TECHNICAL DEVELOPMENT REPORT NO. 310

TESTS OF NARROW-BAND TRANSMISSION OF RADAR BEACON DATA

FOR LIMITED DISTRIBUTION

by

John R. Hoffman
Fred S. McKnight
Robert L. Sorensen

Navigation Aids Evaluation Division

May 1957

Prepared for
The Air Navigation Development Board
Under
Project No. 1.4

by

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT CENTER
INDIANAPOLIS, INDIANA

TESTS OF NARROW-BAND TRANSMISSION
OF RADAR BEACON DATA

SUMMARY

This report describes evaluation tests of a narrow-band radar remoting system for transmitting uncoded secondary radar (beacon) information. During these tests both the remoted beacon data and a local beacon installation were displayed on a panoramic display table to illustrate possible use of the existing military secondary radar system for control of all airspace at high altitudes. Data from the remote ground facility were transmitted over a narrow-band telephone channel by use of Radar Facsimile (RAFAX) video compression equipment. The report primarily covers the technical evaluation of the remoting of the secondary radar information.

These tests indicated that it is feasible to use this system for remoting uncoded beacon returns over telephone channels. By use of these techniques an interim system could be developed to obtain a rapid rate of accurate position data for the efficient control of all airspace at the high altitudes provided that certain operating agreements can be reached with the military agencies using the existing beacon system, and with other users of the airspace.

Continued development effort is desirable to correct the system deficiencies cited in this report. Additional tests of a variable parameter RAFAX equipment are being conducted and will be reported later.

INTRODUCTION

The danger of midair collisions between aircraft has been emphasized in recent years by the advent of jet aircraft. Many instances have been reported by the military and others of actual collisions, and "near-misses" in good visibility conditions because of the high operating speeds of aircraft and limitations of human vision. If another aircraft is observed on a closing course, a finite time is required for the pilot to react and for the aircraft controls to take effect and alter the course of the aircraft. As a result, there is an increasing need for positive traffic control at the higher altitudes where the highest speeds are encountered.

In order that positive control of high-altitude aircraft can be feasible, a higher order of accuracy in navigation and position reporting than is being obtained presently is required. Without such improvement, large blocks of airspace are required for each aircraft to allow safely for the uncertainty of aircraft position. A solution to the problem may be found in the use of radar to determine position information. Of the possible radar techniques, secondary, rather than primary, radar offers many immediate advantages, the most significant of which are:

1. Greater range, altitude coverage, and reliability than are possible by present-day primary radar systems. This is the result of one-way transmission rather than reflection of energy from the target.

2. Freedom from ground echoes, precipitation interference, and returns from aircraft not involved in the traffic control problem. Certain conditions, however, can create serious interference problems in the secondary radar system.

3. Additional equipment development is not required to provide position information. In fact, an existing military tactical system is almost completely implemented in high-altitude aircraft. Certain ground equipment already is installed. Additional equipment which would be required is less expensive than primary radars.

The system tests described in this report were designed primarily to determine if narrow-band transmission equipment is satisfactory for remoting beacon data. They also were designed to indicate the usefulness of beacons for high-altitude traffic control and to reveal some of the problem areas and possible approaches to these problems.

This work was carried out during April and May, 1956, in the Airways Operations Evaluation Center (AOEC) under ANDB Project 1.4, in cooperation with the CAA Offices of Air Navigation Facilities and Air Traffic Control. The American Telephone and Telegraph Company and Haller, Raymond and Brown, Inc., were very cooperative in completing the tests and analyzing the data. The facilities and assistance of personnel of the Wright Air Development Center and the Traffic and Landing System (TRACALS) group at Wright-Patterson Air Force Base were essential to the demonstrations and the success of the tests.

SYSTEM DESCRIPTION

The equipment employed during the tests either is in production or can be placed in production without further development. These equipments were selected to demonstrate a system that could be implemented with existing devices.

Examination of Fig. 1 will disclose the function of the individual equipments and their interrelation in the system. Two ground stations were used, one located at Jamestown, Ohio, and the other at the Technical Development Center (TDC) in Indianapolis, Indiana. These ground interrogators are separated approximately 120 nautical miles (nm). They are similar electronically with one exception; the Jamestown beacon antenna has a horizontal beam width of 6°, while the TDC beacon antenna has a horizontal beam width of 12°. This resulted in the display of a wider target from the TDC beacon. It was necessary for all test aircraft to be equipped with an airborne-beacon transponder in order to be displayed by this system.

The Jamestown beacon information was relayed to Wright-Patterson Air Force Base (WPAFB) by an existing microwave link. The microwave link video and azimuth information were fed into the RAFAX encoder at WPAFB where the radar video was changed to slowed-down video (SDV) or compressed bandwidth signals.[1] The SDV signals were transmitted from WPAFB to Dayton, Ohio, over a local wire loop of the Ohio Bell Telephone Co.; thence via a high-quality Schedule A, AT&T telephone channel from Dayton to Indianapolis, and from the Indiana Bell Telephone Company office at Indianapolis via a local loop to TDC. The signals then were processed in the RAFAX decoder and applied to the IATRON projection equipment for display on the panoramic air traffic control display board.

The Indianapolis raw beacon video in plan-position-indicator (PPI) form was converted to a television video signal by scan conversion equipment.[2] The TV-type signal was fed into TV projection equipment and displayed on the panoramic ATC display board. The "overlap" airspace between the TDC and Jamestown beacons provided an interesting area for study since an aircraft in this airspace quite often replied to both beacon interrogators and was displayed simultaneously by both projection systems.

Estimates of the production costs of the major components of the system are given in Table I.

[1] It may be noted that the RAFAX encoder could have been located at Jamestown instead of at WPAFB, thus eliminating the microwave link; however, for coordination purposes and because of a lack of available land lines of the proper type between Dayton and Jamestown, it was decided to locate the encoder at WPAFB.

[2] If a second IATRON projector had been available at TDC, the scan conversion equipment could have been eliminated from the system, but the direct comparison of two different types of displays would have been lost.

TABLE I

ESTIMATED PRODUCTION COSTS OF EQUIPMENT

Equipment	Est. Cost (Dollars per Unit)
RAFAX	11,000
IATRON Projection System	14,000
Replacement IATRON Tubes	500
Scan Conversion Equipment	20,000
TV Projection System	2,500
Replacement TV Projection Tubes	100

Beacon System.

The beacons used in these tests were military equipments, many parameters of which are similar to the ATC beacon system being developed. The beacon interrogator antenna at Jamestown is approximately 18 feet in length (6° beam-width) and is affixed to, and rotates with, a long-range radar antenna at 6 revolutions per minute (rpm). The TDC beacon interrogator antenna was a 9-foot array (12° beam-width) and was rotated at about 15 rpm for these tests. The airborne antenna is a common omnidirectional receiving and transmitting antenna which usually is mounted underneath the aircraft fuselage. The military beacon system employs pulse multiplex techniques which may be used for identification purposes; however, this feature of the system was not used during these tests, since the primary purpose was to obtain position information. The principles of beacon system operation are described in an earlier report.[3]

RAFAX Encoder.

The RAFAX equipment consists of three major units shown in Fig. 2. The encoder accepts radar signals which intensity-modulate a J-scan cathode ray tube (CRT). See Fig. 3. The sweep speed depends upon the radar range encoder, (150 nautical miles in this case) and the sweep-recurrence-frequency is the same as the radar PRF. A photocell receives light from the CRT through a thin radial slit in an opaque disk that rotates at 30 rps. Each time the slit passes zero range a synchronizing pulse is generated and the photocell output represents targets at time after the sync pulse proportional to their range. Of the total period between each full rotation of the slit, approximately 28 milliseconds is used to represent the encoded range (150 nm), or approximately 185 microseconds per mile. Comparing this

[3] 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," Technical Development Report No. 268, April 1955.

to radar range of 12.36 microseconds per mile, it can be seen that there is a compression of 185/12.36, or 15 times.

The photocell pulses key an audio oscillator on and off. The oscillator in this system operates at approximately 2500 cycles per second (cps) and is keyed on for one cycle for each light pulse received. A standardizer circuit is employed in such manner that only pulses of higher amplitude than the dark current noise of the photocell plus the radar noise pulses key the oscillator. These keyed oscillations are sent over the transmission line. Similarly, the synchronizing signals key an oscillator which is also sent over the transmission line. Combined with the synchronizing and video signals are other signals taken from the antenna servo-transmitters and encoded so they can be transmitted over the telephone line. In this case they were placed on a sub-carrier near 5 kilocycles (kc). All signals so encoded are transmitted over a sigale Schedule A telephone line to the decoder.

The RAFAX decoder accepts the composite audio signal (Fig. 4) from the telephone line, and extracts the several component signals by means of filters and amplitude-sensitive circuits. The trigger, video, and azimuth information is applied to the RAFAX indicator and displayed in normal PPI fashion. The encoder standardizer circuits are actuated by the leading edge of the photocell output voltage pulses. Because the amplitude of these pulses varies with the strength of the radar video signal, the displayed target range goes through a minimum as the radar antenna passes through the target. See Figs. 5 and 6. In the equipment under test there was some trigger jitter wich accounts for the fact that the convex shape is not present to the same degree for all targets shown in Fig. 5.

The principles of operation of RAFAX are explained in greater detail elsewhere.[4]

Transmission Circuit.

After encoding, the beacon information from Jamestown was remoted to TDC by wire line. Such information can be remoted by several means depending upon the quality required. Program circuits of various bandwidths are available between major metropolitan areas. American Telephone and Telegraph Company circuits of various qualities are listed in Table II. For higher quality circuits, radio or microwave links may be used.

---

[4] C. W. Doerr and J. L. McLucas, "Narrow Band Radar Relay System," Radio Electronic Engineering, April 1955.

TABLE II

AT&T CO. PROGRAM CIRCUITS

Type	Approx. Bandwidth (cps)	Delay Distortion	Approx. Cost Per Station Per Month (Dollars)	Approx. Cost Per Mile Per Month* (Dollars)
Schedule C	3,500	Not known	20.00	4.00
Schedule A[xx]	5,000	1 Ms/mile 1 kc to 4 kc	120.00	6.80
Schedule AA[xx]	8,000	1 Ms/mile 1 kc to 6 kc	185.00	9.20
Schedule AAA[xx]	15,000	1 Ms/mile 1 kc to 11 kc	225.00	11.60

* The cost figure is based on 24 hour/day service.

xx Program circuits, A, AA, and AAA require special cable and special equipment in telephone offices. Depending on the availability of existing equipment, some construction time may be required for certain routes.

The RAFAX encoder required a circuit bandwidth similar to that of the Schedule A circuit. This service was available between Indianapolis, Indiana, and Dayton, Ohio, in two forms; a loaded cable, and a Type K Carrier. The circuit characteristics are similar within the required bandwidth and the resulting service is comparable. In the Type K Carrier filters remove transmission from other than the specified bandwidth, whereas in the loaded cable some higher frequencies are available.

In addition to the program circuit, local loop circuits were required from the program circuit terminations at the central exchange offices to WPAFB and TDC. Various quality local loops can be provided. The signal levels over the entire circuit are shown in Fig. 7. It will be seen that the signal attenuation was concentrated in that portion of the Indianapolis local loop from the Belmont exchange to TDC.[5] The circuit attenuation was measured at 2500 cps. Both ends of the circuit were terminated with 600 ohms. A 6-volt trigger input at WPAFB produced a 0.6-volt signal at TDC.

---

[5] AT&T Co. can provide local loops with much less attenuation if the service is to be utilized on a more permanent basis. These circuit facilities were leased for 60 days only, the duration of the high-altitude beacon display tests.

The transmission curve, Fig. 8, shows that the azimuth rate carrier of 5800 cps was attenuated about the same as the video and trigger signals at 2500 cps. All the signals could be adjusted individually at the sending and receiving terminals. Because the azimuth rate modulation was only 90 cps, its side-bands were narrow and were passed without excessive distortion. Experimental operation was conducted with the rate carrier at 8000 cps, when the loaded cable was used. This operation was satisfactory, but the response curve hump at 8000 cps was not an intentional part of Schedule A service and can not be depended upon as it is normally removed with filters in Type K carrier service. For this reason, the azimuth rate carrier was set at 5800 cps. On occasions the local loop between Dayton and WPAFB had intermittent 60 cps interference of an amplitude about equal to that of the azimuth carrier. This interference so distorted the composite signal that it was not usable. High-frequency cross-talk spikes were encountered intermittently also but were eliminated by shunting a small capacitor across the decoder input. A band-pass filter with a low frequency cut-off near 70 or 80 cps would eliminate the 60 cps and the higher frequency spike interference. For the limited duration of the tests, and because the interference was not continuous, band-pass filters or more elaborate means of interference rejection was not tested.

For a short period the Schedule A line was increased in length to 300 nm by using three circuits between Indianapolis and Dayton. Two lengths of loaded cable and one length of Type K carrier were connected in series.

TABLE III

LINE TRANSMISSION LOSS

Input Frequency (cps)	Input Amplitude (peak to peak at WPAFB) (volts)	100-nm Output p/p at TDC (volts)	300-nm Output p/p at TDC (volts)
50 (Test Signal)	2.0	0.17	0.14
2,500 (Sync or Trigger)	2.0	0.31	0.28
5,800 (Azimuth Rate)	1.0	0.16	0.05

Table III shows the effects of increasing the circuit length to 300 nm. The same local loops were used for both the 100- and 300-nm distances. It was necessary to increase the encoder-output voltage level at WPAFB in order to obtain sufficient azimuth rate signal to operate the decoder indicator at TDC. When the azimuth rate signal reached 0.14 volts, azimuth rotation was obtained and the indicator displayed a satisfactory PPI picture. Coordination during these tests was made possible by a direct telephone line and ringing circuit furnished by the AT&T Company between TDC and WPAFB.

This line was a basic necessity during the implementation and operational test periods. Its use was of great value to the entire project. One end was terminated at WPAFB where the RAFAX encoder and a CPS-1 radar indicator were located. The other end was terminated in the AOEC room at TDC, at the location of the decoder and projection equipment. Intermediate drops were made at the AT&T central exchange offices at Indianapolis and Dayton.

In general, operation over the circuit provided by the AT&T Company was excellent. The unusable time was less than three per cent during the hours of operation, and would, undoubtedly, be more reliable if the circuit was rented on a continuous basis.

IATRON Projection Indicator.

The IATRON radar projection indicator is a PPI projector designed around the Farnsworth IATRON, a projection storage tube capable of providing 2.7-foot lamberts of highlight brightness on a 50-inch diameter display. The projected display is a green-yellow color (peak at 5550 A) on a flat white background. The projection indicator consists of a control-console, Fig. 9, and a projection unit, Fig. 10. The projection unit is capable of being remotely operated from the control-console, a maximum of 25 feet. This indicator was designed to display either raw radar or slowed-down RAFAX videos. The projected display employs a refractive optical system using an f/1.9 five-inch projection lens. The specified range resolution is 100 spots per radial.

The useful storage time of the IATRON is a variable factor, the selection of which depends on the scan rate and noise present. The storage time of the IATRON tube itself is variable from 3 milliseconds to 30 seconds. In applications using raw radar video inputs, a shorter storage may be required to prevent loss of targets in receiver noise, precipitation interference, MTI residue, et cetera. When using RAFAX signal inputs, the level of the target video pulses is dependent on the RAFAX standardizer adjustments and phototube integration. The video is relatively free of noise; consequently, a greater storage time can be used. In addition to the normal erase function controlled by adjustment of a potentiometer, the display may be erased by push button; or, an automatic cyclic erasure may be set for complete erasure at intervals of 2, 6, 10, 20, 60, or 100 seconds. The sweep speed can be adjusted to display various standard radar ranges from 20 to 200 nm and RAFAX scan speeds of 30, 60, and 120 rpm.

Bright-Display Equipment.

The Dumont Model SRD-1 Bright Display Equipment[6] (BDE) is a scan conversion equipment designed to provide a television output from a radar PPI video and azimuth input. The television output is used to supply bright tube projector equipment, or direct-view indicators. The BDE basically consists of normal radar indicator circuits for writing the radar information, a Graphecon scan conversion tube, television sync and sweep generators for reading data from the storage tube, and monitor circuits.

The Graphecon tube consists of two diametrically opposed electron guns with an electrostatic target element midway between them. The radar information is written on one side of the target element through the use one electron gun, while the reading electron gun at the opposite end of the tube scans the target at a standard television rate. The reading beam is modulated by a 30-megacycle (Mc) carrier to discriminate between the writing and reading video taken from the target element. The storage time of this tube depends upon the television scan rate and the reading beam current, and is adjustable from 1 to 20 seconds. The picture displayed has an aspect ratio of 1:1. The process of scan conversion makes possible a television scan resolution of 400 elements in a vertical direction and 500 elements in the horizontal direction.

Television Projector.

The television projection equipment used during these tests is shown in Figs. 9 and 10. It consists of a projection head and control-console. The projection head may be remotely operated from the control-console, a distance of approximately 20 feet or less. The projector employs a 5-inch Schmidt optical system and has a brightness of 4 foot-lamberts on a 50-inch diameter display. The projection tube is an RCA Type 5AZP4A. This TV projection system, manufactured by the General Precision Laboratory, Pleasantville, N.Y., is a commercial model intended for industrial use. Some modifications of this model were necessary to obtain an aspect ratio of 1:1 and sufficiently linear sweep voltages. Additional changes were necessary to adapt the system to use with the BDE.

---

[6] William E. Miller, Marvin H. Yost, and David S. Crippen, "Evaluation of the Dumont SRD-1 Bright-Radar Display and Initial Study of Other Display Techniques," Technical Development Report No. 288, July 1956.

RAFAX-TRANSMISSION CIRCUIT TESTS

General.

The quantitative measurements were limited to the RAFAX and the transmission circuit because these were the only parts of the system which had not been operated and tested at TDC previously. The system was operated eight hours per day for approximately 40 days, and the down-time due to equipment failure was less than two hours. When the equipment was operated continuously, adjustments were rarely needed. No noticeable deterioration was observed in the display picture quality during the course of the tests.

RAFAX Range Linearity.

A block diagram of the setup for these tests is shown in Fig. 11. The recorded data are presented in Table IV, and photographs of the display are shown by Figs. 12 and 13. The RAFAX indicator was not used for the recorded measurements. The range mark generator at WPAFB was crystal-controlled and very accurate. The delay generator used at TDC was calibrated with a crystal-controlled time-mark generator immediately before the tests. A fast sweep was used on the precision scope and the trigger was delayed until the range mark appeared in the center of the sweep. The delay was read from the delay generator dials and is believed to be accurate within plus or minus 20 microseconds.

From Table IV it can be seen that the RAFAX-remote circuit did not deliver a linear time base to the display equipment. The display equipment and RAFAX indicator were adjusted for accuracy at the 0 and 150-nm points, but at 90 nm the error reached a maximum of 1.46 per cent, or about 2.2 nm of the 150-nm range. Time base non-linearity of the encoder-scanner circular sweep and optical distortion are believed to have been the principal causes of the error. Rotational speed changes of the mechanical scanner, caused by friction or vibration, may have been a contributing factor. In any even, obtaining a greater range accuracy does not appear to be a serious difficulty, if it were required. The remote circuit itself had no measureable effect on the range accuracy.

Because the range marks were 10 nm apart (123 microseconds), it may be seen that the average compression ratio was 1757/123, or 14.2. The ratio of the beacon PRF (300) to RAFAX PRF (30) is 10. The reason for the difference in ratios is that the J-scope, which displays the raw beacon information, has a much longer proportionate dead time between circular sweeps than is used in the RAFAX scanner.

TABLE IV

RAFAX RANGE LINEARITY

Range Mark (nm)	Spacing Measured (ms)	Spacing Correct (ms)	Successive 10-mile Spacings (ms)	Compressed Range Error (ms)	Compressed Range Error (per cent)
0	0	0			
10	1,750	1,757	1,750	+ 7	0.03
20	3,570	3,514	1,820	- 56	0.21
30	5,415	5,271	1,845	-144	0.55
40	7,090	7,028	1,675	- 62	0.24
50	8,830	8,785	1,740	- 45	0.17
60	10,460	10,542	1,630	+ 82	0.31
70	12,080	12,299	1,620	+219	0.83
80	13,700	14,056	1,620	+356	1.35
90	15,330	15,713	1,630	+383	1.46
100	17,240	17,570	1,910	+330	1.25
110	19,010	19,327	1,770	+317	1.20
120	20,900	21,084	1,890	+184	0.70
130	22,700	22,841	1,800	+141	0.54
140	24,400	24,598	1,700	+198	0.75
150	26,355	26,355	1,955	0	0

RAFAX Sensitivity.

Several tests were conducted using target-simulator and video-signal generator inputs. The target-simulator output provided discrete range and azimuth, whereas the signal generator provided discrete range but at all azimuths. In both cases the CPS-1 radar indicator and the RAFAX indicator lost weak targets at about the same test signal level, when the encoder and the CPS-1 indicator each were adjusted for optimum conditions. When the input noise was low, the encoder internal-noise level was the limiting factor in the maximu usable RAFAX sensitivity. Tests were run with pulse widths of 0.5, 1.5, and 3.0 microseconds. The pulse width did not affect the maximum sensitivity appreciably. A minimum discernible target was displayed on the CPS-1 indicator at 0.12 volts input (normal is 2.0 volts) at which level the RAFAX indicator was just on the threshold of count-down. In Figs. 14 and 15 it will be noted that, so long as the RAFAX standardizer passes the weak input signal, it is received at the standard output level.

RAFAX Signal-Noise.

Figure 16 is a photograph of the radar indicator at WPAFB with 0.5 volt noise and 1.4 volt, 1.0 microsecond wide signal input. Figures 17, 18, and 19 are photographs of the RAFAX indicator at TDC. The signal-generator amplitude was varied from 0.4 to 2.0 volts while the noise was held constant at 0.5 volts. The RAFAX encoder was adjusted so that the 0.5-volt noise level would not produce an output from the decoder and was not changed again. This test represents closely the actualy operating conditions. The CPS-1 radar indicator, under the same conditions, painted a solid signal in each case, whereas the RAFAX indicator began to count down when the signal was 0.5 volt (signal/noise ratio of 1). The 0.5-volt signal (Fig. 18) was about 80 per cent usable. The 0.4-volt signal (Fig. 17) was too intermittent to be relied upon. Figures 17, 18, and 19 reveal that the noise on the RAFAX indicator is essentially constant and quite low. Experience has demonstrated that the encoder may be adjusted so that more noise is encoded (passes the standardizer) and the RAFAX sensitivity is increased thereby. Regardless of this fact, the RAFAX in this test was almost as sensitive to weak targets as the radar indicator.

A second signal-noise test was conducted to simulate the condition when the encoder is adjusted to the standard 0.5-volt noise level, and for some unknown reason, the noise level increased. This often is the case when the parent radar or beacon receiver gain is increased. This situation is illustrated in Figs. 20 through 23. The CPS-1 radar indicator was adjusted for each condition, and the signal is clearly discernible in each case, although the noise level is quite high when the noise amplitude reaches 1.5 volts. The signal level was held at 2.0 volts, and the encoder was not changed from its original condition when it was adjusted for 0.5 volt of noise.

As noise was added to the 2.0-volt video input, the RAFAX signal remained usable when the noise reached 1.0-volt, Fig. 21. At 1.5 volts noise the RAFAX signal was still discernible, and at 2.0 volts noise the encoder failed to pass the signal. It is interesting to note the character and distribution of the noise on the two indicators. This test demonstrates the fact that the RAFAX can tolerate considerable variation in input noise level without readjustment of the encoder at the remote location.

Another indication of RAFAX system sensitivity comes from a statistical analysis of photographs of random beacon targets when both the CPS-1 radar indicator and the RAFAX encoder were adjusted for best operation. The total number of targets identified on the radar indicator at WPAFB was 126. The total of the RAFAX indicator targets at Indianapolis was 122. The pictures were synchronized so that the cameras were recording the same period of time for one or two antenna scans. The same targets were easily identifiable in the photographs of each indicator. The target ranges were random and the altitudes were unknown. The large number of targets counted add reliability to the data and verify the fact that sensitivity of the RAFAX system is only slightly less than that of the radar indicator.

RAFAX Range Resolution.

A two-pulse video signal generator was employed for this test. The video level was set at 2 volts with 1.0-microsecond pulses. The noise level was fixed at 0.5-volt and the encoder and radar indicator were adjusted for best operation. Figure 24 shows the two pulses (input to decoder) at 40-microsecond separation as seen on the RAFAX indicator. At about 35 microseconds, the second pulse began to count down, and at 32 microseconds, Fig. 25, the count-down was quite noticeable. With a separation of 30-microseconds, Fig. 26, the second target was almost eliminated. Count-down began at approximately 2.8 nm or 1.9 per cent of range.

The tests were repeated with 1.0-volt signals, and there was no noticeable change in minimum separation. The minimum separation is basically determined by the video carrier-oscillator frequency, in this case 2500 cps. During the 1/30-second the scanner requires for one revolution, there is a maximum possibility of approximately 83 cycles. RAFAX dead time reduces this to about 69 cycles. Neglecting keying time then, a maximum of about 69 cycles, or video targets, could appear in one RAFAX range sweep since at least one cycle is required for each video signal. The 150-nm range scale would then be able to display targets about 2.2 nm apart. This is an absolute minimum which ignores oscillator keying time. There is another circumstance which could limit the minimum target separation before the basic limit is reached. The phototube output-pulse width is a function of spot size, spot intensity, and slot width. If the phototube output from the first target fails to fall below the standardizer level before the output of the second target has increased above the standardizer level, the video carrier oscillator is not keyed off and the two targets may merge as one large target. A similar phenomenon occurs with primary radar ground clutter. This did not occur during this particular test.

RAFAX targets displayed from the Jamestown beacon (6° antenna beamwidth) are "wider" in azimuth than they are "thick" in range for all distances in excess of approximately 25 nm. The problem of separation of aircraft then becomes more acute in azimuth than it does in range for the major portion of the targets displayed. Improved range resolution would be needed for shorter range radars used for high-density traffic control; but for the high-altitude beacon tests, the range resolution appears to be adequate. Improved and adjustable range resolution is available on the variable parameter RAFAX recently delivered to TDC. The price for improved range resolution in many cases will be the requirement for higher video-carrier frequencies and broader bandwidth-remoting circuits.

Elimination of Fruit.

Beacon fruit is transmitted by airborne units when they are interrogated by ground units whose video information is not synchronized with the display. Its distinguishing characteristic is that it is random or unsynchronized with the video information of interest. When such pulses from a particular transponder reach the RAFAX encoder, they do not appear at the same range on each scan of the J-scope, but they are random and appear over the entire range, and some of them occur during the J-scope dead time. As a result these pulses do not excite the same small area or spot on the J-scope during each transmission, but are spread all the way around the J-scope trace. This distribution of excitation prevents phosphor integration or build-up. The light from a spot which is excited by a single pulse persists for a very short time, much less than the time required for one revolution of the scanner. Unless the spot is directly under the scanner slot, or slightly ahead of the slot, at the time it is excited, the light from the spot will not reach the phototube. This prevents the signal from being encoded and appearing on the indicator.

Figures 27, 28, and 29 illustrate examples of the defruiting action just described. Photographs of the CPS-1 indicator at WPAFB and of the RAFAX indicator at TDC were taken simultaneously. Figures 28 and 29 were taken to emphasize the defruiting action by exposing the film to several antenna scans, thus allowing the fruit to accumulate photographically. These pictures do not show the fruit that appeared on either indicator at any particular time during the exposure, and the apparent trail of the targets is caused by the "memory" or storage of the exposed film. Figure 27 was exposed for only one scan, and it is a true representation of the indicator appearance as seen by the operator. There is no relation between the azimuth mark on the RAFAX indicator and the fruit on the CPS-1 radar indicator. The photographs indicate that the RAFAX encoder prevents at least 80 per cent of the fruit from reaching the indicator.

DISPLAY TESTS

Specific measurements of display quality, such as range linearity and resolution, azimuth accuracy, brightness, and so forth, were not made as a part of these tests. These qualities had been measured previously, either as part of the original acceptance of the display equipment, or as part of the subsequent evaluation. Certain of these qualities were, however, included as a part of the system testing and, while not recorded quantitatively, were observed and are reported below.

Panoramic Display.

The accuracy of both the IATRON and the TV projection system determines the accuracy of the Panoramic Presentation (PANOP), particularly in the overlap area. Two kinds of accuracy are involved; one which refers to the actual geographical position of a specific target and its indicated position on the PANOP, and the second which refers to the registration of the two displays when the target is in their overlap area and is responding to interrogations from both beacon systems. The two kinds of accuracy are related to a degree.

The layout of the PANOP was considered as two Rho/Theta presentations, one centered on Jamestown and one centered on Indianapolis. Navigational aids and airways within a 100-nm radius were plotted from these centers. Where the same point plotted differently from the two locations, a compromise position was used. These differences were due to errors in Radio Facility, Sectional, and other charts used to determine location, and to the plotting process itself. The compromise errors never exceeded two nm.

At ranges within 10 nm, the effects of slant range also introduced measureable display errors. An aircraft flying at an altitude of 40,000 feet over the point, however, is at a radar range of 12 nm and is so displayed by the projection system. At greater distances, slant range error becomes less significant. For example, an aircraft passing over Indianapolis at an altitude of 8 nm is displayed by the Indianapolis system at a range of 8 nm. The same aircraft responding to the Jamestown system is displayed over Indianapolis. The same aircraft is, therefore, displayed as two targets at ranges differing by 8 nm.

In addition to map and slant range errors there were certain inaccuracies in both projections. These were due to sweep non-linearity, IATRON keystone effects, and azimuthal errors. By more careful design, it is believed that these errors can be made negligible in future equipments.

In other areas where lack of registration between the two displays was noted, the two targets were displayed at points differing by as much as 7 nm. These errors were azimuthal errors and range non-linearities which can be minimized through better design. The azimuth following system of the RAFAX equipment does not achieve the accuracies which can be obtained by more expensive and slightly wider band systems.[7] Although RAFAX range non linearities can approach 1.5 per cent (2.2 nm), this is not considered excessive but it can be improved by more careful alignment and designs already developed.

The TV projector used was a commercial product which could provide considerably improved linearity by more careful attention to circuit design and component selection. The IATRON display has inherent accuracy problems because the writing gun is not perpendicular to the storage insulator. The 25° angle from the perpendicular gives rise to ellipticity which requires sweep compensation. Improvement in design and adjustment techniques can be expected as greater experience with this tube is obtained.

Summarizing, the greatest errors occur at short range because slant range differs from surface range to an aircraft. Lack of registration between the two display systems also was greatest at short range. Errors as great as 10 nm were occasionally noted. By blanking the first 10 nm of each display and allowing only the adjacent system to cover the volume so blanked, this problem can be minimized.

Brightness and Contrast.

These projection systems of 50-inch diameter resulted in high-light brightness of between to and three foot-candles. This level appeared usable during the tests but higher brightness is desirable.

With regard to contrast, the TV system was not as good as the IATRON for two reasons; first, because the targets are white on a white display board, and second, because noise background of the display also

---

[7] A new model of RAFAX, delivered to TDC since these tests were concluded, will use a two-phase, single-speed system, which should provide more uniform azimuth following.

is white. However, the TV system was far more usable in the beacon application than in a radar application, since beacon targets were larger and stronger, and there were no precipitation interference or ground clutter with which to contend. At the antenna scan rate of 15 rpm, and freedom from precipitation and ground clutter, excellent storage and target trails were obtained.

The IATRON had excellent contrast due to the nature of the RAFAX signals. Strong signals were always obtained from any signal large enough to pass the encoder standardizer level. There were no intermediate signal levels; they were either strong or non-existent. A problem arises in this type of display which was not encountered in the TV projection. When noise does break through the RAFAX standardizer, it is displayed with a strength equal to the radar signals. The IATRON displays the decoder output accurately, but does not provide many intermediate signal levels. The trail quality of the IATRON is not as good as that of the TV display. Since it is free from precipitation and ground clutter, it may be acceptable when the RAFAX encoder is not passing too much fruit or noise.

Display Resolution.

RAFAX resolution in range, and antenna resolution in azimuth, were limiting factors although the IATRON itself does not have as good resolution as would be desirable. The 9-foot beacon antenna near maximum range provided target signals as much as 20 nm wide in azimuth on the indicator. As stated previously, the RAFAX range resolution was about 3.0 nm. At best, the IATRON resolution did not exceed this amount when used to display 150 nm radius. The manufacturer's data indicate that 60 spots per radius of 150 nm will give a resolution of 2.5 nm. Such resolution appears a little optimistic for continuous service. It would appear that the RAFAX and IATRON resolution are of the same order and that 3.0 nm is about the quality that may be expected.

OPERATIONAL EVALUATION

General.

Operational evaluation tests of the beacon system were conducted in three ways: (1) by following identified aircraft passing through the Indianapolis area; (2) by checks of system performance using DC-3 aircraft; and (3) by vectoring USAF jet aircraft in typical patterns to evaluate possible separation standards.

Numerous military aircraft with operating beacons were tracked on the panoramic ATC display. Flight plan information on many of these aircraft was available from the Indianapolis ARTC Center. By monitoring air/ground communication channels being used by the ARTC Center and INSACS in the area, pilot reports of position were intercepted and the aircraft were identified. Information on Visual Flight Rules (VFR) flights also was obtained in this manner. In some cases aircraft were contacted directly by radio after making position reports and were then requested to turn on their beacons. Figure 30 is a view of the panoramic ATC display with beacon returns from several aircraft displayed.

The Center's DC-3 aircraft were flown in two tests to observe system performance. The first flight, from Indianapolis to Cincinnati to Dayton and return, was entirely within the overlap area of the two beacon systems. Target quality was recorded for each antenna scan. In addition, target quality was recorded simultaneously at WPAFB on the Jamestown system for comparison with the data received at Indianapolis over the RAFAX/telephone line link. Figure 31 indicates the coverage obtained from both beacon systems during this flight. Subsequently, an additional flight check was performed with the TDC aircraft flying from Indianapolis over Dayton and Columbus to Wheeling, West Virginia; thence over Parkersburg to Charleston, and from Charleston via York and Cincinnati to Indianapolis. Each antenna scan was recorded at both locations. Figure 32 is a comparative plot of the Jamestown beacon data before and after remoting.

As a result of the spotty coverage of the Jamestown beacon, additional maintenance work was performed on this beacon system near the end of the test period. Although no additional flight checks were made after this maintenance work was accomplished, considerable improvement in reliability of target returns was noted.

Brief tests also were made with jet fighter aircraft supplied by the USAF from WPAFB. These tests were directed primarily toward determining possible separation standards that might be used with the beacon system under test. Aircraft were vectored in typical patterns to determine usable range and azimuth resolution. In A of Fig. 33 a F-86-D aircraft is shown overtaking and passing a F-94-C aircraft approaching Cincinnati (upper center of photo) with partial target overlap of returns from the Indianapolis beacon system. In B of Fig. 33, obtained a short time later, are shown the Indianapolis beacon returns overlapping as the aircraft passed. A and B of Fig. 34 were taken at WPAFB at the same time as A and B of Fig. 33 and show the beacon returns of these same aircraft from the Jamestown system before remoting to Indianapolis. The affect of the difference in beam width of the two antennas is quite apparent.

Problems Noted.

1. It was noted that many conventional military aircraft operating at the lower altitudes had beacons in operation. Many others did not have

beacons in operation. Similarly, some jet aircraft at high altitudes had beacons turned on while others did not. For positive control of all aircraft operating above a designated altitude, all aircraft should be equipped with an operating beacon. Aircraft at lower levels would be required to turn off their beacons, or change mode, to eliminate undesired returns on the displays.

2. Aircraft returns on the Indianapolis beacon system "occupied" considerable airspace, the targets being long arcs when using the 9-foot antenna. At ranges beyond 100 statute miles these arcs frequently were 20 statute miles long. In normal radar control, controllers do not allow targets to overlap; and, in fact, generally use at least the minimum spacing of three statute miles (five miles beyond 40 miles distance) between adjacent edges of target returns. If this practice were continued with the beacon system, aircraft would have to be spaced 25 statute miles apart laterally at the longer ranges. Present rules permit aircraft to fly on adjacent airways with ten statute miles lateral spacing between centerlines of the airways. The beam width of the beacon system can, of course, be reduced considerably by use of larger antennas.

3. Target fading, due to nulls in the vertical radiation pattern of the beacon antenna, was noticeable beyond 100 nm. These fades become objectionable beyond 120 nm. Better siting of antennas may provide usable ranges up to 150 nm. Also, aircraft making turns frequently faded out, apparently due to shielding of the aircraft antenna by structural parts of the airplane such as the wings. At ranges of less than 10 to 15 nm, returns were lost due to the "cone" over the station. A and B of Fig. 35 show displays of flights observed on the Indianapolis beacon system. They illustrate the effects of the nulls in the radiation pattern at longer ranges. Fruit pulses from the Jamestown system, which were passed by the RAFAX and presented by the IATRON, frequently were as large and bright as the aircraft targets, making it extremely difficult to distinguish actual aircraft returns from false returns. Fruit interference occured in varying degrees. At times, the Jamestown system, as presented on the panoramic ATC display board, was not usable because of the controller's inability to distinguish aircraft returns from fruit pulses. On the Indianapolis beacon system, the aircraft radar returns could be identified readily because of the wide arcs as distinguished from the dot-type fruit returns. Figure 33 illustrates this effect. Known ground interrogators within the test area were located at the Rockville, Indiana, ADC radar site 50 nm west of Indianapolis, at TDC, at Jamestown, at WPAFB on the CPN-18 radar, and at the Bellefontaine, Ohio, ADC radar site, 45 nm north of Jamestown. Other adjacent ADC sites undoubtedly contributed to some of the fruit-type interference. It is not known if there were other military activities within the area using ground interrogators during the test period.

4. Proper identification of aircraft beacon returns in this system also is a problem. Identifying turns are not considered very practical with the 9-foot antenna system because of the wide targets, especially at low antenna rotation rates. Asking pilots to switch a beacon off for a short interval, and then back on, is not positive identification because of possible simultaneous fades in returns from other aircraft, due to either nulls in the ground antenna pattern, or aircraft maneuvers. In the flight-following tests identification normally was accomplished by association of the pilot's position report with observed aircraft returns over a fix. Mode or code selection systems were not available for these tests.

CONCLUSIONS

Technical.

The following conclusions were reached:

1. From a reliability standpoint, the remoting system is about as simple as can be imagined at this time. Once adjusted, it was stable and dependable. The failures that occurred were not excessive, but even greater reliability could be expected with more experience.

2. The remoting system provided good sensitivity to small targets, faithful reproduction with signal-to-noise ratios closely approaching 1.

3. The maximum non-linearity observed in range was 1.46 per cent of 150 nm, maximum range, or 2.2 nm.

4. The RAFAX equipment used permitted a minimum range resolution of 3.0 nm.

5. Under normal operating conditions, RAFAX reduced beacon fruit approximately 80 per cent. There are no intermediate signal levels. Fruit or receiver noise, when it breaks through, has the same level and pulse width as synchronized signals.

6. The 9-foot beacon antenna gave indicator azimuth width to some targets of 20 miles or more. When possible, the 18-foot, or longer, antennas should be employed. With either antenna a beacon range of 100 nm was found dependable. Ranges up to 150 nm were frequently obtained.

7. The IATRON has a resolution comparable to the RAFAX system and provides good contrast. Continued efforts to improve resolution are required.

8. Both the TV projection and the IATRON with 50-inch diameter displays meet the minimum brightness requirements. Display linearity of each requires continued effort toward improvement.

9. In general, the beacon equipment, the narrow-band equipment, the transmission circuit, and the available displays are technically adequate at present to provide usable data for high-altitude control. Continued effort is required to improve the remoting and display techniques as well as the beacon system itself.

Operational.

It appeared that it would be possible to furnish positive air traffic control of all high-altitude, high-speed aircraft by use of existing military beacon equipments provided that:

1. All aircraft operating above an agreed-upon altitude are equipped with an operating beacon.

2. Aircraft operating below this level do not use beacons except as requested by ATC. Jet aircraft making penetration let-downs or during climb-outs might be requested by ATC to turn on beacons.

3. Military ground-station interrogation of airborne beacons is limited in any one area to one site to reduce fruit interference. For example, it might be possible for the ADC long-range radar to be used as the master ground beacon station for a given area, with all other military activities in the area obtaining aircraft beacon data from this station. Beacon data for ATC Centers could be derived from these ADC sites, from beacon equipment installed locally at ARTC Centers, and from other necessary ground installations to provide complete coverage of all airspace above the agreed-upon altitude level.

4. Ground beacon installations arerrepeated approximately ever 200 nm to permit coverage overlap in the high-altitude airspace. Nulls in the vertical radiation pattern become objectionable beyond 120 nm.

5. Discrete clear-channel communications are provided between aircraft and high-altitude sectors in ARTC Centers. Present levels of interference on the common ARTC Center frequency of 301.4 Mc are too high to permit its use for control of all aircraft at high altitudes.

Use of the existing military beacon system with the above restrictions could provide a means for positive air traffic control of all aircraft at high altitudes. It is estimated that this system, with the panoramic ATC display, could accommodate traffic densities of 15 to 20 aircraft within the approximate coverage of each beacon based on 100 nm usable range.

The high speed of aircraft in high-altitude airspace makes this control desirable. Because most military aircraft operating in this airspace are presently equipped with the beacon, such a system should be feasible for use with the proper ground installations. Civil aircraft operating in this high-altitude airspace also would require this beacon equipment. It is anticipated that procurement and installation of ground facilities for such a system would require 12 to 18 months. It should be borne in mind that this is not considered an ultimate solution to this problem, but it is a possible way of providing positive control of all aircraft at high altitudes in the immediate future.

RECOMMENDATIONS

It is recommended that an in-service test using the existing military beacon system for air traffic control be accomplished at the AOEC/Indianapolis ARTC Center for the entire Indianapolis ARTC area.

The following program is recommended:

1. Effect coordination with military and other users of high altitude airspace to conduct tests using the existing military beacon system for control of aircraft on an area basis. A base altitude of 26,000 feet is recommended because most jet aircraft operate above this altitude, and most conventional propeller-type aircraft operate below this level. It is understood that most jet aircraft are presently equipped with beacons. Aircraft operating below 26,000 feet in the Indianapolis ARTC area would not use beacons except as requested by ATC.

2. Conduct tests based on:

   a. Control of IFR flights only with VFR or 1000 feet-on-top operations allowed; and

   b. Positive control of all aircraft in the designated high-altitude airspace. In these tests, only those aircraft equipped with an operating beacon would be allowed to operate in the high-altitude airspace.

3. Obtain agreements with the military to use Mode 1 of the beacon system for normal returns for air traffic control and use of Mode 2 and/or

Mode 3 for identification of particular aircraft as requested by the controllers.

4. Obtain agreement with the military to restrict operation of military ground interrogators within the area to a minimum, if interference becomes a major problem during the tests; that is, military stations normally would be in a stand-by non-operating condition, and turned on momentarily, or for very brief periods as military necessity requires.

5. Install ground beacon systems in the Indianapolis ARTC area to provide complete coverage of high-altitude airspace. Two stations properly located will provide coverage of the entire Indianapolis area above 26,000 feet.

6. Use narrow-band (slowed-down video) equipments and landlines for transmission of remoted beacon data with an additional control line for remote selection of interrogator mode.

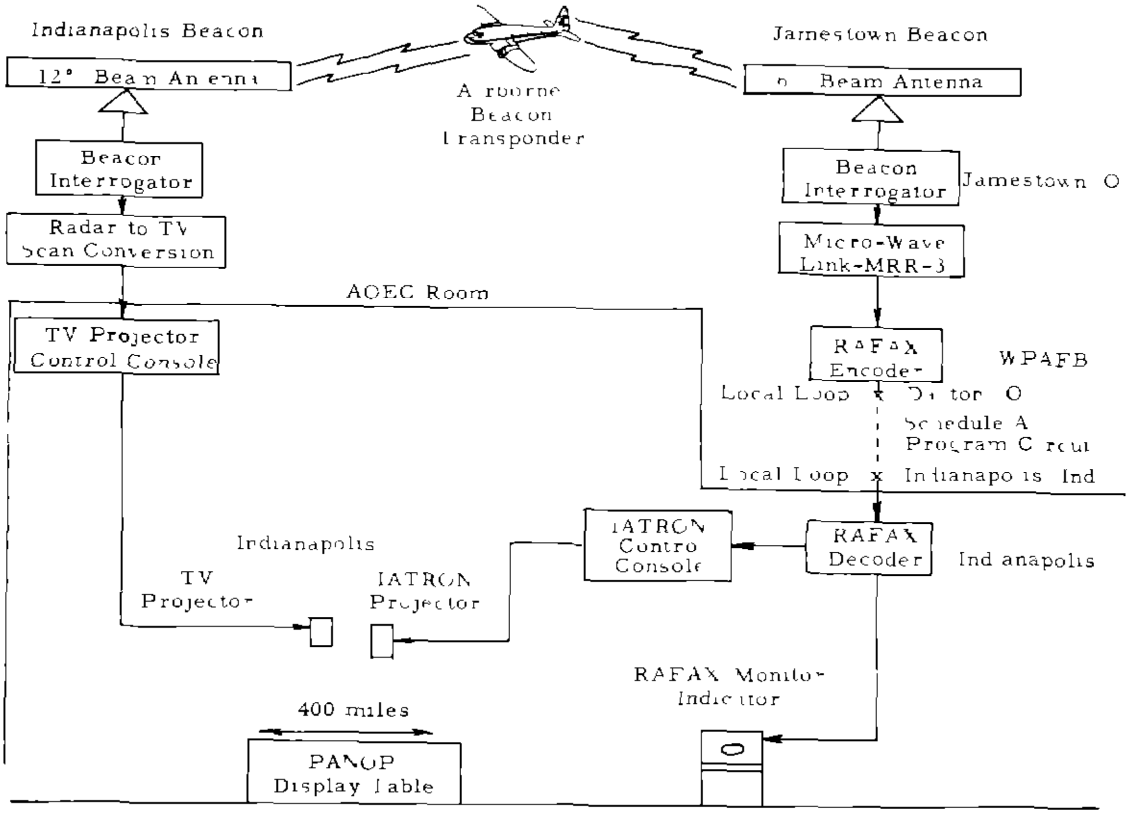
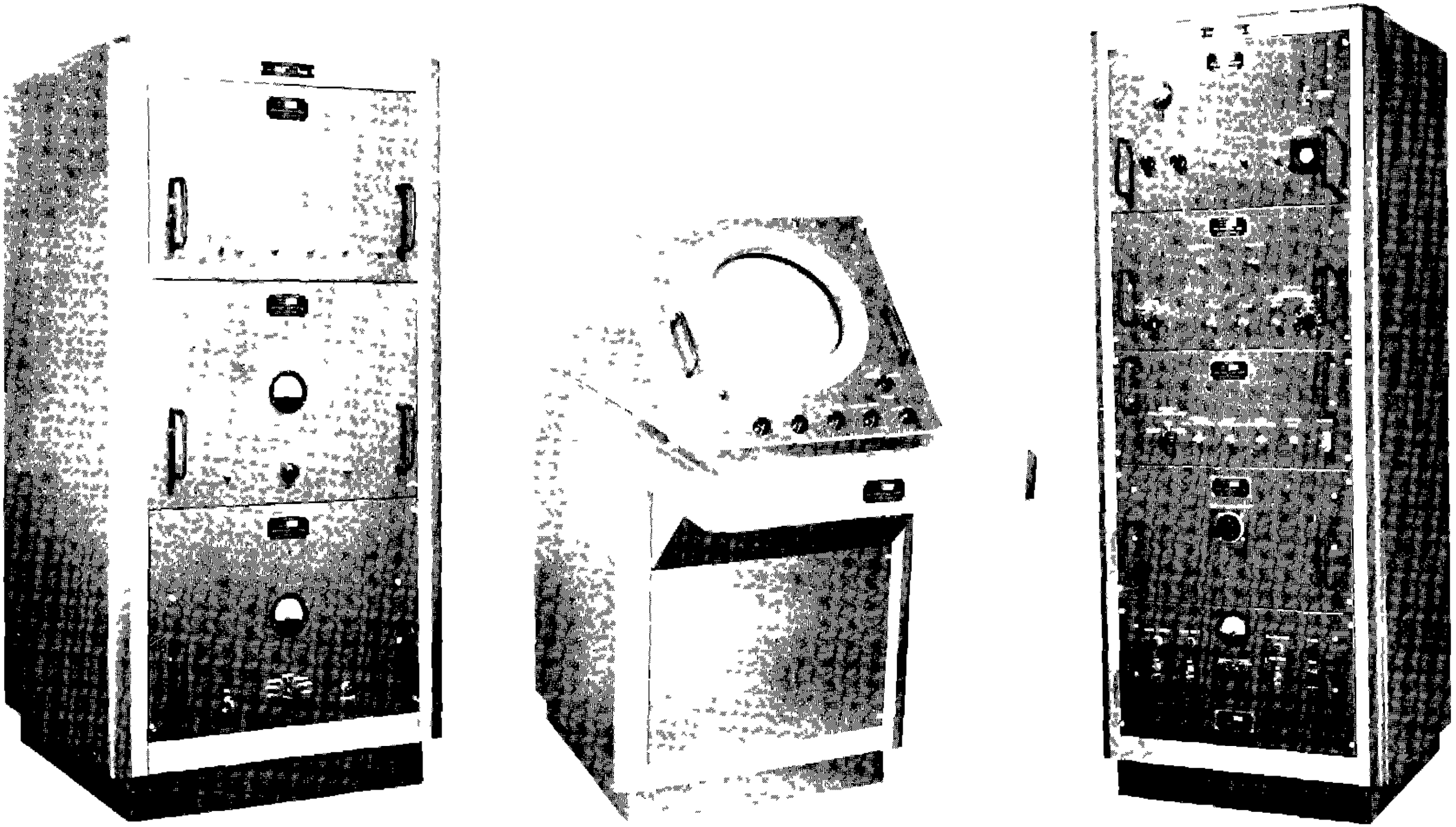


Fig 1 High Altitude Beacon Display System



DECODER INDICATOR ENCODER

FIG. 2 Basic Units of the HRB RAFAX System

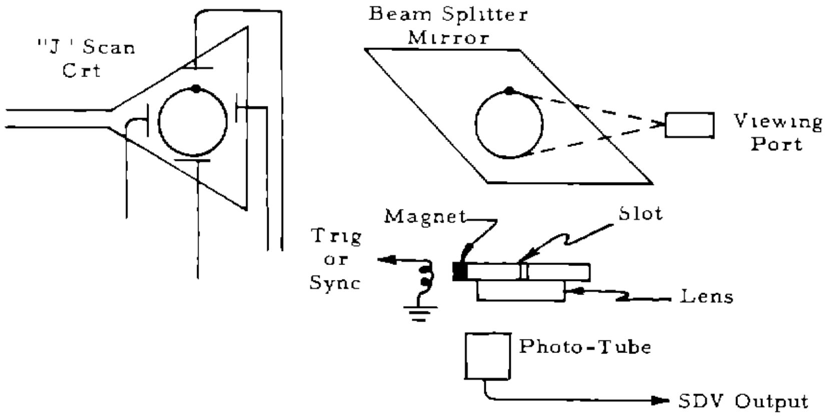


Fig 3 Bandwidth Compressor

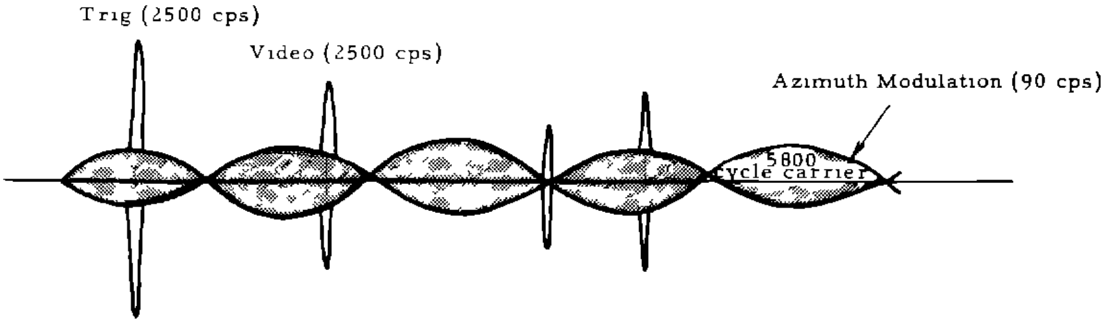


Fig 4 Typical RAFAX Output Signal

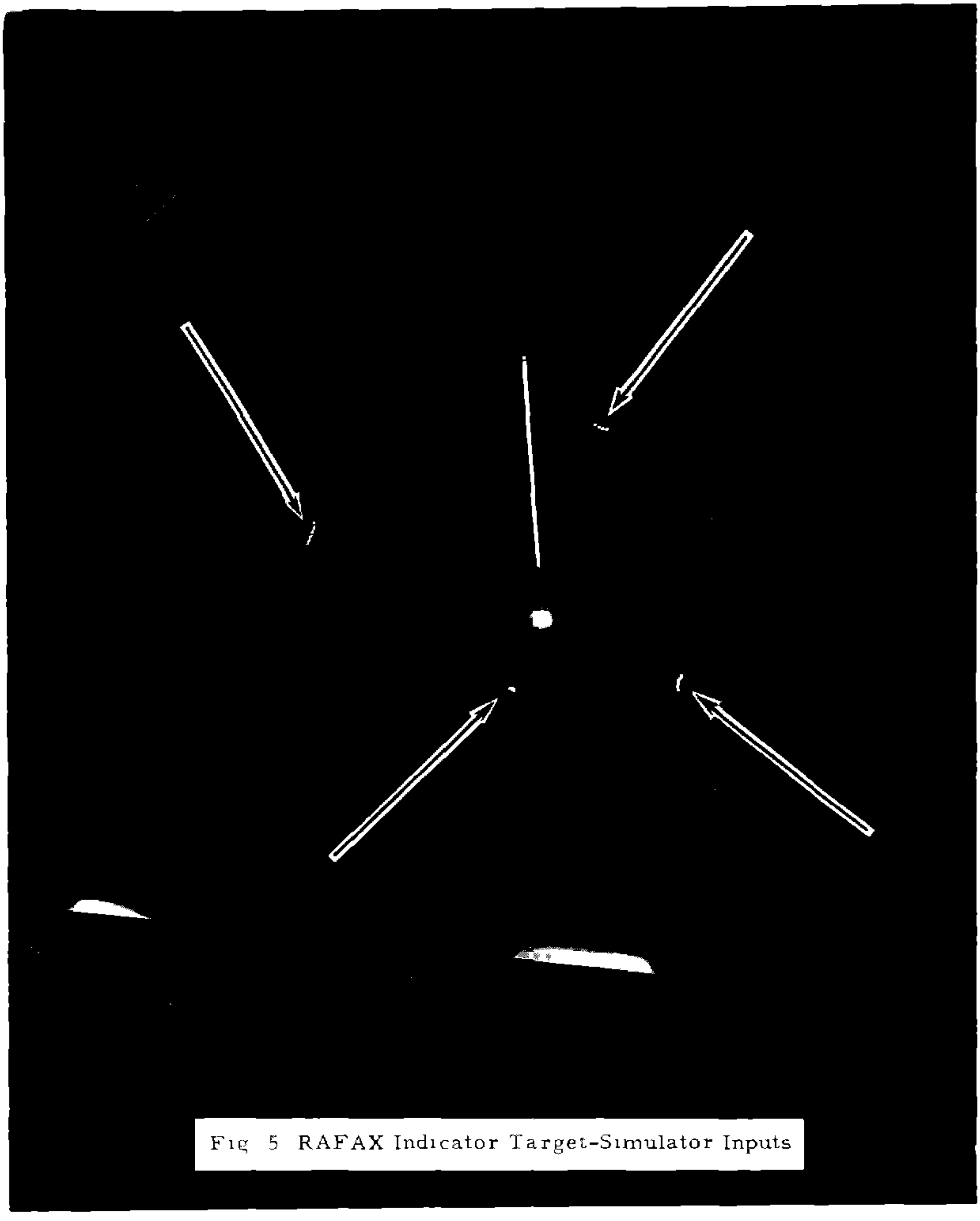


Fig 5 RAFAX Indicator Target-Simulator Inputs

CAA TECHNICAL
DEVELOPMENT CENTER
INDIANAPOLIS INDIANA

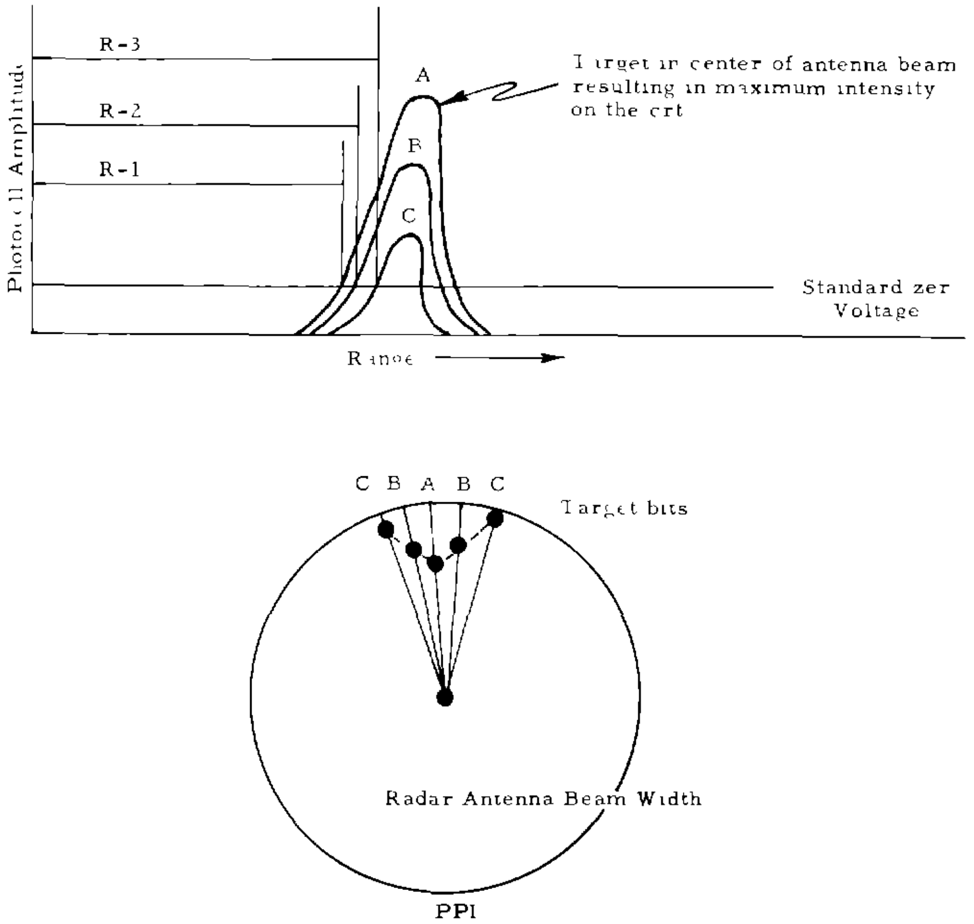


Fig 6 RAFAX Target Inversion

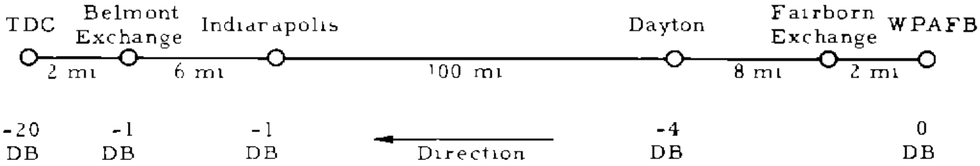
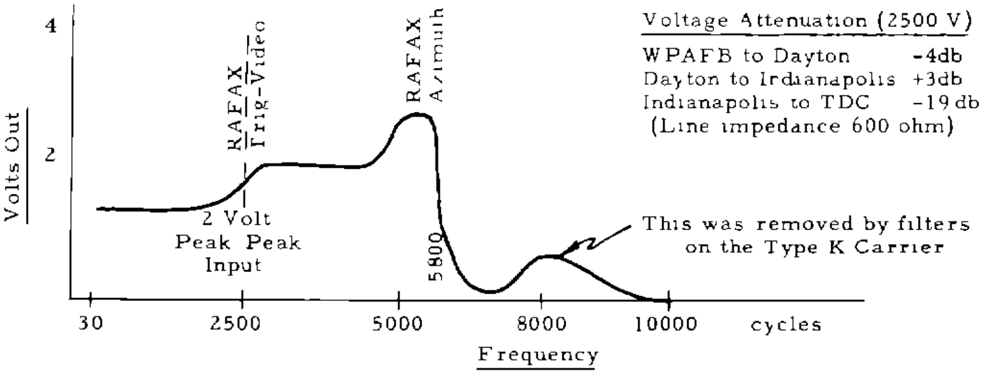


Fig 7 Transmission Circuit Signal Level



Voltage Attenuation (2500 V)	
WPAFB to Dayton	-4db
Dayton to Indianapolis	+3db
Indianapolis to TDC	-19 db
(Line impedance 600 ohm)	

Fig 8 Transmission Curve

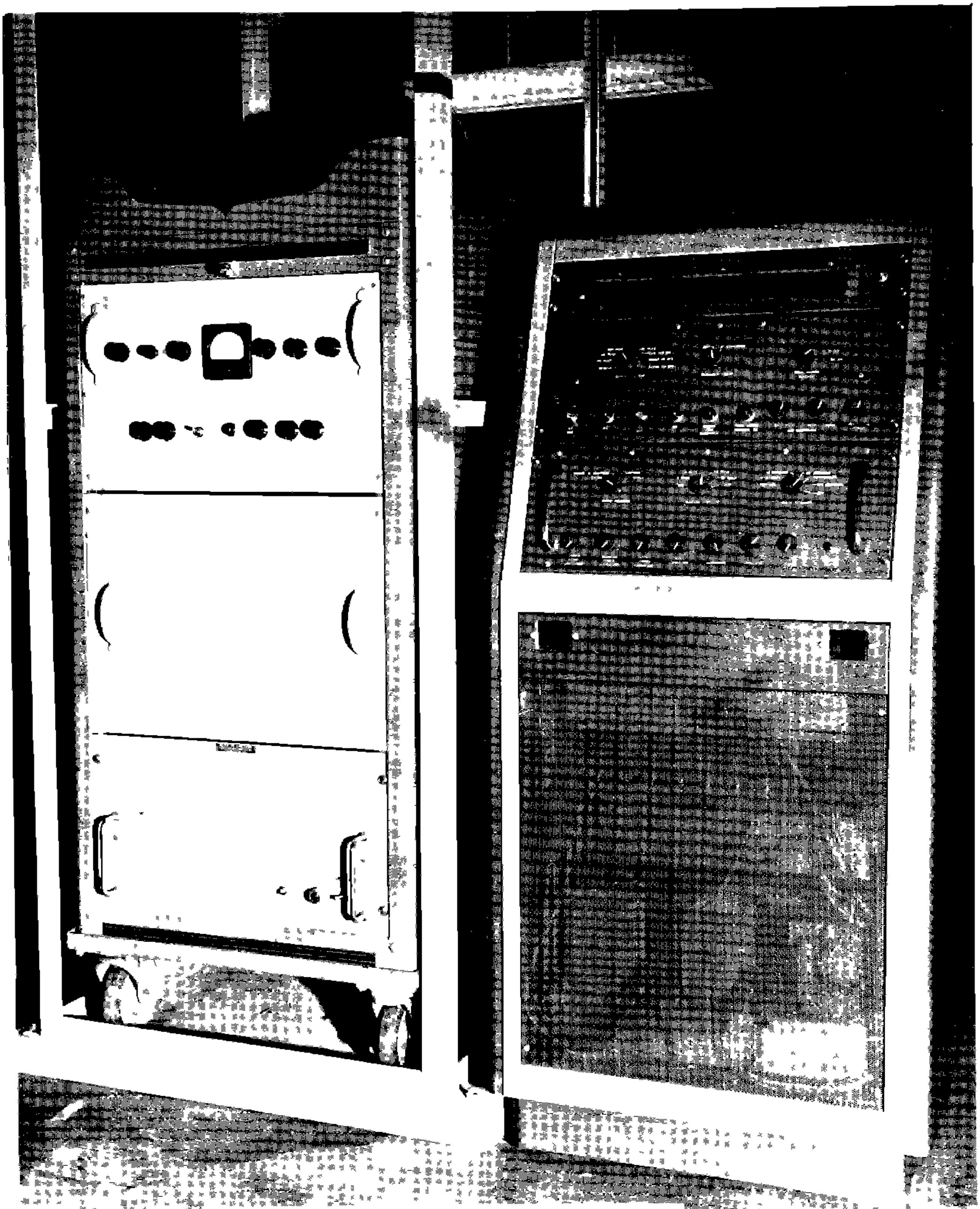


Fig 9 IATRON in GPL Control Consoles

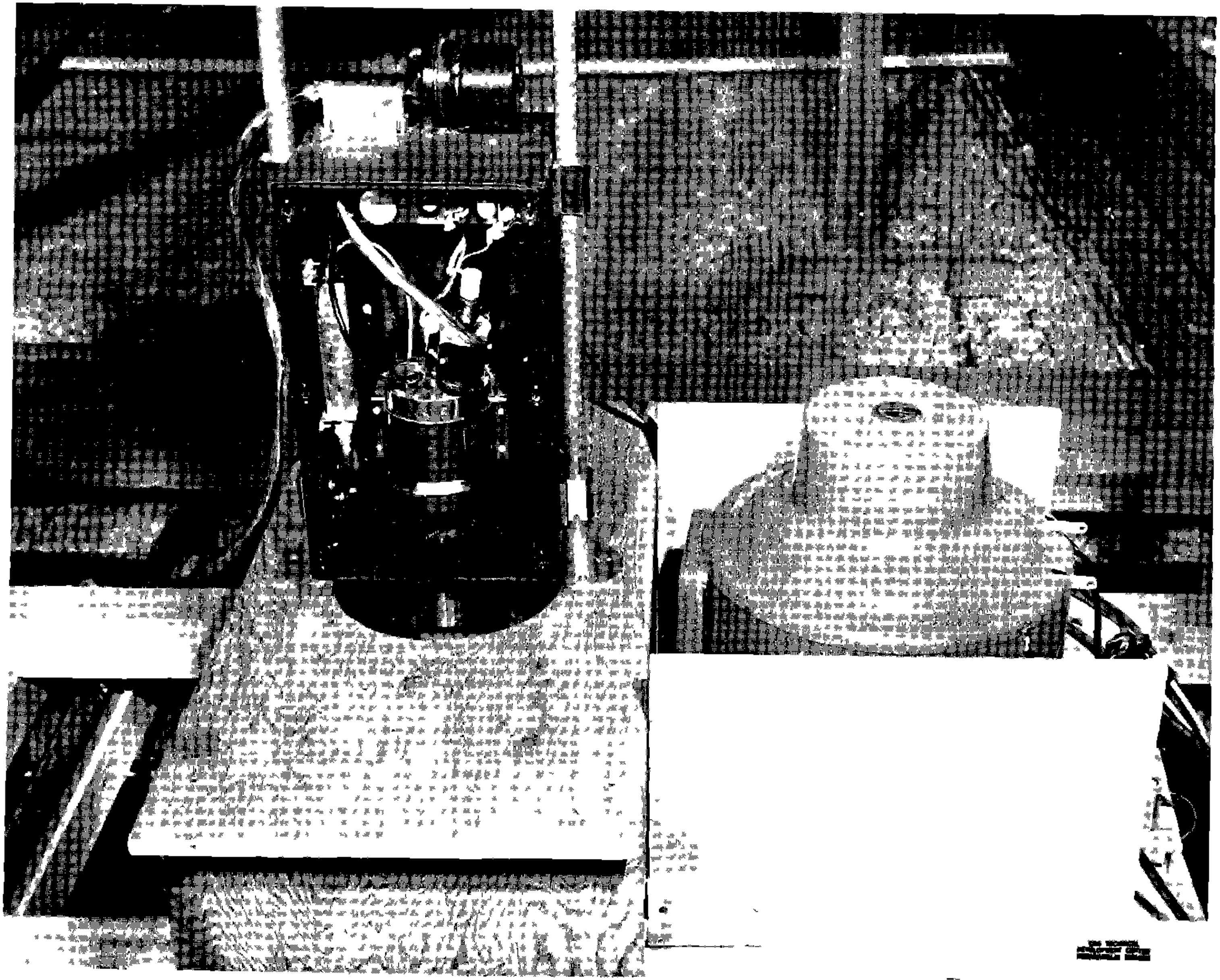


Fig 10 IATRON and GPL Projectors Mounted in Attic Over PANOP Board

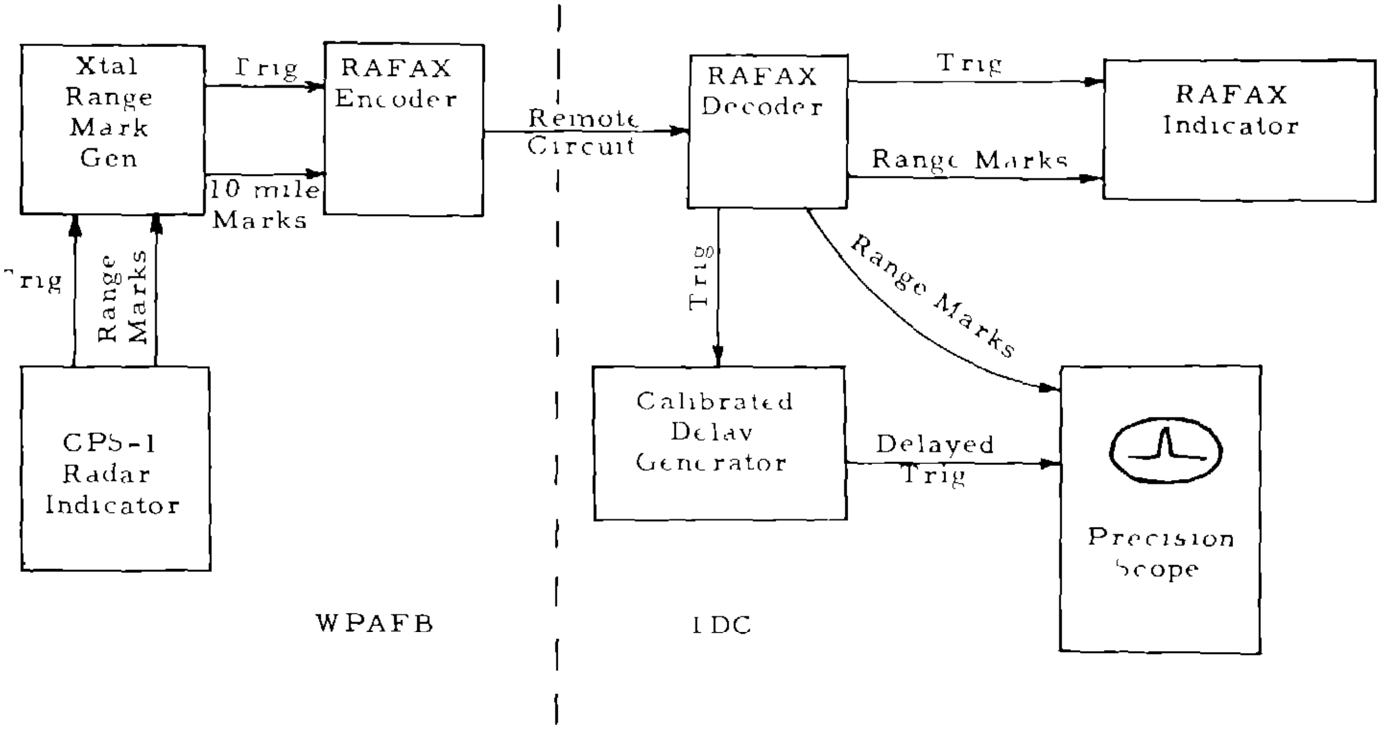
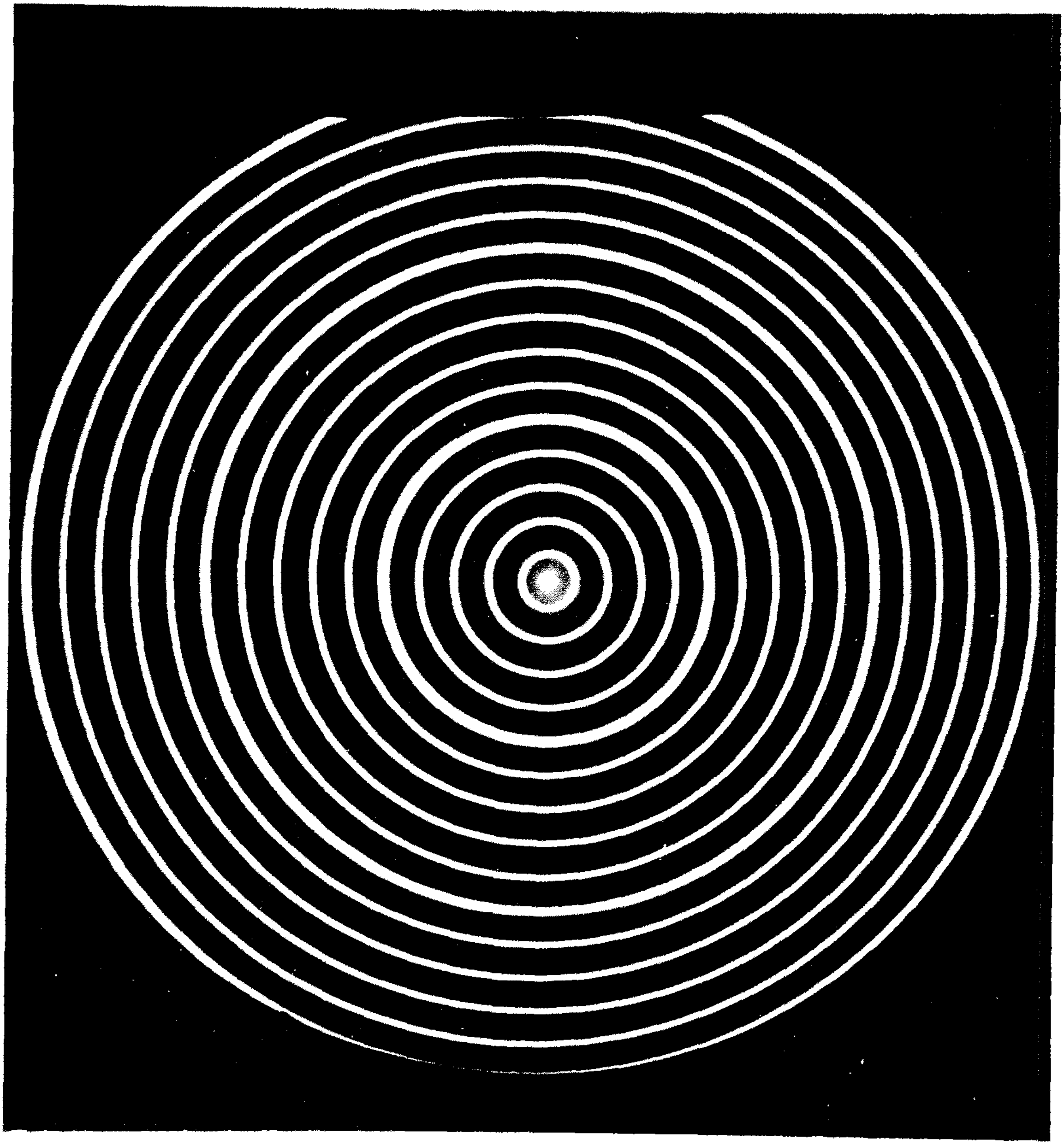


Fig 11 RAFAX Range Linearity Test Arrangement



[illegible]

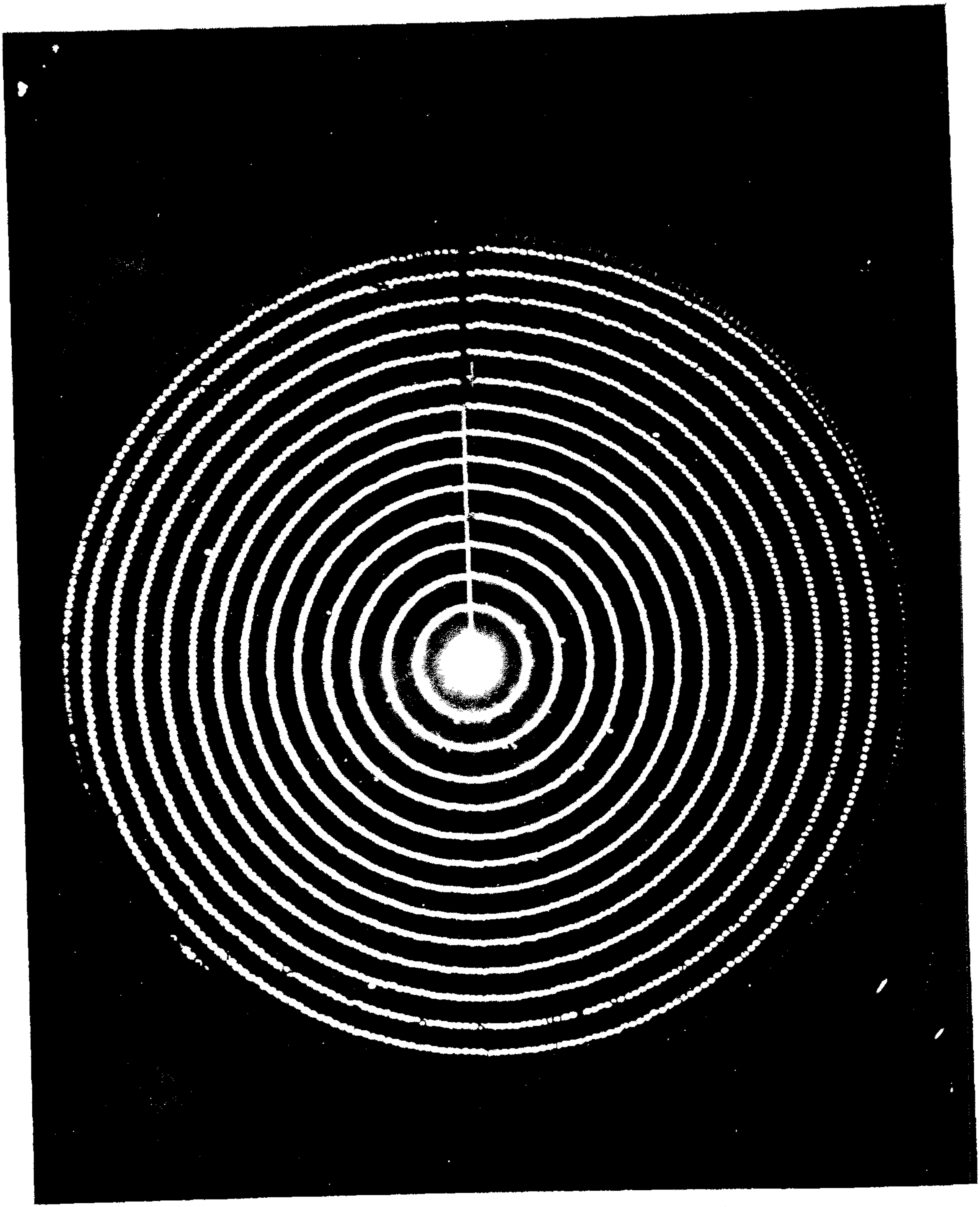


Fig. 1. RAFAX Ring [illegible] RAFAX Indicator

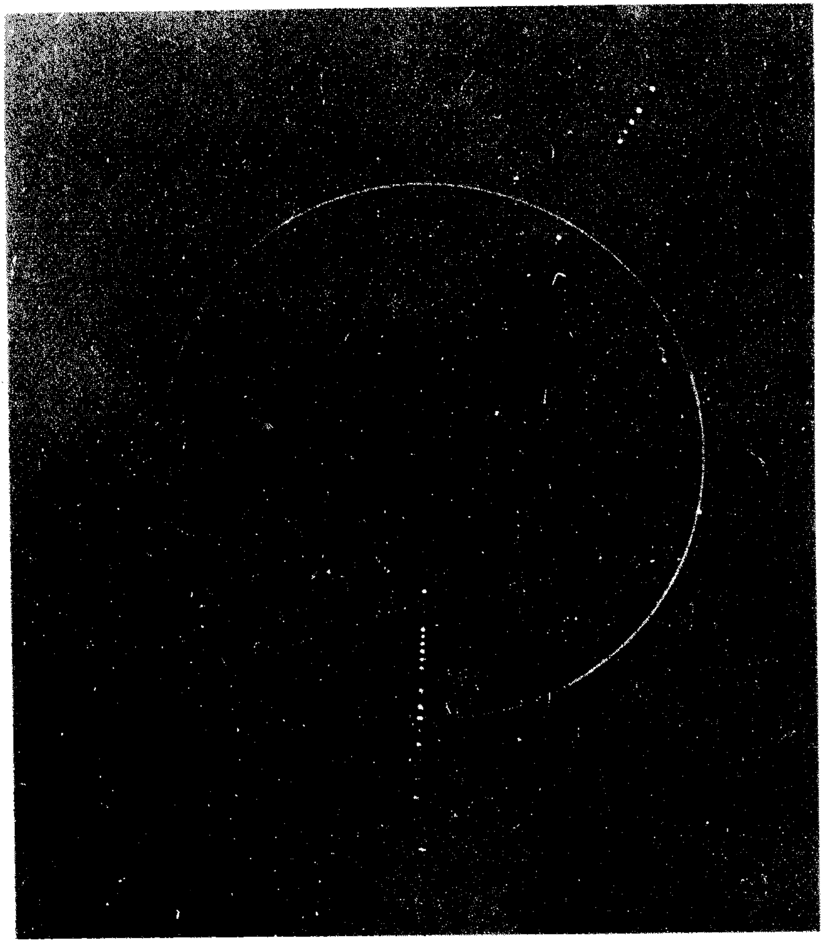


Fig. 14 CPS-1 Radar Indicator Minimum Discernible Target

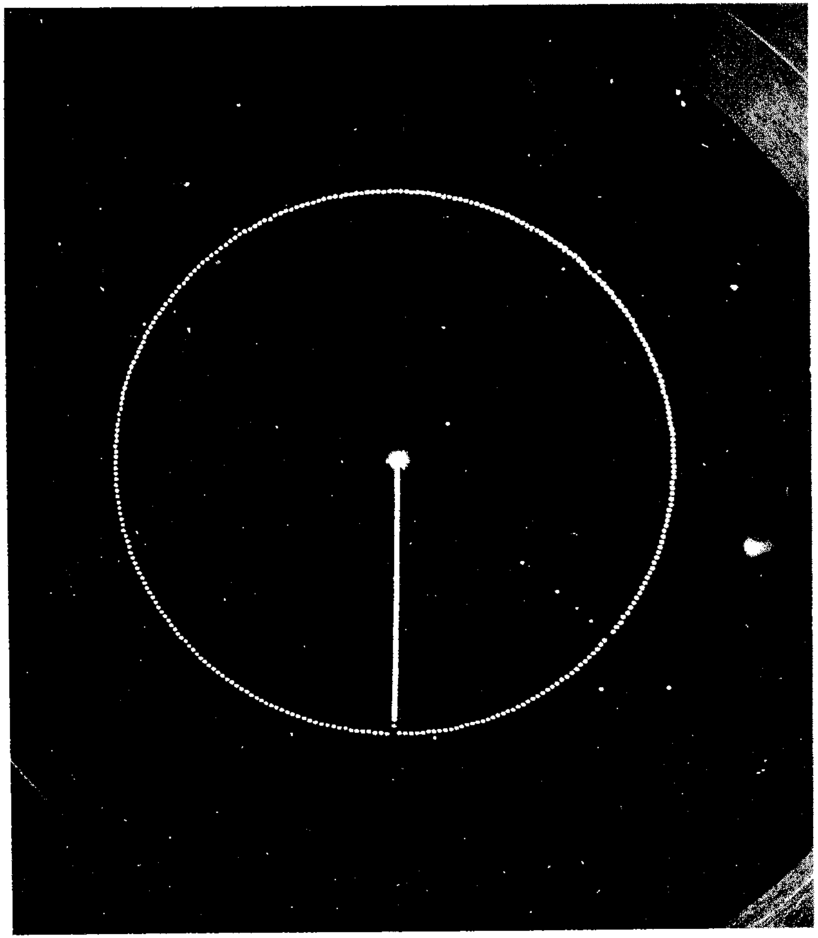


Fig. 15 RAFAX Indicator Minimum Discernible Target

CAA TECHNICAL
DEVELOPMENT CENTER
INDIANAPOLIS INDIANA

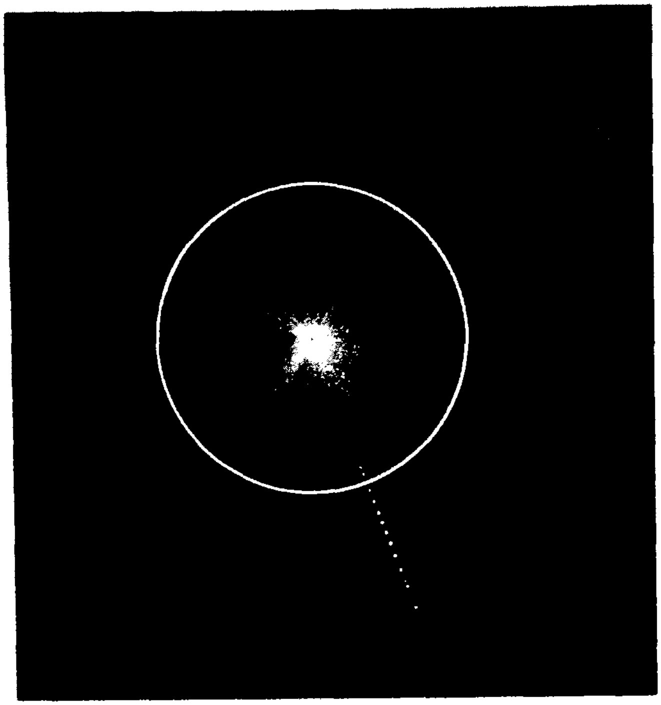


Fig. 16 Radar Indicator Input Signal, 0.4 Volt Video, 0.5 Volt Noise

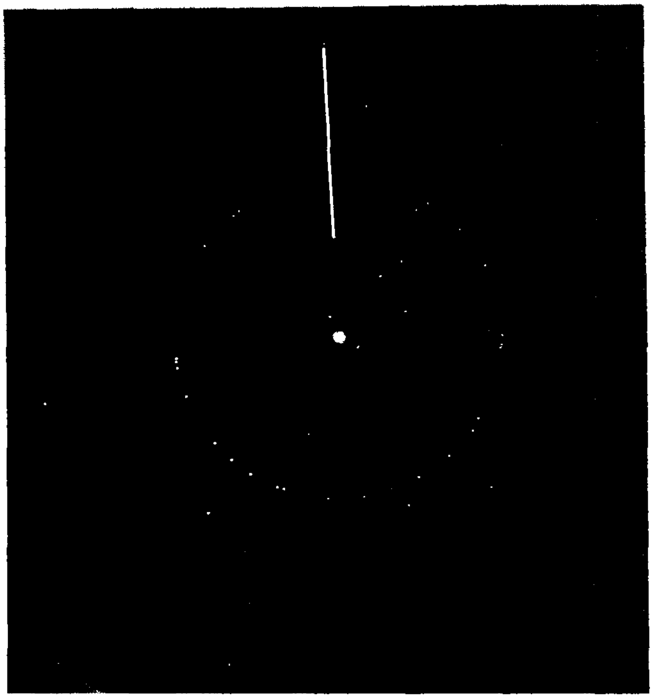


Fig. 17 RAFAX Indicator Input Signal, 0.4 Volt Video, 0.5 Volt Noise

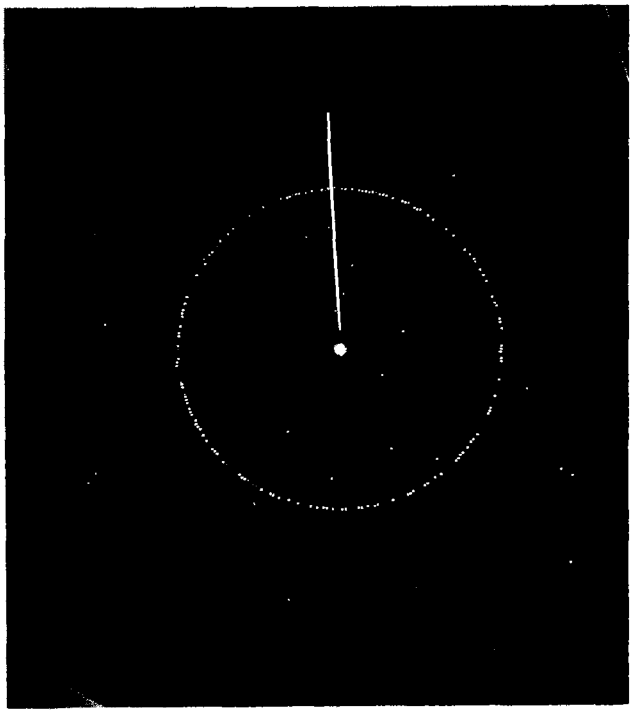


Fig. 18 RAFAX Indicator Input Signal, 0.5 Volt Video, 0.5 Volt Noise

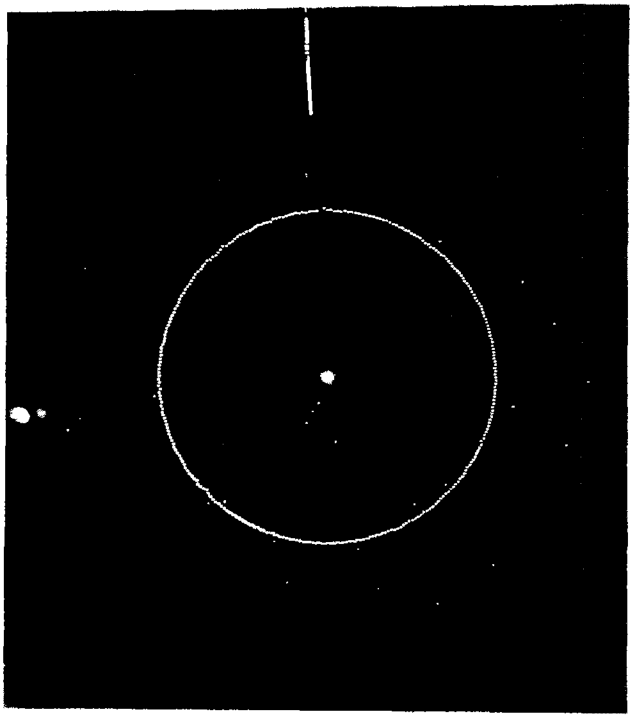


Fig. 19 RAFAX Indicator Input Signal, 1.0 Volt Video, 0.5 Volt Noise

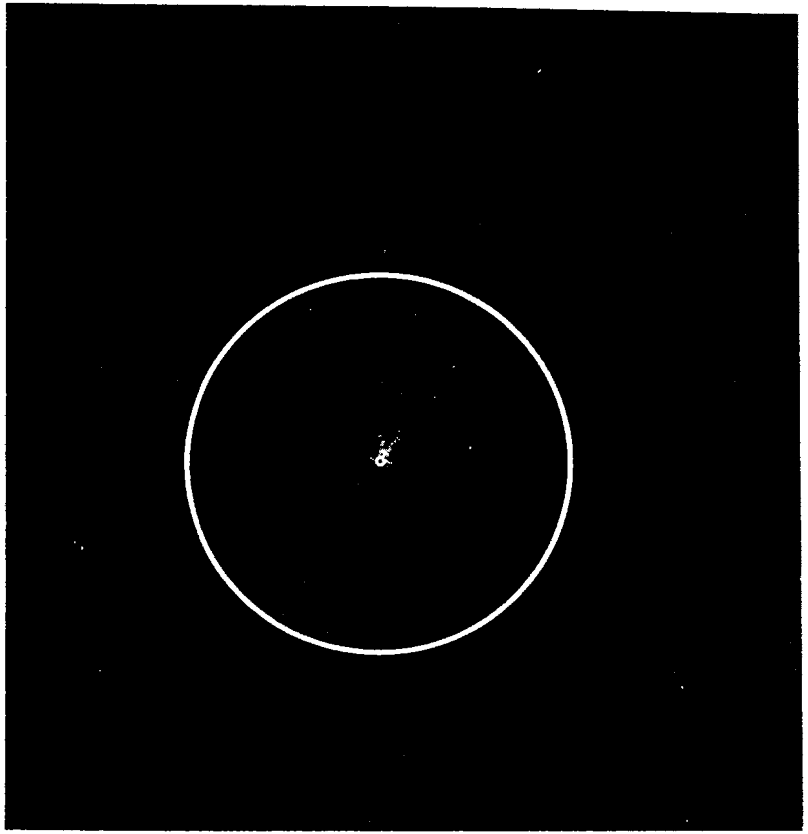


Fig. 20 Radar Indicator Input Signal, 2.0 Volt Video, 1.0 Volt Noise

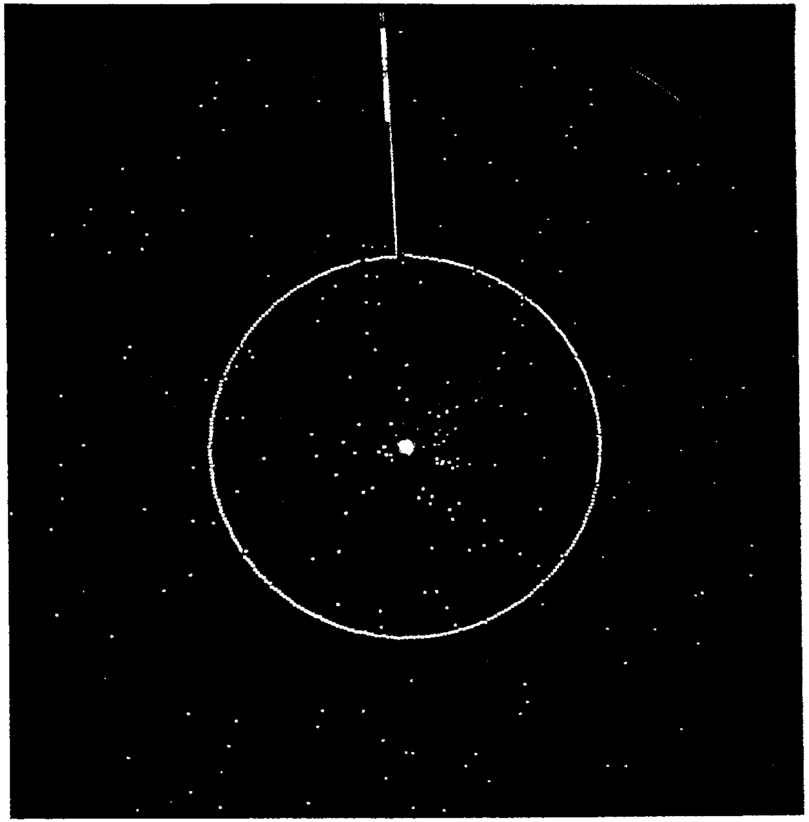


Fig. 21 RAFAX Indicator Input Signal, 2.0 Volt Video, 1.0 Volt Noise

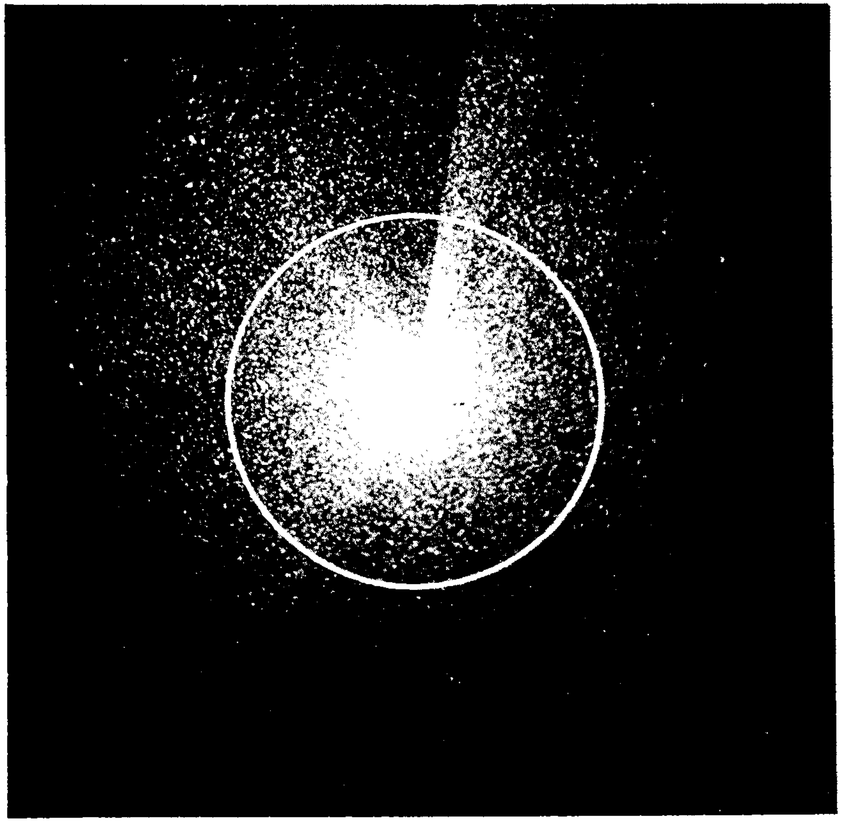


Fig. 22 Radar Indicator Input Signal, 2.0 Volt Video, 1.5 Volt Noise

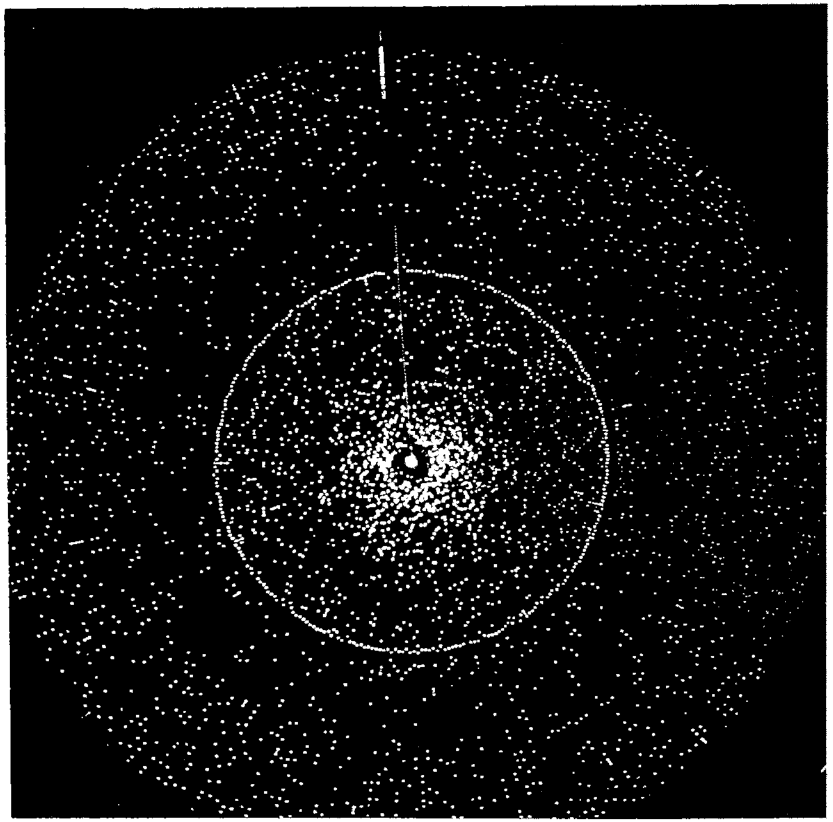


Fig. 23 RAFAX Indicator Input Signal, 2.0 Volt Video, 1.5 Volt Noise

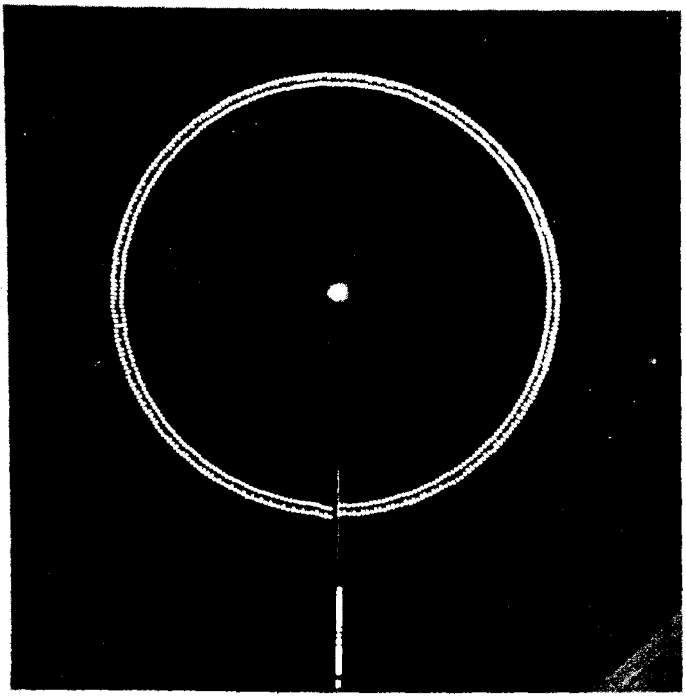


FIG 24 RAFAX RANGE RESOLUTION, 40 MICROSECOND SPACING

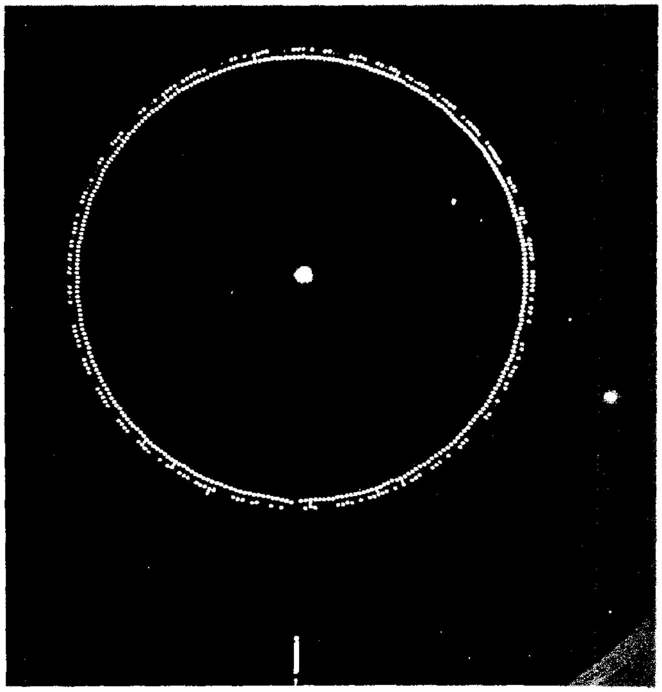


FIG 25 RAFAX RANGE RESOLUTION, 32 MICROSECOND SPACING

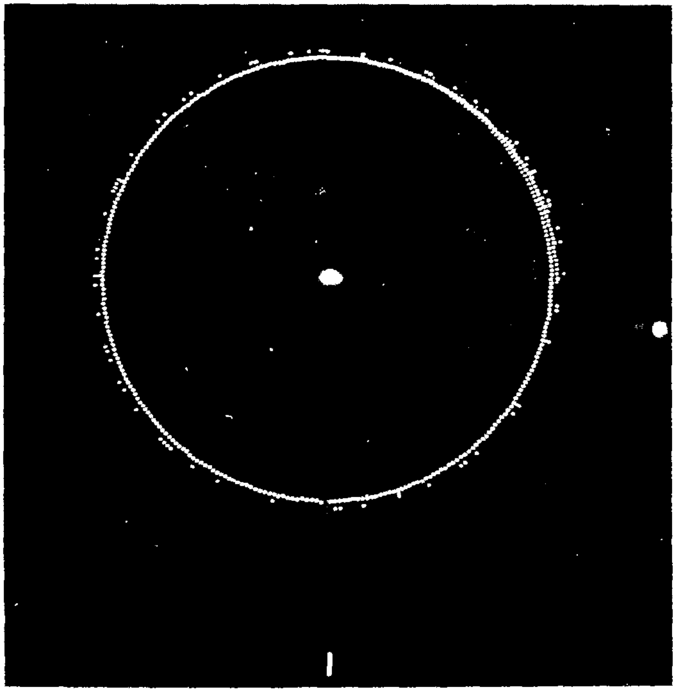


FIG 26 RAFAX RANGE RESOLUTION, 30 MICROSECOND SPACING

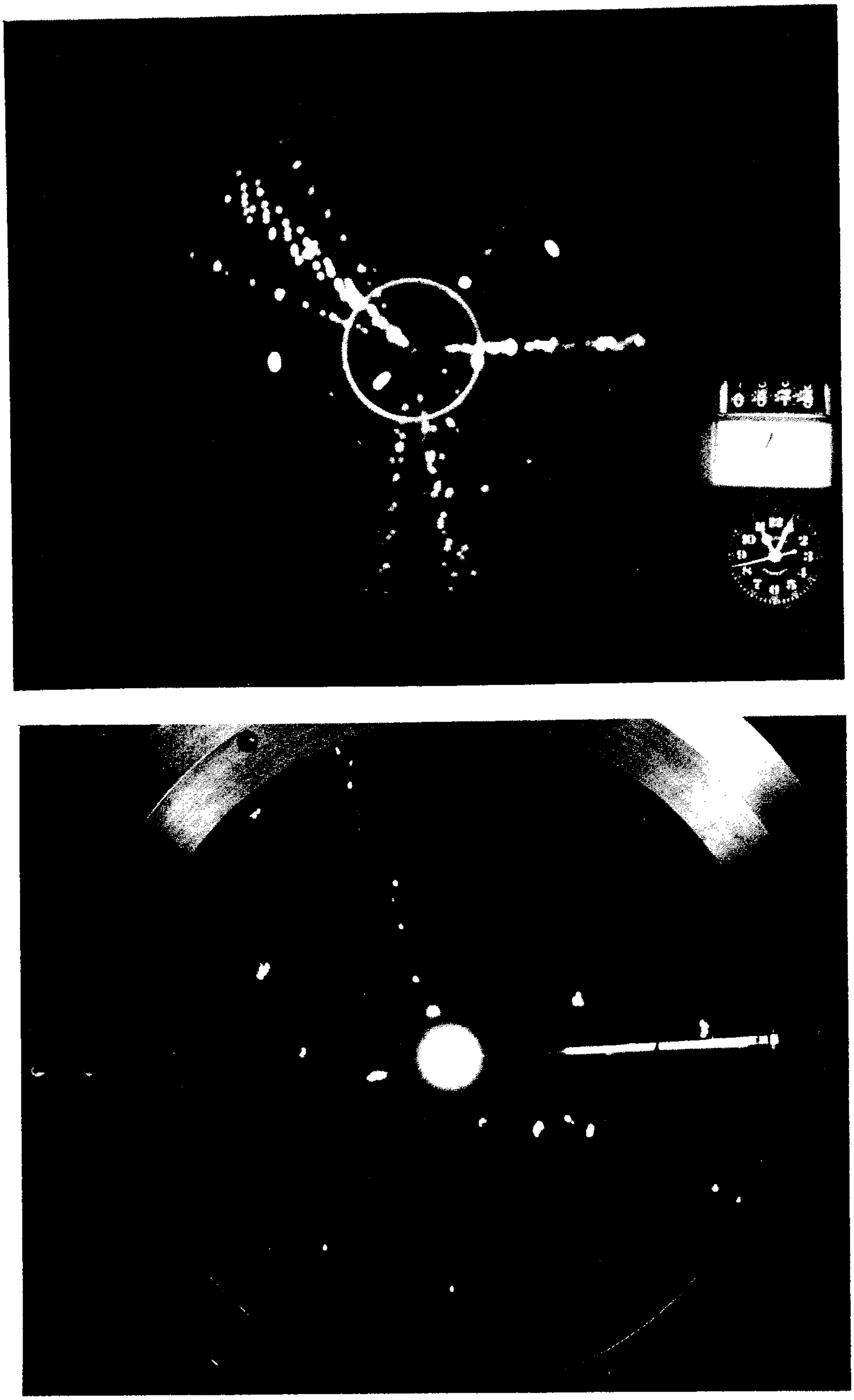


Fig. 27 Fruit Elimination - One Antenna Scan

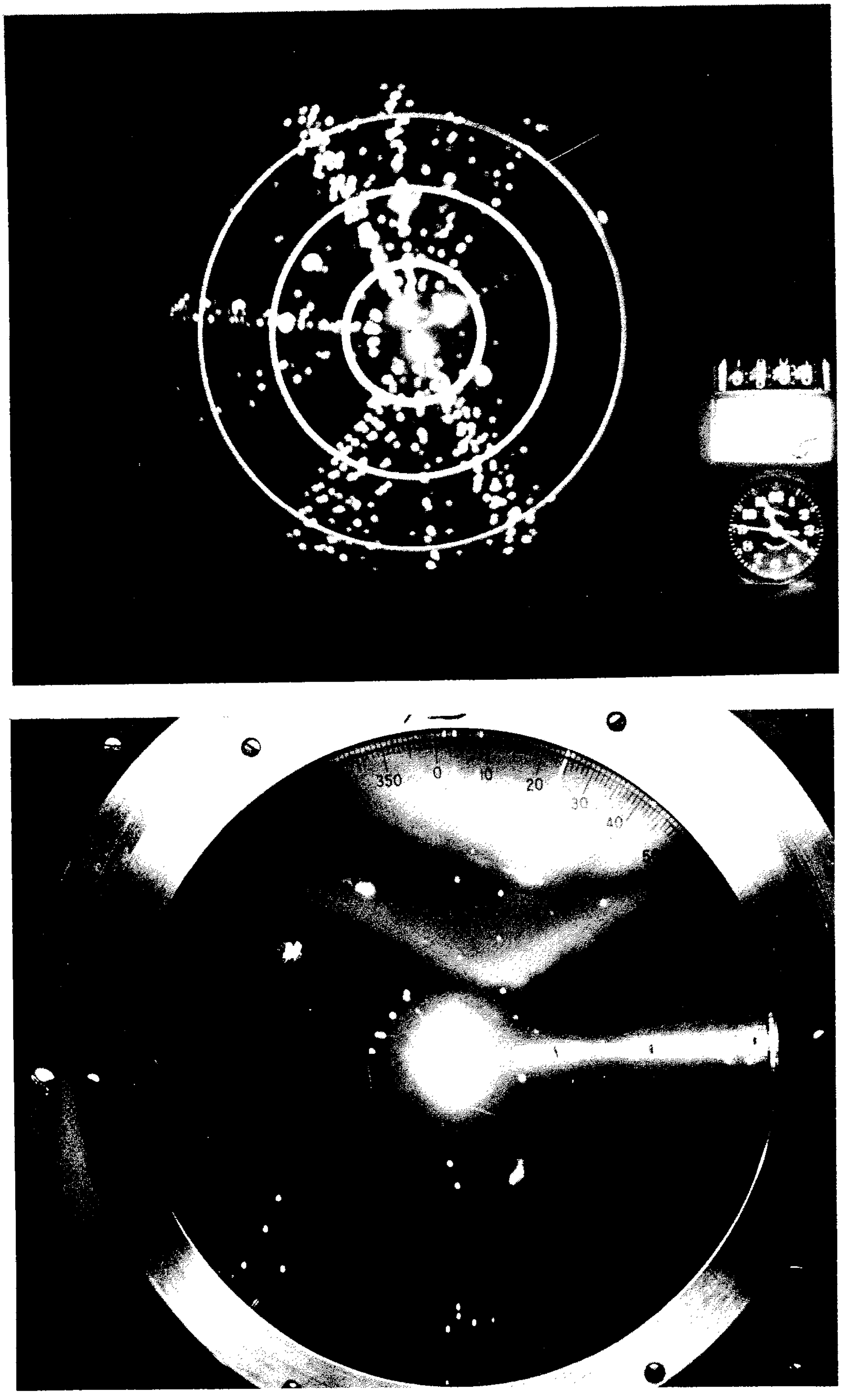


Fig. 28 Fruit Elimination - Five Antenna Scans

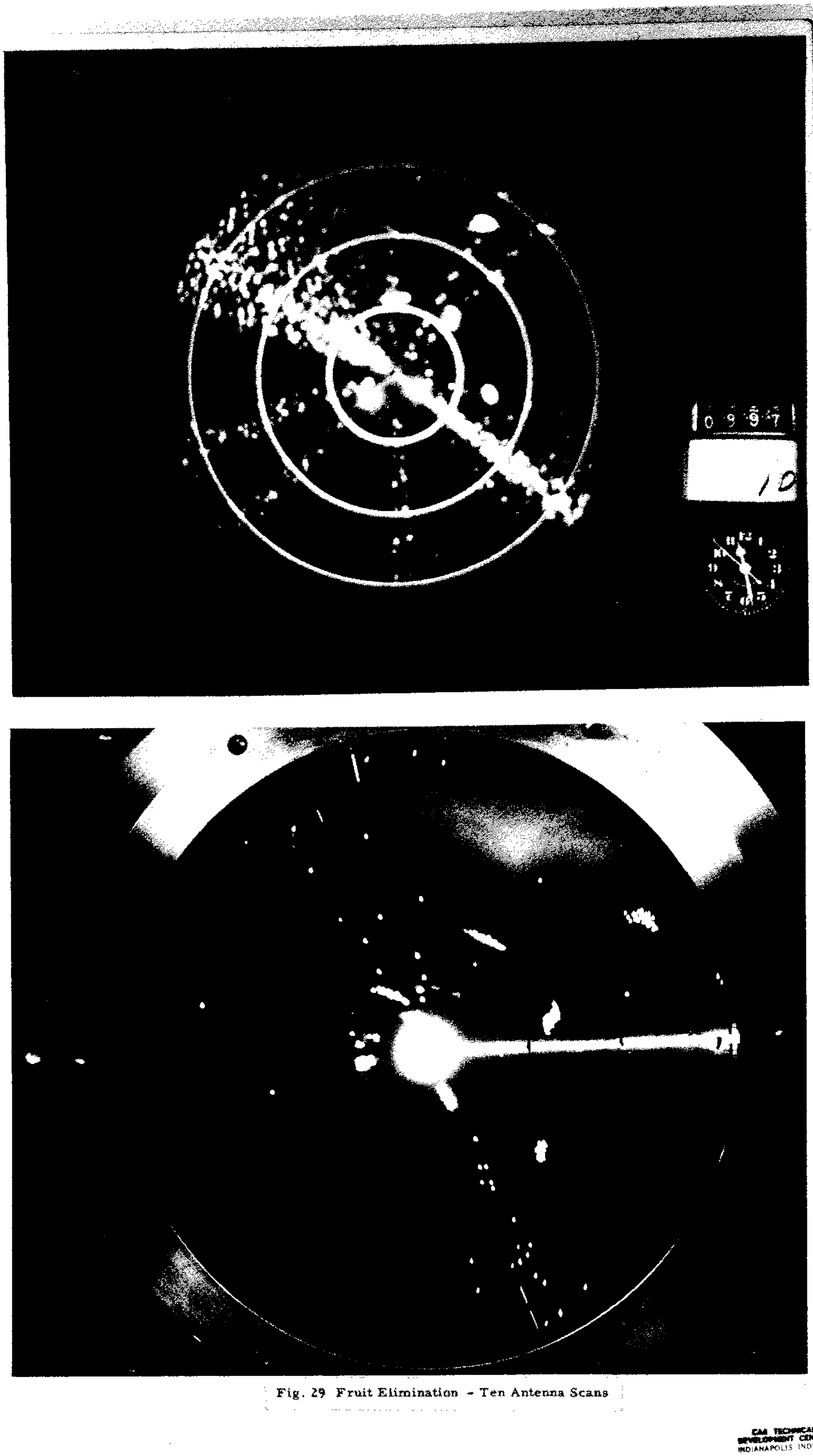


Fig. 29 Fruit Elimination - Ten Antenna Scans

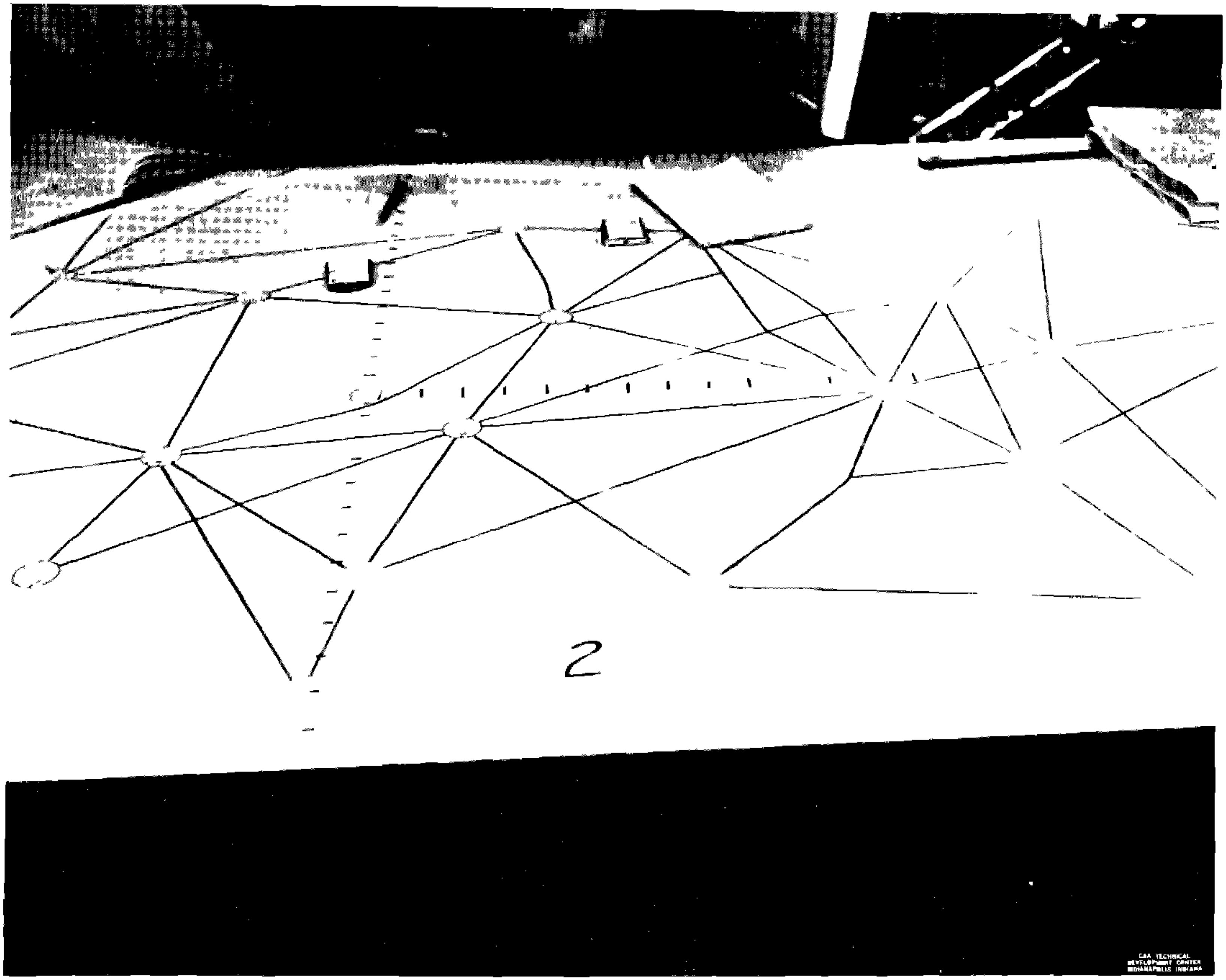


FIG 30 PANORAMIC ATC DISPLAY

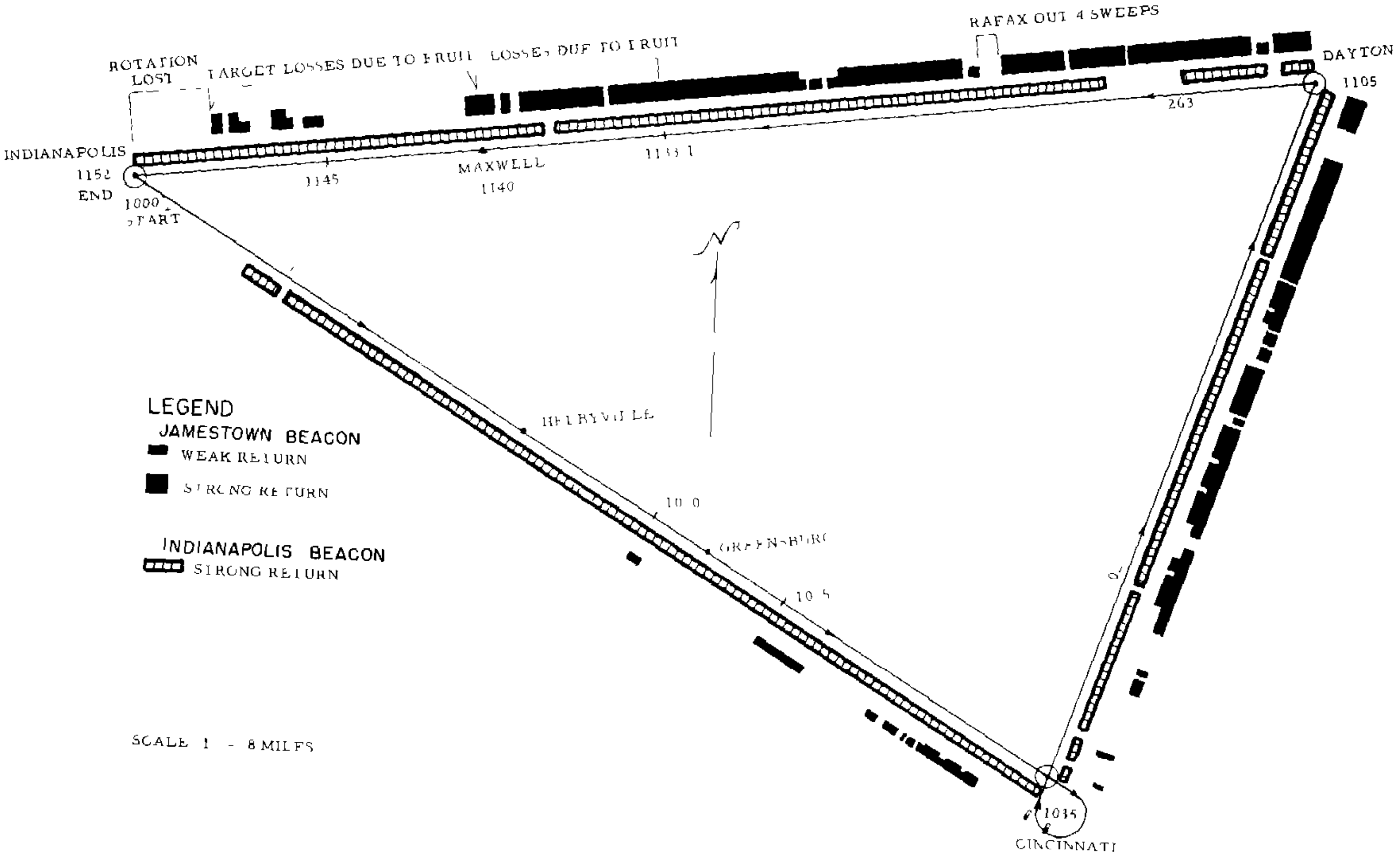


FIG 31 BEACON COVERAGE, FLIGHT TEST NO I

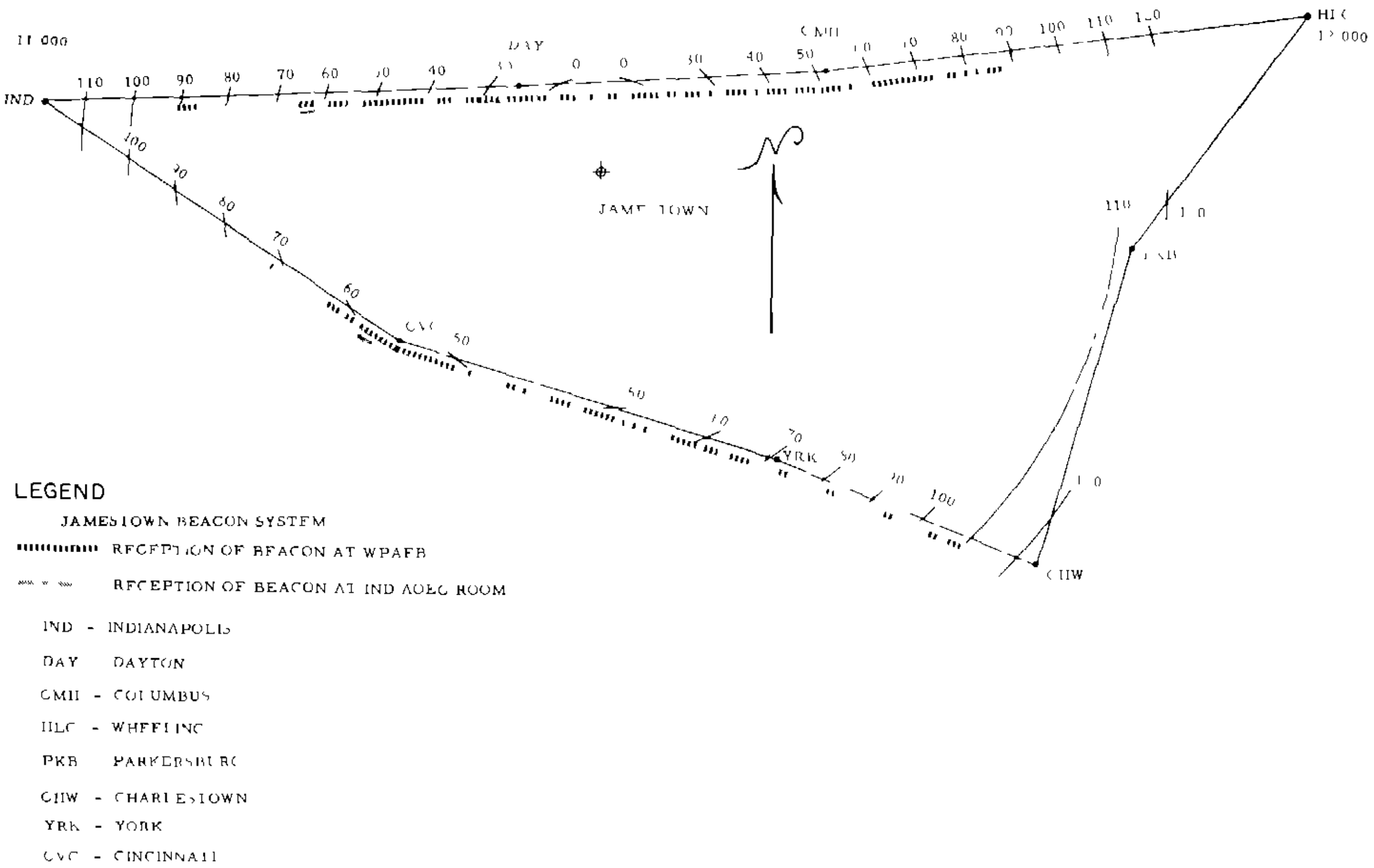
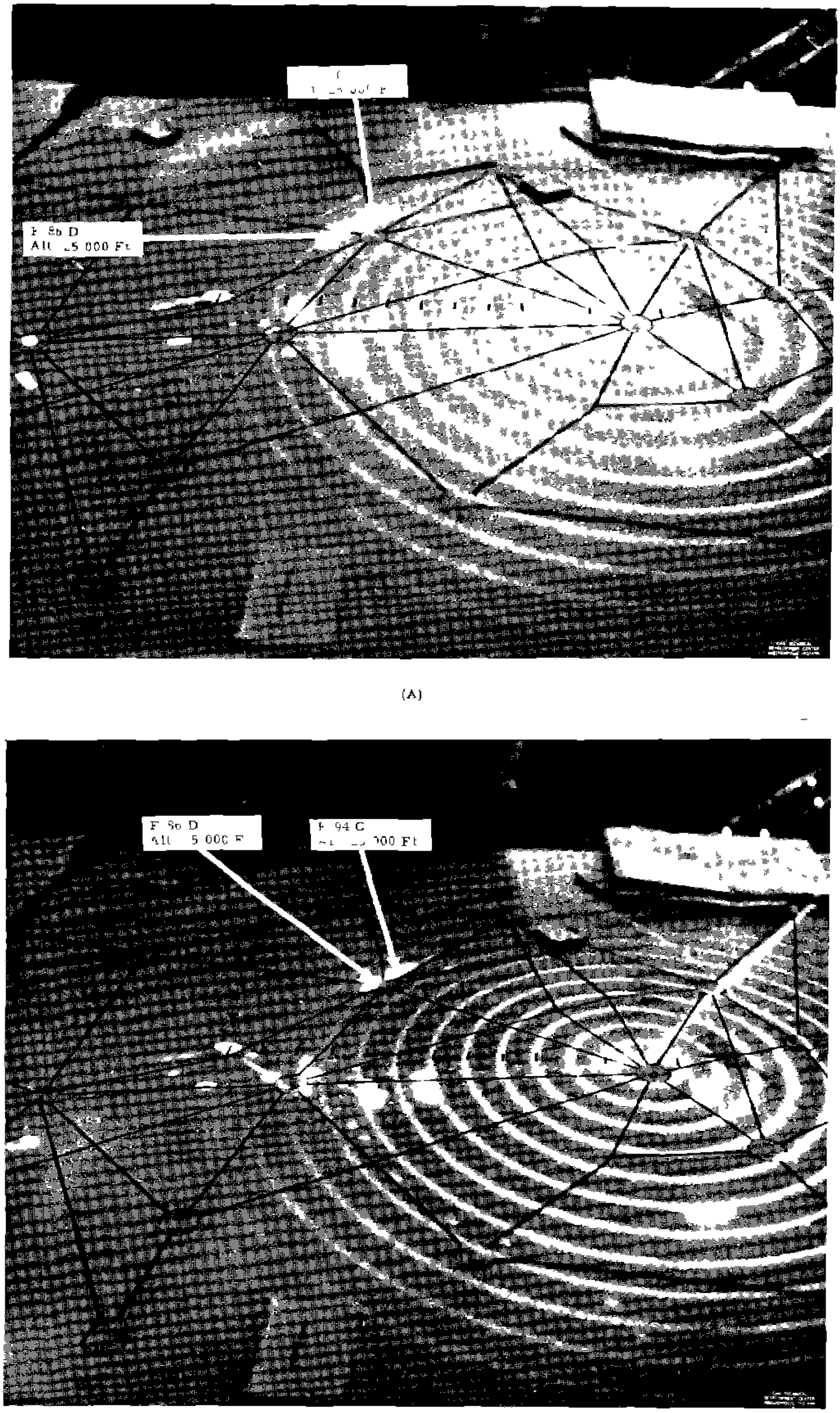


FIG 32 BEACON COVERAGE, FLIGHT TEST NO 2

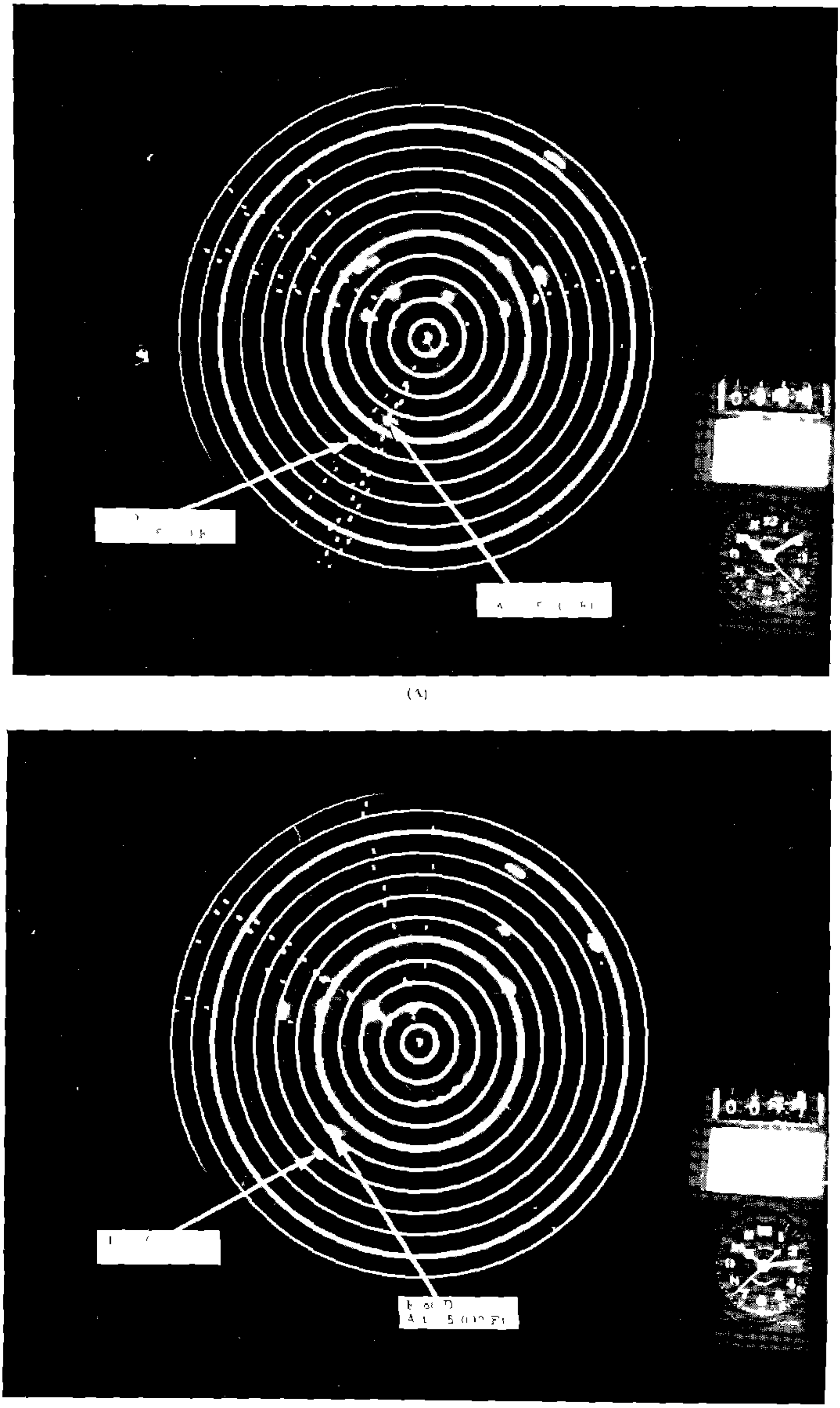


(A)

(B)

Fig 33 (A and B) RESOLUTION FLIGHT TESTS INDIANAPOLIS BEACON SYSTEM

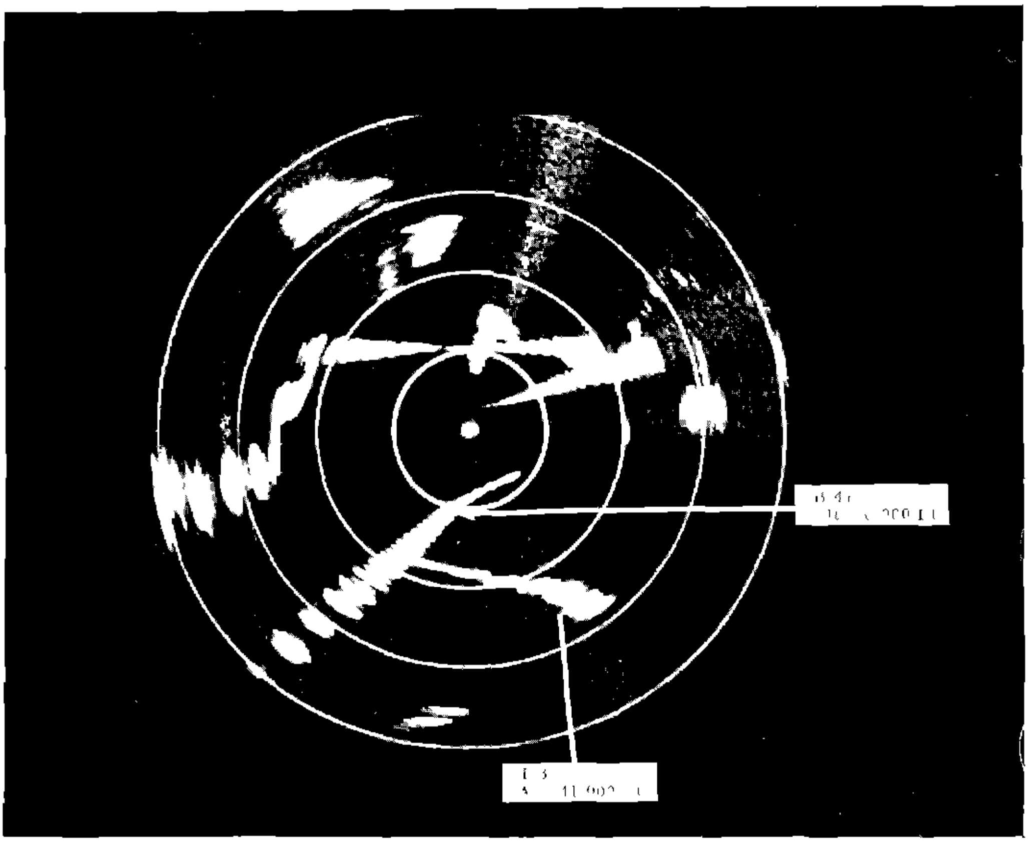
CAA TECHNICAL
DEVELOPMENT CENTER
INDIANAPOLIS INDIANA



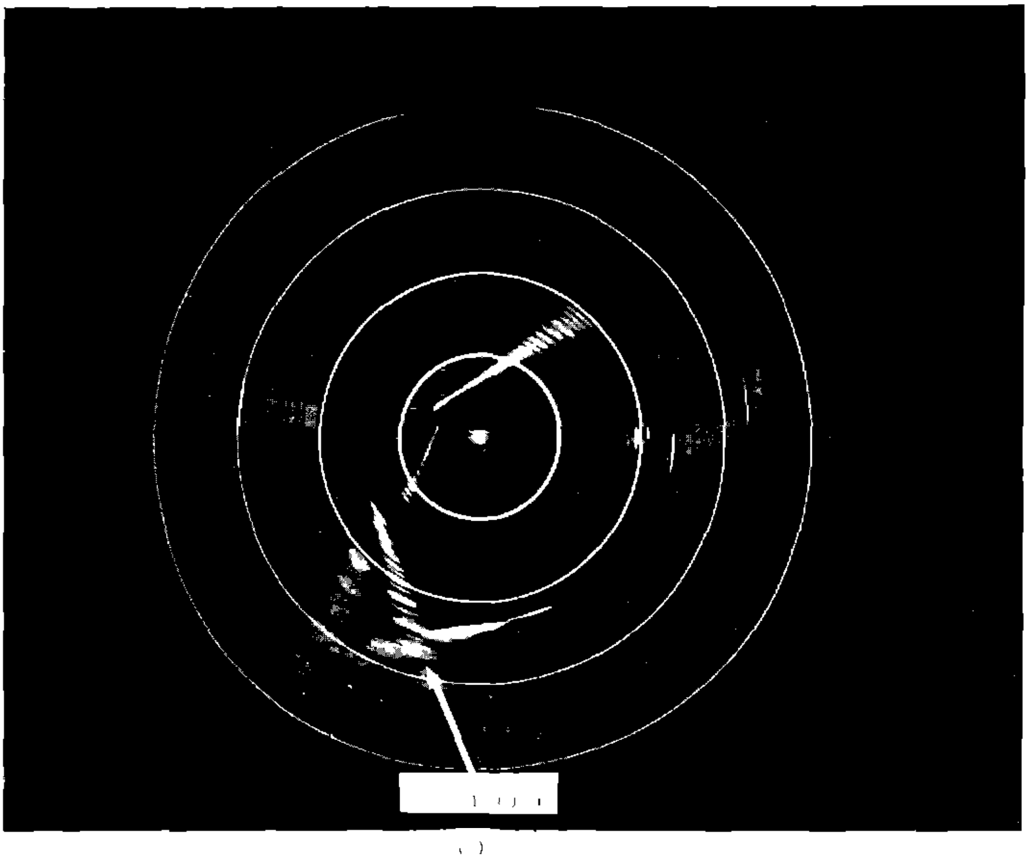
(A)

(B)

Fig 34 (A and B) RESOLUTION FLIGHT TESTS JAMESTOWN BEACON SYSTEM



(A)



(B)

FIG. [illegible] [illegible] INDIANAPOLIS BEACON SYSTEM 200-MILE RANGE

CAA TECHNICAL
DEVELOPMENT CENTER
INDIANAPOLIS INDIANA