Initial Tests of the ANDB L-Band Secondary Radar System in Typical Terminal-Area Traffic Operations

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INITIAL TESTS OF THE ANDB L-BAND SECONDARY RADAR SYSTEM IN TYPICAL TERMINAL-AREA TRAFFIC OPERATIONS*

FOREWORD

This project was performed by the Civil Aeronautics Administration Technical Development Center under the sponsorship of the Air Navigation Development Board as a joint civil/military effort to meet stated operational requirements for a Common System of air navigation and traffic control.

SUMMARY

This report presents the results of initial operational tests of the ANDB L-band secondary radar system, also called the radar safety beacon and the ATC radar-beacon system. These tests were aimed at evaluating the operational importance of certain compromises involved in the selection of ground-antenna aperture and other system options.

Two interrogator-responsor units were installed at the Civil Aeronautics Administration Technical Development Center. One unit was equipped with a 9-foot antenna, and the other was equipped with an 18-foot antenna. The two units were triggered alternately by a single ASR-2 radar. Twin radar displays permitted direct comparison of the beacon-target displays of each I-R unit. A number of transponder-equipped aircraft then were flown through a series of local maneuvers to investigate (1) comparative presentations from both types of antennas, and (2) general characteristics and limitations of the secondary radar system.

It was found that coverage of both antennas was satisfactory for terminal-area operations within a radius of 30 nautical miles. No fadeouts of aircraft in level-flight attitude were noted within this area; however, no tests were made to determine the effect of equipment-receiver sensitivity and transmitter-power variations on system coverage. The 9-foot antenna presented targets averaging about 13° in width. Although targets of this width would have been unsuitable for long-range traffic-control displays, controllers who participated in the tests did not consider the 13° targets too wide for close-in operations such as guiding aircraft to a localizer course or spacing aircraft on the final approach path. Targets presented by the 18-foot antenna averaged 6° in width.

A considerable portion of the flight tests was devoted to the investigation of decoder garble. With the decoder switched to the "all aircraft" position, decoder garble occasionally produced spurious targets on the display. With the decoder switched to display only aircraft on a selected code, decoder garble occasionally caused cancellation of one or both targets. Both of these effects were transient in nature and could be reduced by the manipulation of switches available to the operator. Because of the greater beam width of the 9-foot antenna, decoder garble was more prevalent when this antenna was used.

Spurious targets in certain areas of the indicator were caused by reflections of signals from a nearby building. It is apparent that secondary radar systems are more susceptible than primary radar systems to the effects of ground reflections. Therefore, in the choice of ground-antenna sites, it is believed that thought must be given to the possible detrimental effects of large vertical reflecting areas in the vicinity.

Additional investigation of the interference problem was made after the flight tests were completed. For these tests, an additional I-R unit was operated in conjunction with a remotely sited transponder. The interrogation rate and the relative power of the interfering I-R unit were varied to simulate various degrees of interference. Due to the effects of transponder dead time and automatic overload control, which reduced the number of replies per scan, target quality deteriorated as the pulse-repetition rate of the interfering I-R unit was

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*Report submitted for publication April 1956.

increased. With the increased rate, which simulated an increasing number of ground units, the displayed clutter increased to the point where the automatic overload control went into action. Beyond this point the clutter did not increase, but it became more irregular. The clutter was worst when the indicator was switched to display raw video. Operation of the decoder resulted in a marked reduction in clutter.

INTRODUCTION

Prior to 1954, the Air Navigation Development Board developed and tested two secondary radar systems employing interrogation by primary radar.[1] In February 1953, the Joint Communications Electronic Committee forwarded to ANDB the recommended characteristics of an L-band secondary radar system which would be compatible with certain existing military equipments. The system was built in accordance with these specifications by the Navy Bureau of Aeronautics and Bureau of Ships. It was delivered to the Technical Development Center for evaluation in accordance with ANDB Project 6.2.4.

Evaluation plans for this system included equipment and system tests at TDC and at the Airborne Instruments Laboratory, system operational tests in the TDC Airways Operations Evaluation Center, and service-environment testing at five installations in metropolitan areas.

In August 1954, ANDB formed Advisory Committee No. 2 to guide the evaluation and further development of this system. The Committee was comprised of representatives from the CAA; Departments of the Air Force, Army, and Navy; the Air Transport Association; and Aeronautical Radio, Inc. In order to study the operational importance of some of the characteristics of the system (especially ground-antenna aperture) prior to making certain decisions on equipment to be procured for the five service-test installations, Working Group No. 1 of that Committee, assisted by traffic-control specialists and engineers of this Center, arranged for the limited operational tests which were carried out at Indianapolis on January 17 and 18, 1955. The results of these tests, which consisted of typical terminal-area maneuvers by three CAA aircraft and five aircraft from Wright Air Development Center, are described in this report. The results obtained during the two test days were supplemented by considerable additional testing to investigate certain aspects of the test results.

GROUND EQUIPMENT

A simplified block diagram of the interrogator-responsor units and the associated radar installation is shown in Fig. 1. The 9-foot antenna, ANDB Type 2.3NS2, was mounted on its pedestal and was installed on a free-standing tower as shown in Fig. 2. The rotation of this antenna was slaved to the ASR-2 antenna through a follow-up servo system. No pedestal was available for the 18-foot antenna, ANDB Type 2.3NS3; therefore, this antenna was mounted directly on the A-frame of the ASR-2 antenna as shown in Fig. 3.

Two Navy SPA-8 indicators were installed in the radar room. Because of a shortage of new type decoders, each indicator was equipped with a Naval Research Laboratory decoder to provide comparable displays. The NRL decoder utilizes only codes which have pulses 17.4 microseconds apart instead of the 20.3-microsecond spacing which is used between the framing pulses of this system. On January 10, 1955, a new type of decoder, ANDB Type 2.3NS4A, became available and was connected to one of the indicators. The ANDB decoder was used during the latter part of the tests to demonstrate the special coding features which will be available in the common system.

A control desk was built to accommodate the twin displays and the communications system. Trichromatic[2] lighting was installed to provide adequate desk light without debasing

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[1] David S. Crippen, Joseph E. Herrmann, and Marvin H. Yost, "Evaluation of the Rho/Theta Transponder System," Technical Development Report No. 229, June 1955.

[2] This trichromatic lighting system utilized a combination of three colored fluorescent lamps (red, blue, and green) which provided an apparently white ambient light in the room. The colors were obtained by filters covering each fluorescent-lamp tube. The light originated from a standard three-lamp fixture mounted near the ceiling behind the radar-display cabinets. Short hoods were provided over the front of the display to reduce or eliminate direct illumination on the display scopes, and the scopes were equipped with amber filters. Because the illumination actually was deficient in the yellow-orange portion of the spectrum, the amber filters preserved the picture contrast on the scope faces.

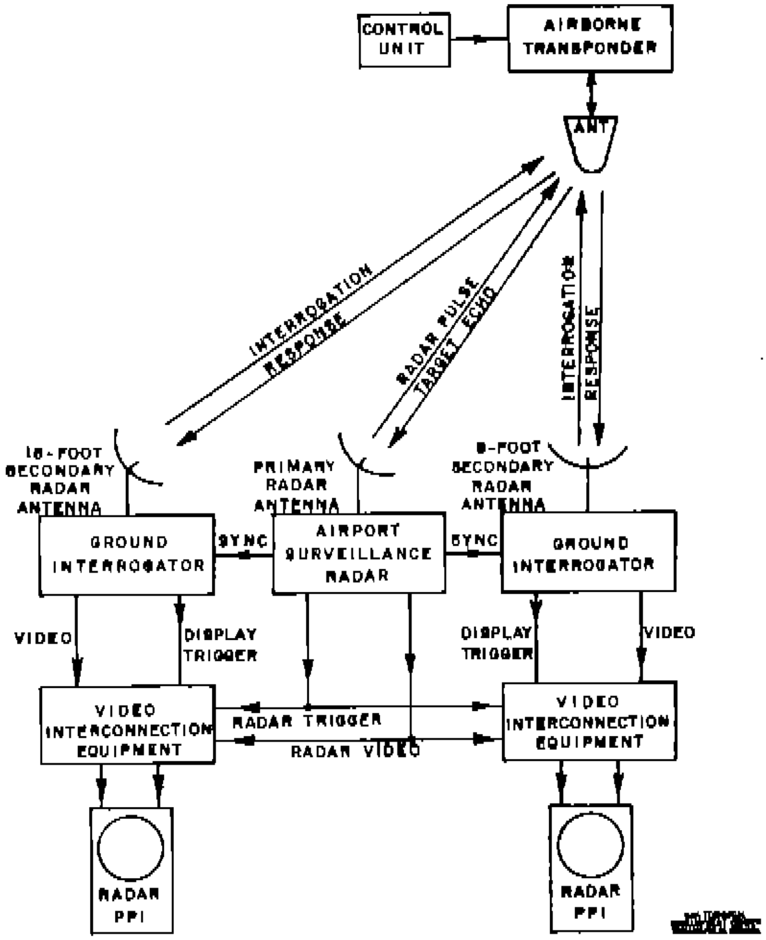


Fig. 1 Simplified Block Diagram of Equipment Layout for Secondary Radar-System Demonstration

the radar picture. Overhead, a movie camera was installed to record the displays on both indicators. Fig. 4 illustrates the layout of control-room equipment used during these comparison tests.

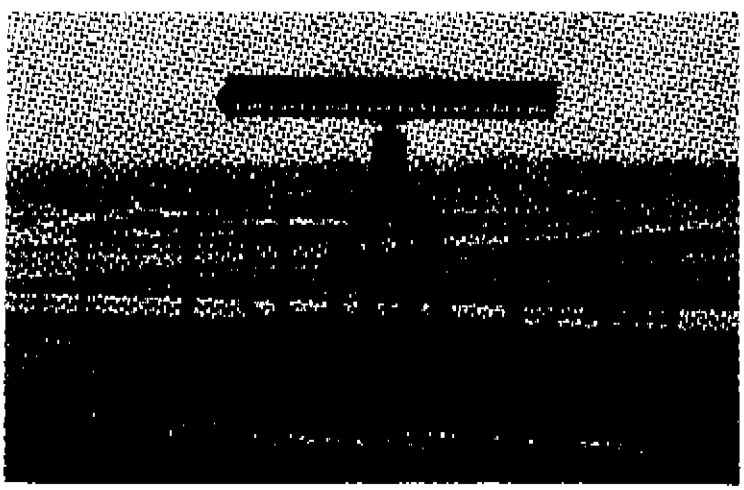


Fig. 2 Installation of 9-Foot Ground Antenna

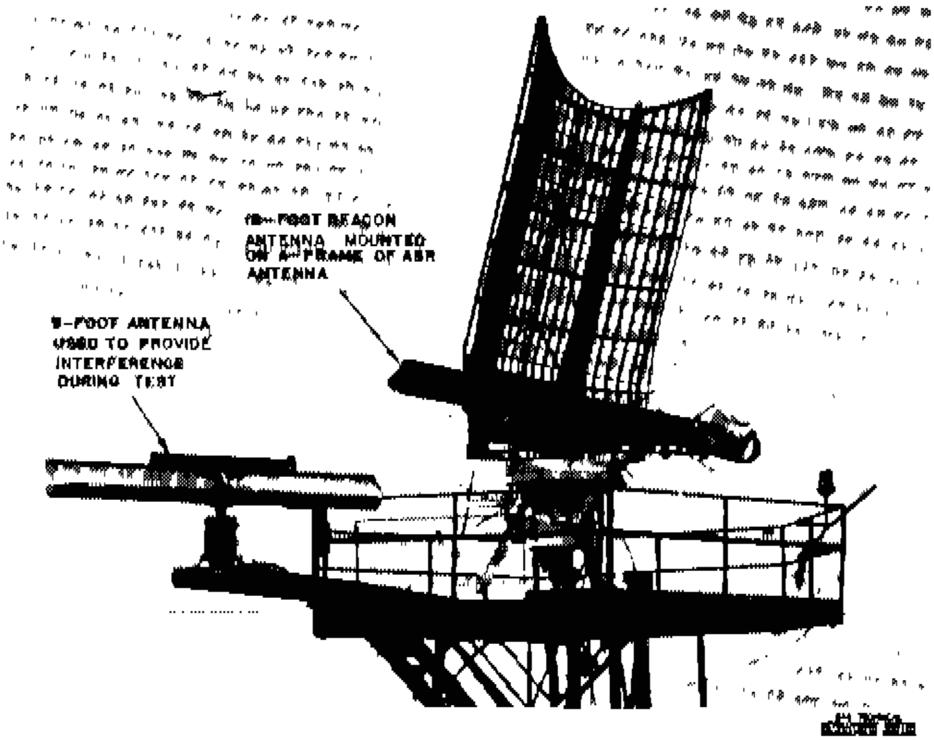


Fig. 3 Beacon Antennas Installed on ASR Tower

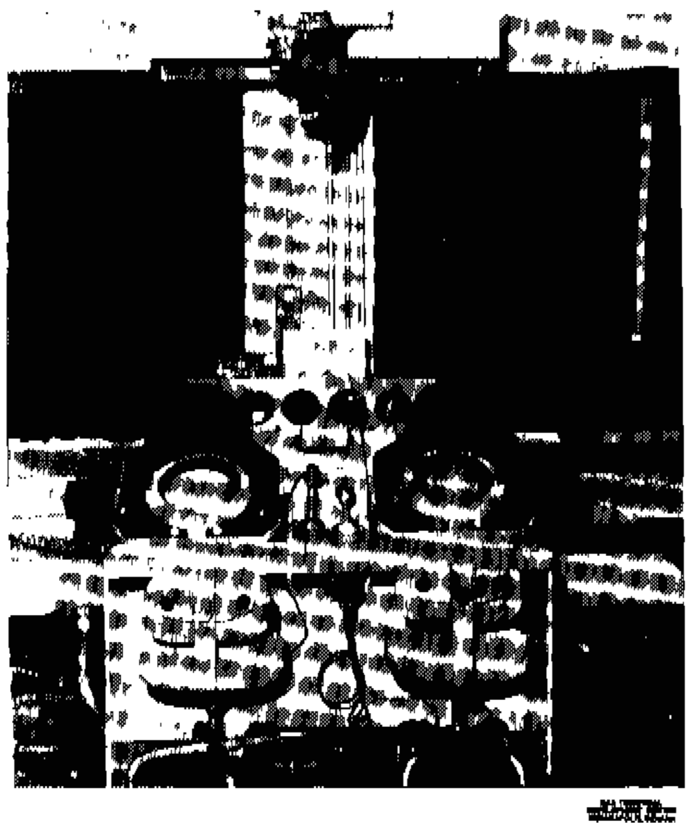


Fig. 4 Control Desk, Radar Indicators, and Camera Installation for Comparison Tests

Modifications.

The sensitivity-time control (STC) in the receiver of the original I-R equipment did not become effective for the first six microseconds of each sweep. This condition resulted in a display of all side lobes at ranges of less than one-half mile. It was corrected by wiring changes in the STC circuit to secure full STC action before the sweep started at zero range. In addition, the STC curves necessary for proper side-lobe suppression were not obtainable with the adjustments provided. For this reason, it was necessary to modify several resistor values in both I-R units before the demonstration.

The ground decoders required a video signal-to-noise ratio of 4:1 for proper operation. The SPA-8 radar indicators could not accept this ratio, however, without excessive "blooming" when raw video was selected for plan-position indicator (PPI) display. This was corrected by reducing the screen voltage of a video-amplifier tube so that it became a limiting-type amplifier. This change was made on both SPA-8 indicators.

TESTS AND RESULTS

Flight Maneuvers.

Aircraft operations conducted during the flight tests included the following maneuvers:

Phase	Maneuver
Shadow Effects	Holding patterns, 360° turns at various rates, altitudes, and locations.
Decoder Garble (Two aircraft)	Converging, diverging, coinciding, and overtaking courses on headings radial to and tangent to the ground antenna.
Decoder Garble (Multiple aircraft)	Four or more aircraft stacked in a one-minute holding pattern.
Vectoring	PPI approaches, approach-spacing operations, and vector approaches from holding patterns to localizer course.
Slant Range	Flights across station at highest practicable altitudes.

The more significant results of these tests are included in the following discussion.

Antenna Shadow.

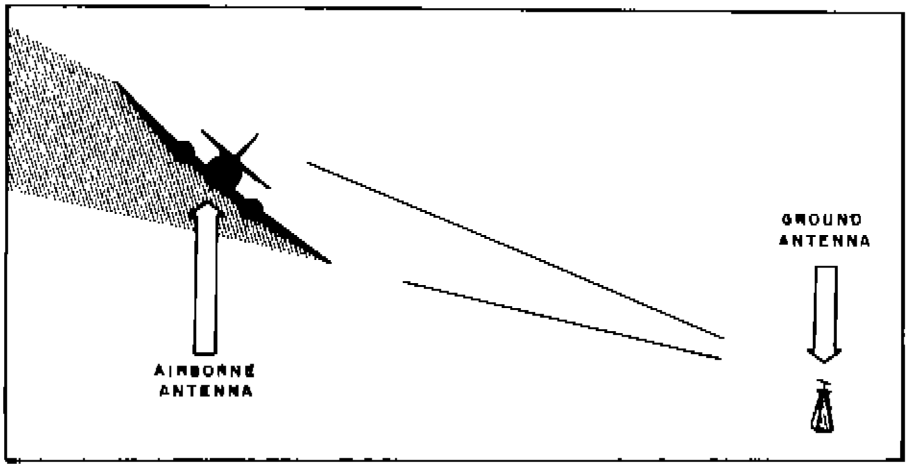
Pilots were instructed to fly a series of 360° turns to demonstrate the target fading which occurs when the airborne antenna is shadowed from the interrogation signal by some portion of the aircraft. All aircraft engaged in the tests were equipped with belly antennas which usually were shadowed by the wing when the aircraft was banked in a direction toward the ground station. Thus, target fades usually occurred when the aircraft was on the far side of a circle or on the outer turn of a holding pattern. This effect is illustrated in Fig. 5.

There was no significant difference in the shadow effects observed on the displays of the 9-foot and 18-foot antennas. Occasionally, however, when the airborne antenna was partially shadowed, the target would fade on one indicator and still would be visible on the other. It is believed that this difference was due to variations in the lobe structure of the vertical patterns, because the two I-R antennas were mounted at different heights above the ground. It was possible, therefore, for an aircraft to be in the lobe of one pattern and in the null of another simultaneously. This effect is shown in Fig. 5.

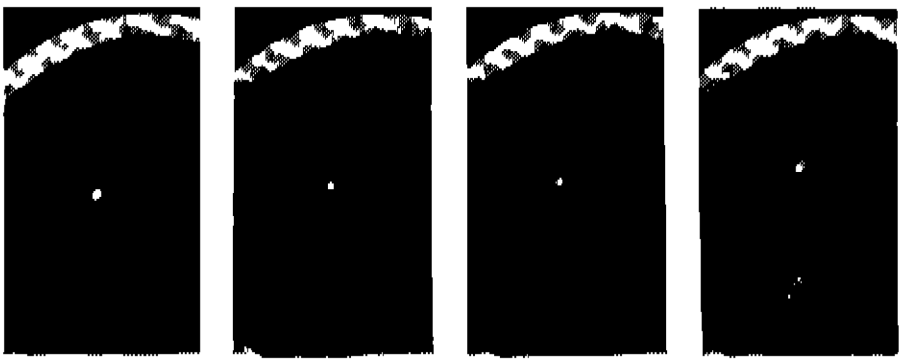
As might be expected, the extent of shadowing depended on the relationship between the angle of bank and the angle of elevation of the aircraft above the horizontal plane of the ground antenna. Lower bank angles and higher elevation angles tended to reduce the shadowing effect.

Decoder Garble.

Some of the most interesting phenomena connected with the operation of a secondary radar system of this type can occur when two or more transponder-equipped aircraft approach each other within one beam width in azimuth and one pulse-train length in range (3.3 nm in this system). The resulting condition is known as decoder garble. The actual effects on the display depend on the way the decoder switches shown in Fig. 6 are set. To understand these effects, it is desirable first to review some of the basic operating principles of the system and decoder.



SHADOWING OF AIRBORNE BELLY ANTENNA DURING BANK TOWARD GROUND STATION



SUCCESSIVE SCANS OF 18-FOOT ANTENNA DISPLAY SHOWING TWO AIRCRAFT TARGETS IN HOLDING PATTERN ONE TARGET FADES OUT DURING TURN THEN REAPPEARS IN LAST PICTURE

Fig. 5 Antenna-Shadow Effects

The ground unit transmits pairs of pulses spaced as shown in Fig. 7A. The airborne unit replies to these interrogations by transmitting groups of four pulses, spaced in accordance with one of the ten codes shown in Fig. 7B. In each group the first and last pulses, known as the framing pulses, are spaced 20.3 microseconds apart.

Decoder Off.

When the display is switched to display raw video, the four-pulse groups bypass the decoder and appear directly on the indicator as four closely spaced blips lined up radially. When decoder garble occurs in a raw video presentation, the blips simply pile up on each other as shown in Fig. 8. This type of display is undesirable for terminal-area traffic-control use because of its cluttered appearance and because of the difficulty in determining the exact positions of the aircraft concerned.

Decoder on "All-Aircraft" Position.

The primary function of the decoder is to reject the unwanted returns so that only the desired signals are forwarded to the indicator. This is accomplished through the use of a delay line and a coincidence circuit as shown in Fig. 9. When the decoder is operating with the all-aircraft switch ON, all raw video signals are fed to a coincidence detector through a 20.3-microsecond delay line in parallel with an undelayed channel. This detector is designed to pass a single pulse each time a pulse from the delayed line reaches it simultaneously with a pulse from the undelayed channel. Because the aircraft-framing pulses are spaced 20.3 microseconds apart, the last pulse in an undelayed group will arrive at the detector simultaneously with the first pulse of the delayed group. When this coincidence occurs, a single pulse is passed to the indicator where it is displayed as a single blip as shown in Fig. 9.

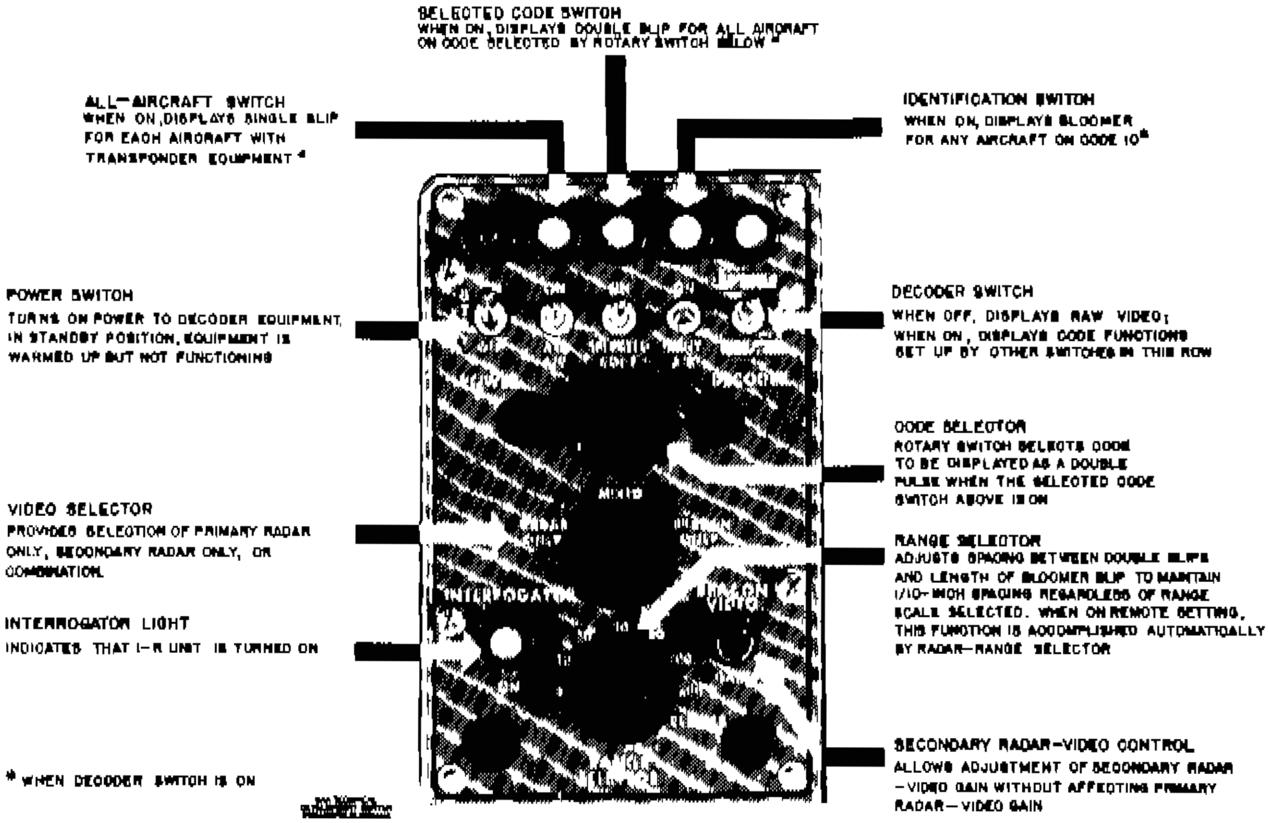


Fig. 6 Control-Panel Functions for ANDB Decoder

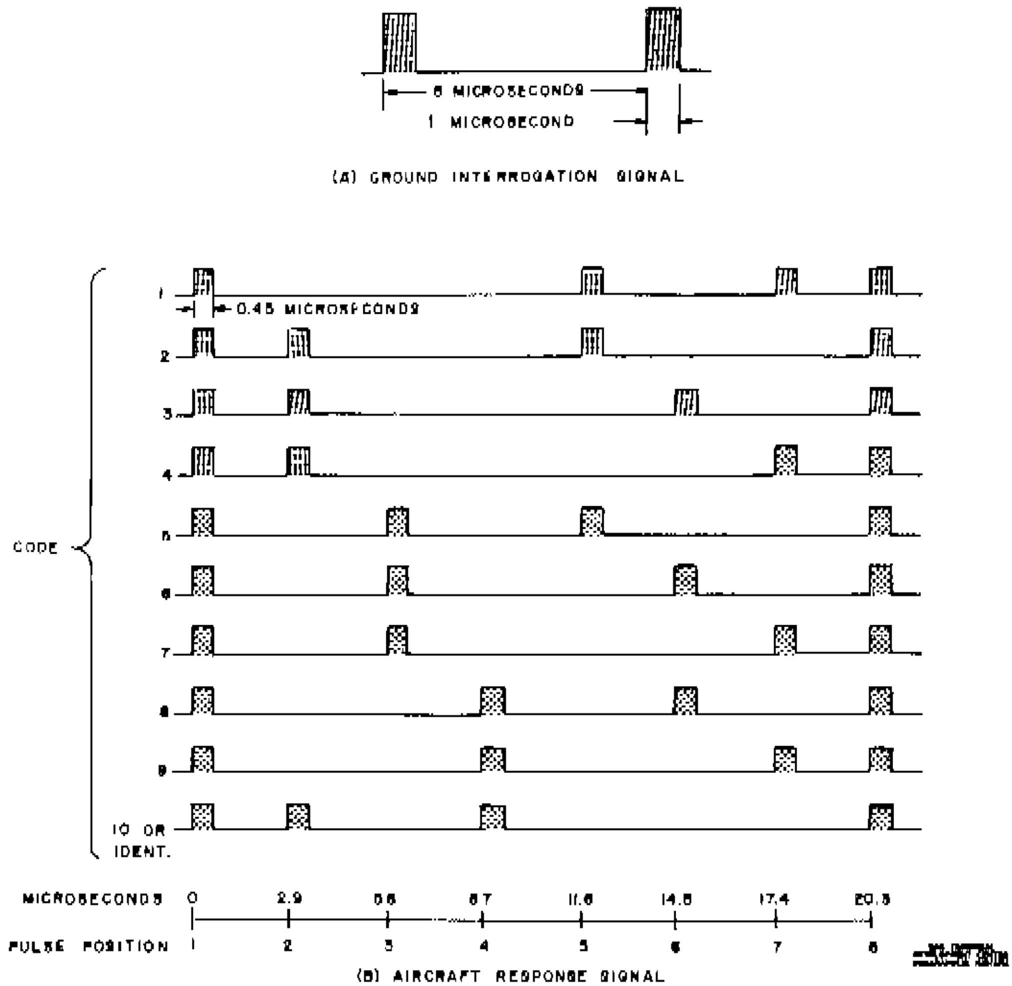


Fig. 7 Codes Used in Secondary Radar System

Fig. 8 Raw Video Presentation

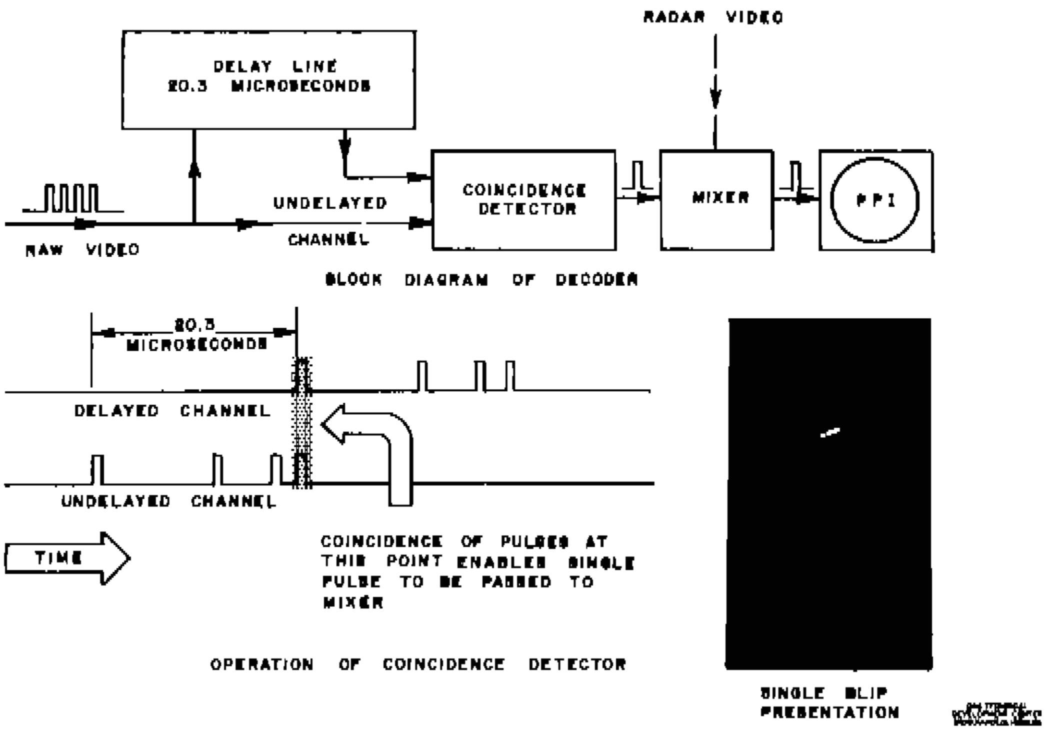


Fig. 9 Function of Decoder in All-Aircraft Position

When replies are being received from two or more aircraft within 40.6 microseconds (3.3 nm of each other in range), coincidence can occur between various other pulses in the groups going through the undelayed and delayed channels of the decoder. Each time such coincidence occurs, a pulse is passed to the indicator where it shows up as a spurious target. As shown in Fig. 10, a single spurious target can occur between genuine targets when the aircraft are at various increments of range within 3.3 nm of each other. When aircraft on the same code are 1.65 nm (20.3 microseconds) apart, all four delayed pulses from the first aircraft coincide with the four undelayed pulses from the second aircraft, producing two false targets between the two genuine targets. Figure 11 shows a number of these effects which were photographed during the flight tests.

Decoder on "Selected-Code" Position.

The higher degree of selectivity required to distinguish targets using one code from targets using the other codes is accomplished through the use of a detector which requires coincidence of all four pulses before any output can be passed to the indicator. In this circuit, the delay line is tapped at 2.9-microsecond delay intervals corresponding to each of the possible pulse positions. Turning the code-selector switch to the desired code position connects certain taps to the coincidence detector. These taps correspond to the pulse positions of the selected code. When a group of pulses enters the delay line, it emerges at the different taps at different times, depending on the amount of delay it receives on each path. If the four pulses of the group are spaced exactly in accordance with the pulse positions of the selected code, coincidence of all four pulses will occur. Normally, when this occurs, a pulse is passed to the modifier which adds a second pulse. This double pulse is passed to the indicator where it is displayed as a double blip as shown in Fig. 12.

Regardless of the reply codes being transmitted, the pulse trains from two or more transponders may interleave to form the selected code and thereby cause an erroneous display. To prevent this effect, the code selector of the ground unit employs a rather drastic feature commonly known as a "killer" circuit.

As stated previously, when the code-selector switch is positioned to select a certain code, taps on the delay line corresponding to the pulse are connected to the coincidence detector. At the same time, the remaining taps are connected to the killer circuit. Thus, a group of pulses going through the delay line emerges at all of the taps; each pulse will appear in the killer circuit as well as in the coincidence circuit at different times as shown in Fig. 12. If a pulse

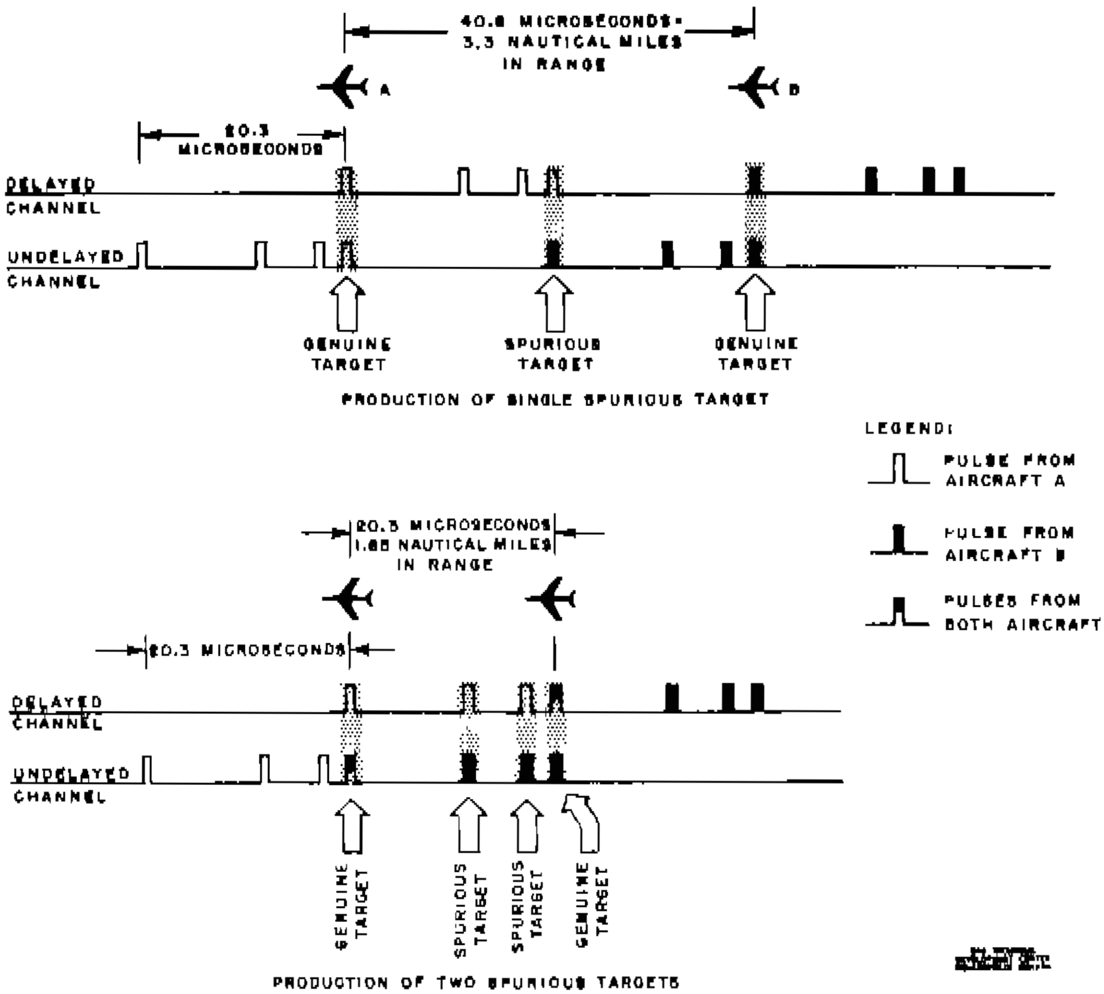
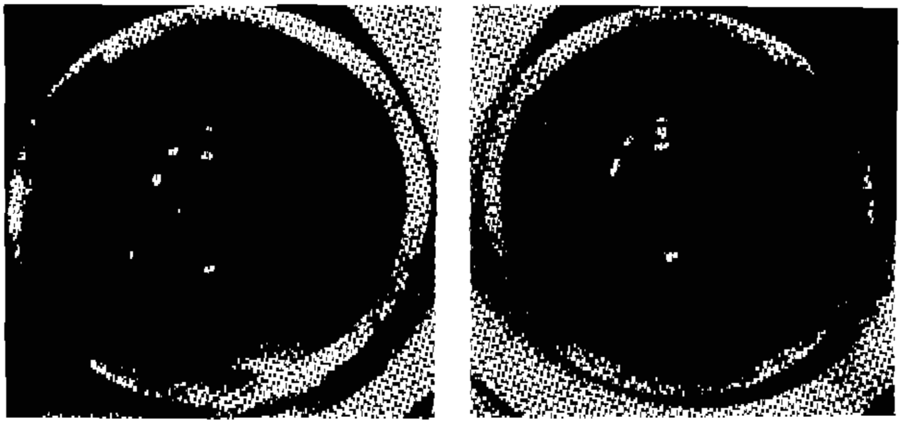


Fig. 10 Decoder Garble with Decoder in All-Aircraft Position

SUCCESSIVE SCANS OF 18-FOOT ANTENNA DISPLAY, SHOWING APPEARANCE AND DISAPPEARANCE OF SPURIOUS TARGET HALFWAY BETWEEN TWO GENUINE TARGETS 3.3 NAUTICAL MILES APART IN RANGE.



18-FOOT ANTENNA 9-FOOT ANTENNA

SIMULTANEOUS PHOTOGRAPHS SHOWING SPURIOUS TARGETS PRODUCED BY OVERLAP EFFECTS OF TWO AIRCRAFT NORTH OF STATION IN THE WIDE BEAM OF THE 9-FOOT ANTENNA. SAME TWO AIRCRAFT ARE FAR ENOUGH APART IN AZIMUTH TO AVOID DECODER GARBLE OVERLAP EFFECTS WITHIN THE NARROW BEAM OF THE 18-FOOT ANTENNA.

Fig. 11 Decoder Garble with Decoder in All-Aircraft Position

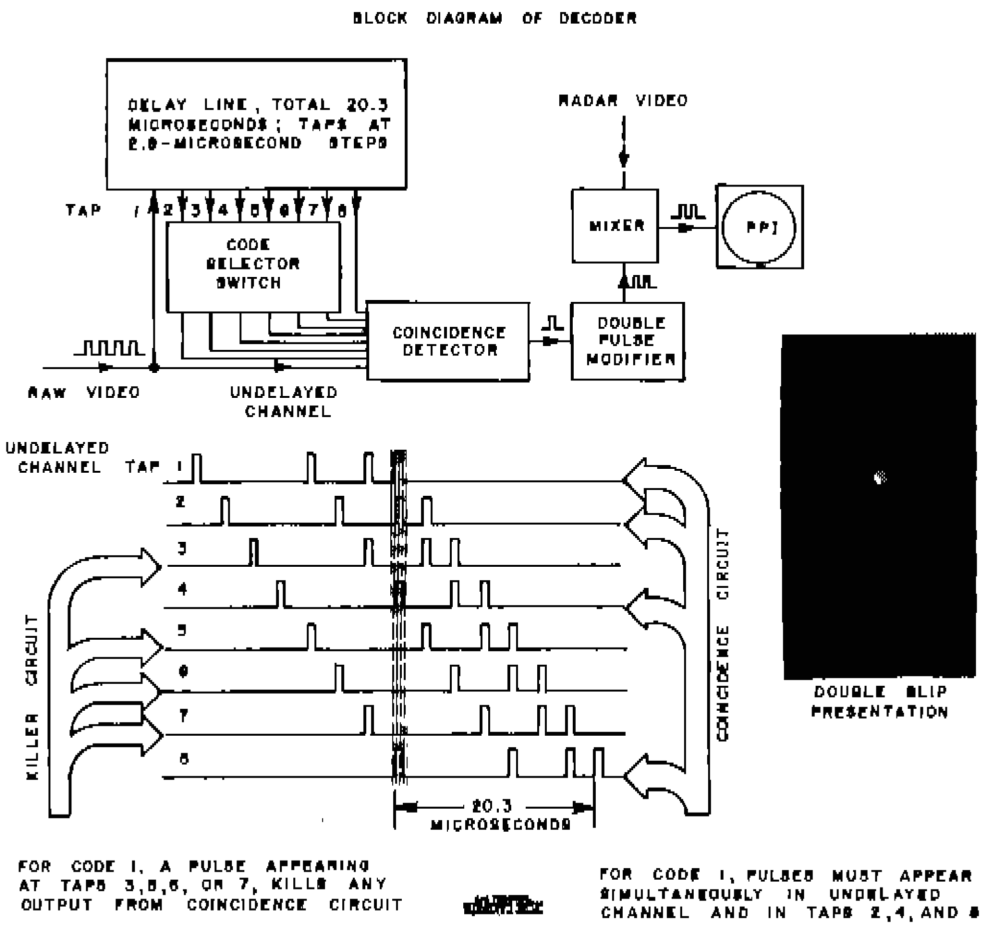


Fig. 12 Function of Decoder in Selected-Code Position

appears in the killer circuit simultaneously with the coincidence of the four pulses in the coincidence circuit, the response is killed and no pulse will be passed to the modifier. This effect is shown in Fig. 13. Thus, in eliminating the undesired effects of false targets, the killer circuit occasionally kills the desired effects by cancelling the overlapping targets. A change has been made in the original decoder to permit momentary inactivation of the killer circuit so that the operator may check the display to determine if any replies are being cancelled.

When two aircraft were flying close together so that their targets merged, a small amount of range separation made it possible for the controller to determine that there were two targets instead of one. On rare occasions, however, it was noticed that cancellation of one end of one target could occur in the overlapping sector. The resulting display made the two aircraft appear to be farther apart than actually was the case.

Target continuity can be maintained on the display by keeping the all-aircraft circuit in operation whenever possible. Then the single blips from the all-aircraft circuit still are visible even though the double blips of the selected-code circuit are cancelled.

Decoder on "Identification" Position.

The identification unit of the ground equipment employs a similar coincidence detector and the same tapped delay lines as the code-selector unit. The basic difference is that the identification unit is wired permanently to select Code 10 only; that is, the identification code. When coincidence of all four pulses occurs at the detector, a pulse is passed to the identification modifier where it is converted to a long pulse for display as a bloomer blip as shown in Fig. 14. The identification unit, however, employs a killer circuit identical to that used in the code-selector unit to prevent the display of false codes and targets. In case of decoder garble, therefore, the bloomer blip is subject to the same cancellation effect as any other selected-code target.

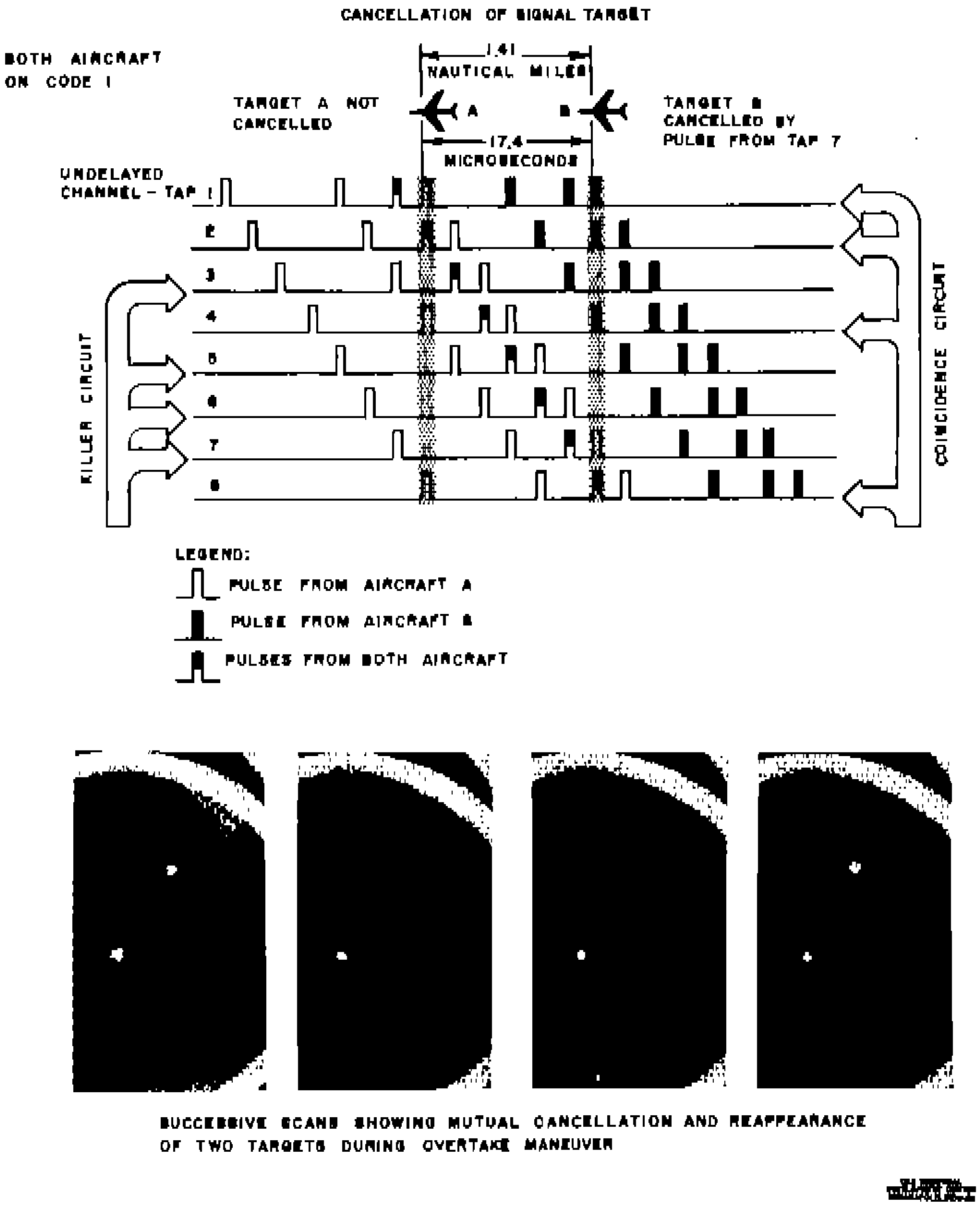


Fig. 13 Target Cancellation on Selected-Code Position

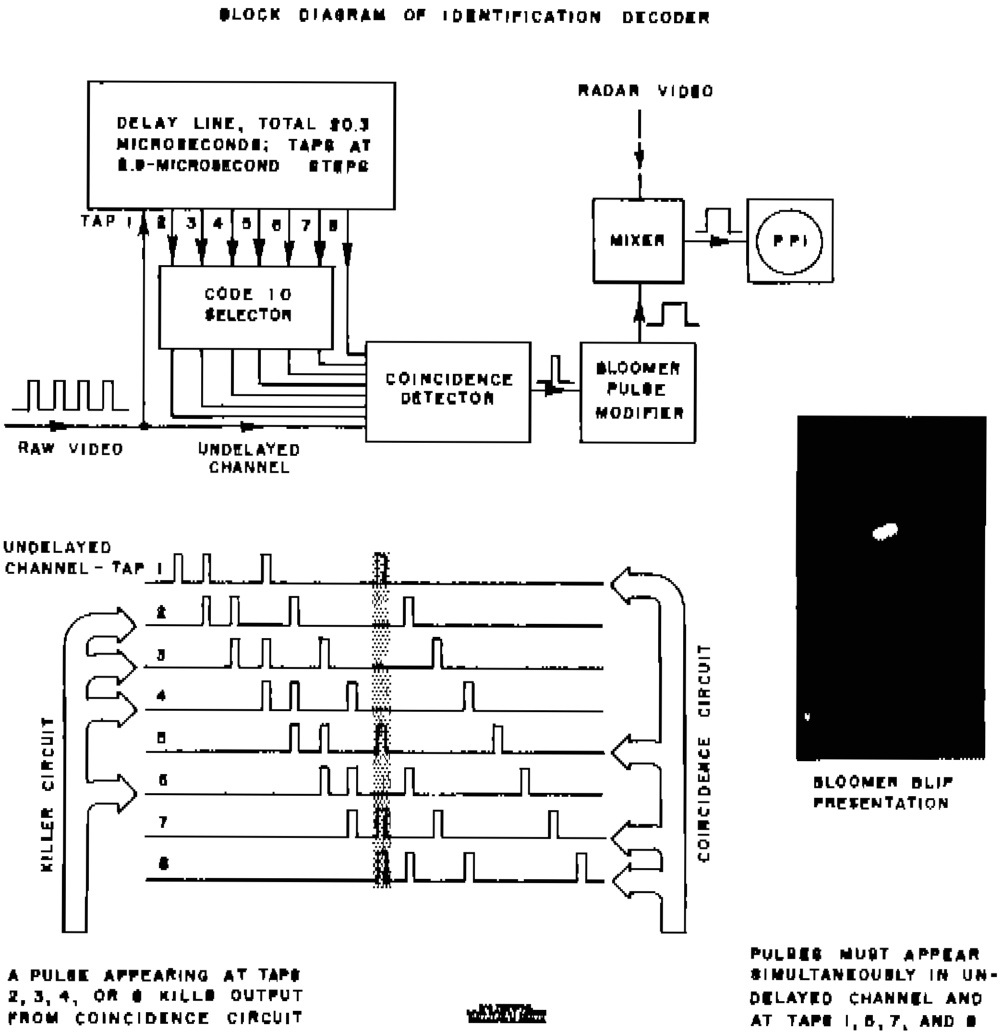


Fig. 14 Function of Identification-Decoder Unit

As indicated in Fig. 15, the pilot's identification switch is connected with a time-delay feature which automatically retains the transponder on Code 10 for a 30-second period when the switch is on IDENT position, or when the switch is on MIC position and the microphone button is pressed.

When an aircraft transponder is on Code 10 it is not on its regularly assigned code. Assuming that each use of the pilot's microphone started a new 30-second identification cycle, it is conceivable that in busy terminal-area operations, aircraft would be transmitting on Code 10 a large percentage of the time. Under such conditions, the inherent advantages of the identification and the selected-code features of the system would be obviated.

A possible design change, now under consideration, involves a method of associating an identification code with each selected code. It also is believed desirable that the identification function be divorced from the microphone system and that the identification switch be replaced with a three-position, spring-loaded type so that the identification code would be transmitted while the switch was in the down position or for a 12-second period when the switch was pushed momentarily to the up position.

Separation of Departure Targets.

An interesting geometrical principle became apparent during the flight tests. Two aircraft were positioned side by side on parallel outbound tracks so that their targets merged. They were flown at the same speed to stay abreast of each other. One aircraft then was given a diverging heading of about 10° to demonstrate how the displayed target would split apart.

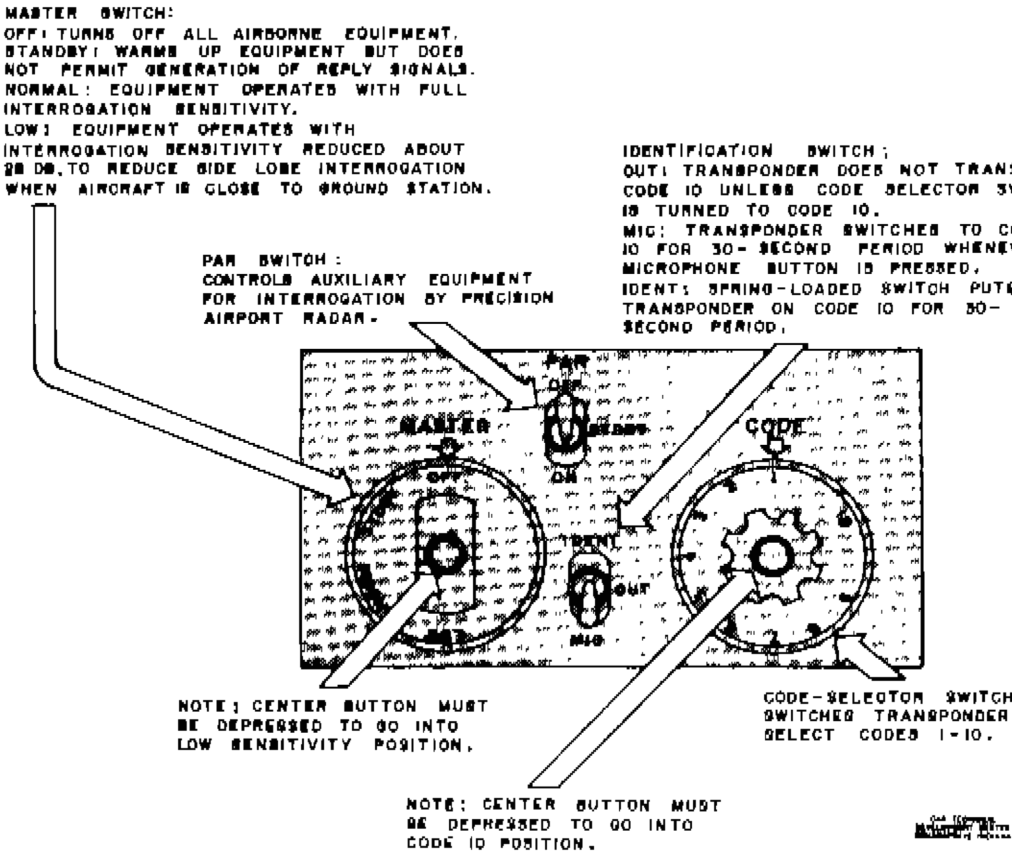


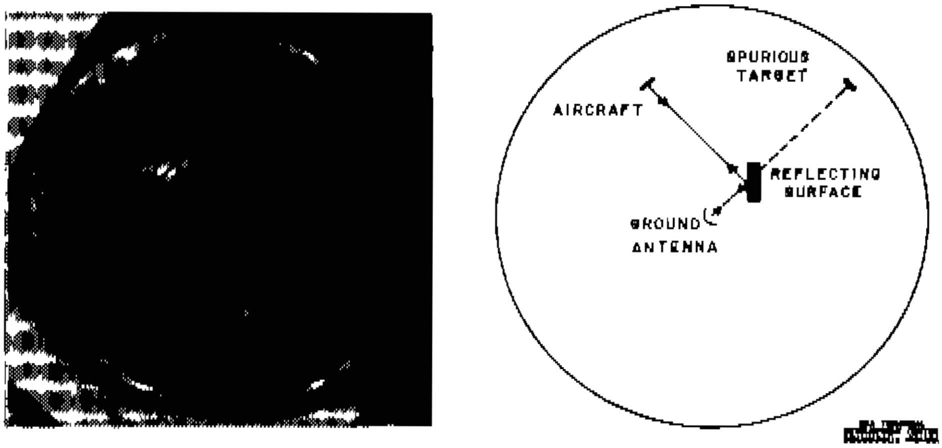
Fig. 15 Control-Panel Functions for Airborne Transponder Equipment

After a considerable time, however, the targets still were merged even though the aircraft were several miles apart. It then became apparent that as the aircraft progressed outbound, the target size of each aircraft increased due to the increased spatial width of the interrogation beam at greater ranges. Finally, to separate the targets it was necessary to issue a radical heading change to one of the aircraft. After the targets were separated, the courses of the two aircraft still had to diverge by an angle of not less than the effective beam width of the ground antenna in order to avoid decoder garble between the aircraft.

Ground Reflections.

Several times during the flight tests, additional moving targets were displayed between 5 and 10 miles northeast of the ground antenna when known targets were flying in a holding pattern 5 to 10 miles northwest of it. The fact that the targets to the northeast changed range in accordance with the northwest targets provided a clue to their identity. These targets were spurious and were caused by reflections of the interrogation and reply signals from the side of a long, low, metal building about 1500 feet northeast of the ground antenna. This effect is illustrated in Fig. 16.

Because secondary radar signals are subject to one-way rather than two-way attenuation, and because the replies are much stronger than primary radar replies, it is apparent that secondary systems are more susceptible than primary systems to the effects of ground reflections. This implies that many sites which would be satisfactory for primary radar antennas may not be suitable for secondary radar antennas because of the presence of large vertical reflecting surfaces in the vicinity. This is a factor which should be given careful consideration during the planning stage of the program.



REPLY SIGNALS OF AIRCRAFT IN NORTHWEST SECTOR WERE REFLECTED OFF AIRPORT HANGAR BUILDING TO PRODUCE SPURIOUS TARGETS VISIBLE IN NORTHEAST SECTOR.

Fig. 16 Reflection Effects Encountered During Flight Tests

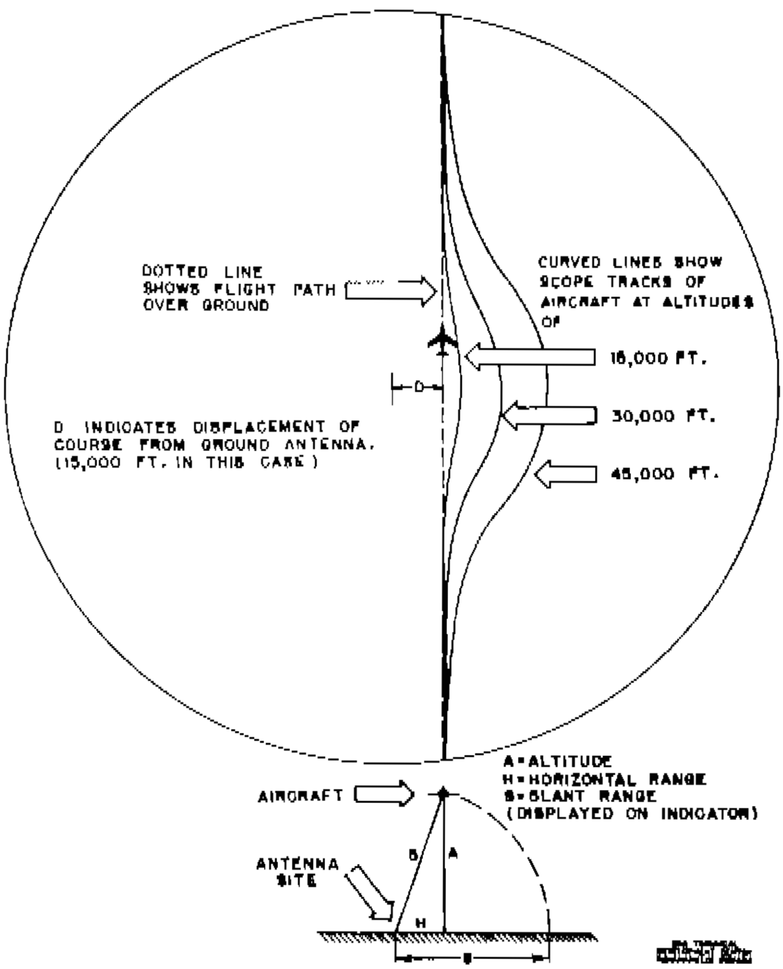


Fig. 17 Slant-Range Effects

Slant-Range Effects.

Target distances are given in terms of slant range; therefore, flight paths of aircraft passing at high altitudes across the station appear distorted on the indicator as shown in Fig. 17. The same effect exists on a primary radar display. The vertical pattern of the secondary radar antenna, however, extends to higher elevation angles and higher altitudes than does the pattern of surveillance radars presently used in traffic control. Therefore, more pronounced effects of slant-range distortion will be visible on the displays. Although this effect is not expected to be serious, controllers will need to make allowance for variations in target speeds and courses when aircraft cross the station at high altitudes.

STC Operation.

The modification and adjustment of the STC of the I-R unit enabled the equipment to operate without any ring-around effects during the flight demonstration. At no time was it necessary to request pilots to reduce interrogation sensitivity from normal to low. Only a few cases of side-lobe presentation occurred during the tests. They were slightly more prevalent with the 18-foot antenna than with the 9-foot antenna. The tests on the system characteristics for eliminating or reducing the side-lobe presentation are incomplete, however, because all of the variations which might occur in the ground and airborne components have not been considered.

Interference Tests.

Special Equipment and Conditions.

Interference is the term used to designate a condition which occurs when a transponder is interrogated by more than one ground station at a time. It is a problem which may assume serious proportions in congested terminal areas where ground interrogators are located within a few miles of each other. To simulate this condition, a third I-R unit was operated for brief periods during the demonstration. This I-R unit was connected to a 9-foot antenna mounted on the side of the ASR-2 radar tower as shown in Fig. 3.

After the flight demonstration, an investigation of the interference effect was started. For this phase of the tests, an airborne transponder unit was installed at the CAA airway light-beacon site at Bargersville, Indiana, about 14 nm from the interrogator. The antenna for the transponder was mounted on the beacon tower approximately 60 feet above the ground.

The 18-foot ground antenna was removed from the A-frame of the ASR-2 antenna and was replaced by the integral-feed installation shown in Fig. 18. The horizontal pattern of the integral-feed antenna approximated that of the 9-foot beacon antenna used in the other tests.

The 9-foot antenna of the interfering I-R unit was pointed toward the Bargersville site and was locked in place. To investigate the effects of interrogation by increasing numbers of ground

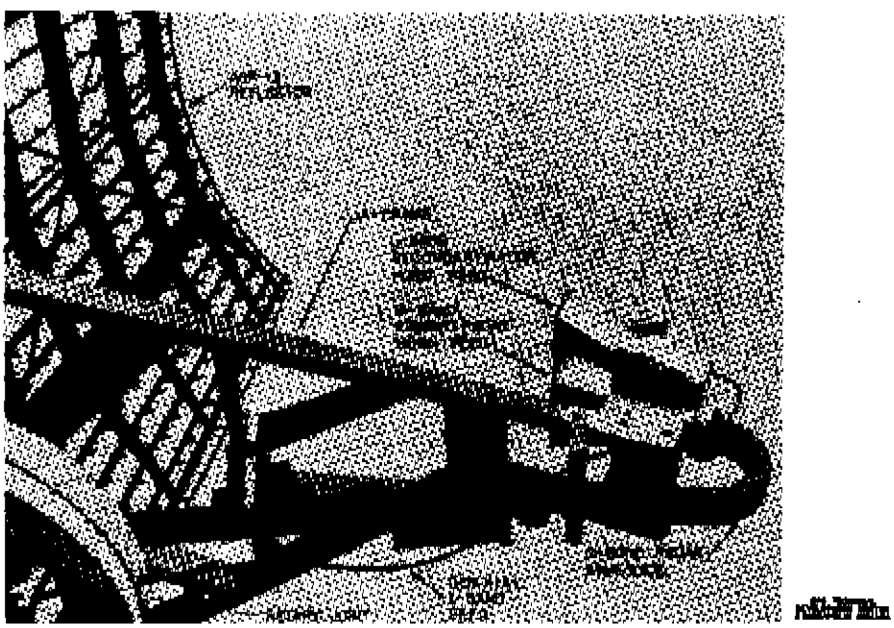


Fig. 18 Integral-Feed Antenna Installation Utilizing Reflector of ASR-2 Antenna

units, the pulse-repetition rate of the interfering I-R unit was increased in steps from 400 to 2000 pulses per second. This simulated conditions in which the transponder was being interrogated steadily by as many as 7 ground units at a time. Steady interrogation can occur when an aircraft is being searchlighted by a stationary or tracking-type radar or when the aircraft is operating within 30 miles of the ground station.

To simulate various geographical arrangements of interrogator sites, the relative power ratio of the two I-R units was varied to include the conditions listed in Table I.

TABLE I

INTERFERENCE-TEST CONDITIONS

Condition No.	Parameter	Participating I-R Unit*	Interfering I-R Unit**	Method Used
1	Relative transmitting power	8	1	Participating unit used lower loss transmission line and higher gain antenna.
2	Relative transmitting power	1	4	Participating unit used higher loss transmission line and reduced plate voltages.
3	Relative transmitting power	1	6	A 12-db attenuator was inserted in transmission line of participating unit.

*The term "participating I-R unit" refers to the unit which is connected to the display under observation.
**The term "interfering I-R unit" refers to any other unit which, by interrogating transponders, elicits replies that are received by the participating unit and are displayed as fruit on the observed display.

Effect of Increased Pulse-Repetition Frequency on Interference.

Interference clutter usually assumes a definite pattern known as "fruit" on the displayed azimuth of the target. This fruit represents the pulses transmitted by the airborne unit in reply to the interfering interrogators. Because these pulses are out of synchronism with the sweep of the participating unit, they appear at various ranges out to the maximum. During the interference tests, the STC circuit usually was effective in reducing fruit out to a range of about 30 miles. Beyond this range, however, heavy fruit could make the transponder returns unusable for en route control operations in many cases.

In addition to adding clutter to the display, interference causes another serious effect; namely, a reduction in transponder-signal response. To prevent overloading the transmitting circuits, present transponders are equipped with some type of overload control. Present transponders have a relatively short dead time of 110 microseconds, in conjunction with an automatic sensitivity control. When the interrogation rate is increased above 1200 interrogations per second (a rate equivalent to constant simultaneous interrogation by four I-R units), the receiver sensitivity is reduced progressively so that the transponder then replies only to the strongest interrogations. This type of operation thereby tends to discriminate against the weaker interrogation signals.

Interference tests showed that an increase in the interrogation rate tended to increase the amount of display clutter from a single target up to the point where the automatic overload control went into action on the airborne equipment. Beyond this point, clutter density did not increase and the clutter pattern became more irregular. Meanwhile, target quality continued to decrease owing to the decreased number of replies per scan.

Effect of Relative Power.

Because of the automatic sensitivity-variation effects previously described, the quality of targets decreased as the power of the participating unit was decreased in relation to the power of the interfering I-R unit for interrogation rates greater than 1200 pulses per second (pps). At

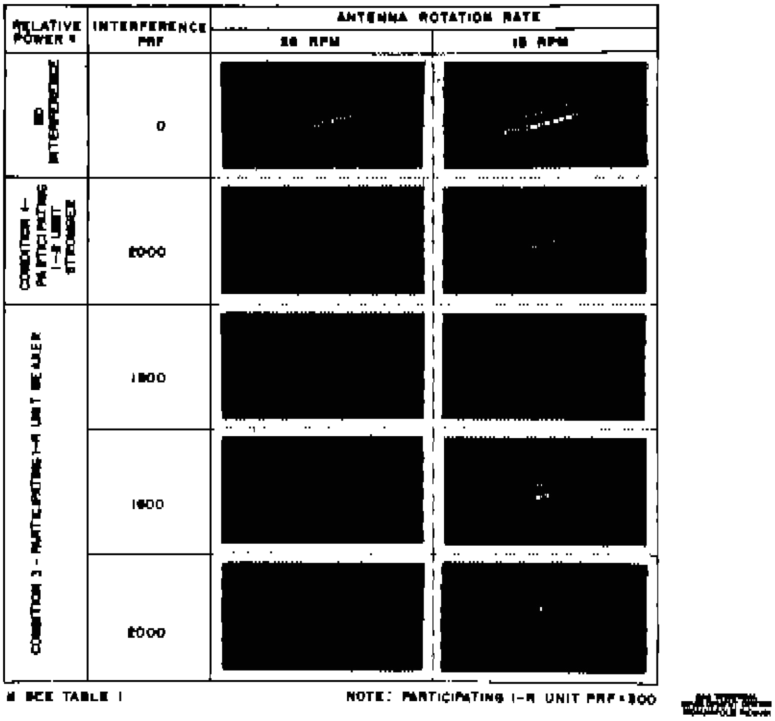


Fig. 19 Expanded View of Decoded Target Showing Effects of Interference on Target Quality

the same time, the display was derogated further by an increase in fruit. These conditions are likely to occur when an aircraft is at considerable range from the participating I-R unit but is much closer to the interfering I-R units. The effects are shown in Fig. 19.

Effect of Antenna-Rotation Rate.

A reduction in antenna-rotation rate tends to increase the number of hits per scan, thereby increasing the number of replies received from each transponder. Under heavy interference conditions, when a considerable percentage of interrogations is being lost due to dead time and sensitivity-control effects, a reduction in antenna-rotation rate may be necessary to see the target at all. Unfortunately, as the rotation rate is reduced, the density of fruit is increased because of the increased number of interrogations per scan. These effects are shown in Fig. 20.

Effect of Decoder Operations.

Fruit is heaviest when the decoder is switched off so that the indicator displays raw video. In this condition, each reply consists of a group of four blips displayed on the indicator. When the decoder is switched onto the all-aircraft position, the individual replies displayed are reduced to one pulse each. This represents a 75 per cent reduction in the amount of fruit. When the decoder is switched to a selected code only, no clutter from aircraft on other codes is displayed; however, clutter from aircraft on the selected code is doubled because each displayed reply consists of two pulses instead of one. When the controller's identification switch is turned on, clutter from any aircraft using Code 10 consists of a series of short lines instead of dots.

Antenna Characteristics.

Horizontal radiation patterns of the three types of antennas used in this test program are shown in Fig. 21. During these operations, the 18-foot antenna consistently presented targets averaging about 6° in azimuth as contrasted with the 13° targets presented by the 9-foot and integral-feed antennas.

Although the controllers who participated in these tests agreed that 13° targets are usable for close-in terminal operations, the extreme length of these targets at longer ranges appeared unsuitable for long-range displays in air-route-traffic control. Operationally, the use of the

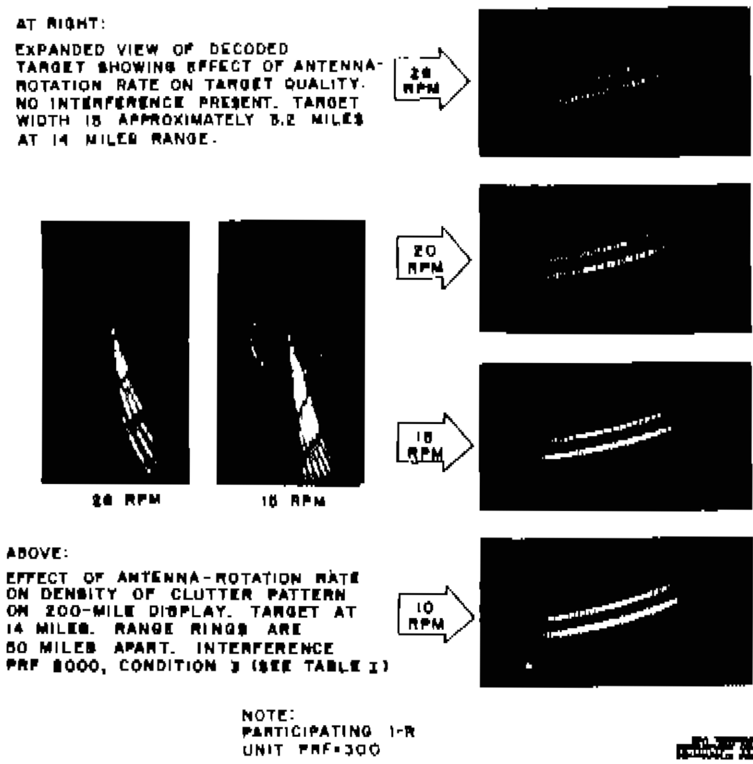


Fig. 20 Additional Effects of Antenna-Rotation Rate on Decoded Display

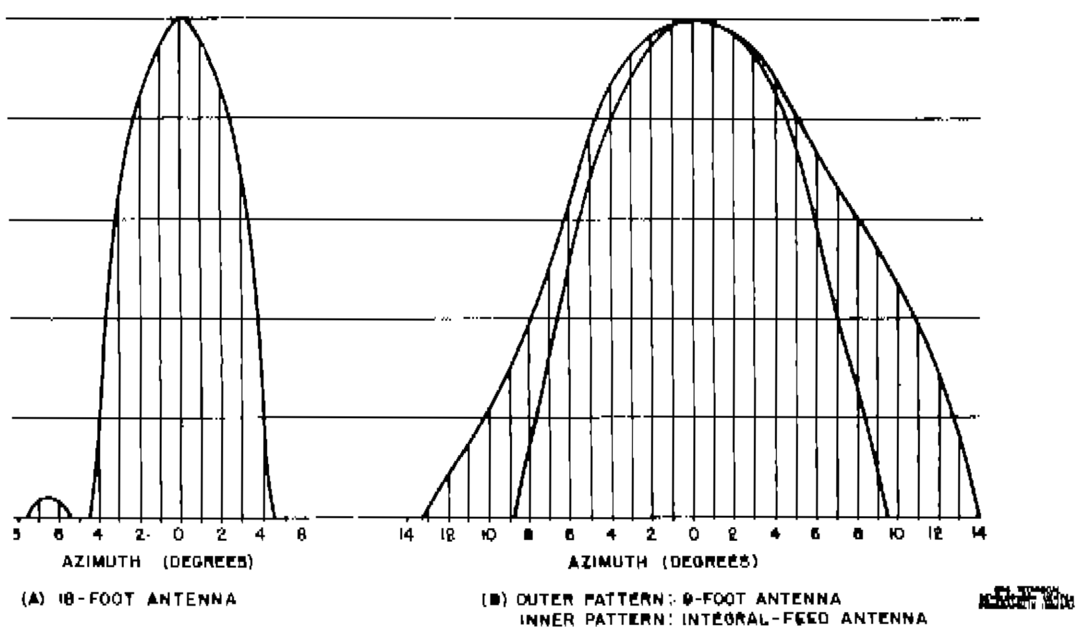


Fig. 21 Horizontal Radiation Patterns of Ground Antennas Tested at Indianapolis

TABLE II

GROUND ANTENNA-INSTALLATION CHARACTERISTICS

Type	Details	Availability 9-Foot Antenna	Availability 18-Foot Antenna	Maximum rpm 9-Foot Antenna	Maximum rpm 18-Foot Antenna	Advantages	Disadvantages
1 Separate slaved antenna	See Fig. 2	Under development	Under development	26	26	More freedom in choice of site to reduce reflections and increase low-angle coverage. Primary and secondary radar antennas need not be disconnected for maintenance at same time.	Display of range and azimuth data from separate sites produces confusing picture at short ranges. Requires new tower, higher installation and maintenance costs. Slaving problem--azimuth error is likely to be greater at high rpm or under high wind conditions. Antennas may shadow each other in some directions.
2 Combination on A-frame	See Fig. 3 for general arrangement*	Yes	Yes	26	26	Mechanically simple installation. No need for separate tower, no slaving problem. Azimuth error negligible.**	Slight restriction on operation of ASR under high wind conditions. Additional bracing of antennas may be required. Reflections and nulls may be serious.
3 Combination top mount	Beacon antenna mounted on top edge of radar reflector	Yes	Structurally undesirable	26	--	Same as No. 2 above. Probably no interference with circular polarization and no interference between primary and secondary radar-radiation patterns.**	Structurally not as good as No. 2 above; not suitable for 18-foot antenna. Possible restriction on operation of ASR under high wind conditions.
4 Integral feed	See Fig. 17	Equivalent to 9-foot antenna	No	26	--	Best system mechanically; no restriction on high wind operation.**	Vertical pattern of secondary radar antenna is distorted due to necessary compromise in location of horn feed; high-angle coverage is reduced.

*For ASR-3 installation, the radar reflector and feed horn will be raised about 14 inches in order that the beacon antenna can be mounted at the base of the radar reflector.

**These comparisons assume that a satisfactory rotary joint will be available for ASR-3.

18-foot antenna decreased decoder garble and fruit about 60 per cent because of the narrower beam width. This assumes that the reserve-system gain is 10 db and that the effective beam widths of the 18-foot and 9-foot antennas for responses 10 db below that of the half-power points of the beam are 6.8° and 16.9° respectively. Under conditions when the associated radar target is not visible, the controller's mental job of bisecting the target returns to determine the actual position of the aircraft is made easier when the target displayed is shorter. For these reasons, the 18-foot antenna is operationally more desirable than either the 9-foot or the integral-feed antenna.

Table II summarizes the advantages and disadvantages of the various types of ground-antenna mountings which can be expected to be available within the near future. Because of the difficulties involved in keeping a separate antenna slaved to the surveillance-radar antenna, particularly at high rotation rates or under high wind conditions, the use of a slaved antenna would not be recommended if a satisfactory combination antenna can be obtained. To avoid the excessive reflections or poor low-angle coverage which may be associated with an existing radar site, however, the use of a separate slaved antenna may be justified. In any case, it is desirable to keep the two antenna sites as close together as practicable to minimize the range and azimuth errors which would be involved in integrating the two displays on the same scan of the radar indicator. Recent tests show that if separate sites are necessary, however, it is possible to use dual-sweep PPI consoles, with the beacon display off-centered an appropriate distance. Such an installation eliminates range and azimuth errors and permits different antenna-rotation rates to be used in the primary and secondary radar systems.

Studies and scale-model tests made by Airborne Instruments Laboratory indicate that installation of the 18-foot antenna at the base of the ASR-3 reflector, as described in Table II, does not affect the S-band radiation pattern or the polarization characteristics. Also, it appears that the patterns of the 18-foot antenna are not affected. Calculations made by Airborne Instruments Laboratory indicate that the modified ASR-3 antenna will withstand 110-mph winds at a temperature of -50° F. when the antenna is stationary. This antenna should rotate satisfactorily at 26 rpm at wind velocities up to 55 mph when the temperature is -50° F. and at wind velocities up to 65 mph when the temperature is +20° F.

The vertical pattern of the integral-feed antenna is not as good as that of either the 9-foot or 18-foot antenna. The L-band horn feed cannot be located at the most effective focal point because the S-band radar-horn feed already occupies this space. This factor reduces the high-angle coverage of the integral-feed antenna.

During the two months preceding the flight demonstration, the 9-foot antenna was used to observe a number of flights of transponder-equipped aircraft operated by Lake Central Airlines, Inc. Most of the flights of this local-service airline are of short duration and, when weather permits, they are made at minimum en route altitudes of between 1300 and 1700 feet above the Indianapolis airport elevation. Observation of many of these flights indicated that the low-angle coverage of the 9-foot antenna, mounted as shown in Fig. 2, extended down to the radio horizon. In some cases, the secondary radar target still was strong after VHF communications had faded out. This type of coverage should facilitate the establishment of low-altitude shuttle procedures between adjacent airports.

CONCLUSIONS

It is concluded that:

1. Implementation of the secondary radar system should make possible a more positive type of all-weather traffic control. Although the full benefits of the system cannot be obtained until a very large percentage of IFR-operating aircraft are equipped with transponders, every increase in this percentage, however small, should offer additional possibilities for the application of secondary radar procedures. Simulation tests are now in progress to determine the best means of utilizing the advantages of secondary radar operation during the partial-implementation stage.
2. The higher resolution characteristics of the 18-foot antenna make it more desirable than either the 9-foot or the integral-feed antenna for air-traffic-control use. These two types, however, still will be satisfactory for close-in operations where excessive target width is not a serious factor.
3. The existence of shadowing and decoder garbling effects as detailed in this report need not seriously handicap the use of the system as long as controller personnel are fully cognizant of these characteristics and make allowance for such occurrences in the procedures employed.
4. Interference effects could become the greatest handicap to efficient operation of the system in congested areas. Further tests must be made to resolve the probable extent of this problem.

Reports of analyses and tests of the system's traffic capacity in the New York City area have been completed and published.[3,4]

5. The display of the identification code for a minimum period of 30 seconds is undesirable in air-traffic-control operations, particularly in areas where several radar-traffic-control facilities are located. It is desirable to modify the airborne equipment to permit momentary use of the identification code.

RECOMMENDATIONS

Although the evaluation of the factors affecting ground-antenna choice and certain other options still is incomplete, the following recommendations were derived from a careful study of the data available to date. These recommendations are made to aid those agencies involved in implementation programs.

1. Ground antennas for terminal-area traffic-control installations are recommended in the following order of preference:

   A. An 18-foot antenna, mounted at base of ASR reflector.
   B. A 9-foot antenna, mounted at base of ASR reflector.

The 18- and 9-foot separate slaved antennas are recommended, respectively, for locations where installation of an antenna on an existing ASR antenna tower would subject the secondary radar system to excessive reflections or poor low-angle coverage. Although an 18-foot antenna and pedestal capable of rotation at rates up to 26 rpm will be available, engineering tests show that the performance of primary and secondary radars is improved when the rotation rate is decreased.

It appears probable that a 15-rpm rotation rate may be operationally satisfactory for terminal-area traffic control. If a dual-sweep PPI console is used, it will be possible to adjust radar and beacon antenna-scan rates independently for individual optimum performance. Tests to determine optimum scan rates should be conducted.

2. It is recommended that the following combination of components be installed at TDC for reliability tests and operational evaluation:

   A. An ASR-3 antenna, modified as described in Table II.
   B. An 18-foot antenna.
   C. A combination S/L-band rotary joint.
   D. Circular polarization components.

3. It is recommended that all available operational information regarding shadowing, decoder garble, reflection, and interference effects be disseminated to local control personnel prior to the implementation of any secondary radar facility.

4. Because the characteristics of ground antennas are of primary importance in the operation of the system, it is recommended that improved antennas be evaluated as they become available, particularly antennas which have lower side-lobe levels and greater resolution.

The development of antennas having lower side-lobe levels should be pursued because such antennas would increase the traffic capacity of the system by decreasing side-lobe interrogations. In addition, their use would permit satisfactory operations with greater variations in transponder performance because the ground receiver could operate at a higher gain without danger of side lobes breaking through.

Consideration should be given to the use of larger antennas having greater resolution, especially in those cases where reflections or other siting problems require the use of a separate tower. It is probable that the use of high-resolution antennas will require a rotation rate slower than 26 rpm to avoid mechanical complications and to secure an adequate number of hits per scan. This type of antenna would be of particular advantage to air-route-traffic control because it would reduce the target size appreciably and thereby reduce the lateral separation necessary to show separate targets at the same range.

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[3] Joseph E. Herrmann, Clair M. Anderson, F. M. McDermott, and David S. Crippen, "Tests of the Capacity of the ANDB Air Traffic Control Beacon System," Technical Development Report No. 281, December 1955 (Classified).

[4] "Final Engineering Report on Pulse-Density Study of the ATC Radar Beacon System," Airborne Instruments Laboratory Report No. 3311-1, November 1955 (Classified).