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USE OF COMMERCIAL BROADCAST FACILITIES FOR EMERGENCY DOD COMMUNICATIONS

David A. Griffith
John R. Martin
Donald Spector

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AFLC, GAFB, N.Y., 2 Sep 66-148

FOREWORD

This report was prepared by personnel under the supervision of Mr. Earl Selover, Project Manager and Chief of the Narrow Band Transmission Section. The work was conducted in support of Defense Communications Agency Project Number 12500, Survivable Communications Support, under the management of Mr. Donald Worthington (Defense Communications Agency Code-333). The program was conducted in cooperation with the Federal Communications Commission. The coordinating official for FCC was Mr. Kenneth Miller, Chief Office of Emergency Communications, FCC Symbol 2500. (Project 9680).

The authors wish to acknowledge the direct contribution of Mr. Earl Selover and Mr. John Entzminger to this report. Mr. Selover's analysis of the cost effectiveness and queuing problems associated with the system are included in Appendix I. Mr. Entzminger's evaluation of available techniques which could be utilized to provide teletype communications in audio spectrum is contained in Appendix II. Mr. Entzminger is with the Long Wave Communications Unit, Telecommunications Section, Communications Techniques Branch of Rome Air Development Center.

Special assistance regarding the selection of radio stations and problems in noise interference reduction was rendered by Mr. Kenneth Miller of the FCC and Mr. E.W. Chapin and staff of the Laurel Labs Facility of the FCC. The authors also wish to thank the personnel of all the participating radio stations for their very gratifying support and cooperation during the installation and testing portion of the program.

All of the items compared in this report were commercial items that were not developed or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

This document is not releasable to CFSTI because it contains comparative data and information on commercial equipment.

This technical report has been reviewed and is approved.

Approved: GEORGE E. BRUNETTE
Chief, Communications Techniques Branch

Approved: CHARLES A. STROM, JR.
Acting Chief, Communications Division

FOR THE COMMANDER: IRVING J. GABELMAN
Chief, Advanced Studies Group

ABSTRACT

This report contains details and results which were obtained during the design, installation and testing portion of a program, the intent of which was to demonstrate the technical feasibility of providing emergency DOD teletype communications through the use of a distributed network of commercial AM broadcast stations. This was accomplished utilizing simplex operation with no degradation to the commercial programming material and by duplex operation with the insertion of a keyed audio tone at 425 cycles. The latter introduced some annoyance to the home listener. However, the degree of intelligibility, which is of primary consideration in an emergency, was not reduced. The system was operated in a trace route mode and in a flood mode and was capable of being checked on a station-by-station basis by any user. The design and equipment problems are discussed and the accumulated data is presented.

TABLE OF CONTENTS

SECTION	I	Preliminary Remarks	1
	II	Logic Design	5
		1. General Introduction	5
		2. Trace Routing	8
		3. Flood Routing	12
		4. System Checkout	12
		5. Timing Problems	14
		6. Equipment Remarks	15
	III	Simplex Consideration	16
	IV	Duplex Consideration	17
	V	Modulating Equipment	20
		1. R.F. Keyer	20
		a. Initial Design Phase	20
		b. Equipment Comparison And Problems	21
		c. Recommendation for Future Consideration	23
		d. Analysis of Interference Problems	25
		2. Audio Frequency Shift Keyer	29
	VI	Receiving and Demodulation Equipment	31
		1. Initial Design Pulse	31
		2. Receivers	32
		a. Receiver Design	32
		b. Equipment Comparison and Problems	32
		c. Recommendation for Future Consideration	35
		3. Demodulators	35
	VII	Regenerative Repeaters	38
	VIII	Duplex Equipment	40
	IX	Duplex Testing & Results	42
	X	Terminal Equipment	43
	XI	Antennas	46
	XII	R.F. Shielded Enclosures	50

SECTION	XIII	Data Collection and Presentation	53
	XIV	Conclusions	76
APPENDIX I		A Study of Survivability for Use of Commercial Broadcast Facilities for Emergency DOD Communications	79
APPENDIX II		A Study of Simultaneous Transmission of Voice And Teletype Over AM Broadcast Stations	87
APPENDIX III		Additional Data	105

LIST OF ILLUSTRATIONS

FIGURE 1	Network Configuration	3
FIGURE 2	Relay Station or Terminal Facility	6
FIGURE 3	Description of Node Operation	7
FIGURE 4	Trace Routing Operation	10
FIGURE 5	Portion of Typical Message Header Utilized in Trace Routing	11
FIGURE 6	Operation in Flood Mode	13
FIGURE 7	Picture of R.F. Keyers	24
FIGURE 8	Effect of Keying Transient Filter	26
FIGURE 9	Expanded View of Single Pulse	26
FIGURE 10	75 Baud Pulse	27
FIGURE 11	Frequency Response of Keying Transient Filter for Sine Wave Input	27
FIGURE 12	Spectrum of Frequency Shifted Carrier	30
FIGURE 13	Receiver Specification	33
FIGURE 14	Receiver Block Diagram	34
FIGURE 15	Regenerative Repeater Testing Procedure	38
FIGURE 16	Block Diagram of Duplex Operation	41
FIGURE 17	Receive Only Facility	45
FIGURE 18	Beverage Antenna	48
FIGURE 19	Beverage Wave Antenna Termination Boxes	49
FIGURE 20A	Equipment Rack Front View	51
20B	Equipment Rack Rear View	52
FIGURE 21	Data Taken 7 September 1965 - 8 September 1965 RADC - WGY - WHAM - FCC	56
FIGURE 22	Data Taken 5 October 1965 RADC - WGY - WTIC - WABC - WHAM - FCC	57

FIGURE 23	Data Taken 5 October - 6 October 1965 RADC - WGY - WHAM - FCC	58
FIGURE 24	Composite 5-6 October 1965	59
FIGURE 25	Data Taken 11 October 1965 RADC - WRUN - WSYR - WHAM - FCC	60
FIGURE 26	Data Taken 11 October - 12 October 1965 RADC - WGY - WWVA - FCC	61
FIGURE 27	Data Taken 12 October 1965 RADC - WGY - WTIC - WABC - WWVA - FCC	62
FIGURE 28	Data Taken 12 October 1965 RADC - WGY - WTIC - WABC - FCC	63
FIGURE 29	Composite 11-12 October 1965	64
FIGURE 30	Data Taken 23 September 1965 RADC - WGY - WWVA - FCC	65
FIGURE 31	Data Taken 28 September - 29 September 1965 RADC - WGY - WHAM - WABC - FCC	66
FIGURE 32	Data Taken 29 September - 30 September 1965 RADC - WGY - WTIC - WABC - FCC	67
FIGURE 33	Data Taken 14 December 1965 RADC - WGY - WTIC - WABC - FCC	68
FIGURE 34	Data Taken 3 December and 27 December 1965 RADC - WGY - WTIC - WABC - WARM - KYW - FCC	69
FIGURE 35	Compilation of Data RADC - WGY - WTIC - WABC - FCC	70
FIGURE 36	Compilation of Data RADC - WGY - WWVA - FCC	71
FIGURE 37	Compilation of Data RADC - WGY - WHAM - FCC	71
FIGURE 38	Data Taken 23 September - 24 September 1965 FCC - WTOP - KYW - WARM - WABC - WGY - RADC	73
FIGURE 39	Data Taken 16 September 1965 FCC - WTOP - WABC - WGY - RADC	74
FIGURE 40	Percentage of Time Average Circuit Error Rate Exceeded Thresholds	75

LIST OF TABLES

TABLE I	Station Parameters	4
TABLE II	Keying Conditions	22
TABLE III	Comparison of Amplitudes of Harmonics of Keying Rate for Square-Wave and Shaped-Wave Modulation	29
TABLE IV	Regenerative Repeater Input Distortion	38

SECTION I

PRELIMINARY REMARKS

This report presents the results of an experimental program conducted by the Rome Air Development Center in support of Defense Communications Agency Project 12500. The project (Use of Commercial Broadcast Facilities for Emergency DOD Communications) involves the design, installation, test and demonstration of a distributed communications system which utilizes standard commercial broadcast facilities as nodes of the network. The intent is to demonstrate the feasibility of establishing a nation-wide network which can provide emergency communications for high priority government traffic.

"Distributed" or Decentralized communication systems are generally characterized by the ability of the system to function when portions of the network are inoperative. The importance of such design is obvious when military type situations are considered. These systems have been treated in the literature and various schemes of operation examined in a hypothetical enemy attack type of environment.[1] Such situations indicate that the reliability of the system under attack is influenced not only by the redundancy level[2] of the system, but also by the flexibility with which switching can occur. Appendix I presents a survivability analysis based on the application of these considerations to this system.

It was with these general concepts in mind that we considered the following specific set of system requirements:

1. The system would be an emergency type system only. It would utilize standard AM Commercial broadcast facility and would do so in a manner which would not interfere with, or in any way degrade, the standard programming material intended for the home listener. This is necessitated by the fact that in an emergency the public becomes almost totally dependent on their home radios for public information.

2. The system was to carry simplex and/or duplex teletype information at a speed of 100 wpm. Since simplex 100 wpm operation had never been attempted in the commercial broadcast environment, it was impossible to know whether such operations could be accomplished without degradation to the standard programming material. Tests conducted early in the program affirmed this capability. Duplex operation at this speed, however, was still questionable with regard to its interference properties. It was for this reason that we included two capabilities in our basic mode of operation. (Simplex operation would be used for performing switching functions.)

---

1. Baran, Paul "On Distributed Communications" Aug. 1964 prepared for United States Air Force Project Rand.

2. Ibid., Page 3, Vol. I Mr. Baran has defined Redundancy "R" as equal to link to node ratio in an infinite array of stations. While such a definition is not numerically accurate in small networks it is still useful as a figure of merit when comparing systems.

Once the circuit had been established it would be possible to operate either simplex or duplex depending upon such considerations as interference level and importance of message.

3. Circuits were to carry secure and non-secure information. This requirement eliminated the possibility of utilizing store forward techniques, since in such a system only the users could be considered secure for purposes of storing classified information. A store forward operation would require a greater amount of completely automatic equipment in each facility. Station personnel will not necessarily be capable of adjusting or manning this equipment and such extensive storage and processing could pose economically insurmountable reliability and maintainability problems. For this reason storage would be limited to information which is utilized in establishing and shutting down circuits within the network.

4. The system would contain a "receive only" capability. Such a facility would be situated relatively close to a radio station and should require only a minimum amount of installation. This capability would be extremely desirable in a command and control situation.

5. Since simplex operation would not afford the user the opportunity of obtaining message acknowledgment until the message header had been completed, we considered it necessary to provide the system with a checkout procedure whereby the user could, through the use of a particular code format, determine if the broadcast station which he intended to use was operational. This technique will be discussed in the portion of the document labeled Logic Design.

In the second section a description of the logic design and system operation is presented. It is presented first to give the reader a better understanding of some of the reasons for selecting particular types of equipment. These equipments will be elaborated upon in the sections of the report which follow. In the section on data analysis the methods used for data collection are discussed and the tabulations presented. The data was gathered on the network shown in Figure 1. Some additional station parameters are shown in Table I. These stations were selected utilizing antenna pattern plots located at the Federal Communications Commission in Washington, D.C. Each facility was then site-surveyed by a member of the engineering staff at RADC and in some cases representatives of the FCC. The survey consisted of erecting a portable version of the beverage antenna and measuring the signal emanating from the various transmitting facilities from which we desired to receive. Some circuits were selected that would be marginal for at least part of the day. This type of information is required for future design information. Such links made the circuit extremely useful in spite of the reduced quality.

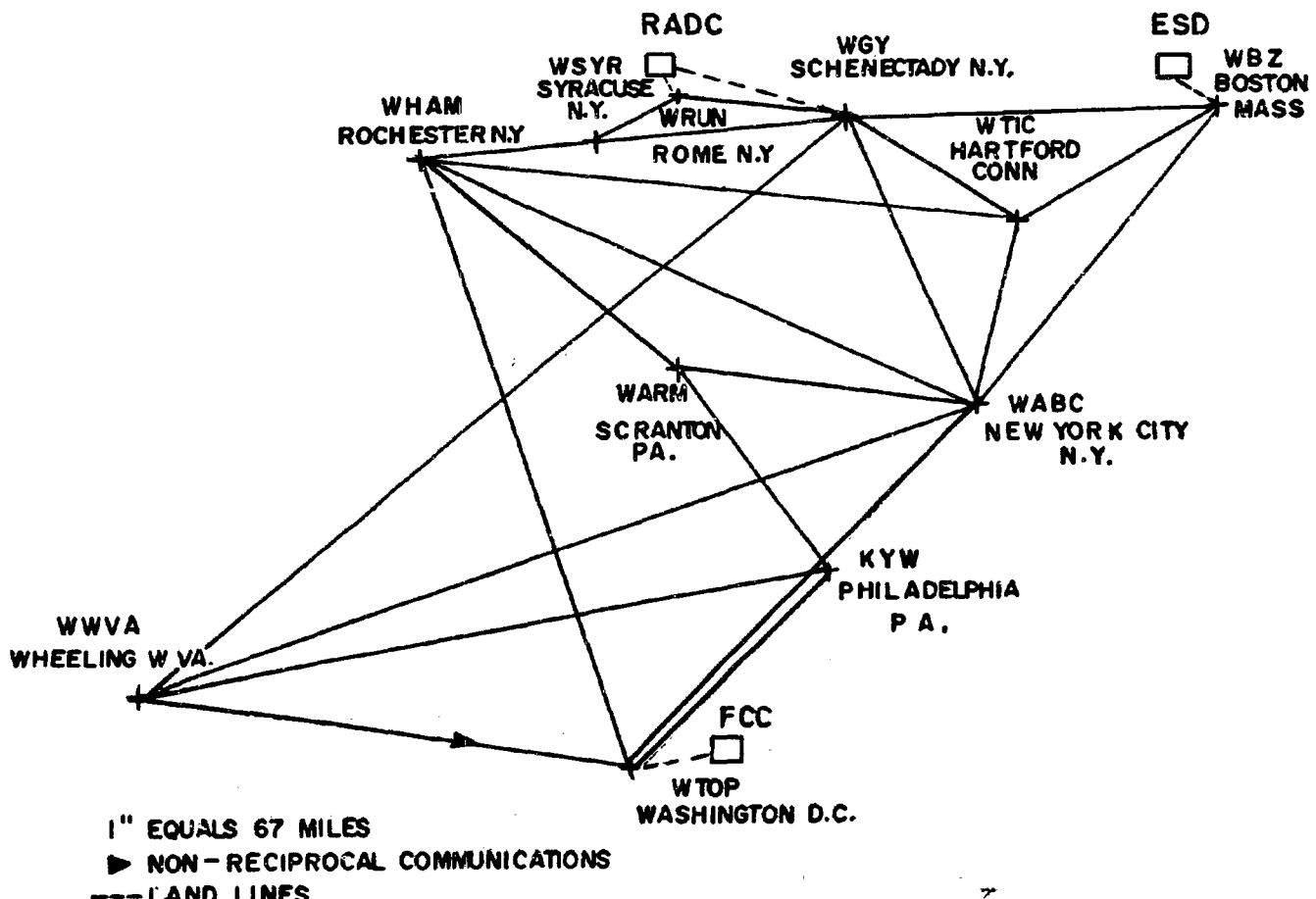


FIGURE 1

NETWORK CONFIGURATION

TABLE I

STATION PARAMETERS

Station Call	Freq.	Power	Location	24-Hour Operation
WABC	770 kHz	50 KW	New York, N.Y.	Yes
WARM	590 kHz	5 KW	Scranton, Pa.	Yes
WBZ	1030 kHz	50 KW	Boston, Mass.	Yes
WGY	810 kHz	50 KW	Schenectady, N.Y.	Yes
WHAM	1180 kHz	50 KW	Rochester, N.Y.	Yes
KYW	1060 kHz	50 KW	Philadelphia, Pa.	Yes
WRUN	1150 kHz	5 KW	Rome, N.Y.	No
WSYR	570 kHz	5 KW	Syracuse, N.Y.	No
WTIC	1080 kHz	50 KW	Hartford, Conn	Yes
WTOP	1500 kHz	50 KW	Washington, D.C.	Yes
WWVA	1170 kHz	50 KW	Wheeling, W. Va.	Yes

SECTION II

LOGIC DESIGN

1. General Introduction

Figure 2 is a block diagram of a typical Relay or Terminal facility. It contains n receivers which monitor the adjacent broadcast stations in the network. Each broadcast station constitutes a node of the distributed network. Each node monitors several adjacent nodes continuously but does not retransmit information unless the information has been preceded by an appropriate code sequence. This routing information is carried in the form of a message header. The incoming information is compared against internally programmed headers and, upon detection of the appropriate code sequence, a group of relays is activated, thereby providing the basis for control. Such a device is commercially available and in the telegrapher's terminology is called a Sequence Selector[3]. These devices are suitably noted in Figure 2 and Figure 3.

For purposes of description we shall define an alarm (sequence detection) as a logical "1" state as opposed to logical "0" when there has been no header detection.

The flow diagram shown in Fig. 3 illustrates both the logic functions and the consequential system functions.

It should be noted that each particular frequency which is monitored has associated with it a sequence selector. This is necessary because a device which would be common to all receivers would be seriously degraded by the noise and interference contributions from all the received signals. When a function is common to all receivers, (i.e. it provides the same system consequence regardless of the node from which the information is received), it is, wherever possible included in Logic System L_2. As will be shown later, L_2 receives no information until there is a logical 1 state in L_1. At this time all receiving systems except the one in which the alarm occurred have been electrically removed from the logic system.

Each sequence selector in (Logic System) L_1 is programmed to detect four sequences of either 4 or 5 characters. These sequences are chosen by systematically arranging groups of characters which have a low probability of occurrence in normal text. Actually it is felt now on the basis of our experience that a three-character sequence would be adequate where false alarms in order of once a day could be tolerated. This false alarm rate was tolerable in the system described because the logical 1 occurrence in the Logic System L_1 activates a station clock which at the end of a specific period of time resets the entire station, i.e. returns all functions to the zero or unactivated state.

---

3. Sometimes known as "Stunt Box"

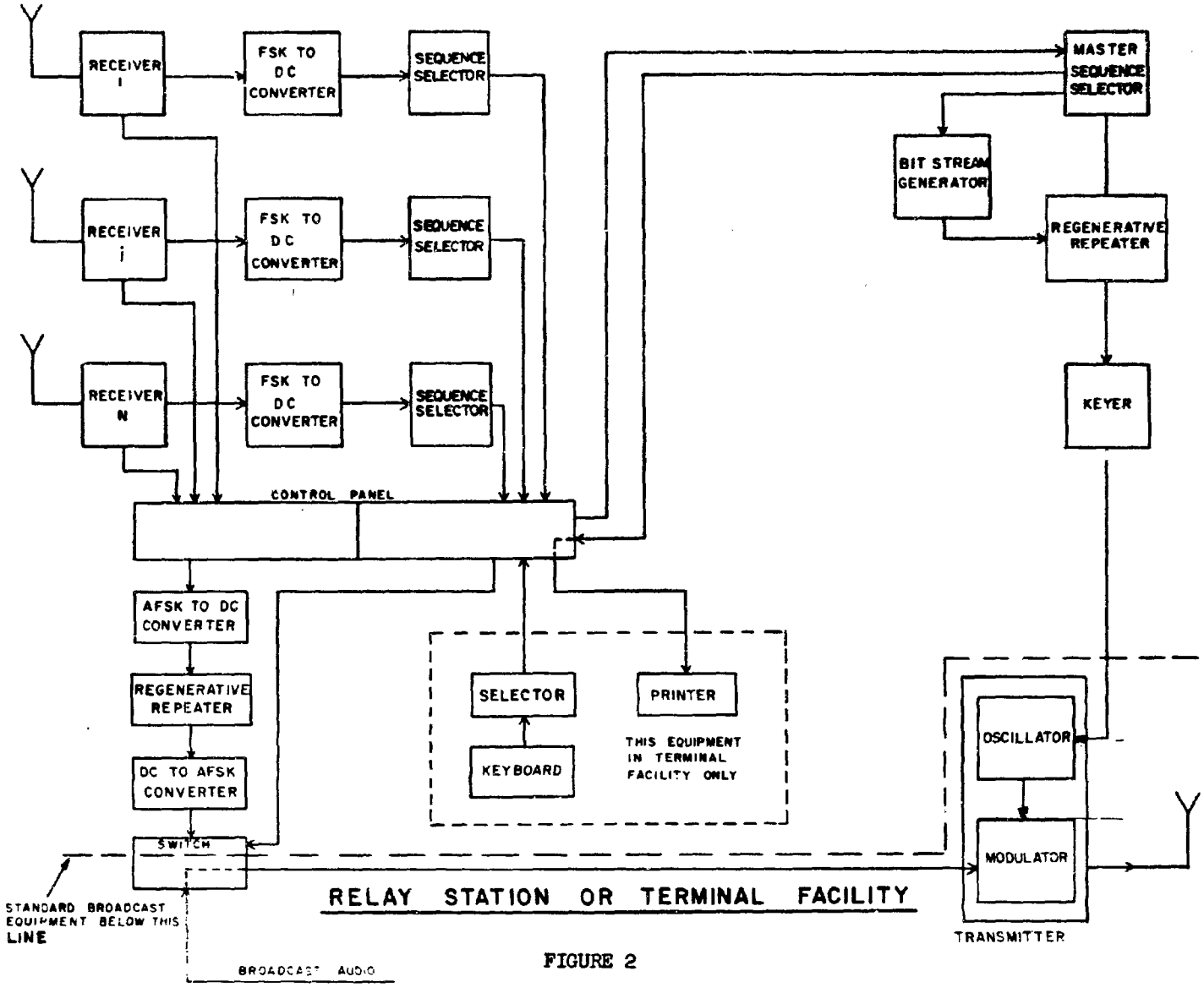
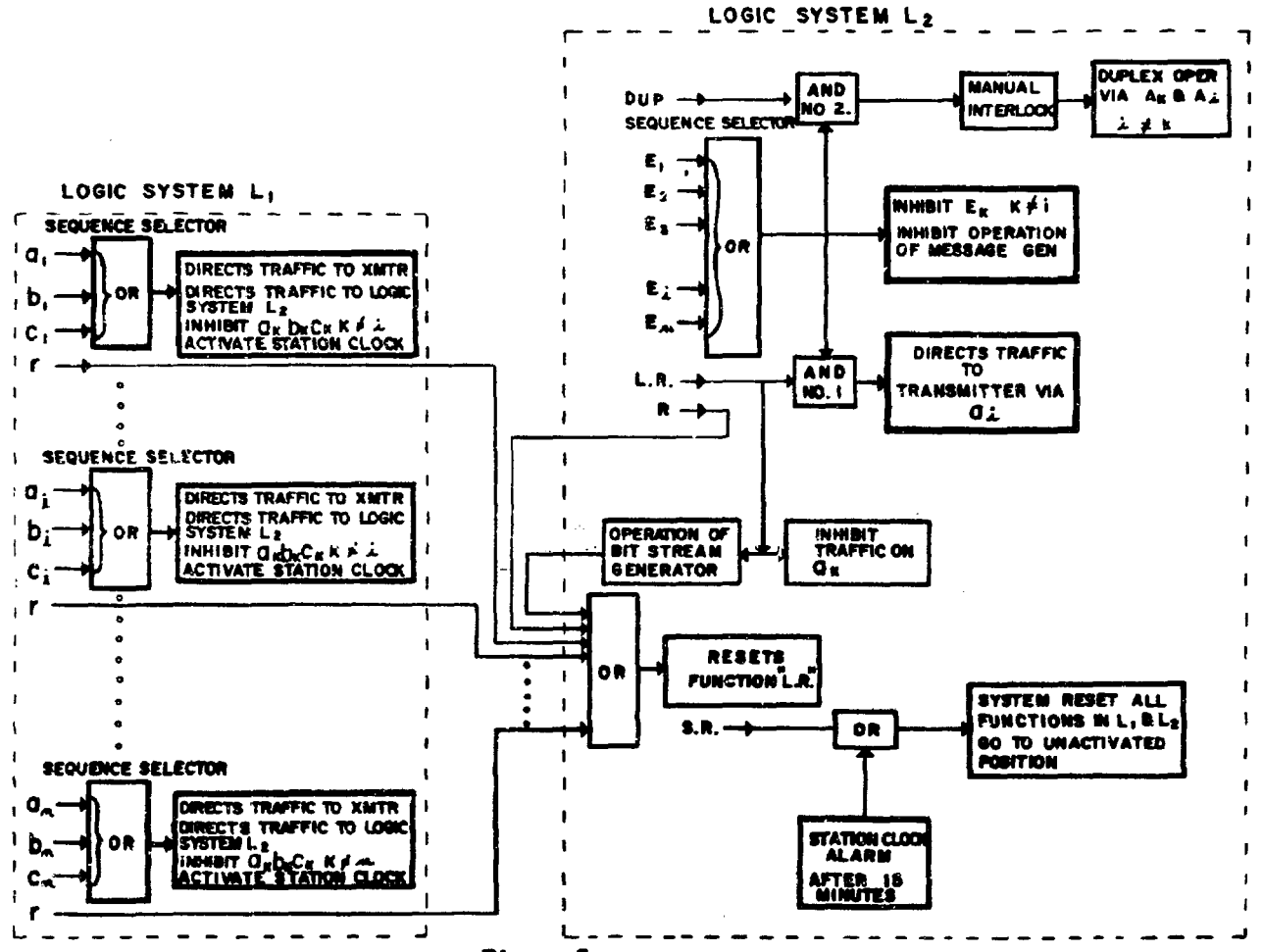

RECEIVER 1
RECEIVER i
RECEIVER N
FSK TO DC CONVERTER
FSK TO DC CONVERTER
FSK TO DC CONVERTER
SEQUENCE SELECTOR
SEQUENCE SELECTOR
SEQUENCE SELECTOR
MASTER SEQUENCE SELECTOR
BIT STREAM GENERATOR
REGENERATIVE REPEATER
KEYER
CONTROL PANEL
AFSK TO DC CONVERTER
REGENERATIVE REPEATER
DC TO AFSK CONVERTER
SWITCH
SELECTOR
KEYBOARD
PRINTER
THIS EQUIPMENT IN TERMINAL FACILITY ONLY
OSCILLATOR
MODULATOR
TRANSMITTER
STANDARD BROADCAST EQUIPMENT BELOW THIS LINE
BROADCAST AUDIO
RELAY STATION OR TERMINAL FACILITY

FIGURE 2



k = 1, 2, 3, ... n
i = 1, 2, 3, ... n

Figure 3
Description Of Node Operation

If this were not the case the system would remain in an alarmed condition until an external reset was applied.

The character sequences (or programmed headers) have been given the notation a, b, or c with a subscript to identify the particular channel on which the information is arriving. The header a_1 differs from a_2 and a_i differs from a_j. The header b_i and b_j may or may not be the same sequence, and similarily c_i and c_j may or may not be the same. In this system b and c sequences are used for purposes of communications with a portion of or with the entire group of network users. Situations where b_i and b_j or c_i and c_j are characterized by the same sequence pose some design problems because there are situations where such headers can arrive at a station from two separate facilities close enough in time that multiple alarms, (i.e. alarms by two separate sequence selectors occur) which cause keying from two separate facilities and consequently could result in garbling of the retransmitted message. This was not a problem in the system described below because propagation time was relatively short compared to a bit length. Had this not been the case the problem could have been alleviated by suitable selection of switching time or by additional logic.

2. Trace Routing

Operation in the Trace Route mode is established utilizing the a_k k = 1.....n sequence. In this type of operation, the communications route is established utilizing a specific group of stations. The reason may be to minimize the number of stations in use, which would minimize the load on network, or because of previous knowledge the user feels that this circuit provides the highest degree of reliability. For purposes of illustration consider the following situations with reference to Fig. 2 and Fig. 3. A message header which contains the a_k sequence has been detected by the sequence selector containing the a_k program providing a logical 1 at the output of L_1. The following system functions occur.

a. All other a, b and c alarms are inhibited, insuring that the station is not alarmed by another user during the operation, and in addition insuring that the problem known to communication system designers as "Ring Around the Rosy" does not occur.

b. Station frequency changes from its assigned carrier to either mark or space frequency (+ 18 cps from carrier) depending upon the particular current conditions in the loop.

c. The station clock is activated. It will run for 15 minutes and then reset the system. The clock prevents the utilization of the network continuously by any one user, and also provides automatic reset if the user is unable to complete the message.

d. Traffic which follows is directed to logic system L_2 and is regenerated and retransmitted.

At this time it should be noted that if only this simplex capability were desired the logic requirement would be considerably simpler. The initiator would simply utilize a string of specific addresses which would travel from node to node alarming each facility in the chain until it arrives at the intended recipient. Additional complexity is required to eliminate the necessity that a return channel be initiated with a new message header. Both circuits must be established by the initiator at the time the original circuit is established. When only the simplex channel capability exists, the subscriber would utilize the circuit in a "push to talk" mode, i.e. when the initiator finishes the message the circuit is transferred to the recipient and vice versa. In situations where full duplex channel is used, simultaneous transmission in both directions can be effected at the time of the message origination.

In Figure 4 a message is being transmitted through three node facilities. If only a simplex capability exists only one direction at a time can be used. Therefore, traffic which eminates from direction 1 in Figure 4 can be received on a_k in node 1, a_o in node 2 and a_s in node 3. All other receivers must be electrically removed from the communications channel. When the direction of transmission reverses, however, a_k, a_o and a_s must be removed and in place communication via a_q, a_m and a_i must be effected. Hence, it is not only necessary for the header to contain information for each node in the link but in addition it must also provide each station with information regarding the return channel. In our system, this was accomplished most efficiently by including second channel information in logic system L_2. Thus in Fig. 3 E_i i = 1, 2, 3.....n corresponds to alarm header of each facility which surrounds the specific node and can form a communication circuit with it. The header corresponding to a_i in Fig. 4 would appear in logic system L_2 of node 2. The header a_o would appear in logic system L_2 of node 1.

To illustrate, consider the sequences of addresses shown in Fig. 5 which could originate from direction 2. Not that a_m not only alarms node No. 2 it also selects receiver a_o in node 3 for the return channel in case a return capability is necessary.

A logical 1 of the output of "and" Gate No. 1 (reference Fig. 3) accomplishes the link reversal function. This logic function requires, in addition to the alarm of the adjacent node address a logical 1 from the function L.R. This link reversing function code L.R. is sent when the initiator has completed his portion of the message.

The message format in Fig. 4 from Direction 1 to 2 would be

a_k	a_o	a_s	message	L.R.

The recipient can now transmit his reply. If he desires to return the circuit to the initiator, this is accomplished by alarming function "R" in L_2 because it simply returns function L.R. to the "0" state. The circuit is then returned to the originator who can either repeat the process until time on the circuit runs out or can drop the circuit.

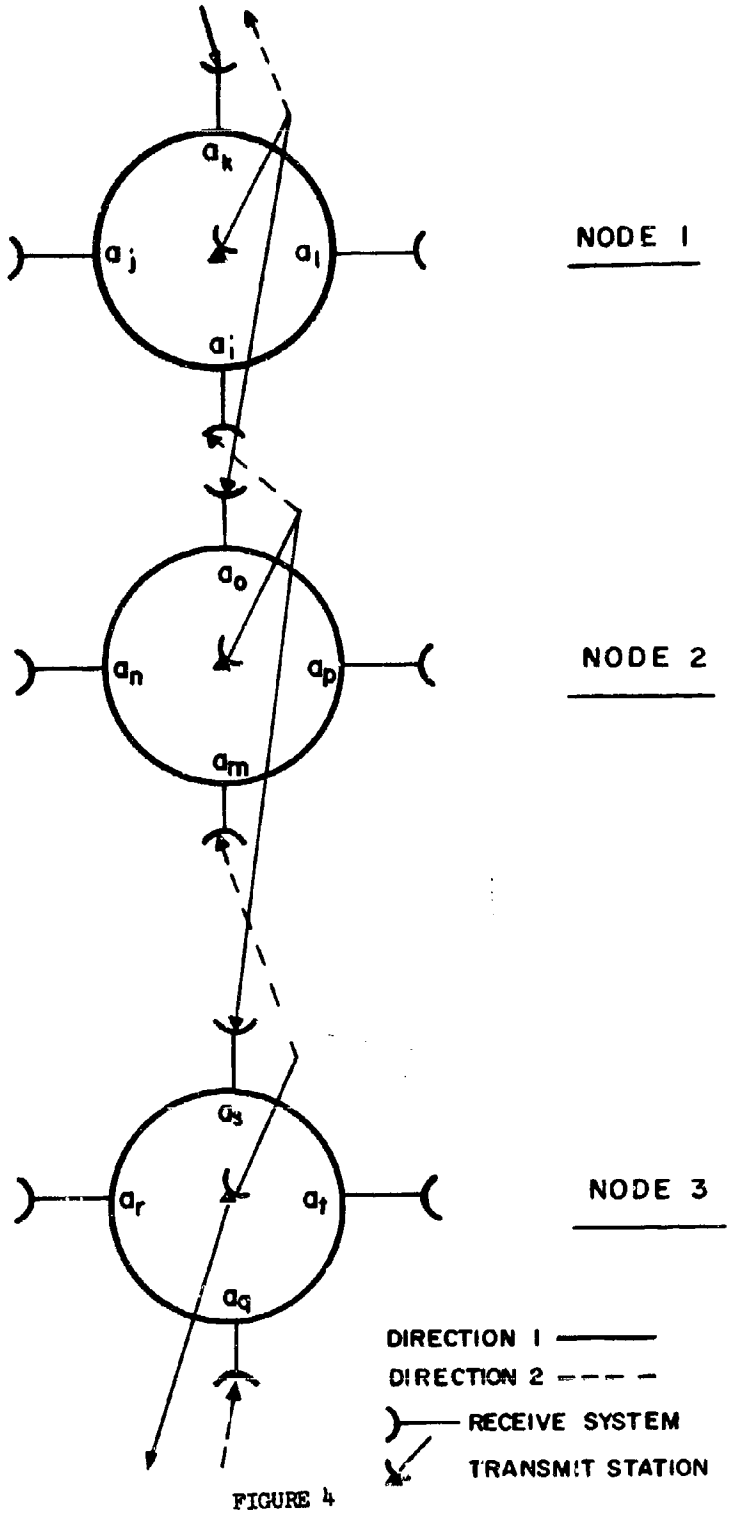


FIGURE 4

TRACE ROUTING OPERATION

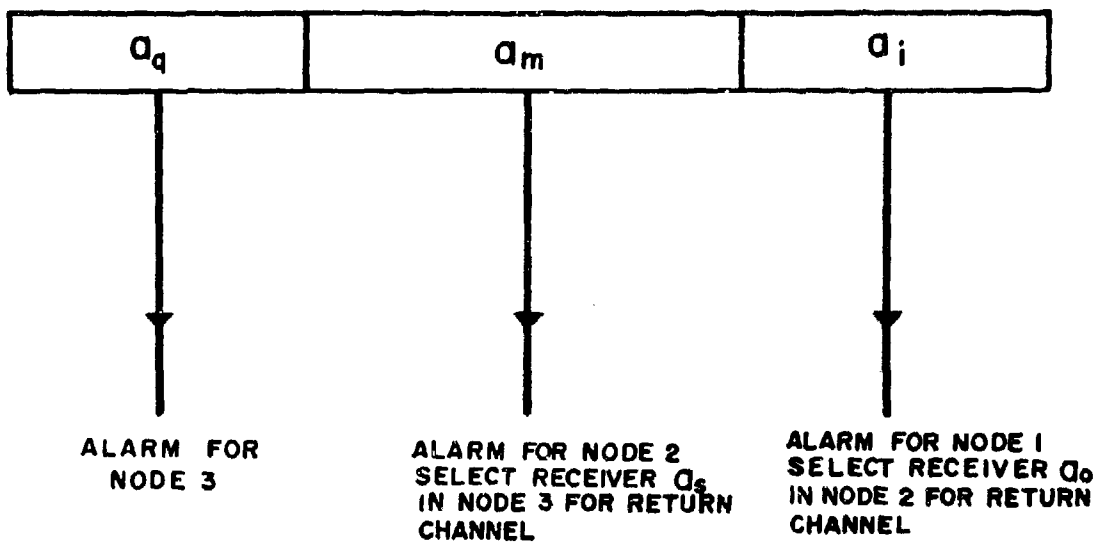


FIGURE 5 PORTION OF A TYPICAL MESSAGE HEADER UTILIZED IN TRACE ROUTING

The duplex operation is logically similar, i.e. logical 1 state is required at "And" Gate No. 2. This logical function occurs when there is an alarm from both function E_i and function (DUP).

The message format for Duplex operation is:

a_k	a_o	a_s	DUP	message

Communications circuits are operational in both directions before the message begins. Thus the initiating individual is in a position to select the stations which are to be utilized and in addition, choose the mode of operation. It should be pointed out that in anticipation of the detrimental effect on commercial programming material during the duplex operation of the network, radio stations have been provided with a duplex lockout capability. This assures the station commercial quality against degradation due to accidental usage of the full duplex capability. Once the integrity of the logic system is assured the station override would not be necessary.

3. Flood Routing

As was indicated previously function b_k and c_k are used when the initiator is interested in communicating with a portion of the network's users or with every user in the network simultaneously. The headers b_k and c_k do not therefore specify any specific channel; they merely stipulate a code which is common to either a portion of the nodes or all the nodes. In this system b_k represents communication to one half the network while c_k represents communications to all the network. The header transmitted from a given node simply alarms each node which is adjacent to it and that node in turn retransmits whatever follows.

It can be shown that while this procedure does not select the most reliable circuit to each user it does effect the communication circuit in the most rapid time. Figure 6 shows the communications links established after each code c_k is sent from RADC over the test network established for this program.

4. System Check-Out

A check-out procedure which could automatically evaluate the operational capability of any particular station was incorporated into the system. This system check-out can be accomplished at any user of the network. Logic System L_2 has been programmed so that the logical 1 state at the output of L.R. activates a bit stream generator. This operation is inhibited when there is also a logical 1 state from E_k k = 1, 2.....n. Therefore, the detection of a_k in Logic System L_1 followed by detection of function L.R. causes the following operation.

Activation of bit stream generator which contains the following information: Identification Code of Station + L.R. Reset Code. This information is transmitted over the air and simultaneously sent to Logic System L_2. The following functional operations have occurred. The relay facility has received the function commonly utilized for link reversal. There has been, however, no second address to indicate routing information for a return channel so Channel a_k of Logic System L_1 has electrically been removed thus insuring that even

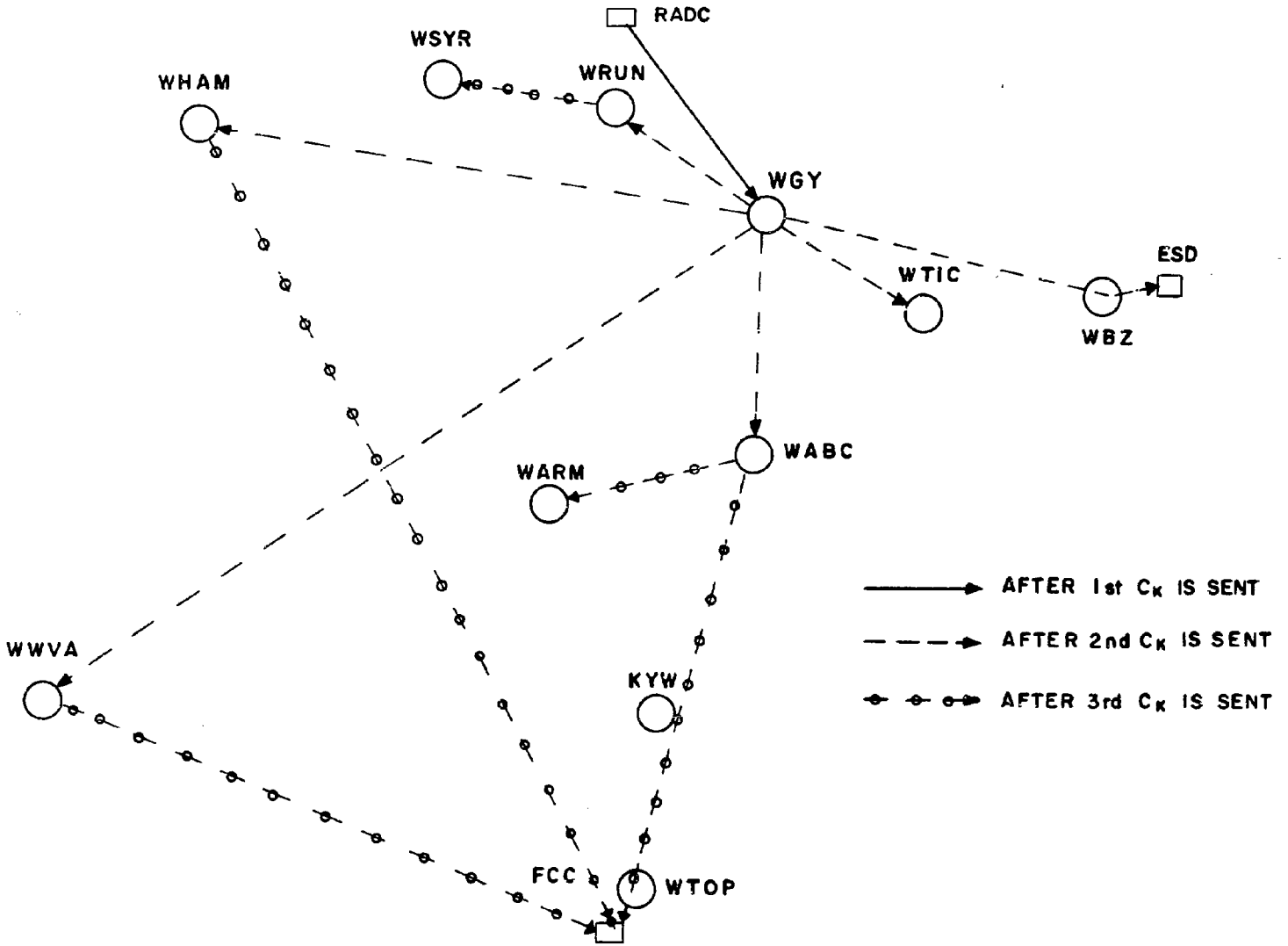


FIGURE 6 **OPERATION IN FLOOD MODE**

though the station has been alarmed no traffic can enter. The bit stream generator having been activated, transmits the station code and follows this with the L.R. reset function. Since L.R. has returned to the 0 state, the a_k channel is reopened and the node is "logically" the same as it was just after the detection a_k.

Now consider a second node facility which is to be checked through the use of the node which was just checked. It is alarmed by the sequence a_j in Logic System L_1 which has a corresponding address E_j in L_2 of the first station. Upon detection of L.R. the following operations will occur. Station 2 will operate exactly as did the station in the first check-out, i.e. channel j will be electrically removed. The bit stream generator will operate transmittingthe station 2 identifying code, the L.R. reset code, and resetting the L.R. function thereby reopening channel j. At station 1, however, the operation is slightly different. E_j has been alarmed in L_2 which inhibits the bit stream generator operation in Station 1. Upon the detection of L.R. function traffic is inhibited on Channel k, however, it is permitted on Channel J (Channel j in Station 1 receives Station 2). The transmission of the code from the bit stream generator of Station 2 is transmitted to Station 1 and back to the initiator. The L.R. reset which is transmitted from Station 2 is received at Station 1 and also provides a reset of L.R. in Station 1 returning the channel for incoming traffic to K.

The initiator can now enter Station 1 on Channel K and the manner described above interrogate each facility on a station by station basis insuring their individual operation. Having accomplished this the user can now either communicate with the intended recipient or is in a position to select an alternate route.

5. Timing Problems

The operating time of the station switching function was found to be extremely important with regard to system operation. The inhibit function which performs lock-out of all channels not in use should occur as rapidly as possible (0.1 times the bit length or less). This not only minimizes the possibility of multiple alarms at one facility, but, also insures that if a multiple alarm occurs during a flood operation that that the distortion will be low enough so that the systems regenerative repeater can properly reconstruct the traffic.

The sequence selector timing circuits begin operation on the first mark to space transition which in practice always occurs before the 5 information bits that make up a character. Therefore, switching operations which direct traffic to another sequence selector must be accomplished at a time which insures that the second sequence selector will not detect a mark to space transition other than one that is at the beginning of a character. This is best accomplished during the stop baud of the code since it is standardized as a mark. Therefore, while actual detection occurs at the center of the fifth information baud (sixth telegraph baud) the switching should not occur until the center of the stop baud (7th telegraph baud). The next header to follow would then by standardization be a space (first bit of the next character), the sequence selected would detect a mark to space transistion and the sequence selector begin its timing operation.

Link reversing function (L.R.) and (R) as well as the system reset (S.R.) function are all characterized by the same timing problem. In this situation the actual relay operation should not occur until sufficient time has elapsed for all information bits to be retransmitted to the next facility. In this system this time is a minimum of 20 ms. Therefore, while the detection of these sequences occurs at the center of the fifth information baud the switching should not take place until a minimum of 20 ms or 1.5 bits later.

The operation of the bit stream generator, which occurs during the check-out portion of the system, should not actuate until link reversal has been accomplished. Switching time for operation of this function should be greater than 20 ms. In the test system this is in the order of 100 ms. The occurrence of this operation before the L.R. function is complete could result in oscillation between nodes until automatic reset occurs.

6. Equipment Remarks

The sequence selectors were provided by two manufacturers, Stelma Co,, Stamford, Connecticut and Graybar Electric, Philadelphia, Pa. The contractors were provided with the additional task of fabricating the control panel to the customers specification. While the sequence selection equipment was solid state, the control panel was fabricated with mechanical relays. Mechanical relays were utilized because it was felt that transistor switching operation would cause problems in providing suitable isolation between traffic and alarm information. Switching would be accomplished at low voltage levels and ultrareliable relays such as reed switches, and mercury wetted contact relays in this situation could be considered as reliable as the transistor circuits. This proved to be the case, because the failure rate from the beginning to the end of the program was for practical purposes negligible.

The sequence selectors which were provided by the Stelma Co. had a deficiency which became apparent as the program progressed. The failure rate was relatively high. It was felt at first that the failures were of the infant mortality type and would decrease as time progressed. As it turned out this was not the case and it became necessary for the company to instrument a minor production change in their equipment. RADC incorporated the change in this system and the reliability since has been extremely high.

No problems were experienced in Graybar sequence selector. The devices maintained extremely high degree of reliability throughout the entire program.

SECTION III

SIMPLEX CONSIDERATIONS

Many of the parameters of the simplex channel were predetermined. FCC regulations prohibit AM broadcast stations from deviating more than ±20 cps from their assigned carrier frequency. Therefore, a frequency shift of ±18 cps was decided on in order to leave some margin for error. Antenna patterns, frequency allocations, radiated power, transmitter location (hence receiver location) and the daily operating schedule of the broadcast station were determined, not by the requirements of this system, but by long standing policy of the radio station. Therefore, the goal of the program was to make the system work in this predetermined environment.

SECTION IV

DUPLEX CONSIDERATIONS

Much more design freedom was granted in selecting the mode for providing the second teletype channel that would result in the full duplex capability, simply because no attempt had been previously made to produce a duplex capability. The only limitation placed on selecting this mode was that it be compatible with all the other emergency systems, and that it not interfere with normal broadcasting operation. Several techniques were considered and are enumerated below.

A technique in which the telegraph signal would be added to the broadcast audio and spread across the audio spectrum (thus appearing as random noise to a home receiver) was considered, but a study by the Human Engineering Section at RADC indicated that random noise would reduce the intelligibility of the audio information to the same degree that a single tone 30 db higher than the average noise level would. If this spread spectrum technique were pursued, the annoyance might be reduced but at the same time the information content of the broadcast audio, which is of primary importance to a home listener in time of emergency, would also be reduced. This is unacceptable.

A twinplex system was considered and rejected. Four frequencies are required for twinplex operation which would necessitate the crystal oscillator being capable of shifting to four discrete frequencies within the allowed 40 cps bandwidth, compounding the modulation and the stability problem. Under these conditions, the frequency separation could be only 13 cps. Discrimination between two frequencies separated by only 13 cycles at a speed of 75 bauds is beyond the state-of-the-art in demodulators. A conventional twinplex system would also require an information bandwidth which would produce harmonics in the audio band and create an unacceptable level of interference to broadcast reception.

A coherent FSK (CSK) system was also considered. This system theoretically would permit two telegraph channels to be utilized in the 40 cps bandwidth and also include an advantage over FSK. CSK is being studied at RADC and is still in the experimental stage. No equipment is currently available.

Both twinplex and CSK would involve two telegraph channels, both obtained by sub-modulating or frequency shifting the carrier. When two users are communicating in the full duplex mode, messages would be received from two different directions at each relay station and would have to be retransmitted simultaneously. Let us assume that one message arrives slightly ahead of the other and is being retransmitted by frequency shifting the carrier of the relay station. The second message is then received and in the process of retransmission also attempts to frequency shift the carrier. Since the oscillator can oscillate only at one frequency at a given time, multiple message modulation can result only in garbled messages and loss of intelligence in both directions. This is the basic problem in implementing twinplex or CSK in a duplex sub-modulation system. It is conceivable that the problem could be eliminated by including some type of combining equipment, utilizing delay techniques with

storage or decision-making devices, but this complexity violates the basic philosophy of this program which is to provide a simple, inexpensive, but reliable system. This problem may be averted by providing a second channel that is independent of the sub-modulation of the carrier.

This may be accomplished by notching out a portion of the audio spectrum and inserting a tone which is Frequency Shift (FS) keyed. This is a standard practice in commercial speech-plus-telegraph communication. Commercially a composite speech-plus-telegraph signal, when received, is split into two channels, one speech, the other telegraph, and useful information is derived from both with no mutual interference. From the standpoint of this system, the speech portion (broadcast audio) contains no useful information and may be rejected, while the telegraph portion containing useful information is retransmitted with no interference from its accompanying broadcast audio. The isolation of the telegraph information is accomplished by an appropriate filter system. Since home radio receivers don't have such a filter system, an individual listening to his radio will hear both the broadcast audio and the FS tone. An individual listening to his radio in time of emergency will obtain useful information from the broadcast audio but the FS tone will be a source of annoyance. This annoyance may be minimized but cannot be eliminated.

Of all the techniques evaluated, the single FS tone approach was considered the most practical. Commercial modulators and demodulators are available for implementation of this approach. The remaining question is what portion of the audio spectrum should be notched out for insertion of the telegraph channel.

An investigation was initiated at RADC to answer this question. The results are listed below.[4]

(1) Lower frequency tones are less annoying and may be tolerated for longer periods of time than higher frequency tones.

(2) Lower frequency tones reduce intelligibility (by masking) of speech less than higher frequency tones.

(3) The response of the human ear is not as sensitive at lower frequencies as it is at higher frequencies.

(4) The response of speakers in home-type commercial table model radios is not as sensitive at lower frequencies as it is at higher frequencies.

(5) Less intelligibility is lost in voice communication if lower frequencies are completely removed from the voice band than if higher frequencies are completely removed.

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4. The investigation was carried out by J. Entzminger at RADC. The complete report is included as Appendix II.

These results indicated that notching out a portion of the lower end of the voice frequency band was most desirable. The center frequency of the notch was chosen at 425 cps. This is the lowest frequency at which commercial equipment is available. The implementation of this technique is described in the Duplex Equipment section.

SECTION V

MODULATING EQUIPMENT

Two frequency shift keyers are required, one for each channel. The audio frequency shift keyer for the duplex channel was commercially available. The Radio Frequency (R.F.) shift keyer used to shift the carrier frequency of the AM broadcast station had to be developed.

1. R.F. Keyer

a. Initial Design Phase

Several problems had been anticipated in providing an R.F. keyer to meet the requirements of this program. They are briefly:

(1) To shift the crystal at the required teletype rate.

(2) To attain long range stability.

(3) To keep the station on its assigned frequency when teletype messages are not being sent.

(4) To provide each station in the system with a means of frequency shift keying.

(5) Not to degrade or interfere with the stations' normal transmission.

The engineering staff of some commercial broadcasting stations, among them WTOP, Washington; KDKA, Pittsburgh; and WSM, Nashville, have constructed frequency shift keyers for their respective transmitters, in conjunction with the FCC for Project "BRECOM" which preceded this program. These keyers were designed for 60 wpm operation. At 100 wpm it has been reported that individual bits would not achieve full frequency deviation. This is not surprising since broadcast crystals are cut for high stability. Crystals may be specially cut such that they are capable of short term instability and when placed in an oven, and in conjunction with a stable tank circuit, exhibit long term stability. A crystal specially cut to a frequency f_o may be shifted ± 18 cps at a 75 baud rate (100 wpm) and achieve full frequency deviation, and yet, after a long period of time still oscillate at frequency f_o. Crystal oscillators with the properties described above have been provided by two manufacturers. A long range stability of 1 part in 10^7 per day has been achieved.

A teletype channel is normally designated by its center frequency (centered with respect to the mark and space frequencies). However, standard teletype keyers have no circuitry which is capable of transmitting the center frequency. When there is no traffic on the circuit, a steady mark is transmitted (mark hold condition). If this normal procedure were followed in this system it would mean that in a no-traffic condition the broadcast station would be transmitting 18 cps above its assigned frequency which is undesirable. Therefore, the R.F. keyer was developed as a three level device. In a no-traffic condition, the keyer will oscillate at its center frequency, which is the

broadcast station's assigned frequency. The same code that alarms the sequence selector will put the keyer in a state in which it is capable of being keyed.

Several different types and models of transmitters are in use at the various radio stations. These include RCA, General Electric and Westinghouse, both 5 KW and 50 KW transmitters. As might be expected, the oscillator section of each transmitter is designed differently. Each transmitter would therefore require a different modification to equip it for frequency shift keying. The undertaking of such a process by RADC personnel, would require an extensive analysis of all the transmitters in the system and would have been too time-consuming. An alternative would have been to give the responsibility of modifying each transmitter to the engineering staff of the respective radio station. Experience indicated that this modification was a difficult task involving a trial and error approach and it seemed unfair to saddle the station engineers with the problem.

One component that is common to all oscillators is the crystal. With this thought in mind, the decision was made to provide a package that would contain a highly stable crystal capable of being frequency shifted, all the control circuitry required to accomplish this end, and be a plug-in replacement for the transmitter crystal. This approach eliminated extensive transmitter modifications and made it possible to use the same package at all radio stations. The keyer unit is mounted inside the transmitter, generally bolted to the base plate or one of the metal plates partitioning the sections of the transmitter. The coax cable carrying the R.F. output and the two wires bringing AC to the keyer are then wired into an octal socket which is plugged into the receptacle ordinarily holding the transmitter crystal. The package and all the control wiring entering the transmitter may be completely installed in a few hours. In the event of failure to the keyer oscillator, or termination of this program, the transmitter may be restored to its original unmodified condition in minutes by simply plugging in the original crystal.

When these aforementioned problems had been solved, at least in principle, as indicated by the thinking outlined in the preceding paragraphs, the specifications were written. To summarize briefly, the RF keyer must be a self-contained crystal-controlled oscillator needing only 115 VAC (accessible in all transmitters) to operate, must be capable of shifting ±18 cycles at a 75 baud rate, must accept a 20 m.a. neutral current keying input, must remain on center frequency during no-traffic conditions, must exhibit long term frequency stability and must provide an output that will directly replace the crystal in the transmitter.

b. Equipment Comparison and Problems

Greenray Industries and Reeves-Hoffman Corp. submitted slightly different designs of RF keyers that would meet the specification. Each design incorporated voltage variable capacitors in the oscillator circuit as a means of attaining the frequency shift.

Teletype is basically a two-level system, one level represented by current (mark), and the other by no current (space). However, a three-level system was desired, i.e., the center frequency was desired. Therefore, it was

necessary to provide a method for obtaining a third level. The method chosen was a control relay. The relay would be in a 20 m.a. current loop and would be closed under no-traffic conditions and would open when the station was alarmed and prepared to transmit.

The crystal in the Greenray keyer is cut to space frequency (f_o - 18 cps) and is shifted 18 cycles to center frequency and a total of 36 cycles to mark frequency. This scheme has the disadvantage of requiring two voltage variable capacitors and also of needing 20 m.a. current through the closed control relay to stay on center frequency. On the other hand, the crystal in the Reeves-Hoffman keyer is cut to the desired center frequency and is shifted ±18 cycles to mark or space, thus requiring only one voltage variable capacitor. Refer to Table II for a comparison of the two keyers for different input conditions.

TABLE II Keying Conditions

Greenray

Control Relay	Current	Frequency
Open	0 ma	Space
Open	20 ma	Mark
Closed	0 ma	Space
Closed	20 ma	Center

Reeves-Hoffman

Control Relay	Current	Frequency
Open	0 ma	Space
Open	20 ma	Mark
Closed	0 ma	Center
Closed	20 ma	Center

There are two minor advantages to the Reeves-Hoffman design. It is somewhat simpler in using a single voltage variable capacitor, consequently requiring only one keying transient filter. Also since no current is required to remain on center frequency, it is possible to turn off the DC power supply, perform maintenance in the equipment racks, and keep the radio station on its assigned frequency. These are slight practical advantages and could be, if desired, incorporated into the Greenray design. They are in no way detrimental to the operational quality of the Greenray keyer.

At this time all keyers have been in continuous operation from seven (7) to eleven (11) months. Both types have operated reliably and shown a high degree of frequency stability with the exception of the 570 kHz and 590 kHz oscillators. The low frequency crystals are inherently less stable than high frequency (above 1 megacycle) crystals and have to be adjusted two or three cps

approximately every two months. The only problem that has occurred to date was a mercury thermostat in a Reeves-Hoffman keyer that failed causing the oven to overheat and the crystal to drift 23 cycles. The thermostat was replaced and the problem has not reappeared.

The major problem concerning the keyers was in output level. An output of 1 volt rms into 1000 ohms (1 milliwatt) was specified and was considered adequate for replacing the crystal in the oscillator circuit. This was indeed the case in the 5 KW transmitters. However, this 1 volt output from the keyer was insufficient to drive succeeding stages of the 50 KW transmitters. This problem was resolved when a single stage transistor amplifier with tuned circuit output was fabricated at RADC and used successfully in all 50 KW transmitters. This amplifier provided an output of 60 volts rms into 100,000 ohms.

Figure 7 shows the two keyers. The Greenray keyer is 4 x 4 x 6 inches. The Reeves-Hoffman keyer is 6 x 6 x 7 inches. This approaches the practical limitation in size.

In conclusion, both keyers have performed as well as could be desired and it is not possible to say either one is superior.

c. Recommendation for Future Consideration

The keyer output should be specified to be continuously variable in two ranges, one range from 1 volt rms to 10 volts rms into 100,000 ohms for use in 5 KW transmitters, the other range from 50 volts rms to 70 volts rms into 100,000 ohms for use in 50 KW transmitters. Thus, additional amplifier stages must be included in the keyer unit.

If the oscillator frequency is to be below 750 kHz, a higher degree of stability could be obtained by utilizing a crystal cut to twice the desired frequency and using a frequency divider network to obtain the lower frequency.

The present keyers are installed inside the transmitters. The transmitters are provided with interlocks so that they may not be opened while in operation. If it is necessary to work on the keyer or make frequency adjustments, this can be done only when the station is off the air for preventative maintenance. This is usually midnight Saturday or Sunday which is an inconvenient time to work. Since the majority of radio stations are off the same night, it also means only one or at most two keyers can be worked on in the same week. The ideal situation would be to install the keyers in the equipment racks and run cables to the transmitter. This would allow maintenance to be performed on the keyer at all times. However, this may not always be possible since the cable from the equipment rack would have to be run through a trench system to the transmitter and could require up to 200 feet of wire. The losses at the RF frequencies may be prohibitive.

Some thought should be given to heat insulating the crystal oven or the entire keyer unit from changes in temperature. In one isolated

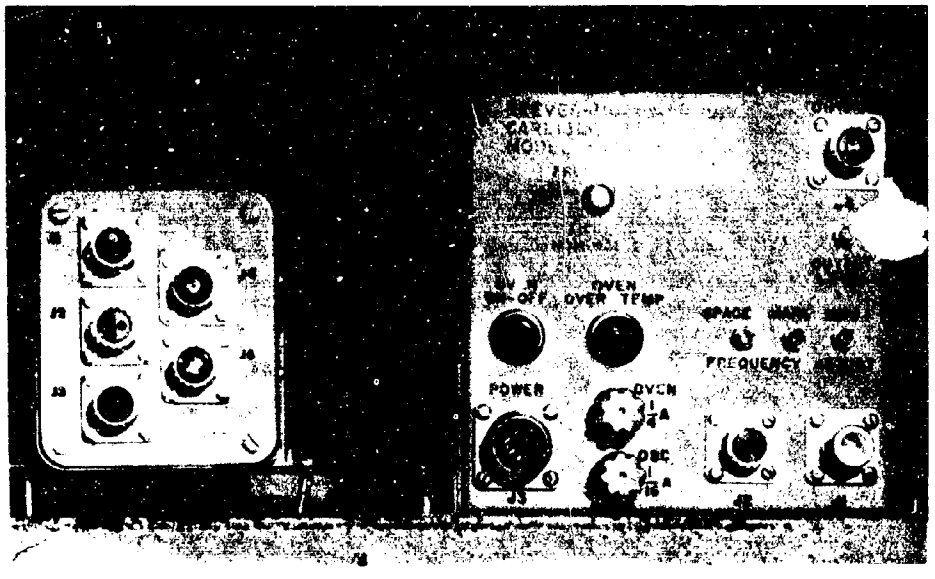


FIG. 7 GREENRAY KEYER (LEFT) AND REEVES-HOFFMAN KEYER (RIGHT)

instance air used to cool the transmitter is brought directly in from outside the transmitter building. When the temperature dropped to below freezing, this cold air flowed directly on the uninsulated keyer resulting in a situation in which the oven heater could not keep the crystal at proper temperature. Hence the crystal frequency drifted. To remedy this situation, the keyer was placed in an airtight metal box filled with fiberglass insulation. No further problems have occurred.

Mark, space and center frequency can be adjusted independently. These adjustments should be available on the front panel.

d. Analysis of Interference Problems

The most stringent requirement placed on the system was that there be no interference with normal broadcasting material caused by frequency shifting the carrier. The modulating wave form will be an undistorted square wave since the keying signal will always be the output of a regenerative repeater. The familiar text book analysis shows that this type of modulation will result in an infinite number of side-bands. However, this is a narrow band system. The criterion for narrow band is that the modulation index be less than 0.5. "Modulation index" is defined to be the frequency shift divided by the modulating frequency. Here the frequency shift is 18 cps and the modulating frequency is 37.5 cps. Thus the modulation index is 0.48. But even narrow band FM requires a considerable bandwidth. Harmonics of the keying rate are generated in the audio band and cause interference to the normal programming. A keying transient filter designed by personnel at the FCC Laurel Lab facility eliminated this problem.

Figures 8 and 9 show the effect of the filter on the keying wave form. The rounding of the pulses is indicative of reduced bandwidth. The bottom trace in Figure 8 shows the square wave keying pulse consisting of a Mark-Space-Mark combination at the input to the filter. The top trace graphically illustrates the rounding of the pulses by the filter. Figure 9 is an expanded view of a single pulse.

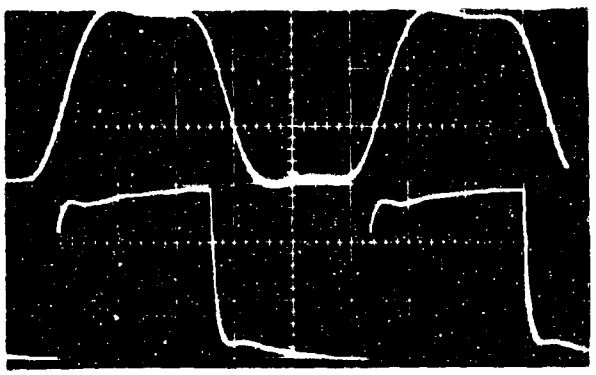
The following paragraphs sketch the theoretical analysis. For the purpose of analysis, a cycle is considered as a mark and space since a series of 1:1 reversals will require a greater bandwidth than any other combination of marks and spaces. The Fourier Series for the pulse shown in Fig. 10 is

$$f(t) = \frac{3}{4} + \frac{3}{\pi} \cos 2\pi f_m t - \frac{1}{\pi} \cos 3(2\pi f_m)t + \frac{3}{5\pi} \cos 5(2\pi f_m)t$$

$$- \frac{3}{7\pi} \cos 7(2\pi f_m)t + \ldots\ldots\ldots \qquad (1)$$

Where f_m is the modulating frequency and is 37.5 cps.

Combining (1) with the frequency response of the filter shown in Fig. 11 and neglecting all terms that are more than two orders of magnitude smaller than the lead term in the series, results in the modulating wave form

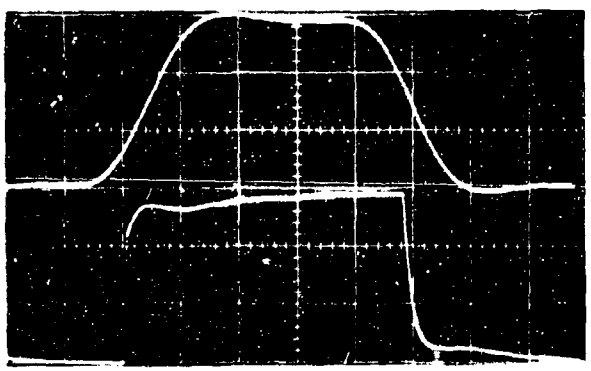


(a)

(b)

(a) Shaped Wave at Filter Output
(b) Square Wave at Filter Input
(c) Scale: 5 msec per centimeter
0.5 volts per centimeter

FIGURE 8 WAVE SHAPING BY KEYING TRANSIENT FILTER



(a)

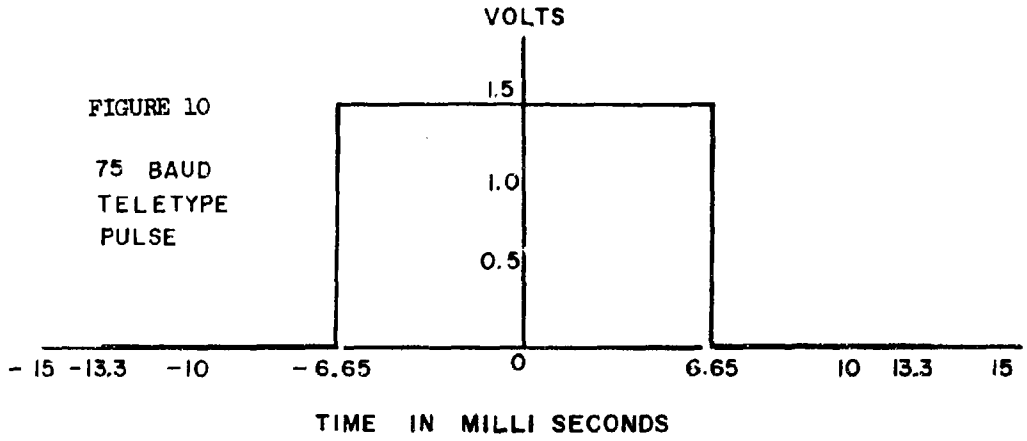
(b)

(a) Shaped Wave at Filter Output
(b) Square Wave at Filter Input
(c) Scale: Uncalibrated

FIGURE 9 EXPANDED VIEW OF SINGLE PULSE

FIGURE 10

75 BAUD
TELETYPE
PULSE



75 BAUD PULSE

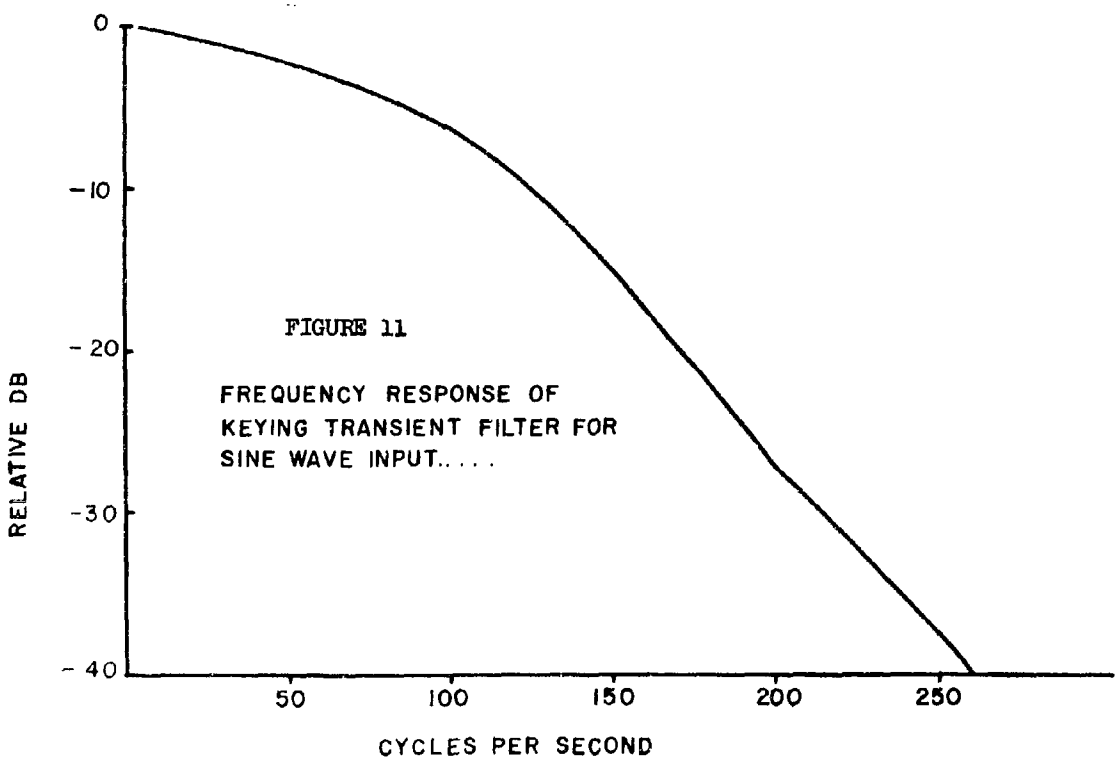


FIGURE 11

FREQUENCY RESPONSE OF
KEYING TRANSIENT FILTER FOR
SINE WAVE INPUT.....

that is given by

$$f(t) = 0.75 + 0.86 \text{ Cos } 2\pi f_m t - 0.16 \text{ Cos } 3(2\pi f_m)t + 0.013 \text{ Cos } 5(2\pi f_m)t \quad (2)$$

Let the carrier be represented by

$$f_s(t) = \text{Cos } 2\pi f_s t \quad (3)$$

and the modulated wave be given by

$$f_m(t) = \text{Cos } \phi(t) \quad (4)$$

The subscript s is written in (3) since the analysis of the pulse began using a zero voltage reference which in a neutral teletype system is the space condition. The instantaneous frequency f is defined as

$$2\pi f = \frac{d\phi(t)}{dt} \quad (5)$$

The deviation in frequency is proportional to the amplitude of the modulating signal. Therefore

$$2\pi f = \frac{d\phi(t)}{dt} = 2\pi f_s + K\left[0.75 + 0.86 \text{ Cos } 2\pi f_m t - 0.16 \text{ Cos } 3(2\pi f_m)t + 0.013 \text{ Cos } 5(2\pi f_m)t\right] \quad (6)$$

$$\phi(t) = (2\pi f_s + 0.75K) + \frac{0.86K}{2\pi f_m} \text{ Cos } 2\pi f_m t - \frac{0.16K}{3(2\pi f_m)} \text{ Cos } 3(2\pi f_m)t + \frac{0.013K}{5(2\pi f_m)} \text{ Cos } 5(2\pi f_m)t \quad (7)$$

$2\pi f_s + 0.75K = 2\pi f_c$ which is the carrier frequency or the center frequency of the teletype channel.

(7) may be rewritten as

$$\phi(t) = 2\pi f_c t + \frac{0.86}{E_m} \frac{KE_m}{2\pi f_m} \text{ Cos } 2\pi f_m t - \frac{0.16}{3E_m} \frac{KE_m}{2\pi f_m} \text{ Cos } 3(2\pi f_m)t + \frac{0.013}{5E_m} \frac{KE_m}{2\pi f_m} \text{ Cos } 5(2\pi f_m)t \quad (8)$$

E_m is the amplitude of the modulating wave and can be determined to be 0.71. The modulation index m is defined as

$$m = \frac{f_d}{f_m} = \frac{KE_m}{2\pi f_m}$$

where the frequency deviation f_d is 18 cps, and the modulating frequency f_m is 37.5 cps.

(8) may now be substituted in (4) resulting in the modulated wave

$$f_m(t) = \text{Cos}\left[2\pi f_c t + 1.2m \text{ Cos } 2\pi f_m t - 0.08m \text{ Cos } 3(2\pi f_m)t + 0.003m \text{ Cos } 5(2\pi f_m)t\right] \quad (9)$$

The frequency spectrum of the modulated wave is determined from (9) using various trigonometric identities and is written as

$$\begin{aligned} f_m(t) = {} & 0.991 \text{ Cos } 2\pi f_c t \\ & + 0.286 \text{ Cos } 2\pi(f_c - f_m)t + \text{Cos } 2\pi(f_c + f_m)t \\ & + 0.046 \text{ Cos } 2\pi(f_c - 2f_m)t + \text{Cos } 2\pi(f_c + 2f_m)t \\ & + 0.003 \text{ Cos } 2\pi(f_c - 3f_m)t + \text{Cos } 2\pi(f_c + 3f_m)t \\ & + 0.0004 \text{ Cos } 2\pi(f_c - 4f_m)t + \text{Cos } 2\pi(f_c + 4f_m)t \end{aligned} \quad (10)$$

A plot of (10) is shown in Fig. 12. A 150 cps tone at 100 per cent modulation would be 6 db down from the carrier. The 150 cps tone shown in Fig. 12 is 69.7 db down from the carrier or is 63.7 db below the 100 per cent modulated tone. It may be seen from this example that the interfering tone would be completely masked by normal programming. A further illustration of the usefulness of the keying filter is shown in Table III. This table compares the amplitude of the harmonics of the baud rate of a square wave modulated signal and the shaped wave modulated signal.

TABLE III Comparison of Amplitudes of Harmonics of Keying Rate for Square-Wave and Shaped-Wave Modulation

Frequency	Shaped Wave	Square Wave	Difference
f_c	0.0	0.5	-0.5
f_m	10.6	10.5	0.1
$2f_m$	27.4	24.3	3.1
$3f_m$	50.3	30.0	20.3
$4f_m$	69.7	37.8	31.9
$5f_m$	Not calculated	40.0	

Numbers are in db below carrier which is normalized.

2. Audio Frequency Shift Keyer

Audio frequency shift keyers were commercially available and were purchased as off-the-shelf items from Stelma and Northern Radio Co. The channel center frequency is 425 cps shifted ±42.5 cps. The required bandwidth is 170 cps at 75 baud. The function of the audio band keyer will be further described in the section on duplex equipment.

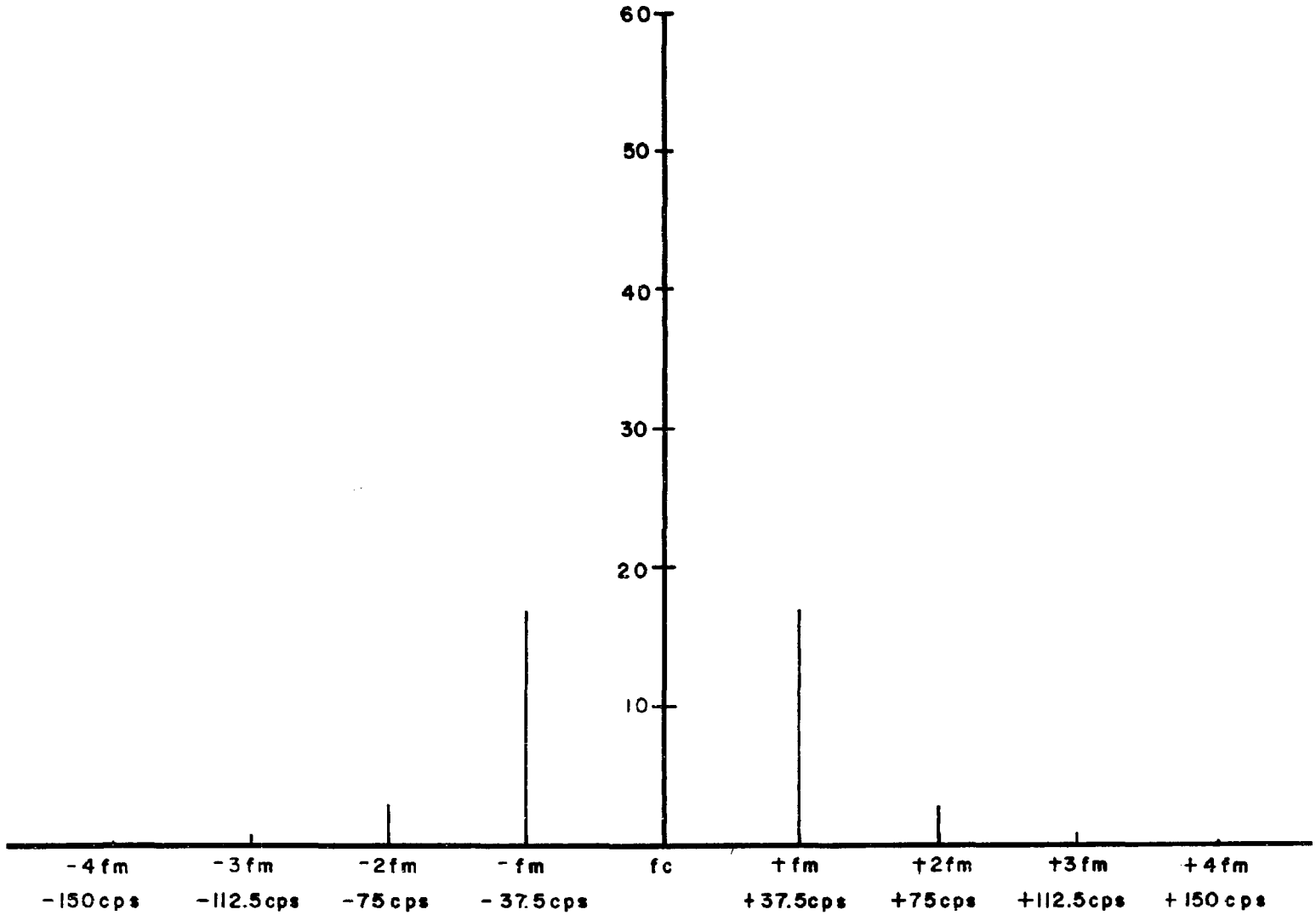


FIGURE 12 SPECTRUM OF FREQUENCY SHIFTED CARRIER

SECTION VI

RECEIVING AND DEMODULATING EQUIPMENT

1. Initial Design Phase

In the early stages of design thinking the receiver and demodulator were thought of as a single problem. Two receivers were considered for use in the system. They were the SP-600 and the R-390. Both receivers have two outputs, an IF (455 kHz) output and an audio output. The dual outputs were considered necessary since two telegraph channels were required and each output would serve a separate channel. It was envisioned that the baseband (frequency shifted carrier) channel be brought out of the receiver at 455 kHz and fed directly to a converter capable of operating from an IF input. The audio frequency channel would be brought out of the receiver at the audio output and fed directly to standard commercial speech-plus-telegraph equipment which separates the telegraph information from the speech information. A search of Air Force stock revealed that new R-390 receivers were available in quantity. The available SP-600 receivers were serviceable but in questionable condition. Hence the decision was made to utilize the R-390 receiver.

Two problems were immediately apparent; (1) demodulating the narrow frequency shift and (2) receiver stability over long periods of unattended operation. Both problems have solutions.

The frequency shift converter of the AN/URA-8 converter-comparator group has a narrow shift demodulating capability. However, it was the experience of the FCC in project "BRECOM" that the converter had to be modified with a phase lock circuit to overcome receiver instability. In addition, the performance of the AN/URA-8 in the presence of noise was not optimum at narrow shift. A search of Air Force standard stock converters was initiated. Frequency shift converter CV-116/URR operates from a 455 kHz input. However, its demodulator circuitry is capable only of detecting frequency shifts of 150 cps or greater. Converter CV-483/URA-17 (manufactured for the Navy) had a demodulator capable of detecting narrow shifts down to 10 cps. (The AN/URA-17 is a solid state version of the AN/URA-8.) Both converters were manufactured by Hoffman Electronics Corporation of Los Angeles, California. It was felt that since both converters were supplied by the same vendor, it would not be difficult to combine the desired features of both into a single unit that would meet our needs. This unit would include a phase lock circuit to compensate for receiver instability. This would provide a solution to both the narrow frequency shift demodulation and receiver instability problems. However, the cost of this solution was prohibitive. The major portion of the cost was the converter. It is a sophisticated device providing greater capability than is required for this particular application.

An alternate step was to stabilize the receivers. If sufficient receiver stability could be achieved, the necessity for phase-locked converters would be eliminated. In its place, a heterodyning unit that would convert the 455 kHz IF frequency to an audio frequency could be substituted. The audio frequency could be fed directly to a simple narrow shift converter of the type used in commercial telegraph circuits.

Westinghouse and Manson Labs previously have built stability kits for the R-390 receivers. These kits are available as off-the-shelf items. This is another solution to the narrow shift demodulation and receiver instability problems. Once again, the cost of this solution was prohibitive. The system cost could be kept at a minimum if R-390 receivers could be obtained from Air Force stock without expenditure of project funds. However, at this point it became apparent that the R-390 receivers would require approximately one-half of the allocated funds to make them compatible with system requirements. A third alternative was greatly desired.

2. Receivers

a. Receiver Design

An analysis of the requirements of the receiver yielded the following description: The receiver should be solid state, fixed frequency in the broadcast band, highly stable, highly reliable, provide two outputs and be as compact as possible. None of these requirements is beyond the state-of-the-art. Two competent manufacturers offered slightly different versions of a receiver answering this description. The cost of purchasing this type of receiver and its associated converters was approximately one-half the cost of either stabilizing the R-390 or providing phase-locked converters for use with the R-390. For this reason, and to provide greater stability and reliability, this third alternative was chosen and instrumented in the system.

Figure 13 is a list of the important receiver specifications.

b. Equipment Comparison and Problems

The best way to contrast and compare the receivers is to refer to Figure 13 and the simplified Block Diagram Figure 14. Telesignal Corp. proposed two separate receivers, one for each teletype channel. This approach has one immediate disadvantage, i.e., the RF signal from the antenna must be divided to feed both the AM and FS Receiver. Therefore, the input to each receiver suffers a 3 db loss in power plus any insertion loss due to the multicoupler. However, some of this disadvantage may be overcome in the FS case since the signal passes through a 200 cps bandpass filter instead of a 1300 cps filter thus reducing the noise bandwidth. Conversely the Manson Receiver has a 1300 cps bandpass filter but amplifies at RF before dividing the signal to feed the two detectors.

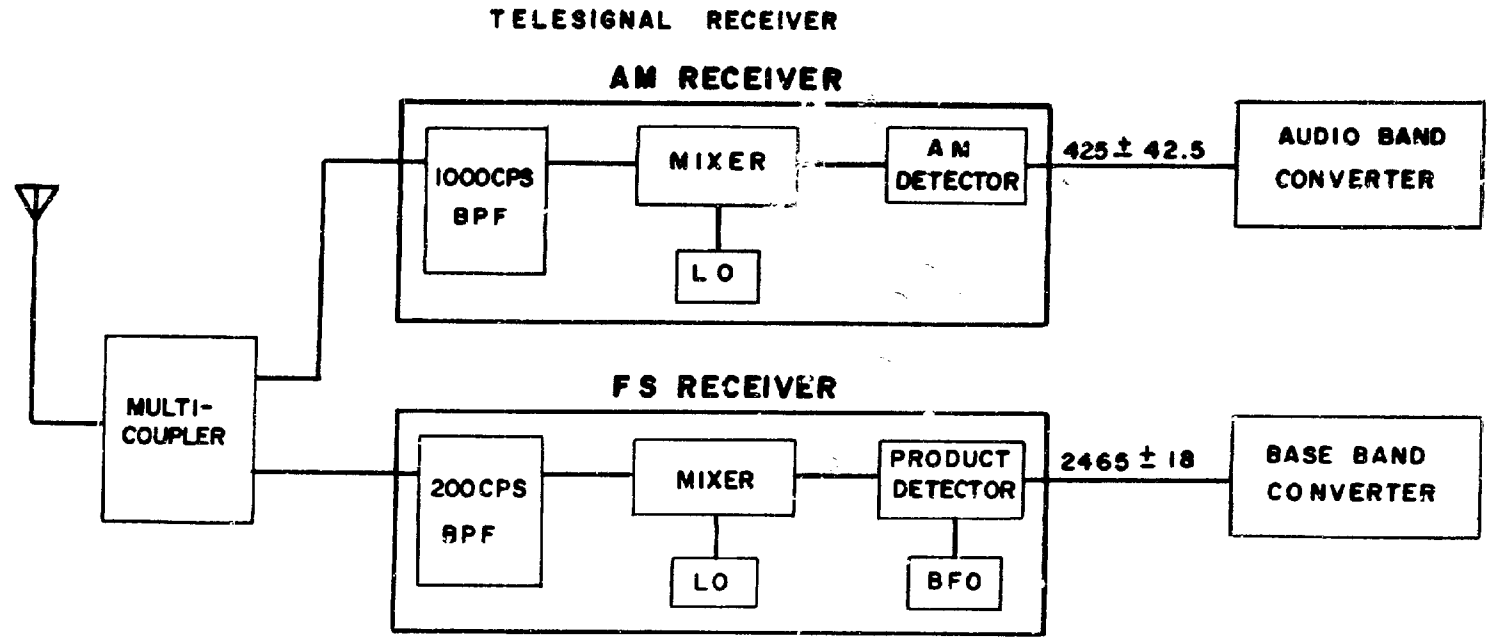
The Telesignal AM receiver utilizes a single conversion technique and AM detects at an audio frequency, while the Manson Receiver AM detects at R.F. The Telesignal FS Receiver uses a double conversion technique for the product detector, while the Manson Receiver utilizes single conversion.

Both receivers have crystal filter front ends and provide overvoltage (lightning) protection preceding the filter.

The biggest contrast is in sensitivity, and this is closely related to the question of tuning. Although the receiver was designed to operate at a single frequency, that frequency might be any place in the broadcast band.

	Manson	Telesignal FS	Telesignal AM
Sensitivity	4 uv	24 uv	40 uv
Input Signal Range	4 uv - 20 mv	25 uv - 100 mv	40 uv - 100 mv
Selectivity	3 db at 1.3 kHz 60 db at ± 6 kHz	3 db at 200 cps greater than 40 db at ± 5 kHz greater than 60 db at ∓ 10 kHz	3 db at 200 cps greater than 40 db at ± 5 kHz greater than 60 db at ∓ 10 kHz
AGC	Not more than ± 4 db variation in output level for input signals between 4 uv and 20 mv	Not more than ± 4 db variation in output level for input signals between 25 uv and 100 mv	Not more than ± 4 db variation in output level for input signals between 40 uv and 100 mv
Output Level	Continuously variable from -40 to +22 dbm	Continuously adjustable between -40 to -15 dbm	Continuously adjustable between -40 and + 10 dbm
Oscillator Stability	1×10^7 Per Day	5×10^7 Per Day	5×10^7 Per Day
Input Impedance	Nominal 50 ohms	Nominal 50 ohms	Nominal 50 ohms
Output Impedance	Nominal 600 ohms	Nominal 600 ohms	Nominal 600 ohms
Size	[illegible]" Wide 6" High 18" Deep	2" Wide 5¼" High 19¼" Deep	2" Wide 5¼" High 19⅓" Deep
Product Detector Output	2465 cps	2465 cps	---------

FIG. 13 RECEIVER SPECIFICATIONS



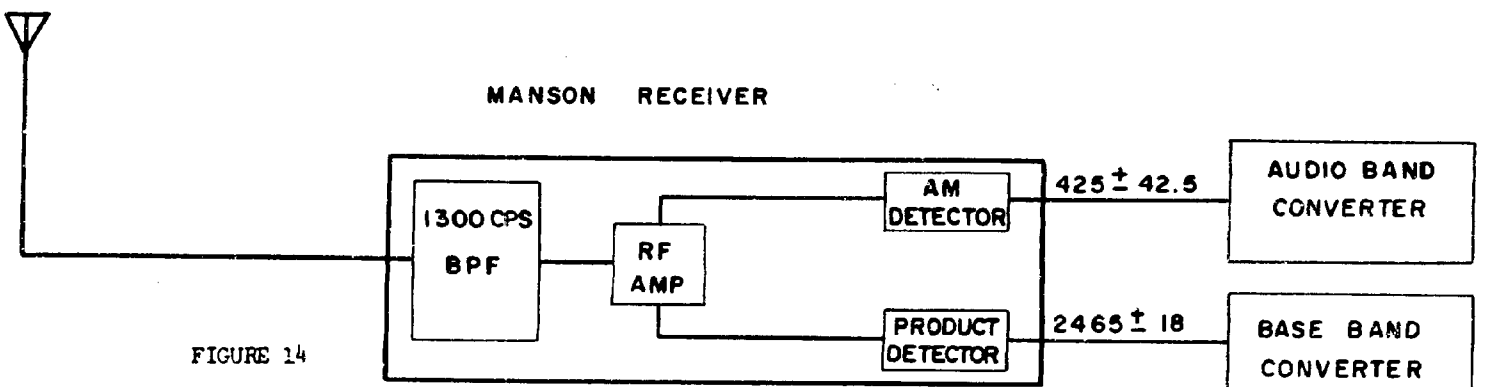


FIGURE 14

SIMPLIFIED RECEIVER BLOCK DIAGRAM

To be able to operate at any frequency, the ideal situation would be to plug in the proper front end filter and the proper local oscillator without having to tune any part of the receiver. This is the capability provided by the Telesignal receiver. The Manson receiver requires tuning of the RF amplifier stages, the input to the product detector as well as the AGC, along with changing the filter and local oscillator. This provides a greater overall gain when compared to a broadband untuned amplifier and in turn results in a better sensitivity. The tradeoff here is between having a truly untuned receiver and a receiver with better sensitivity. The choice would have to be better sensitivity.

c. Recommendation for Future Consideration

Sensitivity in the order of one (1) microvolt is within the state of the art and should be easily attainable. The input signal range is too large. One (1) uv - seven hundred (700) uv would be more realistic.

The concept of a single receiver with two outputs is superior to the idea of separate receivers for each channel for two important reasons. One is economy. A single receiver uses the same power supply, local oscillator, crystal filter and RF amplifier (also IF amplifier if a double conversion technique is used), to provide the two desired outputs, where two separate receivers would obviously require two of each of the items listed above to provide the same two outputs. A second consideration is signal strength. If it is necessary to receive n stations on a single antenna the signal would have to be divided 2n times if the dual receivers were used. This would represent a significant reduction in signal strength if n is greater than 2. The situation could be improved if active multicouplers were used. It has been the experience in this system that active multicouplers in a transmitter facility environment generate high noise levels and intermodulation products which interfere with reception of desired signals.

3. Demodulators

The high stability fixed frequency receiver design simplified the converter problem considerably. 425 cps and 2465 cps are standard frequencies employed in commercial teletype systems. Therefore, the converters were available as off-the-shelf items. It remained then to determine if these converters designed to demodulate frequency shifts of ± 42.5 cps could effectively demodulate shifts of ± 18 cps. Northern Radio Co. and Telesignal Corporation determined independently that their respective converters could demodulate the narrow shift without modification of existing converters.

Converters were purchased from three sources. Stelma converters were supplied as integral parts of Stelma Voice-Plus-Telegraph units, and are used exclusively in the duplex channel. The duplex channel has not been tested extensively as yet and therefore there is no information available regarding their performance in this system. A more detailed discussion may be found in the Duplex Equipment section. Telesignal Model 302 converters are used exclusively for the simplex channel. **One failure has occurred in a cumulative equivalent of approximately ten (10) "converter-years" operation.** Significantly there has not been a single failure of the output keying relay

which is a Clare mercury wetted contact relay. The converter does not appear to be particularly temperature sensitive.

Northern Radio Co. converters are used in both the simplex and duplex channels. The converters are identical with the exception of a plug-in frequency determining network. The following discussion applies equally to both converters.

The voltage vs frequency curve of the two tuned circuits comprising the discriminator should be symmetric with respect to the center frequency of the telegraph channel. However, each converter was found to be off-center by five to ten cycles. This deviation might not be too important for 42.5 cps shifts, for which the converter is designed, but is unsatisfactory for the 18 cycle shift used in this project. All the converters were returned to the manufacturer to correct this fault.

Another problem manifested itself during periods of particularly high temperature during the summer. When the daytime temperature remained in the 90°F - 100°F range for periods of 10-14 hours, it was impossible to alarm stations using Northern Radio converters. An on-site investigation showed that the converters had drifted beyond their operating range. However, if the temperature dropped during the night to the 75°F - 85°F range, the converters could be adjusted for proper operation. When the temperature began to approach the 90°F - 100°F range again, the converter would again drift until it became inoperable. Subsequent controlled testing at RADC proved that the output distortion increased with temperature until the converter would completely stop operating at 40°C (104°F). The cause was isolated and determined to be five temperature sensitive germanium transistors. This information was reported to Northern Radio engineers who eventually found the solution which consisted of replacing two of the germanium transistors with silicon transistors. If the converter is adjusted for operation ata nominal room temperature of 20°C, and then the ambient temperature is varied from 0°C to 50°C, the output distortion will not increase more than 10% over this temperature range. This is acceptable since this temperature range should not be exceeded in any foreseeable application in this type of system.

The transistorized output relay used in the converters and regenerative repeaters caused several problems. The failure rate of the relays is high, approximately 15 per 25 "converter-years" operation. The relay contains an oscillator whose fundamental frequency is approximately 50 kHz. Harmonics of this frequency range over the broadcast band and cause interference to the received signals. This problem has been eliminated by using by-pass capacitors. The output distortion of the relay was approximately 8% on the average for 75 baud operation. The distortion could be decreased at the expense of increasing the operating speed of the relay. It is possible to obtain both low distortion and proper operating speed by selectively replacing a capacitor in the oscillator circuit. This modification was necessary in approximately 90% of the relays.

The bias level potentiometer did not have sufficient range in all cases to pull the converter into proper operation. This condition was improved by replacing a resistor.

All the modifications discussed above have been implemented and it is

anticipated that the Northern Radio converters will now perform up to standards that are acceptable for this system.

SECTION VII

REGENERATIVE REPEATERS

A regenerative repeater is a device used to reshape and retime teletype wave forms that are distorted from propagation or other conditions and to prepare them for retransmission with a minimum of distortion usually less than 3%. Two regenerative repeaters are used in each relay and terminal facility, one for each channel. Northern Radio Company and Stelma provided regenerative repeaters. A simple checkout procedure was used to determine the maximum input distortion that could be fed into a regenerative repeater and still have the repeater function properly. Figure 15 is a block diagram illustrating the checkout procedure.

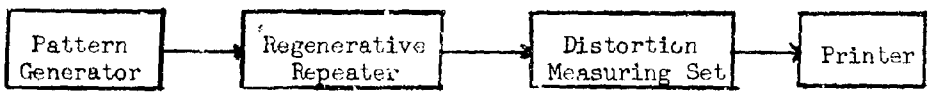


FIGURE 15 Regenerative Repeater Testing Procedure

A pattern generator is a device that can be used to generate a single character continuously. The output distortion of the pattern generator (input distortion to the regenerative repeater) can be increased in increments of 5% from 0 to 45%. The output distortion of the regenerative repeater is measured by the distortion measuring set, and the printer, in series with the distortion measuring set, prints the traffic coming from the regenerative repeater. A malfunctioning regenerative repeater manifests itself in many ways. One indication is that the output distortion increases with increased input distortion. Or if the pattern generator is, for example, continuously sending out the Character A, the printer may be printing some other character, say Q, or it may print every other A, or it may print a series of random characters. Table IV is a chart listing the maximum distortion and type of distortion that a regenerative repeater can accept and regenerate with less than 3% distortion. If the input distortion is increased another 5%, the regenerative repeater will malfunction.

TABLE IV Regenerative Repeater Input Distortion

Type Distortion	Stelma	Northern Radio
Mark	45%	45%
Space	45%	40%
Switching	45%	35%

The Stelma regenerative repeater consists of two printed circuit cards, a Hub card and a regen card. Six of the ten Hub cards received from Stelma had defective components. These components were replaced at RADC by Stelma

engineers before the equipment was sent to the field. Since that time the Stelma regenerative repeaters have been in continuous service with no failures.

The Northern Radio regenerative repeaters suffered from the relay problems discussed in the preceding section. No additional problems have been encountered.

SECTION VIII

DUPLEX EQUIPMENT

The preceding sections have discussed the characteristics and performance of the various equipments. This section is concerned with the implementation of the duplex channel. Stelma and Northern Radio have provided similiar Voice-Plus-Teletype equipments. Figure 16 is a block diagram illustrating the use of this equipment.

The broadcast audio is carried over telephone lines from the studio to the transmitting facility. With the switch in its normal position as shown, the broadcast audio goes directly to the transmitter. The switch is controlled from the sequence selector. When the duplex channel is to be utilized the proper code must be received by the sequence selector. Upon reception of this code by the sequence selector, the switch is thrown into its second position, depicted by the dotted line in the figure, routing the broadcast audio through the notch filter. At the same time another code is received by the sequence selector which then switches the receiver in series with the audio band converter. (In practice the audio output of each receiver in the facility is terminated in the sequence selector. Duplex traffic is allowed in only one link at a time, therefore only one receiver at a time can be utilized. Thus the address header must contain a code that directs the sequence selector to switch the proper receiver in series with the audio band converter. Figure 16 shows only one receiver for simplicity. This method has the advantage of requiring only a single converter for any number of receivers that are required at the relay facility.) The FSK teletype tones are converted to dc current pulses and regenerated. The output of the regenerative repeater is the input to the keyer. The keyer converts the dc current pulses to FSK tones. These tones are then inserted into the notched portion of the broadcast audio spectrum and this composite voice-plus-teletype is transmitted.

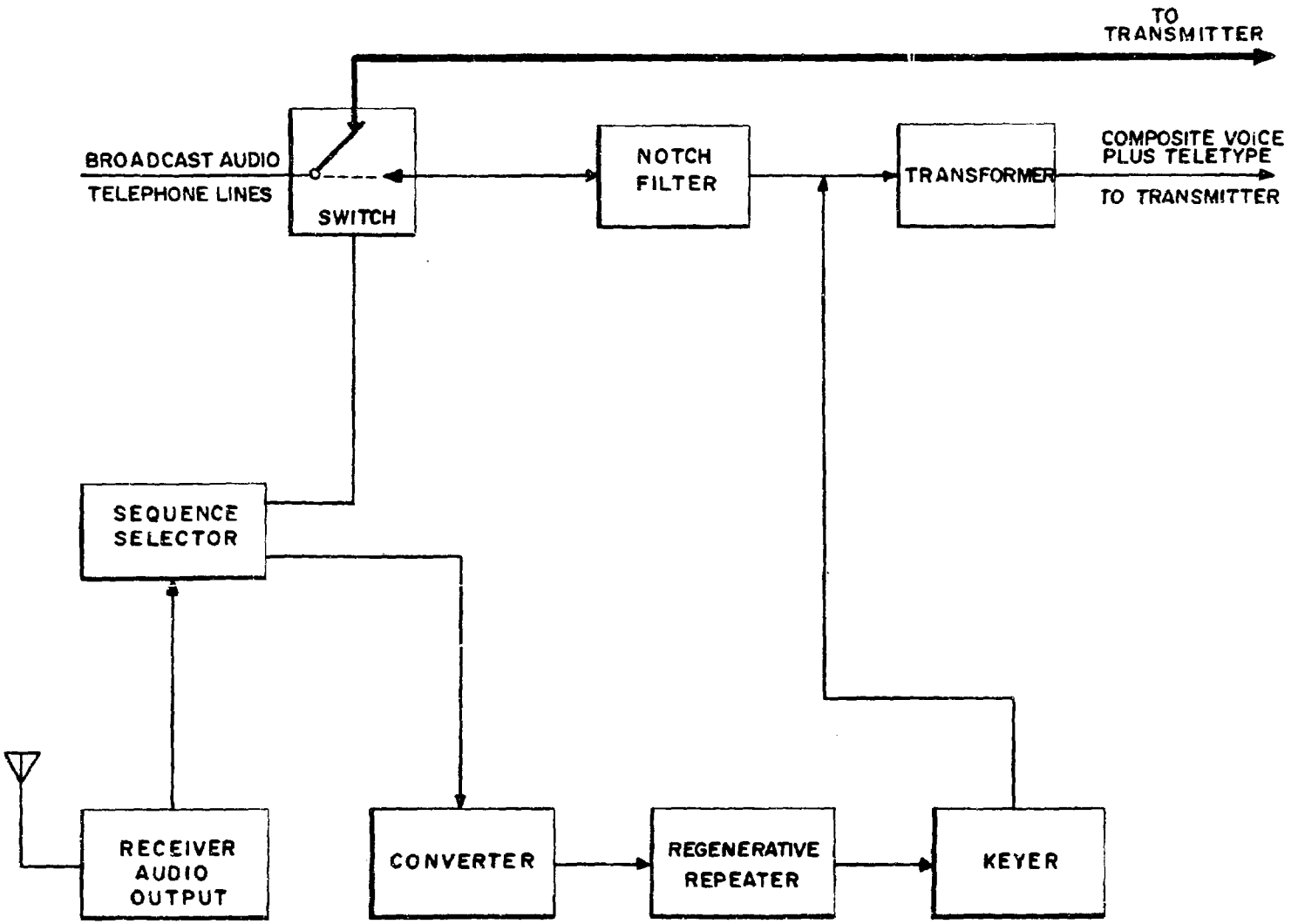


FIGURE 16 DUPLEX OPERATION

SECTION IX

DUPLEX TESTING AND RESULTS

The insertion of a teletype channel in the audio spectrum will certainly degrade the quality of the program material, but the extent of the degradation cannot be estimated. The initial testing of the duplex capability was done after the normal broadcasting schedule was completed. The first experimental link was set up between WRUN, Rome, N.Y. as the transmitting facility and RADC as the receiving facility There were several objectives of the test. First, and most basic, it was necessary to determine if the concept was sound. The testing was conducted in a systematic manner. The process of alarming the station, switching the filter, noting the effect of the tone and sending traffic while some normal program material was being broadcast was carried out a step at a time. Tape recordings of each individual step in the process and a composite speech-plus-teletype transmission were made at RADC using communications receivers, table model and transistor radios. In this way, a permanent record of the effect of this modulation on different types of radios could be determined. At the same time, the receiver-converter combination that is standard equipment in the system was receiving and demodulating the teletype information. The error rate was computed from this data. Indications are that 25-35% modulation is required in the teletype band to give an error rate comparable to the error rate of the baseband channel. Qualitatively the tests bear out the predictions that frequency shifted tones do not destroy the intelligibility of the broadcast material.

Enough experience with this mode of communications has been gained to be able to say that the technique is good and could be implemented although there remain some minor instrumentation problems to be solved.

SECTION X

TERMINAL EQUIPMENT

The network consists of three fixed send-receive terminal facilities and one portable receive-only terminal. Leased land lines connect each of the fixed terminals with one or two (as in the case of RADC) local radio stations. Land lines were utilized because of their low error rate, low cost and maintenance free operation. However, they do not provide the sensitivity that is possible with other means of communications such as H.F. Microwave or Tropospheric Scatter links. The network terminals are not limited to land lines. The system was designed so that any communications media may be interfaced with the network if greater survivability is desired at the terminals.

The user at RADC in Rome, New York is connected via land lines to Radio Stations WRUN and WGY. WRUN in Rome, New York is a 5 KW daytime station located about four miles from RADC, whereas WGY in Schenectady, New York is a 50 KW, 24-hour operation located approximately ninety miles from the user. In an emergency situation, WRUN could possibly operate on a 24-hour 5 KW basis but this would not be possible during the testing phases. It was, therefore, advisable to operate with WRUN for day-time testing to prove the capability of utilizing a 5 KW station in conjunction with a user; and WGY for night-time testing of the network.

Electronics System Division (ESD) which is located at the Murphy Complex near Boston, Mass. is a second user and is interconnected via land lines to radio station WBZ in Boston, Mass., approximately ten miles away. Due to the rigid demands of this program, the ESD-WBZ terminal is not operational as of the writing of this report. However, this terminal can be installed and made operational in a very short time if and when the need arises.

The FCC Laurel Labs in Laurel, Maryland and Radio Station WTOP in Washington, D.C. represents the third terminal facility. This terminal differs from the previous two in that all receiving is accomplished at the FCC and not at the radio transmitter as is the case at WBZ, WRUN and WGY. It was therefore necessary to place all logic equipment at the FCC and perform transmitter switching via the land lines.

Each of the three fixed terminals are equipped with a Teletype Corp. Model 28 Automatic Send-Receive Set (ASR). The ASR teletypewriter will receive messages electrically from the telegraph channel and print them on page size copy paper. With page printer monitoring, it will electrically transmit messages which are originated by either perforated tape or keyboard operation. The ASR will mechanically prepare perforated and printed tape for separate transmission with or without simultaneous electrical transmission and page printer monitoring. In addition to these functions the ASR is utilized in a station check-out procedure. This is accomplished by monitoring outgoing traffic with the mechanical stunt box that is an integral part of the page printer. With the recognition of a character sequence code by the stunt box the tape distributor is stopped and the page printer, along with the stunt box,

is placed in the receive lines to monitor the incoming traffic from the radio station. The radio station then answers its call. The answer back is received and monitored by the ASR. Upon recognition of the second character sequence by the stunt box the tape distributor (T.D.) starts and the page printer along with the stunt box is placed back into the send lines. This procedure continues until all desired stations are called, then by checking the page copy of what was sent and received it is possible to determine which links are operative.

The receive only terminal as illustrated in Figure 17 is a portable teletype receiving station which is used in conjunction with the network of radio stations. This terminal is in a standby condition until properly addressed by a local station in which case it alarms and delivers a tape and printed copy of the message being received. At the end of the message the proper code sequence is sent via the radio station to reset the receive only terminal, thus placing it back into a standby condition.

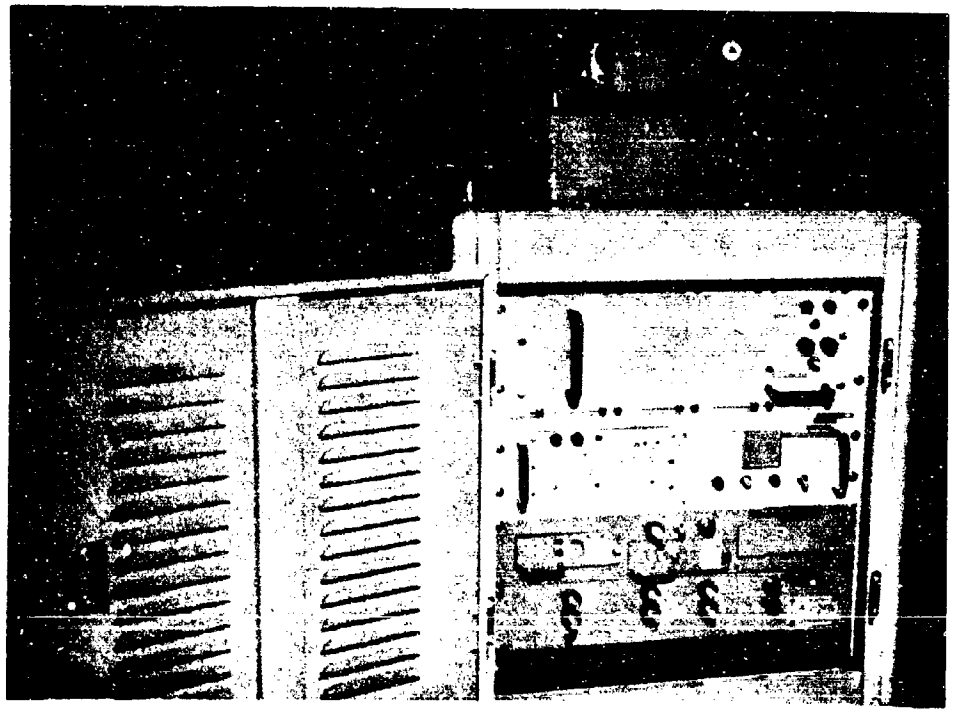


FIG. 7 RECEIVE ONLY FACILITY

SECTION XI

ANTENNAS

There were self-imposed requirements on the types of receiving antennas to be used on the system. Three types of antennas were considered, the Loop, long wire and the "Beverage Wave Antenna".[5] Vertical receiving antennas with properly tuned and phased reflectors are a possibility for improving reception, but the cost of such antennas are prohibitive.

The antennas had to be installed at the radio stations' transmitter location which immediately presented two problems. First, the amount of land available for antenna construction was limited presenting a problem with the wave antenna where 1000 feet lengths are average for reception in the broadcast band. Secondly, any antenna construction would not interfere with the station's pattern. Also, the antenna should provide some rejection of the local station. By placing the wave antenna less than three feet from the ground, interference to the station pattern is eliminated and a certain amount of rejection of the local station is possible. The loop antenna also provides rejection and will not interfere with the station pattern. The long wire however provides no rejection and could cause interference to the station's pattern.

Due to adjacent and co-channel interference present throughout the broadcast band high gain and/or high directivity were desirable. The long wire antenna was not able to provide either gain or directivity. The loop antenna provides very little gain and its directivity is limited. The figure eight pattern of the loop antenna presented problems in orientation in order to provide directivity and/or gain toward the station being received. The Beverage Wave antenna is omni-directional and provides a stronger signal over the entire broadcast band than either the loop or long wire. Atmospheric, industrial and electrical interference are considerably reduced with the wave antenna, especially when the source of interference is in a direction other than that of the received signal.

The radio links as established in the network of stations vary from forty to four hundred miles making it necessary to utilize an antenna that could achieve both skywave and ground wave reception. The wave antenna, if properly oriented, provides excellent sky and/or ground wave reception, whereas both the loop and long wire provide much weaker signals.

It is obvious that the Beverage Wave antenna best meets the requirements and, therefore, it was utilized throughout the network. The wave antenna is low in cost, has an unlikely obsolesence and expected long life. The wave antenna presented some problems in erection, due to their great length; but by careful planning the antennas were installed at every transmitter location except WIOP. Receive antenna and logic equipment for WIOP

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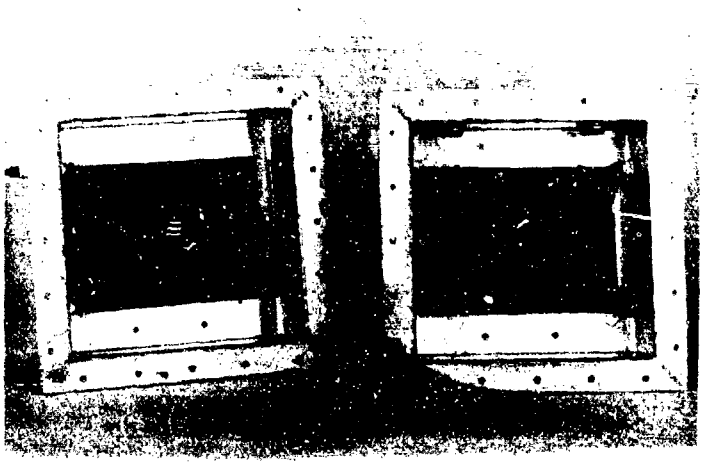
5. H. H. Beverage, O.W. Rice, and R.W. Kellogg, The Wave Antenna Transactions of AIEE, 1923

were placed at the FCC terminal facilities in Laurel, Maryland.

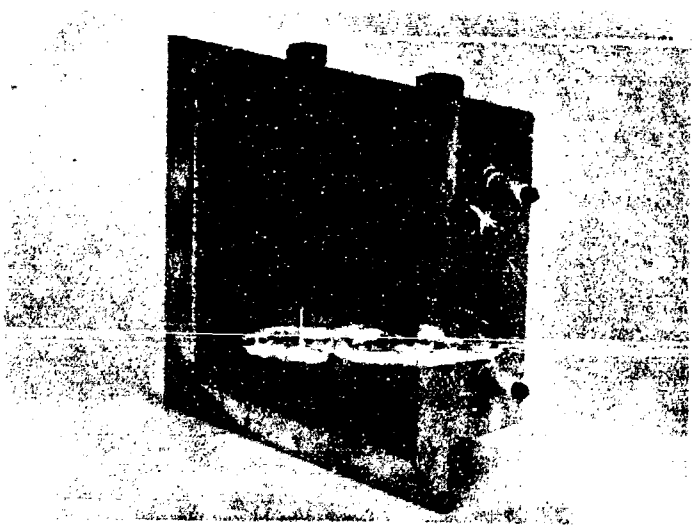
The actual erection of the wave antenna was economically accomplished by utilizing standard electrical fence posts and insulators along with copperweld wire as illustrated in Figure 18. The commercially available terminations for a wave antenna were prohibitive in cost. By purchasing transformers from a local manufacturer and fabricating watertight boxes at GAFB it was possible to assemble wave antenna termination at RADC at a fraction of what they would cost commercially. The termination as illustrated in Figure 19 are used on a two-wire, forward and reverse reception wave antenna.

Placing of wave antenna close to the ground did not entirely eliminate the interference from the local station. This was accomplished by utilizing Twin-T filters in the RF lines to the receiver. The filters were able to provide up to fifty db attenuation of the local station, thereby preventing any receiver overload that could occur. In localities where the desired signal was being interfered with from a local station, phasing of the desired and undesired signal with the undesired signal was effective in reducing the interference.

FIG. 18 BEVERAGE ANTENNA



(a) FAR END TERMINATION (LEFT) NEAR END TERMINATION (RIGHT)



(b) SIDE VIEW

FIG. 19 BEVERAGE WAVE ANTENNA TERMINATION BOXES FOR 2-WIRE BIDIRECTIONAL RECEPTION

SECTION XII

RFI SHIELDED ENCLOSURES

The design of the system required that all equipment, except that of user facilities, be placed at the various radio station transmitting facilities. Anticipating that RF shields as high as 15 volts/meter would be encountered at the transmitter facility all the equipment was placed in an RFI shielded enclosure. A commercially available RFI shielded enclosure providing in excess of 100 db attenuation in the frequency range of 150 kHz to 50 MHz was utilized. The shielded enclosure along with the equipment located at a typical radio station is illustrated in Figures 20a and 20b. Additional RFI filtering in excess of 100 db is provided on the power lines to protect the equipment in the enclosures from any RF which could enter in this fashion.

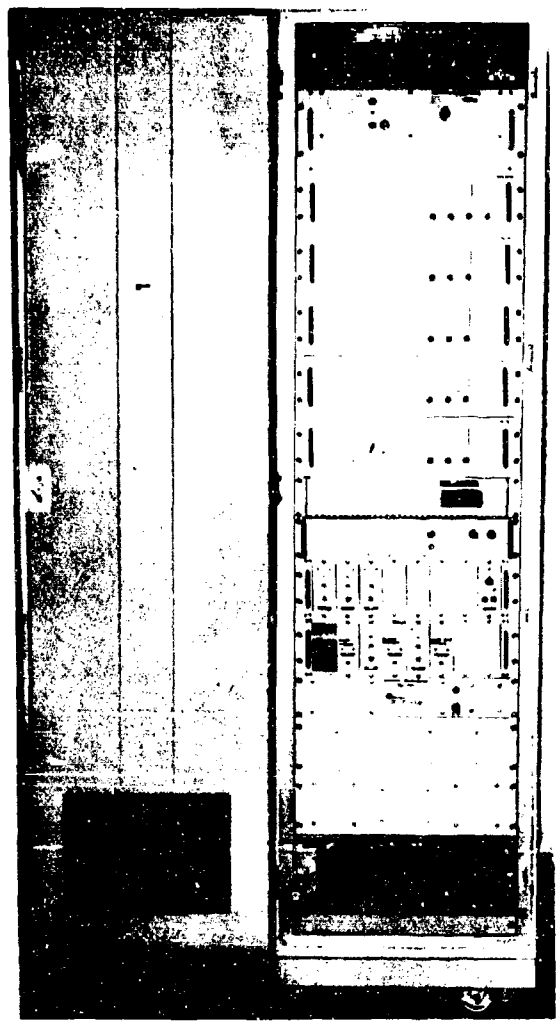


FIG. 20a EQUIPMENT RACK (FRONT VIEW)

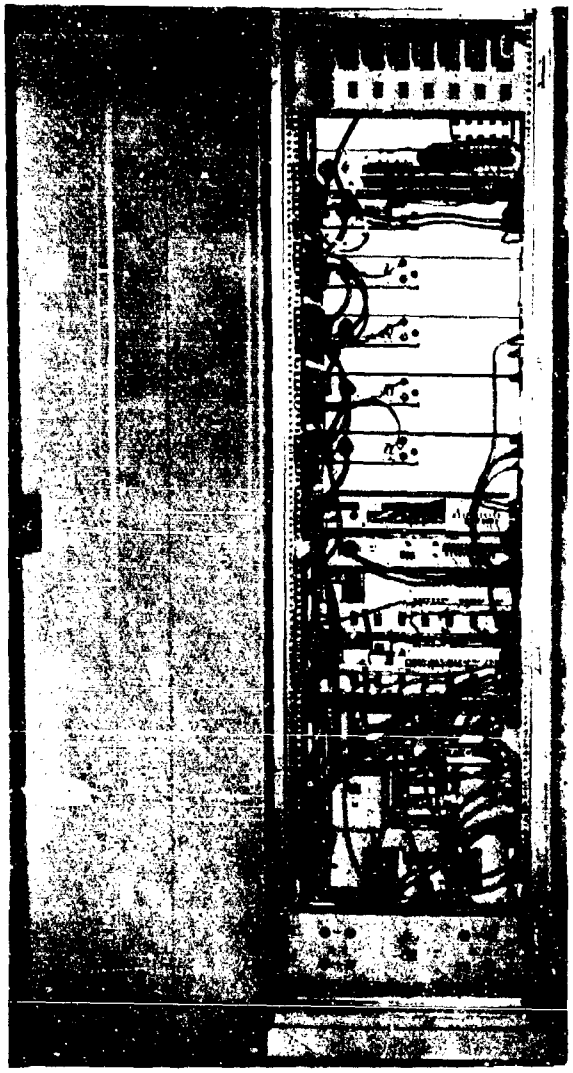


FIG. 20b EQUIPMENT RACK (REAR VIEW)

SECTION XIII

DATA COLLECTION AND PRESENTATION

In this section the data collection phase of the program will be discussed. It must be pointed out that the program requirements did not include the collection of a great amount of data necessary to prepare a long term statistical average. If such a requirement is established, it will have to be carried out as part of a program extension. Therefore, the intent of the data collection phase was to provide enough information to prove that the basic concepts of the distributed communications network as designed were sound. The data collection phase covered a three week period from 20 September 1965 to 12 October 1965. The system was scheduled to be in continuous operation from 0830 Monday to 1700 Friday. It will be noted, however, that tabulated data is not included for all the time blocks in that period. There are two reasons for this: First, at random intervals during the day, it was necessary to stop operations to conduct special equipment or system tests. Second, there is no a priori method of determining which circuits are usable at a given time. Therefore, when a circuit that was operating with an acceptable error rate began to deteriorate, the circuit was not stopped, but continued in order to determine if it would again approach an acceptable circuit. Several hours were allotted for this determination. If the circuit did not again approach an acceptable error rate in this time period, it was discontinued. The circuit was then stated to be unusable and no attempt was made to evaluate and display the data. (An unusable circuit was arbitrarily defined to be a circuit which had an error rate in excess of 100/1000.)

The majority of the data was taken on circuits initiated at RADC and terminated at the FCC Laurel Lab facility. During the data collection period many of the problems discussed in the equipment sections manifested themselves. Data collection was discontinued until the equipment modifications could be made. The modifications were completed about mid-December. The time frame of the project was such that it prevented another period of data collection. Data was accumulated utilizing Northern converters which were later modified to correct for temperature drifts. In addition, positioning of the regenerative repeaters at the top of the keying loop had a marked effect on the distortion of the retransmitted signal. The data, therefore in many cases, presents a pessimistic view of the various circuit reliabilities, and lower error rates can be expected during future operation.

The method of collecting data is described below.

For testing in a particular link an endless tape was prepared which contained the trace routing code for each station. The message which followed usually contained eight lines of repetitious information such as "R" "Y" "Space" "Space" or the "Quick Brown Fox" message. There were two problems which immediately became apparent. First, the station clock which activates on a system alarm and provides automatic reset were not set exactly for 15 minutes. Some were as much as two minutes off. Therefore, the reset functions

at the stations were not occurring simultaneously. This means that one or more stations in the link were reset while others were still in operation. Garbling of the text resulted. It was necessary to wait until the address portion of the tape was reached to alarm the inoperable station again.

An alternate was to turn off the station clocks. This was considered inadvisable, since as was mentioned in Section I, the Stelma logic systems were false alarming frequently. If there were no automatic reset capabilities, operation on a circuit would have to be halted until a manual reset could be applied. Since many stations are operated remotely, this might not occur until as much as 10 or 15 hours later. A format was prepared which would enable the data evaluator to determine the difference between errors due to propagation and faulty equipment and a garbling of the text due to resetting of one or more of the stations in the test circuit.

The header included each station address twice. The first one would alarm the node which had reset and the second would be retransmitted and become the first piece of intelligible information to arrive at the recipient's terminal since the reset had occurred. Therefore, whenever the circuit opened and was followed by an address the evaluator was able to determine that this was a reset and not a group of errors.

The second problem arose because of the repetitious information that was sent. Teletype information in the past has utilized a long stop pulse at the end of each character, i.e., approximately 1.4 times the information bit length. This provided an excellent reference with which regenerative repeaters could synchronize. The stop pulse was unique. It always followed five information bauds and was longer than the others. This system, in order to meet compatibility requirements utilized a 7.0 unit code in which all bits were of equal length. Thus triggering of the timing circuit by an incorrect reference would result in the regenerative repeater operating out of sync with the traffic and subsequently result in errors. Since the information was repetitious, the errors would also occur in some repetitious fashion until the regenerative repeater again regained synchronization. Actually, this would not be more than a minor problem during standard operation of the circuit. In fact this could have been alleviated by transmitting the character "Letters" which is a character that has a unique reference for the regenerative repeaters. This is considered standard procedure in teletype communication.

The total usable data amounted to approximately 256 hours. It will be presented in two ways: First, it will be shown that it is possible to communicate continuously between RADC and the FCC for long periods of time utilizing the same or different routes. Secondly, where possible, data on a circuit collected on different days will be averaged together and displayed on the same graph. This method will show that a circuit will be usable during some periods of time and unusable at other times.

On three separate occasions communications were maintained between RADC and FCC continuously for 24 hours or longer. Fig. 21 is an illustration of a 24-hour period in which a single circuit provided a consistently low error rate communications link with the exception of one-half hour period at sunrise. The next highest error rate was approximately 1 per 100 characters at 2230. This would mean one incorrect character in approximately every one and a half lines of copy printed on standard size teletype paper.

Fig. 24 is a composite of Figures 22 and 23 and presents another 24-hour period of continuous communication. The test began using a circuit that consisted of WGY, WTIC, WABC, WHAM and FCC. This circuit deteriorated rapidly around 1800 and became unusable. Communications were re-established by switching to a circuit utilizing WGY, WHAM and FCC.

Fig. 29 is a composite of Figures 25, 26, 27 and 28 and depicts a 28-hour period of continuous communications in which four different links were used. The test began at 1330 on 11 October utilizing 5 KW stations WRUN in Rome and WSYR in Syracuse. When WRUN switched to their low power transmitter at sunset, communications were established between WGY, WWVA, and FCC and continued until 0630, 12 October. At this time a daytime station in McKeesport, Pa. began broadcasting on the same frequency as WGY causing co-channel interference to reception of the signal from WGY at WWVA. At this time it was necessary to route traffic from WGY, through WTIC, WABC and then to WWVA and FCC. This link provided reliable communications for another hour until conditions no longer supported skywave propagation over the 400-mile path between WABC and WWVA. Finally, a fourth circuit direct from WABC to FCC continued communications until the test was concluded at 1545, 12 October. This is an outstanding example of the switching capability inherent in a distributed communications network.

Fig. 30 presents a situation which is analogous to, but chronologically before the situation shown in Fig. 29. On 23 September the link between WGY and WWVA became unusable when the interfering station in McKeesport began broadcasting. The attempt to establish a circuit between WGY, WTIC, WABC, WARM, KYW and FCC failed, thus disrupting communications. Benefiting from this experience, a different link was chosen on 12 October which was successful in the time period in which the original attempt had failed.

Figures 31, 32, 33 and 34 illustrate four periods of data collection. Figures 33 and 34 have special interest since they represent the only data taken after the system modifications had been completed. Fig. 34 is an example of a link that was in general not usable during the initial period of data collection. An equipment failure at 1300 on 27 December cut short testing for that day but data collected on 3 December in that time block is included.

Figures 35, 36 and 37 represent the compilation of all the data taken on the respective links. Fig. 35 shows that a very low error rate can be expected between 0600 and 1800 indicating that this circuit could be utilized to greatest advantage during those hours. Fig. 36 depicts a night-time only link involving WWVA which can be expected to operate with a low error rate during the hours that the link shown in Fig. 35 is for practical purposes unusable. The link shown in Fig. 37 is reliable for almost the entire 24 hours. Therefore,

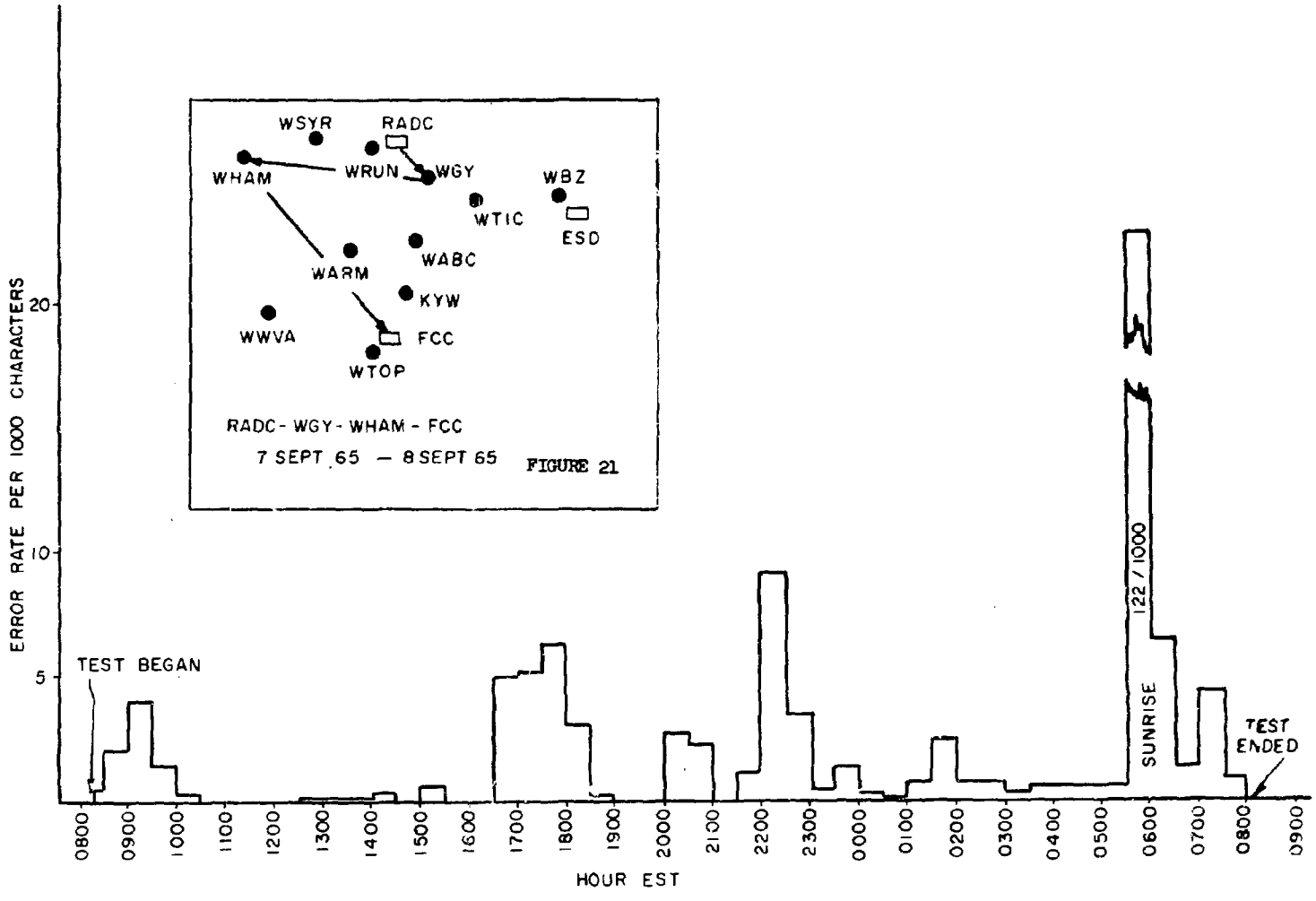

WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
RADC - WGY - WHAM - FCC
7 SEPT 65 — 8 SEPT 65
ERROR RATE PER 1000 CHARACTERS
20
10
5
TEST BEGAN
122 / 1000
SUNRISE
TEST ENDED
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
HOUR EST

FIGURE 21

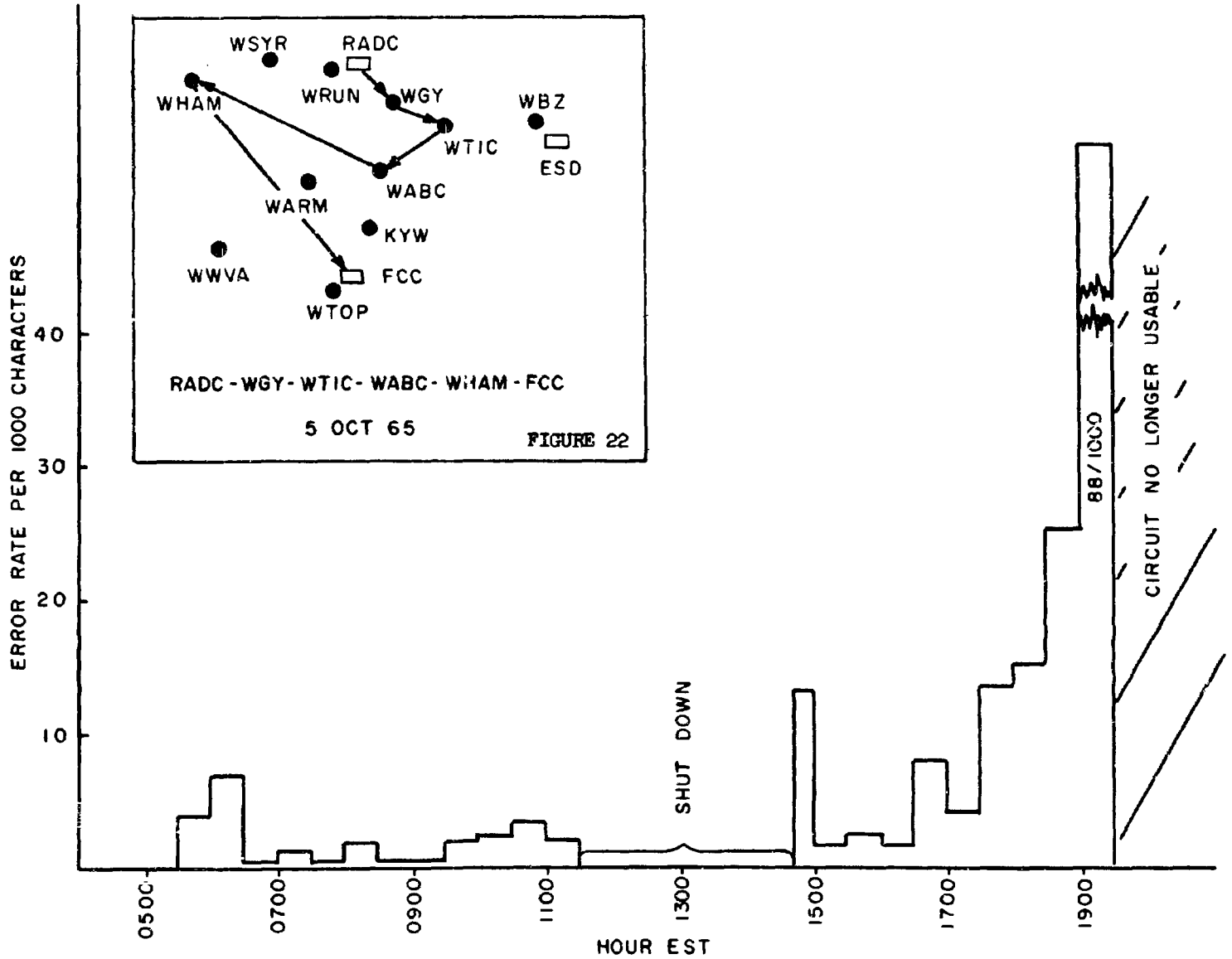

WSYR
RADC
WRUN
WGY
WHAM
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
RADC - WGY - WTIC - WABC - WHAM - FCC
5 OCT 65
ERROR RATE PER 1000 CHARACTERS
10
20
30
40
SHUT DOWN
88/1000
CIRCUIT NO LONGER USABLE
0500
0700
0900
1100
1300
1500
1700
1900
HOUR EST

FIGURE 22

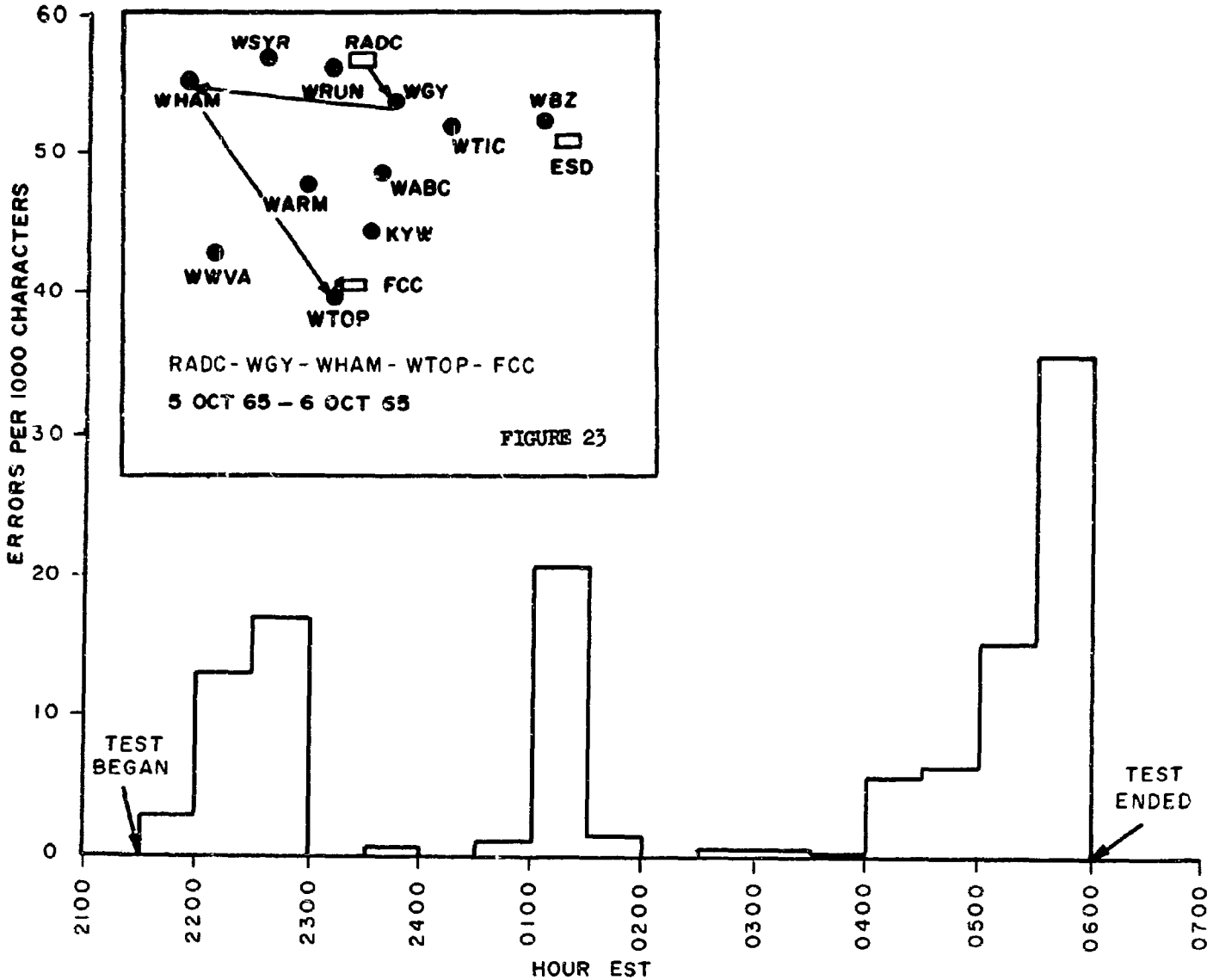

WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
RADC - WGY - WHAM - WTOP - FCC
5 OCT 65 – 6 OCT 65
ERRORS PER 1000 CHARACTERS
60
50
40
30
20
10
0
TEST BEGAN
TEST ENDED
2100
2200
2300
2400
0100
0200
0300
0400
0500
0600
0700
HOUR EST

FIGURE 23

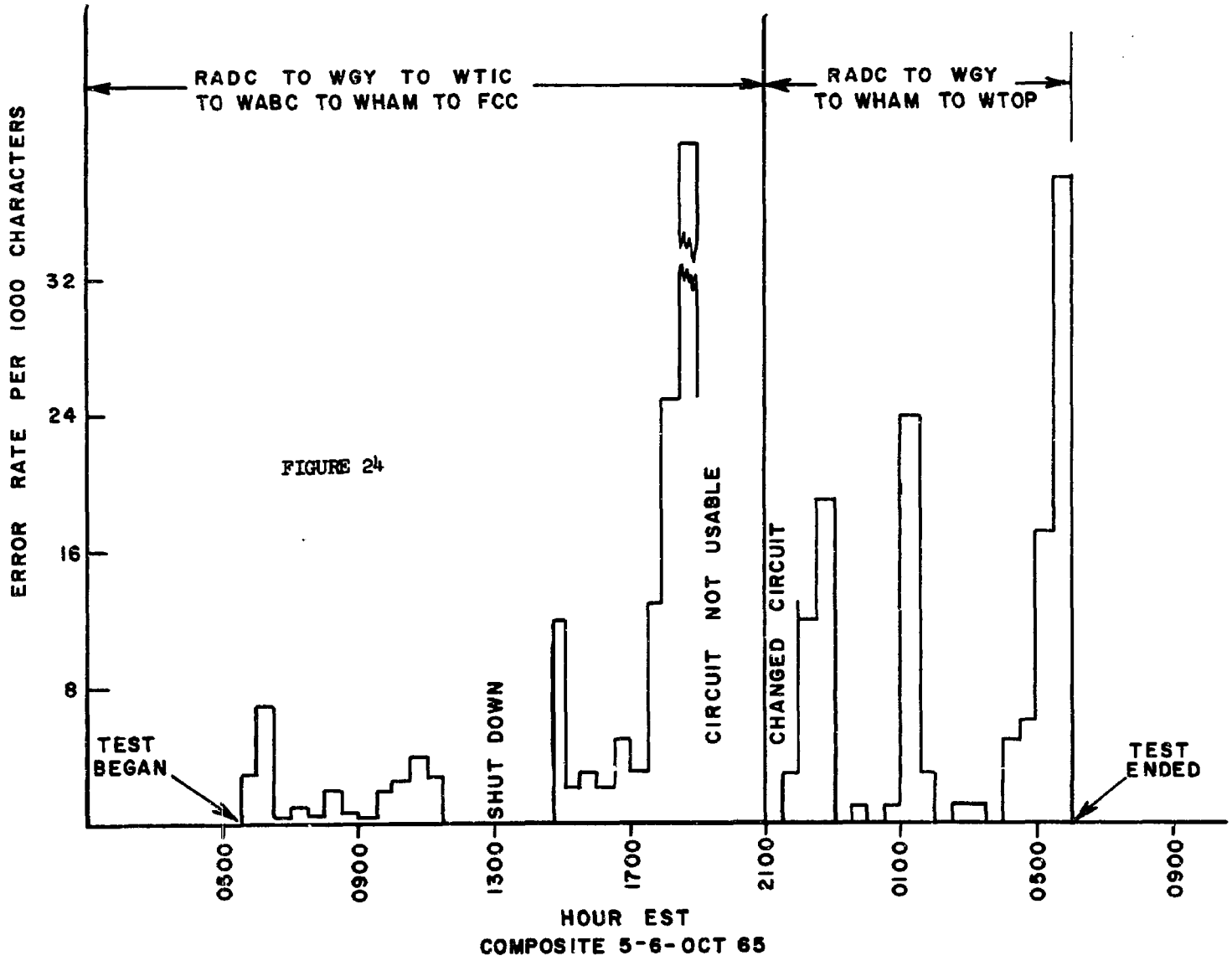

RADC TO WGY TO WTIC
TO WABC TO WHAM TO FCC
RADC TO WGY
TO WHAM TO WTOP
ERROR RATE PER 1000 CHARACTERS
32
24
16
8
TEST
BEGAN
SHUT DOWN
CIRCUIT NOT USABLE
CHANGED CIRCUIT
TEST
ENDED
0500
0900
1300
1700
2100
0100
0500
0900
HOUR EST
COMPOSITE 5-6-OCT 65

FIGURE 24

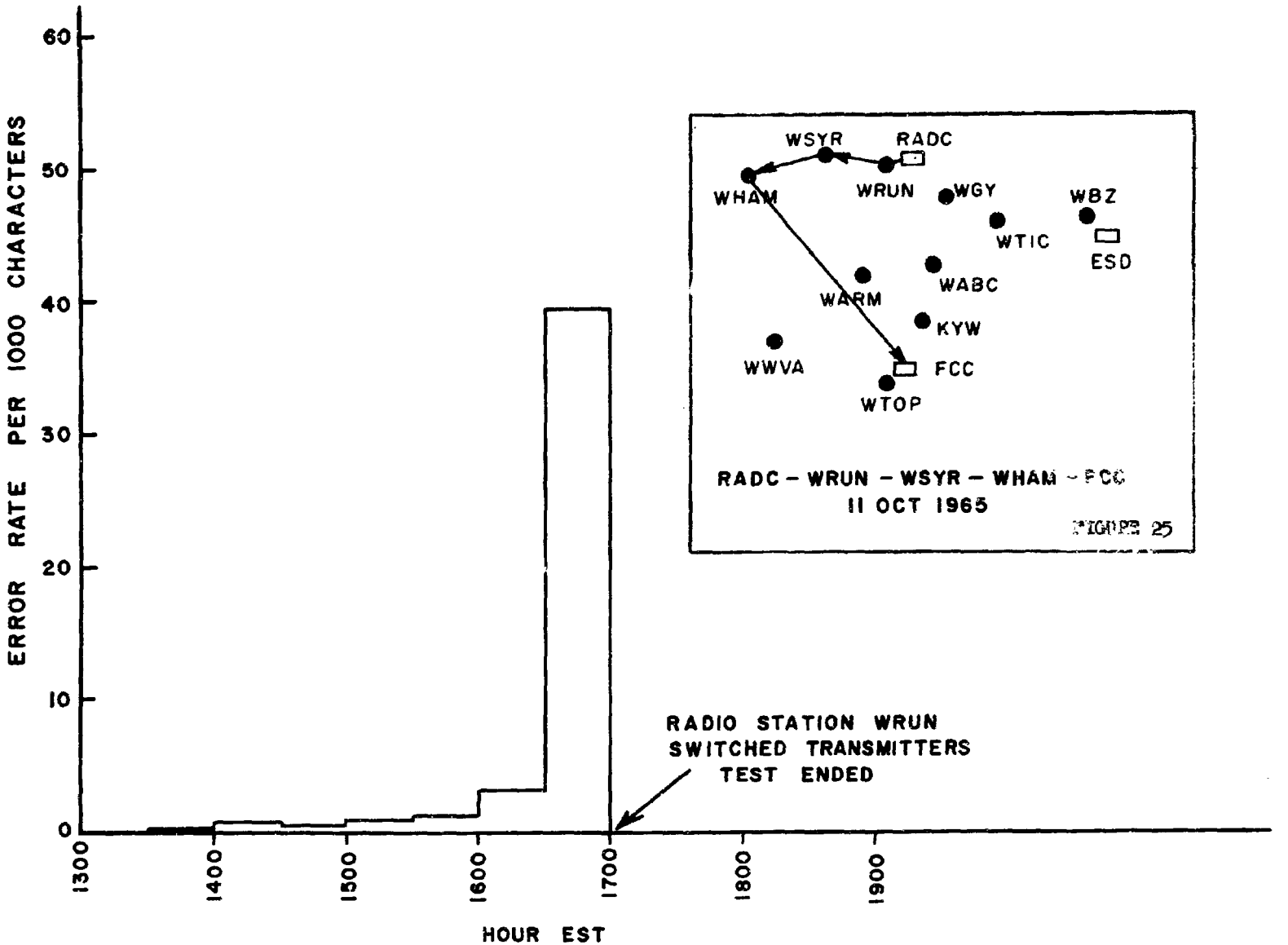
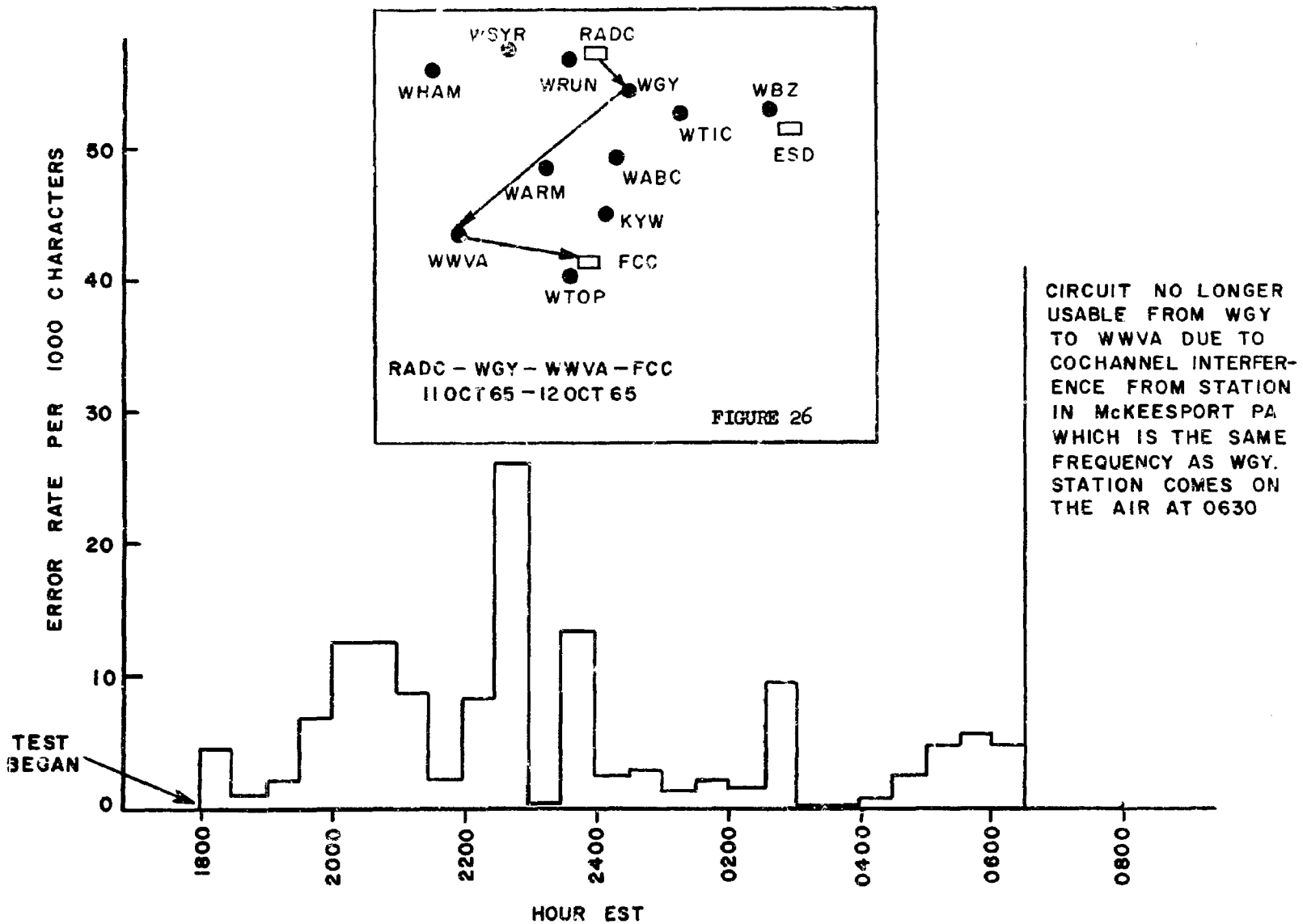

ERROR RATE PER 1000 CHARACTERS
60
50
40
30
20
10
0
1300
1400
1500
1600
1700
1800
1900
HOUR EST
RADIO STATION WRUN
SWITCHED TRANSMITTERS
TEST ENDED
WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
RADC – WRUN – WSYR – WHAM – FCC
11 OCT 1965

FIGURE 25


WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WARM
WABC
KYW
WWVA
FCC
WTOP
RADC – WGY – WWVA – FCC
11 OCT 65 – 12 OCT 65
FIGURE 26
ERROR RATE PER 1000 CHARACTERS
50
40
30
20
10
0
TEST BEGAN
1800
2000
2200
2400
0200
0400
0600
0800
HOUR EST
CIRCUIT NO LONGER USABLE FROM WGY TO WWVA DUE TO COCHANNEL INTERFERENCE FROM STATION IN McKEESPORT PA WHICH IS THE SAME FREQUENCY AS WGY. STATION COMES ON THE AIR AT 0630

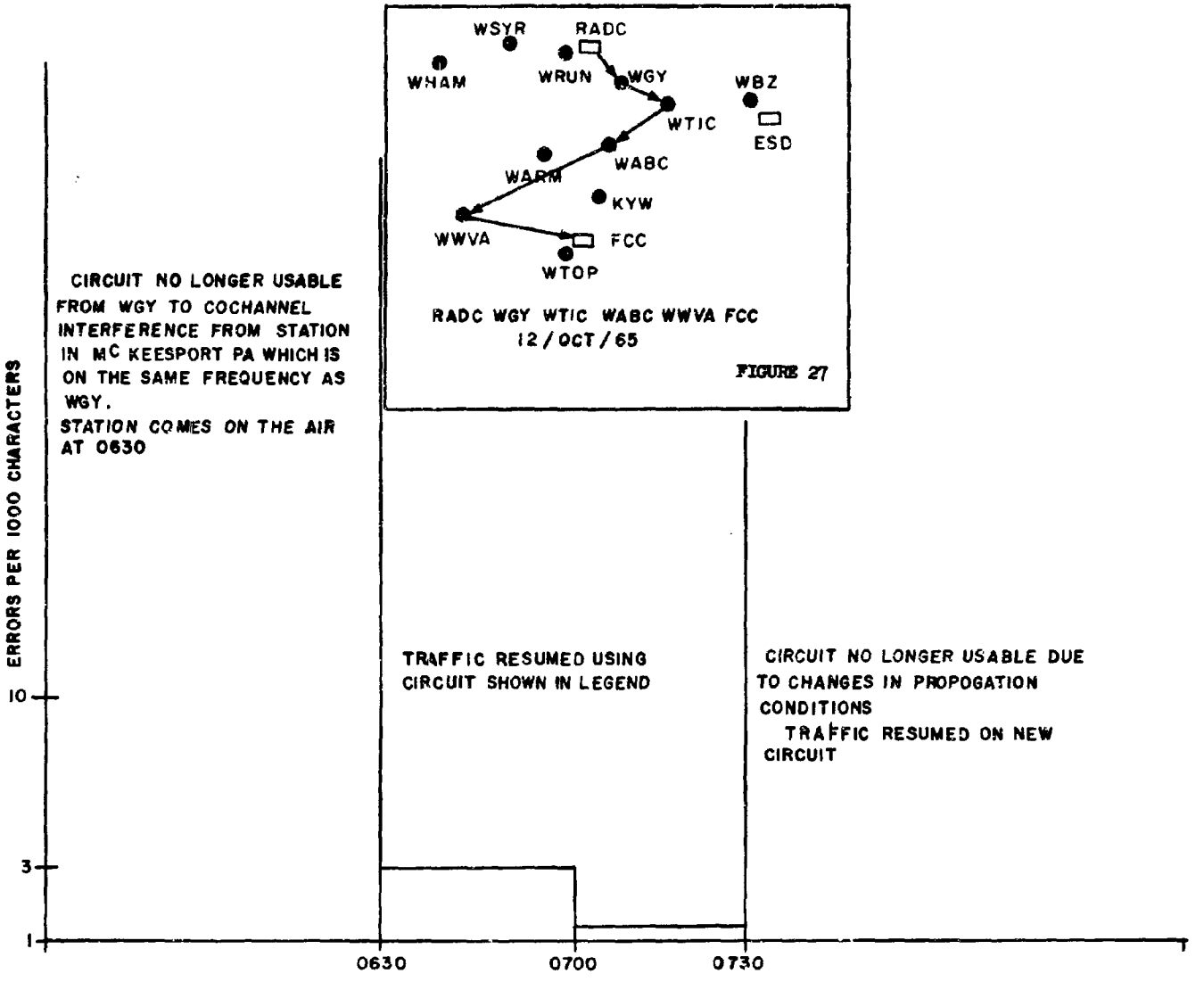

WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
RADC WGY WTIC WABC WWVA FCC
12/OCT/65
CIRCUIT NO LONGER USABLE FROM WGY TO COCHANNEL INTERFERENCE FROM STATION IN MC KEESPORT PA WHICH IS ON THE SAME FREQUENCY AS WGY.
STATION COMES ON THE AIR AT 0630
TRAFFIC RESUMED USING CIRCUIT SHOWN IN LEGEND
CIRCUIT NO LONGER USABLE DUE TO CHANGES IN PROPOGATION CONDITIONS
TRAFFIC RESUMED ON NEW CIRCUIT
ERRORS PER 1000 CHARACTERS
10
3
1
0630
0700
0730

FIGURE 27

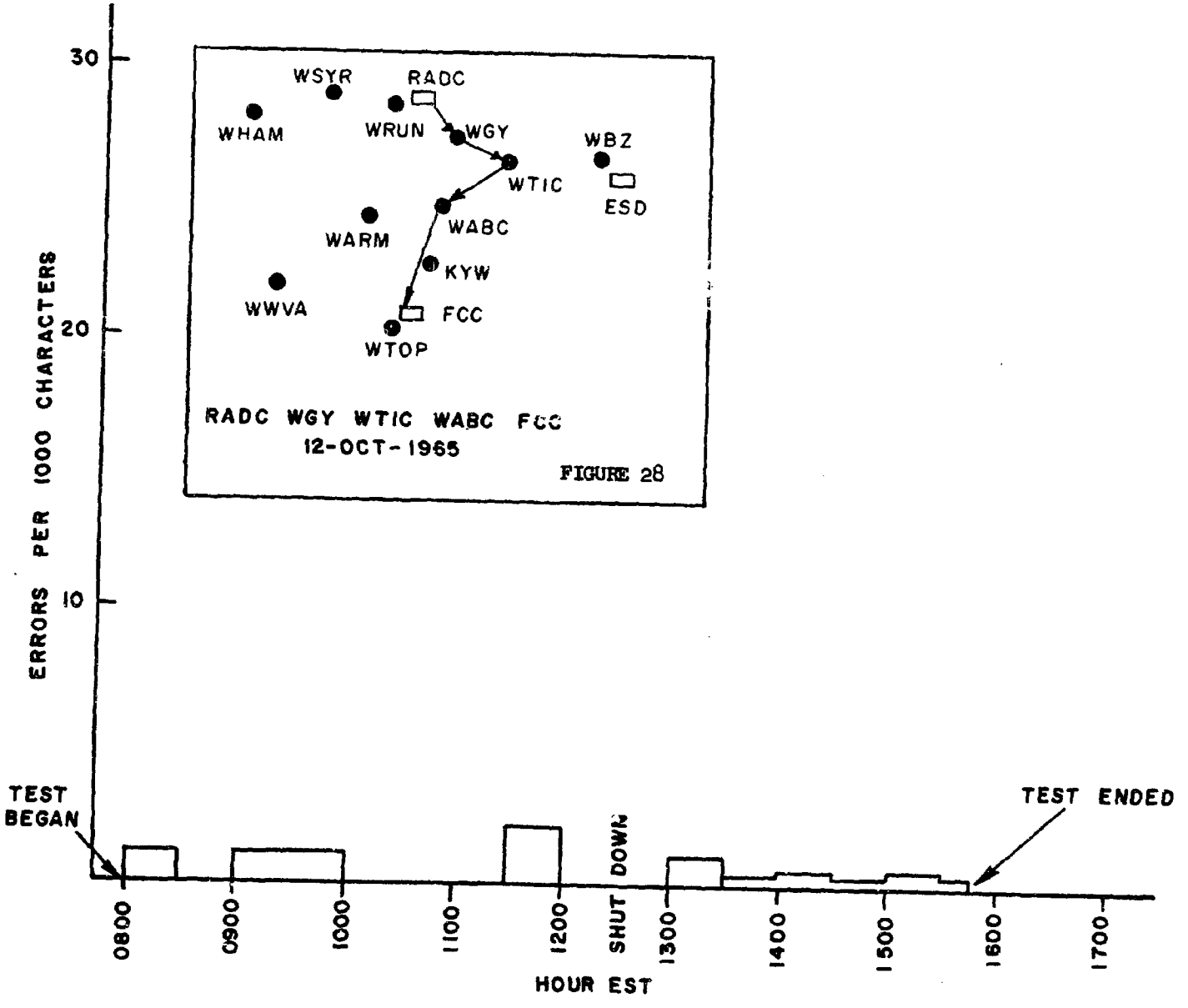

30
20
10
ERRORS PER 1000 CHARACTERS
WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WARM
WABC
KYW
WWVA
FCC
WTOP
RADC WGY WTIC WABC FCC
12-OCT-1965
TEST BEGAN
TEST ENDED
SHUT DOWN
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
HOUR EST

FIGURE 28

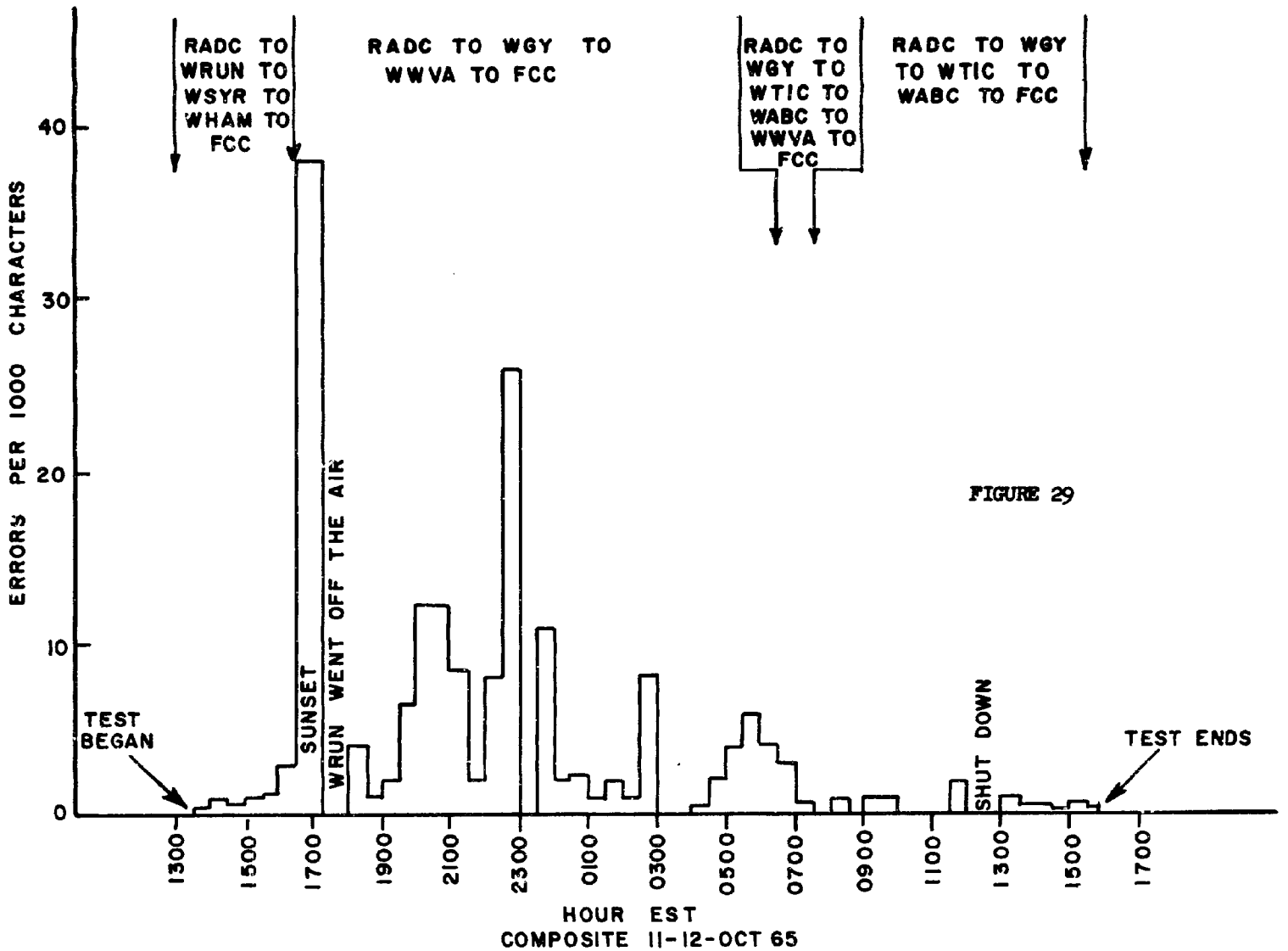

RADC TO WRUN TO WSYR TO WHAM TO FCC
RADC TO WGY TO WWVA TO FCC
RADC TO WGY TO WTIC TO WABC TO WWVA TO FCC
RADC TO WGY TO WTIC TO WABC TO FCC
ERRORS PER 1000 CHARACTERS
40
30
20
10
0
TEST BEGAN
SUNSET
WRUN WENT OFF THE AIR
SHUT DOWN
TEST ENDS
1300
1500
1700
1900
2100
2300
0100
0300
0500
0700
0900
1100
1300
1500
1700
HOUR EST
COMPOSITE 11-12-OCT 65

FIGURE 29

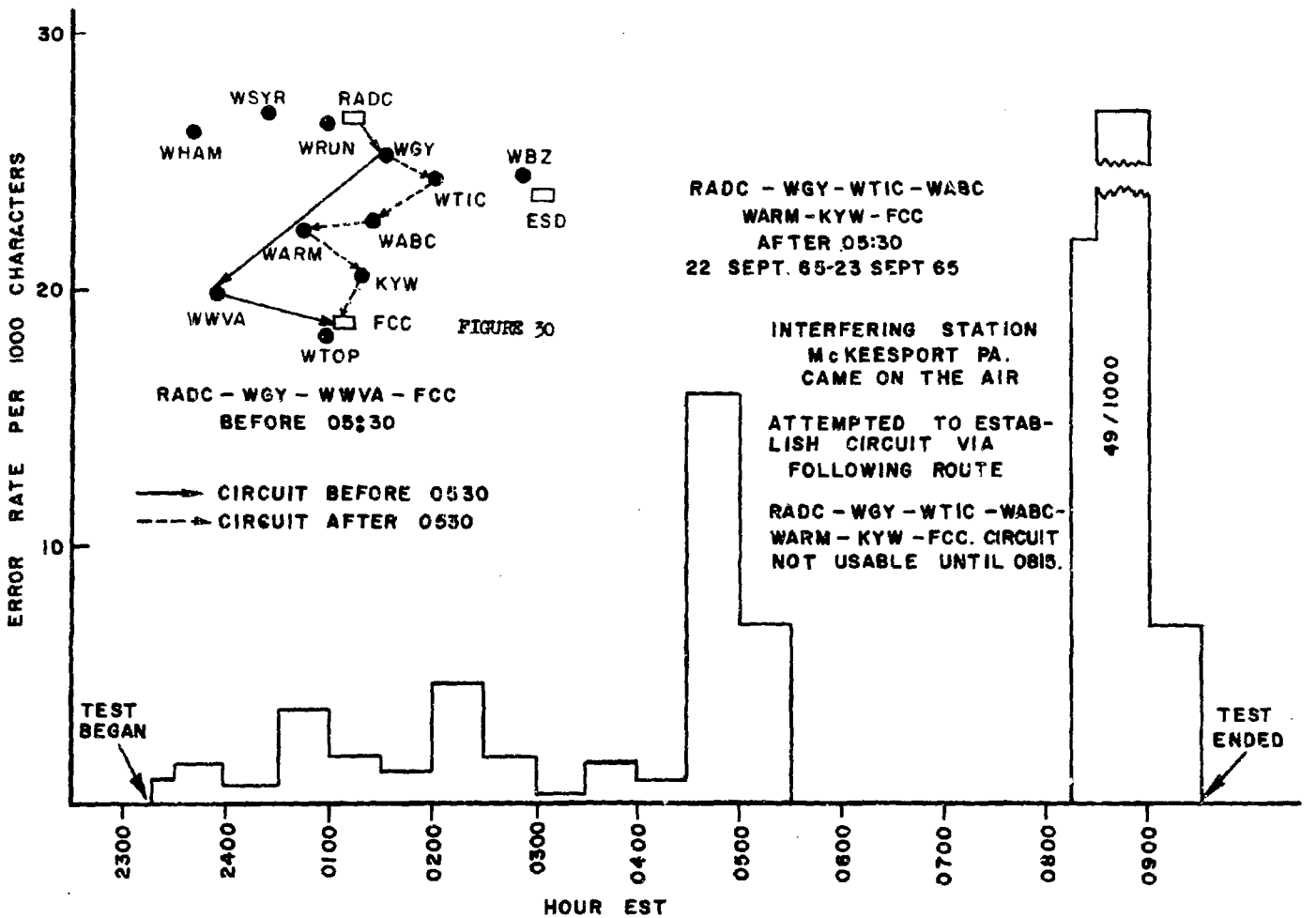

ERROR RATE PER 1000 CHARACTERS
30
20
10
WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
RADC - WGY - WWVA - FCC
BEFORE 05:30
CIRCUIT BEFORE 0530
CIRCUIT AFTER 0530
RADC - WGY - WTIC - WABC
WARM - KYW - FCC
AFTER 05:30
22 SEPT. 65-23 SEPT 65
INTERFERING STATION
McKEESPORT PA.
CAME ON THE AIR
ATTEMPTED TO ESTAB-
LISH CIRCUIT VIA
FOLLOWING ROUTE
RADC - WGY - WTIC - WABC-
WARM - KYW - FCC. CIRCUIT
NOT USABLE UNTIL 0815.
49/1000
TEST
BEGAN
TEST
ENDED
2300
2400
0100
0200
0300
0400
0500
0600
0700
0800
0900
HOUR EST

FIGURE 30

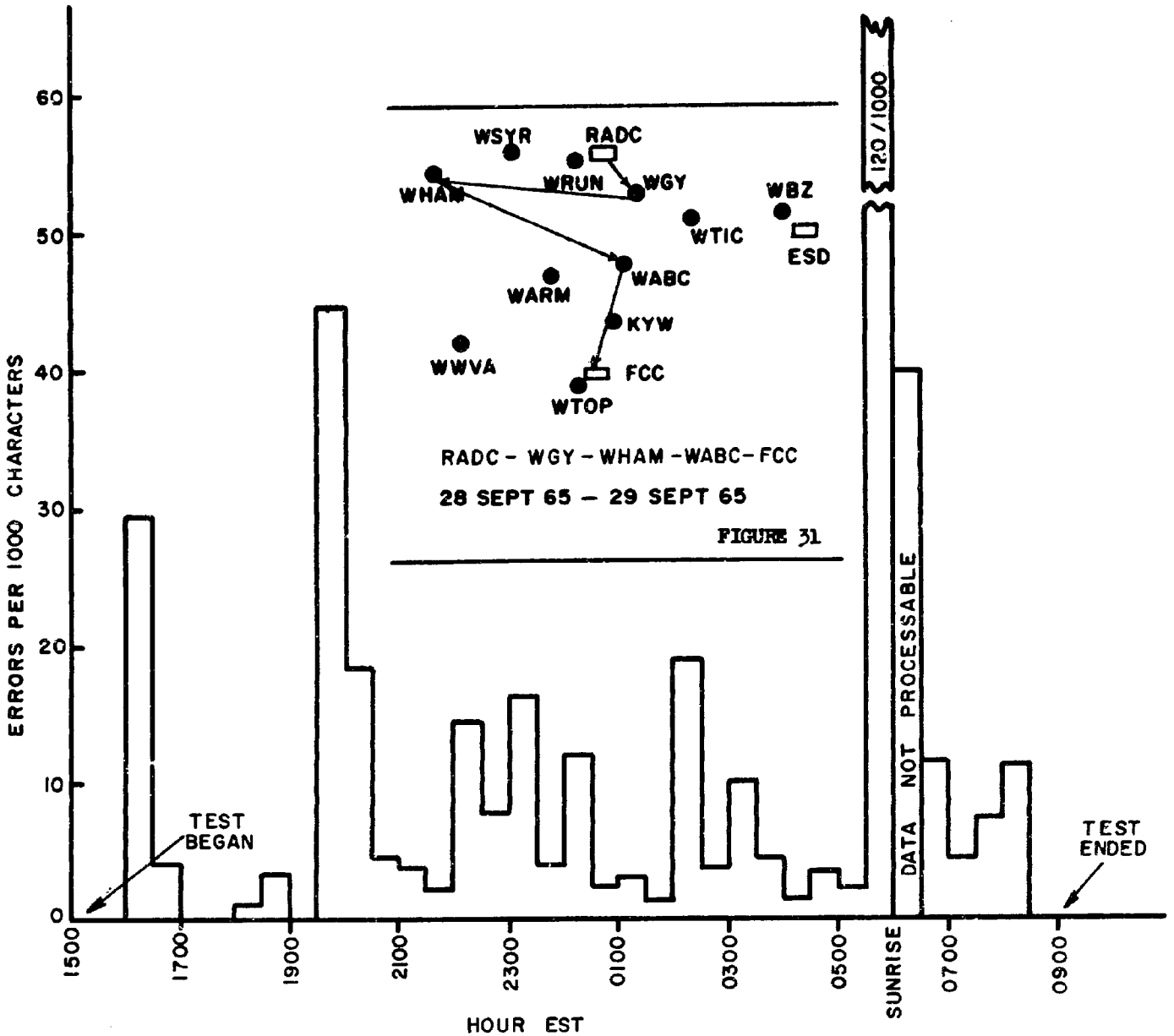

ERRORS PER 1000 CHARACTERS
60
50
40
30
20
10
0
TEST BEGAN
TEST ENDED
DATA NOT PROCESSABLE
120/1000
1500
1700
1900
2100
2300
0100
0300
0500
SUNRISE
0700
0900
HOUR EST
WSYR
RADC
WRUN
WGY
WHAM
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
RADC - WGY - WHAM - WABC - FCC
28 SEPT 65 — 29 SEPT 65

FIGURE 31

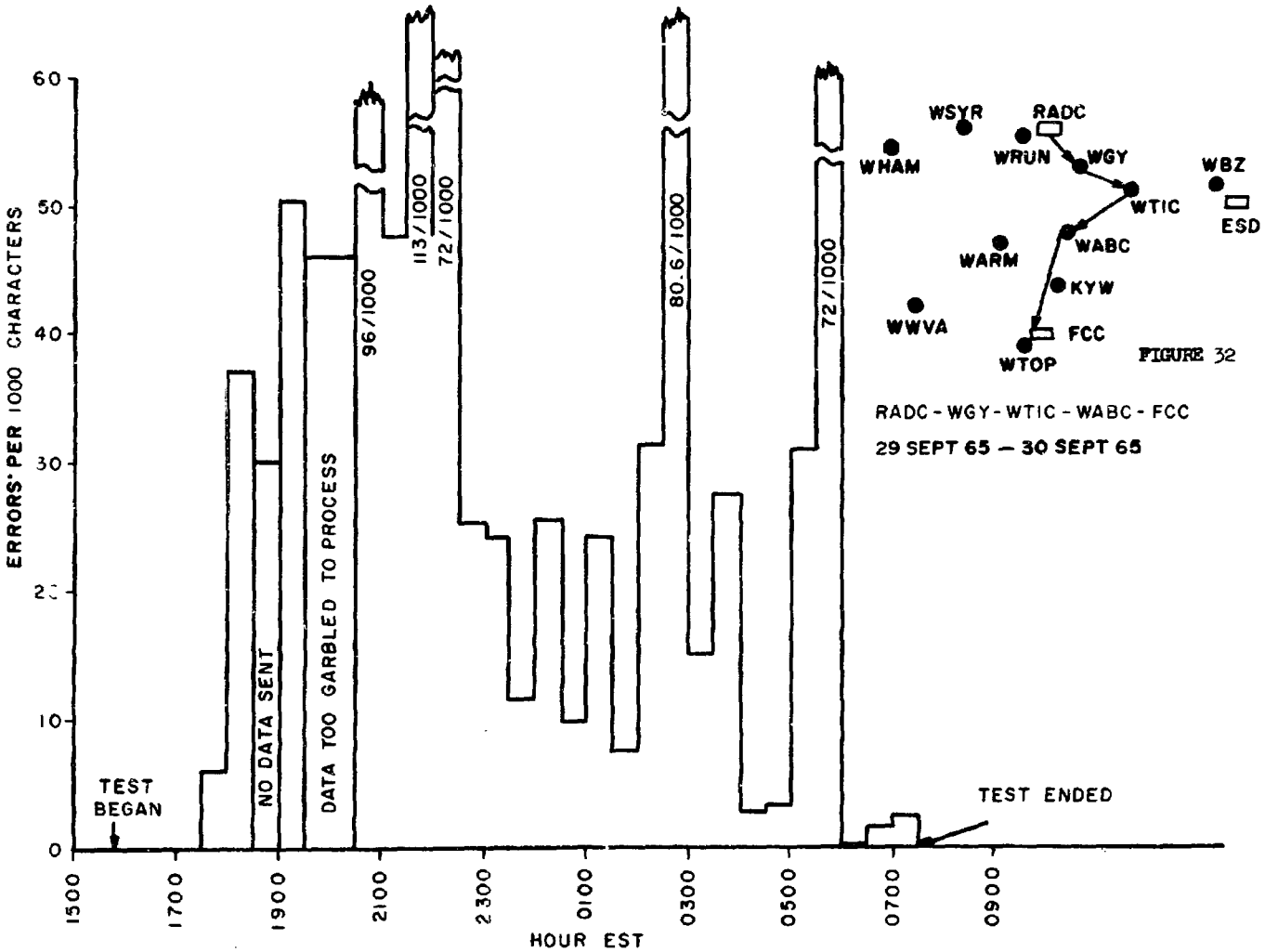

ERRORS PER 1000 CHARACTERS
60
50
40
30
20
10
0
TEST BEGAN
NO DATA SENT
DATA TOO GARBLED TO PROCESS
96/1000
113/1000
72/1000
80.6/1000
72/1000
TEST ENDED
1500
1700
1900
2100
2300
0100
0300
0500
0700
0900
HOUR EST
WSYR
RADC
WRUN
WGY
WTIC
WABC
KYW
FCC
WTOP
WHAM
WARM
WWVA
WBZ
ESD
RADC - WGY - WTIC - WABC - FCC
29 SEPT 65 — 30 SEPT 65

FIGURE 32

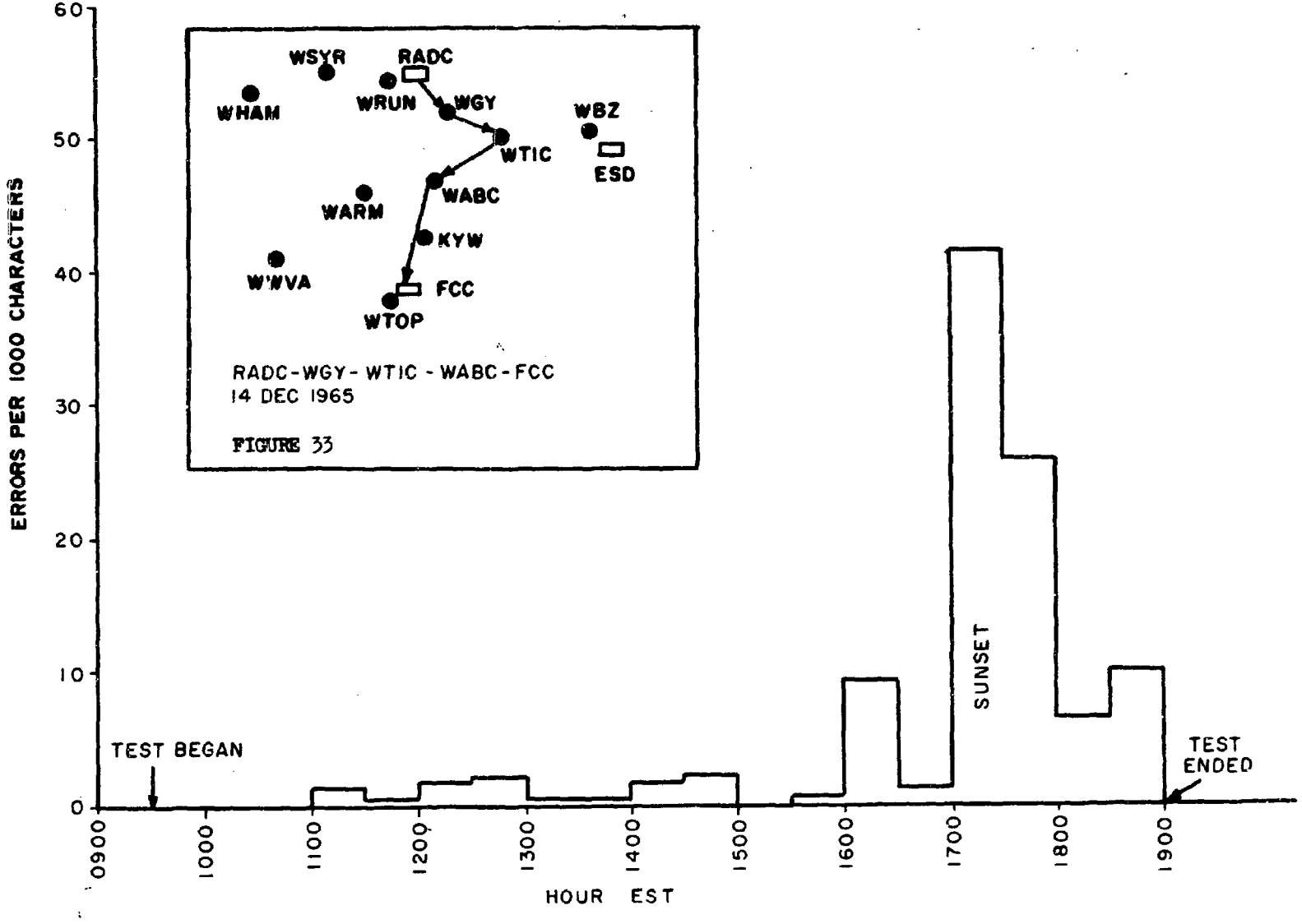

ERRORS PER 1000 CHARACTERS
60
50
40
30
20
10
0
WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
W'WVA
FCC
WTOP
RADC-WGY-WTIC-WABC-FCC
14 DEC 1965
TEST BEGAN
SUNSET
TEST ENDED
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
HOUR EST

FIGURE 33

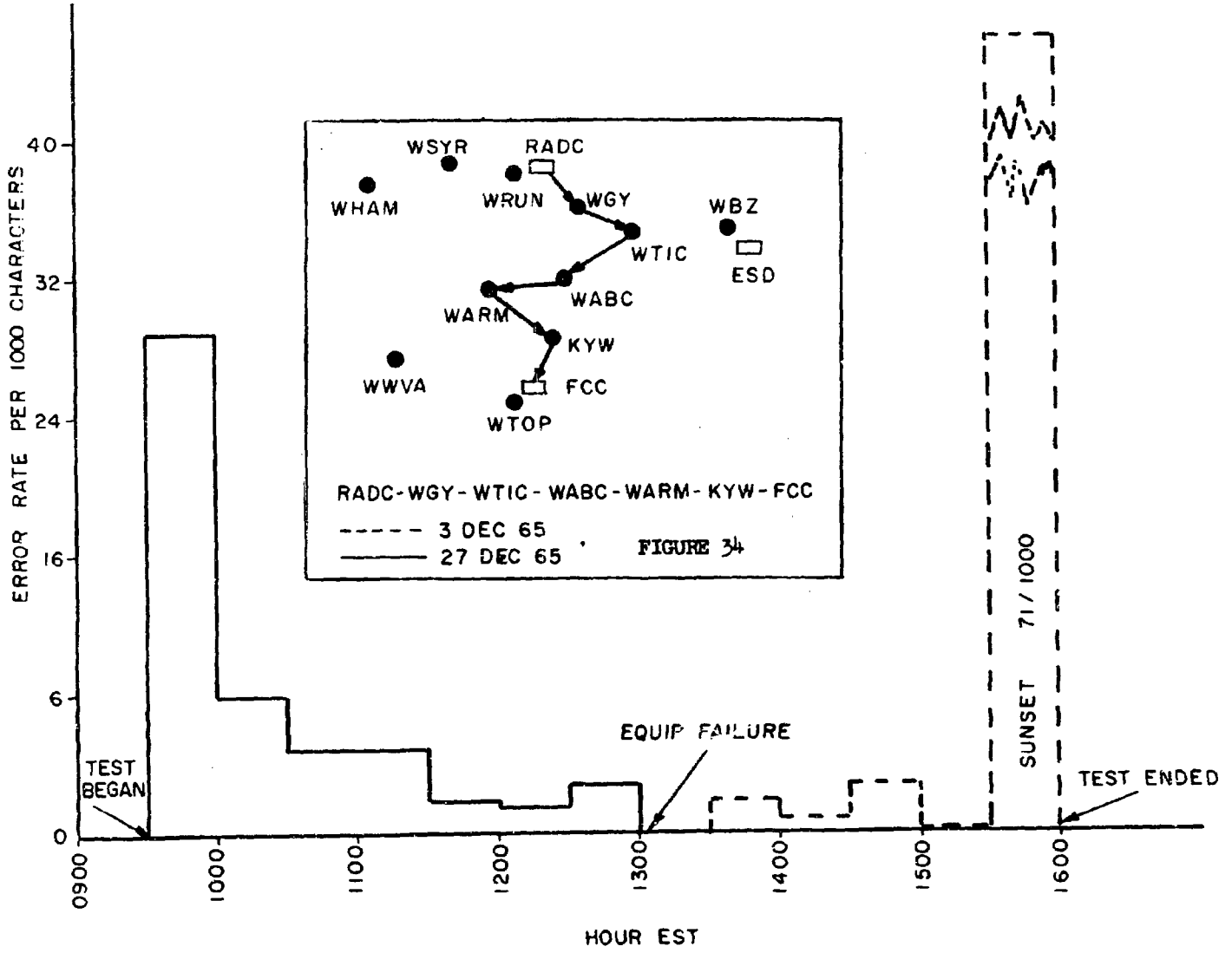
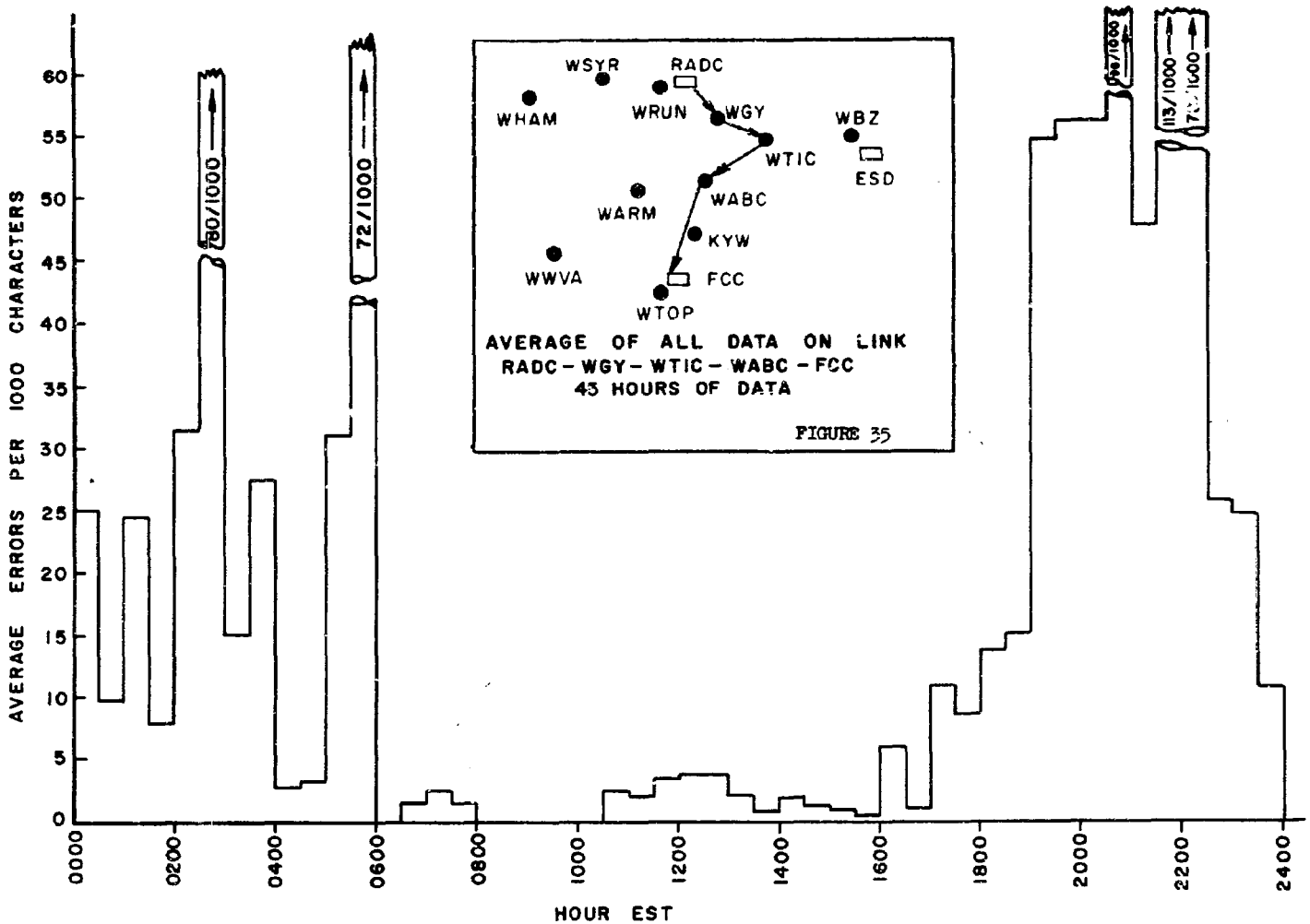
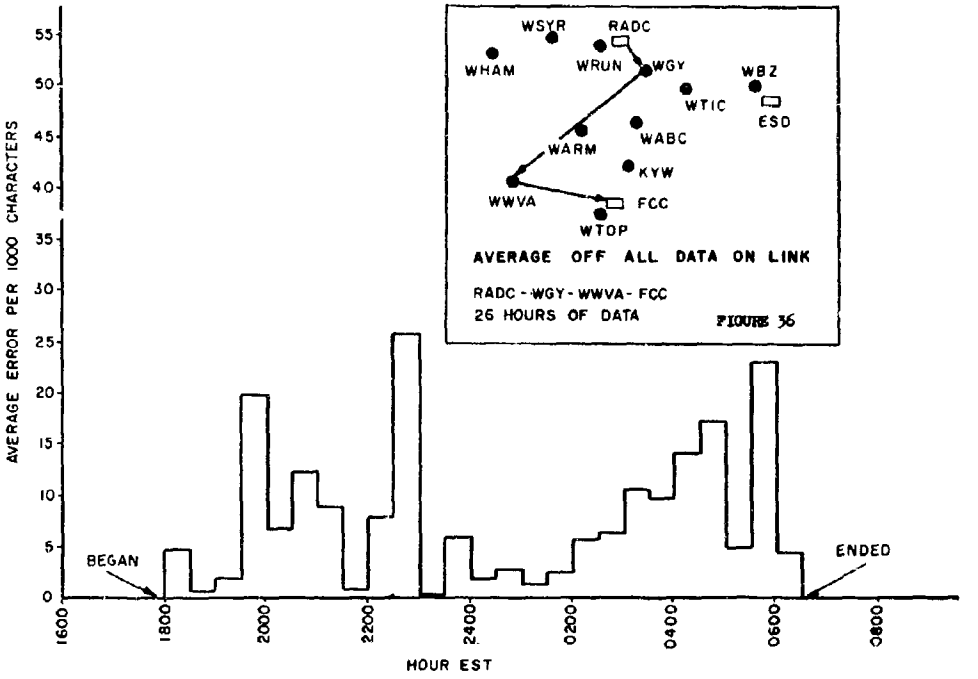

ERROR RATE PER 1000 CHARACTERS
40
32
24
16
6
0
0900
1000
1100
1200
1300
1400
1500
1600
HOUR EST
TEST BEGAN
EQUIP FAILURE
TEST ENDED
SUNSET 71/1000
WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
RADC-WGY-WTIC-WABC-WARM-KYW-FCC
3 DEC 65
27 DEC 65

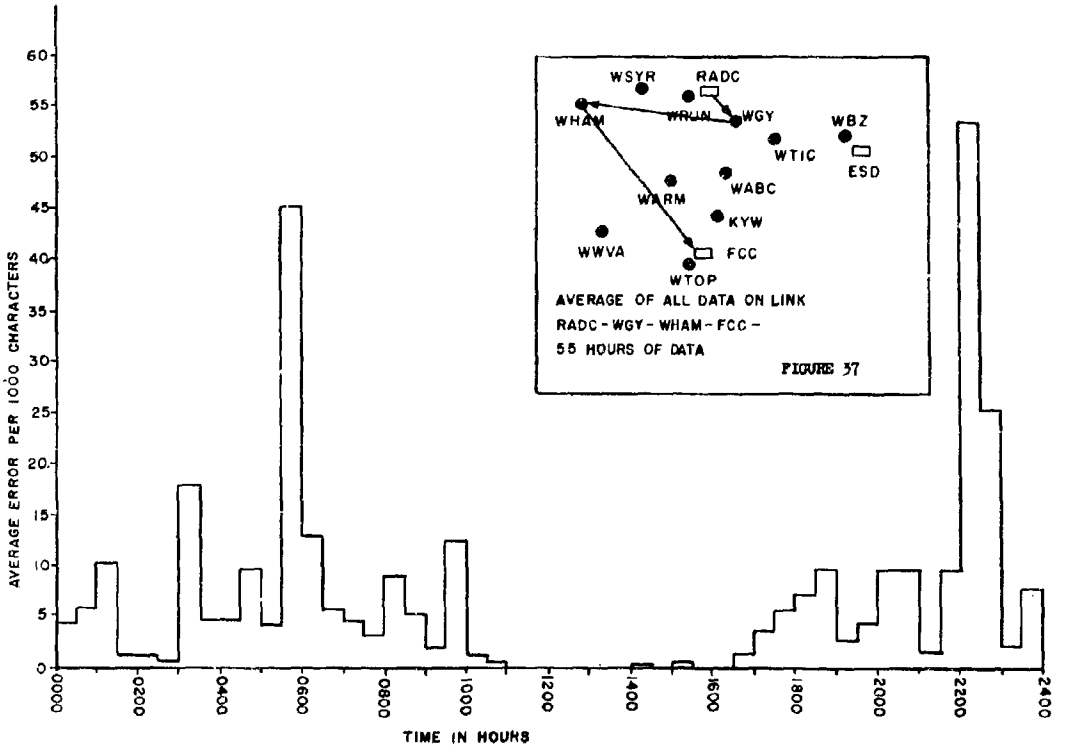
FIGURE 34



AVERAGE OF ALL DATA ON LINK
RADC - WGY - WTIC - WABC - FCC
43 HOURS OF DATA

FIGURE 35


WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
AVERAGE OFF ALL DATA ON LINK
RADC - WGY - WWVA - FCC
26 HOURS OF DATA
FIGURE 36
AVERAGE ERROR PER 1000 CHARACTERS
BEGAN
ENDED
HOUR EST


WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
AVERAGE OF ALL DATA ON LINK
RADC - WGY - WHAM - FCC -
55 HOURS OF DATA
FIGURE 37
AVERAGE ERROR PER 1000 CHARACTERS
TIME IN HOURS

considering just these three links, reliable communications could be established between RADC and FCC for a full 24 hour period on two distinct circuits.

Figures 38 and 39 represent the only usable data taken on return circuits from FCC to RADC. The data is much poorer than was expected. An investigation was initiated to determine the cause. In addition to the equipment problems already discussed, the relay at WGY that keyed the telephone lines that carry the information received at WGY to RADC was faulty and operated with output distortion of 25-30 percent higher than the input distortion. This approaches the maximum distortion that can be tolerated by the M-28 ASR and undoubtedly contributed to the high error rate. With suitable modification circuits from FCC to RADC can be realized with the same reliability that the RADC to FCC circuits have.

The error rates were tabulated in accordance with the percentage of the total time that the particular error rate existed. The results were plotted against error rate thresholds. This information is displayed in Fig. 40. Note the figure indicates that approximately 40 percent of the total usable circuit time had an error less than or equal to 1/1000.

Some additional data is presented in Appendix III.

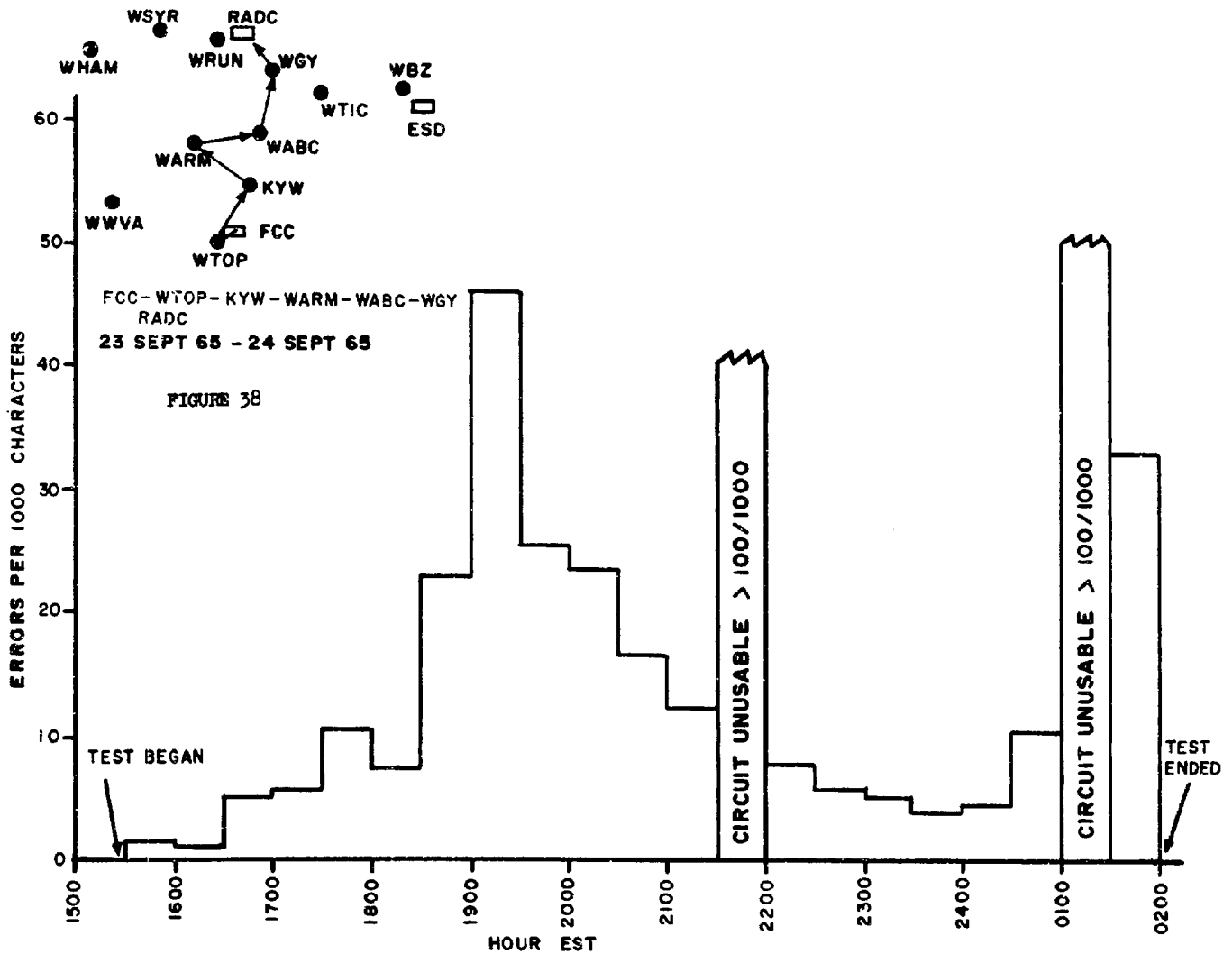
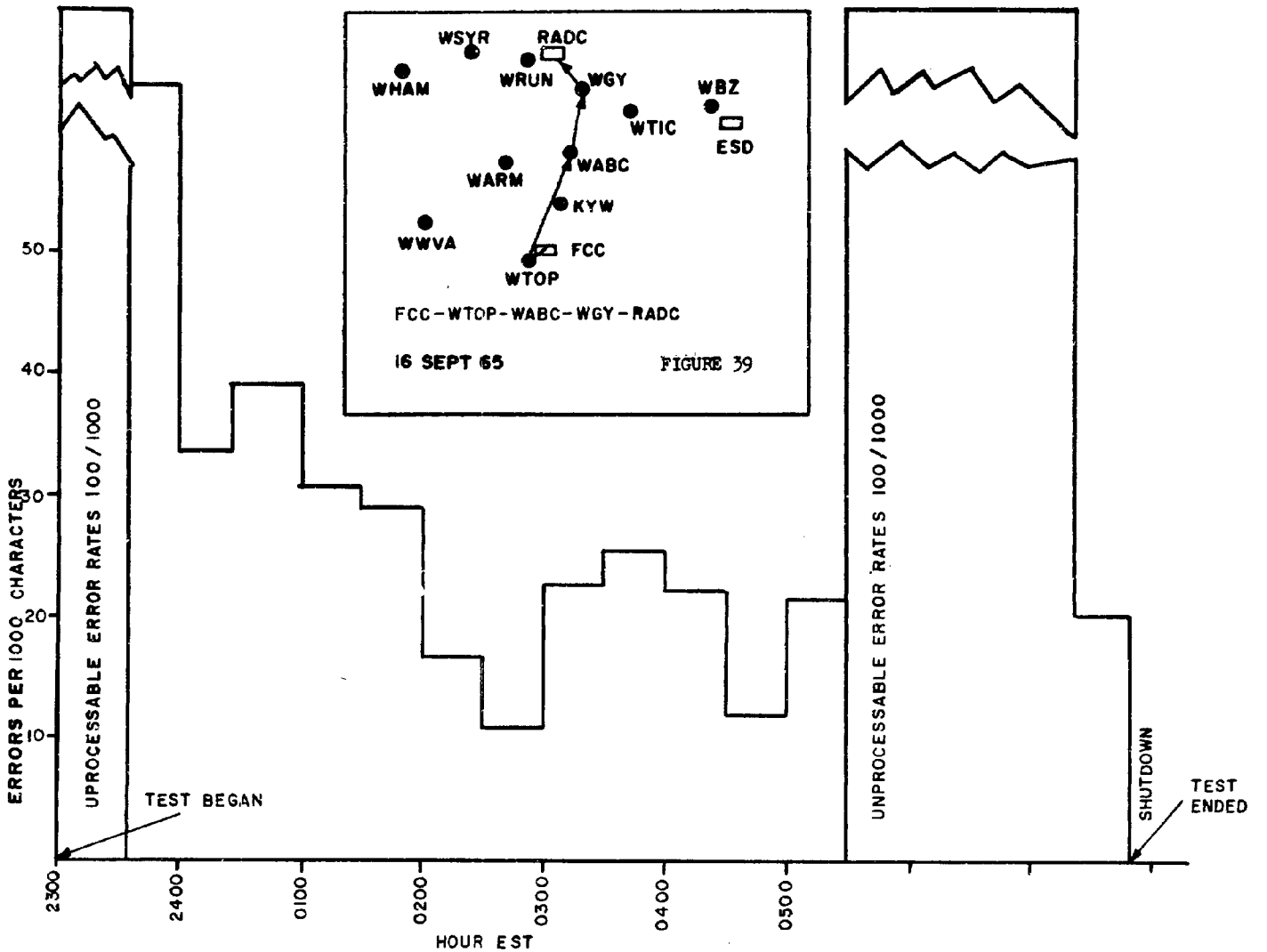
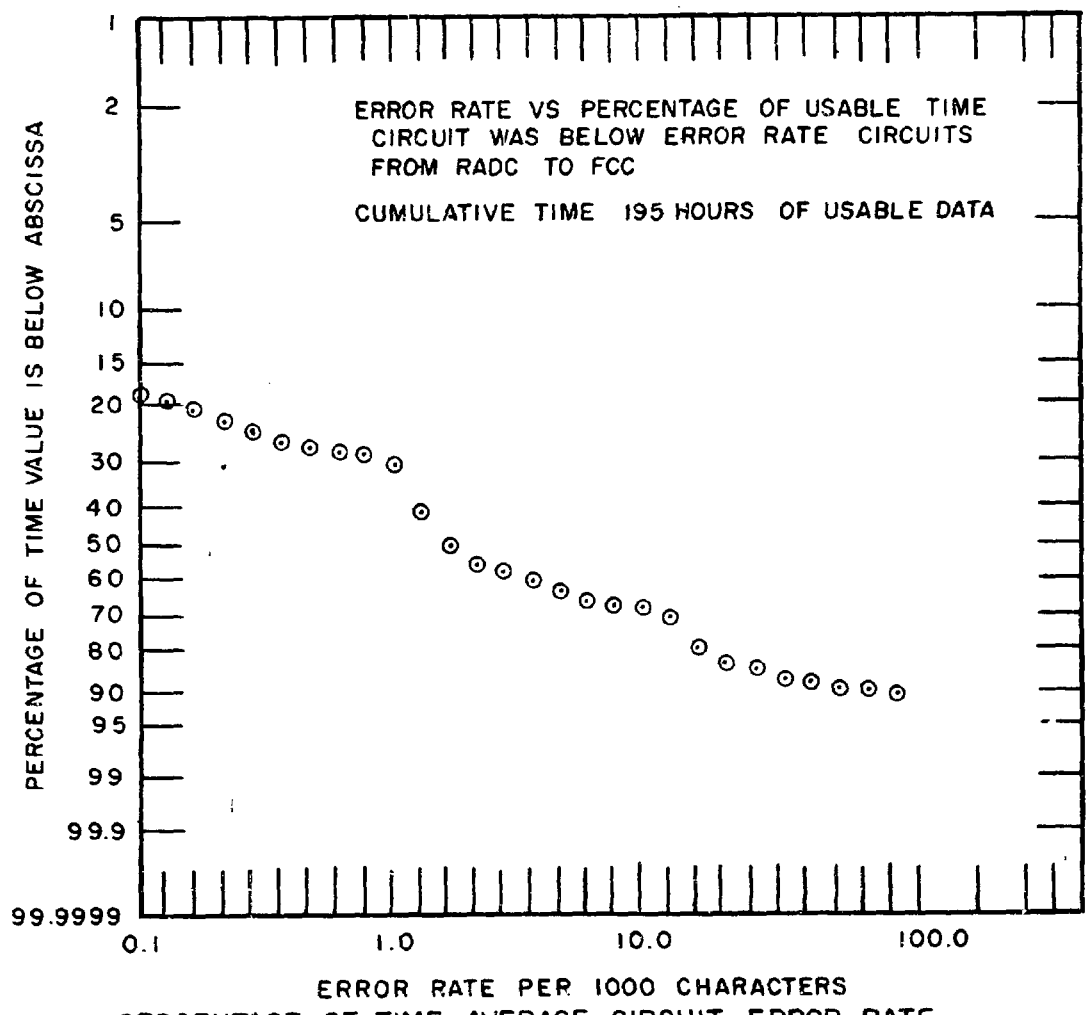

WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
FCC-WTOP-KYW-WARM-WABC-WGY
RADC
23 SEPT 65 - 24 SEPT 65
ERRORS PER 1000 CHARACTERS
0
10
20
30
40
50
60
TEST BEGAN
CIRCUIT UNUSABLE > 100/1000
CIRCUIT UNUSABLE > 100/1000
TEST ENDED
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
0100
0200
HOUR EST

FIGURE 38


WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WARM
WABC
KYW
WWVA
FCC
WTOP
FCC-WTOP-WABC-WGY-RADC
16 SEPT 65
FIGURE 39
ERRORS PER 1000 CHARACTERS
50
40
30
20
10
UNPROCESSABLE ERROR RATES 100/1000
UNPROCESSABLE ERROR RATES 100/1000
TEST BEGAN
SHUTDOWN
TEST ENDED
2300
2400
0100
0200
0300
0400
0500
HOUR EST



PERCENTAGE OF TIME AVERAGE CIRCUIT ERROR RATE EXCEEDED THRESHOLDS

FIGURE 40

SECTION XIV

CONCLUSION

The project, MF Survivable, was undertaken to prove the feasibility of utilizing commercial broadcast stations to provide a survivable network for teletype communications between users. With the design and instrumentation of eleven stations, three fixed and one portable terminal, it was possible to obtain data which proved the desired results.

During the period from May, 1965 to January, 1966 teletype information was sent between users over the network of stations utilizing the baseband channel, ± 18 cycle shift of the carrier. During this period of time no complaints were received from the general public to indicate that there was any interference to normal broadcasting. In addition, the system proved that the baseband channel could support 100 wpm teletype information without interferance to the normal broadcast material. The second teletype channel which consisted of inserting a tone in the audio spectrum was tested at RADC utilizing radio station WRUN. The results were gratifying in that, though there was degradation to the normal broadcast, there was no loss of intelligibility which is of chief importance in an emergency situation.

The logic of the system as designed and incorporated into the network proved the capability of simplex communications between terminals on a trace route mode of operation. The logic also provided the capability of flooding the system. In this situation all stations are used simultaneously to effect communication between users. The flood mode of operation was tested successfully throughout the past eight months.

The testing of the trace mode of operation, depicted on the graphs, demonstrates the communications between terminals is possible around the clock by utilizing various routes. The error rates of the various links are higher than was originally anticipated in the network. This discrepancy is not the fault of the system design. The high error rate, and at time in-operation of the links, was chiefly caused by equipment not functioning the way anticipated. Modifications were made to equipment and design in every station; however, this was not completed until mid December of 1965. By this time, much of the data, which is included in this report, had been taken on links that were not operating at maximum efficiency. Due to the rigid time schedule of the program, further data collection was not possible; therefore, the data included in this report does not represent the system as it is now operating.

The check-out procedure, which is now in operation, is successfully being utilized to determine when various links are operational on a two-way basis.

The crystal oscillators, utilized in the ± 18 cycle shift of the carrier, proved during operation to provide the stability necessary to stay within FCC regulations. The crystal-controlled receivers provided the necessary stability although in certain instances greater receiver sensitivity was desired.

Selection of the radio stations comprising the network is perhaps the most important consideration. Factors that were considered included antenna patterns, frequency allocations and radiated power of various radio stations in the northeastern United States. Utilizing this data, stations were chosen with the assistance of the FCC and an on-the-site survey was conducted. This survey should include an experimental determination of the radio stations that can be received and any interference problems that could arise in a teletype network.

The network has proven its capability in emergency situations. A snow storm which deposited up to eight feet of snow in New York State and throughout most of the eastern United States had no known effect on system operation. The check-out procedure was utilized to poll the various stations affected with positive results. This system is designed so that it can be made compatible with any existing emergency network. Entrance into the network is not limited to the three terminals. Any fixed or mobile terminal, whether air or ground, could, with a minimum of additional equipment, enter the network for communications utilizing any communications media, such as HF, Tropo or Line-of-Sight Microwave.

APPENDIX I

A STUDY OF SURVIVABILITY FOR USE OF COMMERCIAL BROADCAST FACILITIES FOR EMERGENCY DOD COMMUNICATIONS

BY

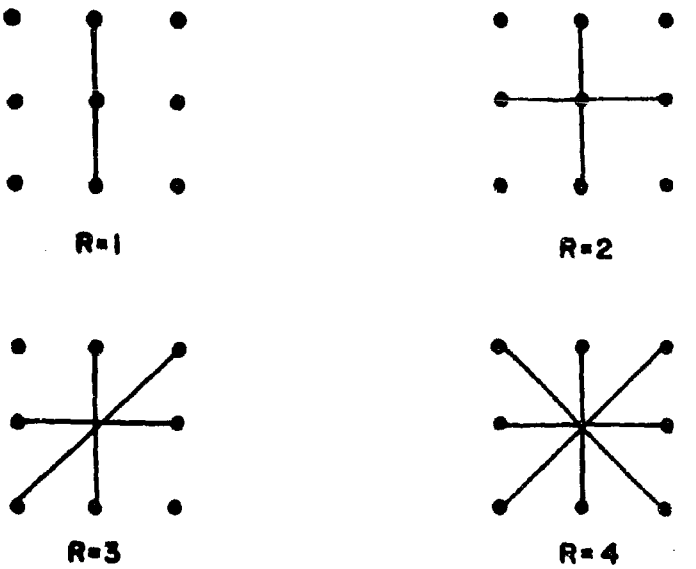
EARL E. SELOVER

1. Survivability of the Network

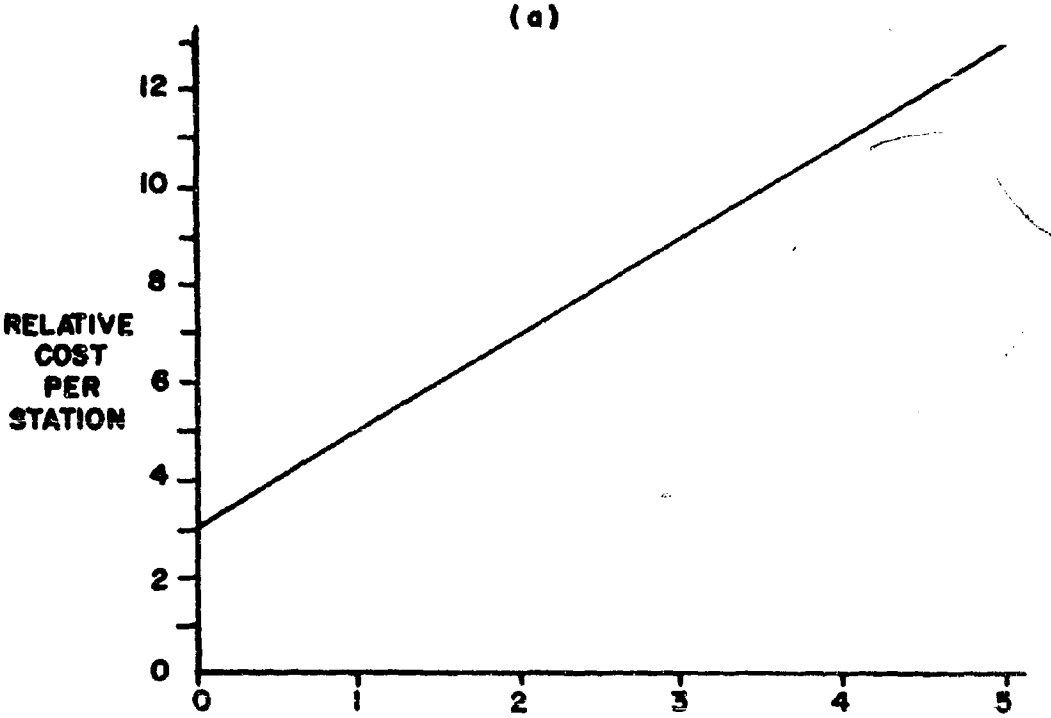
The determination of design of a survivable system must be predicated upon some threat to the system. This threat may be either man-made or natural. The cost of the survivable system will vary with the threat which it is designed to survive and the extent to which it is to survive. The cost is normally the controlling factor as to the extent to which survivability is to be obtained. This analysis will therefore evaluate cost as a function of survivability and then the determination can be made as to the level of survivability that is economically feasible.

The commercial broadcast stations to be incorporated into such a system will have limited survivability based on emergency power generators and "fall-out" shelters. These facilities are part of the FCC Emergency Broadcast System effort. The system survivability is to be obtained by employing the individual stations as nodes of a distributed communications network. Extensive work has been done under United States Air Force Project Rand on a store-and-forward distributed communications system. This work has been published in eleven volumes entitled: "On Distributed Communications" dated August 1964. The system design for the MF Survivable Communications program was completed in July of 1964 and is for a real time communications system but the information on survivability contained in these Rand reports is directly applicable to this program.

The system survivability of a distributed communications network is based upon the redundancy level. See Figure 1 (a). The cost per terminal is also a function of redundancy. See Figure 1 (b). The relative cost is based on a unit cost per receive link and three units of cost for transmit function. This ratio is based on cost data gained on the procurement of the test network. In order to analyze the cost as it is affected by survivability we must make some assumptions of the design limit on a survivability curve. Such a curve is shown on page 7 of Volume 1 of the Rand reports. The design limit selected was that for which ninety percent of the surviving stations remain in communications with each other. (See Fig. 1) This point is selected because it is at the knee of the curve. Values greater than ninety percent would result in a high probability of error due to the limited accuracy of the simulation technique used to gain the curve data or due to the basic assumption of uniform destruction probability used in the simulation. If less than ninety percent of the surviving stations remain in communications, the redundancy required for survivable entrance to the network will tend to increase. There will be an optimum trade-off point resulting from the increased network cost to keep a higher percentage



REDUNDENCY LEVEL IN A DISTRIBUTED COMMUNICATIONS NETWORK
(a)



RELATIVE COST PER STATION AS A FUNCTION OF REDUNDANCY
(b)
FIGURE. 1

of surviving stations in communications on one hand and increased network entrance cost resulting from a lowering of percentage on the other hand. The optimum trade-off point will depend upon the relative cost of a technique to obtain a survivably independent connection from each of the users in the network to a number of the network nodes.

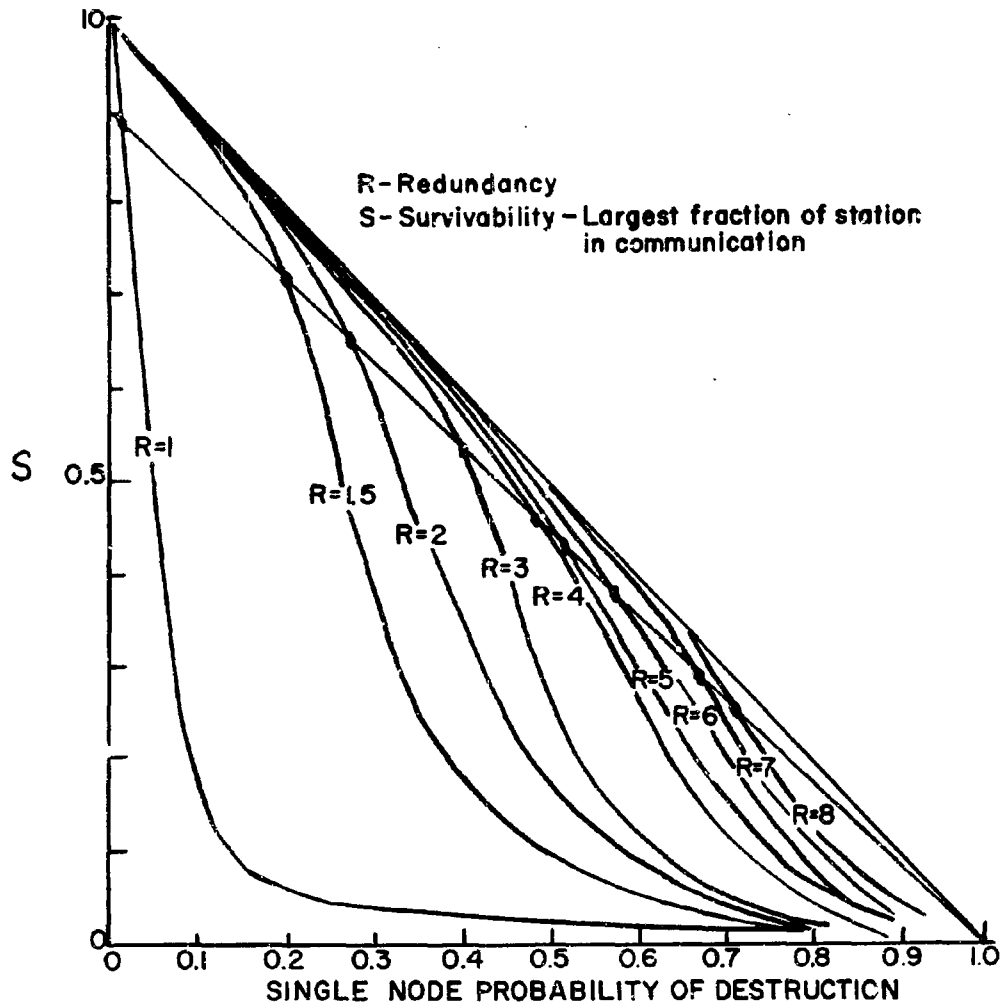
The relative cost per station as a function of single node probability of survival is obtained by combining Figure 1 (b) and the ninety percent data from the survivability curve in the Rand report. Figure 3 (a) was obtained in this manner and as such reflects the relative cost per station required to provide that ninety percent of the surviving stations will remain in communications with each other. The curve is obtained by plotting the cost, (Figure 1 (b)), for each redundancy number against the appropriate single station probability of destruction from the survivability curve of the Rand report (Fig. 2). The appropriate value being that value of single station probability of survival that corresponds to the ninety percent point on the particular redundancy curve. This ninety percent point is the point where ninety percent of the surviving stations are in communication with each other.

2. Survivability of Network Entrance

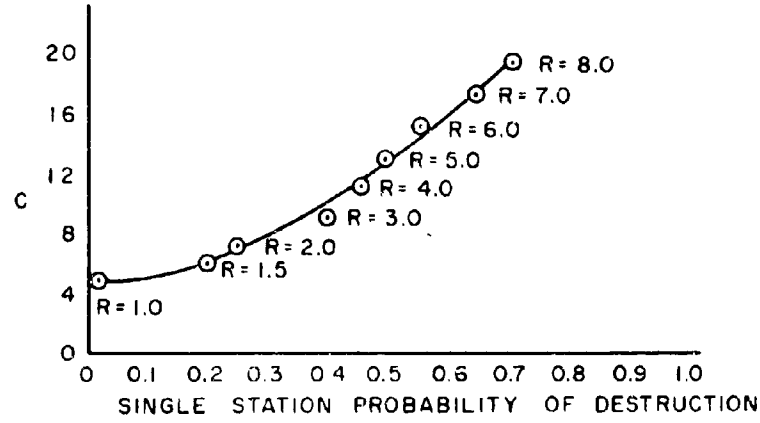
In order for the communications system to survive, the users of the network must be able to get into the network. It is assumed that each user will connect into one or more of the commercial broadcast stations that make up the network. The probability of any one of these conditions being in the ninety percent of the surviving stations that are tied together is 0.9X. The value of X is the value of the single station probability of survival. The quantity (1-0.9X) is the probability that any one connection will be destroyed. The probability that all the connections will be destroyed is $(1-0.9X)^n$ where n is the number of connections. The probability that there will be at least one link into the surviving network is 1- $(1-0.9X)^n$ 2. The curves associated with this expression are shown in Figure 3 (b). Thus Figures 3 (a) and (b) provide the capability of determining the relative cost of a station, the redundancy required in the network and the number of connections each user must have into the network. This can be determined from knowing the single station probability of destruction and the required probability that two users in the network will be able to communicate with each other.

3. The Queuing Problem

The survivable communications system that would be established on a distributed communications network basis will have an original capability much greater than the minimum usable capability. There are potential occurrences that would create a need for such a survivable communications system under conditions that would not have destroyed any of the network. The queuing problem will be evaluated for both the undisturbed network and the maximum disturbed network. Various levels of operation are practical between these two extremes, but the operation at such levels would be controlled by a form of system discipline. No additional design appears to be required to facilitate the transfer between levels.

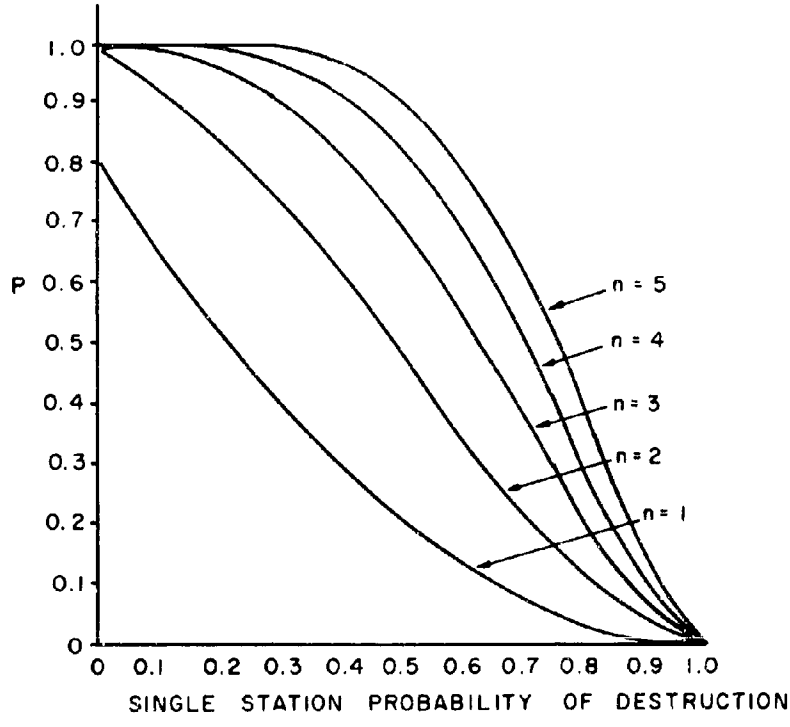


Perfect Switching in a Distributed Network-Sensitivity to Node Destruction. FIGURE 2



RELATIVE COST (C) PER STATION AS A FUNCTION OF THE SINGLE STATION PROBABILITY OF DESTRUCTION SO THAT THE LARGEST FRACTION OF STATIONS IN COMMUNICATIONS WILL BE 90% OF THE SURVIVING STATIONS

(a)



THE PROBABILITY (P) THAT TWO USERS IN THE NETWORK WILL BE ABLE TO COMMUNICATE AS A FUNCTION OF (n) THE NO. OF CONNECTIONS EACH USER HAS WITH THE NETWORK FOR THE SURVIVABILITY SHOWN IN (a)

FIGURE 3. (b)

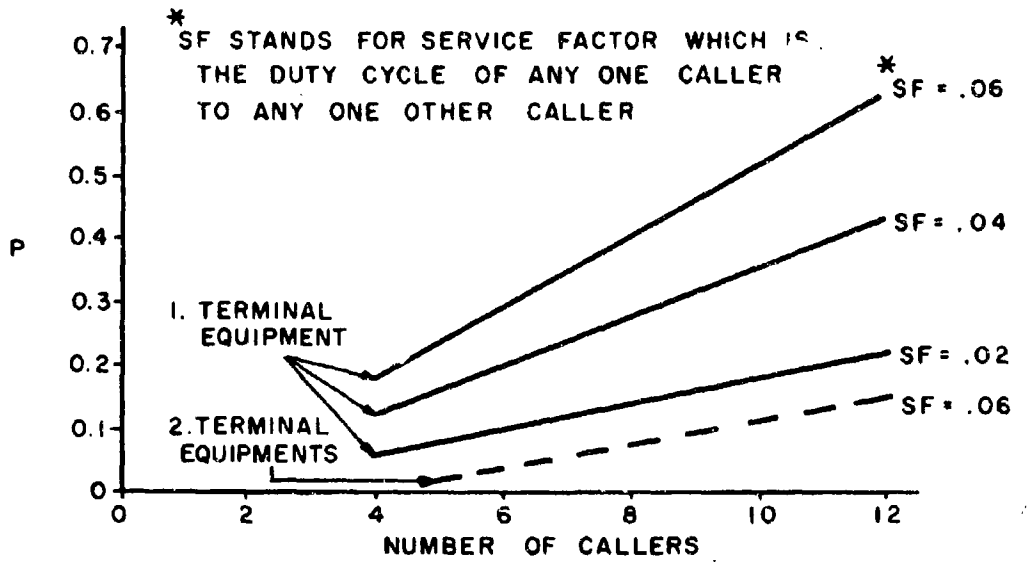
The over-build requirement necessary to obtain a minimal capability in the worst situation could provide a fully connected network in the best situation. Such a fully conne ted network would not have a queue problem except as limited by the terminal facility. If the terminal facility were to be limited, then a queue would be established. This queue would result in a probable delay as indicated in Figure 4 (2). This curve is based on data from "Finite Queuing Tables" by L.G. Peck and R.N. Hazelwood.[2] This table assumes a Poisson input and an exponential distribution of lengths for the messages being transmitted. The significant advantage to be gained by a second on-line terminal equipment is obvious in this situation.

The extreme situation in the direction of a large number of network nodes being destroyed is the most critical situation. As the amount of destruction approaches the value for which the network would cease to be connected, a large number of communications bottlenecks will occur. This bottleneck situation shows itself in the Rand report by a sharp reduction in the "Largest Fraction of Stations in Communications" with a small increase in probability that the individual nodes will be destroyed. This bottleneck situation results in two major problems. First, the finding of an available route by search technique will be extremely time-consuming and second, the number of channels through the network will be extremely limited. In such a case, the usefulness of the network in a trace route mode is extremely doubtful. For such a situation the network must be considered a single shared channel which is used on a flood address basis so that it can serve only one user at a time. The probability that a user will be delayed in an attempt to use this single channel network is shown in Figure 4 (b). From this curve, it is easy to see that the network users must be strongly disciplined. The number of users in the network that can initiate messages must be very limited as well as the frequency and duration of the messages that are to be transmitted over the network.

4. Network Discipline

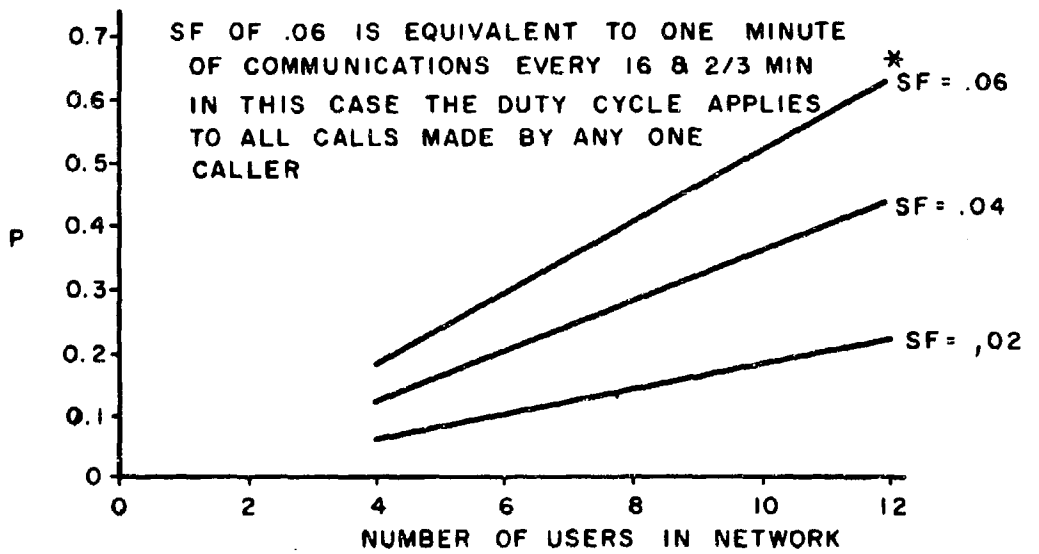
It is anticipated that this communications system, (if, and when, placed into operation), will have extensive requirements placed upon it. Such requirements could result in the communications system becoming overloaded and ineffective. Such an overload might not be apparent until too late. Network discipline technique will help prevent such overload situations. The ultimate limit of such control is to provide each user with a time slot during which he is allowed to communicate. The use of less severe regulations, such as priority and override, are also quite practical.

The users of the system must limit acquisition of the system. It is not anticipated that this system will be used as a standard mode of communications; therefore there will be no experience factor telling the operators that they have vast capabilities available to them by this mode. By the same token, the control of the user terminals could be in a command post type situation to further stress that it is not just another mode of communication. The most positive method is, of course, to provide receive-only facilities that make it impossible to enter the system. Where two-way communications is a limited requirement, the system can be so configured that once such a receiving station had been addressed and provided the proper character sequence code it could then initiate a message into the network. Selected users of the network could be restricted to a limited part of the network and thereby insure that the remainder of the network would not become overloaded by the potential lack of discipline.



THE PROBABILITY (P) OF BEING DELAYED IN CALLING IN A FULLY CONNECTED NETWORK

(a)



THE PROBABILITY (P) OF BEING DELAYED IN ENTERING THE NETWORK WHEN IT IS USED AS A SINGLE CHANNEL

(b)

FIGURE 4

The users of the system must limit the time period for each transmission as well as limiting the number of transmissions. The time period can be minimized by such techniques as using code words rather than wordy messages. Protection can be provided against accidental misuse by automatically turning off the system after a short time from initiation of a message.

References

1. Baran, Paul, "On Distributed Communications", Aug. 1964, prepared for United States Air Force Project Rand.

2. Hazelwood, R.N. and Peck, L.G., "Finite Queuing Tables", published by John Wiley and Sons, Inc.

APPENDIX II

A STUDY OF SIMULTANEOUS TRANSMISSION OF VOICE AND TELETYPE OVER AM RADIO BROADCAST STATIONS

BY

JOHN N. ENTZMINGER

1. Teletype Over Radio Broadcast Stations

The problem we are considering is that of simultaneous transmission of audio and teletype information over normal AM radio broadcasting stations in the band 535 - 1605 kHz.

Since hypersonic (beyond audibility) modulation would create sidebands that would interfere with reception on adjacent channels only infrasonic (below audibility) modulation remains if messages are to be transmitted without causing noticeable noise in the audio portion of the broadcast. It has been showen that 60 wpm, ± 18 cps, FSK of the carrier produces no noticeable noise in the audio band. There are now in the development and testing stages for 487L, coherent FSK systems, which offer the advantage of decreased bandwidth, coherent carrier detections and synchronous teletype operation. It appears that modifications of these may be capable of rates of 100 to 200 wpm in this infrasonic band without interfering with the audio band and would also give considerable improvement (measured 13-15 db) over non-coherent, non-synchronous FSK. The use of existing impulse noise suppression techniques will also give additional improvement.

Since there remains the continuing need for higher data rates and full duplex operation, we have investigated the possibility of inserting a teletype channel in the audio portion of the band. (The AM transmitting bandwidth is flat from 100-5000 cps with amplitude modulation of at least 85 to 95 percent.) Two methods of doing this are immediately obvious (1) Notch out a portion of the audio frequencies and insert an FSK tone at a frequency and level which is tolerable to the home listener. (2) Add the teletype signalto the audio as a spread spectrum noise and re-correlate at the receiver using a matched filter.

Voice plus teletype equipment is readily available because of its use on telephone lines, whereas the spread spectrum approach would require development and be much more expensive. Experiments at RADC (1) on masking of speech by pure tones and random noise indicate that masking with random noise is some 30 db superior to masking with pure tones. This is shown in Fig. 1.

For an intelligibility of 90 percent a speech to random noise ratio of + 7 db is required while a speech to tone ratio can be as great as - 35 db, depending on tone frequency. Since in spread spectrum as much energy would have to be put into the pseudo noise as would be required in the tone for the same level of performance, this indicates that the noise would be more

objectionable than a tone even with a spreading factor of 20 db. While we are not concerned with masking by tones at much higher levels than the voice level, this does indicate a trend that noise is much more objectionable than tones to the listener. For this and economic reasons, it appears that modulation of the carrier by a frequency-shifted tone is the better of the two.

It remains, however, to determine the most optimum tone frequency to use. An experiment as outlined in Appendix I, was conducted to determine the relative annoyance of tones as a function of frequencies. The conclusion from this experiment is that the lower audio frequencies are much less annoying. The curve of equal annoyance followed, very closely, the same shape as published curves of hearing acuity and equal loudness (see Figs. 2,3, 4) and are in agreement with similar experiments using bands of noise. (Ref. 2,3 and 4.)

Another factor which indicates the desirability of using low frequency tones (100 - 400 cps) is the frequency response of typical AM radios. The response of a number of table models, portable radios and car radios were measured and reported in Appendix II. (See Fig. II-1) This data indicates the sharp fall-off withlow frequencies of table and portable radios. Car radios, however, are quite flat across the audio spectrum. Since this teletype channel in the voice band would most probably be used during emergencies and during nuclear attacks when commercial power has failed, most of the population would be using transistorized portables with a very poor low frequency response.

One factor which should be remembered, is the resonant frequencies of the rooms which contain the radio. In the simplest single frequency condition the room behaves as a short organ pipe resonant at a frequency at which the room length is one-half wavelength. (5)

Any enclosure of dimensions L, W, H is characterized by an infinite series of resonant frequencies given by the Rayleigh equation

$$f = \frac{1130}{2}\left[\frac{A^2}{L} + \frac{B^2}{W} + \frac{C^2}{H}\right]^{1/2}$$

Where A, B and C are 0, 1, 2, 3 ----------

For the room length L, in feet, the lowest frequency is $f = \frac{1130}{2L}$

For a small room 15.3' x 11.0' x 8.2(the first 20 resonances range from 36 to 137 cps with peaks of 12-25 db occurring below 100 cps. Furniture, drapes, rugs, people and the type of wall board in the room affect these peaks and valleys quite severely. (5) With this note of caution, it appears that the best choice of tone frequency lies in the range of 150 to 300 cps.

Fig. 5 shows the relative frequency power distribution of speech (6) and Fig. 6, the effects of high and low pass-filtering on articulation. (7, 8, 9). It is apparent from these that although a great deal of the energy of speech is contained in the first 300 - 400 cps, the articulation is affected very little by filtering this out. This is the case in telephone communications where the bandwidth is approximately 300 - 3000 cps. Since a great deal of the speech power lies in this range below 300 - 400 cps, a high-pass filter

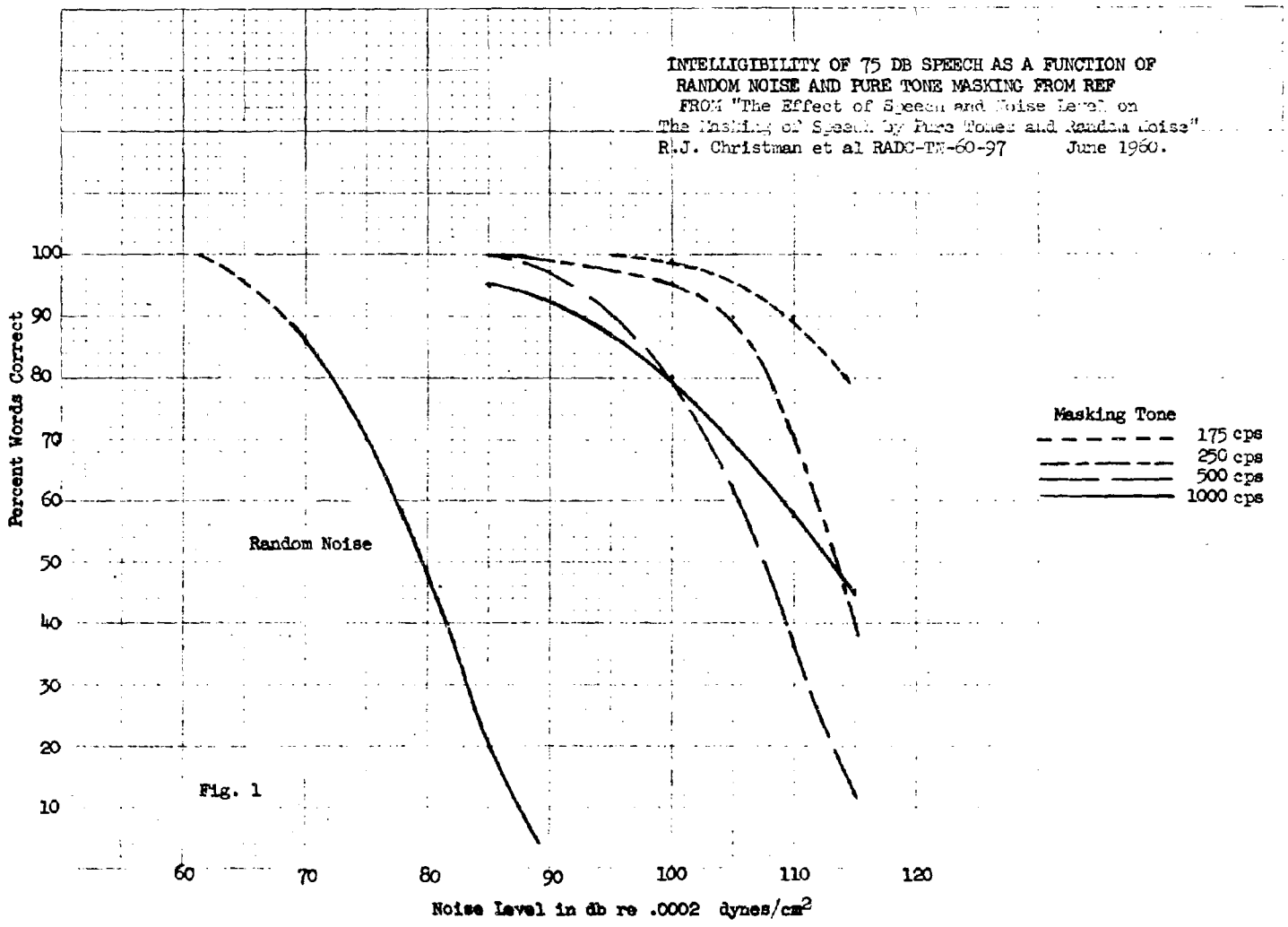

INTELLIGIBILITY OF 75 DB SPEECH AS A FUNCTION OF
RANDOM NOISE AND PURE TONE MASKING FROM REF
FROM "The Effect of Speech and Noise Level on
The Masking of Speech by Pure Tones and Random Noise"
R.J. Christman et al RADC-TN-60-97 June 1960.
Percent Words Correct
100
90
80
70
60
50
40
30
20
10
Random Noise
Masking Tone
175 cps
250 cps
500 cps
1000 cps
60
70
80
90
100
110
120
Noise Level in db re .0002 dynes/cm2

Fig. 1

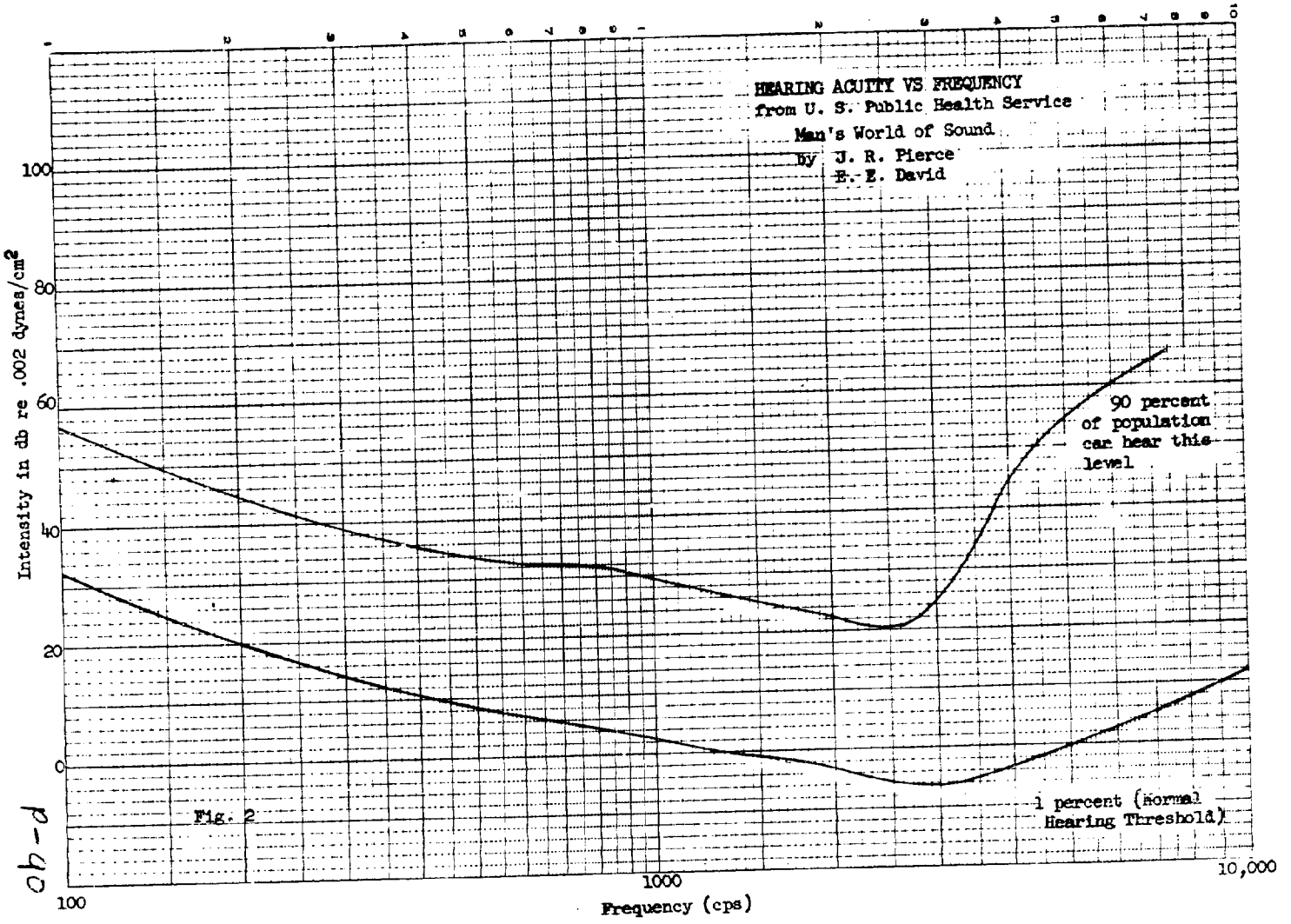

HEARING ACUITY VS FREQUENCY
from U. S. Public Health Service
Man's World of Sound
by J. R. Pierce
E. E. David
90 percent of population can hear this level
1 percent (Normal Hearing Threshold)
Intensity in db re .002 dynes/cm²
100
80
60
40
20
0
100
1000
10,000
Frequency (cps)

Fig. 2

ob-d

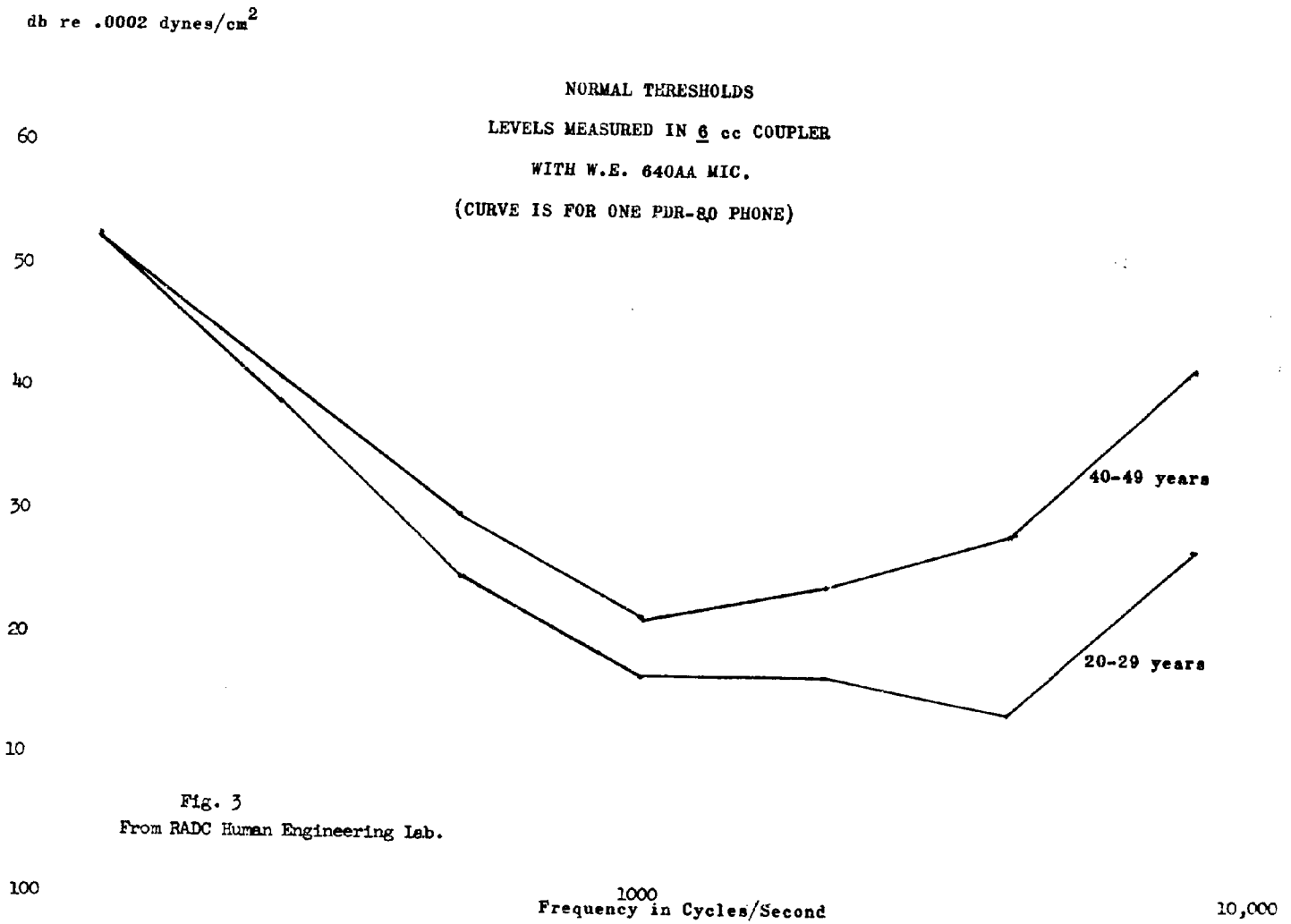


Fig. 3
From RADC Human Engineering Lab.

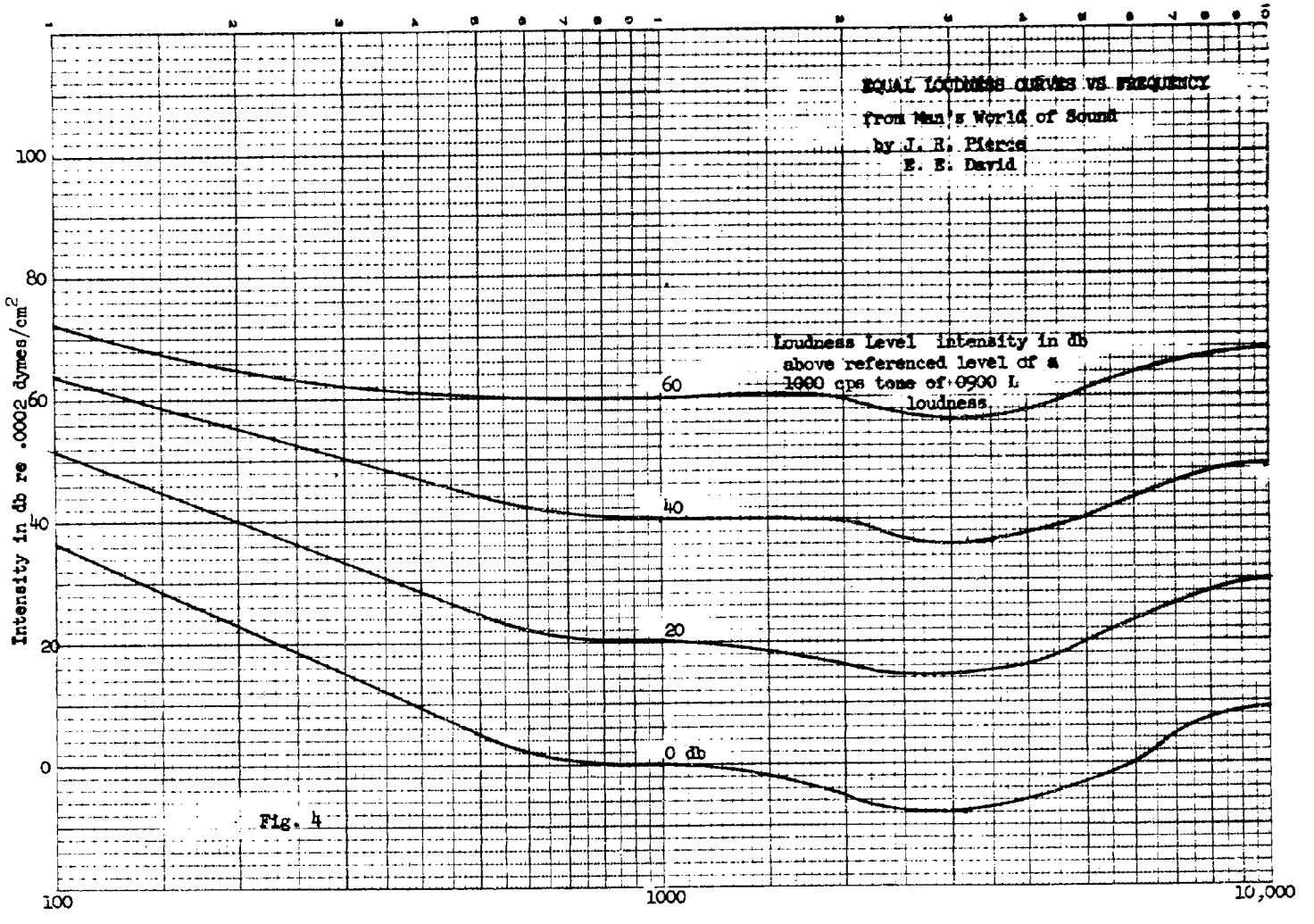

EQUAL LOUDNESS CURVES VS FREQUENCY
from Man's World of Sound
by J. R. Pierce
E. E. David
Loudness Level intensity in db
above referenced level of a
1000 cps tone of 0900 L
loudness.
60
40
20
0 db
Intensity in db re .0002 dynes/cm²
100
80
60
40
20
0
100
1000
10,000

Fig. 4

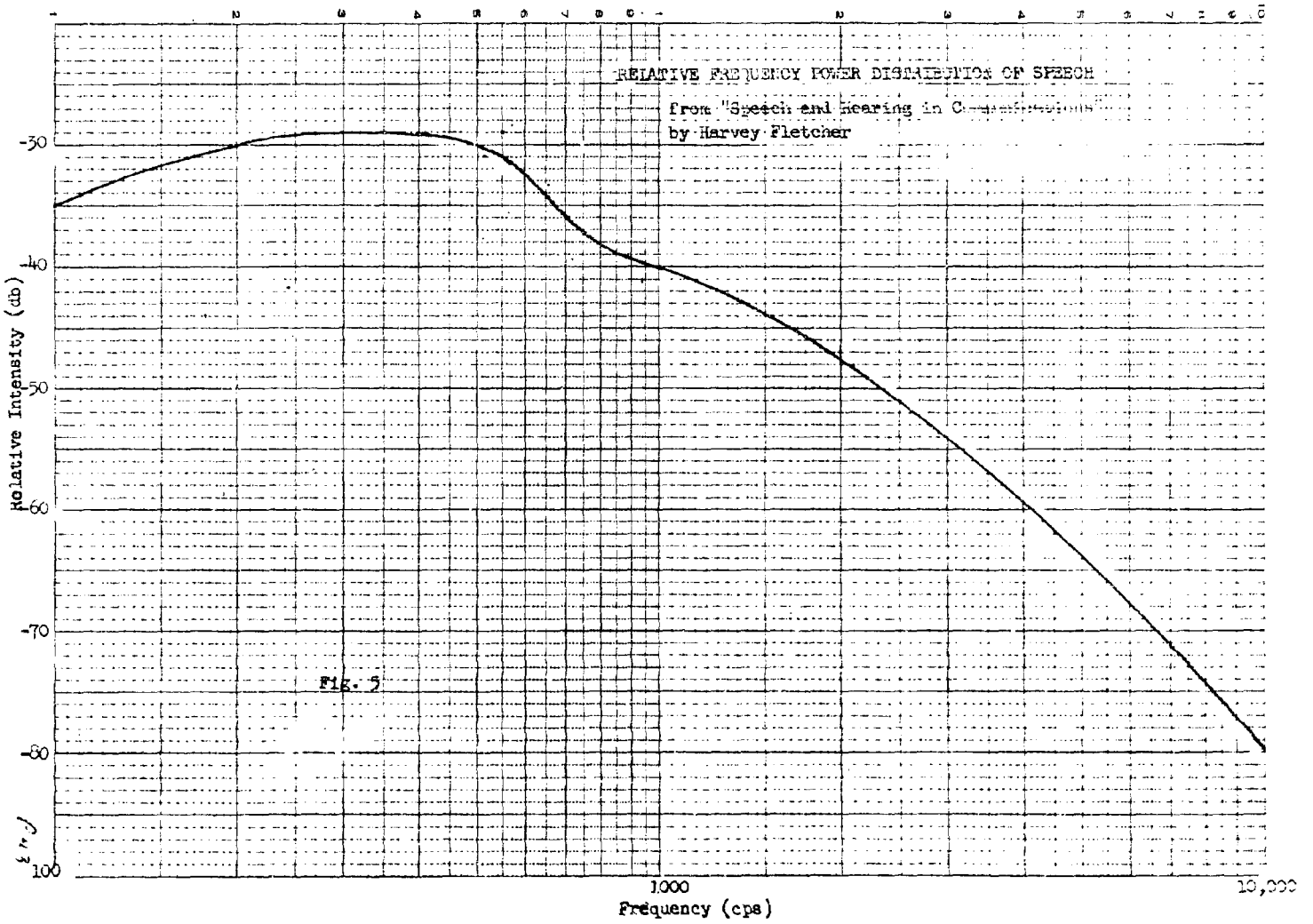

RELATIVE FREQUENCY POWER DISTRIBUTION OF SPEECH
from "Speech and Hearing in Communication"
by Harvey Fletcher
Relative Intensity (db)
-30
-40
-50
-60
-70
-80
-100
1,000
10,000
Frequency (cps)

Fig. 5

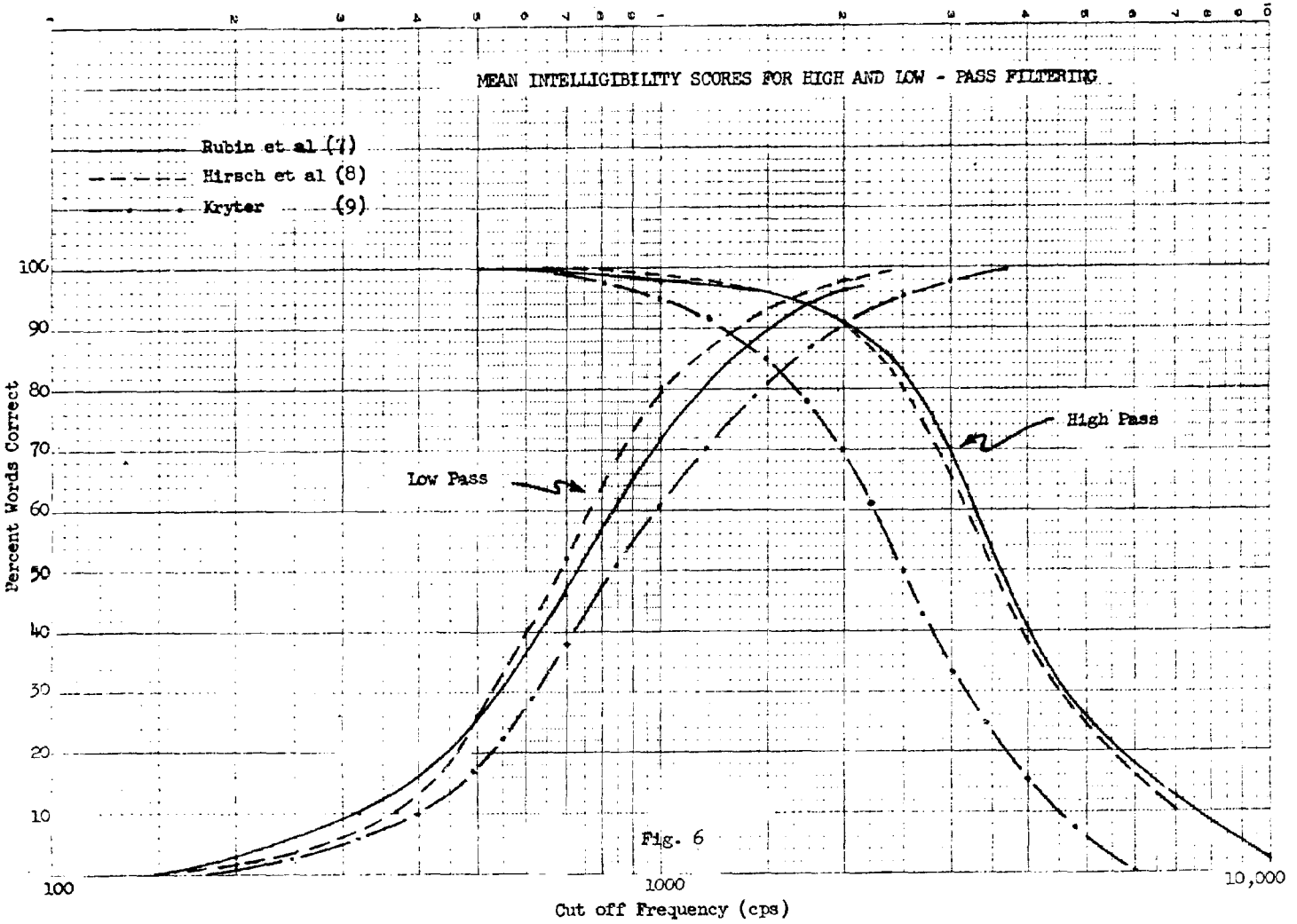

MEAN INTELLIGIBILITY SCORES FOR HIGH AND LOW - PASS FILTERING
Rubin et al (7)
Hirsch et al (8)
Kryter (9)
Low Pass
High Pass
Percent Words Correct
100
90
80
70
60
50
40
30
20
10
100
1000
10,000
Cut off Frequency (cps)

Fig. 6

removing this band would allow a good portion of the power to be put into the tone and yet not over-modulate the transmitter or force the broadcast station to reduce its audio level from what it was prior to inserting the filter and tone.

I Annoyance Level Of Tones

An experiment was conducted to determine the relative annoyance of tones of different frequencies when these tones are superimposed on AM radio broadcasts.

The experiment was set up as in Fig. I-1. The tape recording consisted of several network news broadcasts recorded from local stations using an R-389 receiver with 8 kc bandwidth. The tones used, and the order in which they were presented, were as follows:

1200
200
2000
400
3000
800
4000
1000
5000

Each subject was instructed identically according to the following guidelines:

Background:

Try to imagine yourself in the following situation:

> The Nation is in a state of emergency - Your only source of information is your AM broadcast receiver over which you are receiving Presidential addresses, news broadcasts and Civil Defense information.
>
> In the background, over your receiver, you will hear a tone. This tone is carrying teletype information vital to the Nation's defense.

Object:

Try to find a level of tone which if any louder would be annoying to you if it were present all the time over your receiver under the conditions above.

Procedure:

1. Tone off - Adjust the sound level of the news broadcaster to that which you consider comfortable.

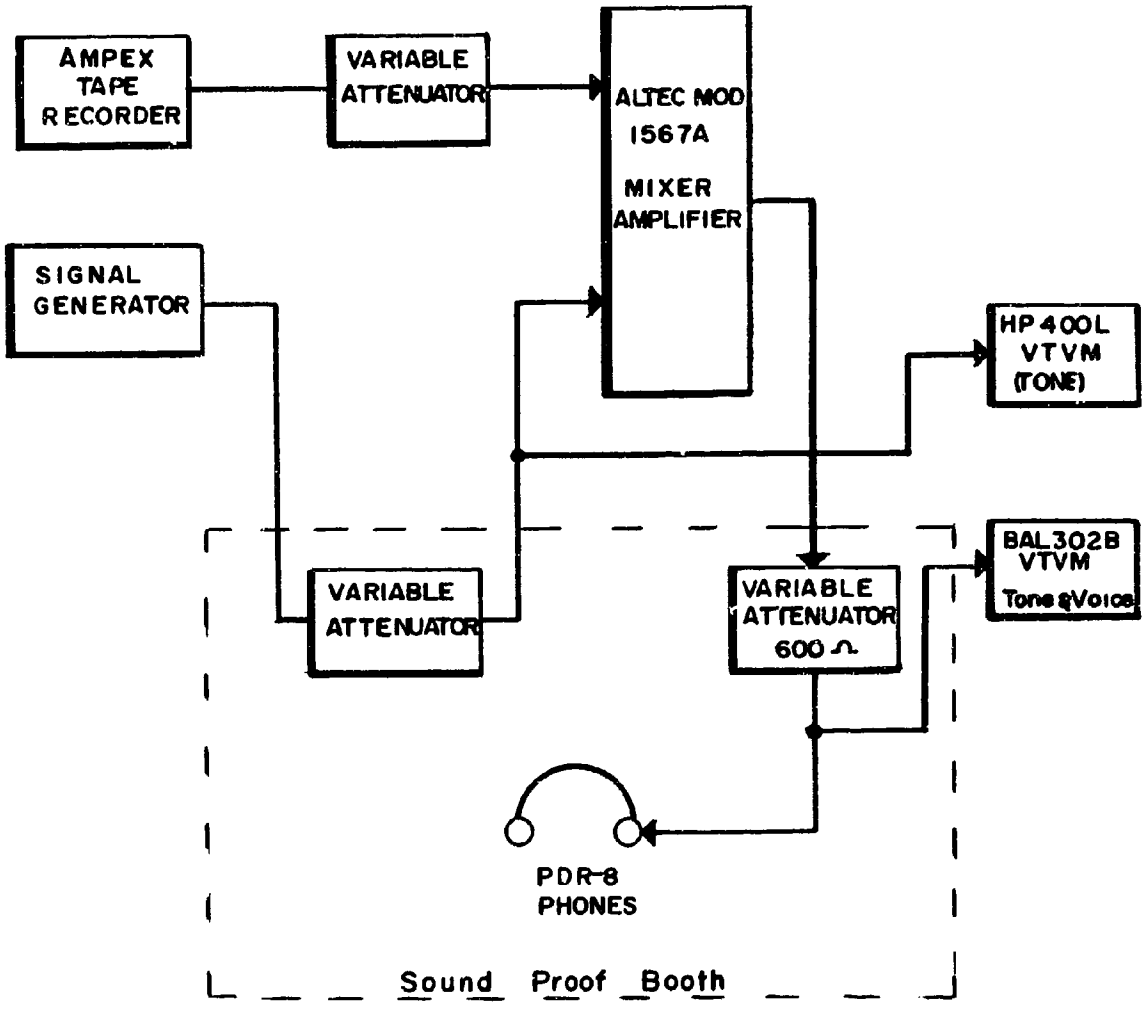

AMPEX
TAPE
RECORDER
VARIABLE
ATTENUATOR
ALTEC MOD
1567A
MIXER
AMPLIFIER
SIGNAL
GENERATOR
HP 400L
VTVM
(TONE)
BAL302B
VTVM
Tone & Voice
VARIABLE
ATTENUATOR
VARIABLE
ATTENUATOR
600 Ω
PDR-8
PHONES
Sound Proof Booth

FIGURE I-1

2. Tone on

   Turn the tone up as loud as it will go, then turn it down to a moderate level and leave it there for about half a minute.

3. Depending on whether or not the first half-minute was definitely annoying, turn the tone to a higher or lower level for another half-minute, and so on, until 4 or 5 half-minute judgments have been made.

4. With the tone at the highest level which you think is not annoying, leave it there for about a minute and then make a final adjustment or not as you wish.

An approximate audio level without tone was obtained from the Ballantine 302B meter which has a highly damped meter response. This meter was checked with a HP 3400A True RMS voltmeter and found to be within ± 1 db. The tone level into the PDR-8 headphones was obtained from the HP 400L VTVM and the attenuator setting.

The data is tabulated in Table I-1[1] and the average annoyance level referred to the audio level is plotted in Fig. I-2. The PDR-8 headphones were calibrated with a W.E. 640AA microphone and their response is shown in Fig. I-3. The deviation of the PDR-8's from a flat response is included in the data in Table I-1 and Fig. I-2.

The data indicates that the lower frequencies are less annoying than the higher frequencies. It is also noted that the equal annoyance curve follows very closely the shape of the equal loudness curves of Fig. 4. This is in agreement with other experimenters (2, 3, 4).

1 Reference is made to Table I-1. Table I-1, in Mr. Entzminger's original report, is a tabulation of the data presented in Fig. I-2. It has been omitted in this appendix.

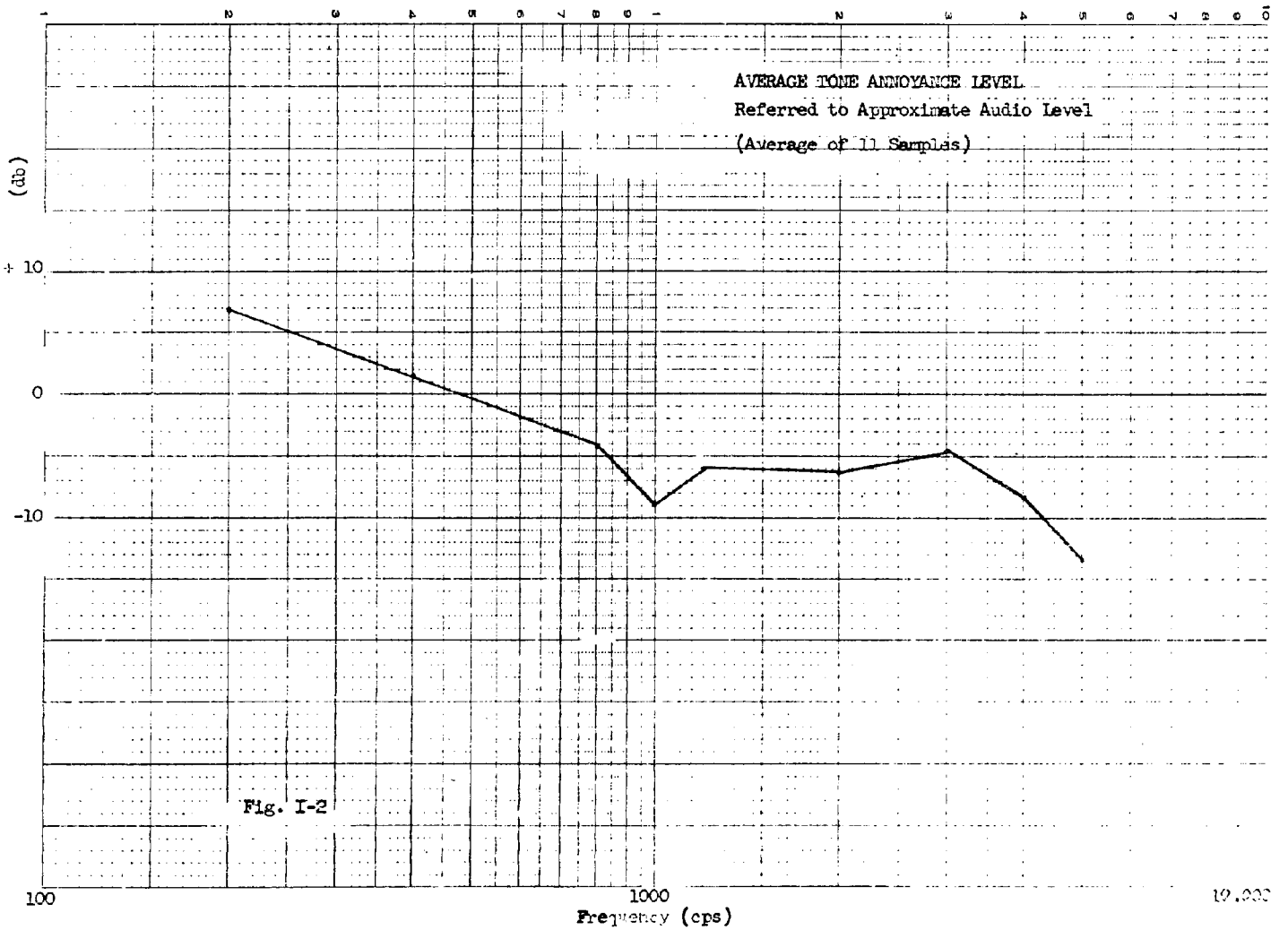

AVERAGE TONE ANNOYANCE LEVEL
Referred to Approximate Audio Level
(Average of 11 Samples)
(db)
+ 10
0
-10
100
1000
Frequency (cps)

Fig. I-2

FREQUENCY RESPONSE OF PDR-8 PHONES (PARALLELED)

0.2 volts input

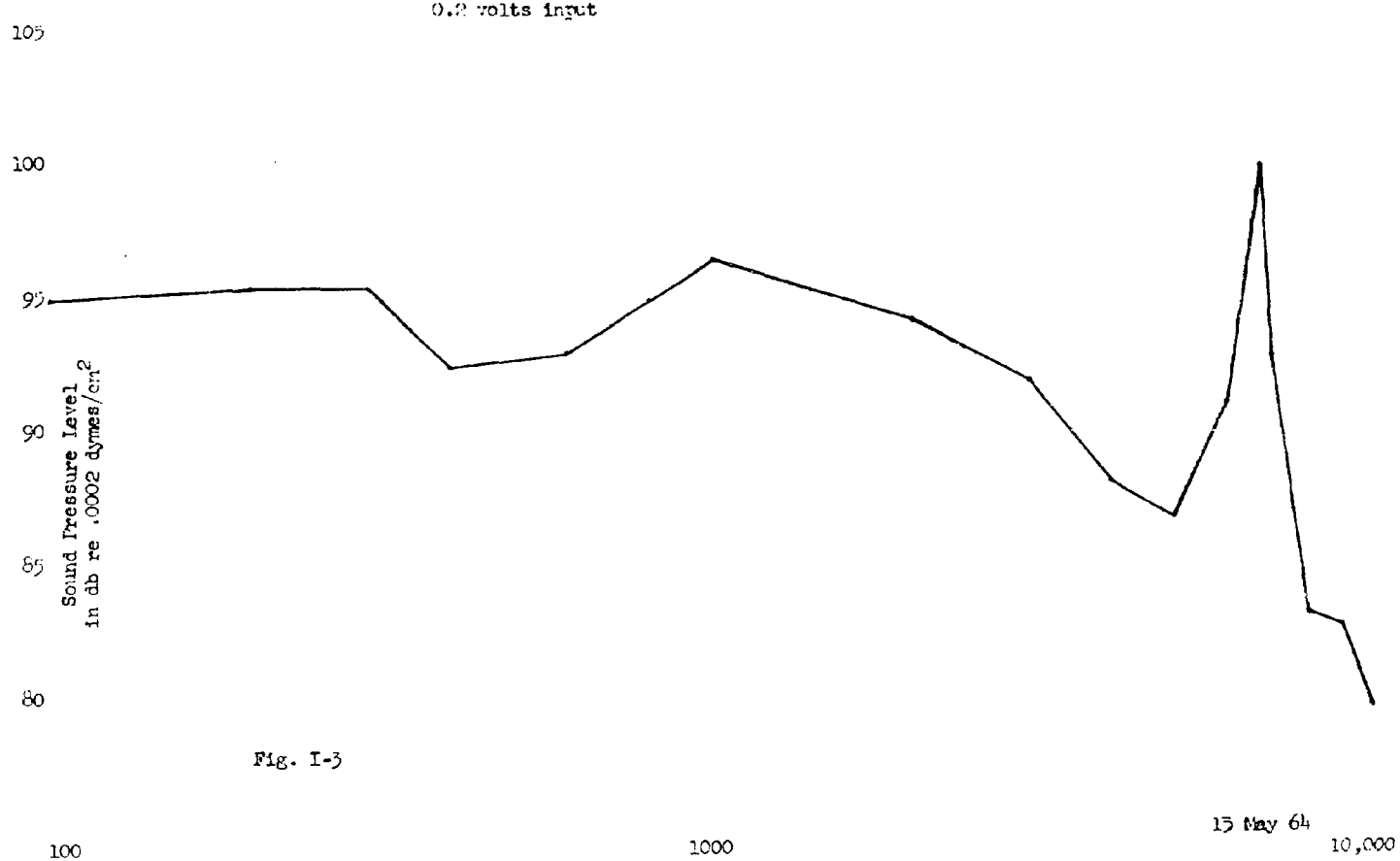


Fig. I-3

15 May 64

II Frequency Response Of AM Radios

The frequency response of various AM radios was measured by modulating the carrier of an RF signal generator with a tone and detecting the speaker output of the radio with a calibrated microphone as shown in Fig. I-1. The results are tabulated in Table II-1[2] and the average response is shown in Fig. II-2. Two car radios were also tested and their response is indicated as typical car radio response on Fig. II-2.

It is noted that table model and transistor radios with approximately 4" speakers are down in response at 100 cps by about 35 db and are down approximately 14 db at 200 cps. Car radios, however, are typically flat from 100 cps to 7-8 kHz and one would expect that higher quality radios using larger speakers such as AM tuners feeding a Hi-Fi system would also have a response similar to car radios.

For emergency conditions with AC power off, most of the population would have to resort to portable transistorized radios having a response no better than that shown in Fig. II-2.

2 Reference is made to Table II-1. Table II-1, in Mr. Entzminger's original report, is a tabulation of the data presented in Fig. II-2. It has been omitted in this appendix.

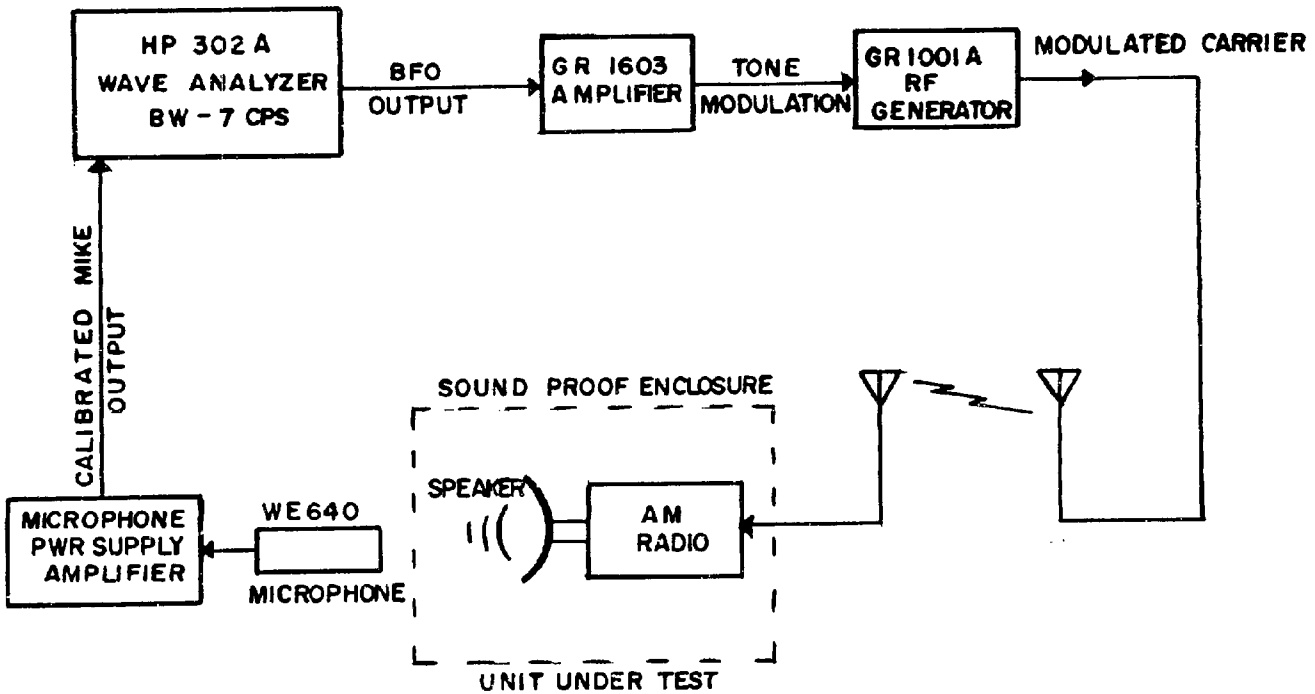

HP 302 A
WAVE ANALYZER
BW - 7 CPS
BFO
OUTPUT
GR 1603
AMPLIFIER
TONE
MODULATION
GR 1001 A
RF
GENERATOR
MODULATED CARRIER
CALIBRATED MIKE
OUTPUT
SOUND PROOF ENCLOSURE
SPEAKER
AM
RADIO
MICROPHONE
PWR SUPPLY
AMPLIFIER
WE 640
MICROPHONE
UNIT UNDER TEST

FIGURE II-1

RELATIVE FREQUENCY RESPONSE OF AN RADIO

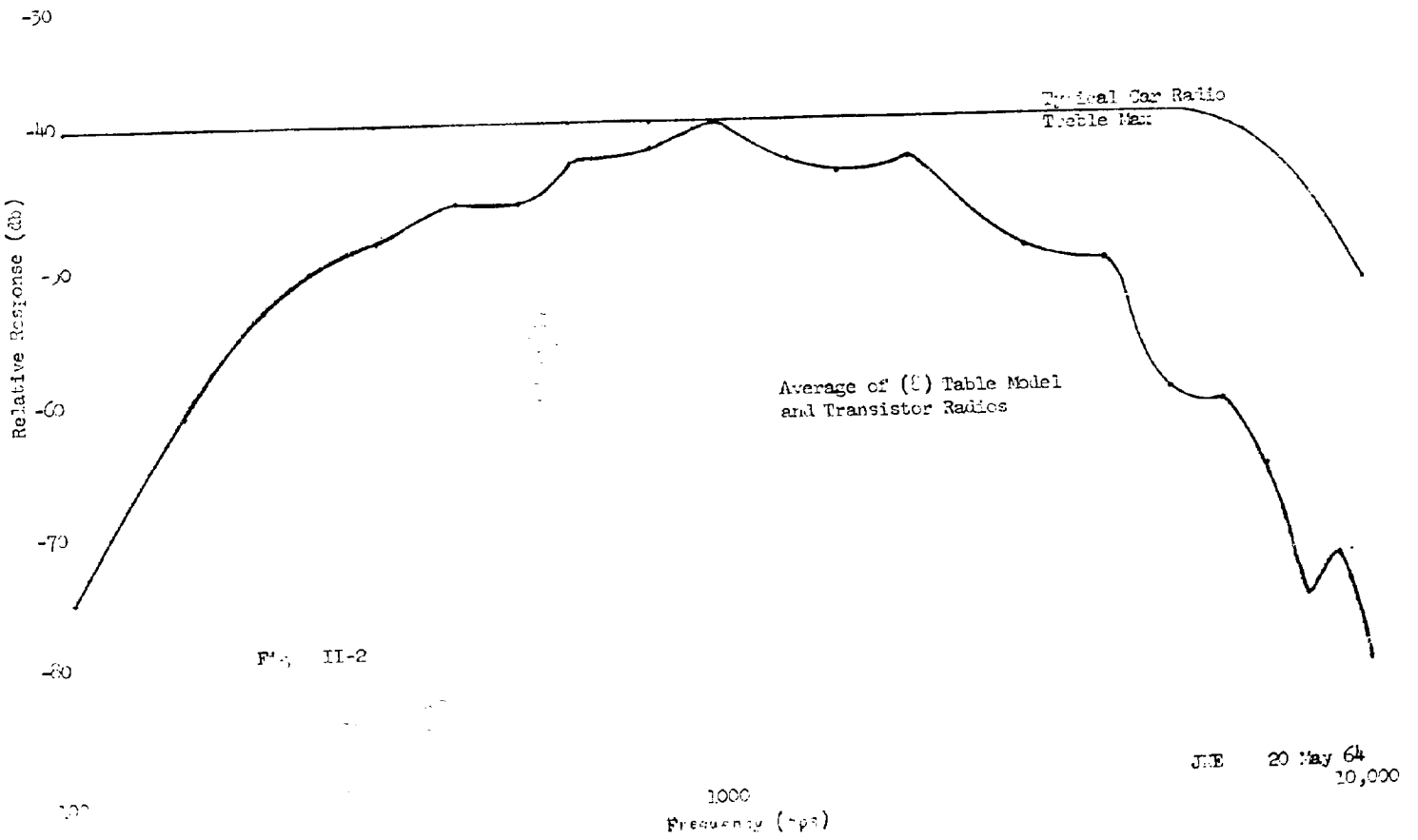


Fig. II-2

JHE 20 May 64

REFERENCES

1. "The Effect of Speech and Noise Level on the Masking of Speech by Pure Tones and Random Noise" R.J. Christman et al RADC-TN-60-97 June 1960.

2. "Annoyance Threshold Judgments of Bands of Noise" by Walter Spieth Journ. of Acount. Soc. Amer Col. 28, No. 5 Sept 1956 p. 872-877, also AFCRC TR-55-6.

3. "The Influence of Noise on Production and Fatigue, as Related to Pitch Sensation Level, and Steadiness of the Noise" D.A. Laird, Jour. of Appl. Psychology Vol XVII 1933 p. 320-330.

4. D. G. Laird & K Coye J. Acoust. Soc. Amer I, 158-163 (1929)

5. High Quality Sound Reproduction - James Moir p. 504 Chapman & Hall Ltd. (1958)

6. Speech and Hearing in Communications by Harvey Fletcher p. 78 D. Van Nostrand Co. 1953

7. "The Effect of High and Low Pass Filtering on Speech Intelligibility" A. Rubin et al RADC-TN-60-243, Nov. 1960

8. "Intelligibility of Different Speech Materials" I. J. Hirsh et al. J. Acoust. Soc. Amer Vol 26, 1954 pp. 530-38.

9. "Speech Communications In Noise" K.D. Dryter AFCRC TR-54-52 (1955)

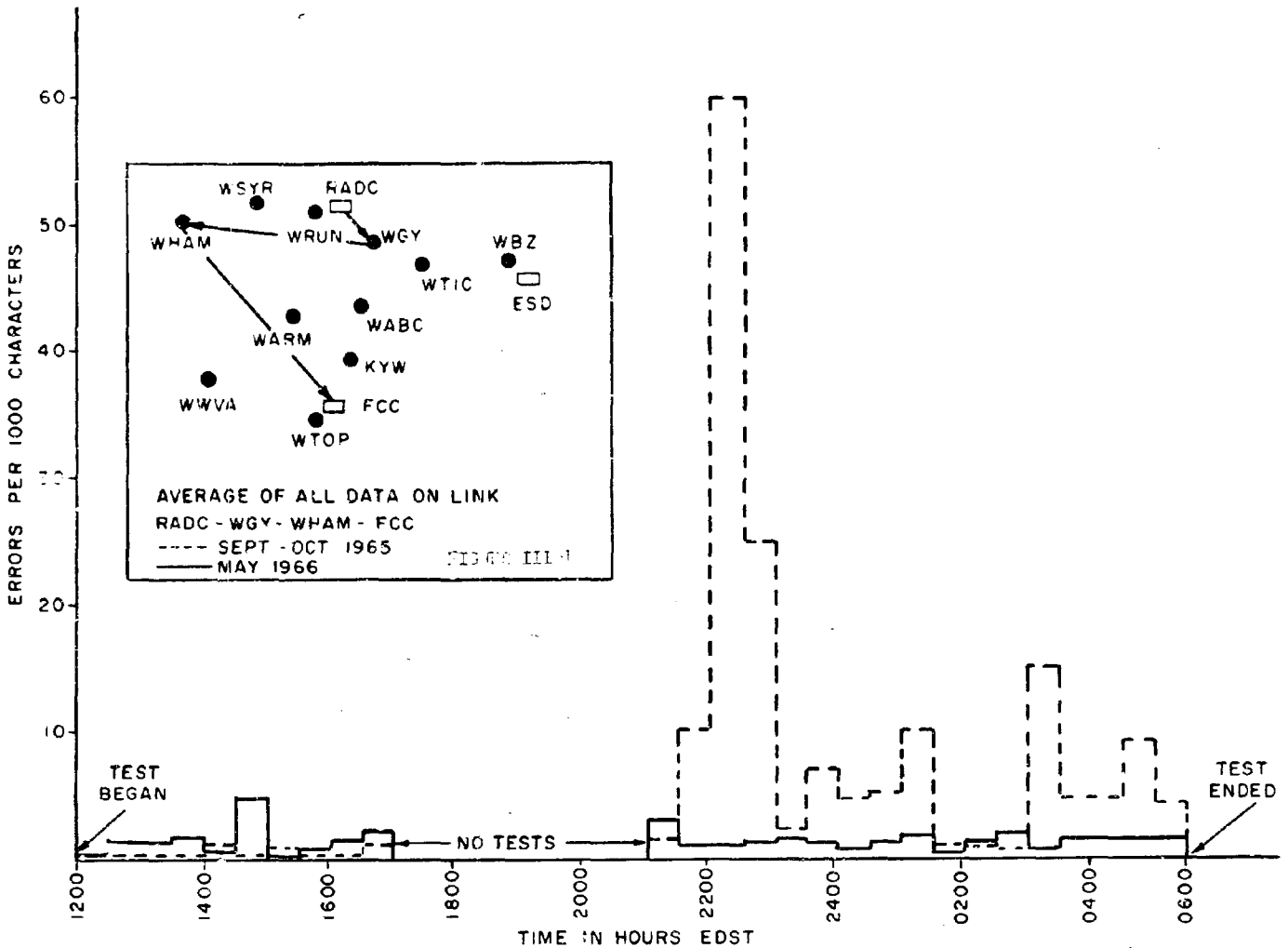
10. "A Comparison of Amplitude and Angle Modulation of Narrow Band Communication of Binary-Coded Messages in Fluctuation Noise" G. F. Montgomery Proc IRE, Vol 42 pp 447-454 Feb 1954

11. "Performance of Some Radio System in the Presence of Thermal and Atmospheric Noise" A. D. Watt et al. Proc IRE Dec. 1958 pp. 1914-1923.

APPENDIX III

ADDITIONAL DATA

During the period while this report was being reviewed, (that is the time between writing and publication), a limited time was available for the collection of additional data. It was felt that some positive evidence was necessary to substantiate the claim that the equipment modification and alignment that was made during and after the initial period of data collection had in fact the desired effect of improving the error rate. Two circuits were chosen for comparison. The first circuit was the RADC-WGY-WHAM-FCC circuit which was very reliable in the initial data collection period. Data taken during May 1966 is shown in Fig. III-1. The dotted line represents data taken on the same circuit during the initial period. (See Fig. 37) The two graphs compare favorably with an improvement in periods of previously high error rates. The second circuit was the FCC-WTOP-KYW-WAHM-WABC-WTIC-WGY-RADC circuit. This circuit was unuseable due to equipment instability problems. Data taken in May 1966 after modification of the equipment is displayed in Fig. III-2. This error rate is considered useable for emergency communications.


ERRORS PER 1000 CHARACTERS
60
50
40
20
10
WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
AVERAGE OF ALL DATA ON LINK
RADC - WGY - WHAM - FCC
---- SEPT - OCT 1965
—— MAY 1966
TEST BEGAN
NO TESTS
TEST ENDED
1200
1400
1600
1800
2000
2200
2400
0200
0400
0600
TIME IN HOURS EDST

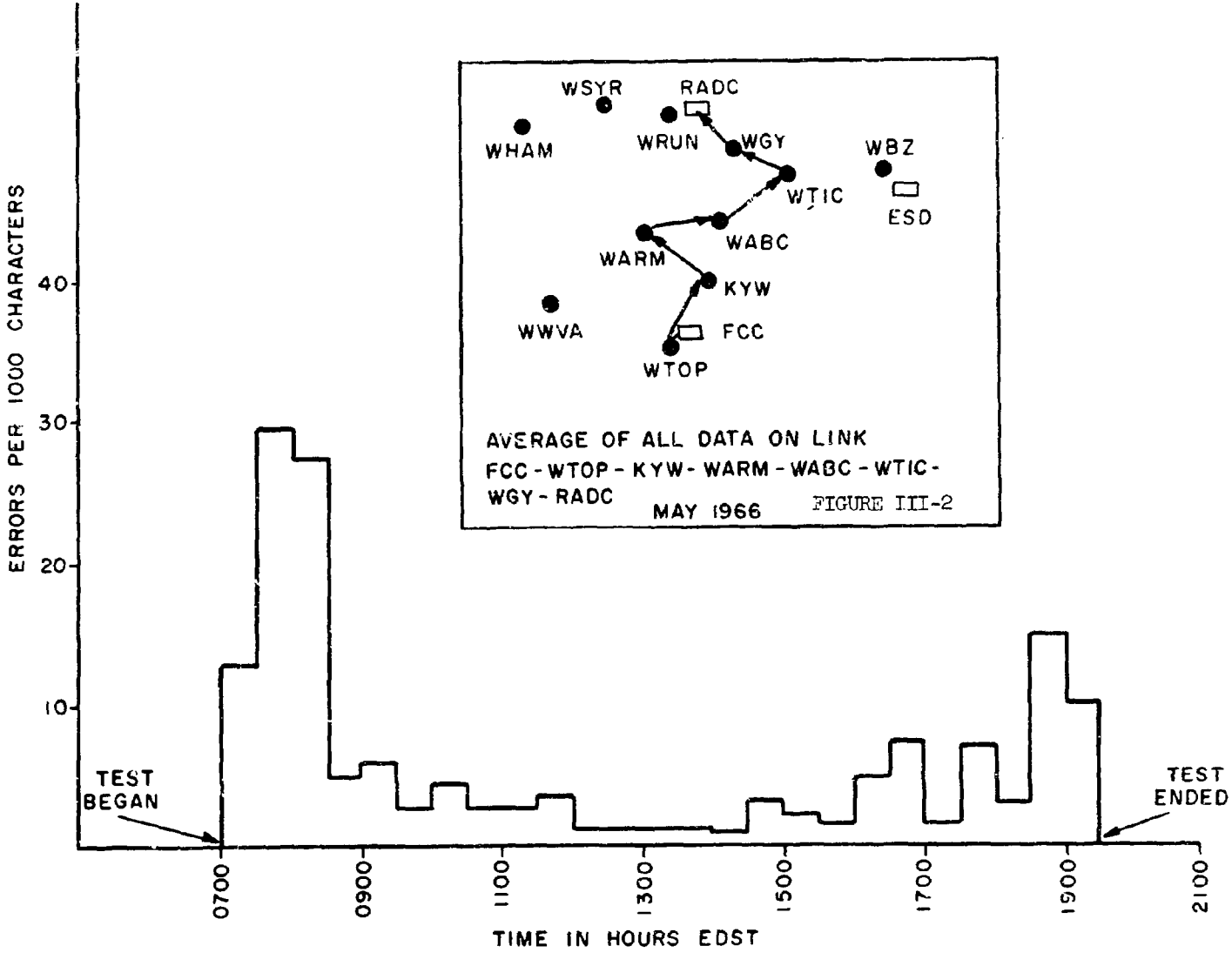

ERRORS PER 1000 CHARACTERS
40
30
20
10
TEST BEGAN
TEST ENDED
0700
0900
1100
1300
1500
1700
1900
2100
TIME IN HOURS EDST
WSYR
RADC
WHAM
WRUN
WGY
WBZ
WTIC
ESD
WABC
WARM
KYW
WWVA
FCC
WTOP
AVERAGE OF ALL DATA ON LINK
FCC - WTOP - KYW - WARM - WABC - WTIC -
WGY - RADC
MAY 1966

FIGURE III-2

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

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

1. ORIGINATING ACTIVITY *(Corporate author)* Narrow Band Transmission Section Communications Division Rome Air Development Center, Griffiss AFB, NY 13440	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

(U) "Use of Commercial Broadcast Stations for Emergency DOD Communications"

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Documentary Final Report on Project 9680 (Title Same)

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

Griffith, David A.
Martin, John R.
Spector, Donald

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1966	107	13

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 9680 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) RADC-TR-66-392 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

Each transmittal of this document outside the Department of Defense must have prior approval of RADC (EMCTN), GAFB, N.Y. 13440.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Defense Communications Agency, (Code 333) S. Courthouse Road & 8th St. Arlington, Va. 20305

13. ABSTRACT

This report contains details and results which were obtained during the design, installation and testing portion of a program, the intent of which was to demonstrate the technical feasibility of providing emergency DOD teletype communications through the use of a distributed network of commercial AM broadcast stations. This was accomplished utilizing simplex operation with no degradation to the commercial program material and by duplex operation with the insertion of a keyed audio tone at 4[illegible].5 cycles. The latter introduced some annoyance to the home listener. However, the degree of intelligibility, which is of primary consideration in an emergency, was not reduced. The system was operated in atrace route mode and in a flood mode and was capable of being checked on a station-by-station basis by any user. The design and equipment problems are discussed and the accumulated data is presented.

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Communications Systems						
Teletype Communications						
Frequency Modulation						
Frequency Shift Keying						
Tone Shift Keying						
Communications Survivability						
Survivability Redundancy						
Speech Interference						

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DEPARTMENT OF THE AIR FORCE
AIR FORCE RESEARCH LABORATORY (AFMC)

1 Jun 04

MEMORANDUM FOR DTIC-OCQ
ATTN: Larry Downing
Ft. Belvoir, VA 22060-6218

FROM: AFRL/IFOIP

SUBJECT: Distribution Statement Change

1. The following documents have been reviewed and have been approved for Public Release; Distribution Unlimited:

ADB084552, "Project Birdwatch at Dover AFB", RADC-TR-84-7

ADB191869, "Acousto-Optic Beam Steering Study", RL-TR-94-121

AD0800669, "Use of Commercial Broadcast Facilities for Emergency DoD Communications", RADC-TR-66-392

ADB058979, "Multi-Rate Secure Processor Terminal Architecture Study", RADC-TR-81-77, Vol 1.

ADB053656, "16 KB/S Modem (AN/GCS-38) CONUS Test", RADC-TR-80-89

ADB055136, "VINSON/AUTOVON Interface Applique for the Modem, Digital Data, AN/GCS-8", RADC-TR-80-341

ADB043556, "16 KB/S Data Modem Partitioning", RADC-TR-79-278

ADB029131, "16 Kilobit Modem Evaluation", RADC-TR-78-127.

2. Please contact the undersigned should you have any questions regarding this document. Thank you very much for your time and attention to this matter.

Kelly Cagwin

KELLY CAGWIN
STINFO Officer
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