Evaluation of the Rho/Theta Transponder System

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Under Project No 6 2 4

by

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT AND
EVALUATION CENTER
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EVALUATION OF THE RHO/THETA TRANSPONDER SYSTEM*

FOREWORD

The Air Navigation Development Board (ANDB) was established by the Departments of Defense and Commerce in 1948 to carry out a unified development program aimed at meeting the stated operational requirements of the common military/civil air navigation and traffic control system. This project, sponsored and financed by the ANDB, is a part of that program. The ANDB is located within the administrative framework of the Civil Aeronautics Administration for housekeeping purposes only. Persons desiring to communicate with ANDB should address the Director, Air Navigation Development Board, Civil Aeronautics Administration, W-9, Washington 25, D. C.

SUMMARY

This report describes the operational and technical evaluation by the Technical Development and Evaluation Center of the Civil Aeronautics Administration of an air-traffic-control aid known as the Rho/Theta Transponder System. The system components were developed and constructed by several contractors under contracts with the Bureau of Ships and the Bureau of Aeronautics of the Navy Department. The contracts were sponsored by the Air Navigation Development Board.

The airborne components of the system are interrogated by either S-band airport-surveillance or X-band precision-approach radars. One or more reply pulses are transmitted for each ground-radar interrogation pulse, and the replies are received by a responsor installed at the radar site. The video output of the responsor is mixed with the radar video signals, and the combined signals are displayed on the radar indicator. When aircraft are equipped with transponder units, the reliability of corresponding targets displayed by the radar indicator is improved and aircraft identification is possible. Range-coding identification is provided when the airborne transponder transmits two or more pulses for each interrogation pulse received.

Two models of airborne equipment were evaluated. The reply frequency of the first model was 1375 Mc, and the reply frequency of the second model, referred to as Mod. II, was 2927 Mc. Except for reply frequency, the two models were similar. Evaluation of the first model was limited, because the modified ASR-2 antenna required to receive L-band transponder replies was not available. Also, because the video interconnection unit required to mix transponder and radar video signals was not available, it was necessary to construct substitute units at the Technical Development and Evaluation Center.

Evaluation of the system and of its components was partially completed when the Air Navigation Development Board requested that the work be terminated. This request was made in accordance with recommendations of the Air Traffic Control and Navigation Panel of the Air Co-ordinating Committee to the effect that evaluation of the Rho/Theta transponder system should be discontinued and that an air-traffic-control beacon system suitable for military and civil use should be developed and evaluated.

Results of the evaluation tests which were completed indicate that the Rho/Theta transponder system is beneficial from the standpoint of terminal-area traffic control except in areas where several S-band radars are operated. Other radars in the area may either "capture" or overinterrogate the transponder. Certain improvements in equipment and components would be required to improve reliability of operation. The tests which were made include determination of capture effect, coverage, effects of aircraft attitude and heading, effects of automatic sensitivity-control provisions, and possibility of display of second-time-around responses.

*Manuscript submitted for publication October 1953.

INTRODUCTION

Primary radar, such as airport-surveillance (ASR) and precision-approach (PAR) radars, is being used at some of the major airports to speed the handling of aircraft in the terminal area. For the safest and most efficient handling of traffic, the radar must provide information that permits traffic controllers to track aircraft continuously. The aircraft targets displayed on the radar indicators should be distinctly visible for all weather conditions regardless of the type of aircraft surface, aircraft size, ground speed, heading, or attitude. Positive aircraft identification is needed to eliminate present identification-turn procedures which cause some delay.

Although the use of primary radar has done much to speed the handling of aircraft and to reduce delay time, it has been found that such radars fail to satisfy all the requirements because of the following disadvantages

1. The performance may be seriously degraded by precipitation interference
2. The target-echoing areas of small aircraft, su h as jet-fighter types or the private-flyer types which have fabric-covered fuselages, are so small that the targets may not be visible at all times.
3. Fixed targets or obstacles on the ground may require the use of moving-target-indicator (MTI) circuits to remove the corresponding clutter from the radar indicator. Moving-target quality is impaired when the aircraft course is such that it causes a zero rate of closure with the radar antenna or when the ground speed approaches or is equal to any of the radar blind speeds. Furthermore, the MTI subclutter-visibility characteristics of some radars do not permit reliable display of moving targets when their range and azimuth coincide with those of ground objects having large target-echoing areas. In some installations, the radar antenna is tilted upwards to reduce ground clutter and resulting MTI problems As a result maximum radar range at the lower altitudes is reduced.
4. The vertical-coverage characteristics of radar antenna are such that the display of targets cannot be assured when the aircraft are at certain vertical angles and ranges with respect to the antenna.
5. The character of all aircraft targets is similar, so that identification of individual aircraft or of different types of aircraft is impossible.

The Rho/Theta transponder was developed to overcome these deficiencies in accordance with the original recommendations made by the Air Traffic Control and Navigation Panel of the Air Co-ordinating Committee. This particular form of safety beacon was developed to obtain a working system as expeditiously and economically as possible and to obtain operational experience with the use of safety beacons in air traffic control. Other forms of safety beacons, including independent secondary-radar systems, have been developed. Generally, these systems were more complex, required extensive modification of the primary-radar equipments, or could not be released for civil use because of military-security classification.

Evaluation of the Rho/Theta transponder was not completed. In March, 1953, the Air Navigation Development Board requested that evaluation of the equipment be terminated in an orderly manner and that a report be made of the results of the evaluation tests. This request was made in accordance with recommendations made by the Air Traffic Control and Navigation Panel of the Air Co-ordinating Committee, in a letter dated February 24, 1953, to the Air Navigation Development Board. This letter also transmitted proposed characteristics of an air-traffic-control beacon system for inclusion in the requirements of the Common System, requested development of equipment to meet the characteristics of such a system, and recommended that previous efforts associated with beacon systems be discontinued. The characteristics of the air-traffic-control beacon system have been approved by the Joint Communications-Electronics Committee of the Joint Chiefs of Staff and are expected to permit civil or military aircraft to operate with civil and military air-control and surveillance-radar systems with reasonable compatibility and without the requirement for two separate beacons

Accordingly, evaluation tests have been discontinued and results of operational and technical studies and tests that were completed have been included in this report

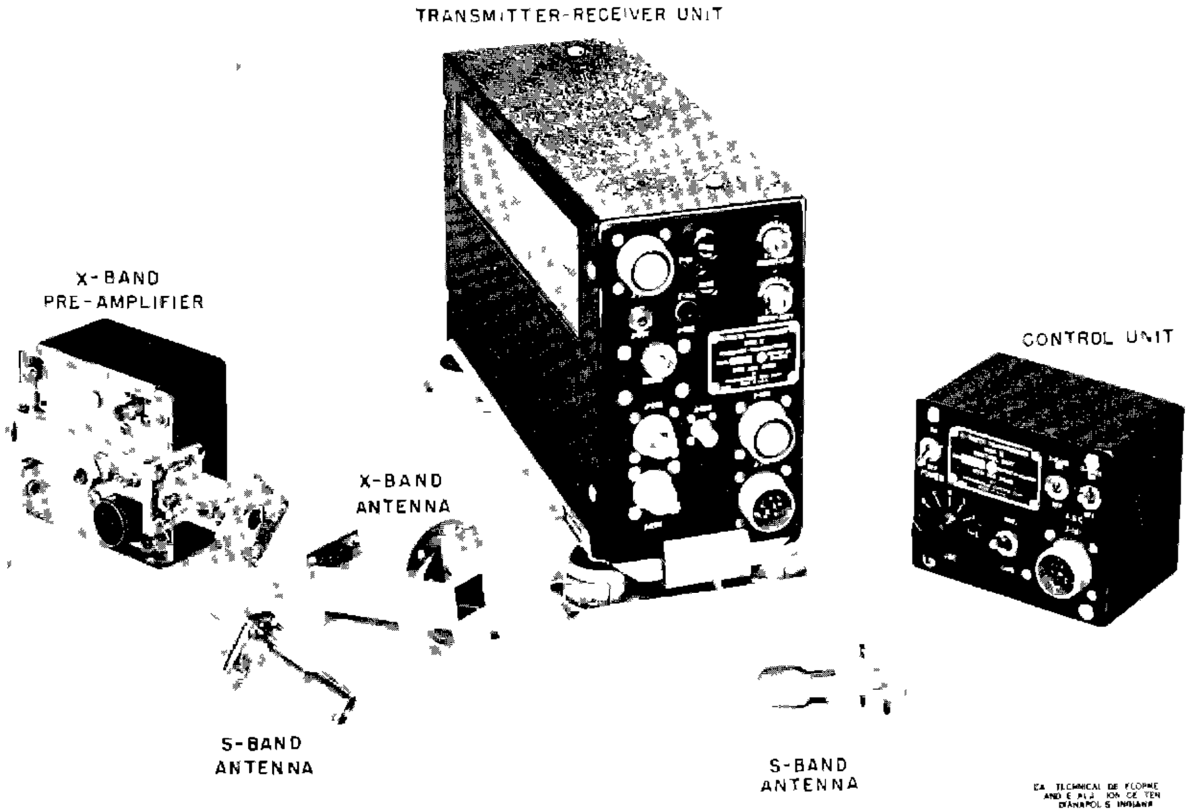

Fig. 1 Rho/Theta Transponder (S-Band Reply)

EVALUATION OBJECTIVES

The evaluation objectives were to

1. Determine the effect of the transponder on the range, accuracy, and resolution characteristics of the ASR-2 and PAR-1 radars when the transponder is installed in a representative sample of aircraft having different headings and attitudes and when it is operated under good and adverse weather conditions.
2. Determine the minimum useful ranges obtainable with the ASR-2 and PAR-1 when the automatic-sensitivity-control (ASC) circuits of the transponder are disabled as compared to the minimum ranges when ASC is operative.
3. Determine the magnitude of the capture effect when the transponder ASC is operative and two radars are in use in the area, the variation in capture effect as the relative power outputs of the radars vary between one and ten, and the magnitude of the capture effect when the transponder ASC is operative and two PAR equipments are in use in the area.
4. Determine the stability limitations, the test-equipment needs, the degree of reliability, and the maintenance needs of the transponder and of associated ground equipment
5. Determine the effect of the transponder on the utility of the ASR-2 as a traffic-control aid. Particular attention is to be paid to the effect of bloomer identity, of four identities in addition to the bloomer, of extended range of the ground radars, of intermingling transponder-equipped and non-equipped aircraft, of capture by other ground radars, and of extraneous triggering by other ground radars.
6. Determine the technical differences between S-band and L-band reply paths.

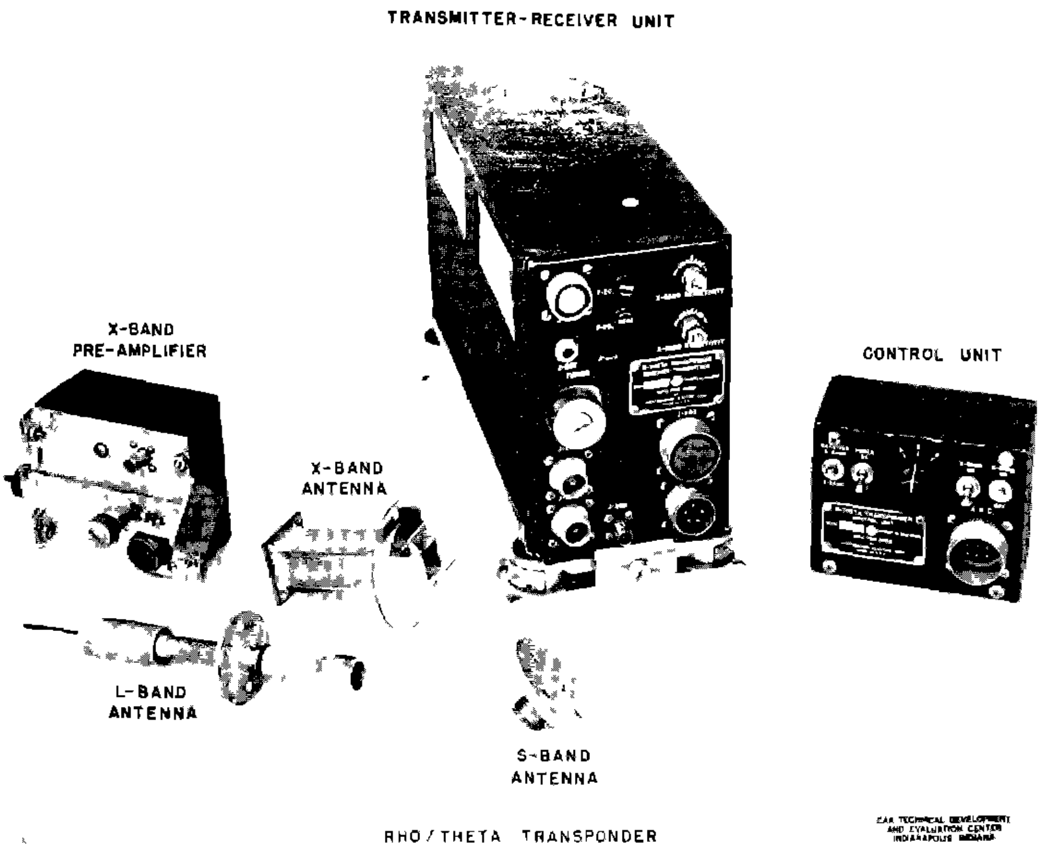

Fig. 2 Rho/Theta Transponder (L-Band Reply)

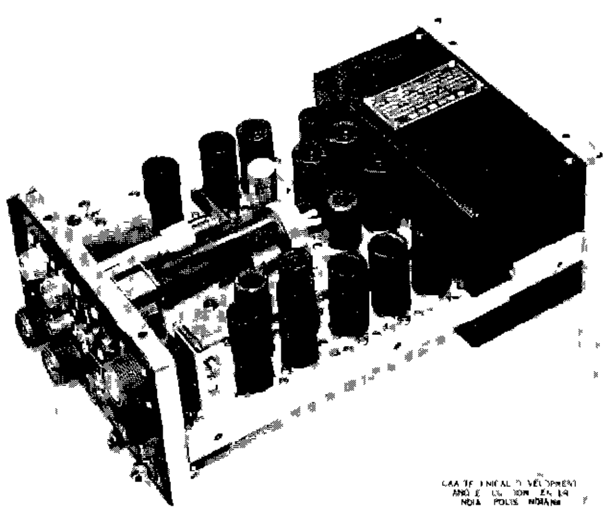

Fig. 3 S-Band Reply Transponder (Cover Removed)

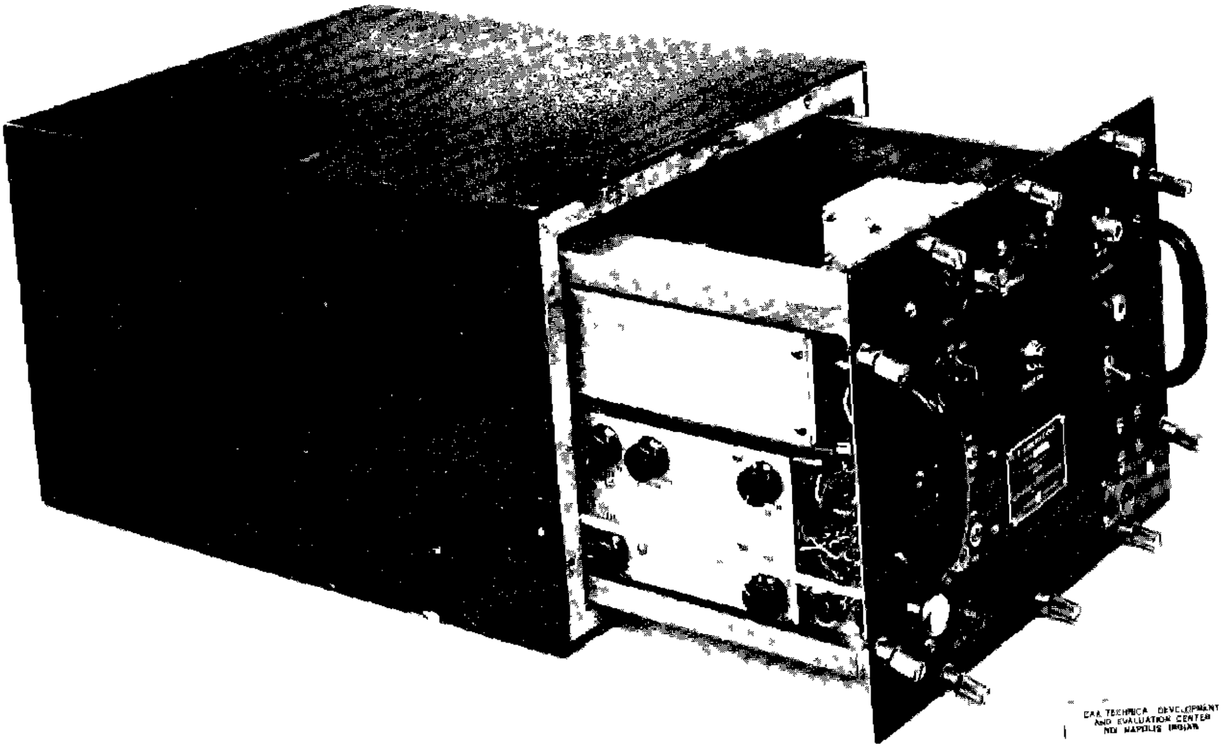

Fig. 4 Responsor

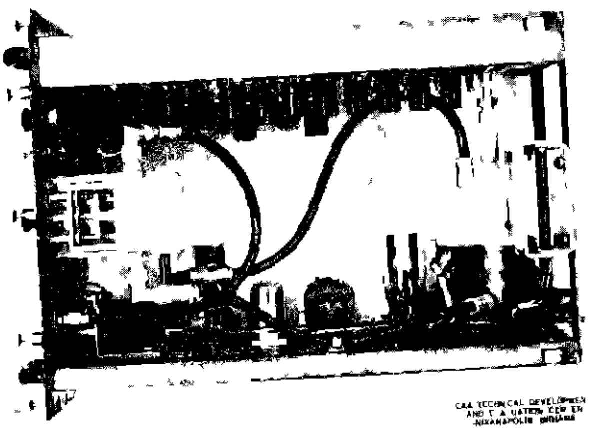

Fig. 5 Top View of S-Band Responsor

DESCRIPTION OF EQUIPMENT

The major components required for a complete S-band reply-transponder system and the display of transponder replies on ASR indicators are as follows

1. Rho/Theta transponder installed in aircraft.
2. TR modification kit installed in the radar waveguide preceding the radio-frequency mixer.
3. S-band receiver (responsor) connected to the TR modification kit.
4. Video interconnection unit (mixer) to mix responsor and radar-receiver information.

When the L-band reply transponder is used, the equipment required is the same as just noted except that an L-band feed and double-rotating joint must be added to the surveillance-radar antenna-and-pedestal assembly, the TR modification kit is eliminated, and an L-band responsor is substituted for the S-band responsor.

The major components required when display of transponder replies on the precision-approach-radar indicators is desired are

1. The Rho/Theta transponder installed in the aircraft.
2. A fixed antenna installed on or near the radar building.
3. A video interconnection unit to mix responsor and radar-receiver video information.

Rho/Theta Transponder.

The airborne transponder was developed and manufactured by Westinghouse Electric Corporation under Bureau of Aeronautics Contract NOa(s) - 12186. The following components, shown in Figs. 1 and 2, are required for installation in the aircraft

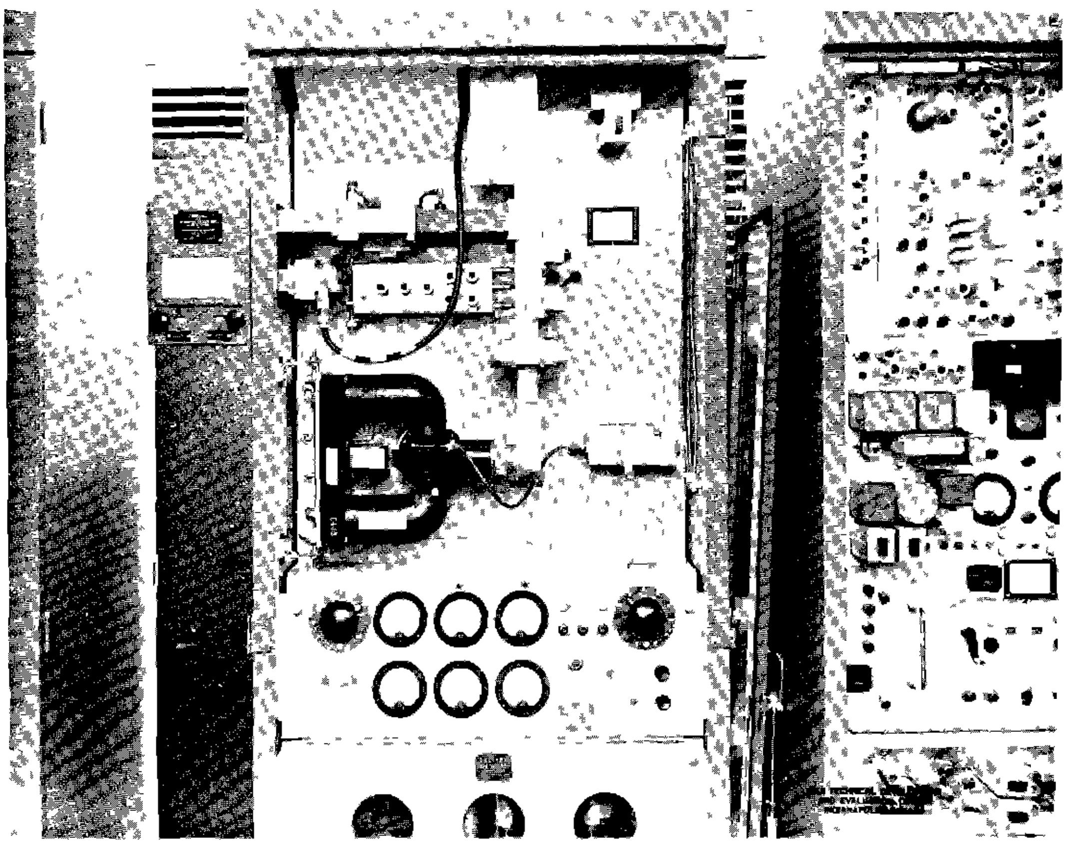

Fig 6 TR Modification Kit Installed on ASR-2 Equipment

1 Receiver-transmitter unit (S- or L-band reply)
2 Control unit
3 S- or L-band transmitting antenna
4 S-band receiving antenna
5 X-band antenna
6 X-band preamplifier

Five AN-type power connectors, two BNC-type connectors, and four HN-type connectors are required Type RG-62/U cable is used for transmission of video signals from the X-band preamplifier to the receiver-transmitter unit, and RG-8/U cable is used between the S- and L-band antennas and the receiver transmitter unit The total weight of the S-band reply-transponder components, excluding connectors and interconnecting wiring, is approximately 18 50 pounds The dimensions and approximate weights of individual components are listed in Table I

TABLE I

RHO/THETA TRANSPONDER COMPONENTS

Unit	Height (inches)	Width (inches)	Length (inches)	Approximate Weight (pounds)
Transmitter-receiver unit with shock mounting	9 1/8	6 1/8	14 1/2	14 5
Control box	4	5	3 5/8	1.5
X-band preamplifier	4	4	6 11/16	1 5
X-band preselector	2 5/16	2 5/16	2 5/8	0 25
X-band antenna	3 (dia)		4 5/8	0 50
S-band antenna (two required)	2 1/2 (dia)		3 3/4	0 25

External power requirements listed by the manufacturer are 0 9 amp at 115 volts, 400 cps, and 1 05 amp at 26 5 volts d-c

Primary performance characteristics are given in Table II

Figure 3 is a view of the S-band reply transponder with the cover removed A further description of the components and their operation is included in Appendix I

S- or L-Band Responsors

Figures 4 and 5 show the S-band responsors. The L-band responsor r-f components are larger, otherwise, the appearance of S-band and L-band responsors is the same The responsors were developed and manufactured by Westinghouse Electric Corporation under Navy Department Bureau of Ships Contract No NObsr-49232

The responsors were designed to receive signals from the transponders in aircraft and to deliver video outputs of approximately 2 volts across a load resistance of 68 ohms The S-band and L-band responsors are identical except for the r-f preselectors, local oscillators, and r-f mixers Modification kits required to convert from S- to L-band and from L- to S-band operation were furnished

S-band responsors can be tuned to receive r-f signals in the frequency range of 2900 to 2950 Mc, and the L-band responsors can be tuned to receive signals in the frequency range of

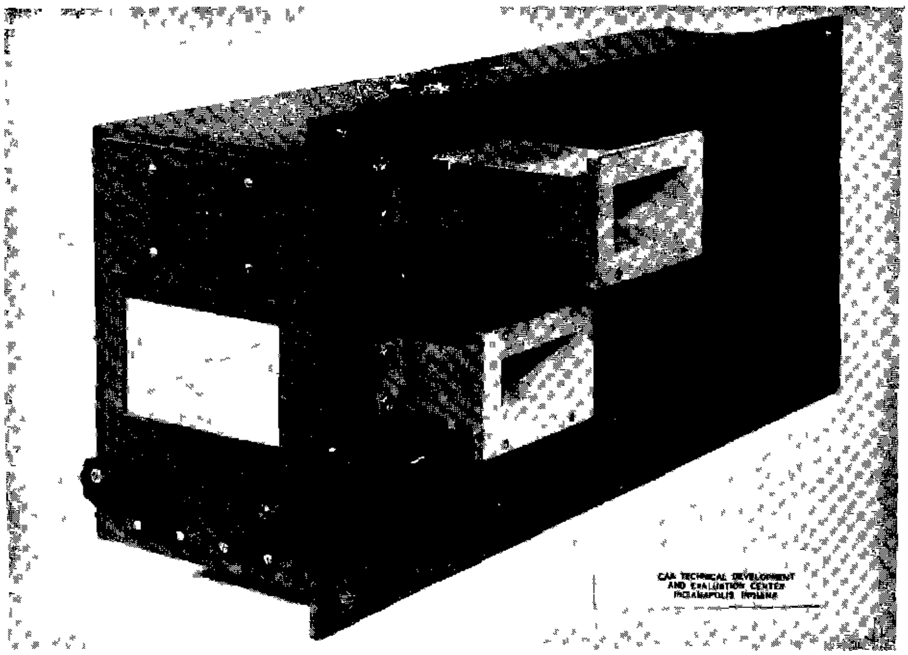

Fig 7 Photograph of TR Modification Kit

1365 to 1450 Mc Normally, the S-band responsor is tuned for operation at 2927.5 ±7 5 Mc, and the L-band responsor is tuned to receive signals at the frequency of 1375 ±7 5 Mc It is necessary to adjust the local-oscillator frequency and the r-f preselector if operation at other frequencies is desired

The responsors consist of an r-f preselector, a local oscillator, an r-f mixer, an intermediate-frequency amplifier strip with detector, a video amplifier, sensitivity-time-control (STC) circuits, and the power supply The major characteristics listed by the manufacturer are

Minimum discernible signal	Approximately -115 dbw
Over-all frequency bandwidth	15 Mc between response points 6 db down with respect to passband response

TABLE II

PERFORMANCE CHARACTERISTICS RHO/THETA TRANSPONDER

	Frequency Band (Mc)	Sensitivity Below 1 Watt (db)	Pulse Width (μsec)	Dead Time (μ sec)	Peak Power (watts)
S-band interrogation	2700 - 2900	74	0 5 to 2 0	250 app	
X-band interrogation	9000 - 9180	69	0 25 to 1 0	250 app	
R-F output	2900 - 2950		1 0 ± 0 2,		100 min

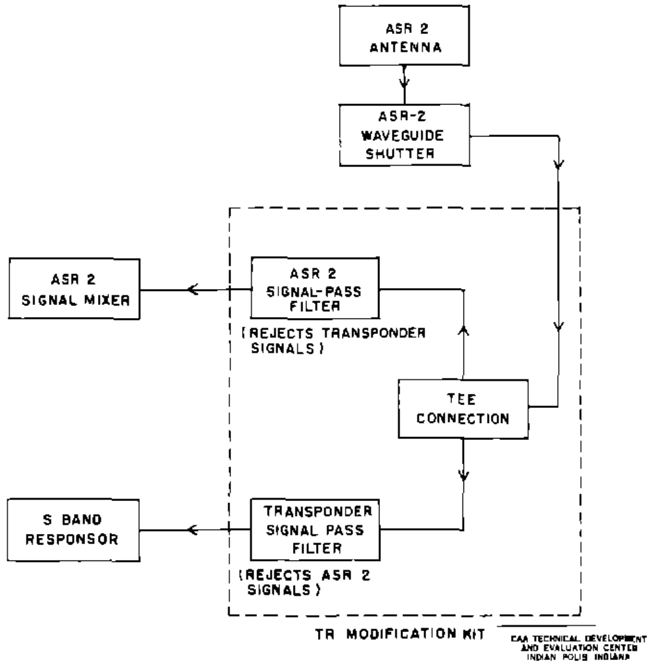

Fig 8 Block Diagram of TR Modification Kit and Connections

i-f amplifier frequency	60 Mc
i-f amplifier selectivity	25 Mc from center frequency at response points 60 db down with respect to passband response
Video output	Maximum of ±2 volts across 68-ohm load
STC trigger requirement	1 to 20-volt positive pulse of 1-microsecond duration
r-f input impedance	52 ohms
r-f input connector	Type N
Video and trigger connectors	Type BNC
External power required	90 watts at 115 volts, 60 cps
Dimensions	12 inches high, 16 1/16 inches wide, and 20 7/8 inches long
Weight	81 5 pounds

Operation of the responsors is described in Appendix II

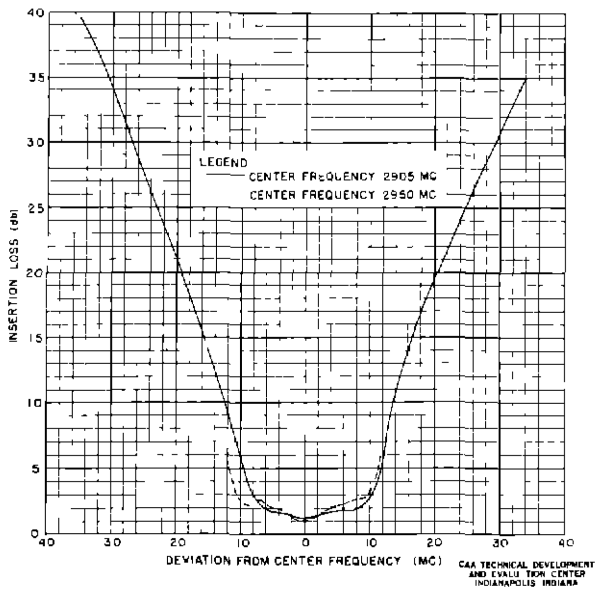

Fig 9 Frequency Response of Transponder Section of TR Modification Kit

TR Modification Kit

The TR modification kit was developed and manufactured by Maryland Electronics Manufacturing Corporation under Navy Department Bureau of Ships Contract NOsr-57070 The kit was designed for installation on the ASR-2 transmitter-modulator assembly for connection between the waveguide-shutter and signal-mixer assemblies The function of the kit is to separate radar and transponder r-f signals so that the ASR-2 antenna can also be used for reception of transponder signals Figure 6 is a view of the kit installed on the ASR-2, and Fig 7 is an oblique view of the assembly A block diagram is shown in Fig 8

The TR modification-kit input connection is a waveguide-to-coaxial-line transition assembly The transition assembly is connected to the center connection of a T-connector, UG-107B/U One end of the T-connector is connected to filter assemblies which pass signals from the transponder The output of this section of the kit is connected to a Type-N receptacle marked BEACON The other end of the T-connector is connected to filter assemblies which pass ASR-2 signals The output of this section is connected to a coaxial-to-waveguide transition assembly and thence to the ASR-2 signal mixer Each filter section consists of three coaxial resonant cavities Individual cavities may be compared to a three-quarter-wavelength short-circuited coaxial line with a lumped capacitance across the open end Power is coupled into and out of the individual cavities by coupling loops Coaxial conductors are used for cavity interconnection

The cavities are tuned by slugs which move up and down inside the cavities as the tuning knob is turned A tuning knob and a counter are provided for each filter section Three worm gears are pinned to the shaft which is rotated by the knob, and the worms are geared to splined shafts on the individual cavities As the knob is turned, the splined shafts control the expansion of bellows which are sealed over the cavity center conductors so that the effective length of the center conductors is varied Each of the splined shafts was bored and threaded internally so that individual cavity-tuning screws could be inserted These screws press on the bellows, and their adjustment provides individual trimming of each cavity The kit was constructed and calibrated so that the reading of the counter connected to each tuning-knob shaft indicates the approximate frequency to which the filter section is tuned To adjust a filter section for operation at a particular frequency, the knob is rotated to obtain the counter reading indicated by the calibration chart Then, the individual trimming screws of the three cavities of the filter section involved are adjusted for maximum output

The center frequency of the ASR-2 filter section may be adjusted from 2700 to 2860 Mc, and the bandwidth is at least 5 Mc The center frequency of the transponder or beacon-filter section may be adjusted from 2905 to 2950 Mc, and the bandwidth is at least 15 Mc Other

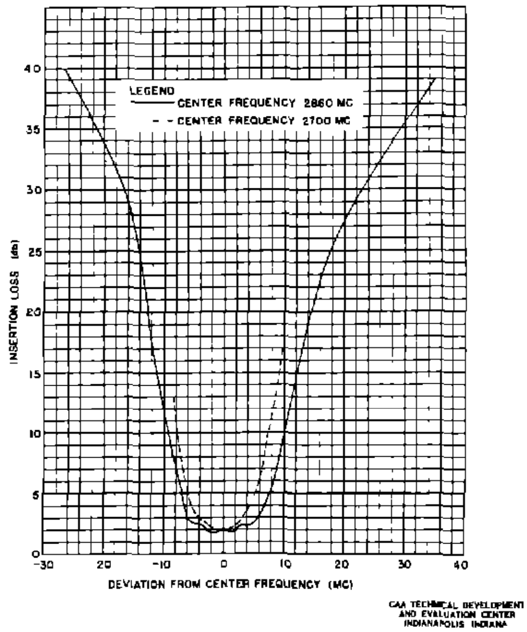

Fig 10 Frequency Response of ASR-2 Section of TR Modification Kit

characteristics, as published by the manufacturer, are isolation against crosstalk, not less than 40 db, isolation of output of one section from local oscillator of receiver connected to the other section, approximately 50 db, insertion loss for signals having frequencies in the pass band, less than 3 db, weight, 39 5 pounds, and over-all dimensions (excluding waveguide projections), 10 9/16 inches high, 6 5/8 inches wide, and 24 1/16 inches long

The manufacturer's curves showing insertion-loss variation with frequency have been replotted and are shown by Figs 9 and 10

Video Interconnection Unit

A video interconnection unit, or mixer, is required to mix video signals from the primary-radar receiver and responsor so that the combined outputs may be displayed on the primary-radar indicator In addition, it is necessary to delay the radar indicator sweep and video information to compensate for delay in the transponder triggering and oscillator circuits A unit was developed by General Electric Company under Navy Department Bureau of Ships Contract No NObsr-49278 It was not available during the evaluation tests, and the mixers used were constructed at the TDEC

The schematic diagram of the mixer used to mix video signals from the PAR-1 receiver and the responsor installed at the PAR-1 site is shown in Fig 11 The mixer was installed in a rack near the PAR-1 indicator console A spare RG-13/U cable installed in the ducts between the PAR-1 transmitter-receiver building and the indicator console was used to connect the responsor video output to the mixer The mixer was designed for input and output video-signal amplitudes of at least 2 0 volts The bandwidth is such that 0 5-microsecond pulses are not appreciably attenuated or distorted

The PAR-1 video is connected to the connector labeled Video No 1, and the responsor video is connected to the connector labeled Video No 2 The delay line connected to the Video No 1 input circuit is a uniform delay line, General Electric Company Catalog No 5111891 The length of the line is 3 feet, and the total delay is 1 5 microseconds The characteristic impedance of the line is 1100 ohms The frequency pass band is from 0 to 2 0 Mc Video signals are mixed by V-1 and amplified by V-2 Tube V-3 is connected as a cathode follower to feed the video cable to the indicator console The delay line delays the PAR-1 video to compensate for delay introduced by the transponder triggering and oscillator circuits Sweeps for the 10-mile and 3-mile indicators are delayed the same amount by adjustment of the sweep delay adjustment in the 3-mile sweep amplifier unit and the 10-mile sweep amplifier unit

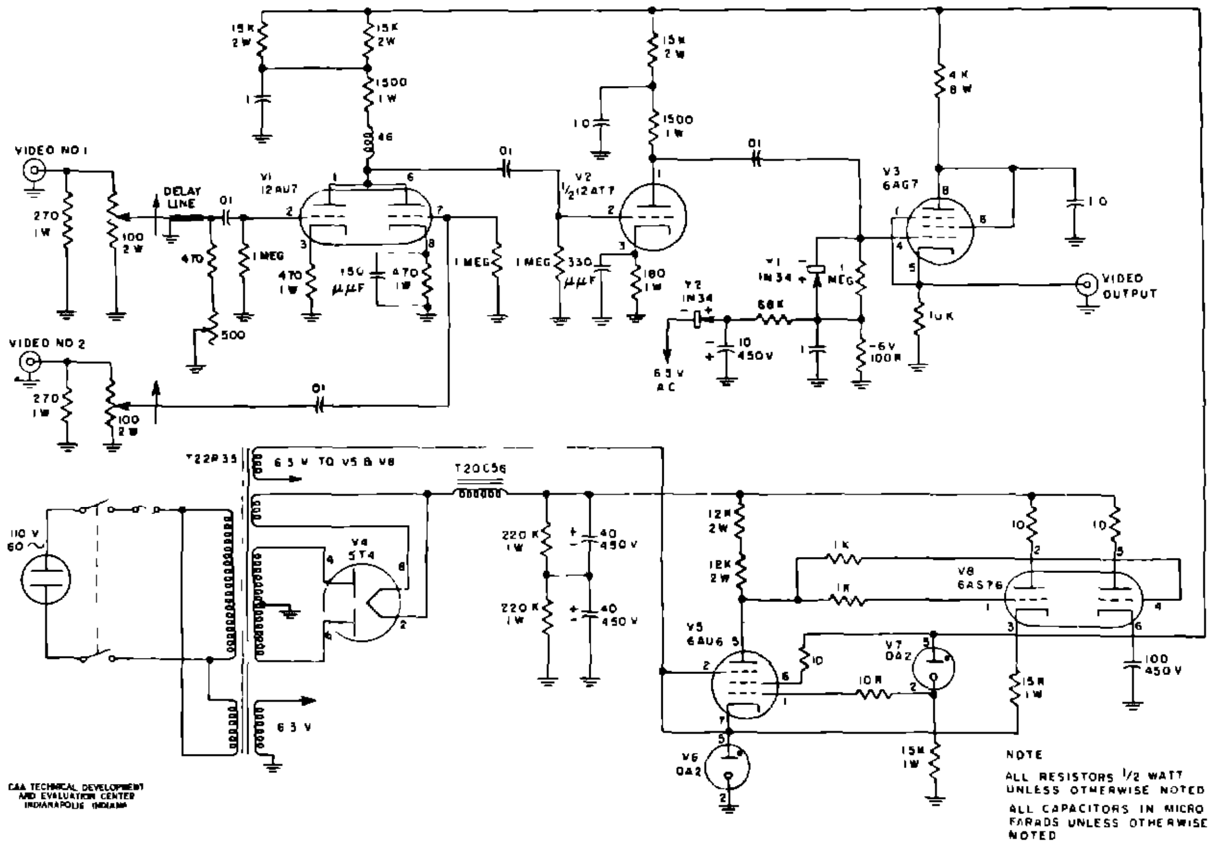

Fig 11 Schematic Diagram of Video Mixer for PAR-1

Figure 12 is a schematic diagram of the unit which was used to mix video signals from the ASR-2 receivers and the responsor Two plan-position-indicator (PPI) consoles were used during the tests The information on one indicator was photographed The other indicator was observed by engineers and traffic-control specialists

The ASR-2 video and trigger signals were connected to one input receptacle, while the responsor video-output signals were connected to the other input receptacle The combined signals of the responsor, ASR-2 trigger, and ASR-2 video at the plates of tubes V-5 and V-6 were connected to the transmission line which normally conveys ASR-2 video and trigger information to the line-compensating amplifier in the equipment assembly rack near the remote-indicator console Mixing of the signals in this manner eliminated the need for another video transmission line between the indicator and the transmitter-receiver rooms and eliminated the need for additional line-compensating components

The second indicator was located in the ASR-2 transmitter-receiver room and was connected to the receptacles marked VIDEO OUTPUT and TRIGGER OUTPUT It was not necessary to delay the ASR-2 video and trigger information since the total delay in the ASR-2 equipment was approximately equal to the total delay in the transponder system

Fixed S-Band Antenna Characteristics

The S-band antenna which was used to receive transponder replies during interrogation by the PAR-1 is shown in Fig 13 This antenna was designed and constructed by the Glenn L Martin Company under Navy Department Bureau of Ships Contract NObsr-49267

The antenna was designed to receive vertically polarized signals in the frequency range of 2900 to 2950 Mc and to be mounted on the roof of the PAR-1 building The antenna is an off-set fed, cylindrical-parabola, reflector-type radiator Provision was made for adjustment of

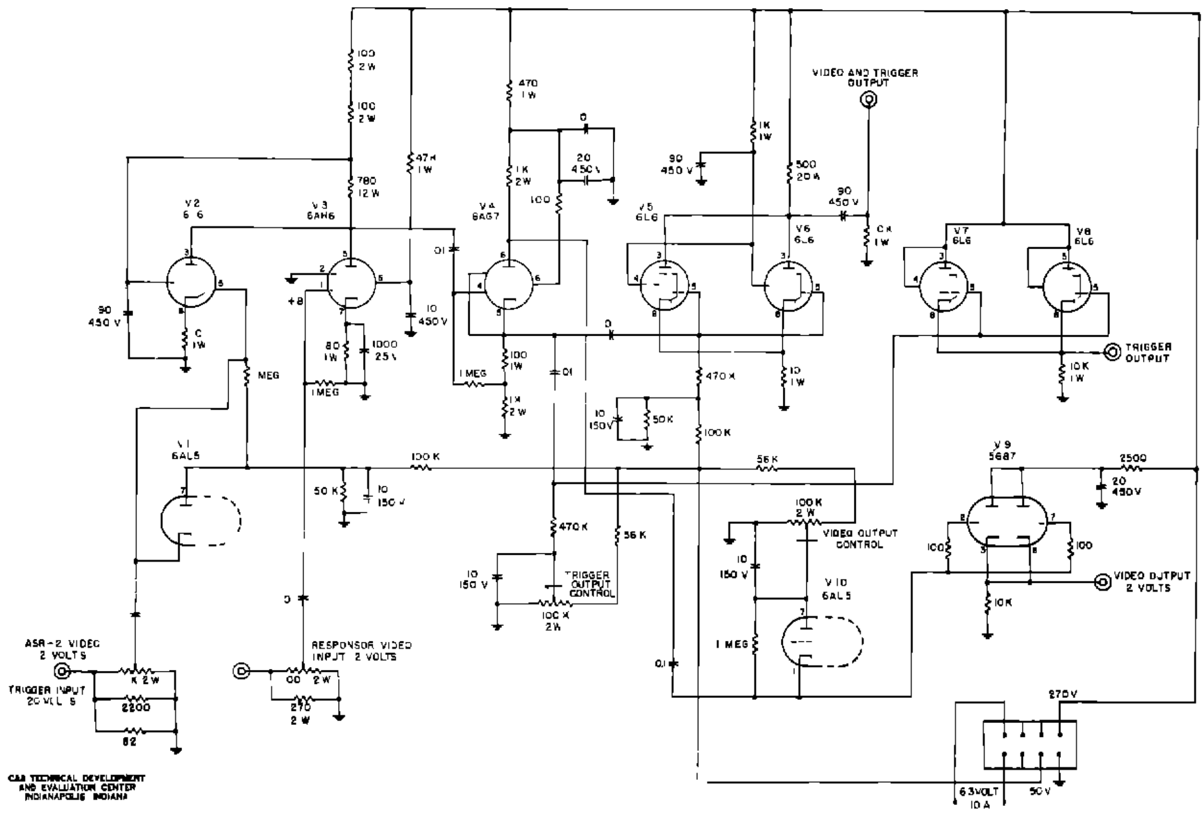

Fig 12 Schematic Diagram of Video Mixer for ASR-2

the azimuth and elevation of the reflector-and-feed-horn assembly relative to the support assembly The elevation adjustment position is indicated on an elevation scale calibrated from minus 30° to plus 30°, and the azimuth adjustment position is indicated on an azimuth scale calibrated from minus 40° to plus 40° The feed horn was designed for 52-ohm coaxial input terminated in a Type N receptacle The characteristics of the antenna as published by the contractor in the final engineering report are

Vertical-plane, half-power beamwidth	11° at 2925 Mc
Horizontal-plane, half-power beamwidth	29 5° at 2925 Mc
Relative side- to main-lobe power in vertical plane	-21 db maximum
Relative side- to main-lobe power in horizontal plane	-26 5 db maximum
Voltage standing-wave ratio	1 29 at 2925 Mc
Gain relative to isotropic radiator	+20 0 db
Total weight	94 pounds

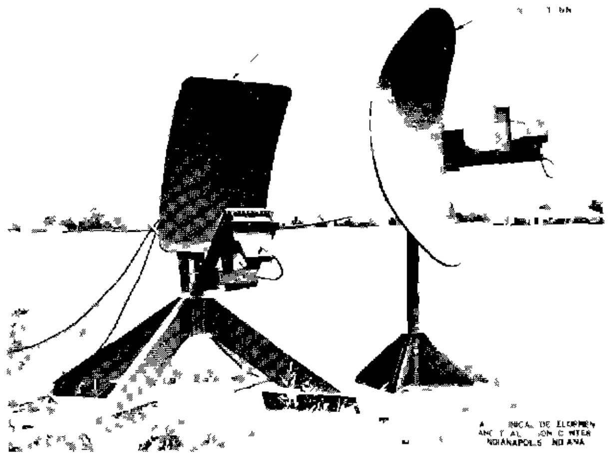

Fig 13 Fixed S-Band and L-Band Antennas Used at PAR-1 Site

Fixed L-Band Antenna Characteristics

The L-band antenna which was used to receive transponder replies during interrogation by the PAR-1 is shown in Fig 13 This antenna also was designed and constructed by the Glenn L Martin Company under Navy Department Bureau of Ships Contract No NObsr-49267

The antenna was designed to receive vertically polarized signals in the frequency range of 1365 to 1450 Mc The antenna is an off-set fed, parabolic-reflector-type radiator Provision was made for adjustment of the elevation and azimuth positions of the reflector-and-feed-horn assembly with respect to the mounting assembly The orientation may be varied 360° in azimuth

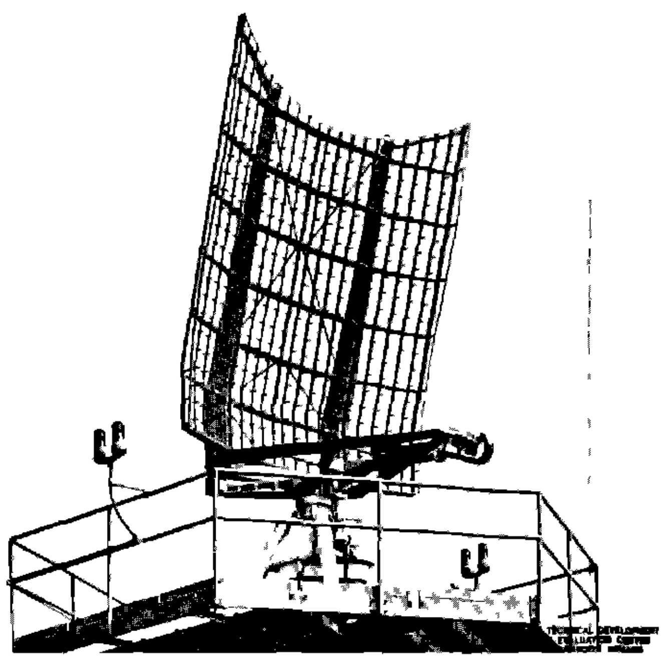

Fig 14 Photograph of ASR-2 Antenna

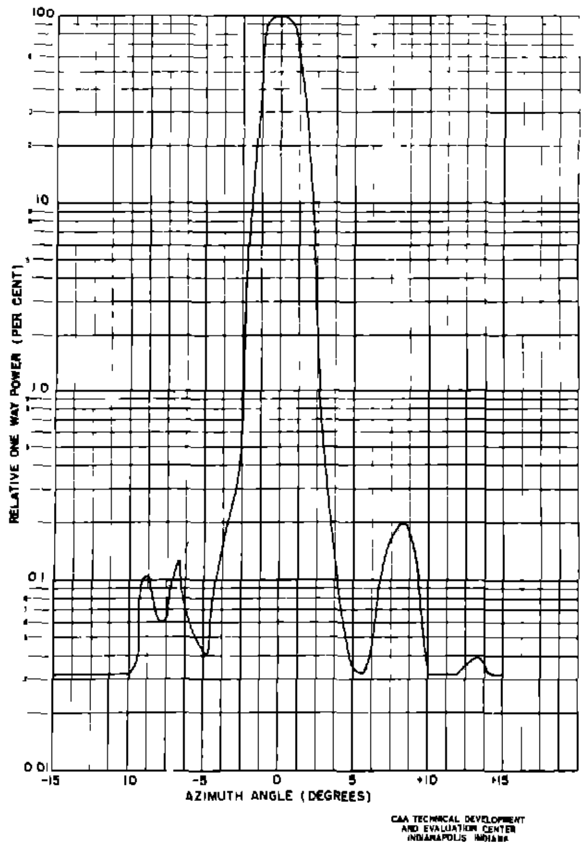

Fig 15 Horizontal Pattern of ASR-2 Antenna Frequency 2900 Mc

and at least ±40° in elevation. The azimuth position scale is calibrated from minus 40° to plus 40°, and the elevation scale is calibrated from minus 30° to plus 30° The feed horn was designed for 52-ohm coaxial input and is terminated in a Type HN receptacle Characteristics of the antenna as published by the contractor in the final engineering report are

Vertical-plane, half-power beamwidth	12°
Horizontal-plane, half-power beamwidth	22 5°
Relative side- to main-lobe power in vertical plane	Less than 26 db
Relative side- to main-lobe power in horizontal plane	-21 5 db maximum
Voltage standing-wave ratio	1 1
Gain relative to isotropic radiator	+21 6 db
Total weight	115 pounds

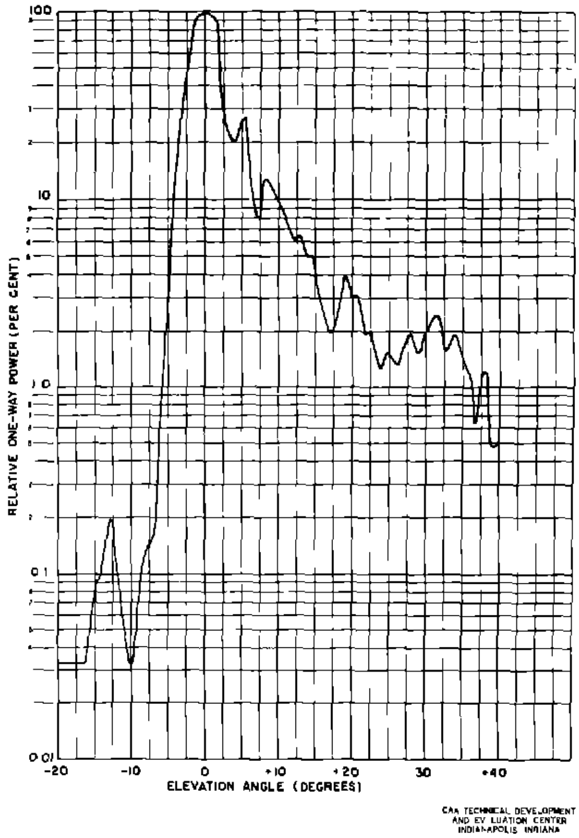

Fig 16 Vertical Pattern of ASR-2 Antenna Frequency 2900 Mc

ASR-2 Antenna Characteristics

Figure 14 is a view of the ASR-2 antenna, which is vertically polarized Major mechanical and electrical characteristics listed by the manufacturer, General Electric Company, are

Horizontal-plane, half-power beamwidth	2 3°
Vertical-plane, half-power beamwidth	Approximately 4 0°
Vertical-plane pattern	Follows cosecant-squared pattern at 10,000-foot contour into an angle 30° above the horizontal plane
Relative side- to main-lobe power in horizontal plane	-27 db maximum
Gain relative to isotropic radiator	+32 db
Reflector dimensions	10 feet wide by 12 feet high
Reflector tilt	Adjustable from 0° to +5°
Antenna rotation rate	25 rpm

Figures 15 and 16 show the horizontal and vertical patterns of the antenna

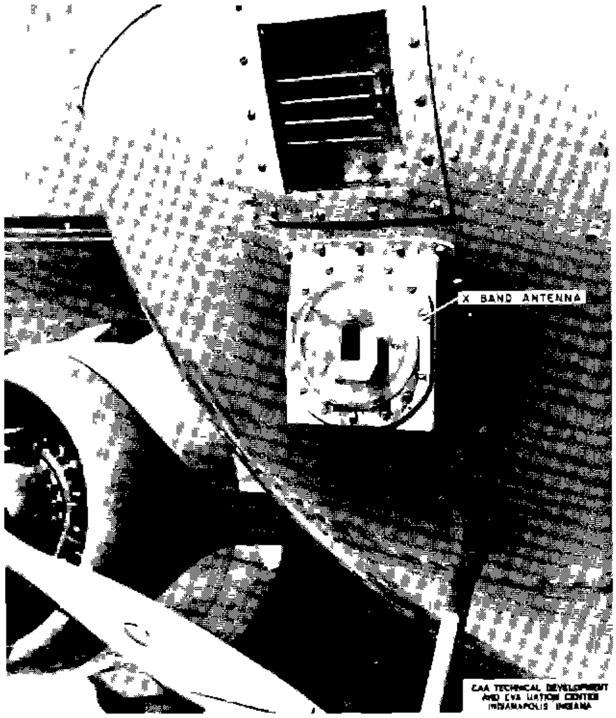

Fig 17 Installation of Rho/Theta Transponder X-Band Antenna on Nose of DC-3 Type Aircraft

PAR-1 Antenna Characteristics

Major characteristics of the PAR-1 antennas according to data furnished by the manufacturer, Gilfillan Bros , Inc , are

1 Elevation Antenna

Polarization	Vertical
Half-power vertical beamwidth	0 6°
Half-power horizontal beamwidth	3 8°
Gain relative to isotropic radiator	40 db
Waveguide, array, and sand-load loss	2 8 db

2 Azimuth Antenna

Polarization	Horizontal
Half-power horizontal beamwidth	0 9°
Half-power vertical beamwidth	1 9°
Gain relative to isotropic radiator	42 db
Waveguide, array, and sand-load loss	2 7 db

TECHNICAL EVALUATION AND RESULTS

Evaluation of L-Band Reply Transponder

It was not possible to make extensive tests of the system when airport-surveillance radar ASR-2 is used for interrogation purposes, because the modification components required to add the L-band feed to the ASR-2 antenna were not available The L-band feed is required for reception of the replies from L-band transponders when the ASR-2 is used for interrogation

Tests were made using the precision-approach radar, PAR-1, for interrogation and a fixed L-band antenna installed at the PAR-1 transmitter-receiver building to receive the transponder replies Figure 17 shows the aircraft installation of the transponder X-band antenna,

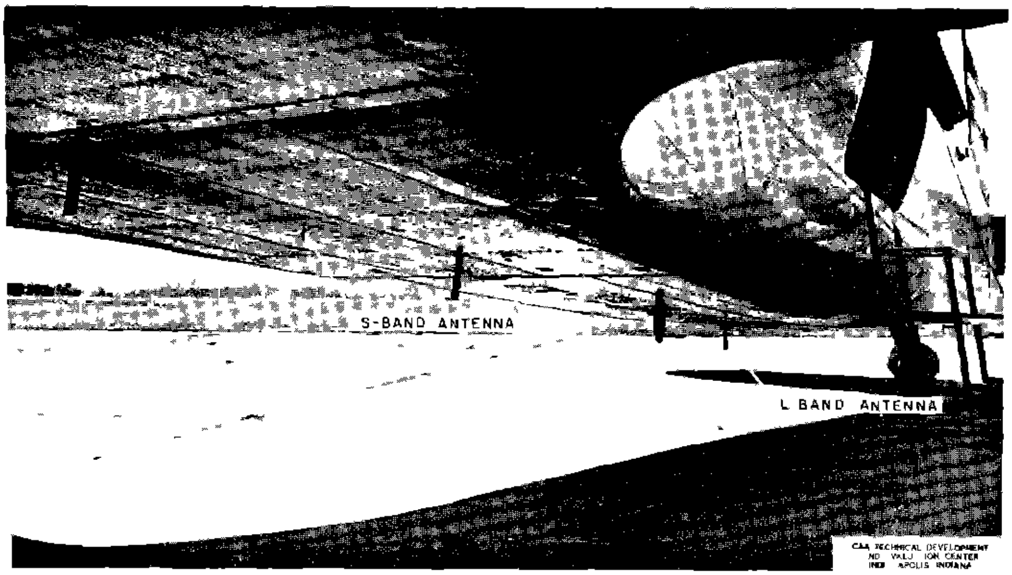

Fig 18 Installation of Rho/Theta Transponder S-Band and L-Band Antennas on Underside of DC-3 Type Aircraft

and Fig 18 shows the aircraft installation of the S-band and L-band antennas The 1 1/2-inch wooden block between the L-band antenna and the fuselage was removed when the test program was started

Several flights were made to determine interrogation and response characteristics Throughout this report, the transponder automatic sensitivity-control switch was in the ON position unless otherwise stated The aircraft was flown along the instrument-landing-system (ILS) approach path starting at a range of ten nautical miles During the first few flights it was found that transponder ASC was required to prevent interrogation by the PAR-1 antenna side lobes The position of the L-band antenna, which is used to receive the transponder replies, is fixed The horizontal and vertical beamwidths are such that the antenna accepts transponder replies from aircraft at any point in space which is scanned by the PAR-1 antennas Therefore, angular resolution is determined entirely by characteristics of the interrogation path, these characteristics including the pattern of the PAR-1 antennas and transponder interrogation sensitivity Display of transponder replies to side lobes when ASC was not used caused serious clutter on the PAR-1 indicator At times, it was impossible to determine the azimuth or elevation positions of the aircraft During one approach with the transponder ASC circuits inoperative, interrogation by one of the elevation-antenna side lobes started at seven miles Interrogation by other side lobes started as the approach was continued When the aircraft was two miles from the PAR-1, approximately 1 5 miles from touchdown, interrogation by side lobes of both the azimuth and elevation antennas was such that the target appeared as a solid line across the azimuth and elevation displays It was not possible to determine the azimuth or elevation positions of the aircraft, since the intensity of the side-lobe responses was equal to that of the main lobes Figures 19 and 20 are photographs of the PAR-1 ten-mile indicator and show the effect of side-lobe responses at ranges of approximately three miles and one mile Correction for transponder delay was intentionally omitted so that characteristics of PAR-1 targets and transponder replies could be observed simultaneously

Figures 21 and 22 are photographs of the PAR-1 ten-mile indicator and show targets at ranges of approximately nine and five nautical miles Figure 23 is a photograph of the PAR-1 three-mile indicator showing the appearance of the targets at 0 75 mile It should be noted that angular resolution of the transponder replies is generally equal to, or slightly better than,

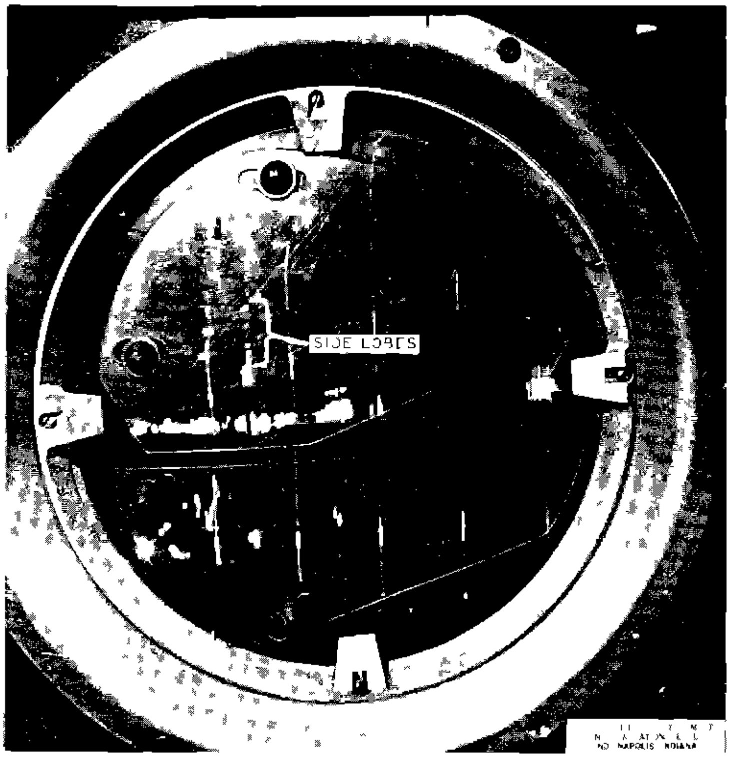

Fig 19 Photograph of PAR-1 10-Mile Indicator Showing Side-Lobe Responses at 3 Miles (ASC Off)

the PAR-1 resolution Range resolution is impaired because the width of the pulses from the transponder is approximately 1 microsecond, while the pulses transmitted by the PAR have a width of approximately 0 6 microsecond

During initial tests when the ASC was operative, there was no interrogation by azimuth-antenna side lobes Interrogation by one elevation-antenna side lobe started at three miles The transponder was interrogated by two side lobes at the range of approximately 1 1/2 miles and by three side lobes at one mile

Following the initial tests, the PAR-1 antennas were lubricated, the toggle points for the movable section of the waveguide in the elevation antenna were adjusted for plane-of-constant-phase conditions, and the patterns of both antennas were checked No adjustment of the azimuth-antenna toggle points was required The level of the strongest azimuth-antenna side lobe was 20 db less than the main lobe, and the strongest elevation-antenna side lobe was approximately 18 db weaker than the main lobe

It was found that the dynamic range of the transponder used during the initial tests was 5 db greater than normal when the input signal level was 1 milliwatt In this report, dynamic range is considered to be the ratio, expressed in decibels, of the level of the weakest signal that can interrogate the transponder to the level of the strongest signal received Replacement of V-202 amplifier tube Type 12AT7, used in the third- and fourth-video amplifier stages, increased video-amplifier gain and restored normal dynamic range The video-amplifier bias level developed by the ASC circuits depends upon the level of the strongest signal received The dynamic range must be large enough to permit interrogation by both PAR-1 antennas even though the signal levels from the antennas are not equal, and at the same time the range must be sufficiently small so that side lobes of neither antenna will cause interrogation These requirements must be met at all signal levels which are received by the aircraft at ranges between

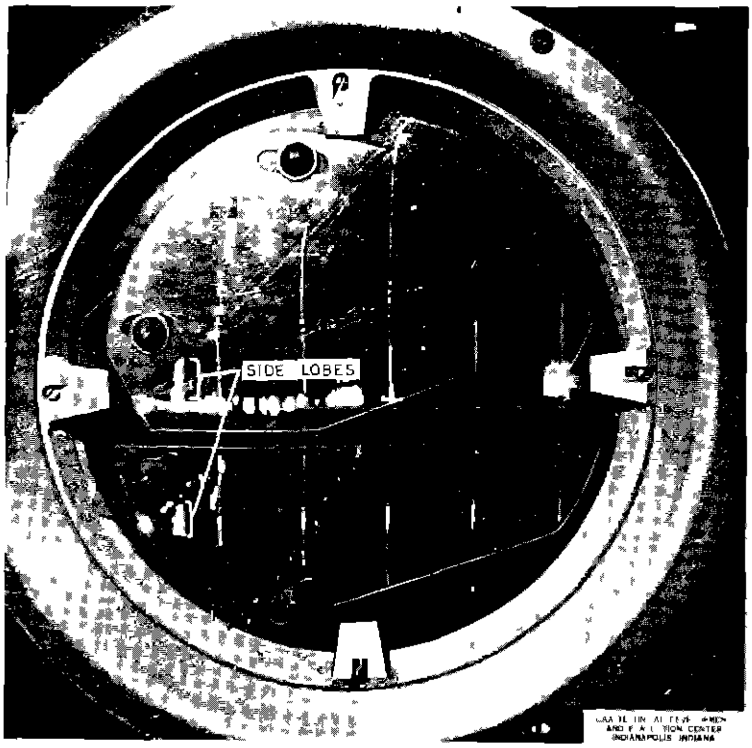

Fig. 20 Photograph of PAR-1 10-Mile Indicator Showing Side-Lobe Responses at 1 Mile (ASC Off)

ten miles and the touchdown point on the runway. Comparative signal-level measurements indicate that signals from the azimuth antenna are approximately 3.0 db stronger than those received from the elevation antenna.

Flight tests were made to check effects of PAR-1 elevation-antenna adjustments and of changing the video-amplifier tube in the transponder. These tests showed that the range at which side-lobe interrogations started was reduced from 3 to 1 1/2 miles. The bias level established by the ASC circuits varied from 3.5 volts d-c for no-signal conditions to 6.0 volts d-c when the aircraft was near the touchdown point. Two other transponders were flight-tested, and it was found that responses to elevation-antenna side lobes occurred at ranges less than 6 miles.

Investigation of the transponders to determine the reasons for side-lobe interrogations showed that the dynamic range was 20 db or more when the largest signal was 1 milliwatt. The signal level at the touchdown end of the runway was approximately 1 milliwatt. The manufacturer's data indicate that the largest signal levels used during type tests were -5.0 dbm. It was found that the dynamic range was effectively increased by amplitude compression in the video amplifiers. Amplitude compression prevented signals from the main lobe of the antenna from building up ASC bias levels sufficiently to prevent interrogation by side lobes.

Limiting in the second stage of the X-band preamplifier was more serious than that which occurred in the receiver-transmitter unit. With the co-operation of Westinghouse engineers, one preamplifier was modified to have only one stage of video amplification and a cathode-follower stage. The sensitivity loss due to the modification was 2.0 db, and the maximum dynamic range was reduced to approximately 10 db. The single-stage preamplifier was installed in TDEC aircraft N-183. Satisfactory interrogation by both PAR-1 antennas without side-lobe interrogation was obtained during three test flights and eight approaches which were made for demonstration purposes.

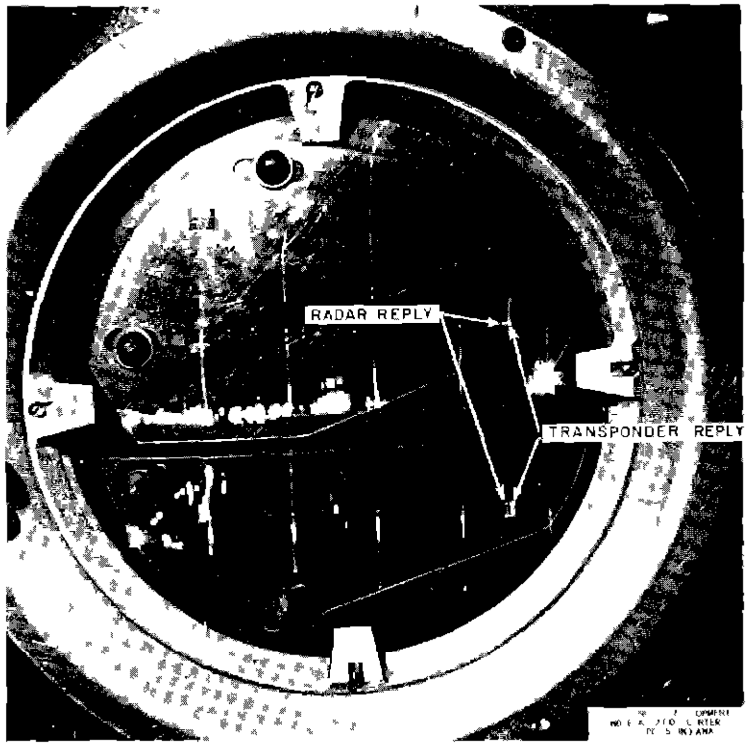

Fig 21 Photograph of PAR-1 10-Mile Indicator Showing Radar and Transponder Targets at 9 Miles (ASC On)

Reasonably satisfactory operation was obtained from the installation in aircraft N-181 during eight approaches An unmodified preamplifier was used in this aircraft, and there was no side-lobe interrogation Interrogation by the elevation antenna was not reliable for a few sweeps when the aircraft range was nine and ten miles from the PAR-1 Investigation showed that the 12AT7 vacuum tube used in the first and second stages of the preamplifier generated excessive noise of an irregular nature The effect of the noise was to reduce interrogation sensitivity, since the squitter control was adjusted during flight to limit triggering by noise to a rate of approximately two triggers per second

A new tube was installed in the preamplifier, and flight tests were made using the transmitter-receiver unit which operated satisfactorily with the single-stage preamplifier installed in aircraft N-183 Interrogation by the main lobes of both PAR-1 antennas was satisfactory during approaches starting from a maximum range of 10 nautical miles There was no interrogation by the azimuth-antenna side lobes Interrogation by elevation-antenna side lobes did not start until the aircraft was 1 75 miles from the PAR-1 during one approach and 1 6 miles from the PAR-1 on a second approach

Flights were made to determine the effect of aircraft attitude upon interrogation The single-stage preamplifier was used during these flights The aircraft was flown over a point nine miles from the PAR-1 on the extended centerline of the runway The transponder replies were observed on the PAR-1 ten-mile indicator, and transponder-triggering multivibrator action was recorded on a magnetic-tape recorder in the aircraft Table III summarizes the information obtained for various aircraft headings

The information in Table III indicates that the characteristics of the X-band antenna are such that satisfactory interrogation is obtained when the aircraft heading varies ±60° with respect to the extended centerline of the instrument runway This variation is much greater than the crab angles which are used during approaches Antenna-pattern curves supplied by

TABLE III

EFFECT OF AIRCRAFT HEADING UPON INTERROGATION BY PAR-1

Aircraft Heading Relative to Runway (degrees)	Observations of PAR-1 Indicator	Information From Tape Recording
0 (toward PAR-1)	Satisfactory Targets	Reliable Interrogations
-15	Satisfactory Targets	Reliable Interrogations
+15	Satisfactory Targets	Reliable Interrogations
-30	Satisfactory Targets	Reliable Interrogations
+30	Satisfactory Targets	Reliable Interrogations
-45	Satisfactory Targets	Reliable Interrogations
+45	Satisfactory Targets	Reliable Interrogations
-60	Satisfactory Targets	Reliable Interrogations
+60	Satisfactory Targets	Reliable Interrogations
-75	Satisfactory Targets	Reliable Interrogations
+75	Satisfactory Target on Elevation Display None on Azimuth Display	Interrogation by Elevation Antenna Only
-90	Satisfactory Targets	Satisfactory Interrogations
+90	Satisfactory Target on Elevation Display None on Azimuth Display	Interrogation by Elevation Antenna Only

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the contractor indicate that the horizontal half-power beamwidth is 90° for horizontal polarization and 100° for vertical polarization at the frequency of 9090 Mc For 120° beamwidth, the response is 9 0 db down for horizontal polarization

In order to check the effects of banking, the aircraft was rolled ±15° and 30° over the point at the same heading as the instrument runway and at headings ±30° with respect to the runway No adverse effects upon transponder interrogation or upon the replies observed on the PAR-1 indicator were noted

To test for the effects of aircraft pitch, the aircraft was flown over the point in both climbing and descending attitudes at angles of approximately 8 0° with respect to the horizon No adverse effect upon transponder replies or upon interrogation were noted Adverse effects upon interrogation were not anticipated because antenna patterns supplied by the contractor indicate vertical half-power beamwidths of 48° for vertical polarization and 55° for horizontal polarization at the frequency of 9090 Mc

The display of side-lobe replies only on either the elevation or azimuth display could cause confusion regarding aircraft position The PAR-1 azimuth antenna can be servoed (or positioned) so that the vertical position of the main lobe can be varied from -1° to +6° with respect to the horizon The elevation antenna can be servoed so that the horizontal position of the main lobe can be varied from +5° to -15° with respect to the bearing of the runway The

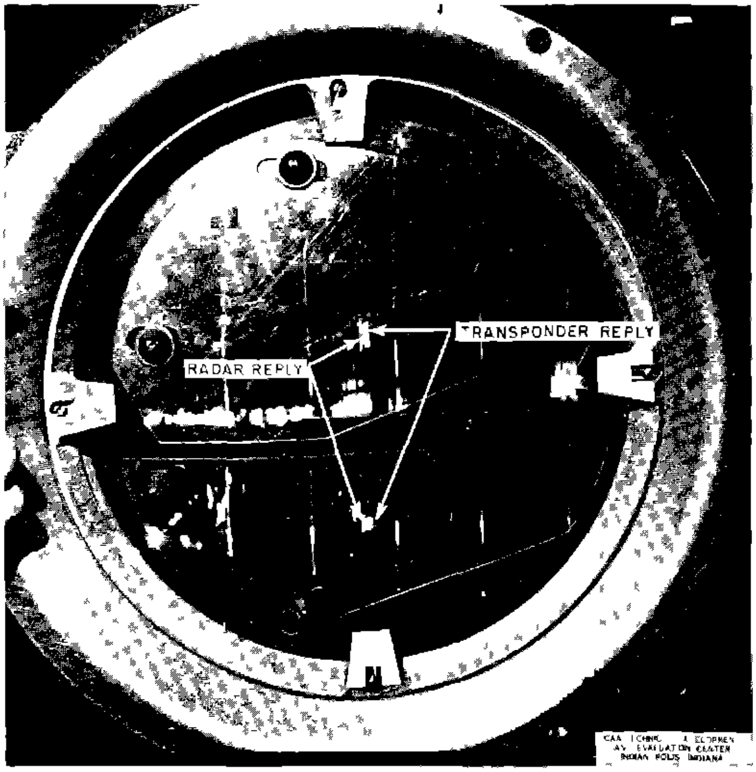


Fig 22 Photograph of PAR-1 10-Mile Indicator Showing Radar and Transponder Targets at 5 Miles (ASC On)

azimuth antenna scans horizontally between the angles of +5° and -15°, and the elevation antenna scans vertically between the angles of -1° and +6° If the aircraft position is slightly above or to one side of the sector of space scanned by the main lobes, it is possible that the transponder will be interrogated only by the side lobes of one or of both PAR-1 antennas Signals from the main lobes of the antennas will not establish ASC bias voltage to prevent side-lobe interrogation, because the aircraft is outside of the sector of space scanned by the main lobes The angular position of side-lobe replies displayed on the PAR-1 indicators is the same as the position of the main lobe at that particular instant Inasmuch as there is angular displacement between the main and side lobes of the PAR-1 antenna, the angular position of the displayed targets is incorrect

Flights were made to determine the possibility that the transponder would reply to PAR-1 antenna side lobes only and to determine that such replies would be displayed on the PAR-I indicators The PAR-1 antennas were servoed along the ILS flight path The aircraft was flown along the localizer on-course path at constant altitudes of 500, 1000, 2000, 4000, and 6000 feet During the passes at altitudes of 500 and 1000 feet, transponder replies to side lobes were not visible on the indicators and normal operation was obtained when the aircraft flew through the main lobes of the antennas. During the pass at 2000 feet, the transponder replied to an azimuth-antenna side lobe above the main lobe at ranges between 2 miles and 3/4 mile The replies did not cause confusion because the angular position on the azimuth display was correct When the aircraft was at 4000 feet, replies to azimuth-antenna side lobes were displayed intermittently at ranges between 4 and 2 miles These replies also were displayed correctly During the pass at 4000 feet, elevation-antenna side-lobe responses were also displayed at the range of 3 miles The replies appeared approximately 1/2 inch below and to the right of the top edge of the elevation display and moved upwards and to the observer's left as the aircraft approached the PAR-1 These replies were not displayed at the correct position

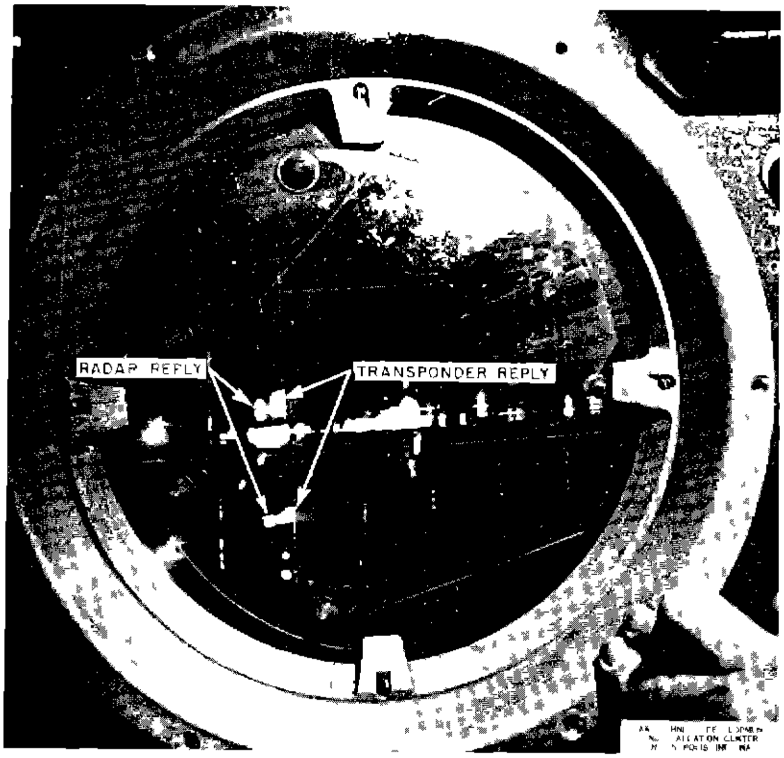


Fig 23 Photograph of PAR-1 3-Mile Indicator Showing Radar and Transponder Targets at 0 75 Mile (ASC On)

No side-lobe responses were displayed during the pass at the altitude of 6000 feet The false targets on the elevation display during the pass at 4000 feet are not considered to be serious from an operational standpoint

After the passes were completed, the aircraft was flown at constant altitudes of 500, 1000, 2000, 4000, and 6000 feet, at right angles to the ILS approach path, and at a range of 8 miles An X-band antenna-and-preamplifier assembly was held at a window in the aircraft and was directed at the PAR-1 to simulate aircraft starting approaches at various azimuths and altitudes Distances flown along the normal path were sufficient to allow interrogation by azimuth-antenna side lobes which scan space outside of the sector scanned by the main lobe No false targets were observed The flights perpendicular to the runway centerline were repeated at altitudes of 500, 1000, and 1800 feet at the range of four instead of eight miles, and no false targets or display of side-lobe interrogations were observed

Tests were made to determine interrogation range The aircraft was flown toward the PAR-1 along the ILS flight path A few interrogations by one antenna were obtained at 67 and again at 63 statute miles Interrogations were monitored by an observer in the aircraft using headphones which were plugged into the interrogation monitoring jack in the receiver-transmitter unit At approximately 50 miles, both PAR-1 antennas partially interrogated the transponder, and distinct second-time-around responses were observed on the PAR-1 indicators at 3 miles The responsor STC was not used during this test Use of STC should have prevented the display of second-time-around targets at this range. Reliable interrogation by both antennas was obtained for ranges less than 40 miles

Measurements indicate that the gain of the X-band antenna is approximately 6 db compared to that of an isotropic radiator Measurements of the PAR-1 transmitter indicated a peak power output of +42 dbw (+72 dbm) at a frequency of 9040 Mc The gain of the elevation antenna, corrected for system losses, is 37 2 db The over-all gain of the interrogation link is

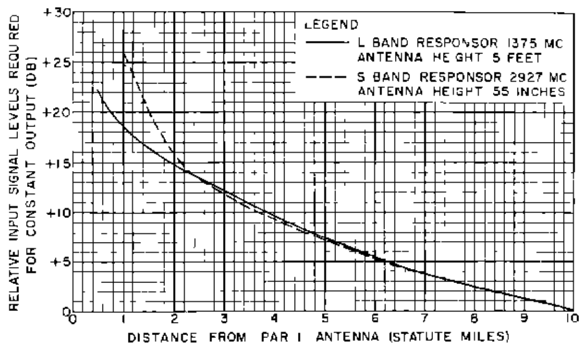


Fig 24 STC Characteristics of Responsors Used at PAR-1 Site

43 2 db The one-way space loss or path attenuation expressed in decibels is equal to 37 + 20 log f + 20 log d, where f is the frequency in megacycles and d represents distance expressed in statute miles Substitution of 9040 Mc and 40 miles in this formula results in path attenuation of 148 2 db Addition of transmitter power, system gain, and path attenuation results in a signal level of -33 dbm at the X-band preamplifier detector Calculated signal levels are -35 dbm at 50 miles and -37 5 dbm at 67 miles

Since the maximum interrogation range was less than that calculated on the basis that interrogation sensitivity during flight should be approximately -40 dbm, the X-band preamplifier and the receiver-transmitter unit were removed from the aircraft for bench tests The measured interrogation sensitivity was -37 dbm The installation of a new IN31 crystal in the preamplifier increased the sensitivity to -44 dbm The calculated range based upon an interrogation sensitivity of -44 dbm is approximately 143 miles, if it is assumed that there are

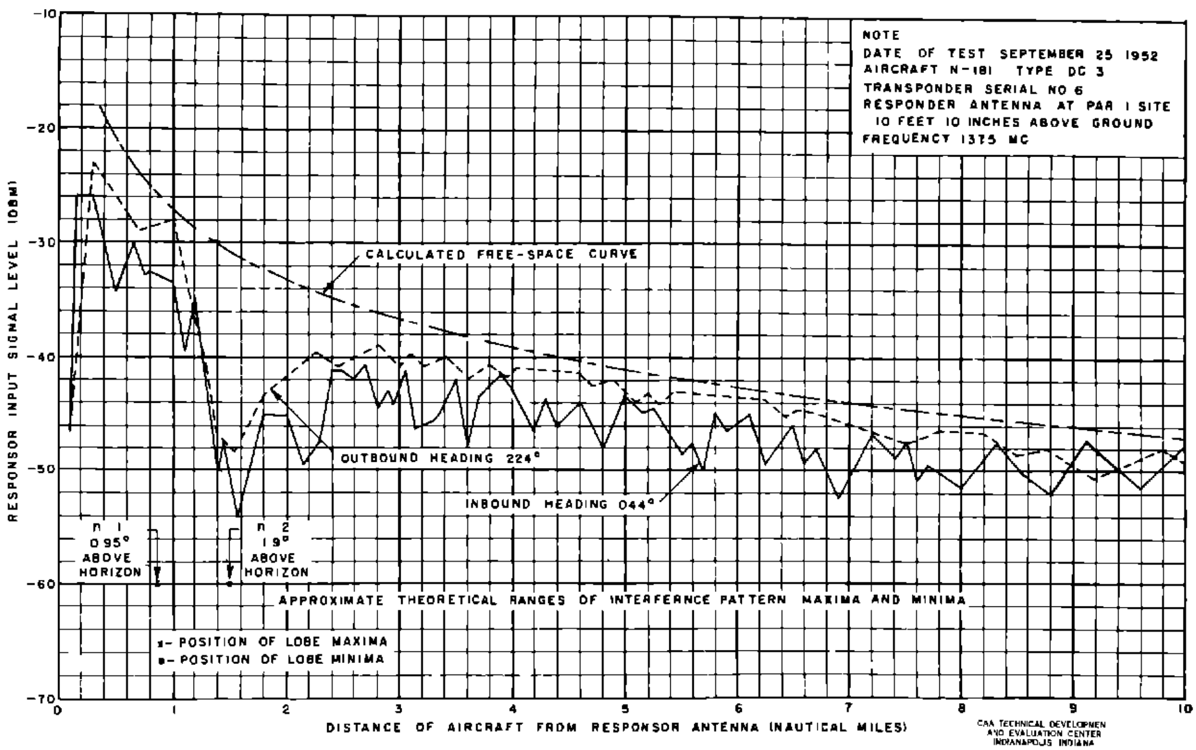


Fig 25 Levels of L-Band Reply Signals From Aircraft Flown Along ILS Flight Path

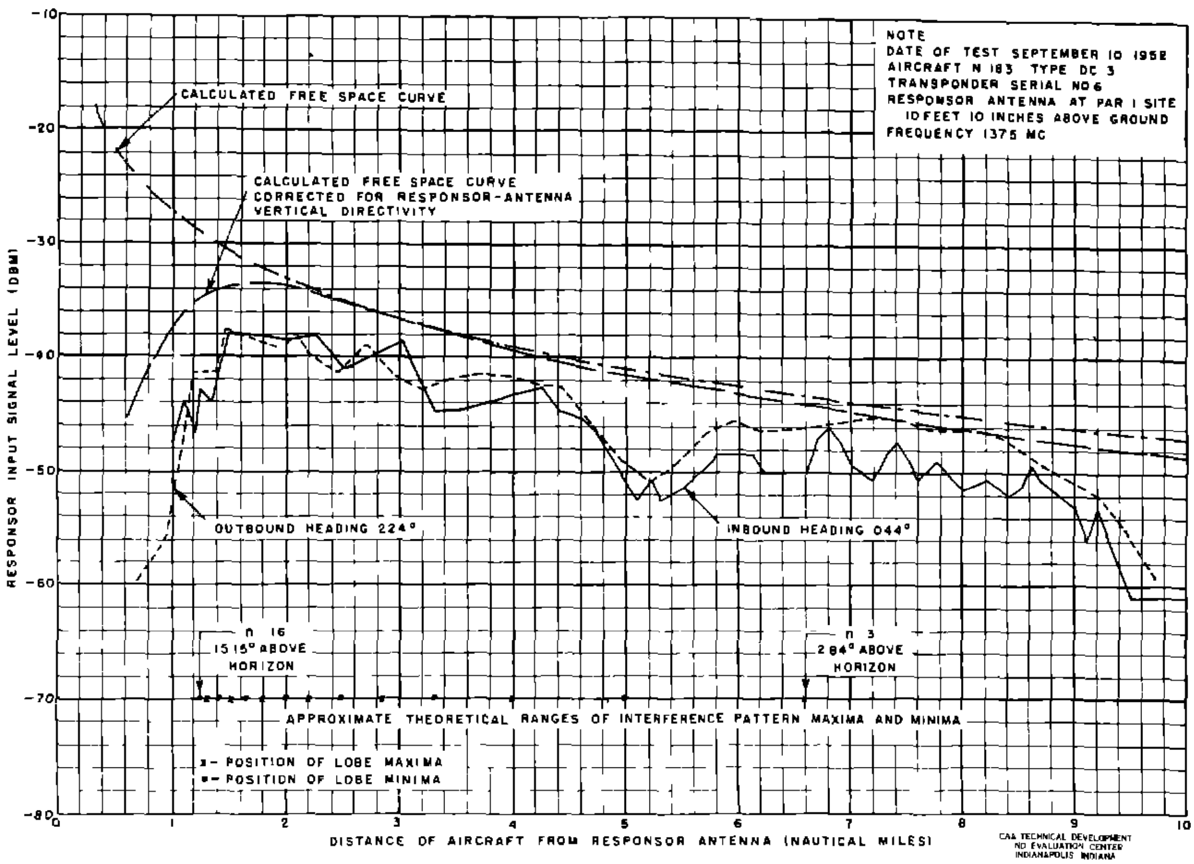


Fig 26 Levels of L-Band Reply Signals From Aircraft Flown at Constant Altitude of 2000 Feet Above Ground

line-of-sight and free-space propagation conditions and that there is no deterioration of sensitivity by r-f noise in the aircraft Also, under these conditions the interrogation range will be reduced to 10 statute miles if interrogation sensitivity, PAR-1 transmitter power, propagation conditions, or other factors affecting the interrogation link degrade interrogation characteristics by 23 0 db

The maximum range of the response link (the aircraft transponder to the L-band responsor at the PAR-1 transmitter-receiver building) during flight away from the PAR-1 was 148 statute miles at an altitude of 10,000 feet above ground This range approximates line-of-sight distance The signal received by the responsor faded very rapidly beyond 146 miles During inbound flight, the signal was first detected at 134 miles and was usable when the aircraft was 131 miles from the responsor antenna The difference in maximum ranges for the outbound and inbound flights is attributed to the horizontal pattern of the L-band antenna as installed on the aircraft The location of this antenna is shown in Fig. 18 During the tests, the transponder was triggered at the rate of 2000 pps by an audio-signal generator in the aircraft The output of the L-band responsor was observed on an oscilloscope having internally synchronized sweeps

The peak power output of the transponder after completion of the response-path range tests was 450 watts or 26 5 dbw The gain of the responsor antenna was 21 6 db, and sensitivity measurements of the responsor indicated that the minimum discernible signal strength was -85 dbm Loss in the transmission line between the antenna and the responsor was estimated at 2 0 db, and loss in the transmission line in the aircraft was estimated to be 3 0 db Display

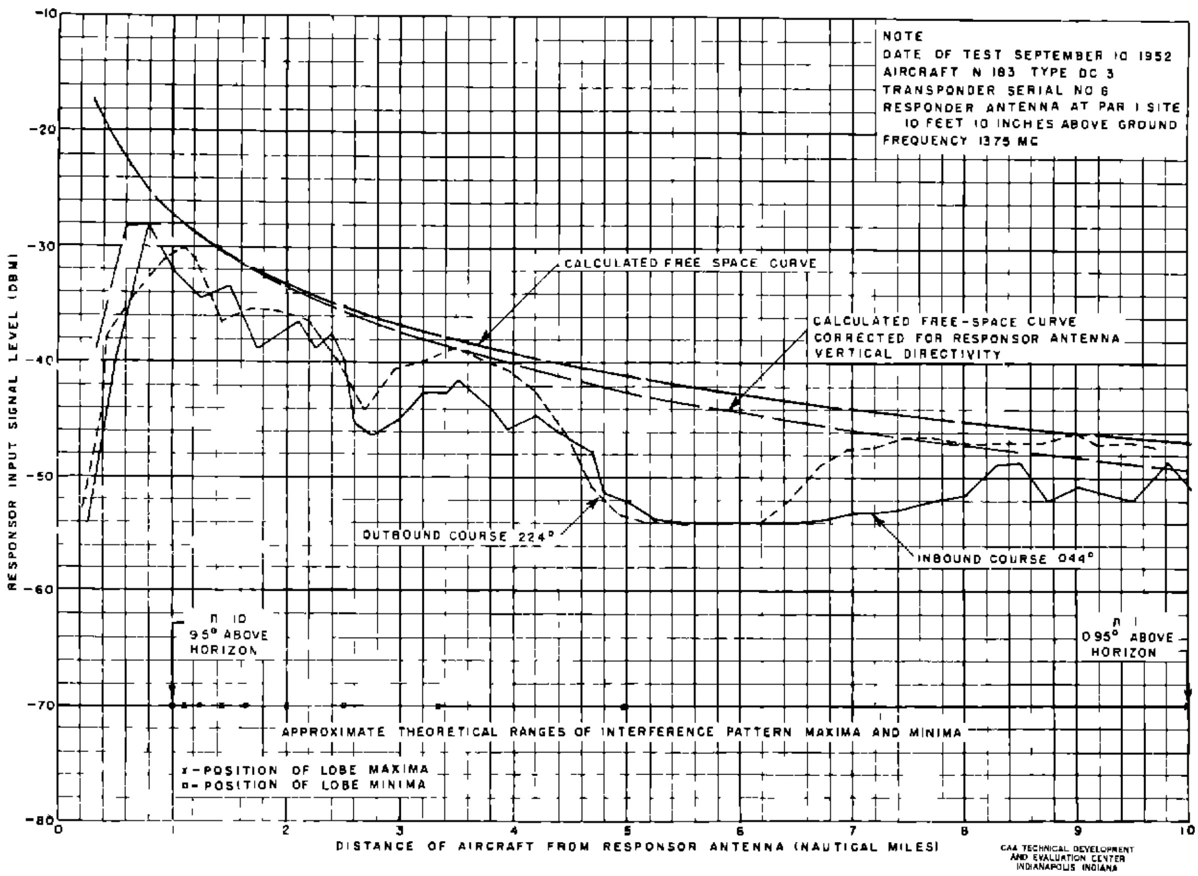


Fig 27 Levels of L-Band Reply Signals From Aircraft Flown at Constant Altitude of 1000 Feet Above Ground

losses of the PAR-1, calculated on the basis outlined by Bailey[1], are 7 5 db for the elevation display and 8 5 db for the azimuth display If it is assumed that the gain of the L-band antenna on the aircraft is 4 0 db, the maximum range for discernible signal on the PAR-1 indicator is 551 miles for the elevation display and 491 miles for the azimuth display A loss of approximately 34 db in the response path would reduce the range to 10 miles Such a loss could be caused by a reduction in transmitted power, the deterioration of propagation conditions due to precipitation, the presence of deep interference-pattern minima in the responsor-antenna vertical pattern, adverse aircraft attitudes, the deterioration of responsor sensitivity, and other factors

From measured and calculated interrogation- and response-path ranges, it is evident that both paths have gains sufficient to allow satisfactory operation even though considerable loss is introduced It is also known that the display of second-time-around responses can be obtained during flight

The interrogation link limits the maximum range of the system to 143 statute miles based on a peak power of 42 dbw for the TDEC PAR-1 transmitter The peak power of other PAR-1 transmitters may be somewhat greater, possibly 44 5 dbw An increase in power from 42 to 44 5 dbw would increase the maximum range to 191 miles Inasmuch as the maximum range of

[1] H H Bailey, "Range Requirements," Sec 2 6 of "Radar Beacons," edited by Arthur Roberts, Radiation Laboratory Series, Vol 3, 1947

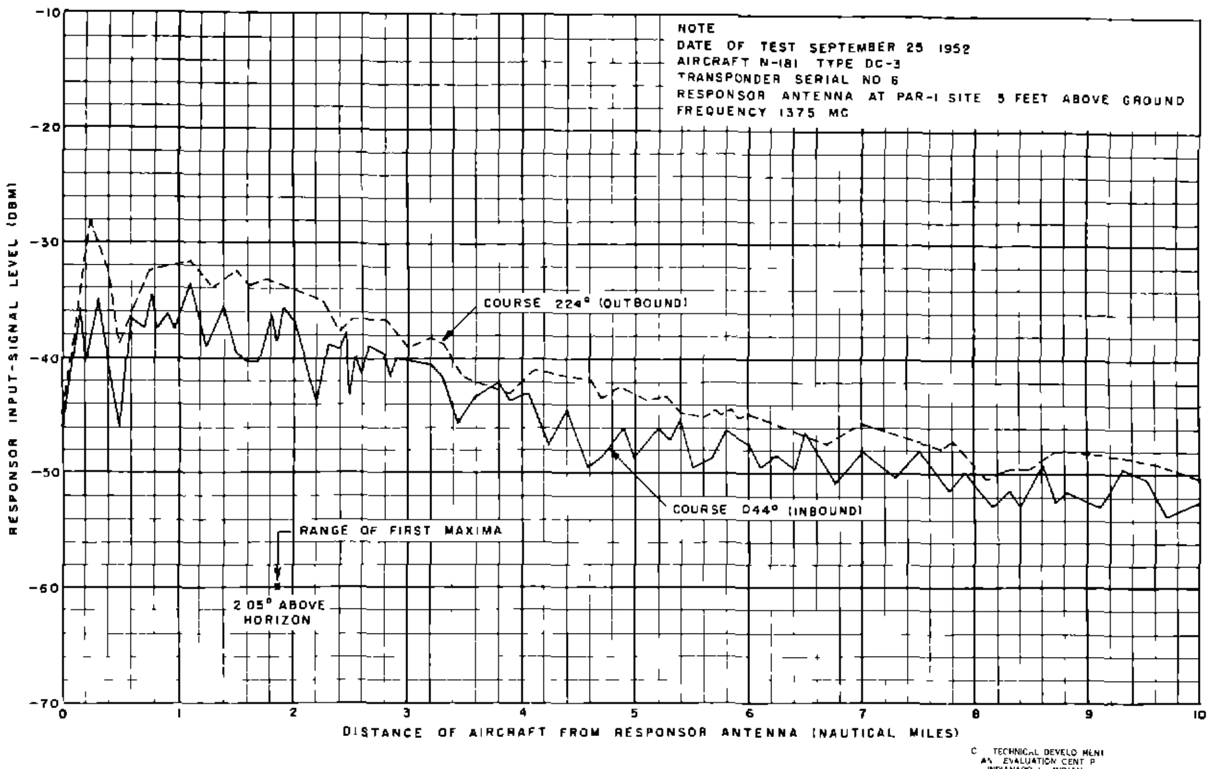


Fig 28 Levels of L-Band Reply Signals From Aircraft Flown Along ILS Flight Path

the PAR-1 indicator is 10 miles, transponder replies from aircraft between 10 and 46 5 miles from the PAR-1 will not be displayed because of indicator dead time if a pulse repetition frequency of 2000 pps is assumed Replies from aircraft at ranges between 46 5 to 56 5 miles, 93 to 103 miles, 139 5 to 149 5 miles, and 186 to 196 miles could be displayed as second-, third-, fourth-, and fifth-time-around replies, respectively Interrogation and display of replies from aircraft at all these ranges is not probable, because the aircraft altitude must be sufficient for line-of-sight propagation conditions, maximum transponder-interrogation sensitivity conditions must exist, a maximum usable responsor gain is required with the STC circuits inoperative, and the aircraft must be flown in the general direction of the PAR-1 The use of the responsor STC and manual gain controls reduces the possibility of display of n-times-around responses, particularly at indicator ranges between 0 and approximately 4 miles, because responsor gain should be controlled to prevent overloading and excessive pulse-stretching when aircraft are close to the PAR-1 The responsor gain should be sufficient to allow the display of transponder replies which are weaker than normally expected and to allow for variations in transponder transmitter power, in aircraft attitude, and in propagation conditions If an allowance of 13 db is made for such variations under actual operating conditions, then the maximum response range under normal conditions is increased from 10 to 45 miles and n-times-around replies will not be visible It is believed that the display of the undesired responses could be prevented most of the time in actual operation Also, from an operational standpoint it is not probable that such responses would be displayed, because the transponder would be used in conjunction with ASR instead of with PAR equipment when the aircraft is more than 10 miles from the PAR

Figure 24 is the STC curve which was used during the tests Data used in setting up the STC curve were obtained from continuous recordings of signal levels received from an aircraft making an ILS approach The airborne transponder was triggered by an audio oscillator A peak-reading, a-c, vacuum-tube voltmeter (RCA Model WV-97A Senior Voltohmyst) was connected to the responsor second detector, and the d-c voltage developed across the meter and the vacuum-tube voltmeter (VTVM) was amplified by a Microsen d-c amplifier and was then

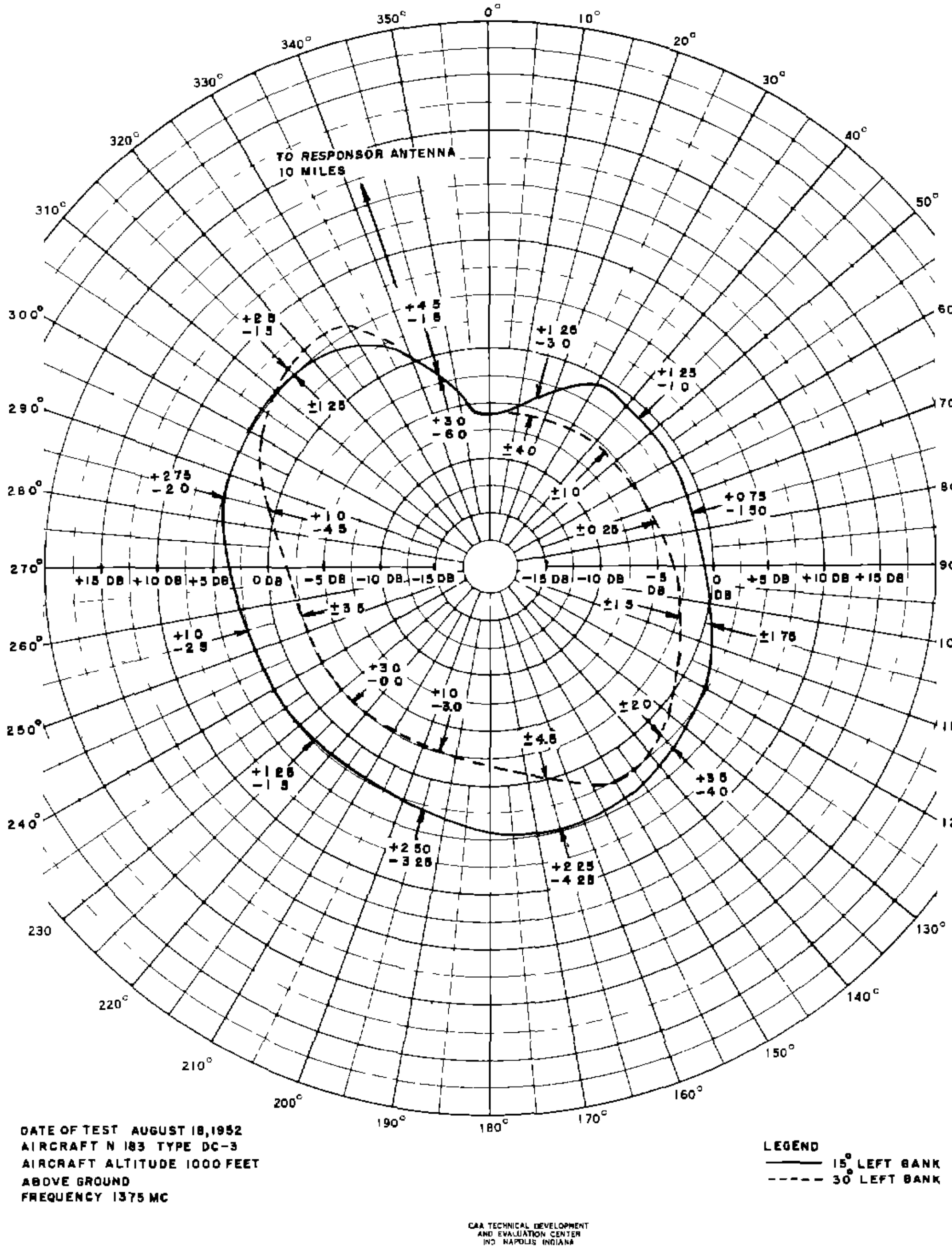


Fig 29 Effect of Aircraft Heading and Bank Upon Level of Transponder Replies Received by Responsor

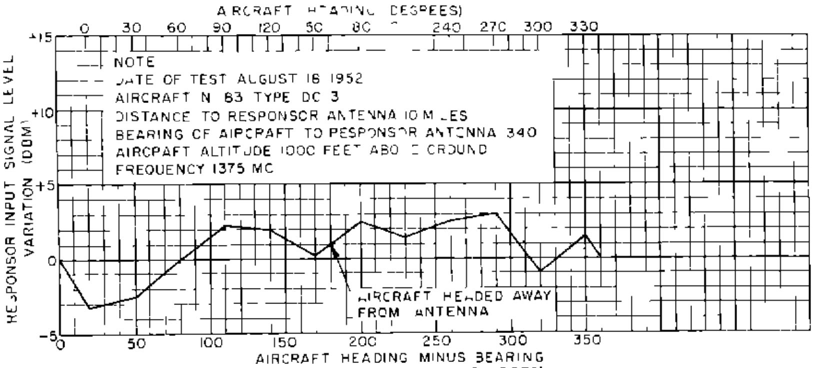


Fig 30 Variation of Transponder Reply-Signal Levels With Aircraft Heading

applied to an Esterline-Angus recorder The trace on the recording was calibrated by means of an L-band signal generator connected to the responsor r-f input circuit The r-f input level to the responsor was varied in steps of 1 or 2 dbm, and the resulting recorder deflections were identified It was necessary to connect a 10,000-ohm resistor in parallel with resistor R-240 in the responsor to obtain the desired curve shape at the smaller ranges

During initial tests it was noted that the transponder replies faded appreciably at the range of 1 5 miles Figure 25 shows a minimum in responsor input-signal level at 1 5 miles due to interference between signals of direct radiation and signals which are reflected from the ground The height of the responsor antenna was 10 feet 10 inches above ground, and the feed-horn and reflector assembly was tilted upward so that the lower half-power point of the main

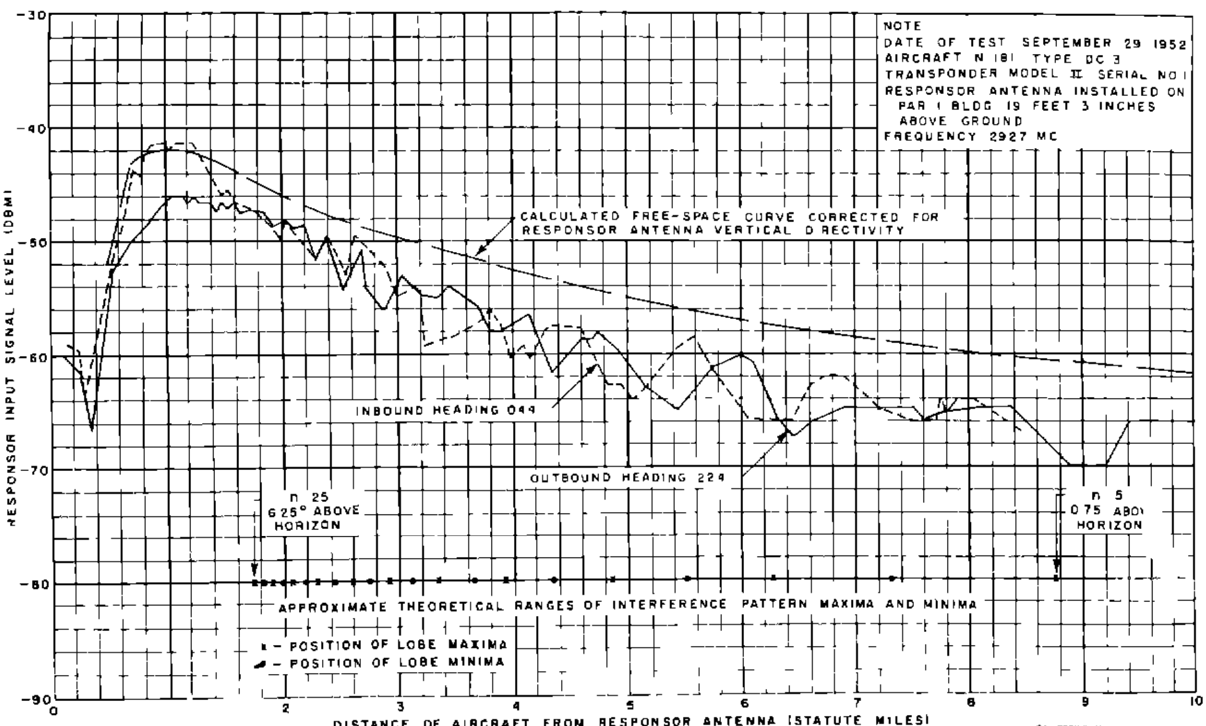


Fig 31 Levels of S-Band Reply Signals From Aircraft Flown at Constant Altitude of 1000 Feet Above Ground

lobe was directed along the horizon Figure 25 was plotted from data obtained by the method used to obtain the STC data The free-space curve was calculated on the basis that the transponder power is +24 dbw, the responsor-antenna gain is 21 6 db, the aircraft-antenna gain is 4 0 db, the combined ground-and-airborne transmission-line losses are 5 0 db, and there is a 1 0-db loss of responsor-antenna gain due to vertical directivity of the antenna The ILS glide-slope vertical angle was 2 75° and was 3 25° below the nose of the main lobe Approximate theoretical locations of interference-pattern maxima and minima are indicated at 0 83 and 1 5 miles Approximate positions of the interference-pattern maxima and minima were calculated from the formula

$$\theta = \frac{n\,\lambda}{4\,h}$$

Where

θ = vertical angle of the lobe maxima, in radians when n is an integral odd number

θ = the angle of the lobe minima when n is an even number

λ = wavelength

h = antenna height

This formula is accurate for small angles only It was assumed that the phase shift during reflection of the waves is 180° During all flight tests it was noted that signal levels recorded during outbound flights were greater than those recorded during inbound flights Also, variations of signal levels were less during outbound flights Data obtained when aircraft N-183 was used were similar to those obtained during N-181 flight tests

Figures 26 and 27 show responsor input-signal levels obtained when the aircraft was flown at constant altitudes of 2000 and 1000 feet above ground along the ILS localizer on-course path Otherwise, test conditions were the same as for Fig 25

In order to prevent fading of the transponder replies when the aircraft was 1 5 miles from the responsor antenna, the antenna height was reduced from 10 feet 10 inches to 5 feet above ground The change of height prevented formation of interference-pattern minima at any points along the ILS glide slope having a range greater than the ILS touchdown point Signal levels recorded during a flight along the ILS flight path are shown in Fig 28 The only minimum along the path occurs at the range of 0 5 mile, which is near the touchdown point Transponder replies observed on the PAR-1 indicators were satisfactory at all ranges when the responsor STC curve shown in Fig 24 was used

Tests were made to determine the effect of aircraft-attitude variations upon the level of transponder replies at the responsor input receptacle The transponder was triggered by an audio-signal generator, and the level of the signals was recorded by means of the peak-reading, vacuum-tube voltmeter, the Microsen d-c amplifier, and the Esterline-Angus recorder used previously The aircraft was flown over a point ten miles from an omnidirectional responsor antenna The antenna height was ten feet above ground, and the maximum of the first lobe was centered at ten miles at 1000 feet The aircraft was flown at an altitude of 1000 feet Figure 29 indicates variations that occurred in the signal levels when the aircraft was flown in circles around the point at 15° and 30° bank angles The lines indicate average signal levels, and the plus and minus numbers indicate random variations from average levels as the heading varied from 0° to 330°, 330° to 300°, and so forth Average signal levels varied approximately ±6 db Maximum random variation from average levels were +4 5 and -4 25 db for 15° bank and -6 0 and +4 5 db for 30° bank This data may or may not be typical of signal variations that would be encountered in day-to-day operation However, such variations are possible, and should be considered

Variations in signal level at the responsor-input receptacle which are due to heading variations alone are shown in Fig 30 The aircraft was flown over the point as previously described and in straight-and-level flight at headings of 0°, 30°, 60°, and so forth Signal-level variations due to variations of aircraft heading were approximately ±3 0 db The strongest signals were obtained when the aircraft was flying away from or at right angles to the responsor antenna The weakest signals were recorded when the aircraft was headed towards the responsor antenna Table IV shows the effect of aircraft pitch upon the level of the transponder replies at the responsor

TABLE IV

EFFECT OF AIRCRAFT PITCH UPON RESPONSOR-INPUT SIGNAL

Aircraft Heading	Responsor-Input Signal-Level Variation For 8° Climb (db)	Responsor-Input Signal-Level Variation For 8° Descent (db)
Inbound	0 Reference	-8 5
Outbound	-0 7	+2 5

Evaluation of S-Band Reply Transponder in Conjunction With PAR-1

Tests were made using the PAR-1 for interrogation and a fixed S-band antenna installed at the PAR-1 transmitter-receiver building to receive the transponder replies Figures 17 and 18 show the installation of the transponder X-band and S-band antennas on an aircraft S-band reply transponders are referred to as Mod II transponders, because they were obtained under the second modification of the contract

Several flights were made to determine interrogation and response characteristics Throughout the following discussions it should be assumed that the transponder switch was in the ON position unless it is stated that the ASC circuits were inoperative No interrogation by PAR-1 antenna side lobes was observed during approaches along the ILS flight path In S-band reply transponders, or Mod II transponders, improved control of side-lobe interrogation is obtained by application of ASC bias voltage developed in the receiver-transmitter unit to the video-amplifier stage in the X-band preamplifier The bias voltage reduces the possibility that amplitudes of signals will be compressed when the aircraft is near the PAR-1 The appearance of Mod II transponder replies on the PAR-1 indicator is similar to that of L-band transponder replies shown in Figs 19 to 23, inclusive

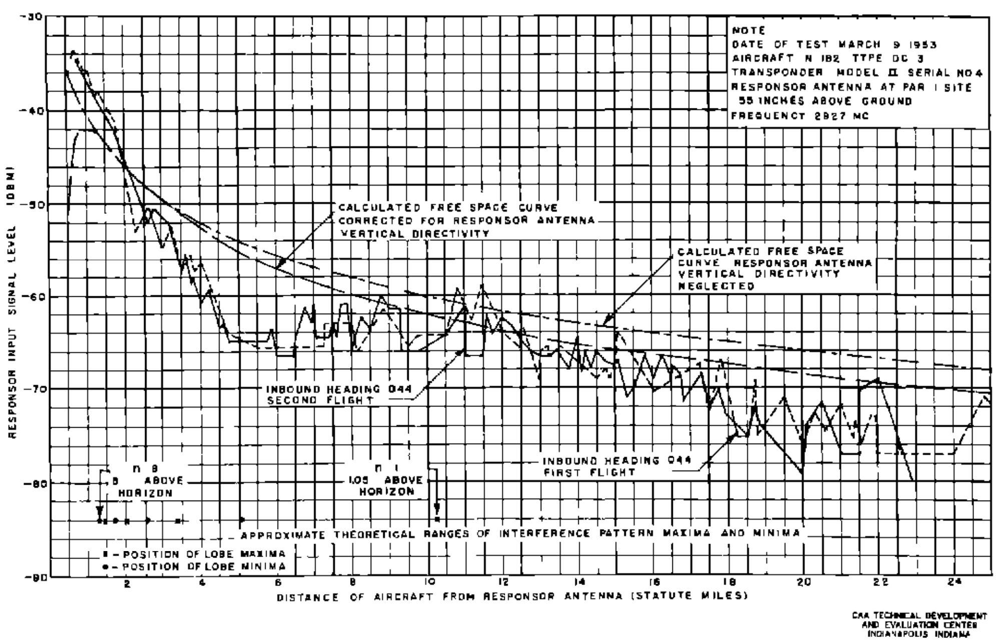


Fig 32 Levels of S-Band Reply Signals From Aircraft Flown at Constant Altitude of 1000 Feet Above Ground

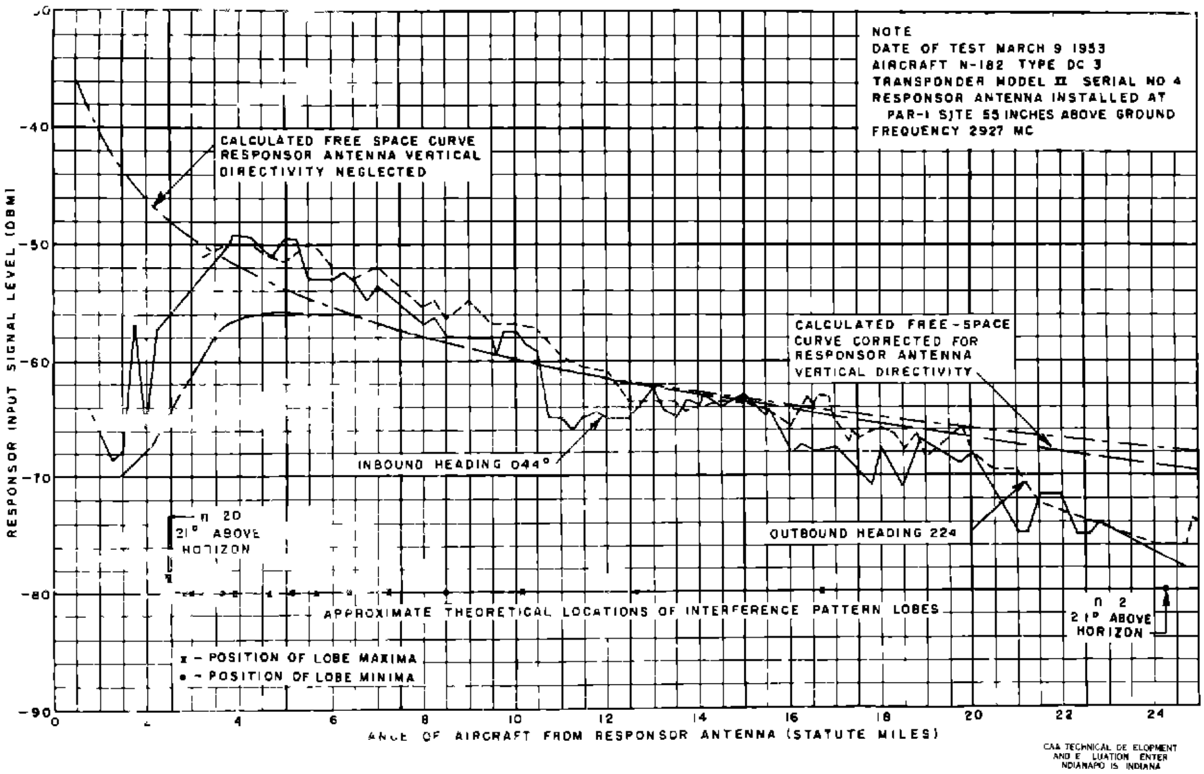
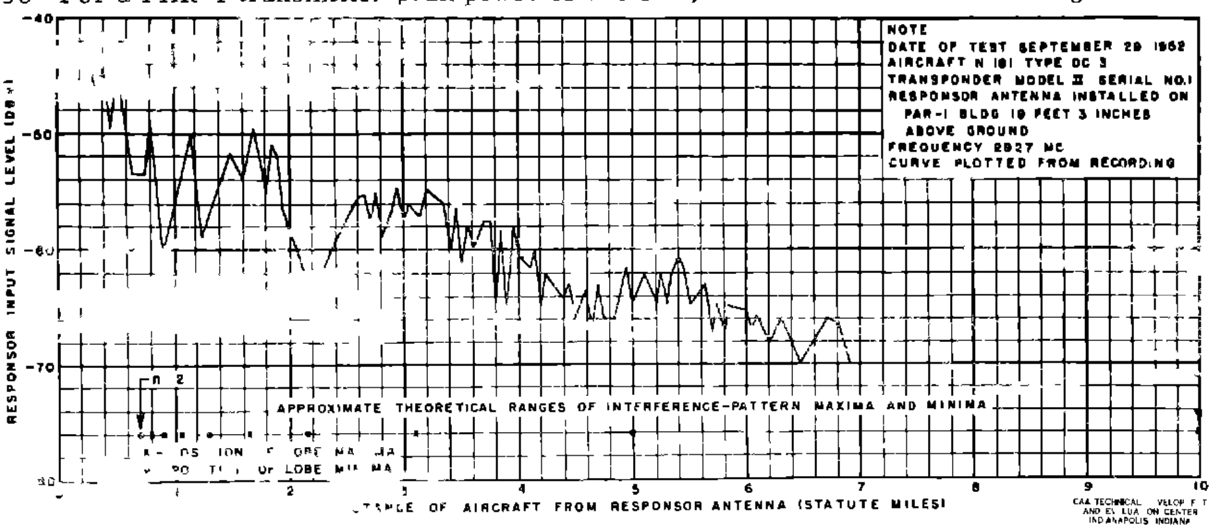


Fig 33 L els ? Ba R ly Signals From Aircraft Flown at Constant Altitude of 5000 Feet Above G und

X-band interrogation sensitivity of the Mod II transponder is approximately -70 dbw and is approximately 4 0 db less than that of the L-band reply transponder Theoretically, the decrease in sensitivity decreases the maximum interrogation range by a factor of approximately 1 58 For a PAR-1 transmitter peak power of +72 dbm, a corrected PAR-1 antenna gain of



Reply Signals From Aircraft Flown Along ILS Flight Path

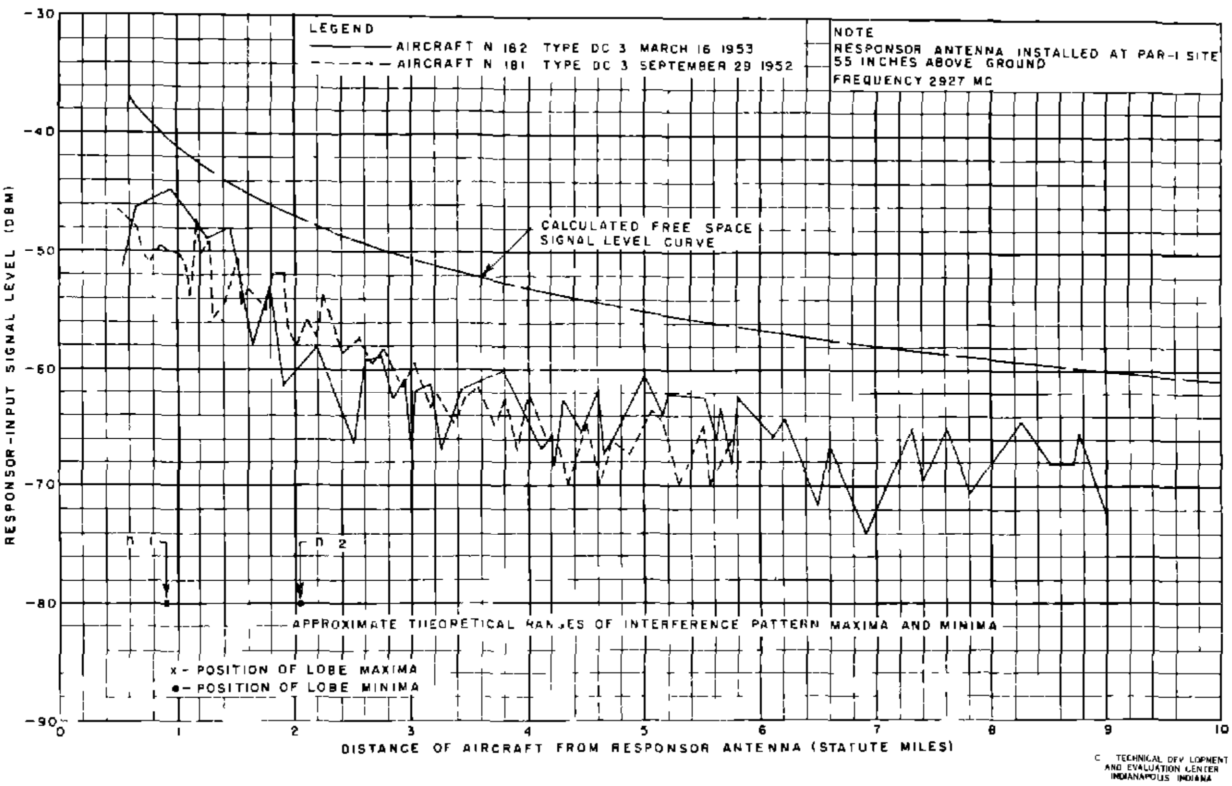


Fig 35 Levels of S-Band Reply Signals From Aircraft Flown Along ILS Flight Path

37 2 dbm, and a transponder X-band antenna gain of 6 db, the maximum calculated interrogation range is approximately 90 miles Degradation of interrogation-link characteristics of 19 0 db would decrease the maximum range to 10 statute miles

The maximum calculated response range is 79 miles, based on a measured transponder peak power of +55.7 dbm, a responsor-antenna gain of 18 6 db, an assumed aircraft-antenna gain of 2 0 db, a measured aircraft-transmission-line loss of 4 0 db, a responsor-to-antenna transmission-line loss of 4 5 db, a responsor minimum-discernible-signal sensitivity of -85 dbm, and a display loss of 8 5 db Degradation of 18 db of the response-link characteristics would decrease the maximum range to 10 statute miles

Figures 31 and 32 show responsor-input signal levels which were recorded when the aircraft was flown along the ILS localizer course at a constant altitude of 1000 feet above ground Data for Figs 31 and 32 were obtained when the responsor-antenna heights were 19 feet 3 inches and 55 inches, respectively The calculated free-space curves were plotted to indicate anticipated signal levels on the basis that no energy is reflected from the ground The methods and equipment used to record signal levels were the same as those used to obtain L-band response-path data Data obtained during a flight at 5000 feet are plotted in Fig 33

Response-path signal levels recorded during ILS flight-path approaches are plotted in Figs 34 and 35 The responsor-antenna heights were 19 feet 3 inches and 55 inches, respectively Average signal-level curves in each are approximately 10 db lower than curves plotted from calculations It is believed that the discrepancy in average levels is due primarily to the angle of aircraft pitch Results from tests made while using two different aircraft were similar

Table V lists signal levels which were recorded as the aircraft descended and ascended at 8° angles over a point 9 8 miles from the responsor antenna As seen in Table V, the total variation in signal level due to variation in pitch may be as much as 6 5 db

Figures 36 and 37 indicate variations in the response-path signal level when the aircraft was flown in circles around a point at 15°- and 30°-bank angles at altitudes of 1000 and 5000 feet above ground The point was 9 8 miles from the responsor antenna The lines of the graph

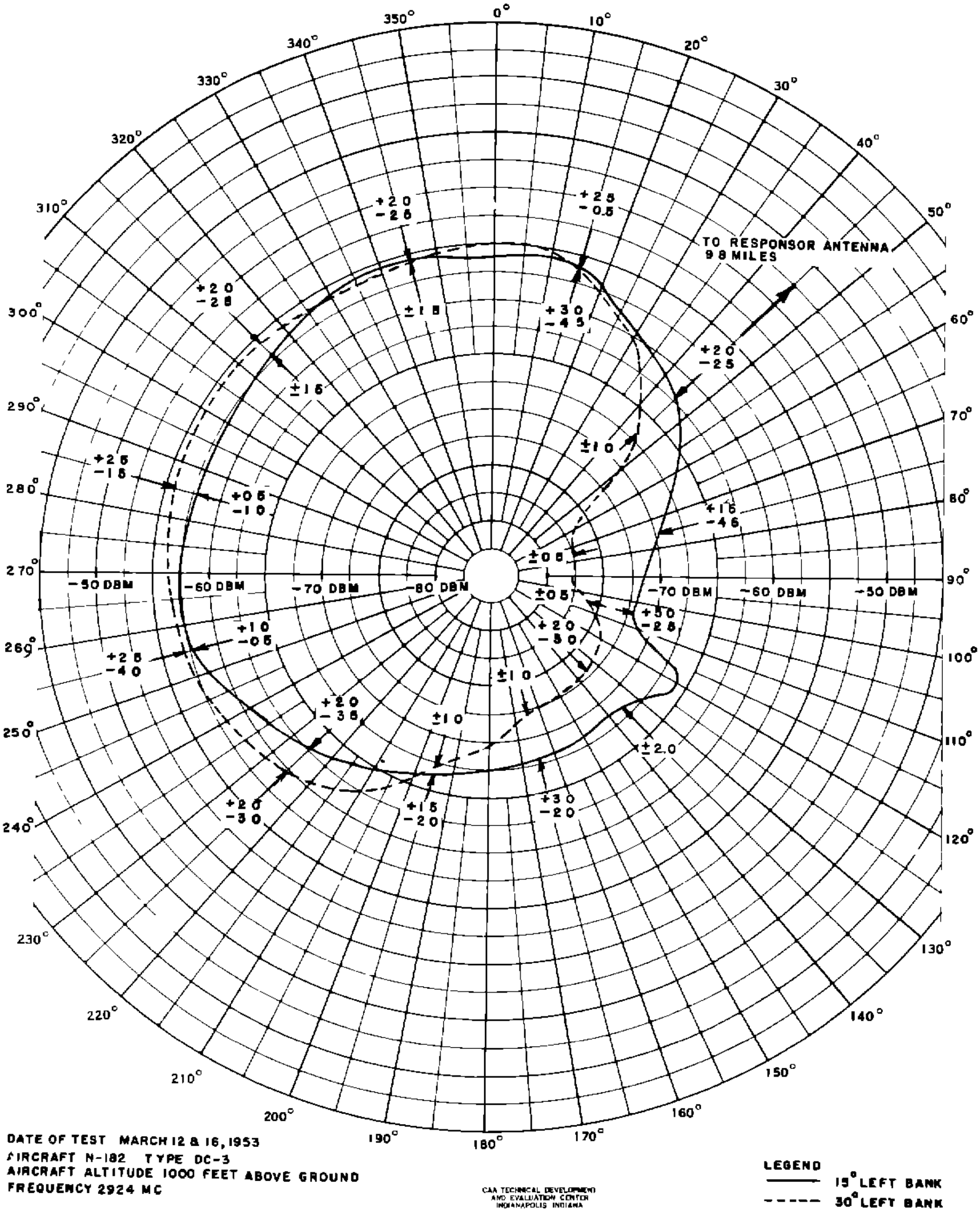


Fig 36 Effect of Aircraft Heading and Bank Upon Level of Transponder Replies Received by Responsor

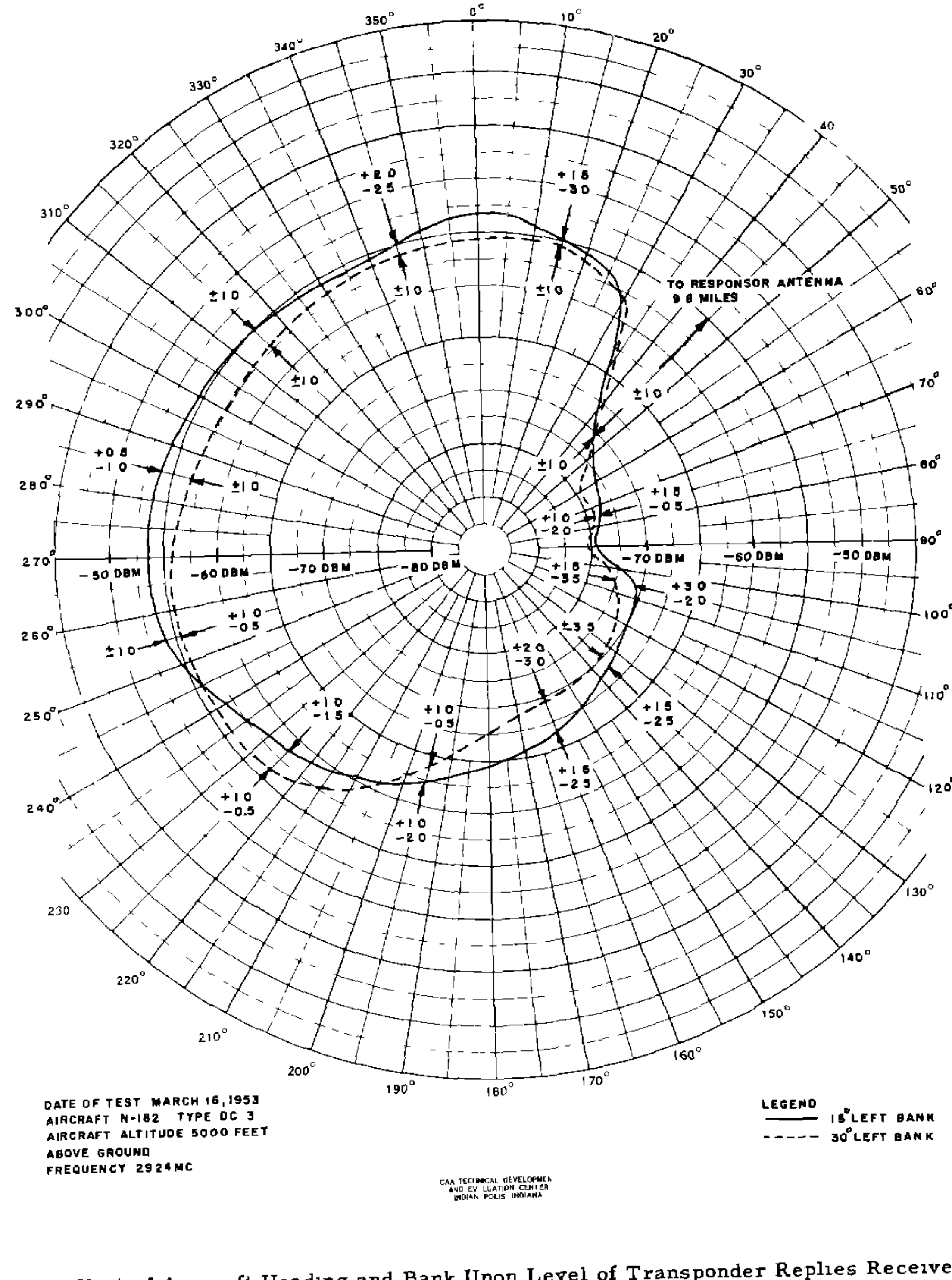


Fig 37 Effect of Aircraft Heading and Bank Upon Level of Transponder Replies Received by Responsor

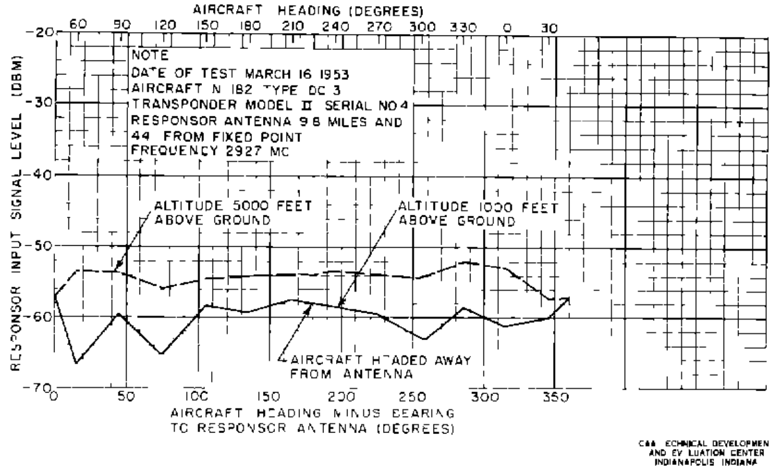


Fig 38 Levels of Reply Signals From Aircraft Flown at Various Headings Over a Fixed Point

indicate average signal levels, and the plus and minus numbers indicate random variation from average levels as the heading changed from 0° to 330°, 330° to 300°, and so forth

Average signal levels varied approximately ±8 0 db for a 15°-bank angle and ±11 5 db for a 30°-bank angle when the aircraft altitude was 1000 feet. When the altitude was 5000 feet, the average signal levels varied approximately 10 5 db for both bank angles Maximum random variations from average levels were +5 and -4 5 db These data may or may not be typical of signal variations that would be encountered in day-to-day operation However, such variations are possible and should be considered

Variations in response-path signal levels due to heading variation alone are shown by Fig 38 The aircraft was flown over the point in straight-and-level flight at headings of 0°, 30°, 60°, and so forth Signal-level variations were ±5 0 db when the aircraft altitude was 1000 feet and ±2 5 db when the altitude was 5000 feet

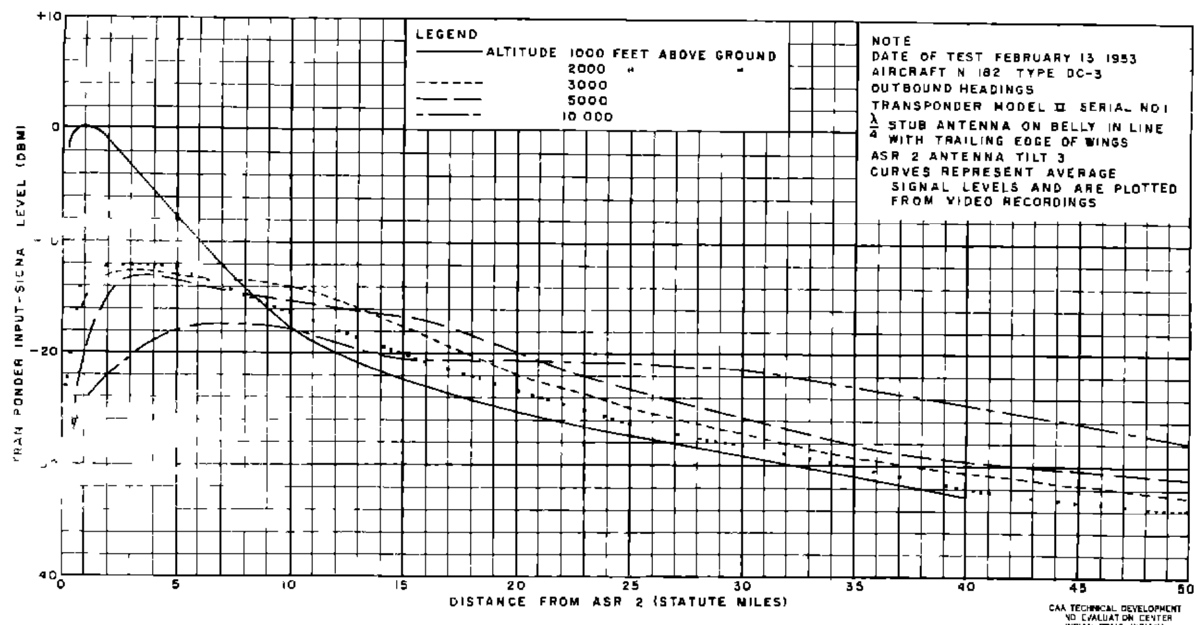


Fig 39 Measured Levels of ASR-2 Signals at Transponder Input Receptacle

TABLE V

EFFECT OF AIRCRAFT PITCH UPON RESPONSOR-INPUT SIGNAL

Altitude Above Ground (feet)	Aircraft Heading	Responsor-Input Signal Level For 8° Climb (-dbm)	For 8° Descent (-dbm)
1000	Inbound	53 5	59 9
1000	Outbound	63 5	56 9
5000	Inbound	54 5	[illegible]
5000	Outbound	60	53 5

The STC characteristics that were used during the tests are shown in Fig 24 Data for S-band responsor STC control adjustment were obtained by the same methods used to obtain data for L-band responsor STC characteristics

Evaluation of S-Band Reply Transponder When Interrogated by ASR-2

It was not possible to conduct extensive tests of the L-band reply transponder in conjunction with the ASR-2 equipment because the modification components required to add the L-band feed to the ASR-2 antenna were not available The ASR-2 antenna modification is required for reception of the transponder replies

Tests were made to determine levels of ASR-2 signals at the transponder input receptacle for various aircraft ranges, altitudes, and azimuths with respect to the ASR-2 The ASR-2

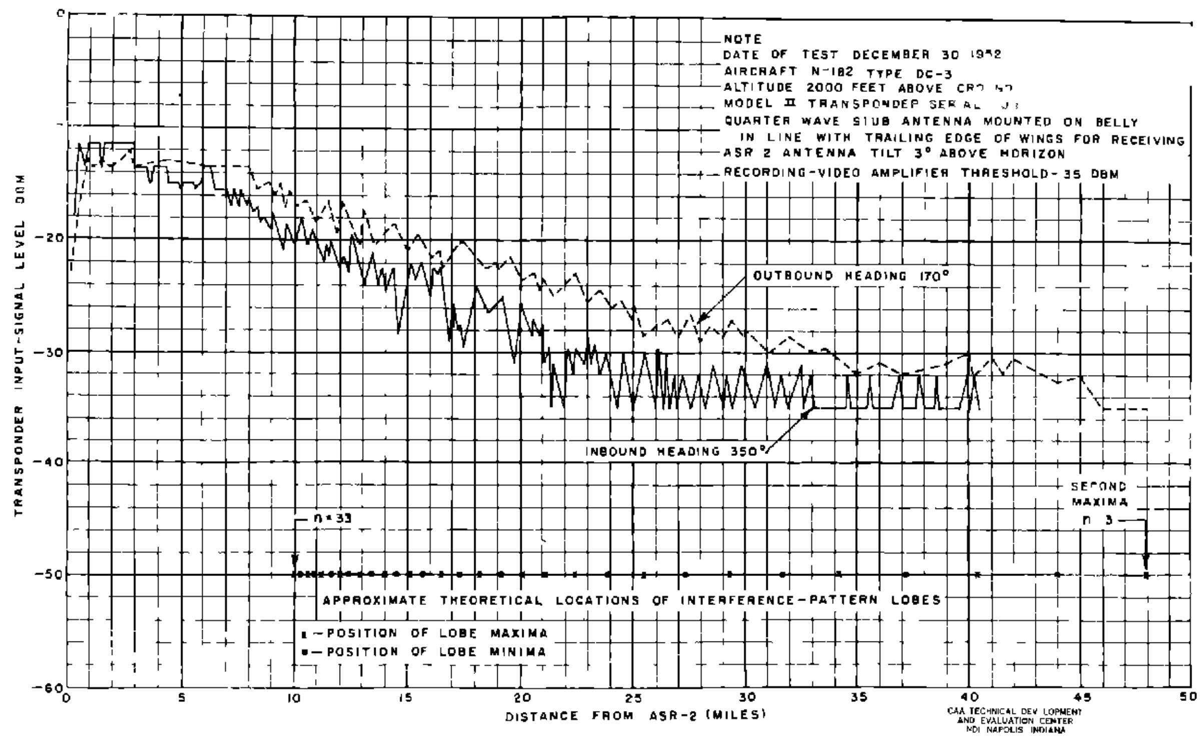


Fig 40 Measured Levels of ASR-2 Signals at Transponder Input Receptacle

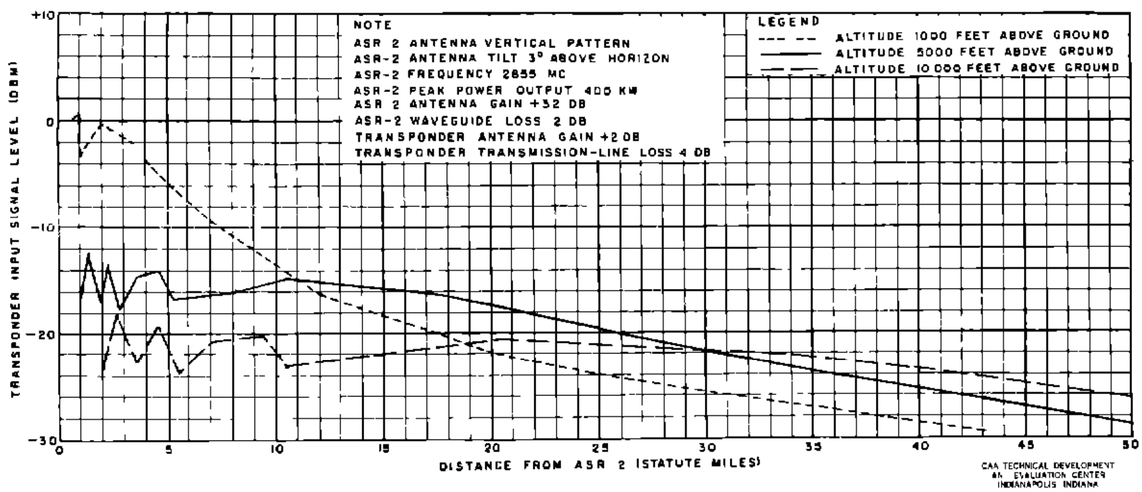


Fig 41 Calculated Levels of ASR-2 Signals at Transponder Input Receptacle

operating frequency was 2857 Mc Variation in levels of response-path signals at the frequency of 2927 Mc should be similar to variations of interrogation signals from the ASR-2 Figure 39 shows curves representing average signal levels measured when the aircraft was 1000, 2000, 3000, 5000, and 10,000 feet above ground and at ranges from 0 to 50 miles Signal levels were recorded by the use of a wide dynamic-range video amplifier and peak-detector equipment (described in Appendix III) connected to one pen of a high-speed Brush Development Co Model

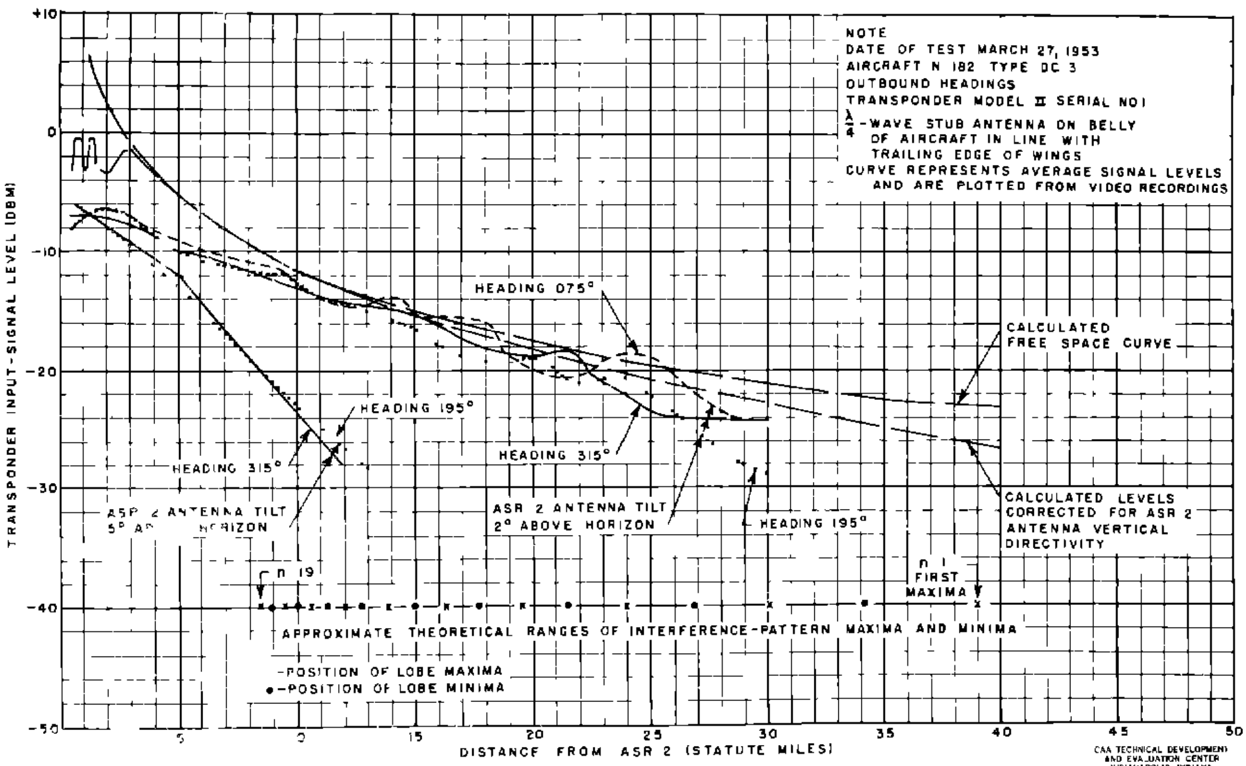


Fig 42 Levels of ASR-2 Signals at Transponder Input Receptacle

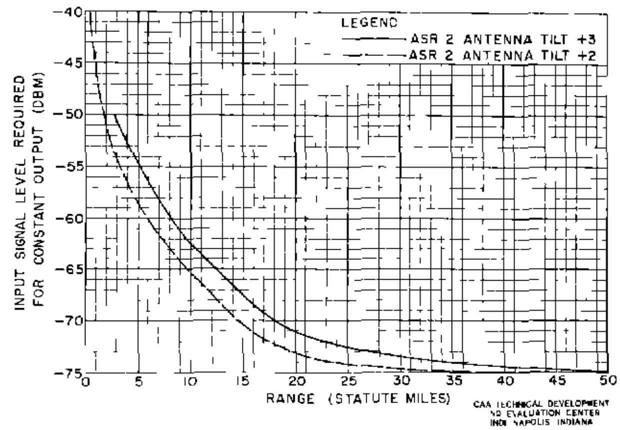


Fig 43 STC Characteristics of Responsor Used With ASR-2

BL-202 direct-writing magnetic oscillograph The video-amplifier input circuit was connected to the output of the transponder r-f detector which was connected by RG-8/U transmission line to a quarter-wave stub antenna mounted on the belly of the aircraft The output of the peak detector was the envelope of the pulse train received from the ASR-2 as the antenna swept by the aircraft The recorder deflection was proportional to the amplitude of the peak-detector output signals In order to calibrate the recordings, a signal generator was connected to the transponder and the recorder deflections obtained for various levels of r-f input signals were marked

Figure 40 indicates levels of ASR-2 signals plotted from the recording obtained when the aircraft was 2000 feet above ground Successive maximum and minimum recorder deflections were plotted to indicate maximum variations which occur during short periods of time Signal-level variations recorded during the inbound flights were much greater than those recorded during the outbound flights Signal levels were also greater during the outbound flight The variation of signal levels and the difference between outbound and inbound levels shown by Fig 40 are typical of the variations and differences obtained for other altitudes However, the difference between the outbound and inbound levels was less at higher altitudes Approximate

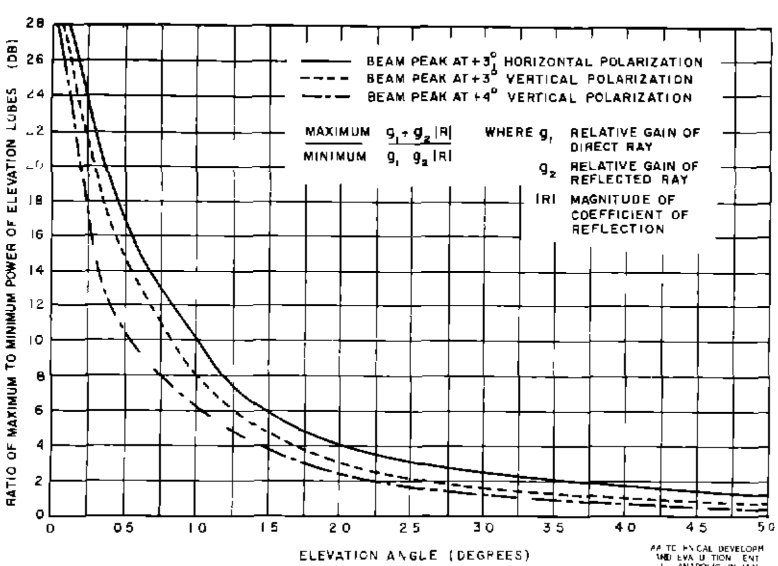


Fig 44 Ratio of Maximum to Minimum Powers of Elevation Lobes for ASR Antennas Over Ground Surface

theoretical locations of interference-pattern lobes were plotted to allow comparison of the ranges of minimum and maximum signal conditions with calculated interference-pattern lobe positions

The lack of a regular interference pattern is attributed to the variation in signal levels with aircraft-attitude variations and to irregularities of the earth's surface It is believed that the surface of the ground from which the ground waves are reflected is not mirror-like to the degree required for coherent reflection of 10-centimeter waves Interference patterns were detected when the responsor antenna was close to the ground For low antenna heights, reflection occurs on the flat surface of the airport near the antenna

Transponder input-signal levels were calculated for aircraft altitudes of 1000, 5000, and 10,000 feet The conditions upon which calculations were based and the results of the calculations are given in Fig 41 Ground-wave effects were not included The variations from smooth curves at smaller ranges are due to irregularities in the vertical pattern of the ASR-2 antenna

Curves representing average interrogation-signal levels at the altitude of 1000 feet when the ASR-2 antenna tilt was changed from 3° to 2° and 5° are shown by Fig 42 In general, the average signal levels did not vary appreciably with the azimuth The signal levels decrease very rapidly with increasing range when the ASR-2 antenna is tilted so that the nose of the beam is 5° above the horizon At the range of ten miles, the calculated and measured one-way loss is 10 db Curves showing calculated levels under free-space conditions with and without correction for ASR-2 antenna vertical directivity are also shown In operation, the tilt of some airport-surveillance radars is as much as 4° above the horizon This has been done to reduce the amplitude of radar returns from ground targets and to obtain improved aircraft targets at smaller ranges, which goals are vitally important for terminal-area traffic control The maximum ranges of the radar and of the transponder are greatly reduced when higher antenna tilts are used and when the aircraft fly at low altitudes

The maximum interrogation range calculated on the basis of conditions listed in Table VI is 468 miles when the aircraft altitude and the ASR-2 antenna tilt are such that the aircraft is at the nose of the antenna beam

TABLE VI

CONDITIONS USED AS BASIS FOR CALCULATION OF INTERROGATION RANGE

Transponder-interrogation sensitivity	-45 dbm
Transponder-antenna gain	2 db greater than isotropic radiator
Transponder r-f transmission-line loss	4 0 db
ASR-2 peak power	400 kw
ASR-2 frequency	2855 Mc
ASR-2 antenna gain	32 db greater than isotropic antenna
ASR-2 waveguide loss	1 5 db

Under the same conditions, a 17 8-db degradation of the interrogation-link characteristics reduces the maximum range to 60 miles If the ASR-2 antenna tilt is +3° and if the aircraft is at the antenna horizon, the loss due to antenna vertical directivity is approximately 5 5 db if free-space propagation conditions are assumed Under the latter condition, the maximum range is reduced to approximately 248 miles and the reserve interrogation-link gain at 60 miles is reduced to approximately 12 3 db

Figure 43 shows responsor STC characteristics which were used when the ASR-2 antenna tilt was 2° and 3° above the horizon The STC circuits were adjusted to provide a variation of the gain required to maintain a constant video output level with a variation of the aircraft range

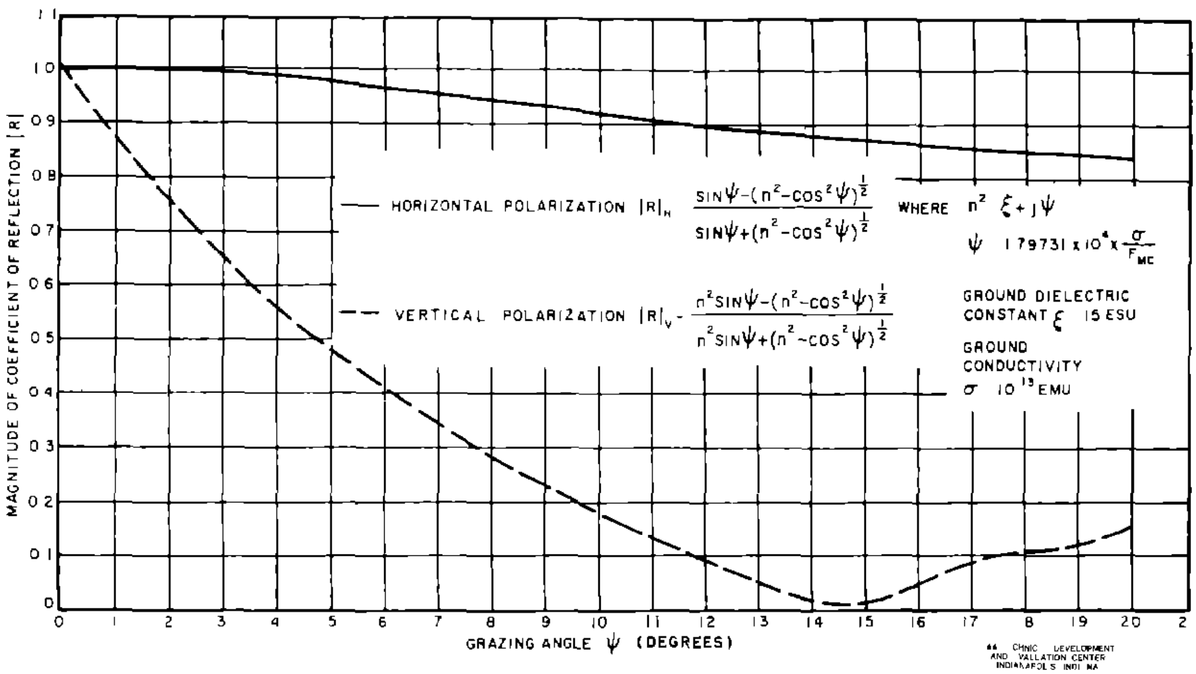


Fig 45 Magnitude of Reflection Coefficient at 2800 Mc Over Ground Surface

at an altitude of 1000 feet above ground It was not possible to obtain the desired rate of change of gain for ranges less than approximately three miles From examination of calculated and measured signal-level-versus-range curves for various altitudes, it may be seen that signal levels at smaller ranges vary greatly with altitude so that it is impossible to set up the STC circuits for a desired gain variation for all altitudes It is believed that optimum performance at lower aircraft altitudes is desirable for terminal-area traffic control If transponder ASC is not used, maximum control of the display of the responses to ASR-2 antenna side lobes is provided when STC circuits are set up on the basis of signal-level variations that occur at the lower altitudes

Throughout the tests at TDEC, it was noted that the interrogation-link characteristics were generally satisfactory Operation of the transponder-triggering multivibrator was recorded on the second channel of the Brush Development Co. Model BL-202 recorder The reply or response link usually limited minimum or maximum ranges for which satisfactory transponder replies on the ASR-2 PPI were obtained During most of the tests, a photograph of the PPI was taken during each rotation of the ASR-2 antenna The camera shutter was normally open A timing and relay mechanism caused the shutter to close, the film to advance one frame, and the shutter to open each time the ASR-2 antenna was pointed in a selected direction

Calculations indicate that the reserve response-link gain is much less than that of the interrogation link The maximum range calculated on the basis of the conditions listed in Table VII is 186 miles, if the aircraft altitude and ASR-2 antenna tilt are such that the aircraft is at the nose of the beam

Under the conditions listed previously, a 9 8-db degradation of response-link characteristics reduces the maximum range to 60 miles If the antenna tilt is +3° and the aircraft is at the horizon of the antenna, the loss due to vertical antenna directivity is approximately 5 5 db, if free-space propagation conditions are assumed Under the latter condition, the maximum range is reduced to approximately 99 miles and the reserve response-link gain at 60 miles is reduced to approximately 4 3 db The display and the TR modification-kit losses reduce the reserve gain appreciably

Variations of response-link signal levels with the variation of aircraft heading and attitude were measured during evaluation of the transponder in conjunction with the PAR-1 The results of these tests are shown in Figs. 36, 37, and 38 Corresponding interrogation-link

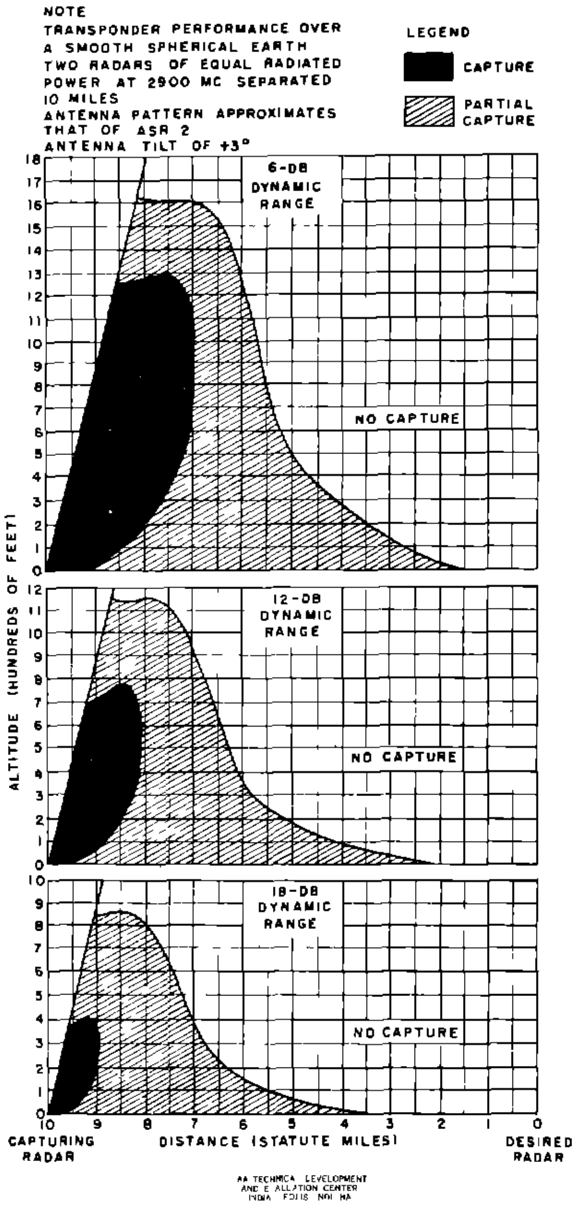


Fig 46 Theoretical Capture Effect for Radar, Separation of 10 Miles

signal-level variations are similar because the interrogation frequency is within 200 Mc of the reply frequency

Tests were made to determine the extent that the transponder ASC circuits prevented interrogation by ASR-2 antenna side lobes Results of these tests follow

An L-band reply transponder was used during these tests The transponder failed to reply to the main lobe during three antenna rotations when the aircraft altitude was 3000 feet and the ASC was operative At the altitude of 7000 feet, as many as 14 main-lobe interrogations were missed when the ASC was operative The lack of interrogation was due to a combination of the nulls of the combined ASR-2 and transponder antenna patterns and to

TABLE VII

CONDITIONS USED AS A BASIS FOR CALCULATIONS OF RESPONSE RANGE

Responsor minimum discernible signal	-85 dbm
TR modification-kit loss	6 0 db
Loss of cable connecting modification kit to responsor	1 5 db
ASR-2 waveguide loss	1 5 db
ASR-2 PPI display loss	10 0 db
ASR-2 antenna gain	32 db greater than isotropic radiator
Transponder peak-power output	+55 7 dbm
Transponder-output frequency	2927 Mc
Transponder r-f transmission-line loss	4 0 db

---

temporary capture by a powerful slow-scan radar 52 miles from the ASR-2 Interrogations by ASR-2 antenna side lobes when the ASC was inoperative decreased rapidly for increasing

TABLE VIII

TRANSPONDER ASC SIDE-LOBE SUPPRESSION

Aircraft Altitude (feet)	Aircraft Heading	ASC Switch Position	Maximum Range of Side-Lobe Responses (miles)
1000	South	On	0 8 North and South of ASR-2
1000	South	Off	Greater than 10
1000	North	On	0 75 North and South of ASR-2
3000	South	On	0 5
3000	South	Off	18
3000	North	Off	21
5000	South	On	0 70 South of ASR-2
7000	North	On	0 75 North of ASR-2
7000	North	Off	22
7000	South	On	0 75 South of ASR-2
7000	South	Off	19

aircraft ranges greater than 15 miles The transponder ASC circuits were very effective during these tests The video-amplifier bias voltage varied from 2 1 volts d-c when the ASC circuits were inoperative to a maximum value 5 9 volts d-c when the ASC circuits were operative Results from similar tests of the S-band reply transponder were essentially the same as those in Table VIII The maximum range for side-lobe interrogation can be expected to vary and depends upon the setting of the transponder triggering-bias potentiometer or squitter control and upon the setting of the noise-level adjustment potentiometer.

The variation of the transponder dynamic range with the level of the strongest signal received is tabulated in Table IX The measurements were made using two S-band signal generators modulated by pulse trains from two modulator units to simulate signals from two ASR-2 equipments The attenuator of the first signal generator was adjusted for various transponder input-signal levels The attenuator of the second signal generator was adjusted for a signal level barely sufficient to trigger the transponder for each input level from the first generator The difference between outputs of the two generators at the transponder-input receptacle is tabulated as the dynamic range The input from the first generator was always the stronger, so that the bias developed by the ASC circuits depended upon the attenuator setting of the first generator

TABLE IX

TRANSPONDER DYNAMIC RANGE

Stronger Input Signal (-dbm)	Bias Developed by ASC (volts d-c)	Dynamic Range for Squitter Bias 35 volts d-c (db)	40 volts d-c (db)	45 volts d-c (db)	50 volts d-c (db)	55 volts d-c (db)
5	7 0	24	19	17 5	14	9
10	6 9	20	15.5	14	11	7
15	6 7	15 5	11.75	10.25	8.5	5
20	6 4	12 5	9 5	7 5	6 0	4
25	6 1	11 0	7 5	6 25	5 0	3 25
30	5 4	10 5	7 0	5 5	4 0	2 5
35	4 8	10	6 5	5 0	3 5	2 0

During the tests, the noise-level adjustment potentiometer was adjusted for rectified noise voltage of 0 32 volt d-c For squitter biases less than 35 volts, the triggering multivibrator was in a free-running condition Interrogation by ASR-2 antenna side lobes should be expected when the squitter bias is less than approximately 40 volts, because main-lobe signals are greater than -10 dbm when the aircraft is at lower altitudes and is near the ASR-2 The squitter-control bias could be varied 10 volts without appreciable change in interrogation sensitivity When the squitter bias was 42 5 volts d-c, interrogation sensitivity was good, side-lobe interrogation suppression was effective, and a free-running condition of the triggering multivibrator did not occur For lower input-signal levels, the dynamic range decreased to approximately 6 0 db so that possibilities of capture by other radars were increased when the interrogating radar power was low or when the range of the aircraft was increased

The data in Table X allow comparison of the dynamic range when the transponder video-amplifier gain is adjusted for rectified noise voltages of 0 32 and 0 67 volt d-c. The squitter bias was 46 volts d-c during the tests

The dynamic range is greater when the video-amplifier gain is increased for a rectified noise voltage of 0 67 Also, possibilities of capture by other radars and a temporary loss of

TABLE X

EFFECT OF NOISE VOLTAGE UPON DYNAMIC RANGE

Stronger Input-Signal Level (-dbm)	Dynamic Range Noise Voltage 0 32 volt d-c (db)	Dynamic Range Noise Voltage 0 67 volt d-c (db)
5	17 5	24
10	14	20
15	10	15
20	7	11 5
25	5	9
30	4 5	8 5
35	4 0	8

interrogation due to a sudden decrease of the interrogation-signal level are decreased However, azimuth resolution is impaired

The maximum transponder range for an aircraft altitude of 1000 feet above ground generally varied between 40 and 45 miles depending upon the power transmitted by the transponder, upon responsor gain, and upon the direction of heading of the aircraft was toward or away from the ASR-2 The interrogation-link range was approximately 53 miles, which is slightly less than the theoretical line-of-sight distance The response link was the limiting factor The maximum response-link range was approximately 3 miles less when the aircraft headed towards the ASR-2 A 10 db attenuator was connected in the responsor input transmission line during one inbound flight The responsor STC was used, and the manual gain control was adjusted for normal gain The addition of the attenuator decreased the maximum response-link range to 18 miles The peak power output of the transponder, measured upon completion of the test, was +20 7 dbw The maximum reliable response range obtained during any of the flights at 1000 feet was 52 miles

At altitudes between 2000 and 10,000 feet, the maximum interrogation- and response-link ranges were greater than 60 miles, which is the maximum range presented by the ASR-2 PPI

Maximum interrogation- and response-path ranges for an aircraft altitude of 10,000 feet were recorded during a flight which was made at a range of 150 miles to determine second-time-around effects During the test, the responsor STC circuits were turned on momentarily to determine the effect of STC upon presentation of second-time-around responses The transponder peak power output was 20 7 dbw During the outbound flight, reliable interrogation was obtained at ranges between 0 and 136 miles and partial interrogation was obtained between 136 and 137 miles When flying toward the ASR-2, partial interrogations were obtained from 142 to 138 miles and the interrogations were reliable for ranges less than 138 miles The interrogation range was somewhat less than the theoretical line-of-sight distance of approximately 154 miles The quality of transponder replies as observed on the ASR-2 PPI for various aircraft ranges is shown in Table XI

The range of the second-time-around responses displayed on the PPI was equal to the aircraft range minus 77 miles During the outbound flights, use of STC eliminated the target when the range was 84 miles, reduced target quality from strong to weak at 87 miles, and reduced it from strong to fair at 94 miles At 104 miles, STC did not change the intensity of the target displayed The target was displayed at 27 miles when the aircraft range was 104 miles From Fig 43 it may be seen that STC has very little effect, approximately 0 5 db, on the responsor gain when the range is 27 miles. Use of STC to control the display of second-time-around and third-time-around responses is not practical, because signal levels decrease less rapidly with increasing range when the initial range is large and because signal levels at

TABLE XI

QUALITY OF TRANSPONDER REPLIES DURING SECOND-TIME-AROUND TEST

Outbound Flight		Inbound Flight	
Range (miles)	Character of Reply	Range (miles)	Character of Reply
0- 60	Strong	0- 55	Strong
60- 77	PPI Dead Time	55- 58	Weak
77- 89	Strong	58- 60	Strong
89- 91	Weak	60- 77	PPI Dead Time
91- 97	Strong	77- 82	Weak
99-101	Weak	82- 92	Not Visible
101-102	Fair	92- 94	Weak
102-105	Strong	94-100	Not Visible
105-107	Fair	100-101	Weak
107-109	Not Visible	101-104	Not Visible
109-117	Fair	104-105	Weak
117-120	Not Visible	105-137	No Signal
120-121	Weak	137-150	PPI Dead Time
121-125	Not Visible		
125-126	Weak		
126-129	Fair		
129-132	Weak		
132-137	Not Visible		
137-150	PPI Dead Time		

any range vary with aircraft altitude If the effects of ASR-2 antenna vertical directivity are ignored and if free-space propagation conditions are extant, the signal level decreases 6 db when the aircraft range is doubled The level decreases 6 db when the range is increased from 30 to 60 miles and another 6 db when the range is increased from 60 to 120 miles

The maximum response-link range depends upon responsor STC characteristics and upon whether the transponder transmitting antenna is on the top or the belly of the aircraft Minimum ranges obtained when the ASR-2 antenna tilt was 3° and when the transmitting antenna was mounted on top of the aircraft are listed in Table XII

Data in Table XIII indicate the effect of transponder ASC and of responsor STC during flights at the altitude of 5000 feet Both transponder antennas were mounted on the belly of the aircraft

TABLE XII

MINIMUM RESPONSE-PATH RANGES

Aircraft Altitude (feet)	STC Switch Setting	Minimum Range Outbound Flight (miles)	Minimum Range Inbound Flight (miles)
1000	On	1	1
2000	Off	1	0 3
3000	Off	1 3	0 5
5000	On	8 2	8 0
10,000	On	10 0	12 2

As seen from the data in Table XIII, the use of STC improves azimuth resolution for ranges less than 14 miles when the transponder ASC is turned off For ranges greater than 14 miles, the resolution appears to be better when the STC is not used This apparent discrepancy occurs because the aircraft was headed toward, instead of away from, the ASR-2 when the STC switch was turned off The signals received from the aircraft were weaker during inbound flights Also, reduction of responsor gain by STC circuits decreases with increasing range

The effect of STC upon the display of the side-lobe response was checked at several altitudes during other flights The gain of the response path was reduced Side-lobe responses were not observed at any time However, the minimum response-path range was affected adversely, and the differences are recorded in Table XIV The transponder ASC was turned off at all times

Generally, the use of STC improves resolution when the transponder ASC is not used Studies of the possibility of using the responsor STC alone to eliminate the presentation of side-lobe responses indicate that compromises in system performance would be necessary. A compromise among maximum range, minimum range, and reliable performance under unfavorable equipment or unfavorable aircraft-altitude and attitude conditions would be required From study of flight-test data, the variations in signal levels listed in Table XV should be expected during normal level-flight conditions at 1000 feet Ranges up to 25 miles are most important for terminal-area traffic control and for the use of STC

If the responsor STC is so adjusted that responsor video output is constant when the signal-level variation is the same as that of the 1000-foot altitude curve in Fig 39, the amplitude of the strongest ASR-2 antenna side lobe is 27 db below that of the main lobe as indicated in Fig 15 Therefore the manual gain control can be adjusted so that signals 27 db weaker than those of the average curve are almost discernible Under ideal conditions, side lobes will not be displayed when the aircraft altitude is 1000 feet, and, as seen in Fig 39, it is evident that main-lobe signals will be displayed when the aircraft altitude is increased to 10,000 feet and when the range is greater than approximately 0 5 mile However, allowance must be made for propagation, equipment performance, and aircraft attitude conditions Actually, for ranges less than 5 miles, the gain should be reduced approximately 1 5 db to prevent "breakthrough" of side lobes when the attitude of the aircraft at 1000 feet is most favorable Signals from aircraft at the higher altitudes should be approximately 5 db stronger than minimum discernible signals in order to provide distinct targets These two conditions require that signals from aircraft at higher altitudes cannot be more than 20 5 db below those from aircraft at 1000 feet if distinct targets are necessary If aircraft at the higher altitudes are flying inbound and the attitude is unfavorable, the 20 5-db ratio is reduced to approximately 17 0 db From Fig 39, it may be seen that the minimum range for a 17 0-db ratio is approximately 1 5 miles for aircraft at 5000 feet and approximately 3 0 miles for aircraft at 10,000 feet The above ranges could be expected if the transponder-transmitter power, the loss in transmission line, and the antenna pattern of all aircraft are identical The minimum range is increased greatly because of shielding effects of the fuselage when the transponder transmitting

TABLE XIII

EFFECTS OF ASC AND STC ON AZIMUTH RESOLUTION

Range (miles)	Aircraft Heading	Condition ASC	STC	Number of Antenna Scans Zero SL*	1 SL*	2 SL*	3 SL*	4 to 6 SL*	6 to 10 SL*	More Than 10 SL*	Target Width Main Lobe (degrees)	Total (degrees)
0 75 - 1 25	In	On	On	0	0	0	0	0	0	0	--	
	Out	On	Off	0	0	0	0	0	0	All	--	360
	Out	Off	On	0	0	0	0	0	0	0	--	
	In	Off	Off	0	0	0	0	0	0	All	--	360
1 25 - 3 0	In	On	On	All	0	0	0	0	0	0	--	
	Out	On	Off	All	0	0	0	0	0	0	--	
	Out	Off	On	All	0	0	0	0	0	0	--	
	In	Off	Off	0	0	0	0	0	0	All	--	360
3 - 4 0	In	On	On	All	0	0	0	0	0	0	4 5	
	Out	On	Off	All	0	0	0	0	0	0	4 5	
	Out	Off	On	All	0	0	0	0	0	0	5 5	
	In	Off	Off	0	0	0	0	2	2	7	--	360
4 0 - 6 0	In	On	On	All	0	0	0	0	0	0	5	
	Out	On	Off	All	0	0	0	0	0	0	5	
	Out	Off	On	All	0	0	0	0	0	0	5 5 - 6 5	
	In	Off	Off	0	0	0	0	3	10	5	--	55-62
6 0 - 8 0	In	On	On	All	0	0	0	0	0	0	5 5	
	Out	On	Off	All	0	0	0	0	0	0	4 5	
	Out	Off	On	10	4	0	0	0	0	0	6 0	7 5
	In	Off	Off	0	0	0	0	0	14	4	9 - 15	50
8 - 10	In	On	On	All	0	0	0	0	0	0	5 5	
	Out	On	Off	All	0	0	0	0	0	0	5 0	
	Out	Off	On	10	6	0	0	0	0	0	6 - 7 5	
	In	Off	Off	0	0	1	6	5	3	0	9 - 15	48
10 - 14	In	On	On	All	0	0	0	0	0	0	5 0 - 5 5	
	Out	On	Off	All	0	0	0	0	0	0	4 5 - 5 0	
	Out	Off	On	5	6	9	6	0	0	0	8 0 - 9 0	20
	In	Off	Off	0	1	7	13	16	2	0	7 5 - 15	48
14 - 18	In	On	On	All	0	0	0	0	0	0	4 5 - 5 0	
	Out	On	Off	All	0	0	0	0	0	0	4 5 - 5 0	
	Out	Off	On	0	5	11	6	3	0	0	8 0 - 9 0	23
	In	Off	Off	7	18	3	7	0	0	0	6 5 - 7 5	19
18 - 22	In	On	On	All	0	0	0	0	0	0	4 5	
	Out	On	Off	All	0	0	0	0	0	0	3 5 - 4 5	
	Out	Off	On	2	3	10	5	7	0	0	8 0 - 9 0	23
	In	Off	Off	32	4	0	0	0	0	0	4 0 - 7 5	12
22 - 26	In	On	On	All	0	0	0	0	0	0	4 5	
	Out	On	Off	All	0	0	0	0	0	0	3 5 - 4 5	
	Out	Off	On	6	5	0	0	0	0	0	6 0 - 8 0	19
	In	Off	Off	32	3	0	0	0	0	0	4 0 - 6 0	7 5

*SL represents side lobes

TABLE XIV

MINIMUM RESPONSE-PATH RANGE

Altitude (feet)	Minimum Range Aircraft Outbound (miles)	Minimum Range Aircraft Inbound (miles)
1000	2 5	2 5
2000	2 5	3 0
10,000	6 0	6 0

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antenna is installed on top of the aircraft During bench tests of several equipments, power variations greater than 6 0 db were observed If it is practical to maintain power levels of units in service within 6 0 db and if the use of different lengths of transmission lines and different antenna locations does not vary transmitted power more than 3 0 db, the ratio of power received from aircraft at 1000 feet under the most favorable conditions to power received from aircraft at higher altitudes under unfavorable conditions is reduced from 17 0 db to 8 0 db The 8 0-db ratio increases the minimum range to approximately 3 5 miles at 2000, 3000, and 5000 feet and to 5 5 miles at 10,000 feet None of the calculations include the large signal variations that occur when the aircraft is making a turn The use of STC alone to control display of side-lobe responses does not appear to be practical from an operational standpoint if reliable transponder targets without any evidence of the display of side lobes are required for each scan of the ground antenna Additional experience involving different ASR-2 sites, including those having salt water in the immediate vicinity, different ASR-2 antenna tilts, and different types of aircraft is required before final conclusions are possible

Capture Effect

The transmitter-receiver-unit ASC circuit was designed to prevent triggering by interrogating radar-antenna side lobes when the power in the major side lobe is 20 db or more below that of the main lobe and when the received power from the main lobe is between -35 dbw and -57 dbw Actual measured performance of the ASC circuit shows a 19-db dynamic range for signals of -35 dbw decreasing to approximately 7-db for -57 dbw levels The ASC circuit automatically sets the level of the video-amplifier bias voltage, which determines the sensitivity

TABLE XV

SIGNAL-LEVEL VARIATIONS DURING NORMAL FLIGHT CONDITIONS

Range (miles)	Signal-Level Fluctuations (db)	Difference Between Outbound and Inbound Signal Levels (db)	Total Variation (db)
0- 5	±1 5	2	+1 5, -3 5
5-10	±2	3	+2 0, -5.0
10-15	±2 5	4	+2 5, -6 5
15-20	±3 0	5	+3 0, -8 0
20-25	±3 0	5	+3 0, -8 0

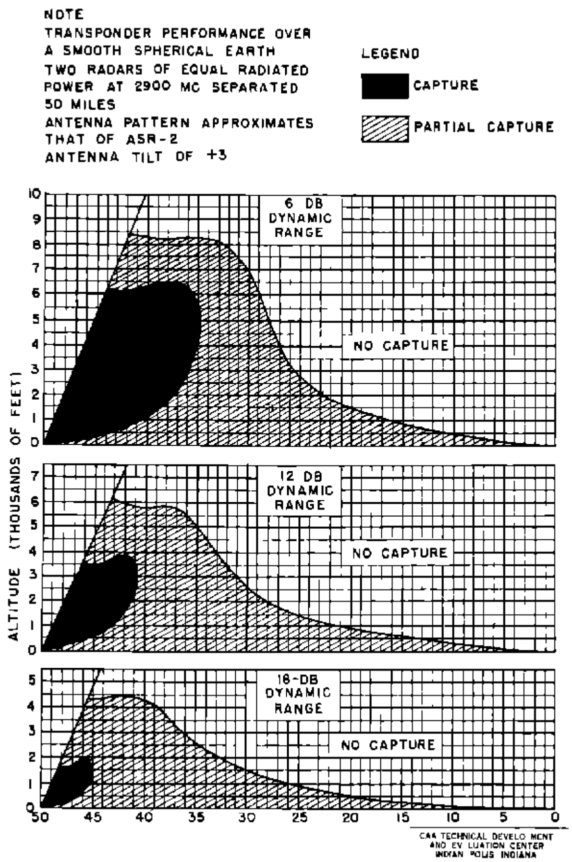

Fig 47 Theoretical Capture Effect for Radar, Separation of 50 Miles

of the transponder The bias level set by the ASC circuit at any instant depends on. (1) the power level of the strongest pulses must recently received from any radar in the r-f pass band of the transponder and (2) the time constant of the ASC circuit "Capture" is a term used when a participating radar does not interrogate the transponder because of the ASC bias voltage The ASC bias may have been set by other participating or nonparticipating radars that are more powerful or are closer to the aircraft The regions of capture that exist about a radar are determined by the relative power outputs of the radars, the spacing between radars, and the antenna radiation patterns The vertical radiation pattern may consist of lobes with maxima and minima because of the interference between directly radiated energy and ground-reflected energy The extent of this lobing depends on the polarization, the free-space antenna pattern, the tilt of the antenna beam, and terrain features Figure 44 shows the extent of this lobing a calculated for several conditions of ASR antennas [3,4] Figure 45 shows the dependence of the magnitude of the reflection coefficient R on the polarization and on the grazing angle

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[3] L A Hartman and A Tatz, "Evaluation of Radar Safety Beacon," Report No 2815-1, Airborne Instruments Laboratory, April, 1953

[4] P L Rice, W V Mansfield, and J W Herbstreit, "Ground-to-Air Co-channel Interference at 2900 Mc," Report No 1909, National Bureau of Standards, August 26, 1952

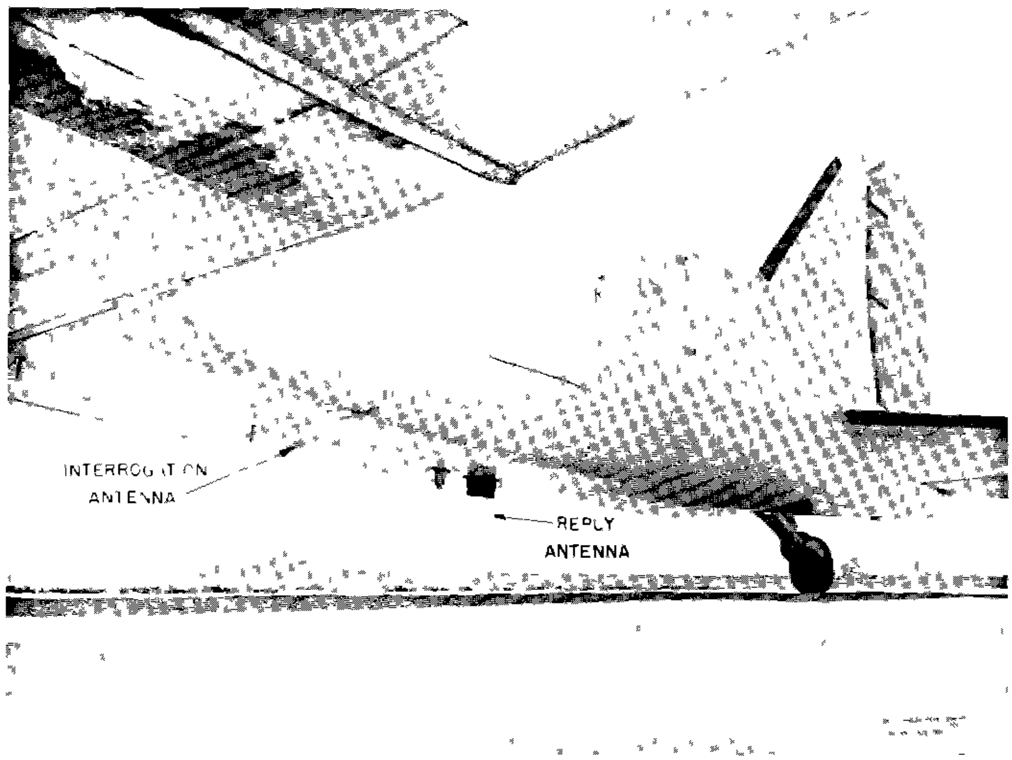

Fig 48 Antennas Used During Capture Tests

The two conditions on which computation of the capture region is made are (1) an aircraft in a maximum of the interference pattern of the observers' radar and the minimum of the other radar and (2) an aircraft in an interference pattern minimum of the observers' radar and in the maximum of the other radar The region of capture will vary because of the effect of different terrain features at different installations upon the magnitude of energy reflected from the ground

In Fig 46 are shown areas of capture, partial capture, and no capture for two ASR-2 radars separated by a distance of 10 miles [5] A comparison of the capture areas of the three graphs indicates the effect of transponder dynamic range The values of dynamic range which are used represent maximum, intermediate, and minimum values that may be expected under actual operating conditions When the radar separation is 10 miles, the levels of the stronger signals should vary from approximately 0 to -13 dbm if the output powers of the two radars are equal Dynamic range should be approximately 18 db when the aircraft is near one radar and should be approximately 12 db when the aircraft is 5 miles from each radar Figure 47 indicates capture areas calculated on the basis of 50-mile separation

Tests were conducted in the New York City area to determine possibilities of capture This area was chosen because of its high radar density During the week of October 13, 1952, flight tests were conducted at the New York International Airport (Idlewild) using a TDEC DC-3 aircraft and an USAF C-47 from the Directorate of Flight and All-Weather Testing, Wright Air Development Center The USAF aircraft was equipped with a Model I transponder modified to reply on S-band The TDEC aircraft was equipped with a Model II transponder and with various recording equipments Both aircraft used circularly polarized antennas, Type AT-329/UPN-9, for receiving interrogating-radar pulses, and replies were transmitted by horizontally polarized, triple-dipole, transmitting antennas (No 658457) manufactured by the Sperry Gyroscope Company

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[5] Ibid

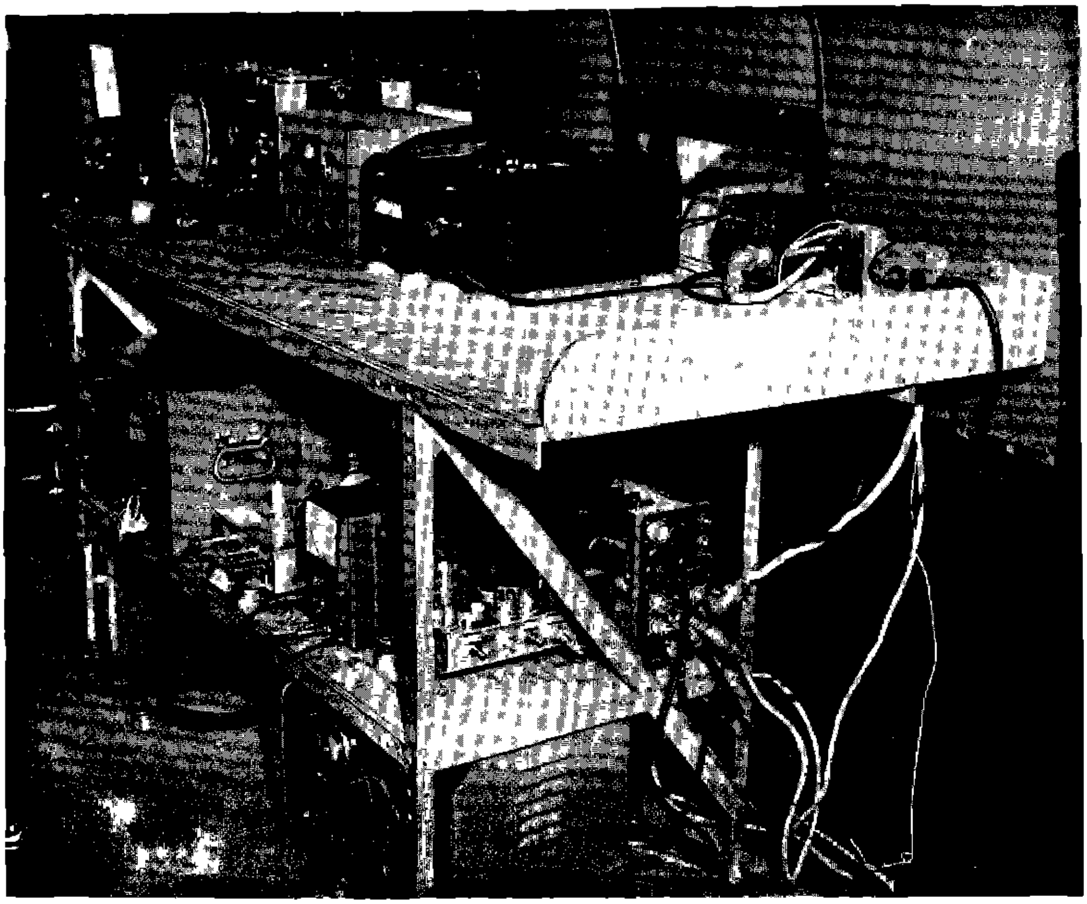

Fig 49 Installation of Test and Recording Equipment Used During Transponder Capture Tests

At the time of the tests, the Newark, New Jersey ASR-2 was not available because acceptance tests had not been completed Personnel of the First Region of the Civil Aeronautics Administration and of Airborne Instruments Laboratory temporarily modified the Idlewild ASR-1 r-f and video components so that transponder replies could be received and displayed It was necessary to use the horizontally polarized reply antenna because the ASR-1 is horizontally polarized A circularly polarized interrogation antenna was used to minimize discrimination against either horizontally or vertically polarized signals

On the USAF aircraft, the reply antenna was mounted on the astrodome cover above the pilot's compartment The interrogation antenna was mounted on the fuselage below the pilot's compartment The TDEC aircraft antennas were mounted on the bottom of the fuselage as shown by Fig 48 A Heiland photographic recorder was used in the USAF aircraft to record multivibrator triggering action during the tests

The various recordings that were made aboard the TDEC aircraft were

1 A magnetic-tape recording of the multivibrator triggering action due to radar interrogations and of radio communications and comments by engineers aboard the aircraft

2 A dual-channel Brush oscillograph recording of the incoming radar-signal levels and of the multivibrator triggering action This recording also had pencil notes of ASC on-off position, aircraft turns, time, altitude, and approximate location of the aircraft

3 An Esterline-Angus recording of the ASC voltage

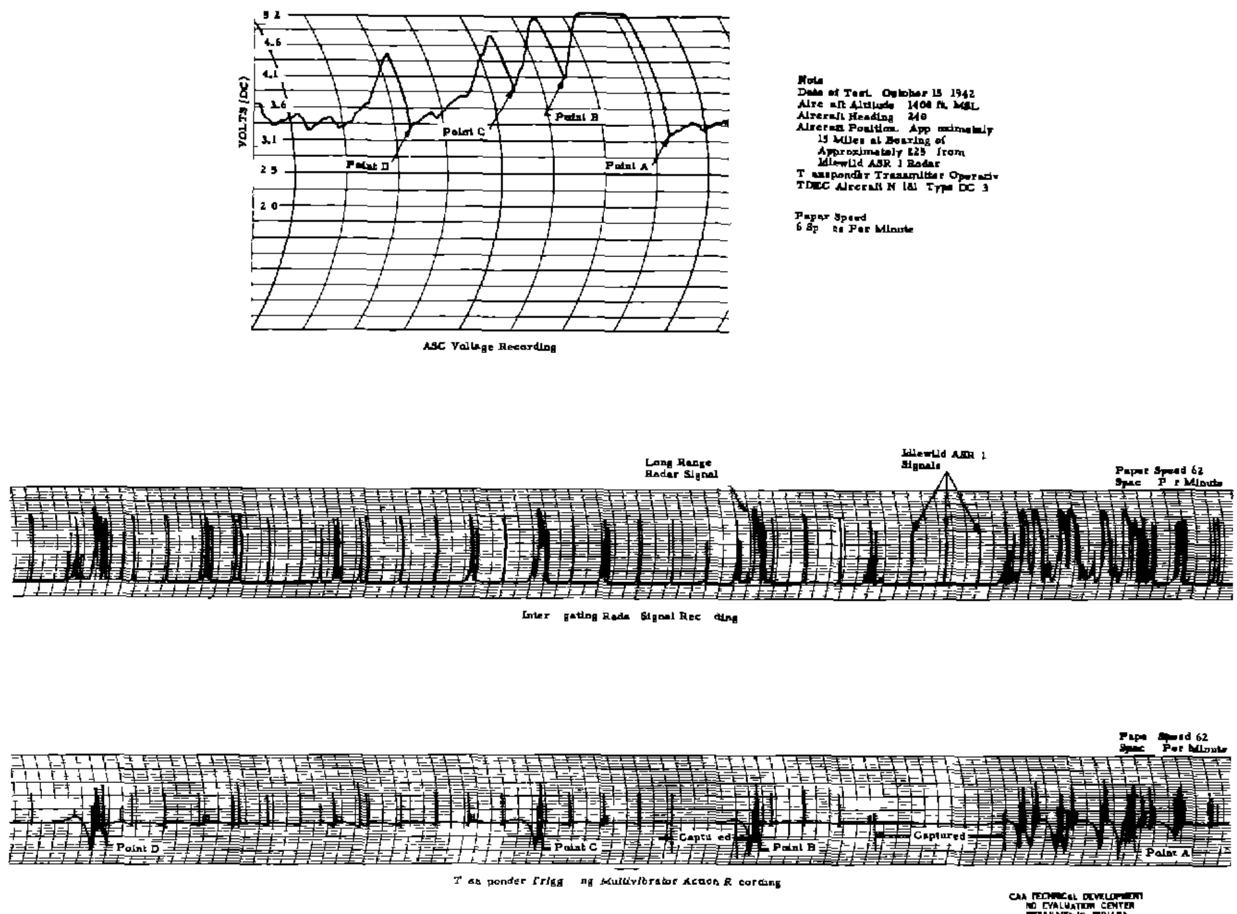

Fig 50 Sample of Recordings Obtained During Capture Tests in New York City Area

Figure 49 shows the test equipment as installed in the aircraft The signal strength of the incoming radar interrogations was measured by means of a special wide dynamic-range amplifier constructed at TDEC A description and a schematic diagram of the circuit are given in Appendix III A typical sample of the oscillogram is shown in Fig 50 The upper trace is a recording of the radar-signal levels at the input of the transponder The lower trace is a record of the multivibrator action An example of capture wherein the multivibrator was not triggered by signals received from several radars is shown in this recording The strong signal which set the high ASC bias voltage was from a long-range radar with a slow antenna scan rate The interrogations from the ASR radar are more numerous on the recording because of the higher antenna scan rate, 25 rpm The ASC bias voltage recording, made at the same time, is also shown in Fig. 50 This shows the effects of the strong signal from the long-range radar upon the ASC bias voltage

Calibration of the wide dynamic-range amplifier and of the recorder was made by use of a Hewlett-Packard Type 616A S-band signal generator Triggering of the signal generator was accomplished by a special radar simulator constructed at TDEC to obtain pulse trains simulating those received from an ASR Figure 51 is a block diagram of the recording-equipment connections

The Idlewild ASR-1 was modified by the addition of a waveguide duplexing section to permit connection of the responsor to the radar antenna To accomplish this change, a

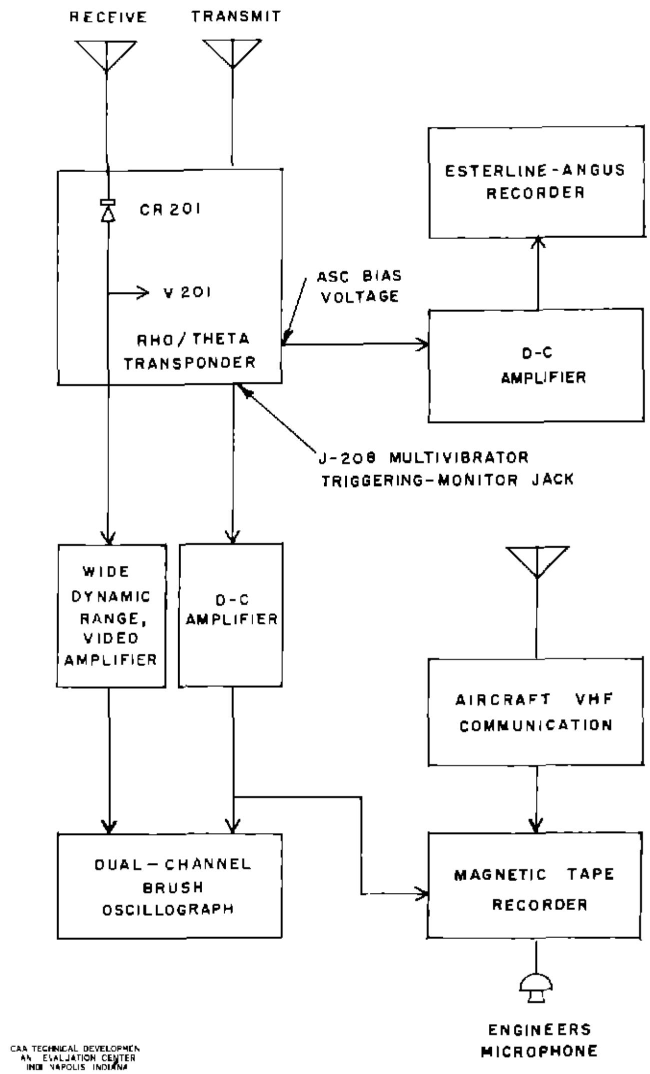

Fig 51 Block Diagram of TDEC Aircraft Equipment

waveguide section having a right-angle bend was replaced with the duplexing section during the tests The video from the responsor was fed to a video mixing unit where it was combined with the radar video and was then transferred to the tower indicator over a coaxial cable The video mixing unit was constructed at TDEC Figure 11 is a schematic diagram of the mixer unit A remote gain control was installed in the tower at the PPI to permit remote adjustment of responsor gains Figure 52 shows a block diagram of the modified ground equipment

A 16-mm motion-picture camera, modified for single-frame time exposures, was mounted on the ASR-1 PPI By means of a microswitch mounted on the antenna pedestal and of a suitable count-down circuit, the camera shutter was opened for three antenna revolutions The shutter was then closed, the film advanced to the next frame, and the cycle repeated Thus, a continuous film record of the ASR PPI presentation was made The camera field of view was adjusted to include an illuminated clock as well as the PPI Each frame consisted of a time exposure for three antenna revolutions with a record of the exact time of the exposure By means of a Gray Audograph recorder in the tower, verbal comments of the time, changes in the radar display, aircraft position, aircraft altitude, ASC on-off position, and other pertinent

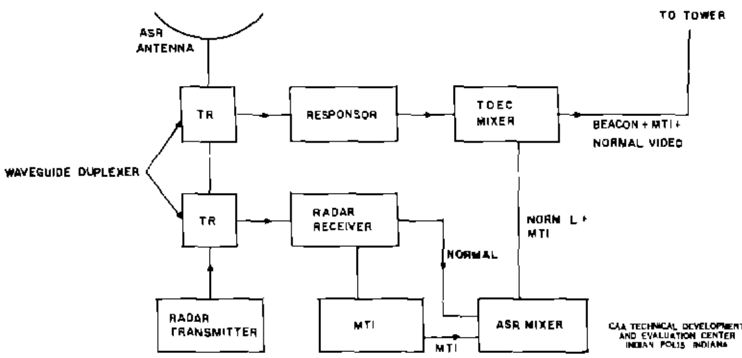

Fig 52 Block Diagram of Responsor Installation on ASR-1

information were recorded The normal tilt of the Idlewild antenna is 4° above the horizon to reduce ground-clutter difficulties This tilt was used throughout the tests

Over a period of five days, holding patterns and flight paths normally used by commercial carriers were flown throughout the Idlewild area Also, circles of 10- and 15-mile radii were flown about the ASR-1 at altitudes of 2500, 3500, and 5000 feet

USAF Flight

On October 17, 1952, the USAF C-47 airplane made an orbital flight which is plotted in Fig 53 Additional flights on the same date are plotted in Fig 54 The notable features of the flights were

1 During the orbit, the aircraft altitude was 3500 feet and the range was about 10 miles The elevation angle of the aircraft was 3 8° During the orbit, the transponder replies were visible 35 per cent of the time

2 For short periods of the flight, the reply code was changed to a single pulse Since a single-pulse reply is not distinguishable from the radar return, these portions of the flight are considered to have indeterminate transponder data These indeterminate periods were not included in computing the percentages of reception

3 The transponder reply was absent from the PPI 46 per cent of the total time of the data

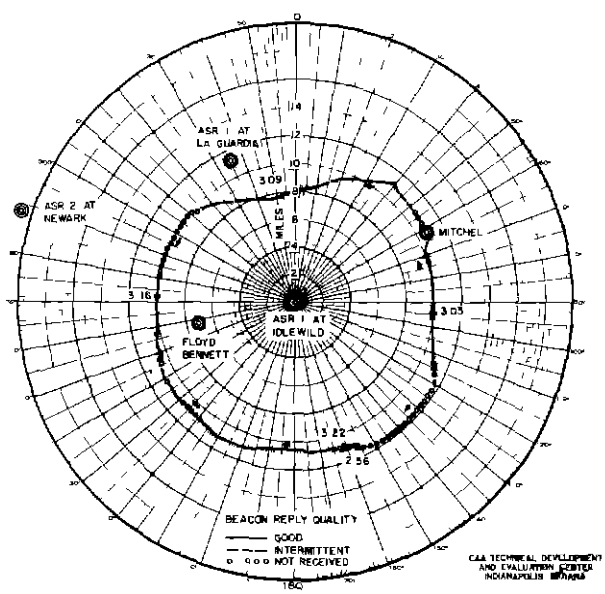

Fig 53 Orbital Portion of Aircraft 9214 Flight Path on 17 October 1952

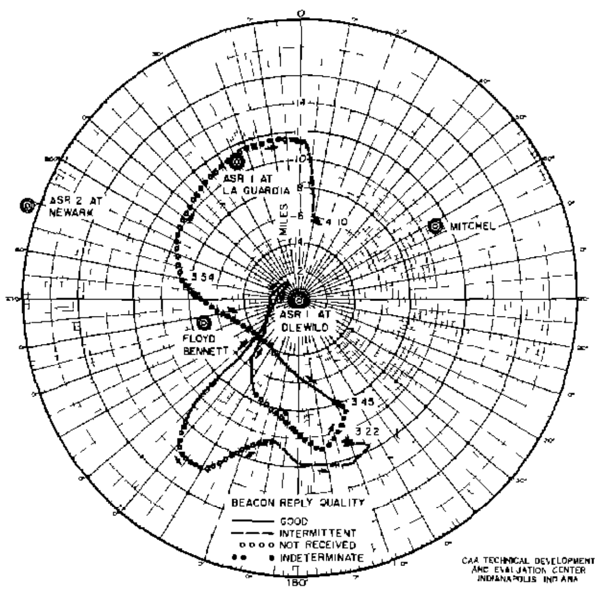

Fig 54 Latter Portion of Aircraft 9214 Flight Path on 17 October 1952

TDEC Flight

The data from the TDEC flight, conducted on October 17, 1952, were analyzed in the same manner Figures 55 and 56 are plots of the flight The orbit shown in Fig 55 was made at the altitude of 2500 feet and at a distance of approximately 10 miles The remainder of the flight was made at various altitudes which were representative of normal flight paths in the area The notable features of the flight were

1 During the orbit, the transponder replies were visible 37 per cent of the time

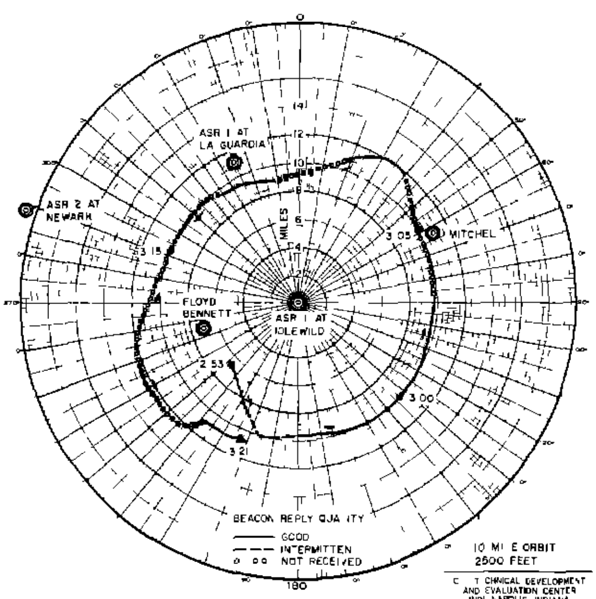

Fig 55 Orbital Portion of Aircraft N-181 Flight Path on 17 October 1952

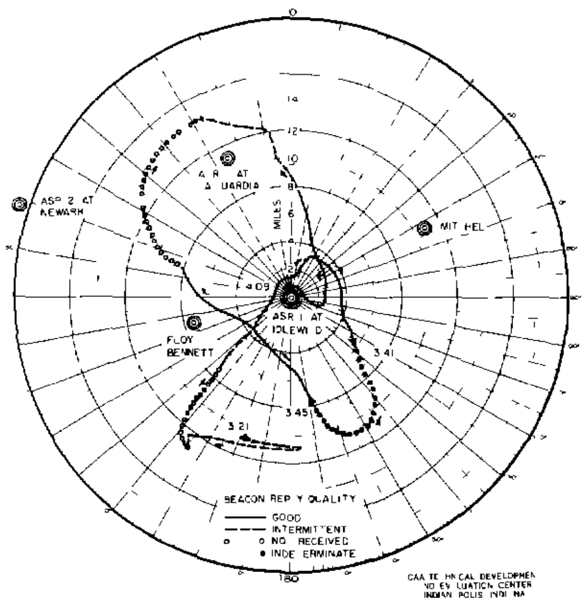

Fig 56 Latter Portion of Aircraft N-181 Flight Path on 17 October 1952

2 For the total flight, the transponder reply was absent from the radar scope for 32 3 per cent of the time

The same flight was analyzed with the assumption that the ASR-2 radar at Newark Airport was the main participating radar A plot of interrogation data in Fig 57 shows that the beacon failed to reply to the ASR-2 for only 9 3 per cent of the total time of the data The higher percentage of transponder replies to the ASR-2 has been attributed to the greater amount of transmitted power (4 5 db above that of the ASR-1) and to the vertical polarization The circularly polarized aircraft antenna may have discriminated to some extent against the horizontal polarization of the ASR-1 radar The antenna carried a security classification, and no information is available concerning the pattern

On October 18, the TDEC aircraft flew various patterns throughout the New York area The transponder transmitter was disabled to permit more accurate measurements of the interrogating-signal levels The multivibrator triggering action, however, was normal, so that it was possible to record interrogation Figure 58 is a plot of the flight paths flown and indicates portions of the flight when the transponder did or did not reply to the ASR-1 at Idlewild At intervals during the tests, the ASC was made temporarily inoperative to determine whether the loss of replies was due to the ASC bias or to other effects An examination of the plot shows that the transponder replied to the ASR-1 at Idlewild a small percentage of the time Mainly, the loss of replies was due to capture effect by other radars Figure 59 shows the same flight during which the ASR-1 at La Guardia Airport was considered as the participating radar Since the La Guardia radar was not operative during the entire flight, the plot covers only that portion of the flight during which it was known to be operating Here again, capture effect was most severe, and examination of these plots shows consistent capture in several areas During these flights, the ASR-2 at Newark Airport was not in operation and was not the cause of capture The antenna tilt of the La Guardia radar was 1 8° above the horizon

Some of the results of examination of the number and types of radar interrogations encountered during this flight are given in Table XVI A typical 10-minute sample from 3 24 to 3 34 p m, as the aircraft flew at 1500 feet on a heading of 270°, was selected The range was approximately 11 miles, and the position of the aircraft moved from 200° to 210° on the PPI

The series of flights conducted in the New York City area showed that the capture problem does exist and is serious The ASC system of antenna side-lobe suppression as used in the transponder can be controlled by any radar operating at a frequency within the r-f passband From the data obtained in New York, it is indicated that the most serious of the

TABLE XVI

TYPES OF RADARS KNOWN TO BE IN OPERATION

Type of Radar	PRF	Antenna rpm	No of Scans or duration*
Long Range	280	6	55
ASR-1 (2 operating)	1000	26	51
ASR-2	1200	25	200
GCA	2000	30	6
Gunlaying**			

* During period interrogations were received
**(Several tracking types with various PRF's) 3 min , 5-1/2 sec

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capturing radars were of the aircraft-tracking type that remained on the aircraft for several miles During this period of continuous interrogation, the ASC bias was held at a high value which prevented interrogation by ASR radars Furthermore, the transponder peak output power decreases as the interrogation rate increases This characteristic is undesirable, because interrogation by several tracking or searchlighting types of radars reduces the peak power of replies to ASR equipments

Flights were made in the Indianapolis area to determine the possibility of capture of the L-band reply transponder by a powerful slow-scan radar 52 miles from the ASR-2 The aircraft was flown from one radar to the other at several altitudes The vertically polarized antenna supplied with the transponder was used The interrogation data shown in Tables XVII and XVIII were obtained

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TABLE XVII

Aircraft Altitude (feet above ground)	Heading with Respect to ASR-2	Distance from ASR-2 for Complete Capture by Other Radar (miles)	Distance from ASR-2 for Partial Capture by Other Radar (miles)
1000	Outbound	37	37
1000	Inbound	27 5	31
3000	Outbound	40	44 5
6000	Inbound	36	43

If the other radar is considered to be the participating radar and the ASR-2 the capturing radar, capture effect is as shown in Table XVIII

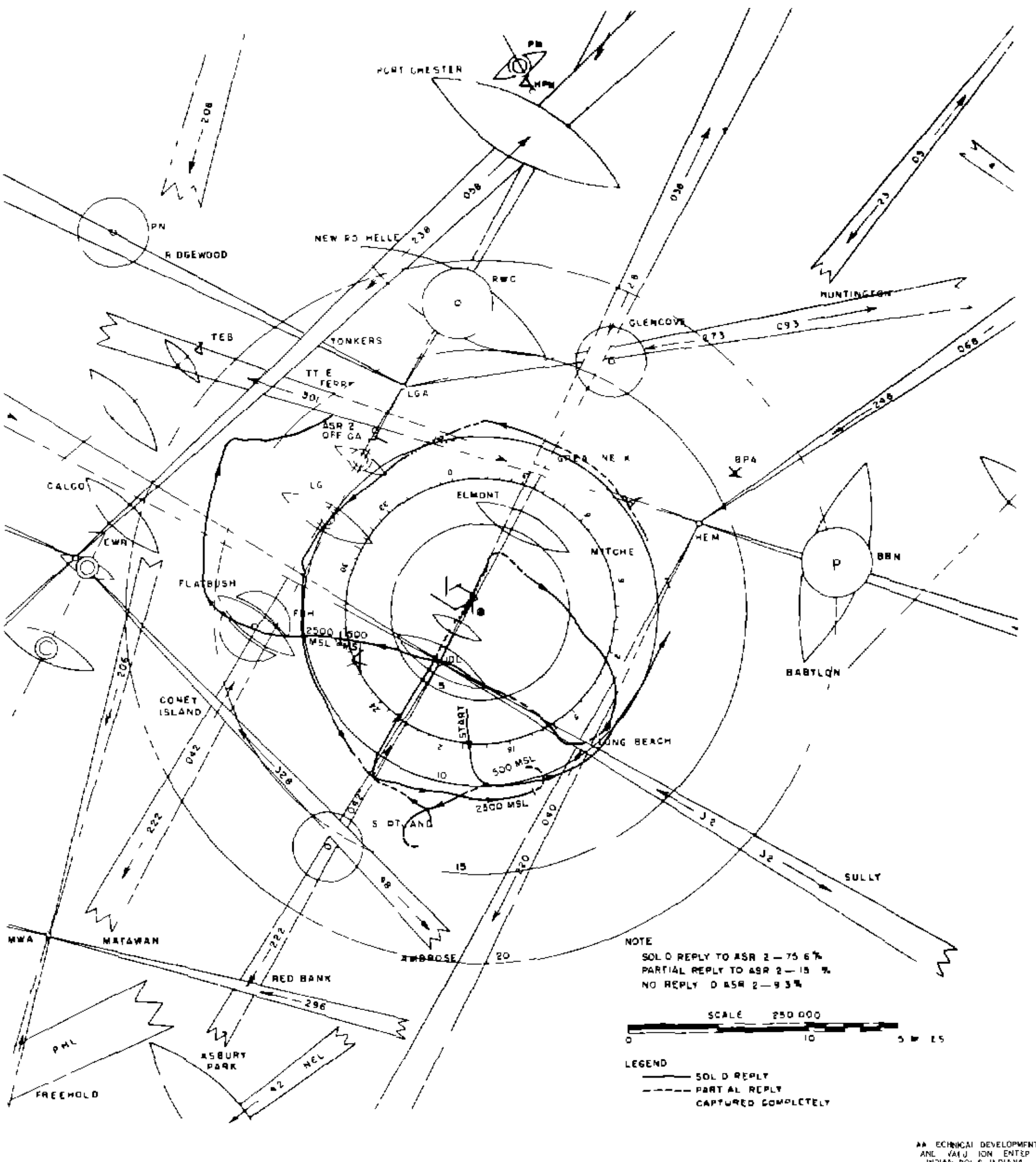


Fig 57 Interrogation by Newark ASR-2

TABLE XVIII

CAPTURE BY ASR-2

Aircraft Altitude (feet above ground)	Heading with Respect to ASR-2	Distance from Other Radar for Complete Capture by ASR-2 (miles)	Distance from Other Radar for Partial Capture by ASR-2 (miles)	Maximum Range of Other Radar Side-Lobe Responses (miles)
1000	Inbound	40	40	3
1000	Outbound	45	45	10
3000	Inbound	51 and 45 to 41	51 to 45 and 41 to 36	6
6000	Outbound	Greater than 52	Greater than 52	19

Data concerning the maximum range of interrogation by the other radar-antenna side lobes are included in Table XVIII to indicate that the transponder ASC does not suppress side-lobe interrogations effectively when the scan speed is very low The bias generated by the ASC circuits decays appreciably between successive antenna scans so that side lobes preceding the main lobe interrogate the transponder

Several methods for decreasing capture possibilities have been advanced Each method tends to discriminate in favor of the ASR and against other radars The suggestions cover r-f selectivity, pulse-repetitive-frequency (prf) selectivity, and antenna-scan selectivity In the case of r-f selectivity, the present frequency passband of 200 Mc would be reduced to exclude as many other radars as possible However, this would restrict the ASR radars to a smaller portion of the spectrum than they now occupy PRF and antenna-scan filters that favor ASR can be constructed The prf filter would limit control of the ASC bias to ASR radars only However, capture between ASR radars and overinterrogation of the transponder would still be possible If the ASC bias is set only by participating ASR radars, then the transponder could reply to the side lobes of the stronger S-band military radars This would overload the transponder, and the overinterrogation problem would be more serious The antenna scan-rate filter would not prevent tracking-type radars from setting the ASC bias It is possible that some combination of these methods would improve the over-all performance of the transponder Tests of such modifications in a high-radar-density area would be necessary to appraise them properly

Equipment Tests and Observations

Interference

During all flight tests it was necessary to turn off all Distance Measuring Equipment (DME) in the aircraft to prevent interference with transponder interrogation Energy from the DME transmitter was coupled from the DME antenna to the transponder-interrogation antenna The DME operates in the frequency range of 963 5 to 986 Mc A pair of 2 5-microsecond pulses are transmitted at a prf of 30 The interfering signals caused the ASC circuits of the L-band reply-model transponder to increase video-amplifier bias levels from 2 3 to 4 9 volts d-c when the transponder was set for interrogation by S-band surveillance radar Increasing the triggering-multivibrator bias from 45 to 73 volts d-c prevented interrogation by the DME transmitter When an S-band signal generator was connected to the transponder, a signal level of -13 dbm was required to establish ASC voltage at 4 9 The generator was adjusted to produce 2 5-microsecond pulses 60 times per second Interference was negligible when the transponder was set for X-band interrogation The operation of navigation receivers, automatic direction finders, marker-beacon receivers, automatic-pilot equipment, and artificial-horizon equipment did not cause interference The operation of communication-transmitting equipment caused temporary interference when the transponder was installed near the transmitter

DME interference was much less when the S-band reply transponder was installed Reduction in interference is due to greater selectivity of the transponder S-band crystal holder It was still necessary to turn DME equipment off during the flight tests The frequency-response characteristics of the crystal holder in two S-band reply transponders were measured In one equipment the center frequency was 2760 Mc Variation within the passband between 2650 and 2870 Mc did not exceed ±2 db, bandwidth between points 3 db down was 235 Mc, and bandwidth between points 18 db down was 380 Mc In the other equipment, maximum response occurred at 2908 Mc The response decreased gradually and was 10 db below maximum at 2680 Mc Variations from a sloping line drawn between the 0 and 10-db points were ±2 5 db Bandwidth between -10-db response points was 265 Mc, and bandwidth between -20-db response points was 365 Mc

The frequency response of the L-band reply-model crystal holder was much broader Between the frequencies of 2700 and 2900 Mc, the response variation was approximately ±0 4 db The half-power bandwidth was approximately 350 Mc, the bandwidth between points 6 db down was 940 Mc, and the bandwidth between points 10 db down was approximately 1600 Mc

Bench tests were made in a shielded room to prevent interference by signals from L- and S-band radars and from arcing between contacts of relays in air-traffic-control interlock systems Interference by signals from commercial low-frequency broadcast stations was also observed Interfering signals cause interrogation and establish ASC voltage that reduces interrogation sensitivity

Transponder-Transmitter Characteristics

In the S-band reply-model transponder, the oscillator tube is a Type 5893 pencil triode During single-pulse operation, maximum average power is limited by countdown of the triggering multivibrator in order to protect the tube against excessive plate dissipation During multiple-pulse operation, maximum average power is limited by countdown and by decreased width of the pulses applied to the oscillator plate as the pulse repetition frequency is increased In the unit tested, the triggering-multivibrator dead time was 240 microseconds and countdown occurred at a pulse repetition frequency of approximately 4160 pps When the pulse repetition frequency was increased from 300 to 4160 pps, the average power increased from 20 2 to 26 75 dbm, the peak power decreased from 388 to 189 watts, and the pulse width decreased from 0 9 to 0 6 microseconds The peak power and the pulse width at 1200 pps were 318 watts and 0 8 microsecond, respectively During double-pulse operation, the peak power decreased from 288 to 92 5 watts and the pulse width decreased from 0 9 to 0 3 microsecond as the pulse repetition frequency was increased from 300 to 3000 During triple-pulse operation, the peak power decreased from 205 to 46 5 watts and the pulse width decreased from 0 9 to 0 18 microsecond as the pulse repetition frequency was increased from 300 to 3000 The peak power at 1200 pps was 173 watts for double-pulse and 132 watts for triple-pulse operation

Bench tests were made to determine the variation of the S-band reply-transponder output power during operation for periods of several hours It was found that the output of two of the four units tested varied greatly The pencil-triode oscillator tubes were interchanged between transponders having stable and unstable output characteristics Results of power-output tests indicated that the instability was caused by the tubes instead of by the cavities Observations of the pulses applied to the plates of the tubes indicated that the modulator output did not vary appreciably during the tests The output of one transponder decreased 6 5 db during a warm-up period of 1 5 hours, and the output of the other transponder decreased 6 5 db during a warm-up period of 3 hours Substitution of tubes decreased the power variation to approximately 1 5 db One of the transponders having unstable characteristics had been used during previous bench and flight tests, but the other unit had been operated less than 10 hours The total frequency drift of the transponder used for bench and flight tests was 11 Mc The frequency was adjusted during the test period so that the maximum frequency drift was 5 5 Mc The maximum frequency drift observed during the warm-up periods was 5 Mc In one unit, transmitter-tube heater pins and corresponding socket jacks did not make reliable connections

The spacings between pulses of multiple-pulse codes may change when the control boxes are interchanged The potentiometers used to adjust pulse delays are located in the control box instead of in the transmitter-receiver unit In one instance, the substitution of one control box for another changed the spacing between the second and third pulses from 15 to 26 microseconds Tolerances established by the manufacturer for pulse delays of 16, 32, and 48 microseconds were ±2 5, ±5 0, and ±7 5 microseconds, respectively Even though the pulse spacings are within the specified tolerances, it is possible that confusion between three-pulse codes will occur The F code, having nominal spacings of 16 microseconds, may have actual spacings that cause the code to have the same appearance as codes C or D The code spacings were not within specified tolerances when the control boxes were interchanged

The triggering-multivibrator and coding circuits are critical with respect to vacuum-tube characteristics In one instance, the second pulse of the two-pulse code B was not present when the 400-cps input voltage was greater than 112 volts The substitution of a new 12AT7 in the socket for V-214, code control and bloomer stage, restored satisfactory operation when the 400-cps input voltage was varied from 105 to 125 volts Tests of the original V-214 in a mutual-conductance tube checker, Hickok Electrical Instrument Company Model 539, indicated that the tube characteristics were normal In several cases, it was noted that the second or third pulses were intermittent or that the delays varied approximately two microseconds Substitution of other 12AT7 tubes in V-213 or V-215 sockets restored normal operation The tubes that were removed from the sockets appeared to be normal when checked in the tube tester Additional investigation of the circuitry and of the tube characteristics would be required to determine reasons for erratic operation

The major difficulties encountered during tests of the L-band reply transponder were insufficient or no transmitter output, short modulator tube life, build-up of ASC voltage when the control switch was turned off, build-up of ASC voltage by stray transmitter energy under low interrogation signal-level conditions, and limiting of signals in the X-band preamplifier

All of the transmitter-oscillator cavities were repaired as recommended by the contractor's representative Repairs that were made restored normal power output Defects which were found included shorting of the screw or nut on the grid-connection strip to the shield, shorting of the locking nut or soldering lug on the heater rod to the frequency-adjustment screw, brass cuttings between the heater rod and the cathode sleeve, poor contact between the heater rod and the tube heater pin, poor contact between the cavity plate connection and the plate of the tube, and improper positioning of the cavity sleeves

One L-band reply transponder was operated for a period of 2950 hours during a life test of the triggering, modulator, and oscillator circuits The transponder was triggered by a pulse generator at the rate of 500 pps The maximum and the minimum peak output power measured during the test was 316 and 135 watts, respectively It was not necessary to replace the oscillator tube or to adjust cavity frequency during the test, but it was necessary to replace the first modulator thyratron, VD-1258, after operation for 211 hours and after operation for an additional 323 hours during the test The thyratrons which were replaced caused jitter and missing of transmitter output pulses When new thyratrons were installed, there was no jitter or missing of pulses until the pulse repetition frequency approached the triggering-multivibrator countdown frequency The maximum repetition frequency for reliable operation decreased as the operation period increased because of changes in the thyratron characteristics

Three L-band reply-transponder oscillator tubes failed during bench tests A Type 5764 planar-grid triode was used The heater of one tube opened, and grid-to-cathode short circuits developed in the other two tubes during a warm-up period of approximately one minute Information obtained from the contractor indicated that grid-to-cathode short circuits are a characteristic of this type of tube At the contractor's plant, some failures occurred suddenly after the tube had been operating for many hours It was also necessary to replace several modulator thyratrons during bench tests A hard-tube, Type 3-E-29, is used in the modulator stage of the S-band reply transponder It was not necessary to replace modulator tubes in these reply transponders

ASC Circuits

Further development or modification of the L-band reply-transponder ASC is needed to improve reliability of the operation During tests of one unit, it was noted that a build-up of ASC voltage occurred when the input signal levels were increased and the ASC control switch was turned off Investigation of video level and bias at the grid of the ASC detector showed that the bias was not sufficient to prevent conduction of the detector The characteristics of the 12AT7 tubes used in the video amplifier and in the ASC detector stages determine whether such a condition can exist The ASC voltage build-up was eliminated by increasing the resistance R251 from 2700 to 3300 ohms to increase the ASC detector bias Increasing the value of R251 reduced the ASC voltage when the ASC switch was turned on and also increased the possibility of interrogation by antenna side lobes Increasing the ASC detector bias also reduced the build-up of ASC bias voltage by transmitter energy introduced into the video amplifier and ASC circuits by stray coupling when the ASC switch was in the ON position and when the input signal level was barely sufficient to cause triggering When there was barely sufficient input signal to cause triggering, an increase of bias voltage by stray transmitter energy decreased the sensitivity so that further increase of the input signal was required to obtain continuous triggering action The effect of stray transmitter energy upon the interrogation sensitivity of the S-band reply transponder was reduced by modification of the ASC circuits

Airborne Antennas

Streamlined antenna housings were not furnished to protect antennas from breakage Several S- and L-band antennas were broken during aircraft-servicing operations The thin plastic insulator and spacer used in the L-band antenna are very brittle and crack easily

Responsors

The local oscillator in the L-band responsor was unsatisfactory and caused much trouble during the tests Cavity modifications similar to those of the L-band transponder-transmitter cavity modifications were necessary The life of the 2C37 tubes in the cavity was not satisfactory Many of the spare oscillator tubes did not oscillate when installed in the cavity The feedback provided within the cavity was not sufficient to insure reliable operation when different tubes were installed Upon investigation of this problem by the contractor, it was found that the inner cavity formed by the grid and cathode sleeves should be modified to increase feedback A modified unit was not available during tests Within a period of continuous operation it was necessary to replace the oscillator tube six times The operating periods between changes were 1500, 649, 34, 174, 291, and more than 284 hours During these periods, it was necessary to adjust the crystal coupling several times to increase the crystal current to the recommended value of 0 6 Ma Except for a slight frequency drift, the operation of the S-band local oscillators was satisfactory

The i-f amplifier strips of three of the four responsors were modified in accordance with recommendations of the contractor in order to eliminate parasitic oscillations at approximately 450 Mc, and the fourth responsor was modified by the contractor before shipment The major portion of the modification consisted of the addition of 33-ohm resistors in series with the screen grids of the Type 5654 amplifier tubes

During alignment of the i-f amplifier, it was necessary to adjust the signal-input level and gain so that the level at the second detector did not exceed 1 5 volts The shape of the over-all response curve changed at higher second-detector levels because of overload in the last two amplifier stages Alignment at lower signal levels provided proper frequency-response and sensitivity conditions when most important Tests of the over-all frequency-response characteristics indicated that the circuits were not stable One measurement indicated that the over-all bandwidth between 3 db points was 13 5 Mc Variations within the band did not exceed ±1 5 db Six weeks later, variations within the same band were ±4 db with a new peak at the low-frequency side of the response curve Slight oscillator-frequency drift or change in i-f amplifier characteristics changed the over-all response curve Adjustment of the oscillator and of the r-f preselector to obtain best over-all frequency response was difficult unless a sweep-frequency type of r-f signal generator was used Further investigation of stability and of means to improve stability is necessary if these responsors are to be used

TR Modification Kit

The attenuation of ASR-2 signals by the TR modification kit was approximately 2 0 db and was the same as that predicted by the manufacturer The attenuation of transponder replies varied from 4 to 6 db, depending upon the over-all bandwidth of the kit and of the responsor From curves furnished by the manufacturer, the attenuation should have been approximately 2 db Apparently, all the tuning adjustments functioned properly The reasons for the difference between the manufacturer's data and the data obtained at this Center have not been determined The frequency-bandpass characteristics are considered satisfactory

Miscellaneous Component Failures

In general, component failures which occurred during bench and flight tests of transponders and responsors did not indicate definite design or construction deficiencies, excepting those failures involving responsor local-oscillator or transponder power-output circuits There were very few failures of component parts such as resistors and capacitors Two L-band reply-transponder 400-cps power transformers failed Because of an error in the first interconnecting-wiring diagram, 28 volts d-c was applied to the primary winding of one transformer and caused overheating and failure It is believed that the other failure was caused by a short of the cavity-heater connection to ground

Test Equipment Required

The following test equipments are necessary for periodic checks of operation and for maintenance of the S-band reply transponder:

1 S-band signal generator, Type TS-403/U or equivalent
2 S-band power meter, Hewlett-Packard Company Model 430B with Model 475B tunable bolometer mount, TS-295/UP, TS-3/AP or equivalent
3 S-band frequency meter, TS-3/AP or equivalent
4 Attenuators, 10- and 20-db, Polytechnic Research and Development Company Type 130 or equivalent
5 X-band signal generator, Type TS-147A/UP modified for pulse operation, or equivalent
6 Pulse generator, Hewlett-Packard Company Model 212A, or equivalent (used with Item 5)
7 Video amplifier, Tektronix Inc Model 121, or equivalent
8 Coaxial crystal detector, Polytechnic Research and Development Company Type 613, or equivalent
9 Synchroscope, Tektronix Model 511-AD, Dumont Model 294A, or equivalent

Items such as audio headsets, vacuum-tube voltmeters, and voltohmeters are not included in this list because these items are available normally Equipment required for tests of the L-band reply transponder is the same as that listed, except that the S-band power and frequency meters should be replaced by Test Set TS-107/TPM, or equivalent

Equipments listed in the following are necessary for tests and for maintenance of the S- or L-band responsors

1 S- or L-band r-f signal generator, Type TS-403/U (S-band), Hewlett-Packard Company Model 614A or Aircraft Radio Corporation Type H-12 or equivalent for L-band
2, Synchroscope, Tektronix Inc Model 511-AD or Dumont Laboratories, Inc Type 294A, or equivalent
3 R-F signal generator, Measurements Corporation Model 80, or equivalent
4 R-F frequency meter, TS-3A/AP for S-band or TS-107/TPM for L-band measurements

OPERATIONAL EVALUATION AND RESULTS

The first operational flight tests were made in the New York metropolitan area The ASR-1 at the New York International Airport (Idlewild) was designated as the primary radar, and flight direction and control were conducted from the instrument-flight-rules (IFR) room at the Idlewild control tower The flight tests were made in co-operation with personnel from the Airborne Instruments Laboratory, the First Region of the Civil Aeronautics Administration, and the Directorate of Flight and All-Weather Testing, Wright Air Development Center, Wright-Patterson Air Force Base The primary purpose of the flight tests was to obtain an appraisal of the transponder capture effect and to provide operational personnel with an opportunity to observe transponder information on the radar indicator Two aircraft equipped with transponders participated in the test program A DC-3 airplane belonging to TDEC was equipped with a MOD II transponder, and a USAF C-47 airplane was equipped with a MOD I transponder which had been modified for S-band reply

It was estimated that between 100 and 200 radars which might affect the operation of the transponder existed in the New York City area The flight tests included

1 Various courses that are normally used in the New York City area during IFR conditions
2 Standard holding patterns over the Glen Cove and Scotland holding markers
3 A 15-mile orbit of the Idlewild ASR-1 at an altitude of 5000 feet
4 A 10-mile orbit of the Idlewild ASR-1 at an altitude of 2500 feet.
5 A 10-mile orbit of the Idlewild ASR-1 at an altitude of 3500 feet
6 PPI approaches and low passes over the Idlewild Airport

Operationally, the following results were obtained from the New York flight tests

1 Analysis of the recorded airborne data showed that the transponder was being captured by other radars during most of the time that replies were not present on the Idlewild indicator Even though there were a multitude of radars which were operating in this area, it was

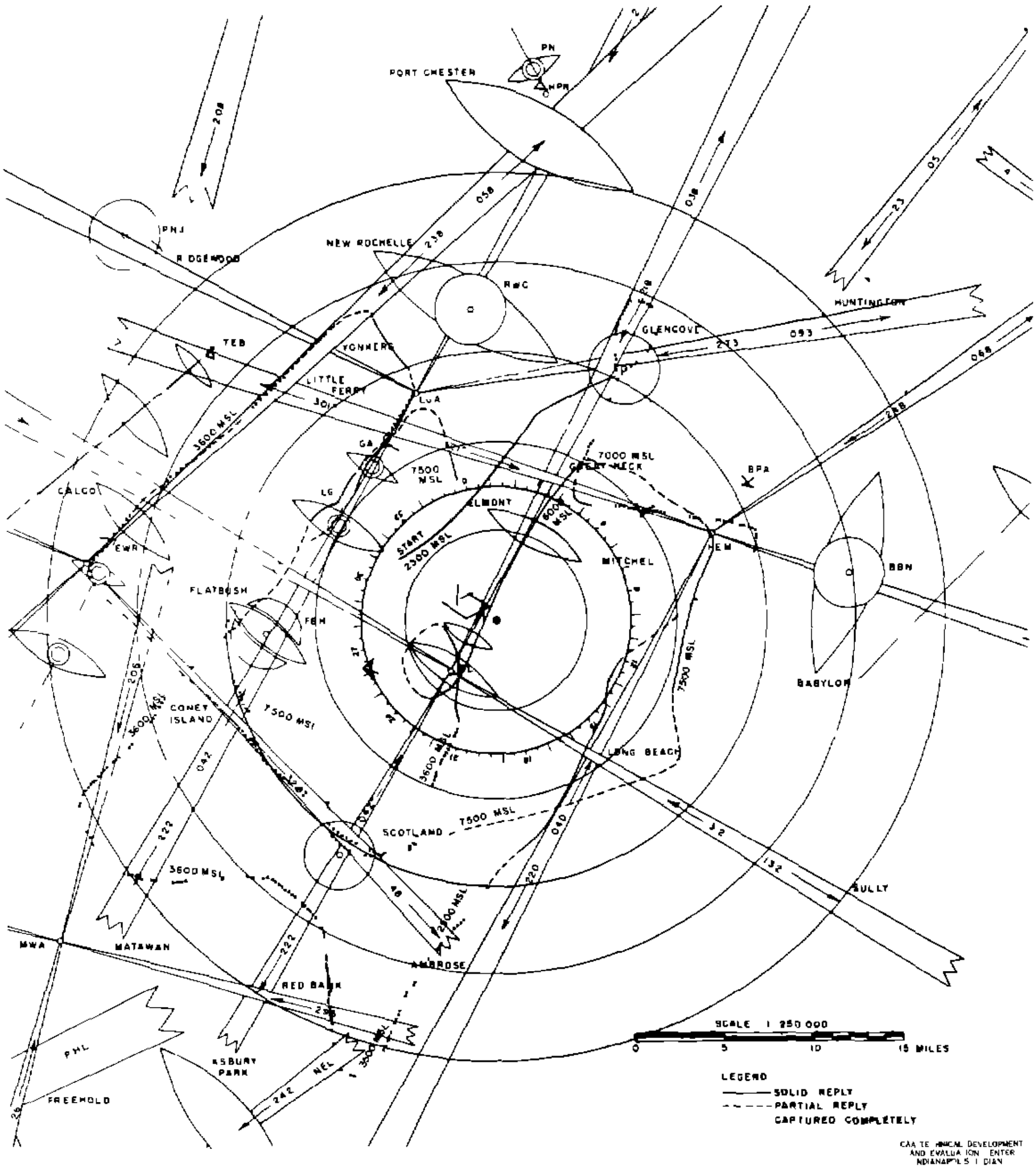


Fig 58 Plot of Transponder Interrogation by Idlewild ASR-1 Radar and of Capture by Other Radars

ible to determine the type of radar which was capturing the transponder at any given time The areas of reply are shown in Figs 57, 58, and 59 Figure 55 shows the areas of reply during an orbit of the Idlewild ASR-1 at an altitude of 2500 feet

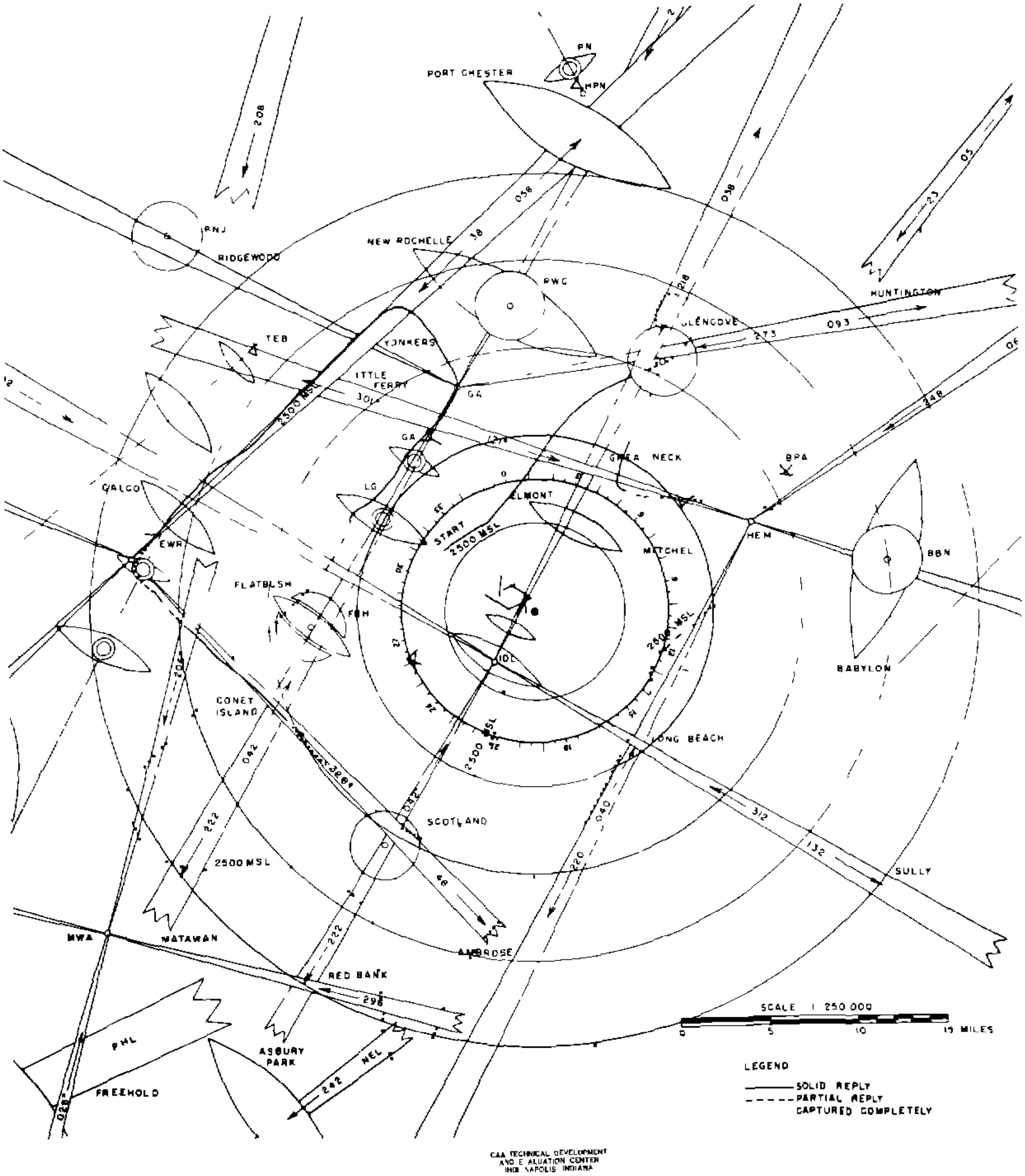


Fig 59 Plot of Transponder Interrogation by La Guardia ASR-1 Radar and of Capture by Other Radars

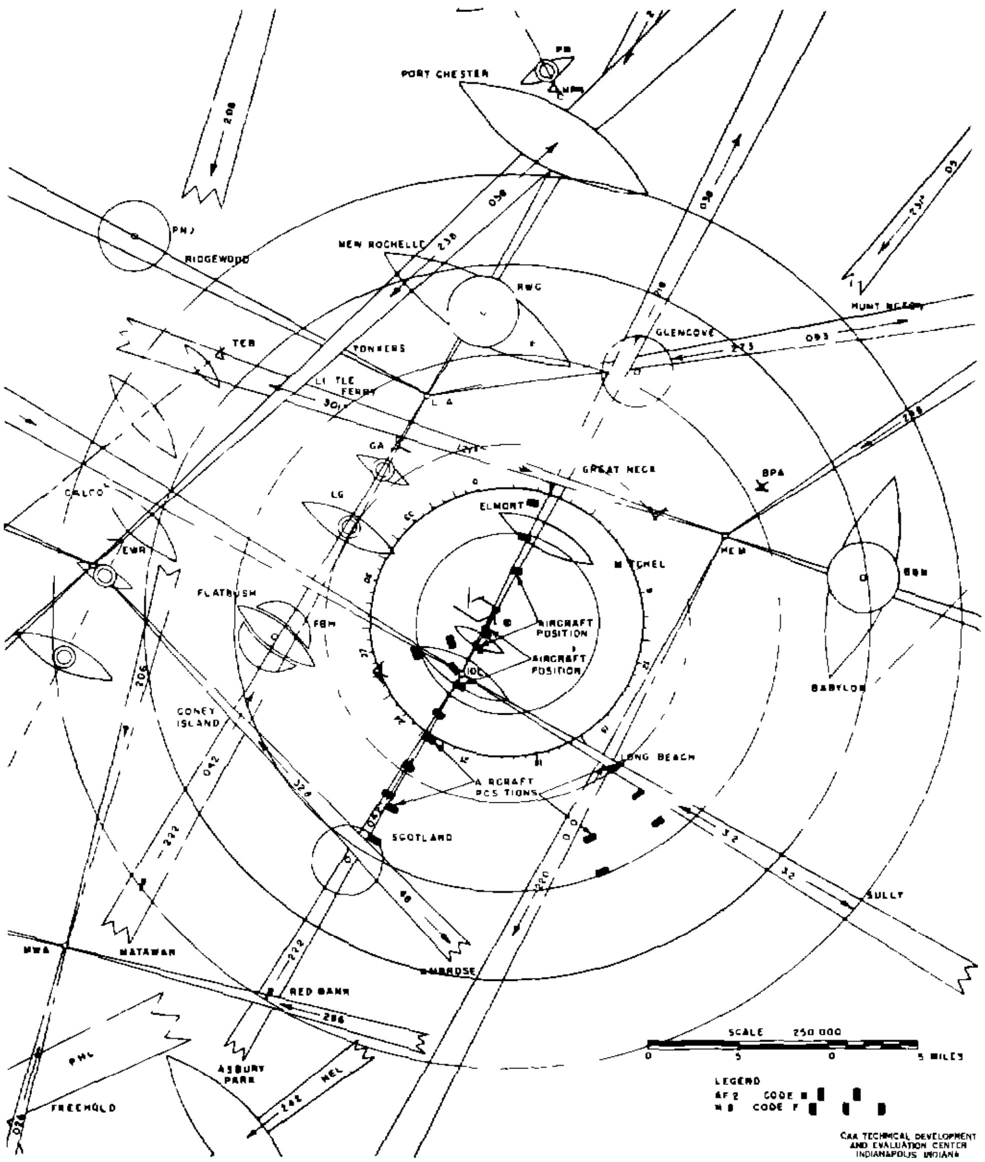


Fig 60 A Sketch of the PPI Showing Two Transponder-Equipped Aircraft in Terminal Area

2 Certain aircraft attitudes caused a temporary loss of transponder reply at the indicator The degree of bank necessary to accomplish a change of direction resulted either in a shielding of the aircraft antennas from the ASR-1 antenna or in a change in ratio of the signal levels of interrogating radars, which change was unfavorable to the participating radar or ASR-1 at Idlewild

3 The use of range-coding to provide identification of aircraft does not appear practical in the terminal area Figure 60 is a sketch showing overlapping identity codes and the difficult problem of distinguishing them

Subsequent flight tests were made in the Indianapolis area when the ASR-2 at TDEC was made available Two DC-3 type aircraft were equipped with transponders and with airborne

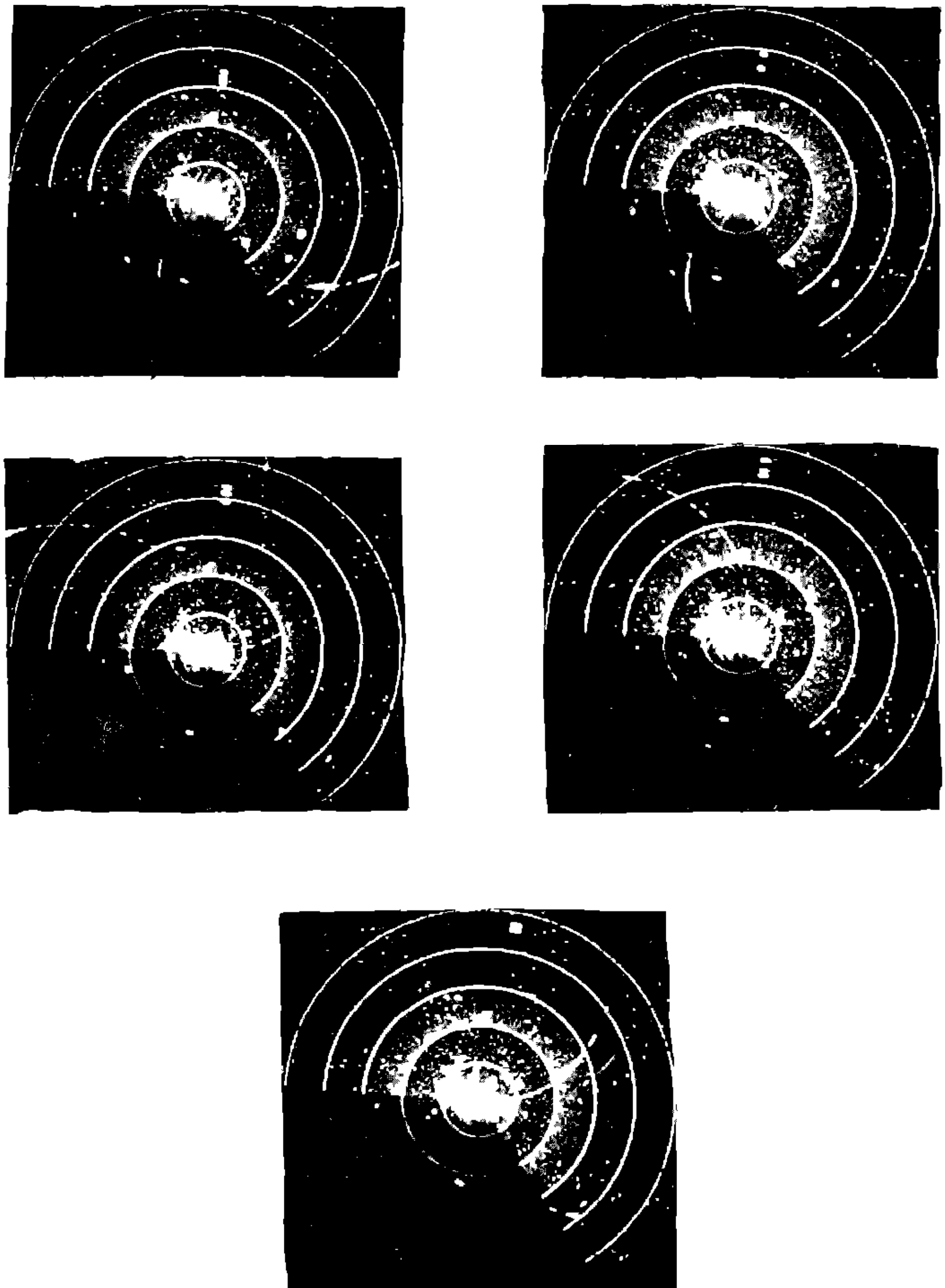
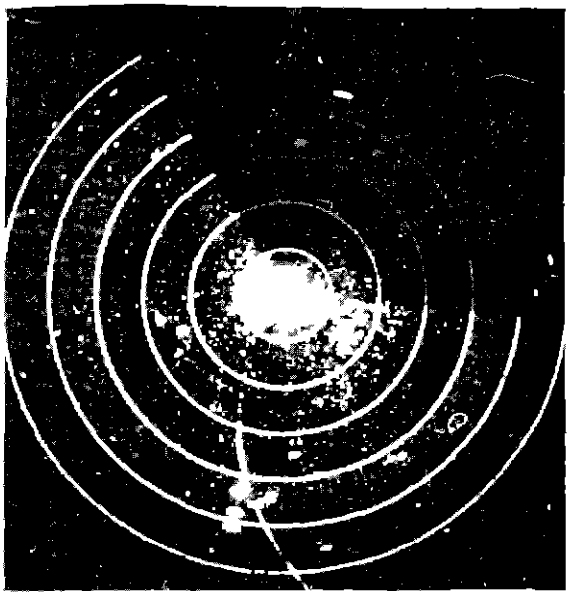


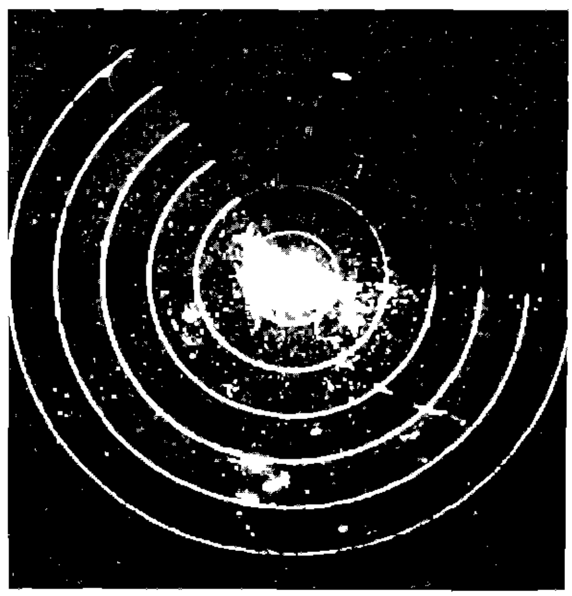
Fig 61 Photographs of Transponder Codes (60-Mile Range)

CODE B

CODE C



CODE D



CODE F

Fig 62 Photographs of Transponder Codes (30-Mile Range)

recording equipment for these flight tests These flights were made to determine

1 Range and altitude coverage
2 Aircraft-attitude effects
3 Second-time-around replies

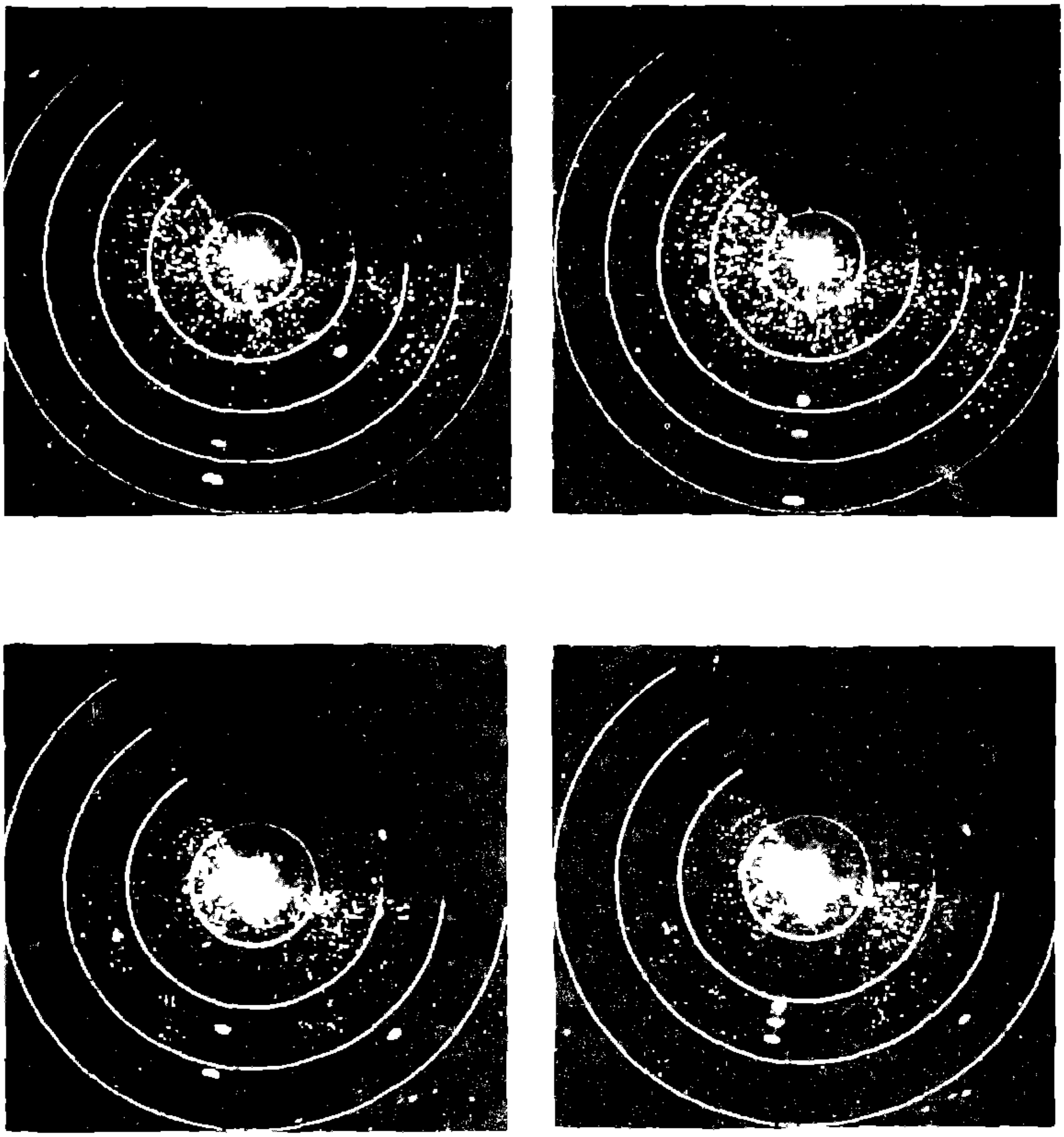


Fig 63 Photographs of Transponder Codes (10- and 20-Mile Ranges)

4 Transponder performance during normal traffic-pattern approaches and PPI approaches
5 Transponder performance when used in conjunction with the PAR-1

Transponder replies were observed on the PPI to a range which is essentially line-of-sight At an altitude of 1000 feet above ground, transponder replies were normally observed to a range of 45 miles The maximum range of transponder replies at an altitude 1000 feet above ground was 52 miles At an altitude of 2000 feet above ground transponder replies were observed on the PPI to 60 miles, or the maximum range of the ASR-2 In subsequent flight tests at altitudes above 2000 feet, the transponder replies were observed on the PPI from the cone of silence over the ASR-2 antenna to the maximum range of the radar Usually, missing and fading were not observed for more than three consecutive scans of the antenna while the aircraft was in level flight

Flight tests show that the attitude of the aircraft with respect to the participating radar does affect the operation of the transponder Although the altitude and the range of the aircraft are a modifying factor, a bank of 15° or more will generally cause loss or fading of the reply at the indicator In some aircraft maneuvers, the loss of transponder target information is the result of a shielding (by the fuselage and wings) of the reply or of interrogation antennas from the participating ground radar In an area containing several radars capable of interrogating the transponder, the fading or loss of target might be a result of a change in the ratio of signal levels which is unfavorable to the participating radar The seriousness of this fading and loss of target during turning maneuvers will be dependent upon operating practices and operator techniques It is expected that radar video will be displayed simultaneously with the transponder video on the PPI The same condition that caused the shielding of the aircraft antennas from the participating radar usually presents a greater reflective surface to the radar antenna, and this provides a better radar target on the PPI

Several PPI approaches were conducted at Indianapolis in an effort to determine the time during which transponder signals were lost because of antenna-shielding The code-selector switch was placed in the B position for these flight tests Normally, this would have provided a two-pulse code reply on the PPI with the first pulse in coincidence with the radar echo and the second pulse delayed 16 microseconds or 1 1/2 miles behind the first pulse For these tests, however, the first pulse was disabled in the airborne transmitter This permitted the display of a radar echo at the aircraft position and the display of the transponder reply delayed 1 1/2 miles During the PPI approaches, the turn from the base leg to the final approach approximated a 90° turn which was made at a distance of 5 miles from the antenna Other radars capable of affecting the test results by capture were not operating during the period of these tests Each approach was observed and photographed on the PPI These data analyses reveal that the transponder reply was lost because of antenna-shielding on an average of three antenna scans during each approach The loss of reply occurred in each instance as the aircraft was turned from the base leg to the final approach The recorded airborne data show that interrogation of the transponder was not interrupted during the turning maneuver, so it is evident that the loss of transponder reply at the PPI was the result of a shielding of the response antenna At the completion of the PPI approaches, an approach was made to each runway from a normal traffic-pattern altitude of 800 feet above ground and at a distance of 2 to 3 miles from the radar antenna During each normal approach, the transponder reply was lost for two or three antenna scans as the aircraft was turned from the base leg to the final approach Some of the transponder replies appeared to be quite weak This indicated that the aircraft was in a partial bank and that some shielding was taking place While this condition of weak and missing transponder replies may appear serious, it is not anticipated that traffic-control procedures would be adversely affected The radar operator can be reasonably certain that the transponder reply will reappear as soon as the aircraft returns to level flight It is interesting to note that the radar echo was displayed at all times during the PPI and normal approaches and that the radar operator was supplied with positional information at all times

A flight which was made to determine the presence of second-time-around transponder replies is described in another portion of this report From an operational viewpoint it was determined, as a result of this flight, that as long as the transponder-equipped aircraft is within the line of sight of the interrogating radar antenna and as long as the equipment is at optimum operating condition and in an attitude favorable for good signals, a false signal can be present on the PPI The second-time-around reply will obviously have an adverse effect on air traffic control

Several flights were made to determine the effect of the transponder when replying to X-band or PAR interrogation Although these flights were made primarily to gather information of a technical nature, some operational results were noted

Transponder replies as displayed on the PAR-1 indicators were constant Missing or fading was not observed The angular size of the transponder reply on the indicator was no larger than the normal aircraft target It was noted, however, that the addition of the

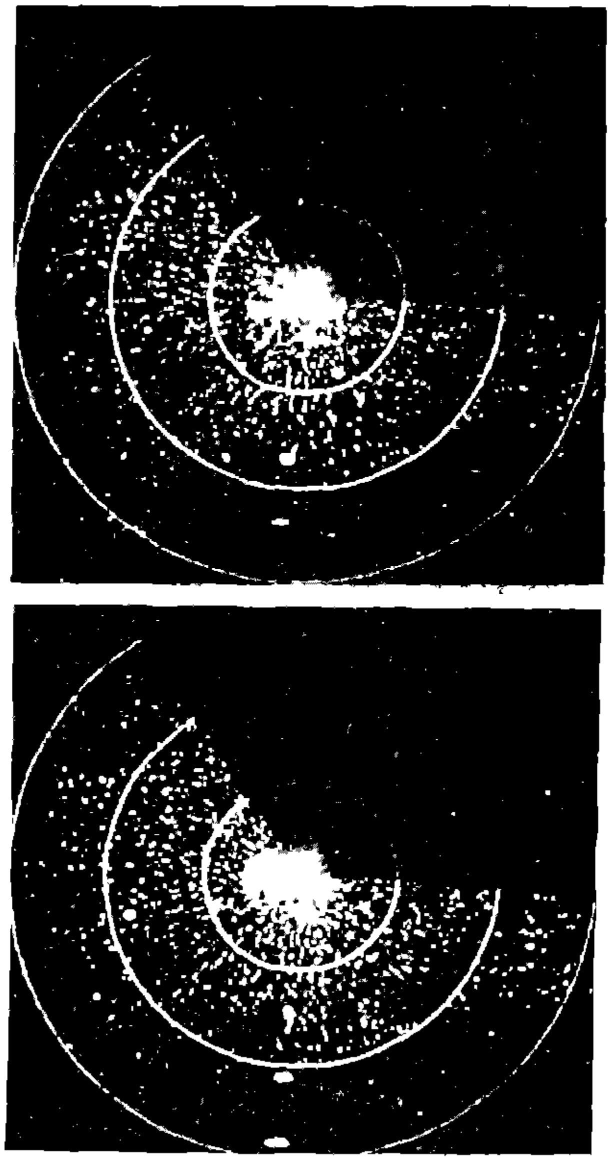


Fig 64 Photograph of Transponder Codes (6-Mile Range)

transponder reply almost doubled the target size in range, because the pulse length of the transponder pulse is approximately 1 0 microsecond The PAR-1 pulse width is approximately 0 5 microsecond The operational effect of this increased target size with respect to the proper spacing of aircraft on final approach is believed to be negligible Figures 21 to 23 are photographs of transponder replies displayed on the PAR-1 indicators The bloomer-code identification was observed on the PAR-1 indicators This code feature placed a second reply, which was separated in range by 1 1/2 miles from the first reply, on the indicator The coding of transponder replies on the PAR-1 is not believed necessary or desirable for the following reasons:

1 Identification has been accomplished before the aircraft target reaches the final-approach course

2 Usually, only one or two aircraft targets are displayed on the PAR at the same time, and identification does not become a factor

3 If smaller spacing were permitted between aircraft, such as in some military operations, then the use of the bloomer identification code would only serve to further confuse the display

The transponder identification codes are explained in Appendix I Figures 61, 62, 63, and 64 are photographs of these identifying codes as displayed on the different range scales of the PPI The spiral-shaped patterns on the PPI are caused by interfering signals from another ASR-2 near the TDEC ASR-2 From an operational viewpoint, one of the chief objections to this method of identification coding is that it takes a large amount of space on the PPI For example, the F code requires a display range of 4 1/2 miles If many transponder replies are to be coded and viewed simultaneously on a PPI, overlapping and clutter might assume serious proportions The problems that arise in connection with PPI clutter and overlapping code groups must be carefully considered Figure 60 is a sketch of a PPI which depicts the seriousness of this problem in the terminal area

Of prime importance in a transponder system is the need of a reliable reply to be used by the ground-control agency for aircraft-position information Identification coding can be considered as of secondary importance in the presently developed terminal-area traffic-control procedures

The importance of positive radar identification of all aircraft which are under radar navigational guidance cannot be overemphasized During the course of simulation studies,[7] it was found possible to design terminal-area control systems which never required a single controller to know the exact identity of more than three radar targets simultaneously Simulation tests show that a trained controller has little difficulty in keeping straight the identities of one to three targets in an approach pattern, provided that he can see them continuously These findings imply that it is far more important to provide a positive, continuous display of aircraft positions than to provide a display capable of showing different identifications for different targets in the approach area To avoid the confusion which would result from the display of several identification codes in the terminal area, it is apparent that the display of a simple bloomer code or of a two-pulse reply is more satisfactory for identification The use of this identification procedure would necessarily be at the discretion of the control agency The simple bloomer code referred to is an identification feature wherein the single-pulse reply changes shape momentarily, assuming an enlarged or elliptical appearance that can be readily discerned This type of bloomer is believed superior to the type provided in the Rho/Theta transponder equipment wherein the bloomer-code position results in the display of a second pip delayed 16 microseconds, or 1 1/2 miles in range, behind the aircraft position This pip is displayed when the pilot activates the communications transmitter and remains displayed for ten seconds after the microphone button is released Usually, the control agency in the terminal area does not require identification for that length of time The radar controller prefers to have identification for one or two scans of the antenna and to then have the reply coding released in order to prevent confusion and clutter It appears, for presently developed traffic-control procedures and for traffic-control procedures under development for future use, that the single-pulse transponder reply superimposed on the radar echo will satisfy the needs for positional information A bloomer code which enlarges or changes the appearance of the reply momentarily or a closely spaced two-pulse code which can be requested by the radar controller as the need for identification arises appears to satisfy traffic-control needs If coding of the transponder reply offers means for developing new traffic-control procedures, then the problems of code legibility and distinguishability and of intermingled transponder replies and radar echoes will have to be considered and resolved

The following operational results were observed

1 The reliable range of positional information is increased through use of the transponder

2 The effects of nulls in the vertical pattern of the radar antenna as observed on the radar indicator are minimized through use of the transponder

3 Capture effect presents a serious operational difficulty in areas wherein several radars are operating in the same frequency band

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[7] C M Anderson and T K Vickers, "Application of Simulation Techniques in the Study of Terminal Area Traffic Control Problems," CAA Technical Development Report No 192, June 1953

4 Second-time-around transponder replies which will have an adverse effect on air traffic control can be presented on the PPI

5 Antenna-shielding which resulted in fading or in loss of transponder reply at the PPI was noted whenever the aircraft reached or exceeded a 15° bank

6 The single-pulse code was found to be most satisfactory for terminal-area radar traffic-control purposes Intolerable PPI clutter resulted from multiple-pulse coding of aircraft transponder replies in the terminal area

7 The use of a bloomer identity code or a closely spaced double-pulse code appears to satisfy the need for reply identification

CONCLUSIONS

It is concluded that the Rho/Theta transponder system which includes the S-band-reply airborne equipment would be beneficial for terminal-area traffic control except in areas where several S-band radars are operated Certain improvements to the airborne transponder and to the antennas, the TR modification kit, and the responsor are needed to achieve better equipment stability and reliability Data and experience pertaining to the system which includes the L-band reply airborne equipment are not sufficient to permit definite conclusions, since the components for modification of the ASR-2 antenna were not available Because interrogation problems of both systems are the same, conclusions regarding the S-band reply system also are applicable to the L-band reply system Response-path characteristics are different because of the difference in frequency At the L-band frequency, response-path azimuth resolution is decreased because the beamwidth of the modified ASR-2 antenna is greater at the lower frequency The increased beamwidth decreases the possibilities that responsor sensitivity-time-control provisions alone can be used to obtain the desired resolution and increases the need for automatic sensitivity control in the interrogation path Also, at the lower frequency, deeper minima in the interference-pattern lobe structure will occur Larger variations in the levels of signals received from the aircraft decrease the possibilities of using responsor STC to control the azimuth resolution if the display of transponder replies is required when aircraft fly through the interference minima

Operation of either system when used in conjunction with the TDEC PAR-1 was generally satisfactory The response path does not present serious problems Modification of the X-band preamplifier of the L-band reply transponder was required to prevent signal-limiting and interrogation by PAR-1 antenna side lobes when the aircraft was near the touchdown point of the runway Tests to determine the probabilities of capture during PAR-1 interrogation were not made However, it is believed that interrogation capture cannot occur unless two PAR-1 equipments or similar X-band approach radars view a common airspace and are physically located so that the aircraft fly toward both radars during approaches Operation during interrogation by other PAR-1 or X-band approach radars may or may not be satisfactory, depending upon the relative power of the antenna main and side lobes and upon relative powers radiated by the azimuth and elevation antennas

Use of the transponder in areas of low S-band radar density effectively increases primary-radar coverage and target reliability When the transponder ASC is used, the azimuth resolution is comparable to that of the primary radar and is satisfactory for traffic-control purposes The range resolution also is comparable to that of the ASR-2 and is satisfactory from a terminal-area traffic-control standpoint

Transponder ASC provisions improve the azimuth resolution and reduce the possibility of overinterrogation by nonparticipating radars when interrogation signals from participating radars are the strongest The use of ASC introduces the possibility of transponder capture by nonparticipating radars when the levels of the signals from nonparticipating radars are much greater than those from participating radars In the New York City area, the effects of capture would be serious Signals from tracking-type radars are especially effective in building up the ASC voltage It is also probable that one of several participating radars would capture the transponder so that the other participating radars could not cause interrogation In areas where capture would be a problem, it would be necessary to turn off ASC and to use responsor STC to reduce the display of ground-radar antenna side lobes This increases the possibilities of countdown and of serious decrease in the transponder peak power and pulse width because of overinterrogation, especially when multiple pulses are transmitted It is possible that better methods of limiting the average power of the transponder could be used

From data available, the use of responsor STC alone to control the display of replies to the side lobes does not appear to be practicable However, it is possible that further study and experience would show that compromises that would be operationally satisfactory could be made between the control of side-lobe display and the reliability of replies from aircraft at higher altitudes Modifications of the transponder to decrease the possibilities of capture when ASC is used have been suggested but have not been developed or tested Such suggestions include the use of an S-band crystal holder having greater frequency selectivity and the use of modifications to allow only those signals from radars having a particular range of scan rates or of pulse-repetition frequencies to activate the ASC circuits

The presence of second-time-around responses on the surveillance-radar PPI is a source of confusion to the traffic controller These responses may become intolerable when traffic densities of the terminal and en route areas are heavy It is not practical to reduce primary-radar pulse-repetition frequencies to increase the range of second-time-around responses to the extent that space attenuation prevents interrogation or attenuates reply signals to levels which are not visible on the PPI One solution of the problem would be to assign different identification codes to transponders in different volumes of airspace Only one code would be assigned to aircraft within 77 miles of the radar Decoding equipment at the radar would accept that particular code and would reject signals from transponders which are transmitting other codes and which are outside of the 77-mile range circle Use of such a system decreases the number of codes available for identification purposes and introduces possibilities of conflict when several radars have overlapping coverages

The interference-susceptibility characteristics of the transponder are not adequate to insure reliable operation when the transponders are installed in aircraft, particularly when DME is operated Measurements were not made to determine whether radiation or conduction of signals from other equipments were greater than normally allowed or expected It is possible that a trigger from the DME equipment could be used to disable the transponder ASC circuits so that DME signals could not control the transponder-interrogation sensitivity

The effects of aircraft attitude upon the reliability of operation warrant consideration from an operational standpoint but are not believed to be particularly serious The operation of other beacon systems is also affected by aircraft attitude

The equipment modifications or investigations needed to improve the reliability and the stability of operation are as follows

1 Reduce the attenuation of the transponder replies in the TR modification kit

2 Improve the design and the construction of the oscillator cavities in the L-band reply transponders and responsors

3 Investigate the frequency-stability characteristics of the oscillators in the S-band reply transponders and responsors and investigate the variations in the peak power output of the transponder

4 Improve the frequency-response stability of the S-band and L-band responsor intermediate-frequency amplifier strips

5 Investigate the means to reduce the effect of stray transmitter energy upon the bias level established by the ASC circuits under low input-level signal conditions

6 Improve the transponder-triggering multivibrator circuits so that larger variations in vacuum-tube characteristics can be tolerated

It is understood that the characteristics of the Rho/Theta transponder system are not compatible with military-beacon requirements Adoption of this system would require that civil and military aircraft carry two types of airborne equipments in case of a national emergency

RECOMMENDATIONS

It is recommended that development and evaluation of the Rho/Theta transponder system be discontinued for the following reasons

1 The Air Traffic Control and Navigation Panel of the Air Co-ordinating Committee has recommended that efforts pertaining to the transponder be discontinued and that Air Traffic Control Beacon System having characteristics suitable for military and civil use be developed and evaluated It is understood that characteristics of the transponder system are not compatible with those required for military use

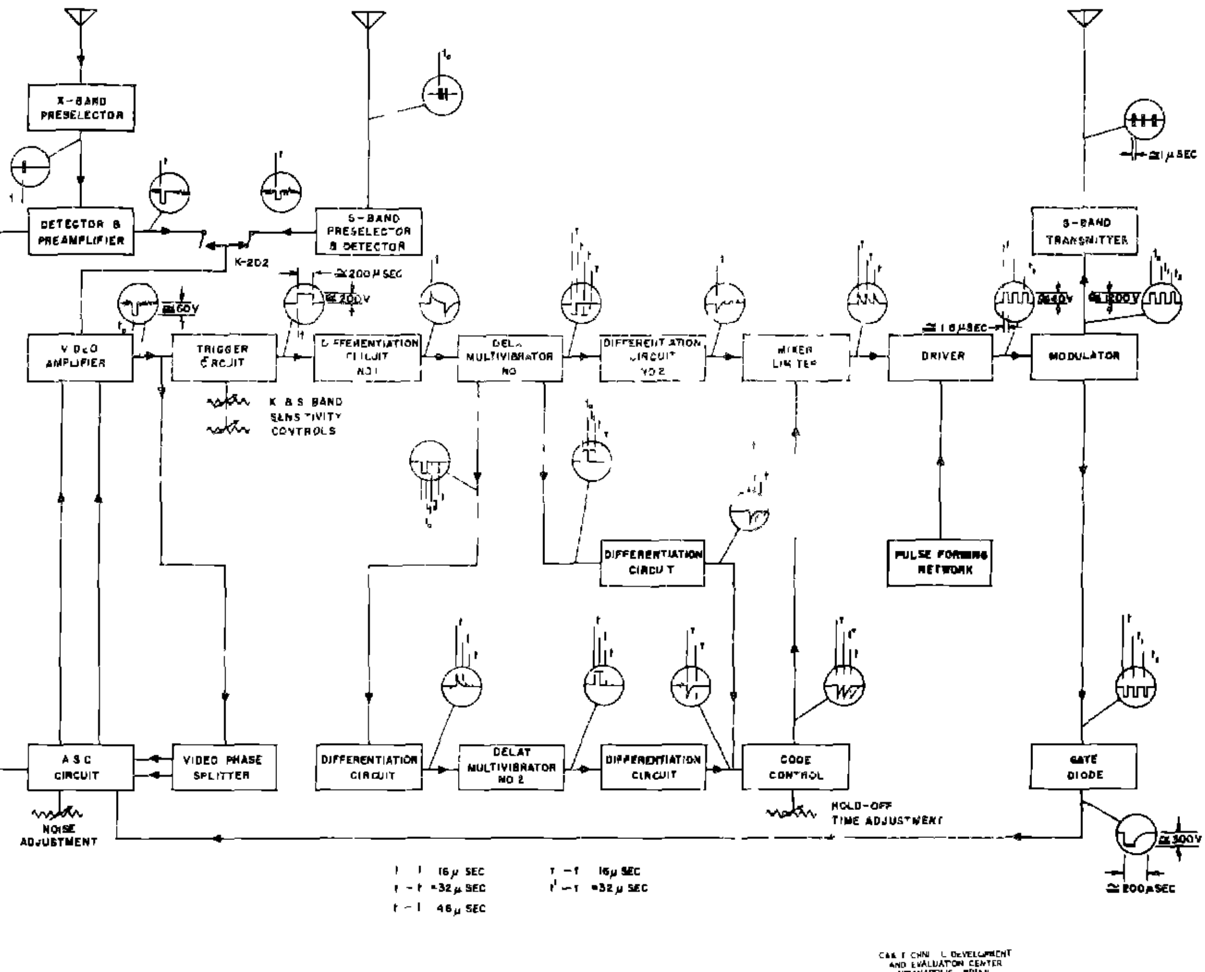

Fig 65 S-Band Reply Transponder, Simplified Block Diagram

2 Results of evaluation work completed indicate that transponder characteristics are not suitable for terminal-area traffic-control purposes because of the detrimental effects of capture and of second-time-around responses.

It is recommended that the following factors be considered during development of any beacon system to be used for air-traffic-control purposes:

1 By equipment design or by the implementation of a secondary-radar system, eliminate capture and second-time-around problems While some degradation of azimuth resolution is tolerable, the display of beacon replies to interrogating-antenna side or back lobes must be held to a minimum

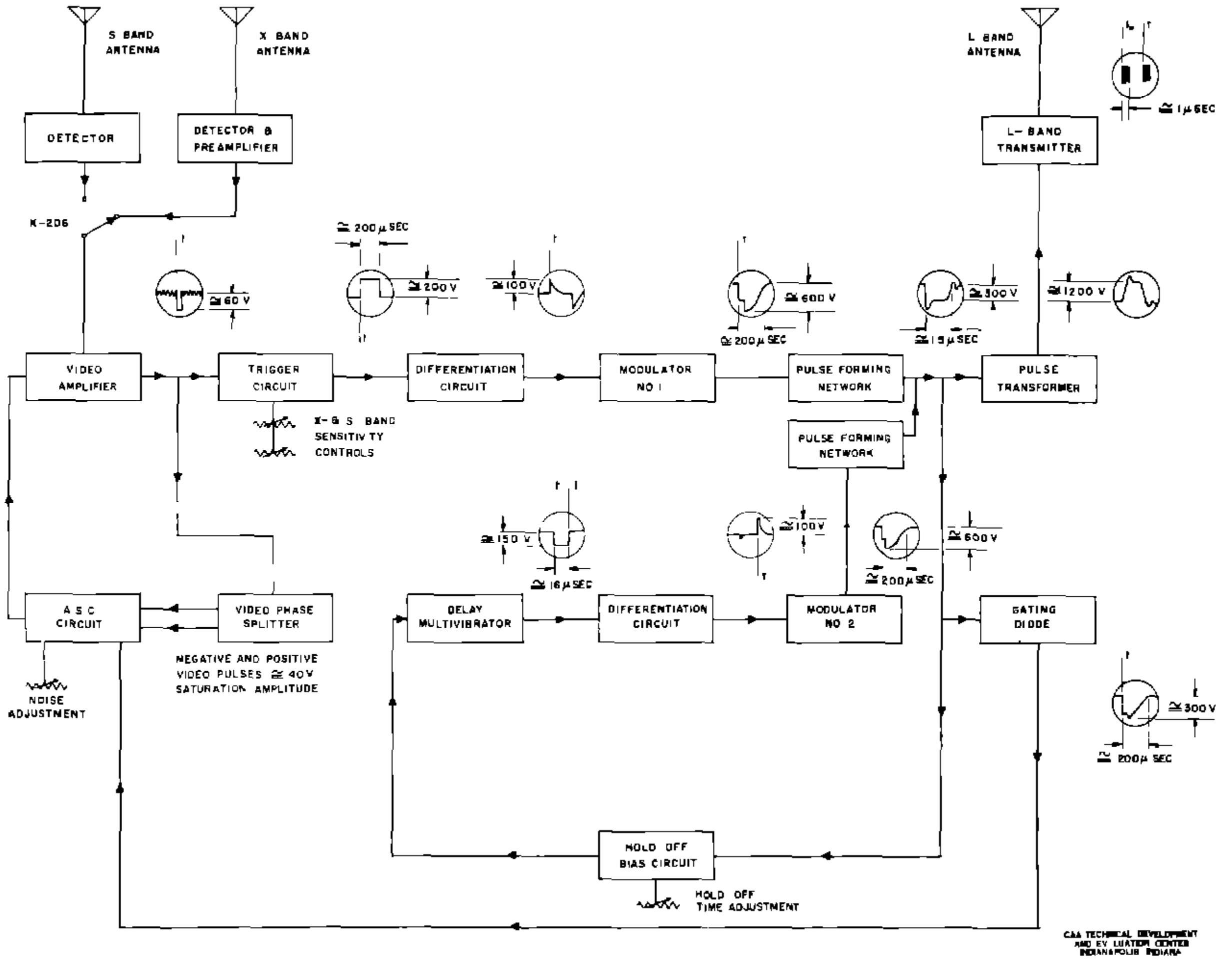

Fig 66 L-Band Reply Transponder, Simplified Block Diagram

2 Develop a means of displaying target identification that does not introduce possibilities of confusion between identification pips and normal radar targets, that does not permit excessive overlapping of codes on the PPI, and that does not clutter the PPI

3 Improve aircraft-antenna designs and placement to minimize the effects of aircraft heading and attitude upon the reliability of the interrogation and response paths

APPENDIX I

DESCRIPTION OF AIRBORNE EQUIPMENT

Figures 65 and 66 are block diagrams of the S-band and L-band reply transmitter-receiver units and X-band preamplifiers As indicated in Fig 65, the S-band transmitting and receiving antennas are vertical quarter-wave stubs with matching transformers built into the bases to match the antenna impedance to that of a RG-8/U transmission line The receiver portion of the receiver-transmitter unit is of the crystal-video type

The r-f signal from the S-band antenna is detected by a 1N32 crystal in a double-tuned cavity The cavity was designed to have negligible attenuation in the frequency passband of 2700 to 2900 Mc and to provide attenuation of at least 17 db at frequencies above 3100 and below 2500 Mc Video signals from the crystal are connected to the video-amplifier stages by the receiver selector relay, K-202, when the control-unit interrogation selector switch is in the NAV position The video amplifier consists of six stages, three 12AT7 tubes, arranged to form three feedback pairs

Negative pulses from the video amplifier are coupled to the trigger circuit consisting of a trigger diode and a cathode-coupled multivibrator The components of the multivibrator circuit have time constants of such nature that the recovery or dead time is approximately 250 microseconds The dead time is provided to limit the transmitter-tube duty cycle in order to prevent excessive plate dissipation and possible damage to the tube The maximum theoretical rate at which the multivibrator may be triggered or the transponder may be interrogated is 4000 pps The trigger sensitivity is controlled by an adjustment of the S-band sensitivity-control potentiometer which varies the positive d-c voltage applied to the cathode of the trigger diode

Positive pulses from the trigger circuit are differentiated by differentiation circuit No 1, and the positive portions of the differentiated pulses trigger delay multivibrator No. 1 Undelayed negative pulses from delay multivibrator No 1 are differentiated in differentiation circuit No 2 and are fed to the mixer-limiter stage The output of the mixer-limiter stage consists of positive pulses of equal amplitude and is applied to a regenerative driver through a pulse-forming network and a winding of the blocking-oscillator transformer Positive pulses in the output winding of the blocking-oscillator transformer are applied to a conventional modulator stage having a pulse transformer in the plate circuit The output of the pulse transformer has an amplitude of approximately 1200 volts and is applied to the plate of a Type 5893 pencil-triode oscillator tube The oscillator tube is used in a plate-tuned re-entrant type of cavity which may be adjusted for operation at any frequency between 2900 and 2950 Mc by changing the position of the shorting choke inside the cavity

The preceding description pertains to single-pulse response, or the transmission of one pulse for each interrogation pulse received This pulse is transmitted at a time t_0 with respect to the time that the interrogation pulse is received A second transmitted pulse occurring at time t_1 is obtained by the delaying action of delay multivibrator No 1, and a third transmitted pulse occurring at time t_2 is obtained by the action of delay multivibrator No 2 For single-pulse response, the code control stage is cut off by the application of negative grid bias through a switch in the control box The negative grid bias is removed when the control-box switch is set for multiple-pulse operation When the third pulse is not desired, delay multivibrator No 2 is cut off by the application of a negative bias voltage The delay time of each multivibrator is determined by the amplitude of the positive bias applied to the grid of the first section of the multivibrator Bias amplitudes are selected by the code-selector switch in the control unit

When the code-selector switch is set to position A or Z, the code control stage is cut off except when a relay is closed, thus grounding the grid This relay is closed when the radio-communication microphone button is pressed The code control stage continues to operate for approximately ten seconds after the microphone button is released because of the large time constant of a resistor and capacitor in the grid circuit connected to the negative-bias supply circuit The time constant is such that approximately ten seconds is required for the capacitor to acquire a negative charge sufficient to cut off the stage The code obtained by the addition of the second pulse when the microphone button is closed has been identified as the bloomer code The identification codes available are given in Table XIX

When the NAV-LAND switch is in the LAND position, the video-amplifier input circuit of the receiver-transmitter unit is connected to the output of the X-band preselector through contacts on relay K-202 and on the video coaxial cable The X-band antenna, the preselector, and the preamplifier are connected together mechanically to avoid loss of r-f signal that would occur if longer lengths of waveguide or transmission line were used The preamplifier contains

TABLE XIX

IDENTIFICATION CODES

Code Letter	Number of Pulses Transmitted for Code-Selector Switch Setting of NAV	LAND	Spacing Between Adjacent Pulses (microseconds)
A	1	1	--
A (Bloomer)	2	1	16
B	2	1	16
C	3	1	16 and 32
D	3	1	32 and 16
E	2	1	48
F	3	1	16 and 16
Z	1	1	--
Z (Bloomer)	2	2	16

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a IN23B crystal, a video amplifier, and a cathode-follower stage The amplification of the video signals in the preamplifier reduces possible deterioration of the signal-to-noise ratio due to noise that may be picked up by the video transmission line

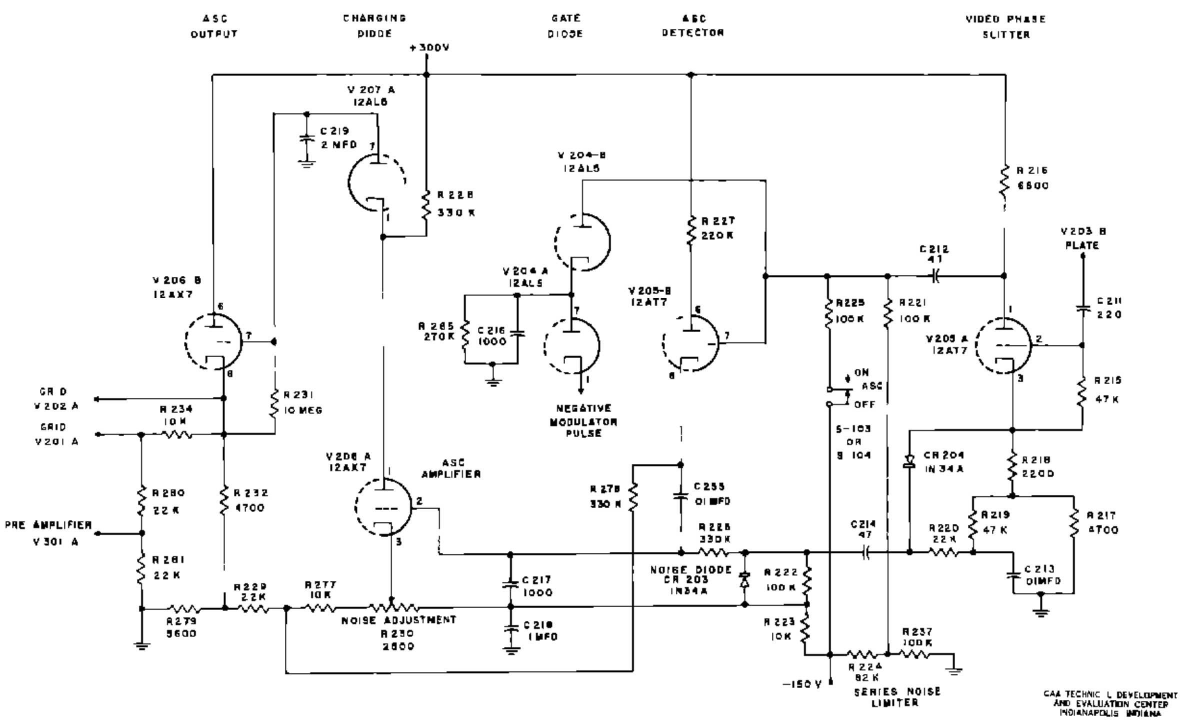

Fig 67 ASC, Simplified Diagram

The X-band antenna is a horn-type antenna which receives horizontally or vertically polarized energy One precision-approach-radar antenna is horizontally polarized, and the other is vertically polarized It was designed to have a minimum vertical-plane beamwidth of ±20° and a minimum horizontal-plane beamwidth of ±45° The antenna is mounted in the nose of the aircraft so that the equipment may be interrogated by precision-approach radars when the aircraft is approaching the instrument runway A triple-tuned waveguide filter is inserted between the antenna and the preselector to increase selectivity The filter was designed to have a negligible insertion loss over the frequency band of 9000 to 9180 Mc and to provide at least 50-db attenuation of signals below 8400 and above 9000 Mc

The most unusual feature of the airborne equipment is the noise stabilization and ASC circuitry The purpose of the ASC circuits is to improve the azimuth resolution and to prevent interrogation by side lobes of the interrogating-radar antenna The ASC circuits develop a bias voltage to control the interrogation sensitivity The bias is applied to the grids of the first and third video-amplifier stages in the receiver-transmitter unit and to the video-amplifier stage in the X-band preamplifier The bias level set by the ASC circuits at any instant depends upon the power level of the strongest pulses most recently received, the rate at which the pulse trains are received, and the time constant of the ASC circuit When signals are received from one radar, such as an ASR-2, the bias is determined by the level of the signals from the main lobe The corresponding bias established by the ASC circuit reduces the video-amplifier gain so that signals from the antenna side lobes, having levels approximately 20 db lower than main lobe signals, will not trigger the transponder Actually, the ratio of the level of the weakest signals that cause interrogation to the level of the strongest signals that establish the bias varies with the level of the strongest signals The ratio is greater for higher bias values

Figure 67 is a schematic diagram of the ASC circuits The video output of V-203B is connected to the grid of V-205A which is operated as a phase-splitter stage Negative signals at the cathode are connected to the anode of the series-limiter diode CR-204 The diode is conductively biased by the voltage drop across resistor R-218, and it limits the negative signals to a level above the normal noise level Noise voltages are rectified and filtered by rectifier CR-203, resistor R-226, and capacitor C-217 The output of the filter is applied to the grid of V-206A, the ASC amplifier stage The bias of V-206A can be varied by adjustment of potentiometer R-230, which is a noise-level adjustment control The d-c voltage at the grid of V-206A controls the voltage at the plate of this tube which is connected to the cathode of diode V-207A If the cathode potential is more than one volt negative with respect to the cathode of V-206B, capacitor C-219 will be charged negatively by conduction of V-207A This increases the negative grid bias of V-206B, which decreases the current in cathode resistor R-232 and increases the negative bias applied to the gain-control tubes V-301A, V-201A, and V-202A The potential of the V-206B cathode is negative to the ground because of the negative voltage which is across resistor R-279 and which is developed by the voltage divider connected to the -150-volt d-c power supply Increasing the negative bias reduces the gain of the video-amplifier stages and reduces the rectified noise voltage at the grid of V-206A Reduction of the rectified noise voltage increases the voltage at the plate of V-206A so that V-207A is cut off and the 2-mfd capacitor C-219 discharges slowly through the 10-megohm resistor R-231 Discharge of C-219 decreases the negative grid bias of V-206B and increases the current in R-232 in the cathode circuit This reduces the negative voltage applied to the grids of the video amplifiers and increases the video-amplifier gain The circuits tend to maintain a constant noise voltage at the output of the video amplifier A small change in the noise voltage can cause a large change in the video-amplifier gain because of voltage amplification by V-206A, the ASC amplifier tube The amplification increases the stabilization of the gain or noise output Adjustment of potentiometer R-230 adjusts the gain of the video amplifier, because a small change in the bias applied to V-206A corresponds to a change in the rectified noise which depends upon gain

Pulses in the plate circuit of V-205A are positive and are fed to the grid of the ASC detector V-205B Normally, V-205B is biased beyond cut-off by means of the voltage-divider network composed of R-224 and R-237 and connected to the -150-volt d-c power supply Positive video signals having sufficient amplitude cause V-205B to conduct and to charge capacitor C-217 The positive charge, which is connected to the grid of the ASC amplifier V-206A, causes the plate potential of V-206A to decrease so that capacitor C-219 is rapidly charged in a negative direction through V-207A Thus, the negative bias of the video amplifier is increased and the gain is decreased Because of the ASC action, the amplitude of the strongest video pulses received is stabilized at a value just below saturation Video signals that are too weak to cause conduction of V-205B have no effect upon the video gain When the

ASC is turned off by the control-unit switches, the ASC detector is biased negatively to such an extent that signals having saturation amplitude cannot cause conduction or affect the video-amplifier bias

A gate is applied to the ASC detector V-205B during the transmission of pulses to prevent a build-up of video-amplifier bias voltage and a reduction of video-amplifier gain due to stray coupling of transmitter energy into the video amplifiers

Interrogation sensitivity is determined by the setting of the X-band and S-band sensitivity controls The setting of these potentiometers determines the positive-bias voltage applied to the cathode of the trigger diode and thus establishes a minimum triggering level for the negative video pulses The controls are mounted on the front panel of the receiver-transmitter unit During bench and flight tests, the controls are adjusted to allow noise peaks to trigger the triggering multivibrator at the rate of approximately two triggers per second This action, sometimes referred to as "squitter," may be monitored by headphones plugged into jack J-207 which is connected to the cathode of the multivibrator Interrogation of the transponder by a radar can also be detected by use of headphones A tone having a frequency equal to the radar pulse-repetition frequency is heard when the multivibrator is triggered by the radar signals

The L-band reply transponder was also developed and manufactured by the Westinghouse Electric Corporation It was delivered before the S-band reply transponder Generally, this equipment is similar to the S-band equipment which has been described, except for reply frequency and identification codes Hard-tube modulators are used in the S-band reply equipment to eliminate trouble experienced with thyratron modulator tubes in the L-band reply equipment Figure 66 is a block diagram of the L-band reply transponder

The reply frequency of the L-band reply transponder is 1375 Mc The transmitter cavity may be tuned for operation at any frequency between 1372 and 1378 Mc The code-selector switch has three positions, A, B, and C A single pulse is transmitted in reply to each interrogation pulse when the code-selector switch is in the A position For B position, two pulses spaced 16 microseconds are transmitted when the pilot presses the radio-communication-transmitter microphone button, and single pulses are transmitted when the microphone button is released When the code-selector switch is turned to position C, the responses are the same as for position B except that transmission of the second pulse continues for approximately ten seconds after the communication-microphone button has been released

Additional information regarding characteristics and operation of S-band and L-band reply transponders is available in instruction books supplied by the contractor [8,9]

APPENDIX II

DESCRIPTION OF RESPONSORS

Figure 68 is a schematic diagram of the S-band and L-band responsors The r-f preselector is composed of three coupled cavities Coupling into and out of the end cavities is accomplished by means of loops Each cavity is tuned by varying the length of the quarter-wave conductor in the cavity The tuning screws are ganged so that the cavities may be tuned by adjustment of one tuning knob The cavity tuning screws can be disengaged from the gang mechanism so that the cavities can be tuned individually The preselector bandwidth is greater than 15 0 Mc for responses 3 0 db less than the passband response A coaxial cable is used to connect the preselector-output cavity to the r-f mixer

The local oscillator is a cavity-type oscillator Adjustment of a screw on the front panel of the responsor varies the length of the resonant cavity and of the operating frequency The oscillator output is capacitively coupled to a Type N output connector and is fed to the r-f

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[8] "Handbook of Service Instructions for R-Theta Transponder (L-Band Reply)," published under authority of the Air Force and the Chief of the Bureau of Aeronautics and approved 18 October 1951

[9] "Instruction Book for Rho/Theta Transponder MOD II," Air Navigation Development Board under Bureau of Aeronautics Contract NO a(s)-12186, 15 August 1952

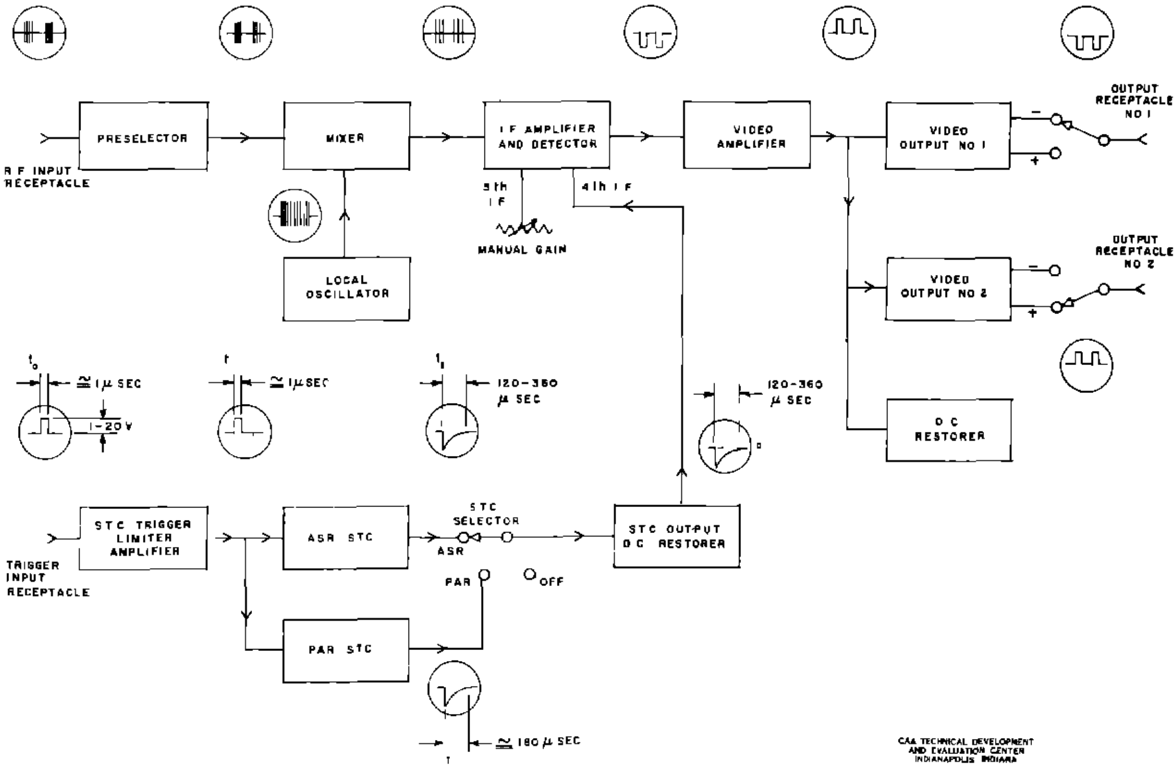

Fig 68 L-Band or S-Band Responsor, Simplified Block Diagram

mixer assembly by means of a coaxial cable A 2C37 planar triode is used in the L-band cavity, and a 5675 pencil triode is used in the S-band cavity The oscillators in both receivers operate at a frequency of 60 Mc above the center frequency of the r-f passband

The mixing of the r-f preselector and oscillator outputs occurs in a coaxial-type mixer containing a Type IN21B silicon crystal diode Signals from the preselector are connected to the crystal through a sleeve transformer, and the oscillator signals are capacitively coupled to the crystal The mixer output is connected directly to the i-f strip by a Type BNC connector

Nine stages of amplification, Type 5654 vacuum tubes, and the second detector are included in the i-f amplifier strip assembly The bandwidth is attained by stagger-tuning three sets of tuned amplifiers at frequencies of 52 5, 60 25, and 68 5 Mc The gain of the amplifiers is approximately 100 db, and the gain of the 6-db bandwidth is approximately 15 Mc Sensitivity of the i-f strip is manually controlled by the adjustment of a potentiometer which varies the negative bias applied to the grid of the fifth amplifier stage The manual sensitivity control is mounted on the front panel Sensitivity time control is provided by negative pulses which are applied from the STC circuits to the grid of the fourth stage The amplitude of the negative pulses varies with time in a predetermined manner Time is related to the primary-radar trigger pulses so that the i-f amplifier gain at the instant that transponder replies are received depends upon the distance of the aircraft from the primary radar

Negative video pulses developed in the second detector-load circuit are connected to the grid of a video amplifier The positive-pulse output of this stage is connected to the video-output stages and to the cathode of the d-c restorer The output stages are identical, and each stage is connected to a separate output receptacle Type SO-239 Polarity switches mounted on the front panel allow selection of a positive or negative pulse output at each receptacle

The sensitivity-time-control (STC) section develops a negative pulse which is applied to the grid of the fourth amplifier stage to vary the gain during each range sweep of the primary

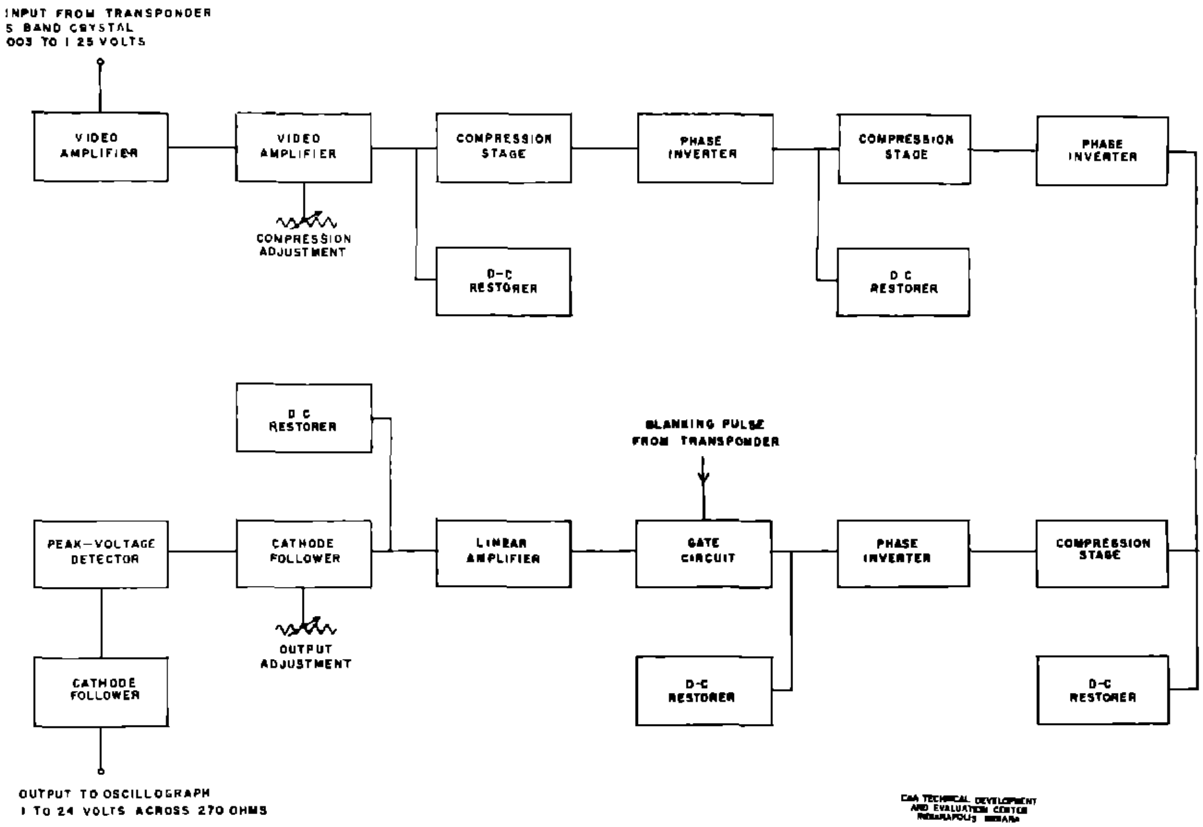

Fig 69 Block Diagram of Wide, Dynamic-Range, Video-Recording, Amplifier

radar The gain is reduced at the start of each range sweep and is allowed to recover to its normal value at a predetermined range or time with respect to the primary-radar trigger which initiates the negative pulse The normal gain is determined by the setting of the manual sensitivity control The time that elapses between the primary-radar trigger, the interrogation of the transponder by the primary radar, and the reception of transponder replies depends upon the aircraft range Because the responsor gain varies in time with respect to the radar trigger, it also varies with range

Ideally, the gain during the range sweep is controlled in such a manner that the responsor video output has constant amplitude regardless of the range of the aircraft Under these conditions, the intensity of the transponder replies presented on the radar indicator is constant for all aircraft ranges Also, under ideal conditions, the responsor manual gain control and the responsor STC can be adjusted so that transponder replies to interrogating-antenna side lobes will not be displayed, regardless of the aircraft range The side-lobe responses of some airport-surveillance-radar antennas are at least 20 db below the main-lobe response If a common antenna is used for interrogation and for reception of transponder replies and if the antenna horizontal pattern is the same at both frequencies, the responsor gain can be controlled so that the main-lobe responses will be visible and so that the weaker side-lobe responses will not be visible The STC section of the responsor consists of a trigger-limiter amplifier, a PAR STC section, an ASR STC section, and the STC output and d-c restorer circuits

The STC OFF-ASR-PAR switch on the front panel disconnects the STC circuits from the i-f strip when the STC section is not desired, or it selects the output of the ASR or PAR sections When the switch is turned to the ASR position the initial amplitude of the output pulse is determined by the setting of a potentiometer, and the start of the pulse can be delayed from 12 to 17 microseconds with respect to the trigger pulse by adjustment of a second potentiometer

A third potentiometer was provided to control the time required for the amplitude of the negative pulse to return to zero and thus the time required for the responsor gain to increase to normal value

When the STC OFF-STC-PAR switch is in the PAR position the initial amplitude of the STC output pulse is determined by the setting of a potentiometer, and the start of the pulse can be delayed from 1 8 to 7 0 microseconds with respect to the trigger pulse by adjustment of a second potentiometer R-233 Operation of the PAR STC circuits is similar to that of the ASR STC circuits Components were selected so that normal gain is restored approximately 180 microseconds after the end of the delayed trigger pulse Charging capacitors and associated components were selected to change gain at a rate which follows the inverse square of range or of time

Additional information regarding characteristics and operation of the responsors is available in instruction books supplied by the contractor.[10]

APPENDIX III

DESCRIPTION OF WIDE DYNAMIC-RANGE VIDEO AMPLIFIER

Figure 69 is a block diagram of the wide dynamic-range video amplifier constructed at TDEC and used to determine signal levels during flight tests The unit contains an amplifier, a compressor, a phase inverter, a peak detector, a cathode follower, and d-c restoration stages required to provide a useful dynamic recording range of approximately 52 db However, the crystal detector in the transponder has nonlinear characteristics so that radar signal-level variation from 0 to -35 dbm is the maximum range that can be recorded The gain of the amplifier is such that the output is 1 volt when the input is 3 millivolts and the output is 24 volts when the input is 1.25 volts The output impedance is 270 ohms, so that the amplifier can be used to drive one pen of a Brush Development Co Model BL-202 direct-writing magnetic oscillograph

The detector output is proportional to the peak amplitude of the input pulses The time constant of the circuit is adjusted to integrate short series of pulses obtained when an ASR antenna sweeps by the aircraft

When the transponder replies to a radar the transmitted energy causes deflection of the recording oscillograph, and no measurement of the interrogating-radar level is possible The gating circuit is included so that a pulse from the transponder modulator can be used to disable the amplifier during transmission periods The blanking provisions were not available during tests in the New York City area One of the transponder triggering tubes was removed during signal-level measurements to disable the transmitter

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[10] "Instruction Book for L-Band Receiver or S-Band Receiver," approved 26 May 1952 by Navy Department Bureau of Ships Contract NO6sr-49232