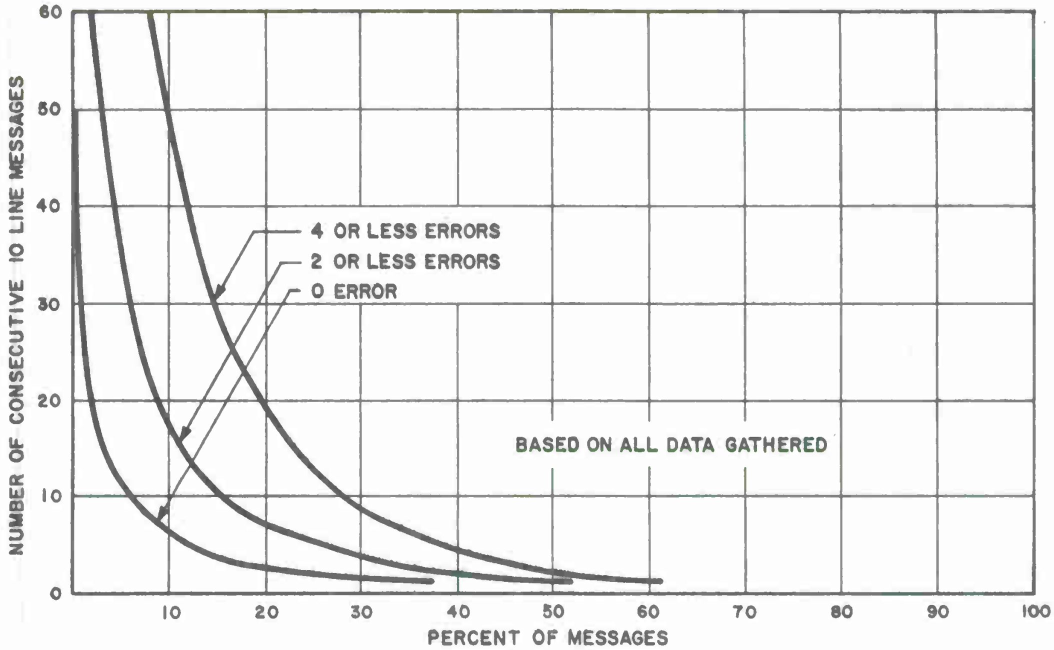
FIGURE A-7



ERRORS PER MESSAGE

(USING ROBERTSHAW AN/FGC-76(V)PSK)

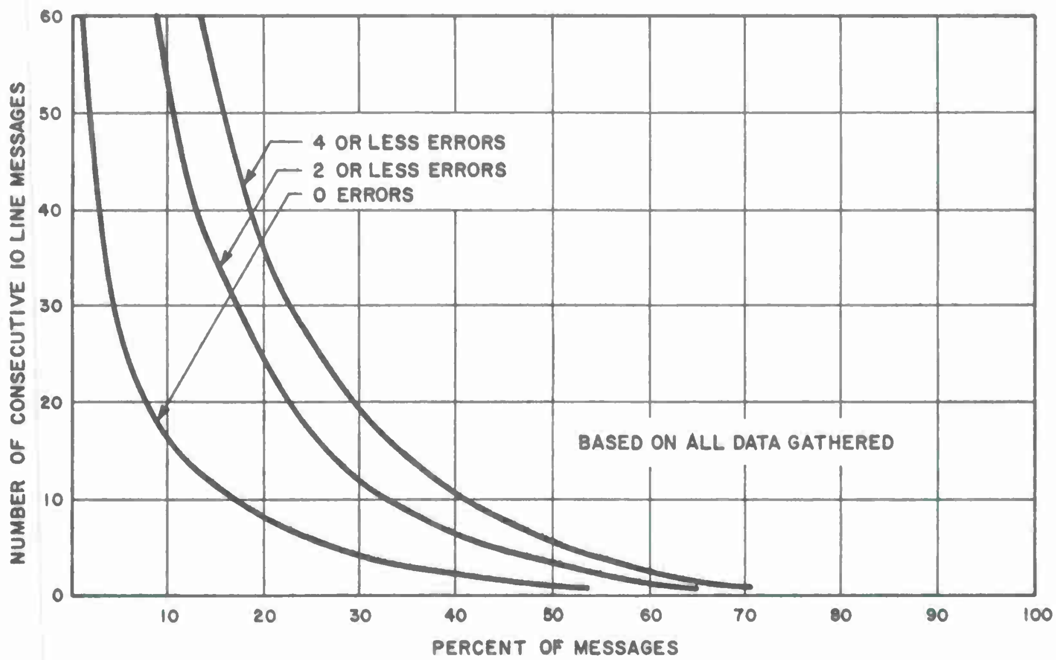
FIGURE A-8



ERRORS PER MESSAGE

(USING TELE-SIGNAL AN/FCC-19 FSK)

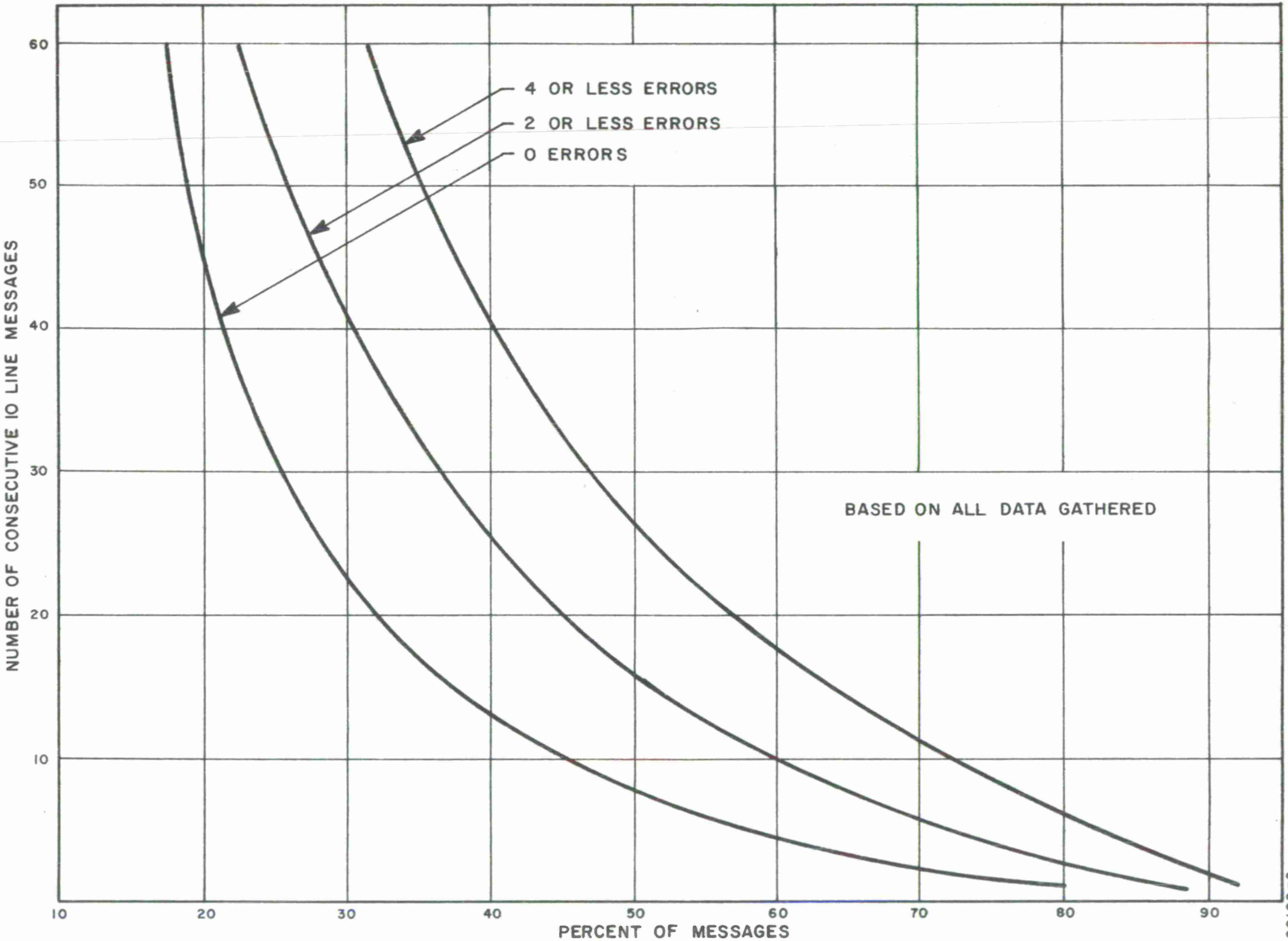
FIGURE A-9



ERRORS PER MESSAGE

(USING TELE-SIGNAL MODEL 163 PEP)

FIGURE A-10



ERRORS PER MESSAGE (USING CODEX MODEL T-1000)
FIGURE A-11

Model T-1000, Tele-Signal Model 163, Tele-Signal Model 2036 (AN/FCC-19), and Robertshaw AN/FGC-76(V) equipment, respectively.

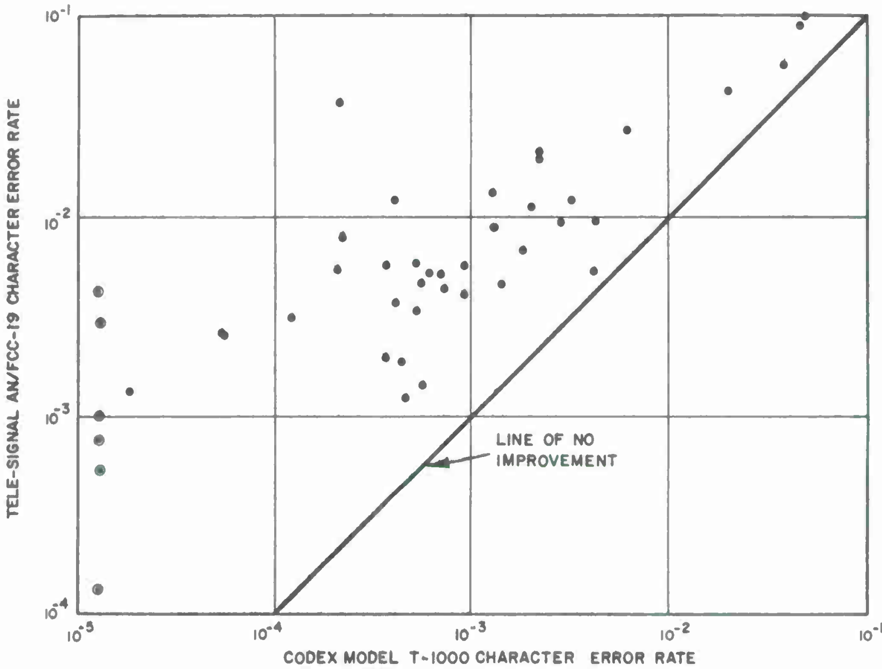
6.0 COMPARISON OF ERROR CORRECTION AND STANDARD FSK

Several attempts were made to provide a direct comparison of the character error rates of the two error-correcting equipments with the standard fsk VFTG equipment. It was hoped that the statistical distributions of the error rates for these three equipments would be related in such a manner as to provide a relationship which would permit an estimation of the expected error rate of the error correcting equipment for given fsk error rates.

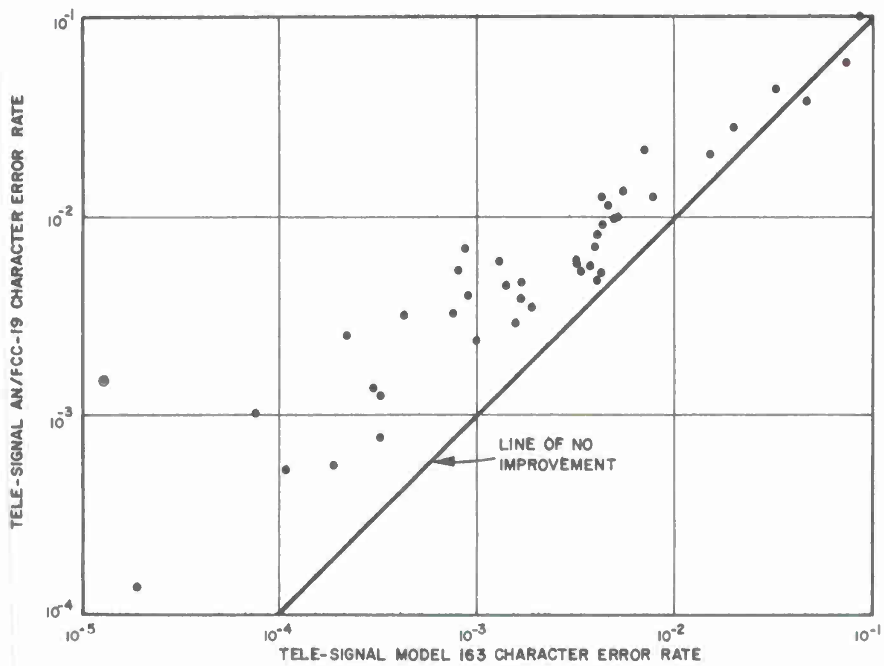
It could be expected for instance, that for extremely low error rates on the fsk equipment, little or no improvement would exist due to the limitations of error correcting equipment itself. Then, as the fsk error rate increased, the improvement would also increase until a maximum value of improvement was reached when the slope of the improvement curve was tangent to the line of no improvement. Thereafter, as the fsk error rate continues to increase, the improvement would decrease and would eventually approach the line of no improvement and possibly even cross over into an area which actually indicates a degradation.

Figures A-12 and A-13 show comparative point plots between the error rates of standard fsk and the error correction equipment and error protection equipment. The error rates were determined for continuous 1-1/2 hour intervals during periods when both error correction techniques and the standard fsk technique were in simultaneous operation. Since there were several intervals in which the error correction techniques had zero errors, these plots were considered to be one order of magnitude lower then the lowest fsk error rate obtained. These are indicated by the circled points. Since for the samples considered the Codex error correction equipment provided error-free operation when the Tele-Signal fsk equipment had character error rates between 1×10^{-3} and 1×10^{-4}, it can be inferred that the most effective error correction will be provided by the Codex equipment at these line error rates.

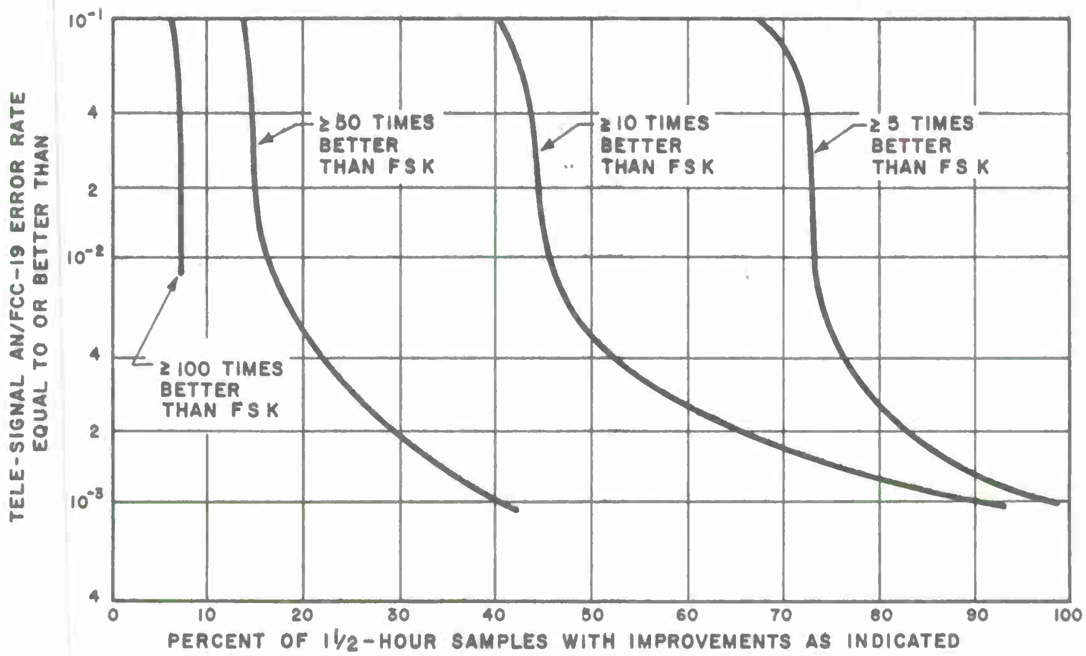
A family of curves is presented in Figures A-14 and A-15 showing the percentage of samples for which the error correction equipment provided improvements equal to or greater than indicated, when the fsk error rate was less than or equal to that shown, on the ordinate. For example, Figure A-14



COMPARISON OF 1 1/2 - HOUR SAMPLES
OF CODEX T-1000 AND TELE-SIGNAL AN/FCC-19
FIGURE A-12

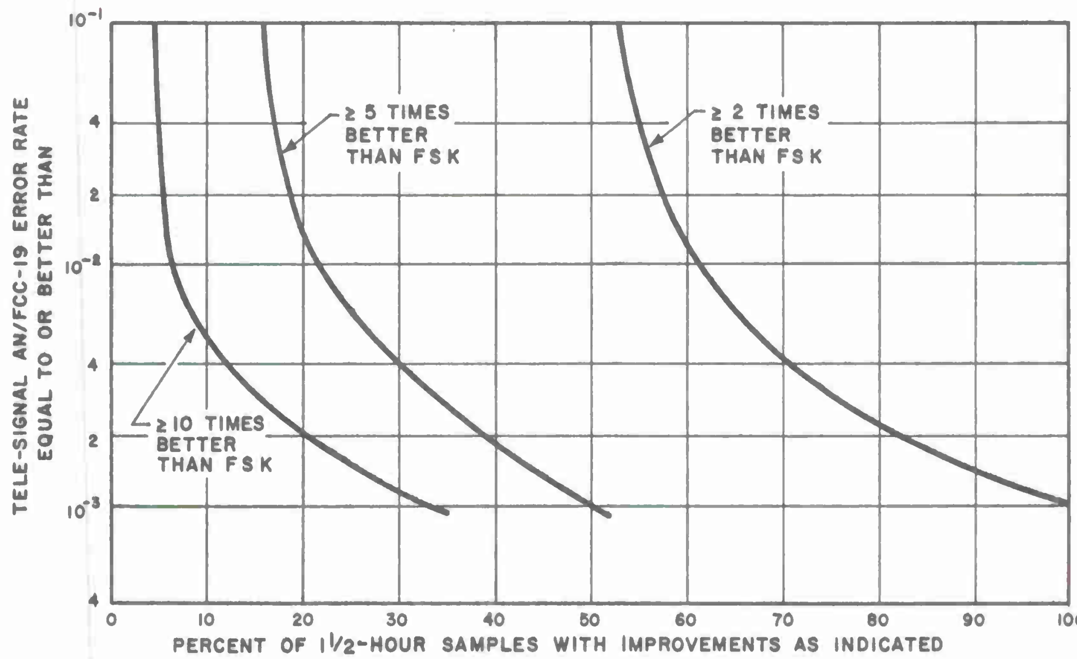


COMPARISON OF 1 1/2 -HOUR SAMPLES
OF TELE-SIGNAL MODEL 163 AND AN/FCC-19
FIGURE A-13



IMPROVEMENT VERSUS PERCENT TIME
(BASED ON COMPARISON OF 1½-HOUR SAMPLES OF CODEX T-1000 AND TELE-SIGNAL AN/FCC-19)

FIGURE A-14



IMPROVEMENT VERSUS PERCENT TIME
(BASED ON COMPARISON OF 1½-HOUR SAMPLES OF TELE-SIGNAL MODEL 163 AND AN/FCC-19)

FIGURE A-15

indicates that 40 percent of the time the Codex T-1000 will provide an error rate at least 50 times better than the fsk error rate of 1×10^{-3}.

A further characterization of the improvement obtained with error correction is given in Figures A-16 and A-17. This shows the percentage of error-corrected samples having error rates equal to or better than 10^{-4} and 10^{-3} for standard fsk error rates equal to or better than those shown on the ordinate.

7.0 FIGURE OF MERIT

A discussion of average error rates encountered during the test period must encompass several factors. A considerable amount of the data exhibited character error rates in excess of 5×10^{-2}, for which an exact count could not be achieved and hence required an estimate. To begin with, there is little benefit to be derived from the knowledge of an exact count at these extremely high error rates. However, it is of significance to know what percentage of the test period contained errors in excess of 5×10^{-3} together with an average character error rate for all samples with less than 5×10^{-3} character errors. (It was established in the Interim Report that a character error rate of 5×10^{-3} would define the border between an operable and a non-operable circuit.)

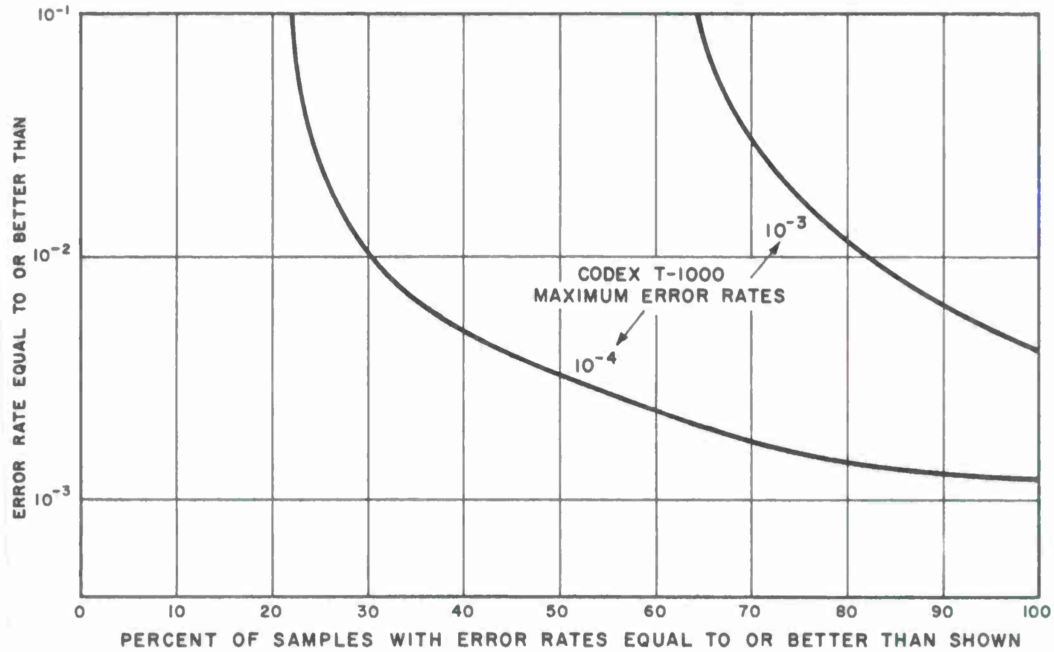
It is possible to discuss an average character error rate which was achieved by the exclusion of data containing errors greater than 5×10^{-3} and then indicate the percentage of time for which it is valid. For comparative purposes, Table III was developed and a Figure of Merit included in the last column. The reference again is taken as the AN/FCC-19 (fsk), and all results are normalized to this equipment. The Figure of Merit is defined as the product of the average character error rate and the percentage of time the character error rate exceeded 5×10^{-3} for the fsk equipment, divided by the product of the average character error rate and the percentage of time the character error rate exceeded 5×10^{-3} for the other equipments. Symbolically the Figure of Merit is expressed as:

$$F = \frac{A_o \quad P_o}{A_i \quad P_i}$$

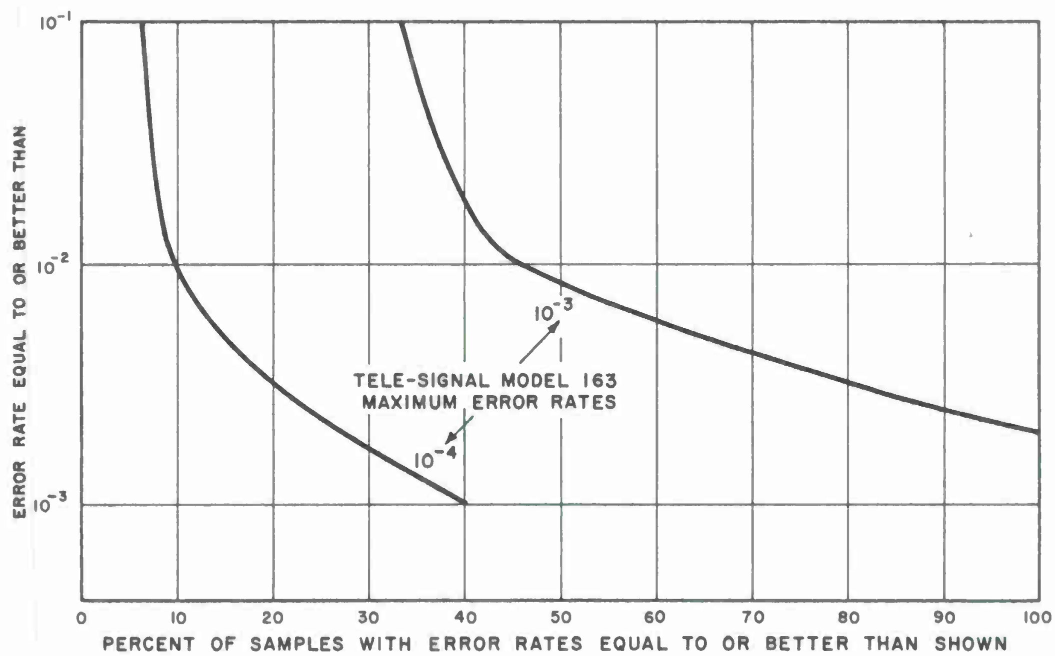
where F = Figure of Merit

A_o = Average character error rate AN/FCC-19

P_o = Percentage of time AN/FCC-19 error exceeded 5×10^{-3}



MAXIMUM ERROR RATE VERSUS PERCENT TIME
(BASED ON COMPARISONS OF 1½-HOUR SAMPLES
OF CODEX T-1000 AND TELE-SIGNAL AN/FCC-19)
FIGURE A-16



MAXIMUM ERROR RATE VERSUS PERCENT TIME
(BASED ON COMPARISONS OF 1½-HOUR SAMPLES
OF TELE-SIGNAL MODEL 163 AND AN/FCC-19)
FIGURE A-17

TABLE III

COMPARISON OF PERFORMANCE
BASED ON ONE MESSAGE (APPROXIMATELY 1.3 MINUTES) INTERVAL

	Average Character Error Rate	Percentage of Samples Used in Evaluating Average Error Rate	Percentage of Samples With Error Rate Exceeding 5×10^{-3}	Figure of Merit (Note)
Codex Model T-1000	3.7×10^{-4}	90.8	9.2	14.8
Tele-Signal Model 163	7.0×10^{-4}	74.1	25.9	2.8
Tele-Signal AN/FCC-19	1.3×10^{-3}	62.0	38.0	1.0 (reference)
Robertshaw AN/FGC-76(V)	1.5×10^{-3}	51.2	48.8	0.7

Note: Improvement achieved over reference equipment.

A_i = Average character error rate of equipment (i)

P_i = Percentage of time equipment (i) error rate exceeded 5×10^{-3}

Obviously the greater value of the Figure of Merit (F), the greater the improvement achieved over the reference equipment. Table III is based on standard test messages (approximately 1.3 minute intervals) and Table IIIa shows similar characteristics for 15 minute intervals. The tabulated results are based on data taken when all equipments were operating simultaneously.

8.0 ANALYSIS OF ERROR OCCURRENCE USING MIT LINCOLN LABORATORIES ADDER EQUIPMENT

8.1 GENERAL

The importance of determining the distribution of bit errors over the North Atlantic Radio System cannot be overemphasized. The ADDER equipment was designed to provide a record of bits transmitted that would permit the calculation of bit error distribution. Such a distribution, if known, can provide a quantitative evaluation of the performance of the communication system. This is particularly true if error correcting and/or detecting codes are to be used.

It is readily apparent that such factors as the mean number of bits between bits in error, the occurrence of various levels of error densities, and the probability of consecutive errors are important in determining the error correcting and/or detecting code to be used. In addition, such information is useful in determining operational factors such a maximum message length, the use of numerics, the amount of service and rerun, and other technical control procedures that will be required as a particular circuit.

The Lincoln Lab ADDER equipment consists of a word generator, a Cobi data modem, a word comparator, and an error recorder with a punched paper tape output. A complete description of this equipment and its operation is included in the Interim Report. However, its operation is briefly described below and the equipment layout is shown in Figure A-18.

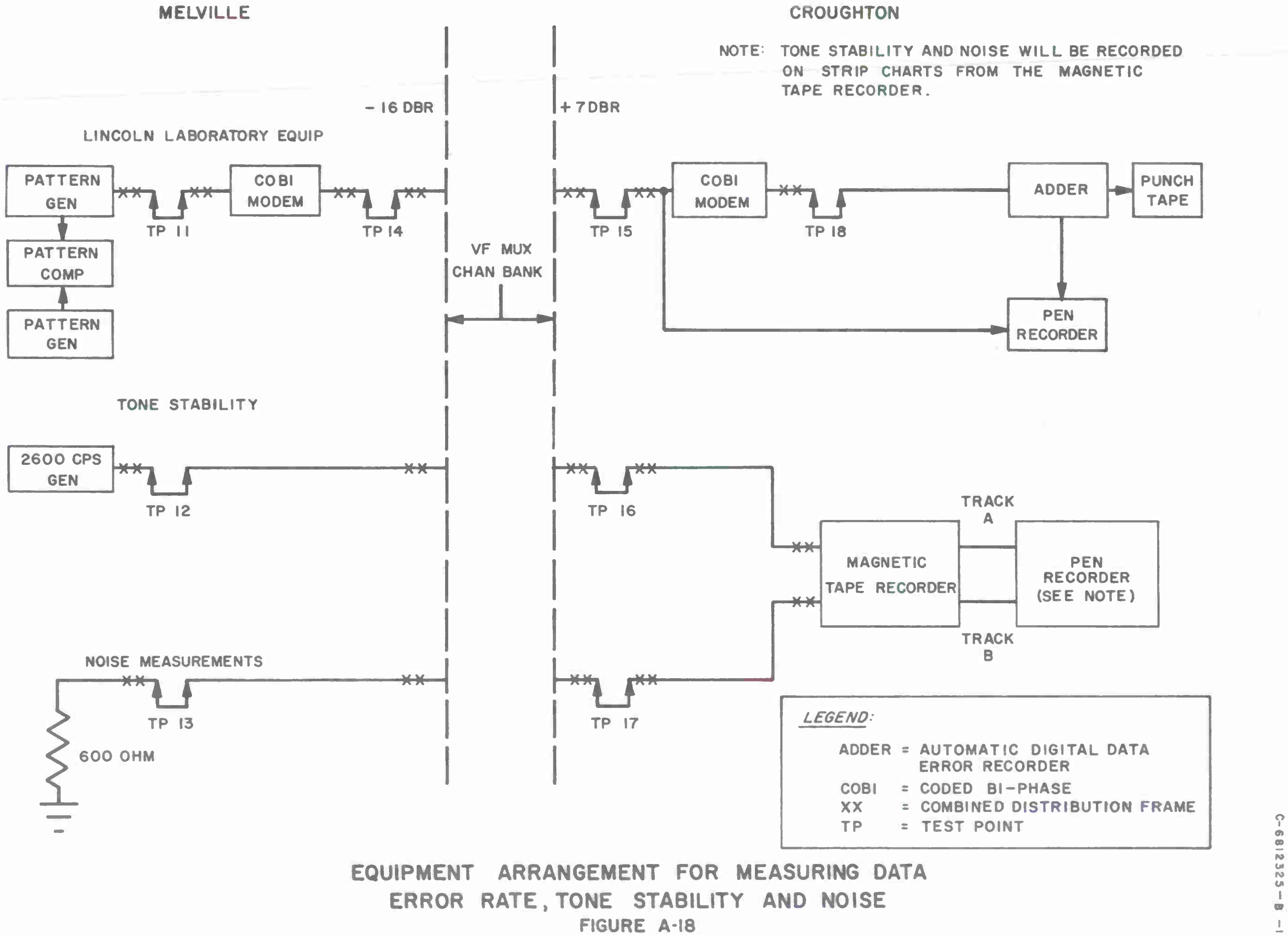
The word generator, located at Goose Bay, Labrador, provided a 1200 bps repetive word, 16 bits long, to a Cobi data modem which transmitted the pattern over the North Atlantic Communication System to Croughton, UK. At Croughton, the received data was compared to the locally generated word,

TABLE IIIa

COMPARISON OF PERFORMANCE
BASED ON 15 MINUTE INTERVALS

	Average Character Error Rate	Percentage of Samples Used in Evaluating Average Error Rate	Percentage of Samples With Error Rate Exceeding 5×10^{-3}	Figure of Merit (Note)
Codex Model T-1000	4.9×10^{-4}	87.0	13.0	10.6
Tele-Signal Model 163	7×10^{-4}	60.3	39.7	2.42
Tele-Signal AN/FCC-19	1.2×10^{-3}	43.7	56.3	1.0
Robertshaw AN/FGC-76(V)	1.3×10^{-3}	31.0	69.0	0.75

Note: Improvement achieved over reference equipment.



EQUIPMENT ARRANGEMENT FOR MEASURING DATA ERROR RATE, TONE STABILITY AND NOISE

FIGURE A-18

errors were counted, and a punched tape record was made of the errors as they occurred.

Due to the difficulty in reducing the punched paper tape output of the MIT Lincoln Labs ADDER equipment to a form that can be used by modem computers, the above error distribution information has not yet been fully reduced.

Appendix IV to this report will be issued on or before 31 July 1964 which will include a complete analysis of the error distribution. However, the initial error distributions that have been obtained indicate that high density error bursts (5 percent of bits in error per unit time) seldom occur for more than one second, and that at least five seconds of lower density error bursts occur between the high density bursts.

If the error distributions indicated by the initial error analysis is supported by the complete error analysis, an error correcting code capable of two orders of magnitude improvement can be designed.

8.2 COMPUTER RESULTS REQUIRED

The following computer results are required in order to determine the error distribution experienced over the Goose Bay to Croughton communication system. As the analysis progresses, further information may be sought such as:

(a) Total number of bits transmitted during the test period

(b) Total number of errors in each bit position per 16 bit word

(c) The percentages of time taken up by all error bursts of specific length.

8.2.1 Error Burst Lengths

In order to obtain an insight into the characteristics of an error burst, it was necessary to define an error burst as the errors that occur between two error free intervals. We define a guard space, of length A, as at least A consecutive error free bits. By specifying a guard space of small length, it is possible to split the record into small error bursts. By specifying the guard space as a longer period small variations in the error pattern will be ignored and listings and curves will then be generated for long error bursts.

8.2.1.1 Guard Space Tabulation

A tabulation will be required for each of the following guard spaces:

Minimum No. of Error Free Bits in Guard Space
96
480
960
4800
9600
19200

8.2.1.2 Burst Length Categories

Those periods which contain errors and are located between two guard spaces are called error burst periods. It is necessary to tabulate the density of the errors in a burst period, and also the total number of errors and total number of burst periods, in order to evaluate the relationship between guard spaces and error bursts.

Error density categories for the burst periods associated with each guard space are listed below:

Guard Space (in bits)	Error Burst Length Categories					
96	1-10 bits in error burst	11-24 bits in error burst	25-48 bits in error burst	49-96 bits in error burst	97 or more bits in error burst	
480	1-24 bits in error burst	25-48 bits in error burst	49-120 bits in error burst	121-240 bits in error burst	241-480 bits in error burst	481 or more bits in error burst
960	1-10 bits in error burst	11-48 bits in error burst	49-96 bits in error burst	97-240 bits in error burst	241-480 bits in error burst	481-960 bits in error burst

Guard Space (in bits)	Error Burst Length Categories						
4,800	1-48 bits in error burst	49-240 bits in error burst	241-480 bits in error burst	481-1200 bits in error burst	1201-2400 bits in error burst	2401-4800 bits in error burst	4801 or more bits in error burst
9,600	1-96 bits in error burst	97-480 bits in error burst	481-960 bits in error burst	961-2400 bits in error burst	2401-4800 bits in error burst	4801-9600 bits in error burst	9601 or more bits in error burst
19,200	1-192 bits in error burst	193-960 bits in error burst	961-1920 bits in error burst	1921-4800 bits in error burst	4801-9600 bits in error burst	9601-19200 bits in error burst	19201 or more bits in error burst

The above error burst length categories will be divided into subgroups of error density where:

(a) Error Density = Number of Errors/Error Burst Length

(b) Error densities to be used are:

$\leq$ 0.01

0.01 - 0.05

0.05 - 0.10

0.10 - 0.25

0.25 - 1.00

8.2.2 Distribution of Intervals Between Errors in Error Burst

The distribution of the intervals between errors will be examined. Interval lengths to be studied will be:

Error Free Bits Between Two Errors

0 bits

1-16 bits

17-80 bits

81-160 bits

161-400 bits

401-1600 bits

Error Free Bits Between Two Errors (Continued)

1601-8000 bits

8001-16000 bits

16,001-160,000 bits

>160,000 bits

8.2.3 Consecutive Errors

The number of consecutive errors can be obtained by looking at the number of errors separated by 0 error free bits.

8.2.4 Number of Errors Per Word

The number of words with 0 errors, the number with one error etc., up to 16 errors will be listed.

8.2.5 Error Rate Each 64 Seconds

The error rate for each 64 seconds will be calculated.

8.2.5.1 Error Rate, 64 Seconds vs. Calendar Time

The error rate for each 64 seconds versus calendar time will be listed.

PART B

RADIO FREQUENCY STUDY

1.0 INTRODUCTION

The radio system between Goose Bay, Canada and Fylingdales, United Kingdom is composed of three major segments: The BMEWS RCS between Goose Bay and DYE MAIN; the DEW East System between DYE-Main and Keflavik, Iceland; and NARS between Keflavik and Fylingdales. AN/FRC-39(V) equipment in quadruple diversity configuration is used on all radio links with the majority of the links having 60-foot parabolic antennas and 10-kw transmitters. Some of these links have 120-foot parabolic antennas and 50-kw transmitters.

Upon receiving the request to perform an RF study on the complete radio system between Goose Bay and Fylingdales, it was decided to examine the following factors for each link:

(a) The reported worst-month median received carrier level

(b) Reports of other noise source problems such as path intermodulation.

Very little data of value was available from BMEWS RCS[1]; however, verbal reports were available indicating that traffic operation between Goose Bay and DYE-Main was satisfactory. The Western Electric Company made two evaluations of the DEW East System [2,3] and it was thought that substantial data was available for our preliminary analysis. There was little reliable information available for NARS. [4,5] It was, therefore, decided that some radio frequency tests should be performed on what appeared to be the longest links of each of the three systems plus the link NARS 41 to 42 which is only 234 miles in length but has an appreciable take-off angle due to the interposition of a mountainous glacier. It was decided initially to test the following links: DYE-Main to RES-X-1, DYE-4 to DYE-5, DYE-5/Site 41 to Site 42, Site 42 to Site 43 and Site 43 to Site 44. However, due to security problems at Site 43, it was not possible to place ICS personnel at this site and it was decided that since 42 to 43 and 43 to 44 were somewhat similar radio links, that tests would only be performed on the radio link 43 to 44. Accordingly, a program was initiated to make the tests and observations of the following parameters:

(a) Path Intermodulation

(b) Path Loss

(c) Threshold Extension Panel Operation

(d) Combiner Operation

(e) Maintenance Techniques

(f) Individual Radio Link Subsystem Teletype Traffic

In accordance with the planned program, radio links 43 to 44, 42 to 41, DYE-4 to DYE-5 were tested but the radio link DYE-Main to RES-X-1 was not tested due to the amount of time required for tests between DYE-4 and DYE-5. This report, therefore, details items a, b, c, d, and e above for the three links which were tested and items b and f for the general system. It is felt that the results obtained are sufficient to indicate the behavior of the main links of the system and remedial actions for improvement are included.

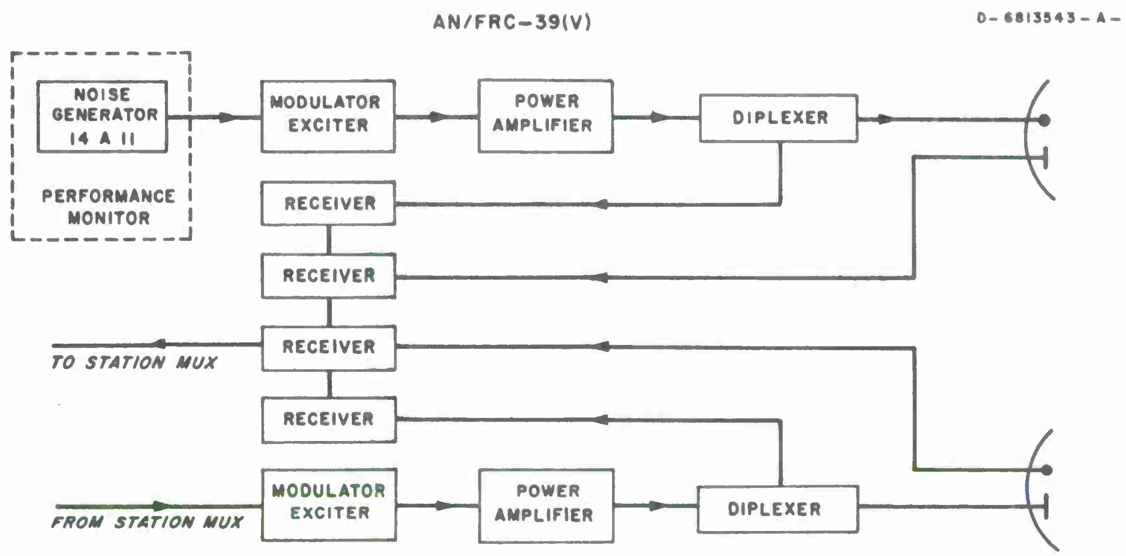
2.0 PATH INTERMODULATION

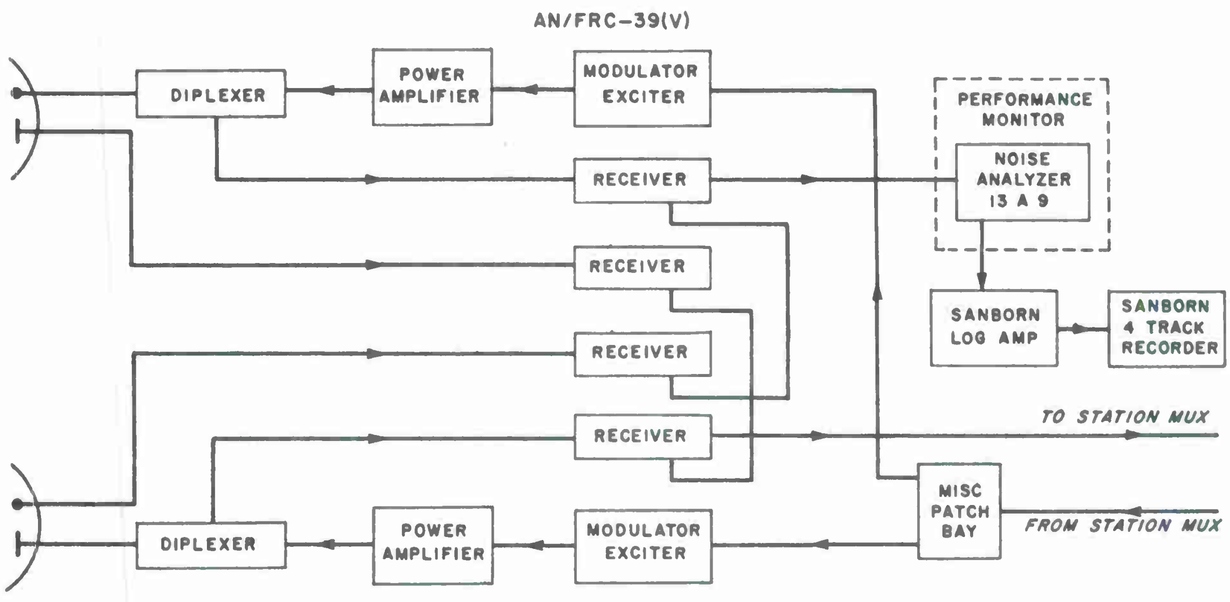
2.1 GENERAL

Due to the short time available to plan the program and procure test equipment, it was not possible to provide sufficient recording equipment for all test teams. Therefore, the tests were planned so as to utilize to a maximum the complement of test equipment that is normally available at radio stations of the type encountered. The results obtained indicate that only minor cost in extra test equipment is required to test in a similar manner almost any tropo link in the United States Air Force system. The testing could probably be done by the Operation and Maintenance (O&M) personnel if they were equipped with adequate test instructions.

2.2 TEST METHOD

Path intermodulation effects were measured by reducing the radio equipment configuration to two dual-diversity radio systems, one carrying the operational traffic and the other used for test purposes. The test dual-diversity radio system was noise loaded with the noise generator of the performance monitor that is a standard part of the station test equipment. At the receiving site, baseband slot-noise was measured using the noise analyzer of the performance monitor. Figure B-1 shows the configuration of the equipment as employed between DYE-4 and DYE-5 and NARS Site 41 and 42. The configuration of the equipment as utilized between Site 43 and Site 44 is similar except that a type 3A amplifier and Texas Instruments recorder were used in place of the Sanborn log amplifier and 4-track recorder. In all three links, the "top" and "bottom" slots of a 60-channel system and 120-channel





CONFIGURATION OF EQUIPMENT ON
PATHS DYE 4/5 AND SITES 41/42 FOR INTERMODULATION MEASUREMENTS
FIGURE B-1

system were used as provided for by the performance monitor. The slots used were located at 55 kc or 80 kc and 265 kc for a 60-channel system, 55 kc or 80 kc and 475 kc for a 120-channel system. Link noise power ratio was measured using these slots. From the value of recorded signal level, the link signal-to-intermodulation noise ratios were measured for various baseband noise signal levels. Where the four-track recorder was employed, agc and dc control voltage and slot noise were simultaneously recorded. On link 43 to 44, only radio slot-noise and the dc control voltage were recorded, and since the dc control voltage is affected by intermodulation, the median receive carrier level was established by removing the modulating signal. Figures B-2, B-3, B-4, B-5, B-6, B-7, B-8, B-9, B-10, and B-11 show the average signal-to-intermodulation noise ratios and the average intermodulation noise above thermal noise for the three radio paths.

2.3 RESULTS

2.3.1 General

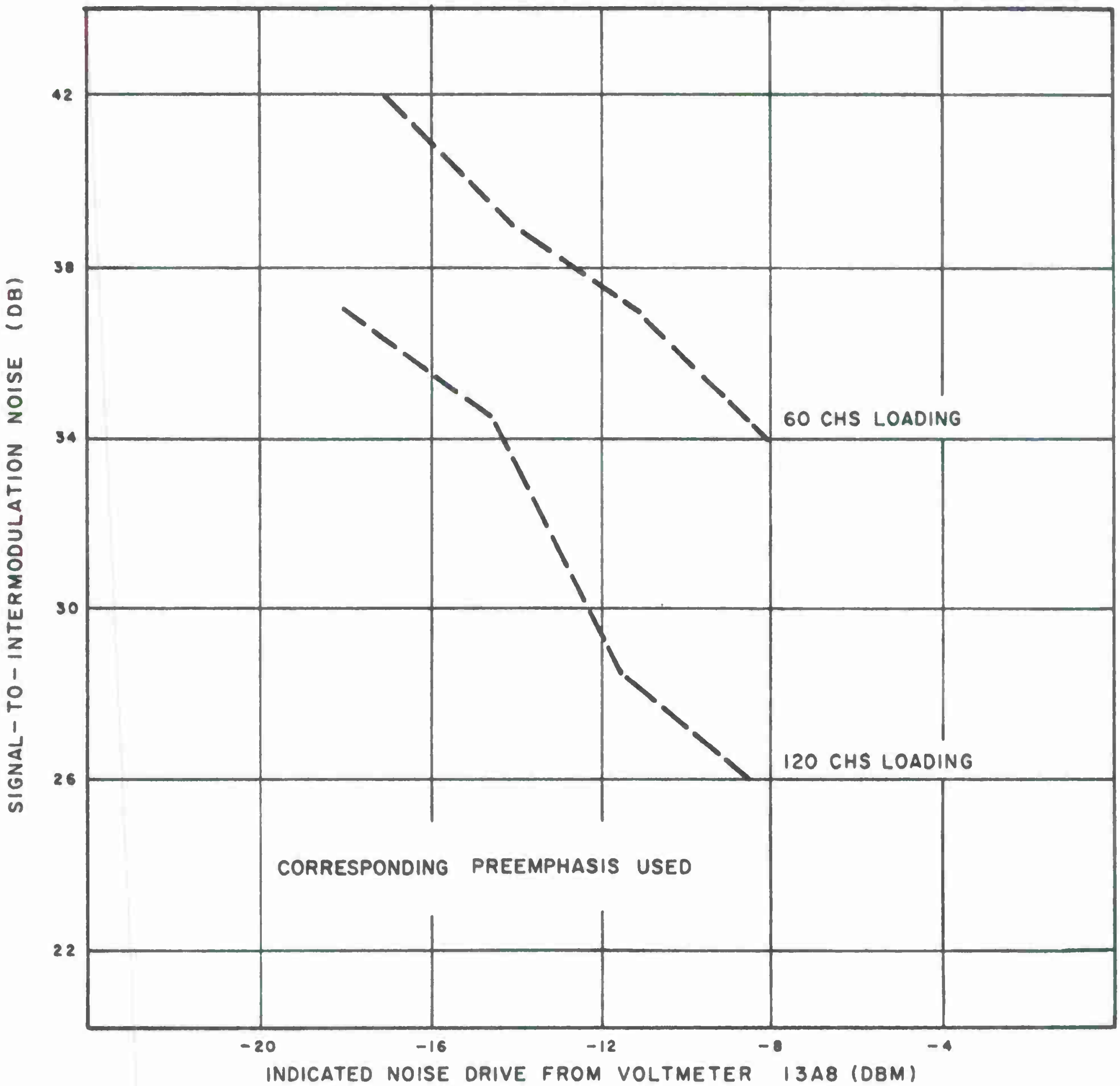
The primary objective of these tests was to determine at what value of noise signal drive to the modulator would the intermodulation noise be equal to the thermal noise in a typical 1-kc baseband slot. This would indicate the optimum drive level of the radio system for least noise under "fully loaded" condition. Since the tests were made during periods of estimated worst propagation, the results would indicate optimum drive levels during such periods.

2.3.2 Drive Levels

The optimum levels from Figures B-3, B-4, B-6, B-7, B-9, and B-10 along with the current normal drive levels are shown in Table IV. It can be seen that the current normal practice is practically optimum for the path 43 to 44 for the "fully loaded" condition, and that deviation could be reduced for the path 42 to 41, and increased for the DYE-4 to DYE-5 path.

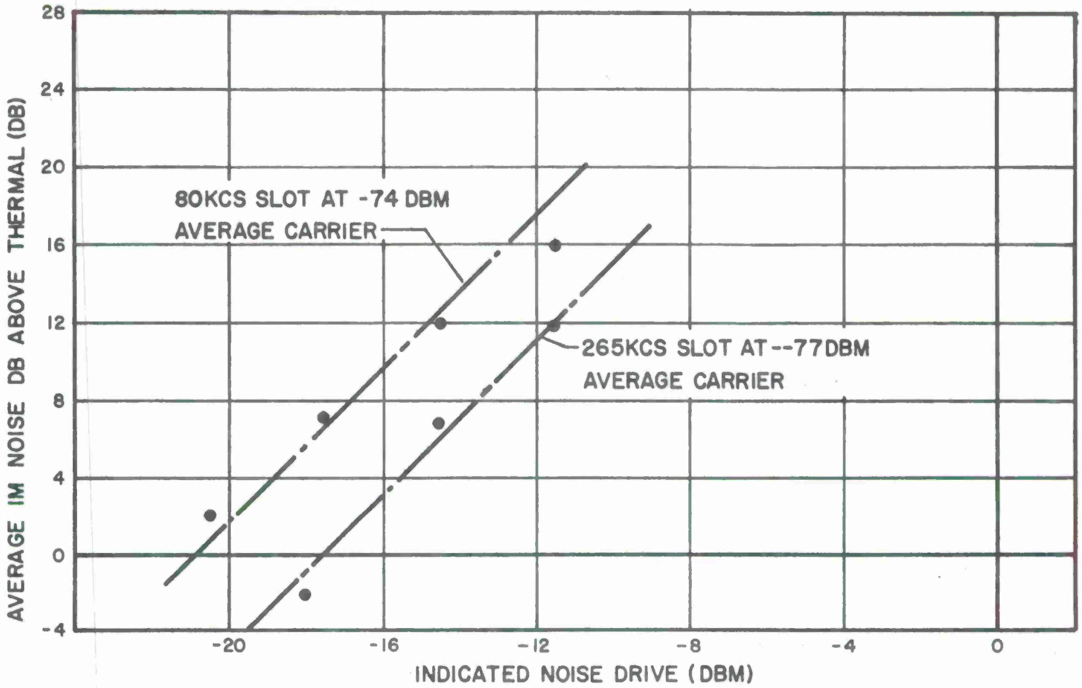
2.3.3 Signal Levels

Upon spot checking the average level of the operational multiplex at Site 42, it was found that the L-carrier signal averaged about 0 dbm0 and the K-carrier signal about -3 dbm0 (as indicated by Voltmeter 13A8). Sudden signal peaks did occur which cause meter swings above +6 dbm0. Thus, although it may appear that the average load is well below design maximum, the occurrence of the signal peaks eliminates any broad assumptions. These signal peaks were due to actual signals and to FM threshold breaks on the DYE-4/ -5 radio path.



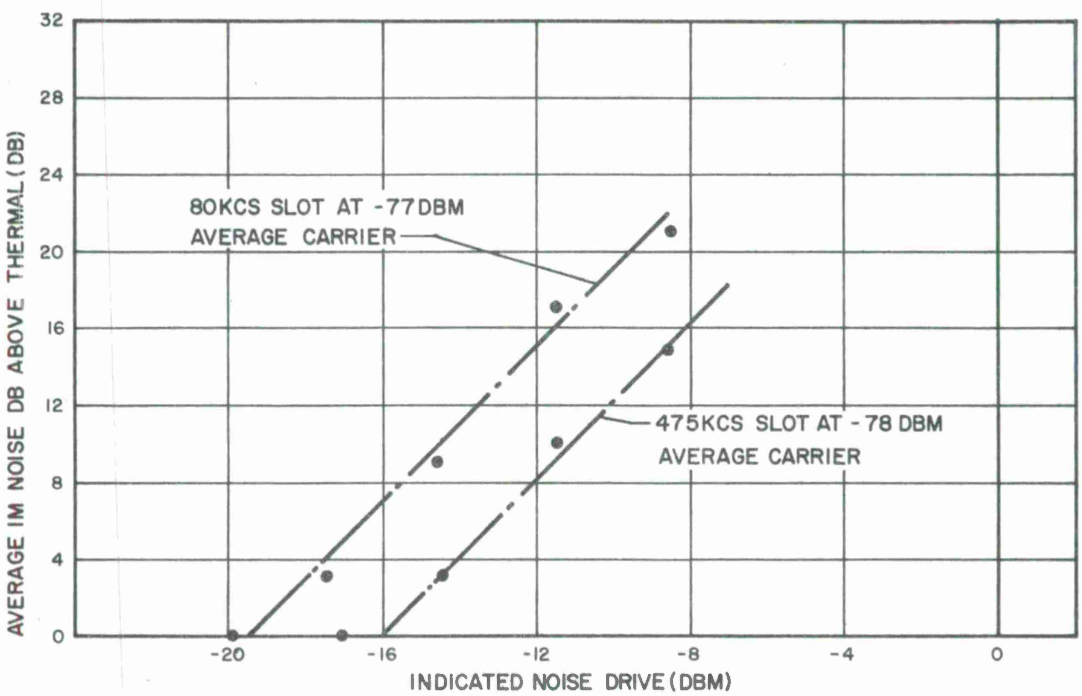
DUAL DIVERSITY MEASUREMENTS OF S/I FOR AVERAGE HF SLOT, PATH 41/42

FIGURE B-2



AVERAGE IM NOISE ABOVE THERMAL FOR 308KCS TOP MODULATION FREQUENCY, RADIO PATH SITE 41/42

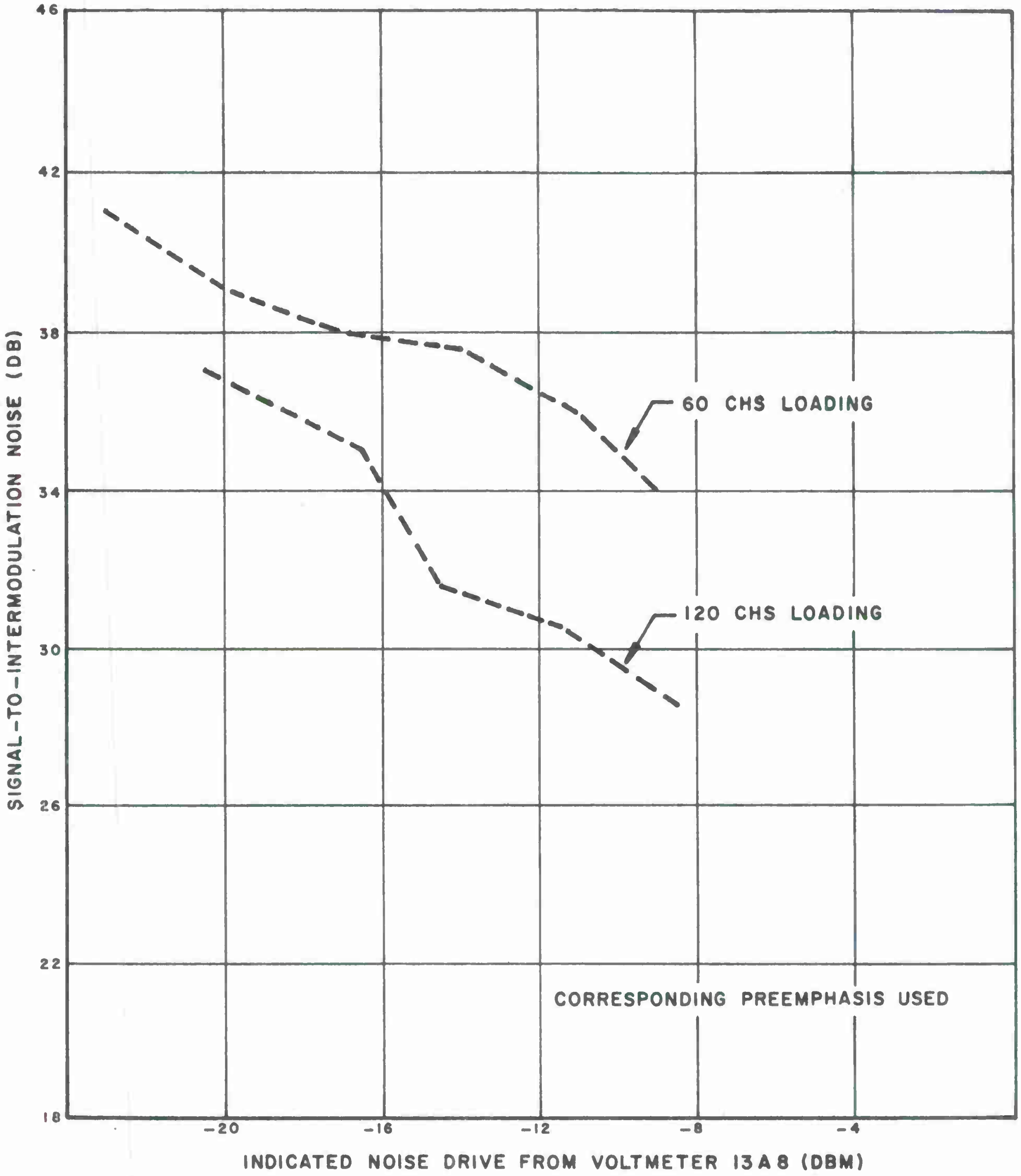
FIGURE B-3



AVERAGE IM NOISE ABOVE THERMAL FOR 552KCS TOP MODULATION FREQUENCY, RADIO PATH SITE 41/42

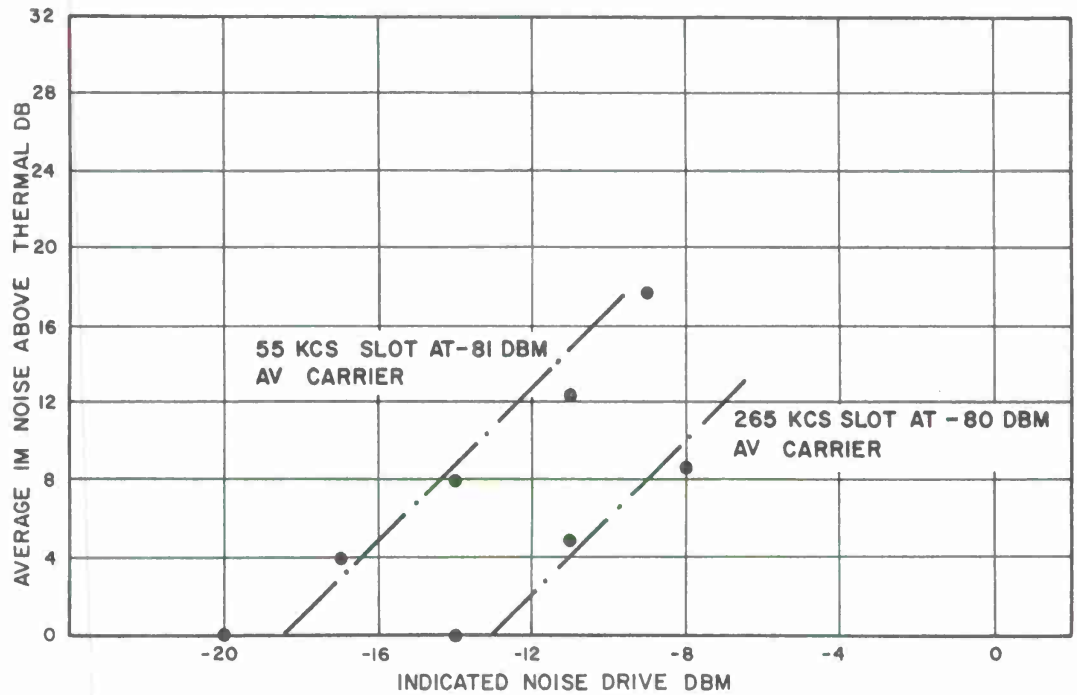
FIGURE B-4

C-6813560-A-1



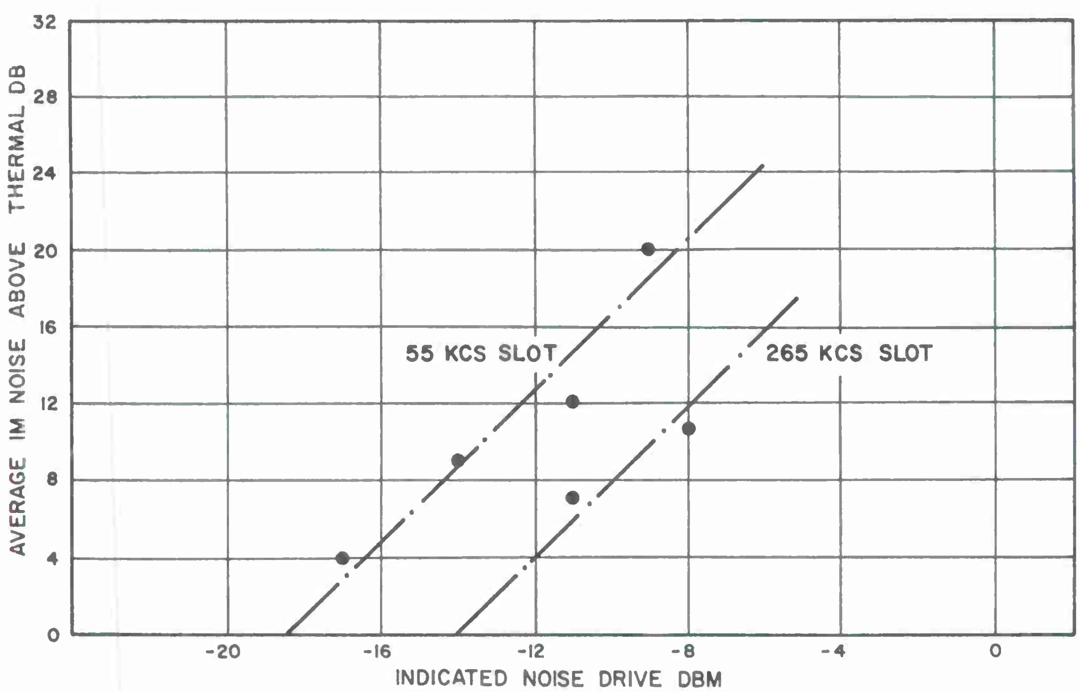
DUAL DIVERSITY MEASUREMENTS OF S/I
FOR THE AVERAGE HF SLOT PATH 43/44

FIGURE B-5



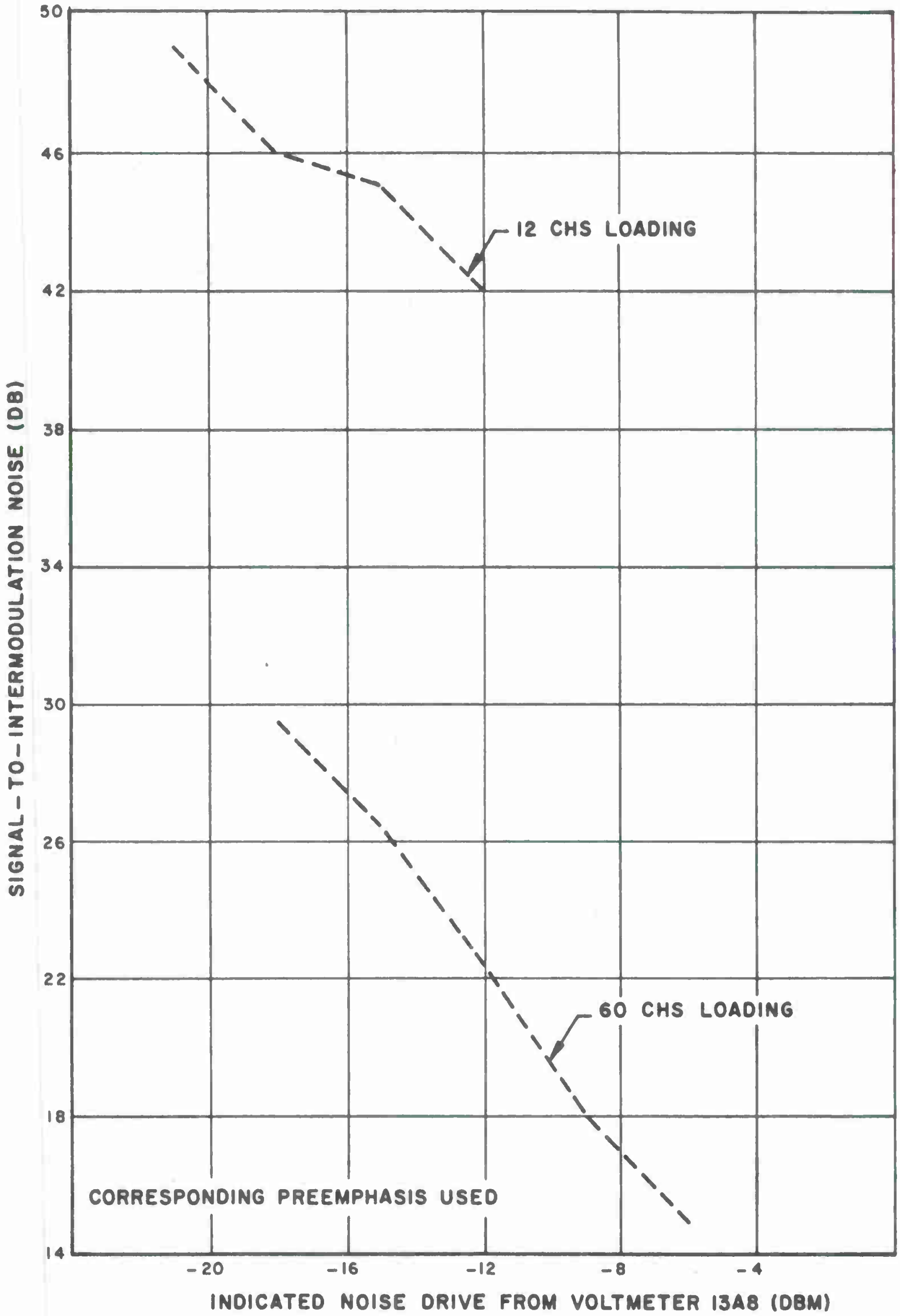
AVERAGE IM NOISE ABOVE THERMAL FOR 308KCS TOP MODULATION FREQUENCY, RADIO PATH SITE 43/44

FIGURE B-6



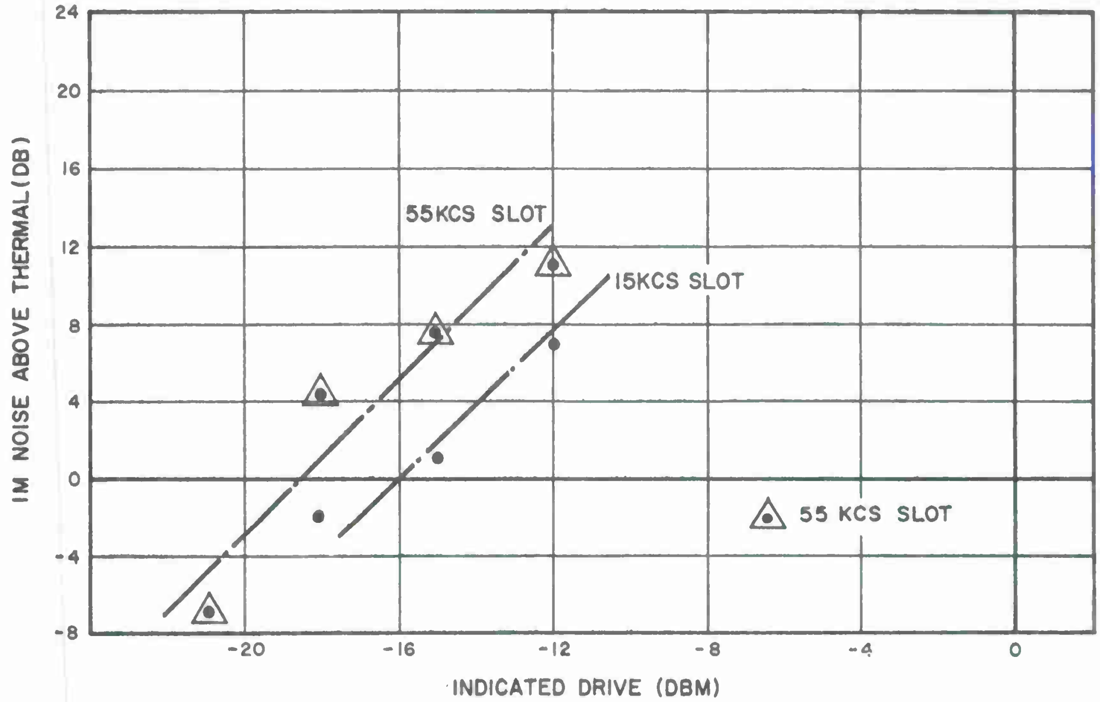
AVERAGE IM NOISE ABOVE THERMAL FOR 552KCS TOP MODULATION FREQUENCY, RADIO PATH SITE 43/44

FIGURE B-7



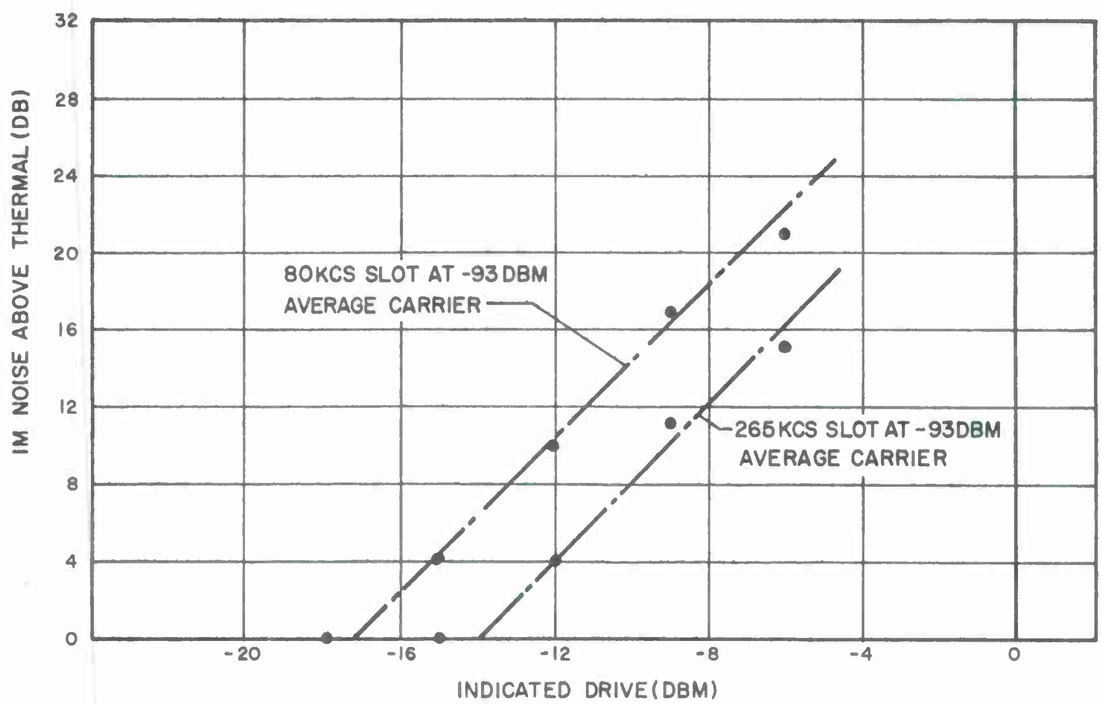
DUAL DIVERSITY MEASUREMENTS OF S/I
FOR AVERAGE HF SLOT, PATH DYE 4/5

FIGURE B-8



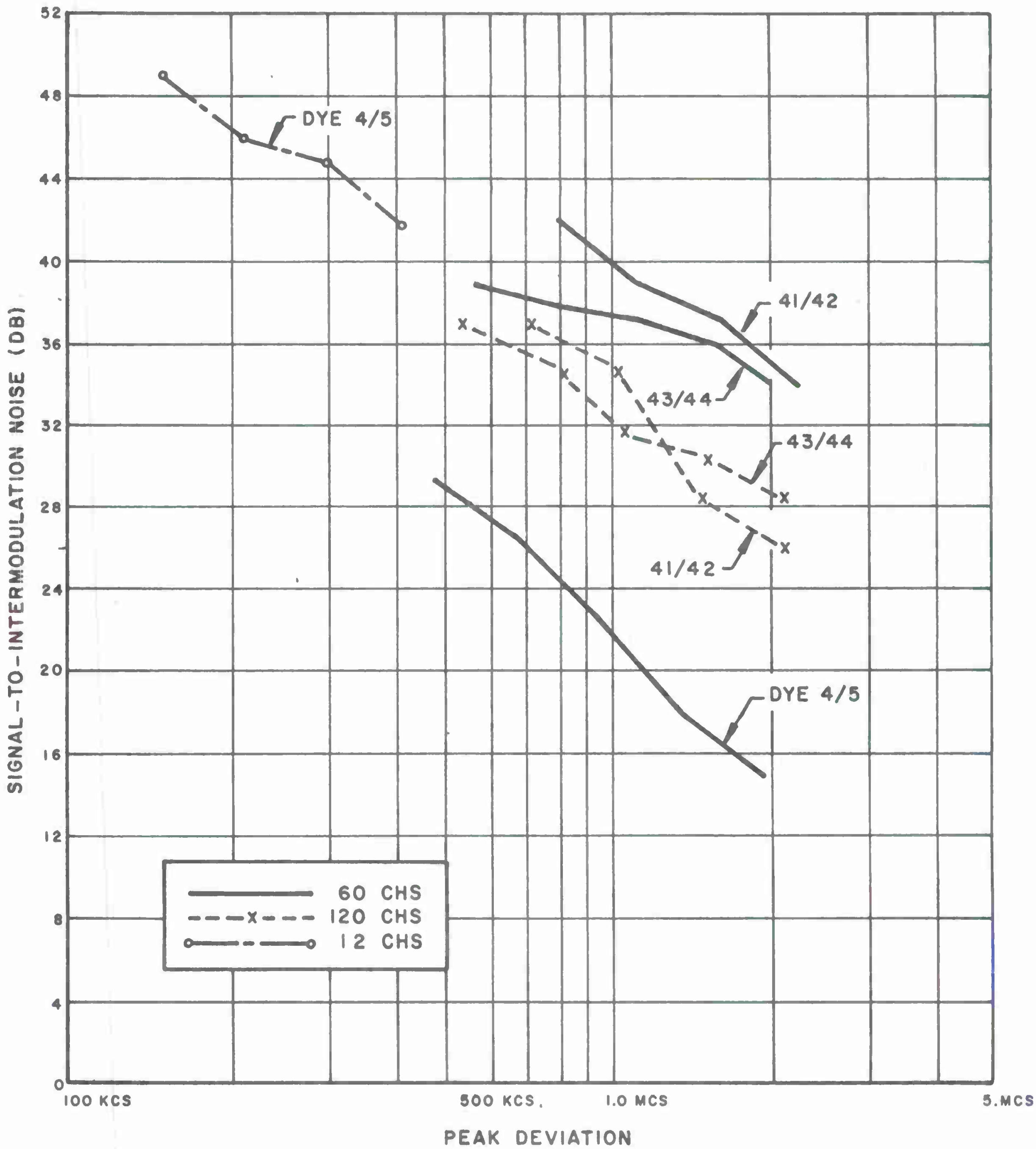
AVERAGE IM NOISE ABOVE THERMAL FOR 60KCS TOP MODULATION FREQUENCY, RADIO PATH DYE 4/5

FIGURE B-9



AVERAGE IM NOISE ABOVE THERMAL FOR 308KCS TOP MODULATION FREQUENCY, RADIO PATH DYE 4/5

FIGURE B-10



MEASURED S/I DATA EXPRESSED IN TERMS OF PEAK DEVIATION

FIGURE B-11

TABLE IV

COMPARISON OF MODULATION NOISE SIGNALS FOR MEASURED OPTIMUM PERFORMANCE AND NORMAL DESIGN PRACTICE

Radio Path	Channelization (channels)	Indicated Optimum Drive Level (dbm)	Indicated Design Drive Level (dbm)
Site 43 to 44	60	-16.0	-18
	120	-16.0	-15
Site 42 to 41	60	-19.0	-15 *
	120	-18.0	-12 *
DYE-4 to -5	60	-15.5	-18
	12	-17.0	-24 **

* Current practice is for the deviation to be set +1.5 db above normal.

** 12-channel operation was never contemplated for this link.

2.3.4 Comparison with Bell Telephone Laboratories' Measurements

Also of interest is the comparison of our results with those of previous measurements made by Bell Telephone Laboratories, Inc. (BTL) [3] in the DYE-4 to -5 radio link and in other areas. Table V shows our measured results for DYE-4 to -5, Sites 41 to 42, Site 43 to 44, and the calculated results using BTL formulas.[6] It can be noted that 12-channel measurements only are available under this program for the DYE-4 to -5 radio link and that these results are displaced in deviation compared to the rest of the measurements due to the low output of the noise generator of the performance monitor. This low output prevented measurements in the other two radio links, as results were masked by the inherent intermodulation of the radio equipment itself. It can be seen from Figure B-12 that previous measurements for the DYE-4 to -5 radio link are different in nature compared to data measured under this program. This is perhaps due to the fact that during the BTL tests, inversions occurred frequently, which provided an extremely large range of path loss. This affected the reported average signal-to-intermodulation noise ratios, whereas, in this test, the average receive carrier level was -93 dbm with a total short-term median variation of +6 db.

Bell Telephone Laboratories' formulas indicate that the signal-to-intermodulation noise ratio should vary inversely as the square of the rms deviation for a given top modulation frequency and inversely as the square of the top modulation frequency for a given rms deviation for values of signal-to-intermodulation noise greater than about 20 db. This result held true for the general BTL measurements for a top modulation frequency range of 1052 kc to 300 kc, but not for the range 300 kc to 100 kc. The measurements made here for 12-channel operation, that is a top modulating frequency of 60 kc, showed by extrapolation, that this relationship held for the range 300 kc to 60 kc. (See Figure B-12.) This result is of importance in the proposed design and utilization of very long FM radio links such as Thule to Fox.

2.3.5 Threshold Breaks

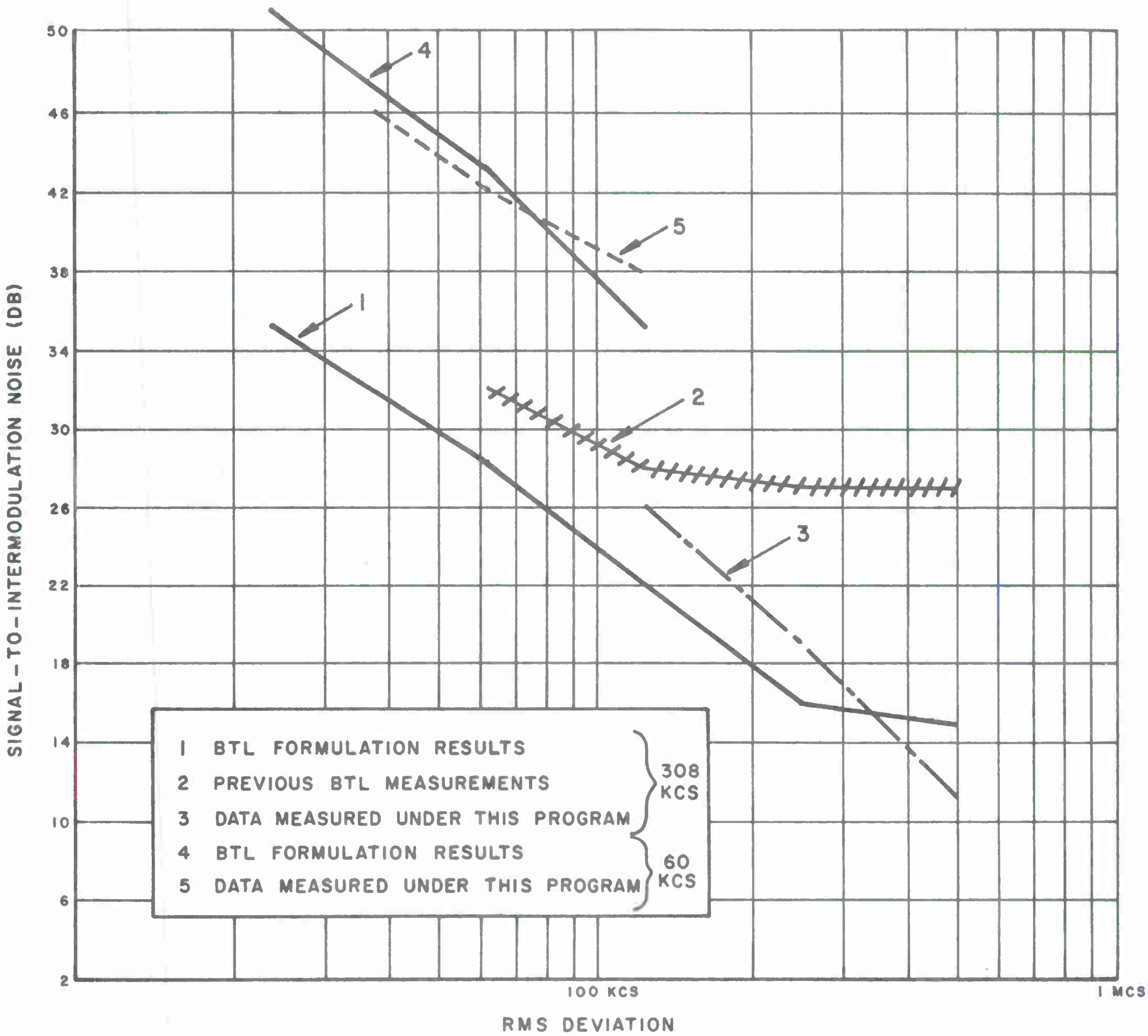
Threshold breaks appeared to produce 1-kc slot noise on the order of -10 dbm0. A through group (width 48 kc) would, therefore, transfer about +7 dbm0 of noise upon a threshold break.

In a system of tandem links where intermodulation is negligible this noise is only observable on those circuits which traverse the radio equipment where the FM threshold was broken. But where intermodulation is

TABLE V

TABULATION OF MEASURED SIGNAL-TO-INTERMODULATION NOISE DATA FOR NO-DIVERSITY (ACTUAL MEASUREMENTS MINUS 3 DB) TOGETHER WITH BTL CALCULATIONS

Radio Path	Source	RMS Deviation in KC						Top Modulating Frequency (kc)
		24	62	125	250	500	800	
DYE-4/5	Measured	-	-	26 db	19 db	11 db	-	308
	Calculated	35 db	28 db	22 db	16 db	15 db	18 db	
Site 43/44	Measured	-	-	36 db	35 db	31 db	-	
	Calculated	-	-	35 db	29 db	26 db	-	
Site 42/41	Measured	-	-	41 db	37 db	32 db	-	
	Calculated	-	-	40 db	36 db	31 db	-	
DYE-4/5	Measured	-	42 db	38 db	-	-	-	60
	Calculated	51 db	43 db	35 db	-	-	-	



COMPARISON OF CALCULATED RESULTS FROM BTL FORMULATION AND MEASUREMENTS, RADIO PATH DYE 4/5

FIGURE B-12

not negligible, the noise burst appears on circuits which have not traversed the radio equipment where the FM threshold was broken.

Since the design "white noise load" for a 72-radio system is +4 dbm0, the additional load of +7 dbm0 per group upon a threshold break can be seen as causing a successively deteriorating situation in a tandem-link situation.

A radio squelch circuit exists in that the present combiner is biased-off upon loss of the radio pilot, but on very deep fades where the pilot is lost for all receivers, this squelch is removed. A modification would, therefore, appear in order to prevent the retransmission of excessive noise during very deep fades.

2.4 POSSIBLE REMEDIAL ACTIONS

2.4.1 DYE-4/ -5 Radio Path

Measurements taken on this path (see Figure B-8 and see also Table IX) indicate that the average intermodulation noise alone, under fully loaded conditions, is about 9 db above DCS requirements for total noise from all sources for the path. With FM radio equipment, this situation can only be alleviated by the following methods:

(a) Reducing deviation

(b) Increasing antenna gain

(c) Increasing diversity

(d) Reducing baseband (i.e. using less channels)

2.4.1.1 Reducing Deviation

Since this radio path also suffers from thermal noise due to the very small level of the received RF carrier, reduced deviation will not provide reduced noise levels. The thermal noise level is so severe that optimization requires increasing deviation at present.

2.4.1.2 Increasing Antenna Gain

Antenna gain advantage is also to be dismissed as antennas are already 120 feet in diameter and increasing transmission frequency would increase the level of thermal noise.

2.4.1.3 Increasing Diversity

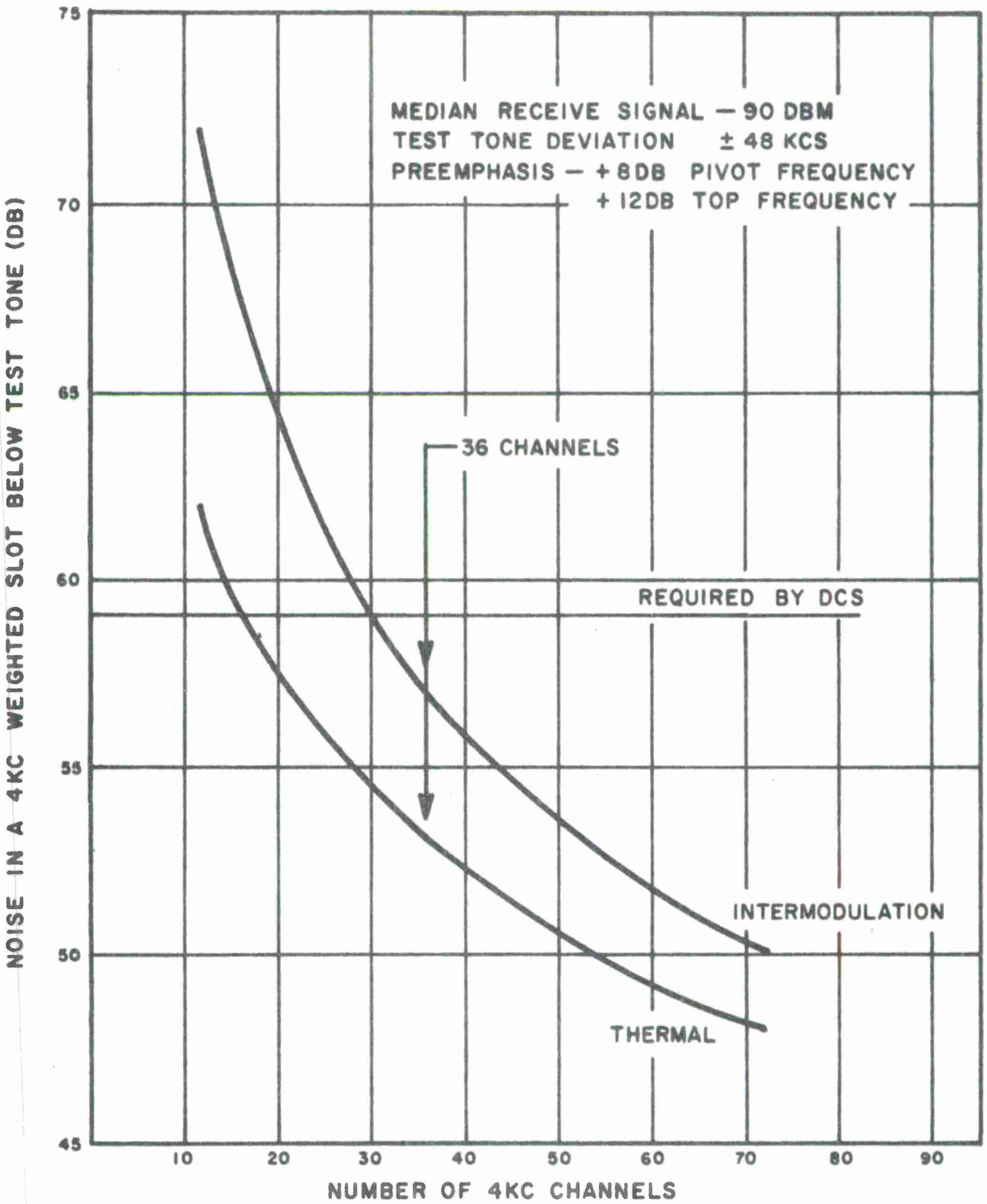
To obtain a 3-db advantage through diversity, the system would have to be increased from 4-fold to 8-fold diversity, which hardly seems worthwhile.

2.4.1.4 Reducing the Number of Channels

Reducing the number of channels provides definite advantages. Figure B-13 indicates how the estimated noise would be reduced by using fewer channels, based on a ±48-kc test-tone deviation and +12-db advantage through pre-emphasis in the top channel. It can be seen that a 36-channel system would be expected to exceed DCS requirements (based on intermodulation only) by 2 db, or provide a 7-db advantage over 72 channels. Reducing the system to 36 channels could be effected at minimum cost.

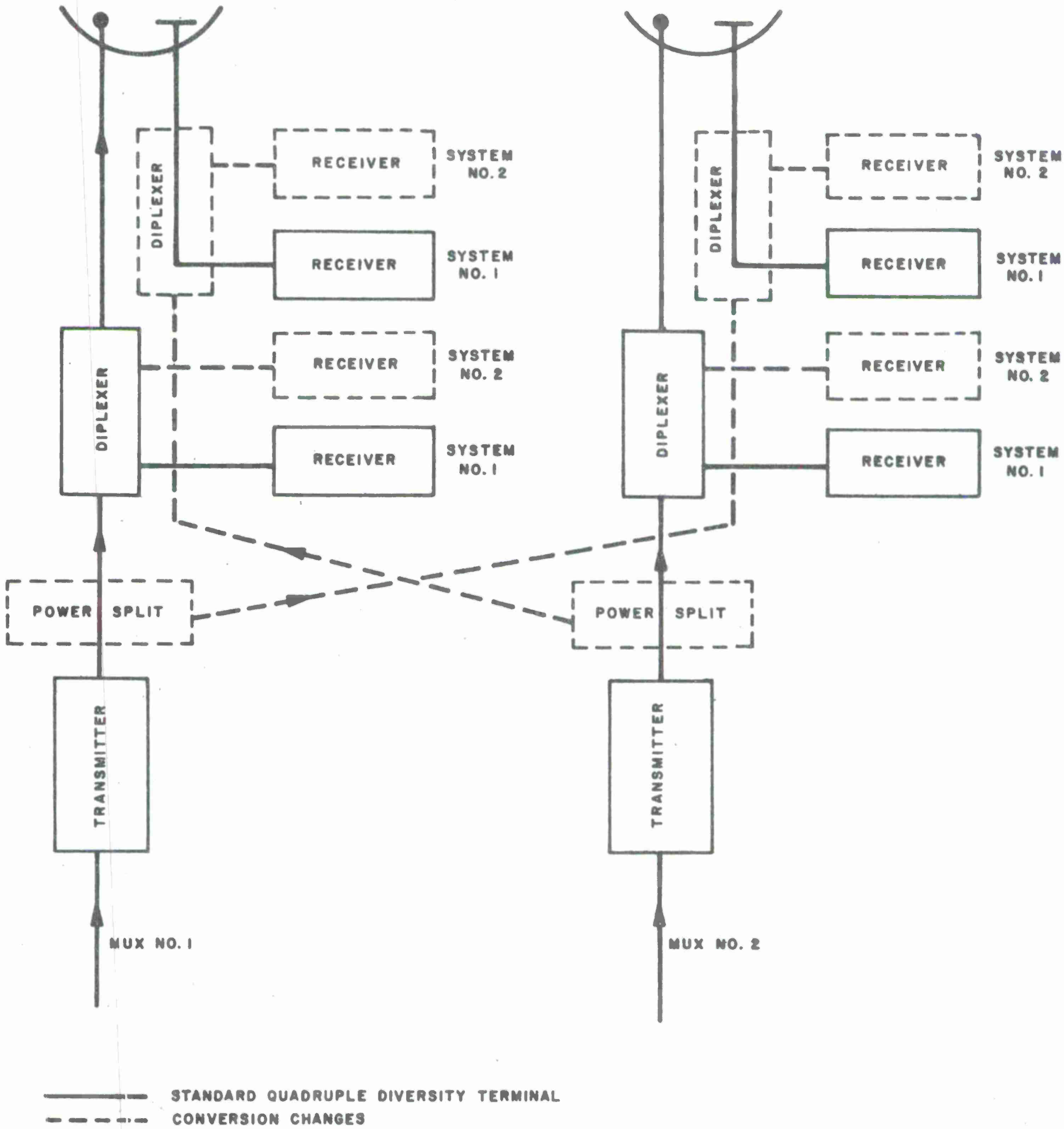
The radio system could be converted to two quadruple-diversity radio systems each carrying 36 channels. This can be done by using each transmitter as an effective dual-transmitter with a power splitter and by adding another four receivers to each terminal. Other auxiliary items are required such as diplexers, L-carrier translation units, etc. The basic scheme is shown in Figure B-14. By acquiring transmitter klystrons capable of the maximum performance of the transmitter (75 kw), the effective transmit power would be similar to that in use today (30-40 kw). The disadvantage of this scheme is that there is no redundancy in the transmit equipment for either bank of 36 channels. The only redundant capability for operational circuits is to either route them over both radio systems or to provide complete spare radio equipment, the latter of which appears out of the question.

Apart from FM modulation schemes, SSB modulation might provide transmission relatively free of multipath distortion for 72 channels. The only SSB equipment in operation is the DYE-Main to Thule radio path of some 700 miles, where the multipath is such that in-band fading occurs with a 24-channel load. This equipment does not meet the fundamental requirements for intermodulation distortion and was basically designed for the instance where the received signal was so low that an FM threshold could not be exceeded. Considerable initial problems were also experienced in achieving the required peak power due to transmitter tube failures. Therefore, it can be expected that to provide 72-channel equipment capable of DCS quality, especially in the peak power requirement, an R&D program is required at present. However, it is recommended that study programs be undertaken to determine what capability can be expected from SSB tropo links since increasing circuit demands may eventually bring about excessive intermodulation noise to even moderate length FM links.



CALCULATED NUMBER OF CHANNELS APPLIED FOR TOP CHANNEL PERFORMANCE FOR DYE 4/5 PATH

FIGURE B-13



CONVERSION OF A QUADRUPLE DIVERSITY TERMINAL TO TWO INDEPENDENT QUADRUPLE DIVERSITY TERMINALS

FIGURE B-14

Based upon the above considerations, the best compromise action in maintaining 72 channels is to increase the deviation by 1.5 db in this link and to group low priority traffic in the upper allocations. This traffic can then be "plugged out" by Technical Control at times of poor transmission, which will serve to reduce intermodulation noise. Naturally, a superior arrangement would be one where the deviation could be automatically changed to provide an optimum balance (see Figure I-3, Appendix I) between intermodulation and thermal noise. Such an arrangement would increase deviation and also lower thermal noise if low priority traffic were removed. Since this type of scheme is not available at this time, it is recommened that the radio system be permanently reduced to 36 channels.

2.4.2 Hopedale - Saglek Radio Path

Calculations performed on the characteristics of this path have produced estimates that a severe intermodulation distortion problem may exist (see para. 7.0). It is recommended that intermodulation tests be performed on this radio link to determine if the calculations are correct and to determine the nature of corrective action.

2.5 RADIO SQUELCH

A radio squelching circuit is necessary where traffic is relayed on a group or supergroup basis, to prevent successive link intermodulation by the noise bursts generated by a FM threshold break in any one link.

This squelching circuit will protect subsystem traffic that is not traversing the radio link which is breaking threshold.

2.6 PATH INTERMODULATION CALCULATIONS

The BTL formulas were used during this study and are advocated as being the best method available for estimating intermodulation noise. The correlation with test results in this program and in other tests appears to contain no more uncertainty than current methods for estimating path loss.

Optimizing deviation for the best compromise between thermal noise and intermodulation noise is most suited for the "fully loaded" condition but the best all-time result is probably achieved by setting deviation above this optimum (see Appendix I and para. 7.0).

3.0 PATH LOSS

3.1 GENERAL

Although no regular tests were scheduled to measure path loss, the operators of the various radio links of the system were requested to report daily the received signal levels and conditions affecting operation for the hour 1800-1900Z during the period 27 January thru 25 February 1964. This data was supplemented with observations by the test teams at the links under test.

3.2 PATH LOSS DATA

The results of the received link data are shown in Table VI where indicated average received signal conditions are compared to reported/estimated receive levels by the Western Electric Co. It can be seen that most links were within 5-db of estimates or previous measurements with the outstanding exception of the Hopedale/Saglek and RES-X-1/DYE-Main path.[1]

Conditions were severe in February in the DYE-4/5 path when an average signal level of -93 dbm was recorded during the path intermodulation tests, and the test schedule was held up several times due to even worse receive signals. Levels of the order of $\leq$-100 dbm were not unusual, and it appeared that February was worse than January in terms of propagation. In addition, received carrier levels were indicated at a fairly steady -102 dbm during a previous visit on 6 December 1963. During the test period, the better transmission period generally occurred in the afternoon.

Although, unfortunately, no recorded signal levels were reported by DYE-4, the reported TTY error rate during the daily TTY tests was such that it can be believed that the signal median was worse than the value -78 dbm quoted in the DEW East Evaluation Report, February 1962. In the appendix of the Evaluation Report, a separate test for intermodulation observed an average received level of -84 dbm which is utilized in this report. This appears to be reasonable in view of the TTY error rate reported by DYE-4.

4.0 EQUIPMENT OPERATION

4.1 THRESHOLD EXTENSION PANELS

4.1.1 General

Threshold extension (TE) panels were in operation in links visited with the one exception of Site 44 receiving from Site 43. In general, the TE panels were working well and were providing good service but there were complaints from the O&M staffs as to the amount of preventive maintenance required. The various TE panel defects noted during the test apparently were caused by improper limiter action and improper automatic frequency control (afc) action.

TABLE VI

INDICATED AVERAGE RECEIVED SIGNAL CONDITIONS COMPARED
TO REPORTED/ESTIMATED RECEIVE LEVELS

Radio Path	Reported Average Received Signal (dbm)	Previous Worst Month	
		Measurements (dbm)	Estimates (dbm)
Melville/Hopedale	-74	-	-65
Hopedale/Saglek	-82	-	-67
Saglek/Resolution	-72	-	-67
Resolution/RES-X-1	- *	-	-
RES-X-1/DYE-Main	-82	-	-66
DYE-Main/DYE-1	EST -55 **	-54	-
DYE-1/DYE-2	-75	-81	-
DYE-2/DYE-3	-79	-74	-
DYE-3/DYE-4	EST -84 **	-78	-
DYE-4/DYE-5	-90	-86	-
Site 41/42	-80	-	-83
Site 42/43	-81	-	-73
Site 43/44	-78	-	-77
Site 44/46	EST -64 ***	-	-62

* No reports were scheduled from this path as it is quite short with height advantage from both ends.

** No reports were received from these links on received carrier levels.

*** No reports were received at all from Site 46.

Figure B-15 shows quieting curves taken 24 hours apart for an AN/FRC-39(V) receiver equipped with a TE panel. The degradation of the equipment performance due to faulty TE panel operation is quite obvious as the threshold without TE panels is at approximately -97 dbm, and the defect illustrated would have created noise transients during TE panel switching. TE panels in good operating condition were found to have adequate afc action and provided the expected improvement in the threshold area. However, the equipment requires frequent and careful maintenance.

The TE panel manufacturer, Radio Electronic Laboratories, has been contacted regarding the above defects, and information on the status of the "improved TE panel"[8], discussed in a Western Electric Company report dated 15 October 1963, was obtained. It was stated by the manufacturer that defects found by field tests of the improved TE panel have been corrected. The improved TE panel requires only a monthly maintenance schedule, provides increased threshold extension and appears to be a most suitable unit for the replacement of existing TE panels.

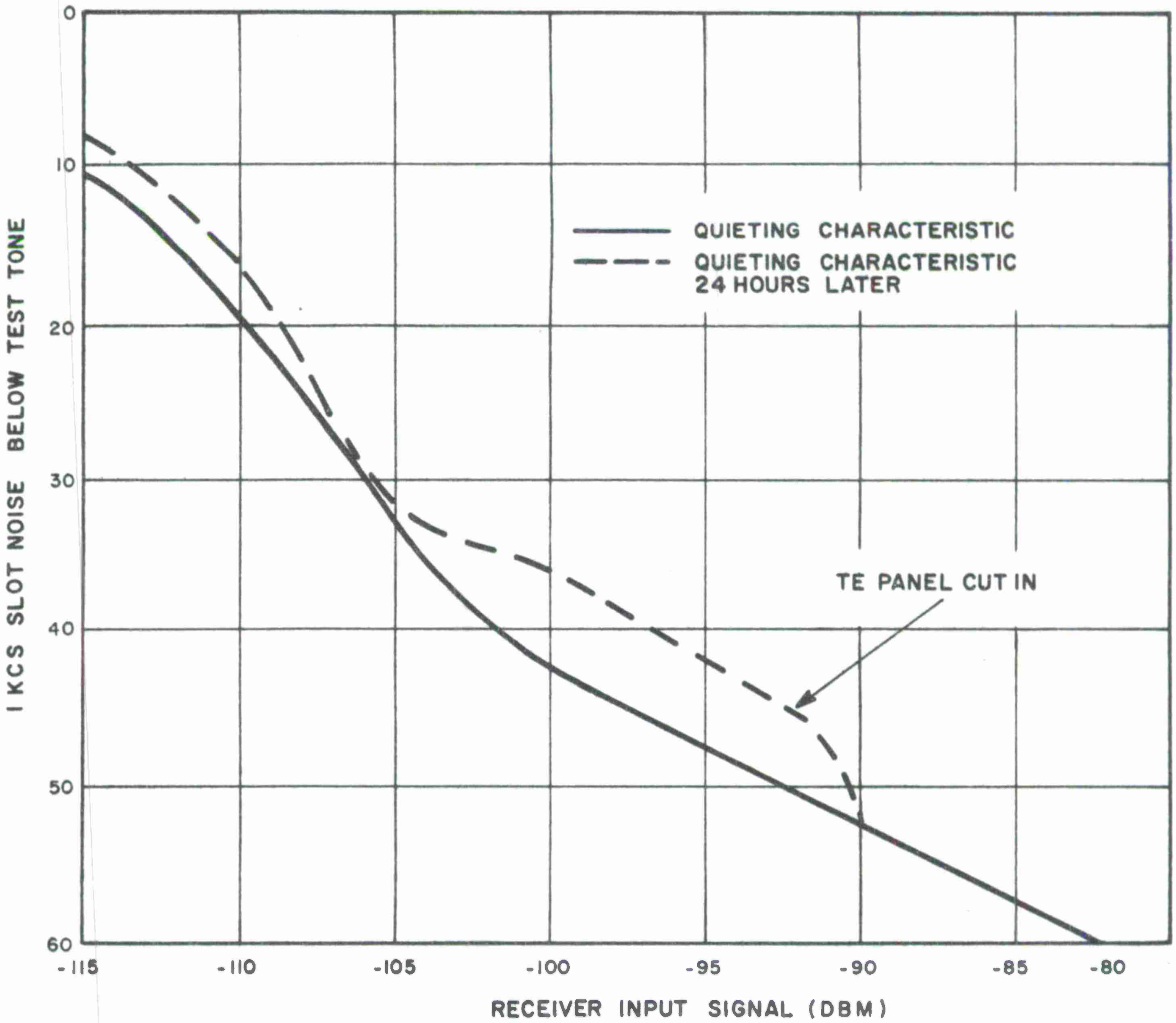
4.1.2 Effects of Intermodulation Noise

The TE panel is electronically transferred into service by the combiner dc control voltage for a predetermined receive carrier level (approximately -90 dbm). When intermodulation effects are present, the dc control voltage tends to indicate a lower receiver carrier level than actually exists due to the generation of intermodulation products in the "out-of-band" noise-slot. This effect tends to prematurely "switch-in" the TE panel. Since tone-level stability and suppression of impulse noise is less with the TE panel "in", this action is undesirable.

4.1.3 Possible Remedial Action

4.1.3.1 TE Panels Versus Filters

Intermediate frequency amplifier filters have an effect similar to TE panels in extending the FM threshold. One advantage of the TE panel lies in the fact that the lower equipment noise power ratio performance, resulting from either device, occurs with the TE panel only upon its being switched into service when the receive signal drops to approximately -90 dbm, whereas, the filter is always present. This advantage is nullified when the worst-month median of the receive signal is close to, or below, the point of operation of the TE panel.



EXAMPLE OF CHANGE THAT CAN OCCUR IN QUIETING CHARACTERISTIC DUE TO THE PANEL IN 24 HRS

FIGURE B-15

From measurements made on the radio equipment at Site 44 (where a 2.0-mc IF filter is permanently used), a TE panel can provide an effective FM threshold always below that of a filter producing a similar noise power ratio. Generally speaking, IF filters appear to be satisfactory and preferable from the viewpoint of cost and simplicity of operation in links where the thermal circuit noise permits increased equipment distortion noise, i.e. the worst-month median received carrier level is some 15 to 20 db above the normal threshold. It is, therefore, recommended that Radio Electronic Laboratories' improved TE panels be supplied to links now equipped with TE panels and that tropo systems under planning or implementation be reviewed for the possible application of IF filters.

4.1.3.2 AGC Modification

The source of TE panel control voltage should be changed by a modification, to be produced by "amplified agc action", so that the intermodulation effects noted in para. 4.1.2 are reduced.

4.2 COMBINER OPERATION

4.2.1 Combiner Noise

Due to previous informal reports of noise generation by the switching action of the baseband combiners, measurements and observations were made to determine if there was any measurable effect in this system. However, this effect was only noticeable in the order-wire receiver at reasonably high receiver carrier levels, i.e. greater than or equal to -70 dbm.

This effect was a "crackling noise". It only occurred when the receivers were in a quadruple diversity configuration and the combiner current of the offending receiver was between 20 ma and 40 ma. In one instance, the noise was eliminated by replacing Tube V5 in the order-wire combiner, but in another case replacing this tube increased the noise. The condition was intermittent in nature and it was not possible to isolate the cause.

In any event, this type of combiner noise problem did not effect the "through" circuit allocations. Other types of noise such as TE panel transfer transients were strongly evident on the order-wire and the order-wire of this radio equipment should not be used for any form of system traffic.

4.2.2 Correlation Between DC Control Voltage and Baseband Slot Noise Thermal Performance

The combiner dc control voltage is derived from an "out-of-band" baseband slot and is used to obtain maximum ratio combining from the baseband combiner. A typical relationship between the dc control voltage and RF input power is shown in Figure B-16. For proper functioning it is mandatory that the response of the dc control voltage be essentially the same for all RF inputs experienced under typical tropo conditions.

4.2.2.1 Combiner Tests

With a quadruple diversity radio set split into two dual diversity radio systems, as shown in Figure B-1, the agc voltage, dc control voltage, and noise analyzer output voltage for the 265-kc baseband slot, were simultaneously recorded on the four-track recorder for an unmodulated radio signal at no diversity (one receiver only). The system was calibrated by introducing a RF signal from the HP-612A Signal Generator so that the static levels of the dc control voltage and noise analyzer outputs were determined for given RF input powers. Recording runs were then made and analyzed to determine the relationship between the noise analyzer and dc control voltage.

4.2.2.2 Test Results

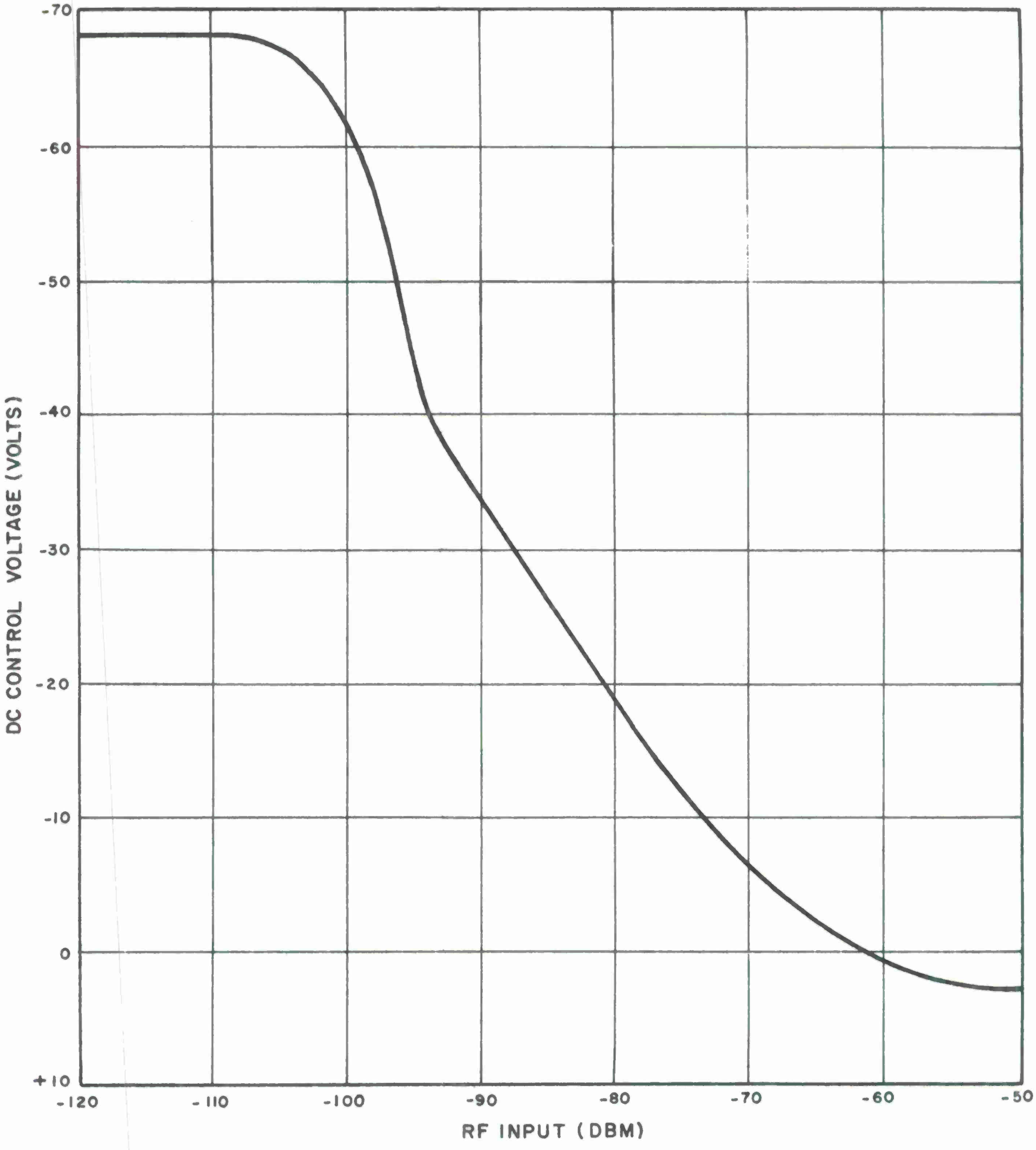
The relationship obtained is shown in Figure B-17. It can be seen that the "least squares line" makes an excellent fit with the "ideal characteristic" but that the relationship appears to fail for signals above -78 dbm. However, this may have been due to unbalanced time constants in the recording equipment. The linear correlation coefficient so obtained was 0.99 and it can be seen that most points fit within a probable reading error of 1 db. It can be concluded that the combiner action for thermal performance is satisfactory.

4.2.3 <u>Improvement in Intermodulation Utilizing Combiners</u>

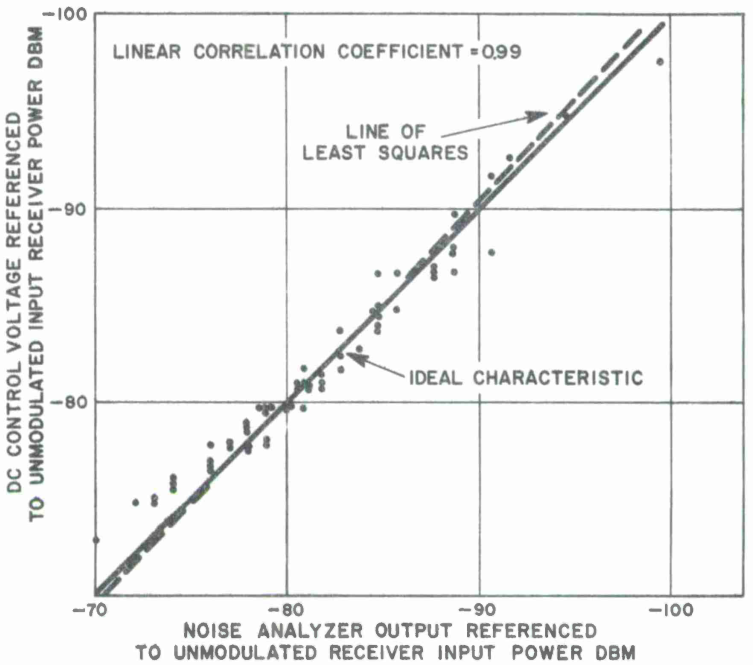
In previous tests by Bell Telephone Laboratories, Inc., a definite improvement with diversity was measured against intermodulation noise. It was, therefore, decided to run a similar test to the thermal case with a noise modulation signal of -11 dbm at the exciter input, which was estimated to provide an average intermodulation noise signal 10 db above thermal noise for the 265-kc baseband slot.

4.2.3.1 Test Results

Figures B-18 and B-19 show the relationships as measured for two independent recording runs. The "least squares line" is now quite separated from the "ideal characteristic" which would be produced

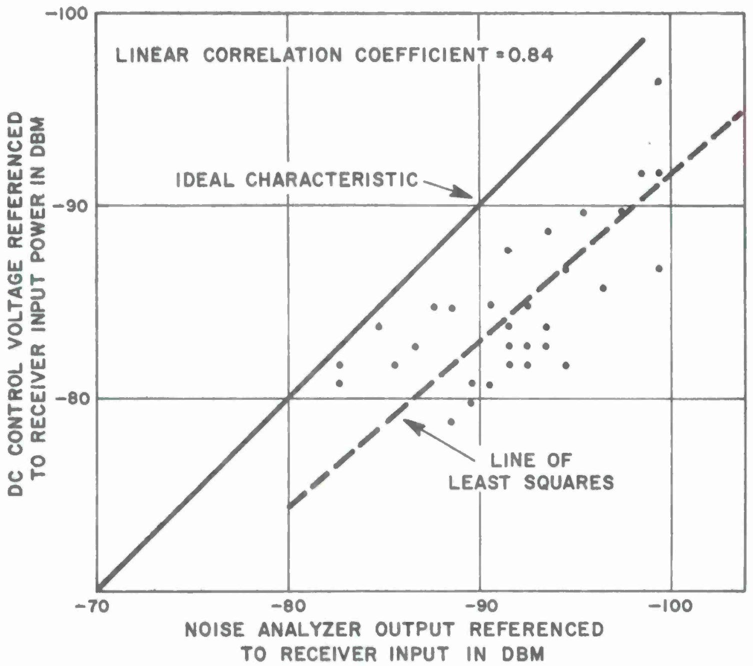


132-CHANNEL DC CONTROL VOLTAGE CURVE
FIGURE B-16



CORRELATION BETWEEN DC CONTROL VOLTAGE AND NOISE ANALYZER OUTPUT FOR NO MODULATION

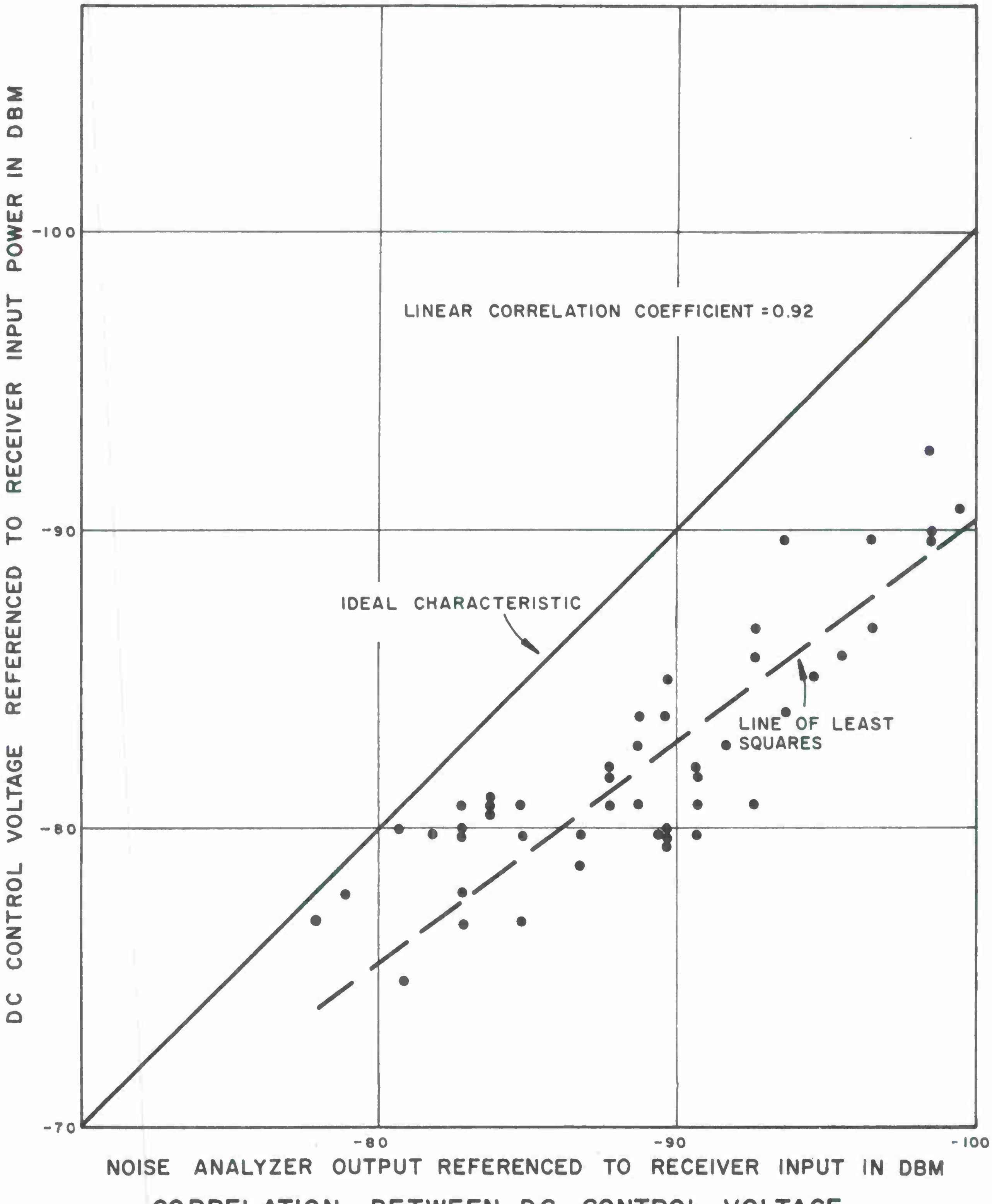
FIGURE B-17



CORRELATION BETWEEN DC CONTROL VOLTAGE AND NOISE ANALYZER OUTPUT FOR -11 DBM MODULATION SIGNAL — RUN # 1

FIGURE B-18

C-6813580-A-1



CORRELATION BETWEEN DC CONTROL VOLTAGE AND NOISE ANALYZER OUTPUT FOR -11 DBM MODULATION SIGNAL - RUN #2

FIGURE B-19

by a dc control voltage varying identically with the total baseband slot noise. The general trend, however, is still one which would produce some discrimination against the intermodulation noise.

The actual discrimination would be less than the thermal noise due to the increased deviation of the measurement points from the "least squares line". In the thermal case, the rms deviation of the measurement points was approximately 1.1 db which can be accounted for in terms of reading errors. In the intermodulation case, the rms deviation of the measurement points from the "least squares line" is about 2.75 db.

Figure B-20 shows how the median of the measurement points of both the dc control voltage and noise analyzer output for a given RF input varied with the RF input. Figure B-21 indicates how the rms deviation of indicated RF input varied from true input. Figures B-20 and B-21 provide linear relationships and show:

(a) The intermodulation component varies directly as the path loss on a median or rms displacement basis.

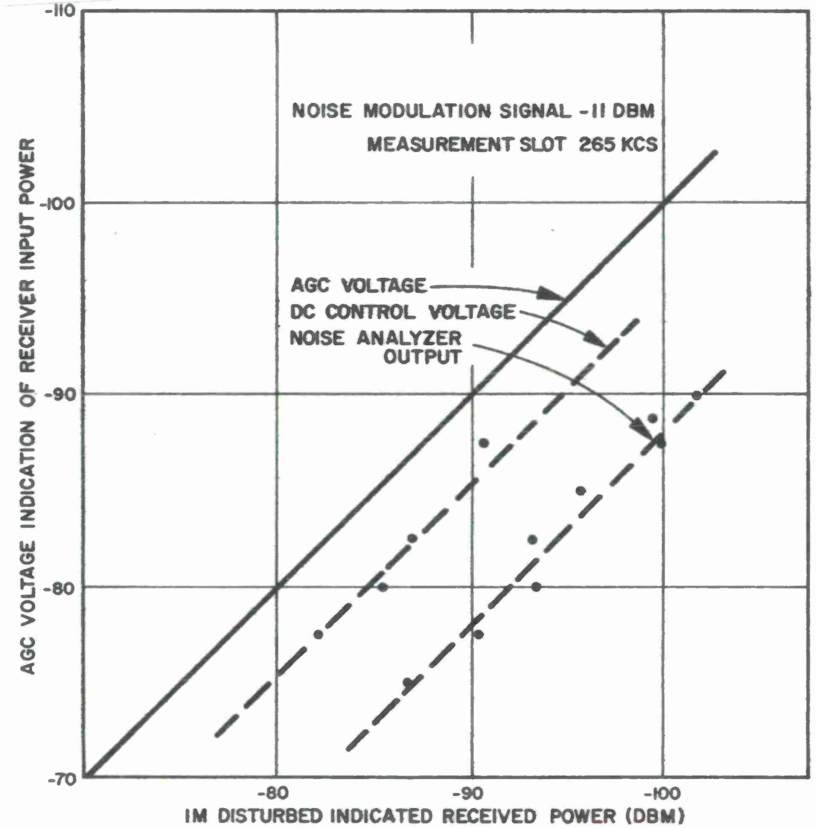
This result could be noted from the longer term measurements for average relationships in Figures B-3 and B-4, etc.

(b) The differential between medians and rms displacements from true was constant at about 2.5 db.

4.2.3.2 DC Control Voltage Slot

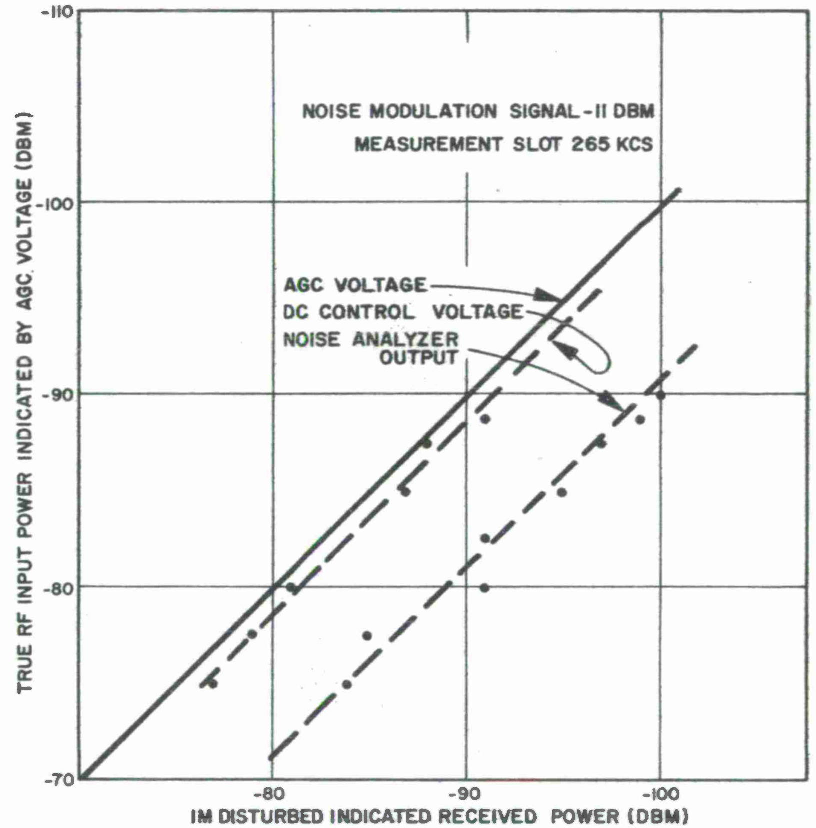
Noise in the "out-of-band" dc control voltage slot varies in the same way as noise in a baseband slot under intermodulation conditions. However, its intermodulation component is less, due to the removed position of the dc control voltage slot relative to the top baseband frequency.

Placing the dc control voltage "out-of-band" slot closer to the top baseband frequency will provide the capability of producing a dc control voltage that more closely represents total baseband slot noise under intermodulation conditions. Also, closer placement will permit a better correlation. Perfect correlation can not be hoped for, however, since the baseband slots themselves will be uncorrelated. Under noise type traffic loading, it may be surmised that the best position would be a vacated, mid-band voice-channel allocation. However, under actual traffic conditions, the dc control slot must be wide to prevent undue weighting by intermodulation from signals on any one voice channel.



DISTRIBUTION OF RMS DEVIATION OF INSTANTANEOUS INDICATED RF INPUT FROM TRUE INDICATED BY DC CONTROL VOLTAGE AND NOISE ANALYZER UNDER PATH IM

FIGURE B-21



DISTRIBUTION OF MEDIAN VALUES OF INSTANTANEOUS INDICATED RF INPUT POWER UNDER PATH IM FROM DC CONTROL VOLTAGE AND NOISE ANALYZER OUTPUT

FIGURE B-20

D-6813591-A-1

4.2.4 Quadruple Diversity Correlation

Correlation between the four received signals of quadruple diversity paths was measured for short time intervals (approximately 1 minute) to determine how capable the systems are in preventing FM threshold breaks. Measurement samples generally showed that the lack of correlation was excellent with the correlation in the order of 0.17. However, odd samples did show correlations as high as 0.5 for up to 15-minute periods and furthermore the short-term medians as measured also indicated that the short-term performance was triple diversity at times due to an anomalous low signal on one receiver.

These results indicate that the theoretical results obtained using standard means (i.e. Rayleigh fading, etc.) for teletype performance should be weighted to accommodate anomalous short-term performance as described.

4.2.5 Possible Remedial Actions

4.2.5.1 Combiner Noise

Radio Electronics Laboratories, Inc., should be requested to investigate the order-wire combiner noise to determine whether the causal effect is capable of disturbing the baseband combiner.

4.2.5.2 The Effect of Intermodulation Noise on Combiner Performance

Radio Electronics Laboratories, Inc., should be requested to investigate the possibility of placing the dc control voltage "out-of-band" noise slot closer to the baseband in order to provide better discrimination against intermodulation noise.

4.2.5.3 Quadruple Diversity Correlation

A study program should be implemented on a domestic test link to determine:

(a) Typical distribution of correlations between receive signals

(b) Results of anomalous effects on correlation and signal medians for data transmission

(c) Accurate guides for radio link criteria to obtain given data performance.

4.3 50-KW TRANSMITTERS

4.3.1 General

Although this program was not planned to incorporate any investigation of the 50-kw transmitters, field observations of the "status quo" are believed in order.

4.3.2 Observations

Of the eight transmitters planned as 50-kw transmitters at DYE-4, DYE-5, Site 41 and Site 42, only one was operating at 50 kw. Typical power settings were as follows:

Site 42	to	Site 41	36 and 52 kw
Site 41	to	Site 42	40 kw
DYE-5	to	DYE-4	30 kw
DYE-4	to	DYE-5	40 kw

As the basic transmitter was designed for 75-kw operation, it is clear that substantial advantage can be gained by improving the current performance. Site operators advanced the following reasons for the various settings of the transmitters.

(a) High body current in the klystron

(b) Noise output

(c) Insufficient replacements for the klystron

4.3.3 Possible Remedial Action

4.3.3.1 Power Klystron

It is recommended that a power klystron be obtained that is thoroughly degassed and evacuated so that it is capable of realizing the full power output of the transmitter, i.e. 75 kw. Increased costs in obtaining a tube having undergone more rigorous vacuum procedures will probably be off-set by increased life.

5.0 OBSERVATIONS OF MAINTENANCE TECHNIQUES

5.1 GENERAL

The maintenance program as noted appeared normal except in the DYE-4 to DYE-5 radio link. Maintenance requiring reduced operation was subject to "Tech-Control" jurisdiction, providing some protection against arbitrary maintenance decisions that would affect system performance. However, no general plan of "system maintenance" was noted. "System Maintenance" as used here means planning station maintenance to conform with the requirements of all stations in each segment of the total system. It is based on mutual action by stations in each link. For example, one station may be scheduled to perform out-of-service maintenance on a transmitter when reduced diversity can be tolerated, and the other station in that link is scheduled to do maintenance on the corresponding receivers during the same period.

Due to the generally poor received signal conditions at DYE-5 (and DYE-4), maintenance requiring reduced operation was often delayed while awaiting improved signal conditions. It can be seen that these conditions practically prevent any plan for organized maintenance. As conditions now stand, there is no alternate action that the radio link operators can take, but it is fairly certain that better traffic performance could be achieved if it were possible to achieve a positive maintenance plan. These comments, of course, apply to any radio link of the system during periods of poor transmission.

5.2 TEST EQUIPMENT

Test equipment appeared to be a special problem at DYE-5/Site 41 and some type of Precision Measurement Electronic Laboratory (PMEL)/Depot support is quite obviously required. The test teams were informed by the local staff that Philco was to implement a PMEL [7] facility at Keflavik and if so, this program should be expedited.

5.3 REDUCTION FROM QUADRUPLE DIVERSITY

Although it was requested that all outages affecting operation were to be reported, only DYE-Main provided a complete report. This report for the BMEWS RCS is used here, but it can be assumed that similar results apply elsewhere.

The initial 14 days of the test period were to be with normal maintenance and the last 14 days were designated as a no-maintenance period. This was in order to determine whether O&M practices had any significant effect on TTY transmission. As it happened, the NARS TTY performance seemed to be wholly controlled by DEW East in the last 14 days so that the "maintenance effect" was completely masked.

The data from BMEWS RCS is presented in order to show the amount of time that paths in a typical subsystem were operating at less than quadruple diversity and the improvement that would be obtained if a spare Type 959 Receiver were available.

Table VII shows the aggregate time that the individual paths of BMEWS RCS were operating at less than quadruple diversity and the aggregate

TABLE VII

BMEWS RCS PATH HOURS BELOW QUADRUPLE DIVERSITY
(NORMAL MAINTENANCE)

Total Period 336 Hours	Individual Path Hours Below Quadruple Diversity	Multiple Path Hours Below Quadruple Diversity
Normal Maintenance Period	314.34	109.36
Normal Maintenance Period If Spare Receivers Were Available	63.23	0.00

TABLE VIII

BMEWS RCS PATH HOURS BELOW QUADRUPLE DIVERSITY
(NO MAINTENANCE)

Total Period 336 Hours	Individual Path Hours Below Quadruple Diversity	Multiple Path Hours Below Quadruple Diversity
No-Maintenance Period	36.12	0.00
No-Maintenance Period If Spare Receivers Were Available	3.11	0.00

time that more than one path was operating below quadruple diversity at the same time. Also shown is the corresponding time that would have been lost if a spare receiver had been available.

Table VIII shows the same information during the "no preventive maintenance" period. Outages in Table VIII are due only to equipment failures.

The improvement that is obtained by providing a spare receiver can be appreciated when the effect of the order of diversity on TTY performance is considered.

5.4 POSSIBLE REMEDIAL ACTION

5.4.1 Maintaining Quadruple Diversity

As diversity is a prime factor in TTY and data performance, it is recommended that all radio paths except Melville/Hopedale, RES-X-1/RES-X, DYE-Main/DYE-1, DYE-1/BW-8, Site 44/46, be provided with one redundant receiver group. Optimum performance can only be achieved with receivers in top condition and the provision of a spare receiver will allow more careful and positive preventive maintenance. This receiver will also be utilized to sustain performance in the event that corrective maintenance is required.

5.4.2 PMEL Support

Optimum operation of radio equipment can only be achieved if the test equipment used for preventive and corrective maintenance can be thoroughly relied upon. PMEL Support, therefore, is imperative for all segments of the North Atlantic Tropo System.

5.4.3 System Maintenance

It is recommended that the subsystem operators develop a maintenance plan that integrates the requirements of all stations and minimizes overall performance degradation.

6.0 SUBSYSTEM TTY

6.1 GENERAL

To supplement the through circuit TTY tests from Melville to Croughton, each segment of the total system (BMEWS RCS, DEW East, and NARS) transmitted TTY test messages over the administrative broadcast circuits from Melville to all stations of BMEWS RCS; from DYE-Main to all stations of the DEW East System and to DYE-5; and from DYE-5 to all stations of NARS, during the hour 1800-1900Z.

The purpose was to examine the increasing error rate through each segment as the transmission progressed through the various radio paths, and to compare the variation with the recorded data at Croughton in order to determine which portion of the total system was controlling.

It was estimated that in this fashion, the error rate would be higher than for the through system due to the "drop-and-reinsert" handling of the traffic at each relay station. Even though individual TTY machine errors might mask the true situation for any one test hour in any one radio path, valid comparisons could be made.

6.2 TEST RESULTS

Figures B-22, B-23, and B-24 show the distribution of errors in the one-hour test messages sent over the three systems. A common GEEIA acceptance requirement is for an error rate of 1 in 10^4 for 99% of the time. If we arbitrarily degrade the required performance to 1 in 10^4 for 90% of the time, in order to take into account the "drop-and-reinsert" handling of the test messages at each station, then only the following segments appear to have satisfactory operation.

Melville to Resolution (RES-X-1)

DYE-Main to DYE-3

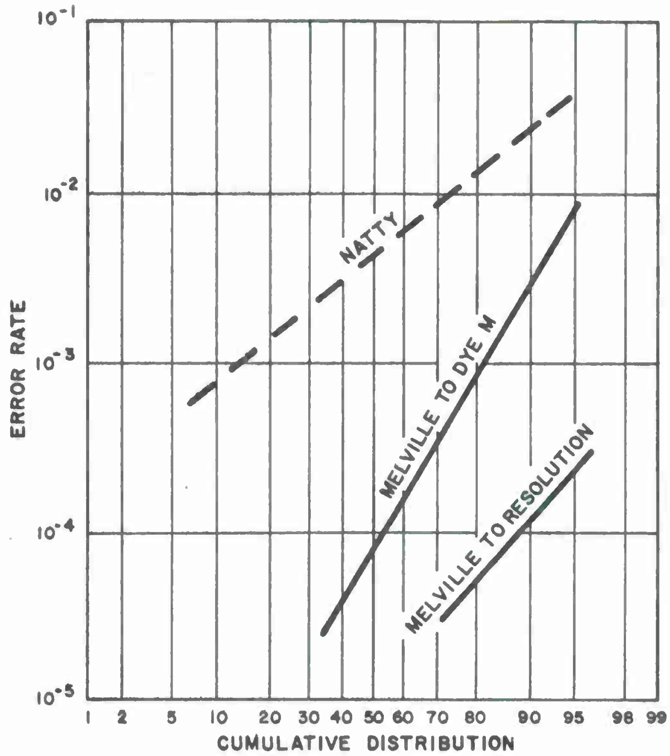
DYE-5 to Site 44 (Site 46)

The stations RES-X-1 and Site 46 were included above since, although for various reasons no data is available, it is estimated the radio paths involved do not materially add to the error rate.

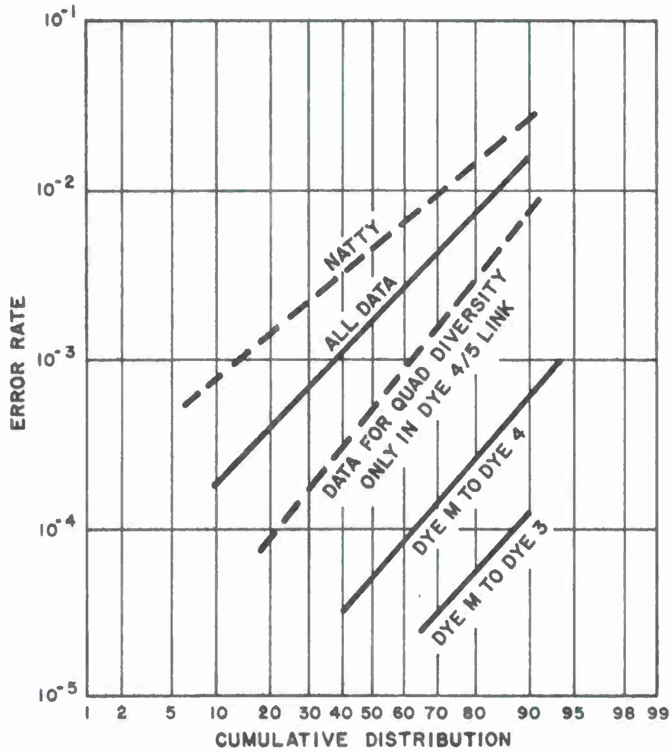
The test results indicate that the required subsystem error rate cannot be presently met by either BMEWS RCS or DEW East.

Figure B-25 shows typical day-to-day comparisons of the one-hour test error rate between both BMEWS RCS and DEW East and the overall North Atlantic TTY System. It becomes quite evident from Figures B-23 and B-25 that at present the controlling subsystem is DEW East.

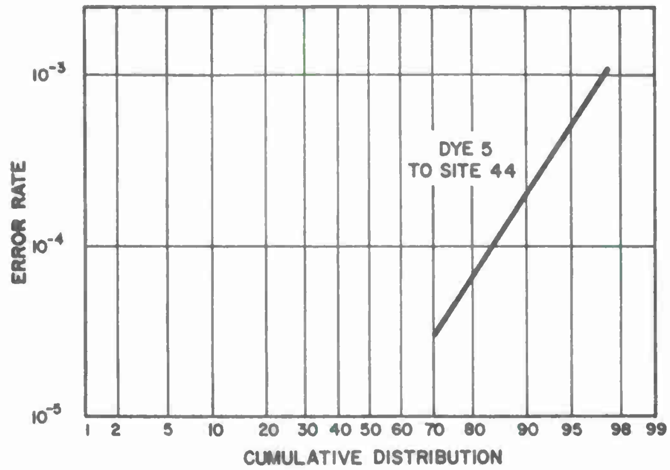
Independent link TTY tests were also performed between Sites 43 and 44, NARS. In these tests, the receive signal was artificially lowered by the use of receiver pads to a no-diversity median of approximately -103 dbm, and the bias distortion was set to zero. It was noted that fades indicated by the combined signal went as low as -115 dbm during the hour test and that error free copy would have been achieved for fades not falling below -104 dbm. The error rate for the hour at quadruple diversity for a channel in the LF allocation was approximately 2×10^{-3}.



SUBSYSTEM TTY PERFORMANCE, BMEWS RCS
FIGURE B-22

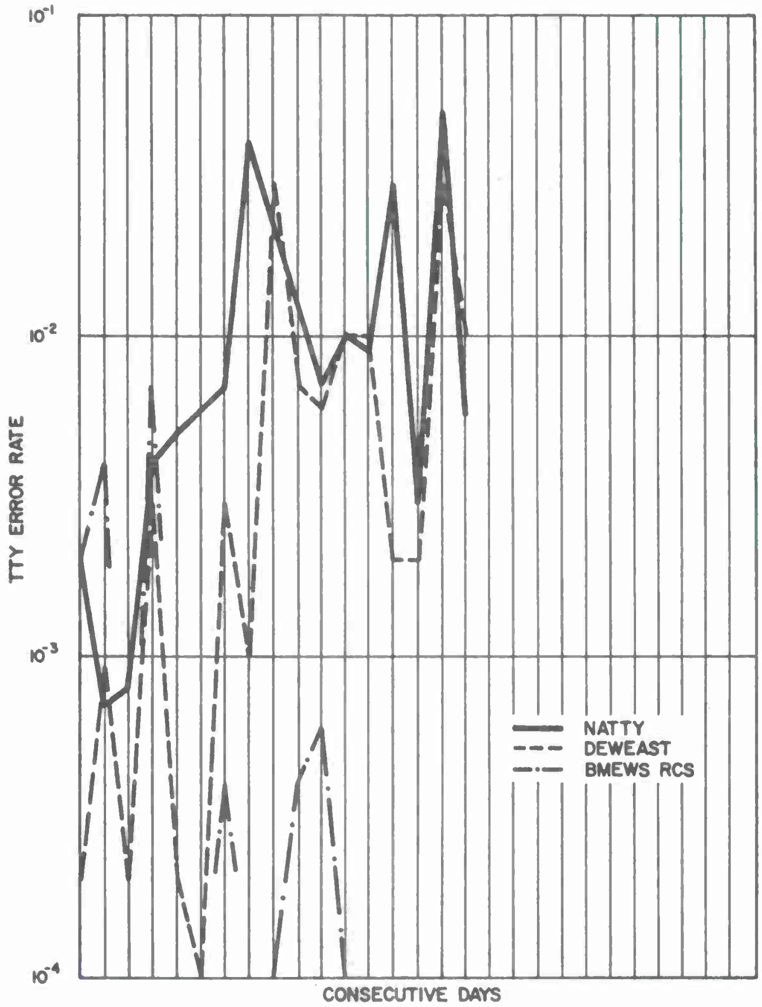


SUBSYSTEM TTY PERFORMANCE, DEWEAST
FIGURE B-23



SUBSYSTEM TTY PERFORMANCE, NARS

FIGURE B-24



COMPARISON OF DAILY ONE HOUR TTY ERROR TESTS

FIGURE B-25

These results indicate that "error-free" copy for a radio path would be obtained for a receive hourly signal median of -92 dbm, if the fading conditions and radio equipment were similar to those on the Site 43 to Site 44 path. Since "error-free" copy for a one-hour run only indicates an error rate of less than approximately 5×10^{-5}, it may be assumed that the term "error free" as used, refers to an error rate of 1×10^{-5}.

To produce an error rate not exceeding 10^{-5} over this radio path for 99% of the worst month, infers that the monthly median received signal should be of the order of -82 dbm, assuming that the standard deviation (σ) is approximately 3.3 db for a link of this length. The problem of extrapolating this result to other links and to links in series is difficult. It involves the probability of coincidence of deep fades and the addition of hourly median noise over radio paths where the fading is probably uncorrelated. However, referring to Appendix I, it can be seen that the required median signals to achieve DCS requirements for thermal noise are sufficiently high to warrant an estimate, that if DCS standards were met for thermal noise, then the typical subsystems BMEWS RCS, DEW East, and NARS would achieve satisfactory performance for TTY.

The increase of the subsystem TTY error rate in BMEWS RCS between Resolution and DYE-Main is probably due to the following factors:

(a) DYE-Main reported trouble with one receiver group for many days during the test period.

(b) TE panels were not in use in the DYE-Main to RES-X-1 path and hourly medians were reported as low as -93 dbm.

The provision of spare receiver groups and the improved TE panel will undoubtedly remove the control exhibited by this path on the BMEWS RCS performance.

6.3 POSSIBLE REMEDIAL ACTIONS

Since the improved TE panel,[8] besides being more stable in operation, further extends threshold performance by approximately 3 db, the TTY error rate may well improve by about one order of magnitude if the TE panels are provided, together with the other minor RF improvements (see Vol. I, para. 2.0), on the following paths.

Hopedale - Saglek

RES-X-1 - DYE-Main

DYE-1 - DYE-2

DYE-2 - DYE-3

DYE-3 - DYE-4

DYE-4 - DYE-5

Site 41 - Site 42

Site 42 - Site 43

Site 43 - Site 44 (Site 43 only)

From Figures B-22 and B-23, it can be seen that if the links RES-X-1 to DYE-Main, DYE-3 to DYE-4, DYE-4 to DYE-5 did not contribute to the TTY error rate, then each subsystem would be capable of TTY transmission at a median error rate of about 1×10^{-5}. Therefore, major improvements on these three links together with the recommended optimum improvements (see para. 2.0, Vol. I) and coupled with error correction equipment could be expected to provide a better than 1×10^{-5} TTY error rate from Goose Bay to Croughton.

7.0 SYSTEM PERFORMANCE

7.1 GENERAL

The received RF signal levels reported by the sites and measurements and calculations of intermodulation noise performed by the test team were utilized to derive comparative tabular data on the current and expected performance of the North Atlantic Tropo System, for radio derived noise.

7.2 CALCULATED RADIO SYSTEM MEDIAN PERFORMANCE

Table IX indicates the calculated worst month median performance of the individual radio paths and the subsystems (based on addition of median values), in terms of thermal noise and intermodulation noise under full design load for the combined full-load performance for a top channel. In establishing noise values for the North Atlantic System, link-by-link calculations were derived for the hour 1800-1900Z. This calculation produced values approximately 1.5 db greater than indicated for the straight addition of worst month path median values and it is the source of the values given for the North Atlantic System in Table IX.

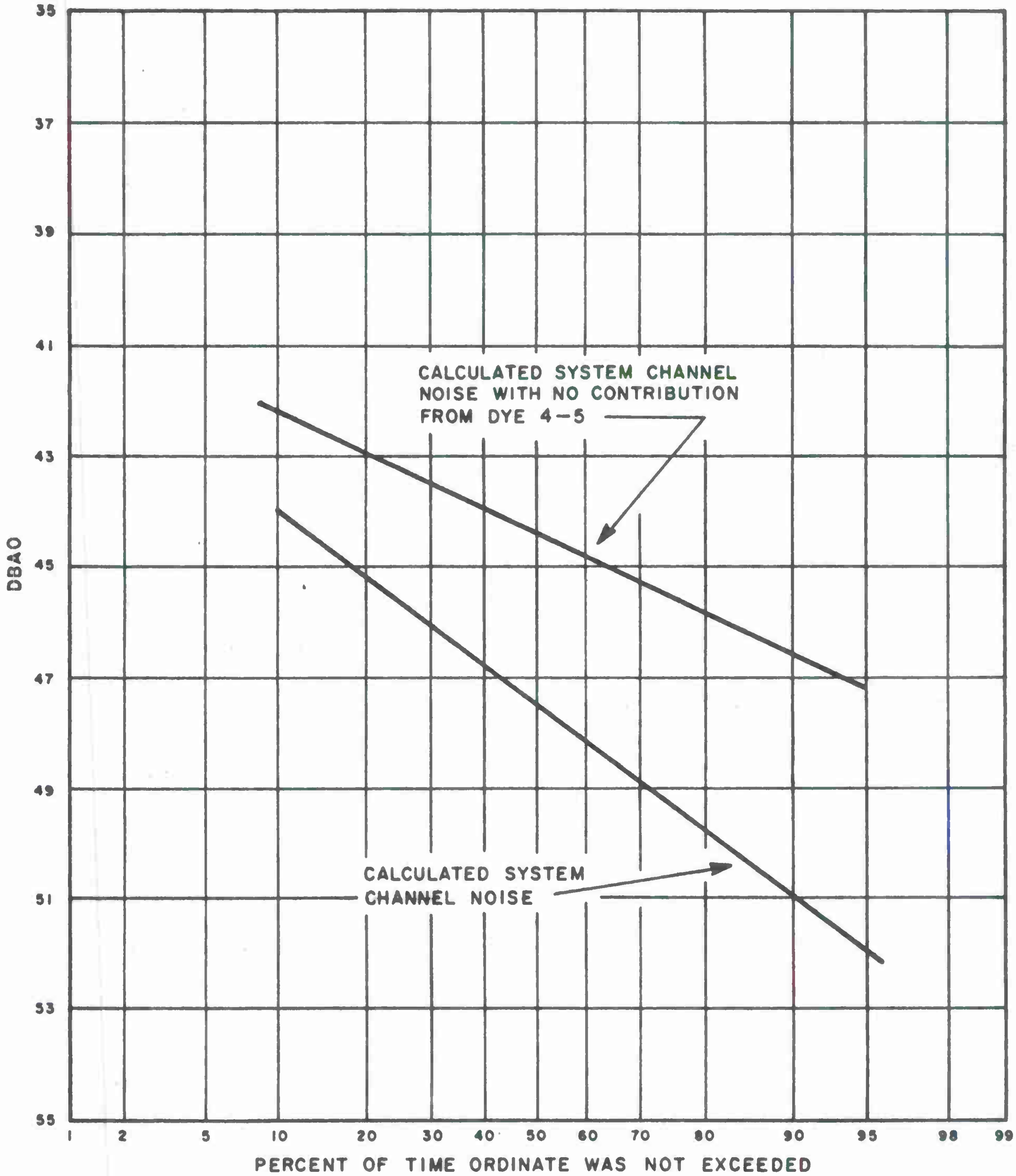
During this one-hour period measurements were also made at Croughton and the results of these measurements deviated from calculated results from 2 to 5 db. These results in turn can be diminished by allowing 2 db for equipment degradation due to reduction of diversity in some links, errors in reporting signal levels, and by providing allowance for other system noise (see Weighting Factor, para. 7.6). Figure B-26 shows the calculated distribution

TABLE IX

CALCULATED RADIO SYSTEM MEDIAN PERFORMANCE DURING TEST PERIOD

Radio Path	Estimated W. M. Median Receive Signal		Reported Average Receive Signal	Calculated 4-kc Weighted Slot Noise			
	ICS (dbm)	WECO (dbm)	(dbm)	Thermal (pwp)	IM (pwp)	Total (pwp)	DCS Required (pwp)
Melville - Hopedale	-70	-65	-74	500	1,250	1,750	450
Hopedale - Saglek	-75	-67	-82	3,000	12,500	15,500	660
Saglek - RES-X	-65	-67	-72	300	1,000	1,300	660
RES-X-1 - DYE-Main	-72	-66	-82	2,400	560	2,960	710
Equipment					630	630	
BMEWS RCS * (by median addition)				6,200	15,940	22,140	2,480
DYE-Main - DYE-1	-60	-53	-	-	-	-	680
DYE-1 - DYE-2	-76	-81	-75	500	50	550	530
DYE-2 - DYE-3	-68	-74	-79	1,250	20	1,270	330
DYE-3 - DYE-4	-72	-78	-84 *	4,000	250	4,250	540
DYE-4 - DYE-5	-90	-86	-90	16,000	10,000	26,000	1,280
Equipment					630	630	
DEW East (by median addition)				21,750	10,950	32,700	3,360
DYE-5 - Site 42	-84	-83	-80	1,000	800	1,800	680
Site 42 - Site 43	-79	-73	-81	2,500	1,000	3,500	860
Site 43 - Site 44	-84	-77	-78	1,250	800	2,050	1,030
Site 44 - Site 46	-76	-62	- *	30	25	55	670
Equipment					630	630	
NARS (by median addition)				4,780	3,255	8,035	3,240
North Atlantic Tropo System (by path addition and 2-db weighting)						46.5 dba0	34 dba0
Total System, Melville to Croughton						47.5 dba0	

* Estimate only, no reported measurement



ESTIMATED DISTRIBUTION OF TOP CHANNEL NOISE, MELVILLE TO CROUGHTON

FIGURE B-26

of channel noise verified by spot measurements at Croughton. Also shown is the calculated distribution if the DYE-4/5 radio path were rendered noiseless. It can be clearly seen that the DYE-4/5 path controls the North Atlantic System.

Of significant interest is the fact that when signal conditions were such that the DYE-4/5 path was not controlling, then system control was being exerted by the following paths having hourly median RF receive signals of approximately -90 dbm:

Hopedale - Saglek	BMEWS RCS
RES-X-1 - DYE-Main	BMEWS RCS
DYE-2 - DYE-3	DEW East
Site 42 - Site 43	NARS
Site 43 - Site 44	NARS

It is also suspected that the DYE-3/4 path may also be a controller at times. Unfortunately, no data was received from this path.

7.3 EXPECTED MEDIAN PERFORMANCE AFTER MINOR EQUIPMENT CHANGES

Table X indicates the expected performance that is possible with the following minimum configuration changes.

(a) Increasing deviation by +1.5 db in several paths. This is accomplished by delivering the MUX traffic +3 db high to the modulator via an amplifier and inserting a 3-db pad at the receiver output.

(b) Increasing transmitter power to 50 kw in the Saglek-to-Hopedale path. This change is based on the distortion noise calculations which prohibit over-deviation on this path. Fifty-kilowatt RF-power implementation should not be made until calculations are verified by field measurements.

(c) Procurement of klystron tubes capable of 75 kw in the DYE-4/5 path.

The result of recalculation of the expected performance, after the above minimum changes are established, is shown in Figure B-27. From the figure, it can be seen that the median of the combined noise is improved by only about 1 db but that the estimated thermal median is only about 5 db above DCS requirements. The results expressed in Figure B-27 also include the 2-db weighting factor found necessary in previous results.

Although no apparent improvement appears to be realized for the full traffic load, the channel noise can be reduced by Technical Control in

TABLE X

EXPECTED MEDIAN PERFORMANCE AFTER
MINOR EQUIPMENT CONFIGURATION CHANGES

Radio Path	Over Deviation (db)	Transmitter Operation Change (kw)	Antenna Change	Projected 4-kc Weighted Slot Noise			
				Thermal (pwp)	IM (pwp)	Total (pwp)	DCS Required (pwp)
Melville - Hopedale	-	-	-	500	1,250	1,750	450
Hopedale - Saglek	+1.5	50	120' at 1700 mc	750	250	1,000	670
Saglek - RES-X	-	-	-	300	1,000	1,300	670
RES-X - RES-X-1	-	-	-	-	-	-	320
RES-X-1 - DYE-Main	+1.5	-	60' + 120'	480	660	1,140	710
Equipment					875	875	
BMEWS RCS (by median addition)				2,030	4,035	6,065	2,820
DYE Main - DYE-1	-	-	-	-	-	-	680
DYE-1 - DYE-2	+1.5	-	-	250	100	350	530
DYE-2 - DYE-3	+1.5	-	-	625	40	665	330
DYE-3 - DYE-4	+1.5	-	30' + 120'	670	160	830	540
DYE-4 - DYE-5	(FM Radio at 36 ch)	75	-	1,250	2,000	3,250	1,280
DYE-4 - DYE-5	(Submarine cable 72 ch)	-	-	-	-	2,400	1,280
Equipment					1,125	1,125	
DEW East (by median addition)			DYE-4 to DYE-5 Radio:	2,795	3,425	6,220	3,360
			Submarine Cable:	-	-	5,120	3,360
DYE-5 - Site 42	-	-	-	1,000	800	1,800	680
Site 42 - Site 43	+1.5	-	60' + 120'	500	125	625	860
Site 43 - Site 44	+1.5	-	60' + 120'	250	800	1,050	1,030
Site 44 - Site 46	-	-	-	30	25	55	670
Equipment					875	875	
NARS (by median addition)				1,780	2,625	4,405	3,240
North Atlantic System (by path addition and 2-db weighting)				37 dba0		41 dba0	34 dba0

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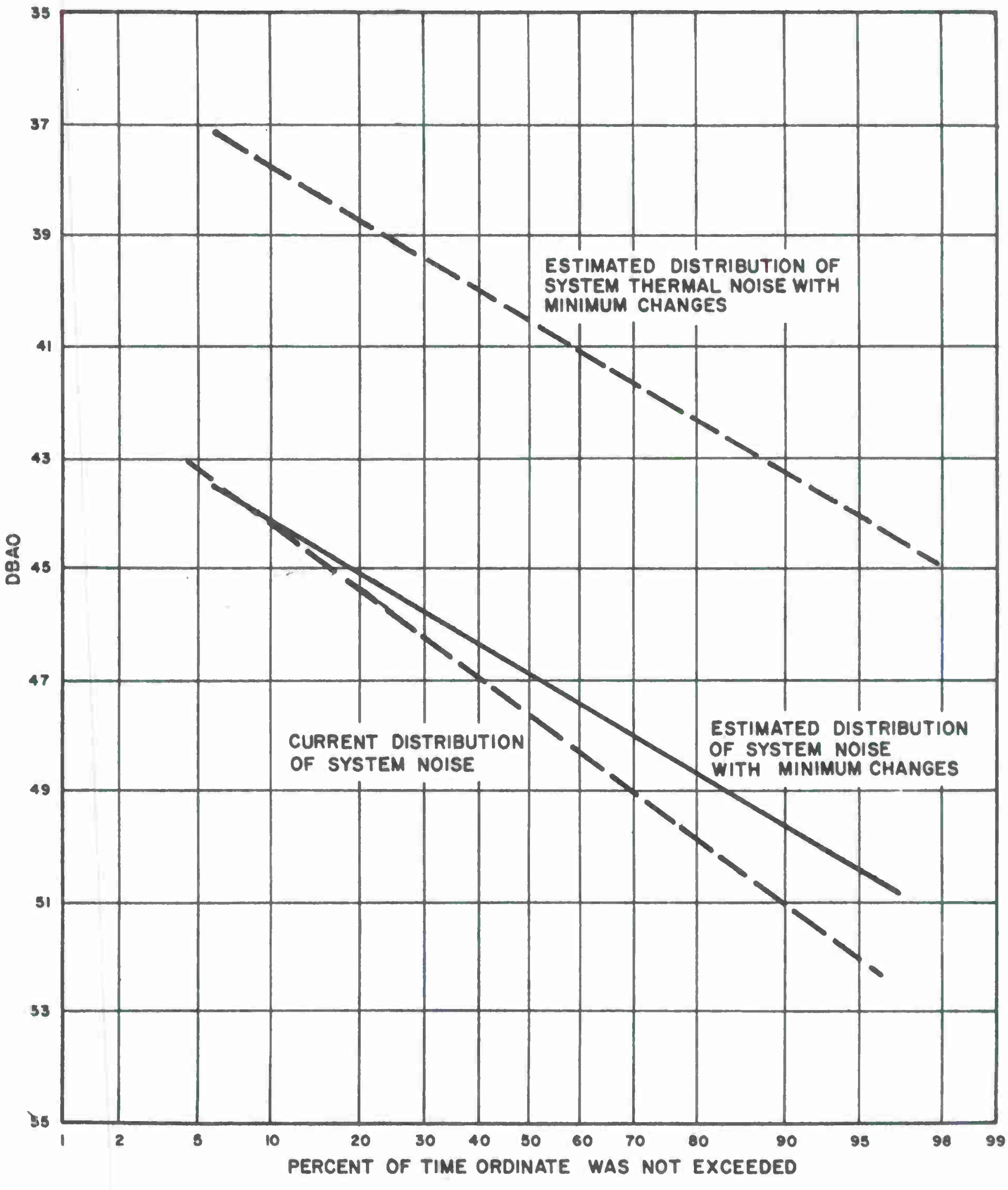


EXPECTED DISTRIBUTION OF TOP CHANNEL NOISE WITH IMPLEMENTATION OF MINIMUM CHANGES

FIGURE B-27

removing low priority circuits at times of poor transmission due to intermodulation. The resulting traffic performance will then be between the thermal and combined distributions, according to the actual traffic loading.

7.4 EXPECTED MEDIAN PERFORMANCE AFTER MAJOR EQUIPMENT CONFIGURATION CHANGES

Table XI indicates the expected performance by employing major changes which are:

(a) Installing 120-foot antennas at one end of several radio paths. Antenna improvement is the best method of improving performance since it reduces both thermal noise and intermodulation products. These antennas are recommended for the links: RES-X-1 to DYE-Main, DYE-3 to DYE-4, Site 42 to Site 43, Site 43 to Site 44. Either end of the link may be used for placement with the exception of DYE-3 to DYE-4 which requires antenna placement at DYE-4.

(b) Operating the Hopedale-to-Saglek path at 50 kw and 1700 mc. This feature would drastically reduce estimated intermodulation noise products, if in fact the condition is proven by measurement. With the exception of the 50-kw klystron dolly assembly, 1700-to-2400-mc radio equipment is already in standard USAF inventory.

(The above improvements have been placed in those paths which have control system capability with the exception of DYE-2/3 which cannot be improved due to the limitation of Ice Cap stations. These improvements will also materially favor TTY performance as these paths are also those which affected TTY error rates.)

(c) Operating the DYE-4/5 path as a 36-channel radio system with the deviation set to produce the performance noted in Figure B-13, or by using a 72-channel submarine cable between DYE-4 and DYE-5, using a 36-channel emergency backup radio system. Since the cable must pass under an ice field for a portion of its length where it will be inaccessible for repairs for the greater part of the year, with opportunities for repair further reduced by frequent bad weather in this area and the need for uninterrupted service, a cable with maximum protection is required. (See Cable Studies in the following section for further details.)

(The above improvement for the radio link (36-channel backup operation) with a matched TE panel would permit approximately a 3-db increased threshold extension which when coupled to an approximate 2-db transmitter improvement would also improve the TTY error rate significantly.)

TABLE XI

EXPECTED MEDIAN PERFORMANCE AFTER MAJOR EQUIPMENT CONFIGURATION CHANGES

Radio Path	Over Deviation (db)	Transmitter Operation Change (kw)	Antenna Change	Projected 4-kc Weighted Slot Noise			
				Thermal (pwp)	IM (pwp)	Total (pwp)	DCS Required (pwp)
Melville - Hopedale	-	-	-	500	1,250	1,750	450
Hopedale - Saglek	-	50	-	600	12,000	12,600	670
Saglek - RES-X	-	-	-	300	1,000	1,300	670
RES-X - RES-X-1	-	-	-	-	-	-	320
RES-X-1 - DYE-Main	+1.5	-	-	1,200	1,120	2,320	710
Equipment					750	750	
BMEWS RCS (by median addition)				2,600	16,120	18,720	2,820
DYE-Main - DYE-1	-	-	-	-	-	-	680
DYE-1 - DYE-2	+1.5	-	-	250	100	350	530
DYE-2 - DYE-3	+1.5	-	-	625	40	665	330
DYE-3 - DYE-4	+1.5	-	-	2,000	500	2,500	540
DYE-4 - DYE-5	+1.5	75	-	4,000	20,000	24,000	1,280
Equipment					1,125	1,125	
DEW East (by median addition)				6,875	21,765	28,640	3,360
DYE-5 - Site 42	-	-	-	1,000	800	1,800	680
Site 42 - Site 43	+1.5	-	-	1,250	2,000	3,250	860
Site 43 - Site 44	+1.5	-	-	625	1,600	2,225	1,030
Site 44 - Site 46	-	-	-	30	25	55	670
Equipment					875	875	
NARS (by median addition)				2,905	5,300	8,205	3,240
North Atlantic System (by path addition and 2-db weighting)				39 dba0		45.5 dba0	
Total System, Melville to Croughton						47.0 dba0	

The expected improvement in operating DYE-4/5 as a 36-channel system is such that the expected median performance is similar to that of a submarine cable operating at a typical figure of 3 pwp/km. Naturally, the cable performance for TTY far exceeds the radio performance. The expected improvement in performance values for a 36-channel radio system with the receive signal improved to -87 dbm, can be seen to be as follows:

Top Channel Weighted Noise - DYE-4/5

	Thermal (pwp)	IM (pwp)	Total (pwp)	DCS Required (pwp)
Current				
72 Channels	16,000	10,000	26,000	1,280
Proposed				
72 Channels	4,000	20,000	24,000	1,280
36 Channels	1,250	2,000	3,250	1,280

Using 36 channels between DYE-4 and DYE-5, the North Atlantic System would be improved as follows:

Top Channel Weighted Noise - NORTH ATLANTIC SYSTEM

	Thermal (pwp)	IM (pwp)	Total (pwp)	DCS Required (pwp)
BMEWS RCS	1,710	3,570	5,280	2,820
DEW East	2,795	3,425	6,220	3,360
NARS	1,780	2,625	4,405	3,220

The distribution that would have been achieved with these major changes during the test period is shown in Figure B-28. It can be seen that the median is improved by 6.5 db with greater improvements in the short-term performance.

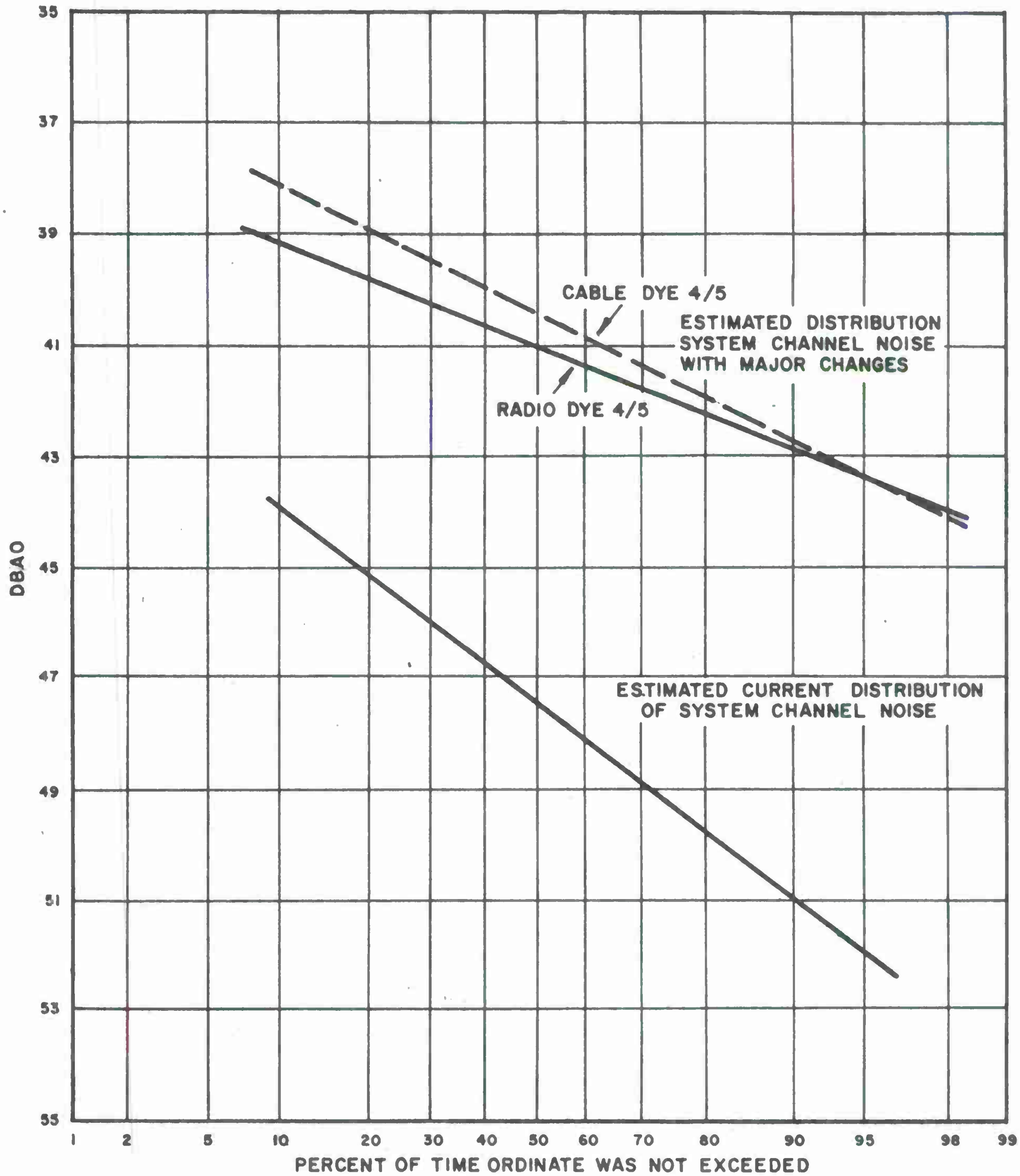
7.5 TELETYPE ERROR RATES

If the major changes are implemented on the RES-X-1/DYE-Main, DYE-3/DYE-4 and DYE-4/DYE-5 links, then the requirements stated in para. 6.3 will be achieved.

7.6 WEIGHTING FACTOR

When the complete circuit, Goose Bay to Croughton, is discussed, the following factors have also to be considered:

(a) Circuit noise due to noise interference at both Goose Bay and Croughton due to improper shielding, use of fluorescent lighting, etc.



EXPECTED DISTRIBUTION OF TOP CHANNEL NOISE WITH IMPLEMENTATION OF MAJOR CHANGES MELVILLE TO CROUGHTON

FIGURE B-28

Estimated values of this noise are -51 dbm0 at Croughton and -41 dbm0 at Goose Bay, due primarily to difference in transmit and receive levels.

(b) UK microwave circuit noise - Measurements of circuit noise from Fylingdales to Croughton indicated that the circuit noise varied between -40 dbm0 and -47 dbm0. The arbitrary value taken for this discussion is -43 dbm0.

(c) Observers indicated that circuit intermodulation noise was higher than expected and calculated, due to the following reasons:

(1) Operator errors in patching without correct pads, etc. are appreciable because of the various levels at which a test tone can reach a 4-wire terminal within the UK.

(2) Certain types of signaling, apparently nonstandard, are inserted into the system at very high levels.

(3) Some users inject signals above normal upon an arbitrary basis. This even includes Technical Control who employ special voice amplifiers.

By direct path addition of noise, the North Atlantic Tropo System median noise was calculated at 44.5 dba0 at design loading and it was found to require 3 db to align with the measurements at Croughton. If the above factors are included, we have:

UK Microwave	38 dba0
Goose Bay Noise	40 dba0
Tropo System	44.5 dba0
Total System	46.5 dba0

If now the calculations for the tropo system are weighted 2 db to allow for error in reported values, reduction in diversity in some links, signal loadings other than the arbitrarily taken values, the method of direct addition of noise (see Long Haul Circuit, Appendix I), and 42 dba0 for terminal equipment areas and the UK Microwave System, the following spot comparisons are possible:

Tropo Noise Calculations (dba0)	2-db Weighting Allowance (dba0)	Noise Allowance for Extra System Noise (dba0)	Resultant Calculated Noise (dba0)	Croughton Measurements (dba0)
48	50	42	51	50
41	43	42	45.5	44
44	46	42	47	48
46	48	42	49	51

In the above manner, the values for the total system, Melville to Croughton were derived in Tables IX and X. Table XI assumes that corrective action has been implemented so that the tropo system is the controlling noise source.

The subject of terminal equipment area noise is more fully discussed under Part D of this report and as the UK Microwave System is under active evaluation by the Western Electric Co., this system is not discussed here.

8.0 REFERENCES

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3. Distant Early Warning System, DEW East Segment, Lateral Communication System Evaluation Report

4. BMEWS Communications - Electronics Test Verification Report, 12 March 1963

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6. A Method for Predicting Interchannel Modulation due to Multipath Propagation in FM and PM Tropospheric Radio Systems, Beach and Trecker, Bell System Technical Journal, January 1963

7. USAF T.O. 33-14-1

8. Final Report of Evaluation Tests - AN/FRC-39(V) Modified Threshold Extension Panels BTL Report File T157(661B) October 15, 1963

9. Nomograms for the Statistical Summation of Noise in Multihop Communication Systems, IEEE Transactions on Communications Systems, September 1963

PART C

CABLE STUDIES

1.0 FEASIBILITY OF CABLE BETWEEN DYE-4 AND DYE-5

1.1 GENERAL

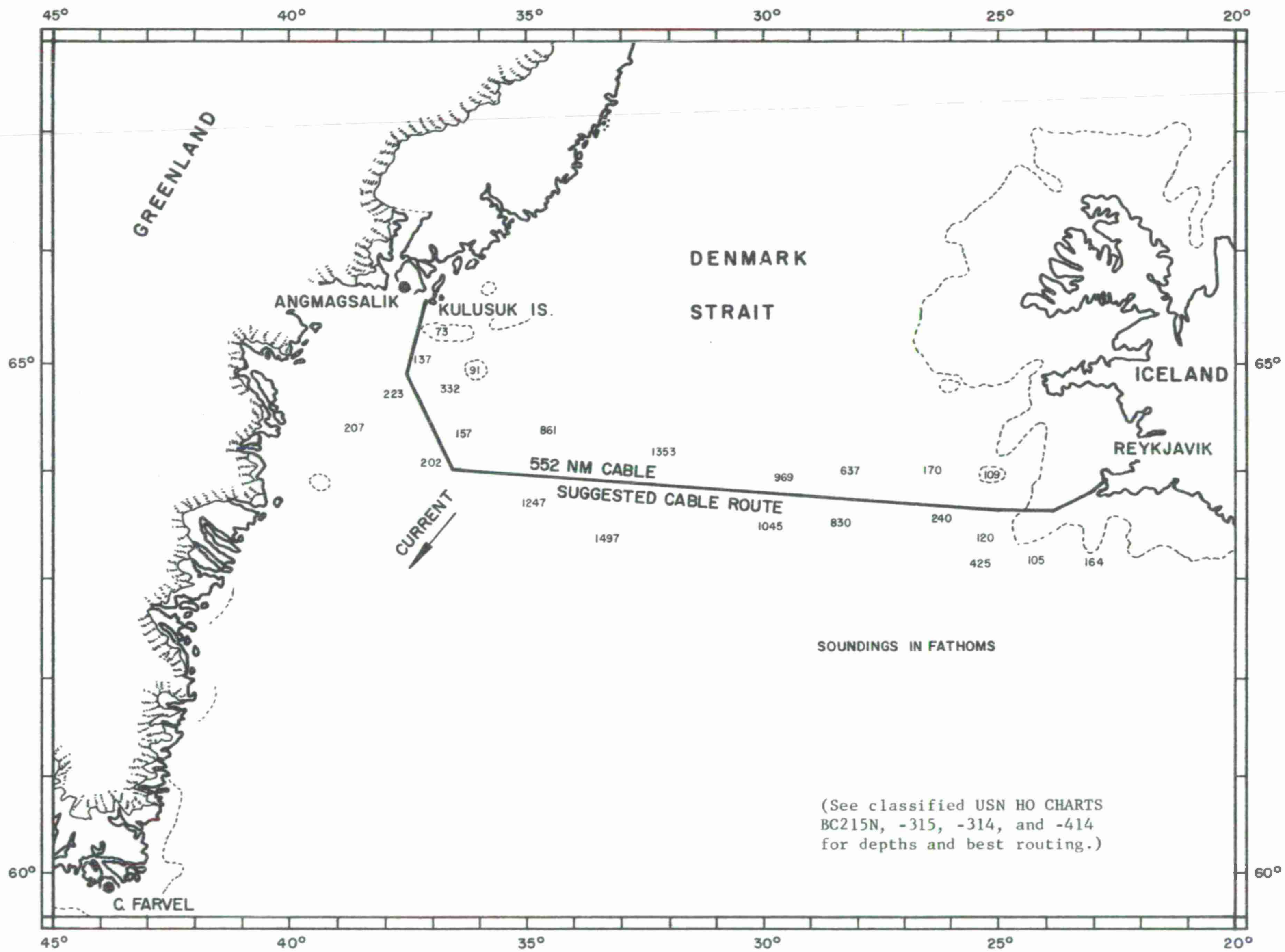
A long-lived submarine cable relatively immune to interruption is possible between DYE-4 and DYE-5 with adequate engineering. A maximum of 120 nominal 4-kc channels (ten 48-kc groups) is obtainable with present repeater designs. With a cable distance of 1025 kilometers (552 nm) the thermal noise contribution from the cable and repeaters, on the top channel, will range from 1000 to 6000 pw. Depending on design the probable value should be 3000 pw.

This cable (see routing diagram, Figure C-1) passes under an ice-field for a portion of its length and will be inaccessible for repairs for a great part of the year. (Figure C-2 charts these ice conditions.) Opportunities for repair are further reduced by frequent periods of bad weather. These factors indicate the need of providing a reliable cable giving uninterrupted service.

Experience with repeatered broadband cable systems has established that it is the cable with exposure to damage, rather than repeater deficiencies that has been the cause of interrupted service. Initially, in telegraph practice, many years would elapse before the strength of the cable would deteriorate and lower its resistance to damage. This level of reliability should be the design objective for planning cable construction and laying. Increased fishing activity as a hazard and the greatly improved communication capacity of telephone cable justify the effort to attain this objective. Paragraph 1.2 discusses the methods of attaining the necessary reliability in a cable for this service.

Two cost estimates are submitted in Paragraph 1.3 for evaluation. One is the cost of a long and safe route and the other is the cost of a direct route with conventional protection which may prove inadequate for this study.

The capacity of the submarine cable discussed is referred to in terms of standard 4-kc channels arranged in groups of 12. The cable is a



POSSIBLE CABLE ROUTING
FIGURE C-1

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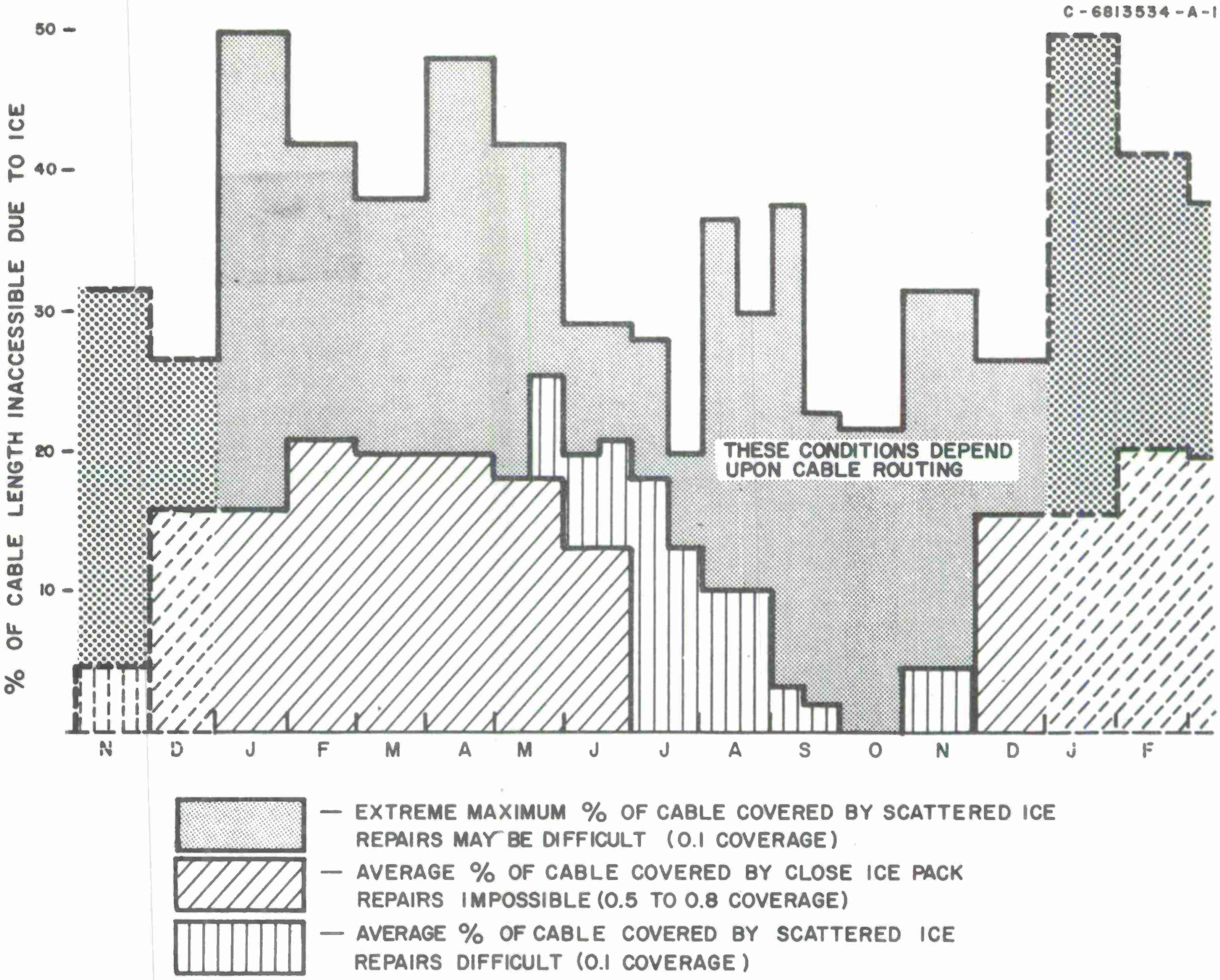


ICE DATA from
USN HO Publication 705, part II
Figures 49 to 66 incl

Under average conditions more than 75% of the cable length will be accessible for repairs throughout the year

Under average conditions there will be five months during which repairs can be made at any point on the cable

Under average conditions 100% of the cable length will be substantially free of ice for 6 to 8 weeks

Under extreme ice conditions more than 50% of the cable will be accessible for repairs throughout the year

ICE CONDITIONS
FIGURE C-2

broadband transmission medium which will accept traffic at the group level and probably at the radio baseband level, depending on the makeup of the baseband and the frequency range accepted by the submerged repeaters. Three-kc channels frequently referred to in connection with submarine cables are not a necessary feature of the technology. They have been developed to increase the cable channel capacity by a third and by ingenious channel band design this has been accomplished at a loss of only about 8% in channel band width that is acceptable for telephony but significant for some military digital traffic.

1.2 RELIABILITY OF CABLE BETWEEN DYE-4 AND DYE-5

1.2.1 Trawler Hazards

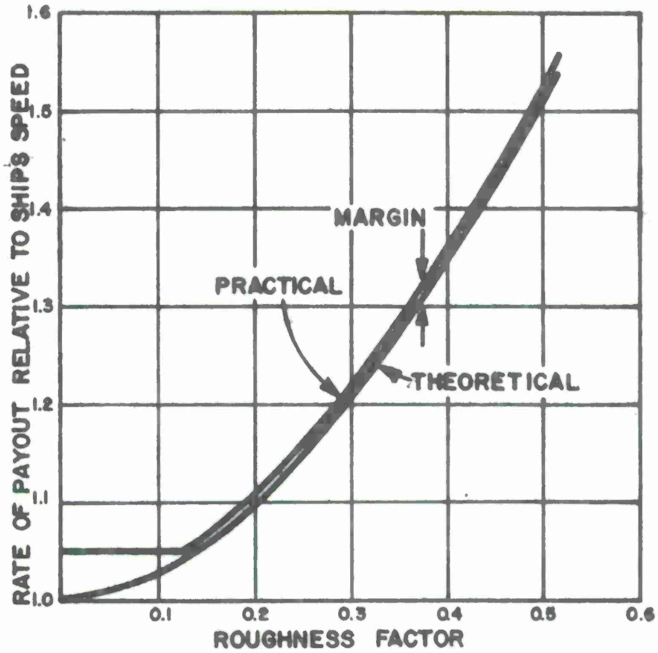
Fishing trawlers must be considered the greatest hazard to a cable in this area, especially at the Iceland end. It must be emphasized though, that trawls infrequently snag the cable when they pass over it; the particular circumstances leading to trawler damage are not definitely known. When placing a new cable, the following protective measures are possible:

(a) Place the cable where trawler fishing activity is either small or non-existent, because of no fish, bottom obstructions or water which is too deep.

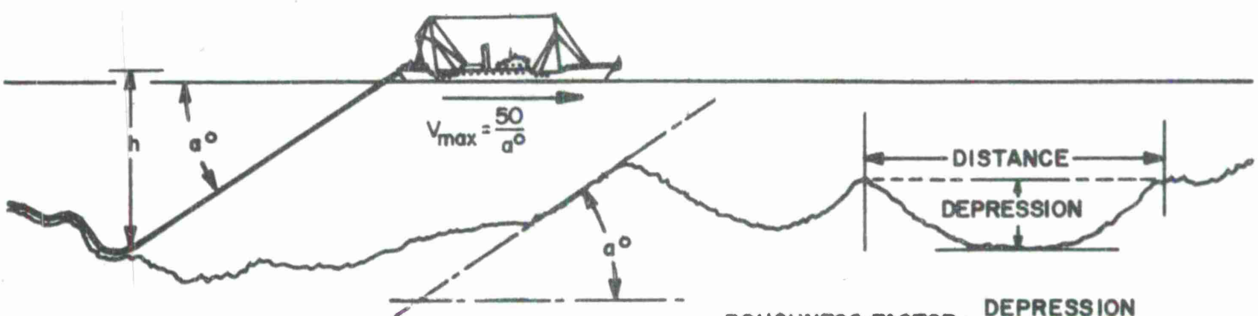
(b) Place the cable on the bottom to minimize suspensions between high points due to insufficient slack and eliminate standing loops due to excessive and wasteful slack. Figure C-3 illustrates a practical means of accomplishing the proper payout of cable. Various methods of exact cable laying are available that are inexpensive and offer the best chance of immunity from trawler damage. The practical applications of the mathematical and hydrodynamic principles involved have recently been brought into use.

(c) Select, if possible, a suitable bottom of soft mud, sand, or gravel into which the cable will eventually embed.

(d) Use heavy armor to protect the electrical structure from abrasion as the heavy "otter boards" of the trawl slide over the cable. Heavy armor makes the cable difficult to break and difficult to lift when snagged by a trawl. This latter advantage cannot be relied upon because of the lifting power of the gear employed by modern fishing operations.



(CATENARY CURVE ASSUMED)



SPEED = 50/a° knots.

MAX SPEED is limited by roughness of the bottom and the ability of the ship's gear to pay out cable at the required rate.

MIN SPEED is minimum steerage way.

MIN RATE OF PAYOUT, above unity and relative to ship speed, (indicated on curve as 1.05) depends upon accuracy with which ship speed is known.

TENSION, at the ship, must not exceed weight of cable (w x h) where w is the weight per foot of cable in water and h is the depth in feet where the cable takes the bottom. Excess tension means tension and suspensions on the bottom.

CABLE LAYING ON ROUGH BOTTOM

FIGURE C-3

(e) Plow the cable into the bottom either mechanically or hydraulically. Plowing non-repeatered cable has been accomplished in water as deep as 400 fathoms. Methods for passing repeatered cable through a submarine plow are under development but the equipment may not be proved and available for several years.

(f) Forbid fishing in the vicinity of the cable or supply the fishermen with cable route information and request their cooperation. This measure is of doubtful effectiveness and may obviate desirable security precautions.

(g) Use the recently developed 2-way repeaters that permit transmission in both directions on one cable. This will reduce the probability of interruption to one-half that of the old two cable systems.

1.2.2 Suggested Trawler Precautions

The principal hazards from trawlers are at the Iceland end where open water suitable for fishing exists during most of the year. Extending westward from the peninsula where Keflavik is located is a chain of rocks which may constitute a barrier to bottom fishing operations. Subject to information obtainable from fishery authorities in Iceland, this appears to be a protected area for cable. Between the end of these rocks and deep water, the cable will have to be carefully laid. This bottom is mud, sand, and gravel where, if not too densely packed, the cable will embed.

Including the protected area mentioned above, about 100 nm of this cable will be in a fishing area. This compares with 650 to 700 nm of the BMEWS cable exposed and subject to interruption by fishing activity.

At the Greenland end ice conditions prevent fishing except for a few weeks in late summer. Here the cable should be laid in the deepest water available.

1.2.3 Pressure Ice Hazards

Pressure ice occurs when the ice field is pushed by wind or ocean currents against the shore producing ridges, the under side of which grinds against the bottom to a depth of 150 feet or more. The present landings of the BMEWS cable at Thule, Greenland are well protected and are reported to be trouble free. This establishes the following minimum requirements:

(a) The landing should be selected for its suitability with respect to ice movement. A cove protected from the prevailing winds and currents where no considerable amount of ice is forced would be suitable.

(b) Heavy armor should be carried out to as great a depth as practical and in no case less than 50 fathoms.

(c) The cable should be entrenched as far out as practical to a depth of 15 or 20 fathoms. Backfill must not include sharp rocks.

(d) Additional protective covering is desirable at the outer end of the trench to prevent the action of the sea from damaging the cable.

1.2.4 Suggested Pressure Ice Precautions

The above are minimum protection requirements. Additional requirements should be considered. Burlap bags partly filled with concrete should be considered for backfilling the tench and possibly in lieu of trenching at greater depths. Existing charts indicate several suitable coves on the west side of Kulusuk Island, but if no survey data is available for these possible landings an examination of the bottom should be made from a small craft equipped with an echo sounder. Advice should be obtained from local people regarding ice conditions.

Because of the success of the BMEWS and other landings in this area, the protection afforded by these means may be regarded as adequate.

1.2.5 Iceberg Hazards

The grounding of even a small iceberg on the cable must be regarded as completely destructive. Precautions must be taken to avoid this.

(a) Place the cable in water of at least 200 fathoms. Any natural ravines available should be utilized. This measure assumes that the bergs will strand on bottoms of lesser depth.

(b) Select, if available, a soft bottom which may provide some protection to the cable from the weight of the berg.

(c) Use a crush resistant armored cable. This may be regarded as effective only for light crushing forces on a suitable bottom.

1.2.6 Suggested Iceberg Precautions

Icebergs are known at the Greenland end of the cable route. At the Iceland end, it is reported that they are not a problem although such precautions as are practical should be observed. Two hundred fathoms may be taken as the maximum probable draft of all ordinary bergs. Water in excess of this depth exists close to the shore of Kulusuk Island. An initial cable course south and somewhat west from the west side of this island will be in depths safe from icebergs. The area between the 200-fathom contour and the landing of latest surveys should be examined for a suitable route, preferably a ravine.

While these protective measures are not absolutely effective against icebergs, damage will be minimized if they are employed.

1.2.7 Seismic and Volcanic Activity

Although the eastern end of the cable route under study is in an area of seismic and volcanic activity this hazard should not disqualify the route. Only by chance could a disturbance of sufficient intensity occur which would damage the cable during its anticipated life. Further, such damage would be at the end of the cable where it is most easily repaired.

1.2.8 Malicious Mischief

As an important military cable, a certain amount of security as to its position or existence may be required. Submarine cables are unique in that they are effectively concealed from view by the ocean. Their destruction by an enemy, if their exact location is unknown, will take a prohibitive amount of time in a hostile environment. Possible security measures follow:

(a) Standard cable laying techniques may be used advantageously to conceal the exact location of the cable from all except authorized personnel.

(b) Methods for concealing the location and the purposes of the shore ends are available.

(c) Government ships and competent personnel are in existence and may be available.

(d) Security methods have been established and utilized by government agencies on recent cable projects.

(e) Particular projects, such as the one here contemplated offer special security advantages.

(f) The hazard of malicious mischief, not necessarily hostile, was considered sufficient to justify a State Department prohibition for publishing the exact position of telegraph cables.

1.2.9 Short Construction Season

Marine construction including accurate cable laying requires good weather. A short season (less than ten weeks) at the Greenland end will require accurate weather and ice forecasts and careful planning to expedite the work. The task must be scheduled and accomplished within this season. At the Iceland end bad weather, rather than a time limitation, will impose construction difficulties. The two shore ends must be placed when conditions are favorable and materials are available. The final operation will be in an area unaffected by ice and may be accomplished independently of the preceeding work when the ship and the cable become available.

1.2.10 Crush Resistant Cable

Some experimental work should be undertaken to develop improved crush resistant cable to withstand ice and the abrasion of fishing trawls. This may be a new design or an adaptation of an existing design.

Commerical carriers have had good results under ice conditions with a unique armor construction. Three armor wires are laid up as a strand. The strands are applied helically to the cable producing a flexible basket structure which deforms in a manner that is regarded less destructive to the electrical structure.

For the shore ends, the diameter of the electrical structure may be reduced (with some effect upon repeater spacing) so that an optimum crush resistant design will be obtained. This design will require experimental development.

1.2.11 Landing Hazards

The cable is exposed to the destructive action of the surf in the area where it emerges from the sea. Some of the practical protective measures used successfully on other USAF cables are as follows:

(a) Select the most suitable landing available (see paragraph 1.2.3). Convenience to the terminal building or the required length of connecting land cable are secondary considerations. Land cable is a magnetically shielded coaxial, otherwise it matches the remaining submarine cable.

(b) Entrench the cable to as great a depth as is practical to work. Cover the cable with interlocking bags of concrete. (The concrete mix is placed dry in partially filled bags.)

(c) Armor the cable as heavily as local conditions require to a depth of 50 fathoms.

(d) Continue concrete bag protection as far as practical and particularly where the cable emerges from the trench.

1.3 TIME AND COST ESTIMATES

1.3.1 Cost Estimates

Because of the hazardous location of this cable, the cost estimate assumes as much protection as seems reasonable and practicable. For comparison purposes only, costs have been estimated for a cable of the shortest possible length laid with a minimum of special protection. The differences that may be ascribed to protection are as follows: (The complete estimates are presented on Table XII.)

	72 Channels	120 Channels
Cable (136 nm)	$697,000	$697,000
Repeaters	448,000	448,000
Equalizers	30,000	30,000
Armor on short cable	(-165,000)	(-165,000)
Survey work	507,500	507,500
Engineering	243,000	252,500
Inspection costs	40,000	50,500
Totals (for protection)	$1,800,500	$1,820,500

It will be noted that about 50% of the cost of protection is the cost of a longer and safer cable route, the remainder is special survey work, engineering and inspection. (Offsetting, part of the difference is the need for a large amount of special armor on the short route.)

The unit costs used in Table XII represent current construction costs.

1.3.2 Construction Schedules

This cable can be laid only during a short ice-free season in late summer. The installation forces will, therefore, require daily ice

TABLE XII

DYE-4 TO DYE-5 COST ESTIMATES

Items	Maximum Protective Precautions				Minimum Protective Precautions			
	72 4-kc Channels		120 4-kc Channels		72 4-kc Channels		120 4-kc Channels	
<u>Material</u>								
Cable @ $5125/nm	552nm **	$2,829,000 *	552nm	$2,829,000 *	416nm	$2,132,000 *	416nm	$2,132,000 *
Repeaters @ $56,000	30	1,680,000 *	30	1,680,000 *	22	1,232,000 *	22	1,232,000 *
Equalizers @ $30,000	3	90,000 *	3	90,000 *	2	60,000 *	2	60,000 *
Special Armor @ $6400/nm	20nm	128,000 *	20nm	128,000 *	46nm	293,000 *	46nm	293,000 *
Land cable installed	5 miles	120,000	5 miles	160,000	5 miles	120,000	5 miles	160,000
Terminal apparatus (MUX, power, Hv. Eq., wiring, etc)		420,000		750,000		420,000		750,000
Spare Repeaters and Equalizers	2 & 2	172,000 *	2 & 2	172,000 *	2 & 2	172,000 *	2 & 2	172,000 *
Subtotal		$5,439,000		$5,809,000		$4,429,000		$4,799,000
<u>Surveys and Installation</u>								
Survey ships @ $2500/day	35 days	$ 87,500	35 days	$ 87,500	none	$ -	none	$ -
Cable ships @ $5000/day	42 days	210,000 *	42 days	210,000 *	42 days	210,000 *	42 days	210,000 *
Shore end protection		1,000,000		1,000,000		1,000,000		1,000,000
Electronic Position Indicator	42 days	420,000	42 days	420,000	none	-	none	-
Subtotal		$1,717,500		$1,717,500		$1,210,000		$1,210,000
<u>Engineering</u>								
Engineering and G&A		$1,331,250		$1,452,250		$1,088,250		$1,199,750
Inspection		260,000		290,450		220,000		239,950
Subtotal		$1,591,250		$1,742,700		$1,308,250		$1,439,700
Total		$8,747,750		$9,269,200		$6,947,250		$7,448,700

* Indicates British prices.

** Distances include 10% for slack, route changes and spare stores.

and weather information as well as accurate forecasts. This service may be available from the appropriate government agencies.

Table XIII indicates that under normal conditions the work can be accomplished in the time available.

The procurement of cable, repeaters, and terminal apparatus must be scheduled about a year in advance to meet the needs of the short season.

Ice studies, similar to those provided by government agencies for the BMEWS cable should be available as early as practical for detailed engineering and scheduling.

TABLE XIII

DYE-4 TO DYE-5 STUDY - POSSIBLE SCHEDULE OF CONSTRUCTION SEASON

	Preseason	1st Week	2nd Week	3rd Week	4th Week	5th Week	6th Week
Survey, Shore Ends	En route Install EPI	Small ship shore end surveys			Return	Remove EPI	
Load Cable	Load						
En Route		En route					
Lay Shore Ends			Lay cable				
Survey Route				Deep water survey			
Lay Cable					Lay cable		MARGIN
Return to Base						Return	
Install Terminals	Greenland, then Iceland						
Install Protection	Prepare landings			Place protection over shore ends			
System Status	Under construction				Operating		IN SERVICE

NOTES: Lead time - 12 months for procurement of cable and terminal equipment.

Total time available ------- 10 weeks, approximately (15 August to 1 November 1964)

Minimum time operations----- 6 weeks, as above

Allowance bad weather------ 4 weeks

EPI - electronic position indicator (USC & GS equipment)

Small ship - preferably a government ship (USNS Redbud) which can work in light ice.

PART D
GENERAL OBSERVATIONS

1.0 GENERAL

During the test, certain operational, procedural, and equipment problems were noted that seriously affected the teletype error rate and contributed to the poor voice quality between Melville and Croughton. These problems are discussed here and remedial actions are proposed.

2.0 TERMINAL STATION NOISE

The terminal equipment was located at Goose Bay and Croughton during the test period. Both of these stations are AIRCOM manual and semi-automatic TTY message switching centers. At such stations noise limitations on in-house cables are not specified in their design since TTY information utilizes 20-60 ma DC current pulsing. The background noise on all cables due entirely to in-station sources including fluorescent lighting, TTY machines, unshielded cables, heavily loaded DC rectifiers, etc. amounted to -51 dbm0 at Goose Bay, and -41 dbm0 at Croughton. Such noise levels are greater than the level allowed by DCS specifications for the whole system and cause excessive random error rates and excessive loading (since the noise would be applied to all channels leaving the station).

The expense of upgrading or redesigning AIRCOM centers that are also wideband terminals would be excessive, and it is probable that the background noise could not be reduced significantly due to the nature of TTY operation. Consequently, it is suggested that the separation of wideband terminals from AIRCOM centers is the only practical solution. The separation need not be wide, but the use of common main frames, cable racks, power buses, etc. must be avoided.

If the wideband terminal is separate from, but in the same building as, an AIRCOM station, it is suggested that standard procedures be inaugurated to detect and correct excessive in-station noise. Certain noise sources can readily be recognized. These are: 160-ma step pulse from Plan 55 equipment, motor noises from TTY equipment due to armature pitting, bad brushes, etc. and noise produced by defective relays and spark suppressors.

3.0 CHANNEL NOISE

The scope of this program did not include a long-term investigation of channel noise. However, one-hour tape recordings were made daily of idle channel noise which, in general, incorporated periods of high error rates. It was hoped that from these recordings, a reference noise level could be established which, if surpassed, would begin to cause errors. It was also hoped that errors could be attributed to noise bursts which were of a particular duration.

From the noise recordings, it was possible to establish that high error rates occurred during periods of noise burst conditions, but it was not possible to establish the length of a noise burst that would cause errors. It was also not possible to establish a definite noise level which, when exceeded, would produce errors. However, since the TTY composite tone level compared to the channel noise level (measured flat) never exceeded 20 db and was often less than 10 db and since high line error rates were experienced throughout the test, then a TTY composite signal-to-noise level exceeding 20 db is required for low error rate operation.

4.0 TONE STABILITY

Observations at Croughton and DYE-5 indicate considerable fluctuation in received test-tone levels. A 2300-cps tone inserted in a voice channel at Goose Bay was observed at Croughton one hour daily during the test period. Technical control at DYE-5 had a looped circuit to Hillingdon in the UK Microwave System with a tone inserted and monitored at DYE-5. Four basic characteristics were observed, namely:

(a) Short-term fluctuations

(b) Long-term variations of the median

(c) Abrupt level changes

(d) Transmission breaks - tone dropouts

The first two characteristics are inherent in most systems and can be tolerated as long as the excursions are within reasonable limits. The latter two, however, are intolerable and, for the majority of cases, can be ascribed to the UK Microwave System. On a weekly basis, the standby power systems are switched in at the various stations resulting in transmission breaks and abrupt level changes. Since the standby power at these stations cannot be used without shutting down the radio equipment and since these power transfers are not effected simultaneously at all stations, these disturbances cause much circuit outage, and a period of 24 hours is generally required before the stability of the system returns. Since modulators are quite sensitive to line voltage variations, especially if the voltage is below 120 volts where voltage regulation is not as effective, they are the probable cause of some of the additional level changes observed. On the tropo radio system, each station has two exciters, one of which is a stand-by unit. If a high- or low-level pilot tone is detected, automatic transfer to the standby exciter takes place with a possible change in the deviation of the RF carrier and hence a change in tone-level in the channel. Simultaneous threshold breaks occurring on all receivers operating on a given path will also give rise to transmission breaks.

Typical examples of some of the observations can be seen in Figure D-1. The strip-chart recordings were derived from tape recordings made at Croughton on a day when power systems were being transferred in the UK Microwave System.

We have been informed that a UK Microwave System upgrading program is under consideration. It is suggested that such a program should include provisions for dual diversity and automatic power switch-over devices.

Level fluctuations caused by long-term variations in the median, and operation near threshold were also experienced. These level variations were sufficient to degrade the system and they probably contributed to the high TTY error rate. It is proposed that automatic group level control equipment should be installed for all groups between Goose Bay and the wide-band terminal station in the UK.

5.0 LEVEL CONTROL

Strip-chart recordings, magnetic tape recordings, and other daily measurements at Goose Bay and Croughton indicated that level control was not being observed by the users and that operating personnel experienced great difficulty in maintaining the required channel levels.

5.1 CAUSES OF IMPROPER LEVELS

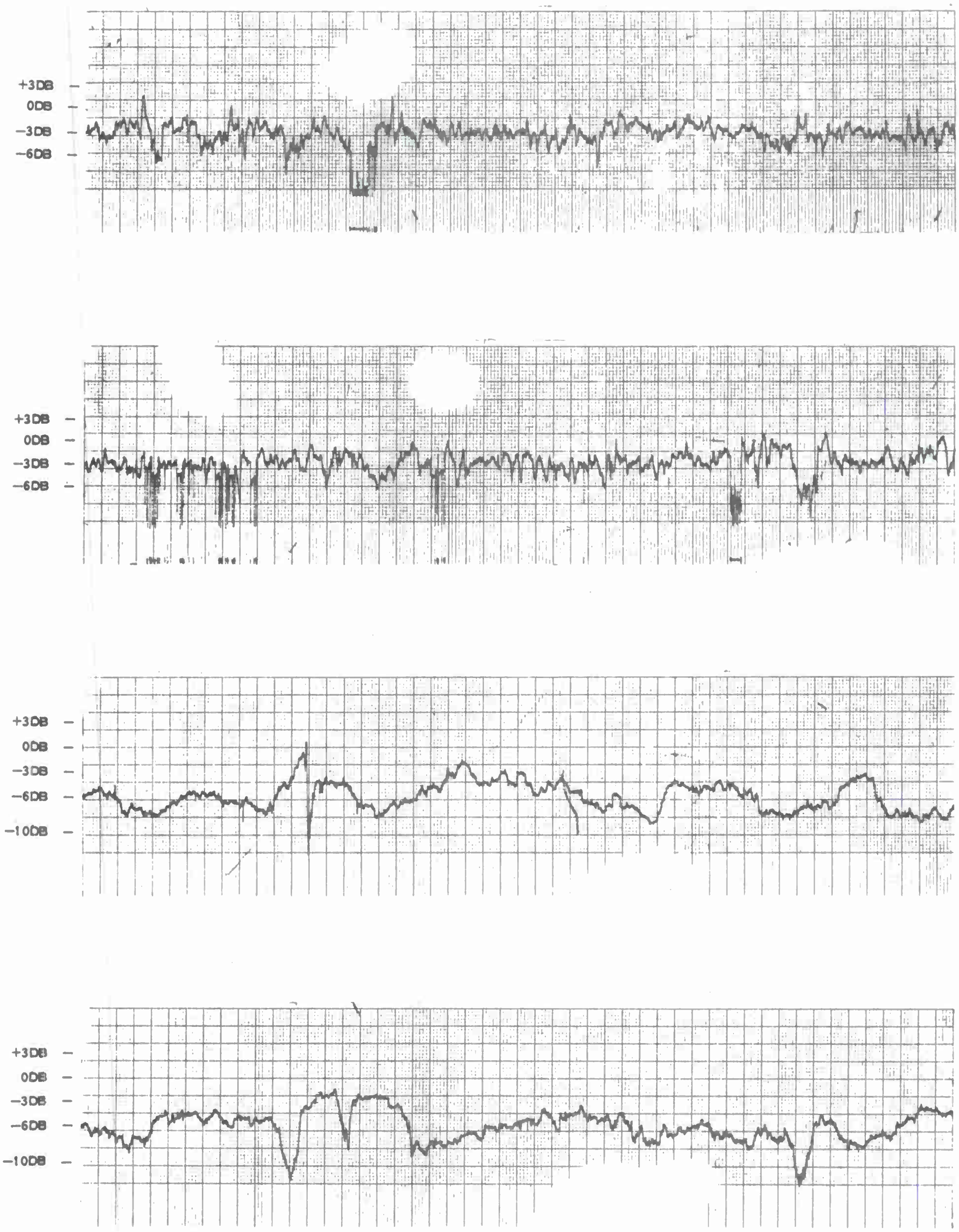
The primary causes of improper levels were as follows:

(a) Within the UK various levels exist corresponding to zero test level (OTL) at 4-wire boards. Thus, operator errors in patching without proper padding or amplification were frequent.

(b) Certain types of signalling, apparently nonstandard, are inserted into the system at high levels.

(c) Teletype users commonly raise their levels above the design limit.

(d) Technical controllers often employ special voice amplifiers on their phones.



TYPICAL TONE RECORDINGS

FIGURE D-1

(e) Different types of level-measuring equipment are available and are used indiscriminately regardless of their applicability to the level being measured. In addition, this equipment is often in need of calibration.

5.2 REMEDIAL ACTION

It is suggested that the following remedial action be taken:

(a) Inform all users of the required level and warn them that they will be removed from the system if they do not maintain level control and lower their signalling levels. Steps should be taken to lower the signalling levels of certain nonstandard equipment utilizing the system.

(b) Establish a common system of levels or provide Zero Level Boards throughout the system. If this is not possible in the UK Microwave System or in other segments, the patchboards must indicate the desired level above each jack, and sufficient pads and amplifiers must be provided.

(c) Provide constant-level amplifiers or limiters that will maintain the level of incoming remote user signals to the required standard when level control by normal technical control procedures is difficult or impossible.

(d) Forbid the use of voice amplifiers by technical control.

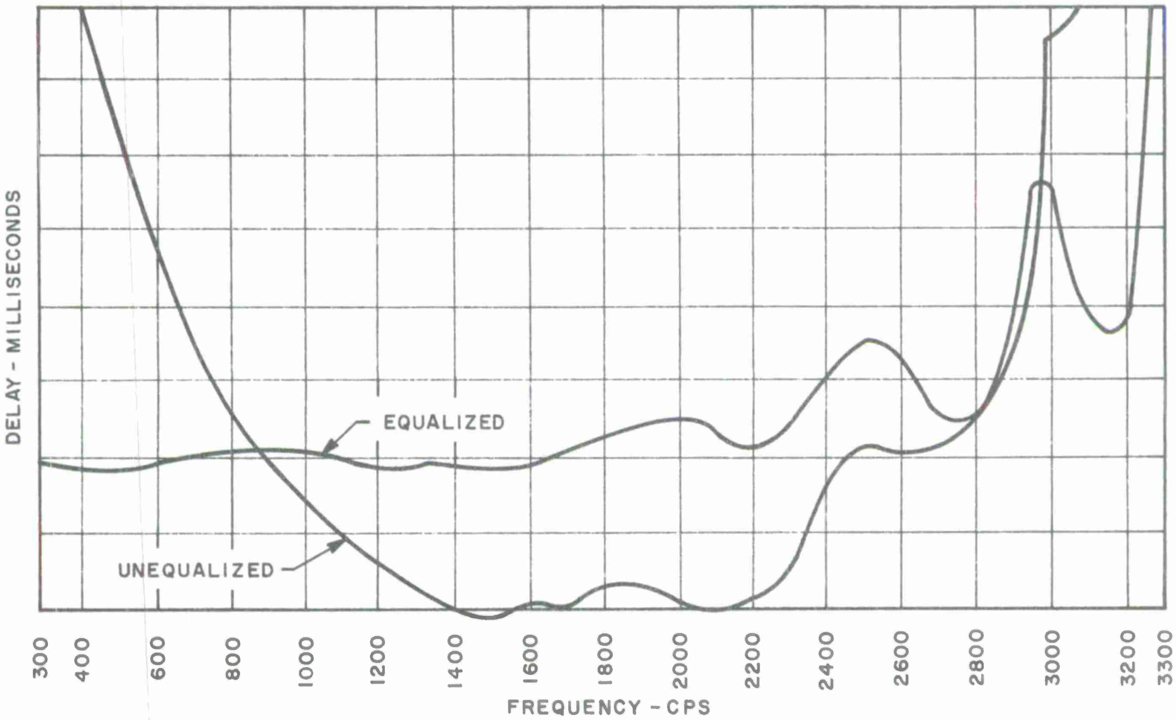
(e) Establish standard level-measuring equipment and maintain calibration.

6.0 CHANNEL DELAY DISTORTION AND AMPLITUDE CHARACTERISTICS

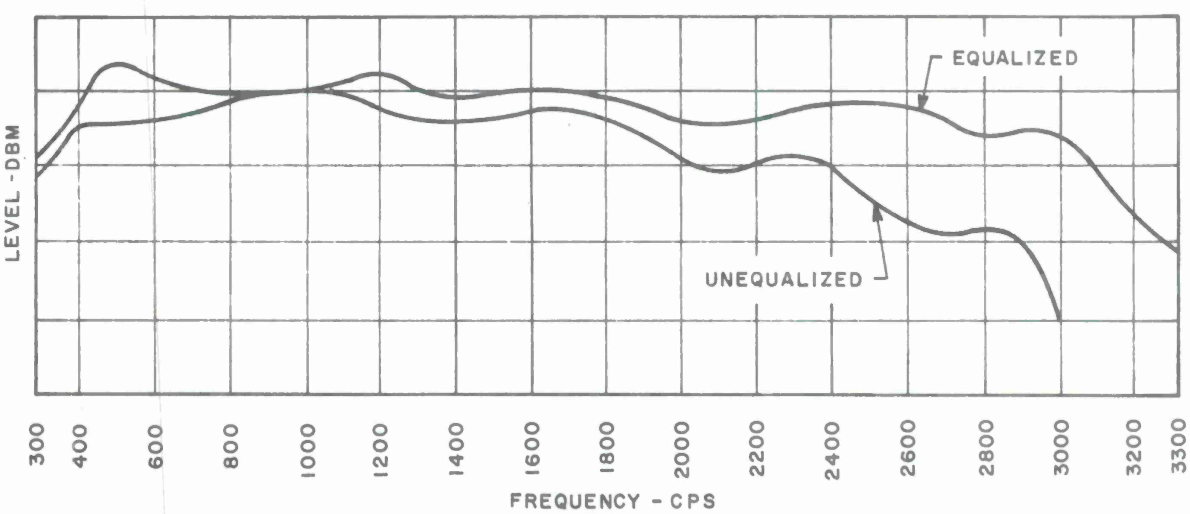
No significant differences in the differential delay distortion and amplitude characteristics were noted between any of the 4-kc channels utilized during the test. For reference purposes, Figures D-2 and D-3 are included to provide an indication of the static channel characteristics experienced during the test.

7.0 REVERSE PATH NOISE CORRELATION

Simultaneous noise recordings were made of idle channel noise experienced in both directions between Goose Bay and Croughton. From these recordings, it was hoped that the correlation of reverse path noise and other disturbances could be ascertained. These measurements would be of use in determining the efficiency of feedback error control systems and might provide significant information concerning the operation of the communication system as a whole. Unfortunately, many of the recordings had to be discarded due to outages and other maintenance problems, and the remaining data are exceedingly difficult to reduce.



DIFFERENTIAL DELAY CHARACTERISTICS
FIGURE D-2



AMPLITUDE CHARACTERISTICS
FIGURE D-3

8.0 NETWORK ENGINEERING

In order to carry out the remedial actions suggested by this study, it will be necessary to consider the implications of various network configurations. For the purposes of this report, it was assumed that all TTY traffic would be present at Melville for transmittal to Croughton and that the circuit would appear at voice frequencies only at Cape Dyer. Such an arrangement might not suit operational requirements however. If other arrangements are contemplated, then the impact of the new network on the recommendations must be studied. It is not believed that any other configuration would materially change the suggested remedial actions outlined in this report, but one configuration may be easier to implement than another. Consequently, it is suggested that a network engineering study be initiated in order to determine the various networks that are possible or likely, and to evaluate the impact of each configuaration on the recommended remedial actions that have been accepted by all agencies concerned with providing adequate TTY service across the North Atlantic.

9.0 SYNCHRONIZATION PROBLEMS ENCOUNTERED IN USING WESTERN UNION MODEM AND CODEX EQUIPMENT

When the Western Union Modem and Codex demultiplexer and decoder were installed and operating, it was found to be impossible to maintain KW-26 synchronization for periods in excess of about ten minutes. It was quickly learned that the SYNC-1C, a clock recovery equipment built by Stelma, Inc. and used in the Western Union Modem was unsuitable for use over the tropo system. It should be pointed out that the unit was designed for use on wire circuits.

The difficulties arose from two sources. First, there is no provision in the unit to prevent noise tracking - a squelch system operating over a 10-db range is provided, which, although effective during a signal drop-out on a telephone line, is totally ineffective on the radio circuit where continuous variations of 4 db occur and where, during a deep fade, one or more of the twenty-two radio receivers is dropped below limiting, and the FM signal is replaced by AM noise which is then received at levels comparable to normal signals. Second, the correction steps of the SYNC-1C are 1/128 of a baud - this is excessive if anything remotely resembling a stable clock is being used for transmission. During some multi-second bursts, the sample point was slewed several bauds from the proper baud. The digital clock servo in the Codex decoder could not follow the Stelma-corrected clock and ended up one baud displaced from frame synchronization and locked in and remained there. This of course causes loss of synchronization. There are four tracking servos in operation: the encoder tracking the KW-26 output, the Stelma SYNC-1C tracking the received data, the Codex decoder tracking the Stelma clock, and the KW-26 tracking the Codex receive multiplexer. It is necessary that the tracking capability of each of these units be able to follow the one before it and further that the slewing capability of each should be limited to a reasonable value to prevent over-correction in the high noise environment in which we are operating. Both of these conditions are violated in the SYNC-1C.

A number of corrective measures were attempted in order to try to achieve satisfactory operation of the SYNC-1C. Although these were about twenty in number, they really were limited to two directions: First, to build an appropriate squelch system - the operating range of the squelch was altered to cover approximately a two-db spread, the signal input to it was sharply filtered at the keying frequencies of one of the Data Modem transceivers (2100 and 2900 cycles), its operating time constant was altered from one second to 10 milliseconds, and the squelch relay was replaced with two switching transistors. Although this helped, it did not solve the problem. Second, various attempts were made to slow down the slewing rate of the unit: it was impossible, without complete rebuilding, to change the 1/128 baud correction since the clock correction logic would not operate at anywhere near the 1.25 megacycle clock input frequency but was rather limited to about 100 kc. Therefore, attempts were made to utilize only every eighth or sixteenth or thirty-second transition and to filter the square-wave input to reject noise so that few clock corrections were made by the SYNC-1C. This helped but did not cure the trouble. At this point, use of the SYNC-1C was abandoned and a new synchronization recovery system was built within the Codex equipment.

The Codex transmit unit at Goose Bay was modified so that it transmitted a distinctive pattern on two channels of the equipment. The Codex receive unit was modified so that it tracked this pattern and thereby maintained synchronization.

The synchronization problems experienced during the tests and the field expedient used to solve the problem proved useful in pointing the way to a general solution of maintaining synchronization over circuits that are subjected to high median noise and noise burst conditions. Normally, cross-over information from the received signal for one period is compared with the cross-over information received during an adjacent period. If any drift (phase difference) between the two signals is noted, the receive clock is advanced or retarded by the addition or subtraction of bits from the clock pulse train. Under extremely noisy conditions, the noise spikes appear to be highly distorted information bits, and the clock is advanced and/or retarded in accordance with the noise even though clock correction might not be necessary.

One practical solution to this problem, based on the field expedient mentioned above, is to utilize stable clocks and to employ a special synchronization seeker system. If a stable clock is utilized, then frequency drift can be limited. With a stable clock, the seeker can be gated so that it only looks for synchronization information for specific periods where cross-over information is expected. If no cross-over information appears within this gate, no clock correction is made; if cross-over information or noise spikes do appear in this gate, then the required clock correction is made. In addition, the clock is corrected by small amounts only; thus, elementary excessive "slewing" occurs if many noise spikes appear within successive gates.

The effect of noise can be further reduced if an additional gate is positioned where transitions are not expected. If these two gates are adjacent, and recalling that noise spikes are not isolated occurrences, then clock correction need be initiated only if a transition occurs at the expected gate when no transition occurs at the adjacent gate.

Such a seeker system takes advantage of the following:

(a) Much of the noise problem is eliminated since the seeker looks at specific periods of the incoming information and this period can be as little as a quarter of a baud. Furthermore, elimination of noise is obtained since clock correction would occur only if the cross-over information is contained solely in the proper gate.

(b) The stable clock requires less correction.

(c) Excessive slewing, which requires any tandem synchronization system to slew at the same rates and which introduces jitter, is avoided.

(d) The additional cost of a stable clock is made up by the reduced cost of the synchronization recovery system.

10.0 CODEX T-1000 THRESHOLD ERROR CORRECTOR

This paragraph briefly discusses the Diffused Threshold Decoding[1] type error correction equipment utilized during the NATTY tests. This equipment utilizes a block constraint length of 12 bits, diffused over 10,000 bits, and a convolutional code of rate one-half. It is capable of correcting two random errors and all errors present during one-second signal drop-out or signal disappearance.

A complete description and a discussion of the operation of the error correction equipment used during the NATTY tests is given in Codex Corporation Technical Bulletin No. 4. This bulletin or equivalent data have not been included here because the manufacturer has designated the data "proprietary." It must therefore be observed that it will be impossible to ascertain whether equipment offered at some future time by this supplier or any other supplier is, in fact, like the equipment tested and reported on herein.

[1] Threshold Decoding is the invention of Dr. James L. Massey, consultant to Codex Corporation. A thorough discussion of the basic theory can be found in his Doctoral Dissertation submitted to the Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass., August 1962. Diffused coding is a technique developed by and proprietary to the Codex Corporation.

APPENDIX I

DISCUSSION OF THE IMPORT OF DCS PERFORMANCE STANDARDS ON TROPOSCATTER CIRCUITS

1.0 GENERAL

DCS performance requirements can be shown to be theoretically difficult for tropo paths of lengths 200 miles or greater to fulfill. Tropo radio paths that exist confirm current theoretical expectations by providing experimental measurements usually with results worse than expected by previous methods of calculation.

One source of difficulty is intermodulation noise which has become a major problem with the baseband expansion that has occurred in recent years.

Thermal noise, which used to be the design limitation, is also a major problem in many radio paths as insufficient confidence factors were applied to the estimated path loss, etc.

This Appendix is intended as a demonstration of typical performance that may be expected with tropo links of various lengths with a comparison to the DCS performance requirements.

It can be shown that definite limitations exist where DCS requirements cannot be met or met only by the use of extremely costly engineering parameters.

2.0 NOISE PERFORMANCE

DCA circular 175-2 requires that for a 6,000 nm circuit, the worst month 4-kc voice channel median noise from all sources attributable to radio should be 20,000 pwp or 37 dba0. This implies that the flat 1-kc baseband slot noise per 100 sm of radio path is to be +69 db below test-tone (0 dbm0).

This level of thermal noise is produced by a no-diversity 120-channel AN/FRC-39(V) radio receiver with a receive carrier level of -65 dbm (see Figures I-1 and I-2 for the quieting curves of an AN/FRC-39(V) receiver for the upper baseband positions). Under quadruple diversity, the average requirement can be stated to be -71 dbm. Similarly, the required receiver signal levels can be calculated for various path lengths:

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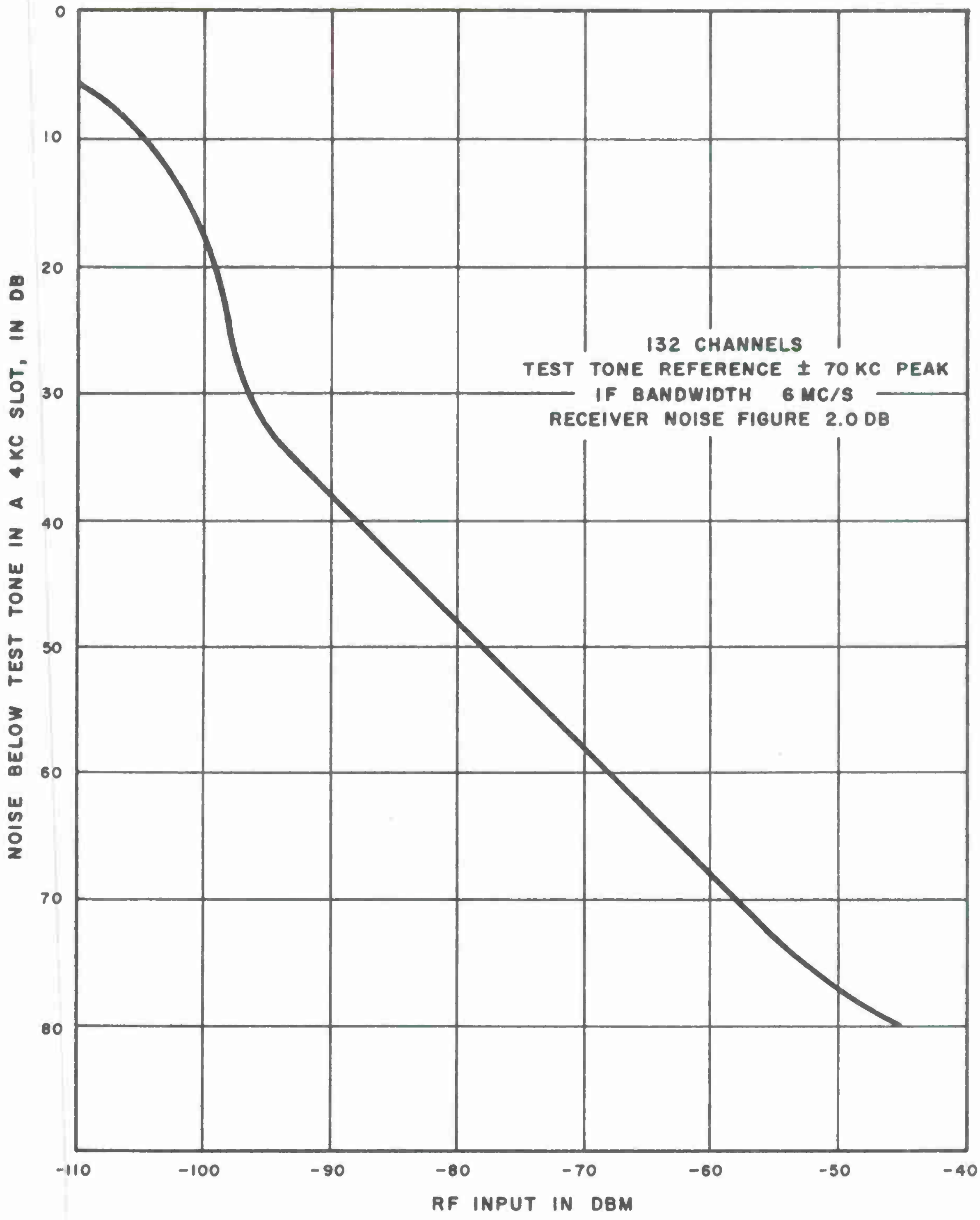
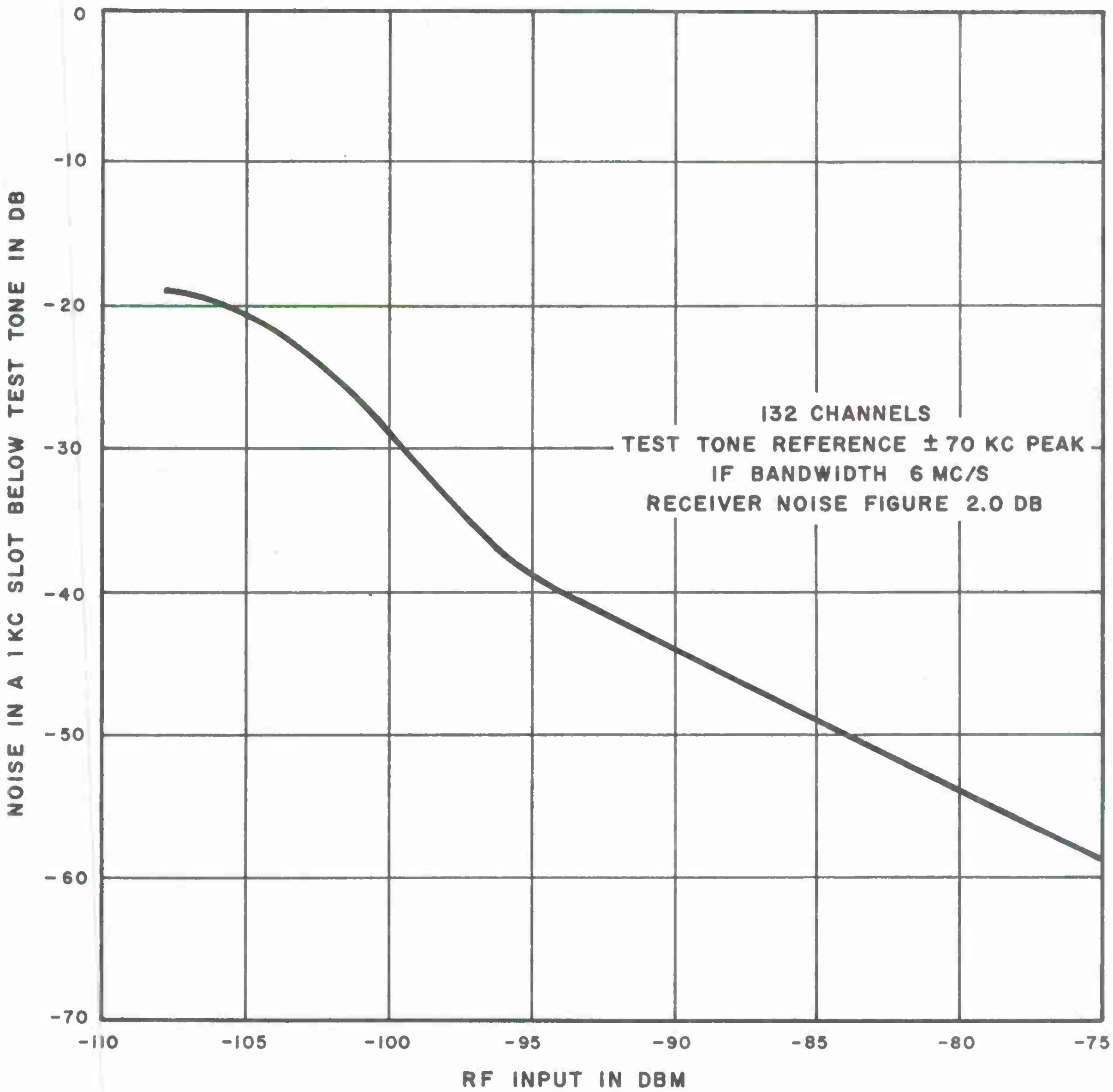


TYPE 959 RECEIVER QUIETING CHARACTERISTICS
NOISE MEASURED IN 265 KC SLOT

FIGURE I-1



TYPE 959 RECEIVER QUIETING CHARACTERISTICS
NOISE MEASURED IN 475 KC SLOT

FIGURE I-2

Path Length	Required Median Receive Carrier
100 sm	-71 dbm
200 sm	-74 dbm
300 sm	-76 dbm
400 sm	-77 dbm
500 sm	-78 dbm
600 sm	-79 dbm

The above results are for the normal drive condition where a test-tone (0 dbm0) is presented as a -20 dbm signal to the exciter input and is obtained as -10 dbm at the receiver.

For a 72-channel system, the AN/FRC-39(V) uses a basic ±48 kcs peak deviation for test-tone versus ±70 kcs for the 120 channel case, and the required receive carrier levels are:

Path Length	Required Median Receive Carrier
100 sm	-72 dbm
200 sm	-75 dbm
300 sm	-77 dbm
400 sm	-78 dbm
500 sm	-79 dbm
600 sm	-80 dbm

Similarly, for a 12-channel system where the standard AN/FRC-39(V) basic test-tone deviation is 21 kcs, we have the following:

Path Length	Required Median Receive Carrier
400 sm	-83 dbm
500 sm	-84 dbm
600 sm	-85 dbm

All the above data are for radio equipment that utilizes the standard pre-emphasis of +12 db at the top modulating frequency, and +8 db at the pivot frequency. The required receive carrier level can only be reduced by over-deviating or applying the information signal to the exciter via an amplifier, so that a test-tone signal is presented at a level greater than -20 dbm to the exciter.

For example, assume that we have the following conditions:

(a) 200-mile path, 120 channels, -80 dbm median carrier

(b) 400-mile path, 72 channels, -90 dbm median carrier

(c) 600-mile path, 12 channels, -100 dbm median carrier

From the given data, we see that the following over-deviations are required:

(a) +3 db - Test noise signal peak deviation = ±2.0 mcs

(b) +6 db - Test noise signal peak deviation = ±1.92 mcs

(c) +7.5 db - Test noise signal peak deviation = ±0.59 mcs

(Assuming the test noise signal to be +6 dbm0 for 120 channels, as per MIL-R-9657, +4 dbm0 for 72 channels and -3 dbm0 for 12 channels.)

If intermodulation effects have to be included for the system loaded with its test noise signal, the situation is further aggravated. The noise power ratio for the AN/FRC-39(V) is 55 db minimum for the described test noise signals applied to the exciter at a level where the test-tone appears as -20 dbm. The following equipment noise contributions therefore occur for 12, 72, and 120 channel radio sets, assuming quadruple diversity advantage:

Number of Channels	IM Noise in 1 Kcs Slot
12	+81 db below test-tone
72	+81 db below test-tone
120	+82 db below test-tone

This noise contribution, however, is a variable and depends on whether over-deviation is employed. The noise power ratio, for instance, falls to 45 db or less, with 1-kcs slot noise rising to at least +72 db below the test-tone for the full peak deviation capability of the AN/FRC-39(V) exciter of 3.0 mcs.

In any event, this noise source can be considered negligible compared to other sources for path lengths in excess of 150 miles.

The effects of path FM intermodulation can be severe. Data measured under this program and others indicate that the Bell Telephone Laboratories, Inc. formulation for this intermodulation noise, based on a white noise signal, provides excellent estimates. Table XIV indicates the expected intermodulation baseband slot noise for various radio path lengths using standard parameters with the following assumptions:

(a) Smooth earth of effective radius 4/3R

(b) No height advantage

(c) Quadruple diversity advantage

(d) Transmitter size adequate to render thermal noise negligible

TABLE XIV

EXPECTED INTERMODULATION BASEBAND SLOT NOISE

Path Length	Antenna		Number of Voice Channels	1 Kcs Slot IM Noise Below Test-Tone	
				Calculations	Required by DCS
100 miles	30 feet	800 mc	120	81 db	69 db
200 miles	60 feet		120	61 db	66 db
300 miles	60 feet		72	54 db	64 db
400 miles	120 feet		72	52 db	63 db
600 miles	120 feet	400 mc	12	53 db	61 db

Calculation of path IM slot noise for test-tone appearing as -20 dbm at input of AN/FRC-39(V) modulator. Equipment contributions are not included.

Table XV indicates the paths and parameters outlined in Table XIV with worst month receive carrier levels calculated for 1, 10, 50, and 100 kw transmitters (the complete composite expected noise).

Note that with the parameters used, DCS requirements cannot be met thermally beyond about 200 miles and that when the "fully loaded test signal" is employed, only the 100-mile path satisfies the requirements. Fortunately, height advantage is now quite common and it is sought after in troposcatter radio links as it alleviates the situation both thermally and from the intermodulation point of view. It is still not likely, however, that DCS standards for the fully loaded condition can be met beyond 300 miles even if 120-foot antennas are used.

Table XVI indicates the change in performance of the radio paths in Table XV when over-deviation of +3.0 db above optimum is employed. These results are tabulated since over-deviation by +3.0 db beyond optimum probably only decreases the fully loaded performance from optimum by 3.0 db but permits the unloaded performance to increase +9.0 db above optimum (see Figure I-3) and hence is probably a better drive point for all-around operation. Naturally, over-deviating without increasing the IF amplifier bandwidth incurs a lower equipment noise power ratio, but the tabulated results for paths of 500 miles length and greater indicate that IF amplifier filters can be used to degrade the noise power ratio performance to 40 db or less without affecting actual performance significantly.

TABLE XV

EXPECTED COMPOSITE WORST MONTH NOISE

Path Length	Antenna		Transmitter	Number of Voice Channels	Calculated WM Receive Signal	1 Kcs Slot Noise Below Test Tone			
						Thermal	IM	Total	DCS Required
100 miles	30 feet	800 mcs	1 kw	120	-73 dbm	67 db	81 db	67 db	69 db
200 miles	60 feet		10 kw	120	-71 dbm	69 db	61 db	60 db	66 db
300 miles	60 feet		10 kw	72	-84 dbm	57 db	54 db	52 db	64 db
400 miles	120 feet		50 kw	72	-89 dbm	52 db	52 db	49 db	63 db
500 miles	120 feet	400 mcs	100 kw	12	-98 dbm	48 db	62 db	48 db	62 db
600 miles	120 feet		100 kw	12	-112 dbm	34 db	53 db	34 db	61 db

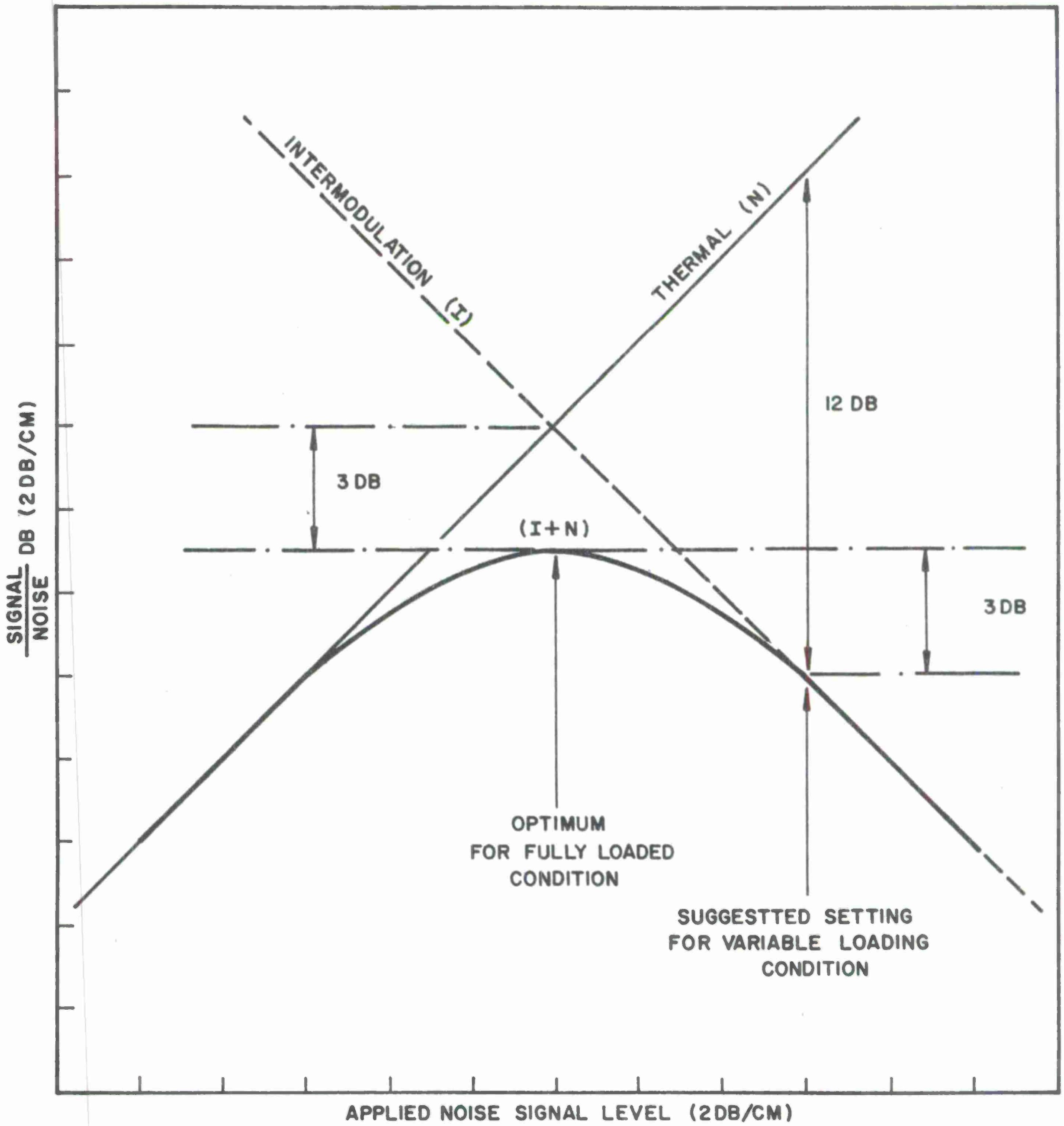
This table has calculated slot noise due to thermal and intermodulation effects with standard noise test signals at normal deviation.

TABLE XVI

EXPECTED PERFORMANCE OF REFERENCE RADIO PATHS
WITH DEVIATION SET +3.0 db ABOVE OPTIMUM

Path Length	Over-Deviation	1 Kcs Slot Noise Below Test Tone			
		Thermal	IM	Total	DCS Required
100 miles	+5.0 db*	77 db	71 db	70 db	69 db
200 miles	+1.0 db	71 db	59 db	59 db	66 db
300 miles	+2.0 db	61 db	50 db	50 db	64 db
400 miles	+3.0 db	58 db	46 db	46 db	63 db
500 miles	+6.5 db	61 db	49 db	49 db	62 db
600 miles	+7.5 db	49 db	38 db	38 db	61 db

* Over-deviation limited by equipment capability.



SETTING FOR MODULATOR DRIVE
UNDER CONDITIONS OF PATH INTERMODULATION

FIGURE I-3

3.0 THE LONG-HAUL CIRCUIT

When attempting to estimate the median performance of a multi-hop circuit, it is usual to add the median noise contributions. Since only mean noise can be added directly, however, some considerable error can be introduced by this method.

Taking as a model 35 200-sm-long tropo links making up the 6,000 nm circuit, it can be determined from Sheffield's work,[1] that an error of some 3 db can be introduced, assuming uncorrelated long-term link fading of gaussian distribution, standard deviation (σ) equal to 5.0 db.

The above model indicates that the resultant mean power of 37 dba will be achieved with standard deviation for the system (σ_S) equal to 0.8 db for individual links providing noise contributions of 18.6 dba. If an arbitrary decision is made as to the relationship of IM to thermal noise, this appears to require a worst month median link carrier of approximately -68 dbm.

Of considerable interest is the low value of σ_S derived for the system. DCS requirements permit σ_S equal to 3.55 db: this could be interpreted with an actual σ much lower so as to permit a worse value for the median noise.

The North Atlantic Tropo System of some 3,000 sm provided a measured σ equal to 2.7 db which was primarily due to the control exerted by the DYE-4/-5 path. Eliminating the effect of this path, an improved σ equal to 1.7 db is derived.

Thus, a review of DCS requirements for circuit noise is required for the following reasons:

(a) Pro-rating allowable noise to multiple tandem links will produce a system noise 3 db high. (It is to be noted that a 2-db weighting allowance was required to match the North Atlantic Tropo System results.)

(b) The current permissible standard deviation for a multiple tandem link system is too large based on real circuits.

(c) Based on (a) and (b) above, apparently two standards are required, one for multiple link circuits and another for systems such as satellites and long-range submarine cables, etc.

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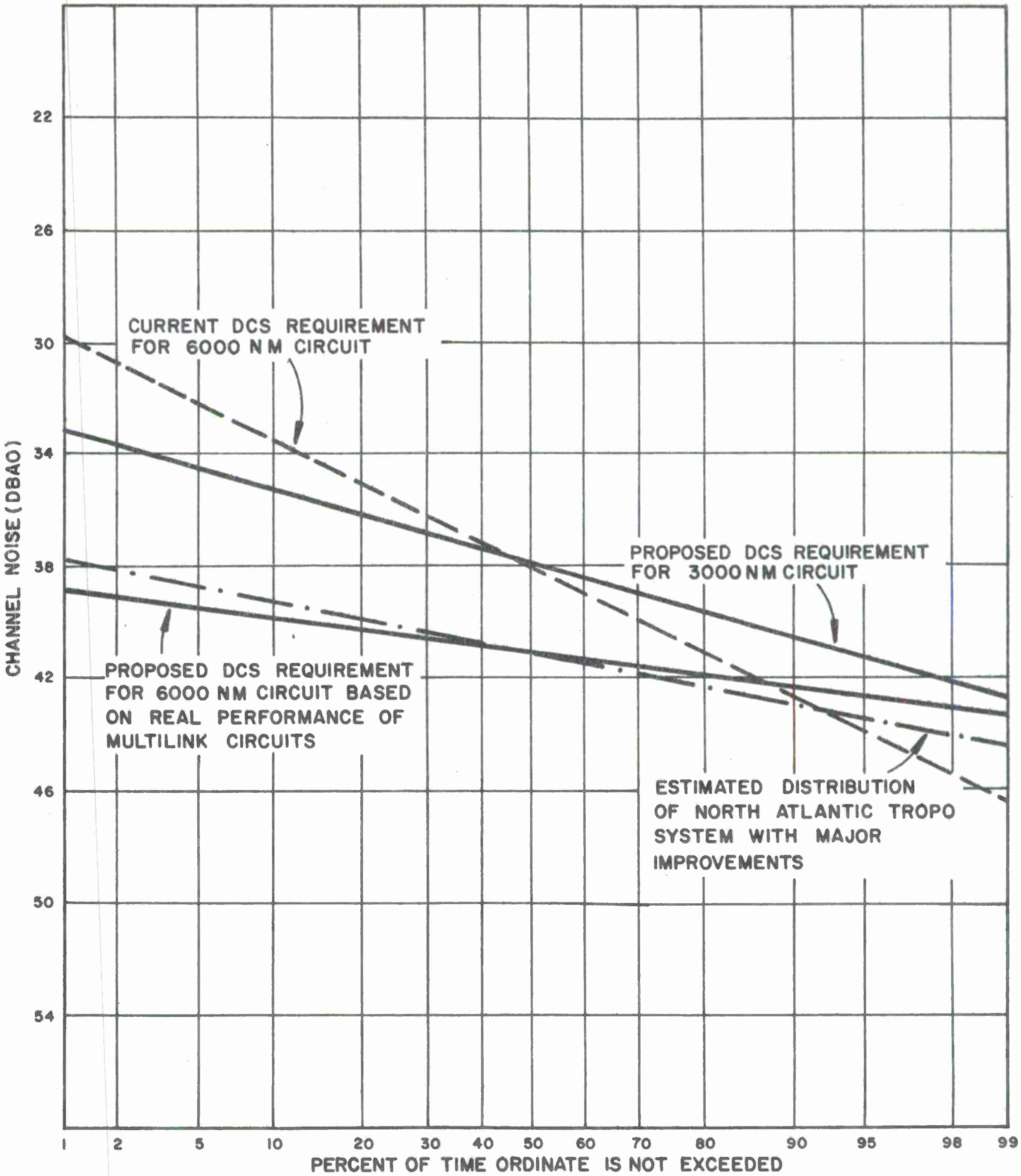
[1] Nomograms for the Statistical Summation of Noise in Multihop Communication Systems, I.E.E.E. Transactions on Communications Systems, Sept. 1963.

Probably the best adjustment to make to the DCS requirement is to still permit noise pro-rating for links on the basis of 20,000 pwp for 6,000 nm but to increase the median 6,000 nm objective to 40,000 pwp and call for σ_S equal to 1 db. The net effect of this on the North Atlantic Tropo System is shown in Figure I-4. The North Atlantic Tropo System is approximately 3,000 nm when the UK Microwave System is included.



COMPARISON OF EXISTING AND PROPOSED CHANNEL NOISE DISTRIBUTION REQUIREMENTS FOR A 6000 N M CIRCUIT

FIGURE I-4

APPENDIX II

"WORST CHANNEL" OPERATION

It has long been held that the top frequency channel allocation of the radio baseband is the worst channel.

This is true for systems operating above FM threshold since the formulation for thermal noise below test-tone is:

$$n = \frac{2NKTB}{m^2 C}$$

Where N = Noise figure

KT = Boltzmans constant and Absolute Temperature

B = Channel bandwidth

C = Received carrier power

m = Modulation index for test-tone at channel frequency F

For unpre-emphasized systems, the thermal noise varies as $(F)^2$ and for pre-emphasized systems this noise increase is alleviated according to the pre-emphasis characteristic used.

The top channel need not be the worst channel for data because of the behavior of the noise characteristic below FM threshold. This point is demonstrated in Figure II-1 which shows the quieting curves for a low and high baseband slot for a 959-type AN/FRC-39(V) receiver. Without threshold extension, the performance for fades below threshold beyond -97 dbm is superior for the 475-kcs slot; however, the superiority of the lower slot (80 kcs) is maintained down to -105 dbm with the "improved threshold extension panel."

Figure II-2 shows the quieting curves for the 55- and 475-kcs slots for the 959-type receiver with a 2.0-mcs IF filter and a noise loaded signal. This is the situation at Site 44 receiving Site 43. Again, it can be seen that the higher baseband slot gives superior performance for threshold fades below -100.5 dbm.

Under conditions where the median receive RF signal is maintained well above threshold, the bottom-channel allocations are without doubt superior. In FM links where median signals are close to the FM threshold, however, data performance might be better in the top-channel allocations _if_ the crossover in the quieting characteristics occurs at a channel noise level below the point of data failure. Provisioning of equipment such as the REL-improved threshold extension panel renders the quieting curve crossover

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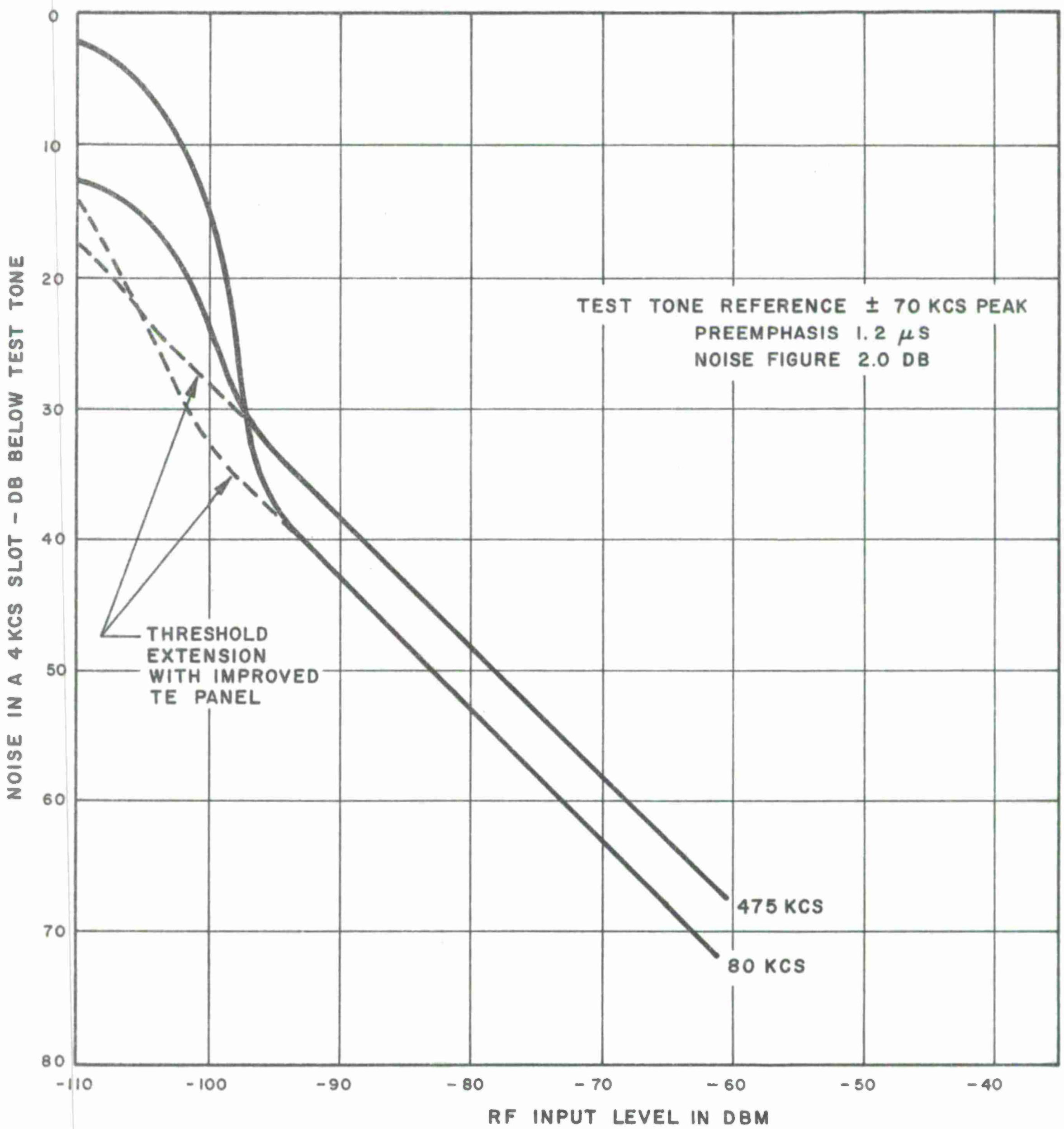
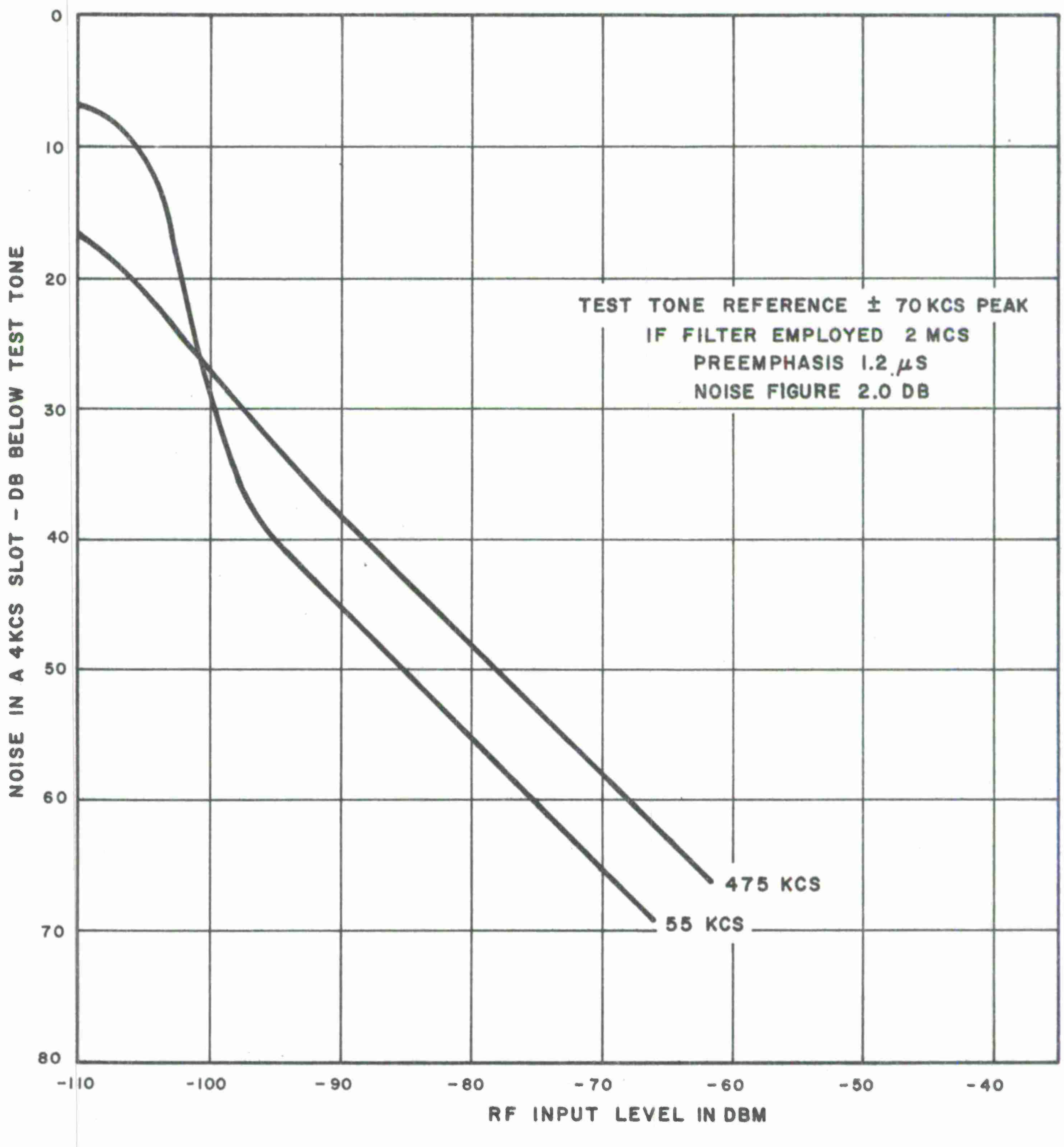


AN/FRC-39(V) RECEIVER QUIETING CHARACTERISTICS
IF BANDWIDTH - 6 MC

FIGURE II - 1



AN/FRC-39(V) RECEIVER QUIETING CHARACTERISTICS
IF BANDWIDTH - NOMINAL

FIGURE II - 2

to such a low receiver input level that the superiority of the lower base-band allocations is maintained.

It is suggested that circuit allocations of data circuits should be made with the above phenomena kept in mind. Receiver quieting curves should be obtained for the receivers utilized and should be marked with the worst month median receive signal power and the channel noise level that will produce data failure.

With the above data, circuit engineers can choose the best allocations for data traffic through various FPTS radio systems.

APPENDIX III

NORTH ATLANTIC TELETYPE STUDY
SUBTASK 1 TEST SPECIFICATIONS

1.0 GENERAL

Four teletype transmission techniques will be tested. The techniques are multichannel frequency shift keying (fsk), multichannel phase shift keying (psk), individual error control of fsk channels, and high-speed single-channel transmission with error correction. The psk technique will be tested with equipment supplied by Robertshaw Fulton; the fsk technique and fsk error-control technique will be tested with equipment supplied by Tele-Signal Corporation; the error-correction/high-speed-transmission technique will be tested with equipment supplied by Codex Corporation.

Channel noise and signal-level stability will be tested and recorded.

System data error rates, error distribution, and the general capability of the system to carry high-speed data will be tested and recorded, utilizing equipment supplied by MIT Lincoln Labs.

The equipment will be arranged in the test line-up shown on applicable figures.

All TTY transmission techniques will be tested simultaneously. All tests shall cease upon equipment failure or similar disturbance of any or all of the four transmission techniques.

When possible, all other tests shall be performed simultaneously with the TTY transmission tests.

2.0 PRELIMINARY PROCEDURES

Prior to starting actual tests, the preliminary adjustments and tests of the Melville-to-Croughton transmission system that are listed below shall be performed:

2.1 SYSTEM ALIGNMENT

2.1.1 Equipment Required

Normally, in-station equipment will be utilized.

2.1.2. Alignment Technique

The project engineer will check with the technical controller to insure that the entire system is operating at the levels and ranges normally present. This procedure will be accomplished by AFCS personnel at all stations between Melville and Croughton.

3.0 PRELIMINARY CHANNEL MEASUREMENTS

The following measurements will be made on all channels assigned to the test program.

3.1 FREQUENCY RESPONSE MEASUREMENTS

3.1.1 Equipment Required

(a) Variable Frequency Oscillator (VFO) (300 cps to 3400 cps)

(b) Hewlett-Packard 400L Log Voltmeter

3.1.2 Measurement Technique

Step 1: At Melville, connect the VFO to the send jack (at the four-wire point) of the circuit under test. At Croughton, connect the 400L Log Voltmeter to the receive jacks (at the four-wire point) of the circuit under test. Proceed with the frequency-response measurement as follows:

Step 2: At Melville, adjust the output of the VFO to 0 dbm0 (normally -16 dbm at the four-wire point). Vary the VFO frequency over the 300 cps to 3400 cps range keeping the sending level constant.

Step 3: At Croughton, read and record the output levels on the 400L meter for the frequencies 300, 400, 600, 800, 1000, 1500, 2000, 2500, 3000, 3200, 3300 and 3400 cps and at the top and bottom of any peaks or valleys.

3.2 RELATIVE DELAY DISTORTION MEASUREMENT

3.2.1 Equipment Required

(a) Delay Distortion Measuring Set (DDMS) consisting of the Acton Labs 451A Transmitter and the Acton Labs 452A Receiver.

(b) Hewlett-Packard 400L Log Voltmeter

(c) 0-dbm Test Tone (available in station)

3.2.2 Measurement Technique

Step 1: At Goose Bay Technical Control, connect a Test Tone to the circuit under test so that 0-dbm is inserted at Melville Tropo at the 0-dbm test-level point. At Croughton connect the 400L meter at the four-wire point of the circuit under test. Note: At Melville and Croughton ensure that the 0-dbm test-tone level is maintained (-16 dbm at Melville and +7 dbm at Croughton at the four-wire point).

Step 2: Follow the operating instructions for the Acton Labs equipment for straightaway measurements. Record the results.

This test will be performed daily on all channels utilized for the tests immediately prior to the test period.

4.0 TONE STABILITY AND CHANNEL NOISE MEASUREMENTS

4.1 EQUIPMENT REQUIRED

(a) 2300-cps tone (available in station)

(b) 1000-cps test tone (available in station)

(c) Hewlett-Packard 400L Log Voltmeter

(d) Ampex 2-channel tape recorder

(e) Strip-chart recorder

4.2 MEASUREMENT TECHNIQUE

Connect the equipment as indicated in Figure III-1.

Step 1: At Croughton, calibrate the tape recorder by inserting a -3-dbm, 2300-cps tone into channel A of the recorder and a -3-dbm, 1000-cps tone into channel B of the recorder. Adjust the record level controls until the recorder will record both tones when they are varied in levels from -45 dbm to -3 dbm. Record two minutes of the -3 dbm levels simultaneously. Precede the recording with an announcement of the time and date of the test on channel A of the recorder.

Step 2: At Melville, insert a -26-dbm, 2300-cps tone on a selected channel assigned to the test program at the 4-wire point.

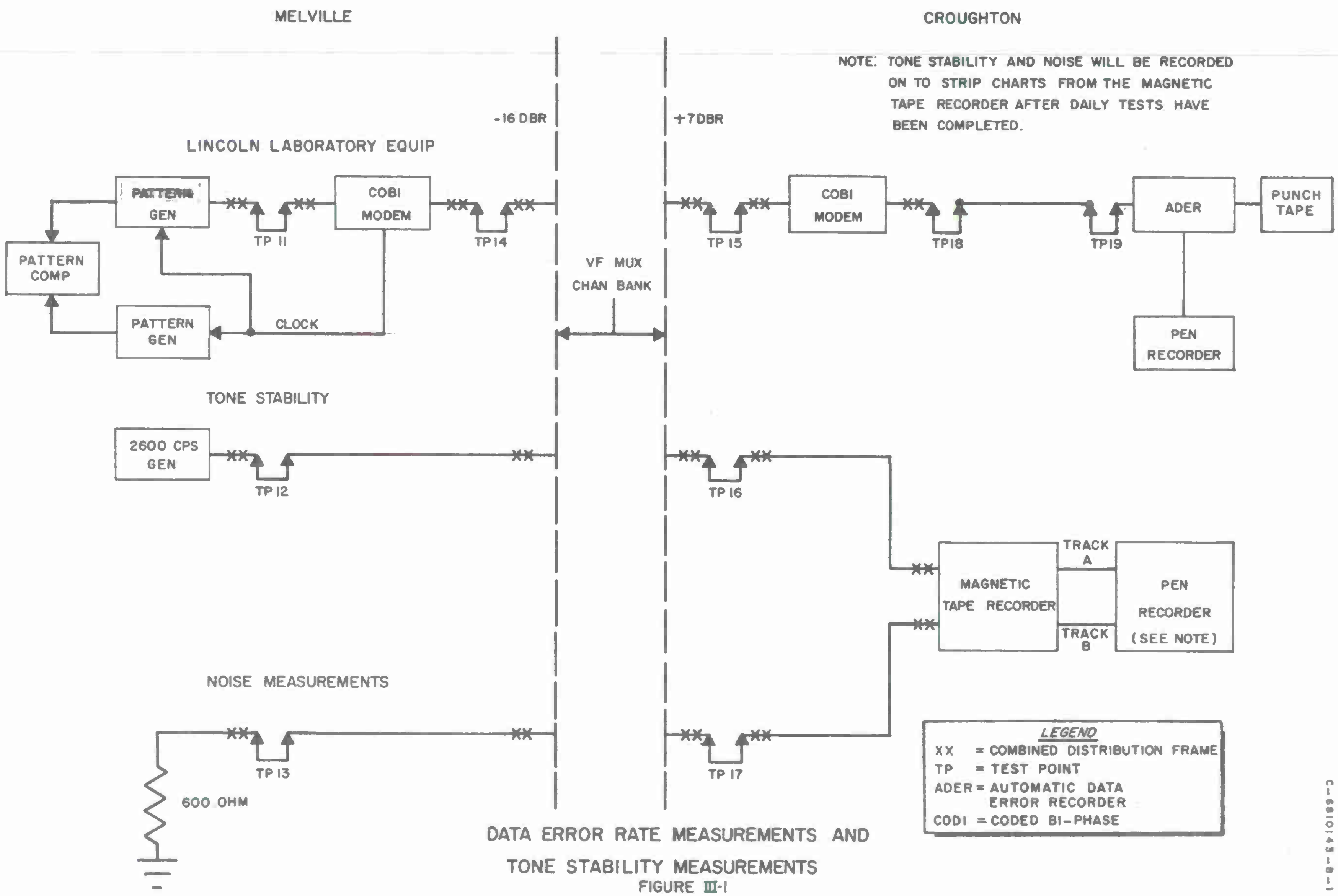
Step 3: At Melville, insert the -16-dbm, 1000-cps test tone on a selected channel assigned to the test program at the 4-wire point.

Step 4: At Croughton, utilizing the 400L Log Voltmeter, adjust the multiplex and 4-wire equipment so that the 2300-cps tone transmitted at Melville is received at a level of -3 dbm at the 4-wire point.

Step 5: At Croughton, utilizing the 400L Log Voltmeter adjust the multiplex and 4-wire equipment so that the 1000-cps test tone transmitted at Melville is received at a level of +7 dbr (+7 dbm) at the 4-wire point.

Step 6: At Croughton, connect channel A of the stereo tape recorder to the multiplex channel containing the 2300-cps tone, and channel B of the stereo tape recorder to the multiplex channel containing the 1000-cps tone.

Step 7: At Melville, remove the 1000-cps tone from the selected channel and terminate the channel in 600 ohms.



DATA ERROR RATE MEASUREMENTS AND TONE STABILITY MEASUREMENTS
FIGURE III-1

Step 8: At Croughton, upon completion of the daily tests, strip-chart recordings will be made of noise and tone stability by playing back the information recorded by the magnetic tape recorder at the discretion of the ICS project engineer.

Step 9: The above recordings will be made daily during periods of poor teletype performance and will be a minimum of one reel of tape per day. At the completion of the recorder calibration and after the announcement of the time and date is made the test recording will begin simultaneously with the marking of all TTY page printer copies to indicate start of tape recording tests. Ensure that sufficient paper is available in each page printer for the duration of any tape recording.

5.0 DATA ERROR RATE MEASUREMENTS

5.1 EQUIPMENT REQUIRED

(a) MIT Lincoln Labs ADDER Test Equipment

(b) 2 ea Pattern Generators

(c) 1 ea Pattern Comparator

(d) Strip-Chart Recorder

5.2 MEASUREMENT TECHNIQUE

Step 1: Connect the equipment as indicated in Figure III-1.

Step 2: Complete self-check operations of test equipment in accordance with the MIT Lincoln Labs instruction manual.

Step 3: At Melville, send a 16-bit word with the following 1200-bps pattern: 0001010110011110.

Step 4: At Croughton, record errors utilizing the ADDER equipment as instructed by the technical manual.

Step 5: At Croughton, attach the strip-chart recorder to record the receive-signal level in accordance with the instruction manual.

Step 6: The above test will be continued throughout each test period.

6.0 TELETYPE TRANSMISSION MEASUREMENTS

6.1 EQUIPMENT REQUIRED

(a) Codex Corporation Time Division Multiplex Equipment (TDM)

(b) Codex Corporation Error Correction Equipment

(c) Tele-Signal Frequency Shift TTY Multiplex Equipment and Error Control Equipment

(d) Robertshaw Fulton Phase Shift TTY Multiplex Equipment

(e) 4 ea Digital Pattern Generators

(f) 3 ea Digital Pattern Comparators

(g) 2 ea Type 545 Tektronics Dual-Beam Oscilloscopes, 0-15 mc

(h) 2 ea 0-1 mc Frequency Counter

(i) Hewlett-Packard 400L Log Voltmeter

(j) 6 ea TTY Tape Reperforators

(k) 6 ea TTY Page Printers with Automatic Carriage Return and Line Feed

(l) 12 ea KW-26 Crypto Equipments

(m) 6 ea TTY Transmitter Distributors

6.2 MEASUREMENT TECHNIQUE

6.2.1 Preliminary Adjustments

Step 1: At Melville, arrange the teletype transmitter-distributor and KW-26 equipments so that sufficient outputs are available for all teletype multiplex equipments as follows:

(a) Codex Corporation high-speed data/error correction equipment requires 20 KW-26 inputs. This may be accomplished by utilizing multiplex jacks on the front panel of the Codex TDM unit, or by utilizing multiple jacks available in station technical control.

(b) Tele-Signal AN/FCC-19 and Tele-Signal error correction equipment require 16 TTY inputs at least two of which are encrypted by KW-26 equipment. This may be accomplished by utilizing multiplex jacks available in station technical control.

(c) Robertshaw Fulton AN/FCC-76(V) requires 32 KW-26 inputs at least one of which is encrypted by KW-26 equipment. This may be accomplished by utilizing multiple jacks available in station technical control.

Step 2: At Melville, align and adjust the TTY and crypto outputs for 61.12 bps, polar operation, 6/6 KW-26 mode. The signal must be free of all bias, start-stop, and fortuitous distortion; that is, each bit will be exactly 16.36 milliseconds in length.

Step 3: At Melville, if more than one KW-26 is used to provide the 20 inputs to the Codex TDM equipment, arrange to have all TTY and crypto equipments synchronized by the "STEP" signal from one of the KW-26's.

Step 4: At Melville, cut master TTY tapes as follows:

1 RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYE
2 RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYE
'
'
'
9 RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYE
Ø RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYE
'
'
' (3 Line Feeds)
'
1 RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYE
2 RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYE
'
'
'
'
9 RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYE
Ø RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYE

At the end of each line, insert a carriage return and line feed.

Step 5: At Croughton, align and adjust the KW-26 crypto equipments and teletype reperforator and page printer equipments for 61.12 bps, polar operation, 6/6 KW-26 mode. Remove hammers of letters R and Y from the page printers or otherwise disengage R and Y printers.

Step 6: At Melville, test the digital pattern generators by comparing the output of two pattern generators with a pattern comparator. Set a digital pattern generator to provide 0001010110011110 to the input of the TDM or encoder specified by Codex Corporation personnel.

Step 7: At Croughton, test the digital pattern generators by comparing the output of two pattern generators with a pattern comparator.

Step 8: At Croughton, connect a digital pattern comparator to the input of the Codex decoder specified by Codex Corporation personnel. Connect the 2445.5 bps digital timing output from the decoder into a digital word generator that is set to deliver 0001010110011110. Connect the output of the pattern generator to the pattern comparator. This test set-up will check the signal being supplied to the decoder prior to error correction (see Figure III-2).

Step 9: At Croughton, connect a digital pattern comparator to the output of the Codex decoder as directed by Codex Corporation personnel. Connect the 1222.75 bps digital timing output from the decoder into a digital pattern generator that is set to deliver 0001010110011110. Connect the output of the pattern generator to the pattern comparator. This test set-up will check the signal being supplied to the decoder after error correction (see Figure III-2).

Step 10: At Melville, connect the output of the KW-26's to their respective TTY multiplex equipments and send the RY test indicated in Step 4 (see Figure III-3).

Step 11: At Croughton, connect the KW-26's and TTY page printers to each of the teletype multiplex equipments (see Figure III-3).

Step 12: Codex, Robertshaw Fulton, and Tele-Signal personnel will align and adjust their equipment for optimum operation.

6.2.2 Test Procedure

All tests will be performed daily, for at least 20 days between 15 January 1964 and 28 February 1964.

Step 1: Perform the tests and the equipment adjustment and alignment outlined in paragraphs 2.0 and 3.0.

Step 2: At Melville, send the test messages and test tones indicated in paragraphs 4.0 through 6.2.1 as follows:

(a) 2300-cps tone

(b) Idle-channel noise

(c) RY master tape to Codex equipment

(d) RY master tape to Tele-Signal equipment

(e) RY master tape to Robertshaw Fulton equipment

(f) 0001010110011110 to MIT Lincoln Labs equipment

Step 3: At Croughton and Melville, perform final adjustments and checks. As soon as all equipments are operating properly, and as soon as relevant data is being recorded, begin the test-for-record.

Step 4: Time Zero - Indicate on all recorded data, the time, date, and channel utilized for a particular test and begin tests-for-record.

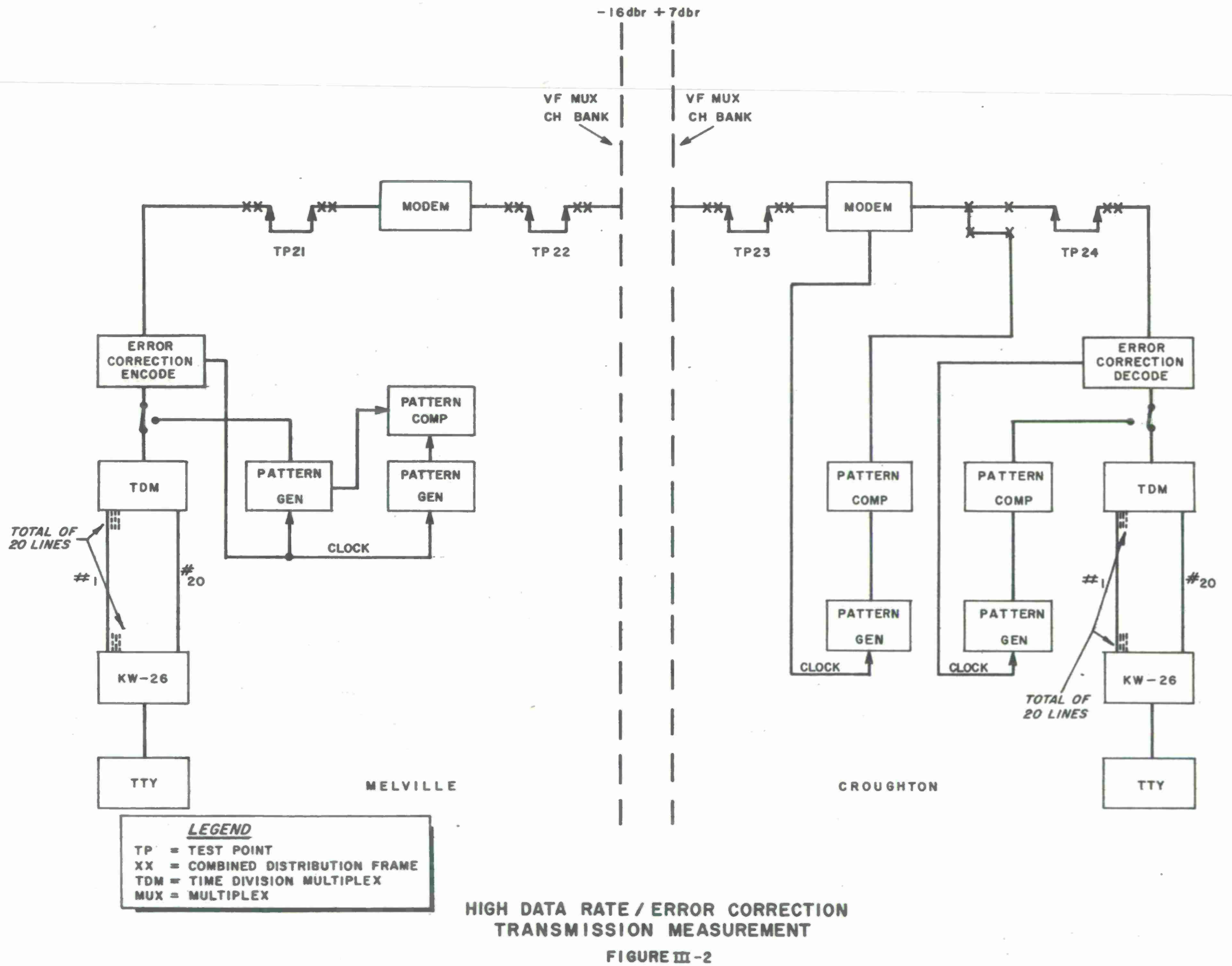
7.0 SPECIFIC TEST PROCEDURES - CROUGHTON

7.1 FREQUENCY RESPONSE MEASUREMENTS

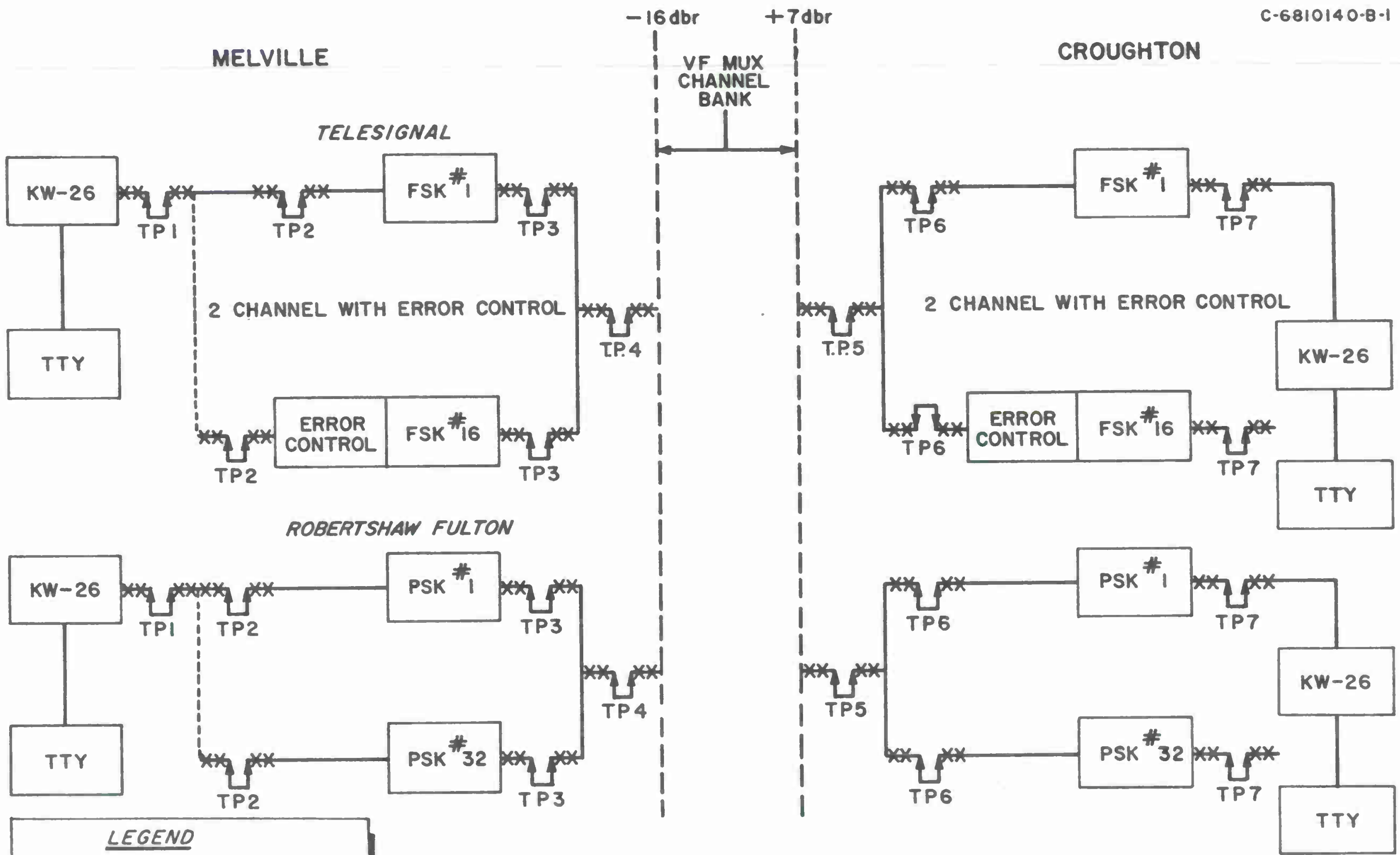
These measurements will be made daily before beginning the data or teletype tests and will be performed on all channels assigned to the test program.

7.1.1 Equipment Required

Hewlett-Packard 400L Log Voltmeter.



HIGH DATA RATE / ERROR CORRECTION
TRANSMISSION MEASUREMENT
FIGURE III-2



LEGEND

PSK = PHASE SHIFT KEYING
FSK = FREQUENCY SHIFT KEYING
XX = COMBINED DISTRIBUTION FRAME
MUX = MULTIPLEX
TP = TEST POINT

FSK-FSK/ERROR CONTROL-PSK TELETYPE TRANSMISSION MEASUREMENTS

FIGURE III-3

7.1.2 Measurement Technique

Step 1: Connect the 400L to the receive jack of the circuit under test.

Step 2: Melville will send a test tone at 1000 cps. Adjust and align the multiplex equipment to produce the correct receive level of +7 dbm.

Step 3: The frequency of the tone will then be varied between 300 and 3400 cps at Melville in accordance with instructions of the Croughton team chief. Readings are to be recorded specifically at frequencies of 300, 400, 600, 800, 1000, 1500, 2000, 2500, 3000, 3200, 3300, and 3400 cps and at the top and bottom of any peaks or valleys.

If necessary, a re-run should be asked for in order to permit complete data to be taken.

Note: Record the data for this test on the attached form and record the time and date together with the recording engineer's signature. Space is provided for comments.

7.2 RELATIVE DELAY DISTORTION MEASUREMENTS

These measurements will be made daily before beginning the data or teletype tests and will be performed on all channels assigned to the test program.

7.2.1 Equipment Required

Delay Distortion Measuring Set (DDMS) Receiver

7.2.2 Measurement Technique

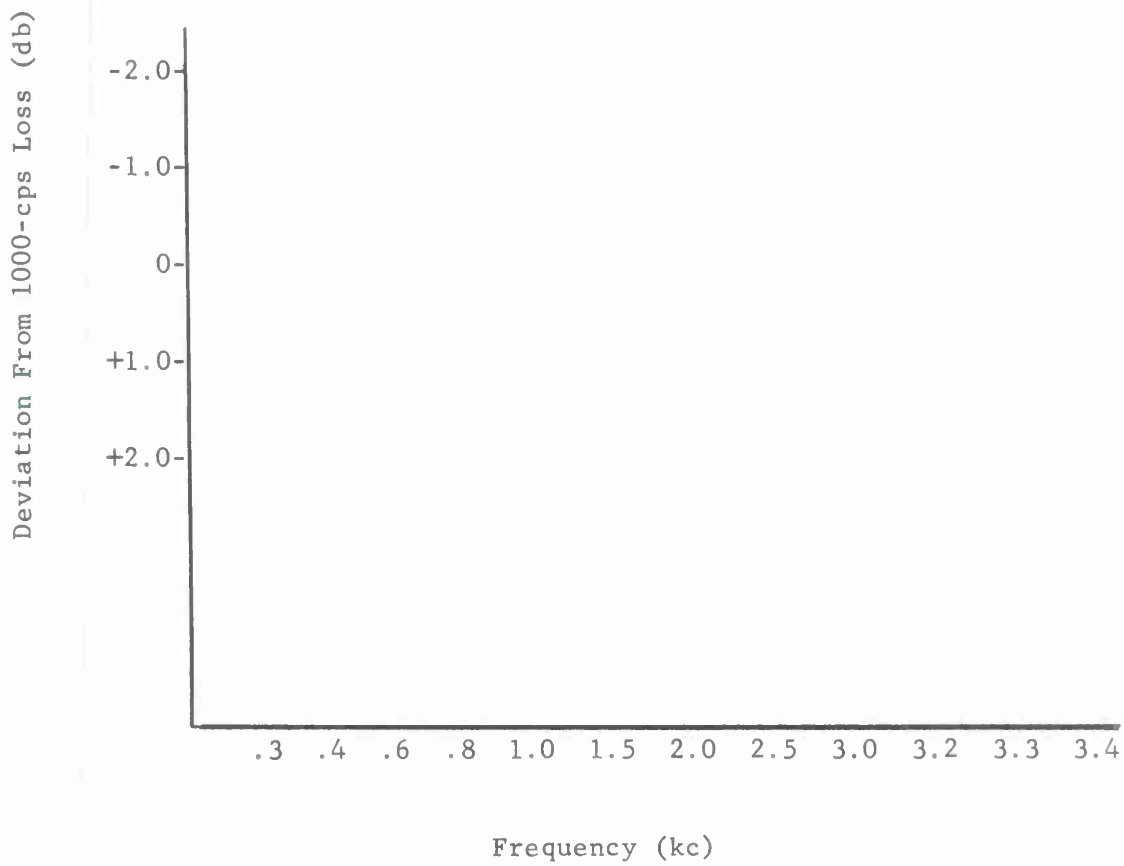
Step 1: Set up the DDMS receiver according to the manual of instructions for the equipment and connect it to the receive jack of the circuit under test.

Step 2: When Melville has completed its test set-up, proceed with the measurement technique as described in the manual of instructions.

Step 3: Readings are to be taken at frequencies of 300, 400, 600, 800, 1000, 1500, 2000, 2500, 3000, 3200, 3300, and 3400 cps and at the top and bottom of any peaks or valleys.

Note: Record the data for this test on the attached form and record the time and date together with the recording engineer's signature. Space is provided for comments. The Croughton team chief will make every effort to obtain four channels of similar characteristics for the TTY multiplex tests. Large differences in characteristics cannot be tolerated.

FREQUENCY RESPONSE - CROUGHTON



Channel No.:

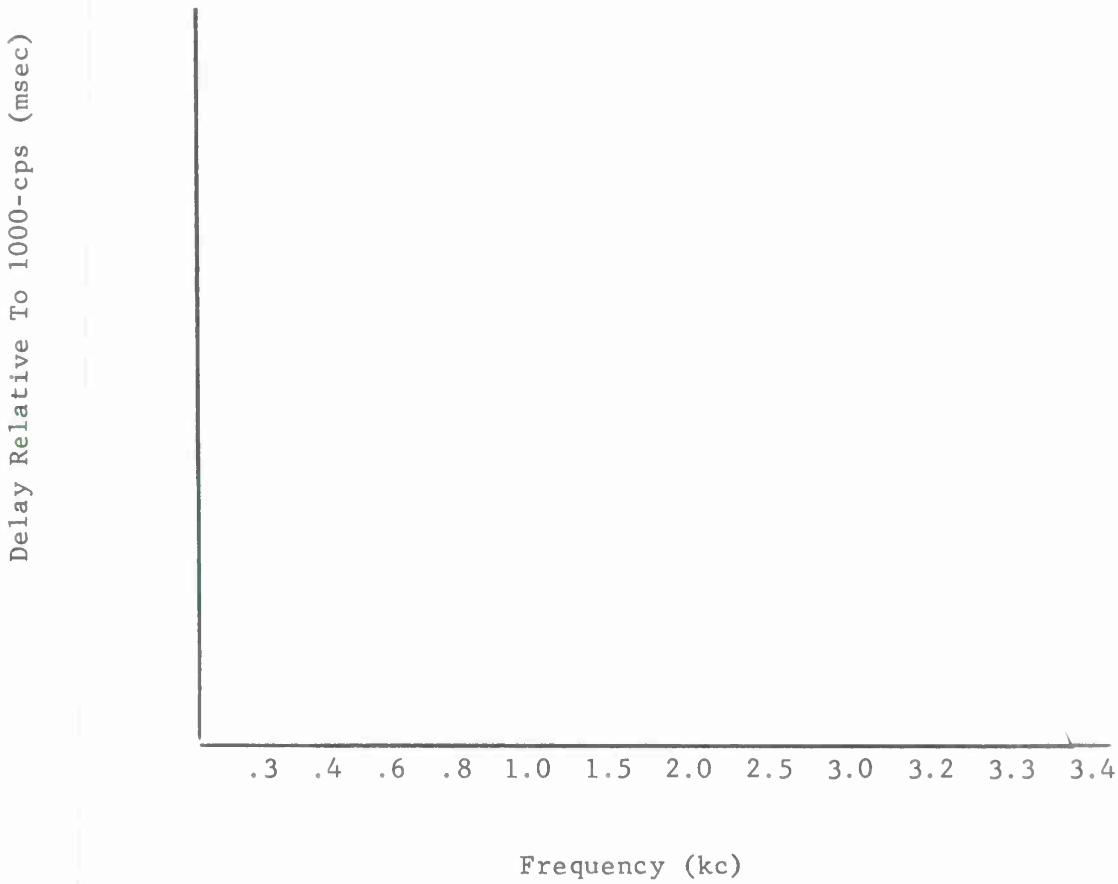
Date: Time:

____

Engineer

Comments:

RELATIVE DELAY DISTORTION - CROUGHTON



Channel No:

Date: Time:

____
Engineer

Comments:

7.3 TONE STABILITY AND CHANNEL NOISE MEASUREMENTS

These measurements will be made daily in conjunction with the TTY tests during periods of poor teletype performance as determined by the Croughton team chief and will be a minimum of one reel of tape per day. (See Note below and Figure III-1.)

7.3.1 Equipment Required

(a) Ampex Stereo Tape Recorder

(b) Hewlett-Packard 400L Log Voltmeter

(c) Strip-Chart Recorder

(d) 2300-cps Tone (available in station)

(e) 1000-cps Tone (available in station)

(f) 2300-cps Active Filter

7.3.2 Measurement Technique

When conditions make the teletype performance poor, proceed as follows:

Step 1: Calibrate the tape recorder by inserting a -3 dbm, 2300-cps tone into track A of the recorder through the 2300-cps filter and a -3 dbm, 1000-cps tone into track B of the recorder. Adjust the record level controls until the recorder will record both tones when they are varied in levels from -45 dbm to -3 dbm. Record two minutes of the -3 dbm levels simultaneously. Precede the recording with an announcement of the time and date of the test on track A of the recorder.

Step 2: Utilizing the 400L Log Voltmeter, adjust the multiplex and 4-wire equipment so that the 2300-cps tone transmitted from Melville is received at Croughton at a level of -10 dbm0 (-3 dbm at the 4-wire point).

Step 3: Utilizing the 400L Log Voltmeter, adjust the multiplex and 4-wire equipment so that the 1000-cps test tone transmitted at Melville is received at a level of 0 dbm0 (+7 dbm at the 4-wire point).

Step 4: Connect track A of the recorder through the 2300-cps filter to the channel containing the 2300-cps tone.

Step 5: After Melville has removed the 1000-cps tone from the other channel, connect track B of the recorder to this channel.

Step 6: Start the recorder and continue recording until the tape reel is exhausted. Be sure to identify the individual tape reel boxes to permit cataloging and selection at a later date.

Note: Upon completing the recorder calibration and time and date announcements, the test recording will begin simultaneously with the marking of all TTY page printer and reperforator copies with time and date to indicate the start of the tape recording tests. Ensure that sufficient paper is available in each TTY page printer and reperforator to last for the duration of any tape recording. At the conclusion of the tape recording, all page printers and reperforators will be marked with time and date to indicate the conclusion of the tape recorder tests.

During the first few days of testing there may be some uncertainty as to the identification of periods of poor teletype transmission. It will therefore be necessary to play back tape recordings into the strip-chart recorder of the MIT Lincoln Labs equipment so that comparisons may be made of the various tapes, and, in this manner, a determination can be made as to the time of day best suited to make the recording. Once this has been established, it is advisable to play back samples of daily tape recordings to ensure that it is still the best time to make the recordings. Additional supporting information should be obtained from the TTY page printer copies and the signal dropout and error indicating equipment of the Lincoln Labs ADDER.

If the TTY equipment should fail during a recording period, the recording should be stopped. All page printer copies will be marked when the equipment fails, and an announcement will also be made on track A of the tape recorder giving the time and reason for stopping the tests. If sufficient unused tape remains on the reel to permit about 30 minutes of recording, re-start the recorder and follow the procedures from Step 1 onwards, after the TTY equipment has been repaired. Be sure to identify the tape reel box appropriately. If insufficient tape is left, store the reel like any other fully recorded reel.

7.4 DATA ERROR RATE MEASUREMENTS

These tests will be performed daily in conjunction with the TTY tests described in paragraph 7.5.

7.4.1 <u>Equipment Required</u>

(a) MIT Lincoln Labs ADDER test equipment

(b) Strip-Chart Recorder

7.4.2 Measurement Technique

Step 1: Connect equipment as shown in Figure III-1.

Step 2: Complete self-check operations of test equipment in accordance with the MIT Lincoln Labs instruction manual.

Step 3: Attach the strip-chart recorder to the appropriate output of the ADDER equipment to record the receive signal level in accordance with the ADDER instruction manual. Indicate time of start and stop, ten-minute interval marking, and the date on each strip-chart recording.

Step 4: Record errors by utilizing the ADDER indicating devices. As the ADDER indicating devices consist of a punched tape output and signal dropout indicator, close observation of the ADDER outputs is mandatory to permit evaluation of any equipment failures that produce excessive and irrelevant errors. The ADDER strip-chart recorder gives an indication of signal dropout conditions. Record the data on the attached form and use it as a check list.

Note: A circuit degradation or partial failure affecting all channels in the transmission system between Melville and Croughton will probably become apparent first on the ADDER equipment, as there will be a sudden increase in the amount of tape being punched. A check of all TTY tests and this data test must be made to ascertain the nature of the trouble encountered.

If the TTY equipment is producing no errors or only occasional errors, and this data test indicates continuous errors, the TTY tests will continue while corrective action is taken to restore this test set-up.

If all equipments are showing continuous errors, mark all page printer and reperforator copies and the ADDER data sheet to indicate the time at which the condition first appeared. While tracking down the cause of the trouble, all equipment will remain in operation. When the condition is cleared up, and normal operation is restored, mark all page printer and reperforator copies and the ADDER data sheet to indicate the time at which restoral took place. An entry will also be made in the log book indicating the nature of the trouble encountered and the corrective action taken.

DATA ERROR RATE MEASUREMENTS

Time	Excessive Tape Condition	No. of Signal Dropouts

7.5 TELETYPE TRANSMISSION MEASUREMENTS

7.5.1 Equipment Required

(a) 2 Digital Pattern Generators

(b) 2 Digital Pattern Comparators

(c) 1 Type 545 Tektronix Dual-Beam Scope, 0-15 mc

(d) 1 0-1 mc Frequency Counter

(e) 1 Hewlett-Packard 400L Log Voltmeter

(f) 6 TTY Page Printers with Automatic Carriage Return and Line Feed

(g) 6 KW-26 Crypto Equipment

(h) 6 TTY Tape Reperforators

7.5.2 Measurement Technique

Step 1: Ensure that the equipment connections are as shown in Figures III-2 and III-3. The various manufacturers' representatives will specify the connections to their respective equipments.

Step 2: Align and adjust the KW-26 crypto equipments and TTY reperforator and page printer equipments for 61.12 bps, polar, KW-26 6/6 mode operation. Remove hammers of letters R and Y from the page printers or otherwise disengage R and Y hammers.

Step 3: Test digital pattern generators by comparing the output of two pattern generators with a pattern comparator.

Step 4: Connect a digital pattern comparator to the input of the Codex decoder specified by Codex Corporation personnel. Connect the 1222.75-bps digital timing output from the decoder into a digital word generator that is set to deliver 0001010110011110. Connect the output of the pattern generator to the pattern comparator. This test set-up will check the signal being supplied to the decoder prior to error correction. This step requires a pattern generator connection to the TDM or encoder at Melville that is set for the identical pattern output.

Step 5: Connect a digital pattern comparator to the output of the Codex decoder as directed by Codex Corporation personnel. Connect the 1222.75-bps digital timing output from the decoder into a digital pattern generator that is set to deliver 0001010110011110. Connect the output of the pattern generator to the pattern comparator. This test set-up will eheck the signal being supplied by the decoder after the error correction is made.

Step 6: Connect the KW-26's and TTY page printers to each of the teletype multiplex equipments. (See Figures III-2 and III-3.)

Step 7: Codex, Robertshaw Fulton, and Tele-Signal Corporation personnel will align and adjust their equipment for optimum operation.

Step 8: The reception of the test message from Melville will result in the following print-out on the page printer copies:

```
1              E
2              E
3              E



9              E
Ø              E
3 Line Feeds, etc.
```

Any characters or figures appearing on the page printer other than the numerics indicating the start of a line, or the character E indicating the end of a line, will, of course, be in error. Since the R and Y hammers have been disabled, the 4 and 6 also will not print.

7.5.3 Schedule of Events

During the one-hour period before tests begin, preliminary channel measurements, equipment checks, and alignments and synchronization adjustments will be made.

8.0 SPECIFIC TEST PROCEDURES - MELVILLE/GOOSE BAY

8.1 FREQUENCY RESPONSE MEASUREMENTS

These measurements will be made daily before beginning the data or teletype tests and will be performed on all channels assigned to the test program.

8.1.1 Equipment Required

(a) Variable Frequency Oscillator (VFO) (300 to 3400 cps)

(b) Hewlett-Packard 400L Log Voltmeter

8.1.2 Measurement Technique

Step 1: Connect the VFO to the send jack (at the four-wire point) of the circuit under test and adjust the output of the VFO to 0 dbm0 (normally -16 dbm at the four-wire point) at 1000 cps.

Step 2: When the team at Croughton has adjusted their measuring equipment vary the VFO frequency slowly from 300 cps to 3400 cps, keeping the output level of the VFO constant.

Step 3: Readings will be taken at Croughton at frequencies of 300, 400, 600, 800, 1000, 1500, 2000, 2500, 3000, 3200, 3300 and 3400 cps and at the top and bottom of any peaks or valleys. If necessary a particular run should be repeated to permit complete data to be taken.

Note: The VFO will be varied at Melville in accordance with instructions received over the order-wire from the team chief at Croughton.

8.2 RELATIVE DELAY DISTORTION MEASUREMENTS

These measurements will be made daily before beginning the data or teletype tests and will be performed on all channels assigned to the test program.

8.2.1 Equipment Required

Delay Distortion Measuring Set (DDMS) Transmitter

8.2.2 Measurement Technique

Step 1: Set up the DDMS transmitter according to the manual of instructions for the equipment and connect it to the send jack of the circuit under test and adjust the output of the transmitter to 0 dbm0 (normally -16 dbm at the four-wire point).

Step 2: When Croughton has completed their test set-up, proceed with the measurement technique as described in the manual of instructions.

Step 3: Readings will be taken at frequencies of 300, 400, 600, 800, 1000, 1500, 2000, 2500, 3000, 3200, 3300 and 3400 cps and at the top and bottom of any peaks or valleys.

Note: Record data on the attached form for this test and record time and date together with the recording engineer's signature. Space is provided for comments. The Croughton team chief will make every effort to obtain 4 channels of similar characteristics for the TTY multiplex tests. Large differences in characteristics cannot be tolerated.

8.3 TONE STABILITY AND CHANNEL NOISE MEASUREMENTS

These measurements will be made daily in conjunction with TTY tests during periods of poor teletype performance as directed by the Croughton team chief (see note below and Figure III-1).

8.3.1 Equipment Required

(a) 1000-cps test tone (available in station)

(b) 2300-cps tone (available in station)

(c) Hewlett-Packard 400L Log Voltmeter

8.3.2 Measurement Technique

Step 1: Insert the 1000-cps test tone on a selected channel assigned to the test program at a level of 0 dbm0 (-16 dbm at the four-wire point).

Step 2: Insert the 2300-cps tone on a selected channel assigned to the test program at a level of -10 dbm0 (-26 dbm at the four-wire point).

Step 3: When Croughton has calibrated the tape recorder, remove the 1000-cps test tone and terminate this channel in 600 ohms.

Note: Step 3 will be performed only when directed by the Croughton team chief. At all other times both the 1000-cps and 2300-cps tones will remain connected to the assigned channel.

8.4 DATA ERROR RATE MEASUREMENTS

These tests will be performed daily for periods to be determined by the Croughton team chief in conjunction with the TTY tests described in paragraph 8.5

8.4.1 Equipment Required

(a) MIT Lincoln Labs ADDER Test Equipment

(b) 2 Digital Pattern Generators

(c) 1 Digital Pattern Comparator

8.4.2 Measurement Technique

Step 1: Connect equipment as indicated in Figure III-1.

Step 2: Complete self-check operations of test equipment in accordance with the MIT Lincoln Labs instruction manual.

Step 3: Send a 1200 bps repetitive pattern 000101011001110. This will be the test signal that will be analyzed at Croughton. A periodic check will be made of the pattern generator output by interconnecting the pattern comparator and another word generator as shown in Figure III-1. In addition the signal will be monitored occasionally at TP 11 and TP 14 to ensure proper waveform and level.

8.5 TELETYPE TRANSMISSION MEASUREMENTS

All tests will be performed daily, for at least 20 days between 15 January and 28 February 1964. The daily test period will be between 0600Z and 2000Z.

8.5.1 Equipment Required

(a) 2 Digital Pattern Generators

(b) 1 Digital Pattern Comparator

(c) 1 Type 545 Tektronix Dual-Beam Oscilloscope,0-15 mc

(d) 1 Hewlett-Packard 400L Log Voltmeter

(e) 6 TTY Tape Reperforators

(f) 6 TTY Transmitter Distributors

(g) 6 KW-26 Crypto Equipments

(h) 1 0-1 mc Frequency Counter

8.5.2 Measurement Technique

Step 1: Ensure that the equipment connections are as shown in Figures III-2 and III-3. The various manufacturers' representatives will specify connections to their respective equipments.

Step 2: Align and adjust the TTY and crypto equipment for 61.12 bps, polar, KW-26 6/6 mode operation. The signal must be free of all bias, start-stop, and fortuitous distortion; that is, each bit will be 16.36 milliseconds in duration at the output of the KW-26.

Step 3: Test the digital pattern generators by comparing the output of two pattern generators with a pattern comparator. Set the pattern generator to provide 0001010110011110 to the input of the TDM or encoder specified by Codex Corporation personnel.

Step 4: Connect the output of the KW-26's to the respective TTY transmission equipments and send the RY test message that has been provided. A simultaneous start should be made on all test circuits.

Note: The test tapes that have been provided are made of Mylar and should withstand considerable usage. The tapes will be looped to provide continuous operation and the output of the transmitter distributors should be checked occasionally during periods where voice channel interchanges are being made. The test message is as follows:

1 RYRYRY---------------------------RYRYE

2 RYRYRY---------------------------RYRYE

9 RYRYRY---------------------------RYRYE

Ø RYRYRY---------------------------RYRYE

3 Line Feeds

1 RYRY, etc.

8.5.3 Schedule of Events

(a) During the one-hour period before tests begin, preliminary channel measurements, equipment checks and alignments, and synchronization adjustments will be made. As soon as all equipments are operating properly, and as soon as relevent data is being recorded, begin test-for-record.

(b) Time Zero - Indicate that tests-for-record have started.

APPENDIX IV

ADDER DATA

(To be issued when available)

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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VOL II, FINAL REPORT

5. AUTHOR(S) (Last name, first name, initial)

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10. AVAILABILITY/LIMITATION NOTICES

QUALIFIED REQUESTORS MAY OBTAIN COPIES FROM DDC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY DEP FOR COMM SYSTEMS MGMT (ESN) HQS ESD L.G. HANSCOM FLD., BEDFORD, MASS. 01731

13. ABSTRACT

In July 1963, the Deputy for Communication Systems, ESD, requested an engineering study in support of the North Atlantic Teletype Program. This program is to provide TTY circuits between North American and Europe over the U.S. Government wholly owned and operated multi-channel communication system between Melville, Labrador (near Goose Bay) and Croughton, UK. This report is an engineering study which involves two areas, namely:

(a) An engineering study that will delineate the relative performance and procurement costs to be expected from a cross-section of teletype multiplex transmission techniques.

(b) An engineering study of the performance of the transmission media between Melville and Croughton.

DD FORM 1 JAN 64 1473

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
COMMUNICATIONS TELETYPE MULTIPLEX TRANSMISSION CIRCUIT RADIO FREQUENCY CABLE DATA PERFORMANCE						

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