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The Navy Electronics Laboratory Pillbox Antenna and its Effect upon ATC Radar Beacon Interrogation

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by

Joseph E. Herrmann, Jr.

Owen E. McIntire

Kenneth Wise

Navigation Aids Evaluation Division

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FEDERAL AVIATION AGENCY

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INDIANAPOLIS, INDIANA

FEDERAL AVIATION AGENCY

E. R. Quesada, Administrator

D. M. Stuart, Director, Technical Development Center

THE NAVY ELECTRONICS LABORATORY PILLBOX ANTENNA AND ITS EFFECT UPON ATC RADAR BEACON INTERROGATION

SUMMARY

This report describes the technical evaluation of the Navy Electronics Laboratory Fox II 15-foot folded pillbox antenna when used in the ATC Radar Beacon System.

The radiation pattern measurements made on the pillbox antenna agreed with the data supplied by the Navy Electronics Laboratory. The amplitude of the side lobes was 38 decibels or more below the level of the main lobe. This level is considerably less than that of the side lobes of the AMB Type 2.3NS3 18-foot beacon antenna. Reduced side-lobe interrogation can be expected when the pillbox antenna is used.

Initial tests with airborne pulse counters to determine the number of interrogations per antenna scan at various ranges were disappointing, because there was little indicated difference between the two types of antennas. Photographic time exposures of an indicator displaying transponder replies showed similar levels of interrogation when either antenna was used; however, a marked difference in the distribution of the side-lobe interrogations was noted. A clear side-lobe pattern was visible on the photographs when using the 18-foot antenna, which was not evident on the photographs when using the pillbox antenna, indicating that interrogations by the pillbox antenna were of a random nature and were due to reflections of the main lobe. Photographs of an airborne A-scope display connected to the transponder video circuits showed the presence of reflections. Both the level and delay of the reflected interrogation signals were recorded during orbital flights at a six-mile radius.

Effective antenna patterns were measured with a high-speed recorder in the aircraft as the pillbox antenna was rotated. Direct and reflected signal levels were recorded during each rotation of the antenna as the aircraft was flown on a six-nautical-mile orbit around the antenna.

Although the pillbox antenna has lower side-lobe levels, there was no significant reduction in interrogation duty cycle, since the reflection of main-lobe signals by objects near the ground antenna at the Technical Development Center is sufficiently strong to offset the improvement in the antenna pattern.

INTRODUCTION

Initial tests of the ATC Radar Beacon System showed a high interrogation duty cycle or large numbers of interrogations per antenna scan at short ranges due to the antenna side lobes.[1] This excessive interrogation by side lobes causes interference to other ground installations called "fruit."[2] Also, in areas where many interrogators are operated, the combined side-lobe interrogations can exceed the duty cycle of airborne transponders. By use of beacon video defruiting equipment, most of the interference can be prevented from reaching the PPI display. However, when the transponder duty cycle is exceeded, the transponder cannot reply to every interrogation received from the ground interrogators. Under these conditions, the delay-line type of defruiting equipment, which requires 2 successive replies for single-defruiting operation and 3 successive replies for double-defruiting operation, may reject the signal from an aircraft. Thus, the use of this type of defruiting equipment increases the possibility that beacon signals may be lost due to over-interrogation by side lobes.

In May 1956, the CAA Technical Development Center (TDC) received a 15-foot pillbox antenna for evaluation as part of the ATC Radar Beacon System, through arrangements made by the Air Navigation Development Board. This antenna, designated Fox II, was designed by the Navy Electronics Laboratory (NEL) for minimum side-lobe level. Theoretically, the use of such an antenna should reduce side-lobe interrogations significantly and permit the use of greater gain in the receiver portion of the interrogator to increase target reliability.

This report describes the results of interrogation tests made with the NEL pillbox antenna to date. Additional tests to evaluate the performance of the antenna on the reply path are planned and will be reported at a later date.

TESTS AND RESULTS

Antenna Pattern.

Pattern data supplied by NEL showed the maximum side-lobe level to be 38 decibels (db) below the main lobe. The pattern submitted by NEL is shown in Fig. 1. Because of the low side-lobe levels of the pillbox antenna, a clear antenna range is necessary to obtain an accurate measurement of the radiation pattern. The antenna was mounted on a 60-foot tower, and patterns were recorded with the transmitting antenna installed at several different azimuths. The presence of another taller radar tower only 75 feet away made it impossible to obtain any single pattern which was free from reflections. By recording radiation patterns with the test oscillator located at several sites, on different radials from the pillbox antenna, it was possible to separate direct antenna responses from those due to reflections. One pattern recording is shown in Fig. 2. The measurements made at this Center confirmed the pattern measured at NEL, and steps were taken to proceed with the evaluation program. A pattern of the 18-foot antenna shown in Fig. 3 was recorded under the same conditions.

[1] David S. Crippen, Tirey K. Vickers, and Marvin H. Yost, "Initial Tests of the ANDB L-Band Secondary Radar System in Typical Terminal Area Traffic Operations," CAA Technical Development Report No. 268, September 1956.

[2] Joseph E. Herrmann, Jr., "A Study of the Air Traffic Control Radar Beacon System Characteristics," CAA Technical Development Report No. 329, October 1957.

If free-space propagation conditions are assumed, the interrogation characteristics of each antenna can be predicted. The following gain and loss conditions were assumed:

IR output power (measured)	62.7 dbm
Transmission line loss (measured)	-3.60 db
Pillbox antenna gain	22.50 db
Aircraft antenna gain	0.0 db
Aircraft transmission line loss	-3.0 db
ATC transponder sensitivity	-74.0 dbm

The maximum calculated range of interrogation under the conditions noted above is 528 nautical miles.

Table I lists the calculated reserve interrogation path gain at various ranges.

TABLE I

RESERVE INTERROGATION GAIN

Range (Nautical Miles)	Reserve Interrogation Gain (db)
52.8	20
29.7	25
16.7	30
9.4	35
6.0	39
5.3	40
3.0	45

The effective horizontal beamwidth can be defined as the total number of degrees over which the main-lobe and side-lobe amplitudes exceed a predetermined level during one complete antenna scan. From Table I, the effective antenna beamwidth at a range of 29.7 nautical miles may be represented by the total number of degrees over which the main- and side-lobe responses are greater than those 25 db down from the nose of the main lobe. The effective antenna beamwidths of both the 18-foot and pillbox antennas are shown in Fig. 4. These calculations are based on actual antenna patterns recorded at TDC. At all ranges less than 14 nautical miles, the pillbox antenna should result in superior interrogation performance under free-space conditions. The better performance of the 18-foot antenna at ranges greater than 20 nautical miles is due to the relative widths of the main lobes. By design, the main beam of the pillbox antenna is wider than that of the 18-foot antenna. For comparison purposes, the 9-foot antenna pattern was recorded and the effective beamwidth of this antenna is shown on Fig. 4 also. The 9-foot antenna should cause interrogation of transponders at a higher duty cycle than either of the other antennas, regardless of range, because of its greater beamwidth.

Interrogation Pulse Counts.

The effective beamwidth of the pillbox antenna was measured by counting the number of interrogations of an airborne transponder for selected intervals of time. A series of flight tests was made at several altitudes and radials from the interrogator site. For comparison purposes, an 18-foot antenna was alternated with the pillbox antenna during the tests. The same interrogator was switched between the two antennas, each radial flight was repeated, and interrogations were recorded in the aircraft. The gain of each antenna system was measured and the two systems were balanced within 1.5 db. The unbalance of the two antennas was corrected in the plotting of recorded data. Additional flights were made using the 9-foot antenna and the results compared with the previous data.

Results of the tests of the 18-foot antenna were close to predictions. Counts of the interrogations made in the test aircraft generally exceeded the expected rate, and the effective beamwidth is shown in Fig. 5. However, the pillbox antenna interrogation duty cycle was almost identical to that of the 18-foot antenna. A large discrepancy existed between the predicted performance and the results of the tests. Results of these tests and of the tests made with the 9-foot antenna also are shown in Fig. 5. Close agreement between the predicted and measured performance of the 9-foot antenna was obtained.

Photographic Time Exposures of PPI.

In order to determine the azimuthal distribution of the interrogations by each antenna, a photographic technique was devised. The interrogator antenna under test was rotated at a constant rate and the PPI sweep was synchronized with the rotation. The transponder replies were received on a separate fixed antenna pointed at the aircraft and displayed on the PPI. A 35-mm camera was used to obtain time exposure photos as the aircraft was flown along selected radials. All flights were duplicated so as to obtain a direct comparison between the two types of antennas. Figures 6 and 7 show the results of a test flight made at 5,000 feet above ground using the 18-foot and pillbox antennas, respectively. After making system gain corrections, the results agreed with the airborne interrogation counts previously recorded, but a marked difference in the photographs was evident. The photographs show a clearly defined side-lobe pattern when the 18-foot antenna was used, but the pillbox photo pattern shows a random side-lobe distribution, indicating interrogation by reflected signals.

Photographs During Each Antenna Scan

An examination of interrogations during each scan of the antenna revealed that the transponder replies in the side-lobe areas were being delayed by varying amounts of time. This condition is shown in Figs. 8 and 9, which are photographs of replies received during single antenna scans. It is evident from these data that the main-lobe reflections of the pillbox antenna were causing interrogations, since some of the replies were displayed at ranges beyond that of the aircraft. This same condition probably is true for the 18-foot antenna, except that the side-lobe signals arrive at the aircraft before the reflected signals. The transponder will reply to the first pair of properly spaced interrogation pulses, and in all cases the direct side-lobe signals will precede the reflected signals. Because of the higher side-lobe level of the 18-foot antenna, there were fewer interrogations by reflected signals.

By measurement of range displacements, it was possible to separate the direct interrogation replies from the reflected interrogation replies. This method was used to reduce data taken on a test flight, and the results are shown in Fig. 10. However, the percentage of interrogation by reflected signals shown for the pillbox antenna did not correlate with the results predicted. It was obvious that many of the reflected signals were delayed very slightly but could not be identified as such on the film.

Photographs of Interrogation Path Reflections.

A more precise method of measuring the delay of reflected signals was tried with satisfactory results. Photographs of an A-scope display were made in the test aircraft. The video output of a wide dynamic range receiver was applied to the vertical input of the A-scope. Synchronization of the A-scope sweep was accomplished by transmitting a synchronizing pulse from the ground on a different frequency, preceding the interrogation pulse. A block diagram of this scheme is shown in Fig. 11. Measurements of direct- and reflected-signal strengths and of reflected signal time delays were made. A typical recording made in the aircraft is shown in Fig. 12.

The results of flight tests made on a six-mile orbit about the pillbox antenna are shown in Fig. 13. Both peak levels and average levels of reflections are plotted. A curve showing the relative duty cycle, or percentage of time when reflections were present at different delays, is included. The calculated reserve interrogation gain of the system is 39 db, as shown in Table I. Reflections whose peak levels exceeded the minimum required for interrogation are present, up to 11 microseconds after the direct signal.

The average level of all reflections received during the 6-mile orbit would not be sufficient to cause interrogation for delays exceeding 1 microsecond, however, by referring to the reflection duty cycle curve of Fig. 13, it can be seen that reflections having delays of 1 microsecond or less occur 90 per cent of the time. Reflections having 5-microsecond delays were present 50 per cent of the time.

A reduction of interrogator power or transponder sensitivity would not change the relative performance of the two antennas. An over-all improvement of interrogation duty cycle would result from either change, but the degree of improvement would be the same for both antenna systems. Figures 14 and 15 are time exposures showing relative performance of the 18-foot and pillbox antennas when the transponder sensitivity was reduced by 12 db.

Effective Pattern Recordings.

When energy radiated directly from the antenna is combined with reflected energy, a resultant radiation pattern is formed which may be called the effective antenna pattern. The reflections may originate from the earth's surface or buildings which fall within the direct radiated field. The resulting pattern will change with distance, azimuth, and altitude of the aircraft with respect to the antenna. In order to measure the effective patterns under various conditions, it is necessary to record the antenna patterns when the aircraft is at various distances, azimuths, and altitudes.

Several airborne patterns were recorded in the Indianapolis area as the test aircraft was flown on a six-nautical-mile orbit around the interrogator antenna. A 25-watt, continuous-wave (cw) transmitter was substituted for the normal interrogator transmitter and adjusted to a frequency of 1,030 Mc. The pillbox antenna was rotated at 15 rpm as the test aircraft orbited 1,000 feet above ground. The signal received in the aircraft was recorded by a high-speed recorder. Figure 16 is a sample of the recordings obtained and includes three scans of the pillbox antenna. During each scan of the antenna, the aircraft moved a distance of approximately 1,000 feet along the orbit. This was an angular change of approximately 1.6° per scan. Reflections are clearly shown, and it is evident that the over-all pattern changes appreciably from scan to scan. The calibration scale indicates the relative strength of the signals. From the patterns made previously on the pillbox antenna, it is known that the maximum side lobes are 38 db below the level of the main lobe. Signals appearing between the main lobes which exceed the measured side-lobe level are due to reflections.

CONCLUSIONS

The NEL Fox II pillbox antenna is an advancement in the state-of-the-art because the side lobes of the radiation pattern are of very low level. The evaluation program was concentrated on a determination of the effects that such an antenna would have on transponder interrogation. The results of the tests clearly indicate that very little improvement in system interrogation characteristics can be gained by use of an antenna having very low side lobes at installations where reflections are equal to, or greater than, those near TDC. Reflected main-lobe signals cancelled the interrogation duty-cycle improvements which were expected. It is felt that a significant improvement could be obtained at better sites. However, results of site surveys completed at some of the major airports indicate that little, if any, improvement can be expected.

Additional tests are planned to determine the effects of the pillbox antenna on the ATC Radar Beacon System replies.

RECOMMENDATIONS

It is recommended that the problems arising from signals reflected from objects near the ground antenna be given due consideration in the development and evaluation of side-lobe suppression and beam-sharpening systems. If the systems are not designed to minimize the effects of reflected signals, the improvements in system performance will be impaired and siting restrictions will be increased.

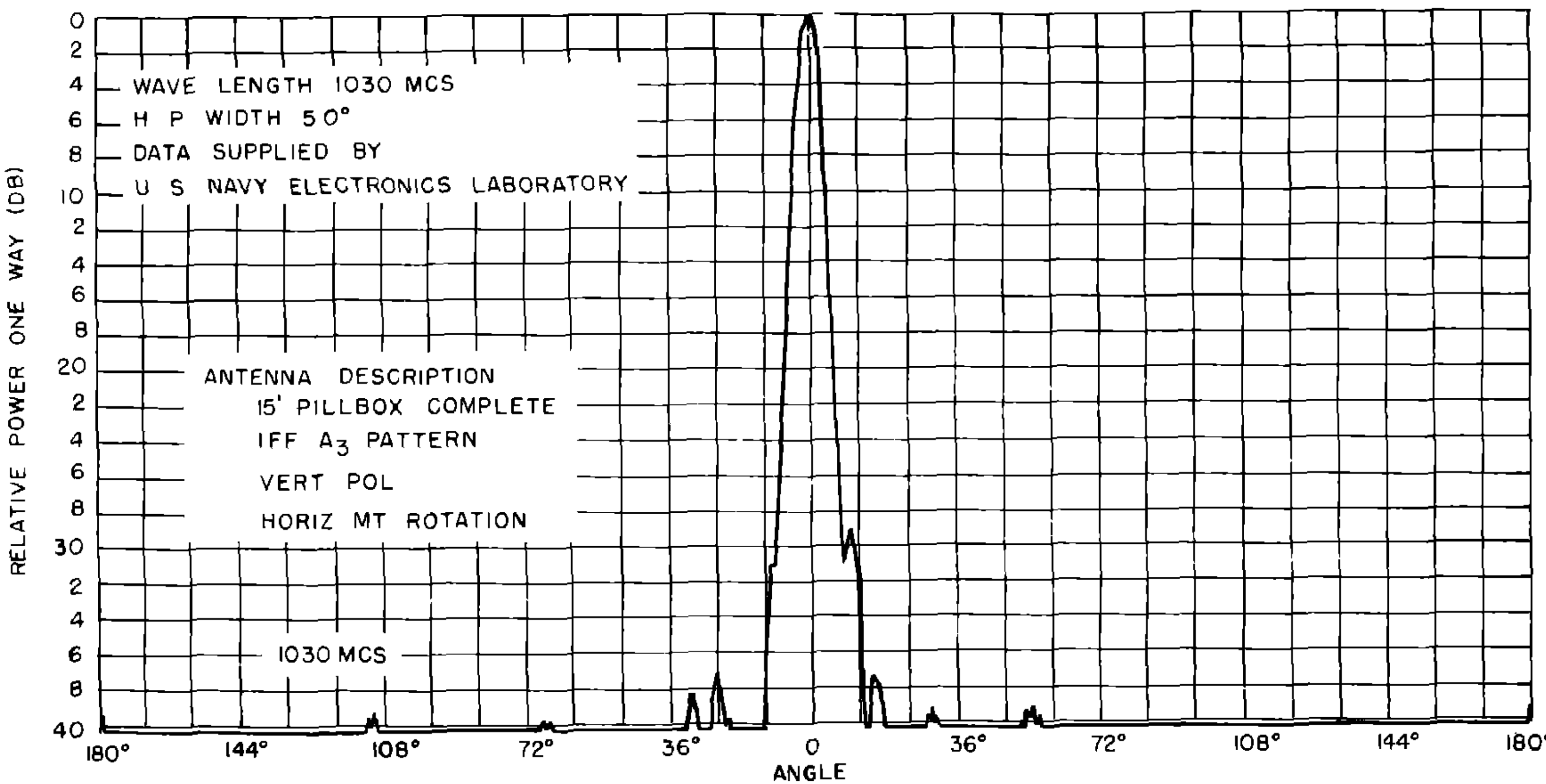


FIG. 1 NAVY ELECTRONICS LABORATORY FOLDED PILLBOX ANTENNA PATTERN

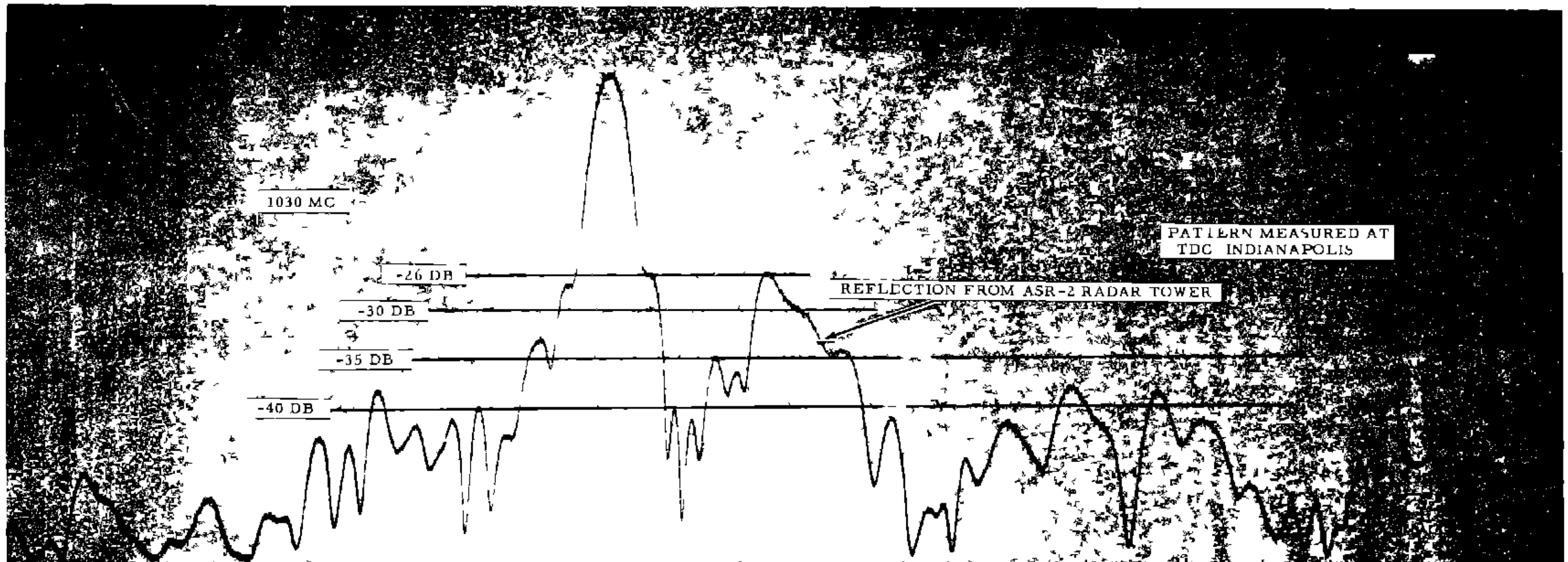


FIG 2 NAVY ELECTRONICS LABORATORY FOLDED PILLBOX ANTENNA PATTERN

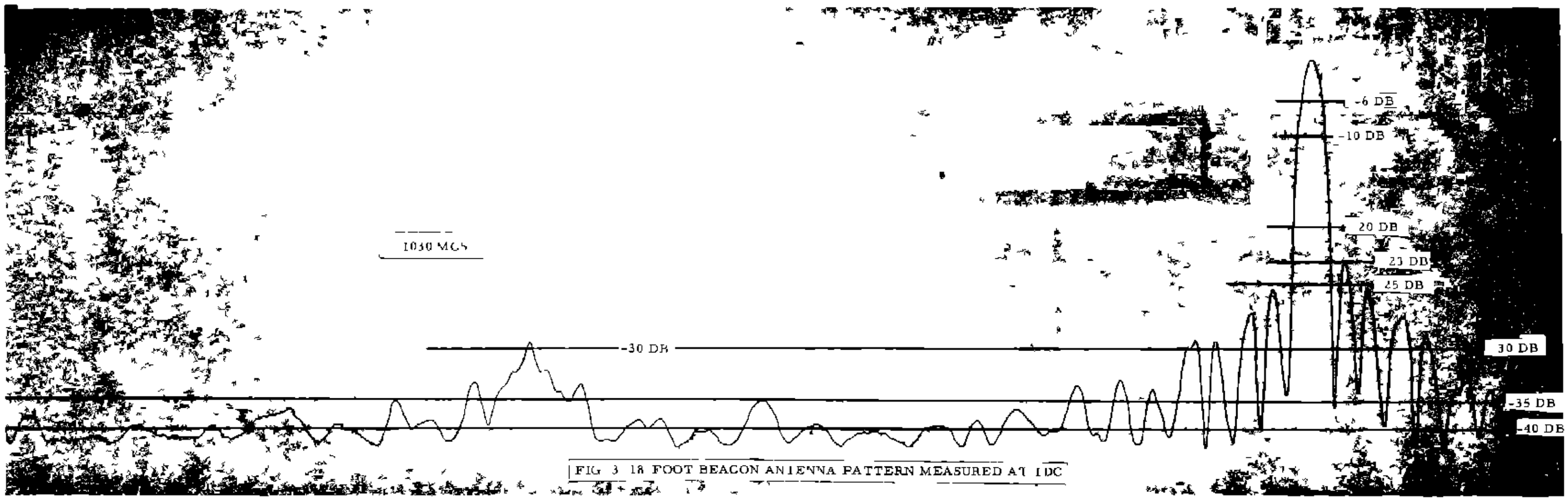


FIG 3 18 FOOT BEACON ANTENNA PATTERN MEASURED AT IDC

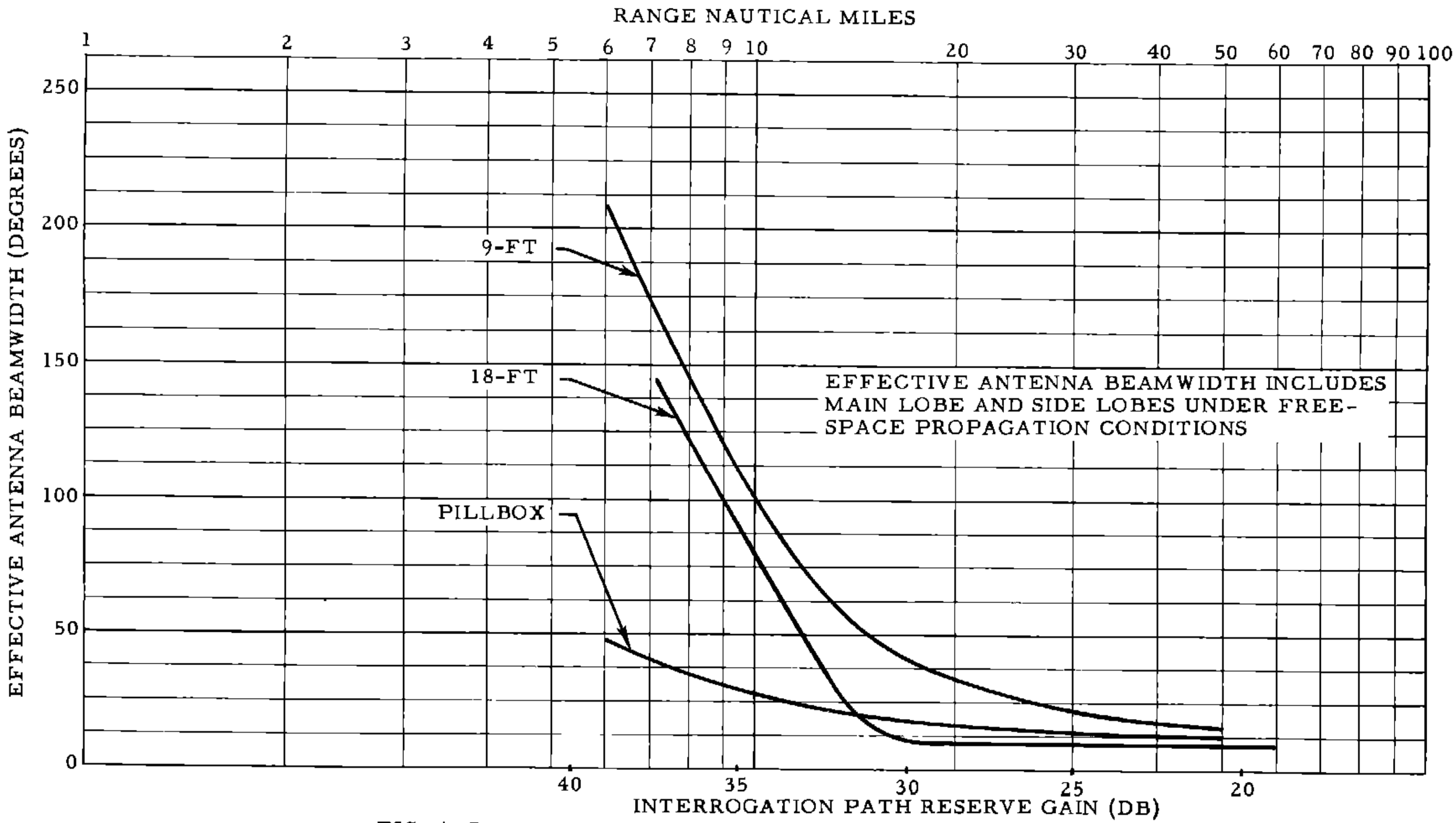


FIG 4 CALCULATED EFFECTIVE ANTENNA BEAMWIDTHS

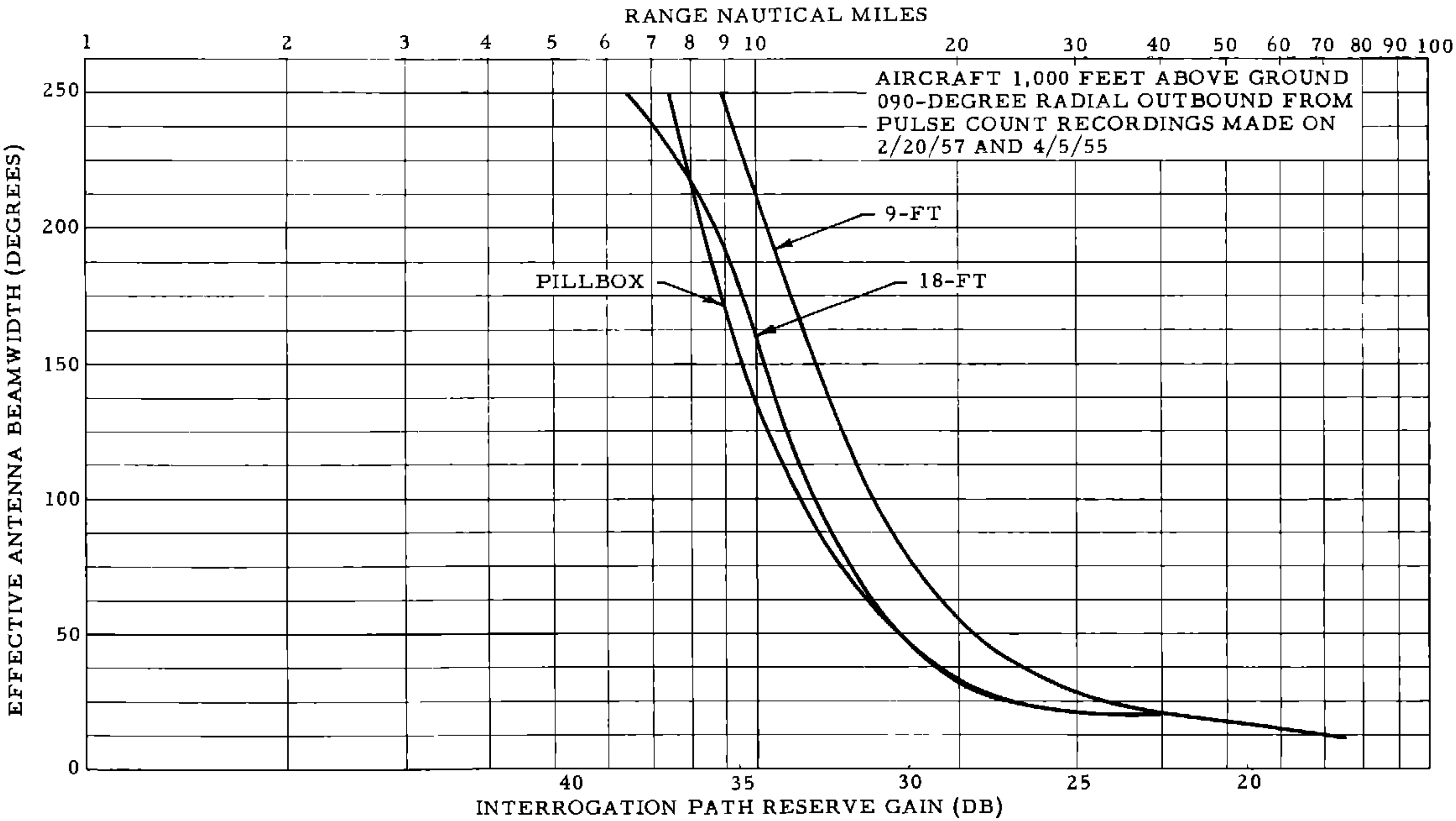


FIG. 5 MEASURED EFFECTIVE ANTENNA BEAMWIDTHS

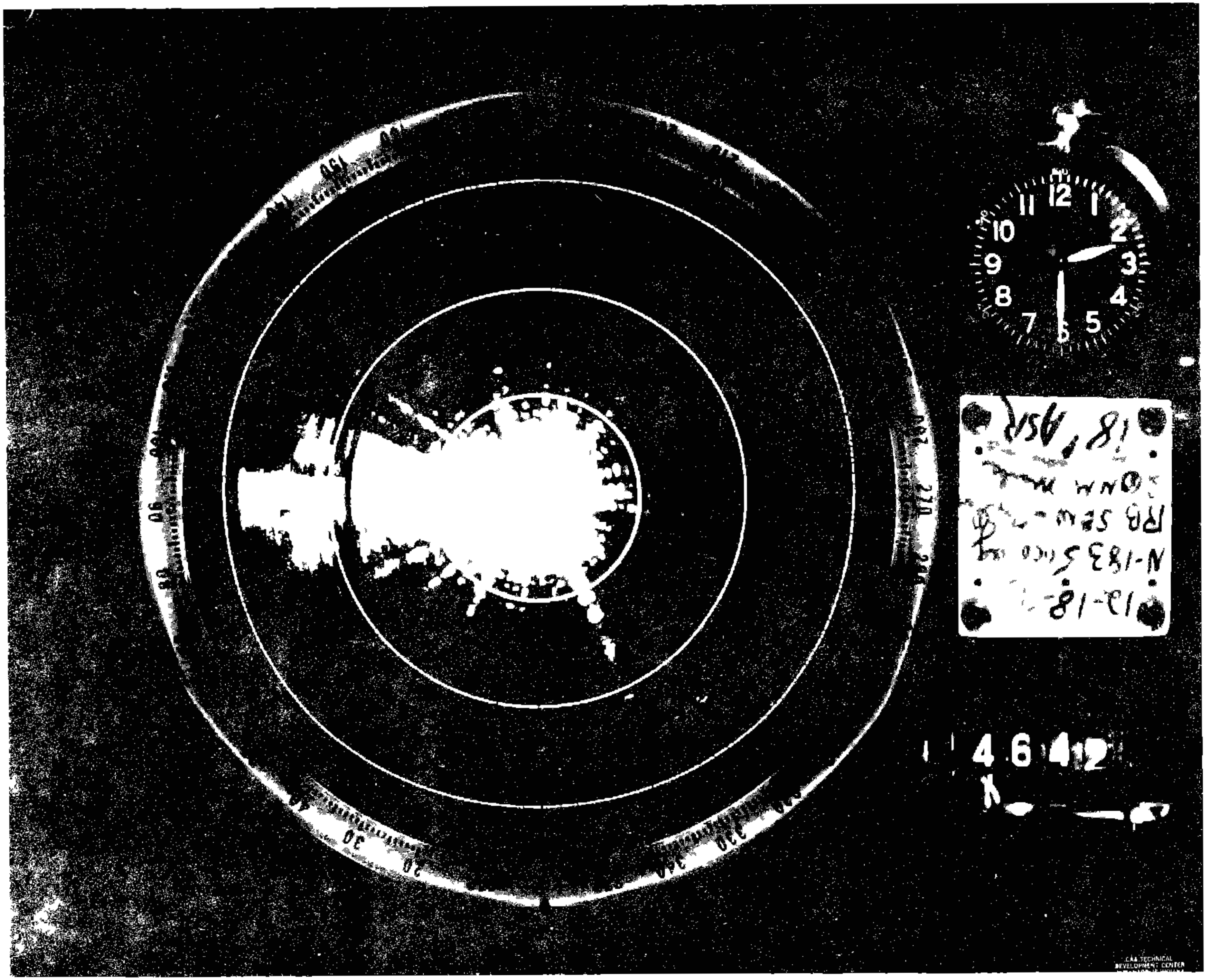


FIG. 6 18-FOOT BEACON ANTENNA INTERROGATION PATTERN

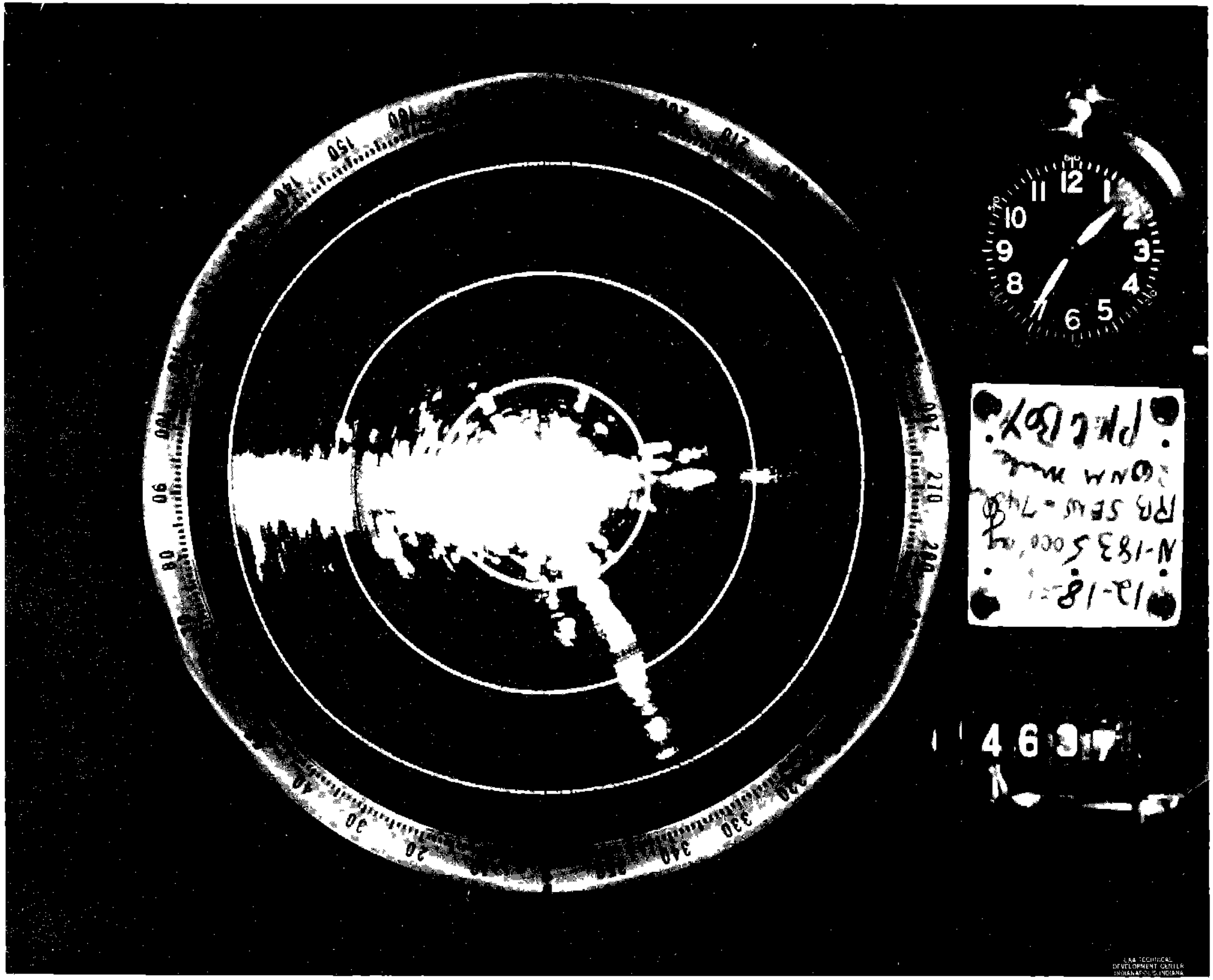


FIG. 7 PILLBOX ANTENNA INTERROGATION PATTERN

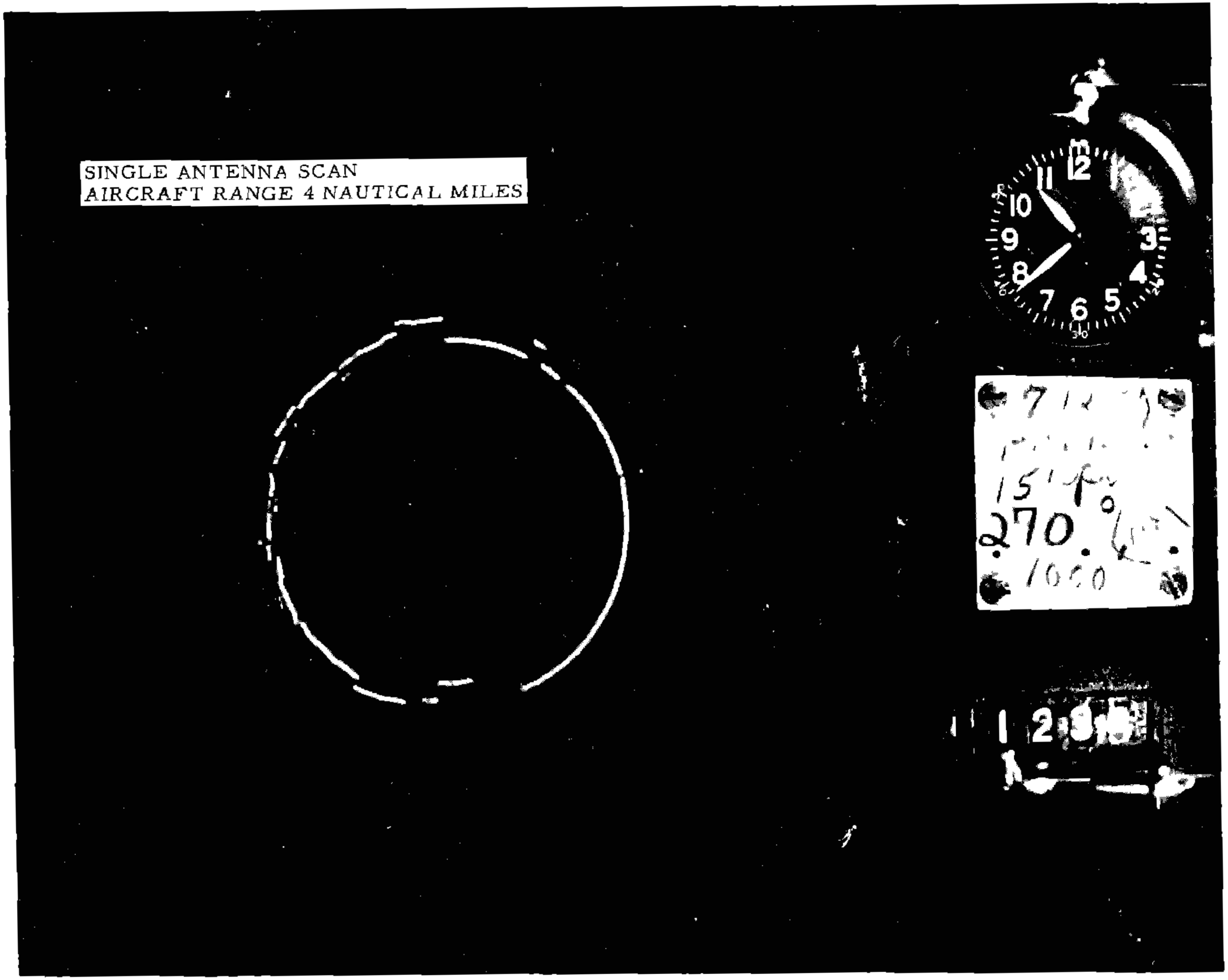


FIG. 8 PILLBOX ANTENNA INTERROGATION PATTERN

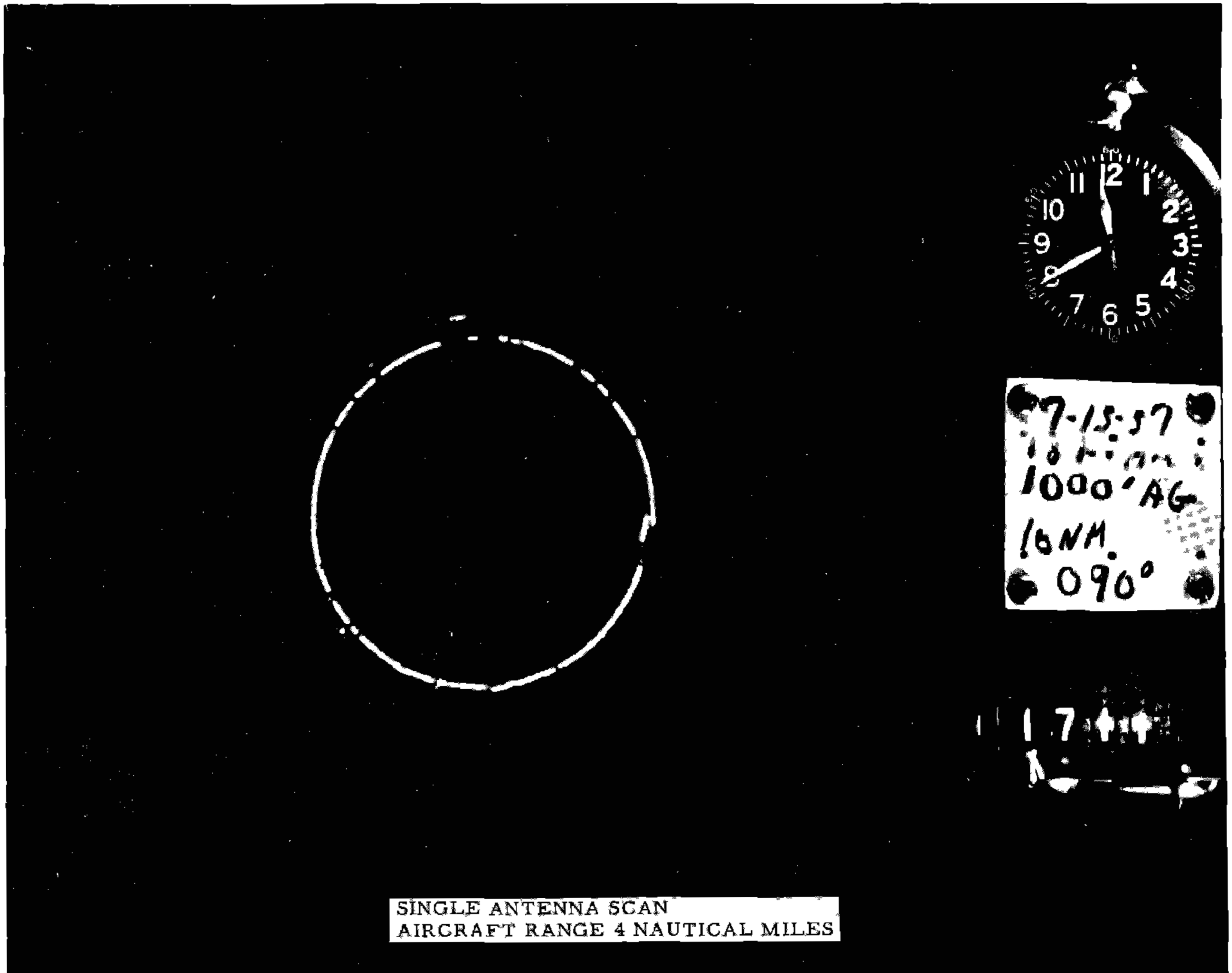


FIG. 9 18-FOOT ANTENNA INTERROGATION PATTERN

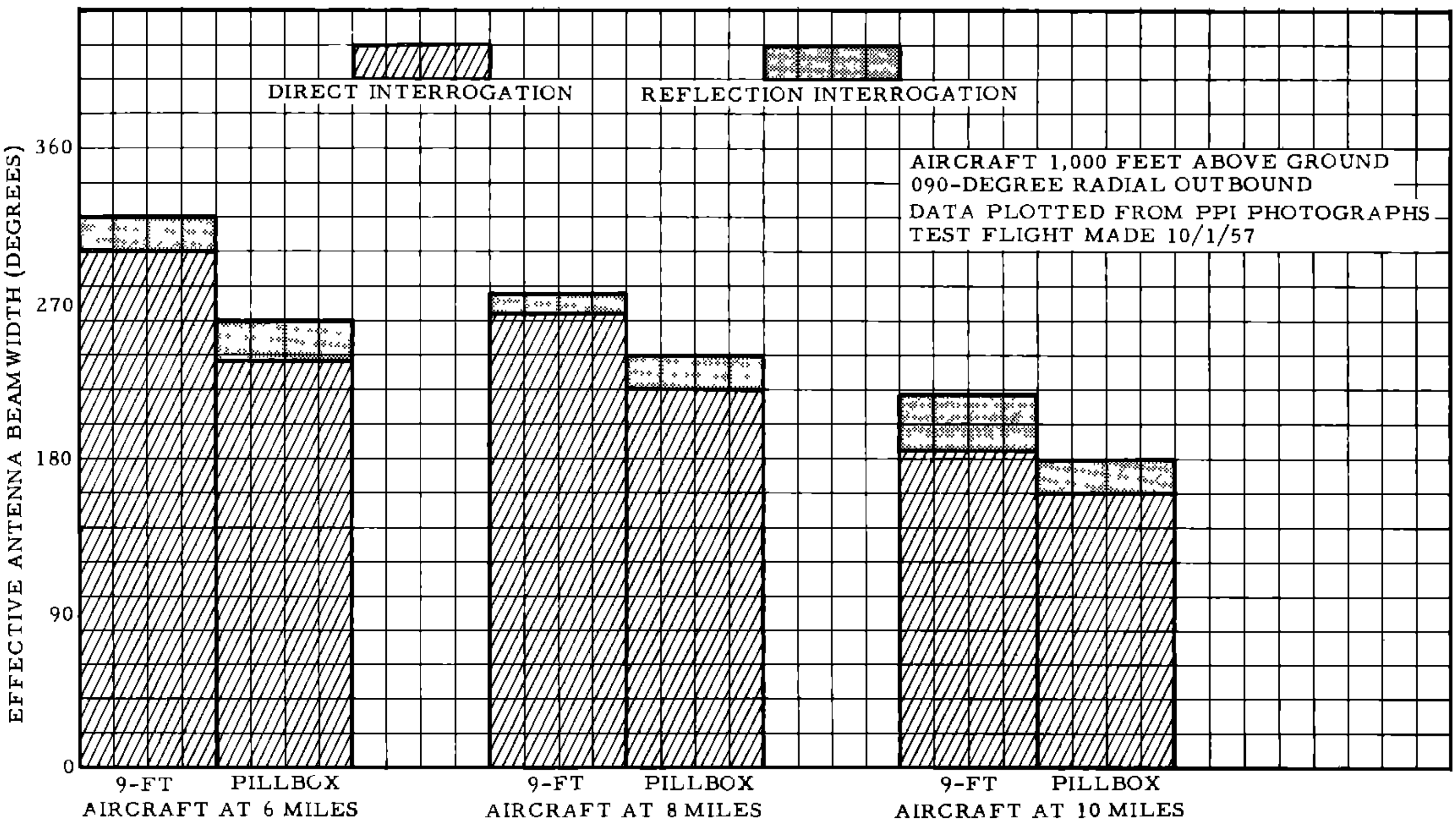


FIG. 10 COMPARISON OF ANTENNA INTERROGATING CHARACTERISTICS

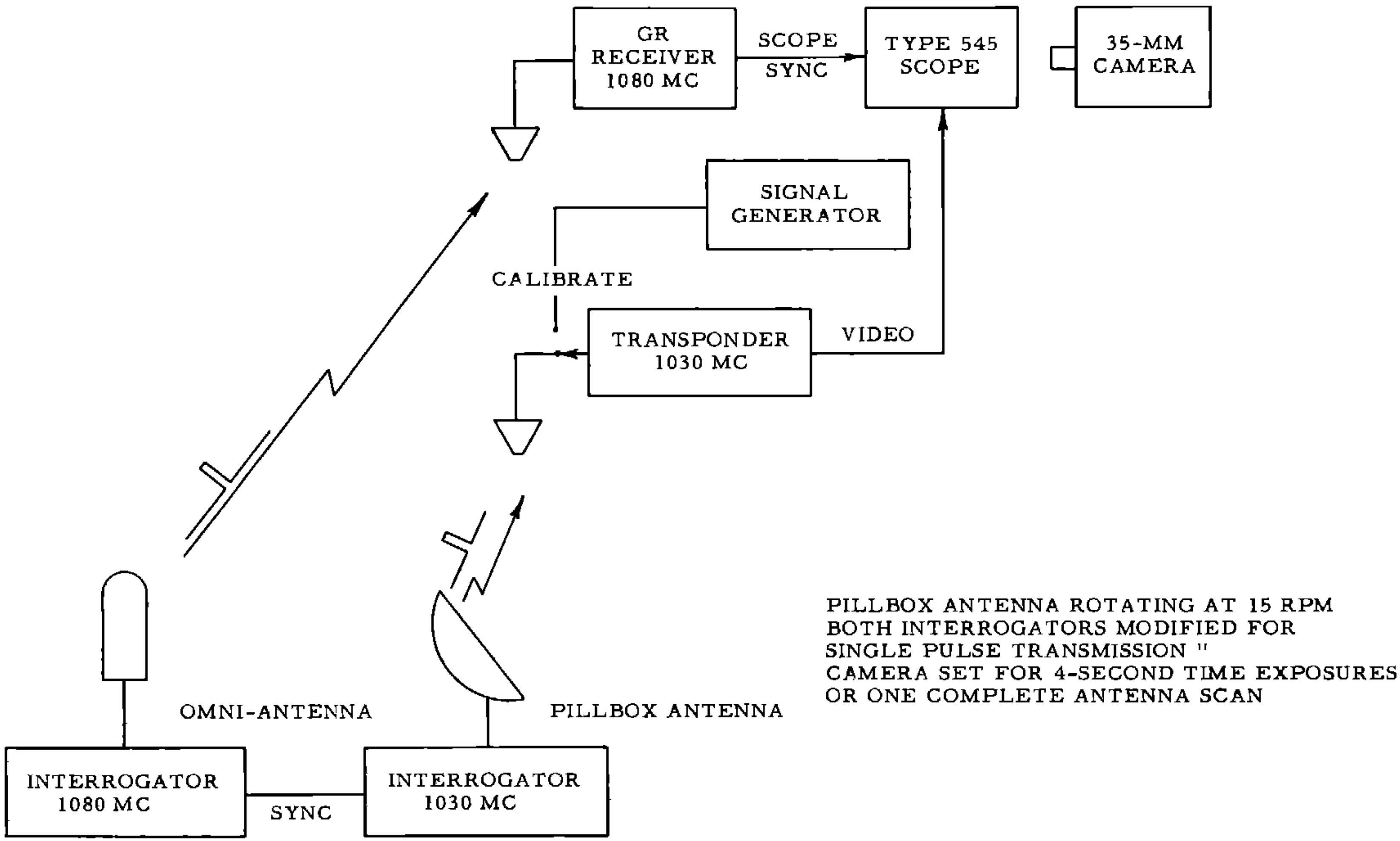
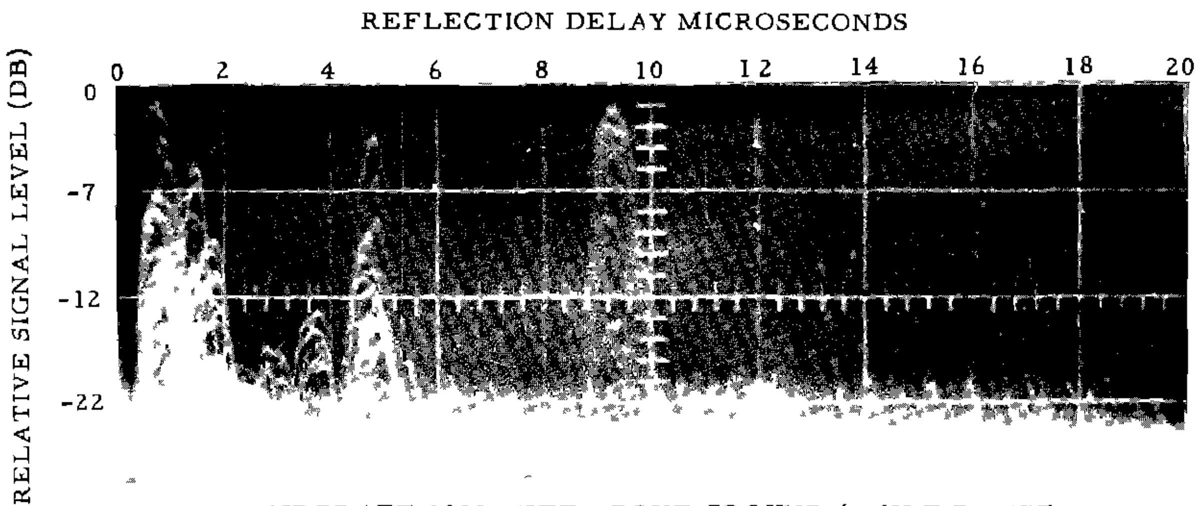


FIG 11 BLOCK DIAGRAM OF EQUIPMENT USED FOR INTERROGATION REFLECTION RECORDING



AIRCRAFT 1000 FEET ABOVE GROUND 6-MILE RANGE
INTERROGATOR TRANSMITTING A SINGLE PULSE
ON 1030 MCS AT 300 PULSES PER SECOND
PILLBOX ANTENNA ROTATING 15 RPM
4-SECOND TIME EXPOSURE

FIG 12 AIRBORNE PHOTOGRAPH OF REFLECTIONS

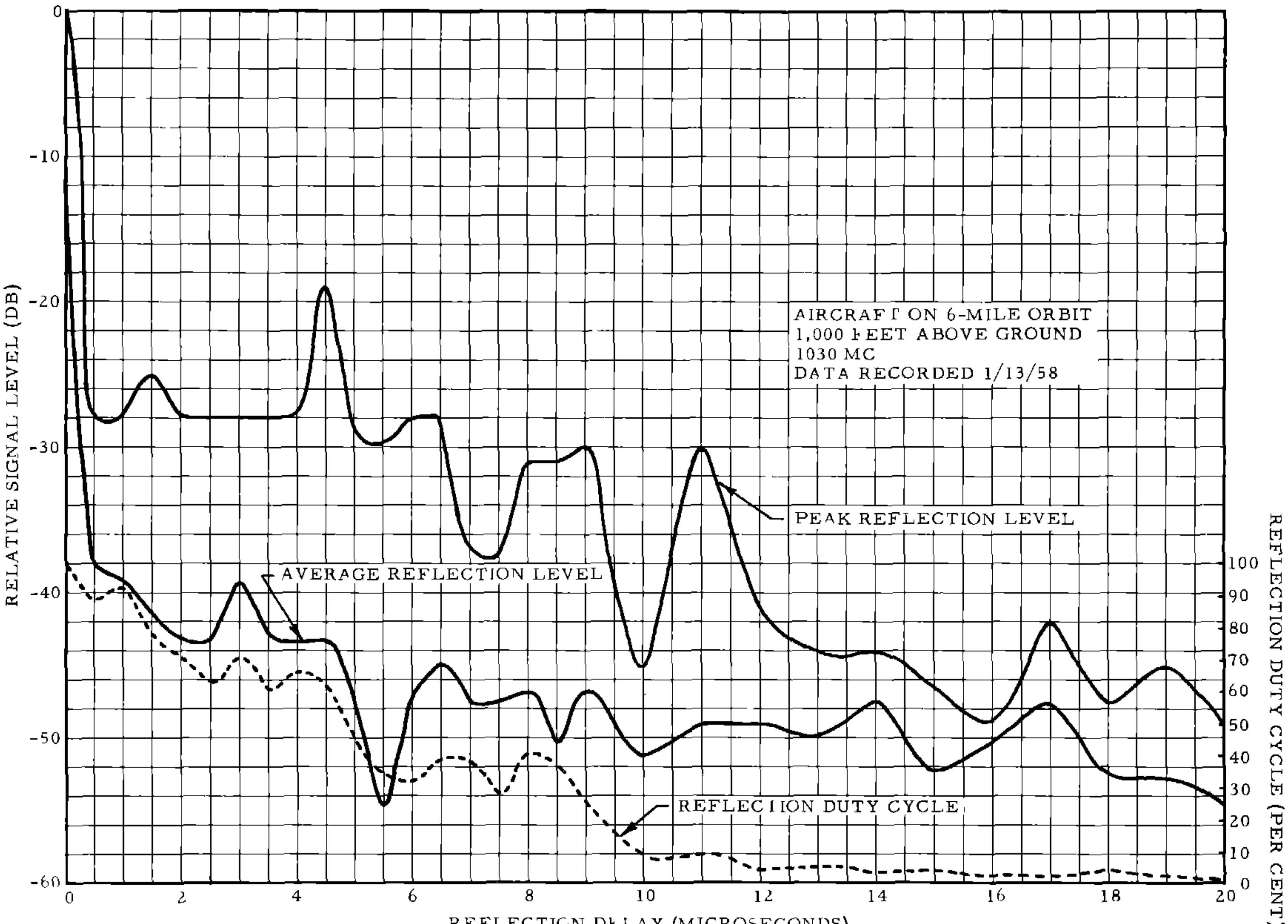


FIG. 13 INTERROGATION PATH REFLECTIONS

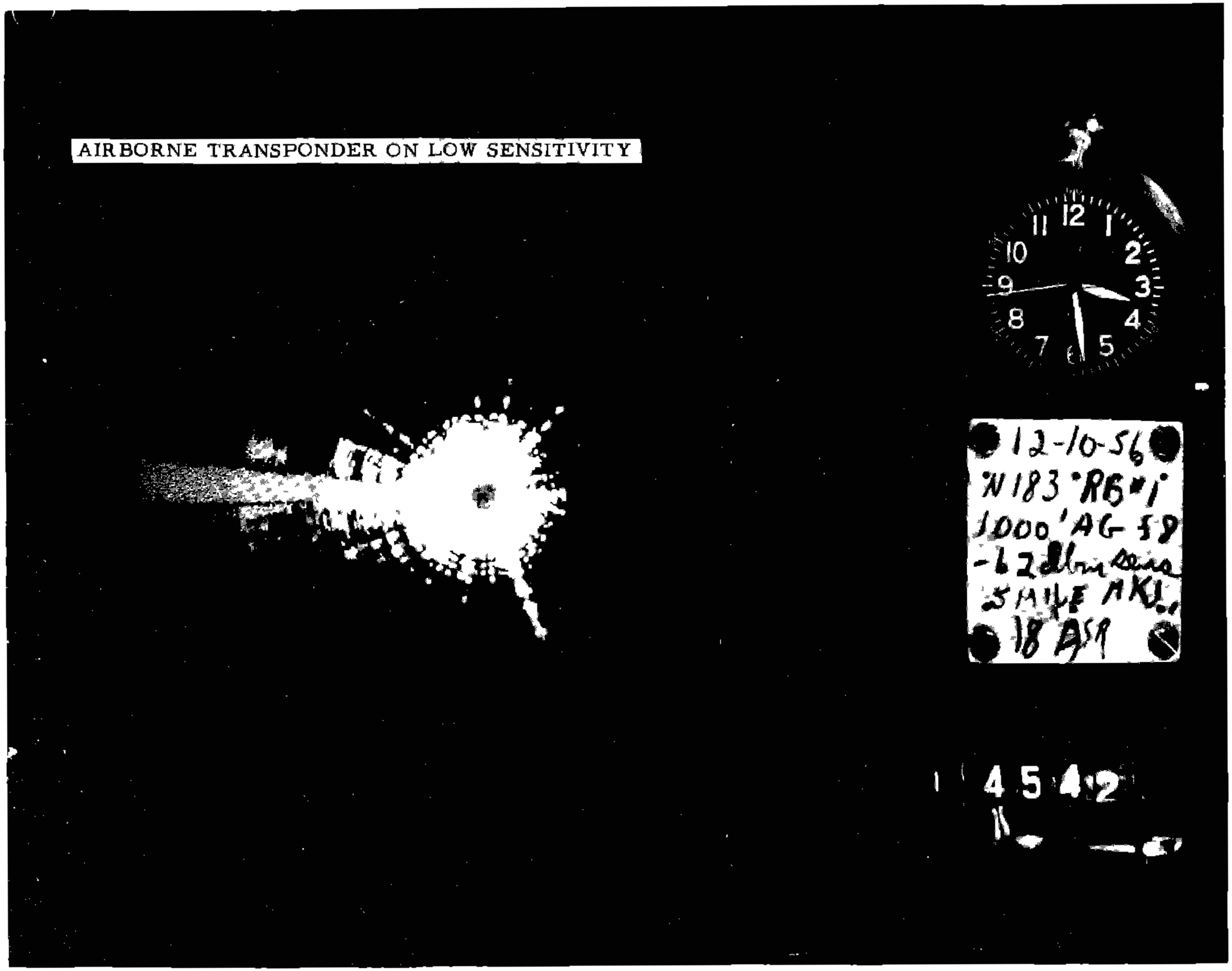


FIG. 14 18-FOOT ANTENNA INTERROGATION PATTERN

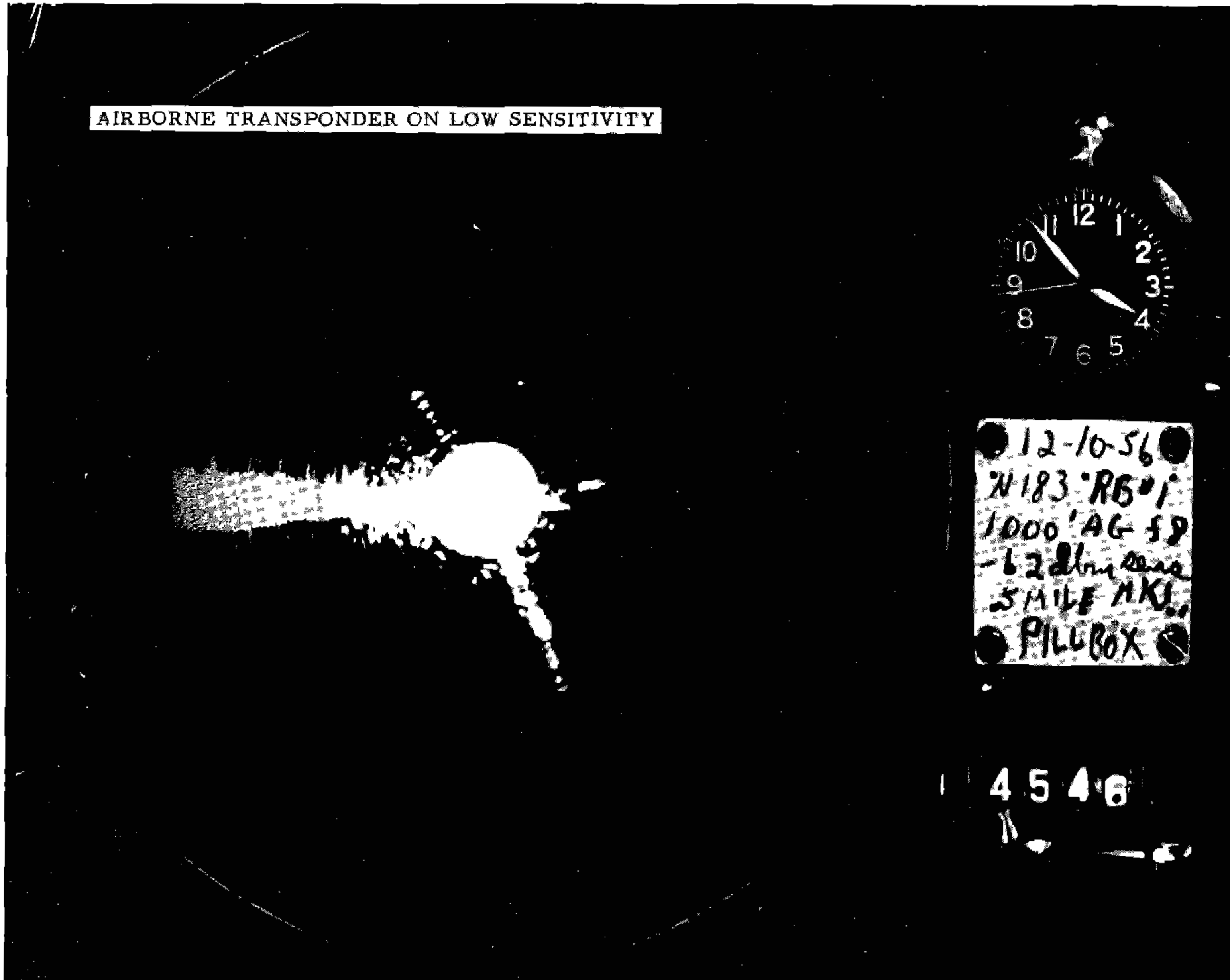


FIG. 15 PILLBOX ANTENNA INTERROGATION PATTERN

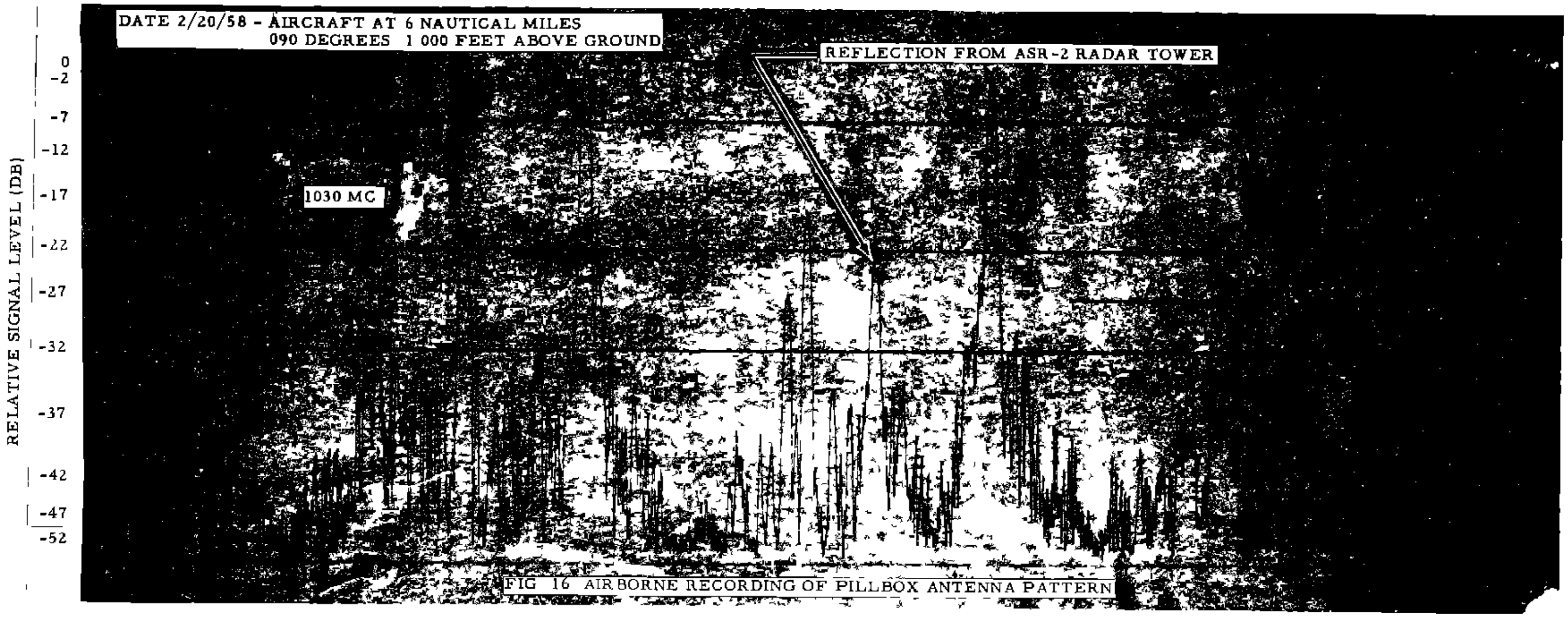


FIG 16 AIRBORNE RECORDING OF PILLBOX ANTENNA PATTERN