UNCLASSIFIED

AD NUMBER
ADB002666
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; JAN 1975. Other requests shall be referred to Rome Air Development Center, Attn: DCCW, Griffiss AFB, NY 13441.**
AUTHORITY
RADC ltr, 12 Aug 1976

THIS PAGE IS UNCLASSIFIED

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

RADC-TR-74-329
Final Report
January 1975

MILLIMETER WAVE COMMUNICATIONS PROGRAM: LINK TESTS OF HIGH SPEED DIGITAL RADIO SET AN/GRC-173(XW-1)

Raytheon Company

Distribution limited to U. S. Government Agencies only; Test and Evaluation; January 1975. Other requests for this document must be referred to RADC (DCCW), Griffiss AFB, NY 13441.

Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York 13441

This report has been reviewed and approved for publication.

APPROVED: Hugh N. Siegel

HUGH N. SIEGEL
Project Engineer

APPROVED: Fred I. Diamond

FRED I. DIAMOND
Technical Director
Communications and Navigation Division

FOR THE COMMANDER: Carlo P. Crocetti

CARLO P. CROCETTI
Chief, Plans Office

Do not return this copy.
Retain or destroy.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
RADC-TR-74-329

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
MILLIMETER WAVE COMMUNICATIONS PROGRAM; LINK TESTS OF HIGH SPEED DIGITAL RADIO SET AN/GRC-173 (XW-1)

5. TYPE OF REPORT & PERIOD COVERED
Final (3rd Phase)
1 July 1973 - 31 May 1974

6. PERFORMING ORG. REPORT NUMBER
None

7. AUTHOR(s)
Stanley J. Kapuscienski, Richard F. Hazel,
Fredric J. Talmanson, Ralph E. Shepherd

8. CONTRACT OR GRANT NUMBER(s)
F30602-70-C-0063

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Raytheon Company
Boston Post Road
Wayland MA 01778

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Program Element 33112F
JO #11500101

11. CONTROLLING OFFICE NAME AND ADDRESS
Rome Air Development Center (DCCW)
Griffiss Air Force Base, NY 13441

12. REPORT DATE
January 1975

13. NUMBER OF PAGES
180

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Same

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
N/A

16. DISTRIBUTION STATEMENT (of this Report)
Distribution limited to U.S. Government Agencies only; test and evaluation, January 1975. Other requests for this document must be referred to RADC (DCCW) GAFB, NY 13441.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
Same

18. SUPPLEMENTARY NOTES
Report on operational test and evaluation of high capacity digital EHF Radio Equipment.
RADC Project Engineer: Hugh N. Siegel (DCCW)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Communications
High Capacity Digital Equipment
Data Transmission
Time Division Multiplexing
EHF
Millimeter Waves
Radio Set AN/GRC-173(XW-1)
Wideband Systems
TV Transmission

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report presents the results of field testing of the AN/GRC-173(XW-1) Radio Set in the Washington, D.C. area. The field testing was conducted to determine the performance characteristics of this wideband millimeter wave digital radio equipment in a typical link configuration. The duplex link operated at 36.6 and 37.6 GHz between sites selected at the Pentagon and a building adjacent to the Washington Navy Yard (WNY). Helicopter lift of the equipment shelters and antenna to the rooftops of these buildings aided in the

20. ABSTRACT (cont'd)

rapid deployment of the link. The two radio sets which were utilized in these tests were the same ones as studied, designed and fabricated under Phase I (feasibility study) and Phase II (development) of this program. Units of the equipment had run between 4500 and 7400 hours through the period of the tests, attesting to a high degree of reliability. System tests on Phase III utilized both wideband and narrowband baseband equipment to interface with the AN/GRC-173(XW-1). A feature of these tests was the digital transmission of high resolution (1025 line) television over the link. Delta modulation type analog-to-digital and digital-to-analog converters were used in coding and decoding the signals at a 80 Mb/s rate. Low speed data at approximately 50 Kb/s was also communicated over the link. The TV test demonstrated the use of a substantial portion of the radio set's 236 Mb/s capacity. The link was shown to be a noninterfering channel for the transmission of the high resolution TV images. The Phase III tests also included demonstration of margin sufficient to communicate over the specified 10 km (6.2 mile) design range when required to do so. Test equipment (variable attenuation) aided this test since the distance of 4.4 km (2.73 mi) between the selected sites was less. Error rate measurements were made for the first time with the radios propagating over a line of sight path. The measured probability of error was lower than 10^{-6}. Relay operation was simulated by including tests where one of the terminals had the received and decoded data looped back through the transmitter for transmission to the originating terminal. Propagation data established the capability of the radio set to operate under a variety of weather conditions, including rainfall, snow, and fog. Measurements showed that the path availability for the link was greater than 99.9% for a three-month period of taking propagation data. The general conclusion drawn from the test program is that the AN/GRC-173(XW-1) millimeter wave radio set can reliably fulfill its intended design function of line of sight communications of wideband signals.

EVALUATION MEMO

This final report on the third phase of the millimeter wave contract covers the unique problems, installation and operational testing of Radio Sets AN/GRC-173(XW-1), which were built for, and delivered to, the Defense Communications Agency in mid-1973. The work accomplished was in response to Defense Communications System requirements of DCA Task 69-R&D-6, as outlined in Appendix 9 of DCA/DCS Plan 70-80(U), Volume II.

These equipments have been in service since October 1973 to satisfy RADC test requirements while simultaneously serving as a test bed for digital data transmission of graphics, video and voice.

The electrical and propagational reliability of this experimental, quasi-militarized, system has been very satisfactory and it has been demonstrated that the basic performance requirements have been met adequately. It is obvious that the wideband, short haul, capability demonstrated here has only special application although recent observations indicate that the digital millimeter radio field now has been entered by several competitive manufacturers and users, where initially there were very few. This was the major intent of DCA in the first place, back in 1968; namely, to stimulate interest and technical progress toward the fully digital communications systems of the future. This millimeter wave communications program has served that end very satisfactorily.

Hugh N. Siegel

HUGH N. SIEGEL
Electronics Engineer (DCCW)

FOREWORD

This report covers work done on Phase III of the "Millimeter Wave Communications Program" for Rome Air Development Center, Griffiss Air Force Base, New York, under contract F30602-70-C-0063, Job Order Number 11500101, between 1 July 1973 and 15 February 1974. This report describes the installation, operational testing and evaluation of Radio Sets AN/GRC-173 (XW-1) and includes acceptance test results.

The testing described herein was performed in the Washington, D.C. area by engineering personnel of the Raytheon Company, Equipment Division, Wayland, Massachusetts with assistance from engineering personnel of the Raytheon Service Company, Burlington, Massachusetts. Principal investigators and authors were Stanley Kapuscienski, Richard Hazel, Fredric Talmanson and Ralph Shepherd. Thomas Joyce provided mechanical engineering support. Jeffrey Bram provided assistance in the analysis and reduction of propagation test data by means of computer.

The authors wish to acknowledge the assistance on various aspects of the program of the following Raytheon engineers and managers: Walter Connor, Terrence Kelly, John Mutty, Edward Rich, James Roche, William J. Smith, Carson Tsao, and David Trask.

Hugh N. Siegel (DCCW) was the RADC Project Engineer. The intensive effort and guidance of E. Phillips Grier, Sr. of the Defense Communications Agency, who provided individual assistance and directed a group of interested Washington, D.C. Government agency personnel in investigating the link characteristics, is furthermore sincerely acknowledged.

ABSTRACT

This report presents the results of field testing of the AN/GRC-173(XW-1) Radio Set in the Washington, D.C. area. The field testing was conducted to determine the performance characteristics of this wideband millimeter wave digital radio equipment in a typical link configuration. The duplex link operated at 36.6 and 37.6 GHz between sites selected at the Pentagon and a building adjacent to the Washington Navy Yard (WNY). Helicopter lift of the equipment shelters and antenna to the rooftops of these buildings aided in the rapid deployment of the link. The two radio sets which were utilized in these tests were the same ones as studied, designed and fabricated under Phase I (feasibility study) and Phase II (development) of this program. Units of the equipment had run between 4500 and 7400 hours through the period of the tests, attesting to a high degree of reliability. System tests on Phase III utilized both wideband and narrowband baseband equipment to interface with the AN/GRC-173(XW-1). A feature of these tests was the digital transmission of high resolution (1025 line) television over the link. Delta modulation type analog-to-digital and digital-to-analog converters were used in coding and decoding the signals at a 80 Mb/s rate. Low speed data at approximately 50 Kb/s was also communicated over the link. The TV test demonstrated the use of a substantial portion of the radio set's 236 Mb/s capacity. The link was shown to be a non-interfering channel for the transmission of the high resolution TV images. The Phase III tests also included demonstration of margin sufficient to communicate over the specified 10 km (6.2 mile) design range when required to do so. Test equipment (variable attenuation) aided this test since the distance of 4.4 km (2.73 mi) between the selected sites was less. Error rate measurements were made for the first time with the radios propagating over a line of sight path. The measured probability of error was lower than 10^{-6}. Relay operation was simulated by including tests where one of the terminals had the received and decoded data looped back through the transmitter for transmission to the originating terminal. Propagation data established the capability of the radio set to operate under a variety of weather conditions, including rainfall, snow and fog. Measurements showed that the path availability for the link was greater than 99.99% for a three-month period of taking propagation data. The general conclusion drawn from the test program is that the AN/GRC-173(XW-1) millimeter wave radio set can reliably fulfill its intended design function of line of sight communications of wideband signals.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (cont)

LIST OF ILLUSTRATIONS (cont)

LIST OF TABLES

SECTION I

INTRODUCTION AND SUMMARY

1. SCOPE

This report covers field testing of the AN/GRC-173 (XW-1) conducted during Phase III of a planned three-phase program. The AN/GRC-173 (XW-1) Radio Set is the result of a study and development program concerning the requirements for high capacity digital communications at millimeter wave carrier frequencies (References 1 and 2).

The radio operates at a data rate of 235.9296 Mb/s in the 36 to 38.6 GHz Government frequency band. The evaluation and testing of two of the radio sets in a link, which is described in this report, was conducted in the Washington, D.C. area from early August 1973, to mid-February 1974.

Technical details covered in this report include the data for measurements of error rate, transmission range, propagation variables and system message transmission capabilities with the radio sets operating in a link configuration. Documentation of installation and facility configuration is also included to assist in future applications. Earlier project technical reports cover the Phase I feasibility design study (Reference 3) and the Phase II development, fabrication and in-plant testing (Reference 4) of the Radio Sets.

2. THE AN/GRC-173 (XW-1)

A view of one of the radio sets installed for testing in Washington, D.C., is shown in Figure 1. The radio set configured for full duplex operation includes multiplexer, transmitter, modulator and demodulator (modem), receiver, demultiplexer and antenna system. The equipment is rack mounted in the shelter, with the adjacent antenna connected to it by waveguide. Figure 2 shows a simplified block diagram of the AN/GRC-173 (XW-1).

3. OBJECTIVES

The purpose of the tests was dual: (1) to demonstrate operational capability of the AN/GRC-173 (XW-1), and (2) obtain experimental data for wideband millimeter wave transmission systems.

The specific objectives of Phase III encompassed the following:

a. Feasibility of Wideband Millimeter Radio

To demonstrate the feasibility of low error rate, high speed digital transmission system operation in a typical Washington, D.C. environment with a line-of-sight millimeter wave radio.

See Section VII for list of References.

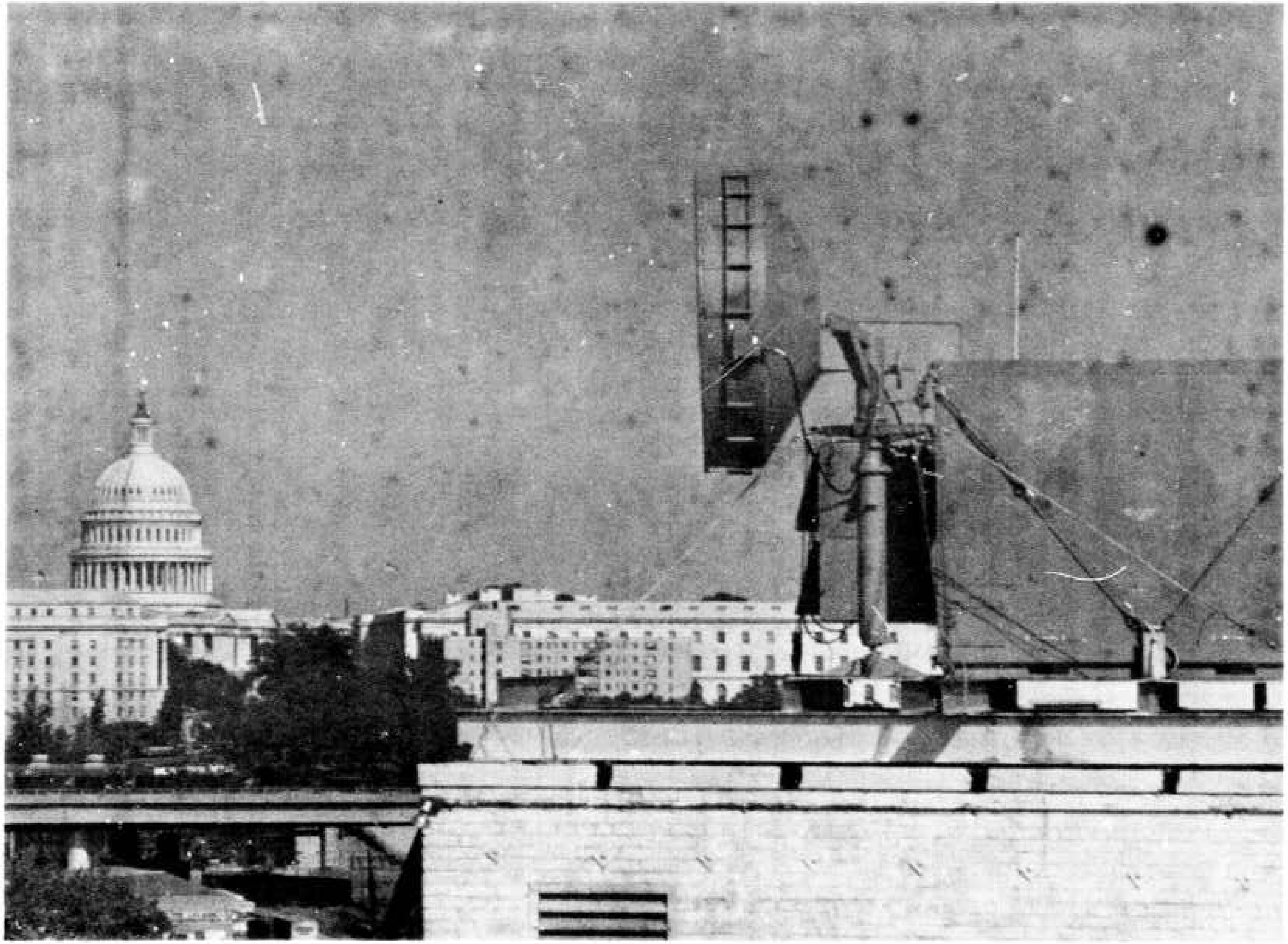


Figure 1. AN/GRC-173 (XW-1) Installed in Washington

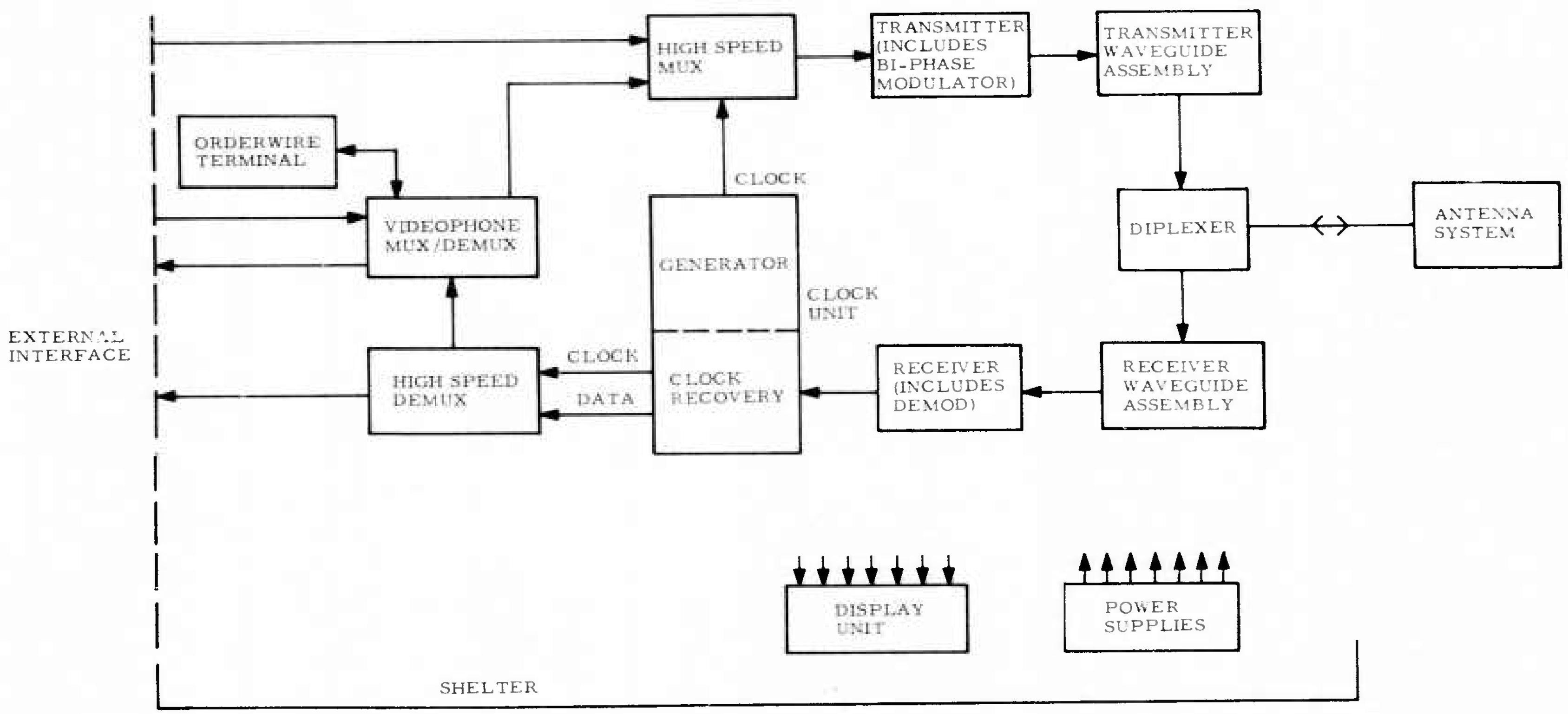


Figure 2. Block Diagram of AN/GRC-173 (XW-1)

b. Range Performance

To demonstrate that the AN/GRC-173 (XW-1) transmitting at a data rate of 235.9296 Mb/s can be installed and operated when necessary between terminals having a separation of 10 kilometers (6.2 miles).

c. Error Rate Performance

To demonstrate the attainment of a probability of error in the link of $P_e = 10^{-6}$.

d. Communications Traffic Capability

To demonstrate a capability of operating with typical user terminal equipment such as digitized television (TV) and low speed multiplexers, by means of loading the AN/GRC-173 (XW-1) with actual or simulated data traffic.

e. Propagation

To obtain link propagation data relating signal attenuation to transmission path variables.

f. Terminal Types

To confirm that the equipment can be set up and operated as a relay terminal as well as an end terminal.

g. Order Wire

To evaluate the effectiveness of the built in voice order wire channel.

h. Operability

To evaluate equipment operability characteristics such as alarms, controls, transportability, reliability and maintainability.

4. RESULTS

The results of the field testing and evaluation are summarized below. Observations are noted separately corresponding to each of the objectives listed in Section 3, above.

a. Wideband Millimeter Radio Feasibility

In the representative Washington environment, the radios proved out their design function of high-speed digital signal communications at low error rate. The link was established on a line-of-sight between the rooftops of the Pentagon and a building at M and 1st Streets, which is contiguous with the Washington Navy Yard (WNY). The latter will be referred to in this report as the WNY station. The Pentagon station transmitter was operated at the millimeter wave frequency of 36.6 GHz and the WNY transmitter at 37.6 GHz. The Pentagon - WNY configuration was selected from among numerous other candidates (Reference 5) for several reasons, including availability of the facilities to the project and suitability of the locations for demonstration in a defense complex environment.

b. Range Performance

The Pentagon - WNY link was set up over a 4.4 km (2.73 mi) distance. The conclusion that the radio is capable of communicating over a 10-km design range was established by evaluating the results obtained at the shorter range. This was done in the traditional way of intentionally introducing the additional losses which will be experienced over a longer link by means of a variable attenuator. During demonstration, wideband digital traffic such as high resolution television was transmitted and found to be unaffected. The tests, together with link budget analysis, confirm the ability to meet performance requirements at the extended range of at least 10 km whenever there is a future need to do so.

c. Error Rate Performance

On Phase III, measurements of the bit error performance of the AN/GRC-173 (XW-1) were run for the first time over a line-of-sight link. Low error rates indicative of digital system capabilities were measured. Figure 3 shows a curve of the probability of bit error (P_e) over the link as a function of signal-to-noise ratio. This discloses that a $P_e = 10^{-6}$ for the link is obtained for S/N approximately 15 to 16 dB and $P_e = 10^{-8}$ for S/N approximately 17 to 18 dB. This is within 1 to 2 dB difference from the performance attained in back-to-back tests on Phase II.

d. Communications Traffic Capability

Interest in the radio set's capability for handling communications signals was high during Phase III with the link in place in Washington, D.C. Considerable time and effort were spent in the implementation of a capability to transmit high resolution imagery over the link via television. A series of tests were performed using the radio and Raytheon supplied breadboard analog-to-digital (A/D) encoder and digital-to-analog (D/A) decoder equipment, operating in conjunction with Government-furnished 1025 line TV camera and monitor equipment. The transmission and reception of TV was accomplished using two 40 MBPS channels of the AN/GRC-173 (XW-1) for a total transmitted signal of 80 MBPS. The digital link was shown to be a non-interfering channel for the video image by running quantitative control tests in the laboratory and then comparing the results when the link was used. The TV test was highly suited to the wideband transmission specification for which the AN/GRC-173 (XW-1) was designed and graphically portrayed the capability to transmit wide bandwidth data in real time. Figure 4 is a view of the received imagery on the TV monitor after transmission over the link. Besides wide bandwidth data, the sending of low-speed digital data over the link was also demonstrated using signals from a pattern generator operating between approximately 1 Kb/s and 1 Mb/s. This testing simulated operation of the AN/GRC-173 (XW-1) with source instruments such as the AN/GSC-24 or other low-speed digital sources. The low-speed

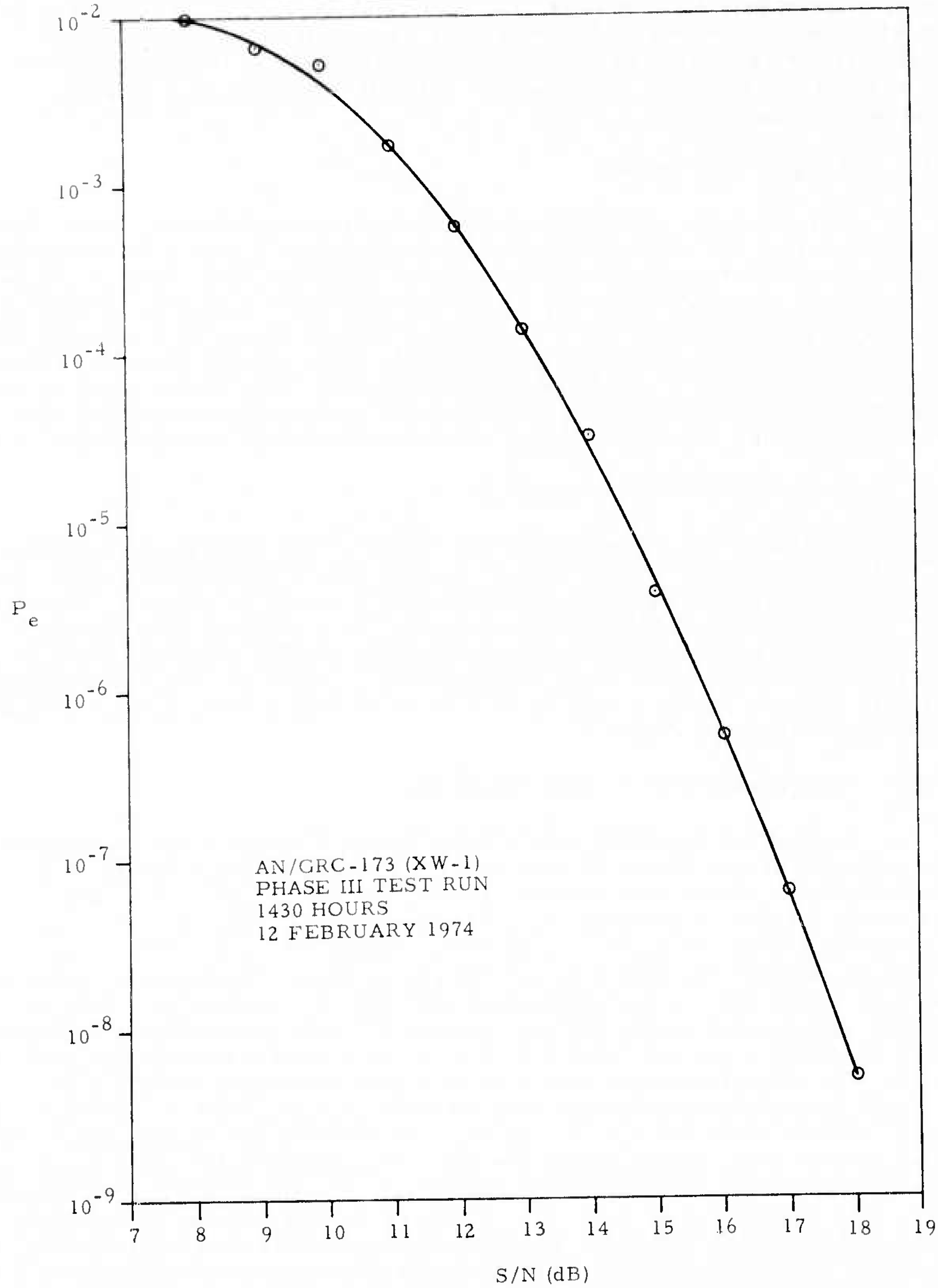


Figure 3. Typical Phase III Link Error Probability Curve

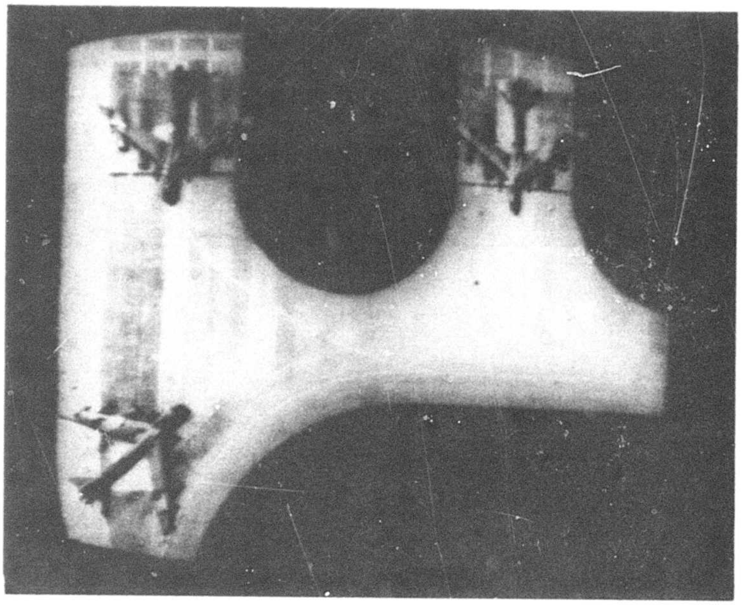


Figure 4. TV Monitor Display of Imagery Transmitted Over Link

data demonstration utilizes the 9.8 MBPS channel of the set's Videophone Mux Demux unit operating as a sampling mux and regenerator.

e. Propagation

Propagation tests demonstrated the high transmission system reliability of the AN/GRC-173 (XW-1) in Washington, D.C. Atmospheric conditions of rain, snow, fog and pollution which occurred during the test period provided a rigorous test of a millimeter wave link. Propagation testing was facilitated by recording rainfall rate data at the Pentagon, the WNY site, and at East Potomac Park (which is approximately midway between the two end terminals), and by recording received signal level as a function of time at the radio receivers. Propagation data recording was carried out for a three month period beginning in mid-November 1973 and ending in mid-February 1974. Signal strength recordings were obtained for 2054 hours out of the 2112 hours total in this period. It was not possible to obtain an estimate of the attenuation coefficient as a function of rainfall rate (dB/km per mm/hr of rain), since it was found that rain wetting the surface of the antenna cover (or radome) produced a loss whose effect could not be isolated by the instrumentation arrangement from that due to rain in the rest of the path. However, this result did not preclude obtaining of statistical data on total link propagation reliability. Figure 5 summarizes the statistical results of the measurements. showing the

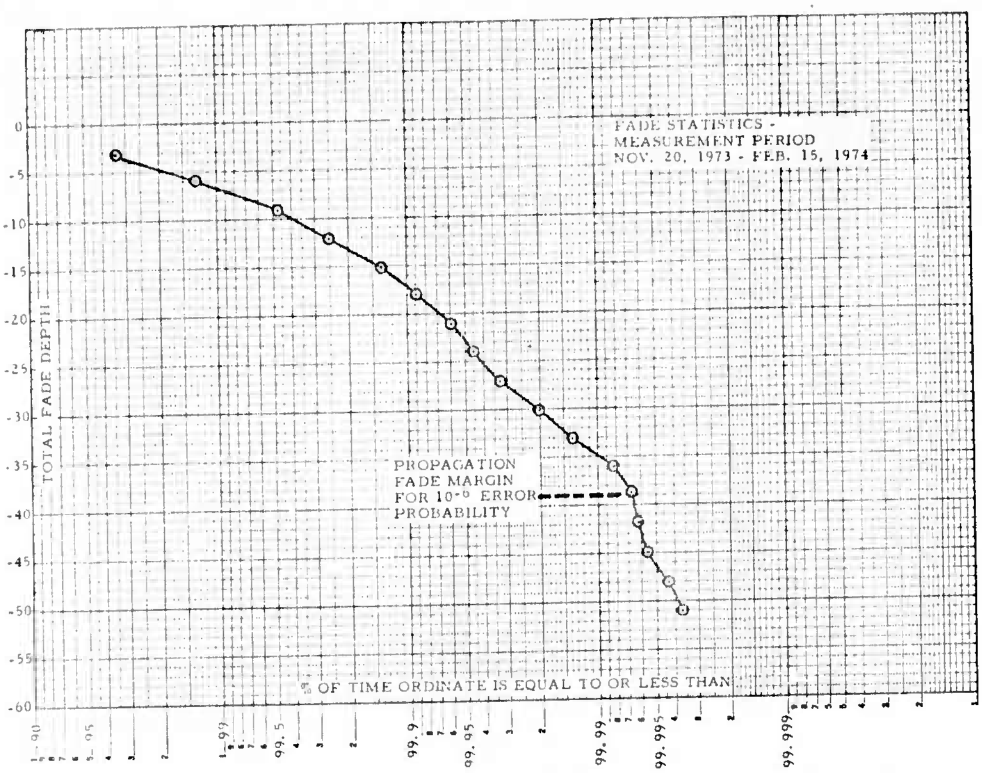


Figure 5. Propagation Fade Statistics Data

percentage of time for which a given fade depth occurred. For the system margin, rainfall produced only a single instance of communications outage of about five minutes duration during the recording period. The path availability for the link in this period was greater than 99.99 percent.

Besides propagation in the natural atmospheric variables, construction machinery (high cranes) was also encountered, and is an unusual operating condition for a microwave line-of-sight radio. Momentary fades up to approximately 10 dB could be produced by the cranes in or near the path line, but the loss was well within the system margin tolerance. This type of consideration will be entirely eliminated upon completion of the transportation system construction in the vicinity.

f. Terminal Types

The normal mode of operation of the radios, as set up in Washington, D.C., was a duplex terminal at each end. Each of the radios simultaneously communicated one with the other, and each served as an originating and ending point. However, for portions of the testing, the radio sets were operated in a "loop-around" configuration, wherein at the WNY terminal the received signal stream (which originated at the Pentagon) was patched back through the WNY radio set equipment for sending back to the Pentagon. This simulated relay operation without using an actual interposing terminal, and conserved program resources.

g. Order Wire

A minor test program objective, which was often demonstrated, was the effectiveness of the built-in order wire channel. It was used in operations such as assisting in link alignment and in controlling the sequence of TV pictorial data for transmission. A switchable phone-patch to other voice circuits was also implemented to demonstrate compatibility with external plant. The quality of the 30.5 Kb/s order wire voice communications (using a Continuously Variable Slope Delta (CVSD) modulator) over the link, was found to be suitable for the intended purpose.

h. Operability and Equipment Reliability

The obtaining of operability data on the AN/GRC-173 (XW-1) was an adjunct of the installation and test operations. The installation in itself included demonstrations of transportability via flatbed truck and helicopter (see Figure 6) and rapid erection of the antenna systems. The displays, alarms, and technical manual were proved suitable for installing, operating and maintaining the radio sets. Routine unattended operation was also proved.

Equipment problem areas were generally minimal. They included failures in the down-converter mixer and Avalanche Diode Oscillator, but not until after they had been used for several thousand hours. Re-establishment of the link could be rapid, based on the spares philosophy of module and card level replacement. Since spares were unavailable at the time of testing, field or factory repairs within a few days time were actually employed. More than 3000 hours operation in the link per-terminal (6000 hours total for both terminals combined) were logged up to 15 February 1974. (Note: some of the individual units of equipment had logged over 7000 hours each, when considering both Phase II and Phase III operations.) The reliability achievements are attributed mainly to the solid state configuration of the radio sets and the application of advanced technology in millimeter wave and digital system design.

5. GENERAL CONCLUSIONS

During Phase III, the two AN/GRC-173 (XW-1) Radio Sets developed and fabricated under Phase II were successfully installed and operated as a line-of-sight link in the Washington, D.C. area. These final operational and evaluation tests demonstrated reliable system performance for a high-capacity digital millimeter link and disclosed the utility of the radio for communication in a representative defense environment.

6. ORGANIZATION OF REPORT

Section II describes the radio set hardware and the auxiliary test equipment utilized in Phase III.

Section III gives information on the communications path and the sites at the Pentagon and the WNY.

Figure 6. Helicopter Lift of AN/GRC-173 (XW-1)

Section IV presents the details of the test data and the experimental results obtained during the testing period. This includes data on evaluation of transmission range, bit error probability, high and low-speed data transmission, and propagation testing.

Section V discusses data relative to transporting and installing the radio sets and presents equipment operating logs and reliability data.

Section VI presents the conclusions and recommendations derived from the Phase III operations.

Section VII lists the references used in this report.

The appendices contain additional data and analyses supporting the test phase requirements.

7. ADDITIONAL SCOPE

After the effort as outlined above was completed under the basic contract, an engineering change was implemented to cover an additional investigation from February 15, 1974 to May 31, 1974. A report on the effort during the extension period is included as an addendum at the back of this report. The main purpose of the engineering change was to operate and demonstrate the link using TV terminal equipment connected to the AN/GRC-173 (XW-1) radio from a remote demonstration area in the Pentagon. This effort was in addition to the initial TV digital communications link tests with the radio and TV equipment co-located in the shelters, as described in Section IV-5. The final report and the addendum are combined in a single permanent record in order to facilitate understanding of equipment and site configuration relationships in the supplementary effort.

SECTION II

EQUIPMENT USED IN TESTS

1. GENERAL

In this section, the AN/GRC-173 (XW-1) equipment used in the Phase III field tests is described, together with the test equipment (including peripheral terminal equipment) which was utilized to support the tests and demonstrations.

2. AN/GRC-173 (XW-1) EQUIPMENT

Information regarding the radio set needed to understand the test setups and results, is described in this section. Development and design type details may be obtained by referring to References 3 and 4.

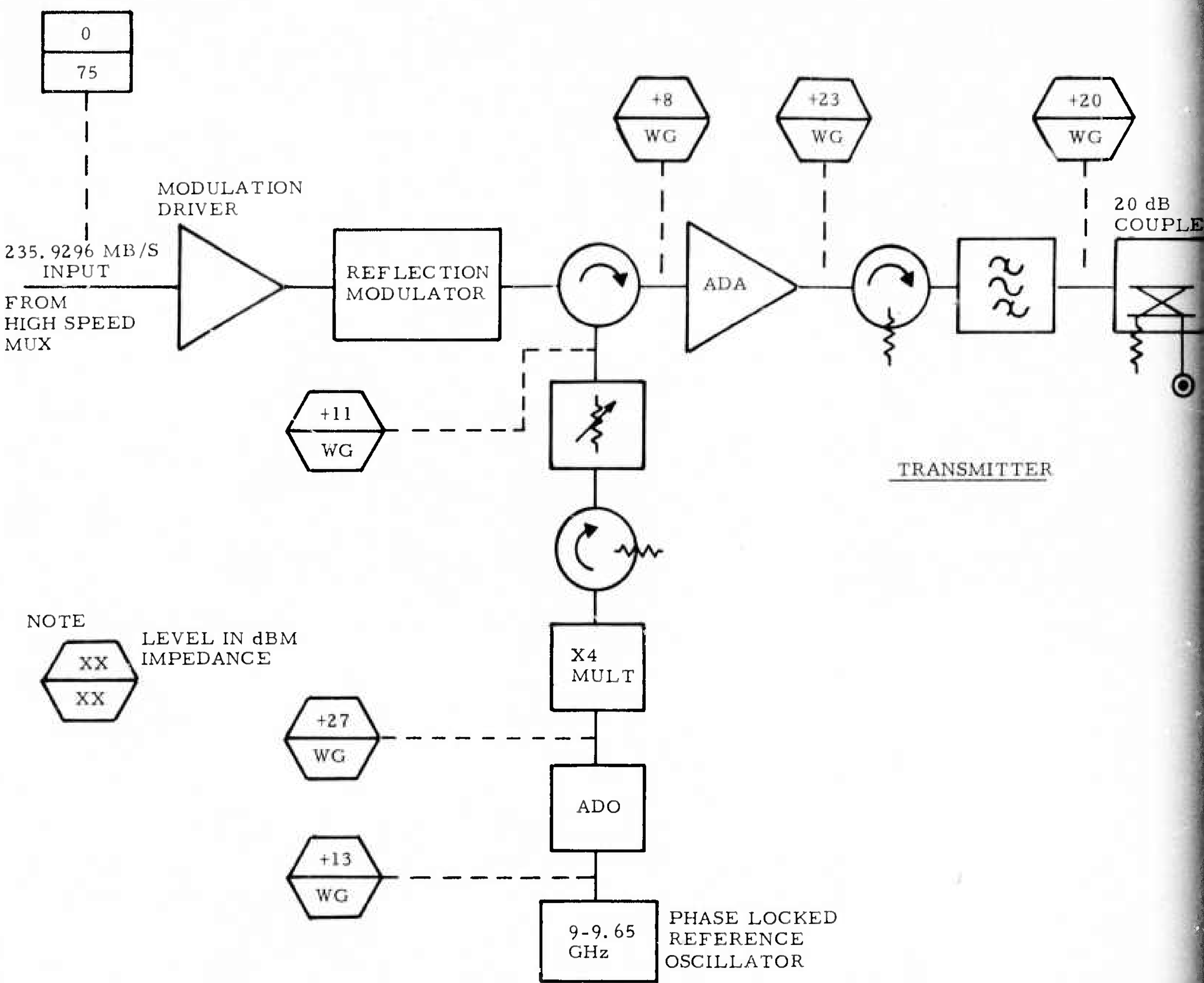
The AN/GRC-173 (XW-1) is an all solid state radio that combines time division multiplexing (TDM) and radio transmission and reception functions in one facility. It transmits signals at a 235.9296 Mb/s data rate in the 36 to 38.6 Government frequency band. An overall block diagram of the radio is shown in Figure 2. A block diagram of the transmitter and receiver is shown in Figure 7, and the digital multiplexing equipment is shown in Figure 8.

The equipment is integrally contained in a shelter, except for the parabolic dish and front-feed antenna system, which is mast-mounted adjacent to the shelter and connected to an rf input/output bulkhead via RG-96/U waveguide. Vertical polarization was used for the antennas in the link although horizontal polarization could as well have been employed. Digital data inputs and outputs of the radio are of the non-return to zero (NRZ) type. Data and clock line coaxial type connectors are included at the digital equipment units, as well as at a bulkhead on the shelter.

The AN/GRC-173 (XW-1) equipment employed in the Washington tests was designed and fabricated by Raytheon under Phase II of this contract (F30602-70-C-0063). Besides the two shelters, antennas, and radios actually employed in the link, there were four additional antennas and another shelter which were built under Phase II and shipped to the Washington area for storage for future use. Figure 9 presents the total equipment availability and usage.

Figure 10 is a view of the shelter interior details, including the rack-mounted radio and digital equipment. The exterior bulkhead for input and output connectors is shown near the door.

During the test period, the link was generally operated in the full duplex mode, simultaneously transmitting and receiving data signals. Thus, simultaneous two-way transmission was possible for any of the tests, unless limited by the availability of test equipment or terminal equipment for the particular test.


0
75
+8
WG
+23
WG
+20
WG
MODULATION
DRIVER
20 dB
COUPLE
235.9296 MB/S
INPUT
FROM
HIGH SPEED
MUX
REFLECTION
MODULATOR
ADA
+11
WG
TRANSMITTER
NOTE
XX
XX
LEVEL IN dBM
IMPEDANCE
X4
MULT
+27
WG
ADO
+13
WG
9-9.65
GHz
PHASE LOCKED
REFERENCE
OSCILLATOR

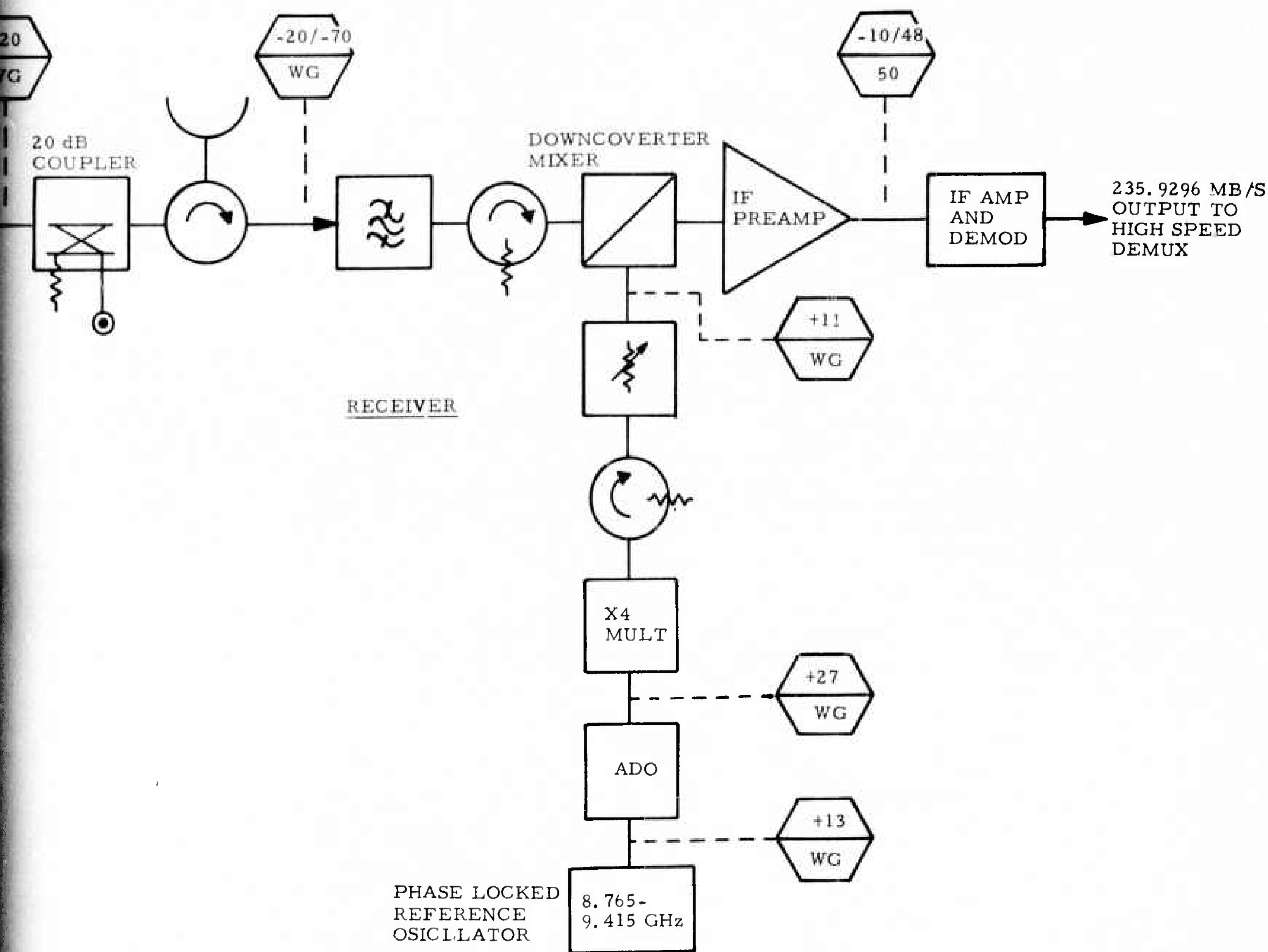
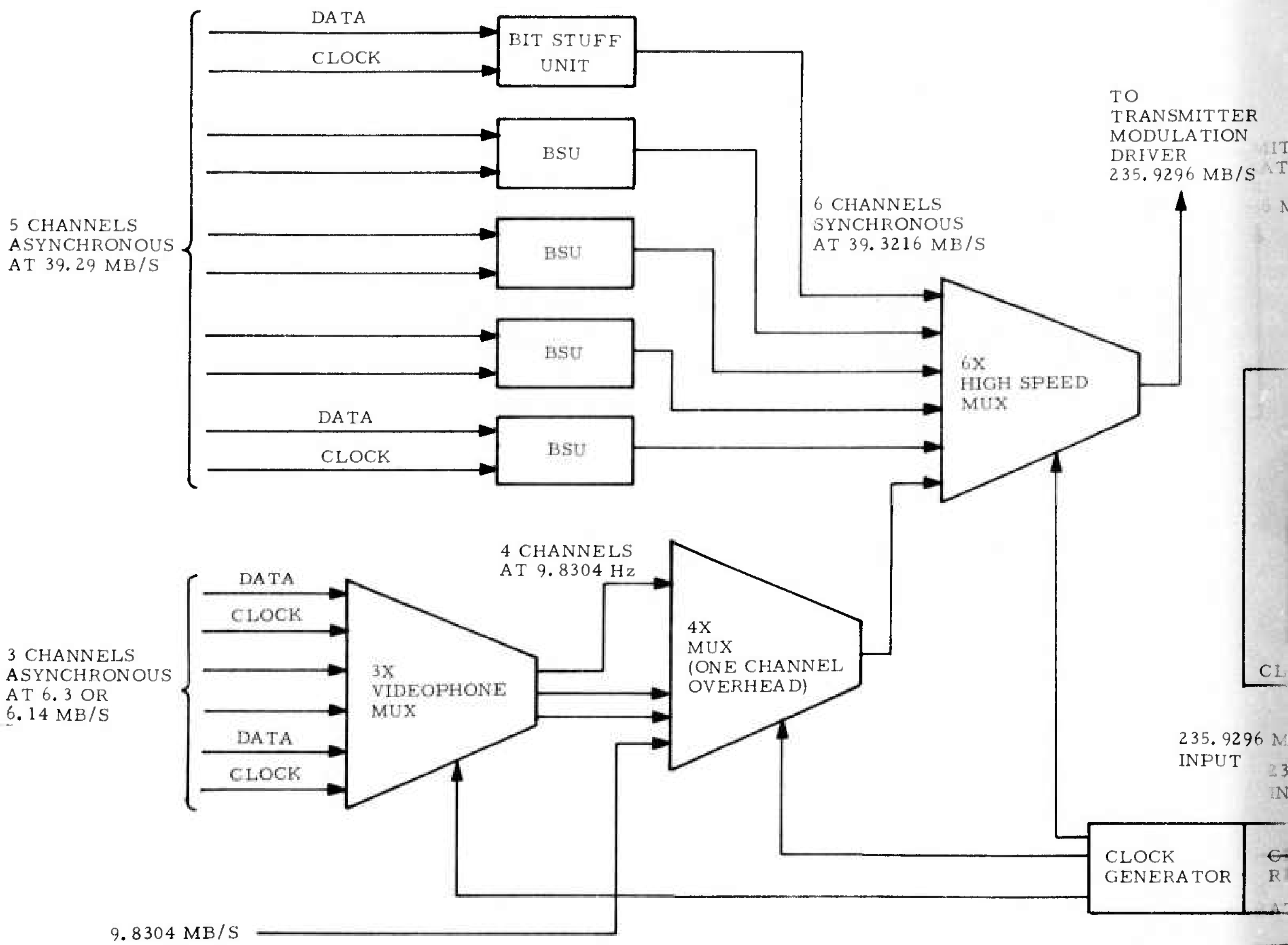


Figure 7. AN/GRC-173 (XW-1) Transmitter and Receiver, Block Diagram

2



DATA
CLOCK
BIT STUFF UNIT
BSU
BSU
BSU
DATA
CLOCK
BSU
5 CHANNELS ASYNCHRONOUS AT 39.29 MB/S
6 CHANNELS SYNCHRONOUS AT 39.3216 MB/S
6X HIGH SPEED MUX
TO TRANSMITTER MODULATION DRIVER 235.9296 MB/S
4 CHANNELS AT 9.8304 Hz
DATA
CLOCK
DATA
CLOCK
3 CHANNELS ASYNCHRONOUS AT 6.3 OR 6.14 MB/S
3X VIDEOPHONE MUX
4X MUX (ONE CHANNEL OVERHEAD)
235.9296
INPUT
CLOCK GENERATOR
9.8304 MB/S

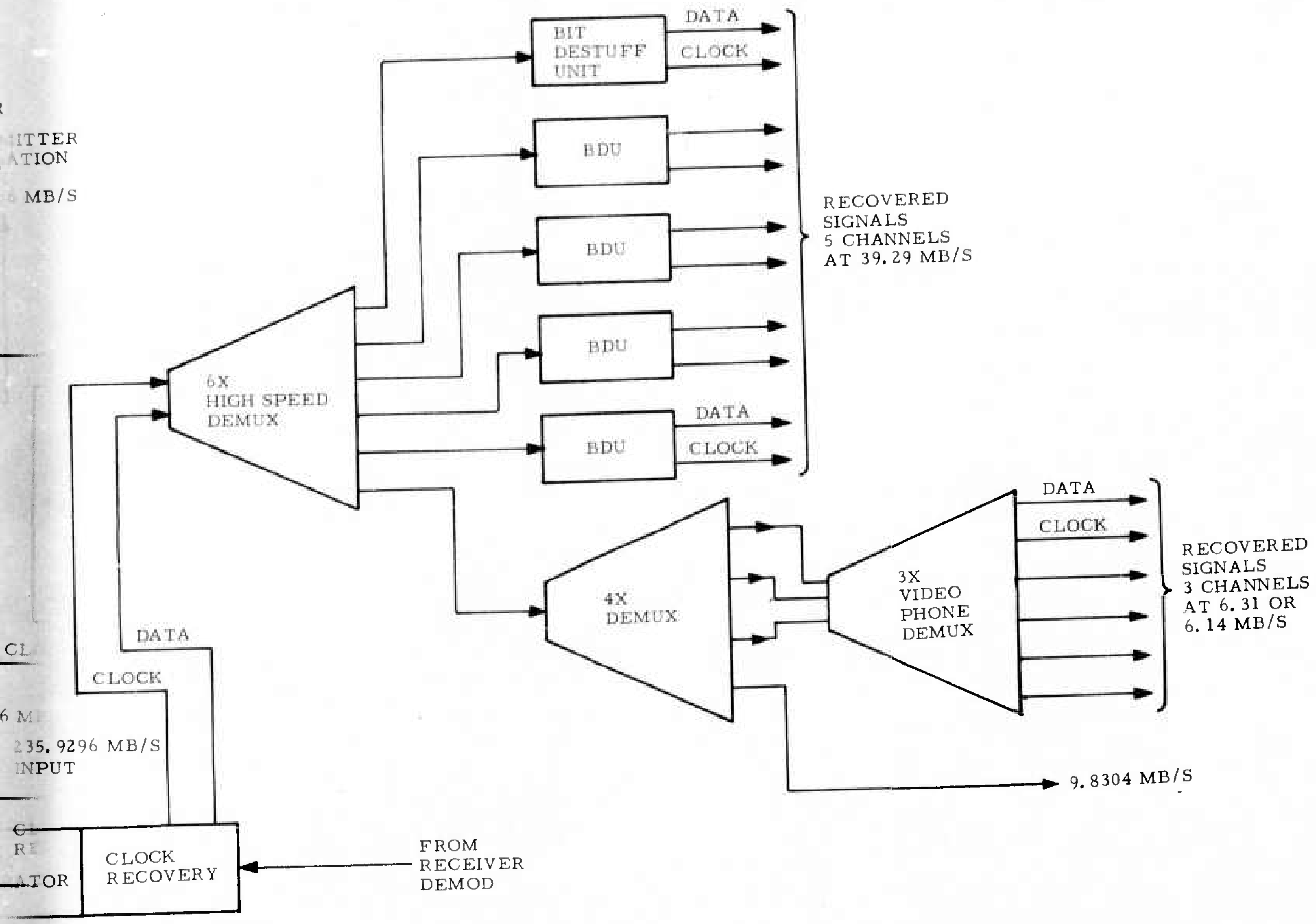
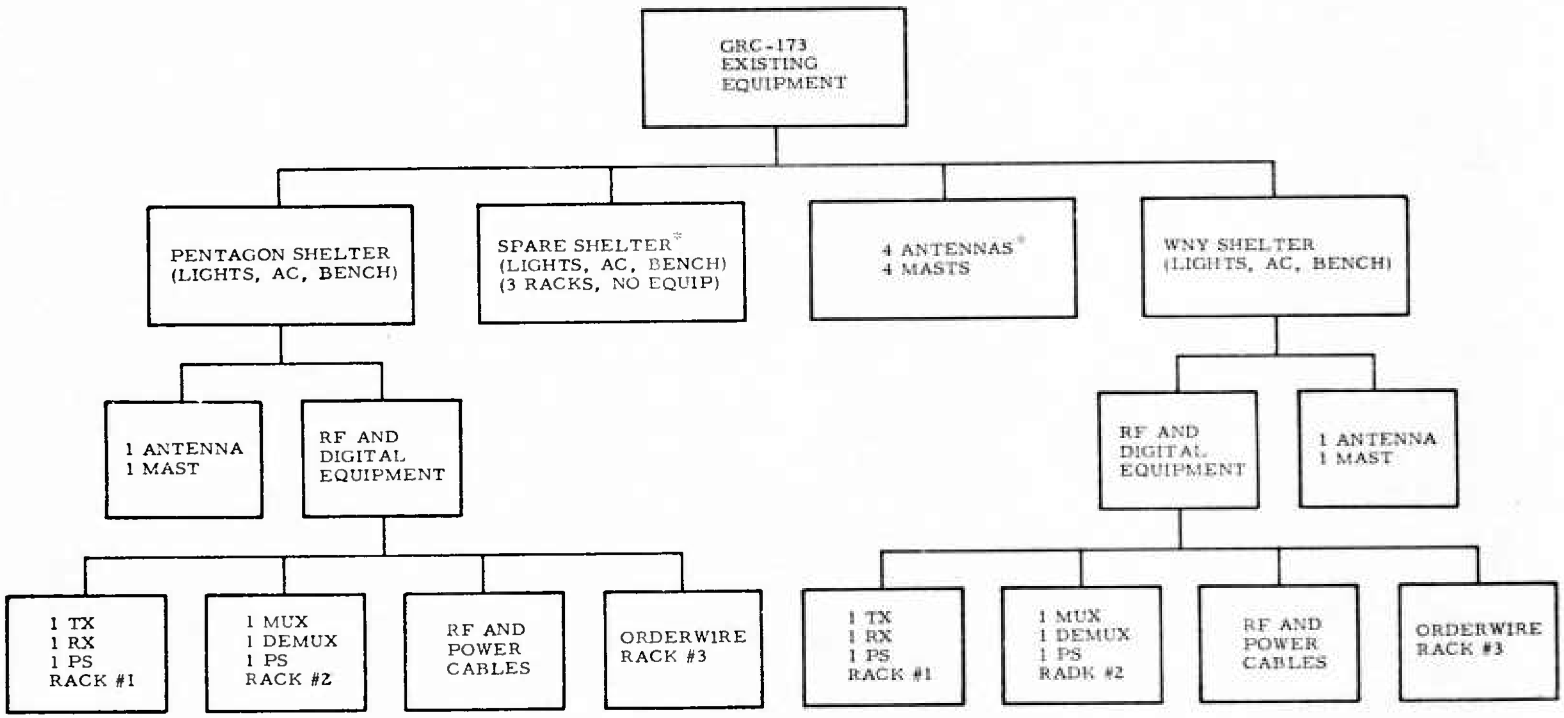


Figure 8. AN/GRC-173 (XW-1) Digital Mux/Demux Equipment, Block Diagram

2



* NOT USED IN PHASE III

Figure 9. AN/GRC-173 (XW-1) Equipment Developed Under Phase II

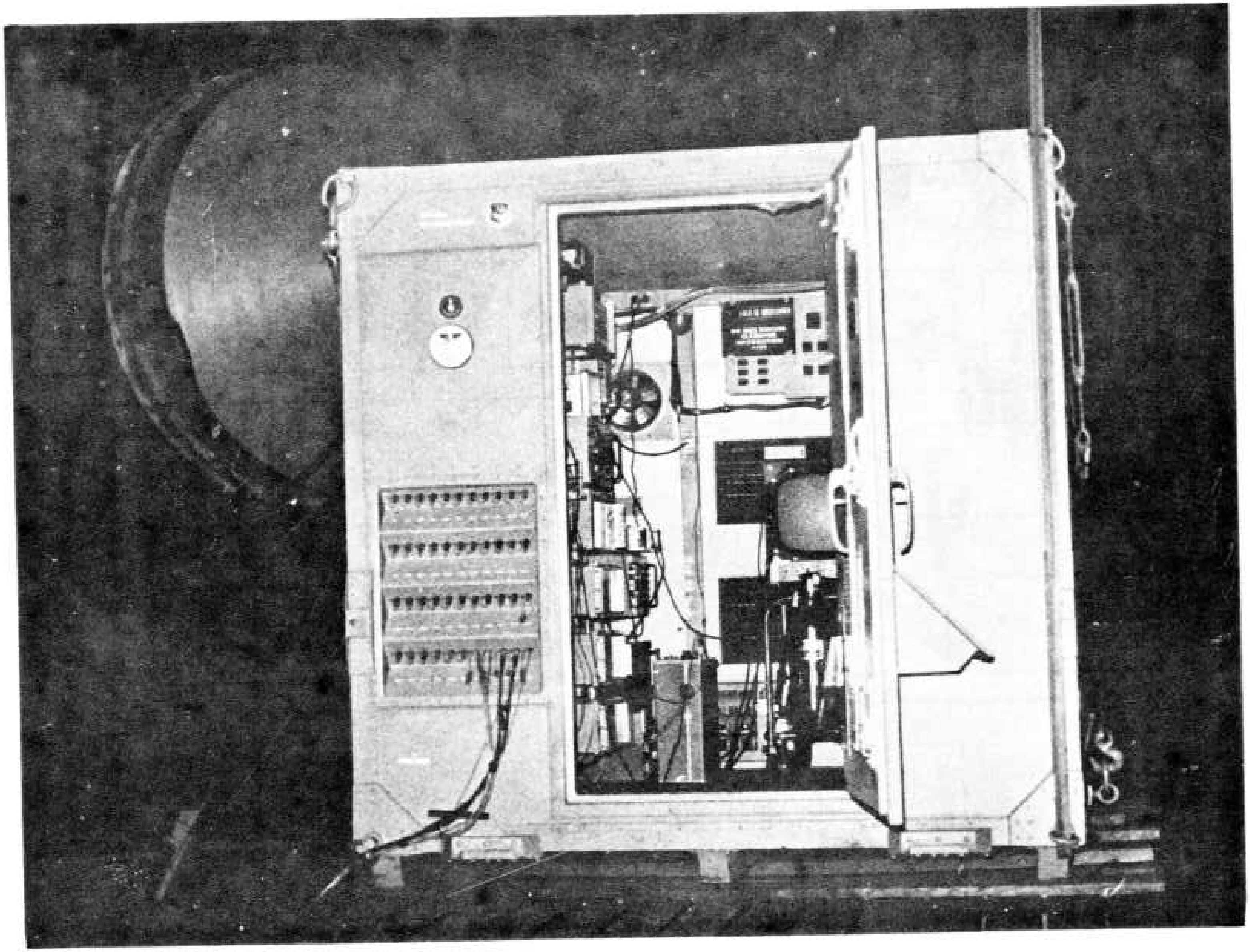


Figure 10. AN/GRC-173 (XW-1) Shelter Interior View

In a portion of the testing, the radio sets were operated in a loop-around configuration as discussed under BER testing. This configuration permitted BER testing with the available quantity of test equipment. In addition, it simulated relay operation with the available quantity of radio equipment as deployed in the Pentagon - WNY link.

There are several digital input/output ports at various data rates incorporated in the AN/GRC-173 (XW-1). Table I, below, lists these.

The 39.29 Mb/s and 6.14/6.31 Mb/s ports operate asynchronously through bit-stuffing and bit destuffing units incorporated into the radio. The stuff control information is carried on a separate overhead data channel. When the 6.14/6.31 Mb/s ports are not being utilized, two additional 9.83 Mb/s ports are available. Note that any of the inputs can be taken from some other multiplexer, hence the system can be expanded to accept facsimile, computer data, voice, videophone, etc., or a combination of these.

To summarize, Table II lists the basic specifications of the AN/GRC-173 (XW-1).

Table I. Input/Output Ports

Number of Ports	Bit Rate Per Port	Typical Use
5	39.29 Mb/s	Digitized High Speed TV
3	Selectable either 6.14 or 6.31 Mb/s	Low Speed Mux (e.g., AN/GSC-24 or T-2)
1	9.83 Mb/s	Low Speed Mux (e.g., AN/GSC-24)
1	30.5 KBPS Built-In Order Wire	Voice

Table II. Basic Specifications Radio Set AN/GRC-173 (XW-1)

1.	TRANSMITTER	
	Power Output:	Greater than 100 mW
	Operating Frequency:	36 to 38.6 GHz band
	Type of Modulation:	Bi-phase shift keying
	Modulation Rate:	235.9296 Mb/s
	Type:	All solid state
	Input:	Differentially encoded baseband signal
2.	RECEIVER	
	Type:	Superheterodyne, all solid state
	Local Oscillator:	Fixed-tuned below carrier frequency
	IF Frequency:	940 MHz
	Noise Figure:	Less than 15 dB at diplexer
	Method of Detection:	Differential phase
	Output:	Differentially decoded baseband signal
3.	HIGH SPEED MULTIPLEXER	
	Number of Channels:	5
	Type Inputs:	Asynchronous
	Type of Conversion:	Bit stuffing
	External Data Inputs:	NRZ, 39.29 Mb/s nominal
	External Clock Inputs:	39.29 MHz nominal

Table II. Basic Specifications Radio Set AN/GRC-173 (XW-1) (cont.)

4.	HIGH SPEED DEMULTIPLEXER	
	Number of Channels:	5
	Type Outputs:	Asynchronous
	Type of Conversion:	Bit destuffing
	Data Outputs:	NRZ, 39.29 Mb/s nominal
	Clock Outputs:	39.29 MHz nominal
5.	VIDEOPHONE MUX/DEMUX	
	Type:	Asynchronous
	Inputs/Outputs:	3 data and 3 clock
	Data Rate:	3 selectable either 6.14 or 6.31 and 1 at 9.83 Mb/s
6.	CLOCK UNIT	
	Clock Generator Output:	235.9296 MHz, 0.5 Vrms $\pm 10\%$
	Clock Aging Rate:	$\pm 5 \times 10^{-10}$ per day averaged over 30 days
	Clock Recovery:	235.9296 MHz clock and two data lines
7.	ALARMS AND DISPLAYS	
	Visual Alarms:	30 illuminated indicators
	Monitored Equipment:	All rf and digital units
8.	POWER SUPPLIES	
	Quantity:	1 for rf, 1 for digital
	Primary Power:	120/240V $\pm 10\%$ single phase, 47 - 420 Hz
	Outputs:	+5, -5, +15, -15, +12, +34, +85 Vdc
	Additional Power Provision:	Dc/ac inverter and filter to convert 12 or 24V battery to ac

Table II. Basic Specifications Radio Set AN/GRC-173 (XW-1) (cont.)

9.	ORDERWIRE GROUP	
	Handset:	Type H-156 ( )/
	Incoming Call:	Buzzer and lamp
	Outgoing Call:	Call-ring push button switch
	Type:	Voice audio, digital at 30.5 KBPS, continuously variable slope delta modulation type
10.	ANTENNA ASSEMBLY	
	Type:	Button-hook fed dish assembly on AZ-EL adjustable mast assembly
	Diameter:	6 ft
	Gain and Beamwidth:	54 dB (0.35° half-power angle)
	Environmental Provisions:	Heater and hypalon cover for ice and snow protection
	Feed Waveguide:	RG-96/U
11.	SHELTER	
	Exterior Dimensions:	99-in. L x 76-in. W x 78-in. H
	Includes:	Air conditioning, work table, fire extinguisher, etc.
	Weight:	1400-lbs shelter only; gross weight 2000-lbs with equipment
12.	PRIMARY POWER	
	Voltage:	120/240V $\pm$10% single-phase
	Frequency:	47 - 420 Hz
	Power:	0.5 to 2 kW depending on auxiliary equipment interior to shelter

Table II. Basic Specifications Radio Set AN/GRC-173 (XW-1) (cont.)

13.	OPERATING CONDITIONS	
	Temperature Range:	-40°F to +125°F
	Humidity:	96% relative at 86°F
	Altitude:	10,000 ft
14.	STORAGE CONDITIONS	
	Temperature Range:	-62°F to +160°F
	Humidity:	96% relative, with condensation
	Altitude:	50,000 ft

3. TEST EQUIPMENT

Three categories of test equipment were used to support the Washington Phase III operations:

1. Standard laboratory test equipment - contractor supplied.
2. Special high speed test equipment - contractor supplied.
3. Terminal equipment - contractor and Government supplied.

Lists of the above are given in Tables IV, V and VI, respectively, indicating the usage of each item. The quantities are total for the phase.

A description of the special high-speed digital equipment items is given below; these are Raytheon items built for other programs and were supplied at no cost for the tests.

a. Digital Encoder and Decoder

These breadboard printed circuit boards perform the functions of analog-to-digital (A/D) and digital-to-analog (D/A) conversion and Delta Modulation coding/decoding. The input to the Encoder was the high speed TV camera video output signal. When clocked at 39 MHz nominal, the output was on two lines each at 39 Mb/s. The two lines contained the Delta Modulation 2-bit code as indicated in Table III below. The decoder operated in reverse, decoding the Delta Modulation signal and regenerating the video signal.

Table III. Encoder Output Coding

Step Size	Line 1	Line 2
Large (+)	1	1
Small (+)	0	1
Small (-)	1	0
Large (-)	0	0

b. Pseudo-Random Sequence Generator Cards and Adaptor Box

These digital circuit boards operate at a bit rate of 39 Mb/s nominal, and generate pseudo-random sequence signals. Four cards with word lengths of 15, 31, 63, and 127 bits were employed in Phase III. When operating synchronously, the bit stuff units of the AN/GRC-173 (XW-1) equipment are removed and the clock from the radio is used to drive the cards.

c. Bit Error Rate Test Set

This test set determines the difference between a 39.29 Mb/s pseudo-random pattern ((2^{15} - 1) bits in length) generated locally for muxing and transmission and the similar pseudo-random pattern received and recovered by the demux. This is done by synchronizing the local pseudo-random sequence to the remote word, then allowing the unit to free run. A counter, connected to the BER test set, registers an error each time the transmitted and received patterns differ by one bit. A diagram showing interconnection with the counter and other peripheral equipment is shown in Figure 11.

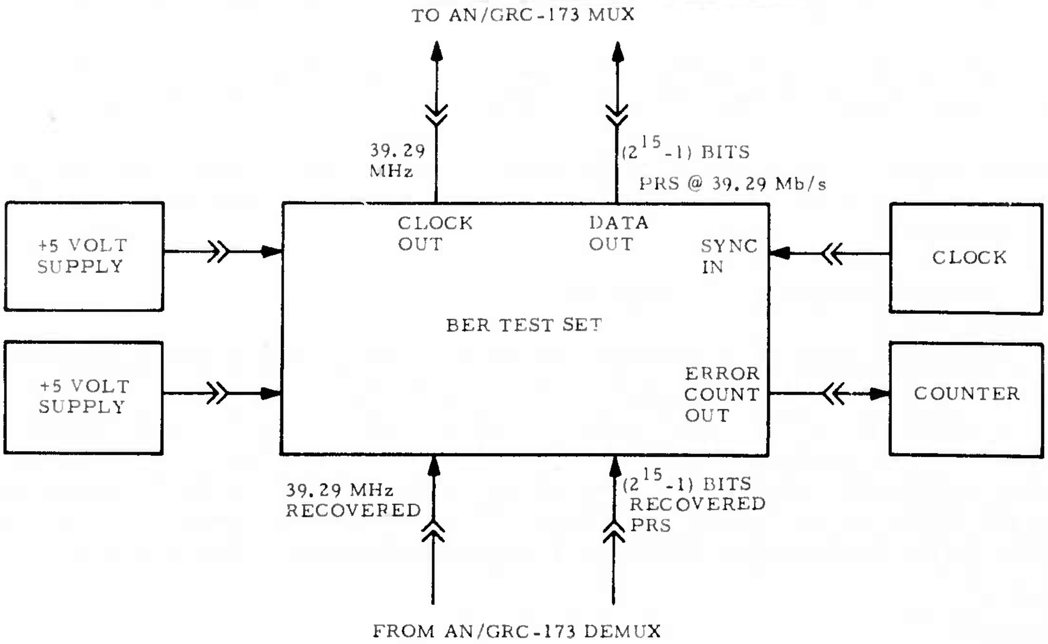


Figure 11. Interconnection Diagram for Using Bit Error Rate Test Set

Table IV. List of Standard Laboratory Test Equipment

Description	Quantity	Manufacturer/Mod. No.	Use/Test
Power Meter	2	Hewlett-Packard 432A	Measure rf power
Thermistor Head	2	Hewlett-Packard 478A	Measure rf power
Thermistor Head	2	Hewlett-Packard R486A	Measure rf power
Frequency Counter	1	Electronic Industries Products 351C	Monitor frequency
Frequency Counter	1	Hewlett-Packard 5340A	Monitor frequency
Storage Oscilloscope	2	Tektronix 564B	Checkout/general
Random Sampling Sweep for 564-B Scope	2	Tektronix 3T2	Checkout/general
Dual-Trace Sampling Amplifier, for 564-B Scope	2	Tektronix 3S2	Checkout/general
Sampling Head, 1 GHz Bandwidth, for 564-B Scope	2	Tektronix S1	Checkout/general
Sampling Head, 4.5 GHz Bandwidth, for 564-B Scope	1	Tektronix S2	Checkout/general
Chart Recorder	2	Hewlett-Packard 680 - Electric Write	Record signal level and general
Chart Recorder	2	Hewlett-Packard 680 - Ink Write	Record signal level and general

Table IV. List of Standard Laboratory Test Equipment (cont.)

Description	Quantity	Manufacturer/Mod. No.	Use/Test
Oscilloscope	2	Tektronix 454	Checkout/general
Function Generator	1	Wavetek 110	Low speed message test
RF Voltmeter	1	Boonton 91-D	Checkout/general
Volt - Ohmmeter	2	Simpson 260	Checkout/general
Tipping Bucket Rain Gauge	3	Aerojet - General P-501	Propagation
Rain Gauge Recorders	3	Standard Instruments	Propagation
Unit Oscillator	1	General Radio 1211B	Digital encoder checkout
Unit P.S. for above	1	General Radio 1203B	Digital encoder checkout
Camera	2	Polaroid CR-9	Photograph scope displays
Frequency Counter	1	Hewlett-Packard 5245-L	BER
Multi-Function Volt-meter	1	Hewlett-Packard 410-C	General purpose
Sampling Rf Section meter	1	Hewlett-Packard 3406-A	General purpose
Signal Generator	1	Hewlett-Packard 8614-A	General purpose

Table IV. List of Standard Laboratory Test Equipment (cont.)

Description	Quantity	Manufacturer/Mod. No.	Use/Test
Waveguide Attenuator	1	TRG-A510	BER and range evaluation
Crossguide Coupler	1	De Mornay Bonardi	RF checkout
Receiver	1	Scientific Atlanta 1710	Alignment
Spectrum Analyzer Display Section	1	Hewlett-Packard 141-T	Checkout/general
Spectrum Analyzer Rf Section	1	Hewlett-Packard 8555-A	Checkout/general
Spectrum Analyzer I. F. Section	1	Hewlett-Packard 3552-B	Checkout/general
Event Recorder	2	Rustrack 202-8	Test point monitoring
Power Supplies	8	Sorenson QRB-40, QRD15-2, QRD-40	Various
Voltage-Controlled Crystal Oscillator	1	Greenray Industries Mod N201-C-G-60 (39.290 MHz)	Drive BER test set
Waveguide Tunable Crystal Mount	1	Waveline 1014 with 1N53R Crystal	For use with spectrum analyzer

Table V. List of Special Test Equipment

Description	Quantity	Manufacturer	Use/Test
Pseudo-Random Sequence Generator (PRSG) Cards	4	Raytheon	Error rate
Loop-back Adapter	1	Raytheon	Back-to-back checkout of digital and TV equipment
Digital Bit Error Rate Test Set	1	Raytheon	Measure BER
Waveguide Attenuator Adaptor Section	1	Raytheon	In transmitter output, allows variable power output for BER and range tests - Uses TRG A510 precision attenuator

Table VI. List of Terminal Equipment

Description	Quantity	Manufacturer/Mod. No.	Use/Test
Digital Encoder	1	Raytheon, Delta Modulation Type	TV transmission, A/D conversion
Digital Decoder	1	Raytheon, Delta Modulation Type	TV transmission, D/A conversion
Low Pass Filters	3	Raytheon (5, 10, 15 MHz Cutoffs)	TV image evaluation
High Resolution TV Monitor*	2	Conrac RQA-17	TV image display
High Resolution TV Camera*	1	Sierra Scientific LSV Type	TV pickup
TV Camera Control Unit*	1	Sierra Scientific (for above camera)	TV tests
Light Table*	1	Richards Co. Catalog No. 910-639-1 Flat Type, approximately 8" x 10" plate area	TV - for illuminating transparencies
Tripod and Lens	1	-	For TV camera
*Government furnished for tests			

SECTION III

SITE, PATH AND SCHEDULE DATA

1. INTRODUCTION AND BACKGROUND

Numerous potential sites and link configurations for the Phase III tests were investigated; these were in the geographic areas of Boston, Massachusetts, Rome, New York, and Washington, D. C. (see Reference 5). Placing of the link stations at the Pentagon and adjacent to the Washington Navy Yard (WNY) enabled the meeting of key criteria such as:

a) Reasonable accessibility to terminals and availability of basic supporting facilities, such as transportation, security and power.

b) Line of sight available, and L. O. S. without use of periscope antenna systems preferred, since periscope installations would entail additional contract scope.

c) Present or anticipated future communications traffic warrants test of a high-speed digital transmission facility.

d) Resident agencies interested in cooperating and possibly supplying terminal equipment for tests.

Besides compatibility with the above factors, the selected Pentagon-WNY configuration was felt to be highly suitable for demonstration to Government agencies as a test bed. This was borne out; e. g., during January and February 1974, nine link demonstrations and briefings were conducted for Government agencies.

One criteria which unfortunately could not be met by the Pentagon-WNY link was maximum transmission distance. The link length was 4.4 km (2.73 mi), which is shorter than the range design specification of 10 km (6.2 miles) which the equipment can meet. However, it was known that the 10-km condition could be simulated at the shorter range, and accordingly plans were laid in early spring 1973 to proceed with installation of the Pentagon-WNY configuration upon the completion of Phase II.

2. LINK CONFIGURATION AND INSTALLATION

a. Configuration

Figure 12 is a diagram of the test link laid out upon a section of the U. S. Geological Survey map for the area. The path of 4.4 km crosses over an urban area of apartments and office buildings, a small area of park, river and channel waterway, and a busy highway interchange and parking area fronting the Pentagon.

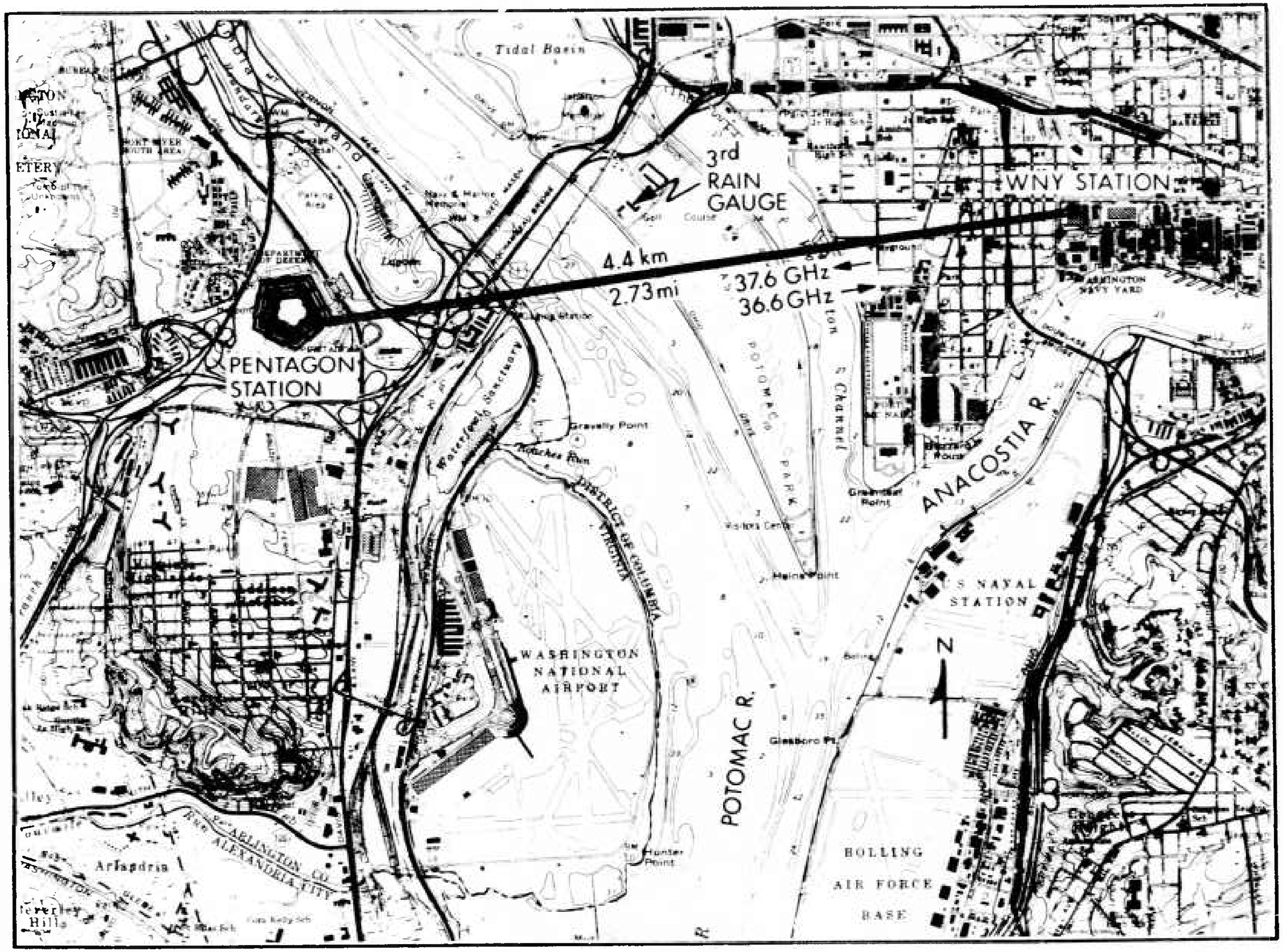


Figure 12. Link Configuration in Washington, D. C.

b. Installation by Helicopter

The equipments were lifted to rooftop locations from closeby staging areas by CH-54 Skycrane helicopter. The lifts took place on 6 August 1974 (Pentagon) and 29 September 1974 (WNY). The schedule difference was due to delays encountered in constructing a channel-iron framework for the equipment shelter at the WNY site. Additional data relating to the helicopter lift operation can be found in Section V.

c. Coordinates

The radio sets, designated as Shelter Groups 1 and 2 during Phase II, were deployed in Phase III as indicated in Table VII, which also lists the site coordinates and transmission frequencies.

Table VII. Equipment Locations

Site	Coordinates	Equipment Identification
Washington Navy Yard (Building 213-M and 1st Streets)	38° 52' 33" N Lat 77° 00' 18" W Long	Shelter Group 1. Transmit at 37.6 GHz, Receive at 36.6 GHz. Vertical polarization.
Pentagon	38° 52' 15" N Lat 77° 03' 22.5" W Long	Shelter Group 2. Transmit at 36.6 GHz, Receive at 37.6 GHz. Vertical polarization.

d. Path and Antenna Beam Details

The ground terrain over the path is characteristically flat and nearly at sea level. However, buildings several stories high along the path line raise the effective height of the terrain and this dictated the use of rooftop installations to achieve clearance. Towers (e.g., periscope antenna systems) to further increase clearance were, however, found to be unnecessary. Figure 13 is a view from the Washington Navy Yard looking generally towards the direction of the Pentagon and taken from a height approximately 20 feet lower than the final antenna boresight.

It is estimated that the first Fresnel zone clearance is approximately 13 feet. The antenna beam is narrow (0.35° half-power beamwidth) and traverses a line high enough above the Potomac River so the communications channel is relatively free of surface layer and duct effects associated with non-standard atmospheric conditions above the surface of the water.

Figure 13. View from Rooftop at WNY Site - Looking Towards Pentagon

Another link consideration was the aircraft flight path for nearby Washington National Airport. Aircraft using the field normally fly along the Potomac River for safety and noise abatement reasons. However, FAA regulations constrain their minimum altitude to be 300 feet at the link azimuth. Thus, as further discussed in the section on propagation testing, this potential multipath or beam-blockage problem did not occur in practice.

One unpredicted factor beyond the control of the project was the use of tall construction cranes in the path of the antenna beam. They were used in construction of the Washington Metro Transportation System. Their presence, when operated in the path, at times caused a modest fade (see Section IV). The cranes started producing a line-of-sight obstruction in October 1973, but it is expected their use will stop during 1974.

e. Pentagon Installation

The Pentagon shelter was strapped down to a channel-iron framework which in turn was secured to the asphalt and reinforced concrete roof structure by means of tie-down bolts. The antenna mast was secured to a rigid plate on the channel-iron framework and further tied down to the roof by four cables. The external antenna rf feed was connected to the shelter flange bulkhead over the radio rack via RG-96/U waveguide which was fabricated and fitted in place after the antenna and shelter installations were complete. The access-way to the shelter area was from a fifth-floor stairway. A rain gauge was installed about 40 feet from the shelter in an open area. Primary power (single phase, 3-wire plus ground, 120/240V, 60 Hz, 10 kW capacity) was run up to the shelter via grounded conduit from a junction box at the bottom of the stairwell on the fifth floor.

Figure 14 is a view of the installation from roof level, and Figure 15 is an aerial view. There was considerable roof area and foreground features between the antenna and the edge of the building. Further description of the Pentagon installation is contained in Section V.

f. Washington Navy Yard (WNY) Installation

The WNY station was installed on the building at the corner of M and 1st Streets in Washington. It is six stories to the main roof level of the building and another 18 feet to the roof of an elevator shaft penthouse on which the shelter and antenna equipment is emplaced. The emplacement at this end utilizes steel I-beams and steel plate framework to which the AN/GRC-173 (XW-1) is attached by means of tie-down cables. The framework itself is mechanically secured to the load-bearing walls of the penthouse. Access to the shelter from the main roof level is by ladder. Primary power to this shelter was obtained by tapping into the main building lines as in the case of the Pentagon installation. A rain gauge was installed at main roof level in a cleared area.

Figure 16 is a view of the WNY station taken from main roof level. Section V contains additional data on this installation.

3. SCHEDULE

Several tasks were included in the overall schedule for Phase III. This schedule is shown in Figure 17 and lists the following:

a) Physical installation of the stations.

b) Checkout and alignment of the equipment at the unit level, i.e., transmitter, receiver, clock unit, high speed mux, etc.

c) Baseline testing to establish the link and to integrate the test equipment into the system.

d) Link tests of range performance, bit error rate and propagation.

e) Investigation of baseband terminal equipment to interface with the AN/GRC-173(XW-1).

f) System test to evaluate operational performance of the AN/GRC-173(XW-1) when it is interfaced with typical baseband terminal equipment.

A log listing the chronology of events and activities during Phase III is given in Appendix B.

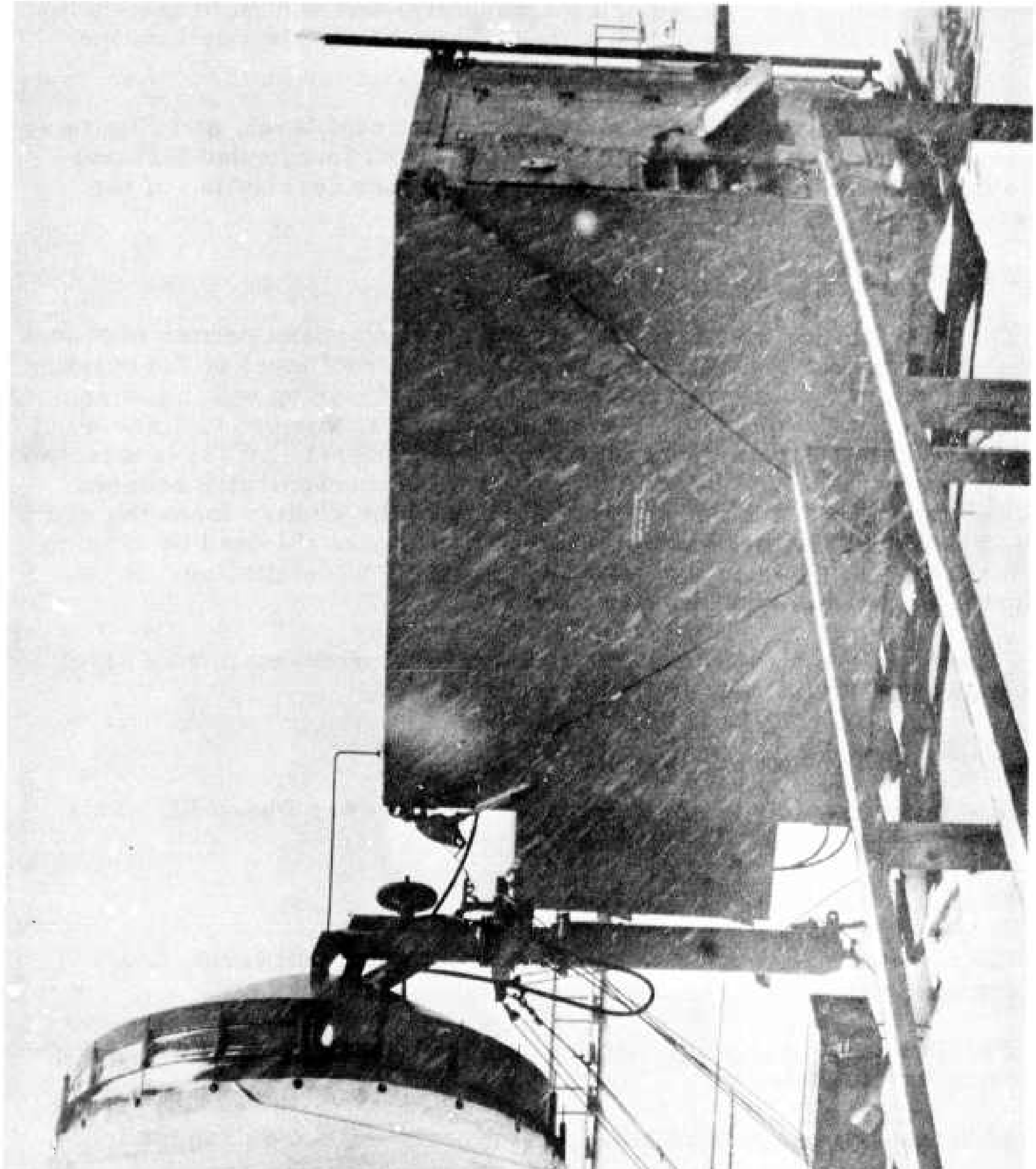


Figure 14. AN/GRC-173 (XW-1) Installed on Pentagon Roof

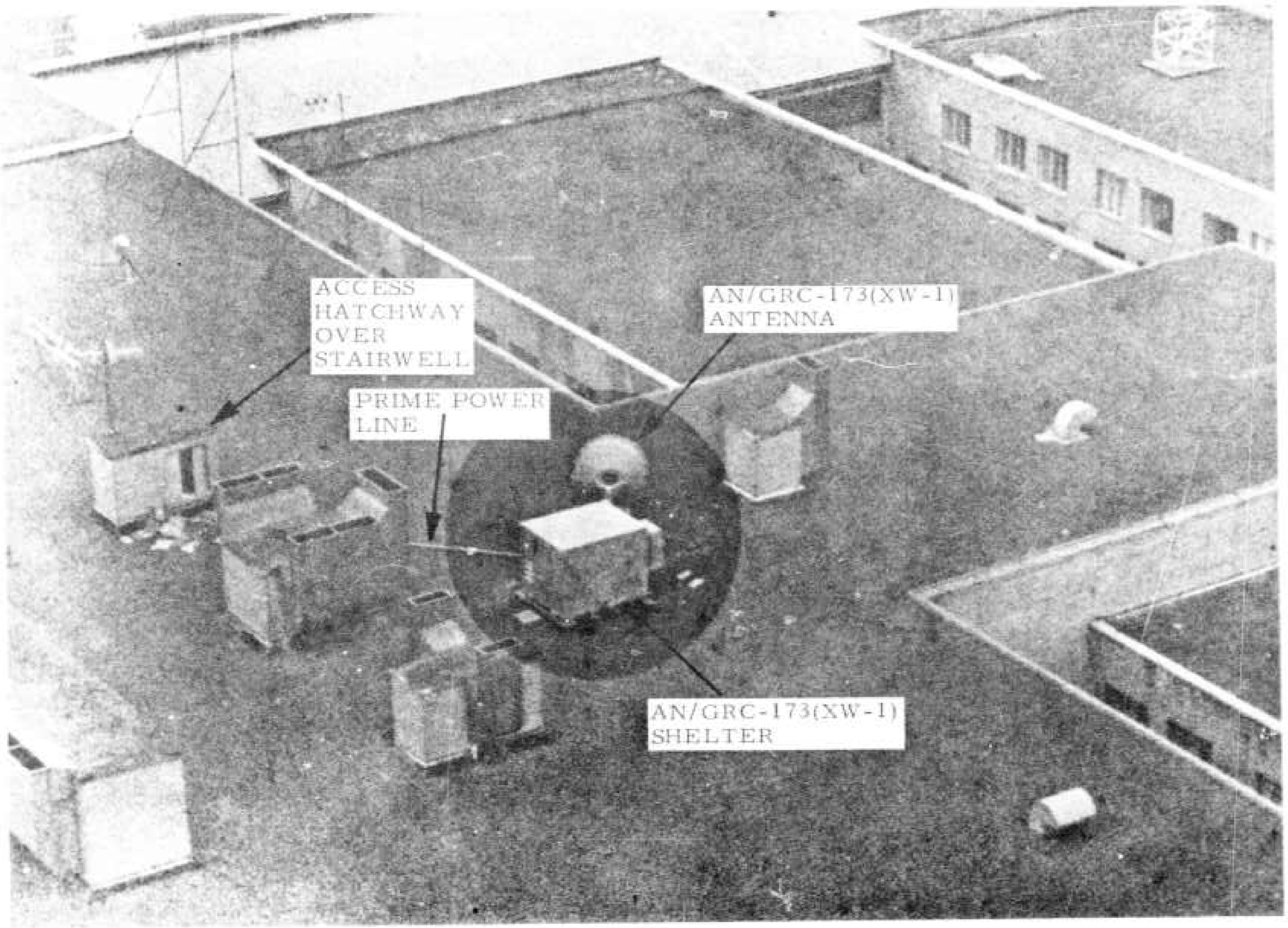


Figure 15. Aerial View of AN/GRC-173 (XW-1) on Pentagon

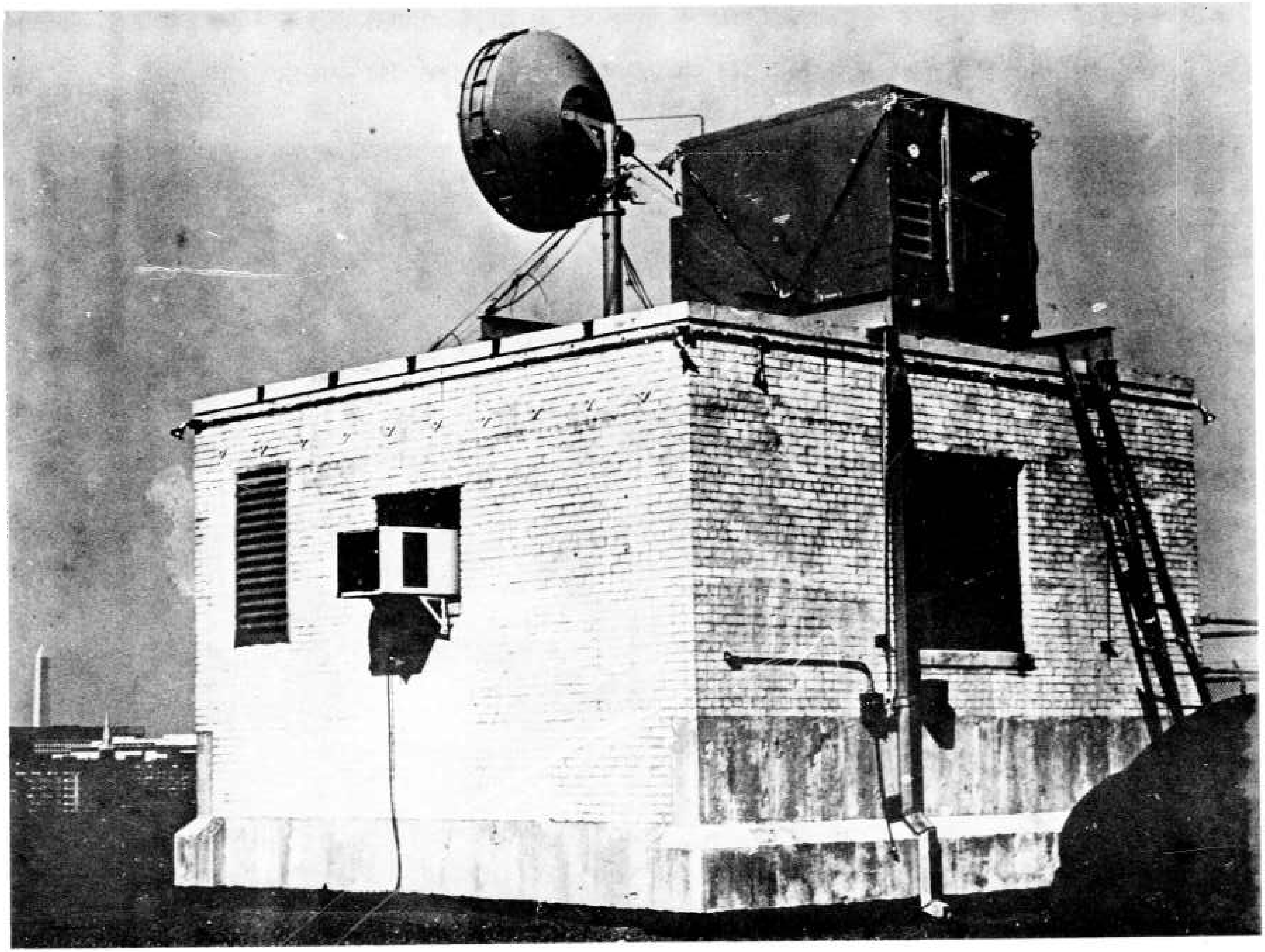


Figure 16. WNY Installation from Main Roof Level

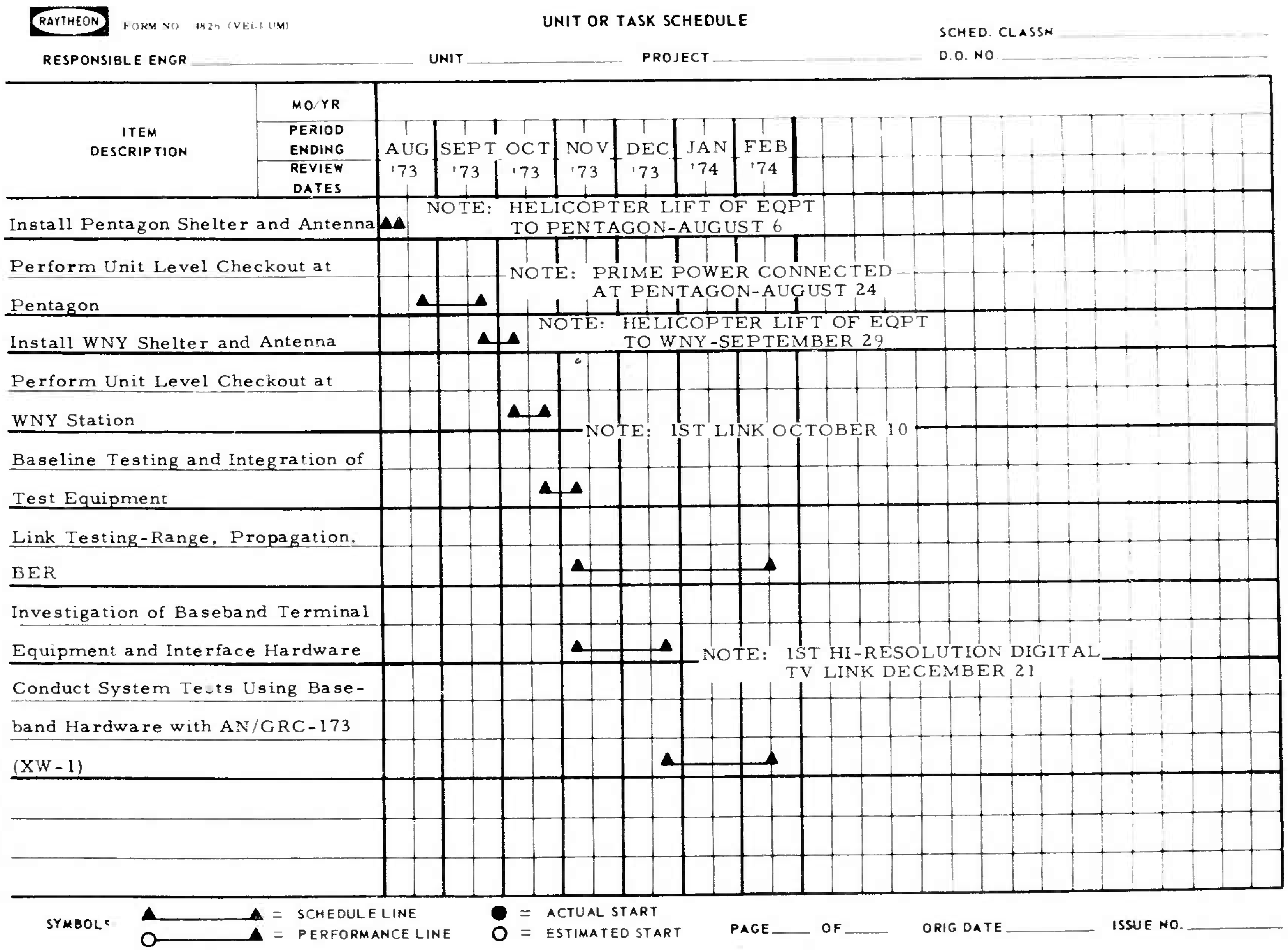


Figure 17. Phase III Project Schedule

SECTION IV

TESTS AND RESULTS

1. INTRODUCTION

The following paragraphs disclose the engineering data and test results which were obtained for the various tests under Phase III. The findings of measurement procedures as well as qualitative evaluations and demonstrations are discussed. Included are range performance evaluation, bit error rate performance evaluations, system message tests and propagation tests. The AN/GRC-173(XW-1) equipment reliability experience is summarized in Section V.

2. LINK BUDGET DISCUSSION

The link power budget is used in interpreting system performance. The received signal power level is a function of the equipment parameters and the condition of the transmission medium, including clear weather conditions or the fading effect of precipation. The bit error rate (BER) is a function of the signal to noise ratio ($S/N = P_R/N$) of received signal power level (P_R) to noise power (N) in the data bandwidth. The parameter values and link budget calculations for determining P_R and N for the AN/GRC-173(XW-1) Phase III configuration are summarized below.

In clear air, the received signal power is:

$$P_R\,(\text{dBm}) = P_T\ (\text{dBm}) + G\ (\text{dB}) - L\ (\text{dB}) \qquad (1)$$

where:

P_T = Transmitter power

G = Antenna gains

L = Equipment and medium losses

The value of L consists of a number of factors:

$$L = L_p - L_A - L_T - L_R - L_F \qquad (2)$$

where

L_p = Free space spreading loss over the link distance

L_A = Atmospheric loss over the link distance due to Oxygen and Water Vapor

L_T = Transmitter line loss

L_R = Receiver line loss

L_F = Field loss allowance for equipment

The term L_F is a field use factor that takes into account miscellaneous effects such as: antenna misalignment, dry radome losses, and field degradations in antenna gain and receiver noise figure. The antenna and receiver parameters were measured under Phase II, but the values could not be accurately re-measured in the field after shipment to the sites or after field changes were made to the mixer. Approximate measurements made in the field served mainly to verify that some field degradation had taken place and that the planned loss L_F was realistic.

The baseline budget value for received signal power level, P_R, from equation 1 and the foregoing term expansion in equation 2 is tabulated in Table VIII. Of the total S/N budget, the marginal portions required for various error probabilities were determined during the bit error rate testing. Table VIII also gives the signal to noise ratio, S/N, in the data channel, obtained by using the equation:

$$\frac{S}{N} = \frac{P_R}{N} - \delta = \frac{P_R}{KTBF} - \delta , \qquad (3)$$

where

K = Boltzmann's Constant

T = Noise Temperature

B = Noise Bandwidth

F = Receiver Noise Figure

δ = Distortion Value Allowance

The distortion value allowance is for intersymbol interference and symbol distortion which can arise in the recovered digital bit stream and produce additional errors. Intersymbol interference refers to the distortion due to overlapping symbols within a data channel or between data channels. Symbol distortion is due to a change in shape of the received symbol. These effects are due to linear or non-linear amplitude or phase operations on the signal by the medium or by system hardware. Potential causes of intersymbol interference and symbol distortion in the Phase III link were multipath due to relative time delays among multiple propagation paths, and non-optimum data channel timing effects or AM to PM conversion of the modulated carrier. These effects produce bit errors in the data stream and in a way they can be viewed as being due to additional system noise. It is difficult to predict an estimated budget value for these distortion effects. A value of 3 dB was used as an operating minimum in view of the potential multipath causes (flat

Table VIII. Baseline Received Power Link Budget (Clear Weather)

Parameter		Case I: WNY Station Transmit, Pentagon Receive		Case II: Pentagon Transmit, WNY Station Receive	
		Value	Note	Value	Note
P_T	Transmit Power, dBm	20.4	1	21.6	1
G	Antenna Gains, dB	107	2	107	2
L_P	Free Space Loss in 4.4 km, dB	137		137	
L_A	Atmospheric Loss, O_2+H_2O, dB	0.7		0.7	
L_T	Transmit Line Loss, dB	3	1	3	1
L_R	Receive Line Loss, dB	3	1	3	1
L_F	Field Allowance, dB	6		6	
P_T+G	Total, dBm	127.4		128.6	
L	Total Losses, dB	149.7		149.7	
P_R	Power Received = P_T+G-L, dBm	-22.3		-21.1	
KT	Boltzmann Const. X Noise Temp., dBm/Hz	-174		-174	
B	Noise Bandwidth, dB	83	3	83	3
F	Noise Figure, dB	10.7	2	11	2
N	Receiver Noise = KTBF dBm	-80.3		-80	
P_R/N	Received Power to Receiver Noise, dB	58.0		58.9	
δ	Minimum Distortion Allowance, dB	-3.0	4	-3.0	4
S/N	S/N in Data Channel, dB	55.0		55.9	

NOTES:
1) Field measurement, highest value
2) Highest value before shipment to field
3) Theoretical, based upon Phase II measurements
4) For intersymbol interference and symbol distortion

Pentagon roof foreground and machinery and building clearances) in the Pentagon - WNY path, and the equipment receiver characteristics measured during Phase II.

The resultant S/N values for the data channel shown in Table VIII are the estimated clear weather and clear path values for the link performing at the specified parameter values. A number of effects can modify these values. They are discussed separately below and some are elaborated further in the discussion of specific tests. Their consideration is required in this as well as any other link for wideband microwave signal transmission.

One effect which reduces the received signal level and is more pronounced at millimeter wave frequencies than at lower frequencies is the loss due to precipitation. The amount of fade depends upon the amount of water in the path or on the surface of the antenna radome and is considered in detail subsequently.

Blockage due to a path obstruction which removes power from the beam will also reduce the signal level. The construction cranes in the path at times were believed to be a cause of multipath and at other times, a source of blockage fade.

Time dependent amplitude fading due to variations in the atmosphere's refractive index can produce "scintillation" of the signal or ducting. Turbulence in the atmosphere can produce fluctuations of propagation time (and of the phase of the received signal) along a path. Low altitude temperature inversions in the atmosphere can produce ducting. Scintillation occurred infrequently and ducting not at all on the test link.

Changes in hardware performance will occur during an extended test program and thereby at times directly modify the effective S/N. For example, for a time the modulator and ADO were operating outside of specification value. This affected the transmitter chain of multiplier-modulator - final amplifier, which was then operating with non-optimum drive levels. Correcting the equipment problem restored the link to its normal operation condition. The equipment operation effects, which also included the method of loading data into the system in the loop-around configuration, are further discussed in Appendix A.

A final modification of the received S/N was the intentional one produced by varying the transmitted power output (via an attenuator) during bit error rate tests or margin demonstrations, as discussed in the following paragraphs.

3. RANGE PERFORMANCE TEST

a. Purpose and Requirements

The purpose of this test was to demonstrate through measurement and analysis that the radio set is capable of communicating over the specified

10 kilometers (6.2 miles) design range when it is required to do so. Since the 4.4 km (2.73 miles) link set up in Washington was shorter than required, this was accomplished through the use of additional attenuation in the feed line amounting to the additional free space path loss which would be experienced over a longer link. The amount of additional link attenuation required in this case was approximately 7 dB. Any further additional attenuation over 7 dB would demonstrate other margin conditions or requirements. An additional 6 dB simulates further range doubling or the realizability of additional propagation margin. A total attenuation of 15 dB nullifies the gain of the transmitter final Avalanche Diode Amplifier (ADA) and thereby demonstrates operational performance of the link minus this component.

b. Test Setup

The block diagram for this test is shown in Figure 18. The radio sets were operated in their normal operational configuration with the exception that a waveguide attenuator section was substituted for an operational section at a convenient point in the waveguide feed line. A photograph of the special waveguide attenuator section, consisting of a TRG Co. A510 Precision Attenuator and bends, is shown in Figure 19. The replaced operational section was the hybrid coupler and load that go between the transmit circulator and filter and the final transmit waveguide bend. The attenuator section was normally used at the WNY station, though it was also inserted at the Pentagon transmitter to establish received signal level calibration at the WNY station.

c. Test Procedure

The sequence of operations in this test was as follows:

(1) Put both ends of link into normal operation (clocks stabilized, antennas aligned, displays/alarms normal, no additional attenuation).

(2) Check communications status of link using order wire, error rate measurement or TV picture transmission.

(3) At receive terminal note the receive level indication on the recorder.

(4) At transmit station decrease amount of transmitted power by increasing attenuation.

(5) At receive station note new received signal level indication.

(6) Repeat (2).

(7) Repeat (4), (5), and (6) until maximum desired attenuation level is reached.

NOTE: This procedure was also followed in calibrating the link in clear weather as necessary to later determine rain fade depths, and in establishing received carrier to noise levels for bit error rate tests.

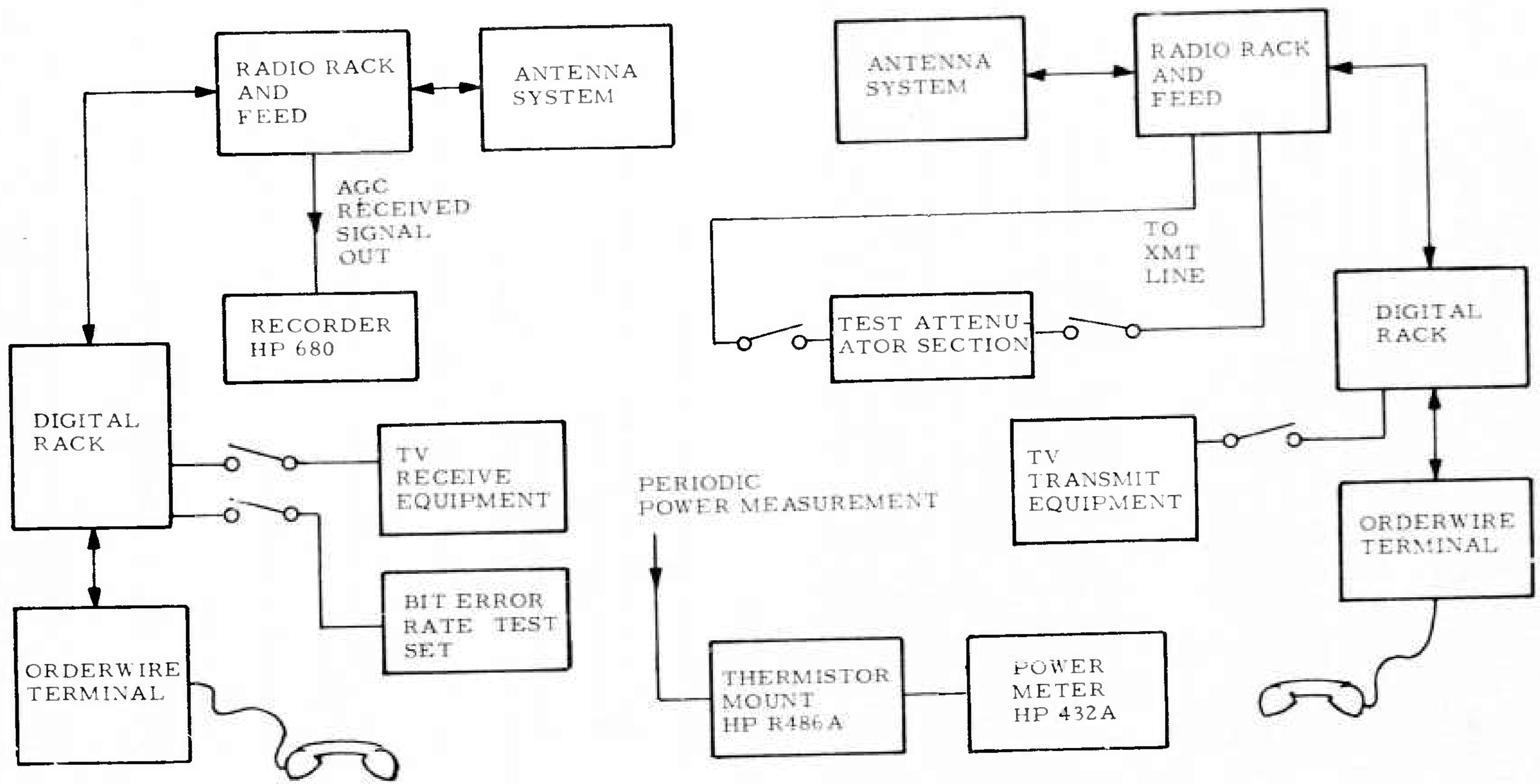


Figure 18. Range Performance Test. Block Diagram

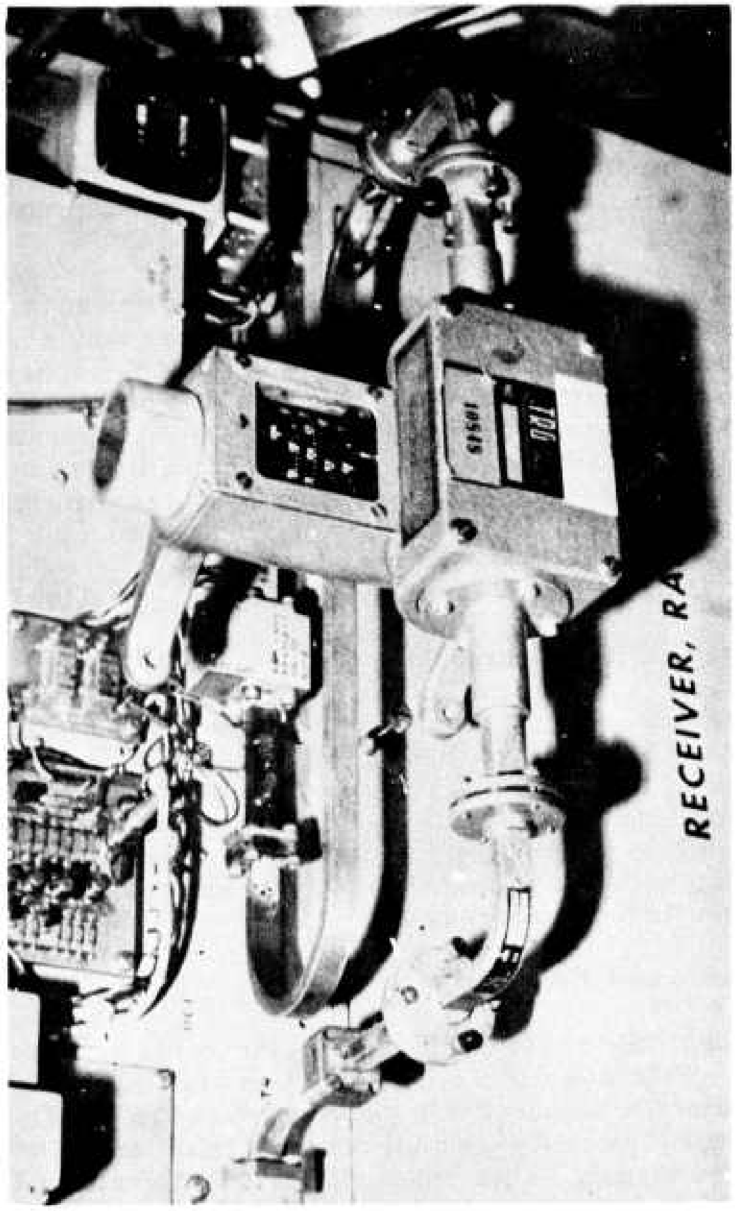


Figure 19. View of Waveguide Attenuator Section

d. Results

As expected, the additional 7-dB attenuation produced no noticeable degradation in the link performance regarding the voice order wire quality or the wideband TV picture quality. The results were similar at the 15-dB attenuation level which simulated elimination of the ADA amplifier as mentioned above. Again this result was as expected, still leaving margin to achieve low outage over the short link range. At longer range, the result of 15-dB attenuation would be to cut considerably into the system margin which would otherwise be available to offset heavy rain attenuation.

A typical trace of the signal level recording made during this test is shown in Figure 20. This is a portion of the recorder strip chart at the Pentagon made on 7 January 1974.

Besides being a specific means of evaluating range performance, this procedure was also found to be a rapid and satisfactory way of demonstrating the margin capability during demonstration periods. During this type of demonstration, if the TV transmissions were being sent, it was possible to show that imagery quality was still acceptable even at low S/N (error rates of 10^{-2} to 10^{-3}) and that after signal was lost (and then regained), the digital system would automatically regain synchronization. Figure 21 shows five different margin demonstrations of this type over approximately an hour's time on 24 January 1974.

4. BIT ERROR RATE (BER) MEASUREMENTS

a. Purpose and Requirements

A major criterion for performance of a digital transmission system is the Bit Error Rate (BER) or the Probability of Error (P_e) in the presence of noise. The purpose of this test was to measure the error performance of the AN/GRC-173 (XW-1) in a line of sight link configuration. Previous tests, under Phase II at Raytheon laboratories, provided a measurement of the BER in a back-to-back configuration with the same two radios connected to each other with a short section of waveguide (Reference 4).

b. Test Setup and Procedure

In the link BER tests of Phase III, the radio sets were operated in a loop-around mode. This was done since only one high-speed BER test set was available on the project. Its operation required that the locally generated pseudo random key generator digital signal source for transmission be co-located with the received detected signal. The "master" terminal contained the BER test set. The remote terminal had the digital demux channels connected by cable to the corresponding mux channels, hence the designation of the operation as "loop-around". The rf signals went through the transmitter and receiver of each station.

A simplified link block diagram of the loop-around configuration for the BER test measurement is shown in Figure 22. In all the test runs for which

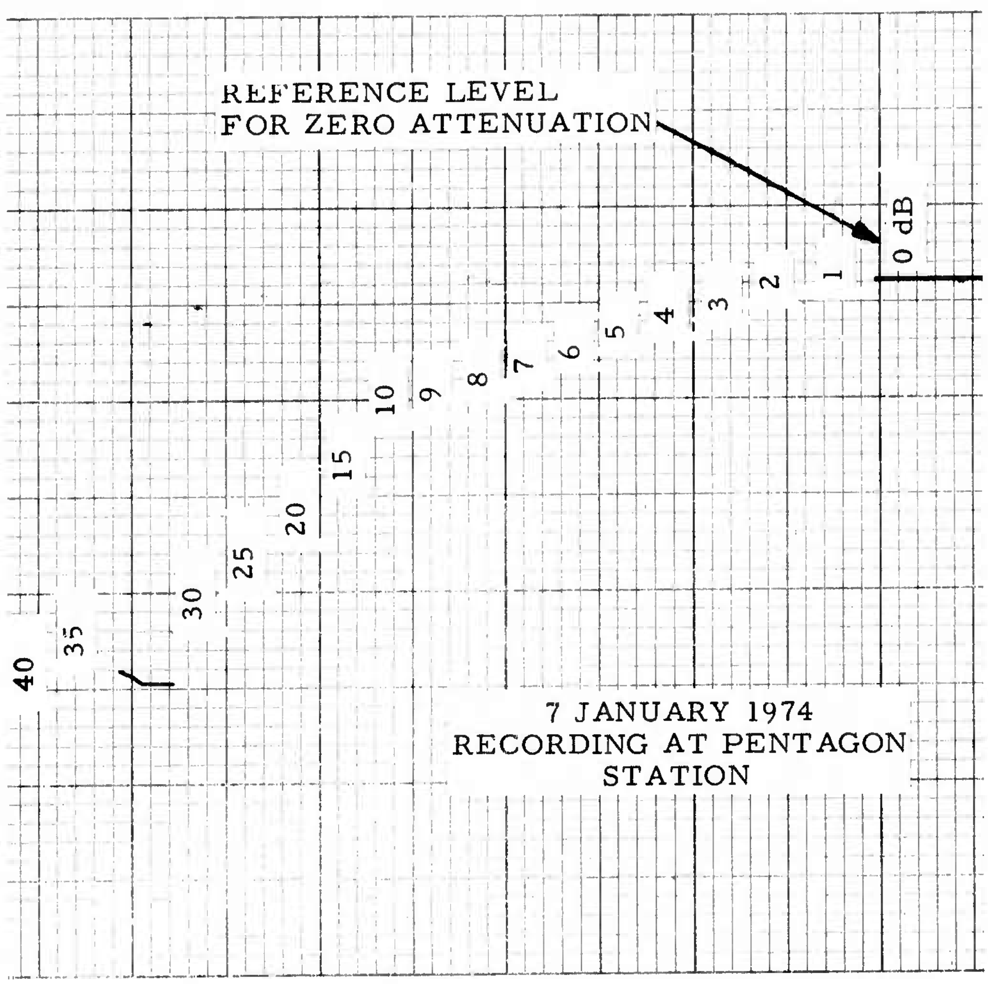


FIGURE 20. RECEIVED SIGNAL LEVEL AT PENTAGON VS ATTENUATOR SETTING AT WNY STATION

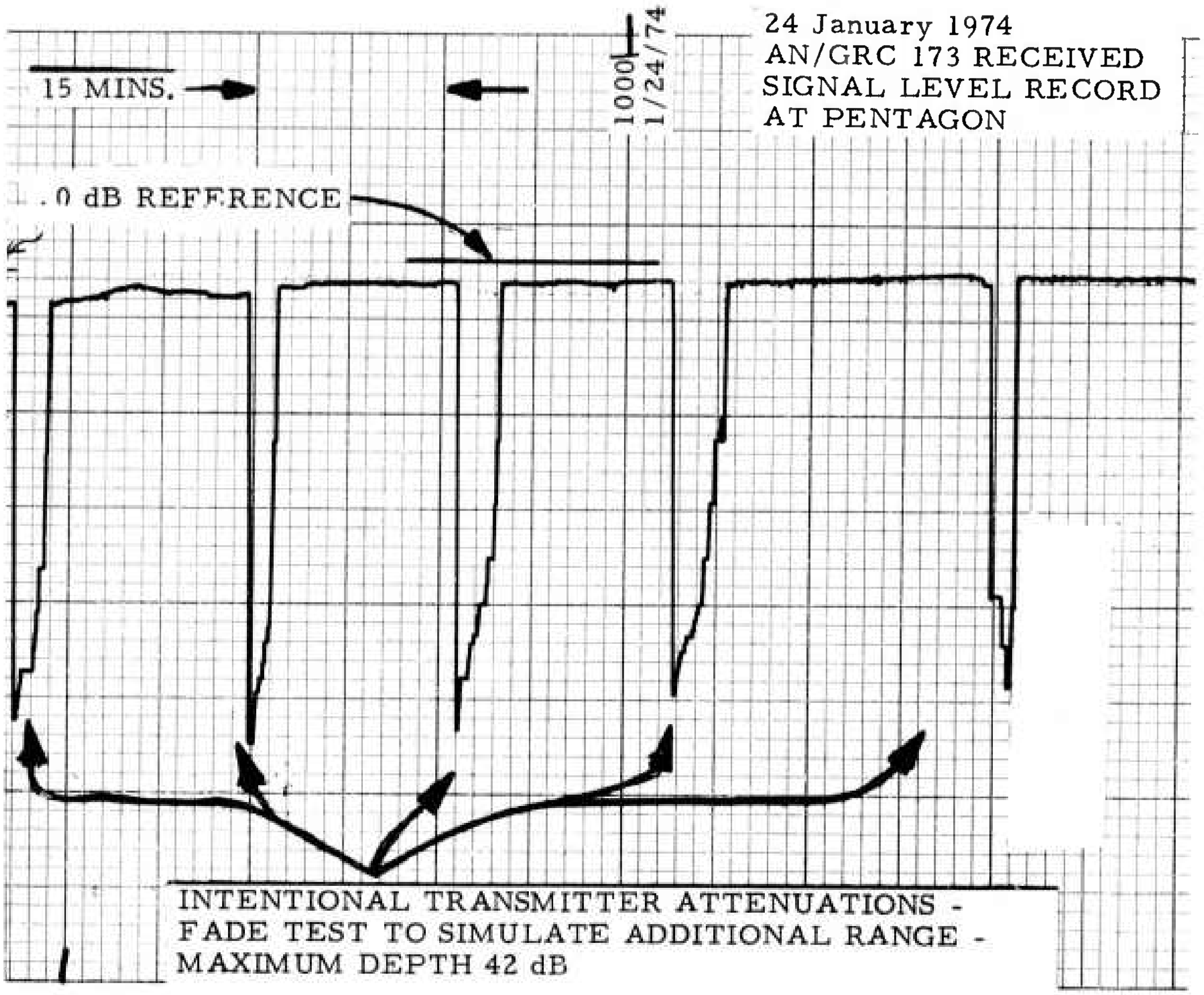


FIGURE 21. TYPICAL FADE MARGIN DEMONSTRATIONS

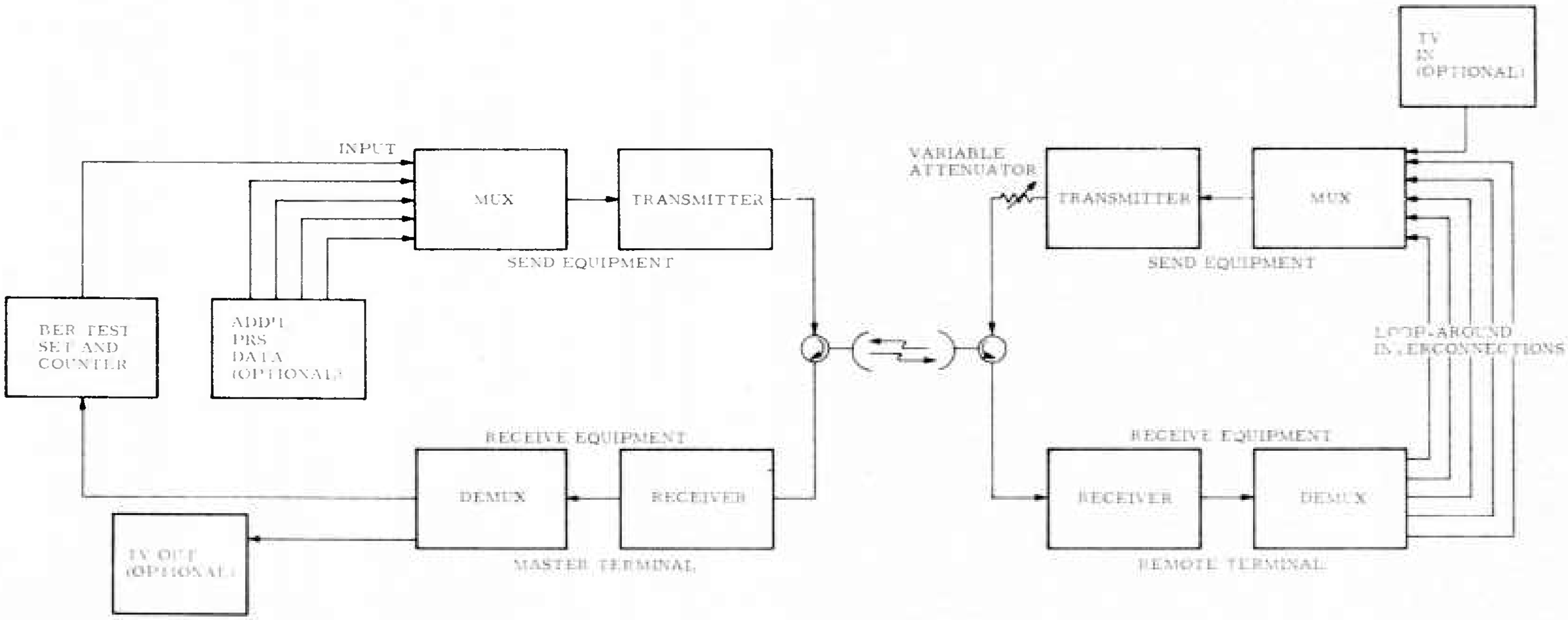


Figure 22. Loop-Around System Operation, Simplified Block Diagram

BER data was taken, the Pentagon was the master station and the WNY station was the remote. All of the additional attenuation to vary the signal level was applied to the transmitter output at the remote (WNY) station. Figures 23 and 24 are detailed block diagrams for the equipment arrangements at the master and remote stations, respectively. The BER test set used one of the high speed channels at 39.29 Mb/s. The loading of the other channels was optional and is discussed in Appendix A.

The procedure for measuring error rate was to compare the bit sequence from the Pseudo-Random-Sequence (PRS) generator of the BER test set, after passing through the radio set, with that of the similar and synchronized local PRS signal. The BER test set is operated from a reference clock which is common to the transmitted and received PRS signals and is capable of directly providing an error count output signal. A separate counter with a variable time base gate registers the number of outgoing and incoming bits which differ during the measurement interval. The probability of error (P_e) is obtained by dividing error count in errors per second by the channel data rate (39.29×10^6). Due to inherent link margin in the system at the link range, the error rate was normally too low to register an error count during any reasonable measurement interval. Therefore, the received signal level (and S/N ratio) was varied intentionally to produce errors around the region of interest, which is $P_e = 10^{-6}$. This was accomplished by changing the attenuator setting at the remote station. A curve relating S/N to the errors was obtained by subtracting the attenuator setting from the normal S/N reading and plotting against P_e. The order wire voice circuit was used by the two operators to coordinate the attenuator setting and error counts.

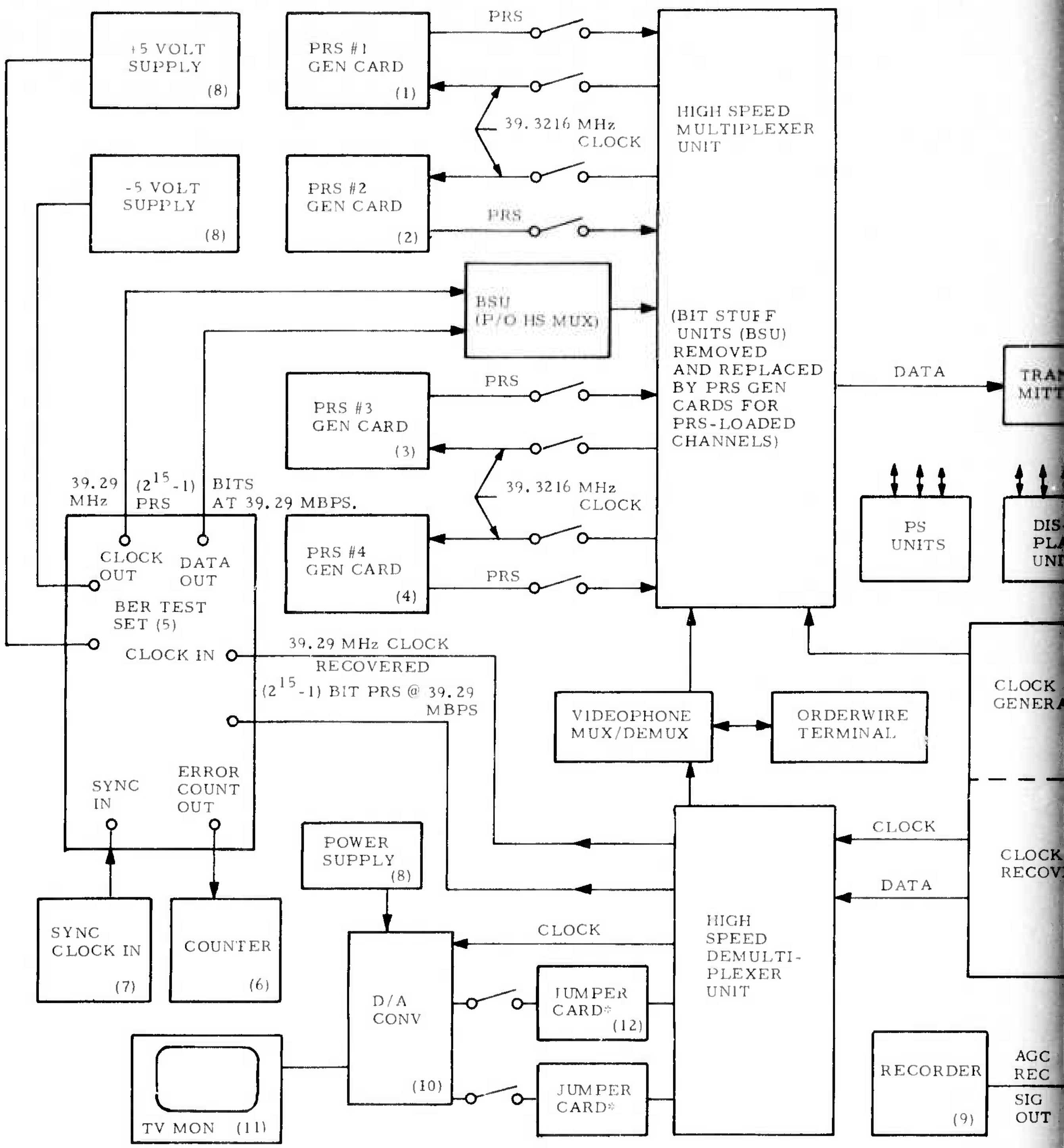
A BER test run was generally attempted under conditions of no path-obstructions (cranes). Sometimes, however, these conditions would not remain static during a run thus producing anomalous data.

c. Test Results and Discussion

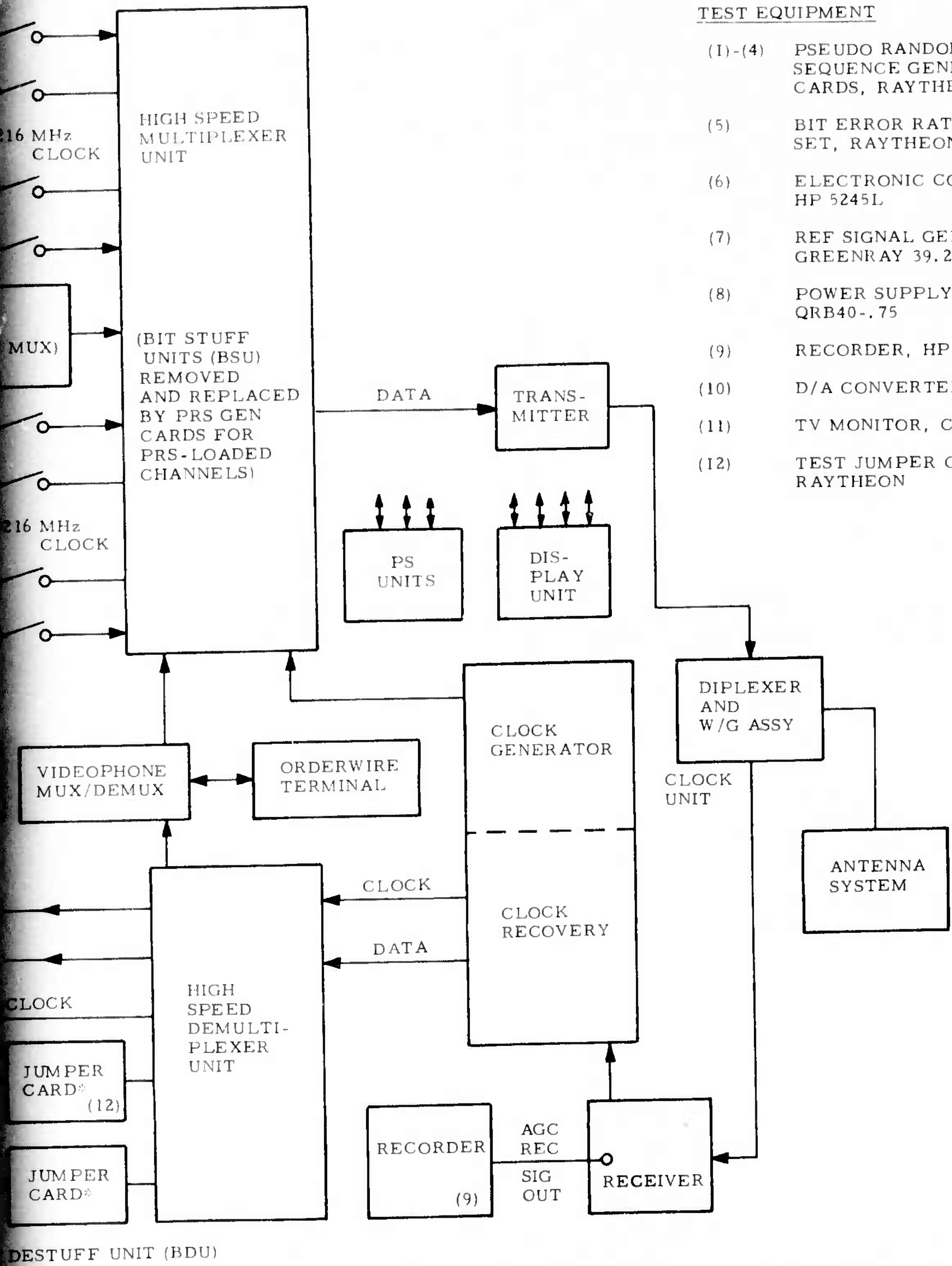
Typical curves of P_e vs S/N obtained during the test period are shown in Figure 25. The experimental data from which these curves were plotted is given in Tables IX through XII. The curves disclose that a $P_e = 10^{-6}$ for the link is obtained with S/N at approximately 15 to 16 dB and a $P_e = 10^{-8}$ at approximately 17 to 18 dB.

A consequence of the loop-around configuration is that it simulates relay operation. Relaying demonstration was done this way primarily because of schedule and resource constraints and it did not actually require the interposing of a third terminal.

In the loop-around configuration where the additional system attenuation is all at one end, as in the case here, the measured P_e is dominated by the direction of lower power transmission. Note that P_e is inversely proportional to the S/N ratio and that for two links (1 and 2) in tandem:



*REPLACED BIT DESTUFF UNIT (BDU)

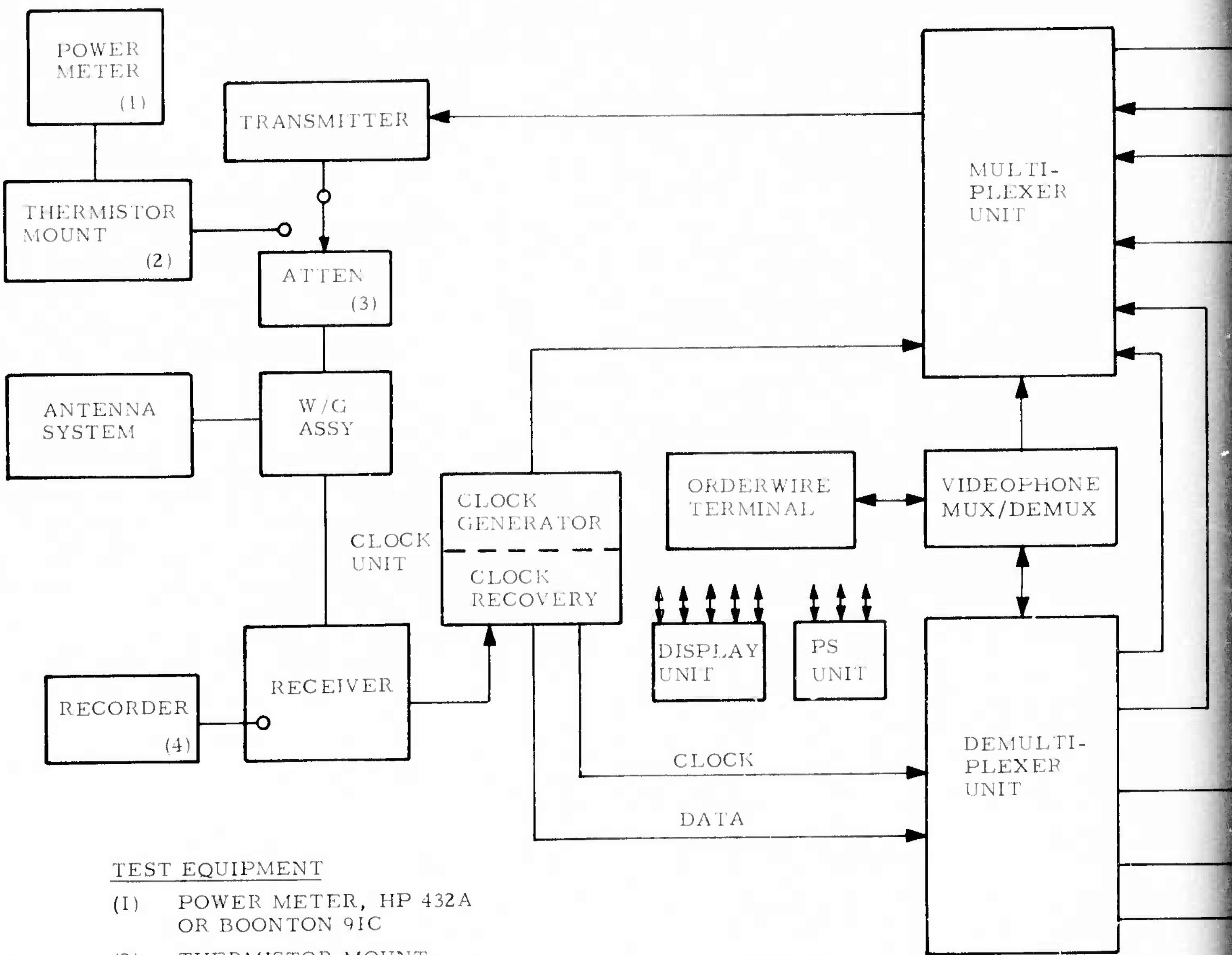


TEST EQUIPMENT

(1)-(4)	PSEUDO RANDOM SEQUENCE GENERATOR CARDS, RAYTHEON
(5)	BIT ERROR RATE TEST SET, RAYTHEON
(6)	ELECTRONIC COUNTER HP 5245L
(7)	REF SIGNAL GENERATOR, GREENRAY 39.29 MHz VCXO
(8)	POWER SUPPLY, SORENSEN QRB40-.75
(9)	RECORDER, HP 680
(10)	D/A CONVERTER, RAYTHEON
(11)	TV MONITOR, CONRAC
(12)	TEST JUMPER CARD FIXTURE, RAYTHEON

Figure 23. BER Test Setup At Master Terminal

2



TEST EQUIPMENT

(1) POWER METER, HP 432A OR BOONTON 91C

(2) THERMISTOR MOUNT, HP R486A

(3) TEST ATTENUATOR, SEE TEXT

(5) A/D CONVERTER, RAYTHEON

(6) TV CAMERA, SIERRA OR TELEMATION

(7) TEST JUMPER,CARD FIXTURE, RAYTHEON

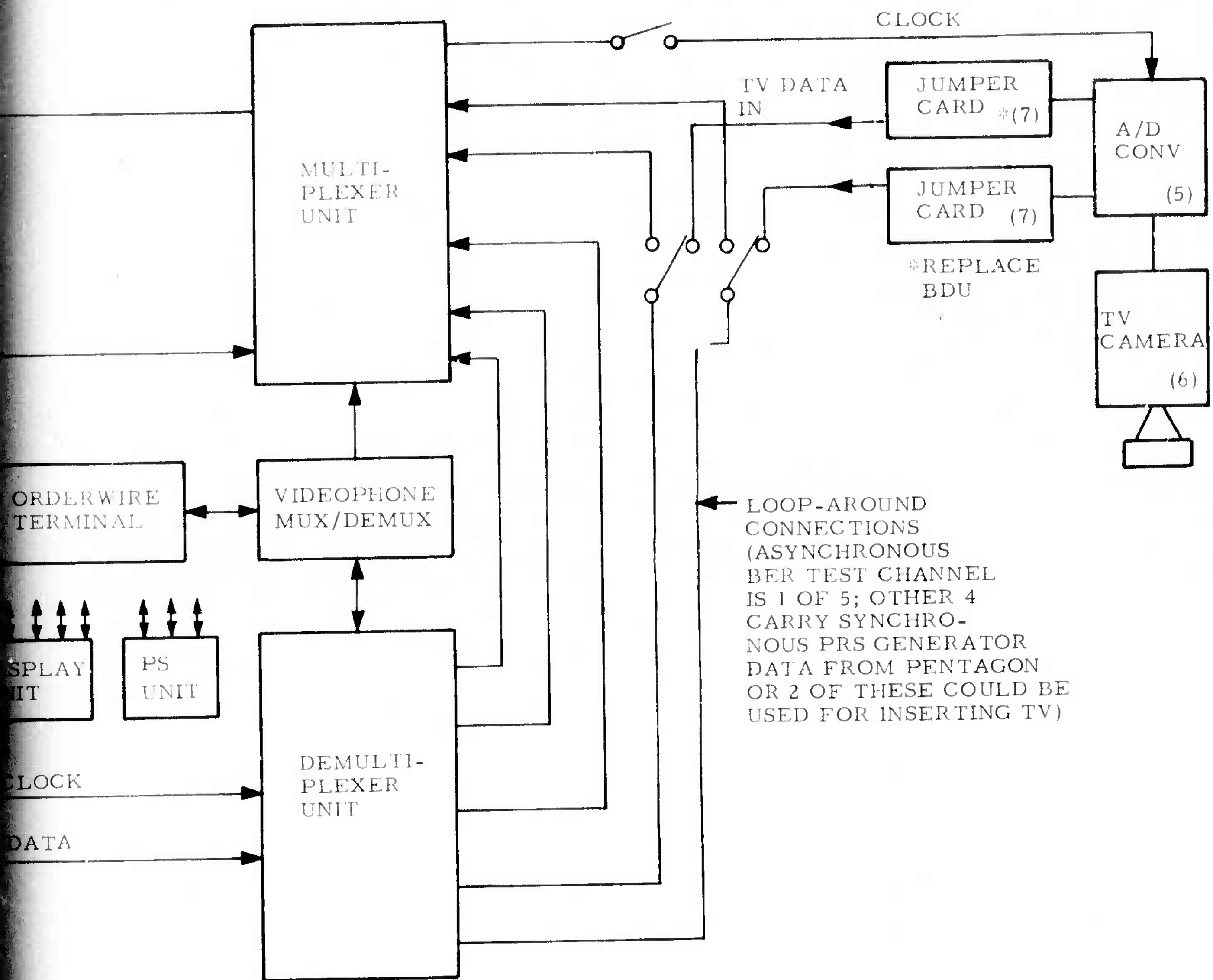


Figure 24. BER Test Setup At Remote Terminal

2

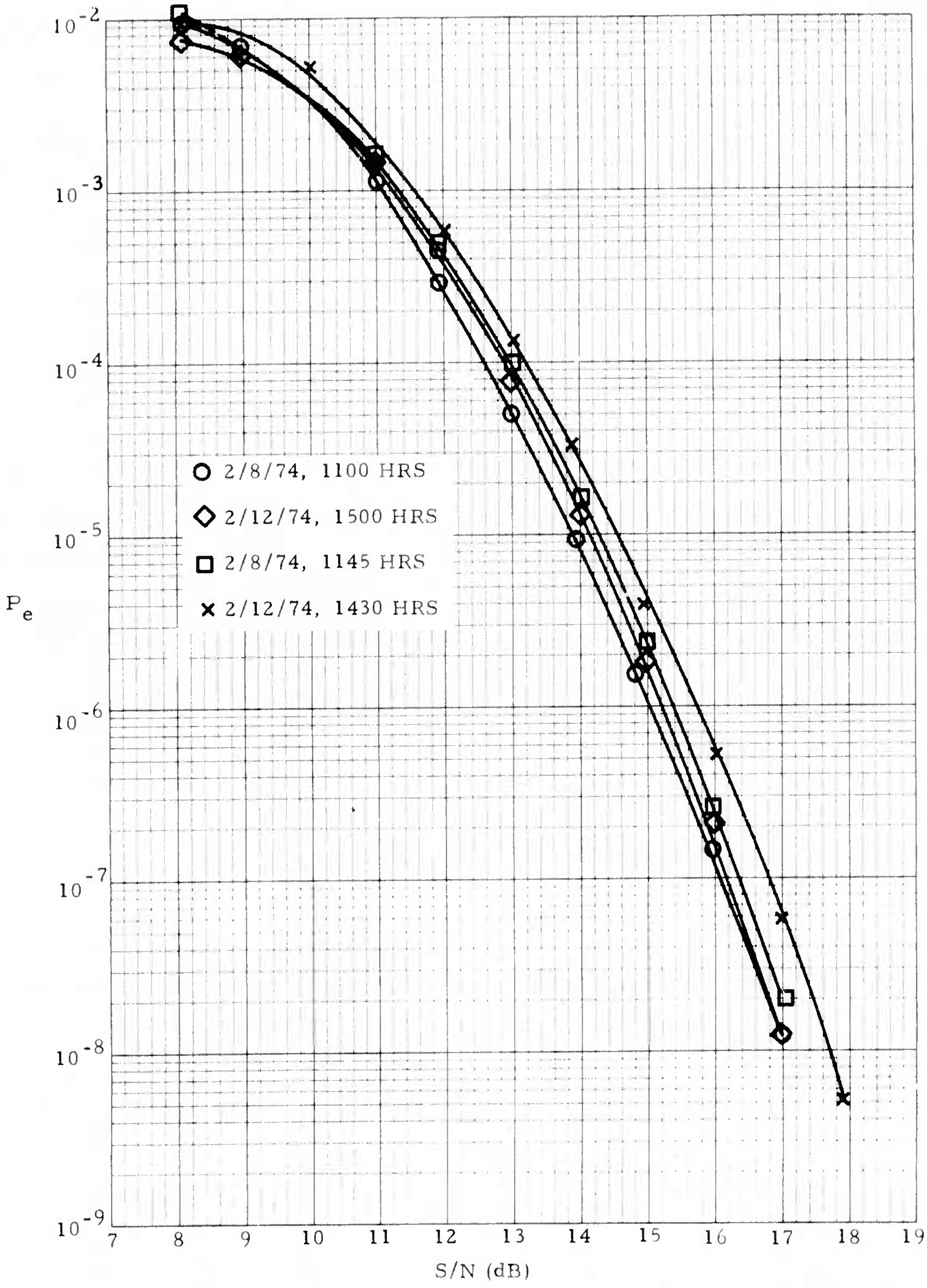


Figure 25. Typical Curves of P_e vs. S/N For Phase III Link

Table IX. Experimental Data For P_e Test of 8 Feb. 1974, 1100 Hours

Error Frequency (Hz)	P_e	Attenuator Setting (dB)	S/N (dB)
0.5	1.27×10^{-8}	-38	17
5.9	1.5×10^{-7}	-39	16
52.4	1.33×10^{-6}	-40	15
384.0	9.77×10^{-6}	-41	14
2,000.0	5.09×10^{-5}	-42	13
11,100.0	2.82×10^{-4}	-43	12
46,500.0	1.18×10^{-3}	-44	11
147,000.0	3.74×10^{-3}	-45	10
269,000.0	6.85×10^{-3}	-46	9
371,000.0	9.44×10^{-3}	-47	8

Table X. Experimental Data For P_e Test of 8 Feb. 1974, 1145 Hours

Error Frequency (Hz)	P_e	Attenuator Setting (dB)	S/N (dB)
0.8	2.04×10^{-8}	-38	17
11.6	2.95×10^{-7}	-39	16
90.7	2.31×10^{-6}	-40	15
783.0	1.99×10^{-5}	-41	14
4,570.0	1.16×10^{-4}	-42	13
17,300.0	4.40×10^{-4}	-43	12
53,500.0	1.36×10^{-3}	-44	11
152,000.0	3.87×10^{-3}	-45	10
247,000.0	6.29×10^{-3}	-46	9
460,000.0	1.17×10^{-2}	-47	8

Table XI. Experimental Data For P_e Test of 12 Feb. 1974, 1430 Hours

Error Frequency (Hz)	P_e	Attenuator Setting (dB)	S/N (dB)
0.2	5.1×10^{-9}	-37	18
2.8	6.62×10^{-8}	-38	17
20.8	5.29×10^{-7}	-39	16
148.0	3.77×10^{-6}	-40	15
1,250.0	3.18×10^{-5}	-41	14
5,690.0	1.45×10^{-4}	-42	13
23,100.0	5.88×10^{-4}	-43	12
70,400.0	1.79×10^{-3}	-44	11
221,000.0	5.62×10^{-3}	-45	10
260,000.0	6.62×10^{-3}	-46	9
373,000.0	9.49×10^{-3}	-47	8

Table XII. Experimental Data For P_e Test of 12 Feb. 1974, 1500 Hours

Error Frequency (Hz)	P_e	Attenuator Setting (dB)	S/N (dB)
0.5	1.27×10^{-8}	-38	17
7.6	1.93×10^{-7}	-39	16
70.7	1.79×10^{-6}	-40	15
617.0	1.57×10^{-5}	-41	14
3,480.0	8.86×10^{-5}	-42	13
16,800.0	4.27×10^{-4}	-43	12
52,100.0	1.33×10^{-3}	-44	11
161,000.0	4.10×10^{-3}	-45	10
234,000.0	5.96×10^{-3}	-46	9
313,000.0	7.97×10^{-3}	-47	8

$$(S/N)_{TOTAL} = \frac{1}{\frac{1}{(S/N)_1} + \frac{1}{(S/N)_2}}$$

If one of the signal-to-noise ratios is much lower than the other, then the errors attributed to the lower ratio dominate (e.g., $(P_e)_1 = 10^{-2} \gg (P_e)_2 = 10^{-5}$. The above considerations obtain when the errors produced in the two links are uncorrelated.

The curves of Figure 25 were obtained when the link was in its normal operating condition, and the errors in the two links were uncorrelated. This normal operating condition is defined as:

(1) Equipment parameters were as specified by the link budget.

(2) The data traffic was asynchronous, per design specification.

(3) The medium was clear (clear weather and no obstructions in the line of sight).

Limited attempts were also made to obtain developmental type data under variations in these experimental conditions. This included conditions for which the errors in the loop-around links were correlated. Appendix A describes these results.

A curve of the Phase III link P_e is shown in Figure 26 together with one made back-to-back in Phase II. The Phase III curve is for one of the runs (12 February 1974, 1430 hours) previously shown in Figure 25. The data for the Phase II curve is given in Table XIII. While a rigorous comparison of the two results cannot be made due to differences in the experimental arrangements, note that the performances are similar. Figure 26 also shows a P_e curve for

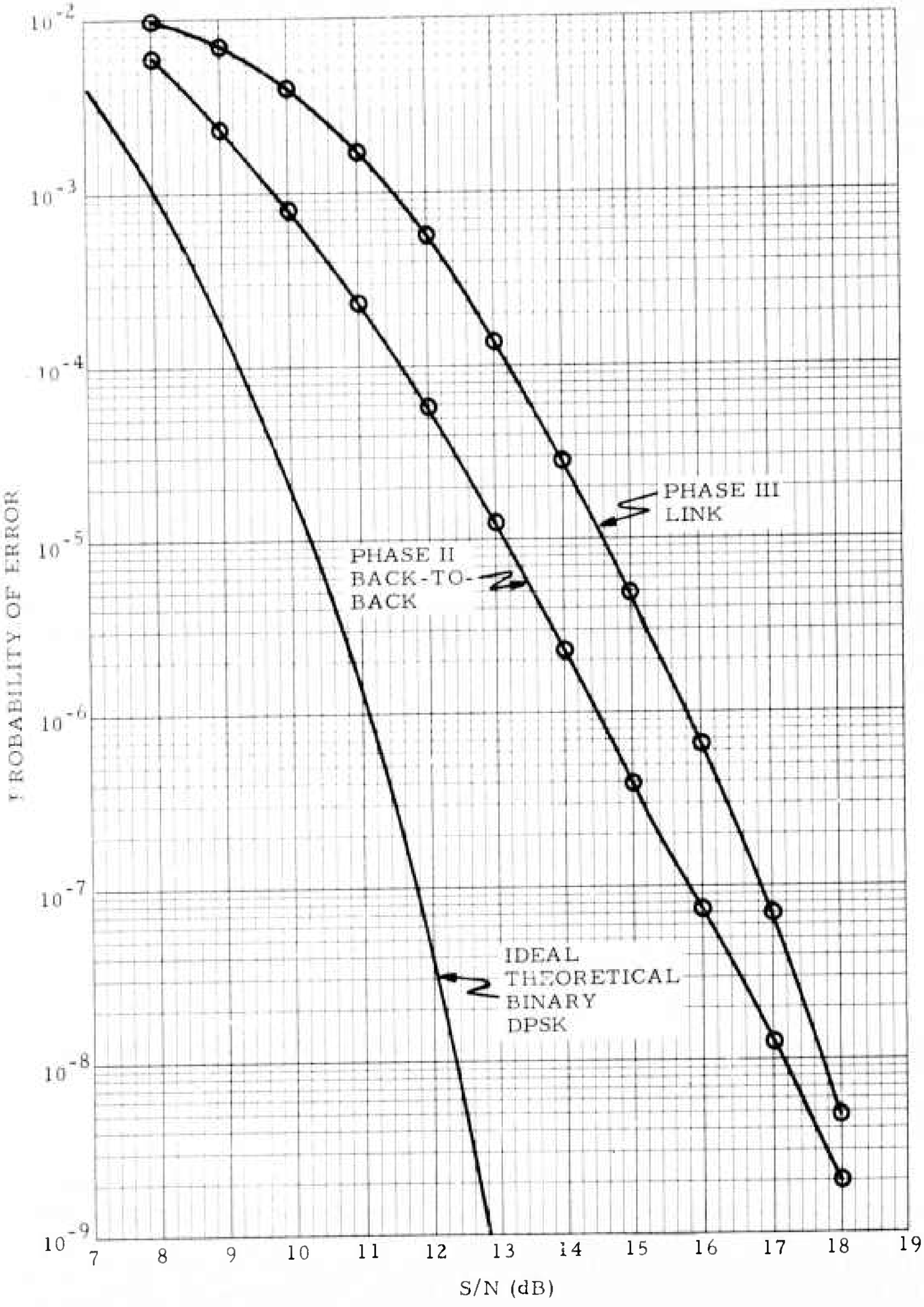


Figure 26. Comparison of P_e vs. S/N Curves

Table XIII. Experimental Data For Phase II P_e Test - 3 April 1973

Error Frequency (Hz)	P_e	S/N (dB)
0.08	2.03×10^{-9}	18
0.49	1.25×10^{-8}	17
2.8	7.12×10^{-8}	16
13.0	3.3×10^{-7}	15
81.0	2.06×10^{-6}	14
480.0	1.22×10^{-5}	13
2,250.0	5.72×10^{-5}	12
9,800.0	2.49×10^{-4}	11
23,800.0	8.6×10^{-4}	10
97,000.0	2.5×10^{-3}	9
236,000.0	6.0×10^{-3}	8

ideal binary differential phase shift key modulation with no band limiting. The experimental curves approach the theoretical curve and are considered highly representative of the performance of practical systems.

5. SYSTEM MESSAGE TESTS

a. Purpose and Requirements

The purpose of the system message tests was to demonstrate the use of the AN/GRC-173(XW-1) in the communications of digital data signals; both wideband and narrowband type. Accordingly these tests included the transmission of high resolution (1025 line) television (TV), utilizing two of the five high speed 39.3 Mb/s data channels (80 Mb/s nominal total). In addition, narrow bandwidth data at 100 kb/s was sent over a low speed (9.8 Mb/s channel).

b. Terminal Equipment Investigation

Availability of baseband terminal equipment was a major consideration in attempting system message tests. The AN/GRC-173(XW-1) is an integrated radio and TDM facility with specified digital interface rates (see section II for the design characteristics and data rates). Baseband terminal equipment is required to tie into the AN/GRC-173(XW-1) to demonstrate a total operational "user" system.

No terminal equipment was built or purchased under the project, so it was necessary to use equipment available from other sources. Accordingly, investigation was made of potential terminal equipment. A related consideration was the interface circuitry which would be necessary to integrate the terminal equipment with the AN/GRC-173(XW-1).

One of the wideband terminal equipments which was investigated was the high speed laser scanner/recorder set originally built for the Joint Services In-Flight Data Transmission System Project. It has wide bandwidth signal processing requirements which could potentially load the AN/GRC-173 (XW-1) to up to 80 Mb/s of its total 236 Mb/s capacity. Upon studying this hardware, it was decided that the integration could not be accomplished during the test phase. Therefore, other devices were investigated.

The requirement for wideband terminal equipment was ultimately solved by the Government's loan of high resolution 1025 line TV camera, control and monitor equipment which was being used on other programs, together with basic lens and light table equipment and suitable imagery. To interface the TV terminal equipment with the AN/GRC-173(XW-1), it was also necessary to obtain appropriate analog-to-digital (A/D) coder and digital-to-analog (D/A) decoder circuits. A set of breadboards of such equipment sufficient for one-way transmission tests was made available by Raytheon. Photographs of the encoder and decoder are shown in Figures 27 and 28, and a further discussion of their design is given in Section II. These breadboards were originally designed for another application, and initially it was intended to use them for demonstration with standard 525 line TV equipment. The coder and decoder were optimized as much as possible for higher resolution (1025 line) TV equipment and subsequently found to be acceptable. Since the 1025 line system transmission would make for a more stringent test, the equipment was set up accordingly.

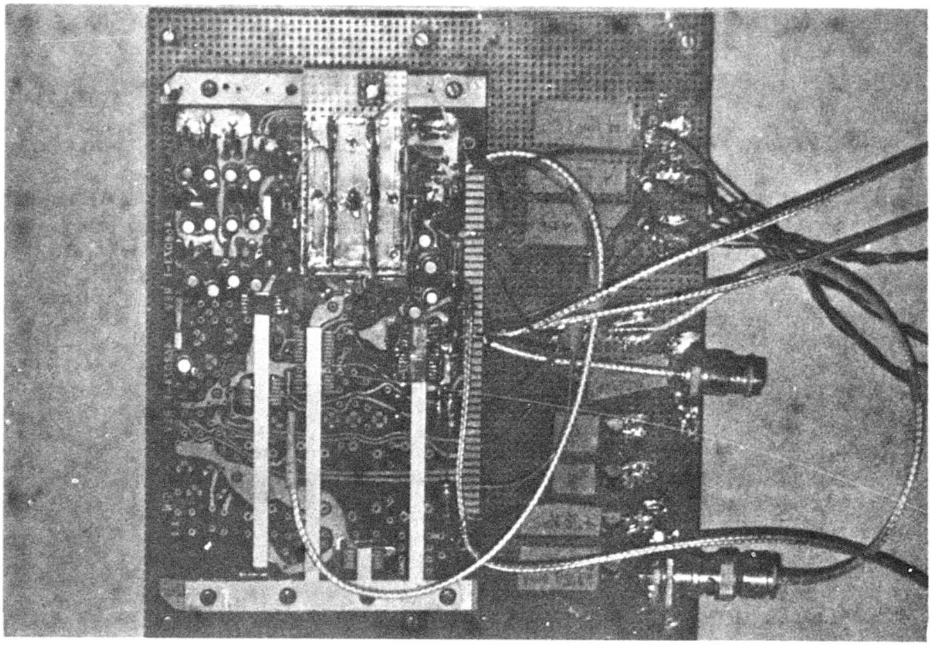


Figure 27. Breadboard Video A/D and Delta Modulation Encoder

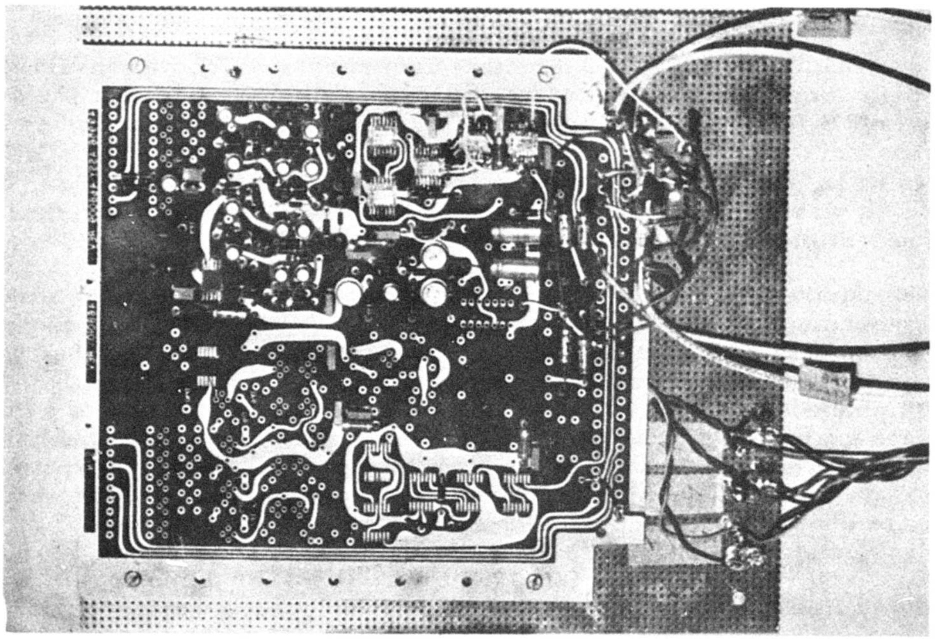


Figure 28. Breadboard Video D/A and Delta Modulation Decoder

Narrowband tests were considered less important than wideband tests of the AN/GRC-173 (XW-1) (in terms of demonstrating potential capacity); however, some investigation was also made of the availability of suitable low speed terminal equipment. It was originally anticipated that Multiplexer Sets AN/GSC-24 would become available during the test period, but this did not occur. The AN/GSC-24 is a low speed TDM equipment also being developed by the Air Force and the Defense Communications Agency. The AN/GRC-173 (XW-1) was designed for compatibility with the AN/GSC-24 at both the nominal 6.3 Mb/s and 9.8 Mb/s port rates and under Phase II, this compatibility was demonstrated through lab tests and analysis. Since delivery of the AN/GSC-24 equipment to the Washington test sites could not be accomplished under Phase III, it was necessary to devise other narrowband demonstrations. Although for a time it appeared that 10 to 50 KBPS laser scanner equipment would be tested, it was found that no low speed terminal equipment could be made available within schedule requirements. Finally, it was decided to simulate narrowband digital traffic using test equipment. As shown later, a standard pattern generator was suitably adapted to this purpose.

The remaining paragraphs of this section will address the wideband and narrowband system message tests separately due to the quite disparate requirements as regards to test arrangements. It should be noted, however, that the simultaneous mixture of narrowband and wideband data traffic is possible with the AN/GRC-173(XW-1) and this, in fact was shown using the test link.

c. Wideband Tests of High Resolution TV

(1) Laboratory Tests

Closed circuit tests were first performed in the laboratory without the link to establish a performance standard, or operation baseline. Later, it would be possible to determine if the link produced any degradation in image quality.

Facilities in Washington were provided by the Government for the laboratory tests, together with the TV terminal equipment which would subsequently be used in the link. The TV equipment and the Raytheon encoder/decoder were set up as shown in Figure 29. Four different positive image transparencies were used in these tests:

- Standard resolving power test chart (see Figure 30)
- 16 level gray scale
- Continuous tone photograph of a ship in the Anacostia River
- Continuous tone photograph of an aerial view of Washington, D. C.

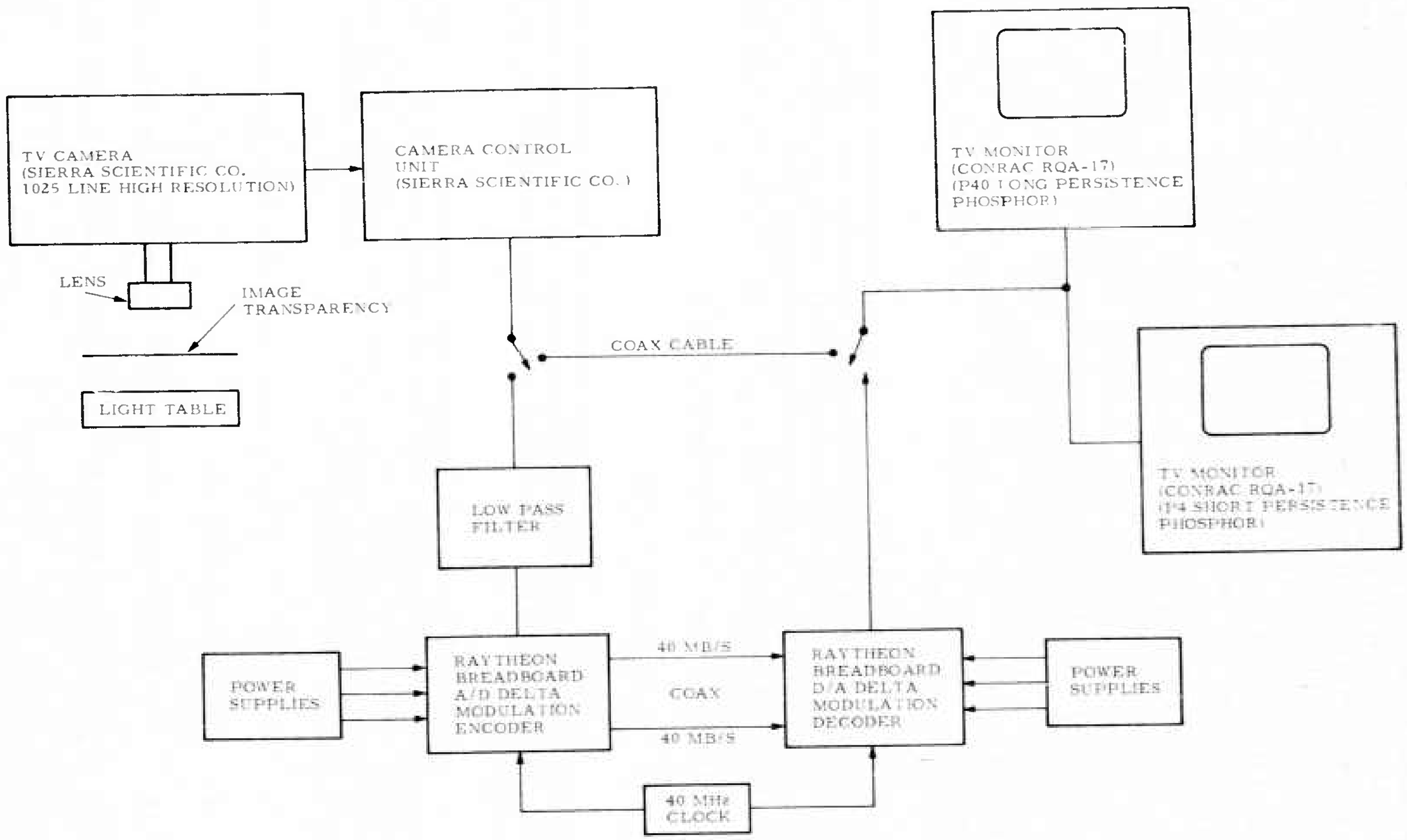


Figure 29. Laboratory TV Test Configuration

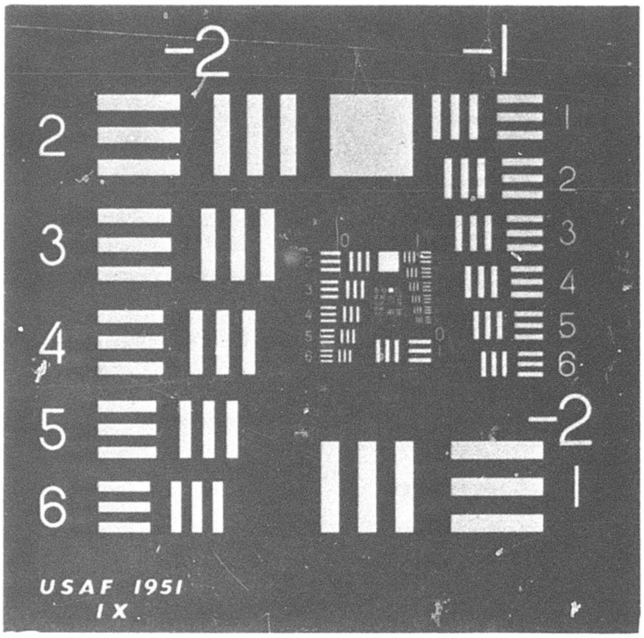


Figure 30. Standard Resolving Power Test Chart

A minimum of three observers participated in the evaluations.

(a) Closed Circuit Baseband Tests Without Digital Encoding

Refer to the block diagram, Figure 29. The first group of tests was run "straight-through" without digital encoding and with the cameras simultaneously driving both monitors. There was interest in comparing the results with both monitors, since it was expected that phosphor persistence would influence background noise. The 1025 line camera and monitors operated at 30 frames/second, or, 60 fields per second.

The following observations of the cosmetic value* of the video presentation were made using image transparencies of the ship on the river and the aerial view of Washington:

P40 phosphor display· clear, bluish image, pleasing and restful.

P4 phosphor display: clear, whitish image, high apparent contrast and more "snow" than P40.

The gray scale tests produced the result that 11 of the 16 levels were distinguishable on both monitors by the observers.

*As used in this discussion, "cosmetic value" is a qualitative term for the general visual appearance of that which was observed.

The resolving chart image was viewed with the following results:

P40 phosphor display: 12.7 line pairs per millimeter (lp/mm)*.

P4 phosphor display: 14.3 lp/mm.

The system magnification from image to monitor was measured to be 8 x and the resolution values were then normalized to "per power", an important criterion which is discussed later. The results of measuring resolution value per power are:

P40: 1.59 lp/mm/power

P4: 1.79 lp/mm/power

(b) Laboratory Tests with Digital Encoding

In this group of tests the TV signal was digitally encoded and "hard-wire" connected to the decoder (see Figure 29). As explained in Section II, the coding is of the Delta 2-bit type with one of four possible digital code outputs split between two lines. The two lines each have a data rate equivalent to the clock frequency, which in this case was supplied by a laboratory source operating at around 39 MHz.

Again, both monitors were connected to view the output simultaneously. The same image transparencies of the ship on the water and the aerial view of Washington were observed. The cosmetic value was subjectively evaluated as "quite satisfactory" by the observers. Slightly more noise was present than in the non-encoded baseband tests, but the cosmetic value was still judged as adequate and better than for conventional 525 line TV. Different values of low pass filters, with cutoffs between 5 and 20 MHz were used in the line between camera control and A/D converter to limit baseband noise; a 15 MHz filter was found to produce the best display qualities.

The tests using the same gray scale transparency as before showed that 11 of 16 gray values were distinguishable on either monitor. This result is identical with the previous non-coded result.

Viewing of the resolution chart produced the following results:

P40 display: 11.3 lp/mm

P4 display: 12.7 lp/mm

---

* A line pair (lp) is a standard pattern of a black line plus a white line, or a line and a space. A resolution of 12.7 lp/mm means that a pattern of 12.7 black lines plus white lines in one millimeter is resolved.

It was determined that the same magnification (8X) was present in the system, and the resolution values normalized to "per power" then were:

P40 display: 1.41 lp/mm/power

P4 display: 1.59 lp/mm/power

(c) Discussion of Results of the Laboratory Closed-Circuit Tests

Table XIV summarizes the results of the laboratory tests. In general, the use of the breadboard digital coding equipment was found to produce satisfactory results. When the coding equipment was interposed, the imagery cosmetic quality was only slightly reduced and gray-scale values were the same as without it.

The resolution "per power" rating used above is a figure of merit which is a function of numerous variables since it takes into account all components in the system, including viewer, optics, lighting, display screen and camera target as well as the electronics and the environment. A value of 1 lp/mm/power is considered representative of a good 525 line closed circuit TV system, while approximately 2 lp/mm/power may sometimes be obtained under the most ideal conditions for a 1025 line system. Examinations of the above results show intermediate values of the "per power" figure of merit for both the baseband video and the digitally coded video tests. The reason for any difference in performance between the P40 and P4 displays is not fully known, but it is possibly due to different aging processes in the phosphors. The TV equipment had been in use for some time and the difference in performance with and without the digital converter equipment in the system was only about 12 percent. This result was encouraging because, as mentioned, the converter circuits were originally designed for another application.

The baseline laboratory tests above were repeated and the findings were the same. The overall result was that the 1025 line TV image quality with the converters was judged satisfactory to pass video over the link for demonstration of the link's effect on video image quality.

(2) Link Tests

The link tests of TV transmission used the WNY station as the sending end and the Pentagon station as the receiving end. For these tests all equipment was self-contained in the shelters. A block diagram of the test setup is shown in Figure 31 and the terminal configurations are shown in Figure 32. A basic discussion of the comparative results (lab vs link tests) will be given first for purposes of continuity with the above discussion, then additional details will be provided on the test setups and the further TV demonstrations with the AN/GRC-173(XW-1).

Table XIV. Summary Of Results For TV Laboratory Tests Without Coding/Decoding

Parameter	P4 Phosphor Monitor	P40 Phosphor Monitor
Cosmetic value	Excellent	Excellent
Gray Scale	11 shades	11 shades
Resolution	14.3 lp/mm	12.7 lp/mm
Per-power value	1.79 lp/mm/power	1.59 lp/mm/power

With Coding/Decoding

Parameter	P4 Phosphor Monitor	P40 Phosphor Monitor
Cosmetic value	Adequate and better than 525 line TV	Adequate and better than 525 line TV
Gray Scale	11 shades	11 shades
Resolution	12.7 lp/mm	11.3 lp/mm
Per-power value	1.59 lp/mm/power	1.41 lp/mm/power

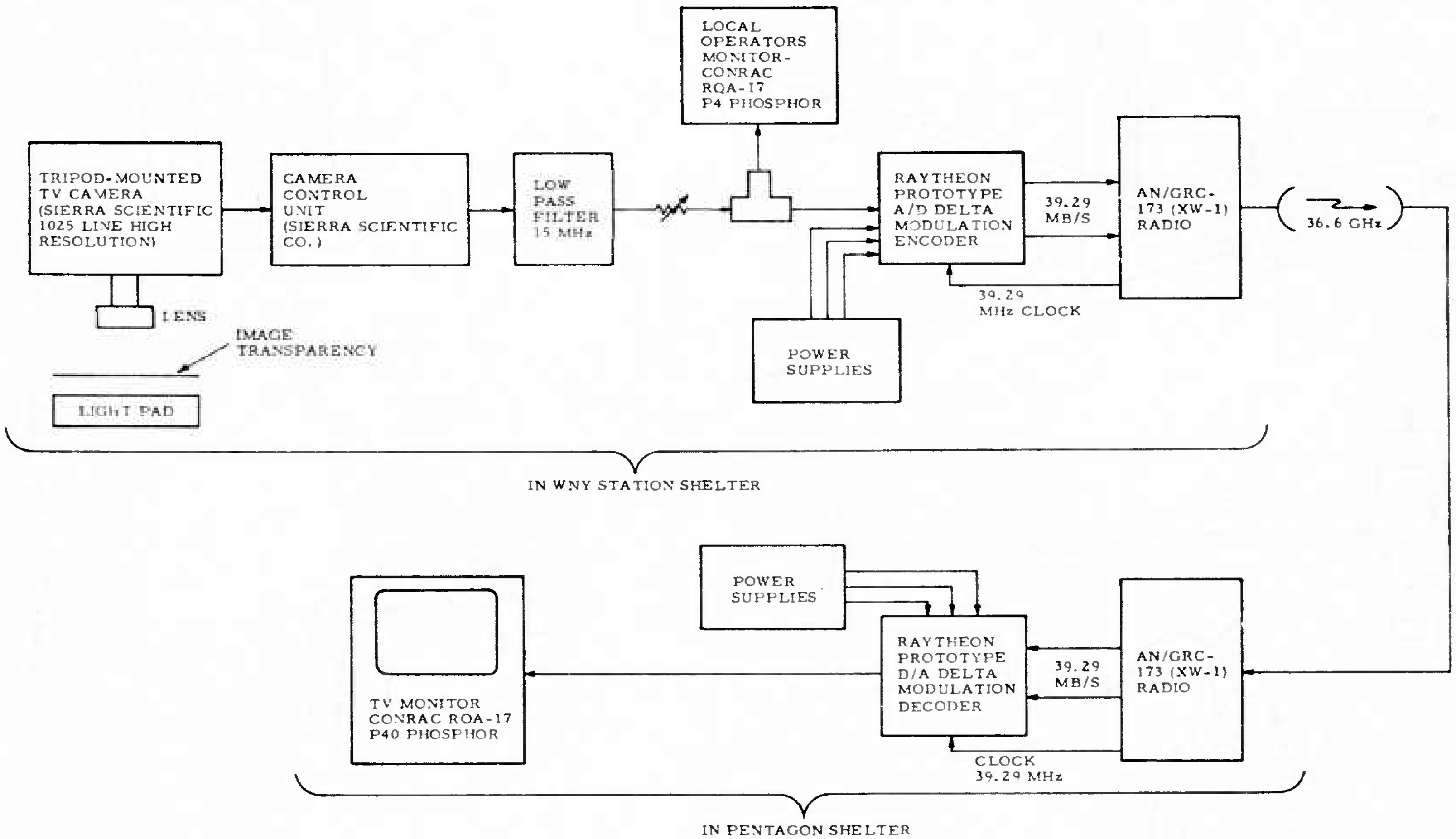


Figure 31. Configuration For High Resolution Digitized TV Link Tests

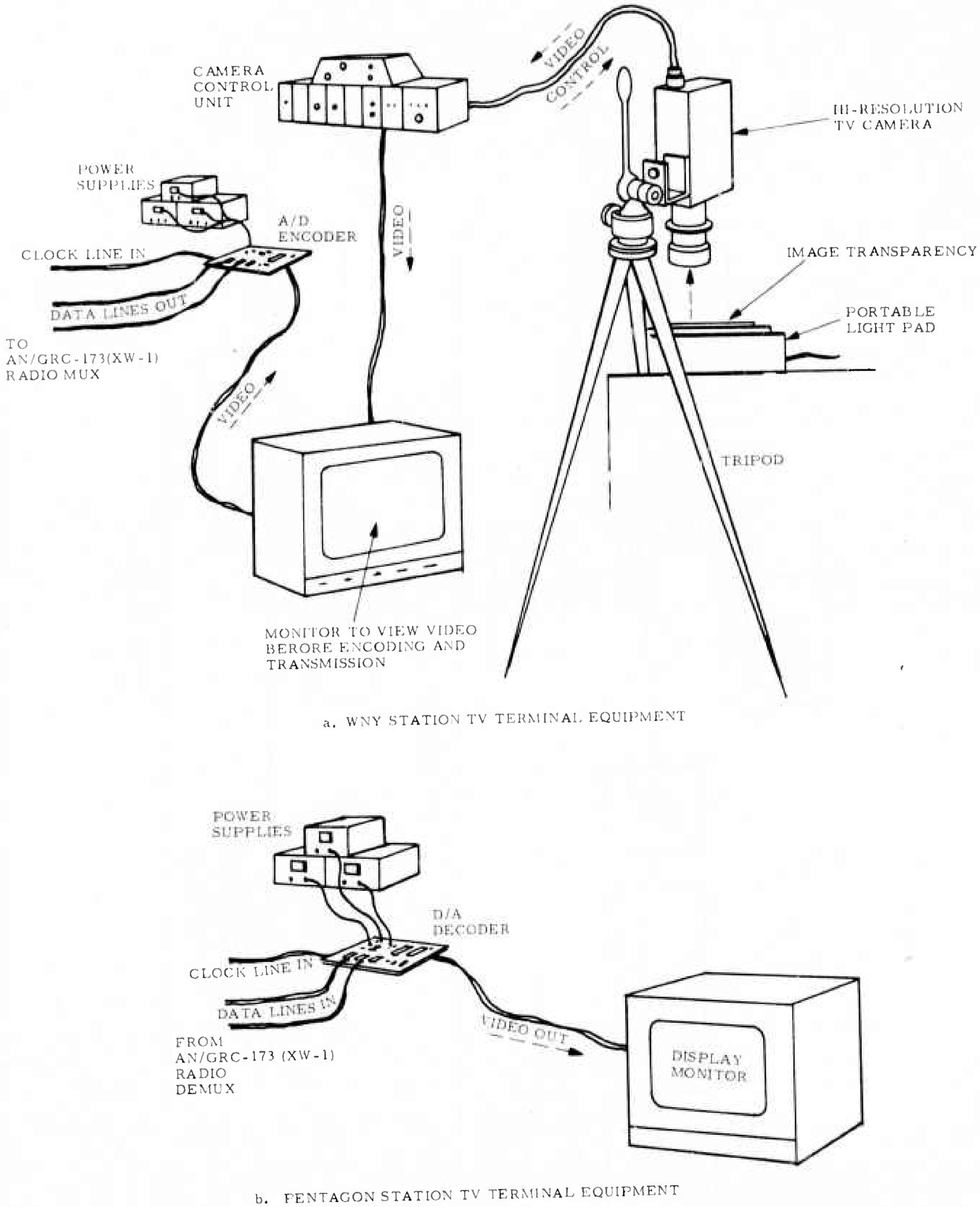


Figure 32. Terminal Configurations

(a) Results and Comparison with Lab Tests

The evaluations performed over the link were similar to the ones performed in the laboratory and included: cosmetic value of the image display, gray scale, and resolution. The imagery samples were the same as used in the laboratory baseline tests.

Table XV summarizes the results of the link evaluation.

Table XV. Summary Of Results For TV Link Test

Parameter	Display on WNY Monitor Before Encoding and Transmission	Received Display on Pentagon Monitor After Receiving and Decoding
Monitor Scope	P4 Phosphor	P40 Phosphor
Cosmetic Value	Same as in laboratory	Same as in laboratory
Gray Scale	11 Shades	11 Shades
Resolution	11.3 lp/mm	11.3 lp/mm
Per-power Value	1.41 lp/mm/power	1.41 lp/mm/power

The results in Table XV should be compared with the laboratory test results summarized in Table XIV. In the link tests, the cosmetic value of the display after coded link communications was observed to be equivalent to that seen in the coded laboratory tests. The gray scale definition was identical to that found in the laboratory, i.e., 11 shades. Also, regarding resolution, it was found that the link did not cause any degradation. Note the results in Table XIV for the local WNY P4 monitor and the Pentagon P40 monitor; the values of resolution and per-power value are the same, 11.3 lp/mm and 1.41 lp/mm/power respectively. Referring again to Figure 31, the local WNY P4 monitor was ahead of the digital encoder and the link and the P40 Pentagon monitor was after the link and the digital decoder. Therefore, since the resolution results were the same, the conclusion is reached that the AN/GRC-173(XW-1) link was transparent in the transmission process. The difference between the laboratory resolution of 1.59 lp/mm/power obtained on the P4 phosphor and the WNY shelter mounted display value of 1.41 lp/mm/power (both obtained without digital processing) was found to be produced by vibration effects at the rooftop location. In the laboratory, the environment was ideal. In the link tests, vibration of the shelter was mechanically transmitted to the light pad, tripod, camera, lens, and image transparency, and this produced the drop in resolution. The link itself introduced no measurable change in the image quality. The conclusion was therefore reached that the AN/GRC-173(XW-1) link acts as a "non-interfering" channel for the video signal. Environmental effects on the TV terminal equipment such as vibration would be eliminated in any future application.

(b) Additional Details of TV Link Configuration and Demonstration

The following paragraphs further document the equipment arrangements and the demonstrations conducted in support of the wideband link performance evaluation of the AN/GRC-173(XW-1).

Note: Upon completion of the controlled TV link tests, the above mentioned camera, monitor and light pad equipment, or others, were used for demonstrations depending on availability of the exact item. In particular, a Telemation Company Model TMC2300 High Resolution TV camera and other types of Conrac Company monitors were also used. The following illustrations are representative of the usage of any of these equipments.

Figure 33 is a view of the tripod-mounted TV camera at the WNY shelter pointing down at an image transparency on the portable light box. Figure 34 is a view of the camera control equipment at the WNY station. The A/D Video Encoder is shown in Figure 27. The display monitor setup at the Pentagon station is shown in Figure 35. Some auxiliary test equipment to support the overall tests is visible and the operator's use of the order wire channel to coordinate test sequences is also shown.

Figure 36 is a photographic print similar to the positive transparency image of the ship in the Anacostia River used in the controlled evaluation tests. Photographs of the same subject taken right off the Pentagon station TV monitor are shown in Figures 37 and 38. These are off the display screen after being digitally transmitted and received.

Other photographs taken off the Pentagon display monitor after digital communications over the link are shown in Figures 39 and 40. Note: Magnifications of the viewed subject of between 5X and 25X were produced by the TV camera lens prior to transmission. For example, in obtaining the ship details shown in Figures 37 and 38, the TV camera lens magnification was set at approximately 20X and the TV camera was pointed at the ship scene (as shown in Figure 36) at stations about 1/4 aft of the bow and at the stern.

The photographs of the TV display screens for this report were obtained with a 35-millimeter Minolta SRT-101 camera used with available light. The rendition for this report naturally cannot be considered optimum because of photographic processing. Observers at the actual demonstrations generally remarked that the displayed quality was "adequate" to "excellent."

The TV camera could also be pointed at objects inside the shelter. Visually-aided conferences and communications of graphics were demonstrated in this way.

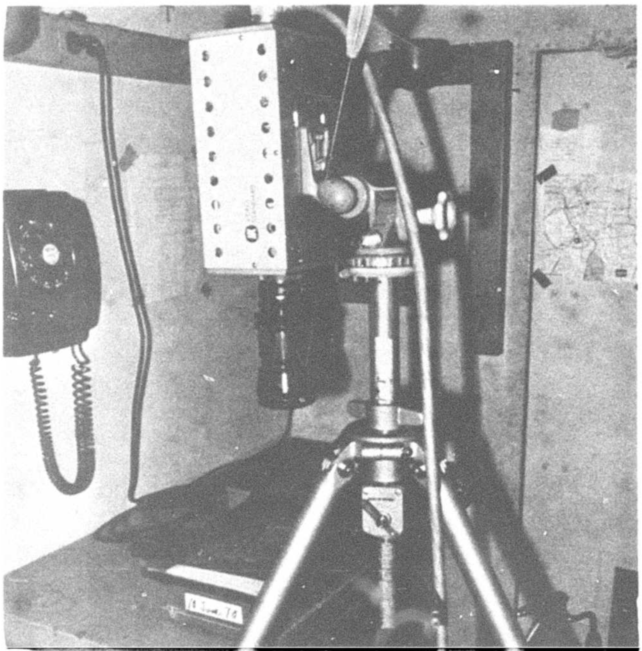


Figure 33. High-Resolution TV Camera At WNY Station

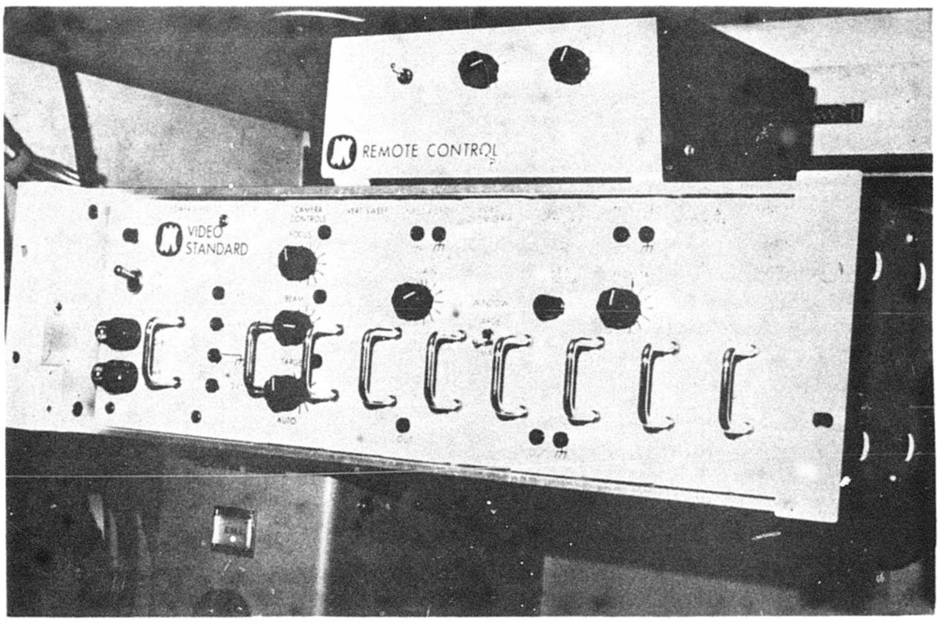


Figure 34. TV Camera Control Equipment **At WNY Station**

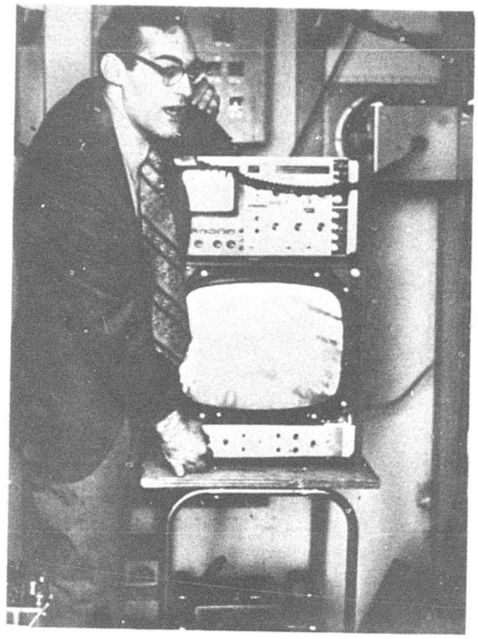


Figure 35. Display Monitor Setup At Pentagon Station

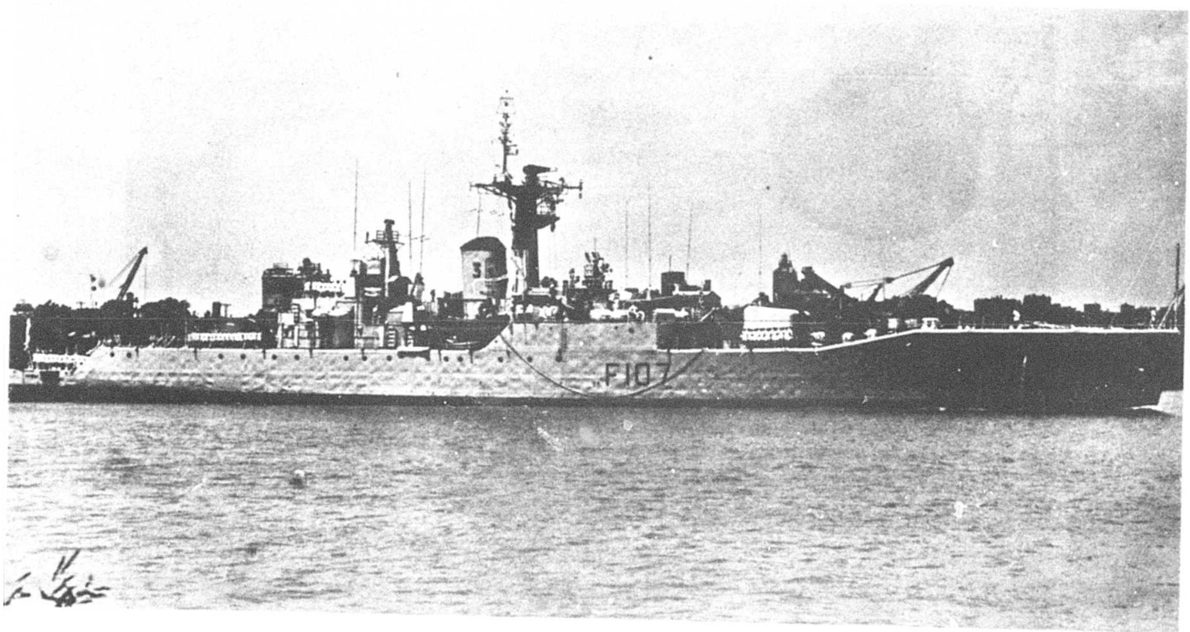


Figure 36. Photographic Print Similar To Image Transparency of Ship in Anacostia River

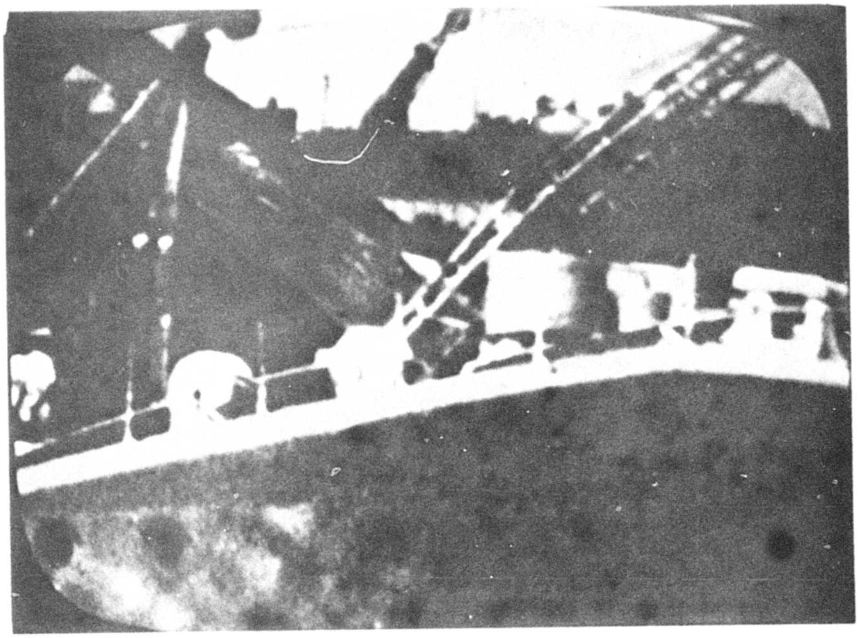
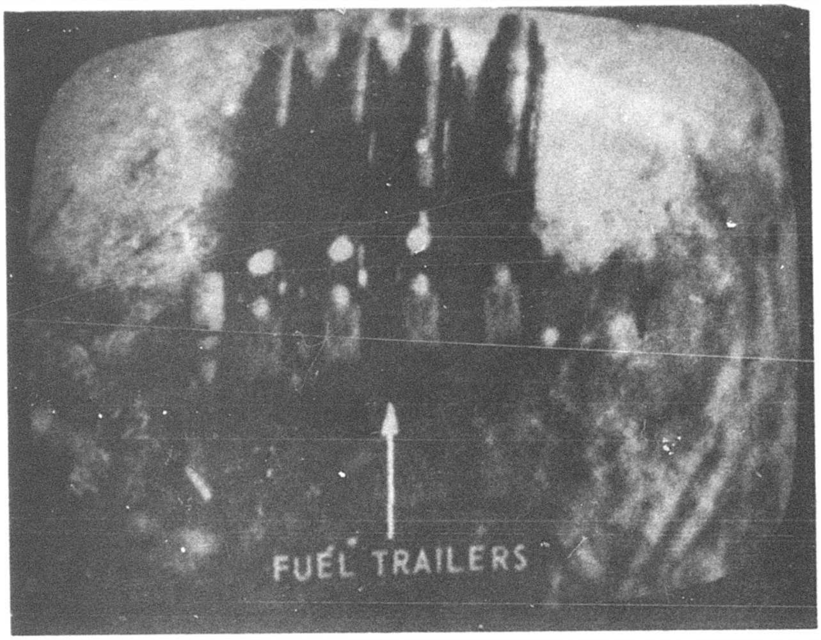
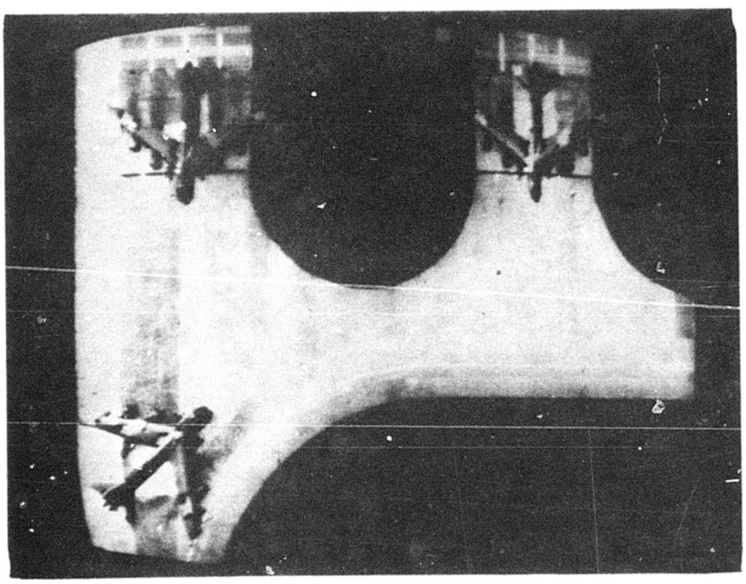


Figure 37. Detail of Ship After Digital TV Transmission

Figure 38. Another View of Ship Detail After Digital TV Transmission



A. Example



B. Example

Figure 39. Other Examples of Image Transparency Digital TV Transmission

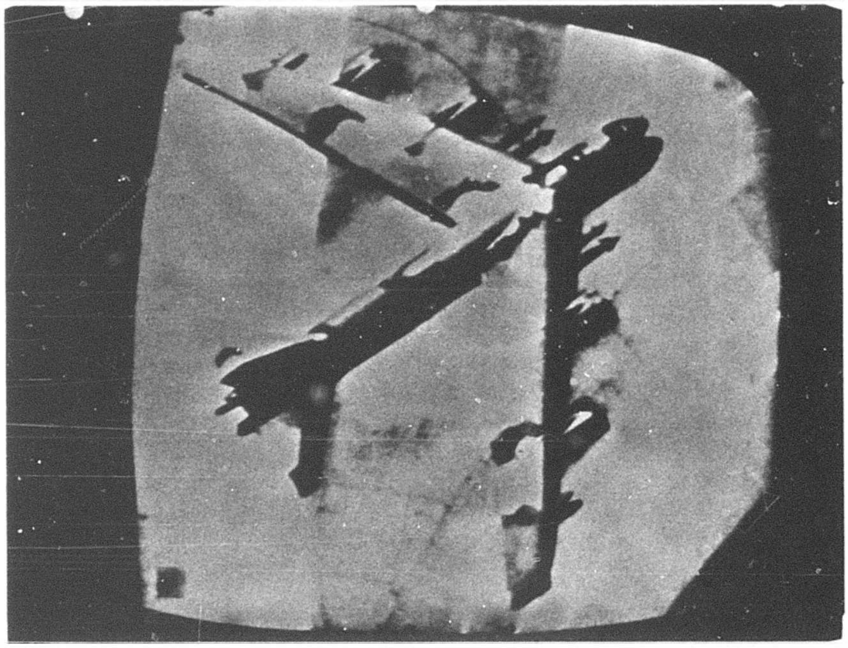


Figure 40. Display After Higher Magnification and Digital Transmission

During demonstration periods it was at times instructive to transmit "live action" scenes by pointing the TV camera through the open door of the shelter towards objects outdoors. It was found that untrained observers would verbalize more readily over live transmission because the scenes were "more familiar" than the image transparencies and, unlike the latter, the live scenes had not lost quality in prior photographic processing. The reaction was very favorable. The observers generally stated that the digitally coded 1025 line transmission over the link was superior to the 525 line standard analog transmission that they were accustomed to seeing.

The demonstration also included intentional system margin fades while a TV picture was being transmitted. An attenuator in the WNY station transmitter was used to simulate the fade. It was found that reasonable image quality was maintained down to 10^{-2} to 10^{-3} error probability corresponding to fades greater than about 42 dB. After a total loss of picture (corresponding to very high attenuator settings) automatic resynchronization of the system would be demonstrated when the attenuation was removed.

For completeness, further mention is made of the clock drive for the breadboard A/D and D/A converters since this involved field modifications. The only available external clock at the time of the tests was instead used for operating the BER test set. To accomplish the digital converter clocking while faced with this test equipment limitation, it was necessary to modify the radio equipment proper to make the 39.3206 MHz clock signal externally available. Two ways were used. One was to utilize a mux or demux card which had been specially built for the engineering model during Phase II, and which had provision for clock extraction built into it. Another way was to tap into an appropriate point on the mux/demux cards of the Phase III unit. Preferred over either method in the future for convenience would be an external clock at 39.29 MHz. This would also allow the synchronous operation of the system as specified. The above comments should be taken into consideration in the design of future models of A/D and D/A converters for this application.

It is also mentioned that one peripheral investigation suggested during Phase III that could not be carried out because of other commitments was a test at different TV camera frame rates and digital encoding rates. This was brought under consideration while noting the display results with the high persistence P40 phosphor. The apparent noise smoothing effect of high persistence screens would potentially reduce the required TV camera frame rate from the standard 30 frames/second when "still" scenes are viewed. The resultant reduction of encoding rate is not important to per se usage of the AN/GRC-173(XW-1) due to the 236 Mb/s bandwidth capability already inherent in the radio. However, it could be of some significance to future employment of additional baseband devices at the interface.

Note: The use of subjective terms in several instances in this section when describing TV image quality is regretted, but unavoidable due to the nature of the subject matter. Attempts have been made to maintain scientific approach through the use of specific quantitative measures or meaningful comparison wherever possible.

(c) Narrowband Tests

For reasons mentioned earlier, the communications of narrowband data over the link was demonstrated using a pattern generator between approximately 1 Kb/s and 1 Mb/s to represent the terminal device. To process the narrowband signals, the 9.83 Mb/s channel of the radio's Videophone Mux/Demux unit was used as a sampling mux and regenerator.

In this arrangement, which operates inherently in the 9.83 Mb/s channel through design, the mux samples a low speed signal at a rate very much higher than the signaling rate so that many sampling intervals are utilized to process the input. The signal from each sampling interval is time division multiplexed in the radio with other signal bits. Framing information is also supplied so that the original input is regenerated in the demux unit. While this type sampling is not an efficient use of bandwidth (e.g., a 9.83 Mb/s channel to process a 100 Kb/s signal), it should be apparent that the overall 236 Mb/s capacity of the radio can readily accommodate such inefficient usage while simultaneously processing multiple wideband signals. The main advantage is that it is a very simple arrangement and has a great deal of inherent flexibility for a variety of rates, as demonstrated by varying the input signals over several octaves without altering the results. The optimum arrangement, of course, would be to use a specifically designed low speed mux such as the AN/GSC-24 or commercial models.

The block diagram for the low speed demonstration is shown in Figure 41. The first tests were run back-to-back within the Pentagon shelter; then link transmission tests were run. The AN/GRC-173(XW-1) has balanced inputs, but no difficulty was experienced in driving the radio with the single-ended output from the pattern generator. The pattern generator was a Wavetek Co. Model 110 unit. The test fixture shown in Figure 41 was used only for the back-to-back tests and was required to perform differential decoding of the multiplexed data stream and level matching, functions normally performed in the receiver. The receiver was bypassed in the back-to-back tests.

Figure 42 gives the results of back-to-back tests within the Pentagon station using square waves of 1, 10 and 100 Kb/s. Demonstrations were also run at 1 Mb/s, although no data was specifically recorded at this rate. In each oscilloscope photograph, in Figure 42, the top trace is the signal generator input to the 9.8 Mb/s channel while the bottom trace is the recovered output.

Figure 43 illustrates the results of transmission over the link. These are oscilloscope photographs of the signal after detection and regeneration at the WNY station. The sweep expansion at 0.05 microsec/cm shows the discrete phase jitter of 100 nanoseconds on the data pulses. This effect is introduced by the sampling process, however, and it would not be detrimental in most applications. The use of a low pass filter would make the recovered low speed data transmissions immune to this effect.

Another aspect of low speed data handling with the AN/GRC-173(XW-1) is the order wire. The order wire audio channel capability is "built in" to the radio with digital conversion and subsequent framing and multiplexing into the output data stream taking place within the radio set. The order wire audio is recovered at the receiving end. The data rate of the order wire channel is 30.5 Kb/s and a handset is the input/output device. Presently, no provision is made for any other external digital input into this channel at this rate, but it could be implemented in future models if required for specific applications. One potential use of this channel would be for telemetry of status or similar information from an unattended station to an attended station.

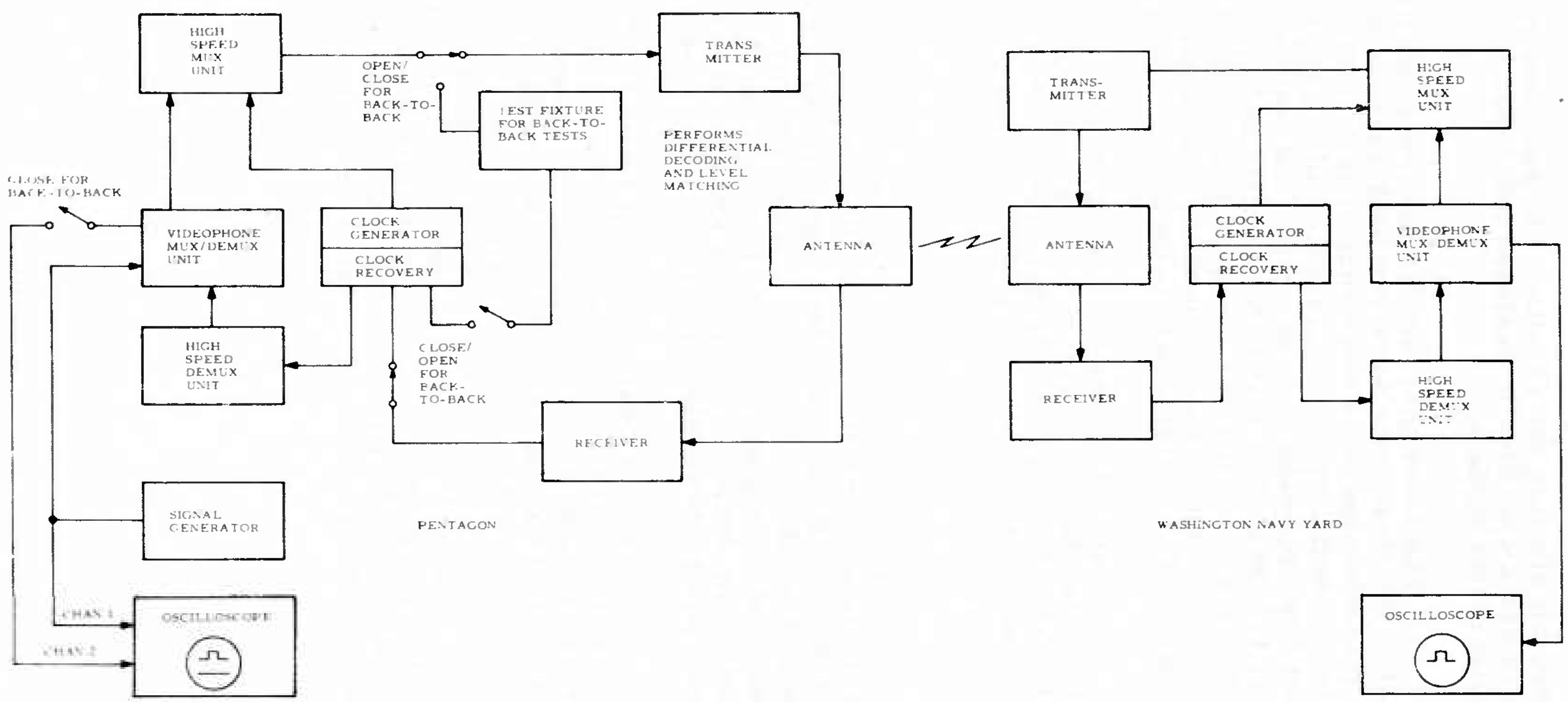
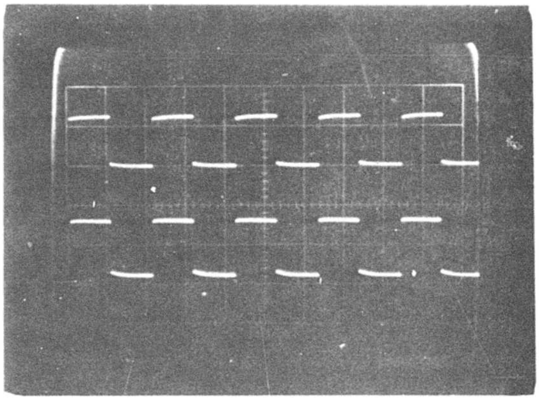
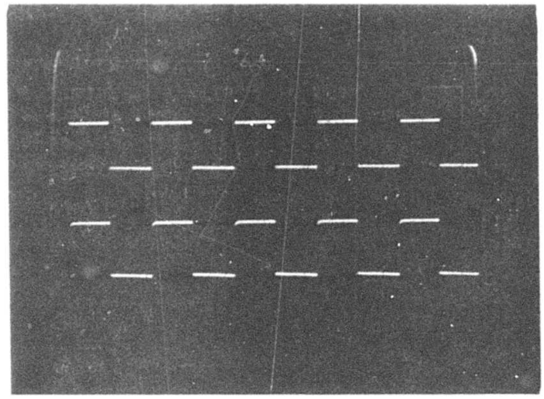


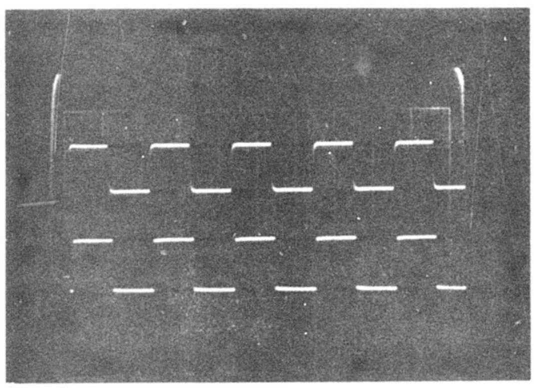
Figure 41. Narrow Band Tests, Block Diagram



1 KHz Square wave, 500 μsec/cm sweep

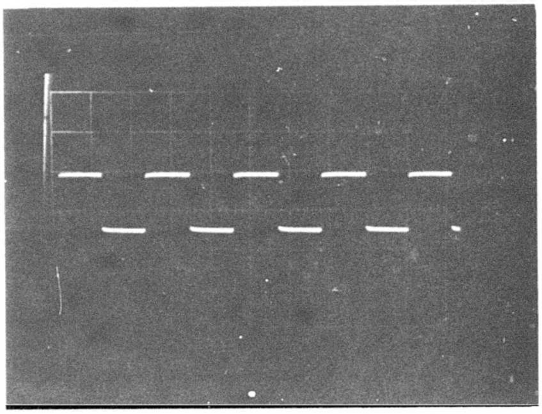


10 KHz Square wave, 50 μsec/cm sweep

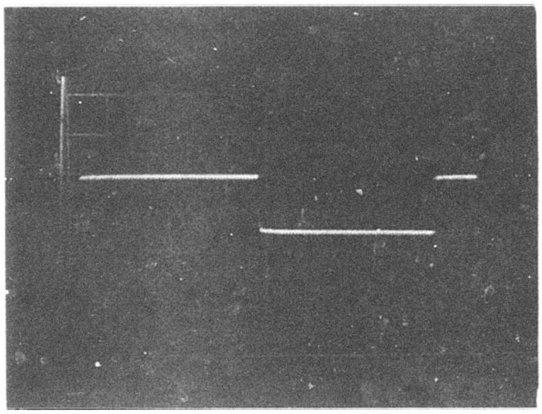


100 KHz Square wave, 5 μsec/cm sweep

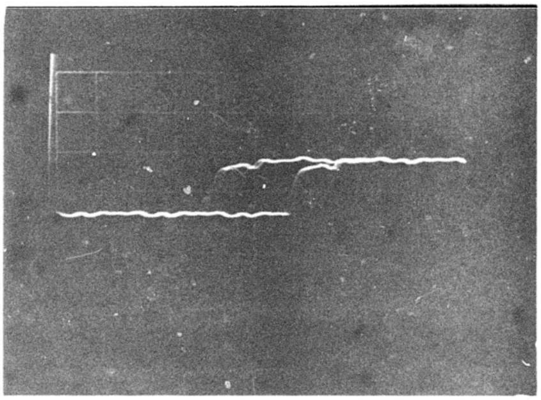
Figure 42. Slow Speed Data in 9.8 Megabit Channel; Back-to-Back at Pentagon



5 μsec/cm sweep



1 μsec/cm sweep



0.05 μsec/cm sweep

Figure 43. 100 kHz Square Wave on 9.8 Mb/s Channel as Received at WNY; Signal Transmitted From Pentagon

6. PROPAGATION TESTING

a. Purpose and Summary

During Phase III, propagation test data was obtained to evaluate the transmission characteristics of the AN/GRC-173(XW-1) radio in the line-of-sight channel under the ambient link conditions in Washington, D. C. The propagation tests were conducted over a period of about three months (mid-November 1973 to mid-February 1974), yielding approximately 2054 chronological hours of measurement records, on site, for subsequent reduction and analysis. A large quantity of relevant propagation data was obtained because of: a) around-the-clock operation of the radio sets, both attended and unattended, and b) the timely occurrences of a variety of ambient conditions.

Numerous considerations have been cited regarding the propagation of millimeter wave signals; these include rain, fog, snow, and pollution (References 6 and 7). Measurements were made under all these conditions during Phase III. In addition, siting of the link became a consideration due to numerous construction machines in the vicinity of this particular path.

As expected from theoretical studies and the results of previous measurement programs (References 8, 9, and 10), rainfall proved the most significant effect among all those mentioned above. Intense rainfall produced deep fades for short periods of time. A result on Phase III of specific interest in practical applications was the conclusion that the loss during rain could consist of a factor associated with wetting of the surface of the antenna radome (an elastomer coated fabric) which could, under some conditions of wind and rain direction, and temperature, be as significant as the loss due to absorption and scattering by rain in the rest of the path. While studies have been conducted of loss due to rain on the surface of radomes, at lower frequencies (Reference 11), this was the first opportunity to evaluate the effect under millimeter link conditions. The effect is not of serious consequence to a short link of high margin such as the link between the Pentagon and WNY, but it may become more important for communications over longer ranges. However, it appears that the wet radome surface loss can be largely negated by mechanical design approaches such as anti-wetting films or rain shields, or perhaps by removing the radome and using other measures such as heating to exclude rain effects from the feed or dish. While no schedule time or effort could be expended either to isolate the path-produced from the localized rain losses, or to demonstrate the reduction of the radome surface loss, it appears that these can be accomplished by future efforts.

The aforementioned appearance of construction machinery (cranes) in the path resulted in modest fades at times, but the loss was always well within the system margin tolerance. Though the effect is reported here as potentially representative of urban microwave communication problems, it should be noted that it will be completely eliminated from consideration upon completion of the associated construction in the vicinity in the near future.

The main result of the propagation tests was verification of the high propagation reliability of the link. Considering all possible sources of propagation loss as mentioned above, there was only a single instance of outage (loss of margin), of about 5 minutes duration (during the 2054 hour period of recording received signal strength), which could be attributed to the propagation effects. This was due to very intense rain. Propagation reliability for the AN/GRC-173(XW-1), therefore, was greater than 99.99 percent for this period, where propagation reliability is defined as the percentage of time that fade or loss depth is less than the link margin for 10^{-6} bit error probability.

The paragraphs below provide further details on the propagation testing. The measurement configuration and procedures are described, and then the data which was obtained during the testing is described and discussed.

b. Measurement Apparatus for Propagation Testing

(1) General Configuration

Installation of test equipment as described below permitted the collection of records which could later be analyzed. At each AN/GRC-173(XW-1) station, strip chart recorders were set up to record the received signal strength as a function of time, and event recorders were installed to monitor selected equipment operating parameters. The strip chart recorders were Hewlett-Packard Co. model number 680 and the event recorders were Rustrack Co. model number 202-8. Also, as part of this project, tipping bucket rain gauges were set up to monitor rainfall rates at each terminal and at a site (Potomac Park) about midway between them. Figure 44 portrays this configuration and details of the rainfall data collection system follow.

(2) Rainfall Measurement System and Use of the Rainfall Data

In calculating the attenuation over a communications path, it is noted that a rainstorm may not be uniform in intensity over the path. Therefore, it is desirable to use as many rain gauges as possible and to obtain an average rate along the path (Reference 8). Three project rain gauges were installed. In analyzing the rainfall attenuation records of Phase III for this report, the average rainfall rate over the three recording stations is used wherever possible. On occasions when any of the gauges did not operate properly for any of various reasons, the data averaged over the remaining gauge(s) is used. Data from the National Weather Service at Washington National Airport is also used for backup analysis. However, its location of 2.7 km distance from the path does not provide for strict correlation with the path conditions. Note that this consideration also applies somewhat to the Potomac Park records, although this station's distance off the path line was only 0.4 km.

The project rainfall measurement apparatus was identical at the three sites and consisted of a tipping-bucket rain gauge and a pen chart recorder at each location. The rain gauges were Aerojet General type P-501 with an eight-inch orifice. The tipping-bucket sensor activated a switch closure

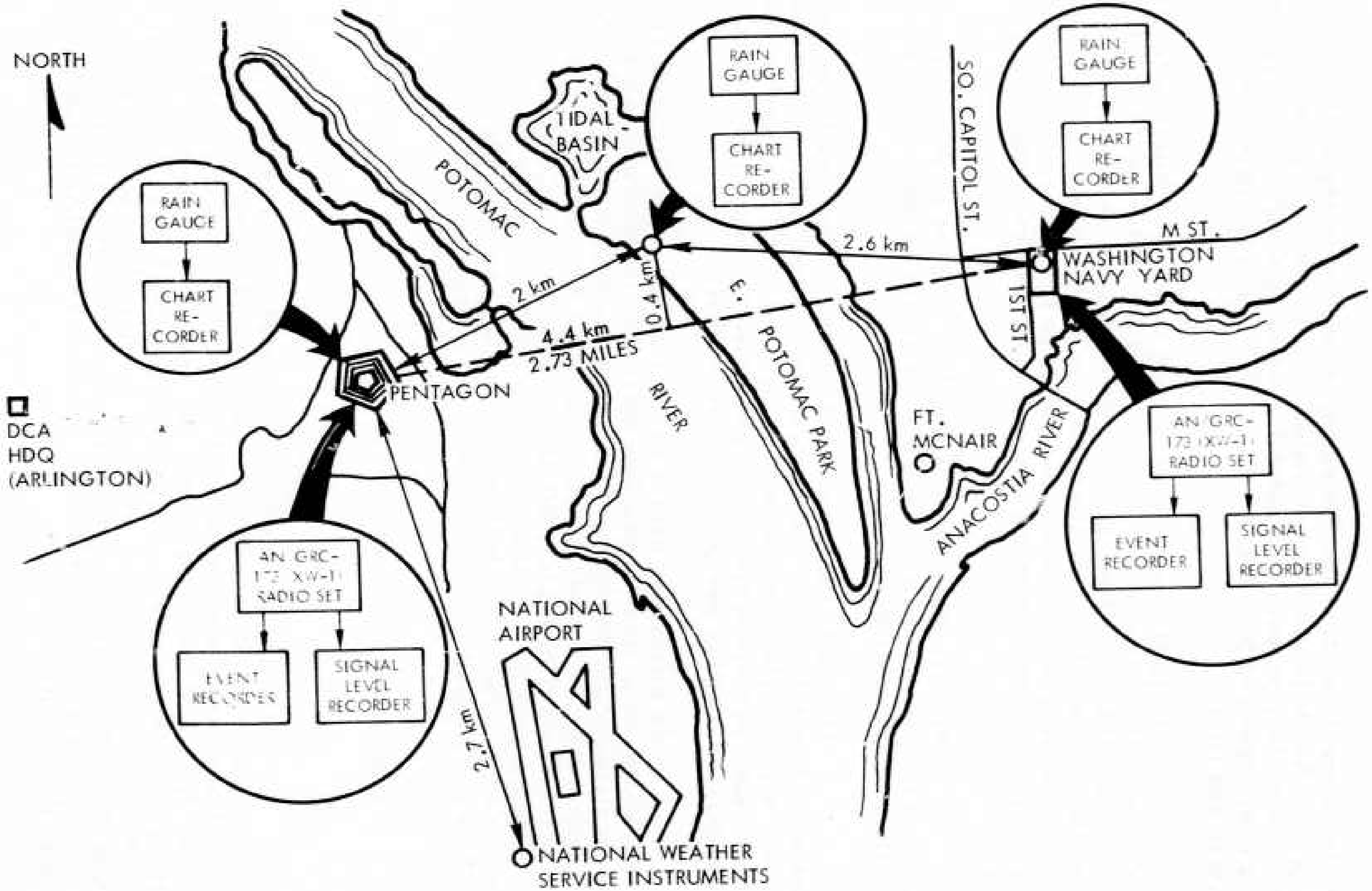


Figure 44. Propagation Measurement Configuration

which placed a mark or "tick" on the chart record for every 0.01 inch (or 0.254 mm) of rain. The switch has an estimated closure time of 0.1 second. Accuracy of the rain gauge is 1 percent at a rainfall rate of 25 mm/hr. The recorder utilized a chart speed of four inches/hour. The recorder paper was marked for each minute and hour.

The project rain gauges were located on rooftops in clear areas free of any possible obstruction or sheltering of the collecting orifices. The rain chart recorders at the Pentagon and WNY stations were located in the equipment shelters about 50 feet away from the rain gauges. At Potomac Park the recorder was installed in an enclosed storage area below the roof level. Dc voltage supply to the rain gauge sensors was provided from the recorder locations.

All installations were similar. Figure 45 shows the rain gauge installation at the Pentagon Station and Figure 46 shows the recorder installation at the Potomac Park station.

The rain gauges were not heated, therefore, there were a few instances when freezing of the tipping mechanism occurred, or when snowfall covered the orifice. These instances are included in the periods for which no precipitation data was available via project sensors. Care was also taken so as to exclude delayed melting periods from the analysis.

As mentioned before in the summary, the ultimate result of analyzing loss vs. rain data showed that there was an attenuation contribution from the localized water surface on the antenna radome during rain. An approximation of the magnitude of this attenuation was obtained from some elementary tests described later, but the localized surface loss could not be isolated from the rest of the path loss during a given rainstorm. Therefore, while total fade loss data was obtained for the link, an estimation of the attenuation coefficient (attenuation per unit distance) versus the rain rate cannot be given.

c. Propagation Test Data and Results

(1) Introduction

Data and results for the propagation testing period are described below. First, the overall data base is summarized giving the kind and quantity of data records obtained and the general procedures used to reduce and analyze them. Then details of the observations and results for each type of encountered propagation condition is given. This includes normal clear conditions, man-produced obstruction in the path, and fog, snow, pollutants, and rain. The rainfall data includes the major findings of link loss and leads to an estimate of the overall statistics for fading durations. The high reliability of the link is concluded from the results.

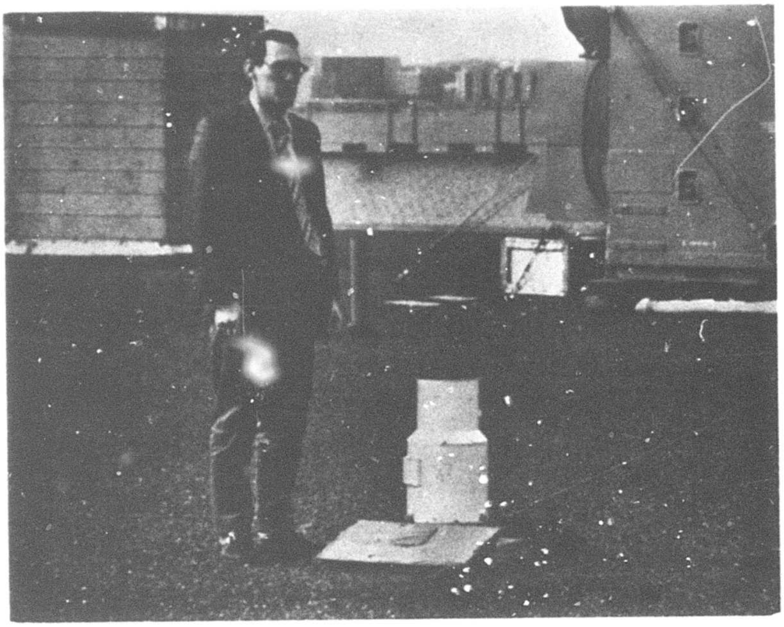


Figure 45. Rain Gauge Installation at Pentagon Station

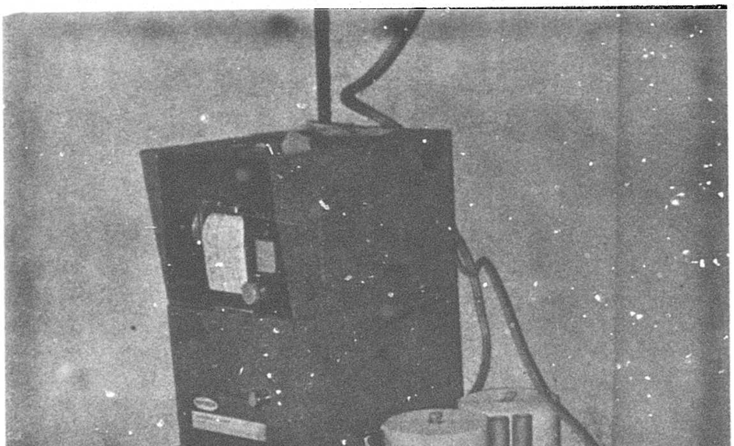


Figure 46. Recorder for Rainfall at Potomac Park Site

(2) Data Base

The propagation data was obtained while running the link and by making observations and records as time progressed and as different path conditions were presented. Propagation testing, although identified as a specific test entity, was actually conducted in conjunction with the other project link tests and demonstrations. After the supporting test equipment described above was set up during November 1973, unattended recording on a continuous basis was possible until completion of the propagation tests in February 1974. Exceptions to this occurred for various reasons, such as periods of: (a) special demonstrations, (b) radio set maintenance, (c) integration of off-line equipment, or (d) test equipment down-time. Chart-recorder down time due to problems with recording pens and mechanisms was one of the most irritating aspects of the entire test program. Nevertheless, thousands of feet of valid chart records were obtained for subsequent study.

Reduction and analysis of the propagation data took place in the field and at the Raytheon plant. The field reduction of recordings was of a "quick-look" nature, intended mainly to spot those data periods of most significance. The field reduction included tabulations, versus site, date and hour, of: (1) the total rainfall in that hour and (2) the maximum fade and fade exceedances in the hour for different limits (3, 6, and 9 dB). The tabulations were made from a study of the recorder charts. Figures 47 and 48 are specimen data sheets used in this process. The final data reduction and analysis utilized further visual analysis and computer assistance, and is presented by various means in this report.

The valid chart recordings obtained from the five total possible project recording instruments is depicted in Figure 49. This histogram-type illustration shows the availability of the chart versus the instrument (and site) versus the date. Where a blank space occurs, the particular chart record was unavailable for one or more of the reasons cited above.

Various analyses can be performed depending upon the objective. Following are numerical summaries of the records available for the analyses described later. The period from November 20, 1973 through February 15, 1974 encompassed a total of 2112 hours. During this period, signal strength records at the WNY station are available for approximately 1738 hours, and at the Pentagon station for approximately 1346 hours. Only a one-way signal strength record (choice of either the Pentagon to WNY link or the WNY to Pentagon link) is needed for arriving at an estimate of the propagation reliability, and this is possible for approximately 2054 hours. A rain gauge recording for at least one of the three project rain recording stations is available for approximately 1770 hours, and for all three of the stations simultaneously for approximately 1098 hours. Note that the weather data of the National Weather Service (NWS) station at the Washington National Airport was available for all times. For reasons elaborated earlier, precedence is given to the rainfall record of the project instruments. The NWS data is used only for backup analysis or to correlate with signal strength records in the absence of project records during periods of no rainfall, light rainfall, or snow.

AN/GRC-173 LINK
RAINFALL DATA - HOURLY

DATE ______

TIME PERIOD	TOTAL INCHES PENTAGON	TOTAL INCHES NATIONAL PARK BLDG.	TOTAL INCHES WNY	NATIONAL WEATHER SERVICE
00:00 - 01:00				
01:00 - 02:00				
02:00 - 03:00				
03:00 - 04:00				
04:00 - 05:00				
05:00 - 06:00				
06:00 - 07:00				
07:00 - 08:00				
08:00 - 09:00				
09:00 - 10:00				
10:00 - 11:00				
11:00 - 12:00				
12:00 - 13:00				
13:00 - 14:00				
14:00 - 15:00				
15:00 - 16:00				
16:00 - 17:00				
17:00 - 18:00				
18:00 - 19:00				
19:00 - 20:00				
20:00 - 21:00				
21:00 - 22:00				
22:00 - 23:00				
23:00 - 24:00				

Figure 47. Specimen Sheet for Logging Rainfall Data

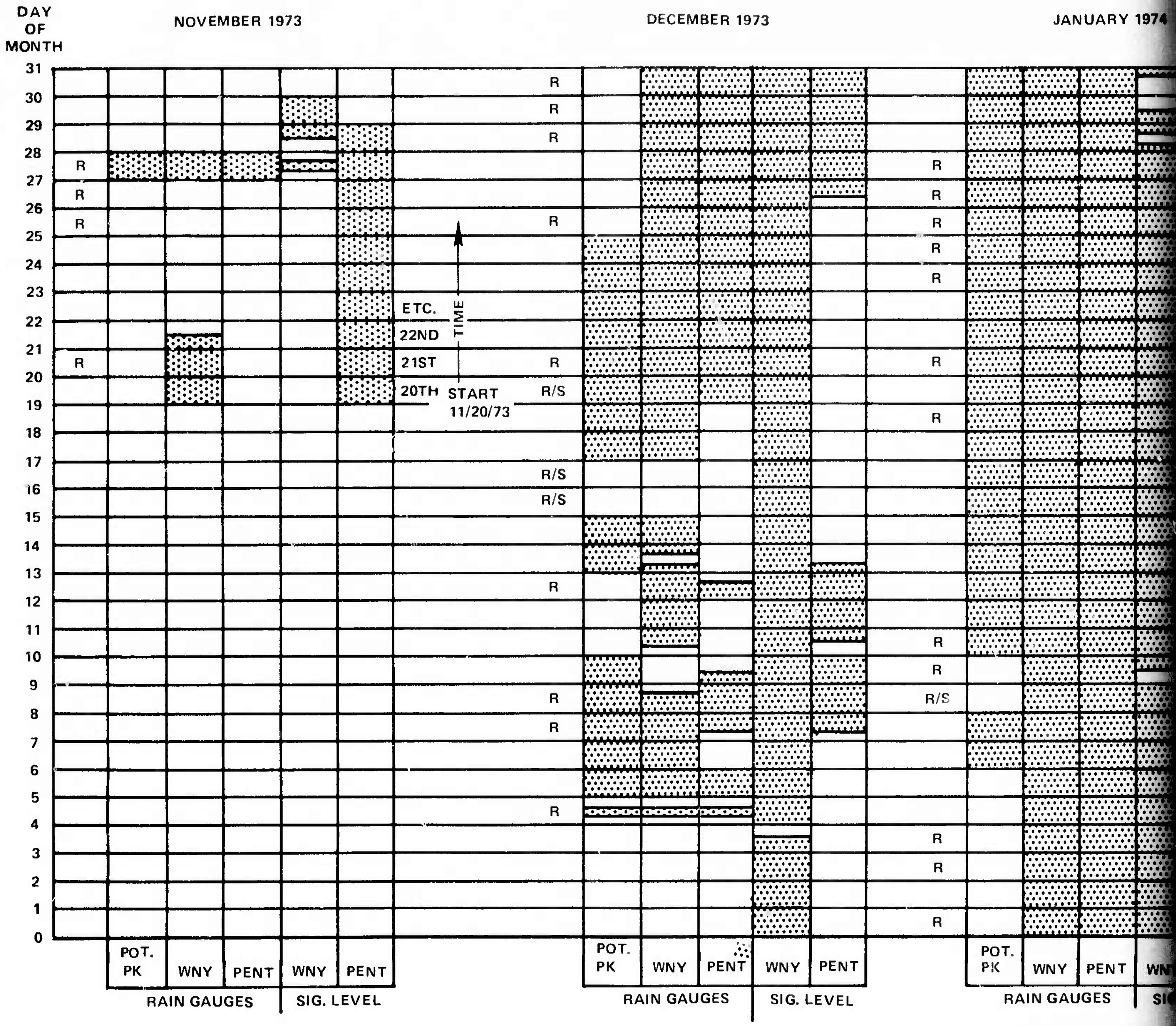
DATE ____________

AN/GRC-173 LINK
RAIN FADE IN MINUTES

STATION ____________

TIME PERIOD	MINUTES >3dB	MINUTES >6dB	MINUTES >9dB	MAXIMUM FADE	COMMENTS
00:00 - 01:00					
01:00 - 02:00					
02:00 - 03:00					
03:00 - 04:00					
04:00 - 05:00					
05:00 - 06:00					
06:00 - 07:00					
07:00 - 08:00					
08:00 - 09:00					
09:00 - 10:00					
10:00 - 11:00					
11:00 - 12:00					
12:00 - 13:00					
13:00 - 14:00					
14:00 - 15:00					
15:00 - 16:00					
16:00 - 17:00					
17:00 - 18:00					
18:00 - 19:00					
19:00 - 20:00					
20:00 - 21:00					
21:00 - 22:00					
22:00 - 23:00					
23:00 - 24:00					

Figure 48. Specimen Sheet for Logging Fade Data



DAY OF MONTH
NOVEMBER 1973
DECEMBER 1973
JANUARY 1974
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
R
R/S
ETC.
22ND
21ST
20TH
TIME
START 11/20/73
POT. PK
WNY
PENT
RAIN GAUGES
SIG. LEVEL

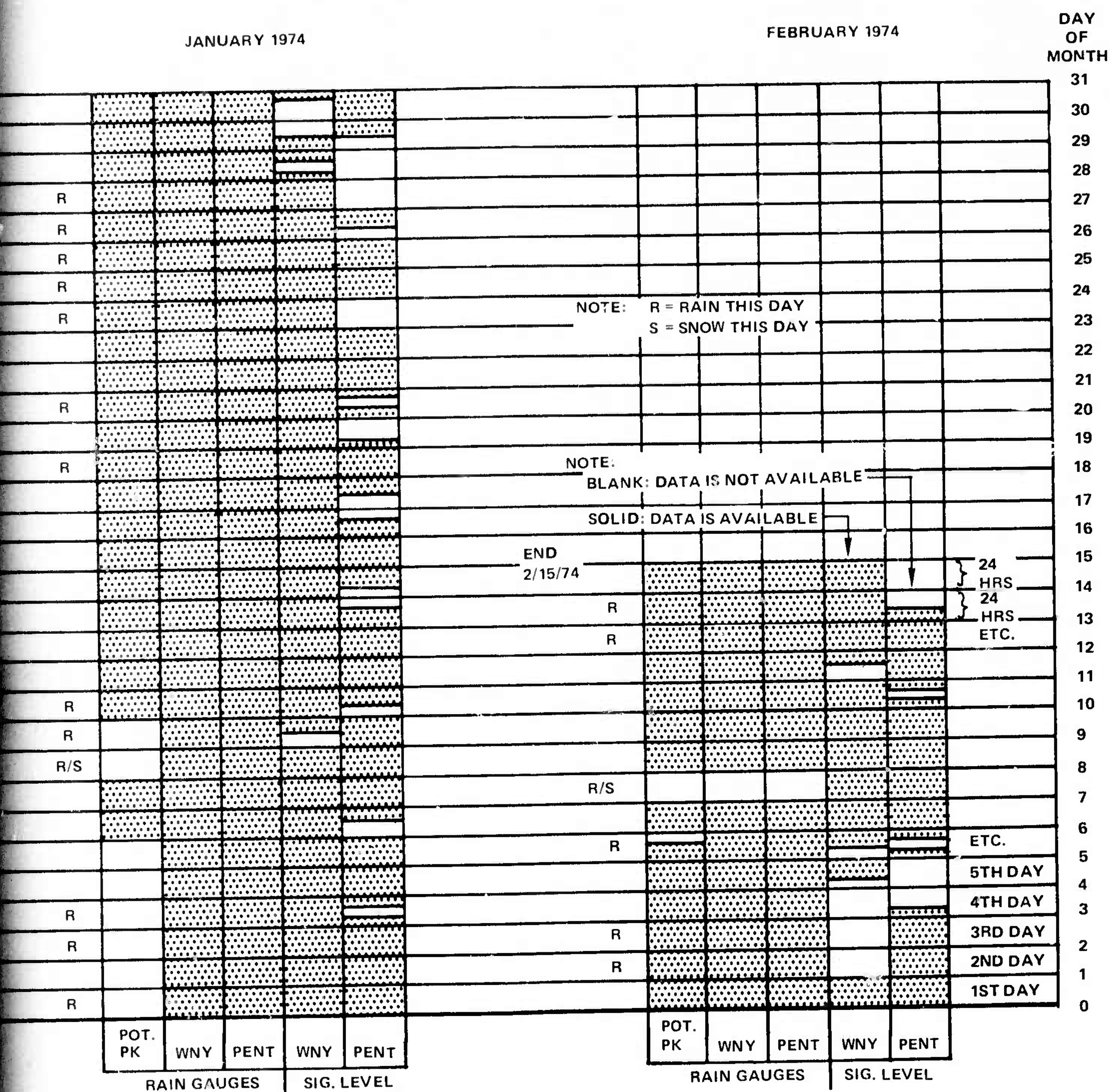


Figure 49. Chart Recordings Available for Propagation Analysis AN/GRC-173(XW-1) Test Link

2

Table XVI summarizes the hours and percentages for which data is available for subsequent analysis.

Table XVI. Summary of Recordings Obtained for Propagation Analysis

Period: 20 November 1973 through 15 February 1974 [total possible chronological time: 2112 hours (126,720 minutes)]

Item	Chart Record Available	
	Hours	Percent of Total
1) Signal Level Recordings		
a) At WNY	1738	82%
b) At Pentagon	1346	64%
c) Simultaneous	982	46%
d) At Least One Way	2054	97%
2) Rain Gauge Recordings		
a) Project, Three Simultaneous	1098	52%
b) Project, at least one of the three	1770	84%
c) National Weather Service for Backup	2112	100%

The event recorders mentioned earlier were used mainly to monitor the alarm and display test points which were connected to the radio set. They were found to have little utility in this portion of the test program.

(3) Propagation Under Normal Conditions

As a starting point for reference, the normal received signal recorded during the vast majority of the operating time will be described. During such times the signal level recording was flat and steady. Figure 50 is typical of the normal operations and is a chart record of the signal level at the Pentagon station for a two-hour period around 1900 to 2100 hours during 2 January 1974. (Note: time of day references on the strip charts are generally given on the basis of 24 hour military time of day.) The chart speed of 4 inches/hour for signal level recording was more or less standardized for the test program as it coincided with the chart speed of the rain gauge recorders and made subsequent correlations easier. A slower signal level recorder chart speed of 2 inches/hour was sometimes utilized during holidays or when chart paper stock was running low. Figure 51 is a signal level recording for about 5 hours on 2 January 1974 at the WNY station at the slower chart speed of 2 inches/hour.

Note that different reference levels (0-dB attenuation) on various recordings were selected for operator convenience at different times

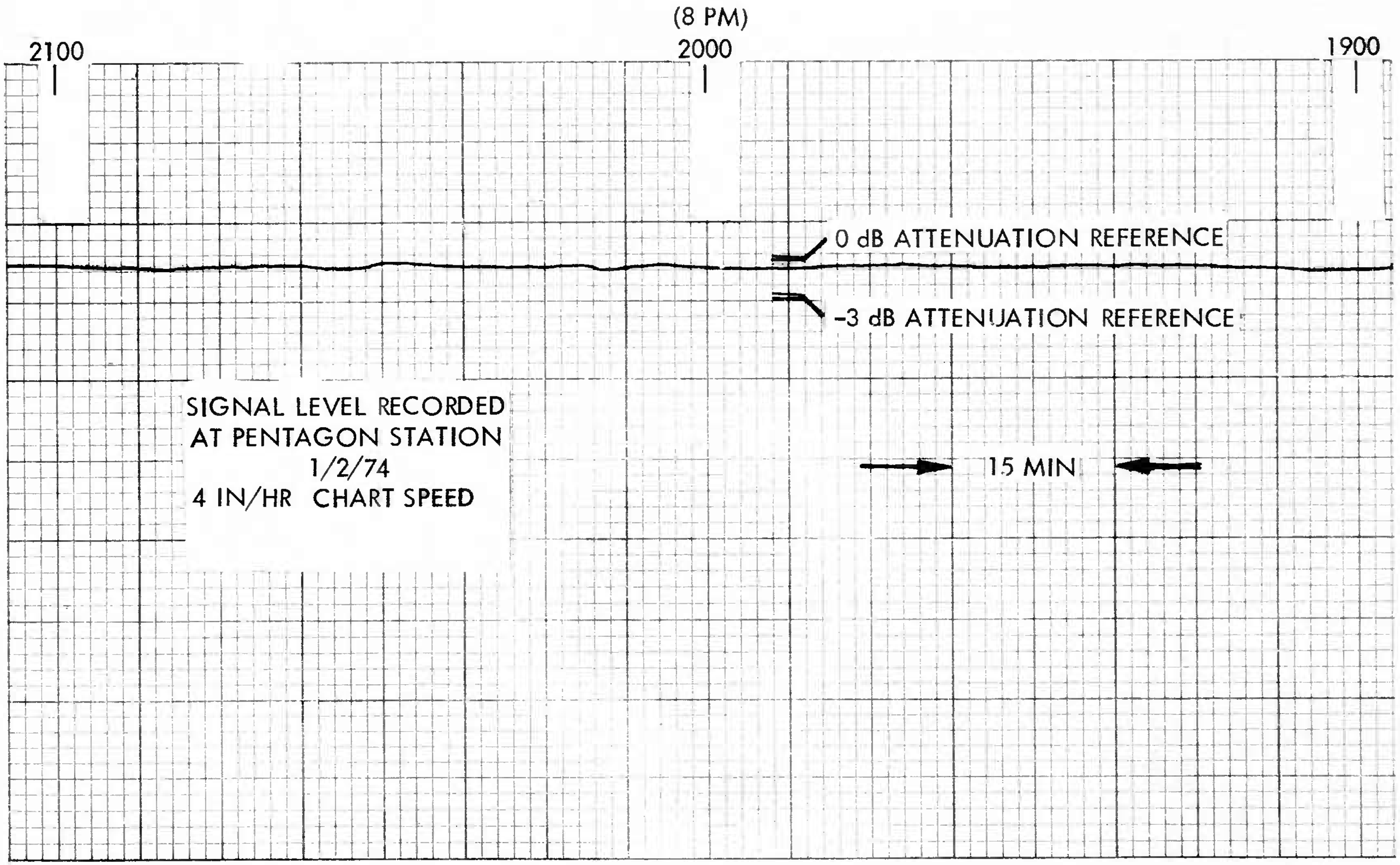


Figure 50. Typical Received Signal Level Under Normal Conditions - Pentagon Station

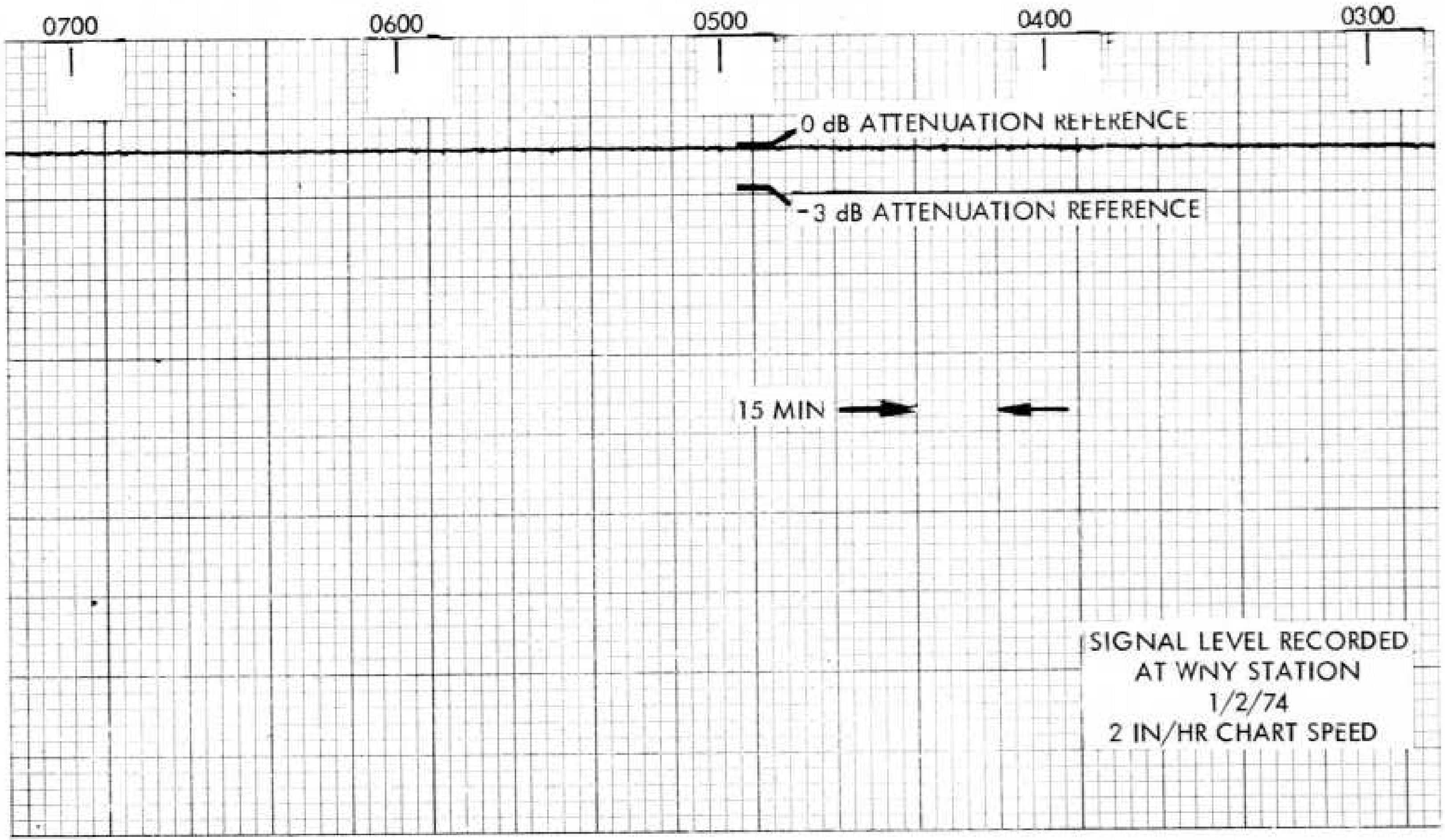


Figure 51. Signal Level Record for Approximately Five Hours Normal Operation - WNY Station

or instruments, and they are of no special consequence. Also to be noted is that on some charts presented in this report, enhancement of a trace is made as required for quality in the reproduction process.

Scintillation is also considered a normal signal condition on microwave line of sight paths (Reference 12). It is manifested as fluctuations at rates of the order of many milliseconds of a few dB below the steady, no-attenuation reference value. It is caused by turbulence along the path and the very short time delay atmospheric multipaths in the cross-section of the antenna beam. Scintillation produced no system consequence in view of the adequate link margin. Figure 52 is an observed sample of this effect. It was very rarely seen on the link between the Pentagon and the WNY, and seemed to be associated with the passage of storm fronts through the area, as in this case. The rare occurrence is attributed mainly to the short path length and to the generally well mixed atmosphere at the height of the beam.

(4) Effect of Construction Obstructions

As mentioned on other occasions in this report, construction operations in the vicinity of the Pentagon produced some effects on the signal transmissions and they will be discussed in some detail here. The construction was associated with building of the Washington, D. C. metropolitan transportation system (Metro) and will cease to have any effect once the work near the path is finished. The propagation aspects are reported here for completeness, since they did occur during the test period, and also for general technical interest for microwave path engineering in urban areas.

It was found that given sufficient system margin, as with the test link, communications traffic can generally be maintained without disruption in the face of such construction. At least the situation can be tolerated for a period of time such as encountered in Phase III. Television demonstrations were handled at all times irrespective of the construction conditions.

Figures 53 and 54 illustrate the type of construction which occurred. The tall cranes were believed to have caused the worst problem. It is also possible that reflections from the other metallic surfaces had an effect at times. These photographs were taken standing near the edge of the Pentagon building and within a few degrees of boresight.

The photograph in Figure 55 further illustrates the situation. It was taken with the camera pointed through the boresight telescope of the Pentagon station antenna. The WNY station antenna can be seen beyond the crane in the crosshair of the telescope. Other cranes can be seen both in the foreground and background. They seemed ubiquitous during the test period.

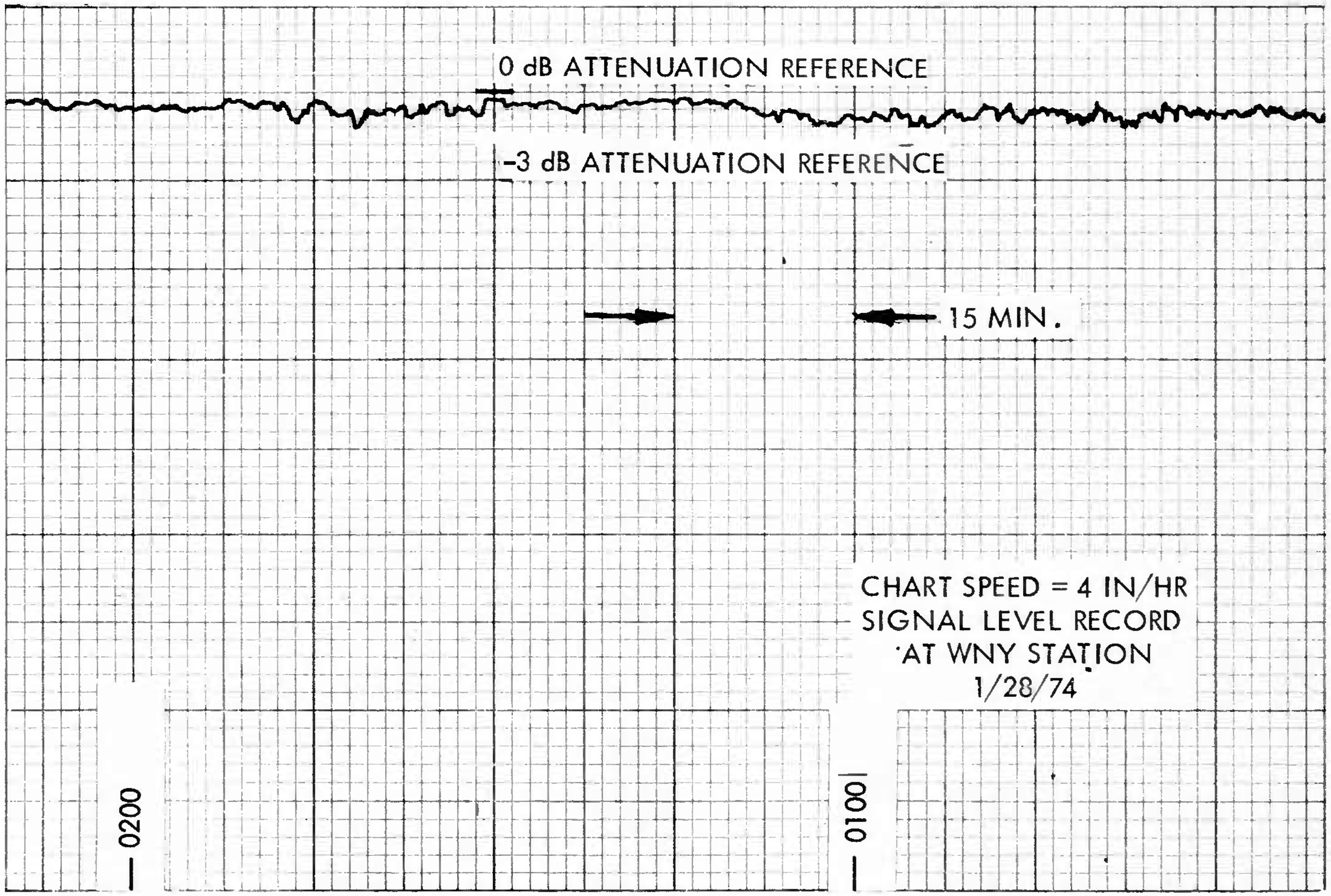


Figure 52. Example of Scintillation

Figure 53. View of Construction in Link Path Near Pentagon

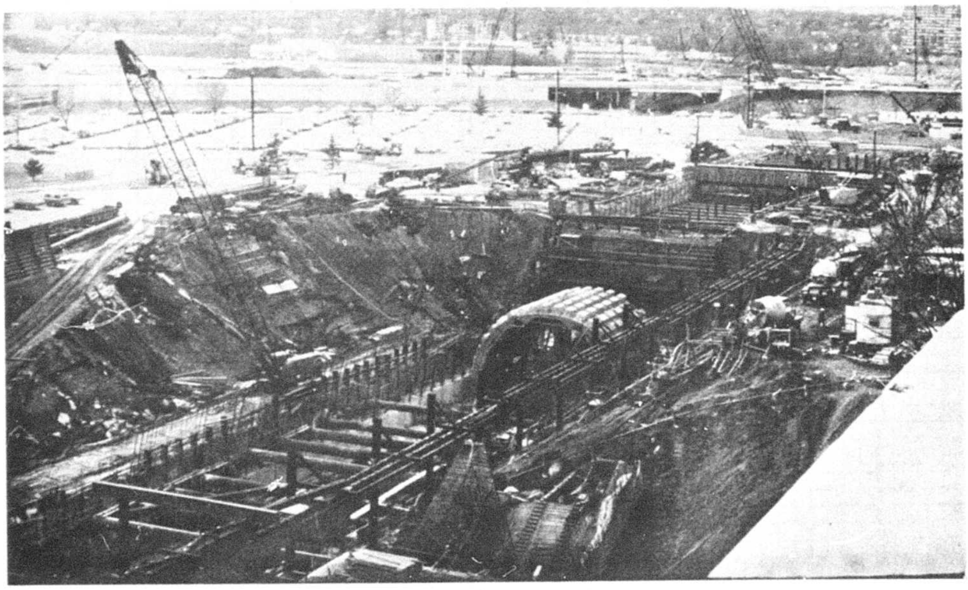


Figure 54. Another View of Construction in Link Path Near Pentagon

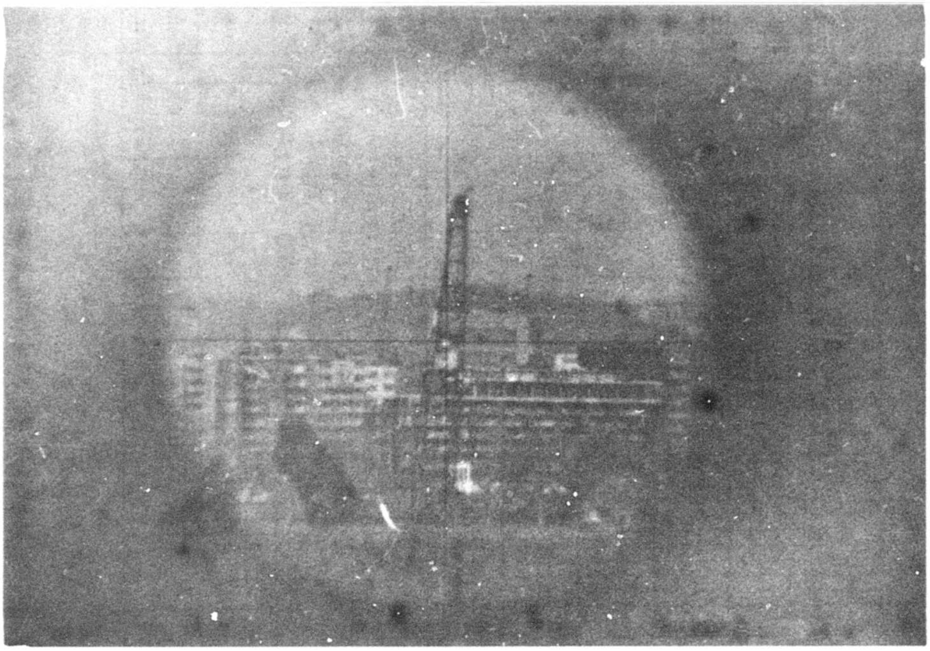


Figure 55. Crane as Seen Through Antenna Beam Boresight Telescope

The effect of the cranes and similar equipment on the signal is believed to be at least two-fold, with one or the other of the mechanisms being dominant at different times. The two considerations are:

a) Blockage, which removed part of the beam energy through reflection or scattering

b) Secondary reflections, which caused multipath differences in time of arrival of signal energy at the receiving antenna.

The multipath due to the cranes could at times also be viewed as a change in the Fresnel zone clearance over the path. It is also possible that diffraction or other effects could occur with the relative placement of some types of machinery.

Signal level recordings made during periods of crane activity are shown in Figures 56 and 57. Figure 56 shows observations made for both a crane on boresight and a crane near boresight on 14 February, 1974. Figure 57 is a record from 30 November, 1973. These typical records show momentary decreases of up to 10 dB in signal level attributed to the cranes, with normal signal conditions experienced in between. These records also show very brief periods during which the signal level was actually higher than normal, i.e., it rose above the 0-dB attenuation reference level. This might be due to positive phase reinforcement of multipath signals. It does not seem to be due to overshoot of the recording pen mechanism, since these positive swings were seen

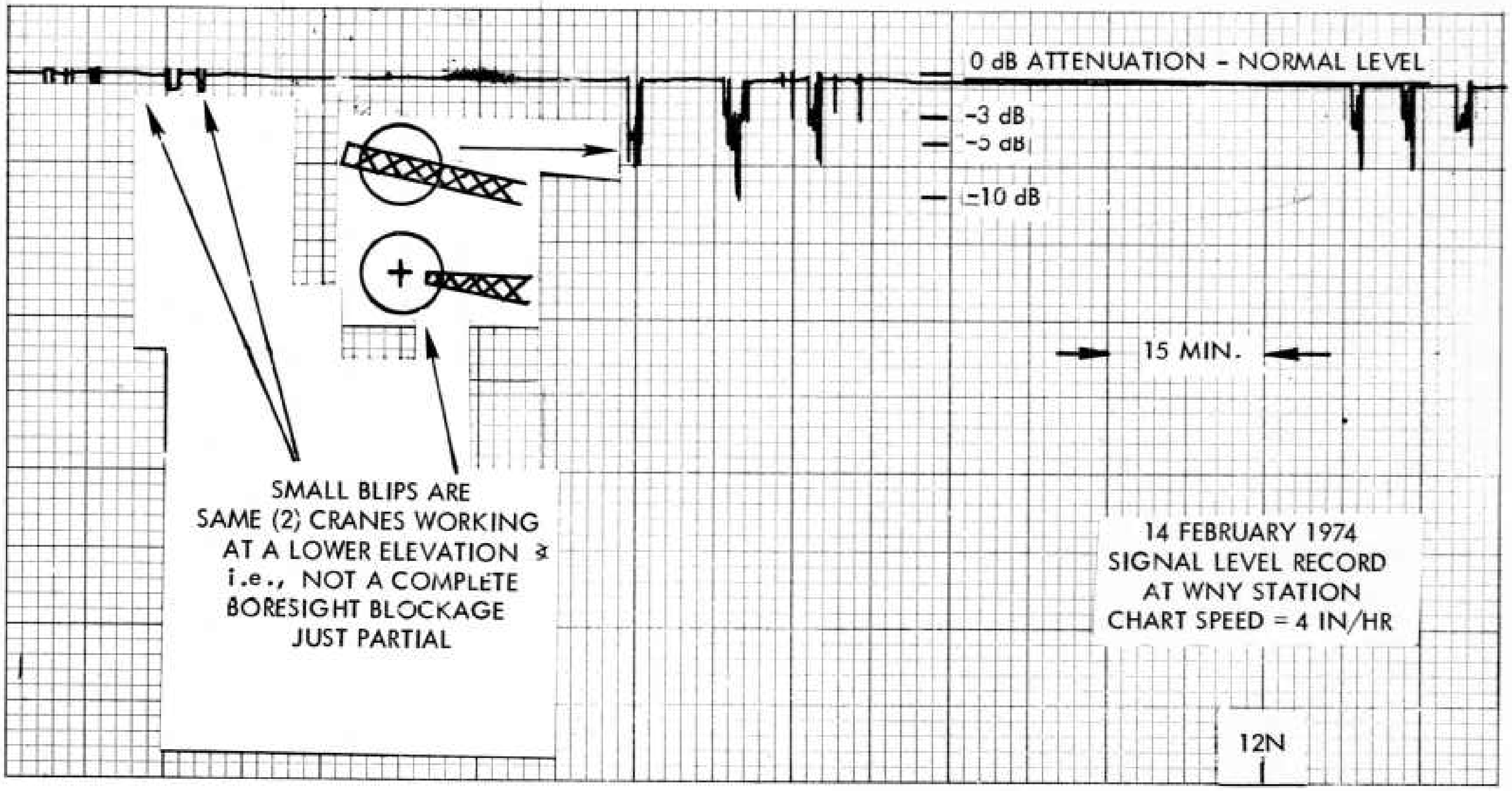


Figure 56. Received Signal Level Recordings with Cranes In and Near Line-of-Sight

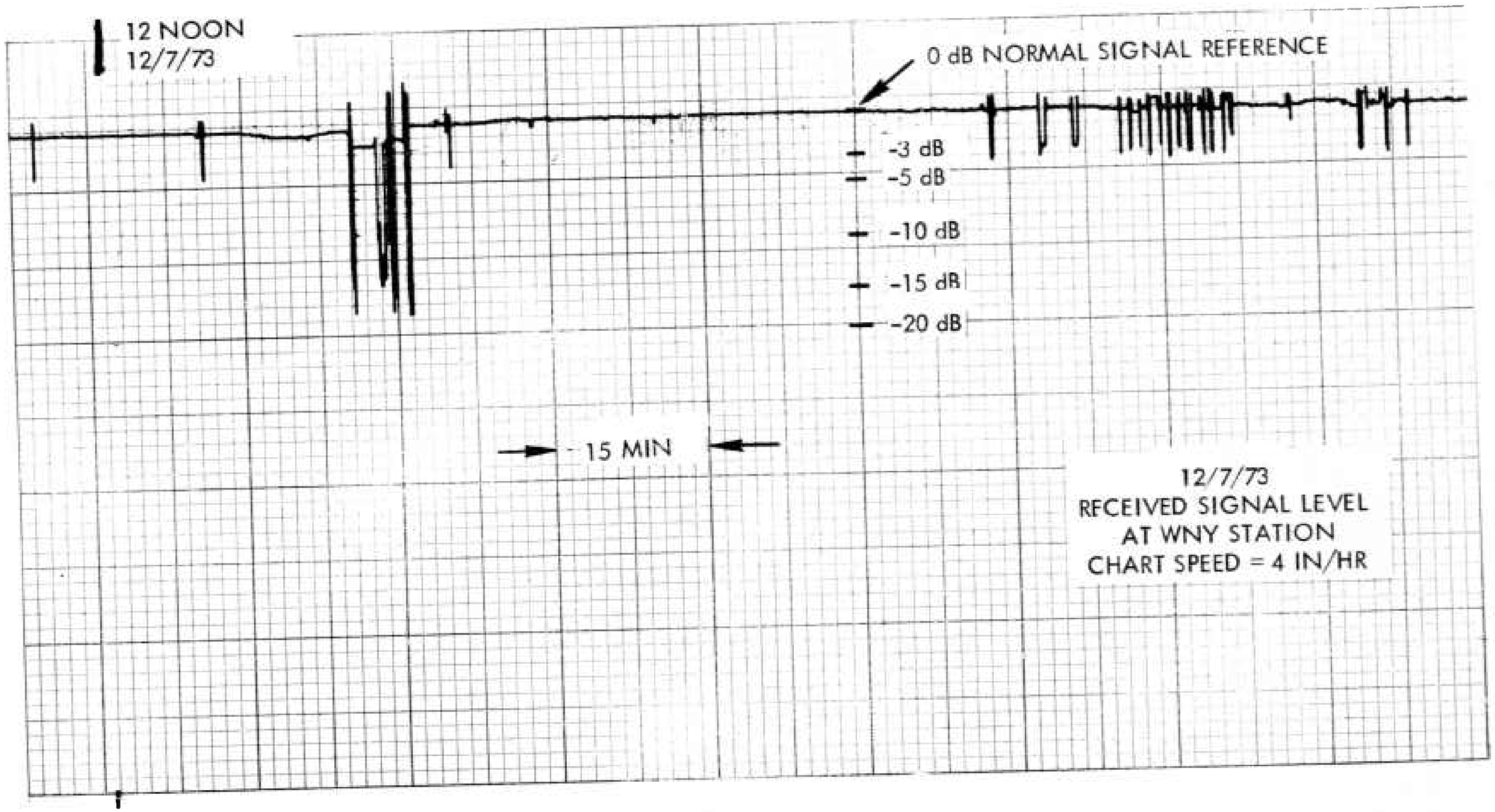


Figure 57. Effect of Cranes on Signal Level Record

to occur at both the beginning and end of a crane-produced signal dip (see the charts). The multipath reinforcement theory seems plausible, however it is possible that some sort of Doppler or other effect may also be operative as the crane swings through the beam. A cooperative venture between project and construction personnel to fully quantize and characterize the observed phenomena was not feasible.

Data transmission during the periods of crane activity included digital television at 80 Mb/s. Generally speaking, there was no observable effect on the quality of transmission when the television and coding equipment was adjusted for normal operation. The interest in these crane effects was, however, not strictly phenomenalogical and is also discussed in Appendix A from the standpoint of modifications to Bit Error Rate performance in the presence of multipath mechanisms. The system consequence is that the attenuation produced by these obstacles briefly reduces the fade margin which would otherwise be available to offset losses due to other causes; principally rainfall for AN/GRC-173(XW-1) links. The link in this case has sufficient margin to cope with the simultaneous effects, but other links might prove to be marginal. In any event, this problem is not a usual one for a microwave line-of-sight link, and it will be eliminated in time upon completion of the construction operations.

(5) Observations for Aircraft in the Vicinity

While propagation perturbations due to commercial aircraft in the vicinity did not occur on the test link, there was considerable interest in this matter. Washington National Airport is within a few miles distance of both link terminals. Initially there was concern that heavy aircraft traffic of this airport would cause frequent link outages by multipath reflections. This potential problem was addressed during initial site surveys and considered then to be no deterrent to installing the link. It was verified that there was no effect on link operations from this source during the actual tests. The reasons are discussed below.

The Potomac River, which is seen to flow between the link stations, forms an approach and departure lane for aircraft using the airport for safety and noise abatement reasons (see Figure 12). Figure 58 was taken from the Pentagon roof and shows an aircraft on this approach path. A casual observer at the sites might consider that there are frequent crossings of the signal by the aircraft. This is actually not the case, however, since the beamwidth of the transmission is small (0.35^{o}) and the sidelobes are low (>20 dB below main beam). By regulation, aircraft at the intersection of the Potomac River with the beam line are prohibited from flying below 300 ft altitude above sea level, whereas the half-power beam spread at that point is only about 50 ft above boresight, or less than 150 ft above sea level. Figure 59 depicts the relevant geometry.

Figure 58. View of Aircraft on Flight Path for National Airport

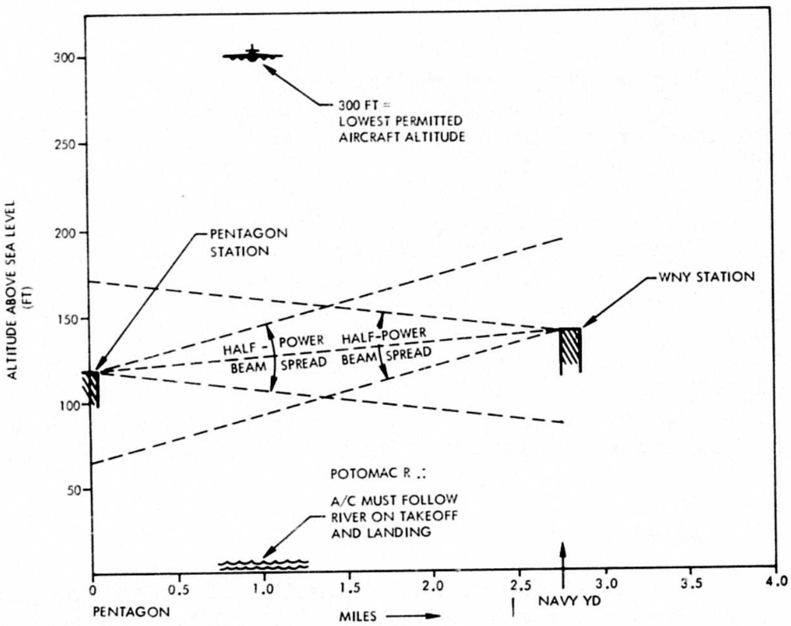


Figure 59. Link and Aircraft Path Parameters

An interesting comparison can be made here of the AN/GRC-173(XW-1) at 36 GHz with a hypothetical microwave radio at around 10 GHz. If the same antenna dish size (6 ft) were used by both systems to transmit between the Pentagon and WNY, the millimeter wave radio operates satisfactorily, but the 10 GHz radio beam would be marginal or prohibitive from the standpoint of multipath interference produced by interaction with the aircraft traffic.

The discussion above was for the fixed wing aircraft traffic in the vicinity of the link terminals. Helicopter traffic is not constrained to follow the same flight regulations. Occasionally a helicopter was observed flying through the beam. This could cause a momentary decrease of several dB in signal strength. The interference was limited and rare and did not appear to have any operational significance.

(6) Pollution

There is not a great deal to report about propagation of millimeter waves through pollution, except to document the qualitative view that pollution did not appear to produce any adverse effects on link performance. Project personnel made numerous observations that the opposite terminal was completely obscured from view by smog or smoke, and that the received signal was normal at those times. The analysis of signal strength records versus air quality index, or similar criteria, does not appear warranted.

(7) Fog

Fog is composed of very small condensed water droplets suspended in the air. Under this condition, fog is expected to produce small, but noticeable absorption of a millimeter wave signal. Scattering losses can be neglected since the wavelength is larger than the particle size.

The amount of signal attenuation due to fog was very modest on the test link. Figure 60 is the signal level record the night of January 21, 1974. It was made during a period of heavy fog when project personnel found visibility to be very poor, and flight operations at the Washington National Airport were closed down. Project personnel estimated the visibility at a few hundred feet. The report from the National Weather Service for this time was a ceiling of 100 feet and visibility between 0.25 and 0.50 mile. The maximum total excess attenuation measured for the link in this fog was about 5 dB. On other occasions of fog observations the attenuation was less. The system margin for fog is adequate.

(8) Snow

Snow is another form of precipitation which is considered in the propagation of microwave signals (Reference 7). Although Washington, D.C. has a generally mild climate, there are occasions when snow can fall for several hours and a communications disruption for that length of time would be intolerable. Heaters on the antenna shrouds prevent localized ice and snow buildup, therefore

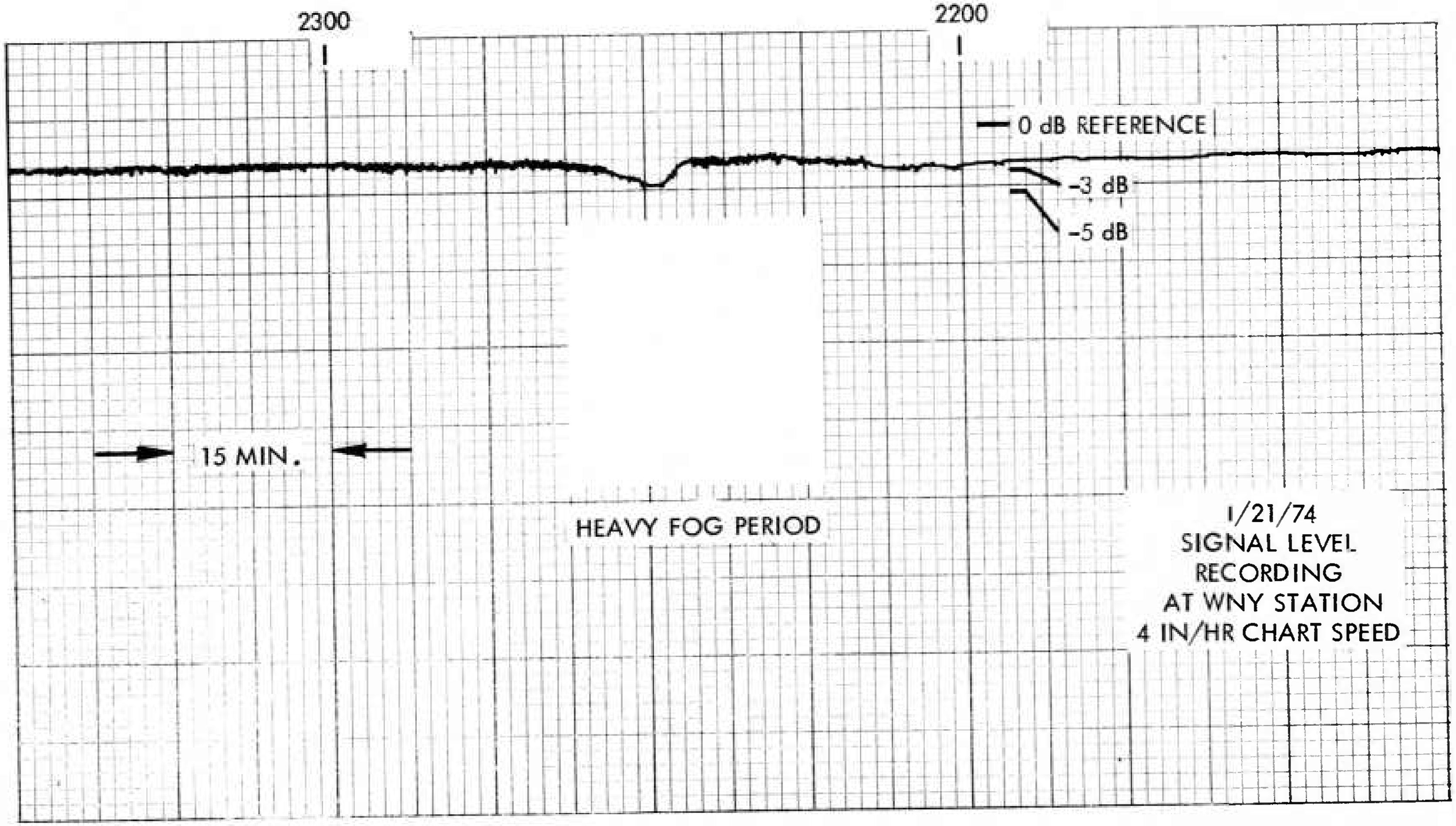


Figure 60. Signal Level Record During Heavy Fog Period

the link propagation effect can be studied separately. It was found that scattering and absorption attenuation due to snowfall has considerably less effect than rainfall. Test data illustrating the negligible effect of snow in the link path is presented below. During the test period, measured snowfall was reported by the National Weather Service at The National Airport on five days and traces on three other days. Table XVII below tabulates the amount of measured snowfall versus the date. The table also shows the total amount of precipitation in the day. This includes melted snow and ice, and rain, if it also occurred that day. The data is from the National Weather Service station at the Washington Airport. As mentioned previously, the project rain gauges were not heated, therefore these sensors could not function properly during such days.

Table XVII. Snowfall in Washington, December 1973-February 1974*

Date	Total Snowfall, Inches	Total Precipitation, Inches
16 December 1973	6	0.62
17 December 1973	4.2	0.45
21 December 1973	0.8	0.77
9 January 1974	1.5	0.35
8 February 1974	4.0	0.30

*Source: National Weather Service at Washington Airport
(Traces on 3, 11, 14, 16, February 1974)

Comments regarding each of these snow periods are made below:

<u>16 December 1973</u> - This was a very blustery type storm. Precipitation was recorded during 21 one-hour-periods of the day. The received signal level recording was flat and steady for the entire 24-hour period, with perhaps 1-dB attenuation noticed for some periods. Figure 61 is a portion of the day's chart record.

<u>17 December 1973</u> - The storm continued into this day, together with a cold trend. The signal level generally remained steady, but some very low amplitude fades of a few dB occurred during parts of the day. Figure 62 is part of the signal strength obtained in the morning.

<u>21 December 1973</u> - Project personnel were away from the site and did not make visual observations this day, but based on experience, inspection of the chart record seems to show periods of rain, periods of snow, and possible mixtures of the two (Figure 63). This is consistent with the meteorological data provided by the National Weather Service.

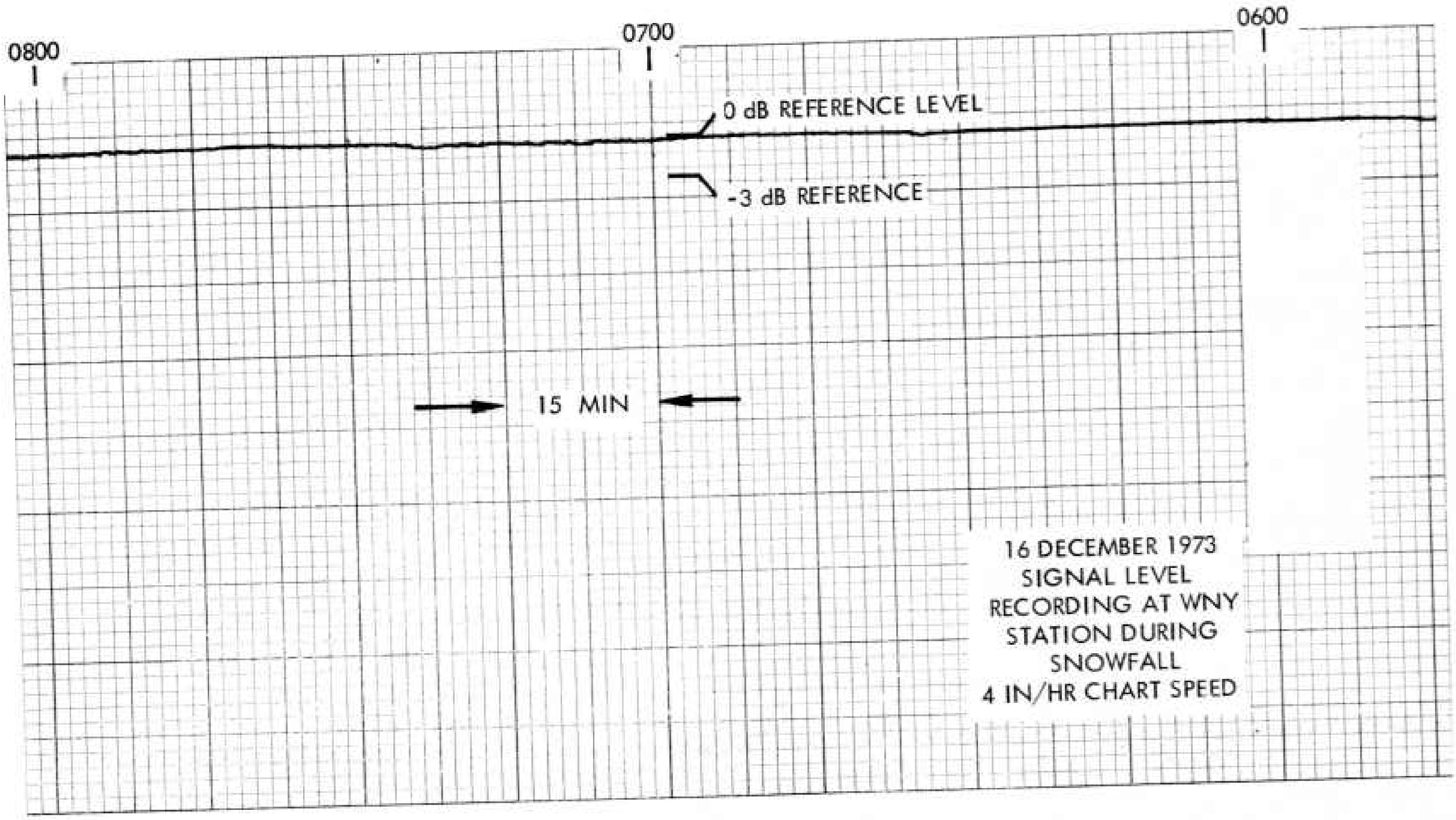


Figure 61. Signal Level During Snowfall - 16 December 1973

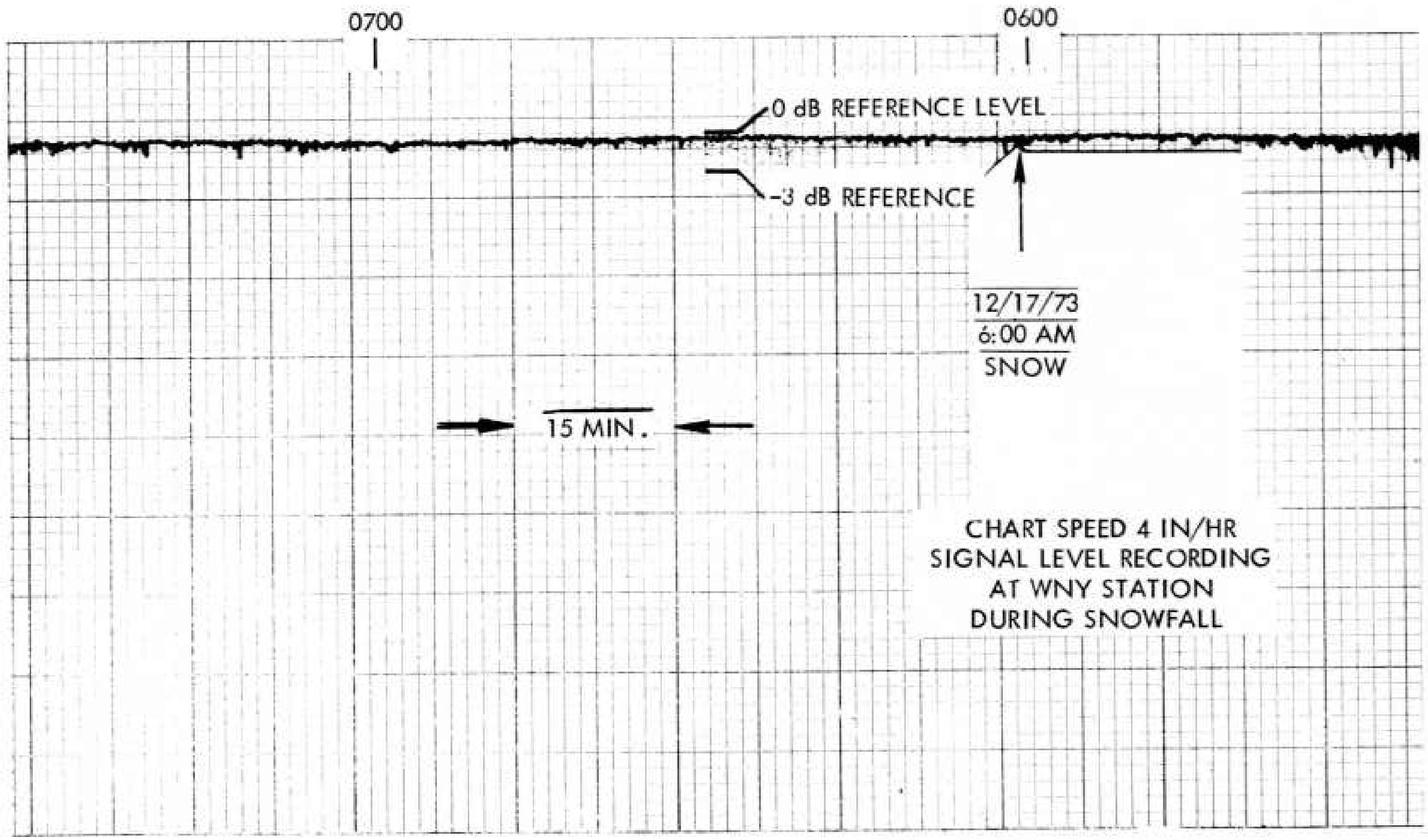


Figure 62. Signal Level Record During Snowfall - 17 December 1973

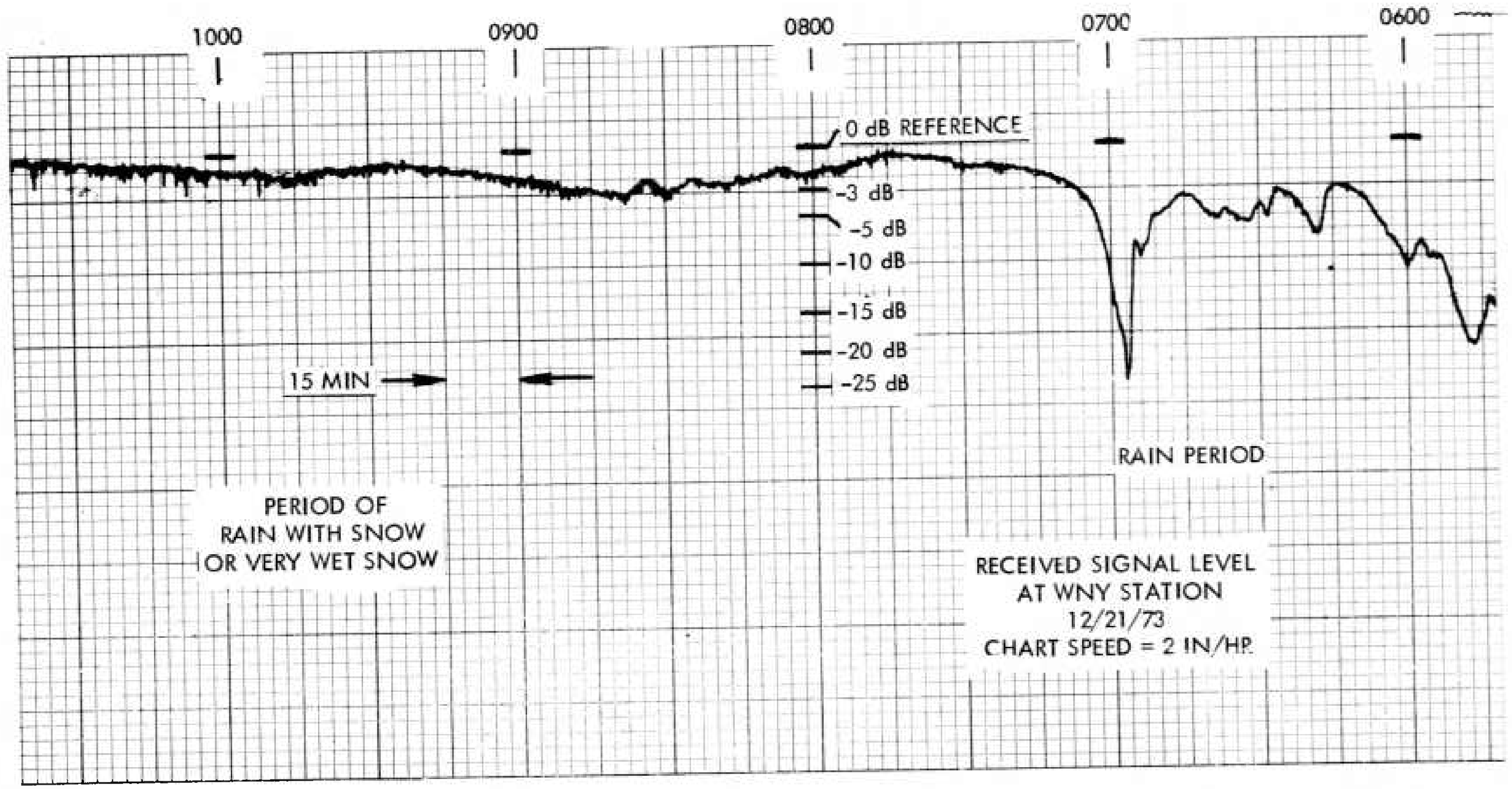


Figure 63. Signal Level Recorded During Rain and Snowfall - 21 December 1973

9 January 1974 - Alternating periods of snow and rain occurred this day. The record of signal strength shows charts typical for light rainfall during the early morning, slow fade to about 5 dB maximum loss occurring for the hours around noon and flat and steady no-loss conditions the rest of the day. Figure 64 shows the portion of the signal record with slow fading. (No visual observations are available to correlate with the conditions at a given time.)

8 February 1974 - Visual observations made of storm conditions were similar to 16 December. The signal level recording (flat and steady) is also similar (see Figure 62). Bit error rate measurements made this day showed that similar error performance was obtained during either the clear or snow periods.

Although the number of samples of propagation in snow is small, some conclusions appear valid from the test data. The AN/GRC-173(XW-1) link performs substantially the same during very cold, dry type snowstorms as during clear weather, and substantially the same during soggy snowstorms as during light rainfall. The operational effect of snowfall is not significant. This is not unexpected. The dielectric constant of ice is much smaller than that of water (Reference 7). This means that the scattering cross-sections of snowflakes will be smaller than for water drops of comparable size. Also, absorption of power by an ice particle is much smaller than the absorption by a raindrop of comparable size.

(9) Rain Effects

(a) Relationships

Precipitation in the form of rain produced the deepest fading of the test link signals, and thus it was the most significant of the propagation variables. Even so, only one rain-produced fade deep enough to cause an outage was encountered in the propagation measurement period, and the link propagation reliability was high.

The link loss in rain appears as the sum of two separate losses; one due to the localized rain conditions at the antennas, and the other due to the water in the rest of the path.

The latter (loss in the path) is described by theoretical and empirical investigations (References 8, 9, and 10). The amount of signal loss in the microwave radio path is a function of the density of water along the path and is higher at millimeter wavelengths than at longer wavelengths, as the wavelength approaches the size of the rain drops. The loss in the path is related to the instantaneous rainfall rate; rain gauge sensors were set up to measure the rainfall rate.

The path loss in rain appears to be the only significant attenuating effect usually considered in millimeter wave propagation test programs, and this may be why there is a marked tendency for the measured values

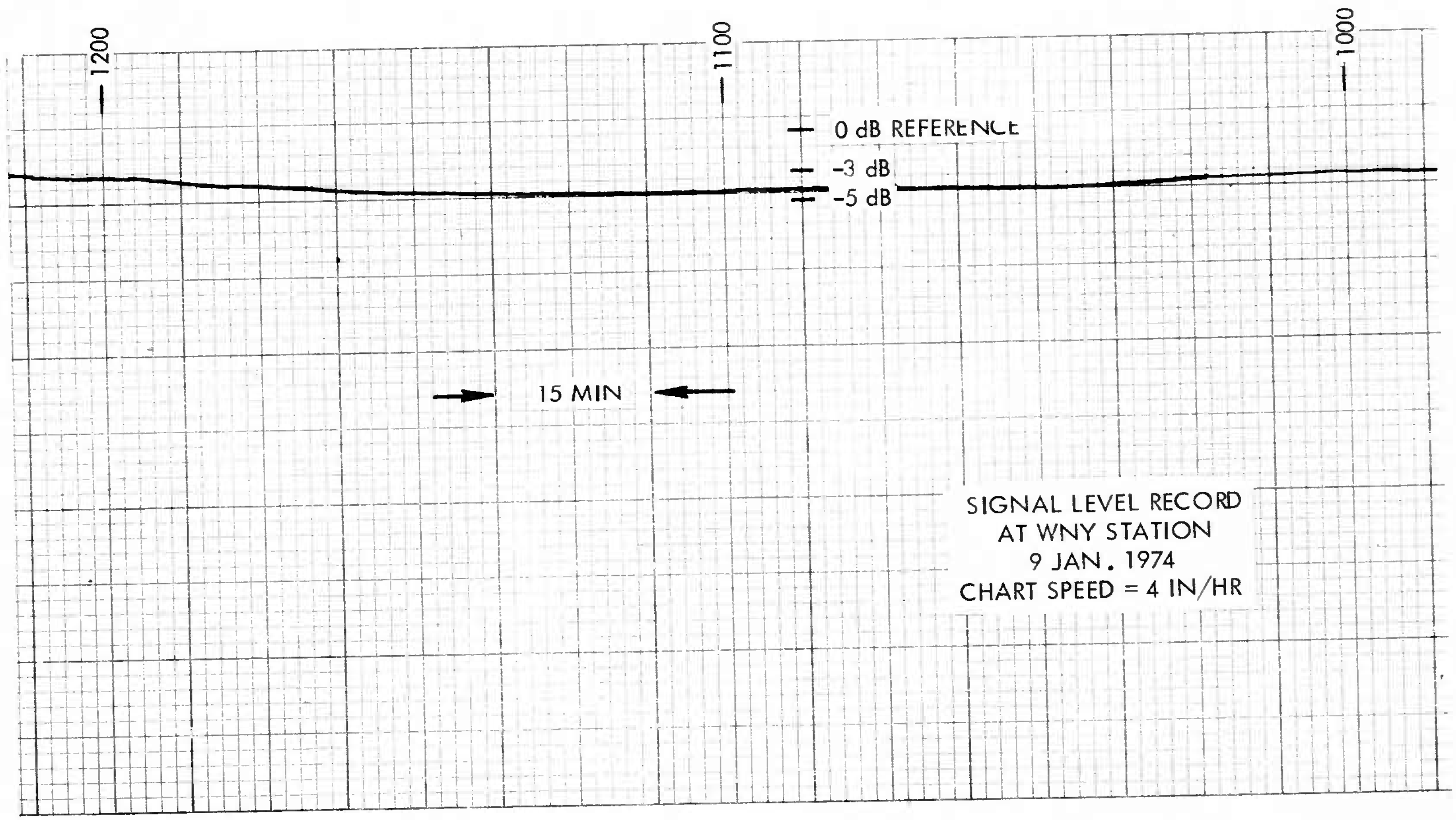


Figure 64. Signal Level Record During Snowfall - 9 January 1974

of attenuation coefficients (loss in dB/km vs. rain rate) reported by other experimenters to be higher than theoretically predicted (Reference 8). Localized effects of water or moisture at the antenna (feed, primary or secondary reflectors, or radome) generally seem to be neglected in the calculations. This could not be done on this test program.

The radio system uses a flat sheet of hypalon* to cover the front of the antennas, forming a radome. The radome was provided mainly to exclude snow and ice from the reflector dish and the feed, and secondarily to keep rain water off the same surfaces. It was found, however, that water on the surface of the radome could produce a loss of signal which, under some conditions, might be as significant as the loss due to rain in the rest of the path. While it was qualitatively expected that loss mechanisms for rain on radomes at lower microwave frequencies (Reference 11) would be similar at millimeter wavelengths, the test link was the first opportunity to obtain quantitative data. The measurement configuration, however, did not permit separation of the localized loss effects at the antennas from those in the rest of the path. Therefore, even though considerable data was obtained for signal intensity as a function of rainfall rate, the results can only be used to characterize the total link loss or fade. An estimate of the attenuation coefficient normalized to unit distances will not be given, as the loss attributed to the water on the radome surface cannot be calibrated out.

(b) Meteorology

Rainfall statistics depend upon the geographical location. Figure 65 shows the variability of rainfall versus month in a year in Washington, D.C. The total precipitation in a month versus the month is shown as (a) 30-year record, (b) normal and (c) the precipitation measured during the months of the propagation test period. Refer also to Figure 49 which includes a daily notation of rainfall occurrence during the period.

The precipitation measured during December 1973 was well above the normal and close to the 30-year record. During the other months of the test period, rainfall was below normal. The test period did not include the months of heaviest rainfall in Washington, D.C., which according to the chart, occur in the summer. In all, however, the opportunity was presented to obtain data for a variety of rain conditions and rain rates.

*Hypalon is a chlorosulfonated polyethylene elastomer which is coated over the nylon fabric of the radome. When the hypalon surface is new it appears very smooth and shiny. Some of this characteristic appears to deteriorate with age in weathering. After several months exposure, it appeared somewhat more abraded than when new. This factor may contribute to the adhesion of water to the surface. A view of the radome may be seen in some of the photographs of the stations in this report, although for a time it was removed for cleaning and some of the photographs were taken then. Propagation testing was conducted with the radome on.

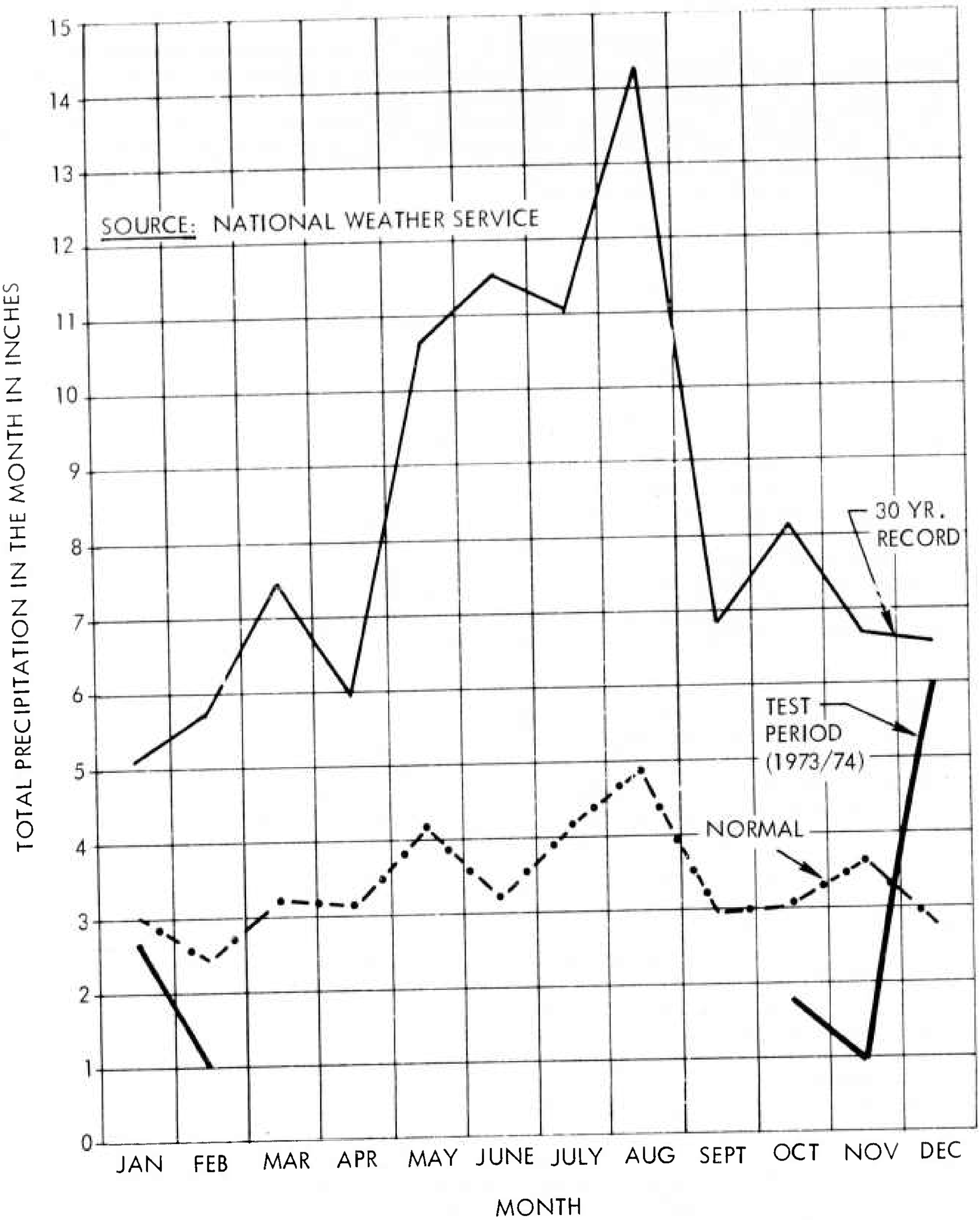


Figure 65. Precipitation in Washington, D. C. vs. Month

Regarding rain rate, the statistics for Washington, D.C. are quite well documented. Figure 66 presents a graph of the annual distribution of instantaneous rainfall rates for this city based on 57 years data (Reference 13). The abscissa gives the percent of time per year that the rainfall rate indicated by the ordinate is exceeded. As an example, rainfall intensities of 12.5 mm/hr or greater can be predicted to occur only during 0.2 percent of the year. This is 17 hours spread out over a year.

(c) Typical Data Records

Examples of data records will be given for the antenna wet radome loss and for link fades in conditions ranging from light to severe rainfalls.

Figure 67 illustrates the loss due to wetting of the radome surface. It is a signal level recording made before, during, and after wetting of the radome surface by splashing a bucket of water on the radome. In this elementary test, the signal level dropped approximately 12 dB when the water struck the surface, rose to the -3 dB level after about 1 minute, and returned to the normal reference level after several more minutes. This test was later repeated with the same quantity of water aimed at various points of the 6-ft. diameter radome surface to exclude the possibility of the hypalon sheet striking the feed and momentarily defocusing it. The results were similar. Sprays and smaller quantities of water were also impinged on varying areas of the surface, and attenuations varying from about 3 dB to about 12 dB were noted.

The above tests, though somewhat inelegant, were the only tests possible in the test period due to other priorities. They were sufficient to indicate the potential order of magnitude of the localized rain losses due to the wet radome surface, namely between 1 and 12 dB per terminal. As mentioned earlier, when it rained, it was not possible to separate the signal loss recordings into any constituent contributions. Visual observations of the radome made during rain did disclose that there should be considerable variability in how the wetting takes place (drops, film, rivulets, etc.) and how long it lasts. Specific meteorological variables would seem to include: the intensity and duration of the rain, its direction, the wind, and the temperature in the localized area. The condition of a radome at a given time would also influence the results, e.g. its tautness can be a function of temperature and humidity. Consequently, it is expected that the signal loss would also vary considerably in magnitude. It is also not certain to what extent absorption, scattering or reflection contribute to the total wetting loss or antenna pattern modification. For these reasons, even if the capability did exist for isolating the radome surface loss contribution from the path loss, it is expected that there would be a spread in the measurements for a given rainfall rate for a practical link.

Figure 68 shows the link signal strength recording typical for a light rainfall. It was obtained between 0530 and 0730 hours on 11 January 1974. The maximum fade depths occurring shortly after 0600 and 0700 were between 8 and 10 dB. The rainfall rates, as averaged for the 3 project sensors,

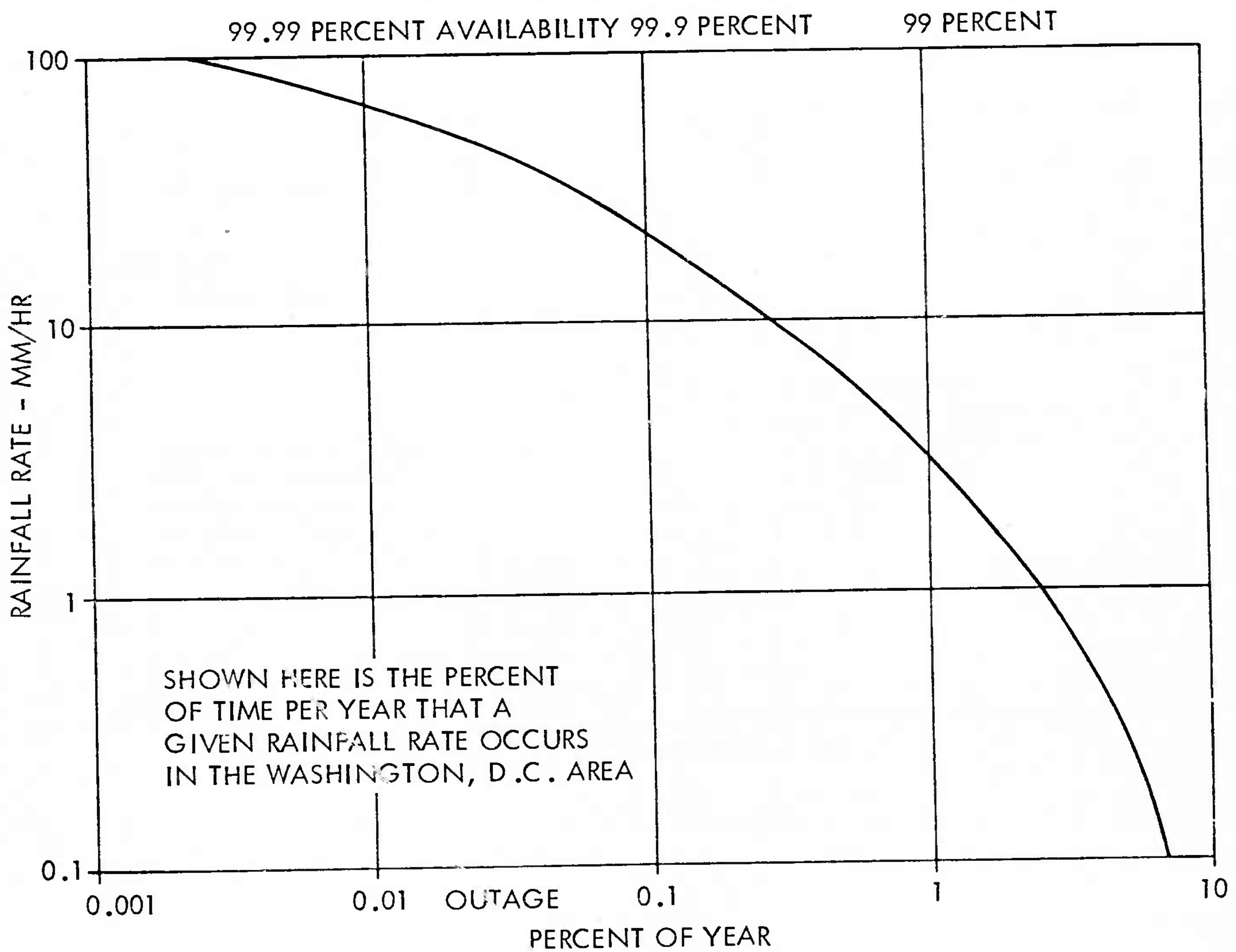


Figure 66. Distribution Function of Rainfall Rates for Washington, D.C. Based on 57 Years Data

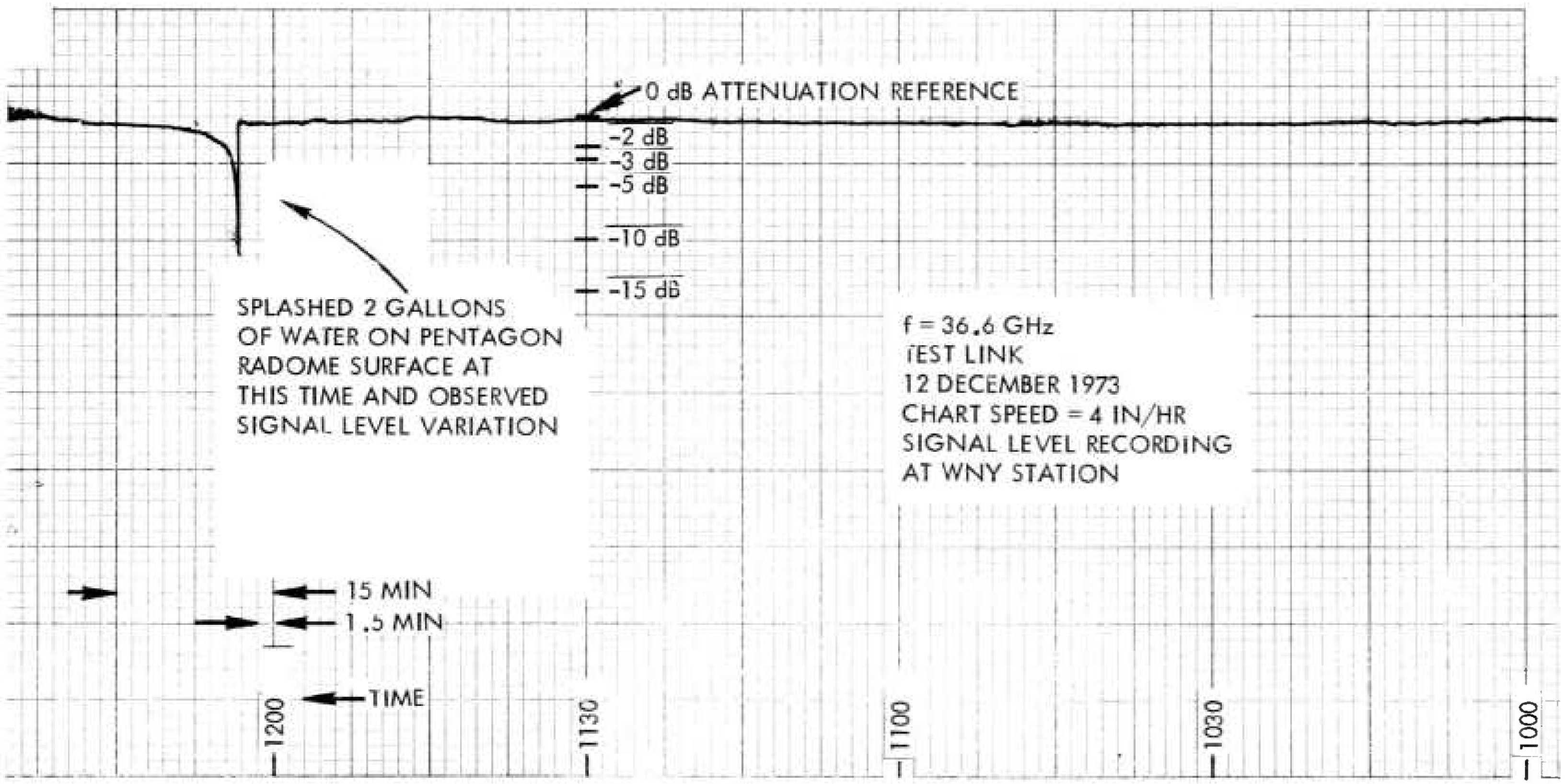


Figure 67. Antenna Radome Surface Wetting Test

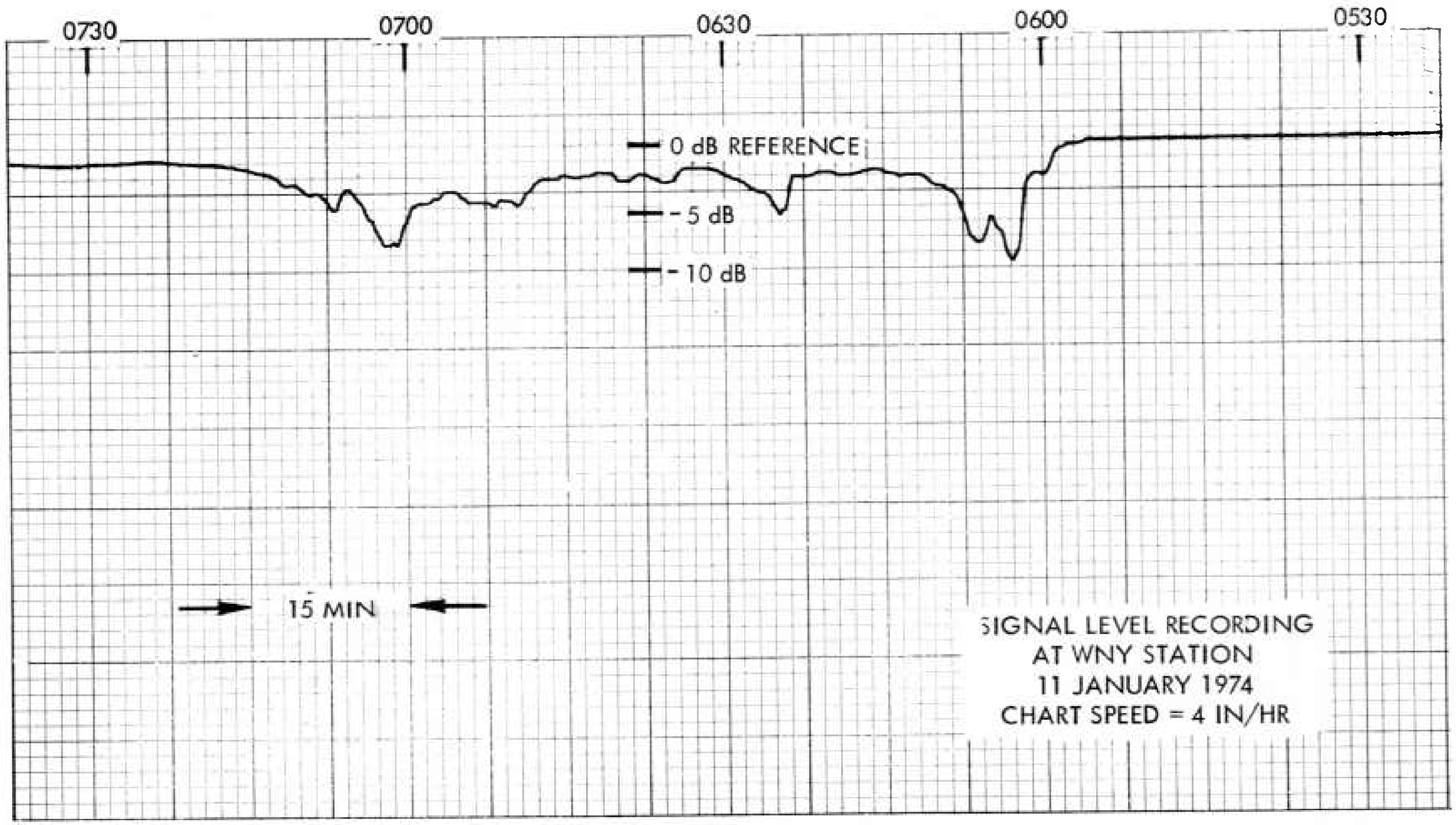


Figure 68. Signal Level Record During Light Rain

were between 1.5 and 2.0 mm/hr. for the corresponding fades. The tendency for a slow "roll-up" in signal strength following the maxima is typical of many of the recordings made in rain periods and seems to be similar to the effect which might be produced by a gradual lessening with time of the amount of water on the radome surface.

When rainfall increased in intensity, the depth of the fade increased. Figure 69 is an example of a signal level record during moderately heavy rainfall on 5 December 1973. There was considerable fluctuation of the rain intensity and signal level over the two hour period shown. The maximum rainfall rate was approximately 7 mm/hr. at around 1050 hours and the fade depth measured as maximum was about -26 dB.

Figure 70 shows the record for a very intense rainstorm on 28 November 1973. This is the only instance of a rainstorm during the test period which caused a signal loss in excess of the system margin. The signal level record shows two significant fade periods. The first deep fade is between 45 and 50 dB. The second fade began about five minutes later and is resolved into two separate fade sections divided by a brief period of recovery; fading in excess of 55 dB lasted between four and five minutes. The records of all three project rain gauges were available to analyze this storm. The rainfall rate was not temporally or spatially uniform as the intense rain cell moved through the area. It was difficult to resolve the number of marks made corresponding to each time the rain bucket tipped at the peak count period of the record, but the maximum point rainfall rate was estimated at approximately 40 mm/hr. Note that a determination of the exact depth of the fade is prevented by the non-linearity of the signal level measurement system and the "bottoming-out" of the recorder. It is clear, however, that the full link margin was exceeded and a communication outage would occur for between four and five minutes.

(d) Rain Data Summary

The attenuation and rainfall data for the measurement period from 20 November 1973 through 15 February 1974 was reduced with the aid of a digital computer. The basic inputs to the computer were the fade depths and their durations from the signal level recordings, and the rainfall rates from the rain gauge recordings. The inputs were obtained by visual analysis of the strip charts. All fades due to propagation effects (rain or some other cause) were used in this data base except those believed to be produced by the construction cranes, which could be neglected because of their anomalous nature on a microwave line-of-sight link. This data was also used to estimate path reliability for the measurement period (see next subsection).

The data entered into the computer is shown in Figure 71. The first column is merely a line number. The second column is the date by year, month and day of month. The third column is the hour ending the particular measurement involved. The fourth column is the rainfall rate in inches per hour, averaged over as many as the three project rainfall gauges. Where no quantity (***) appears in this column, it is due either to the fact that it did not

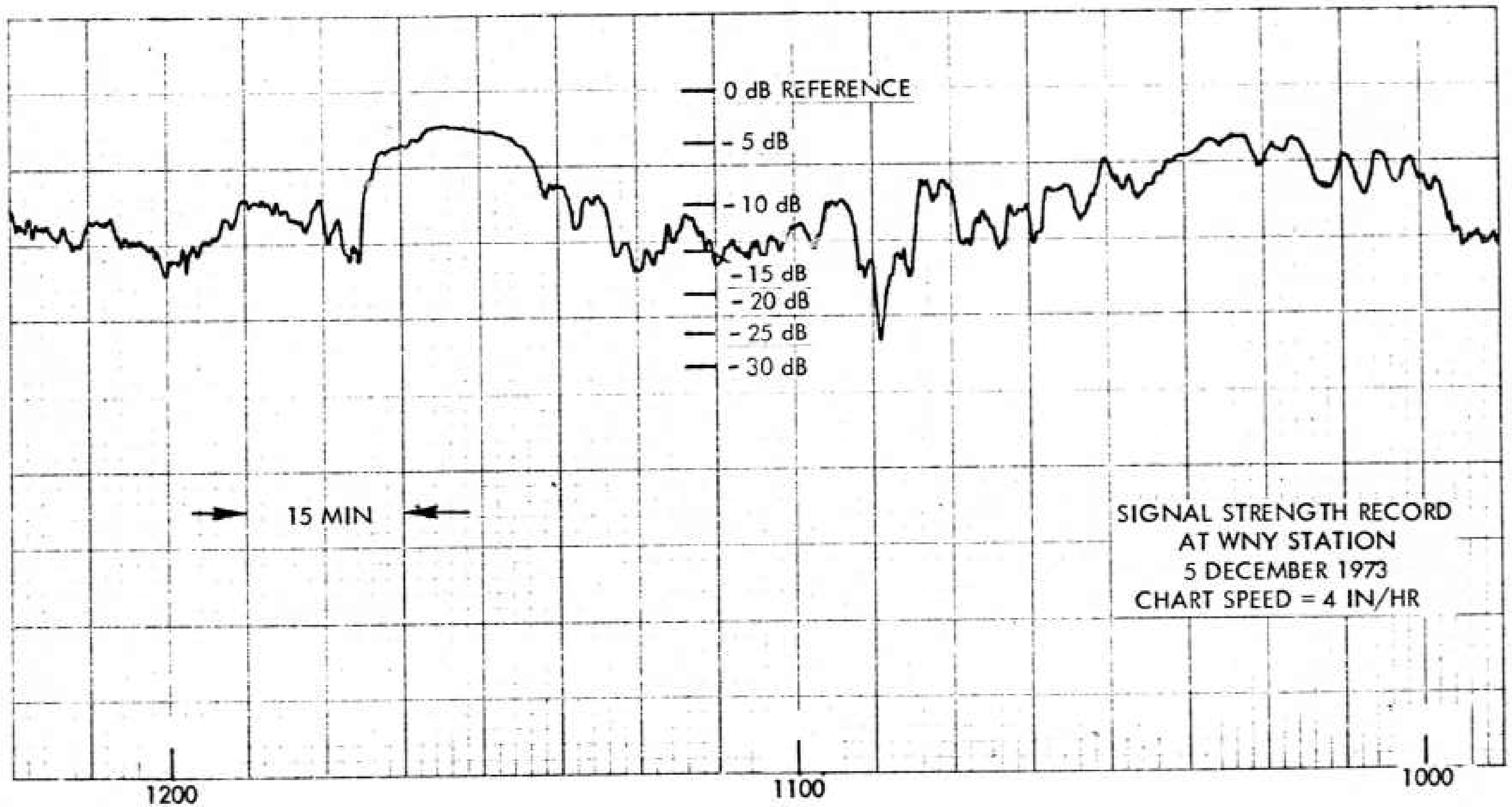


Figure 69. Signal Level Record During Moderate Rain

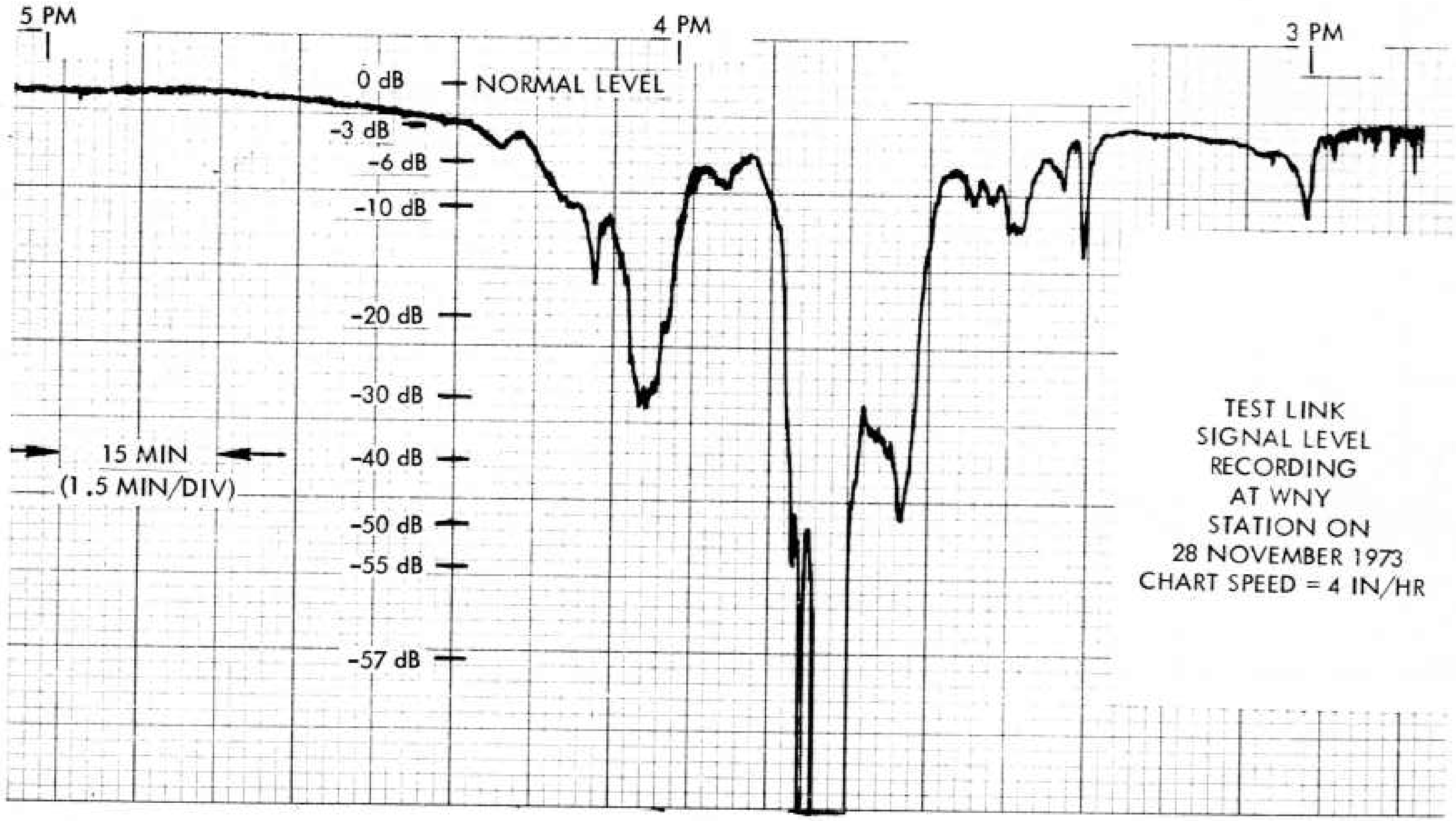


Figure 70. Signal Level Record During Intense Rain

LNH

```
00100 731121 18 ****  8 13 2.5 0
00110 731123 05 **** 4 30 0 0
00120 731123 06 **** 4.5 60 0 0
00130 731123 07 **** 5 60 0 0
00140 731123 08 **** 5.5 60 0 0
00150 731123 09 **** 5 60 0 0
00160 731124 11 ****  7 10 2 0
00170 731126 19 **** 5 60 0 0
00180 731126 20 ***  3.5 4 0 0
00190 731127 13 **** 5 8 0 0
00200 731127 14 **** 4 12 0 0
00210 731127 18 **** 10 9.5 3 .5
00220 731128 13 ***  4 9 0 0
00230 731128 14 **** 5 12 0 0
00240 731128 16 1.596 55 58 39 21
00250       16 13.5 13 12.5 12.3 12.2 12.1 12 9 8 7.5 6.7 5.3 4.5
00260 731128 17 .480 32 20 13 11
00270                          8 6 4 3.7 3 2.3 .8 0 0 0 0 0 0 0
00280 731128 18 **** 5 2 0 0
00290 731205 11 .264 25 60 46 18
00300                          10.5 4.5 1.5 .75 0 0 0 0 0 0 0 0 0 0
00310 731205 12 .204 16 58 43 27
00320                          22.5 1.5 0 0 0 0 0 0 0 0 0 0 0 0
00330 731205 13 .156 16 60 52 16
00340                          6 1 0 0 0 0 0 0 0 0 0 0 0
00350 731205 14 .084 14 33 21 12
00360                          5.3 0 0 0 0 0 0 0 0 0 0 0 0 0
00370 731205 15 .003  3  1  0  0
00380 731205 16 **** 7 2 .5 0
00390 731205 18 .060 5 3 0 0
00400 731205 19 .156 21 24 15  7
00410                          3 2.5 1.5 0 0 0 0 0 0 0 0 0 0 0
00420 731208 20 **** 3 10 0 0
00430 731208 21 .040 4 6 0 0
00440 731208 22 .096 8 60 12 0
00450 731208 23 .132 12 60 22 3
00460                          1 0 0 0 0 0 0 0 0 0 0 0 0
00470 731208 24 .048 6 46 7 0
00480 731209 01 .120 9 54 39 3
00490 731209 02 .160 11 60 60 13
00500 731209 03 .204 15 60 46.5 19
00510                          5 0 0 0 0 0 0 0 0 0 0 0 0 0
00520 731209 04 .096 11 55 40 13
00530 731209 05 .108 10 56 38 4
00540 731209 06 .440 20 60 54 29
00550                          22 9 3 0 0 0 0 0 0 0 0 0 0 0
00560 731209 07 .072 6 12 1 0
00570 731209 08 ***  1 0 0 0
00580 731209 12 .120 5 7 0 0
00590 731209 13 .036 4 6 0 0
00600 731209 14 **** 3 4 0 0
00610 731209 15 **** 3 12 0 0
00620 731213 13 **** 3.5 3 0 0
00630 731213 14 **** 3.5 4 0 0
00640 731213 15 .240 14 36 30 10
00650                         3 0 0 0 0 0 0 0 0 0 0 0 0 0
00660 731213 16 .180 8 15 3 0
00670 731213 19 .060 6 21 5 0
```

Figure 71. Attenuation and Rain Data for Computer Analysis (Sheet 1 of 4)

```
00680 731213 20 .015 6 19 3 0
00690 731220 14 ****  4 3 0 0
00700 731220 15 **** 5 15 0 0
00710 731220 16 .072 4 9 0 0
00720 731220 18 .040 6 30 3 0
00730 731220 19 .516 39 60 54 42
00740                           39 33 27 21 21 12 6 4 1 0 0 0 0 0
00750 731220 20 .516 30 60 60 54
00760                           26 21 9 4.5 3 2 0 0 0 0 0 0 0 0
00770 731220 21 .240 10 54 45 3
00780 731220 22 .072 5 9 0 0
00790 731220 23 ***  3 6 0 0
00800 731220 24 **** 4 12 0 0
00810 731221 01 .040 5 36 0 0
00820 731221 02 .180 23 57 15 9
00830                           6 4.5 4 2 0 0 0 0 0 0 0 0 0 0
00840 731221 03 .040 13 18 9 3
00850                           1.5 0 0 0 0 0 0 0 0 0 0 0 0 0
00860 731221 04 .240 19 60 54 33
00870                           18 6 1 0 0 0 0 0 0 0 0 0 0 0
00880 731221 05 .360 23 54 45 9
00890                           8 4 2 1 0 0 0 0 0 0 0 0 0 0
00900 731221 06 .360 20 54 42 18
00910                           15 7 4 0 0 0 0 0 0 0 0 0 0 0
00920 731221 07 .240 24 60 33 6
00930                           4.5 3 2 1 0 0 0 0 0 0 0 0 0 0
00940 731221 08 .120 3 6 0 0
00950 731221 09 **** 4 21 0 0
00960 731226 09 .204 7 27 15 0
00970 731226 10 .204 11 60 23 6
00980 731226 11 .132 6 24 3 0
00990 731226 12 **** 3 3 0 0
01000 731226 15 .132 10 6 4 3
01010 731226 16 .360 30 60 45 18
01020                           13.5 8 4.5 4 3.3 0 0 0 0 0 0 0 0
01030 731226 17 .360 33 60 51 27
01040                           24 13.5 12 6 4 2 1 0 0 0 0 0 0 0
01050 731226 18 .036 4 9 0 0
01060 731229 23 **** 4 15 0 0
01070 731229 24 **** 4 54 0 0
01080 731230 01 **** 5 60 0 0
01090 731230 02 **** 5 45 0 0
01100 731231 03 **** 4 6 0 0
01110 731231 13 **** 3 3 0 0
01120 731231 14 .040 6 40 3 0
01130 731231 15 .060 7 36 3 0
01140 731231 16 .060 7 16 15 0
01150 731231 17 .040 8 60 12 0
01160 731231 18 .120 11.9 60 33 9
01170 731231 19 .100 10 60 18 3
01180 731231 20 .100 9 60 36 6
01190 731231 21 .120 11.9 60 21 12
01200 731231 22 **** 4 27 0 0
01210 731231 23 **** 7 54 0 0
01220 740101 07 ***  3 1 0 0
01230 740103 02 **   6 8 1.5 0
01240 740103 07 ***  4 9 0 0
01250 740103 08 .060 9 36 11 0
01260 740103 09 .015 5.5 60 0 0
```

Figure 71. Attenuation and Rain Data for Computer Analysis (Sheet 2 of 4)

```
01270 740103 21 .060 5.5 10.5 0 0
01280 740103 22 .100 11.9 15 8 2
01290 740103 23 .120 9 40 20 1.5
01300 740103 24 .120 9 60 27 1.5
01310 740104 01 .050 4 22 0 0
01320 740104 02 .050 4 42 0 0
01330 740104 03 .040 3 0 0 0
01340 740109 05 **** 4 9 0 0
01350 740109 06 .240 10 11 8 4
01360 740109 07 .030 11.9 28 21 3
01370 740109 08 .040 11 28 21 6
01380 740109 09 .040 8 60 6 0
01390 740110 09 .120 6 21 1 0
01400 740110 12 .028 7.5 15 4.5 0
01410 740110 24 .040 5 9 0 0
01420 740111 07 .060 10 24 6 1
01430 740111 08 .070 8 10 3 0
01440 740111 09 .120 8 10 7 0
01450 740111 10 **** 4 10 0 0
01460 740111 11 **** 3 1 0 0
01470 740111 12 **** 4 18 0 0
01480 740111 17 .036 3.5 1 0 0
01490 740119 03 **** 4 5 0 0
01500 740119 04 **** 4 6 0 0
01510 740119 05 **** 3 1 0 0
01520 740121 08 .120 11.9 10.5 5 1
01530 740121 09 .204 25 47 18 5
01540                         4 2 1.7 1.5 0 0 0 0 0 0 0 0 0 0
01550 740121 10 .324 26 60 21 10.5
01560                         6 2.2 1.5 1 0.8 0 0 0 0 0 0 0 0 0
01570 740121 11 .636 40 60 60 25
01580                         17 11 10 7 4 3 2 0.8 0 0 0 0 0 0 0
01590 740121 12 .150 21 58 30 19
01600                         9 6 1 0 0 0 0 0 0 0 0 0 0 0
01610 740121 13 **** 4 15 0 0
01620 740121 21 **** 3 3 0 0
01630 740121 22 **** 3 6 0 0
01640 740121 23 **** 4 5 0 0
01650 740124 11 **** 4.5 6 0 0
01660 740124 12 .080 4 21 0 0
01670 740124 13 .060 5.5 23 0 0
01680 740124 14 **** 5 10 0 0
01690 740124 15 **** 4 13 0 0
01700 740124 16 **** 3 3 0 0
01710 740125 01 .050 4 39 0 0
01720 740125 02 **** 3 16 0 0
01730 740125 03 **** 3.5 27 0 0
01740 740125 04 **** 4.5 9 0 0
01750 740125 05 .080 4.5 7 0 0
01760 740127 03 **** 4.5 3 0 0
01770 740128 18 .120 14 12 3 1
01780                         0.5 0 0 0 0 0 0 0 0 0 0 0 0 0
01790 740128 19 .720 33 17 13 9
01800                         8 7 5 4.5 4 3 2 0 0 0 0 0 0 0
01810 740202 15 **** 5 6 0 0
01820 740203 11 **** 3.5 3 0 0
01830 740206 14 **** 4.5 41 0 0
01840 740206 19 **** 4 10.5 0 0
01850 740206 21 **** 5.5 6 0 0
```

Figure 71. Attenuation and Rain Data for Computer Analysis (Sheet 3 of 4)

```
01860 740206 22 **** 3 1 0 0
01870 740206 23 .016 6.5 15 1 0
01880 740206 24 .033 6.5 18 3 0
01890 740207 01 .028 7 21 3 0
01900 740213 24 **** 8.5 16.5 10.5 0
01910 740214 01 .072 7.0 14.5 7.5 0.0
READY.
```

Figure 71. Attenuation and Rain Data for Computer Analysis (Sheet 4 of 4)

rain or that the project rain gauges were inoperative for one reason or another, as previously discussed. Use of backup information from the National Weather Service would depend upon the specific case in the analysis. The fifth column is the maximum fade for the overall path. The next three columns are the durations, in minutes, of the fade level during the hour for the 3, 6 and 9 dB levels respectively. If the fading during the hour exceeded 11.9 dB, the next subsequent line entered is the duration of the fade for the 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48 and 51 dB levels, if they were exceeded.

The major result of the analysis is shown in Figure 72. This is a plot of the logarithm of the link attenuation in dB versus the logarithm of the rainfall rate in mm/hr. as plotted on the computer printer. The attenuation in dB and rain rate in mm/hr. are also shown typed in. The data points on the printout are shown as X's and the printer grid points are shown as +'s.

The scatter of the measurement points is expected and is similar in this respect to the results reported for other empirical investigations (References 8 and 9). On the Phase III program, the scatter is likely based on the following considerations: 1) the nature of rain drop size distributions which produce alternative distributions of drop sizes for different rainfall rates, 2) the nature of rain cell size distributions which produce differences between point rainfall rates and the actual path average, 3) differences in time between a change in signal intensity and the rain measurement produced by the tipping rain bucket mechanism, 4) possible variations in wind conditions at the rain gauges, and 5) possible variations in the character of the localized radome surface wetting previously described.

All values of rainfall data below 1.3 mm/hr. were suppressed on Figure 72 and do not show since the validity of the gauge readings is most questionable at such low rates and could cause an error in the curve fit to the scatter points to be described subsequently. The maximum fade data point of 55 dB (storm of 28 November 1973) is shown on Figure 72 but was not used in the curve fitting since it was known that the fade depth actually exceeded 55 dB. Its full depth was not measured due to nonlinearity in the measurement system.

It was attempted to fit polynomial expressions from degree one through nine to the data points. The best result was from a polynomial of degree 1 (a straight line). The linear equation is of the form $y = 0.781x + 0.614$ with a standard deviation of 0.162736.

The best linear fit was plotted over the data of Figure 72. The maximum theoretical attenuation for rain in the path alone as obtained from Reference 8 was also plotted in Figure 72. From the curves, the measurements give a higher attenuation than predicted by theory for the path alone. The difference is believed due mainly to the radome surface wetting as described earlier. The result is also higher than previously published for another measurement program conducted by Raytheon in Washington, D. C. (Reference 9). The antennas on that program did not use a radome cover.

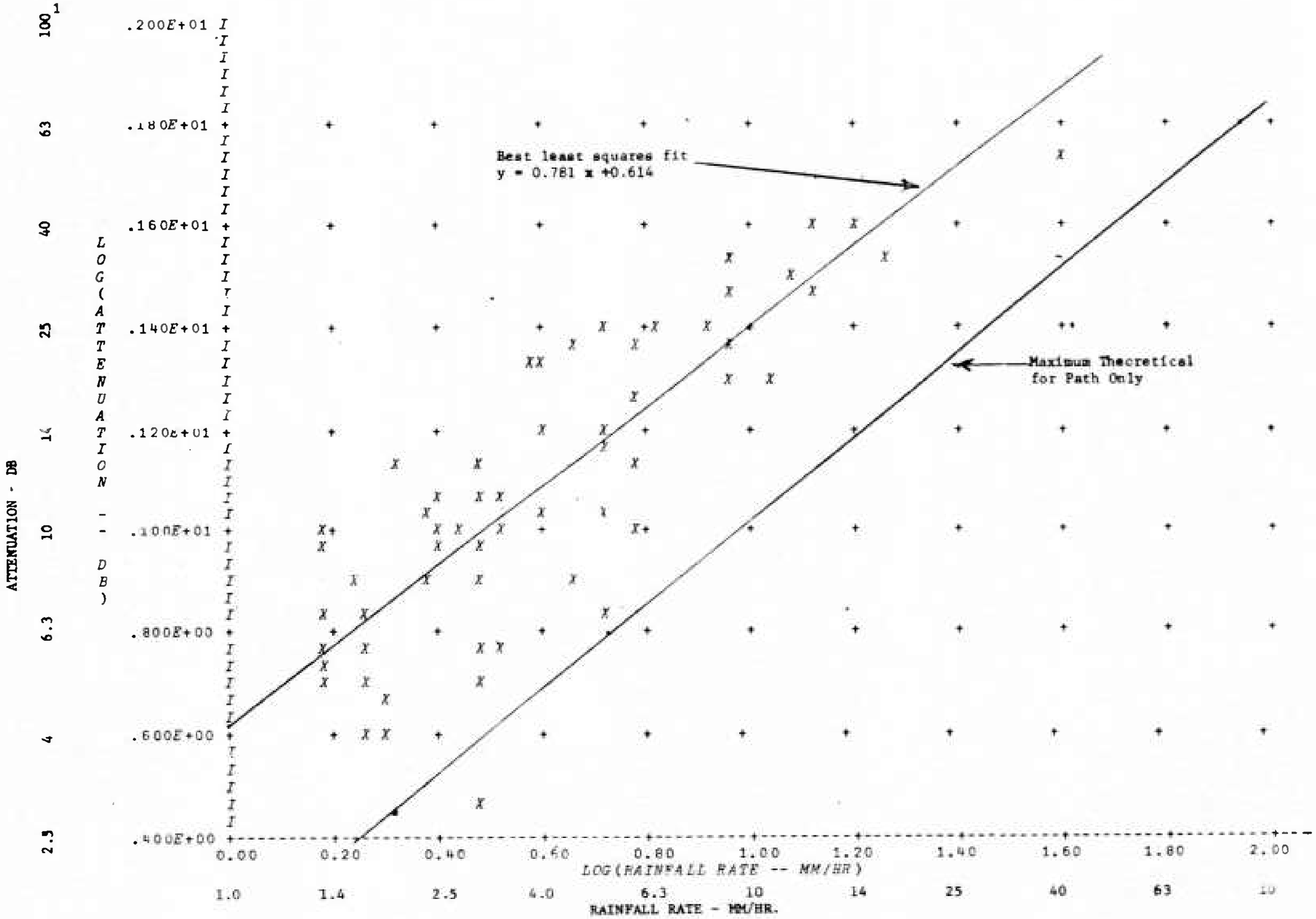


Figure 72. Graph for Attenuation vs. Rainfall Rate

(e) Measurement Period Propagation Reliability

The data shown in Figure 71 was also used to estimate the total measurement period propagation reliability for the link. Fades believed due to the construction cranes were excluded from the data as mentioned above. All other propagation fades for whatever reason are included in Figure 71 and were used in this estimate.

Table XVIII shows the fade in dB, the percentage of the time that the fade was not exceeded, and the total time in minutes that the fade did occur. The percentages were calculated using a total measurement time of 2054 hours, which is the time the signal level record was obtained for at least one station between 20 November 1973 through 15 February 1974.

Table XVIII. Total Measurement Period Fade Statistics

FADE--DB	PERCENT TIME NOT EXCEEDED	TIME--MIN
3.0	96.65936	4117.00
6.0	98.73458	1559.50
9.0	99.54804	557.00
12.0	99.75471	302.30
15.0	99.86514	166.20
18.0	99.91261	107.70
21.0	99.94284	70.45
24.0	99.95529	55.10
27.0	99.96795	39.50
30.0	99.98061	23.90
33.0	99.98637	16.80
36.0	99.99189	10.00
39.0	99.99351	8.00
42.0	99.99391	7.50
45.0	99.99456	6.70
48.0	99.99570	5.30
51.0	99.99635	4.50

Figure 73 shows the data of Table XVIII plotted as a curve. Bit error rate measurements on the program have established that the rain fade margin at an error probability of 10^{-6} is approximately 39 dB. For this fade value, the propagation reliability from the curve of Figure 73 is greater than 99.99 percent. While this reliability is high and is greater than 99.8 percent specified for the AN/GRC-173(XW-1), it must be noted that the link was shorter than maximum and the measurement period was only a part of the year; therefore, caution should be exercised in using the results for predictions for other links.

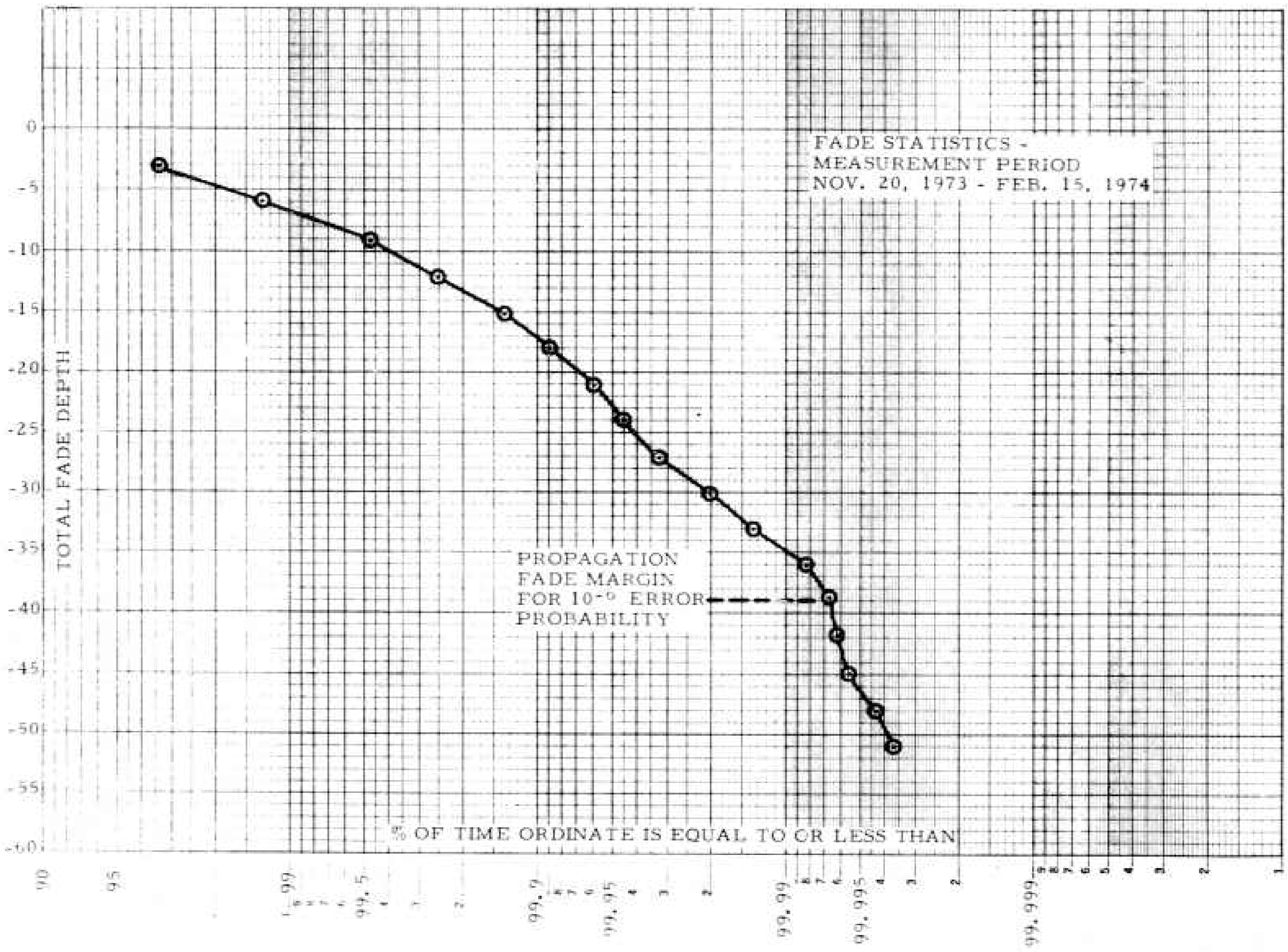


Figure 73. Curve of Total Measurement Period Fade Statistics

SECTION V

DEPLOYMENT AND OPERABILITY

1. INTRODUCTION

Engineering information and data from Phase III relative to transporting, installing, operating and maintaining the AN/GRC-173(XW-1) Radio Sets is documented in this section. Data of this type was required to be documented during the initial field tests so as to guide the future application and deployment of this, or similar equipment. Photographs are used to assist in disclosing essential details. Included in this section are elapsed running time logs and reliability experience on Phase III.

2. TRANSPORT AND INSTALLATION

a. Shipment to Test Area

Shipment of the equipment from the Raytheon plant at Wayland, Massachusetts to a storage facility at Fort Belvoir, Virginia in the vicinity of the test area was made by two flatbed trucks.

The shipment comprised two shelter groups and antenna systems designated for the installation at the Pentagon and the Washington Navy Yard (WNY), plus a third shelter group and four additional antenna systems. The first two aforementioned shelter groups each contained a complete duplex radio set installation, while the third shelter group contained rack and cable assemblies (but no radio hardware) which could be used in connection with a possible repeater facility at some future time. Stored inside of the three shelter groups, by means of separate shipping containers or strap-down arrangements, were items such as tools, air conditioners, drawings, cabling and installation hardware, which would be used or installed later at the test site. A carefully prepared and complete list of the location of hardware and auxiliary items inside the shelters and the antenna assembly crates subsequently proved to be of great value to the field personnel in performing the final installation and antenna erection.

A total of fifteen pieces were involved in the shipment (three shelter groups and the twelve antenna equipment crates). The weight of each shelter in its shipping configuration is approximately 2000 pounds. Each antenna system consisted of two shipping crates, one (approximately 300 pounds loaded) containing the reflector dish assembly, and the other (approximately 500 pounds loaded) containing the mast assembly and hardware. Six antenna systems were shipped.

Figure 74 is a photograph of the loading operation onto one of the flatbed vehicles at the Raytheon plant.

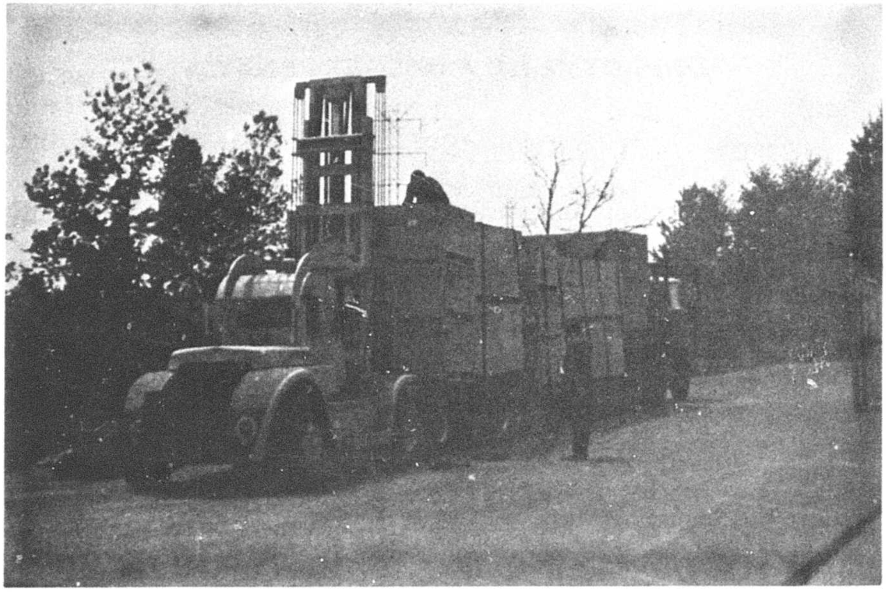


Figure 74. Loading Equipment For Shipment By Flatbed Trailer Truck

b. Storage and Preparations for Installation

Storage was in an outside exposed area provided by the Government at Fort Belvoir, Virginia, for about two months prior to the actual installation. Note: the antenna systems had been stored at the Raytheon plant for about a year during Phase II and the shelter groups for about a month prior to shipment. Arrangements were also made while the equipment was at Fort Belvoir to hold briefings with helicopter base personnel from Fort Eustis, Virginia, and Davison U.S. Army Airfield at Fort Belvoir. Part of the briefing meeting included preliminary fly-over of the shelters, which were moved temporarily from their storage area to nearby Davison Airfield for this purpose. Figure 75 shows some of the radio set equipment near the flight apron at Davison Airfield during a meeting with the helicopter personnel. The helicopter shown in this picture, a Bell UH-1, was one of those considered for the lift mission, but not used, primarily since safety considerations required the use of a fail-safe multi-engine craft for a lift over areas of the type of the Pentagon and WNY. The lighter craft shown, however, did prove of considerable utility for site inspection flights during final preparations.

A recommendation resulting from the storage experience is to put deeper openings in the shelter skid to accommodate standard fork lift truck forks. Special forks were obtained by Fort Belvoir personnel for the local lifting.

Figure 75. Equipment at Davison Airfield for Briefing During Storage Period

c. Lift by Helicopter

During the day of the lift, the equipment was moved the distance of about 30 miles from Fort Belvoir to the holding area in Washington, D. C. via a flatbed truck provided by the Government. The truck was loaded only with the shelter, antenna mast assembly and antenna reflector assembly designated for the particular site. Preparatory steps taken in loading the shelter and crates on the truck included arranging them with the necessary strap, sling, cargo net and lift-ring configuration for the eventual lift by helicopter. This preparation beforehand conserved time and fuel during the actual lift mission. While awaiting the arrival of the helicopter, the truck carrying the equipment was parked in the holding area, which at the Pentagon was the abutting heliport area and at the Washington Navy Yard was a cleared area near the Anacostia River docks about a quarter mile distant from the target building site.

The helicopter used to perform the lifts was a Sikorsky CH-54 Skycrane type flown by a crew from the 355th Aviation Company stationed at Fort Eustis, Virginia. This craft is capable of lifting very large loads, far in excess of the volume and weight of the radio equipment. In addition to this lifting capability, it has the aforementioned safety feature of multiple engine configuration for fail-safe lift over civilian occupied areas.

On the day of the lift, the CH-54 flew about 150 miles from Fort Eustis to Davison U.S. Army Airfield for a short stopover, then the remaining approximately 30 miles to the holding area. Command and crew personnel from the Rotary Wing Division at Davison Airfield coordinated with Fort Eustis on the mission.

For reasons of safety and physical security, the lifts took place after regular facility working hours. This was August 6, 1973, in the case of the Pentagon lift, and on September 29, 1973, in the case of the WNY lift. The precautionary schedule minimized any possible risk to other activities in the site areas.

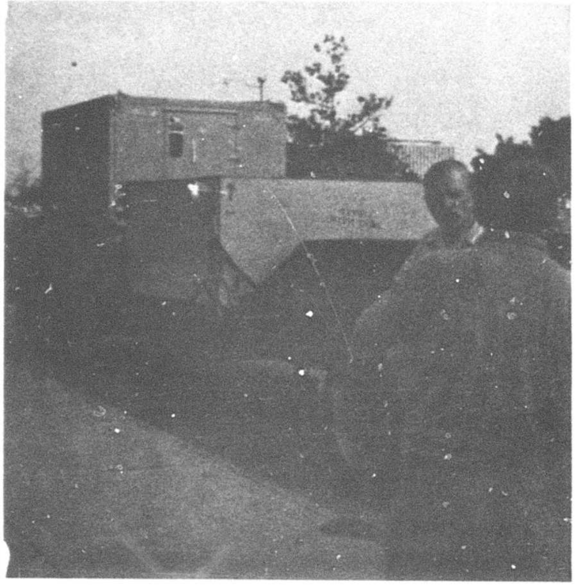
Figures 76 and 77 contain several photographs made of the lift missions. The photographs disclose details, such as methods of rigging and suspension, flight and personnel procedures, etc. The basic sequence of steps were as follows:

- Policing of the lift and drop-off zone to clear it of people and debris.
- Helicopter hovering over the shelter on truck and attaching of shelter to cable and winch of helicopter. (One person on the ground was required for this, with another standing by to assist with any possible last minute repositioning of equipment on the truck.)
- Lowering the equipment to the target point. Personnel positioning it where desired, using guide ropes. (Four personnel were employed around the target point.)
- Repeating for all packages of the station grouping (three total).

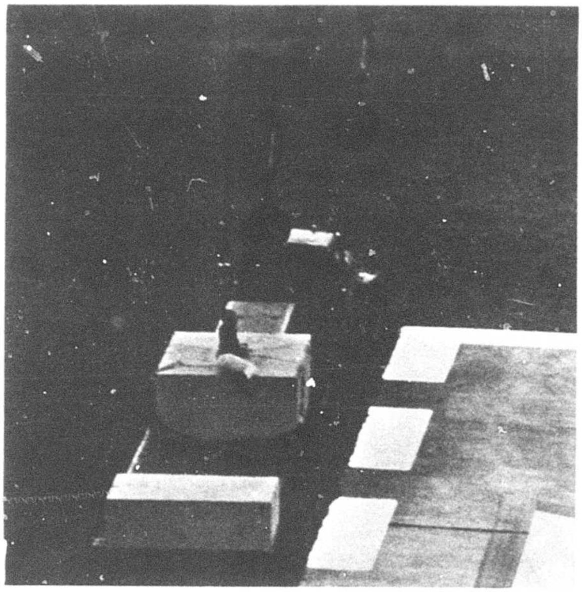
d. Installation

The details below supplement the information provided earlier in Section III by describing and illustrating key steps during the installation.

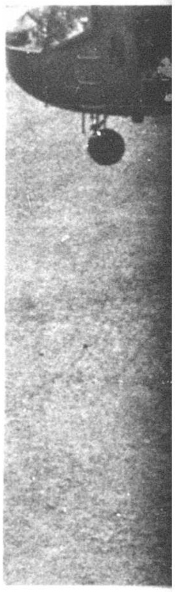
Installation comprised both physical and electrical equipment. Generally speaking, it consisted of final positioning and tie-down of the shelter, unpacking and installation of the air conditioner units, running primary ac electrical power to the shelter, rack interconnection, erection of the antenna system, fabrication and connection of the shelter to the antenna feed run and connection of dry nitrogen gas to the waveguide run. Following these installation steps, the radio system checkout could proceed.



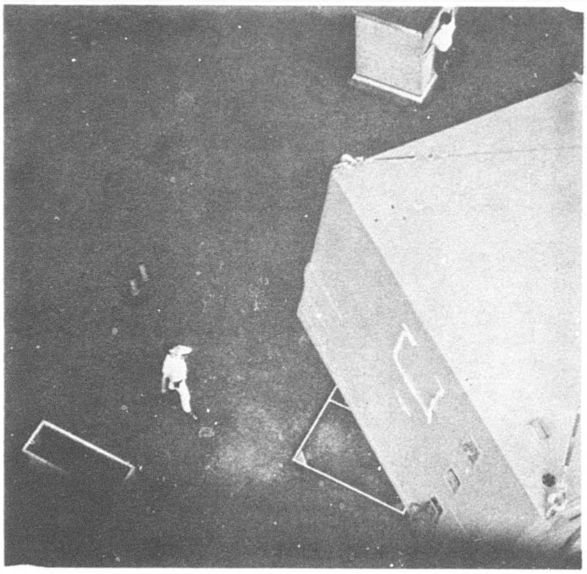
a. Loaded truck near holding area



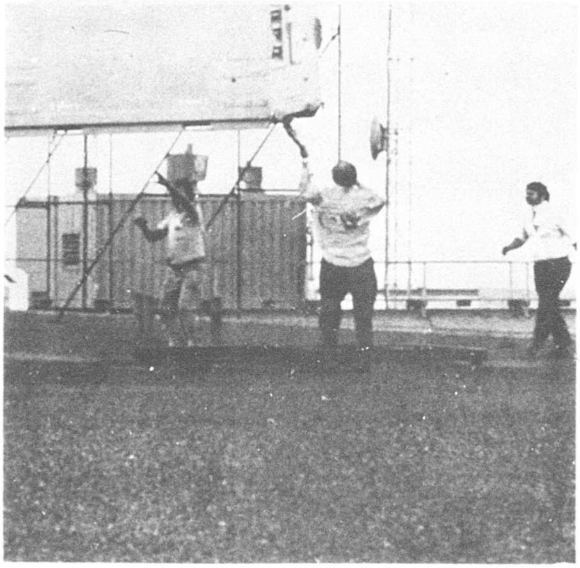
b. Attaching antenna crate to helicopter winch



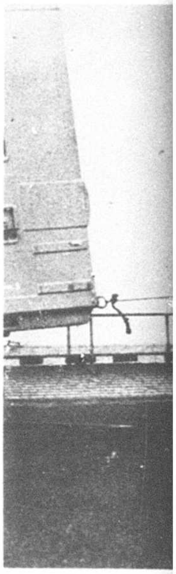
c. Helicopter begi



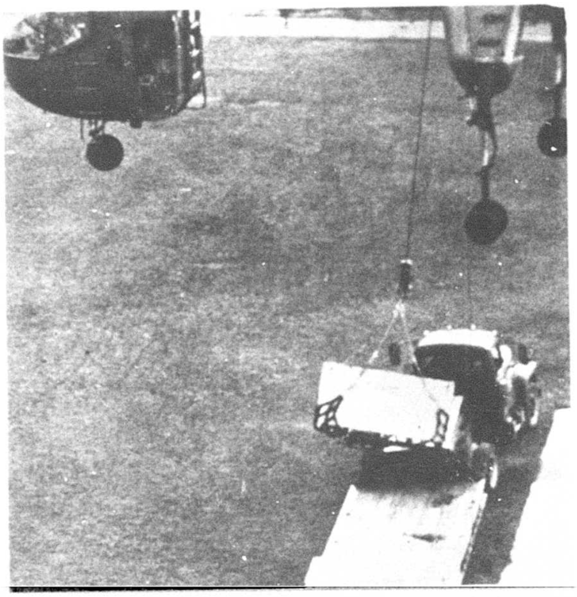
e. Over target point



f. Lowering shelter

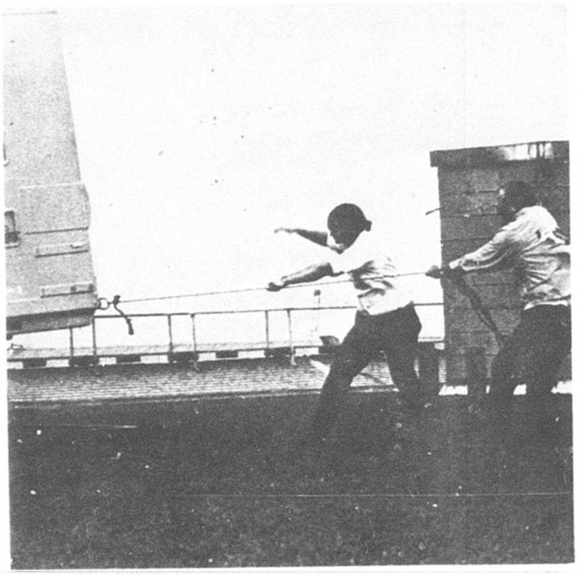


g. Guiding onto fr

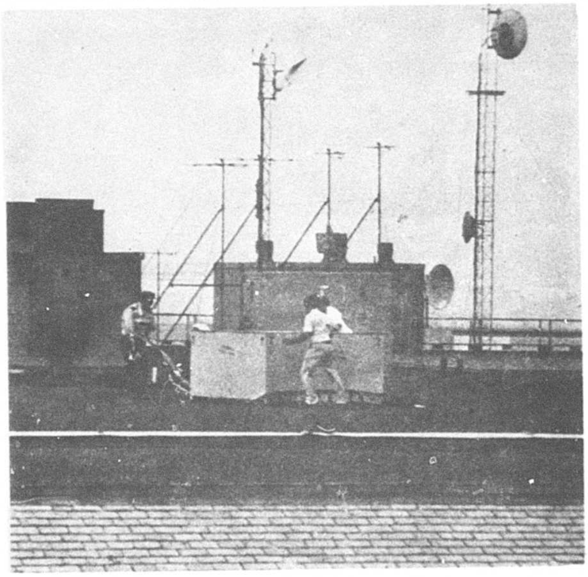


c. Helicopter begins lift

d. Helicopter flying with shelter



g. Guiding onto framework

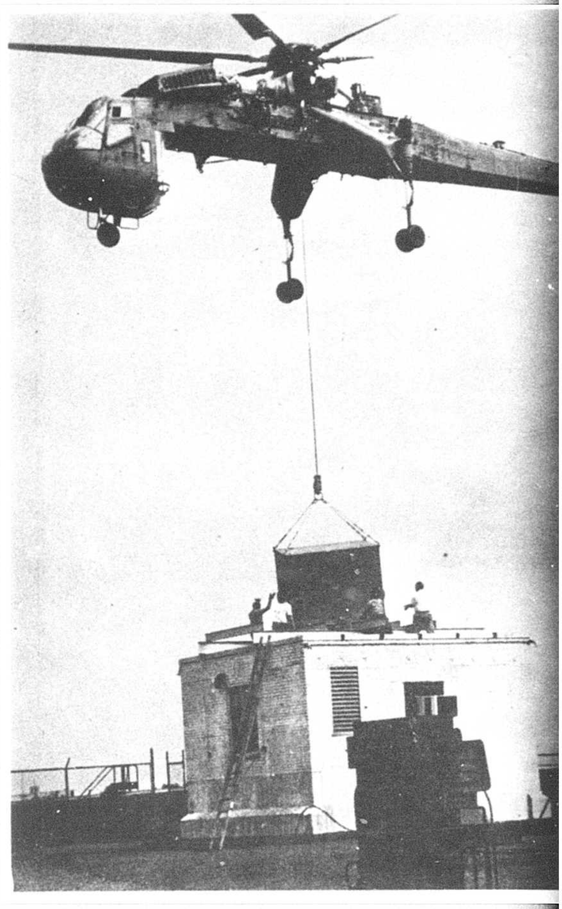


h. Shelter and antenna unloaded

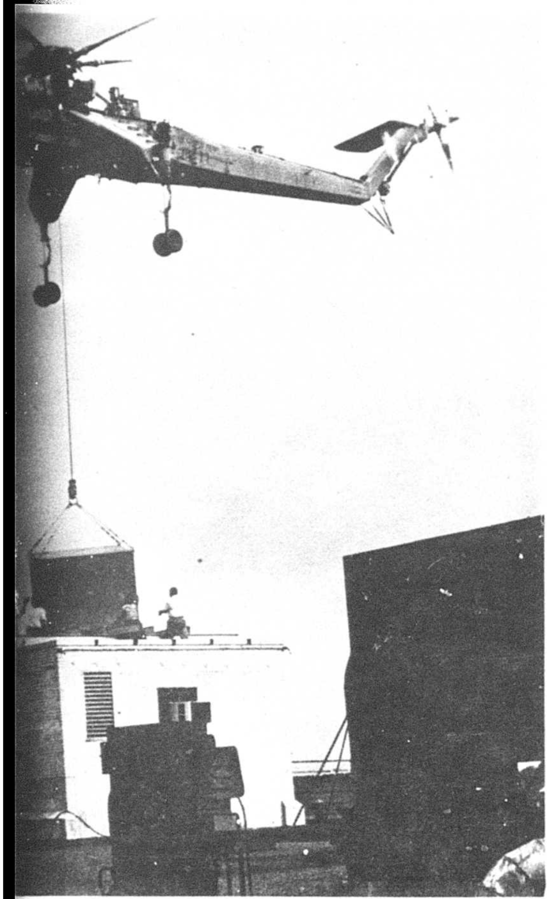
Figure 76. Helicopter Lift at Pentagon

2

a.



b.



b.

c.

2

Figure 77. Helicopter Lift at Washington Navy Yard

Figure 78 shows several photographs taken during installation of the Pentagon station. Captions are included with the photographs to point out signigicant details.

The installation of the WNY station differed from that at the Pentagon in many respects. This was primarily due to limited mobility area on the secondary roof level (covering a penthouse-type elevator shaft), and the necessity to mount the shelter and antenna on a metal framework superstructure a few feet above level space on the penthouse. The superstructure spanned over the top roof level and was fastened to the penthouse walls so that they (the penthouse walls) bear the load, rather that roof members. Figure 79 contains photographs and explanatory notes covering the installation of the WNY station.

Test equipment items and normal working tools were sent separately to Washington or procured locally. Nitrogen gas in pressurized metal containers was procured locally. It may be preferable to include these items in the shipment of the shelter group for future installations. The rooftop locations at times proved relatively inaccessible for ingress by normal means with bulky items and the progressive partial shipments of these items was time consuming.

Installation of the meteorological equipment in support of the propagation tests, which took place at the Pentagon, WNY and a third site at later times, is discussed separately in this report.

e. Management and Coordination

Arrangements for the above described transportation and installation phases involved considerable liaison and coordination between the responsible contractor, Raytheon Company, and several Government groups. A partial listing of these is given below to indicate typically the kind of arrangements and cooperation which were required.

Table XIX. Government Groups Participating

	Group/Agency and Location	Function
1)	Defense Communications Agency, Washington, D. C.	Overall program management, technical assistance and on-site support.
2)	USAF Systems Command, Rome Air Development Center, Griffiss Air Force Base, NY	Technical and program management, monitoring and assistance.
3)	Office of Pentagon Building Commandant, Washington, D. C.	Plans - coordination and approval

Table XIX. Government Groups Participating (Cont)

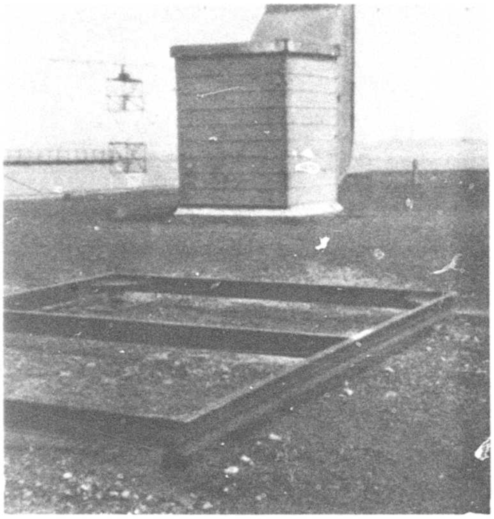
	Group/Agency and Location	Function
4)	Office of Pentagon Building Superintendent, Washington, D. C.	Engineering coordination, approval and liaison
5)	Security Offices; Pentagon, WNY and DCA, Washington, D. C.	Security Requirements
6)	General Services Administration, Washington, D. C.	Support in installation; physical construction and supervision
7)	Military District of Washington, Washington, D. C.	Plan coordination and approval
8)	Naval District of Washington, Washington, D. C.	Installation support
9)	Federal Officer Protection Agencies, Washington, D. C.	Protective physical security support, police and fire departments
10)	355th Army Aviation Company, Fort Eustis, Virginia	Provided helicopter and crew for equipment lift and rehearsals
11)	Rotary Wing Division, U.S. Army Davison Airfield, Virginia	Provided support of helicopter operations
12)	Various groups, Fort Belvoir, Virginia	Storage and motor pool facilities
13)	Department of the Interior, National Parks Office, Washington, D. C.	Provided permission and space for installation of rain gauge at Potomac Park

3. EQUIPMENT RELIABILITY CHARACTERISTICS

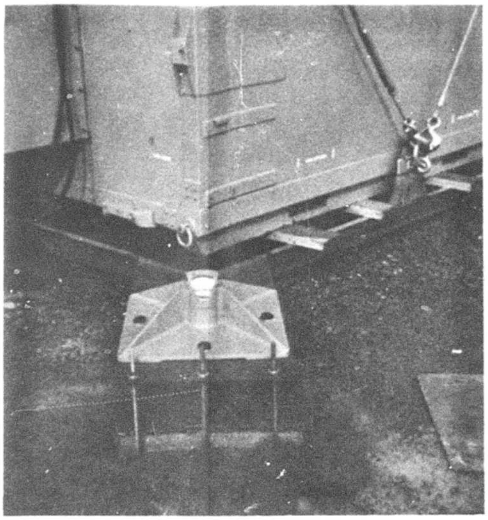
a. Log of Equipment Operating Times

The AN/GRC-173(XW-1) equipment at each station logged more than 3000 hours operating time in Washington, D. C., on Phase III up to February 15, 1974. Considering both radio sets, this is a combined total of more than 6000 hours operating time on Phase III, and is in addition to the time accumulated under Phase II. The combined Phase II plus Phase III running time up to February 15, 1974, varied between approximately 5200 hours and 7400 hours depending on the unit of equipment.

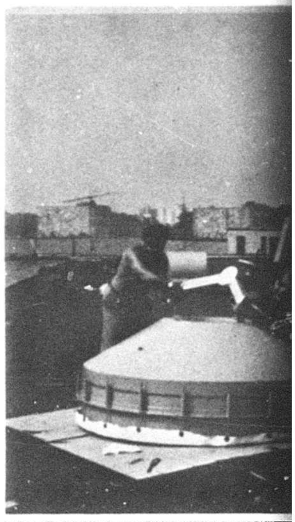
Table XX below lists the running hours accumulated by the equipment. Elapsed time meters on each unit facilitate the logging of this type of information. The variation of running time from unit to unit was a result of the use of cycle of the particular unit during design, development and test.



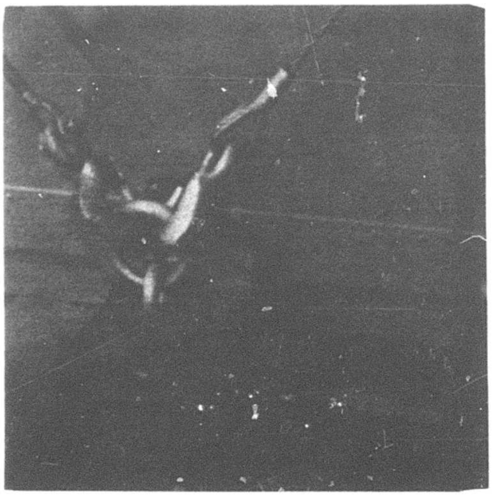
a. Shelter base frame weldment support. Feet of frame were bolted to reinforced concrete roof below gravel and tar level. Wooden boards were later added to provide additional lateral support.



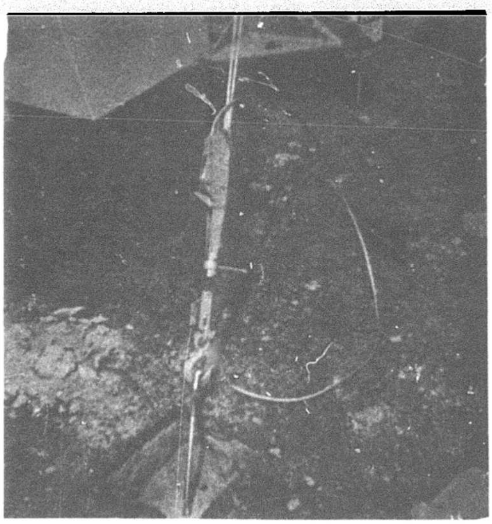
b. Antenna mast pedestal base bolted to sheet iron plate which is welded to channel iron framework. Front rod supports of plate were bolted to reinforced concrete roof.



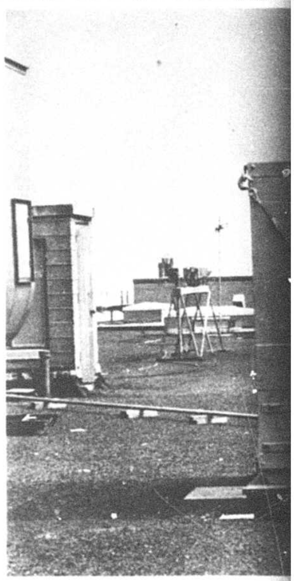
e. Attaching antenna mast to d
to erection. Packing crate c
face of dish from abrasion b



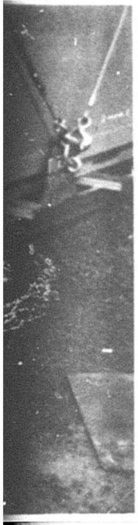
c. Detail of shelter tie-down to framework. The lift cables and ring as supplied with the shelter were connected to a plate welded to the framework. Other ends of cables are attached to lift rings on shelter corners.



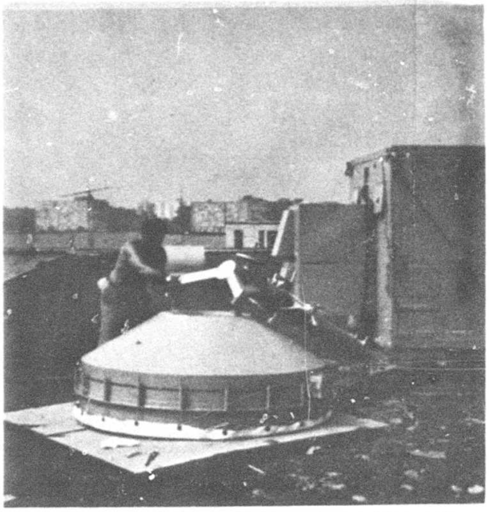
d. Detail of antenna tie-down cable device at point of attachment to roof. Pocket hole, about 12″ X 10″ X 6″ deep, was later filled with pitch.



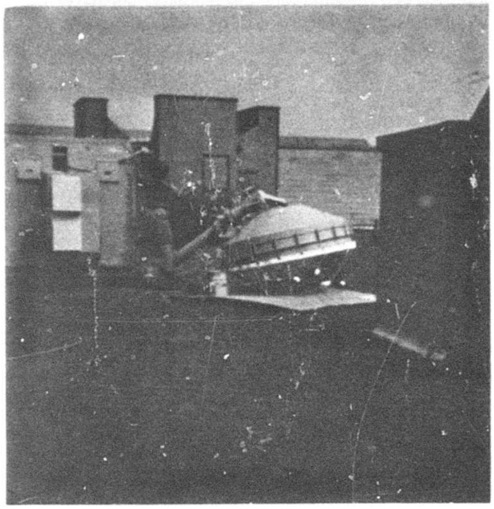
g. Completed installa
Power line conduit
added later.



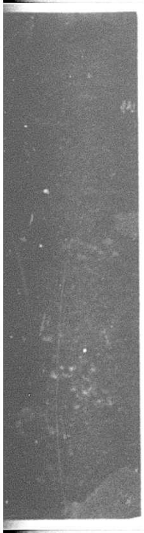
sheet iron
framework.
ed to

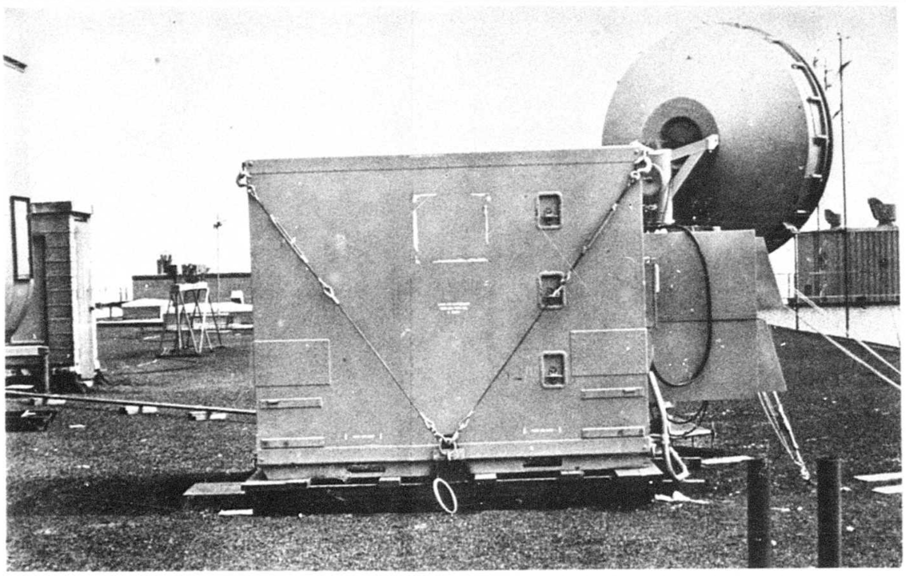


e. Attaching antenna mast to dish reflector prior to erection. Packing crate cover protected front face of dish from abrasion by the roof.



f. Raising antenna to erect position using ratchet device. Antenna was emplaced so as to have minimum possible length of feed run (waveguide) from shelter to dish.



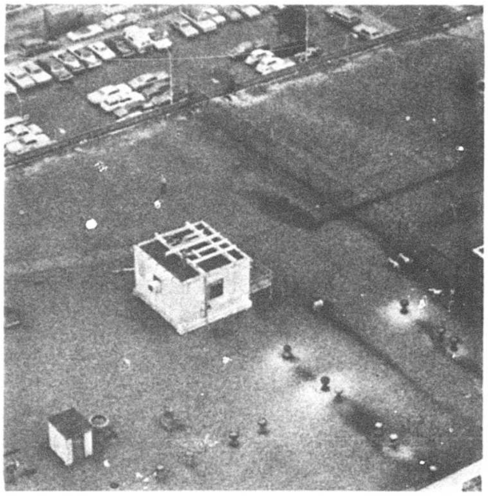


ce at point
bout 12" X
itch.

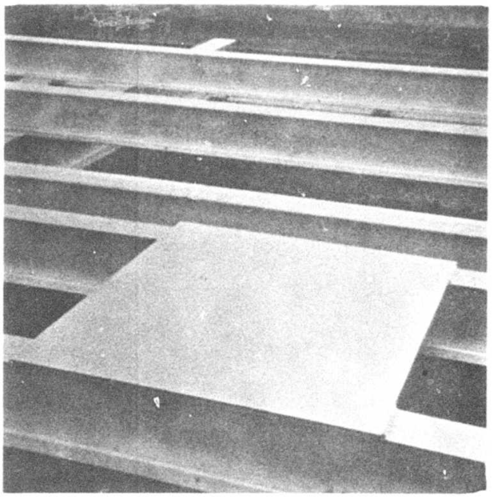
g. Completed installation. This photo was taken several weeks after the ones in previous sequence. Power line conduit running to shelter is seen at left. A wooden walkway to the shelter door was added later.

Figure 78. Details of Station Installation at Pentagon

2

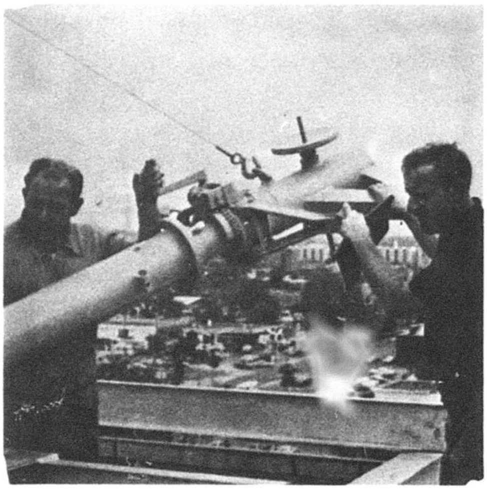


a. Aerial view of framework on second roof level before installation of shelter. Note main channel beam spans topped by secondary beams.

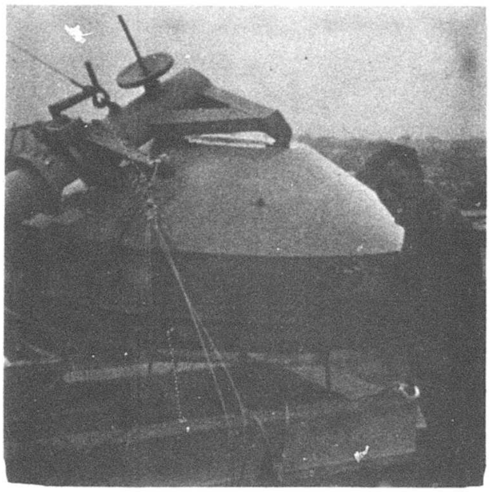


b. Close-up view of channel iron framework. Note plate to which antenna mast was subsequently attached.

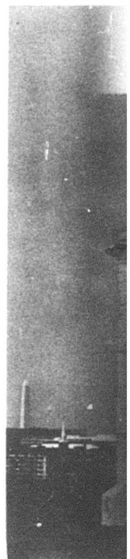
e. Detail of take-up ratche
assembly to erect positi



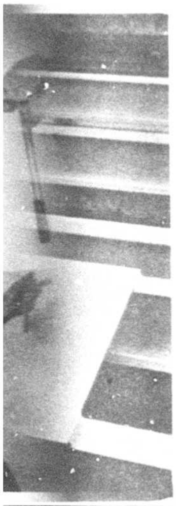
c. Estimating placement of antenna mast orientation relative to shelter before attachment to dish. Note wire holding mast attached to shelter.

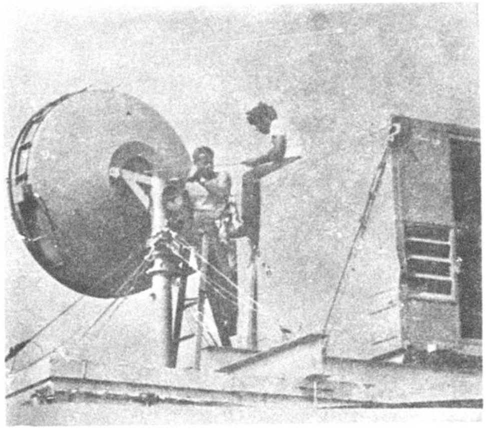


d. Antenna dish and mast during erection. Edge of building and structure helped support the assembly during this procedure.



g. Complete
ladder wa

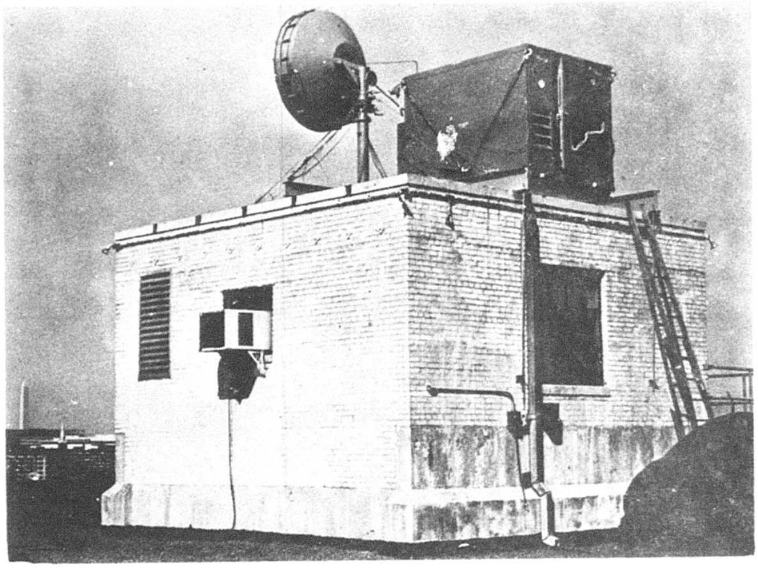




tchet
ositi work. Note plate
ently attached.

e. Detail of take-up ratchet used to hoist antenna assembly to erect position.

f. The waveguide run between antenna feed and shelter was fabricated and fitted after final positioning of antenna and shelter.



pletec ection. Edge of
r was port the assembly

g. Completed installation viewed from main roof level. Later a permanent ladder was added together with a safety railing near the door of the shelter.

Figure 79. Details of Station Installation at WNY

2

Table XX. Record of Equipment Operating Times

1) SHELTER GROUP MARKING #P10343-1 (WASHINGTON NAVY YARD STATION)

Rack	Unit	Accumulated Operating Time (Hours): Phase III in Washington, D. C. up to 2/15/74	Accumulated Operating Time (Hours): Project Total, Phase II plus Phase III to 2/15/74
Digital	High Speed Demux	3058	7437
Digital	High Speed Mux	3058	7436
Digital	Videophone Mux	3058	7433
Digital	Clock Unit	3057	7437
Digital	Power Supply	3058	7458
RF	Transmitter	3077	5213
RF	Receiver	3078	6355
RF	Power Supply	3077	6476

2) SHELTER GROUP MARKING #P10343-2 (PENTAGON STATION)

Rack	Unit	Accumulated Operating Time (Hours): Phase III in Washington, D. C. up to 2/15/74	Accumulated Operating Time (Hours): Project Total, Phase II plus Phase III to 2/15/74
Digital	High Speed Demux	3618	7356
Digital	High Speed Mux	3618	7356
Digital	Videophone Mux	3623	7361
Digital	Clock Unit	3623	7345
Digital	Power Supply	3618	7330
RF	Transmitter	3075	6220
RF	Receiver	3079	5470
RF	Power Supply	3080	5584

No formal reliability demonstration program was specified for this project, but a reliability data base has been developed from the system test experience. A mean time before failure (MTBF) of 3000 hours was established as a design objective for the radio set. As noted above, the equipment has operated in excess of this time. The two parameters, MTBF and elapsed running time, do not functionally equate. However, the total operating experience, including the minor nature and low frequency of the problems which were uncovered (see below) indicates that the equipment reliability achievement is good and production version will meet the desired MTBF objective. The results are considered to be better than typical for microwave radio relay systems and are partly attributed to a) the solid state configuration and b) the application of advanced digital and millimeter wave technology to the design. The high equipment reliability is in addition to the high demonstrated propagation reliability. (See Section IV.) A summary and discussion of the Phase III equipment reliability problems that did occur are given below.

b. Problem Areas

Problem areas uncovered during Phase III were corrected to restore the radio to full specification performance. In some cases, design modifications were made during Phase III or are suggested below. Eighteen problems were found and reported from August, 1973 to February, 1974. Analysis shows that more than half of these arose during the critical installation checkout and startup period, and were corrected prior to beginning any link test operations. About one-fourth of the problems were caused by operator errors. It was anticipated that there would be startup and operator problems since this was the first time the radios were being set up in the field. Four of the problems were caused by component malfunctions which occurred during the link tests, and in each of these instances considerable running time had elapsed before failure of the particular component. Each problem and corrective action is discussed below:

(1) Startup

Two problems were associated with the shelter equipment. At the Pentagon station a louvered cover of the air conditioner had to be straightened so that it would not interfere with rotation of the fan blade. This problem could be averted by exercising more care in handling the unit during packing. At the WNY station a cold solder joint was found in the ac power plug at the power interface panel and had to be resoldered.

There were some problems connected with the antenna system, including the shipping configuration. The vendor was notified and participated in on-site meetings to review the problems. The reflector crates were found to have water trapped in them after about a year's storage time since delivery on Phase II. The water entrapment and temperature cycling produced paint blistering on the antenna dish and discoloration of the Hypalon cover radome with time. At first these problems were thought to have electrical consequences, but they turned out to be only ones of appearance. They were corrected simply by washing the Hypalon with commercial cleaner and letting the dish dry out in the air. An approximate antenna pattern measurement was then run by project personnel at the test site. This showed that the antenna system appeared to have the proper pattern characteristics. While the resultant problem proved to have an effect only on appearance, an improved crating procedure is recommended for the future. In addition, the spare antenna crates should be drained and stored under protective cover.

During the Pentagon station installation, a take-up device on the antenna assembly guying snapped due to over-tightening with a wrench handle. It was replaced, and a fail-safe precaution was taken on all the guying at both stations by installing safety wires. In general, care should be taken so that tightening is done by hand until taut, and then performing routine checking. Retention of the safety guys is advisable. A possible change in material from aluminum to steel for the take-up device would also be advisable.

Loosening of the antenna mast assembly guy wires under excessive windloads at the WNY station also occurred several times. This station is relatively unsheltered from winds in comparison with the Pentagon site. The loosening could produce a drift of boresite with time. After it appeared that this could be a problem, project personnel generally did a visual check for this condition whenever they worked at the station. For unattended operation of a permanent installation, such as at WNY, consideration should be given to replacement of the present flexible wire rope guying with a modified design using solid members.

The final problem with the antenna system was disclosed when checking electrical and optical boresite. It is believed that the waveguide feed on the WNY antenna had migrated slowly during long term storage of the antenna. After erection to the horizontal position, the feed migrated slowly back to the correct position. The optical boresite telescope had to be shimmed at first to achieve correspondence. Although the condition corrected itself with time, some strengthening of the buttonhook feed support may be desirable in production versions.

A failure of the mixer crystal diodes at the Pentagon station was uncovered during initial checkout and is attributed to improper station startup procedure as explained below. Inspection of the failed unit under a microscope showed that the diode wafers were covered with rust and a residue, and the diodes were in open-circuit condition. It was found that this was caused by condensation from the air. The condensation was due to the lack of dry nitrogen gas supply for a one-week period from the time that the external shelter waveguide run was installed. During this period, the shelter also did not have electrical power available, hence the radio rack temperature could be quite cold at night and become a sink for the accumulated condensation. The mixer downconverter being the lowest (physical) point of waveguide in the radio rack then made it the terminus for the accumulated condensation. The diodes were replaced and the down-converter was disassembled and the hybrid transitions and diode mounts completely cleaned. This was a satisfactory repair and normally would call for a spares replacement. (Note: the engineering model down-converter assembly was available during the test period in lieu of a spare and was substituted until completion of repair to the failed unit.) In order to prevent the above conditions from recurring during subsequent installations, it is recommended that the dry nitrogen gas supply should be immediately connected upon completion of the waveguide connections. Also, a moisture trap could be incorporated in any long vertical waveguide run.

A pinhole leak in the Pentagon station's external shelter-to-antenna feed waveguide section was located in November, but was attributed to a problem which persisted since installation in September. This waveguide run was custom fitted and fabricated at the site. During troubleshooting for the leak, a waveguide window was installed at the pressurization section of the waveguide, which served to isolate the active radio components from the pressure line. High loss of dry nitrogen was still experienced. Finally, soapy water bubble tests on the external section served to locate a pinhole leak in the solder connection of the flange to waveguide. The pinhole leak was then sealed with epoxy.

Power supply malfunctioning was troublesome during the checkout period and was at least partly due to vibration encountered in shipment and installation. The difficulties were finally remedied by returning all the voltage regulator printed circuit cards to the vendor for improvement modification. The redesign, presently incorporated in the power supplies at both stations, consisted mainly of replacing a capacitor in the power supply alarm circuits and increasing the filtering of the alarm reference voltages.

(2) Operator-Induced Problems

Introduction of a new equipment into the field invariably seems to produce some problems associated with operator errors, and this one was no exception. In one instance, during September, 1973, a diode in the ADO at the Pentagon station was burned out by a power supply transient from the +85 V power supply caused by turning the radio off and on from the radio rack circuit breaker instead of the radio power supply switch. In another case, (during December, 1973) the mixer diode crystals in the Pentagon station down-converter were burned out by a transient put across them with a volt-ohmmeter probe. Similarly, a transistor was shorted in a circuit card of the clock unit during December by improper use of an oscilloscope probe. Misalignment of printed circuit board pins in their sockets were the cause of two separate problems during November in the bit stuffing unit and in the digital group power supply at the Pentagon station. These last two problems could have been prevented by double-checking for positive insertion and alignment of pins in their sockets, and the first three by observing proper operating and test equipment procedures. In all cases, corrective actions or repairs were made to retrun the equipment to specification performance.

(3) Component Malfunctions

As mentioned earlier, there were four problems in this category. Of these, one was in the digital group and the rest were in the radio group. For a short period around 11 November, 1973, intermittent alarms were observed on high speed channels 4 and 5 and were traced to poor solder joints on integrated circuit studs on the back of one of the high-speed demux cards. There was no apparent problem from this cause prior to that time, and it was corrected by resoldering.

On 27 January 1974, a mixer failure occurred in the Pentagon receiver, and the assembly was repaired (diode replacement) and replaced. The exact cause of this failure was not traced, although it is suspected that it might have been caused by a momentary outage of half of the prime power line feeding the shelter, which placed a transient on the supply line to the bias dropping resistor. The signal level recording at the Pentagon provided a clue as to the time of occurrence of this failure, and it was subsequently found that ac power line problems might have been experienced in the Pentagon building during that time. A recorder on the power line to the shelters would be desirable for the project, but was not provided, so that absolute certainty as to the cause of the failure was never established. In any case, the suspected surge condition does lead to the recommendation for an input power line filter at the shelter power panel and it also led to a straightforward modification of the mixer assemblies to prevent recurrence of a transient spike shorting out the diodes through the bias resistor. It is noted that this was the third and final of the mixer failures. They were all for different reasons, this one because of the line voltage condition. The others were caused by procedural problems. The mixer is not considered a special reliability problem, however, it is a relatively high-cost item, and care should be taken in handling and using it.

On 4 February 1974, the ADO at the WNY station was noted as having low power output and dc current drain and was replaced with another unit. The ADO malfunction produced insufficient drive to the modulator and a lowering of the system margin. The problem in the failed unit was subsequently traced not to the microwave circuit, but to a part in the current regulator in the ADO assembly. Again, this ADO problem is not of the same nature as the procedural problem with the Pentagon ADO experienced during system checkout, as mentioned earlier.

Problems with the modulation circuitry at the WNY station were observed near the end of the test program in February. This was manifested as a time variation of the modulation index of the transmitter causing the fade margin to vary. The modulator-driver printed circuit card and the power supply and input leads and connectors to this PC card were at first suspected, and systematically tested, but the malfunction was ultimately traced to the modulator itself. It was found that intermittent contact was being made to the pin in the Sharpless-type diode mount. The metal fingers on the mating block which make contact to this pin were cleaned and crimped, and the unit was restored to full performance. There was no problem with the semiconductor device itself.

(4) Problem Areas Summary

On Phase III, several failures were experienced during installation and checkout and others were attributed to operator errors. Some of these seem typical for a system being field-tested for the first time, and the experience thus obtained will prove of value in future applications. The main relevant failures were the component problems which occured when operating the link for communications tests. These occurred only after considerable running time in the affected units. They occurred after the approximate operating hours in the system during Phase II and Phase III as shown below:

- High Speed Demux Card: 4200 hours
- Avalance Diode Oscillator: 4800 hours
- Modulator: 4800 hours
- Mixer: 1200 hours

Note that in the case of the mixer, the time is that which was accumulated since field replacement after procedural problems, and if that were neglected, the elapsed time would be adjusted to 4700 hours.

c. Maintainability

Maintenance on Phase III was generally informal and was conducted as the need arose to replace replenishable items (such as the dry nitrogen gas supply or shelter light bulbs) or to effect corrective action on problem areas. Some general observations regarding the maintainability experience with the radio set are presented below:

- The alarms and monitors display unit proved adequate for localized operation and for the level of engineering/technician personnel used in the test operations. Consideration should be given to a remote display unit when the interface equipment is not co-located with the radio. This is particularly desirable since the radio set was shown to be capable of unattended operation. Also, marking of additional explanatory material on the display panel may be desirable if the skill or training level of maintenance/operator personnel is lower.

- The technical manual was suitable for use in installing, operating and maintaining the radio sets. Several minor revisions to the manual were suggested as a result of the test phase and will be included in the update of that data item.

- While the use of gaseous nitrogen to provide a dry environment in the waveguide componentry proved completely manageable for the test installations, it is possible that this requirement would produce logistic problems in more inaccessible locations. Although use of sealed microwave components would alleviate this potential problem, there would be a resultant increase in the equipment unit cost.

- The modular construction of the equipment in general proved to be correct for access for test and service.

- The built-in test equipment (BITE) and test point capabilities proved adequate for troubleshooting and maintaining the digital equipment. The BITE and test points were not quite as suitable for the rf equipment. It was recognized during the design and development phase that the minimum BITE for the rf equipment would be a subsequent inconvenience. Cost considerations precluded incorporation of several additional desirable microwave test features. It is suggested that this area be at least re-evaluated during any subsequent production phases.

d. Spares

Spares provisioning for the AN/GRC-173(XW-1) was generally planned at the level of digital printed circuit cards and radio equipment modules. Spares were procured during Phase III, but they were mostly unavailable during the reported test period due to the lead times associated with their procurement. This led to field repairs in some cases and/or substitution of engineering model equipment for the failed units while repairs were expedited either in the field or at the factory. Frequent demonstrations and test schedules required that the link be kept running almost continuously during Phase III, much as would be required of a fully operational communications system.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

Phase III completes the development and test of a millimeter wave radio providing the Government with the capability for digital transmission of wide-band signals. The AN/GRC-173(XW-1) suitably performed its design function of high capacity communications in a defense environment. This conclusion is drawn from the following accomplishments and demonstrations during Phase III.

a. Digital link communications was established with the radio sets in Washington, D. C. at the data rate of 235.9296 Mb/s in the 36 to 38.6 GHz millimeter frequency band.

b. A substantial portion of the 235.9296 Mb/s capacity was utilized for the transmission of wide-bandwidth signals in the form of digitized 80 Mb/s television. Only the unavailability of additional terminal equipment precluded full operational loading of other high speed channels with this type data.

c. The digital TV transmission facility was demonstrated as having utility for the instantaneous point-to-point communications of high resolution imagery type information. It was verified through laboratory control tests followed by link tests that the AN/GRC-173(XW-1) can serve as a non-interfering digital facility for the transmission of wideband signals.

d. The radio set was shown to have the capability for sending low speed signals (e.g., 50 Kb/s) over a 9.8 Mb/s channel at the same time as the 39 Mb/s high speed channels.

e. The possibility of rapid transport and deployment of the radio sets by means of helicopter lift was demonstrated.

f. Communications in an uncrowded part of the spectrum with an antenna of narrow main beamwidth (0.35 degree) and low sidelobe levels (>20 dB down) was tested to show that this is a means of reducing susceptibility from the electronic environment and interaction with it.

g. High propagation reliability of the system was demonstrated, greater than 99.99 percent propagation reliability over the 4.4 km path during a three-month period of propagation test measurements.

h. The high equipment reliability of the all solid state hardware was proved. The units of equipment in the radio sets operated between 5000 and 7000 hours, including both Phase II and Phase III operation through the period of this report.

i. It was shown that the link has a low probability of error, better than 10^{-6}.

j. It was demonstrated that 10 km transmission range can be accomplished when necessary.

k. It was shown that the radio set can be configured for relay operation when transmission around line of sight obstacles or ranges greater than 10 kilometers is required.

l. Unattended operation of the radio was demonstrated.

2. RECOMMENDATIONS

The AN/GRC-173(XW-1) is a quasi-militarized and, now, fully tested, wideband radio set which can be produced in quantity. The development and maturing of system requirements for high-speed digital transmission which match the capacity of this radio will obviously pace any widespread use of it.

As demonstrated in the Washington, D. C. tests, high resolution TV and imagery are certainly suitable requirements, as are combinations of these with traffic such as computer data, pictorials, high speed data, and multiple voice, facsimile and teletype channels. The factor of instantaneous communications (i. e., no time delay for compression or other processing) provided by the wideband AN/GRC-173(XW-1) can be operationally significant and cost effective. The digital design of the radio set is also suitable for employment where cryptographic security is a requirement.

Continued use of the link now installed in Washington, D. C. is suggested as a means of furthering the demonstration of the features and advantages of the equipment. The link has flexibility for serving as both 1) an operational system and 2) a test bed. The future use of the present link could include integration with additional source instruments and terminal equipments as they become available for various applications.

Few design modifications are suggested for consideration for any future production versions. The main ones are: a) a parallel/remoted display panel, b) externalization of the clock lines at 39 Mb/s and lower speeds for accessibility by terminal equipment, c) a possible reconfiguration to include the clock unit as part of the radio group, instead of the digital group, or both, d) additional test points for RF modules of the equipment, e) modifications to reduce the loss attributed to the antenna radome, and f) continued incorporation of field modifications such as relocation of the mixer bias dropping resistor and the power supply circuit changes.

Millimeter wave and high-speed digital technology development should also be continued, particularly with the intent of further reducing system costs through a) design improvements and exploitation of semiconductor device and logic circuit developments, b) the use of new modulation and transmission system techniques, and c) further knowledge of propagation effects. The objectives could include a functionally and parametrically simpler millimeter radio to serve as a low-to-medium data rate feeder to a high speed trunk facility comprised of AN/GRC-173(XW-1) high capacity radios. This network of medium/wide bandwidth digital radios at millimeter wave frequencies would be a practical utilization of this frequency band for the alleviation of spectrum crowding. Extension of the AN/GRC-173(XW-1)'s 236 Mb/s capacity to even higher data rates can be accomplished as the need arises.

SECTION VII

REFERENCES

1. Siegel, H.N. and Waszkiewicz, L.R., "High Speed Digital Communications at Millimeter Wavelengths," Proceedings of the IEEE Fall Electronics Conference, Chicago, Illinois (October 1971), pp. 207-210.

2. Worthington, D.T., "Millimetric Wave Communications for the DCS," 1970 IEEE International Conference on Communications, San Francisco, June 1970, p. 6-1.

3. Contract F30602-70-C-0063, Final Technical Report on Phase I, "Millimeter Wave Communications Program: High Speed Digital Transmission Design Study Radio Set, AN/GRC-173(XW-1)," Raytheon Company (RADC-TR-71-153) (July 1971).

4. Contract F30602-70-C-0063, Final Technical Report on Phase II, "EHF Digital Radio Set AN/GRC-173(XW-1)," Raytheon Company (RADC-TR-74-10) (February 1974).

5. "Preliminary Planning Report for Phase III Testing of Radio Set AN/GRC-173(XW-1)," Raytheon Company (January 1973 and addendum February 1973).

6. Hogg, D.C., "Millimeter Wave Communications Through the Atmosphere," Science, pp. 39-46, Vol. 159, Number 3810 (January 5, 1968).

7. Kerr, D.E., Propagation of Short Radio Waves, Volume 13, MIT Radiation Laboratory Series; New York, McGraw-Hill, 1951.

8. Medhurst, R.G., "Rainfall Attenuation of Centimeter Waves: Comparison of Theory and Measurement," IEEE Trans. on Antennas and Propagation, AP-13, No. 4.

9. Roche, J.F., Lake, H., Worthington, D.T., Tsao, C.K.H. and de Bettencourt, J.T., "Radio Propagation at 27-40 GHz," IEEE Trans. AP-18, No. 4 (1970).

10. Hogg, D.C., "Statistics on Attenuation of Microwaves by Intense Rain," Bell System Technical Journal (November 1969).

11. Cohen, A. and Smolski, A., "The Effect of Rain on Satellite Communications Earth Terminal Rigid Radomes," Microwave Journal (September 1966).

12. Clifford, S.F. and Strohbehn, J.W., "The Theory of Microwave Line of Sight Propagation Through a Turbulent Atmosphere," IEEE Trans. on Antennas and Propagation, AP-18, 264 (1970).

13. Bussey, H.E., "Microwave Attenuation Estimated from Rainfall and Water Vapor Statistics," Proc. IRE, Vol. 38, pp. 781-785 (1950).

APPENDIX A

ADDITIONAL ERROR RATE TESTS

Section IV presented the results of bit error rate testing for the normal baseline operating conditions of the link. This appendix presents data which was obtained when the test conditions were varied. These results were recorded to obtain on-site developmental data in consideration of the opportunity which presented itself to do so. It should be emphasized that the data in this appendix should be considered in this context. The Radio Set achieves excellent error performance when operated under the required conditions, and it deviates from this performance when it is not, as expected.

The baseline link and equipment conditions were summarized as:

a) Clear medium, including clear weather and no construction conditions in the path.

b) The data traffic was asynchronous to the radio set per design specification.

c) Equipment components aligned and parameters per link budget.

For various practical reasons, it was not possible to conduct an extensive and rigorous series of experiments under varying conditions, so the investigation was limited in scope. Among other considerations, the quantity of auxiliary test equipment was restricted and system message demonstrations established the priority requirement for link usage. The testing conditions were sometimes at the control of the project, and sometimes not. However, the limited observations which could be made demonstrated the trends in how the error performance could be affected by changes in the conditions.

Several extraneous mechanisms could increase the errors in the link when it departed from baseline operation. The ones believed to be most dominant during the test period are summarized as follows:

a) Path Effects: Construction cranes and other man-induced conditions in the path produced blockage fading or multi-path fading.

b) Equipment Effects: Synchronous loading of additional channels, produced interchannel intersymbol interference (ISI) and symbol distortion in the asynchronously loaded BER test channel. Likewise, non-optimum drive conditions in the components of the transmitter chain or non-optimum alignment in the receiver, produced ISI and symbol distortion.

The first effect was entirely beyond the control of the project and is a matter which will be negated with time when the construction is finished. The second was aggravated by the aforementioned lack of test equipment or spares and, also, the necessity to run synchronous pseudo-random-sequence (PRS) generator signal traffic in the loop-around configuration.

Figure 80 illustrates the probability of error in the presence of the above-mentioned extraneous error conditions. This shows the results of error-rate measurements at various times when one or more of the effects was being produced. A curve obtained during normal operating conditions is also shown for comparison.

The baseline curve is plotted against S/N as well as the attenuator setting at the WNY station transmitter. The comparison of the baseline curve with the other curves should only be made on the basis of relative attenuator setting, as the signal level could actually vary from its normal value during the test runs for which the data was obtained. The test conditions precluded the possibility of isolating the aberrant effects and apportioning their values accordingly. The following paragraphs, however, will describe how they arise and how they theoretically could contribute to a higher error rate than normal.

1. EQUIPMENT EFFECTS

One class of equipment effects were those caused by non-optimum component alignment in either the receiver or transmitter as a consequence of temporary malfunctions. In the case of the receiver, it was sometimes necessary to adjust the slicer threshold level or set the local oscillator frequency to the correct value. When these steps were taken, this unit operated satisfactorily. In the transmitter, there was a period of time when the avalanche diode oscillator at the remote station (WNY) was not delivering rated power due to a faulty inductor in its voltage regulator circuit. This affected operation of the rest of the transmitter chain (X4 multiplier, modulator and final avalanche diode amplifier), but when the problem was traced and the unit repaired, performance was returned to normal. There was also a period of time when extraneous errors were traced to intermittent malfunctioning of the phase modulator or modulator-driver circuit at the WNY remote station. This produced intermittent variations in the error count produced at the Pentagon master station (Note: the nomenclature master and remote is that of the loop-around configuration as discussed in Section IV). This intermittent condition produced variations in the modulation conditions, changing the spectrum of the modulated carrier and the sidebands. At times the modulated carrier-to-sideband power ratio as observed by a spectrum analyzer jumped abruptly from the design value of 4 to 6 dB to a new value of 17 to 25 dB. It had been shown previously in design tests that the adjustment of the modulator circuits was critical. When not adjusted as required, the amount of power in the modulated symbol is reduced, the shape is changed and the consequence is an increase in the intersymbol interference and symbol distortion. Again, when it was possible to trace and correct this problem, the performance of the link returned to baseline.

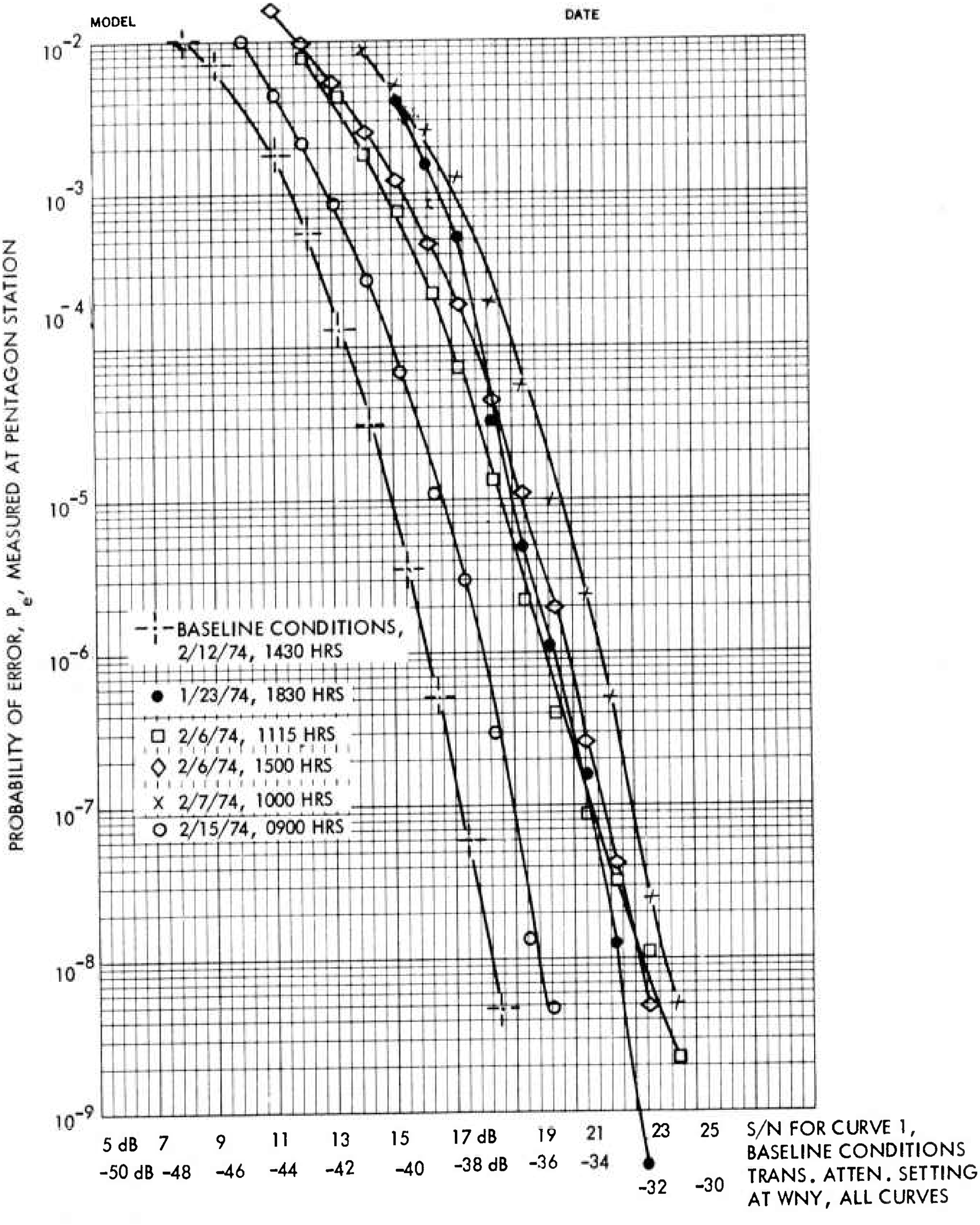


Figure 80. Error Probability Curves For Various Testing Conditions

The other variable related to the equipment usage was the method of loading of data into the TDM. This will require elaboration because of complexity. One high speed channel was used for the pseudo-random sequence (PRS) signal of the BER test set, and it was used asynchronously. The BER test set was driven by a separate 39.29-MHz square wave voltage controlled crystal oscillator, which was an item of test equipment. The input to the high speed multiplexer bit stuff unit (BSU) from the BER test set at the master station included the PRS data as well as the separate clock signal. At the remote station, the detected and recovered BER test set PRS symbols (still asynchronous), and the recovered clock signals were looped by cable into the BSU and high speed mux there, and subsequently relayed back to the master station. After detection and recovery, the returned PRS was compared with the local PRS of the master station, and the errors were counted. There was flexibility concerning which one of the five high speed channels was used for the BER test set data, and there was likewise some flexibility in how the other remaining channels were loaded during a run. It was found that misleading results could be produced under some channel loading conditions, as explained below.

The potential remaining high speed data sources available to the project were four pseudo-random sequence generator circuit boards and the high resolution TV terminal equipment. The usage of these data sources simultaneously with usage of the BER test set was complicated by a practical problem, namely the lack of requisite stable test generators in the field to drive each of them asynchronously. It was also not possible to build a distribution network to use the available test equipment clock for multiple purposes. Thus it was found necessary to connect any additional data sources synchronously. To do this, the AN/GRC-173(XW-1) clock at 39.3216 MHz (235.9296 MHz ÷ 6) clocked the signal out of the additional data sources. When the additional PRS test boards were used in the system, they replaced the bit stuff unit (BSU) cards in the high speed multiplexer in order to connect them (the PRS boards) to the 39.3216 MHz clock. Note: clocking for the TV coding/decoding equipment was also derived from the AN/GRC-173(XW-1) in a similar manner.

The synchronous operation of some channels was found inherently unsuitable during a BER test run in the loop-around configuration, even though the BER test channel was itself in asynchronous operation. This was due to improper use of the overhead and clock recovery circuits, which were designed for bit-stuffing operation with inputs of lower rate. The recovered data symbols in the demux at the remote terminal could have a high error probability in synchronous operation and, depending on exact circumstances, might be as high as 50 percent. The consequence of this is that when the recovered data was looped back from the demux into the mux at the remote terminal, the intersymbol interference and symbol distortion would avalanche in the return (remote-to-master) direction. Because of the nature of the framing process, which time-multiplexes channel signals, this in turn would create interchannel ISI and symbol distortion which spilled over into the BER test channel and produced additional errors. This would increase the error count in the BER test channel over what should be expected if all of the channels were run asynchronously, as they were designed to do.

The effect of the loop-around configuration with synchronous channels (and, in fact for the earlier-mentioned equipment alignment problems at the remote station) can also be explained by referring to the expression for S/N ratio (see Section IV, 4. c), for tandem links 1 and 2:

$$(S/N)_{TOTAL} = \frac{1}{\frac{1}{(S/N)_1} + \frac{1}{(S/N)_2}}$$

In general, the probability of error (P_e) is inversely proportional to the S/N ratio. If the errors in the two links are uncorrelated, the S/N value for the remote to master link of lower power (note that all of the intentional transmitter attenuation was at the remote station), would dominate in determining $(P_e)_{TOTAL}$ and, the error probability in the master to remote direction could be neglected. However, because of the loop-around configuration, the errors were related during periods such as those described above. Therefore, under these conditions of correlated errors $(P_e)_{TOTAL}$ is not representative of the actual system capability.

2. MEDIUM EFFECTS

Here will be discussed the departure from baseline error performance attributed to the propagation channel. The main incidence of medium effects was created by the construction operations which took place in the path. These at times placed objects (cranes) directly in the optical line of sight. At other times, the construction machinery was off the optical line of sight, but still near to the main beam of the antenna. Photographs illustrating the nature of the construction operations are shown earlier in this report.

The result of the above could be either blockage, which would remove a portion of the beam energy, or differences in the time of arrival of direct and reflected signals (multi-path), or both. Simple blockage of the beam would directly reduce the received signal level. Note that this would not necessarily increase P_e for a given S/N. However, assuming that a given baseline S/N is prevalent over the link, then the occurrence of a momentary blockage would increase the error rate at that particular time. An increase of signal strength would be sufficient to combat this effect, and would return the system to the previous P_e vs. S/N condition. This also happens when the blockage leaves the path.

The multi-path condition, on the other hand, cannot be combatted alone by increasing the signal strength. It is caused by differences in times of arrival among multiple signal propagation paths. It produces intersymbol interference due to overlapping symbols caused by the relative time delays. The ISI will be responsible for additional errors, and again it can create interchannel effects discussed earlier. This problem can be viewed as being due to additional system noise.

Figure 81 illustrates the type of effects observed on the test link with crane activity. It is a portion of the received signal level recording made at the WNY station on 14 February 1974. The normal received level is the straight line, while the dips in recorded level were caused by the crane conditions as sketched on the chart record. Figure 82 shows another chart record in which the signal level changes are caused by crane activity.

The effect is obviously transitory and unpredictable, but as mentioned earlier, it will be removed from consideration in the future when the construction is finished. As with the error performance variations produced by improper operation of the equipment, the system consequence in this case is also to reduce the margin of tolerance which would otherwise be available to offset signal losses due to very heavy rainfall. To explain the system consequences further, the clear weather effect on signals such as TV would be almost unnoticeable, and similarly light and medium rainfall would not affect the operation. However, the fade margin for heavy rainfall would decrease.

Concerning the isolated effect of rainfall it is mentioned here for completeness that there arose only a few specific opportunities to attempt BER test runs during rainfall. It was found at those times that the link behaved as theoretically predicted. A general shifting of the overall P_e vs. S/N curve was produced consequent to the lower received signal power, but otherwise there was no apparent aberrant behavior of the link.

3. CONCLUSIONS

Some developmental type data has been presented which illustrates the extraneous errors that a wideband microwave link can encounter when the equipment or line of sight conditions are varied. Alleviation of the error mechanisms is made by operating the system as prescribed (all components in alignment, data inputs asynchronous and line of sight conditions returned to clear). Then, the margin for additional fades is fully restored.

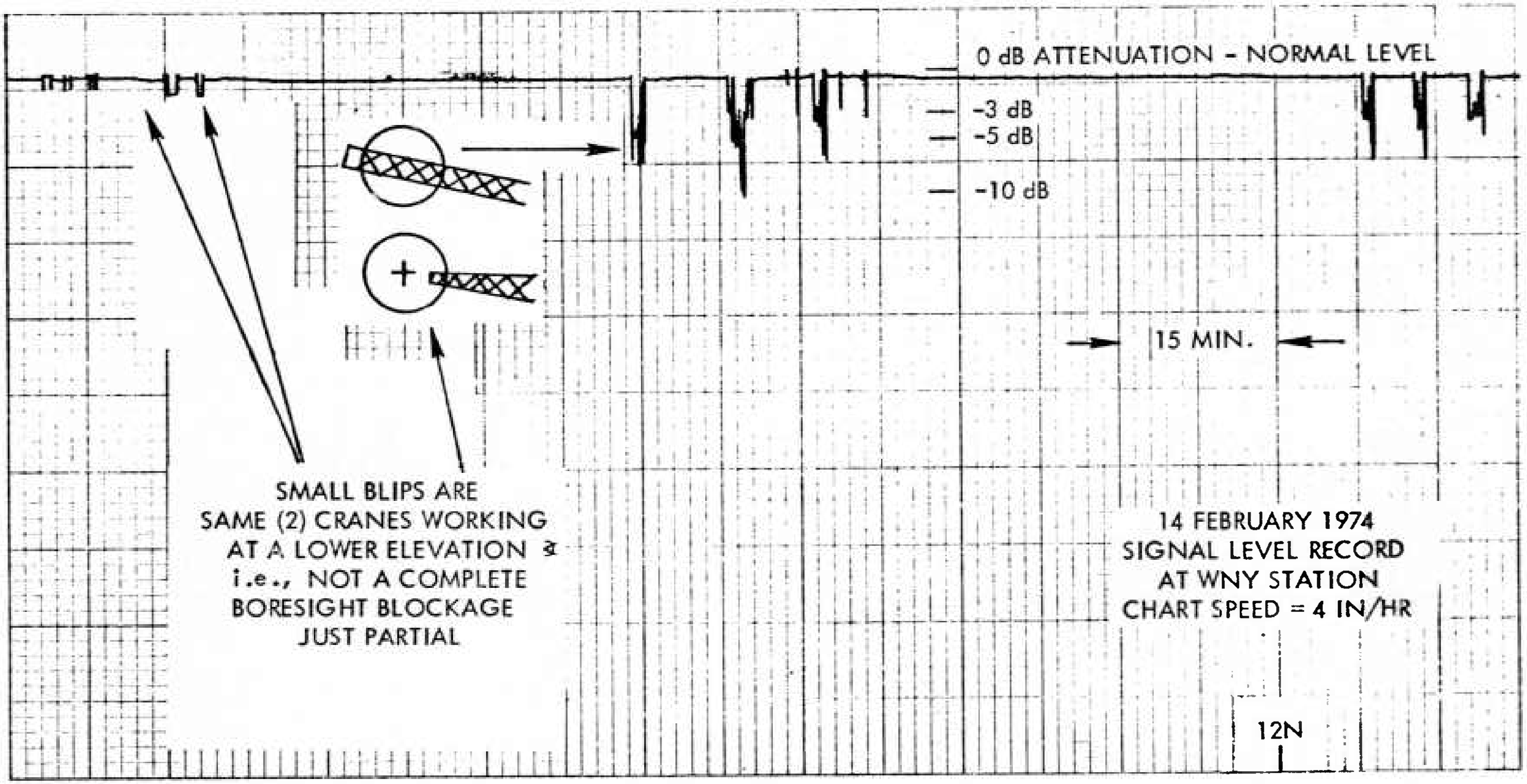


Figure 81. Received Signal Level Recordings With Cranes In And Near Line-of-Sight

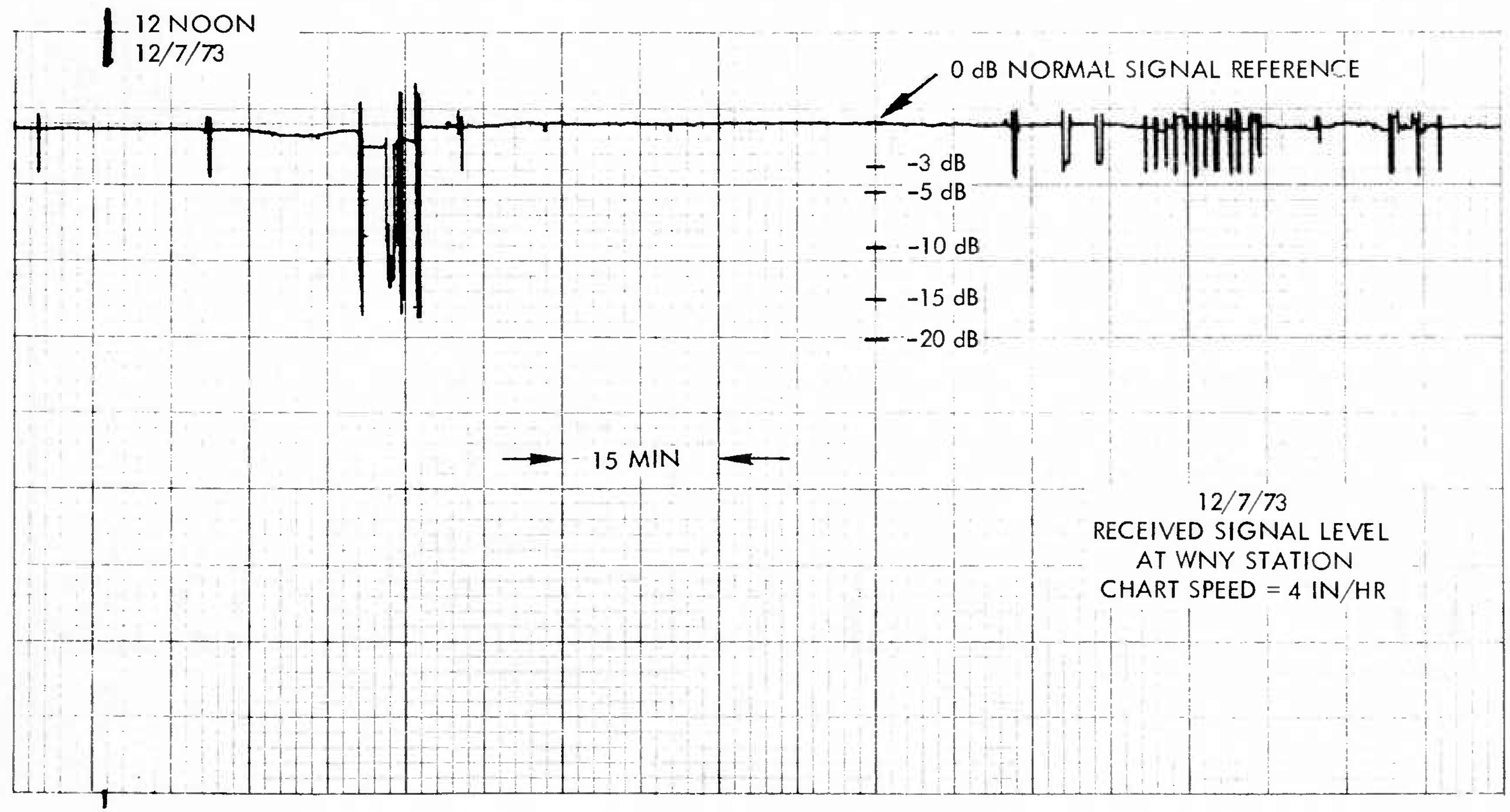


Figure 82. Effect of Crane Activity on Signal Level Record

APPENDIX B

CHRONOLOGY OF PROJECT EVENTS ON PHASE III

Listed below are activities, milestones and occurrences of Phase III.

Date	Description
Spring 1973	Surveyed sites. Pentagon and Washington Navy Yard (WNY) sites selected. General planning for test program begun.
June 1973	Shipment of AN/GRC-173(XW-1) equipment inspected at Fort Belvoir, Virginia. Equipment placed in temporary storage until needed.
July 1973	Final planning initiated for installation of stations at Pentagon and WNY.
6 August 1973	Performed helicopter lift of equipment to Pentagon station.
7 August 1973	Began unpacking Pentagon station equipment. Re-aligned orientation of shelter on framework. Strapped down shelter to framework.
8 August 1973	Completed unpacking. Started and completed antenna system erection. Noted paint blisters on dish and poor appearance of Hypalon cover after one year's storage. (These problem areas were later corrected by air-drying the reflector and washing the Hypalon.)
15 August 1973	Fitted, fabricated and installed external waveguide run (approximately 6 feet) between shelter and antenna at Pentagon. Mast take-up device snapped due to excessive tightening. (Used gin pole as temporary strain relief, then later replaced take-up device and installed extra safety cable.)
-- August 1973	Meetings held regarding forthcoming installation at WNY. Final design of framework for shelter and antenna at that site. Decision made to use spanning-type framework to have wall members bear the load instead of roof.
24 August 1973	General Services Administration completed installation of primary ac power conduit line between Pentagon fifth floor and radio set station.

Date	Description
29 August 1973	Primary power connection made between shelter and building power. Air conditioner problem was discovered and corrected. Began radio set checkout at unit/drawer level. Elapsed time meters at Pentagon station read 3057 hours for digital equipment and 3077 hours for rf equipment. These totals had previously been accumulated under Phase II.
30 August 1973	Local procurement of dry nitrogen gas. Connected gas to Pentagon waveguide system. Noted problem with ADO and returned it to factory. Failure was caused by turning radio rack on and off from rack circuit breaker instead of radio power supply switch, causing transient on +85 V power supply line. (Approximately 3090 hours on transmitter at that time.) Submitted final Program Plan to RADC.
-- August 1973	Initial shipments of Raytheon commercial test equipment to support tests were made and received. Project office established in Raytheon facility at Arlington, Virginia, to serve as local base of operations in Washington area.
5 September 1973	Continued unit level checkout at Pentagon. Began noting high leak rate from waveguide dry nitrogen gas supply. Turned gas off at intervals to conserve supply.
11 September 1973	Located and corrected first of two pinhole leaks in the flange-to-waveguide solder connection of external waveguide line at Pentagon station.
12 September 1973	Received additional test equipment to proceed with digital rack checkout. Found mixer assembly to have open diodes due to water condensation (previously caused by conditioned air temperature cycling and the leaking of dry nitrogen gas). Mixer assembly returned to factory for repair. Arrangements made to get engineering model to Pentagon for interim use.
-- September 1973	Coordination of preparations for WNY installation.
19 September 1973	Washed and re-installed Hypalon cover at Pentagon.
24 September 1973	Final fabrication of steel framework for shelter and antenna base was started at WNY site.

Date	Description
27 September 1973	Installed new nitrogen gas supply at Pentagon. Began moving installation tools (crowbars, drills, etc.) from Pentagon to WNY facility.
28 September 1973	Installed the repaired mixer at the Pentagon station.
29 September 1973	Made helicopter lift of equipment to WNY rooftop station.
1 October 1973	Unpacked and uncrated equipment at WNY site. Strap-down of shelter to framework was completed.
2 October 1973	Started antenna system erection at WNY site. It was more complex than at Pentagon since framework is elevated off roof level and there was less freedom of placement.
3 October 1973	Antenna erection at WNY station completed.
4 October 1973	Discovered and corrected defective ac power cord.
5 October 1973	Installed safety tie-downs for antenna systems at both stations. Installed nitrogen gas supply for waveguide at WNY station. Noted Pentagon nitrogen gas supply had ran out again. High leak rate still experienced there.
8 October 1973	Fitted and installed waveguide run at WNY station. Started turn-on of units at WNY station. Readings of time meters at WNY station were 3620 hours for digital units and 3080 hours for rf units, including Phase II.
9 October 1973	Aligned optical with electrical boresites. Washed and re-installed Hypalon cover at WNY station.
10 October 1973	Established first communications over link.
11 October 1973	Made approximate check of antenna pattern using an auxiliary receiver.
-- October 1973	Received additional test equipment to run checkout and tests. Experienced several power supply alarm failures. Calibrated rain gauges. Installed same at Pentagon and WNY stations. Held meetings regarding possible future remote cable routing.
17, 18 October 1973	Project meeting held at Wayland, Mass., including RADC, DCA and Raytheon representatives.
22 October 1973	Installed equipment for BER testing.

Date	Description
26 October 1973	Completed connections for loop-around configuration.
31 October 1973	Coordinated with vendor on modifications to power supply alarm printed circuit cards and regulators.
1 November 1973	Problems experienced and corrected for high-speed demux cards and a transistor in the clock unit. Approximate hours in field to this time on affected units were 1000 hours for Pentagon equipment and 500 hours for WNY equipment.
6 November 1974	Installed modified power supply alarm printed circuit cards and voltage regulator circuitry.
12 November 1973	Second of two pinhole leaks located and repaired in Pentagon waveguide run. This corrected the situation of excessive nitrogen gas leak rate.
13 November 1973	Meeting held with Department of Interior and General Services Administration regarding installing rain gauge at Potomac River Park.
-- November 1973	Prepared A/D and D/A converter breadboards for use in TV demonstrations. Performed study and investigation of other terminal equipment availability for system message demonstrations. Experienced numerous difficulties with test equipment including chart recorders for propagation tests.
14 November 1973	Experienced difficulty with Pentagon station demux unit bit stuff card on channel No. 3 while testing pseudo-random generator inputs. Corrected same by correcting pin alignment in socket.
15 November 1973	Meeting held at NADC, Warminster, Pennsylvania regarding laser recorder as possible terminal equipment. Unable to use on Phase III due to refurbishment requirements.
20 November 1973	Obtained rental TV equipment (525 line) and checked it out for possible use in system message tests. The model obtained was unsuitable due to light sensitivity and circuit problems. Started study of Government furnished Conrac CKDG model monitor, which subsequently proved unsuitable because of its frame rate.

Date	Description
26, 27 November 1973	Field personnel returned from holiday. Equipment running satisfactorily. Installed rain gauge and its recorder at Potomac Park.
28 November 1973	Assembled and installed variable waveguide attenuator section. Very intense storm caused only instance of link outage due to rain, lasting for approximately five minutes.
29 November 1973	Erratic +5 V regulator in power supply of digital group tracked down to misalignment in socket. Corrected by resetting in socket. Approximate Phase III hours to date: 1800 hours for Pentagon station digital equipment and 1200 to 1300 hours for remainder of equipment at both stations. Completed Wayland lab preparation for high-resolution TV tests.
3 December 1973	Failure of Pentagon station mixer by misuse of test equipment probe; replaced same with engineering model.
4, 5 December 1973	Feasibility testing in laboratory in Washington regarding integration of coding equipment with Government-supplied high-resolution TV terminal equipment.
6, 7 December 1973	Conducted low-speed data transmission tests. Started to run bit error rate tests using pseudo-random generators in 40 Mb/s channels and loop-around configuration.
10-13 December 1973	Conducted control tests of high-resolution TV performance in Washington laboratory. Replaced mixer at Pentagon station after factory repair (see 3 December).
16, 17 December 1973	Propagation in heavy snow. No significant effect on signal strength.
-- December 1973	Held several meetings on terminal equipment investigation. Received feedback on suitability of acceptance test procedures. Obtained extra test equipment chart recorders for standby, since other units were experiencing difficulties with pen and recording mechanisms. Began quick-look field reduction of propagation data. Performed a preliminary test on radome losses when wet.
20 December 1973	Performed high-resolution digital TV communication over link for first time prior to personnel leaving equipment running unattended over holiday period. Approximate Phase III hours as of this date: 2300 hours for Pentagon station digital equipment and 1700 to 1800 hours for remainder of units at both sites.

Date	Description
27, 28 December 1973	Modifications were being made at Wayland, Mass. on interface between A/D and D/A cards and high-resolution TV terminal equipment. This was mostly to optimize drive levels.
2-4 January 1974	Sent digital high-resolution TV over link and performed tests for comparison with results of previous laboratory control tests. Link is shown to be a non-interfering channel for transmission of TV. Conducted demonstration test.
8 January 1974	Demonstration test. This included TV test, attenuator run to simulate longer range or fade, order wire demonstration and general briefing on station operations.
9 January 1974	Conducted tests in snow conditions.
-- January 1974	Continued collection of propagation data. Conducted BER tests and system message tests.
15 January 1974	Conducted demonstration test. Met with DCA project personnel of AN/GSC-24 project to review interface.
18 January 1974	Conducted demonstration tests.
24, 25 January 1974	Conducted demonstration tests.
27 January 1974	AGC recorder indicated Pentagon mixer failure (believed due to momentary outage of power to shelter which caused transient surge). Subsequently made modification to mixer bias line to prevent recurrence in future.
28 January 1974	Held meeting with RADC personnel on potential AN/GSC-24 interface. Final determination that this equipment will be unavailable on Phase III. Simulation of the interface had been conducted previously.
30 January 1974	Replaced engineering model mixer with repaired unit which failed 27 January.
1 February 1974	Conducted demonstration test.
4 February 1974	Transmitter power output down at WNY station. Traced to problem with ADO, viz., malfunctioning regulator circuit. First spare was available, an ADO, which was used to replace defective one until repaired.

Date	Description
5 February 1974	Conducted demonstration test.
6 February 1974	Conducted demonstration test.
-- February 1974	General link operations included completion of BER tests and collecting of additional propagation data. Effects of construction machinery cranes became more frequent as they had increased their activity in test area. WNY station transmitter intermittent observed. Troubleshooting ultimately isolated problem to failure in modulator diode.
13 February 1974	Held project review meeting at Raytheon with DCA, RADC and Raytheon representatives. Agreement reached on extension of work primarily to cover remote hookup of TV terminal equipment with AN/GRC-173(XW-1) radio equipment.
15 February 1974	Conducted demonstration test. Completed Phase III test requirements per basic contract. Started preparation for extension phase by installing some of WNY TV terminal equipment in designated remote area in Pentagon. Approximate accumulated operating times as of this date in Phase III links: 3600 hours for Pentagon digital equipment and 3000 to 3100 hours for remainder of equipment at both stations. Approximate hours considering both Phase II and Phase III are 7300 to 7400 hours for all digital units, and 5200 to 6500 hours for rf units, up to this date.

ADDENDUM

ADDITIONAL TV COMMUNICATIONS TESTS DURING THE EXTENSION PERIOD TO THE AN/GRC-173 (XW-1) PROJECT

1. INTRODUCTION AND PURPOSE

This is an addendum to the Phase III Final Report on the AN/GRC-173 (XW-1) project. It is prepared for the purpose of documenting the work done during the extension period from February 15, 1974 to May 31, 1974, under an engineering change to the basic contract.

The main purpose of the investigation under this change was (a) to continue operating the AN/GRC-173 (XW-1) millimeter wave high capacity digital radio link between the Pentagon and the Washington Navy Yard (WNY) for demonstration of television imagery transmission, and (b) to investigate connecting of the AN/GRC-173 (XW-1) and Raytheon-supplied breadboard analog-to-digital (A/D) and digital-to-analog (D/A) coding equipment to Government-supplied TV and auxiliary terminal equipment. The main difference between this and earlier Phase III efforts on TV transmission was in the remoted location of the TV terminal equipment at some distance from the radio set. The investigation of this additional capability is described in the following paragraphs.

2. DATA AND RESULTS

a. System Configuration and Use

During the latter part of February 1974, the Government-furnished high resolution TV terminal equipment was re-distributed between the Pentagon and WNY facilities, and other items were added in order to establish a remoted demonstration area. Previously, all TV terminal equipment has been co-located with the radio set in the two shelters. One remote area was established in the Pentagon.

The sending end at the WNY site remained essentially the same although there were some hardware additions. The arrangement there included a 1025-line high resolution TV camera which could be pointed at a photographic image transparency mounted on a light table. The light table was an improved version over that previously used. Different TV lenses could also be interchanged. To this setup was then added a "TV cursor control unit" connected to the camera; the control unit will be subsequently described. The TV camera output (or, by reconnection, the composite video of the camera and cursor control unit) was the input to the same breadboard analog-to-digital (A/D) encoder as had been used previously. The A/D encoder, in turn, interfaced with two high speed channels (39.29 Mb/s each) of the radio set for a total transmitted bandwidth as before of 80 Mb/s nominal. All TV terminal equipment at the WNY site remained co-located in the shelter with the radio equipment. Some study was made of remoting equipment at the WNY end, although it was not implemented for various reasons.

The remote demonstration area was established at the Pentagon in a cleared stairwell between the fourth and fifth floors. Coaxial cable (Belden Corp. No. 8281) was run between the shelter and the demonstration area to connect the two Pentagon facilities. The distance was approximately 150 feet. At the shelter, the coaxial cable was connected to the exterior connector bulkhead. The interface to the radio set was accomplished internally to the shelter using the same breadboard digital-to-analog (D/A) decoders as had been used before. A Conrac RQA-17 monitor was kept in the shelter for viewing of the received signal; it could be switched in-or-out of the system alternately with a similar display monitor which was located at the remote area.

The remote monitor was part of a console which had been built previously for the Government on another contract. This console had TV cursor control switches and circuits in it which previously had been used in a hardwire hook-up for controlling the x/y position and intensity of a visual cursor as displayed on either the console mounted monitor, or on another one which was connected to a TV camera. The visual cursor was basically a pointing or annotating device. The cursor control display was superimposed on the video signal generated by the camera as it viewed photographic images or other like subjects. An attempt was made to duplicate this hard-wire control function via the radio link, as described later.

Also, in the remote demonstration area, there was located a light table and a TV camera at a distance of a few feet from the remote area TV monitor. This arrangement permitted alternative observation of (a) locally generated direct video images or, (b) similar images sent via the digital AN/GRC-173 (XW-1) link. By switching between the link and local signals, a comparison of the two could be obtained. Various other functional tests of real time high resolution TV communications capability could also be conducted by the Government with this arrangement. The Government also supplied a large photographic unit including a lens system and Polaroid camera which could be locked in place directly over the TV screen. It was used to obtain a photographic print copy of the display.

b. Performance

Controlled standardization tests of TV quality as conducted earlier in Phase III were not repeated. However, when all the equipment units were connected and operating properly within specification, the quality of the TV communications over the link appeared to observers to be equivalent to the prior experience (when all the equipment had been co-located in the shelters).

Link transmission performance under variable atmospheric conditions was reliable as before, and the only significant fades were caused by heavy rainfall. One unusual atmospheric occurrence having no effect on link propagation was produced on April 22, 1974, by a very high pollution level at approximately the height of the shelter (and antenna beam) near the WNY station. The heavy concentration there may have been caused by an atmospheric condition which trapped the pollutants at the station altitude. One of the operating personnel was made ill by the heavy fumes when they were blown into the shelter by the air conditioner, but subsequent inspection of the received signal recording made at that time showed that there was no decrease in the signal strength. Note: propagation data collection had been completed before the start of the extension period, but the related instruments had been left in place and were monitored at certain times.

The main equipment problem area in the radio set during the extension period was an intermittent condition in the modulator as described previously in the final report. This condition decreased system operating margin for a time. The problem was traced to the modulator diode mount contact, and corrected during the extension period.

Some early difficulties were encountered in integrating all of the equipments, primarily because of unfamiliarity in trouble-shooting some of the auxiliary equipment when it developed faults and failures. The cursor control unit was, in fact, removed from the system after repeated difficulties, although it was in service long enough to demonstrate that pointing of the cursor at the WNY site could be controlled from the Pentagon site via the link.

c. Remote Cursor Control

A cursor control line multiplexer and demultiplexer were specially designed and built on the project on short order to take six control signals at the Pentagon and to multiplex them for transmission over the link using a 9.8 Mb/s low speed channel of the radio set. An the WNY site the respective signals were demultiplexed and used to vary the signal voltages on the unit which was connected to the camera there. The control voltages determined the composite video signal level consisting of the cursor image superimposed on the viewed image.

Each of the cursor control signals was an on-off logic level signal. The specially-built multiplexer buffered the signals, performed parallel to serial conversion, added framing bits and provided an output to the radio when driven by its 9.8 MHz clock. The 9.8 Mb/s channel signals were muxed with the other high and low speed channels of the radio and transmitted. At the receive end, the specially-built demultiplexer performed serial to parallel conversion and provided the outputs at the required logic level. In this manner the radio link duplicated at a distance of 4.4 km the control function which had previously been performed locally using coaxial cable of much shorter length.

The link capability permitted the viewer of the TV display at the Pentagon to remotely control the location of the cursor while observing the image being transmitted from the WNY site. (Note: The radio itself operates full duplex, but there was only enough auxiliary equipment for unidirectional operation of the TV transmissions or the control signals.)

d. Additional System Design

For reasons of general utility, the radio set order wire unit at the Pentagon was re-configured. The modification consisted of re-wiring the order wire to permit operation both locally from the shelter and remotely from the stairwell remote demonstration area. The remote handset, call button and audible alarm were connected to the like items at the shelter, via #18 stranded shielded wire. The order wire re-configuration enabled using the link for three-point audio hook-up, i.e., WNY shelter, Pentagon shelter, and Pentagon remote area. This capability, together with a commerical inter-communications set between the shelter and demonstration area, proved quite helpful in coordinating the various activities during the period.

Near the end of the project, total system hands-off unattended operation capability was demonstrated in a somewhat fundamental way by connecting an inexpensive commercial 24-hour clock timer to the TV camera and using it to turn the camera on and off at preset times. This appeared preferable to running the camera continuously, which might deteriorate the vidicon target during the extended periods of use. When the camera was automatically switched on, the signal was also automatically encoded and transmitted over the link. The radio link equipment was kept running continuously.

e. Update of Operating Hours Record

During the extension period, approximately 2500 hours running time was added to most of the radio set equipment. Considering the whole link test program from August 1973 up to May 31, 1974, and the previous development use on Phase II, units of equipment in the radio sets had operated between 7500 and 9500 hours.

3. SUMMARY AND CONCLUSIONS

The configurations of AN/GRC-173 (XW-1), television and auxiliary equipment as described above were used in conducting numerous high resolution TV image communications demonstrations during the extension period. These tests supplemented the earlier Phase III experiments with co-located TV and radio equipment and helped to establish the methods which can be followed in future applications. The preliminary requirements for interfacing the radio set with additional wideband terminal equipment were established.

The completion of the extension period also concluded the operational evaluation and testing of the AN/GRC-173 (XW-1) in the Washington, D.C. link. The link was left in full operating status to continue to serve as a wideband communications facility or flexible demonstration test bed.

MISSION
of
Rome Air Development Center

RADC is the principal AFSC organization charged with planning and executing the USAF exploratory and advanced development programs for electromagnetic intelligence techniques, reliability and compatibility techniques for electronic systems, electromagnetic transmission and reception, ground based surveillance, ground communications, information displays and information processing. This Center provides technical or management assistance in support of studies, analyses, development planning activities, acquisition, test, evaluation, modification, and operation of aerospace systems and related equipment.

Source AFSCR 23-50, 11 May 70