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LINCOLN LABORATORY

PROGRESS REPORT

TO

WESTERN ELECTRIC COMPANY

Subcontract X-213
(Prime Contract AF 18 (600)-572)

8 December 1952 - 31 December 1953

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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PROGRESS REPORT

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under

Subcontract X-213

(Prime Contract AF 18(600)-572)

8 December 1952 – 31 December 1953

This report is submitted by Lincoln Laboratory as a subcontractor under Contract No. AF 18(600)-572 (Western Electric Contract X-213). Other work within Lincoln Laboratory, supported directly by the Department of the Army, the Department of the Navy, and the Department of the Air Force, under Contract No. AF 19(122)-458, has contributed in varying degrees to the research described herein.

LEXINGTON MASSACHUSETTS

I. INTRODUCTION

A. SCOPE OF REPORT

This report is a summary of progress during 1953 on the programs undertaken by Lincoln Laboratory, Massachusetts Institute of Technology, under subcontract to the Western Electric Company Subcontract X-213 (Prime Contract AF 18(600)-572). Its purpose is to summarize the work performed and the results obtained; it is not intended to reiterate the detailed information contained in applicable Quarterly Progress Reports, Technical Reports, Technical Memoranda, and Manuals of the Lincoln Laboratory. (Many of these documents are listed on page I-2.)

B. HISTORY OF PROJECT CORRODE

During the summer of 1952, a Study Group under the auspices of Lincoln Laboratory conducted a study of the defense of the United States against enemy air attack. This Summer Study Group recommended the establishment of a distant early-warning (DEW) line in the arctic region to provide warning of impending air attack sufficiently early so that effective defense measures could be initiated before enemy aircraft entered vital areas.

Late in 1952, PROJECT COUNTER CHANGE (now PROJECT CORRODE) was established under Air Force cognizance to provide for the installation of a model DEW line and for the development of improved equipment for early-warning application. As prime contractor for PROJECT CORRODE, the Western Electric Company agreed to furnish the necessary equipment and install it during the summer of 1953. Certain phases of the initial development and engineering design were undertaken by Lincoln Laboratory in December 1952, and the commitments for the first phase of the field installations were fulfilled on the scheduled date of 1 May 1953.

The Lincoln Laboratory also provided supporting technical services. These included training of Western Electric operating personnel, and the installation and initial adjustment of radar and communications equipment at the domestic sites. In the Far North, Laboratory personnel assisted in the adjustment and initial operation of the VHF scatter-communication equipment (at this writing, similar services are being furnished for radar equipment).

C. BREAKDOWN OF EFFORT IN LINCOLN LABORATORY

The p icipation of the Laboratory in PROJECT CORRODE started as crash programs in the fields of ground-based radar and long-range communications. As time went on, the Laboratory activity for PROJECT CORRODE evolved into a more extensive and continuing program of research, development and field engineering, handled principally by Group 31 (Radar Systems), Group 36 (Communications Systems Engineering) and Group 45 (Airborne Early Warning). Personnel of Group 33 (Long-Range Communications) and Group 34 (Communications Techniques) also contributed materially to the CORRODE program. The work on acoustic detection was carried out directly under Division 5 (Special Systems).

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II. DEVELOPMENT OF AUTOMATIC ALERTING RADAR

A. INTRODUCTION

One of the requirements of the DEW line is that reliable results from radars be obtained over a prolonged period with minimum use of field personnel. The Summer Study Group therefore recommended the use of automatic-alarm devices rather than constant watch by PPI operators. To fulfill this requirement, a development program was carried out to modify the AN/TPS-1D radar to provide automatic alerting. (This radar equipment was chosen mainly because it was available in the quantities required and because it was of moderate size and complexity.) In order to meet the time scale for shipment of equipment to the Far North, it was necessary to make compromises in system performance. The system parameters – such as pulse-repetition rate, gate length, time-on-target, alarm circuitry, and audible presentation – were interrelated and dependent to a large extent upon the design characteristics of the basic radar equipment.

The program for modifying the AN/TPS-1D radar and providing for audible-presentation and alarm circuits was divided into several parts:

(1) Design of the gating, filtering and alerting circuits.

(2) Comparison of the performance of automatic-alarm systems with the performance of human operators.

(3) Evaluation of the capabilities and limitations of the radar set, particularly with regard to increasing its pulse length and/or repetition rate.

(4) Procurement and production of components needed for the field equipments.

(5) System testing of completed equipments.

B. AUTOMATIC ALERTING RADAR X-1

The basic techniques for obtaining automatic alarms, including analytical work, experimental bench testing, auditory perception tests, experimental flight tests, and the establishment of a practical design, were evolved on a crash basis in the early spring of 1953. A program to modify ten AN/TPS-1D radars and to fabricate an equal number of X-1 Radalarm units was subsequently activated. The engineering design, drafting and procurement of the necessary components were accomplished by Lincoln Laboratory personnel. Contracts were awarded to several local electronic concerns in the greater Boston area for the fabrication of system components. The system assembly, including radar modifications to provide for long-pulse operation and improved MTI performance of the AN/TPS-1D radar, was handled within the Laboratory. At the Illinois test sites, assistance was provided to the Western Electric Company by Lincoln Laboratory personnel with the assistance of Raytheon field engineering services obtained under a separate field service contract with Raytheon Manufacturing Company. Special test equipment for the radar and alarm circuits was developed or procured from Government Furnished Equipment sources and turned over to the Western Electric Company.

Figure II-1 is a block diagram of the Automatic Alerting Radar X-1 which was the designation given to the AN/TPS-1D (Mod A) equipped with X-1 Radalarm. Figures II-2 and II-3 show the arrangement of the components in the X-1 Radalarm which are installed in two 7-foot relay cabinets. Each unit contains six range gates and associated automatic alarms that provide for monitoring six adjustable annular rings centered at the radar.

C. COMPARISON OF AUTOMATIC VS AUDITORY DETECTION BY HUMAN OPERATORS

An experiment was carried out in the Laboratory to evaluate, under controlled conditions, the performance of the Radalarm X-1 as a detection device in comparison with the performance of attentive operators hearing the same signals. A block diagram of the apparatus used in the test is shown in Fig. II-4. The apparatus presented simulated "targets" simultaneously to the Radalarm and to an audio amplifier driving loudspeakers in the subjects listening booths. At each frequency (audio tones between 210 and 360 cps to simulate the Doppler component of the radar return), "targets" of gradually increasing intensity were presented, and recording equipment noted the target strength at which the Radalarm meter was tripped and at which the Naval enlisted men serving as subjects (20 in all) reported the signals.

The principal results of the experiment are shown in Fig. II-5. These results may be interpreted to mean that, if the Radalarm meter is set at a level of sensitivity at which its false-alarm rate equals the false-alarm rate of the average human operator, the difference between the signal intensities necessary to insure a given probability of auditory detection by human observers and by the alarm is slight – of the order of one decibel. Since the human observers were alert and not subject to the dulling effects of long watches in an area where the air traffic is extremely low, this finding may be taken as favorable to the efficacy and sensitivity of the automatic-alarm circuits. In view of the results of this experiment, it was decided to eliminate the audible display from subsequent Radalarm units.

Further information on the comparison of human and automatic detection is contained in Lincoln Laboratory Technical Reports.

D. IMPROVED RADARS FOR PROJECT CORRODE

It was recognized at the outset that the Automatic Alerting Radar X-1 would have several operational deficiencies as an early-warning radar. As soon as the rush program to produce the X-1 system was completed, attention was directed to the problem of obtaining an improved alerting radar. A survey of production radars indicated that only two sets merited serious consideration. One was the AN/TPS-1D (already used in the Automatic Alerting Radar X-1), and the other was the AN/FPS-8.

1. AN/TPS-1D Modification Program

Three possibilities for further improving the AN/TPS-1D were investigated. One was to use the antenna built for the AN/FPS-8 radar to provide increased range and high-altitude coverage. (This antenna has a 25-foot horizontal aperture and cosecant-squared vertical coverage.) The second was to increase the magnetron pulse length in order to obtain a more satisfactory ratio of gate width to pulse length. This possibility was discussed with the Power Tube Division of the Raytheon Manufacturing Company, but it was found to be infeasible because of the characteristics of the 5J26 magnetron used in the AN/TPS-1D. (Raytheon is continuing to investigate what can be done to improve the life and long-pulse operation of the 5J26 magnetron.) The third possibility was to redesign and repackage the Radalarm unit, incorporating ideas accumulated during the crash development and testing of Radalarm X-1. A new alarm unit, called X-2, was built; this was functionally equivalent to the X-1, but occupied only 40 per cent of the volume, and required fewer tubes per alarm channel. By August 1953, development of an even more refined and simplified audio-alarm unit had progressed to the stage where it could be turned over to the Raytheon Manufacturing Company for production engineering as part of the Automatic Alerting Radar X-3. A description of the X-3 system is contained in Sec. II-E of this report.

2. AN/FPS-8 Evaluation Program

A paper investigation was carried out to determine the suitability of the AN/FPS-8 radar for use with an automatic-alarm system. The AN/FPS-8 is a higher-powered L-band search radar of the AN/TPS-1D type but designed for fixed installations.

At the request of the Lincoln Laboratory, personnel of General Electric Company investigated the feasibility of stretching the magnetron pulse length from 3 to 6 μsec, or longer if possible. A preliminary check indicated the feasibility of this change, but lack of performance data on the QK358 magnetron has prevented the necessary detailed evaluation of long-pulse operation.

An AN/FPS-8 radar was released by the Air Force in the summer of 1953 for use of Lincoln Laboratory and was installed at the Lexington Field Station. Certain component difficulties, such as leaky pulse transformers, AFC instability, etc. were encountered in setting up this equipment. After a period of approximately six weeks, the system settled down to provide consistent performance. Late in 1953, a flight-test evaluation program commenced, which will attempt to ascertain the over-all radar performance characteristics, with particular emphasis being placed upon the high-altitude coverage of the system. After the radar calibration has been completed, a modified Radalarm X-3 will be attached to this radar to evaluate its operation as an automatic-alerting radar system.

E. AUTOMATIC-ALERTING RADAR X-3

In August 1953, a contract was awarded to the Raytheon Manufacturing Company to engineer for production and to fabricate two complete models of an automatic-alerting radar system utilizing the Radalarm X-3, a modified AN/TPS-1D, and the AN/FPS-8 antenna. This combination of units will provide: (1) good high-altitude coverage with a csc^2 antenna, (2) detection of B-29 type aircraft (head-on aspect) at ranges of about 90 nautical miles, and (3) detection of aircraft flying at radial speeds of up to 450 miles per hour. The first prototype system is scheduled for delivery by the end of January 1954. (At the time of writing, both models have been delivered to Lincoln Laboratory; one is being installed in Building C, the other will be shipped to Illinois for use in the domestic CORRODE trials.)

Vertical-coverage diagrams, showing the relative performance of the X-1 and X-3 Automatic Alerting Radars, are presented in Fig. II-6.

Figure II-7 is a block diagram of Radalarm X-3. It differs from Radalarm X-2 in the following respects:

(1) The sampling pulse is produced by a modulator circuit employing a pulse-forming network and thyratron;

[redacted]

(3) An AVC circuit has been incorporated to replace the noise-balance circuit in order to improve the stability of the detection sensitivity and false-alarm rate;

(4) System-tuning procedures have been simplified.

The Radalarm X-3 has been designed to fit in a standard case of the AN/TPS-1D radar, while still providing a high degree of accessibility (Fig. II-8).

F. ALARM CIRCUITRY FOR AN/FPS-3

The possibility of providing automatic-alarm circuitry for the heavy radars (AN/FPS-3 and AN/CPS-6B) currently used in early warning and/or GCI stations was studied. Since the AN/FPS-3 is more widely used than the AN/CPS-6B and, from the standpoint of adaptability to automatic alerting, had better design characteristics, it was decided to investigate circuitry that might be applied to this radar. Provision for operation in ground clutter was not considered a requirement because the alerting band would be for early warning only, and therefore the range gates could be placed at ranges well beyond the clutter.

Two alarm circuits were designed and constructed – one employing normal video, the other phase-detected bipolar video. Preliminary tests on an AN/FPS-3 radar located on Katahdin Hill in Lexington, Mass., indicated that the performance of the two circuits was equal and of approximately the predicted sensitivity.

Two models of an alarm unit for the AN/FPS-3, to be called Radalarm X-5, are being fabricated for field-evaluation trials. Designed to operate on the normal video from the lower beam of the radar, Radalarm X-5 will provide one alarm band six miles wide around the radar, [redacted]

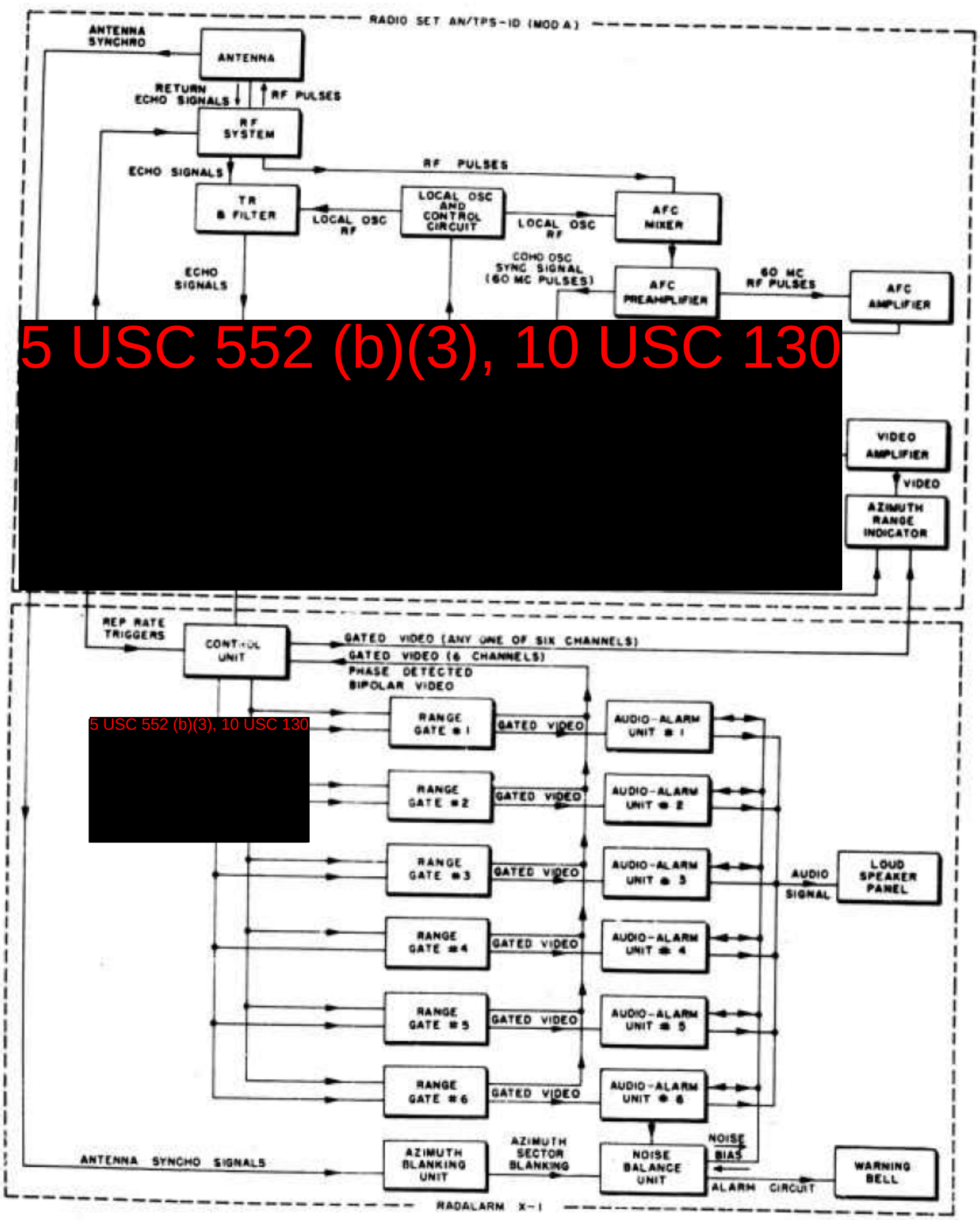

Fig. II-1. Block diagram of Automatic Alerting Radar X-1.

Fig. II-2. Radalarm X-1, range gate cabinet.

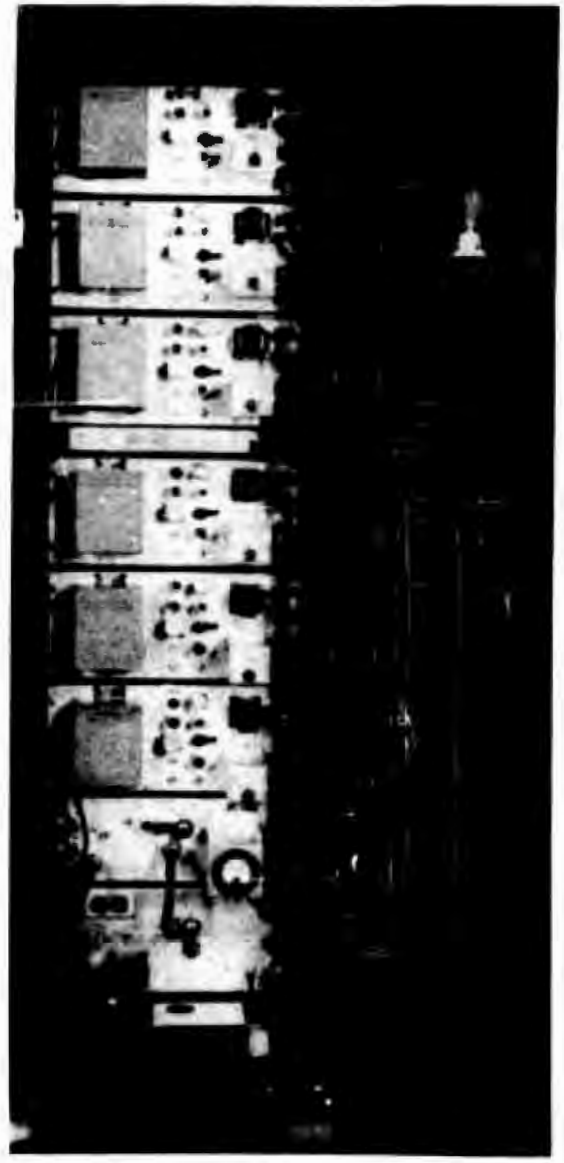

Fig. II-3. Radalarm X-1, audio alarm cabinet.

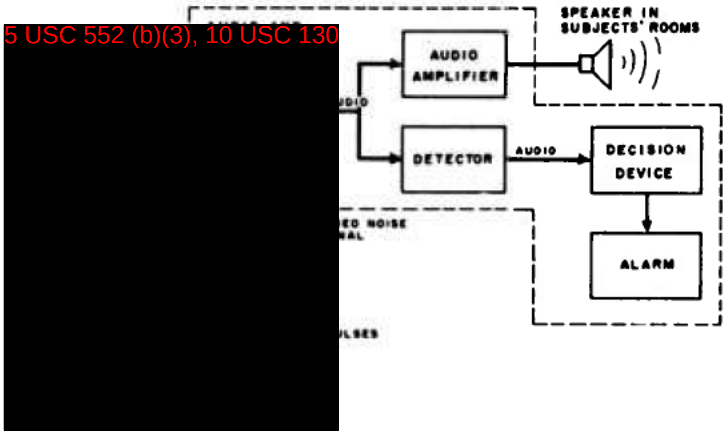

Fig. II-4. Apparatus used in test of electronic vs human detection.

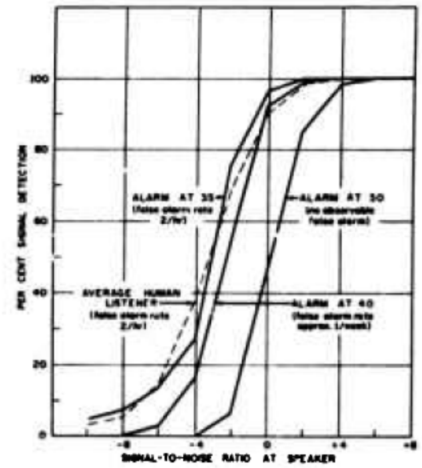

Fig. II-5. Detection by human listener and by alarm at various sensitivities.

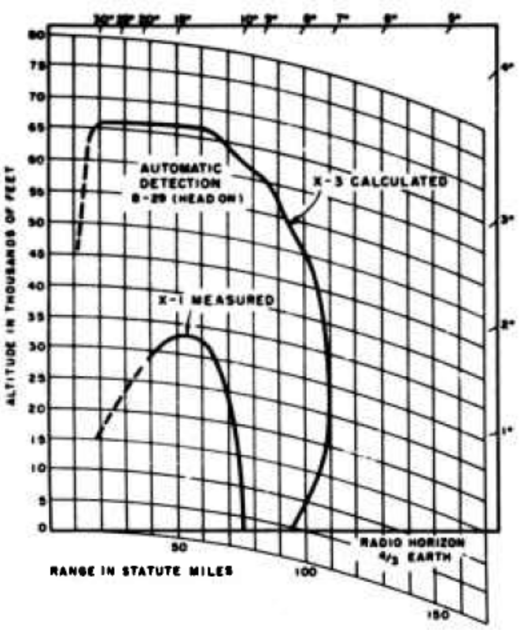

Fig. II-6. Vertical-coverage diagram, Automatic Alerting Radars X-1 and X-3.

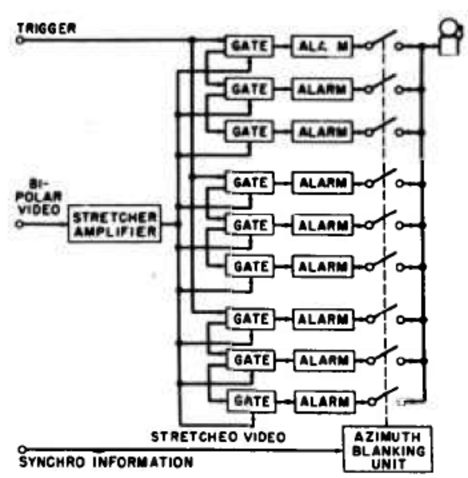

Fig. II-7. Simplified diagram of Radalarm X-3.

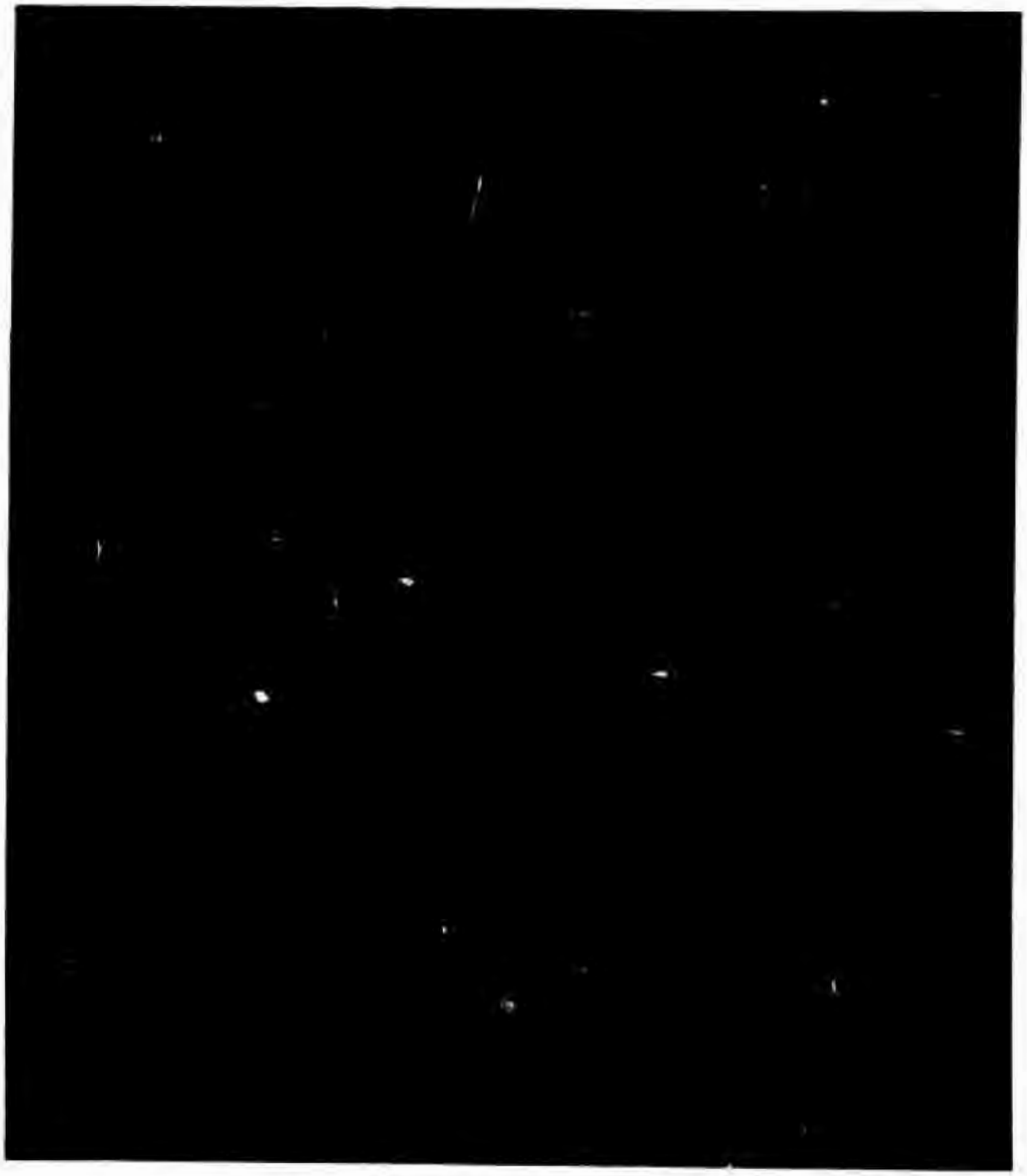

Fig. II-8(a). Radalarm X-3, front view.

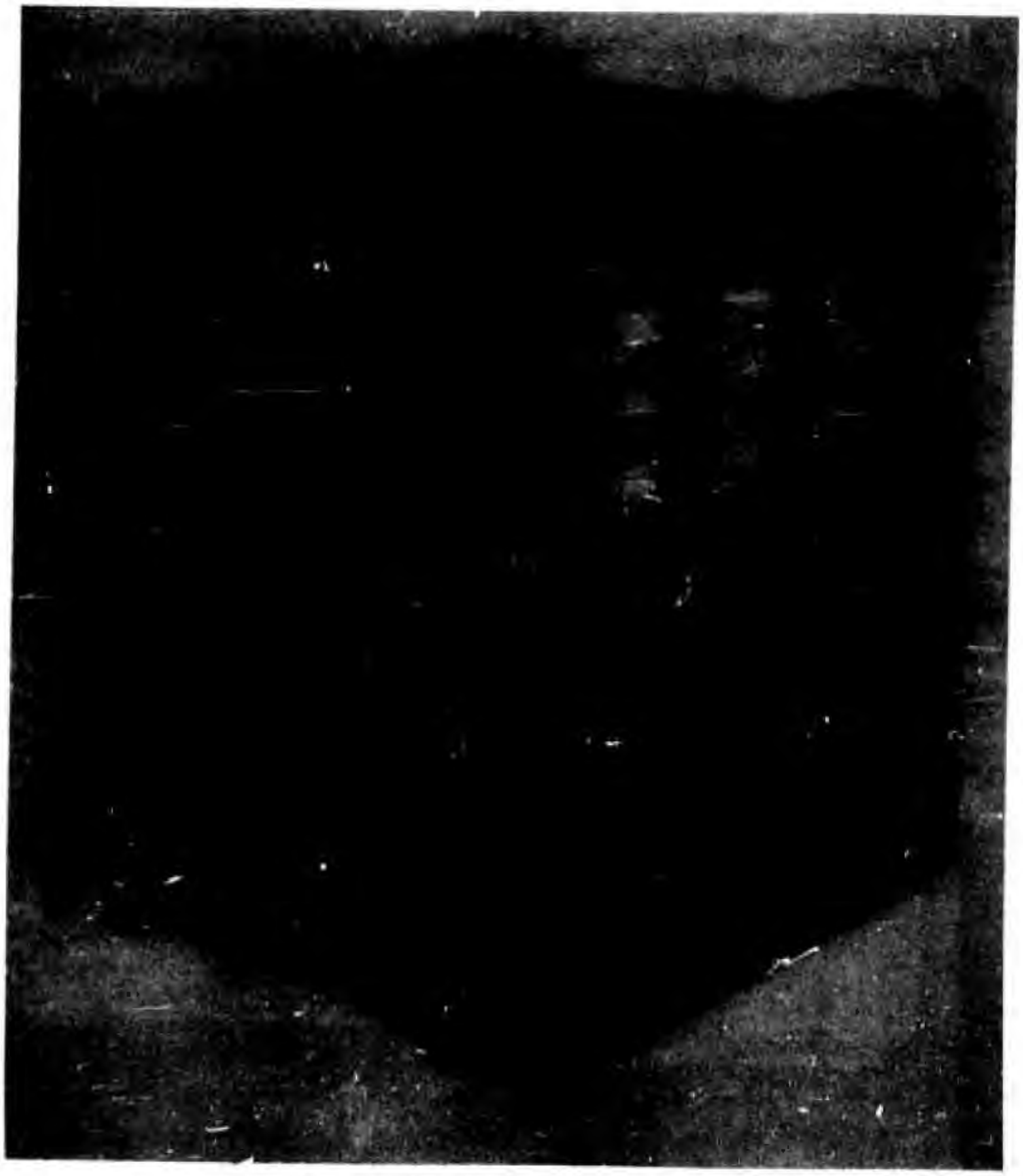

Fig.II-8(b). Radalarm X-3, side view.

III. CW FENCE RADAR (FLUTTAR)

A. INTRODUCTION

One type of detection system considered by the Summer Study Group for use in a DEW line was a CW Doppler radar employing separated transmitter and receiver. Because this radar system produces output signals at much lower frequencies than those of conventional Doppler radars, it was given the name "Fluttar". At the time of the Summer Study, it was known that a Fluttar system had been developed in Canada at the Eaton Laboratories of McGill University, and an experimental 30-mile link of "McGill fence radar" installed near Montreal. In November 1952, several members of the Lincoln Laboratory visited this installation to observe flight trials of the equipment and recommended its use in the DEW line as an adjunct to search radar. A description of the characteristics of the Fluttar system is given in the Division 3 Quarterly Progress Report of 15 January 1953. Figures III-1 through III-6 are included here for reference.

B. GENERAL SYSTEM TESTS

1. Short-Baseline Tests

The earlier efforts of Lincoln Laboratory were with a Fluttar link of approximately 30 miles, intended primarily to check in the Laboratory the operation and results of the Canadian system. Equipment was necessarily makeshift, but late in December 1952 an experimental [redacted] was considerably less than was anticipated, it was possible to detect aircraft passing through the link. It was established that the percentage modulation was over 50 in most cases when the aircraft was directly over the baseline. Quantitative tests were difficult because of the low signal-to-noise ratio and the high noise level at the receiving site. Therefore plans were made to locate the equipment in a more favorable environment.

Late in the spring of 1953, a 34-mile link was installed between Kingston, N.H. and [redacted] transmitter (see Figs. III-7 and III-8). Although test data are still being taken from this link, subsequent developments in the program tend to make the equipment obsolete.

2. Long-Baseline Tests

While earlier tests were being conducted on 30-mile baselines, it was decided to determine propagation characteristics and system coverages over longer paths, using the existing 160-mile circuit between Alpine, N.J. and the Round Hill Field Station at South Dartmouth, Mass. [redacted] output i[redacted] reflector.

Using a B-29 as a controlled target, the plane was reliably detected in the region of radio line-of-sight, but operation below this was spotty.

Subsequently, the Alpine transmitter was used with mobile receiving equipment in

Connecticut: over water to New London, over land to Norwichtown, each a path of approximately 100 miles. These and the 160-mile tests were primarily intended to obtain system coverage and target cross-section data, using available facilities, and to acquire an understanding of the over-all design criteria.

From these tests it appeared that propagation conditions imposed severe problems [redacted] Fluttar operation over long baselines might require very-high-power transmitters.

3. <u>50-Mile Baseline</u>

The first intermediate-distance link was installed early in 1953. The transmitter was located at Rockport, Mass. (200 feet above sea level), with the receiver at an AFCRC site [redacted] strength data for several runs were gathered. [redacted] modified AM channel was used here, and a 100-watt 4X150A straight-through amplifier with Motorola 10 – 20-watt transmitter. Both the receiving and transmitting antennas were 17-foot paraboloids, with no vertical beam shaping. Because of the high traffic density in the vicinity of Logan International Airport and the consequent interference with flight tests, the transmitting site was moved to Magnolia, Mass., where it is presently located.

a. <u>Flight Tests</u>

Three flight tests have been conducted, employing a B-29 aircraft flying courses perpendicular to the system baseline. The summary of the low-coverage data is shown in Fig. III-9. It will be noted that no flights were made over 5000 feet since the antennas employed in the test were not suitably shaped to provide good vertical coverage. Flights at the Deer Island end had to be kept above 500 feet because of the flying hazards in the region.

[redacted] correspon[redacted]

The possibility of obtaining sense information from a single line was investigated by swinging either one or both antennas off the baseline so as to produce an asymmetrical system. Figure III-10 is a typical target signal for a B-29 at 25 miles and 1000-foot altitude for the symmetrical case, while Fig. III-11 is the target signal observed with the receiving antenna 10° off-center. It will be noted that a time-on-target ratio, with reference to zero beat, of at least 2/1 was observed. A subsequent test was attempted with both antennas off baseline, but propagation conditions deteriorated sufficiently so that the transmitting antenna had to be realigned on the baseline. Figure III-12 is the calculated performance of a system with both antennas [redacted] system. It should be possible to extract this information by either a series of band-pass filters, a frequency meter, or a visual presentation as shown in the previous figures.

b. Calculated Performance – 50-Mile Fluttar System

The performance of a 50-mile baseline system has been calculated. In making these calculations, equipment parameters were assumed that should be achievable in 1954 as the result of development work already initiated.

[redacted]

The height of 370 feet has been chosen to eliminate lobing considerations. We assume a target cross section of 800 square feet for a plane comparable to a B-29. With our antennas

[redacted]

The antenna pattern was calculated, ignoring lobing variations, to give a constant received signal along the mid-ordinate and along the baseline at 50,000 feet. On a flat-earth basis, this would be the contour of minimum target signal intensity, at a mean level, as we have seen, of −135 db, as shown in Fig. III-13. A more critical examination of propagation beyond the line of sight indicates the low-coverage pattern shown in Fig. III-14. At very low altitudes, the signal strength of −153 dbw (see Fig. III-14) must compete with a receiver noise correspond- [redacted]

5 USC 552 (b)(3), 10 USC 130 [redacted] noise figure, corresponding to a receiver noise level of 5 USC 552 (b)(3) 10 USC 130 [redacted] safety factor of two in the computations. Narrow-band audio filtering will remove the excess noise energy carried through the IF stages.

Also competing with the signal is transmitter noise. If the noise in the bandwidth of interest is 80 db below carrier level and the direct signal for the most part is below −108 dbw, then the competing transmitter noise will be below −188 dbw.

The three possible schemes of detection available to give reliable detection of targets with their corresponding margins of safety are indicated in Table III-1.

Since our direct-signal strength is at −108 dbw, we have 68 db margin of safety to take care of severe fading and topographical difficulties. Note that the target signal almost always is line-of-sight and independent of adverse fading conditions.

Consequently, with the system described, signal information is always more than adequate to provide sense data.

TABLE III-1

DETECTION METHODS WITH CORRESPONDING MARGINS OF SAFETY

5 USC 552 (b)(3), 10 USC 130 [redacted]	Traffic Count	Sense	Presence	5 USC 552 (b)(3), 10 USC 130 [redacted]
[redacted]	X	X	X	[redacted]
		X	X	
			X	

4. Prototype Systems

Although the goal of a Fluttar system for the DEW line is a 100-mile separation between stations, the results of tests over varying distances, as described earlier in this chapter, clearly indicated that effort in the immediate future should be directed towards achieving reliable, unattended operation between stations approximately 50 miles apart. Such a spacing will eliminate the communications difficulty, which is considered to be probably 50 per cent of the problem in the Far North.

Therefore, a set of component specifications for a 50-mile baseline system (of which the present overwater North Truro-Magnolia Fluttar link is a breadboard version) was drawn up, and competitive bids were solicited from commercial sources. A contract was awarded* to Motorola, Inc. for two sets of prototype equipment, with the first set scheduled for delivery in August 1954. The specifications are given below.

*The negotiations leading to the contract culminated in 1953.

TRANSMITTER

5 USC 552 (b)(3) 10 USC 130 [redacted]

5 USC 552 (b)(3), 10 USC 130 [redacted]

5 USC 552 (b)(3) 10 USC 130 [redacted]

Prime Power	115 volts, 60 cps, single-phase
Power Amplifier	Eimac klystron amplifier 3K2000LA modified for air cooling
Exciter	Dual, low-power crystal-controlled, with automatic switchover
Fault Indication	6 fault alarms

RECEIVER

5 USC 552 (b)(3) 10 USC 130 [redacted]

Output	Fluttar output and voice-frequency output
Prime Power	115 volts, single-phase, 60 cps
Type	3-conversion, superheterodyne, non-limiting AM IF channel; limiting FM IF channel
Fault Indications	Audible and visible
Alarm Circuitry	Frequency meter with a fixed threshold
Alarm Indication	Audible and visible

5 USC 552 (b)(3), 10 USC 130 [redacted]

ANTENNA

The antenna design is to be specified at a later date when the AFCRC Ground Antenna Laboratory (CRRDG) completes an investigation on target cross-section variation. A tentative design is now in the process of fabrication by this group and should be finished in 30 to 60 days, at which time the antenna will be flight-tested on a 50-mile link using a 250-watt transmitter.

C. L-BAND SYSTEM

An experimental L-band CW fence system, also utilizing a CW klystron transmitter, is under construction by Radio Engineering Laboratories, Inc., and is scheduled for delivery in May 1954.

D. COMPONENTS

Paralleling the system tests has been work on the various components of a Fluttar link, including alarm circuitry, filter development, magnetic-tape memory, etc. These will shortly receive field evaluation tests.

[redacted] 5 USC 552 (b)(3) 10 USC 130

Fig.III-3.

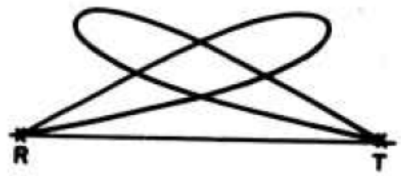

Fig.III-4.

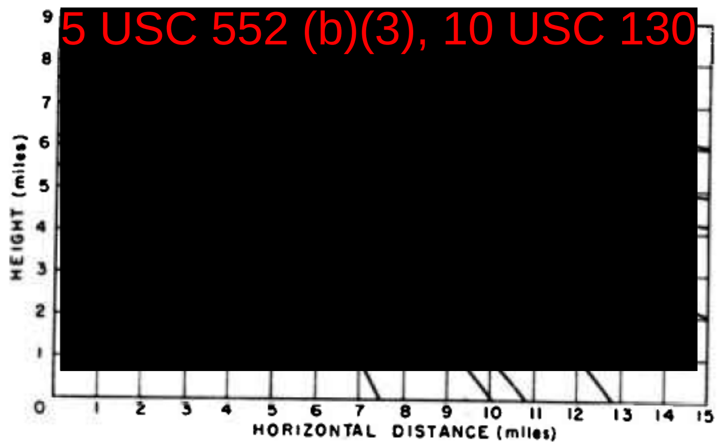

Fig.III-5.

Fig.III-1. Doppler frequency vs distance from station (perpendicular crossings).

Fig.III-2. Doppler frequency vs time from baseline (perpendicular crossings).

Fig.III-3. Doppler frequency vs time for trajectories perpendicular to baseline passing over station.

Fig.III-4. Horizontal orientation of antenna patterns.

Fig.III-5. Fluttar sensitivity curves.

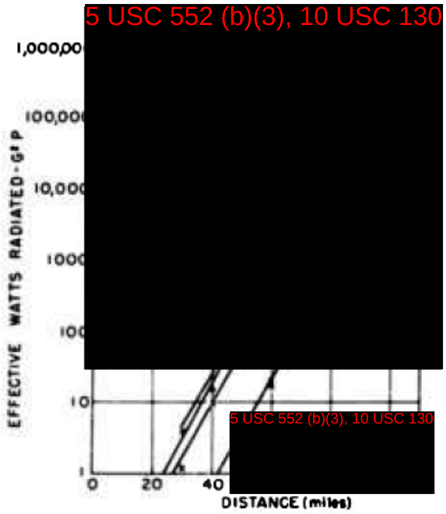

Fig. III-6. Theoretical propagation curves.

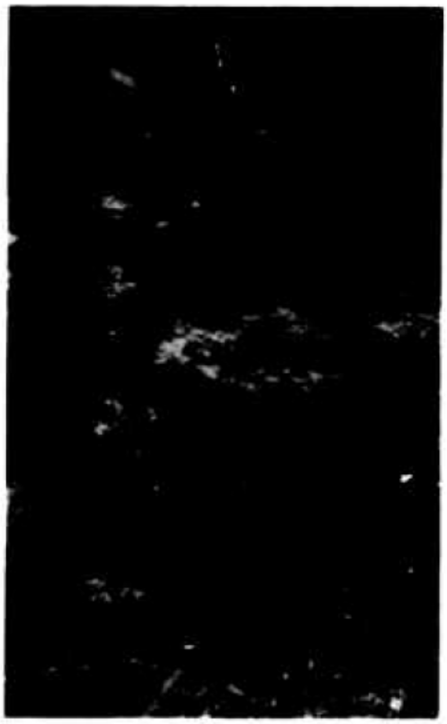

Fig. III-7. Experimental installation at Rock Rimmon.

Fig. III-8. Antenna installation at Lexington Field Station.

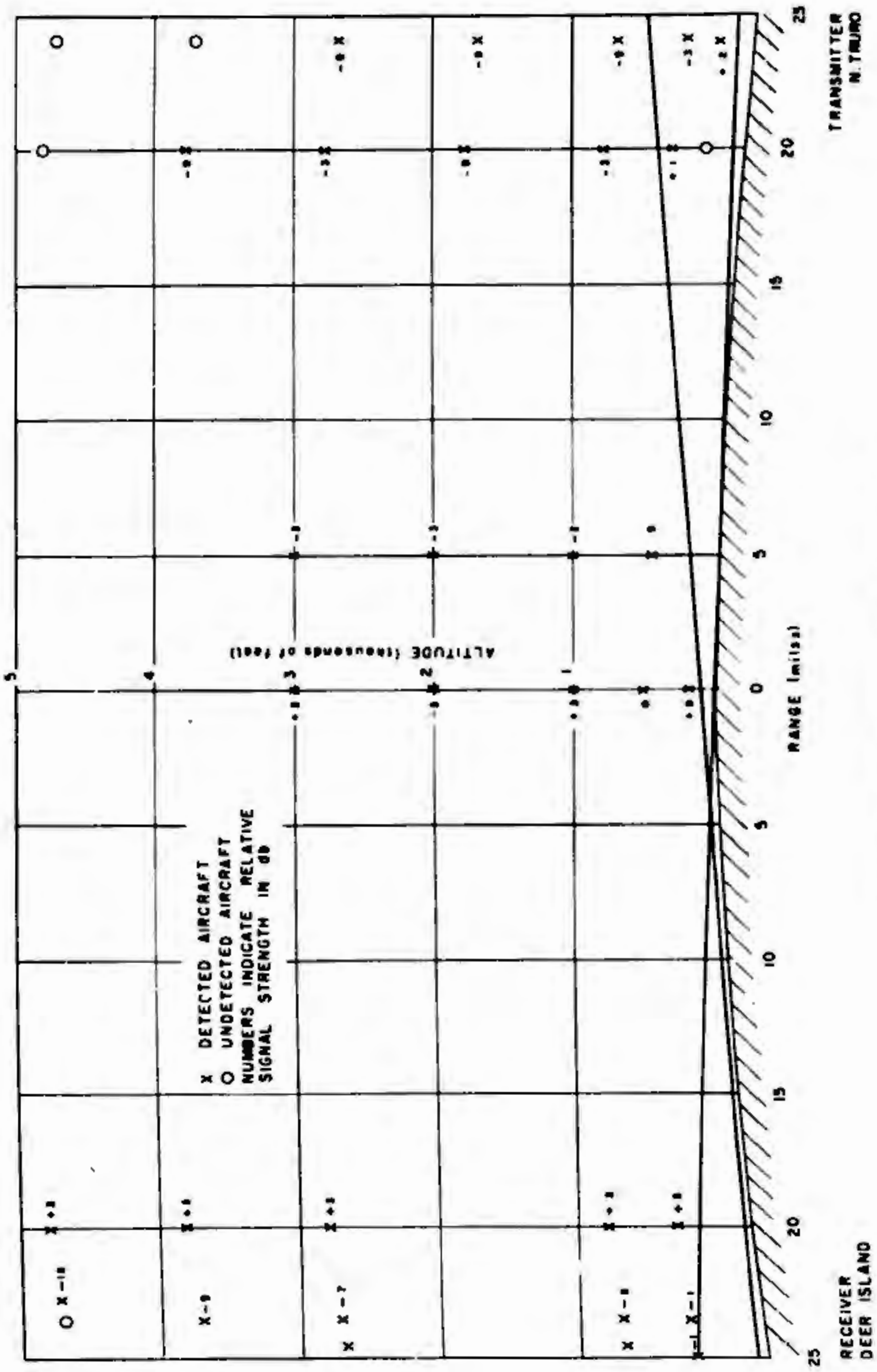

Fig. III-9. Profile and low-coverage pattern, North Truro to Deer Island Flutter System.

Fig. III-10. Doppler signals, antennas centered along baseline.

Fig. III-11. Doppler signals, receiving antenna oriented 10° off baseline.

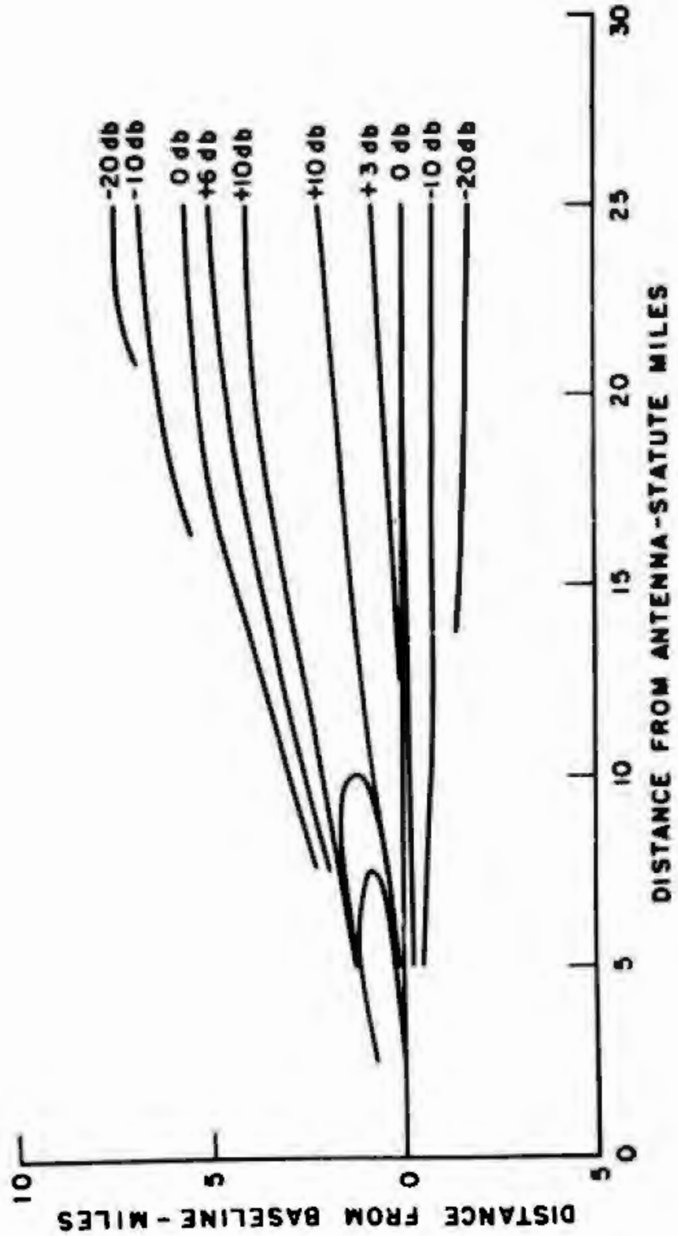

Fig. III-12. Calculated performance of system with both antennas oriented to reduce baseline signal 12db.

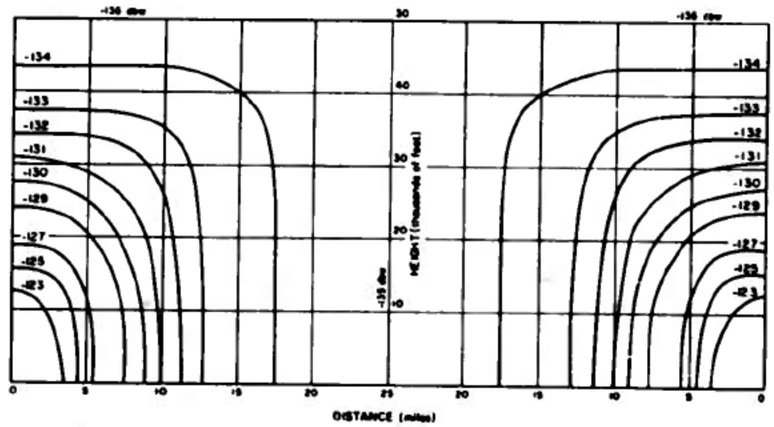

Fig. III-13. Contours of constant reflected signal for 50-mile base.

5 USC 552 (b)(3), 10 USC 130

[redacted]

Fig. III-14. Low-coverage pattern for 50-mile, curved earth, Type F radar.

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5 USC 552 (b)(3) 10 USC 130

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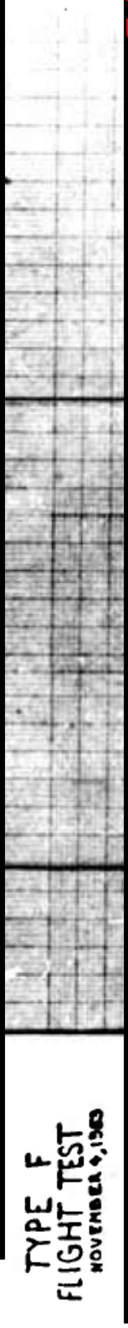

IV. ACOUSTICS PROGRAM FOR PROJECT CORRODE

A. INTRODUCTION

The objective of the acoustics program for PROJECT CORRODE was to determine the value of acoustic detection as a supplementary technique to radar detection, especially for low-altitude application.* The work done during the year 1953 falls into three principal categories:

(1) Propagation,
(2) Detectors (i.e., microphones and windscreens),
(3) Analysis and presentation.

B. PROPAGATION

From information available in the summer of 1952, it was clear that the limiting factor in the use of acoustic detectors would be the variation in detection range due to variations in background noise and in sound-propagation conditions. Preparations for an experimental determination of the range distribution in the Far North were made during the latter half of 1952 and, in January 1953, a flight-test program was undertaken at Skull Cliff (near Pt. Barrow), Alaska. In these tests, a B-29 aircraft flew controlled courses at altitudes from 500 to 5000 feet (plus a few flights at 10,000 feet), making straight passes over the pickup and at radial distances up to 40 miles from the pickup. The pickup was an omnidirectional microphone mounted in a windscreen; the analysis-presentation system was LOFAR.** The flight-test program was completed in March.

During the summer and fall of 1953, the results of the Alaskan tests were analyzed to obtain statistical distributions of detection range for the conditions encountered during the flight-test program. Climatological records for Pt. Barrow for the period 1946 through 1952 were studied and correlated with the observed data in order to obtain estimates of range distribution on a year-round basis. It was concluded tentatively that, in the Pt. Barrow region, the range by acoustic detection on a B-29 aircraft flying at 2000 feet altitude or lower would be 5 to 10 miles during 80 per cent of the time. In this region, the two controlling factors are surface wind and sound refraction in the atmosphere.

C. ACOUSTIC DETECTORS

1. Microphone Arrays

At the request of Lincoln Laboratory, General Electric personnel conducted experiments to compare the performance of a single omnidirectional microphone with the performance

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*See, in this connection: (1) H. Schecter and A. L. Cudworth, "Acoustic Detection Range for a Low-Flying B-29," published jointly by Electronics Research Division, Air Force Cambridge Research Center, Air Research and Development Command and Acoustics Laboratory, M.I.T. (September 1952); (2) A. L. Cudworth and H. Schecter, "Factors Affecting Range of Acoustic Detection of Aircraft," published jointly by Acoustics Laboratory, M.I.T. and Electronics Research Division, Air Force Cambridge Research Center, Air Research and Development Command (September 1952).

**Low-frequency analyzing recorder designed and built by Bell Telephone Laboratories for the Office of Naval Research. This analyzes the band from 1.5 to 150 cps with an effective filter bandwidth of about 1 cps and gives a continuous display of the spectrum on a Teledeltos paper tape. See Quarterly Progress Report, 1 June 1951, on Contract NOnr-210(01), Project VLF, Bell Telephone Laboratories.

of 4- and 9-microphone linear arrays. The spacing between microphones was 7 feet. Flight tests using a B-29 aircraft indicated gains in detection range of about 15 and 23 per cent, respectively, for the linear arrays. (Although this program was not supported under the X-213 subcontract it is included for its relevance to the CORRODE program.)

2. Windscreen Study

A study of windscreen performance was made by the acoustical consulting firm of Bolt, Beranek and Newman in an attempt to arrive at guide lines for the design of windscreens, and to estimate the maximum benefit to be expected from a windscreen of optimum design. In this study, the approach was to formulate a theory for the noise generated by turbulence at the windscreen, and to make empirical estimates of the parameters in this theory by analyzing performance data for a wide variety of windscreens.

Study of performance data on cylindrical shapes indicated that, to obtain maximum effectiveness at frequencies up to a few hundred cycles per second, the optimum configuration is a circular cylinder with length/diameter ratio of at least 2:1 and diameter of about 2 feet or more. Most of the enclosure may be acoustically opaque; about one-fifth or more of the area should be open. The openings should be covered with material having a flow resistance of 0.02 to 0.2 ρc.

Performance data on noncylindrical screens were not available. However, considerations of the aerodynamics of noncylindrical shapes indicate that no appreciable advantage over cylindrical screens would be gained except by resort to a windscreen having directional characteristics.

D. ANALYSIS AND PRESENTATION

1. Commutated R-C Filter

At the request of Lincoln Laboratory, personnel at Melpar, Inc. designed and built two models of a mechanically commutated R-C filter. The frequency characteristic of this filter is such that it passes any periodic waveform having a fundamental frequency equal to (or an integral multiple of) the commutator shaft-rotation frequency. Since the filter passes all the useful harmonics of the aircraft sound spectrum, it offers some advantage (in cases where the spectrum envelope varies with time) over a filter that passes only one harmonic at a time. The filters will be delivered early in 1954. If the performance of the filters is found to be satisfactory, the possibility of designing a tracking version that will follow the spectrum through the Doppler shift will be investigated.

Another possible application arises from the fact that by a simple switching operation the filter can be changed to a rejection filter. Thus, it can be used to reject any periodic background noise, such as that from a diesel power plant.

2. Spectrum Analyzer

Lincoln Laboratory is procuring from Raytheon Manufacturing Company a high-resolution spectrum analyzer similar to one developed by Raytheon under a Navy contract (NOas-51-706c). This analyzer utilizes an array of 420 magnetostriction rod filters covering [redacted] The filters are excited in parallel, and their outputs are sampled in time sequence by a commutator. Using this spectrum analyzer in conjunction with the LOFAR frequency-multiplication system, it is planned to analyze aircraft sound spectra with an effective [redacted]

3. Auditory Analysis and Presentation

An experiment has been carried out in the Laboratory for the purpose of comparing several different methods of stimulus presentation useful in the acoustic detection of aircraft. The methods compared included aural presentation and LOFAR display. In aural presentation, recordings of aircraft sounds (obtained in the Alaska flight tests) were played back, not only at the original recording speed, but at higher speeds ranging from 4 to 53 times original speed. The results showed that, for speedup ratios of about 20:1 to 30:1, a listener could detect aircraft about as well as an operator observing a LOFAR display.

The speedup aural presentation appeared to have two advantages over normal-speed presentation: (1) the false-report rate for untrained observers is lower, and (2) the observer need not concentrate on listening but can engage in other activity (for example, reading). It was also noted that, for speedup aural presentation, the false-report rate is reduced to the same as, or slightly less than, the false-report rate using LOFAR.

A preliminary report on these tests has been issued (Lincoln Laboratory Technical Memorandum No. 43) and a Technical Report describing in detail the equipment setup is in preparation.

E. GENERAL CONCLUSIONS FROM ACOUSTICS PROGRAM

From the field trials and laboratory experiments, it has been concluded that acoustic-detection methods are so sensitive to local meteorological conditions as to limit their guaranteed ranges of detection against aircraft to not more than two to five miles. Accordingly, there does not appear to be a place for acoustic-detection devices in a remote warning line. They may still have application as an identification aid at selected stations, or to assist the Ground Observer Corps. However, the Laboratory is not including further work in acoustic detection as part of the early-warning program.

V. AIRBORNE EARLY WARNING

A. INTRODUCTION

The primary objective of this program for PROJECT CORRODE is the development of improved airborne early-warning search radar. This radar must be capable of detecting aircraft targets over the sea at ranges as great as 200 miles and at altitudes of 40,000 to 50,000 feet down to sea level.

The principal problems are to obtain this detection range in a radar package that can fit into an aircraft, and to make the operation of the radar independent of the presence of sea clutter, clouds and rain.

Two main programs are being considered:

(a) Modification of existing S-band radars [AN/APS-20A (or AN/APS-20C) and AN/APS-20B] to improve the clutter rejection, and to give the operator better display and warning devices.

(b) Design and construction of a [redacted] to be installed and tested first in a blimp and later in a Super Constellation.

B. SEA-CLUTTER MEASUREMENTS

The sea clutter that appears on the return signal of a radar scanning over water was studied experimentally by taking three elementary types of measurements.

(1) On most radar test flights, stop-scan PPI photographs were taken of the various presentations used. These are useful for recording general radar performance as well as the extent of sea clutter.

(2) Clutter profiles were recorded by taking measurements of the sea-return level relative to noise. With the radar antenna searchlighting, signals from a pulsed RF generator were fed into the antenna section of the radar through a calibrated attenuator and a directional coupler. Using the A-scope as an indicator, signal blips were set to match the height of the sea return at various ranges and the level above noise read from the attenuator. Figure VB-1 shows a sample set of clutter plan and profiles.

(3) The third part of the program of sea-clutter investigation was the development of an "Ideal Gate" with which in-flight recordings of boxcar sampled video could be made. The term "Ideal Gate" has been applied to the system for the following reasons:

(a) Although the device is similar in operation to an ATI Adaptor, improved layout and reduction of operational controls have simplified the operation of the equipment.

[redacted] 5 USC 552 (b)(3), 10 USC 130

(c) The gate back-to-front resistance ratio is high. A low-impedance cathode-follower driver and vacuum diodes are used in the gate circuitry.

(d) Optimum operation of the boxcar is indicated by means of a front-panel meter.

(e) Front-panel adjustment of the gate balance is available.

(f) A high-gain audio amplifier has improved the listening sensitivity when the "Ideal Gate" is used as an ATI device.

Since the sea-clutter spectrum can be expected to extend from 0 to 100 cps, a very-low-frequency recording device was required. In order to avoid the bulky FM tape-recording system with its associated frequency-regulated supply, an AM system was devised. The boxcar output is used to modulate a 5-kcps carrier, and this signal is then recorded on a Model 400 Ampex tape recorder. When the recording is played back through a demodulator, the clutter spectrum is analyzed on a Kay Electric Co. Vibralyzer. The low-frequency limit of the over-all system is 3 cps.

In flight, the radar antenna is positioned at a bearing of 0° relative to the aircraft's heading on an upwind leg. This accomplishes two things:

(a) Spectral dispersion due to the aircraft's speed and antenna scanning are minimized.

(b) Sea-clutter return is maximized.

At angles other than 0° relative, one would expect a spread of the clutter spectrum due to the different radial velocities of the returned signal. Calculation shows that this spread would be a function of ground speed, antenna aperture, and azimuth. The gate, therefore, should be located at a range such that the spectral dispersion introduced by the depression angle of the antenna is negligible while a large clutter/noise ratio is maintained. Recordings are then made.

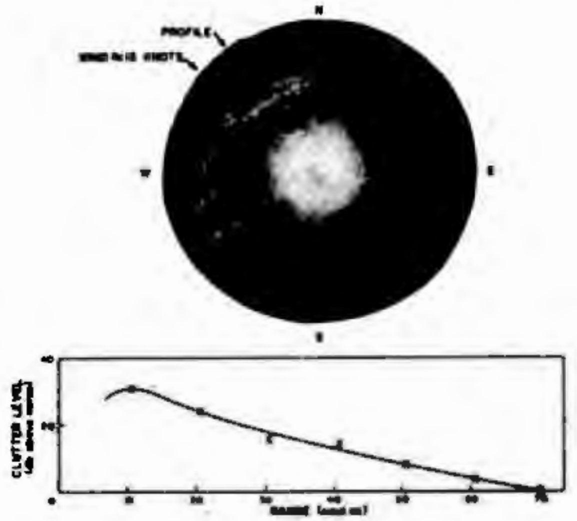

Fig. VB-1. Clutter plan and profile, 10 June 1953: radar altitude, 10,400 feet; radar horizon, 125 nautical miles; 10-nautical-mile range marks.

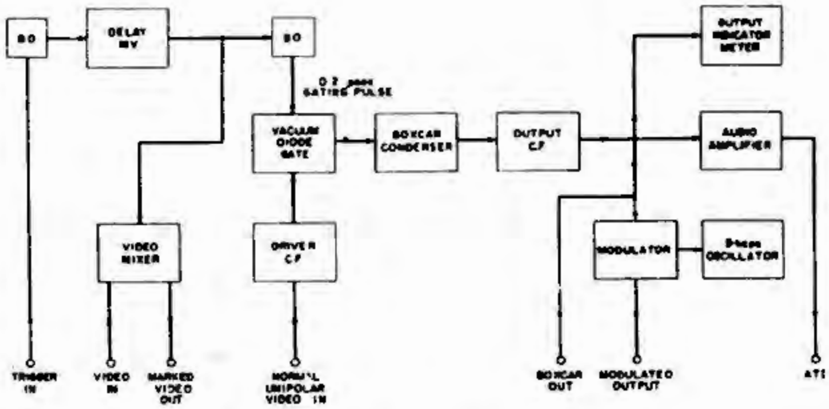

Fig. VB-2. "Ideal Gate" block diagram.

C. COHERENT AMTI

It is generally accepted that sea clutter may present a serious problem to airborne early warning. With this in mind, work was initiated to modify an airborne AN/APS-20 radar for coherent MTI. The mercury delay line and cancellation unit from an AN/TPS-1D radar were incorporated into the AN/APS-20 in a Navy P2V-3W aircraft for flight testing over water. Two limitations are encountered in such an airborne system which are not involved in ground-based systems:

(1) The inability to precisely correct for the platform's motion relative to the ground.

(2) The dispersion of the frequency spectrum of returned signals due to the motion of the finite antenna aperture.

A method for compensating for the motion of the moving platform is described in the literature. According to this method there is added to the coherent oscillator a correction frequency f_d where

5 USC 552 (b)(3) 10 USC 130

[redacted]

quency correspondence of the coho is not required. The addition of f_d to the coho frequency must be performed at a point in the system subsequent to the coho-lock operation. This is accomplished in Olson's system.

The system designed and constructed to accomplish this purpose differs in detail but not in principle from Olson's system, but is easier to construct. A block diagram of the system is shown in Fig. VC-1. The low-frequency oscillator and the low-frequency variable oscillator are both crystal-controlled oscillators working at the same base frequency with identical stages of multiplication. The output of the low-frequency oscillator is mixed in the first mixer with the output of the coherent oscillator. All frequencies with the exception of the lower sidebands are rejected by the filter, the output of which is mixed with the output of the low-frequency variable oscillator and multiplier in the second mixer. The output of the second mixer is thus the output of the 60-Mc coherent oscillator plus or minus the frequency introduced by the low-frequency variable oscillator.

The tank circuit of the low-frequency variable oscillator consists of a crystal in parallel with a variable capacitor. A block diagram of the variable capacitor drive is shown in Fig. VC-2. A synchro-motor introduces the angular difference between the aircraft's heading and ground track.

The parameters associated with the aircraft when it is used as a platform for a moving-target system were deduced from the characteristics of a Navy type P2V-3W airplane. A reasonable spread of true air speed was considered to be somewhere within the range from 150 to 180 knots. If a wind of arbitrary direction and a velocity of 30 knots is assumed, then the possible ground speeds vary from 120 to 210 knots.

Since it is desirable to make the system effective within 5 knots, the tolerable error in the system [redacted] The problem as stated requires a unit that will cancel out the radial motion of the platform for velocities up to 210 knots. This means that the fre- [redacted] from its locked frequency.

A number of choices is available for constructing a highly accurate control system. A fairly simple version was constructed using a scotch yoke as the sine-function generator. Unfortunately, this simplified version did not permit variation of the maximum frequency correction. In order for the correction system to operate, the plane speed had to be held to a predetermined value with a precision of better than one knot. The simplified version was constructed to permit flight checking of the system, but the conditions under which the tests must be conducted are restrictive.

The motion of the platform, in addition to contributing a Doppler velocity to fixed targets, also produces a dispersion of the spectrum returned from extended-area targets. Sea clutter falls into the category of extended-area targets. It can be shown, for simple models of an extended-area target where the components of the target have no motion, that the width of the [redacted]

[redacted] a convolution of the spectrum due to the clutter itself and the dispersion due to the motion of the aircraft. If the dispersion introduced by the motion is equal to or larger than the spectrum due to the clutter itself, then a variation in the degree of cancellation obtained will be noted as the antenna rotates. The poorest cancellation will occur when the antenna has a direction perpendicular to the platform course.

The integration of MTI components into the AN/APS-20 system is shown in Fig. VC-3. The system as shown was assembled and bench-tested, functioning as a normal radar. Tests of minimum discernible signal indicated that the over-all performance of the system was about 6 db below that of the AN/APS-20 with the AN/APR-12 receiver. Initial flight tests indicated that the system was giving some clutter cancellation. Figure VC-4 shows normal video, and Fig. VC-5 shows the same area using coherent AMTI video. (The straight white line indicates the plane's course.) Note that a large part of Long Island has disappeared.

For the antenna size in use and for an aircraft speed of 180 knots, the spectrum [redacted] This wide spectrum

The photographs shown were taken with the elementary capacitor-control system which had no provisions for correcting for variable plane speed and cross winds. Consequently, it was necessary to fly with or against the wind at a fixed ground speed.

Considering the restrictive conditions, the results, while not conclusive, were indeed encouraging. Therefore increased emphasis was placed on obtaining a more accurate capacitor-control system which has provisions for inserting drift-angle and speed corrections.

Two paths are being pursued:

(1) A servomechanism drive capable of generating the required sine function was designed and built by J. Ward of the M.I.T. Servomechanisms Laboratory. A block diagram of this system is shown in Fig. VC-6. The system, while retaining the basic concepts of the other one, has the advantages of aircraft ground-speed adjustment from 100 to 270 mph, and allows crab-angle adjustment to ±45°. All the above controls are mounted in a small box easily accessible to the operator. A preliminary investigation indicates that the accuracy of the coherent oscillator corrector will be within ±1-1/4 miles throughout its range. The equipment will be installed in the aircraft by 15 February 1954. The objective of the early tests will be to determine the frequency of manipulation of the controls necessary to maintain good cancellation at the output of the delay-line cancellation system.

(2) A method of coho-frequency variation using electronic circuits rather than mechanical devices.

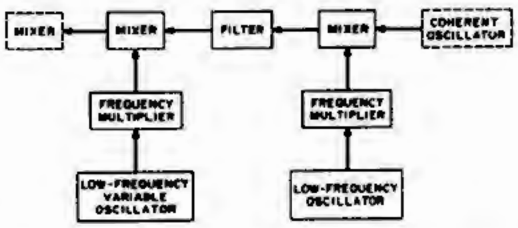

Fig. VC-1. Block diagram of proposed coherent oscillator conversion unit.

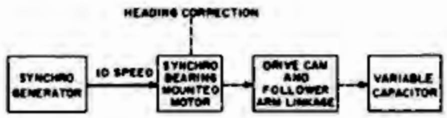

Fig. VC-2. Block diagram of proposed variable capacitor drive.

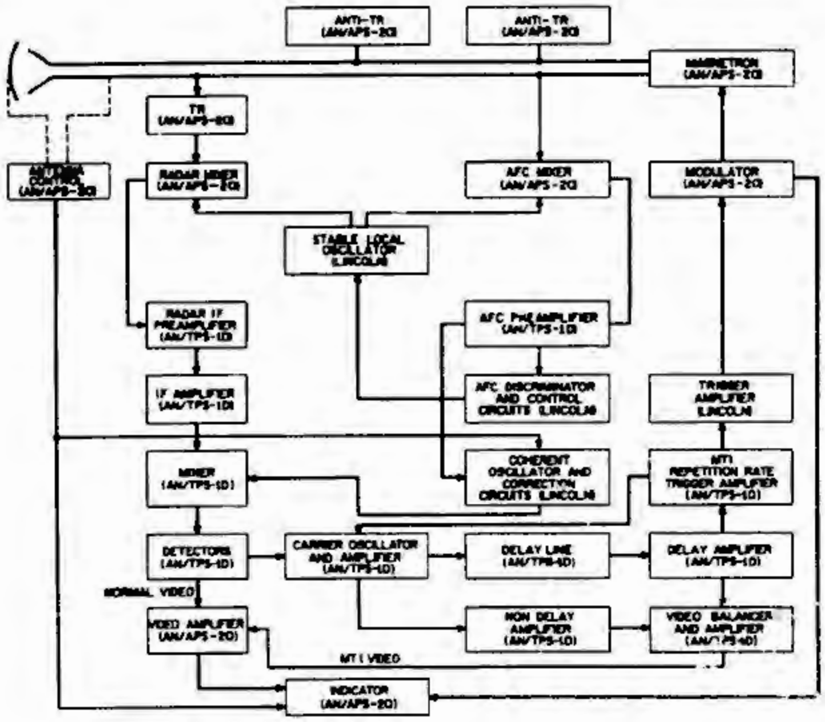

Fig. VC-3. Block diagram of coherent AMTI system.

Fig. VC-4. PPI photograph showing normal video display.

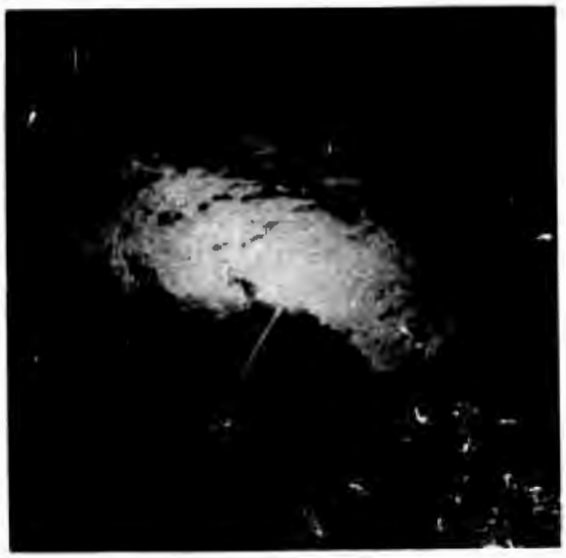

Fig. VC-5. PPI photograph showing cancellation achieved using a coherent AMTI system (mercury delay line).

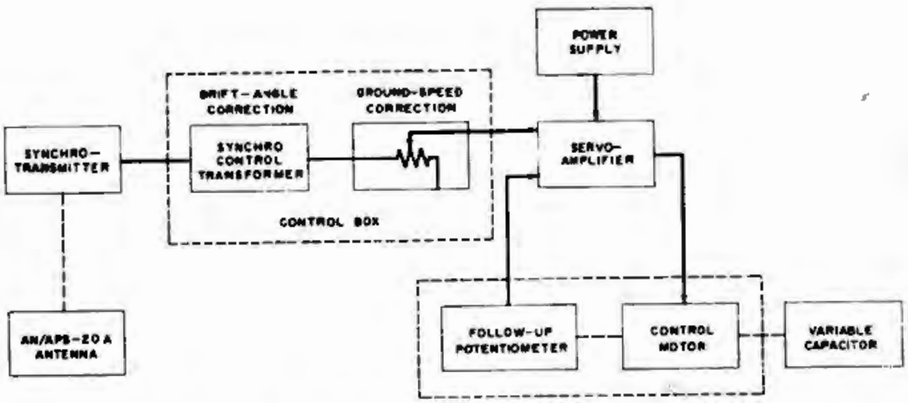

Fig. VC-6. Simplified block diagram of servomechanism drive.

D. ECHO DEPOLARIZATION

Previous scattered experiments both here and in England indicate that the echoes from certain man-made targets have depolarization characteristics different from extended background reflectors such as sea and ground. It is hoped that this differential phenomenon may be utilized to discriminate between a plane or a submarine echo and sea return. More data, however, are needed before such radars can actually be designed.

The Philco Corporation, under contract with the Bureau of Aeronautics, constructed an airborne X-band system which permits operation with vertical, horizontal, and circular polarization. This equipment was recently transferred to Lincoln Laboratory for investigation of polarization phenomena and their possible utilization for rejecting sea clutter. The equipment as delivered by Philco (see Fig. VD-1) consists of a radar set and data-recording unit to be located in an aircraft or other test site, and a beacon equipment which is carried by the target. The beacon reply is received at the radar and used to locate the target by automatic range gating. 5 USC 552 (b)(3) 10 USC 130 [redacted] pulses per second. Transmission may be selected by the operator to be of horizontal, vertical, or circular polarization.

When transmitting with either horizontal or vertical polarization, one of the two receiver channels employed is responsive to horizontal polarization and the other to vertical polarization. When transmitting with circular (right- or left-hand) polarization, one receiver is responsive to right-hand circular radar return and the other receiver is responsive to left-hand circular radar return.

Three PPI displays are provided, one each for the two receiver channels and the third for displaying the difference between the video outputs of the two receiver channels. Stop-scan recording cameras are mounted on all these scopes.

The digital data-recording unit was replaced by a DC-coupled, twin-track, magnetic-tape recorder. Pulse returns in both channels in a desired range interval are sampled by boxcar circuits whose outputs are then recorded.

It was deemed wise to ground-test the system prior to its installation in an aircraft. For this purpose, the equipment was installed at a temporary field station at Rockport, Mass. The site is 120 feet above sea level and 430 feet from the mean high-tide water mark. The maximum possible angle of depression is four degrees. The location provided opportunity to obtain some limited data on sea return, to track aircraft, ships or submarines, and to evaluate and generally debug the cross-polarization equipment.

Work on the system extending over a period of some ten weeks resulted in some preliminary data and an overwhelming conviction that the entire system needed major overhaul before serious work, particularly in a plane, could be undertaken. All the cables connecting the various racks had to be replaced and some of the chassis had to be completely reworked in order to conform to Air Force Safety Standards and minimize failures after installation in the B-29 aircraft provided for this project by the Air Force.

Figure VD-2 shows a spectral analysis of sea-return echoes which were recorded as described above.

The analysis was made with a Kay Electric Company Vibralyzer, modified to increase its normal integration time of 0.1 sec to 17 sec.

Figure VD-3 shows spectral analyses of the radar return from a snorkeling submarine, USS BECUNA, SS319. Unfortunately, on the day of these tests the sea was very quiet, and sea return was low. It is apparent that the main component of the echo is displaced in frequency from the origin. This is believed to be a Doppler shift resulting from the beating of the direct echo from the moving snorkel with the echo from its wake.

After overhaul, the equipment was sent to Hanscom Field at Bedford for installation in the B-29. Figure VD-4 shows the equipment after installation in the bomb bay.

In conjunction with the aircraft installation, field-pattern studies were made with the antenna inside the proposed radome. The RF plumbing and antenna were designed and constructed [redacted] made by Lincoln personnel, indicated a field-strength ellipticity for circular polarization along [redacted] with the radome). The specifications of the system restrict [redacted] design frequency, but no measurements were available to indicate the ellipticity as a function of frequency. A check of the actual operating frequency of [redacted] place the fixed tuned magnetron (Type 4J52) with a tunable one (Type 2J51) and then tune to the correct frequency. This involved mechanical and electrical changes and has just been completed at the time of this report.

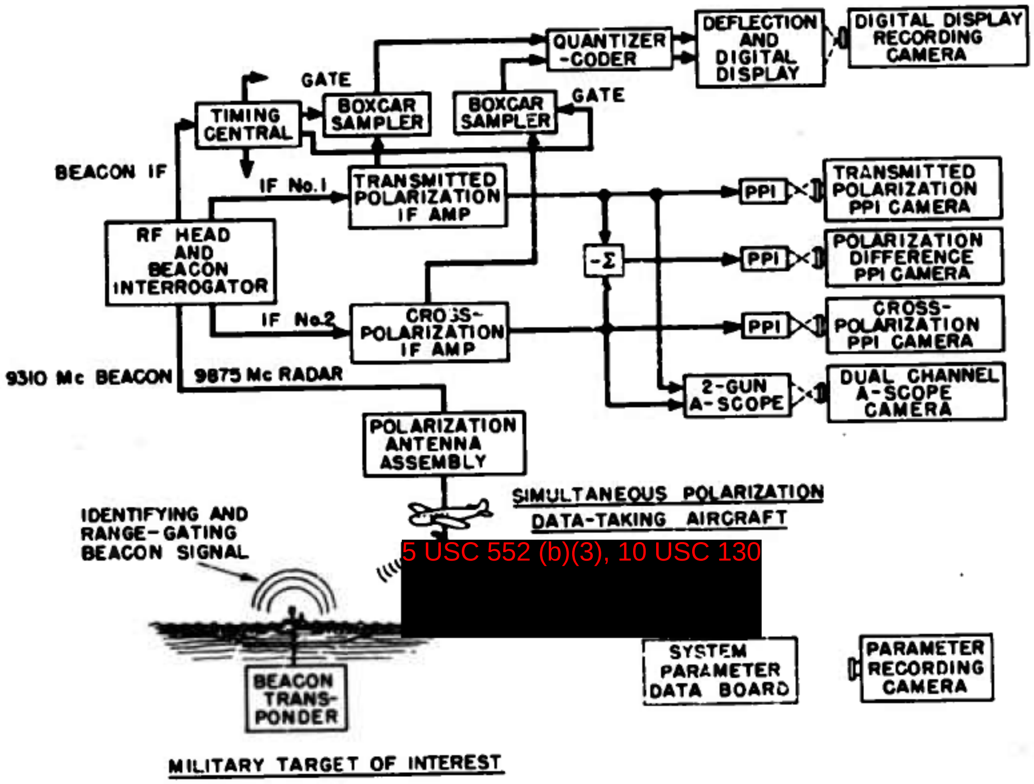

Fig. VD-1. Functional block diagram of simultaneous polarization data-recording radar system.

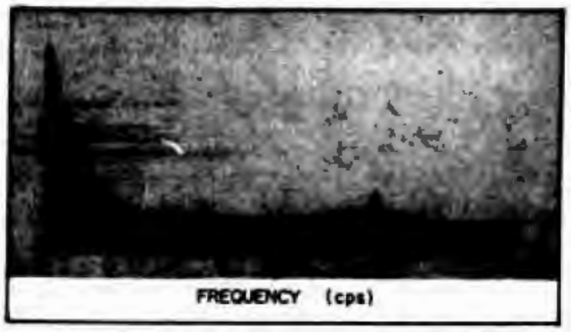

Fig.VD-2. Spectrum of sea return, Halibut Point, 6 February 1953. Transmitter vertically polarized; receiver horizontally polarized. The small spikes are due to modulation of the transmitted pulse. The amplitude is proportional to voltage.

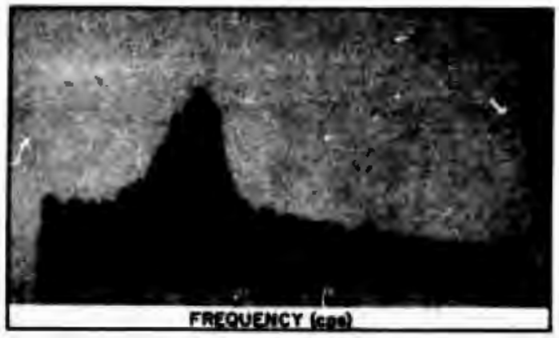

Fig.VD-3. Snorkeling submarine, Halibut Point, 3 February 1953. Medium snorkel height, speed 6 knots, transmitter horizontal, receiver vertical.

Fig.VD-4. Airborne radar installation for echo depolarization studies.

E. PRESENTATION DEVICES

The work on presentation devices for airborne early warning is aimed at a more efficient data display peculiar to the conditions of AEW. The low expected target density, both spatial and temporal, and the long watches produce problems in operator fatigue and boredom in addition to the standard engineering problems. Work is now in progress along the following lines.

(1) A bright flicker-free display.

(2) A stationary display over the period of one antenna rotation.

(3) Data storage that will allow the operator to refer back and re-examine previous scans.

(4) Motion-picture presentation of past recorded data.

Rapid-photographic-development systems are the only devices available at present for achieving such displays. The time delay inherent in these systems, which diminishes their utility for GCI and ACI applications, is not important for AEW. The reliability of the photographic systems has been a moot question. However, it is possible that a reliable device can be constructed for the limited requirements of AEW display.

The possible advantages to be derived from items (1) and (2) are under study with the Polaroid rapid-process camera. This equipment is built for airborne use and can project a photographic picture of a PPI 20 seconds after exposure. The equipment has now had 20 hours of intermittent operation in the laboratory and, although this is too short a time to yield conclusive results, the results warrant further investigation.

In addition to the instrumental tests, such as resolution and dynamic range of the films, it is planned to run some test with observers that will allow statistical evaluation of the equipment under AEW conditions. These experiments are now being planned with the cooperation of another group in Lincoln Laboratory.

The testing of items (3) and (4) is also now in the planning and equipment-design stage. Recently, several new equipments have been considered for AEW indicator use. The latest models of the skiatron (dark-trace tube) were observed in operation. They have the advantage of brightness and long persistence, but it is felt that their very limited contrast will preclude their use at this time.

Several new tubes from the General Electric Co. tube laboratory in Syracuse are of interest. The long-persistence silicate phosphors are of particular interest, and two such tubes have been acquired for testing. Also of interest is the G. E. development of internal magnetic focusing. This eliminates the outside focusing coils and removes the need for focusing adjustment.

The Xerography reproducing process was considered as a substitute for photography. Preliminary studies are not very encouraging. Since another group in the Laboratory is actively interested in this process, we shall await the verdict there.

The development of the Kenyon rapid-process camera is being followed for comparison with the Polaroid equipment. For the same purpose, a British-made rapid-process camera has been requested through military channels.

F. AUTOMATIC-ALARM SYSTEMS (ARGUS)

The design of automatic target-detection systems is of considerable importance for any future AEW patrol, particularly in view of the physical discomfort of standing a long radar watch in a patrol plane and the infrequent appearance of real targets. The application of automatic-alarm systems to conventional ground-based search radars promises to be very fruitful; the Argus program for CORRODE is concerned with the extension of these techniques to airborne search radars.

To establish efficient automatic surveillance of all returned radar signals would require a great deal of equipment and would scarcely be worth while. Argus (Automatic Range-Gated Alarm System) will guard ringlike regions produced in range by gating and in azimuth by the antenna's scanning. Once a possible target is detected by automatic means, the operator can be alerted to devote his attention to some particular portion of the guarded region during succeeding scans. Argus will do the crude work of detection; the operator must then exercise intelligence and discretion for the evaluation of the alarm targets.

Three features characterize the echo from an airplane, or from another target: (1) intensity; (2) Doppler shift, and (3) polarization.

If the clutter level is negligible, automatic detection based on intensity is the simplest. Improved signal-to-noise performance may be achieved by integrating all the returns from the particular target. This integration might be carried out by:

(1) Storing video information on a cathode-ray-tube phosphor having suitable persistence characteristics.

(2) Feeding the video signals into a conventional recirculating delay-line integrator.

(3) Charging a capacitor with the video voltage through a suitable resistor.

(4) Applying the video signals to a meter element possessing a suitable electromechanical time constant.

In each of these possible systems, a selection level is set. If at any time the level of the output of the integrator exceeds the selection level, an alarm circuit is tripped. The selection level is chosen on the basis of a compromise between false-alarm rate and detection sensitivity.

If the clutter intensity is comparable to that expected from a target, then detection of the Doppler shift provides a more reliable system. The Doppler shift may be detected by an airborne moving-target indicator (AMTI) system in which the delay-line output is fed into one of the integrators described above. The filter characteristics of a single-delay-and-cancellation system may result in rather poor performance against sea clutter. A multiple range-gate system with more carefully tailored filters was designed; this project is called Argus I.

The operation of this system can be explained by reference to the block diagram in Fig. VF-1. The main bangs from the radar are delayed and then used to gate the radar's video output. The sampled video is stretched by a boxcar generator to full repetition-period length. A bandpass filter rejects most of the clutter spectrum, passing a substantial amount of energy from any target moving with respect to the effective clutter patch near it in space (there are blind speeds in this system). The output of the filter is rectified and integrated. A level discriminator monitors the resulting signal, triggering an alarm device when some set level is exceeded. A strong mark should then be impressed on the PPI display to show the operator where to look for a possible target on the next scan, though this feature has not yet been incorporated in the system.

In a boxcar gated system, if the duration of the sampling time T_s is used to set the length of the gate (i.e., when T_s is greater than the video pulse length τ), it is found that the sensitivity of the gate varies with the position of the target pulse within the gate. If uniform sensitivity is to be obtained, the sampling time must be small compared to the video pulse duration.

Therefore it is best to use the video pulse length to establish the gate width. When a gate width larger than the video pulse width is required, the video pulse width must be stretched artificially.

The stretching merely serves the purpose of establishing the gate width in the boxcar system. It does not alter the fact that a signal-to-noise ratio loss, equal to the ratio of the effective gate width to the unstretched video pulse, is encountered. A practical pulse-stretching circuit is shown in Fig. VF-2.

The separation of clutter from moving targets is dependent on the choice of the low-frequency cutoff in the high-pass filter section. The choice is in part dependent on speculation, since the precise nature of the sea-clutter spectrum is not known. Sufficient experimental evidence exists to indicate that the shape of the sea-clutter spectrum is roughly Gaussian. For

5 USC 552 (b)(3) 10 USC 130 [redacted]

attempt is made to reject more clutter by increasing the frequency of the low-frequency cutoff point, then, of course, the percentage of moving targets eliminated will further increase. Thus, in part, the difficulty of designing a good sea-clutter-rejection system at S-band and with comparatively low prf's is illustrated (see Fig. VF-3).

If the greatest velocity with which any target closes on the radar is V_{rel} knots, and

5 USC 552 (b)(3), 10 USC 130 [redacted]

second. The guard ring is established by means of a number of contiguous shorter gates, however. This added complication improves both the signal-to-clutter and signal-to-noise ratios of the system.

It is possible to improve the performance of the system still further by building each bandpass filter from a number of contiguous narrow-band filters. This refinement is not scheduled for inclusion in Argus I.

The first complete equipment (Argus I, Mk 1) has been flown. Operating on coho-corrected bipolar video from the modified APS-20-TPS-1D radar in the P2V-3W airplane, it tripped the alarm on targets as far as 80 miles away.

Construction of the new, advanced equipment (Argus I, Mk 2) has been completed.

As can be seen in Fig. VF-4, the front-panel dimensions of Argus I guard rings have been reduced to little more than the areas of the instrument faces. The meter relay is a simple and reliable piece of equipment which accomplishes its several tasks well, but any further substantial reduction in the size of the equipment will require abandonment of the one-meter-per-channel alarm circuitry now in use. Equivalent circuitry is under development.

In the early Argus I equipment, provision was made to balance out, in the meter relays themselves, the average component of gated, boxcarred, filtered, rectified video noise. This was done so that slow changes in this average "noise" component, being cancelled out as well, would not affect appreciably the false-alarm rate.

It has at last been realized that the simplest way to achieve this end is to keep the average "noise" component out of the alarm device altogether. This can readily be achieved.

Argus II is a system of automatic radar alarm using a "Rafax Bandwidth Compressor" as the integrating device. It may be simply described by stating that it uses the persistence characteristics of cathode-ray-tube phosphors as the storage element in a closed-loop system.

Various phosphors have been investigated as to integration efficiency and decay time. For the constraints imposed by the radar systems of interest (TPS-1D and APS-20A), it was found that the P12 phosphor was the most suitable. This phosphor has a specified exponential decay with a 0.1 sec time constant. A test of the tube in use revealed that it actually had a decay time constant of approximately half the listed value. This cut down the number of pulses actually integrated and therefore lowered the detection efficiency of the system.

Sensitivity tests were conducted in conjunction with the X-1 Radalarm system at the Lexington Field Station. [redacted] able to compare the two systems on an equal false-alarm rate basis. On this basis, the Rafax system was approximately 1 to 2 db less sensitive than the Radalarm.

Increasing the gate width by a factor of 25 only resulted in a 3-db loss in sensitivity. (The parameter held constant is the false-alarm rate.)

The Rafax successfully detects signals of the order of minimum discernible signal as measured by eye on an A-scope presentation.

The main drawback to the system tested was its long-time instability. The troubles experienced in this connection are similar to those reported by another group in Lincoln Laboratory, and result in an unstable false-alarm rate. The re-engineering suggested by that group, such as use of automatic gain control, gain-stabilized amplifiers and low-temperature-coefficient components, should be adequate. The solutions to these problems do not appear to be unusually difficult but, due to the work commitments of the group, will not be pursued until some later date.

Argus III is a proposed automatic-alarm system utilizing a video delay line as the storage element in the integrating circuit. No hardware activity has been attempted in this program.

Argus IV is another integration alarm system. The principal difference between IV and II or III is that the integration takes place after the gating rather than before. Conventional lumped-parameter circuitry is utilized. A simplified block diagram of the system is shown in Fig. VF-5. Gated video is applied to a circuit that generates not a nice, square boxcar waveform but, rather, one that has a marked exponential droop during each interpulse period. The prf component of this signal can be maximized by proper choice of the decay time constant.

A narrow bandpass filter centered on the prf extracts this component, and it is rectified. The time-on-target integration is by an RC circuit.

The explanation just given assumes that conventional (unipolar) radar video is supplied to the gate. It is believed that Argus IV should work about as well when supplied with rectified bipolar video from a coherent radar. Use of both Argus I and IV with the same radar is contemplated, the former working at closer ranges where there is sure to be clutter, the latter working at long range in the clear. A cyclical switching arrangement in the Argus I driver input should allow it to serve both.

Work on Argus IV is in the developmental phase. By comparison with Argus I, it is relatively simple.

PHYSICAL CHARACTERISTICS OF ARGUS I, MK 2

Unit	Number of Vacuum-Tube Envelopes	Plate Current at 300-v Reg. (m amp)	Filament Current at 6/12 v (amp)	Size (inches)
Power supply for 6 guard rings	6	400*	10/7*	5 × 7½ × 19½(½ATR)
Driver and noise-balance auxiliaries for any number of guard rings	12	180	6/0	10½ × 7½ × 19½(ATR)
One guard ring, 5 USC 552 (b)(3), 10 USC 130 [redacted]	9	30	0/1.35 or 2.7/0	10½ × 15½ × 15½
Total for one complete guard ring	27	210	6/1.35	

*Capacity

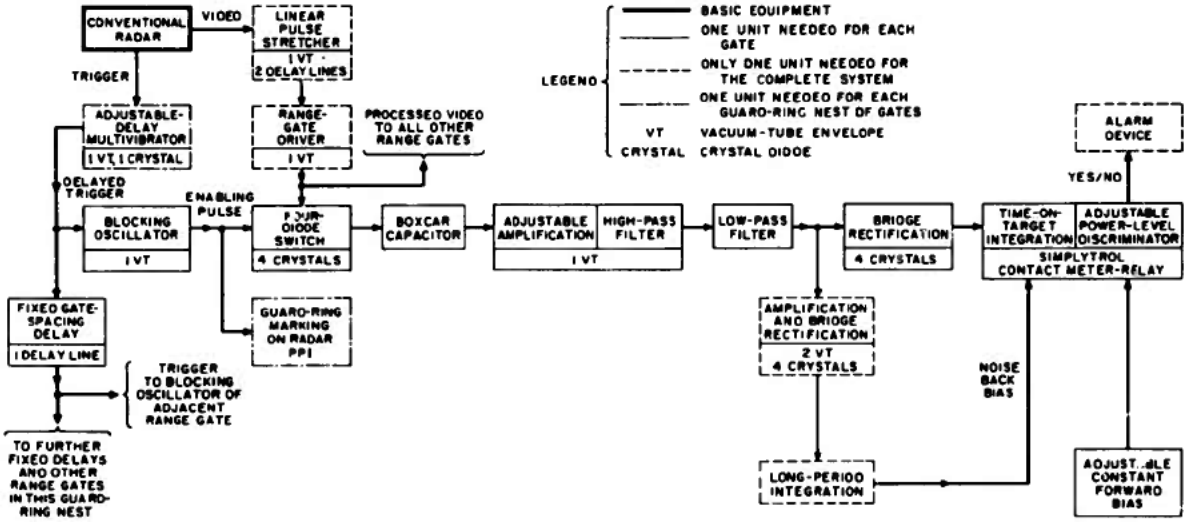

Fig. VF-1. Detailed block diagram of Argus 1, Mk 2.

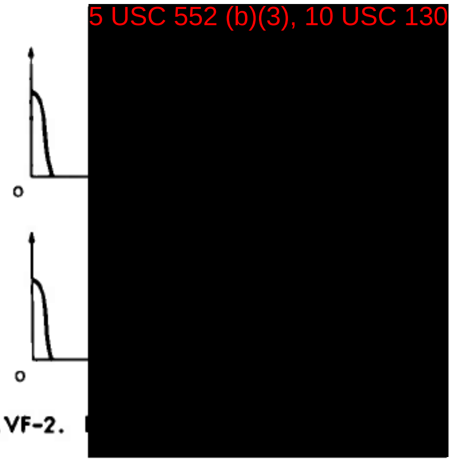

Fig. VF-2. [redacted]

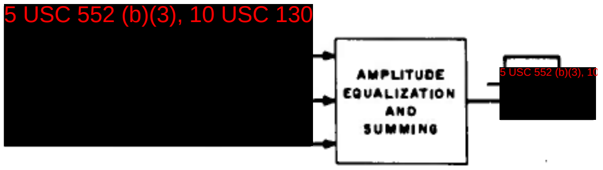

Fig. VF-3. Spectra of gated clutter for two repetition rates.

Fig. VF-4. Master chassis and No. 1 guard ring of Argus I, Mk 2. The former (bottom unit) is 10-1/2 inches wide and weighs 16 pounds; the latter (top unit), 15-1/2 inches and 46 pounds. The power supply is not shown.

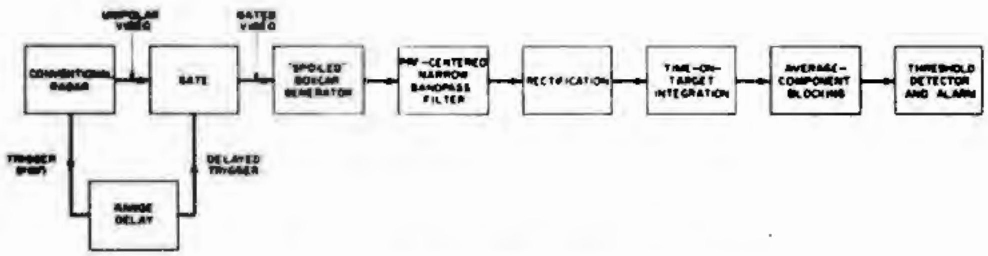

Fig. VF-5. Simplified block diagram of Argus IV.

G. AEW UHF RADAR

One approach to the problem of minimizing clutter interference is to reduce the operating frequency of the radar system. The advantage to be gained against rain clutter is rather large, since the intensity of rain clutter varies with the cube of the operating frequency; the advantage obtained against sea clutter does not appear to be as large but is significant. Based on the experimental evidence at hand, it appears that sea clutter varies approximately as the 3/2 power of the frequency. The power spectrum of sea clutter appears to have a half-power width [redacted] repetition-rate system can reduce the blind-velocity region. However, a reduction in wavelength by a factor of ten will reduce the percentage of blind velocities to a negligible value and will permit satisfactory use of simple filter systems.

The principal deficiencies of a low-frequency system both are dependent on the constraint in antenna aperture that is obviously imposed on an aircraft radar set. These are: (a) diminished resolution, (b) diminished antenna gain. In an early-warning system, in so far as resolution is concerned, it is only necessary to plot a track of reasonable length (e.g., 50 miles) on penetrating aircraft and to obtain a crude estimate of the size of the flight. In the air battle over Britain, 200-Mcps radar systems with 8° beamwidths were used for intercept operations. It would appear reasonable then that this order of performance would be adequate for advance warning.

The dependence of the range of the radar system on operating wavelengths must be examined, bearing in mind the constraints imposed by the problem. Thus, the size of the aircraft will limit the (a) antenna area, and (b) the average transmitting power; and these limits are independent of the choice of frequency. The nature of the problem, i.e., early warning, will set a lower limit on the antenna rotation speed, and this, too, is independent of the choice of operating frequency.

With the constraints which must be imposed, the range of the radar system is not [redacted]

A strong argument in favor of lower-frequency systems is the likelihood that the coefficient of reflection of the sea surface will remain large under all probable sea states, thus giving enhanced detection ranges. This likelihood undoubtedly increases as the frequency decreases.

The low-frequency AEW radar showed sufficient promise to merit experimental investigation. We therefore embarked on a [redacted] will be ready for experimental flights early in 1954 (see Fig. VG-2).

The antenna consists of a horizontal row of dipoles at the focus of a cylindrical parabola 17 1/2 by 4 feet. The vertical beamwidth is expected to be about 40° and the horizontal 9°.

The antenna fits within the radome constructed for the 17-1/2-foot AN/APS-20 antenna.

A Type N blimp is avaiable for the installation of this system. The characteristics of this airship are such as to permit testing in fairly rough weather at altitudes of about 3000 feet. This should be adequate to provide data on sea-clutter performance. The antenna is constructed from aluminum and is to weigh about 250 pounds. It will be mounted on the antenna pedestal from the AN/APS-20C radar. In order to pass UHF, the original rotating joint will be replaced by one that is completely coaxial.

5 USC 552 (b)(3) 10 USC 130 [redacted] amplifiers to obtain a low noise figure. By using the Western Electric 416A triode, it was hoped to obtain an over-all noise figure of 5 db. The output of the RF amplifier is fed through a crystal mixer and then into the preamplifier of the receiver. The receiver is the AN/APR-12 whose bandpass has been narrowed for the longer transmitter pulse. The receiver has been further modified to allow the optional use of instantaneous automatic gain control (IAGC).

The duplexer is constructed from 3-inch rigid coaxial transmission line to mate with the output connector of the Western Electric 7C22 tube. A 3-inch to 1 5/8-inch transition after the duplexer reduces the coaxial line to the antenna to a more convenient diameter.

The construction of the antenna, duplexer, RF amplifier and modified receiver has been undertaken by the Search Radar Division of the Naval Research Laboratory at Washington, D.C.

The transmitter for the early experimental model is a tube developed during the last war, the 7C22. This tube can deliver 500 watts of average power under pulse conditions, which should be adequate for a test system.

The transmitter consists of a pair of push-pull triodes packaged in a single envelope, the Type 7C22. The tuning cavities are an integral part of the tube. In the radar, the 7C22 5 USC 552 (b)(3), 10 USC 130 [redacted]

The modulator is a major modification of the AN/APS-20C modulator. It is a conventional line-type modulator.

There are two indicators: (1) the indicator from AN/APS-20C, which consists of two 5-inch PPI's (one of which is delayed) and one 3-inch A-scope; and (2) the AN/APA-81, which has a 7-inch PPI along with other operating conveniences.

A single set of components, excepting the antenna, has been connected together to form a system. A dummy load was substituted for the antenna. The receiver was found to have a noise figure of 6.5 db. The noise figure is 1.5 greater than anticipated, but no effort is being made to improve it in this version. Independent development of a low-noise-figure RF head is under way in another group in the Laboratory.

A second set of components will be assembled at Lincoln Laboratory. It is planned to order a second antenna which, when available, will be used to continue further component development and some system testing.

A free-space range has been computed for the experimental radar using a range-gated alarm system of the Argus type. The approximate range on a B-29 target is expected to be 100 miles. This should be adequate for testing, considering that the result may be considerably better due to reflection from the sea surface. If the system shows promise, it will be possible to increase the range appreciably by further increase in transmitter power (which is moderate in the experimental system), and by improving the receiver noise figure.

The use of an antenna as large as that proposed in the sidewise-looking antenna development would, of course, increase the range by a considerable factor.

[redacted]

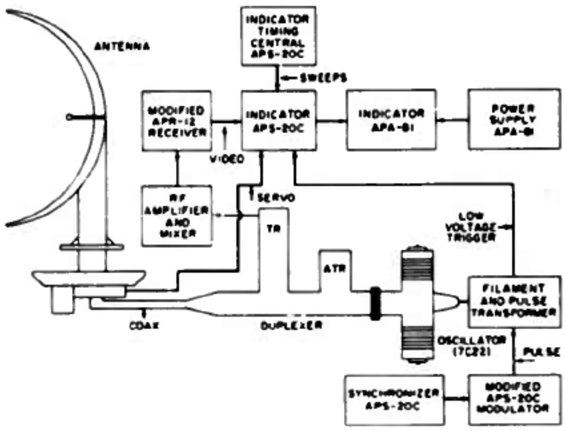

Fig. VG-2. Block diagram of UHF radar.

H. BARRIER DETECTION STUDIES

The purpose of these studies is to evaluate quantitatively the effectiveness of a barrier patrol consisting of N airborne search radars. In the first of these studies, it was assumed, in working out the theory, that the patrol planes were all flying the same straight-line course with constant velocity $\vec{v}_o$ and that an enemy plane, the "target," would fly with a constant velocity $\vec{u}_o$ in a direction perpendicular to the direction of the patrol, the vectors $\vec{u}_o$ and $\vec{v}_o$ being coplanar. It was further assumed that the radars were scanning circularly in the following manners: (1) all-around scanning for all radars, (2) sector scanning in which the radar is on for an angular measure of 2β radians, off for $(\pi - 2\beta)$ radians, on for 2β radians, off for $(\pi - 2\beta)$ radians, and so on. This latter situation is the consequence of assuming that the radar antenna is designed to scan through a sector angle of 2β whose bisector is perpendicular to the flight path of the search aircraft. In examining the geometry of the situation, it is assumed that the barrier is stationary, so that the target path pictured in Fig. VH-1 is $\vec{w}$, the velocity of the target relative to the velocity of the patrol, i.e., $\vec{w} = \vec{u}_o - \vec{v}_o$.

The spacing D_o between planes to guarantee at least one radar look at any target whose velocity does not exceed u_o was determined as a function of the range R, β the radar scan sector semi-angle (the scan sector being symmetric about an axis perpendicular to $\vec{v}_o$), and the angle $\Phi_o = \cot^{-1}(v_o/u_o)$. It was found that

$$D_o = 2R\,(\sin\beta + \cos\beta \cdot \cot\Phi_o)\ (\beta < 90^\circ) \quad ,$$

$$D_o = 2R \csc\Phi \quad \text{(all-around case)} \quad .$$

If ℓ_b represents the length of the segment along one of these target paths intercepted by the scanned sector, then the formula developed for the number of looks at a target is

$$K = \frac{60\, m\ell_b}{\sqrt{u_o^2 + v_o^2}} \quad , \qquad (2)$$

where m is the number of antenna revolutions per minute, ℓ_b is distance in miles, and u_o and v_o are both given in mph.

Assuming certain specific values for R, β, and Φ_o, a great deal of computing has been done to measure the effectiveness of various possible patrol patterns. Probabilities of detection for targets whose speeds are different from the speed u_o assumed in determining the spacing have also been computed.

Finally, assuming a constant barrier speed of v_o = 200 mph, as before, the target velocity $\vec{u}$ was considered to vary randomly in such a way that the vectorial angle for the resultant vector $\vec{w} = \vec{u} - \vec{v}_o$, viz., α was random between 0 and π.

The numerical work is complete, and the results of this analysis will appear in a Lincoln Laboratory Technical Report. Certain variations in the originally assumed patrol pattern are being studied.

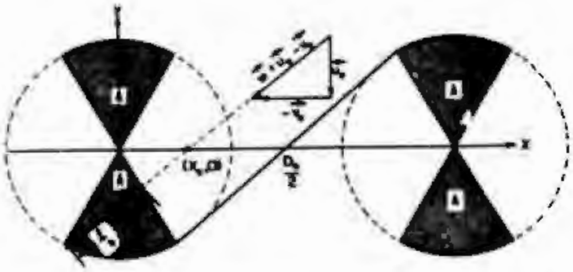

Fig. VH-1. AEW geometry showing interception of a direction path by scanned sector A (darkened area).

I. INTERFERENCE PATTERNS OVER THE SEA

The fact that the sea presents a reflecting surface to a search radar operating above it could result in increasing the free-space range of the radar – at most, doubling it. On the other hand, it could also result in reducing the range to far less than the free-space range – even to zero.

The sea causes the resultant signal strength in the space surrounding a radar antenna to become oscillatory with respect to height or distance because of the alternate reinforcement and reduction of direct-path energy by the sea-reflected-path energy. As the energies of these two paths unite in phase, the resultant is a maximum; as they unite out of phase, the resultant is a minimum. Vertical-coverage diagrams can be constructed to study this situation (see Fig. VI-1).

As an enemy plane flies toward A, say, at constant altitude, it encounters the edge of a lobe and thus passes into a region of detectability, the strength of the field increasing from minimum detectability level at the edge of the lobe to maximum value as it crosses the center line or lobe angle. Then the strength declines, approaching the minimum detectability level at the farther edge of the lobe, where it enters a null region (there, the signal strength, being below detectability level, may be considered as at zero level). This condition persists until the plane encounters the next lobe, when the process is repeated. It is conceivable, then, that these null regions may be sizable enough so that a plane flying in this manner is "lost" in them and/or can predetermine such nulls and fly through the patrol barrier undetected.

We have considered the particular case of a high-site radar (flying at 10,000 feet), using horizontal polarization over a smooth sea. Under such circumstances, the number of lobes exceeds 8000. Consequently the null regions at, say, ranges under 100 miles, appear to be nonsignificant. However, farther out, and with respect to the lowest lobes, there does exist a definite threat. It is hoped to consider the effect of rougher sea states on the pattern

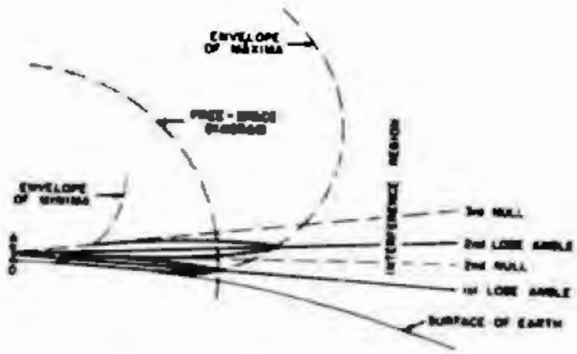

Fig. VI-1. Interference diagram.

VI. RADIO COMMUNICATIONS

A. INTRODUCTION

During 1953, under PROJECT CORRODE, Lincoln Laboratory undertook a program of research and development to provide suitable techniques for facilities for long-range point-to-point radio communication for distant early warning. Attention was confined to two methods of communication: one utilizing VHF ionospheric propagation by so-called "scatter" mode; the other utilizing tropospheric propagation at UHF and SHF.

The VHF scatter technique had been under investigation at the Massachusetts Institute of Technology since January 1951. On the basis of results that had been obtained, Lincoln Laboratory recommended, and undertook to assist in the implementation of, single-channel teletype VHF scatter circuits for the 1953 DEW trials under PROJECT CORRODE. For these trials, Lincoln Laboratory designed, constructed or otherwise provided the following VHF communication equipment:

[redacted]

(2) Six sets of Lincoln FSK teletype equipment, each including: an exciter for use with the AN/FRT-6A transmitter, a dual-diversity receiver, and a test oscillator.

(3) Six sets of NOMAC (P9D) teletype equipment, each including an exciter and dual-diversity receiver.

In addition, continuing technical support was provided in connection with installation and initial testing of equipment and the training of operating personnel. Attention was given also to the problem of providing VHF scatter-circuit antennas having characteristics superior to those of rhombics.

[redacted] between Alpine and Round Hill.

Other work included development and procurement of suitable equipment for multi- [redacted] receivers, and voice and teletype channeling equipment. Arrangements were made with various manufacturers to furnish equipment of this kind for use in the Bell Telephone Laboratories-Lincoln experimental programs. In addition, FM modulators and driver amplifiers for use with the high-power klystrons and narrow-band FM receivers were designed and constructed in the Laboratory.

B. VHF POINT-TO-POINT RADIO EQUIPMENT

For implementation of the PROJECT CORRODE VHF ionospheric-scatter circuits, Lincoln Laboratory assumed responsibility for providing transmitters, receivers, and special modulating and test equipment, together with necessary instruction manuals. Bell Telephone Laboratories assumed responsibility for antenna designs.

[redacted]

[redacted] Modification kits were obtained from Collins Radio Co., and the E. C. Page Co. of Washington, D. C. was retained to install the kits and train operating personnel. A prototype installation was made at the Lexington Field Station and, subsequently, installations were made at Streator, Illinois and the Northern sites. The prototype was used to train personnel, check out the conversion kit, and to test the operation and connections of the Lincoln-designed teletype modulating equipment. It was also used to develop methods and equipment that would allow remote operation and metering, as requested by Bell Telephone Laboratories Four special kits were fabricated to achieve this.

Two modulation systems designated as "Lincoln FSK" and "NOMAC" (P9D) were provided. These systems are described below.

1. Lincoln FSK Equipment

The Lincoln FSK equipment was designed and constructed for use in the VHF ionospheric main-to-base full duplex radio circuit. The original design provided channel capacity for one 60-word-per-minute teletype circuit. (Subsequent modifications, not incorporated in PROJECT CORRODE installations, allow four teletype circuits.)

Preliminary study of the problem of providing satisfactory main-to-base VHF radio circuits led to the conclusion that the use of conventional, commercially available modulating and receiving apparatus would result in inferior performance. Accordingly, it was decided that Lincoln Laboratory would design and manufacture special equipment, including complete receivers, and transmitter exciters suitable for use with the AN/FRT-6A transmitters. Six complete terminal equipments, each comprising one dual-diversity receiver and one transmitter exciter, and also four test oscillators for use in receiver alignment, were designed and fabricated. Two equipments were installed in the domestic system, and four equipments, one regular and one spare at each terminal, were installed in the North.

Knowledge of VHF ionospheric radio communication was rather incomplete when PROJECT CORRODE was undertaken. Accordingly, it was deemed necessary to design the most conservative practicable teletype modulation system, taking all reasonable precautions to minimize signal errors which might arise from propagation disturbances. In retrospect, some features of the equipment actually provided now seem unduly conservative.

Specifically, the three unfavorable propagation characteristics considered were (1) weak signal strength, (2) rapidly varying signal strength, and (3) Doppler-like shifts in received-signal frequency. The latter two characteristics are caused by signal reflections from ionized meteor trails. It was felt that, because of the weak and varying signal strength, a frequency-shift system was the best that could be designed and constructed in the time available.

In order to prevent a meteoric shift in frequency from causing a MARK to be read as a SPACE, or vice versa, [redacted] Because of the expected weak signals, however, it was necessary that the effective receiver bandwidth, before nonlinear operations, be as narrow as possible. The receiver as built contained two narrow-band channels: one tuned to MARK frequency, the other to SPACE frequency. The bandwidth of these channels was made as narrow as possible consistent with the teletype signal spectrum. The noise bandwidth of each channel [redacted] following the narrow filter channels makes MARK-SPACE decisions on the basis of signal levels in the two channels. Notwithstanding the narrow bandwidth, the receiver had to be made fast-acting to prevent errors arising from sudden changes in signal strength. Limiters were installed to operate when the signal exceeded three to four times the expected weakest value. The limiters do not impair the receiver's weak-signal performance.

Because of the narrow receiver bandwidth employed, good frequency stability in transmitter and receiver was essential. Considerable care was taken in the design of crystal oscillators. The over-all system frequency stability achieved was about $3/10^7$/day.

The transmitter exciter was designed to supply appropriate drive for one of the low-level transmitter stages. The exciter was arranged to provide clean frequency-shift excitation with rapid transitions.

The performance of the equipment with nonperturbed signals was about one per cent character error with 0.025 microvolt open-circuit input voltage referred to 50-ohm impedance level. The input signal level for one per cent error, as measured on the Streator-Holmdel VHF circuit, was 20 db poorer.* It was found that the 700-mile Streator-Holmdel circuit was operable nearly all the time with a transmitter output power of only 100 to 500 watts.

Further details on the Lincoln FSK System are contained in the equipment instruction book (Lincoln Manual No. 2), and in a Lincoln Laboratory Technical Report now in preparation.

2. NOMAC (P9D) Equipment

The Lincoln NOMAC (P9D) equipment was provided as an alternate single-channel teletype facility for use on the domestic and Northern VHF ionospheric radio circuits of PROJECT CORRODE.

In operation, the system transmits a reference signal and one of two discretely keyed signals. [redacted] In the transmitting section, the exciter generates a continuously transmitted reference band of noise. From this reference band of noise, the exciter also transmits, in an adjacent frequency channel, one of two bands of noise that are alternately keyed by the teletype transmitter to represent either a MARK or a SPACE. These two alternately keyed bands of noise are delayed in time with respect to the reference band by an amount sufficient to make correlation of the two bands impossible by simple multiplication.

As in the case of the Lincoln FSK, six complete sets comprising transmitter exciter, and dual-diversity receiver were fabricated at the Laboratory and supplied to the Western Electric Co.

A detailed description of the system is contained in the equipment instruction book (Lincoln Manual No. 3).**

3. VHF Antenna Studies

Preliminary studies were made to determine suitable electrical and mechanical features of improved high-gain antennas for VHF ionospheric-scatter circuits. Attention was given to an array of corner reflectors, rhombics, arrays of rhombics, broadside arrays, arrays of helices, and paraboloidal reflectors. It was concluded that an array of corner reflectors

*,**(Footnotes on p.VI-8.)

would have significant advantages over conventional rhombic antennas of comparable gain. The advantages that the corner array appears to offer are: (1) somewhat reduced side lobes; (2) opportunity for control of side-lobe structure, and (3) simpler siting requirements. In addition to theoretical studies, model tests were started to determine suitable details for reflecting surfaces, illuminating sleeve dipoles, and baluns. A full-scale single 90° corner reflector of the type proposed for a high-gain array was fabricated and tested with a modified AN/FRT-6A transmitter.

Contract negotiations were undertaken for fabrication and installation of an array of 18 corner reflectors of the type illustrated in Fig. VI-1. This array has a calculated maximum gain of 30 db and is to be installed at the Round Hill Field Station where it will be used with a pulse transmitter (being constructed for another project of Lincoln Laboratory) having an average [redacted]

C. TROPOSPHERIC RADIO PROPAGATION TESTS

Tests were conducted to determine the practibility of beyond-the-horizon point-to-point communication at UHF and SHF. These tests were directed primarily at determination of path losses, transmitter power requirements, bandwidth limitations, practical limitations on [redacted] transmitter at Holmdel (Crawfords Hill), N. J., and receiving facilities at the Round Hill Field Station. In the fall of 1953, additional limited tests between Holmdel and Round Hill were made [redacted]

Figure VI-2 shows the path between Holmdel and Round Hill. This path is largely over water and crosses Long Island. The path length is 180 miles. The distance from Round Hill to Alpine is about 165 miles.

The 28-foot diameter paraboloid antenna which was installed at Round Hill for use in the Holmdel and Alpine tests is illustrated in Figs. VI-3, VI-4 and VI-5. This antenna was constructed of plywood from plans furnished by the Bell Telephone Laboratories. The reflecting [redacted]

Figure VI-7 shows the Holmdel-Round Hill path profile in the immediate vicinity of the Holmdel transmitting terminal. The antenna is at an elevation of 372 feet above sea level. There are no near obstructions and the site is quite satisfactory. Figure VI-8 shows the corresponding profile at the Round Hill receiving terminal. Owing to the obstruction provided by Salter's Point, conditions here are not so satisfactory as at Holmdel.

[redacted] signal levels and trials of wide-band FM. The Alpine transmitter, which was operated by Major E. H. Armstrong under a separate Air Force contract, had a [redacted] included a high-quality FM exciter. The transmitting antenna was a 16-foot-diameter paraboloid (23 db gain) mounted on a short tower. At Round Hill, three receiving antennas were used: the 28-foot-diameter antenna described above; a 17-foot-diameter paraboloid antenna, and a small corner reflector. Typical signals received with these three antennas are shown in Fig. VI-9. The FM recei[redacted] required an input signal of two microvolts (at [redacted] reduction. When modulated, the power deviation of the transmitter was ± 75 kc, and standard preemphasis and deemphasis circuits were used. Numerous transmission tests were made with voice and music during periods of typically strong and weak signals. At no time was there evidence of appreciable delay (multipath) distortion, although the receiver output signal contained occasional noise bursts when the RF input signal faded momentarily below the receiver quieting threshold.

[redacted]

modified SV radar equipment. The transmitted pulses were essentially rectangular and about [redacted] by means of a U.S. Navy 0/76-U primary frequency standard. The peak power output was about 400 kw and the average power was about 350 watts. A second identical frequency standard was used at the receiver to control an A-scope presentation [redacted] that with every pulse transmitted it was possible to observe and photograph the corresponding received pulse. Test results showed that for every pulse transmitted one – and only one – pulse was received. Except during very weak signal periods, there were no marked changes in pulse shape. During very deep fades, there was evidence of pulse elongation and breakup. Observed "jitter" in received pulses was not appreciably greater than that in the transmitted [redacted] Facilities were provided for making signal-level recordings, using a Sanborn high-speed recorder with a time constant of 0.025 sec, and time totalizing equipment to show cumulative level distribution. The receiver had a bandwidth of [redacted]

During the period from 18 June to December 1953, over 250 hours of signal-level re- [redacted] and Round Hill. Results of these observations are plotted in Figs. VI-10 and VI-11. Records of received signal level made with the Sanborn apparatus indicated very rapid fading, with level variations as great as 25 to 30 db within a small fraction of a second.

[redacted] and Round Hill were made during the period 18 November to 4 December 1953. These included signal-level recordings and intermodulation tests. Transmitting and receiving equipment for these tests was assembled with assistance from Bell Telephone Laboratories. The transmitter comprised a 600-watt klystron amplifier arranged for operation with modified TD-2 terminal equipment. The receiver also included components of a modified TD-2 system terminal. Transmitting and receiving [redacted] showed that, when received signal levels were sufficient to limit the FM receiver, moderately good quality transmission was provided. There was no evidence of intermodulation distortion due to propagation phenomena. Detailed analysis of intermodulation tests is being made by the Bell Telephone Laboratories. Typical results [redacted] level measurements at Round Hill appear in Fig. VI-12. [redacted] at Round Hill are described and analyzed in detail in a Lincoln Laboratory Technical Report now in preparation.

On the basis of results of tropospheric radio propagation tests completed during 1953, it appears entirely feasible to design highly reliable point-to-point radio circuits of moderate bandwidth [redacted] ty for operation over distances as great as 200 miles, on frequencies [redacted]

D. UHF EQUIPMENT FOR TROPOSPHERIC RADIO CIRCUITS

A program was undertaken to develop and procure prototype equipment suitable for multichannel voice and teletype UHF radio circuits for distant early-warning systems. From results of the tropospheric propagation tests described in Sec. C above, it was possible to establish tentative basic requirements for UHF transmitters, receivers, and high-gain antennas. Special attention was given to the problem of designing terminal equipment for [redacted] radio circuit having 3 voice channels, up to 12 teletype channels, and a path length of from 100 to 200 miles.

A power amplifier, having an output of more than [redacted] was procured from the Ewen-Knight Corp. This amplifier was built around the Eimac 3K 20000 LA 3-cavity klystron and requires less than one watt of driving power. A suitable FM exciter for this amplifier was designed and constructed at Lincoln Laboratory. The amplifier was installed at the Round Hill Field Station where it is being used in transmission tests to the Signal Corps Engineering Laboratories at Ft. Monmouth, N.J. Negotiations were undertaken for procurement of higher-powered klystron amplifiers to operate in the same frequency range. Extended tests with the Ewen-Knight amplifier, shown in Fig. VI-13, indicate that equipment of this type has the reliability, tube-life expectancy, and other characteristics necessary for distant early-warning applications.

Arrangements were made with Radio Engineering Laboratories, Inc. for fabrication [redacted] Essential features of these receivers are low noise, good center-frequency stability, and high-performance limiters and discriminators. Owing to the extended delivery schedule for these receivers, it was decided to construct in the Lincoln Laboratory additional interim receivers having generally similar characteristics but narrower bandwidth and an improved low-noise front end incorporating General Electric Co. grounded-grid triodes Type GL-6299. Both the R.E.L. receivers and the Lincoln Laboratory receivers have facilities for dual or triple diversity. Essential specifications for both the R.E.L. and Lincoln Laboratory UHF receivers follow.

(1) Front End: – A low-noise front end employing the General Electric low-noise triode No. GL-6299 is required. The cavities in the front end should be made tunable [redacted] The General Electric Type No. GL-6299 tube should be followed by a 2C40 stage for best noise figure. This front end will have 50-ohm input and output.

(2) Local Oscillator: – The local oscillator should be crystal-controlled on one [redacted] Center-frequency stability shall be three parts in ten million per day or better. Design details for a crystal oscillator meeting this specification in the 1 to 4 Mcps band will be furnished if required. No test of the frequency stability is required. Local oscillator-to-mixer connections are to be made through BNC 75-ohm connectors so that triple-diversity arrangements may be run with common local oscillators. Power output from oscillators must be sufficient to operate three mixers.

(3) Mixer and IF: – A silicon diode mixer followed by an IF with the following specifications should be used: As measured at a point immediately preceding the limiters, the receiver shall attenuate all signals [redacted] center frequency by at least 60db, and all signals [redacted] frequency by at least 120db. As measured at a point immediately preceding the limiters, the voltage amplitude for constant signal input shall not vary more than 5 per cent from the center-frequency voltage over a band 60 kcps each side of center frequency. The 3-db points shall be 75 kcps each side of center frequency. The output of the IF section should be at 75 ohms BNC.

(4) Limiter-Discriminator Section: – There should be gain enough in the receiver so that front-end noise drives the first limiter to the point where the slope of the limiter input vs output characteristic has decreased to 10 per cent of its initial value. Limiters and discriminators to be designed embodying the principles set forth in Research Laboratory of Electronics (M.I.T.) Technical Report No. 42.

(a) At least 4 stages of limiting greater [redacted]

(b) Essentially zero time constant in important elements of limiters.

(c) Discriminator peak separation [redacted]

(d) Over a band 1 Mcps each side of center frequency, the discriminator characteristic shall be monotonic and linear within 10 per cent of its maximum value, that is, the direct voltage output of the discriminator as a function of frequency shall not depart from a straight line of arbitrary slope drawn through the zero-voltage point of the discriminator curve by more than 10 per cent of the voltage corresponding to a fre- [redacted]

External input to the limiters shall be provided through a 75-ohm BNC connection. [redacted] the total harmonic distortion in the receiver output shall not exceed 1 per cent. With one millivolt signal input, the rms noise in the receiver output shall be at least 60 db below the voltage corresponding to ±60 kcps deviation. The output is to be flat [redacted] The output connections are to be balanced/unbalanced at 600 ohms. Output signals shall be at least 10 volts rms for ±60 kcps deviation.

(5) Primary power: — ~120 volts ±15 per cent, 47 to 63 cps, standard R.E.L. rack-mounted.

Arrangements were made with the D.S. Kennedy Co. for fabrication of six 28-foot-diameter, 12-foot focal-length paraboloidal antennas suitable for operation on frequencies as high [redacted] antennas are made of aluminum and were built to the following specifications:

(1) Surface tolerance: true paraboloidal surface to ±1/16" to 5 foot radius, ±1/8" at perimeter.

(2) Reflectivity: better than 96 per cent at X-band.

(3) 100-mile wind with 1-inch ice coating shall produce not more than one inch deflection at the perimeter and no permanent deformation.

(4) Sectionalized design suitable for air transport.

Suitable illuminating dipoles and matching sections for these antennas were designed and constructed. [redacted] A photograph of one of the antennas appears in Fig. VI-14. Several of these antennas were delivered to Bell Telephone Laboratories for Northern tropospheric propagation tests. Specifications also were established for 60-foot diameter paraboloidal antennas having similar characteristics.

Voice channeling equipment suitable for use with the UHF transmitters and receivers mentioned above was procured from Lenkurt Electric Co. Compatible channeling equipment for FSK teletype was procured from Northern Radio Co.

Arrangements were made for full duplex multichannel tests between Round Hill and Ft. Monmouth using (1) Lincoln Laboratory narrow-band receivers and exciters, and (2) AN/TRC-24 radio equipment and TCC-7 and TCC-3 channelizing equipment, furnished by the Signal Corps.

Results of the Lincoln Laboratory UHF equipment development program were available for use by the Bell Telephone Laboratories in establishing equipment specifications for the PROJECT PINE TREE tropospheric radio-relay system.

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*Including approximately 10 db degradation due to cosmic noise.
**This (P9D) transmitted-reference system, constructed especially for PROJECT CORRODE, should not be confused with the stored-reference system under development at Lincoln Laboratory for another application.

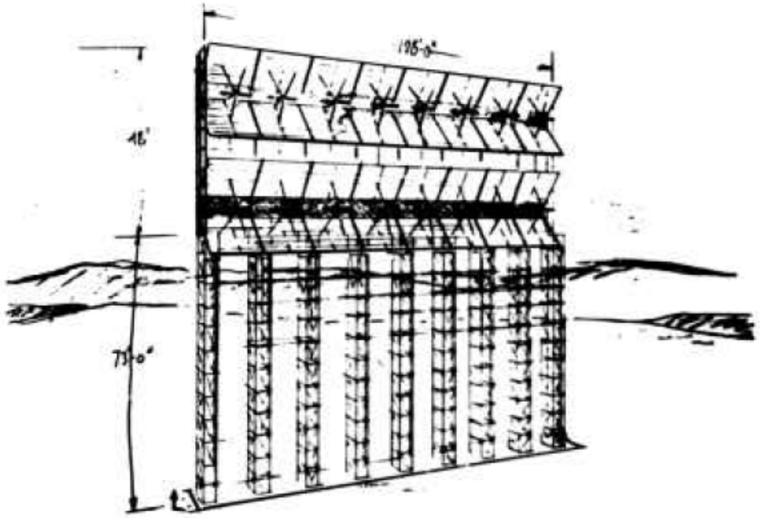

Fig. VI-1. Corner-reflector array: [redacted]

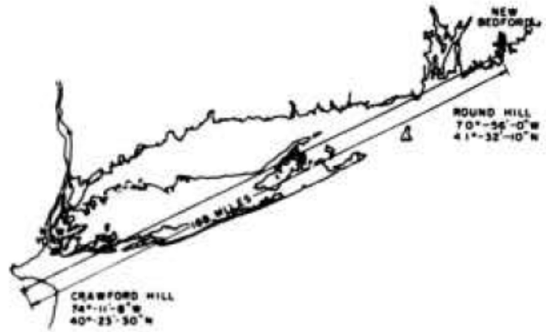

Fig. VI-2. S-band experimental propagation path between Crowfords Hill, N. J. and Round Hill Field Station.

Fig. VI-3. Rear view of the 28-foot diameter paraboloidal antenna installed at Round Hill for SHF signal propagation studies.

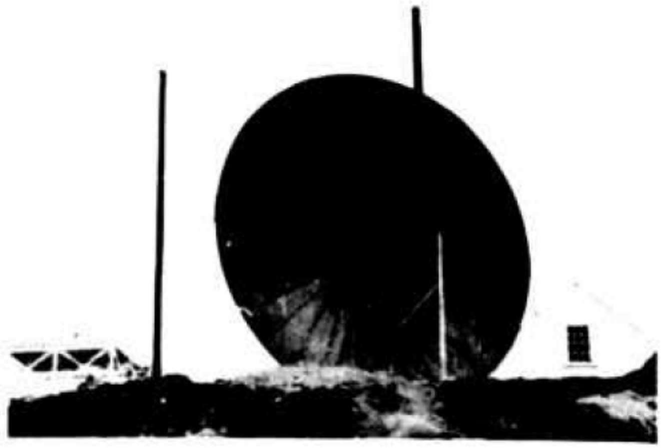

Fig. VI-4. Front view of the 28-foot diameter paraboloidal antenna installed at Round Hill for SHF signal propagation studies.

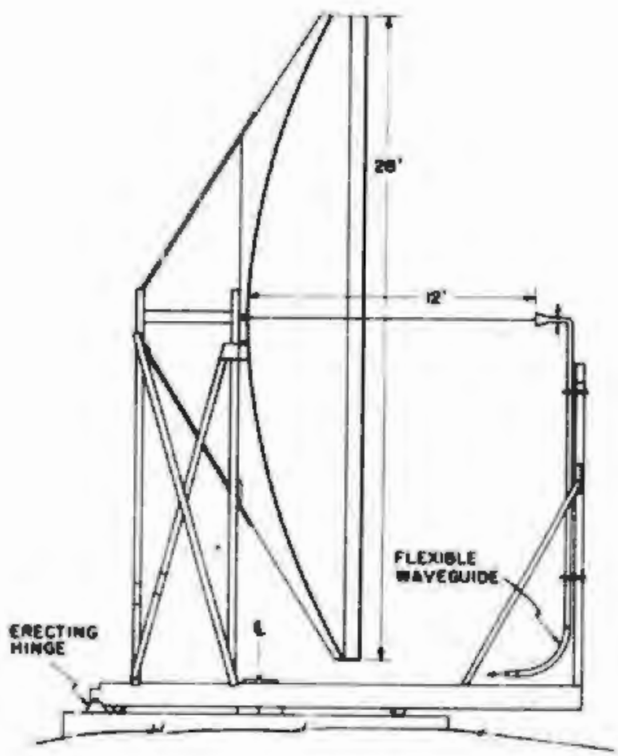

Fig. VI-5. Twenty-eight foot paraboloidal antenna.

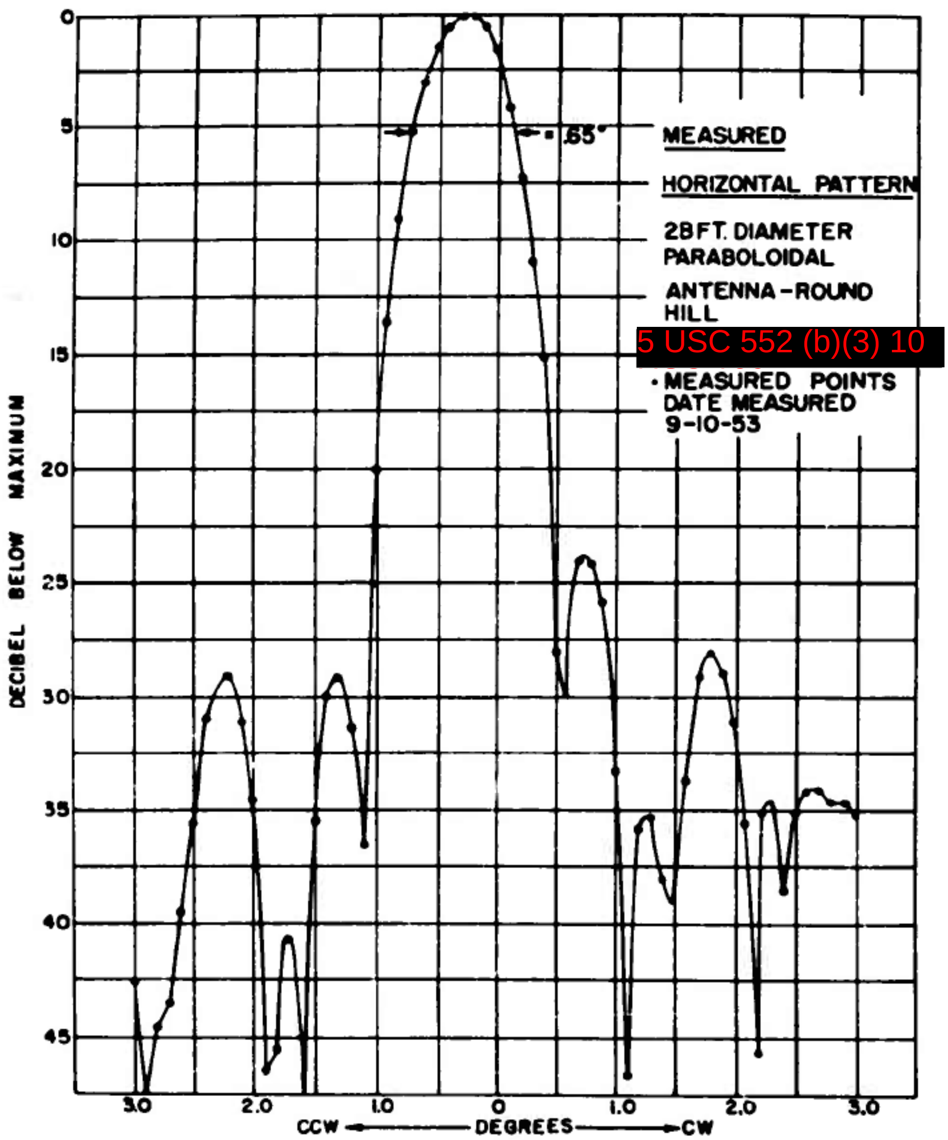

Fig. VI-6. Measured horizontal radiation pattern of 28-foot paraboloidal antenna (maximum gain 44 db).

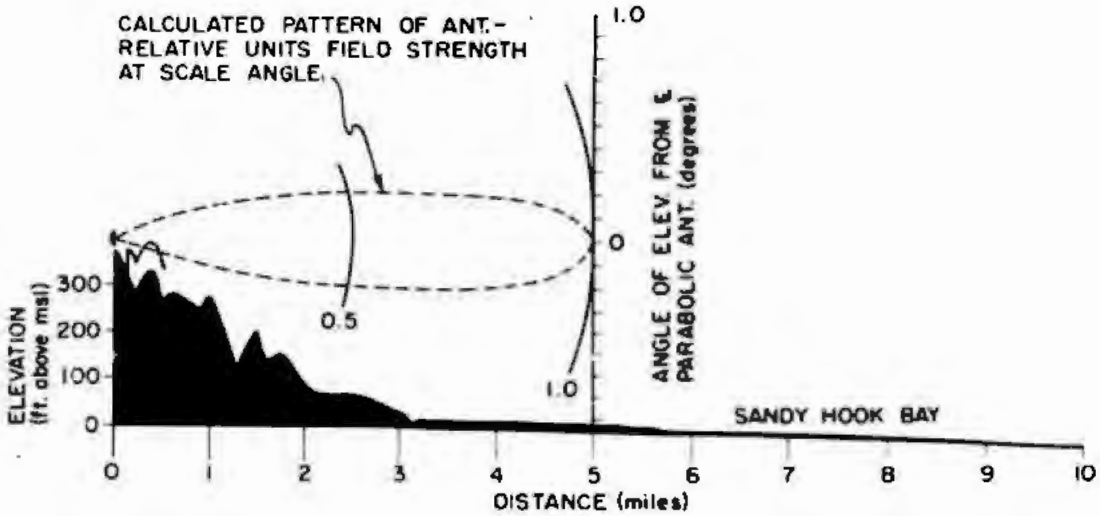

Fig. VI-7. Terrain profile from Crawfords Hill, N. J., along a true bearing of 53° 56' toward Round Hill.

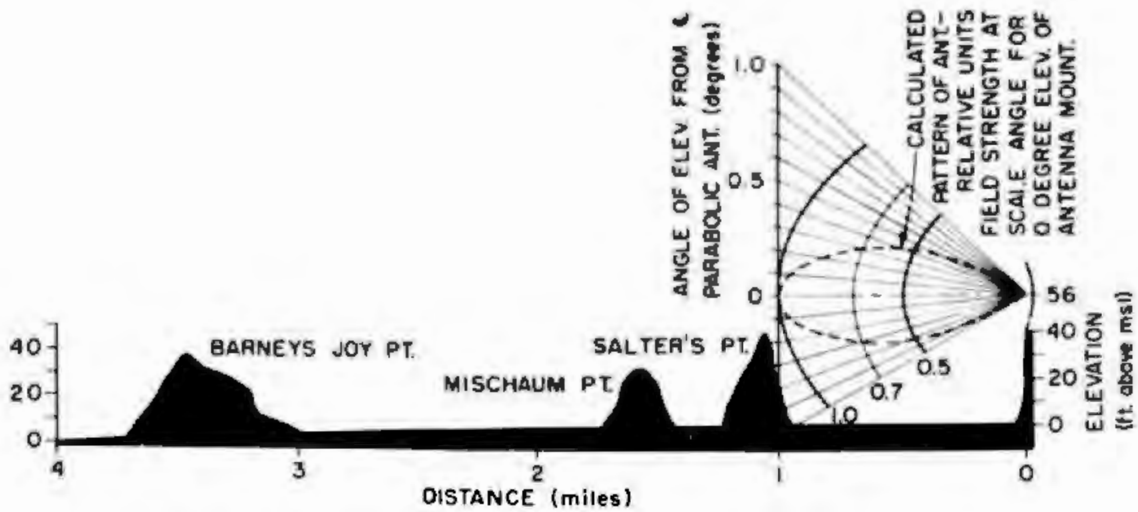

Fig. VI-8. Terrain profile from Round Hill Field Station along a true bearing of 246° toward Crawfords Hill, N.J.

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[redacted]

5 USC 552 (b)(3) 10 USC 130

[redacted]

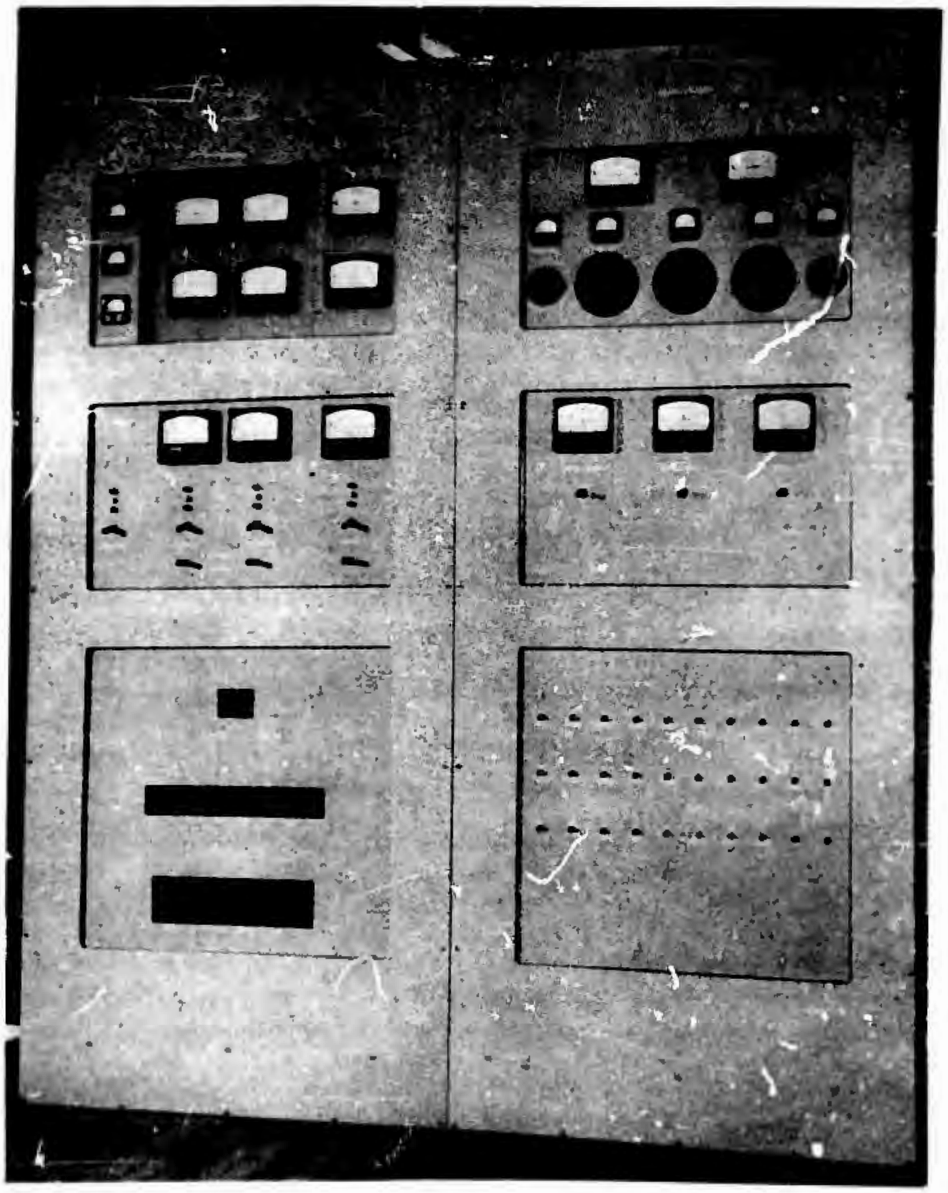

Fig. VI-13. Front panel view of 5-kw klystron amplifier (frequency range 390-440 Mc).

Fig. VI-14 Twenty-eight foot paraboloidal antenna.