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**DUAL PATTERN ANTENNA,
APPLICATION TO IFF INTERROGATION SIDE LOBE SUPPRESSION**

R. E. Scott

TECHNICAL DOCUMENTARY REPORT NO. RADC-TDR- 63-257

June 1963

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Project No. 6502

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FOREWORD

Acknowledgment is given to Gilfillan Corporation for use of certain information taken from their Technical Proposal entitled "Three-Pulse IFF/SIF Beacon Interrogator System for AN/CPN-4 and AN/MPN-11 ATC Radar," dated 21 July 1961.

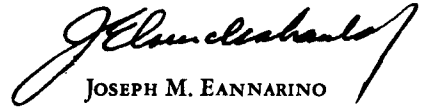
ABSTRACT

The purpose of this report is to acquaint interested personnel with a non-conventional IFF antenna system developed for use with the AN/CPN-4/GPX-8A ATC Radar-IFF System. A flight test program was conducted at RADC's Verona Test Site at Verona, N.Y. for the purpose of testing the capabilities of this antenna to function properly in an IFF Side-Lobe Suppression System. The data presented is, for the most part, in the form of composite pictures of returns from an aircraft flying various radial paths across the Verona Test Site, and free space antenna patterns taken at the Newport Antenna Test Range, Newport, N.Y. Results show that the antenna has the desired capability.

PUBLICATION REVIEW

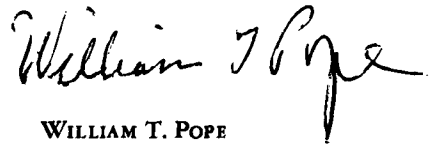
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1. INTRODUCTION

The presence of side-lobe energy is inherent in the radiation patterns of all antennas. The presence of such energy from IFF antennas has a detrimental effect upon the efficient performance of the associated IFF System. The Setrin Fix was developed within RADC as a method of eliminating the effects of side lobes in the IFF ground to air interrogation path. At present, RADC is in the process of implementing this fix with various radar complexes within the Air Defense Command. The Setrin Fix requires a directional antenna and an omni-an-

tenna to radiate its three-pulse interrogation mode.

The subject antenna has been developed to provide this requirement in one package, to be used with another type of radar complex within the Air Force inventory; namely, the CPN-4/MPN-11 Air Traffic Control type radar.

The test program performed by RADC was for the purpose of determining the capabilities of this antenna in an IFF interrogation side-lobe suppression (ISLS) environment and is detailed in this report.

2. AN/CPN-4/GPX-8A RADAR SYSTEM

The AN/CPN-4 GCA radar has an integral feed for its search radar/IFF systems. This means that the search radar equipment and the associated IFF equipment (GPX-8A) share the use of the radar reflector for transmission and reception of their individual signals. This arrangement provides a real mechanical economy in that only one antenna is required for both systems. However, it leaves much to be desired in electrical operation of the IFF system since the design of the reflector, placement of feed structures, etc. were optimized for the radar system. As a result, the side-lobe areas of the IFF radiation pattern are comparatively large (see Figures 1a, b, c and d) causing increased false target returns and, at short ranges (under 10 miles), complete "ring-around" to be painted on the associated

PPI oscilloscope. This condition makes target tracking by IFF returns extremely difficult or impossible at the short ranges involved for GCA.

This is perhaps a blacker picture than actually exists at some operational sites. It is possible to obtain considerable improvement in target presentations on the associated PPI by use of the receiver "gain time control" (GTC) circuitry of the AN/UPX-6 IFF receiver-transmitter unit. This reduces receiver gain in close range and has the effect of cancelling aircraft returns picked up by the antenna side lobes in the air-to-ground path. However, this is a passive method for cancellation of the side-lobe effects and does not prevent overloading an aircraft transponder by side-lobe interrogation in areas of high interrogator density.

3. IFF INTERROGATION SIDE LOBE SUPPRESSION

The following is a brief description of the IFF Interrogation Side-Lobe Suppression scheme (Setrin Fix).

The normal IFF interrogation mode is two pulses of 0.8 microsecond width, spaced 3, 5 or 8 microseconds apart, depending upon the mode of interrogation selected. (See Figures 2a, b and c.) The IFF

ISLS system inserts a third 0.8 microsecond pulse (called the Suppression Pulse) into the interrogation mode at a spacing of 2 microseconds after the leading edge of the first interrogation pulse (see Figures 3a, b and c). Normally, the two interrogation pulses are radiated from a directional-type antenna while the suppression pulse is radiated from

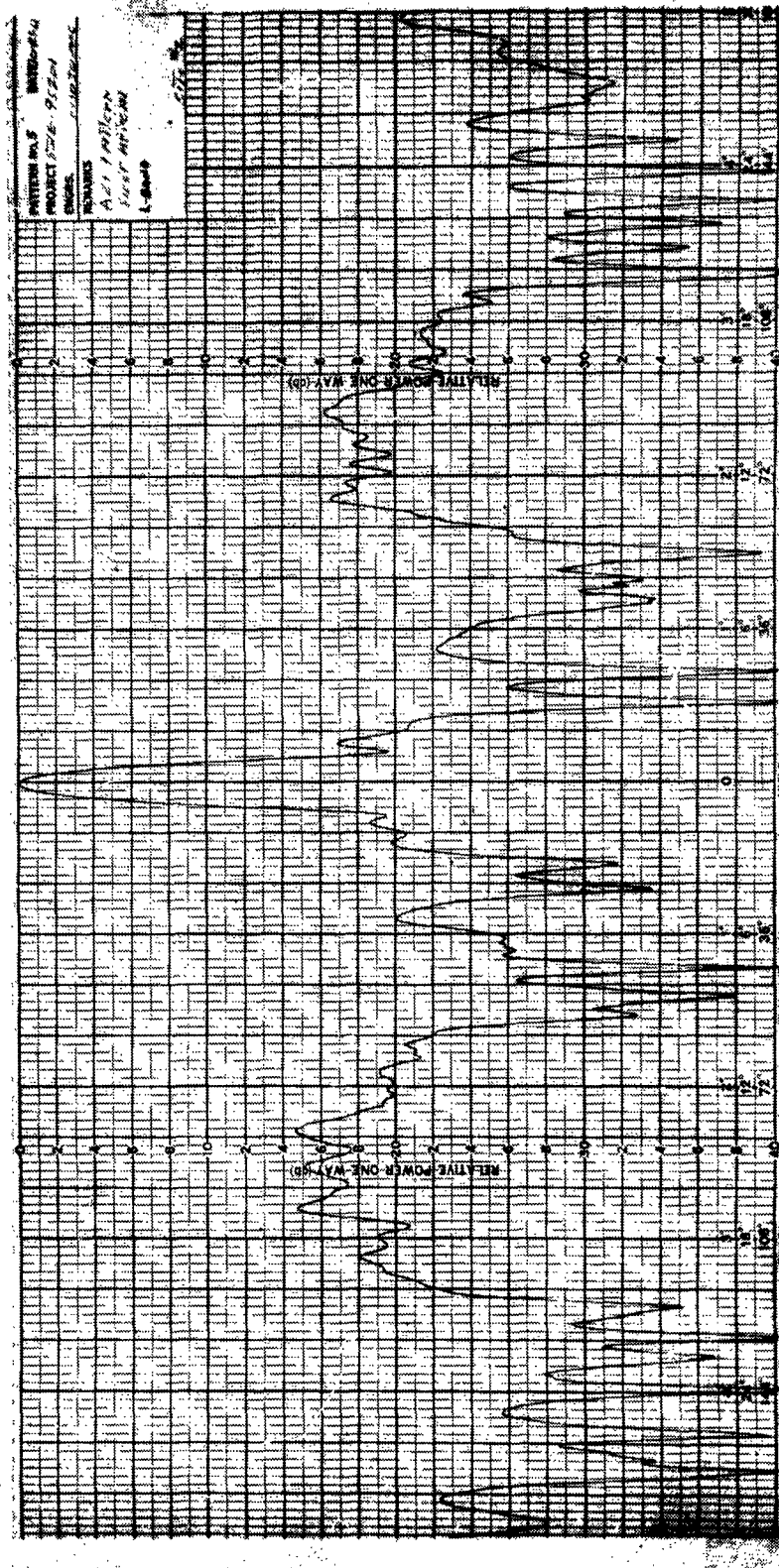


Figure 1a. H-plane Pattern (CPN-4) — 1030 mc

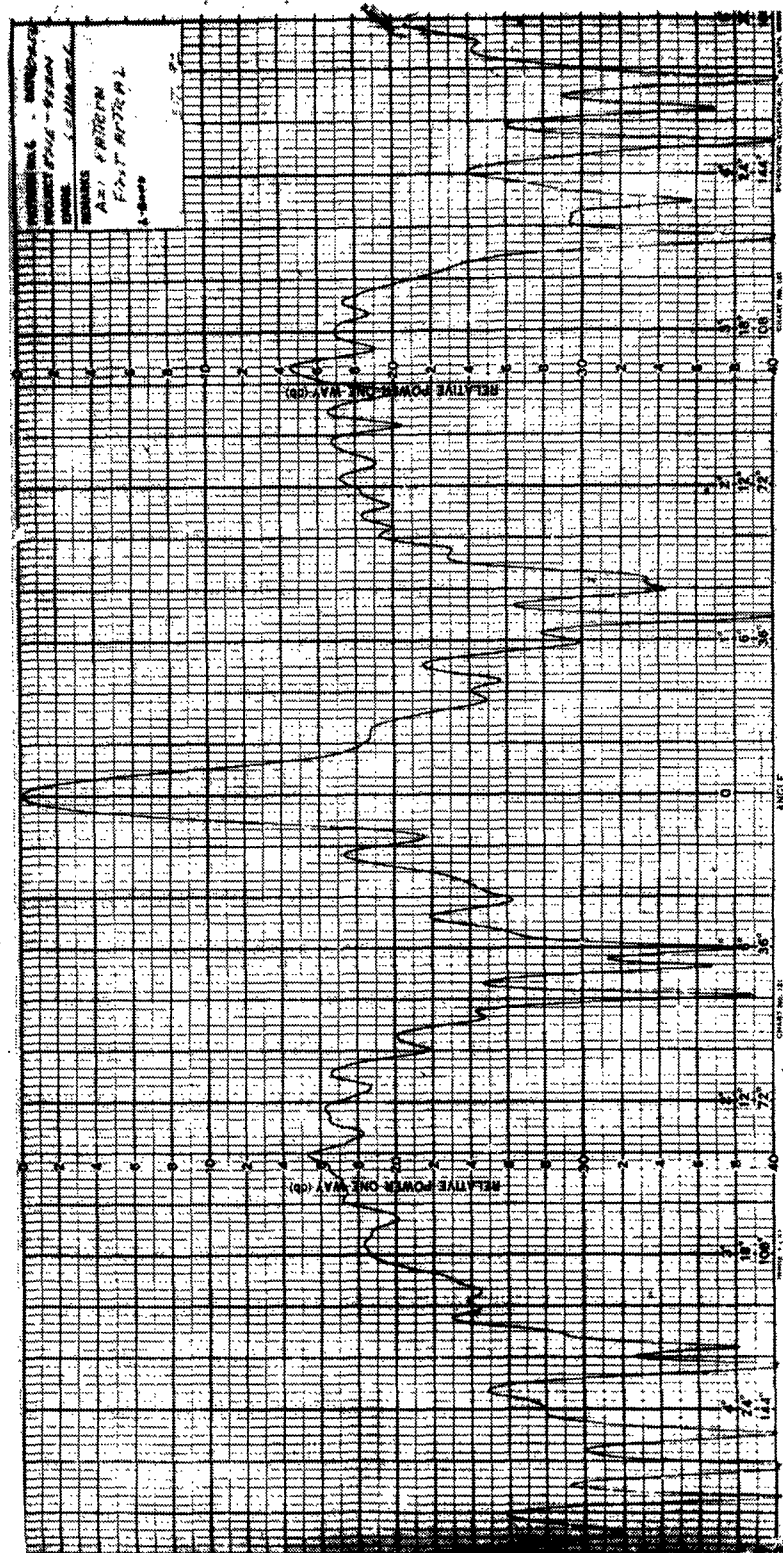


Figure 1b. H-plane Pattern (CPN-4)—1110 mc

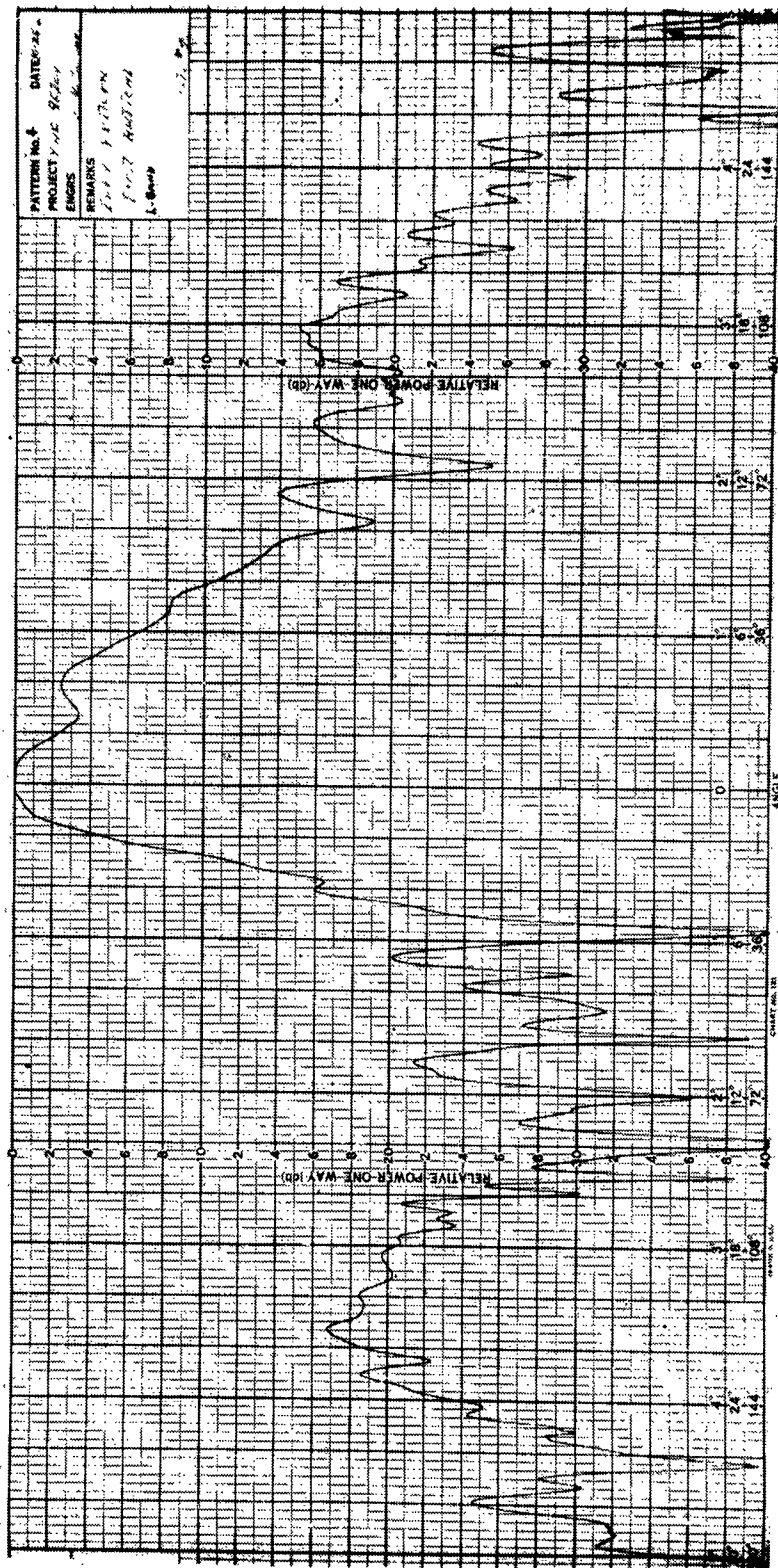


Figure 1c. E-plane Pattern (CPN-4) — 1030 mc

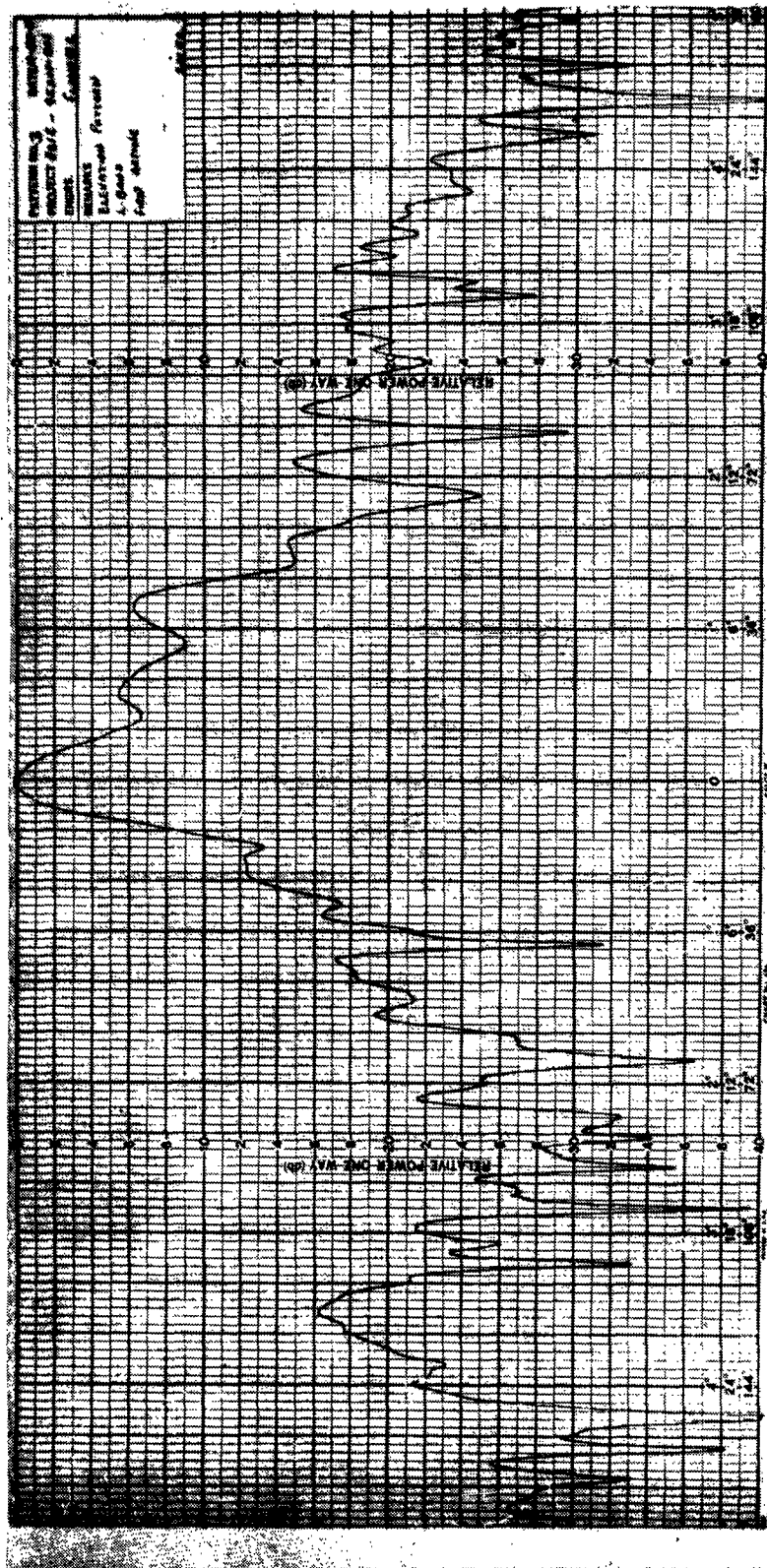


Figure 1d. E-plane Pattern (CPN-4)—1110 mc

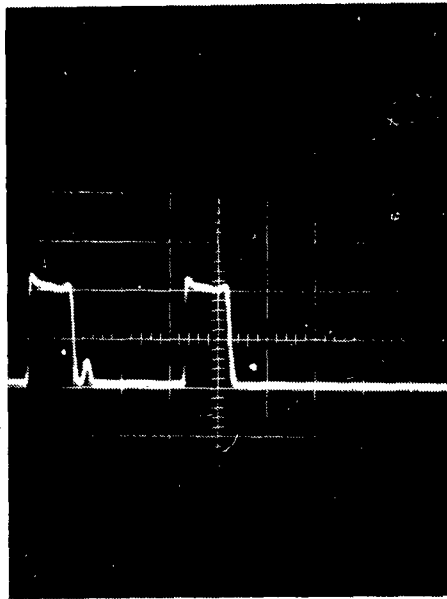


Figure 2a. Normal IFF Interrogation (Mode 1)

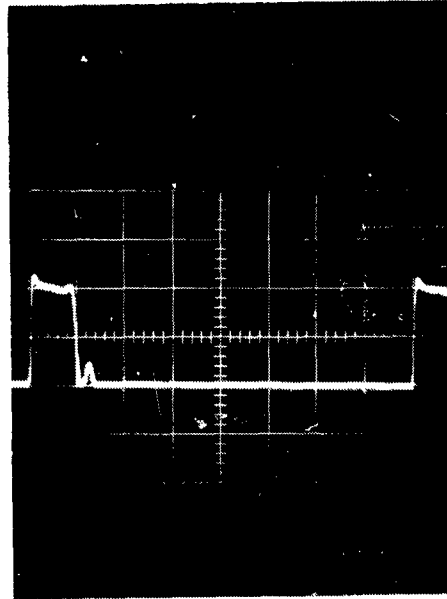


Figure 2c. Normal IFF Interrogation (Mode 3)

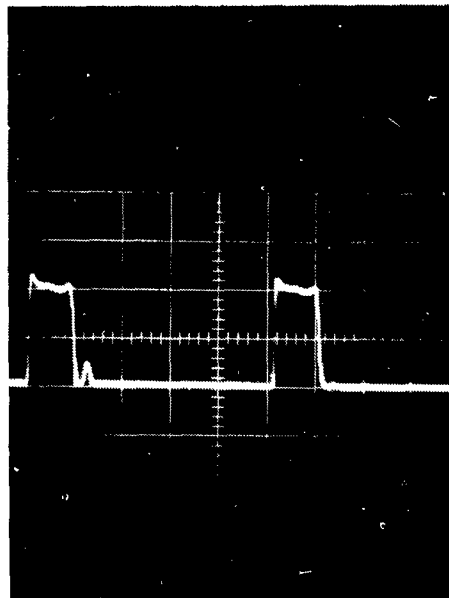


Figure 2b. Normal IFF Interrogation (Mode 2)

an omni-type antenna. Proper operation of this ISLS system is dependent upon the correct spacing of the first directional pulse and the suppression pulse, and the relative amplitudes of these two pulses. The correct spacing is achieved by triggering the associated transmitter at the proper time. The instantaneous relative pulse amplitudes are a function of the radiation characteristics of the associated directional and omni-antennas. The airborne transponder, modified for operation in an ISLS system, answers only when the first interrogation pulse is at least 10 db greater than the suppression pulse. In theory, this occurs only in the main beam area of the directional pattern. Therefore, no aircraft responses should be triggered by antenna side-lobe interrogations.

Unmodified airborne equipment will still respond in an ISLS environment since a conventional two-pulse interrogation is still present in the ISLS mode. The effectiveness of the ISLS system will become apparent as more ground and air modified equipment are put into service.

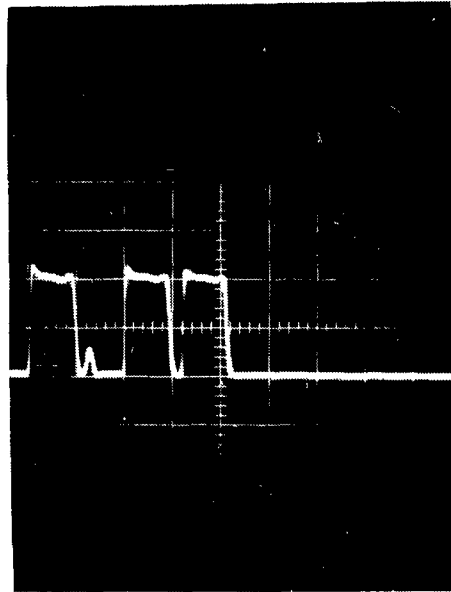


Figure 3a. IFF Interrogation Side-Lobe Suppression (Mode 1)

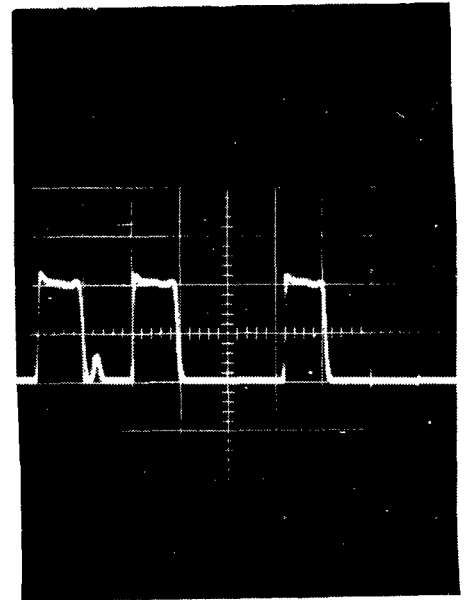


Figure 3b. IFF Interrogation Side-Lobe Suppression (Mode 2)

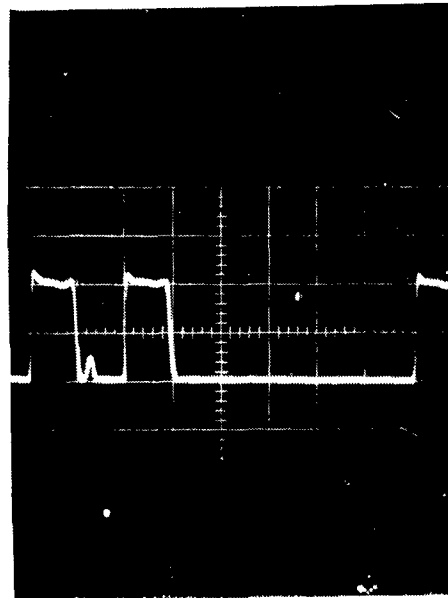


Figure 3c. IFF Interrogation Side-Lobe Suppression (Mode 3)

4. ANTENNA HISTORY AND OPERATION

Gilfillan Brothers, Inc. of Los Angeles, Calif. developed and fabricated an antenna for RADC under Contract AF30(635)-25279. The antenna was designed for its purposes, to be used in conjunction with the AN/CPN-4 Radar. A "sum-difference" type of antenna was constructed which would have the capability of radiating not only the conventional two-pulse interrogation pattern but could be utilized to radiate the three-pulse ISIS pattern. (The ISIS modifications for ground and airborne equipment are presently being prepared.) The antenna would be mounted on top of the AN/CPN-4 reflector (see Figures 4 and 5 for complete antenna assembly).

Pertinent information concerning the antenna is summarized below.

a. The primary components of the antenna assembly are:

- A 10-foot "sum-difference antenna" (divided into two sections)
- A backfill antenna (corner reflector)
- A hybrid junction
- An r-f switch

b. R-f energy is transmitted from the AN/UPX-6 Interrogator-Responser, via the AN/CPN-4 rotary joint, to the r-f switch which channels the energy, to a "sum port" or "difference port" of a hybrid junction. The hybrid junction splits the energy equally and channels it, via the associated cabling to the two end-feed connectors of the antenna and thence to the radiators in the two halves or sections of the antenna. If the energy comes to the hybrid junction through the "sum port," both antenna sections are fed in-phase and the pattern shown in Figure 6 is radiated. If the energy arrives at the hybrid junction through the "difference port," the

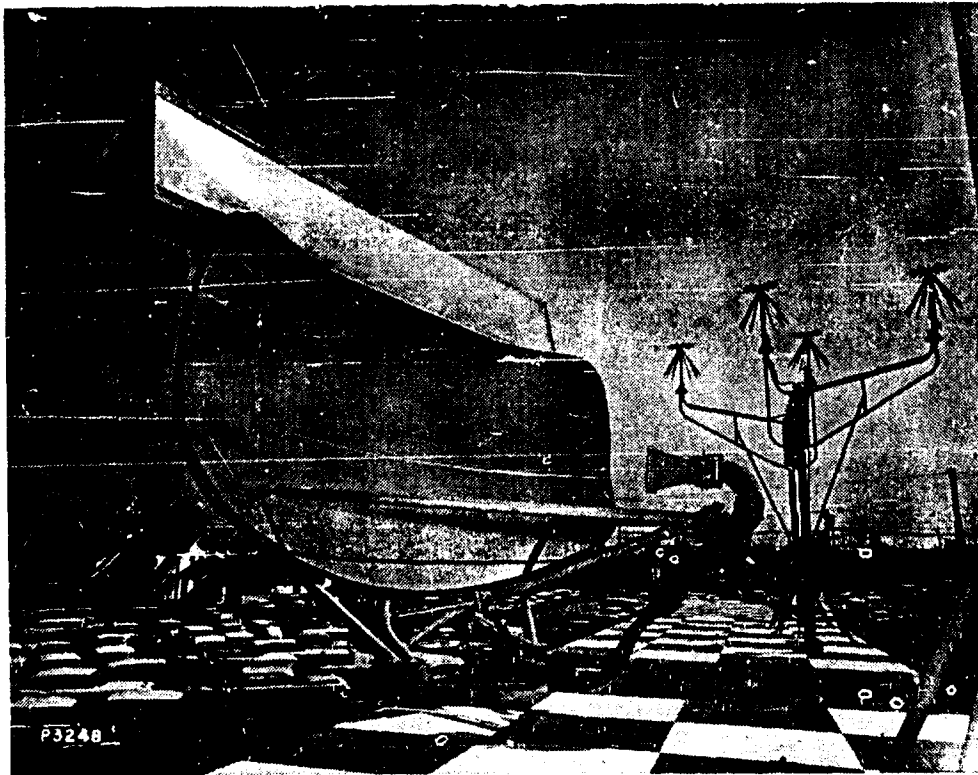


Figure 4. Sum-Difference Antenna Mounted on AN/CPN-4 (Front View)

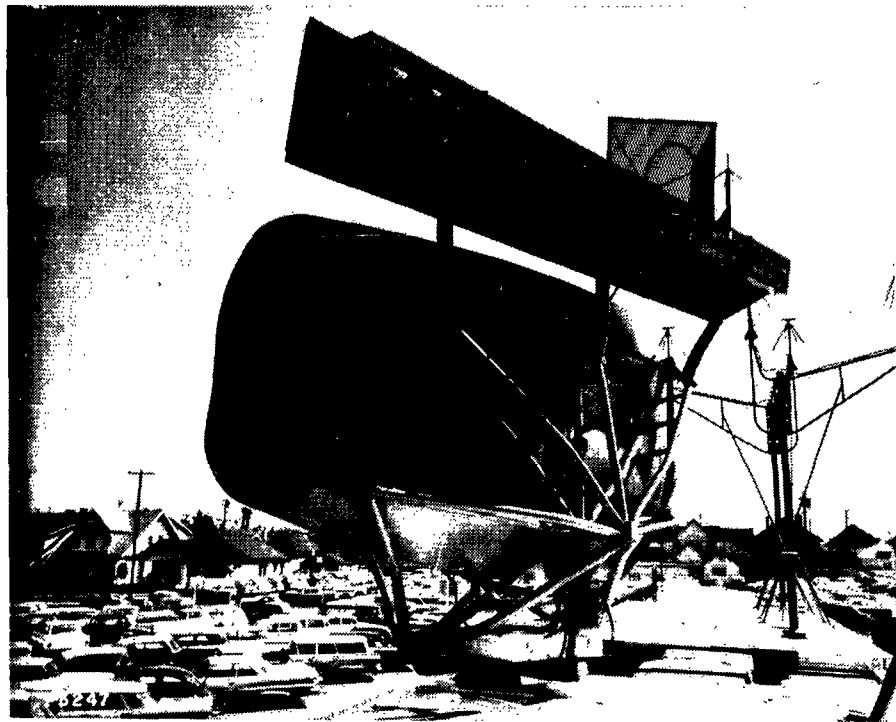


Figure 5. Sum-Difference Antenna Mounted on AN/CPN-4 (Rear View)

antenna sections are fed 180° out-of-phase and the pattern shown in Figure 7 is radiated. A portion of the energy in the difference path is fed, by means of the appropriate power-splitting device, to a small corner reflector on the back side of the antenna. This small antenna is used to radiate energy into the back field of the difference pattern to insure that it

is greater than the back field of the sum pattern at all azimuths. Figures 8a and b show the relationship of the two patterns at 1030 mc and 1090 mc. Special note should be taken of the fact that the maximum of the sum pattern and the deepest null of the difference pattern occur at the same position, *i.e.* the pattern midpoints.

5. USE OF SUM DIFFERENCE ANTENNA FOR IFF ISLS ON AN/CPN-4

This antenna is basically two antennas in one package with the beam configurations shown in Figures 6 and 7. The sum pattern (Figure 6) corresponds to a conventional directional antenna beam. The difference pattern (Figure 7) corresponds somewhat to an omni-antenna pattern except at approximately $\pm 24^\circ$ of boresight where it builds up to, in effect, two lobes with a deep null between them at 0° . Both "antennas" have the same focal

point since the same radiators are used with the same reflector at the same frequency. They will therefore "see" in space from the same aspect. This capability is ideal for the operation of IFF ISLS.

The proposed method for utilizing this antenna takes advantage of the known relationship between the two radiation patterns. The sum pattern radiates the two interrogation pulses which would be the first and last pulse in the three-pulse ISLS interroga-

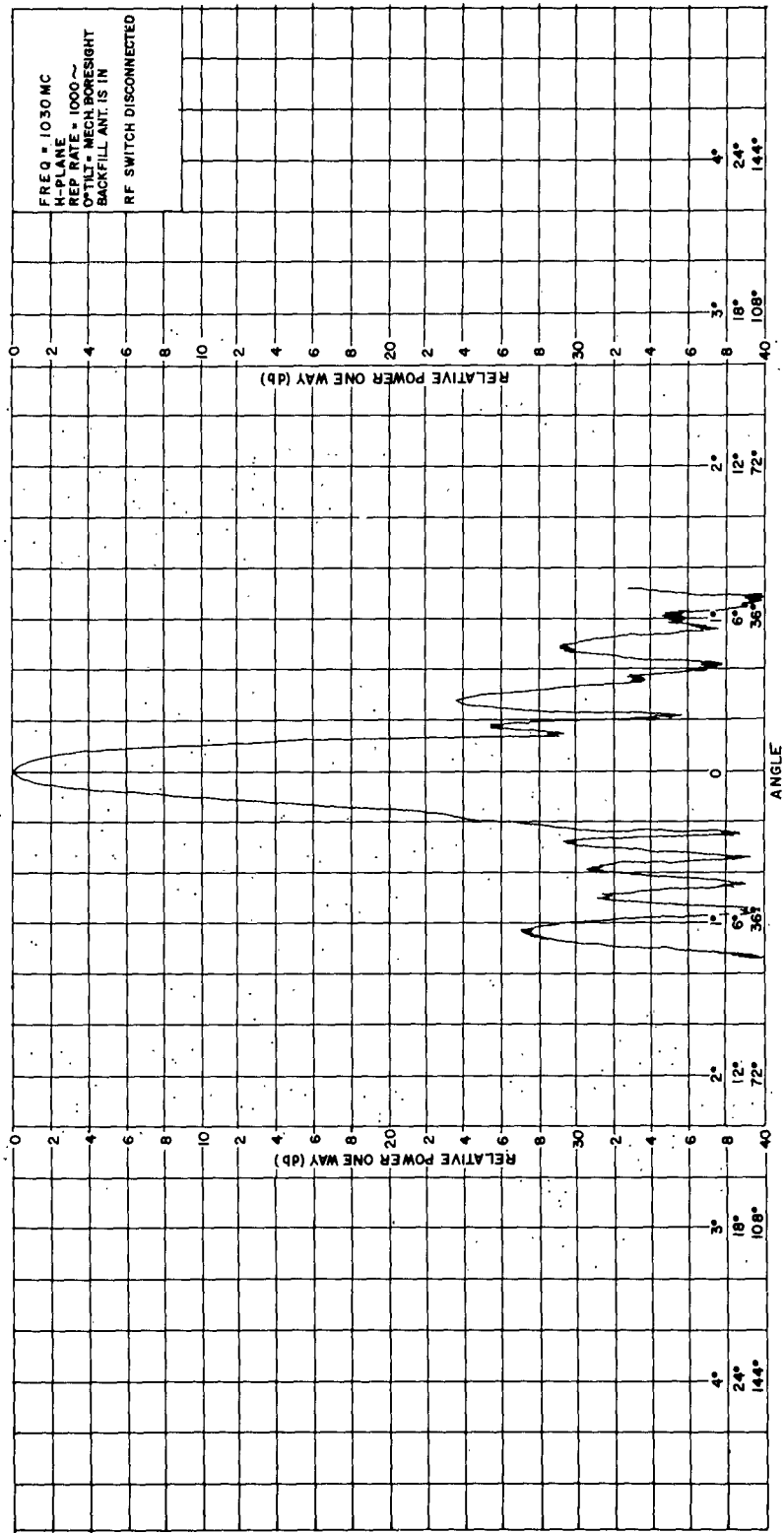


Figure 6. Antenna Sum Pattern — 1030 mc

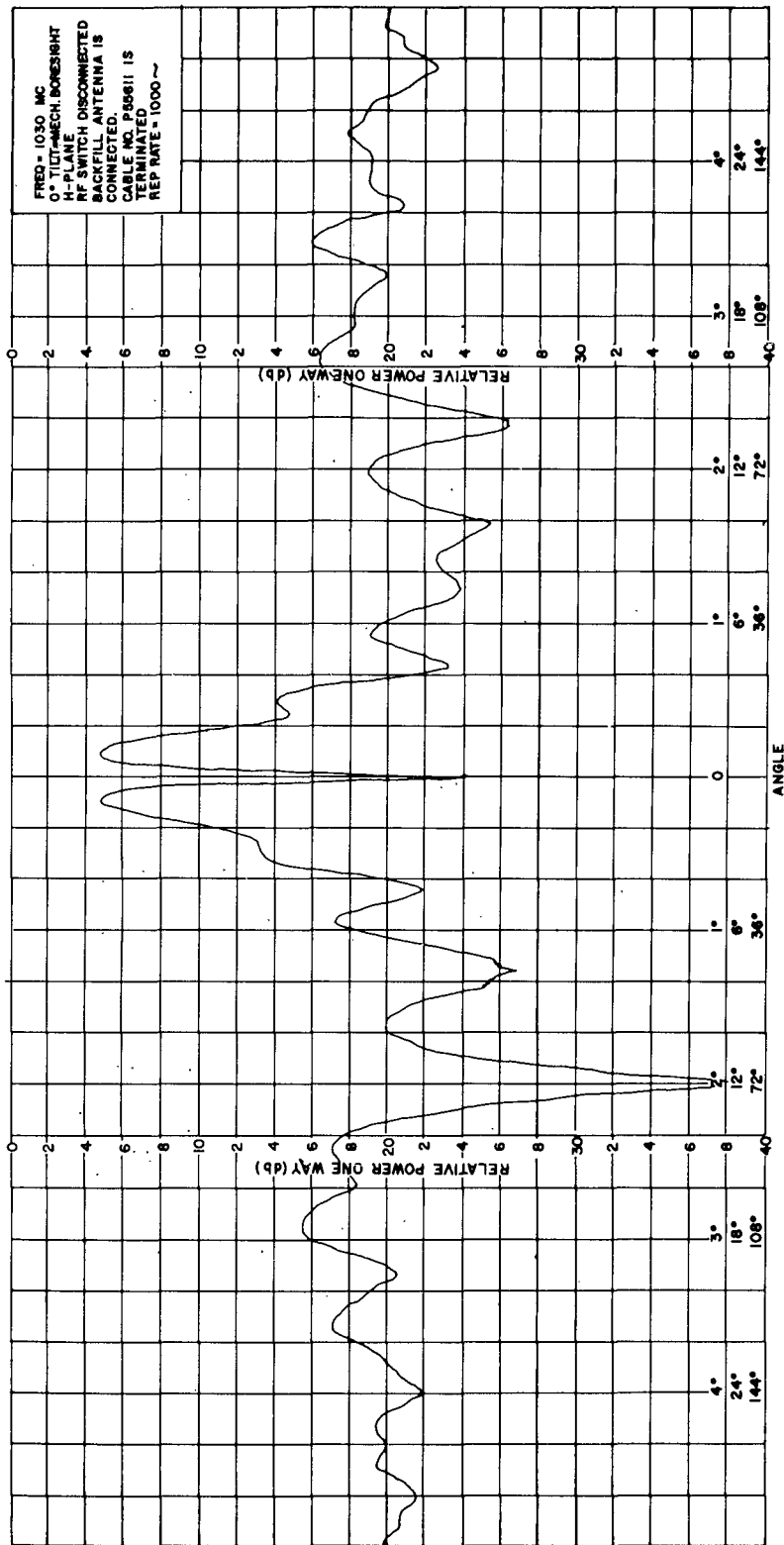


Figure 7. Antenna Difference Pattern — 1030 mc

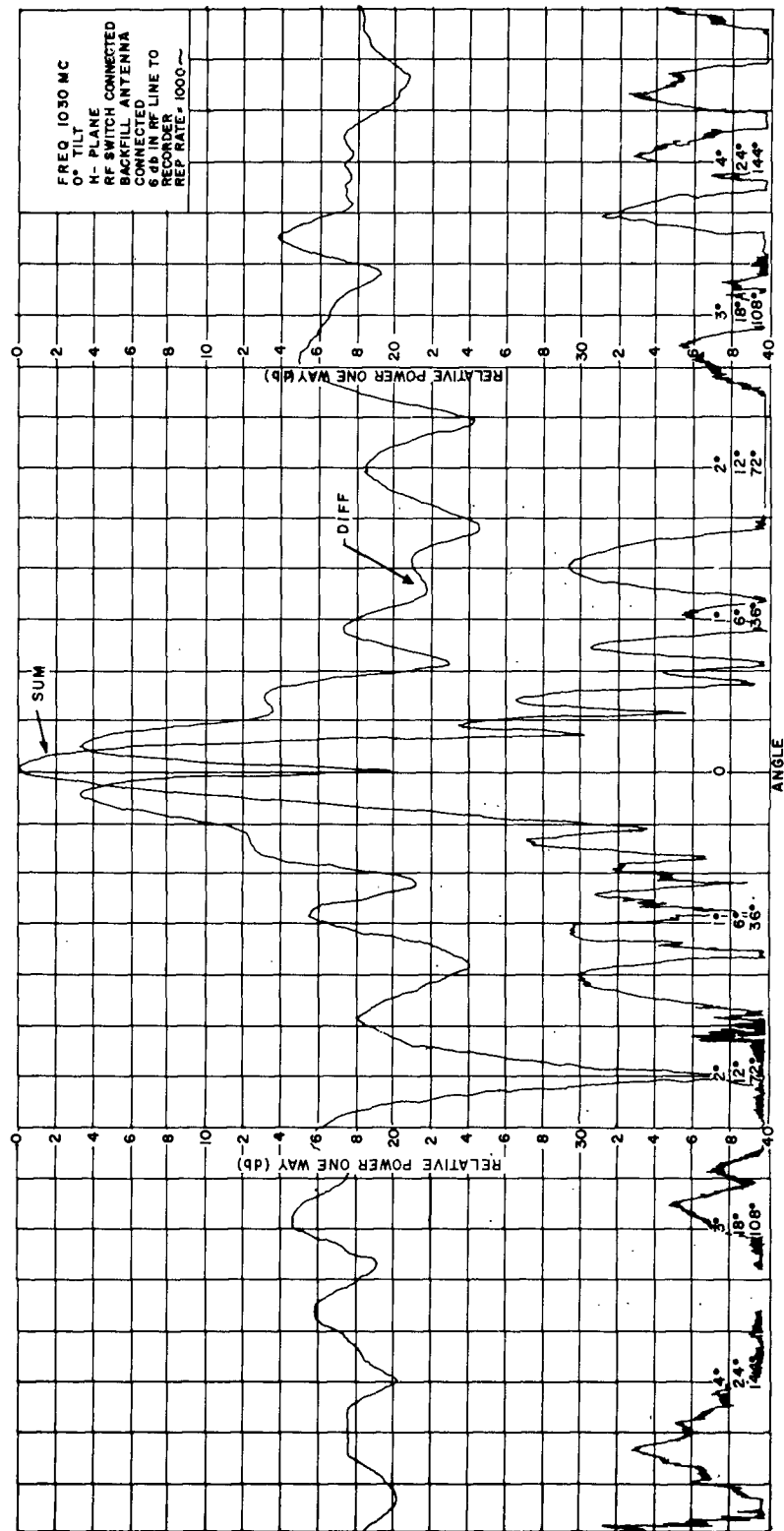


Figure 8a. Antenna Sum-Difference Pattern — 1030 mc

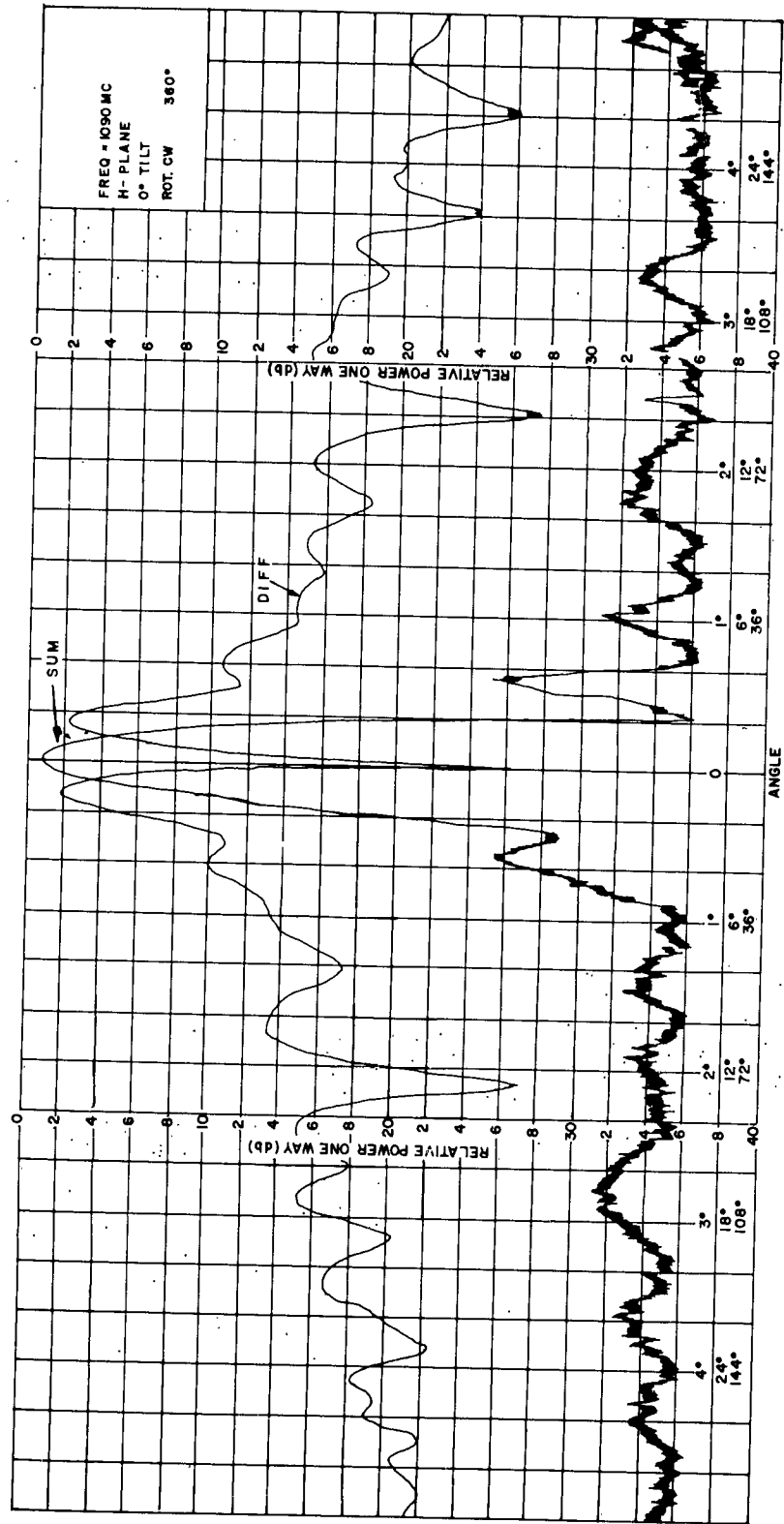
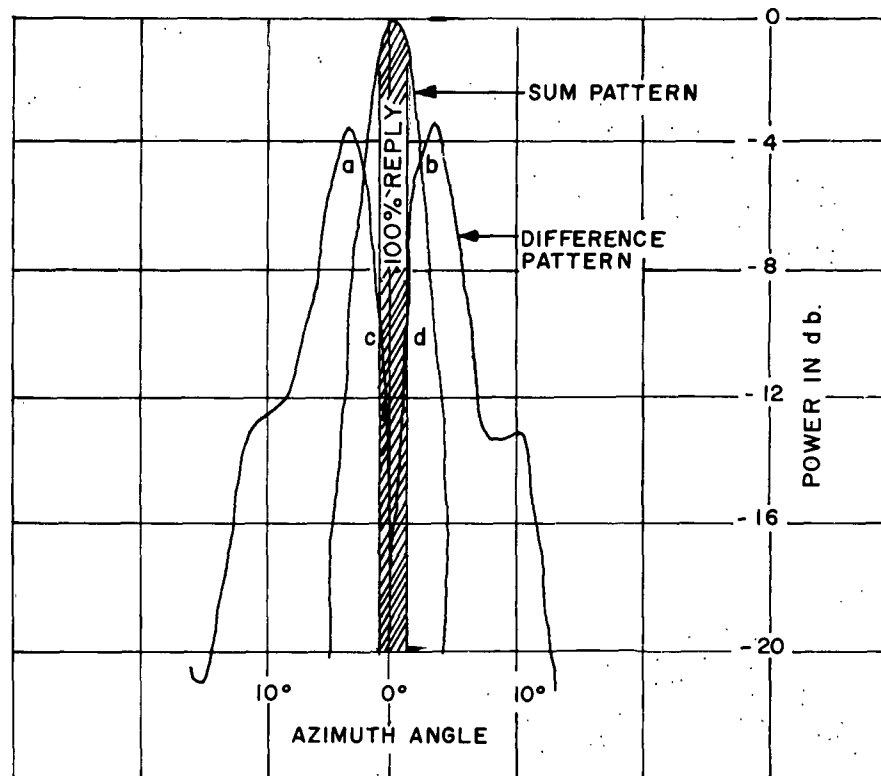


Figure 8b. Antenna Sum-Difference Pattern — 1090 mc



The above figure is a tracing of the antenna pattern. The IFF ISLS system requires a nominal 10 db advantage of the directional antenna (sum pattern) over the omni-antenna (difference pattern) for 100% reply. This advantage is first achieved at points c and d on above tracing. Therefore, the dimension enclosed between these points in the sum pattern (shaded area) will determine the width of the returns to be indicated on PPI. The area outside of points a and b (crossover points) is the area where no replies will be expected. The area between points a and c and b and d is called the "gray area" where the probability of replies is shifting from no reply at crossover points a and b, to 100% reply at points c and d. During this "gray area," replies will be dependent on instantaneous conditions and therefore a reply for every interrogation cannot be predicted.

Figure 9. Antenna Pattern Tracing

tion mode. The difference pattern radiates the suppression pulse which would be the middle pulse in the three-pulse ISLS interrogation mode. In this manner, it is possible to predict where responses should be received from an airborne transponder. Responses should be received only where the sum pattern has a 10 db or greater advantage over the difference pattern which covers a narrow area in the middle of the sum pattern main beam. Interrogations at any other point in the beam patterns should not trigger a reply from the transponder. (See Figure 9 and accompanying narrative for detailed explanation.)

An r-f switch controls the instantaneous radiated antenna pattern. The proper timing for radiating first an interrogation pulse, then the suppression pulse, and then the second interrogation pulse is achieved by designing the associated circuitry to trigger the ground transmitter and to key the switch in the proper sequence to radiate the desired pat-

terns and interrogation mode. In general, this operation is as follows: The first pulse from the KY-166 IFF coder triggers the AN/UPX-6 transmitter for generation of the first interrogation pulse. It keys the r-f switch to the difference port preparatory for the arrival of the suppression pulse. It is also delayed the necessary 2 microseconds and used to trigger the transmitter for generation of the suppression pulse. The second pulse from the KY-166 coder triggers the AN/UPX-6 transmitter to generate the second interrogation pulse at 3, 5 or 8 microseconds spacing from the leading edge of the first interrogation pulse, dependent on the interrogation mode used.

The r-f switch remains at the "sum port" except when it is keyed to the "difference port" by the first pulse from the KY-166 coder. It remains at the "difference port" for the duration of the suppression pulse after which it returns to the "sum port" until keyed again by the next PRF of the coder.

6. TEST PROGRAM

The contractor submitted data to RADC from a test program which they conducted showing the operation of this antenna at their Fontana Site in California. RADC monitored part of this test program and considered the results worthy of further study. A flight test program was therefore planned and conducted at the Verona Test Site (RADC), Verona, N.Y.

The antenna was received from the contractor for testing in the fore part of 1962. Free space patterns at the IFF operating frequencies of 1030 mc and 1090 mc were taken of the E and H fields of the antenna at the USAF Antenna Test Range at Newport, N. Y. Gain and vswr measurements were also taken at the Newport Site. Flight testing commenced in July 1962 and continued for the period covering the next two months, depending on the availability of aircraft.

A C-131 aircraft was used, which had an ISLS modified transponder installed for the test purposes. The aircraft flew at an altitude of 2000 feet on various radial headings across the Verona Site, a distance of 15 miles on each side of the site for a total leg of 30 miles. Data was accrued in the form

of time-exposure pictures taken of the returns from the aircraft for each 15-mile radial as displayed on a PPI. Each radial was repeated five times with one of the following conditions* existing in the interrogation mode:

1. AN/CPN-4 integral feed radiating two-pulse interrogation mode.
2. Sum pattern radiating two-pulse interrogation mode.
3. Sum-difference patterns radiating three-pulse ISLS mode.
4. Sum pattern radiating two-pulse interrogation mode, AN/UPX-6 receiver operating with short GTC and the GPX-27 Defruiter in the receive path.
5. Sum-difference patterns radiating three-pulse ISLS mode, UPX-6 receiver operating with short GTC and the GPX-27 Defruiter in the receive path. In addition, some 200-mile radials were flown to check the range of the antenna.

*These conditions are used as part of the subtitles on the data in the test results following.

7. TEST RESULTS

The test program conducted on the antenna at the Newport Antenna Test Range produced the following results:

VSWR MEASUREMENTS

Frequency	Connection	VSWR
1030	Sum	1.10
	Difference	1.18
1090	Sum	1.68
	Difference	1.73

GAIN MEASUREMENTS (Sum Pattern)

Frequency	(Vertical Polarization)	Gain
1030	No rf Switch	21.25
	With rf Switch	21.25
1090	No rf Switch	19.6
	With rf Switch	19.6

Free space patterns are shown in Figures 6 to 8b.

Results of the flight test program conducted at the Verona Test Site are shown in Figures 10 to 20. Refer to Section 5, TEST PROGRAM for test conditions on individual pictures.

8. TEST COMMENTS

Evaluation of the data taken during this program points out certain facts concerning this antenna.

Note: No IFF antenna patterns were available of the particular AN/CPN-4 IFF system used for this test program. Therefore, only general conclusions can be drawn in using the particular AN/CPN-4 IFF patterns included in this test report.

a. The free space patterns of this test antenna show that the sum pattern has a configuration similar to that of conventional IFF directional antennas; that is, a main lobe with decreasing side lobes on each side. The IFF radiation pattern of the AN/CPN-4 antenna has the same general configuration. Comparison of the patterns of these antennas should be an indication of their relative field performances, especially in side lobe coverage which was of particular interest during this test program. Using the free space patterns included in this report, one would expect considerable improvement by using the test antenna over the use of the AN/CPN-4 antenna from which these particular patterns were obtained. Such an expectation would be based on the greater height and width of the side lobes shown on the AN/CPN-4 patterns. The results of these greater side lobe areas would be more extensive false target indications and "ring-around" on the associated PPI

scopes used for displaying the aircraft replies. Further comment follows, partially verifying such a prediction.

b. Observation of the pictures taken of target aircraft replies using various combinations of system parameters with normal or ISLS interrogation modes shows certain facts. Comparison of the CPN-4 IFF returns with the sum pattern returns using the normal two-pulse interrogation mode shows little difference in the range of coverage by the side lobes of the antenna. This is contrary to the expectations discussed in Section 7a. Therefore, this would indicate that the height of the side-lobe levels of the AN/CPN-4 antenna used during this test program were comparable to those of the test antenna.

On the other hand, the area of coverage by the AN/CPN-4 IFF side lobes is greater than that of the sum pattern coverage, as is shown by the greater "ring-around" on the AN/CPN-4 returns. This indicates the greater width of the AN/CPN-4 side lobes over those of the test antenna.

Use of the sum-difference capability to radiate the three-pulse IFF ISLS mode shows a marked improvement in tracking capability over the use of either the AN/CPN-4 radar or the sum pattern alone. (See Figures 10 to 20 in Section 7 marked Condition 1 and 2 as compared to Condition 3.) The

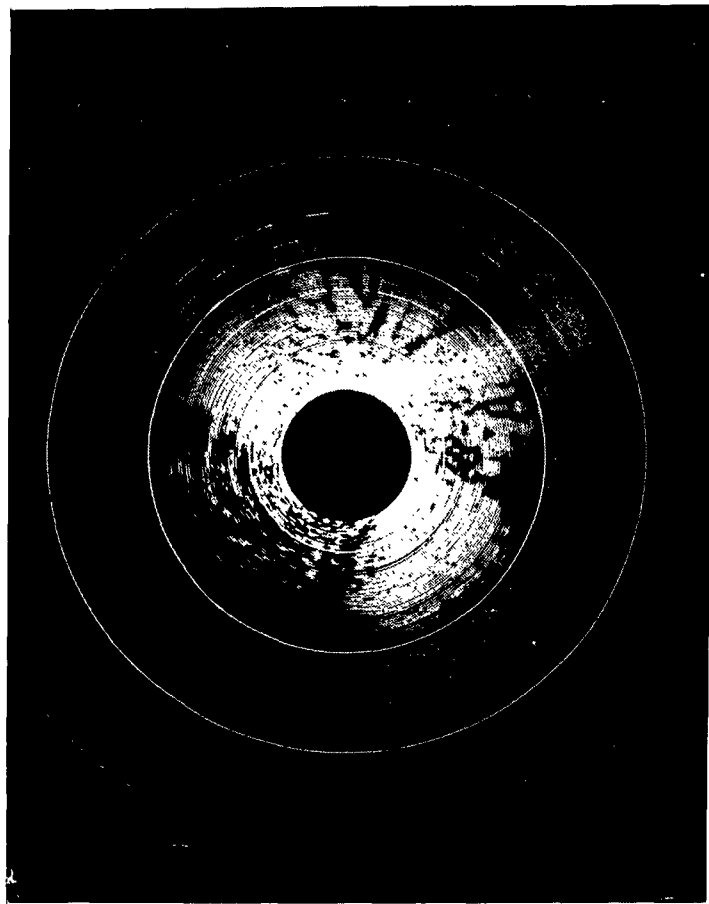


Figure 10. Azimuth—270° Outbound (Condition 1)



Figure 11. Azimuth— 270° Outbound (Condition 2)



Figure 12. Azimuth— 270° Outbound (Condition 3)

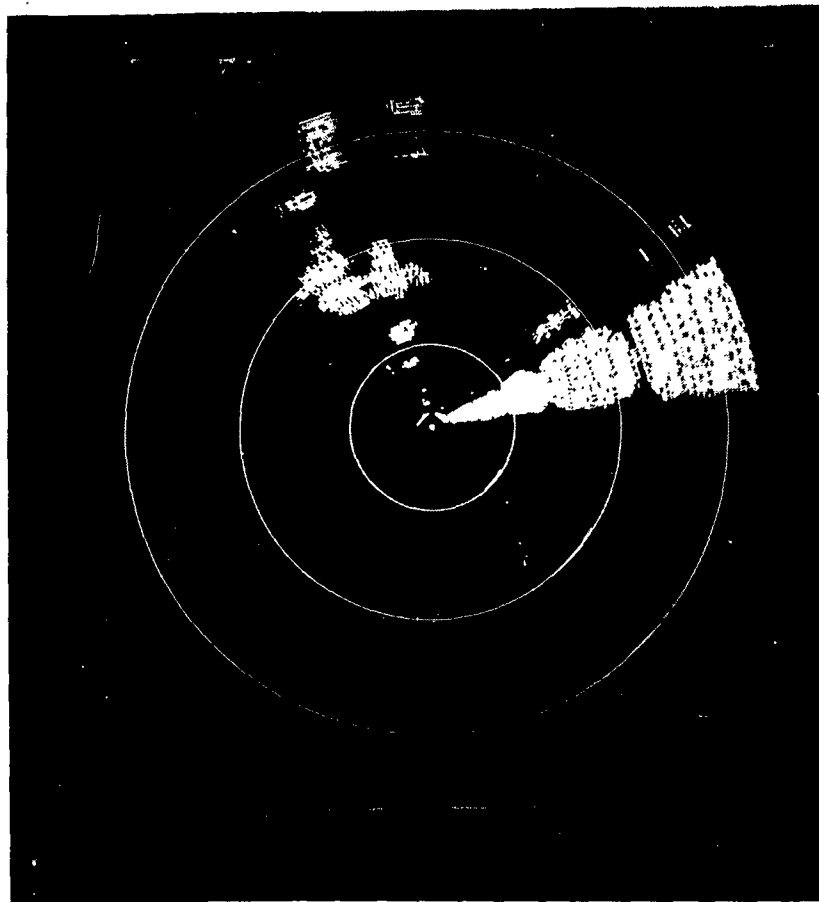


Figure 13. Azimuth — 270° Outbound (Condition 4)

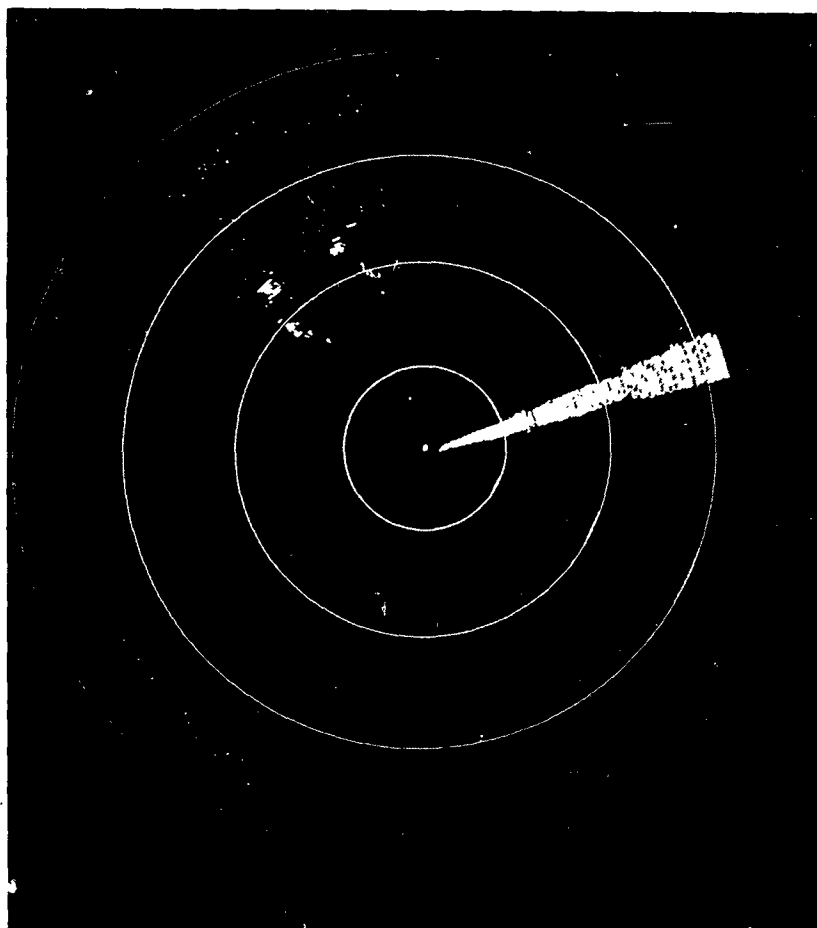


Figure 14. Azimuth—270° Outbound (Condition 5)

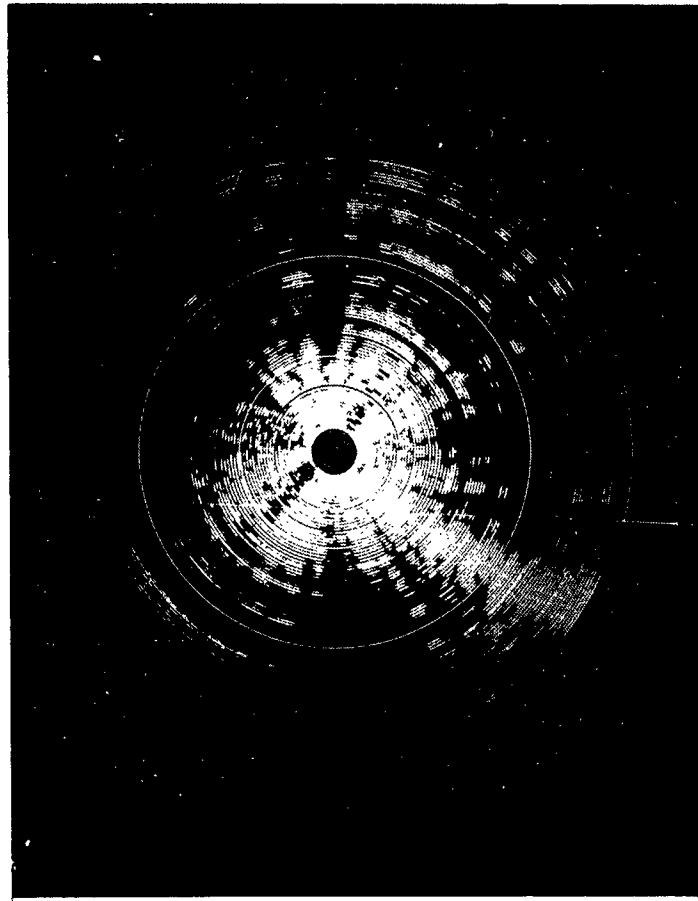


Figure 15. Azimuth—135° Inbound (Condition 1)

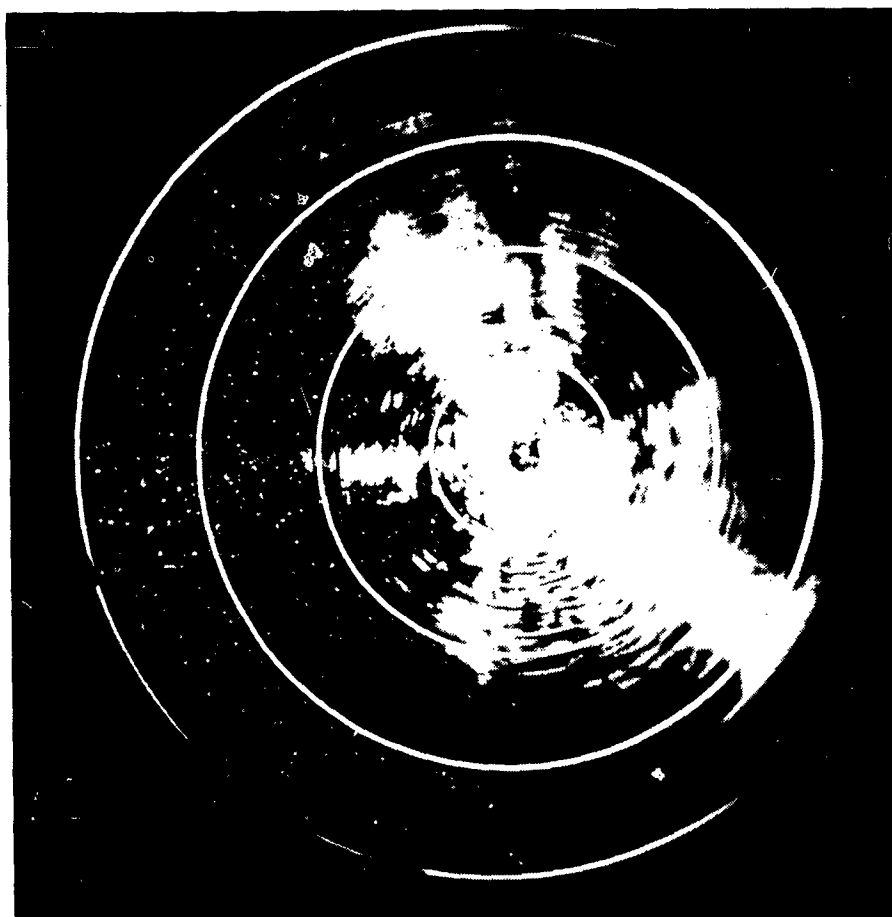


Figure 16. Azimuth— 135° Inbound (Condition 2)



Figure 17. Azimuth — 135° Inbound (Condition 3)



Figure 18. Azimuth — 135° Inbound (Condition 4)

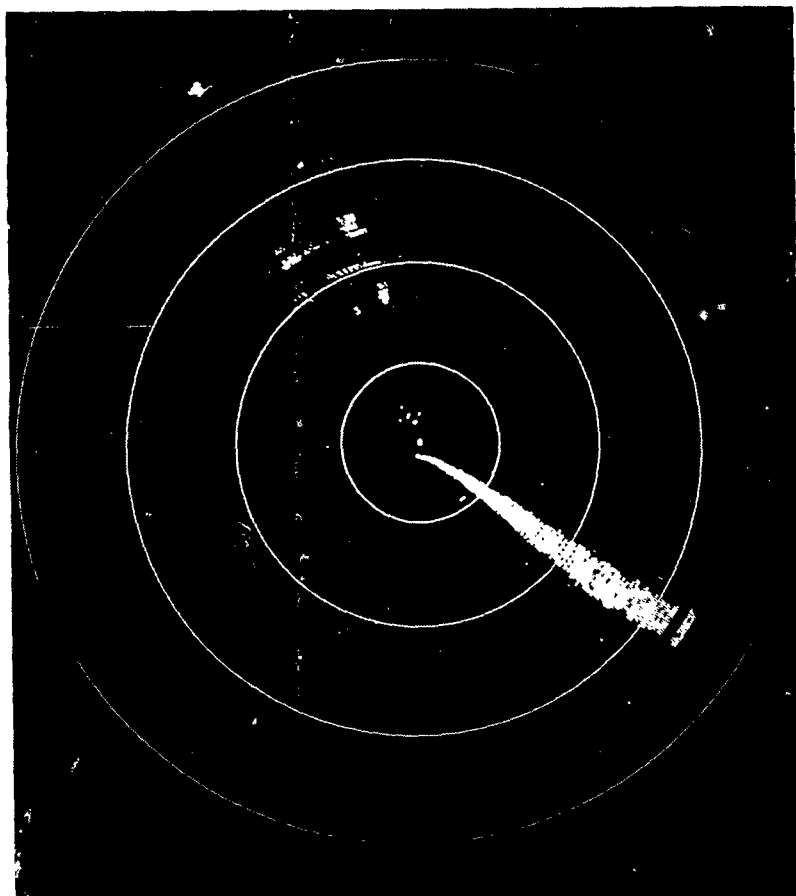
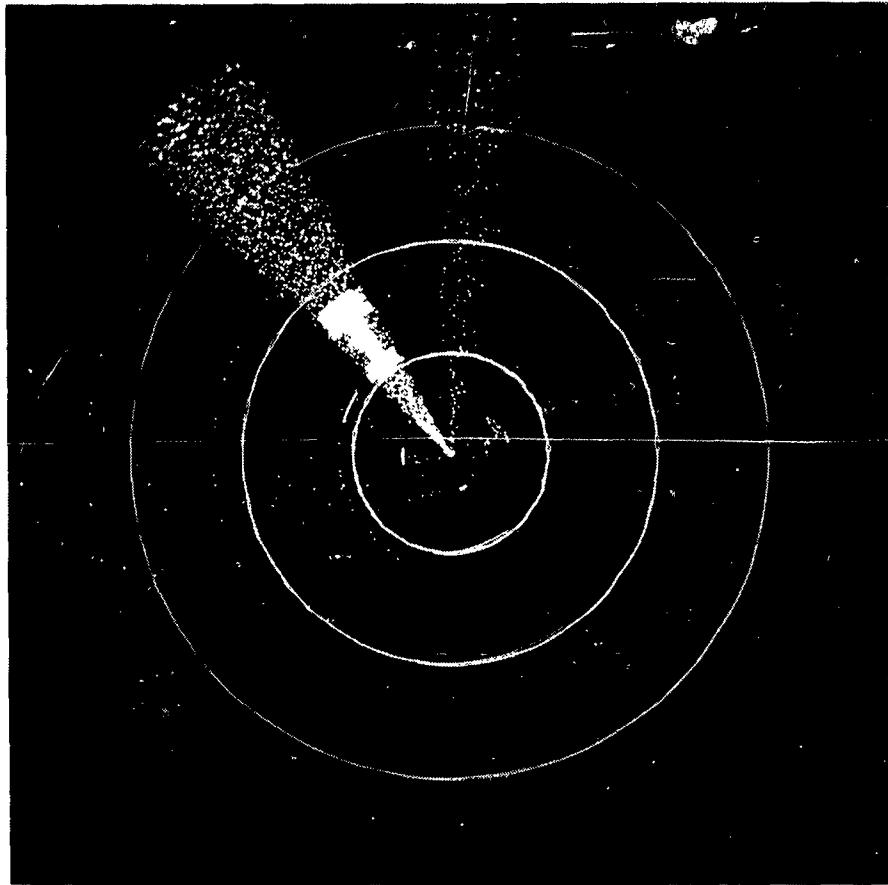


Figure 19. Azimuth — 135° Inbound (Condition 5)



This shows the narrowing of the area of response from the aircraft by use of the sum-difference pattern as compared to use of the sum pattern only. This is one picture of returns taken from one of the 200-mile radials. Range marks are set at 50 miles. The sum pattern was used from approximately 50 to 60 miles in range. The sum-difference pattern was used from 60-80 miles and the sum pattern was used again from 80-90 miles. Aircraft altitude was 20,000 feet.

Figure 20. Sum Pattern and Sum Difference Pattern Returns

addition of the AN/GPX-27 defruiter to eliminate non-synchronous returns from being displayed, and the set-up of the AN/UPX-6 receiver for short GTC which desensitizes the receiver for a set period of time, makes the aircraft returns stand out and makes tracking a simple matter. (See figures in Section 7 marked Condition 4 and 5.)

Tests of vswr and gain measurements show that the antenna has better characteristics at 1030 mc than at 1090 mc though the difference in performance is not great. Insertion of the r-f switch into the system does not greatly affect these measurements.

The data shows the narrowing of target returns. (See figures with Condition 1, 2 and 4 versus figures with Condition 3 and 5; also Figure 20.) The effect of using the sum-difference pattern is shown very clearly in these pictures as the returns are narrowed by a factor of about 3:1 or from about 25° to about 8°. This narrowing would be especially advantageous in multiple target tracking.

The effects of reflections and target shielding are evident in these pictures. These effects are more apparent in some photos than in others, particularly where the target aircraft's flight path closely approached the azimuth where the reflecting surfaces were located. (In this test situation the reflecting surfaces were a large set of radar horns located close by the AN/CPN-4 installation at about 170° azi-

muth.) As can be seen, use of the three-pulse IFF ISLS mode eliminated some of the effects of these reflections but could not do so entirely.

A range of 200 miles is claimed for this antenna with normal IFF equipment. Flight tests to check this feature showed a maximum capability of 125 miles for tracking the target aircraft. The target aircraft was flown at an altitude of 20,000 feet and requested to keep a constant azimuth outbound from the Verona Site for a 200 mile run and then return on the same azimuth. Target returns were received consistently up to approximately 100 miles where misses in returns started to become more numerous.

Random targets were observed at around 175 miles in range. In this situation, nothing is known about the height, equipment, etc. of such targets.

c. An un-modified AN/UPX-6 does not have the capability to generate a Mode 1 ISLS code because of the inability of the blocking oscillator triggering circuit to recover in time to generate the second interrogation pulse after generating the suppression pulse. An AN/UPX-6 was modified to provide this capability, with the satisfactory results shown in Figures 2a and 3a. This capability eliminates the need for two transmitters to generate the IFF ISLS interrogation, with an obvious saving of space and money.

9. AN/CPN-4/GPX-8A SYSTEM TEST MODIFICATIONS

MODIFICATIONS TO THE AN/CPN-4 SYSTEM ARE LISTED BELOW:

- a. 10-foot Sum-Difference Antenna (added, new).
- b. R-f Switch (added, new).
- c. Diplexer (added, new).
- d. Racks (modified).
- e. UPX-6 Interrogator-Responzor (modified).
- f. SN-87 Synchronizer (modified).
- g. KY-166 Coder (modified).
- h. Monitor Antenna (added, new).
- i. Power Supply (added, new).

PURPOSE

- a. Explained previously.
- b. Explained previously.
- c. For passage of dc and r-f power to the r-f switch.
- d. For modified and/or additional cabling and connectors.
- e. For capability of generating the three-pulse IFF ISLS mode.
- f. For capability of generating the three-pulse IFF ISLS mode.
- g. For capability of generating the three-pulse IFF ISLS mode.
- h. For monitoring the radiated interrogation mode.
- i. For dc power for the r-f switch.

10. CONCLUSIONS

The test results tell the story adequately. Operation of the system has been shown with and without the use of IFF Interrogation Side Lobe Suppression. Modes 2- and 3-type interrogations were utilized for this test program with complete success of operation. Mode 1 interrogation was not used during this flight test program. However, the system was proven capable of generating the ISLS code using Mode 1 (see Figure 3a).

In addition, the mechanical burden which this

antenna would put on the AN/CPN-4 antenna system cannot be predicted for conditions more adverse than encountered during the test program. Only light to moderate wind conditions were encountered during the test period. In addition, the test program was conducted during summer months. Therefore, the burden which would be added to the AN/CPN-4 antenna system by heavy winds, and ice and snow conditions, has not been indicated by this test program.

11. RECOMMENDATIONS

It is recommended that serious consideration be given to the usage of this antenna on the AN/CPN-4 antenna and its various modified forms. The improvement is not outstanding when operating with a transponder not modified for ISLS performance. However, the performance with a modified transponder is equivalent in beamwidth and azimuth resolution to an antenna of three times the aperture. Many military and civil aircraft are already equipped with the ISLS capability and, since FAA has made it an ATC beacon requirement, it will be

only a matter of time before ISLS modified transponders are predominant in aircraft.

Further work would be desirable on the mechanical design of this antenna if it were to be used in all types of environmental conditions.

Some discretion is necessary in the placement of the entire radar complex to achieve maximum efficiency from the IFF ISLS system returns. As is apparent from the data, strong reflections from natural or manmade environments detract from the overall operation of the system by generation of false targets and also shielding of the target aircraft.

Rome Air Development Center, Griffiss AF Base, N.Y. Rpt No. RADC-TDR-63-257. DUAL PATTERN ANTENNA. APPLICATION TO IFF INTERROGATION SIDE LOBE SUPPRESSION. Jun 63, 33 p. incl. illus. Unclassified Report The purpose of this report is to acquaint interested personnel with a non-conventional IFF antenna system developed for use with the AN/CPN-4 GPX-8A ATC Radar-IFF System. A flight test program was conducted at RADC's Verona Test Site at Verona, N.Y. for the purpose of testing the capabilities of this antenna to function properly in an IFF Side Lobe Suppression System. The data presented is, for the most part, in the form of composite pictures of returns from an aircraft flying various radial paths across the Verona Test Site, and free space antenna patterns taken at the Newport Antenna Test Range, Newport, N.Y. Results show that the antenna has the desired capability.	1. Antennas 2. IFF Antennas 3. Side Lobe Suppression I. AFSC Project 6502 II. Scott, R. E. III. In ASTIA collection	Rome Air Development Center, Griffiss AF Base, N.Y. Rpt No. RADC-TDR-63-257. DUAL PATTERN ANTENNA. APPLICATION TO IFF INTERROGATION SIDE LOBE SUPPRESSION. Jun 63, 33 p. incl. illus. Unclassified Report The purpose of this report is to acquaint interested personnel with a non-conventional IFF antenna system developed for use with the AN/CPN-4 GPX-8A ATC Radar-IFF System. A flight test program was conducted at RADC's Verona Test Site at Verona, N.Y. for the purpose of testing the capabilities of this antenna to function properly in an IFF Side Lobe Suppression System. The data presented is, for the most part, in the form of composite pictures of returns from an aircraft flying various radial paths across the Verona Test Site, and free space antenna patterns taken at the Newport Antenna Test Range, Newport, N.Y. Results show that the antenna has the desired capability.	1. Antennas 2. IFF Antennas 3. Side Lobe Suppression I. AFSC Project 6502 II. Scott, R. E. III. In ASTIA collection	1. Antennas 2. IFF Antennas 3. Side Lobe Suppression I. AFSC Project 6502 II. Scott, R. E. III. In ASTIA collection	1. Antennas 2. IFF Antennas 3. Side Lobe Suppression I. AFSC Project 6502 II. Scott, R. E. III. In ASTIA collection
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