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A WIDE-APERTURE HF DIRECTION-FINDER WITH SLEEVE ANTENNAS

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RADIO DIVISION

20 August 1958

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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by
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Radio Division
U. S. Naval Research Laboratory
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ABSTRACT

This report gives the progress made in the development and instrumentation of a circularly disposed antenna array. A previously tested array of vertical rhombic antennas had shown some polarization errors and was replaced at the same site by a ring of omnidirectional sleeve monopole antennas. It was felt that this array could be materially improved for df use. Therefore, a complete antenna reflecting screen was erected behind each element. Antenna patterns are shown after the reflector installation for both a single antenna and antenna beam patterns.

Antenna multicouplers are nearly completed and will be installed shortly. This will enable the simultaneous installation of several instruments, such as the remote indicator and bearing readout system now under development together with additional capacitive goniometers and fixed antenna beams.

A measure of bearing wander has been made and, although good results were obtained, it is felt that better bearing readout instrumentation will result in considerable improvement.

PROBLEM STATUS

This is an interim report; work is continuing on this problem.

AUTHORIZATION

NRL Problem 54R06-28
BUSHIPS Problem S-1891
NSA Problem 330-5800-01
R and D Project NE 071 200-818F.3

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A WIDE-APERTURE HF DIRECTION-FINDER WITH SLEEVE ANTENNAS

INTRODUCTION

A previous report[1] discussed the development and test of a 400-foot-diameter circularly disposed antenna array that used vertical half-rhombic antennas as the individual elements. The nominal designed frequency range was 4 to 20 Mc. The measured standard deviation for this array was 2.6 degrees for a frequency range of 7 to 20 Mc.

The vertical half-rhombic antennas did provide an economical method of constructing a steerable-beam antenna array in the high-frequency band and could prove useful over a 3 to 1 frequency range for search, monitoring, and relatively accurate direction finding. However, this array exhibited polarization errors of such a magnitude that the effect of wide-aperture space averaging in the reduction of wave interference errors was masked.

As a result of its susceptibility to polarization error, the vertical half-rhombic element has been replaced at the same site by a vertical sleeve monopole.[1] The installation of this new array of elements has been made in two steps. Initially, the circle of 40 elements was installed without a reflecting screen. Secondly, a complete reflecting screen was installed behind each element.

The report that follows describes the df results achieved to date using the new array with reflectors, and progress made in instrumenting the facility for different applications.

DESCRIPTION OF ANTENNA AND SITE

The present array is a 434-foot circle of 40 equally spaced sleeve monopoles. Figures 1 through 4 show air and ground views of the installation and surroundings at the Coast Guard Station, Alexandria, Virginia. The basic site has a ground mesh, with 3-foot-square openings covering the entire area between 200-foot and 600-foot diameters, and 580 equally spaced radials that extend beyond to a 1000-foot diameter. A circular array of 40 equally spaced 70-foot poles was erected for use as antenna or reflector supports on a 400-foot diameter circle.

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The installation of the sleeve antenna (Fig. 3) was made at a distance of approximately 17 feet outside the circle of poles, so that the poles could then be used to support a reflecting screen for each antenna element.

Circular Array of Omnidirectional Elements

The installation of the 40 antenna elements in a single ring, 434 feet in diameter, was made to evaluate the performance of the Wullenweber array without a directive element. The Department of Electrical Engineering of the University of Illinois had computed antenna beam patterns (1) for this array with omnidirectional sleeve antennas. These patterns indicated that difficulty would be encountered for direction-finding applications in the frequency range from 3 to 10 Mc as a result of a low ratio of main lobe to side and back lobes and that the beam patterns would also deteriorate rapidly for all frequencies (3 to 25 Mc) at vertical angles above 40 degrees. This will limit its usefulness for df to signals arriving at vertical angles below 40 degrees.

This omnidirectional array was completed in October 1957, a few days before the first Russian satellite was launched. This satellite provided a very useful target for evaluation at 20.005 Mc. The rapid deterioration of the antenna beam for higher angles was confirmed by close passes of the satellite. Difficulty was experienced in determining its position accurately when it was less than 125 miles away. This would be for a period of time less than 1 minute. For distances beyond this, the df data checked closely with that of a GRD-6 direction finder, located at a site within a few thousand feet, which was used simultaneously to supply tracking data. An evaluation of these tracking data will be made when information on the exact position of the satellite versus time becomes available.

Pattern distortion was also very evident during fading periods, especially in thelower frequency range from 3 to 10 Mc. This reduced the ratio of antenna beam gain to back and side lobe levels to a greater extent than had been shown by the computed patterns. Therefore, the array was considered unacceptable for general df use.

Antenna Array with a Reflecting Screen

Because of the deficiencies of the ring of omnidirectional elements, plans were made for the erection of a complete reflecting screen at the earliest possible date. This reflecting screen installation was completed in June of 1958. The completed screen and the sleeve monopole

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elements are shown in Figs. 3 and 4. A sketch of the screen construction is shown in Fig. 5. It consists of 65-foot vertical wires spaced at 3-foot intervals around the circle of poles. These vertical wires are bonded to a continuous grounding pipe at the lower end; this, in turn, is electrically connected to the ground mat at each crossing.

Projecting arms from each pole are used to support a cable between the poles. These arms can also be used to adjust the wires so that they are vertical. The vertical wires are completely insulated from each other at the top and the supporting cable is also broken into 3-foot lengths and separated by insulators.

The single-element antenna pattern is determined by the spacing between the element and the reflecting screen. For a spacing of a half wavelength, the antenna pattern will have a null directly forward. The highest operating frequency should be about 20 percent below the frequency for this half-wave spacing. As a result, a horizontal spacing of 16.5 feet was used between the antennas and reflector. This limits the highest operating frequency to 25 Mc or slightly above.

Measured horizontal antenna patterns for a single sleeve antenna with the reflecting screen installed are shown in Fig. 6 using a ground wave signal. At 25 Mc the patterns begin to show the formation of a forward null, but are still suitable for df use. The pattern shown for 3 Mc exhibits a reversed direction. This is a result of the reflecting screen resonance at a frequency where the electrical length of these 65-foot wires is a quarter wavelength. This exact frequency was measured more closely in photographing cathode-ray-tube displays of the antenna beam. The lower frequency limit for df use is approximately 3.6 Mc as a result of this reversal. In order to extend the operating frequency to 2 Mc with this type of reflector, it would be necessary to increase the vertical wire height to 120 feet.

Antenna impedance measurements were made both before and after screen erection. The measured VSWR at the antenna output transformer for these two conditions is shown in Fig. 7. The curves show that the screen erection increased the VSWR at the lower frequencies and improved it between 14 and 20 Mc. Above 20 Mc the two curves followed quite closely. This VSWR might be improved slightly by a change in either the antenna matching stub or transformer.

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ANTENNA ARRAY PATTERNS

The erection of the reflecting screen greatly improved the shape and stability of the antenna beam patterns. Previous pattern distortion had been very severe at frequencies below 10 Mc during fade periods. The elimination or reduction of back and side lobes also considerably reduced the interference from signals and man-made noise at the same frequency.

The beam patterns for the antenna array with the reflecting screen are shown in Figs. 8, 9 and 10. These patterns were taken at several frequencies below 4 Mc to determine the point at which the antenna beam reversed in direction. This reversal as previously noted occurred at a frequency near 3.3 Mc and sets a practical lower frequency of 3.6 Mc for df use. The upper frequency for the 434-foot-diameter 40-element array is about 25 Mc due to the increased VSWR for the antennas and the high side-lobe levels. As the spacing between antennas approaches three-quarters of a wavelength, symmetrical side lobes begin to appear (Fig. 8). These side lobes can be eliminated by adding more antennas or by reducing the diameter of the array.

Null and inverted-null antenna patterns are shown in Fig. 11. The null patterns also possessed a much greater stability than either the vertical rhombic or omnidirectional antenna patterns. Previously, the antenna null patterns for ionosphere-propagated waves originating close to the skip distance were very unstable but now displayed only slight variations for a greater percentage of time.

INSTRUMENTATION

Antenna multicouplers are under construction for this array and will be installed during the fall of 1958. They provide outputs for (a) 3 high-precision df goniometers, (b) 3 steerable-beam goniometers, and (c) 40 fixed beams. Without these antenna multicouplers, the present array has only one output and would require parallel operation for more than a single goniometer. This parallel operation results in large losses when several goniometers are placed in parallel. Goniometers used at the present time are of the capacitively coupled type and are directly connected to the cathode-ray-tube indicator. When these additional outputs are available, several goniometer arrangements will be used.

Remote Automatic Bearing Indicator

Figure 12 shows a block diagram of a remote automatic bearing indicator that is under development at the present time. Several indicators

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may be operated from the same goniometer by using individual resolvers and duplicating the system from that point on. It will also be necessary to use a multicoupling amplifier at the goniometer with an output for each operating position.

The toothed disk attached to the goniometer shaft is instrumented to provide an electronic strobe which is displayed on the cathode-ray tube. The position of this strobe pulse may be aligned with the display center or with any other azimuth and then either recorded visually by in-line decade counters or printed for a permanent record on tape by a digital printer.

The remote indicator display is obtained in the following manner. A resolver or two-phase generator whose rotor is mechanically coupled to and rotated synchronously with the goniometer has its rotor excited by a 50-kc signal from a modulator tube. As the resolver is rotated in synchronism with the goniometer, two suppressed carrier signals (one from each stator) with side bands determined by the rotational frequency are generated. These two suppressed carrier signals are fed back to the indicator by balanced lines, amplified, and then detected by a ring demodulator. The carrier frequency of 50 kc is applied longitudinally as the switching voltage for the ring demodulator and the suppressed carrier signal as a balanced input.[2] For continuous signal input to the resolver, the output of the ring demodulator will be a sine wave with a frequency equal to the rotational rate of the goniometer. Since the two resolver windings are spaced 90 degrees apart, the two sine wave outputs will also be 90 degrees apart in phase.

These two signals are applied to the input of a cathode-ray-tube indicator. This indicator has identical amplifiers and deflection coils on both axes, and as a result the two signals produce a circular time-base synchronized with the goniometer rotation.

Bearing errors may result from this method of indication due to distortion or nonlinearity of the circular trace resulting from unbalances or lack of similarity in any component part such as deflecting coils, amplifiers, detectors, and resolvers. These instrumental errors will be eliminated by a bearing readout system (Fig. 12) currently under development for the Wullenweber.[3] This system will also permit the use of additional operating positions with one spinning goniometer. It has an 1800-tooth tone wheel mounted on the goniometer shaft. Magnetic pickups mounted close to the wheel generate pulses as the teeth pass the pickup, and by counting zero crossings 3600 pulses will be generated for the complete 360 degrees. This enables the shaft position to be read to the nearest 0.1 degree. For remote

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indication, each operating position will be equipped with an analog-digital converter whose output is compared with the output of an electronic counter connected to the tone wheel output. When the two are coincident a "pip" or strobe is produced on the indicator. The use of this system automatically calibrates the circular trace on the scope for each revolution and reduces the need for precise balance of the indicating system except when a symmetrical pattern is needed to determine the center position. This system is described in detail in reference 3. The goniometer with which the complete system is to be tested is described in the following paragraphs.

Printed-Circuit Goniometer

The fabrication cost of precision capacitively coupled goniometers for use with the Wullenweber antenna array is relatively high because of the great amount of machine work required to fabricate the rotor and stator plates and to position them with the required precision.

The use of printed-circuit techniques appears to offer a cheaper method of producing various rotor and stator designs and duplicating them in quantity. The master diagram may be made precisely and at a low cost by the use of precision ruling instruments and will be available for duplication at any time.

A capacitively coupled goniometer employing this technique is currently under development. Figure 13 shows a cross section of the goniometer and Fig. 14 shows one design for rotor and stator plates. These rotor and stator plates are secured to larger metal plates in the goniometer and can be removed and changed readily. The plates shown were printed on an epoxy-base fiberglass material. These are not precise plates but will be used in the first experiments to evaluate certain performance characteristics and phasing techniques. A final design may use some of the newer ceramic materials which may be formed and will remain within close tolerances due to their temperature stability. The two adjacent surfaces on which the rotor and stator segments are printed or plated can be ground flat to tolerances exceeding those required for this use.

Fixed Antenna Beams

One of the problem requirements is for fixed antenna beams that will cover the complete azimuth with the beam overlaps at or above the 3-db points. A beamwidth of 9 degrees will result at 20 Mc if 8 antenna elements of this array are used. Thus 40 beams are required to cover the complete 360 degrees.

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Figure 15 shows the phasing lines and the lengths required to phase the 8 antenna elements properly so that all antennas are in phase for a signal arriving along their center-line. These phasing lines will be identical for each beam, but must be properly connected to form all of the beams in the correct positions. Figure 16 shows the phasing required to form a beam with antennas 1 through 8. This beam will be directed half way between antennas 4 and 5. The next beam is formed by antennas 2 through 9, and the beam will lie between antennas 5 and 6. This process is continued around the complete ~~circle and~~ 40 equally ~~spaced antenna~~ beams are formed.

Figure 17 shows the phasing lines required to form each antenna beam and the connection of antenna inputs to the delay lines. The 40 individual delay networks required are all identical and are duplicated by using a printed circuit "strip line." These delay lines are printed on a 1/16-inch-thick sheet of epoxy resin fiberglass material with copper on both sides. The final sheet size is 9 inches high and 11 inches wide. In order to simplify the wiring, they are arranged in the form of a cylinder with five delay lines in each circle. Eight similar concentric circles are therefore required to form the 40 antenna beams. This circular form simplifies the connection to the delay lines where antennas such as 34 through 1 are used (Fig. 16).

Forty inputs to this fixed antenna beam-forming network are obtained from a similar number of antenna multicouplers. The input impedance of the line from the multicoupler is 50 ohms; the gain is approximately 10 db over the antenna input voltage to the multicoupler. Each input from the multicoupler must be power-divided 8 times to form the necessary inputs for the 40 beams. This is accomplished by use of a power divider consisting of autotransformers. The output of each of these transformers is down 9 db from the multicoupler input or at approximately the original antenna voltage level. There are no large additional coupling losses, so the final power gain of the fixed antenna beams will be several times that of a single antenna input.

Patterns for these fixed antenna beams were obtained by switching the phasing network (Fig. 17) to consecutive groups of 8 antennas around the complete circle and plotting the level of the output for each position. The plotted antenna beam patterns are shown in Fig. 18.

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RESULTS OF BEARING-WANDER TESTS

An attempt has been made to measure the bearing wander or variation on fixed stations versus time so that the results might be compared with similar data now available from narrow-aperture direction finders such as the GRD-6. In making a study of bearing variation for a particular frequency over long periods, it is necessary to devise some method of randomizing the indicated displays so that the operator will be unable to apply a bias by learning the bearing position on the indicator. It is relatively simple to change the indicated bearing position for systems employing shaft digitizers. The present method of automatic bearing indication for the Wullenweber uses a cathode-ray-tube display with a rotating yoke directly connected to the goniometer shaft; as a result it is difficult to make tests or alter the system to avoid operator bias. It is also impossible to read the bearings more accurately than ±1 degree with the goniometer spinning. The indicated bearings can be randomized by decoupling the deflecting yoke from the goniometer shaft and resetting to a new position at frequent intervals. By manually rotating the goniometer it can be positioned and the bearing information is then read from an accurately calibrated scale directly attached to the goniometer shaft. This scale is calibrated in 0.2-degree intervals.

The following method has been used to study bearing variation. A clutch, installed between the goniometer and indicator coupling, is automatically declutched at 1-minute intervals by spinning the goniometer. During the declutched period, a new setting for the cathode-ray indicator is obtained. The operator then obtains bearings manually. This method eliminates operator bias as he is unable to see both the indicator and scale at the same time.

Bearings were taken manually for periods of approximately 1 hour. During this time a minimum of 300 individual bearings were obtained for each station. This study was made at frequencies ranging from 5 to 21 Mc and for distances ranging from 500 to 6000 miles. The results of this test are shown in Fig. 19, with the frequency, location and approximate distance of each station recorded in table form in Fig. 20. This series of observations did not exhibit the expected result of an increasing standard deviation for the nearer stations, but instead gave a slight decrease. The results obtained to date maybe insufficient to determine the performance of this antenna array. They could also be partially a result of the manual operating technique that was used to record bearings. This will not eliminate the operator's judgement nearly so completely as would be possible with a more automatic readout system.

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Further studies and comparison of data taken simultaneously with the GRD-6 direction finder may give information which will enable the formation of more definite conclusions concerning the variation of standard deviation with distance and propagation conditions.

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CONCLUSIONS

A 434-foot circular ring of omnidirectional sleeve monopole elements is suitable for df use over a narrow bandwidth and at vertical angles below 40 degrees. The addition of a reflecting screen for the same antenna has resulted in a reasonably good VSWR over the frequency range from 4 to 20 Mc and good antenna beam patterns from 4 to 25 Mc.

The erection of the reflecting screen greatly improved the shape and stability of the antenna beam and null patterns. This improvement is consistent over the entire frequency range. The elimination or reduction of back and side lobes also considerably reduced the amount of interference from signals and man-made noise at the same frequency.

Statistical studies made up to the present time have used data obtained by manual operating techniques for measuring bearing-wander and have shown good results. However, results from other equipments using automatic bearing readout indicate that additional improvement in accuracy should be expected if used in connection with this direction finder. Such a system is now under development, which will give indicated bearing position readout to 0.1 degree during automatic operation.

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REFERENCES

(1) NRL Memorandum Report No. 746 "A Wide-Aperture HF Direction-Finder" by Raymond F. Gleason and Robert M. Greene

(2) NRL Memorandum Report No. 825 "A VHF Elevated H-Adcock Direction-Finder" by R. Gleason

(3) NRL Memorandum Report No. 830 "Bearing Readout Systems for Goniometer Direction Finders" by B. Wald and R. D. Misner

(4) ASRE Monograph 806 "The Wullenweber" by A. H. Mugridge and R. G. Redgment

(5) NRL Memorandum Report No. 832 "An Inductively Coupled Goniometer for Wide-Aperture DF Arrays" by R. F. Gleason and C. V. Johnson, Jr.

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LIST OF FIGURES

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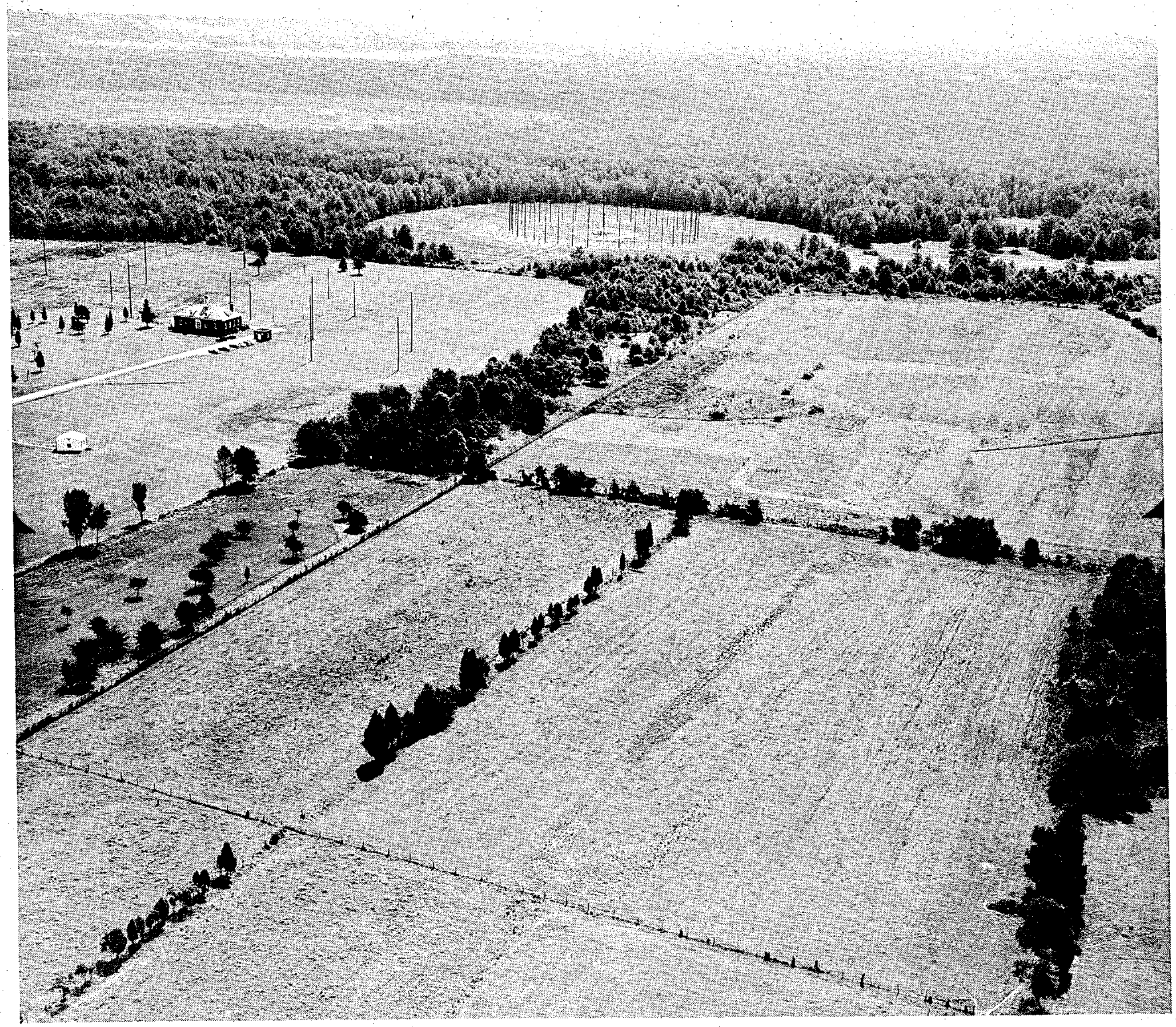

Figure 1 - Air view of Wullenweber antenna array

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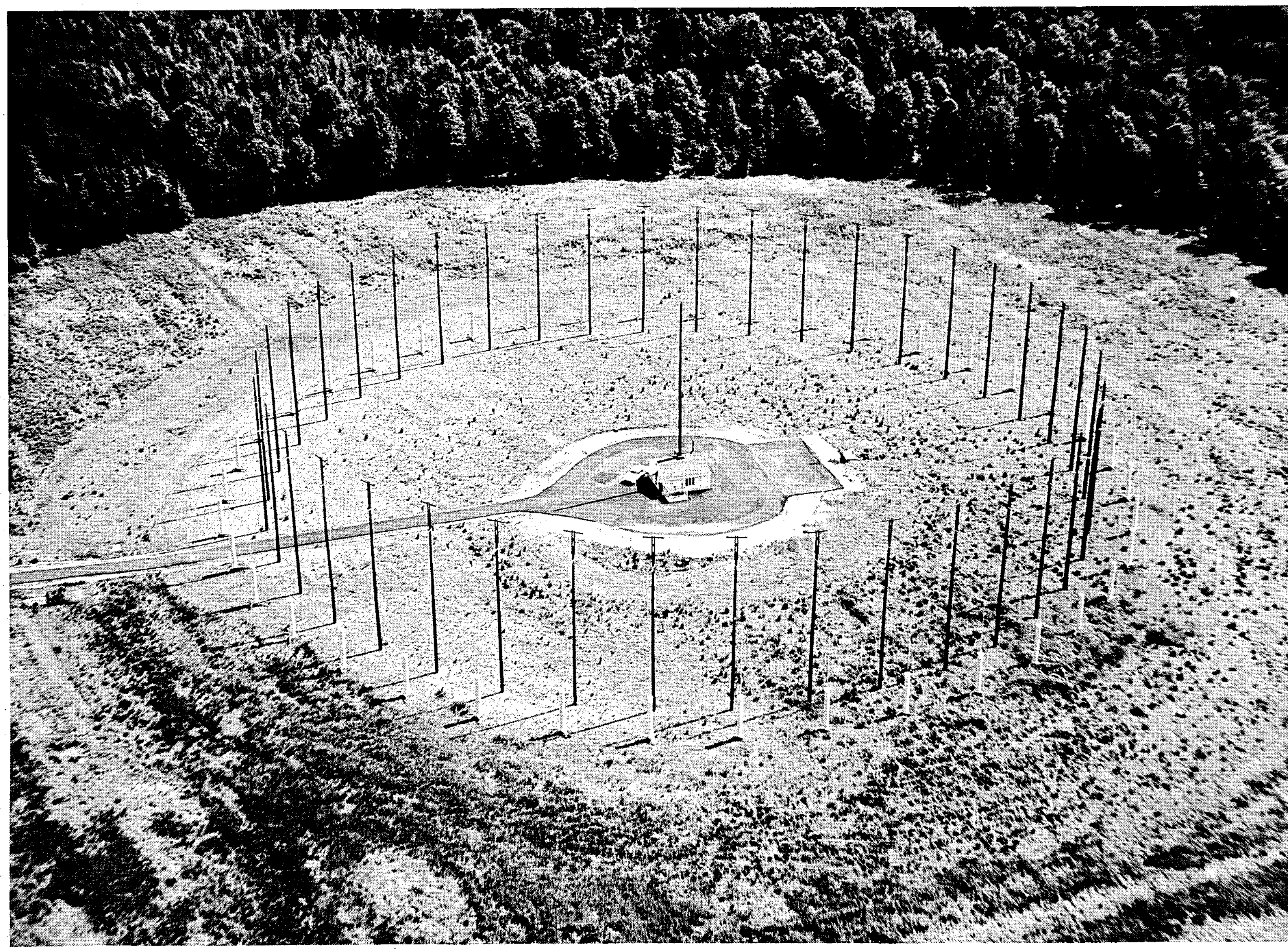

Figure 2 - Air view of Wullenweber antenna array

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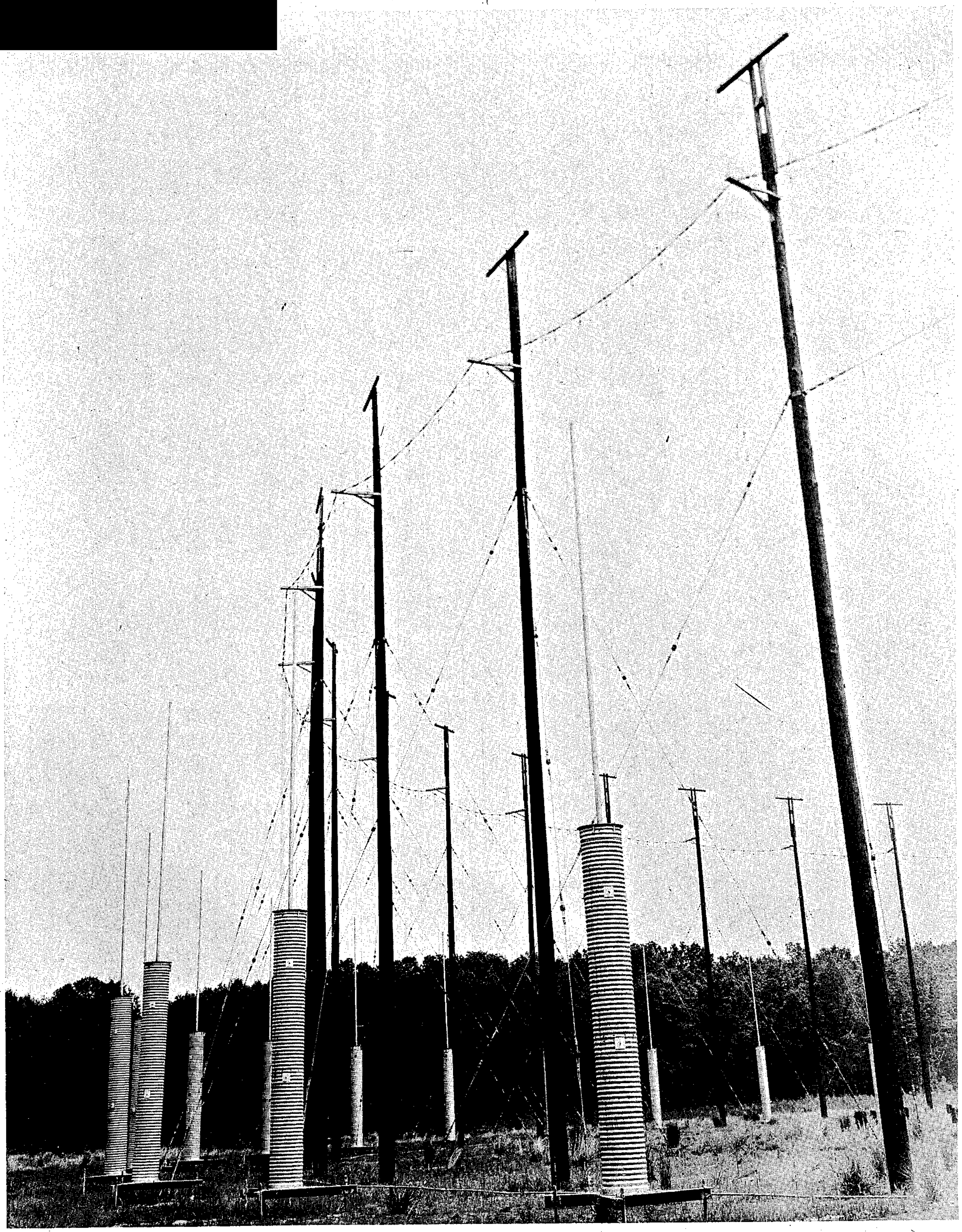

Figure 3 - Sleeve monopole with a reflecting screen

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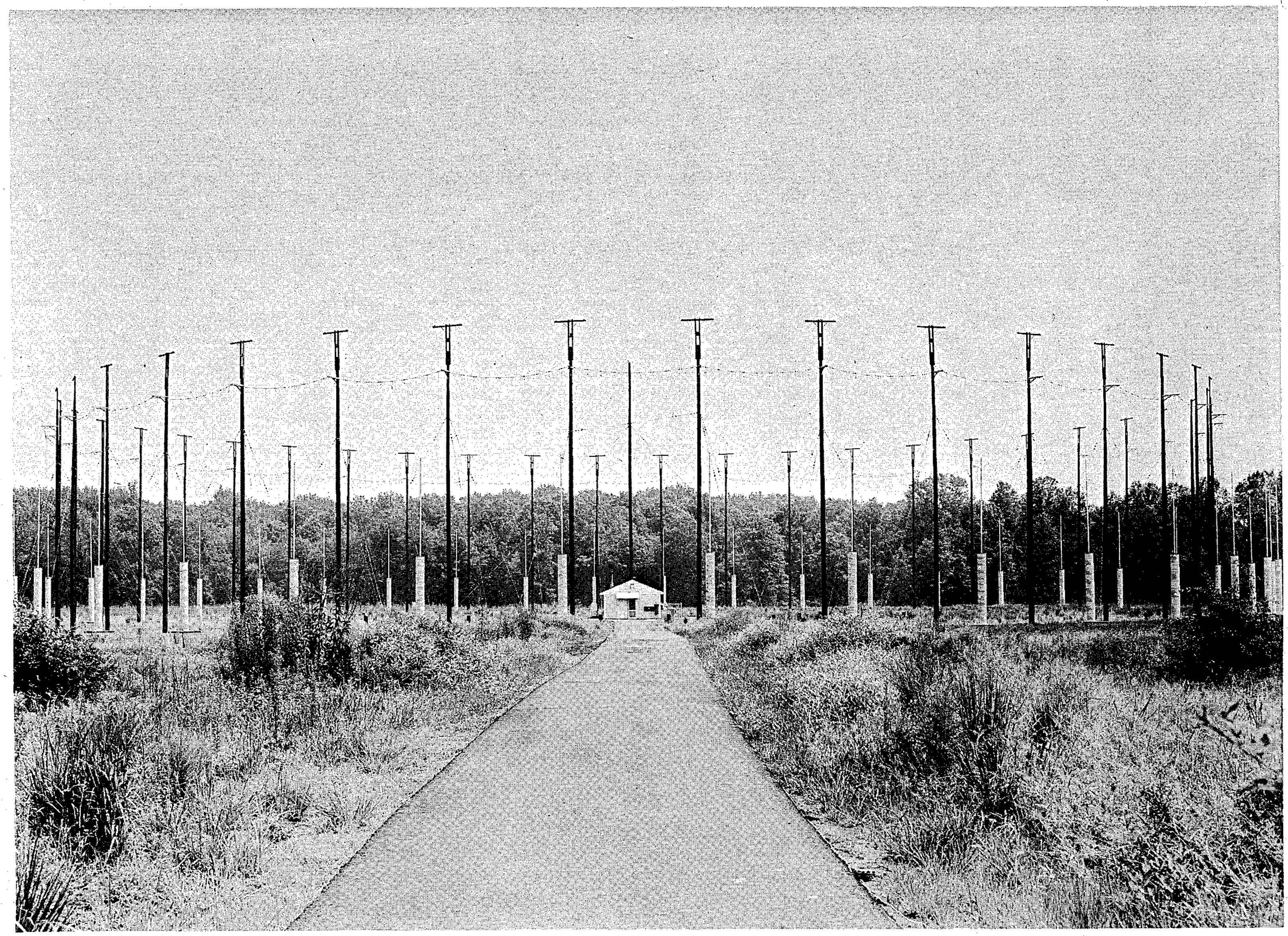

Figure 4 - Ground level view of antenna array

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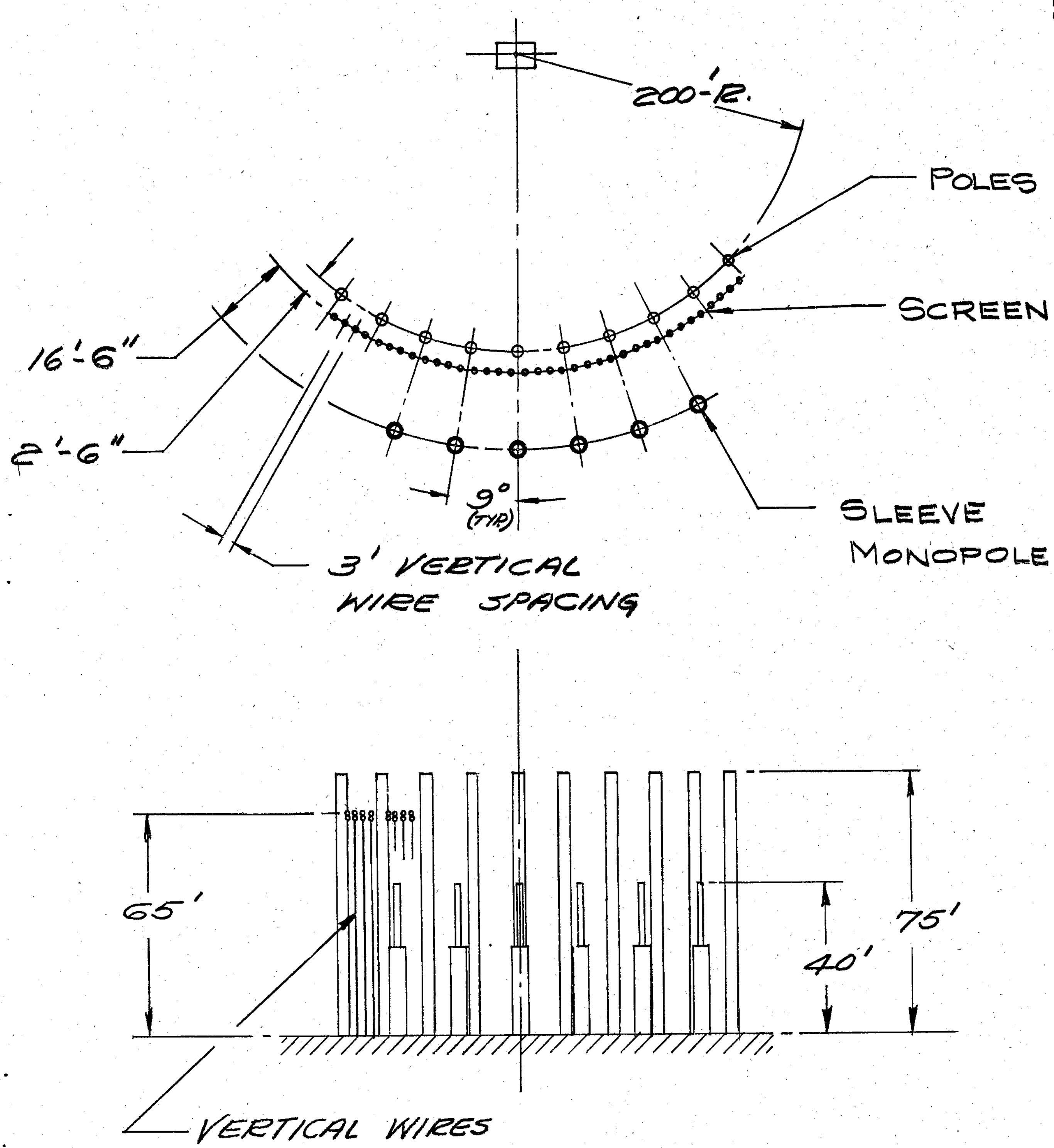

Figure 5 - Antenna reflecting screen

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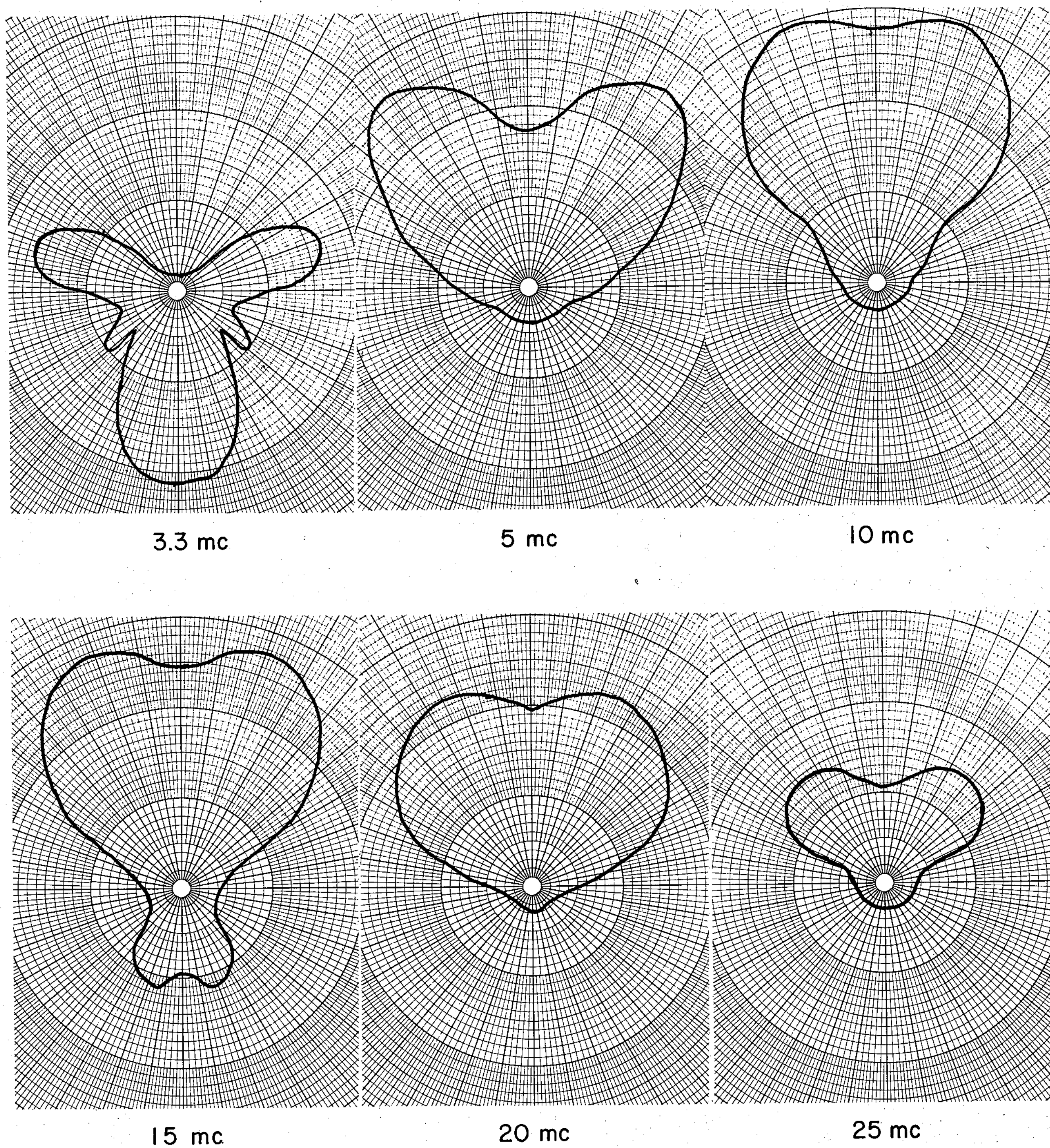

Figure 6 - Antenna patterns for a single element with a reflecting screen

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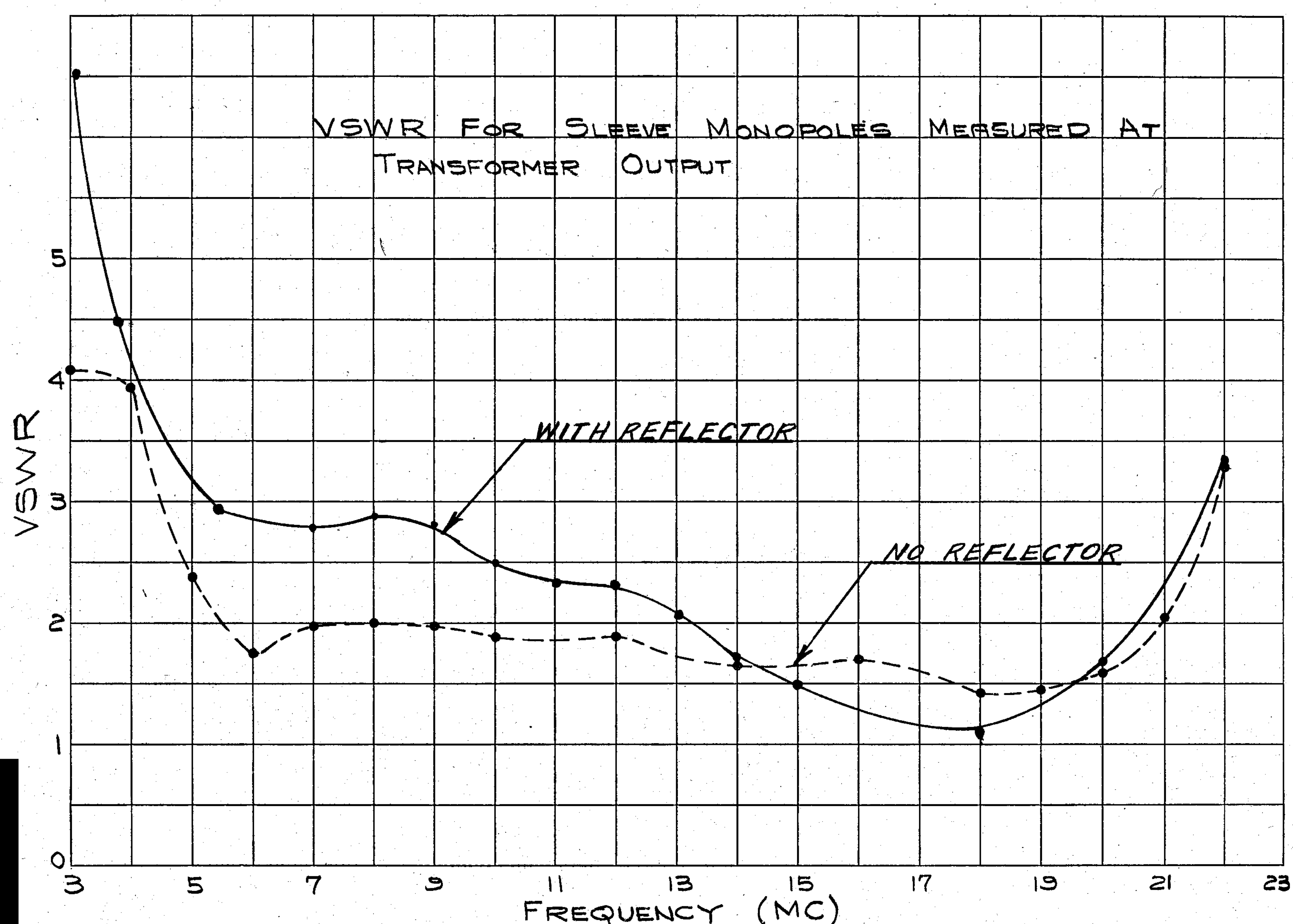

Figure 7 - VSWR for sleeve monopoles measured at transformer output

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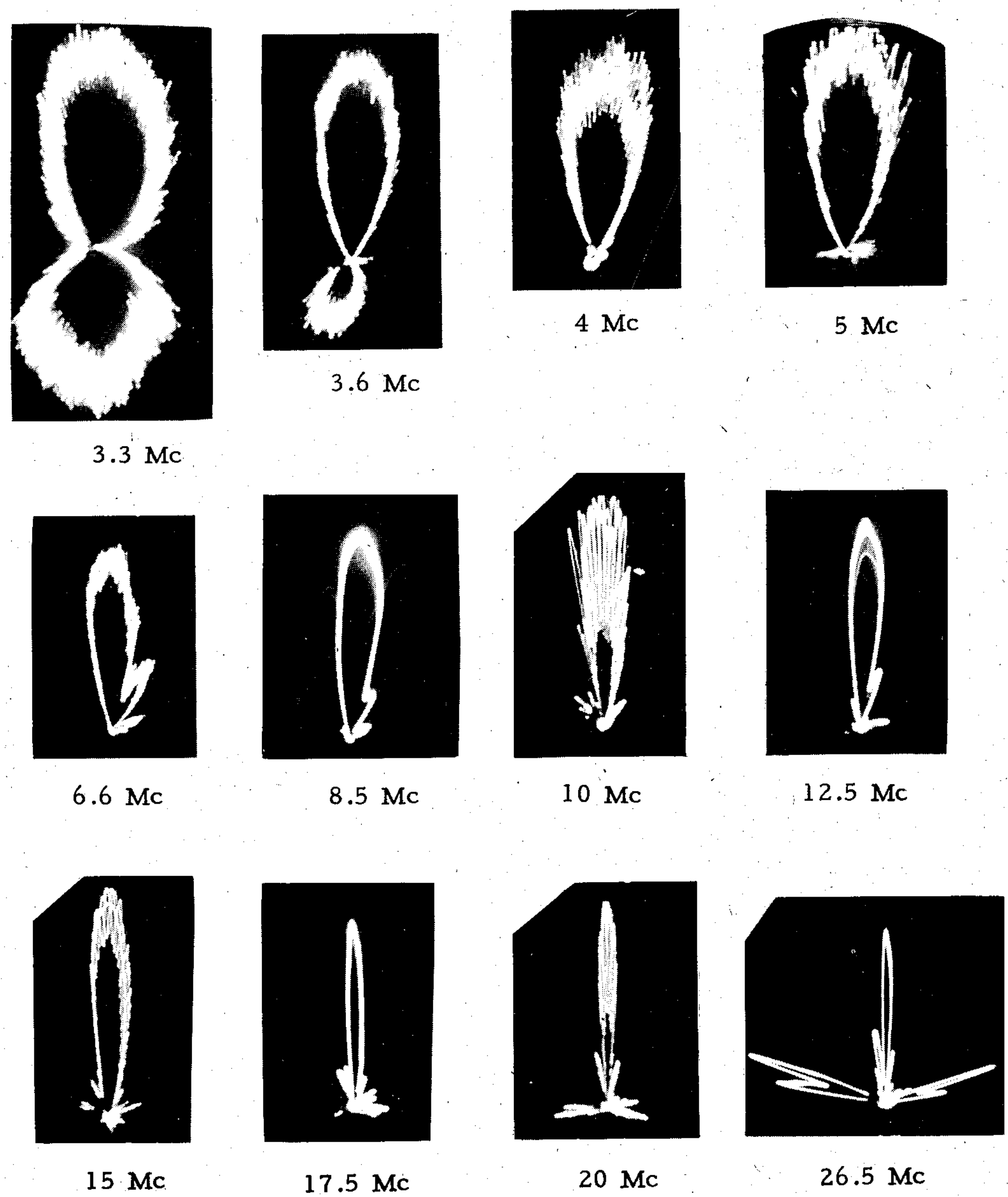

Figure 8 - Antenna beam patterns for array with reflecting screen

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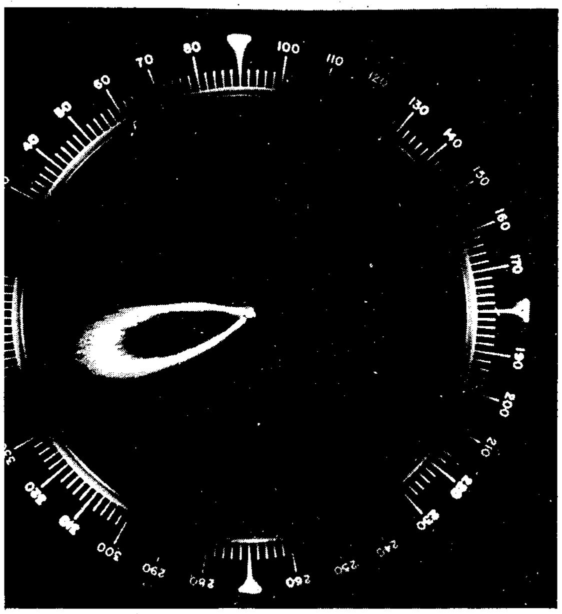

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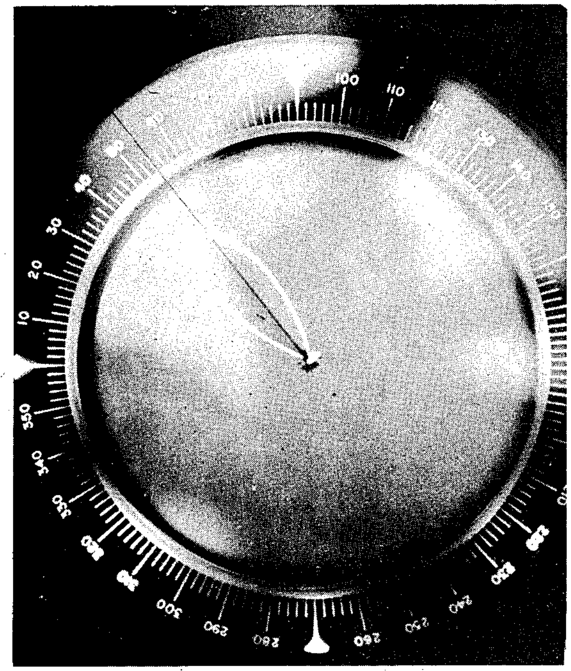

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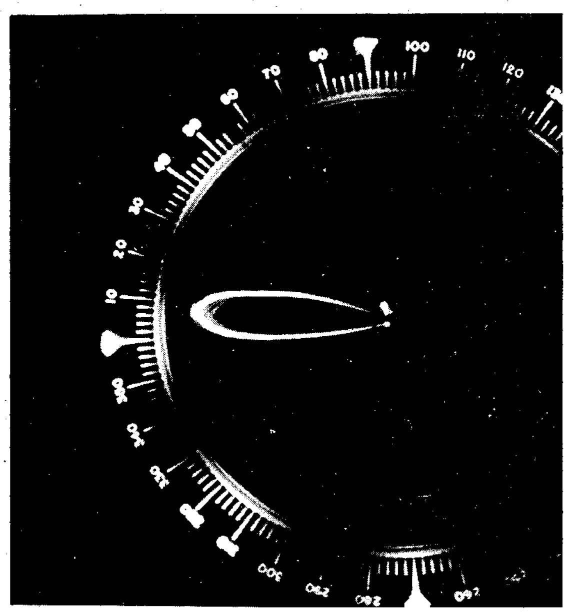

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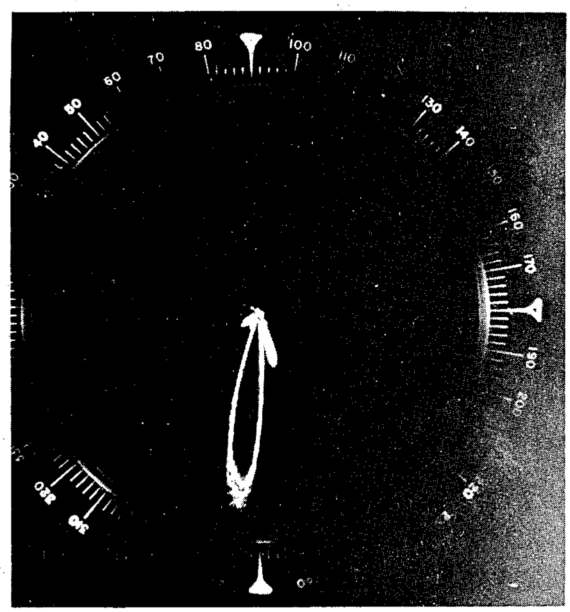

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Fig. 9 - Antenna beam patterns for array with reflecting screen

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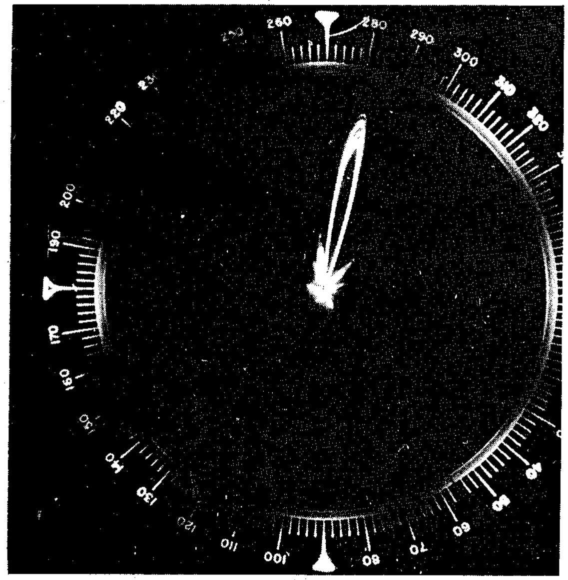

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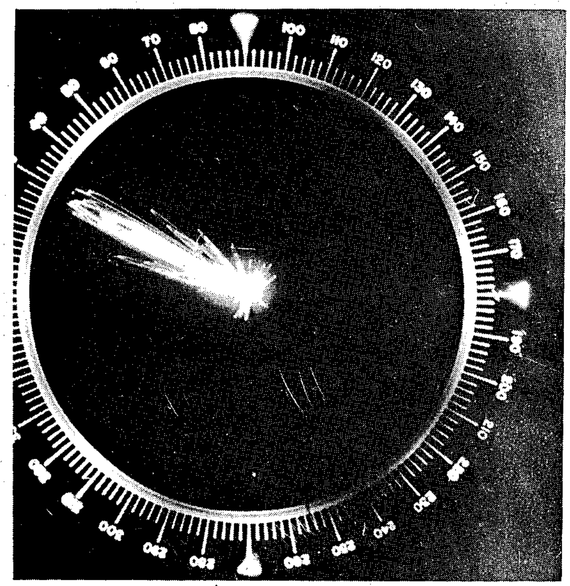

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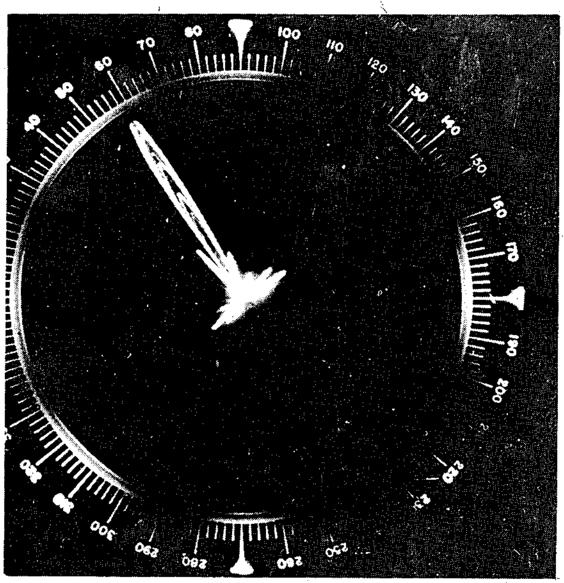

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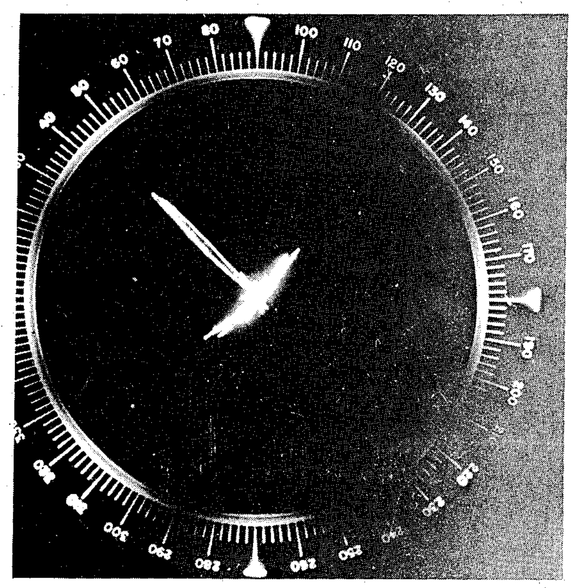

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Fig. 10 - Antenna beam patterns for array with reflecting screen

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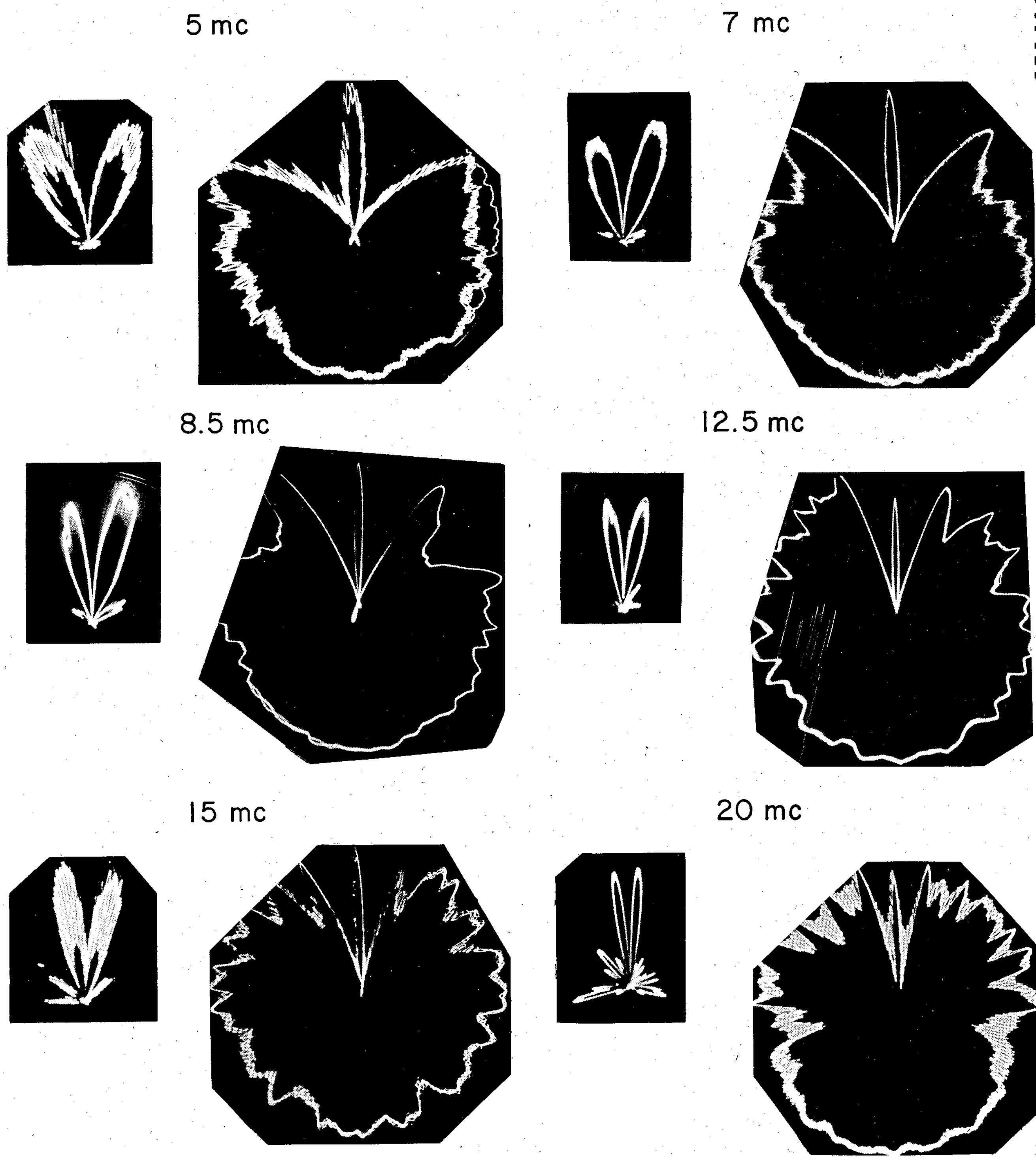

Figure 11 - Antenna null patterns for array with reflecting screen

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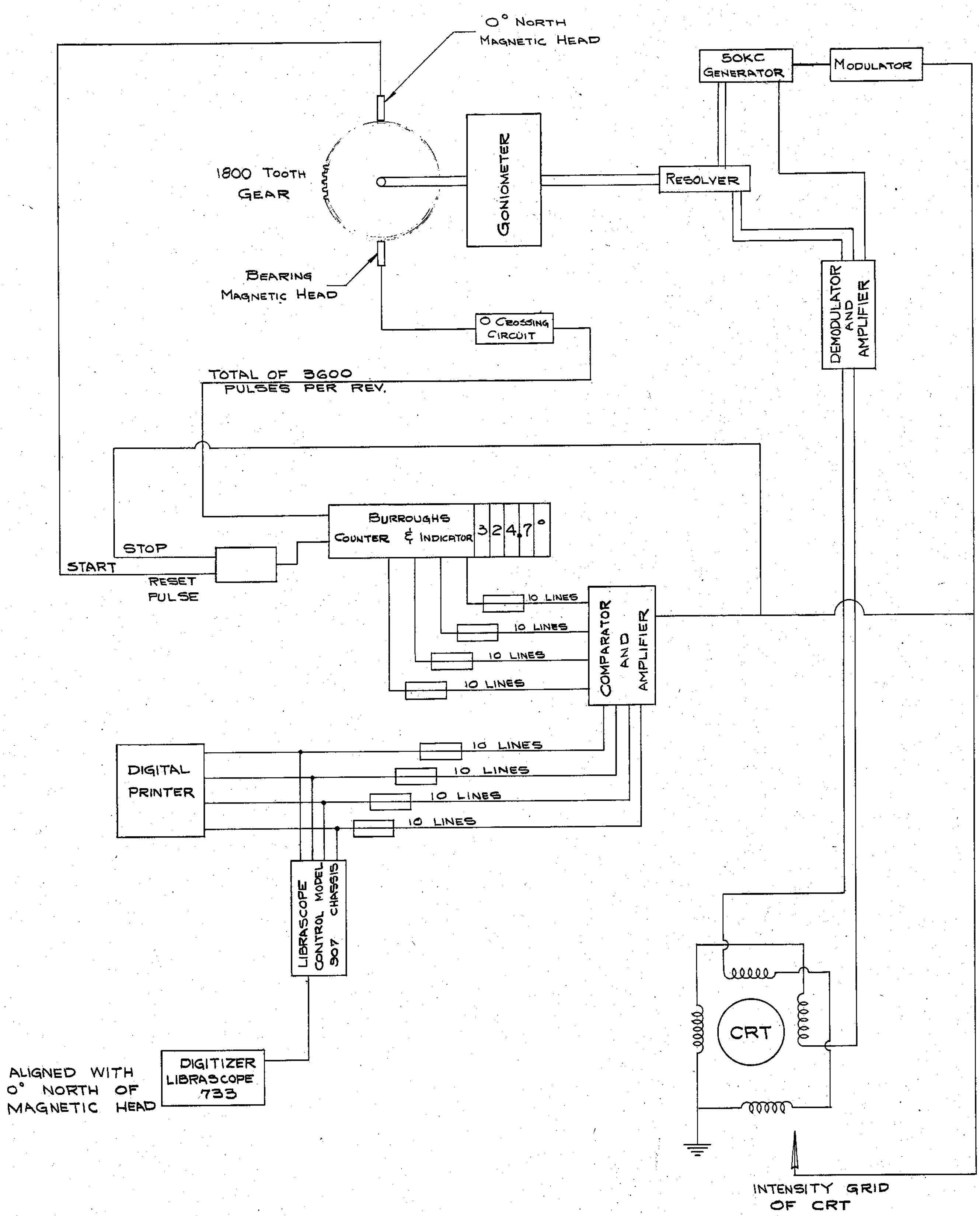

Figure 12 - Remote automatic bearing indicator

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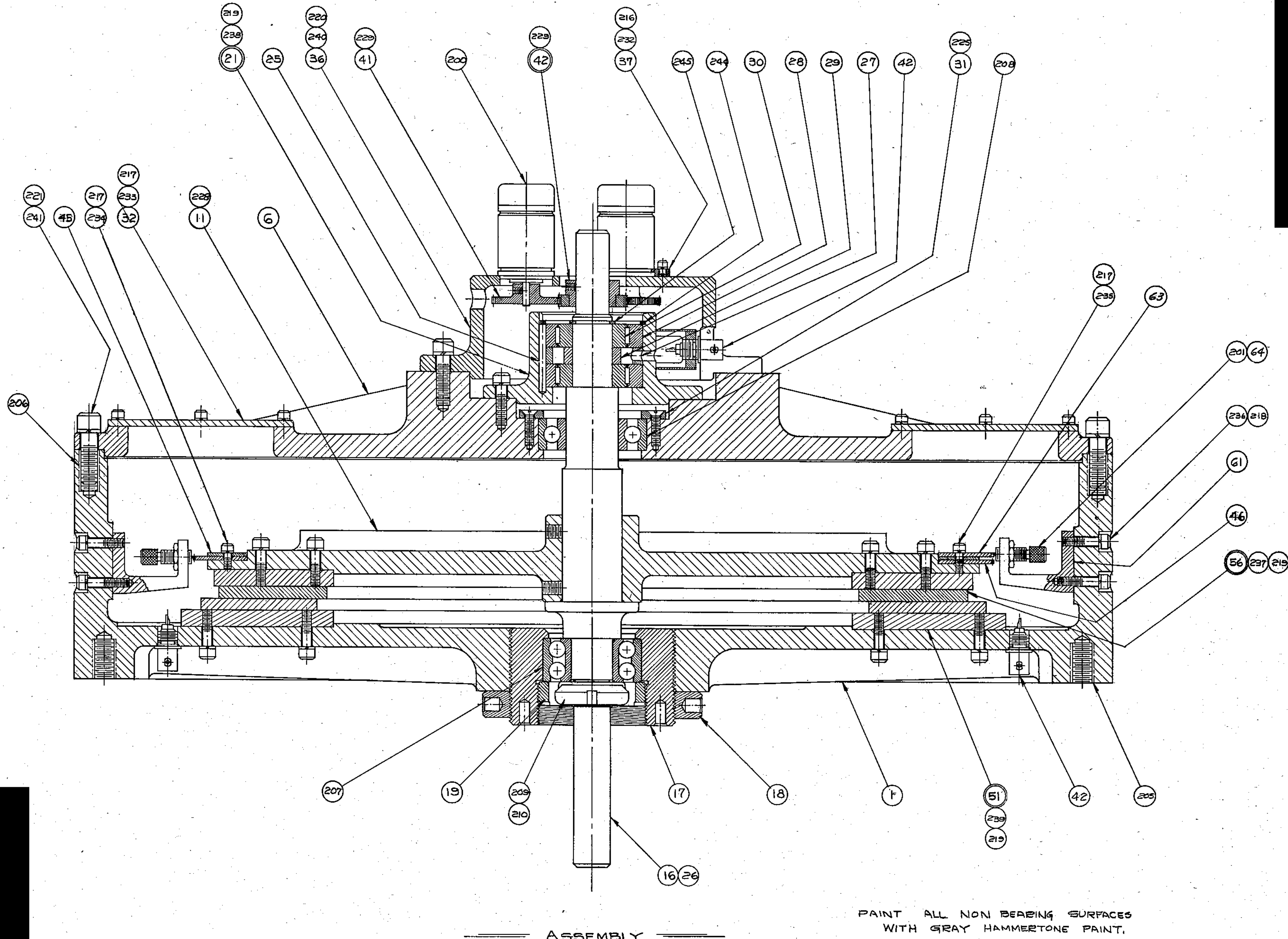

Figure 13 - Cross section view of printed circuit goniometer

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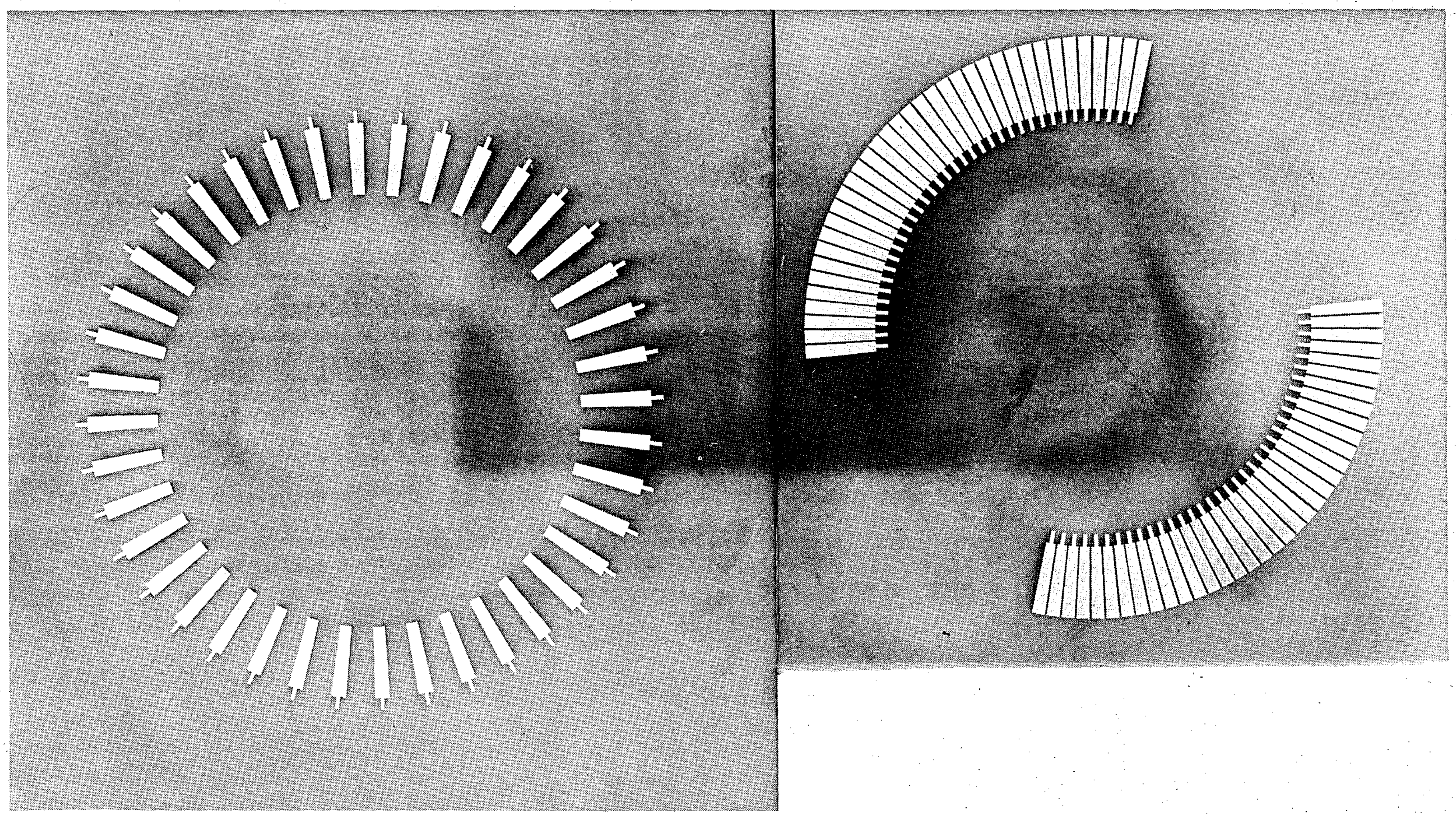

Figure 14 - Printed rotor and stator plates

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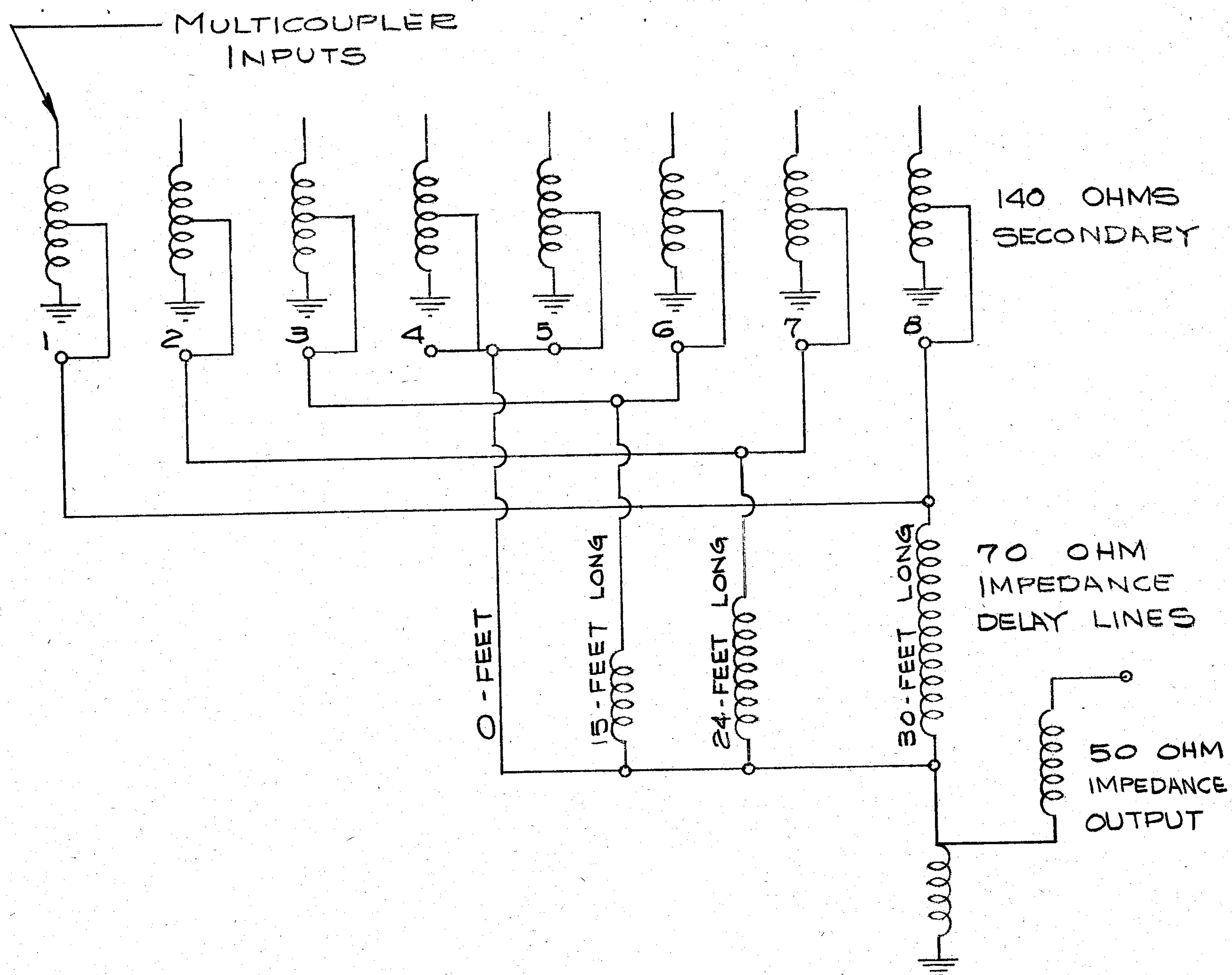

Figure 15 - Fixed beam phasing lines

[redacted]

[redacted]

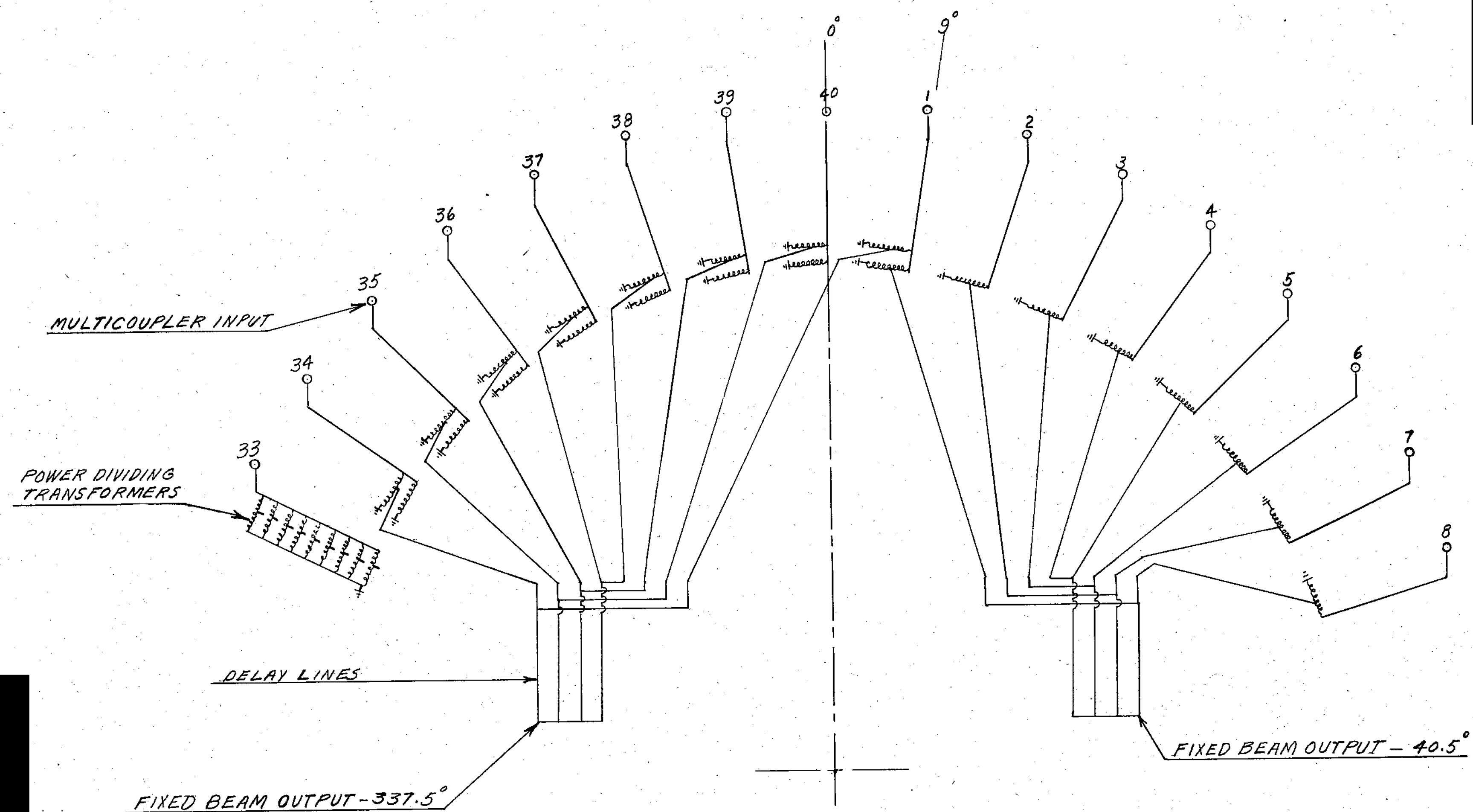

Figure 16 - Circuit to form fixed antenna beam

[redacted]

[redacted]

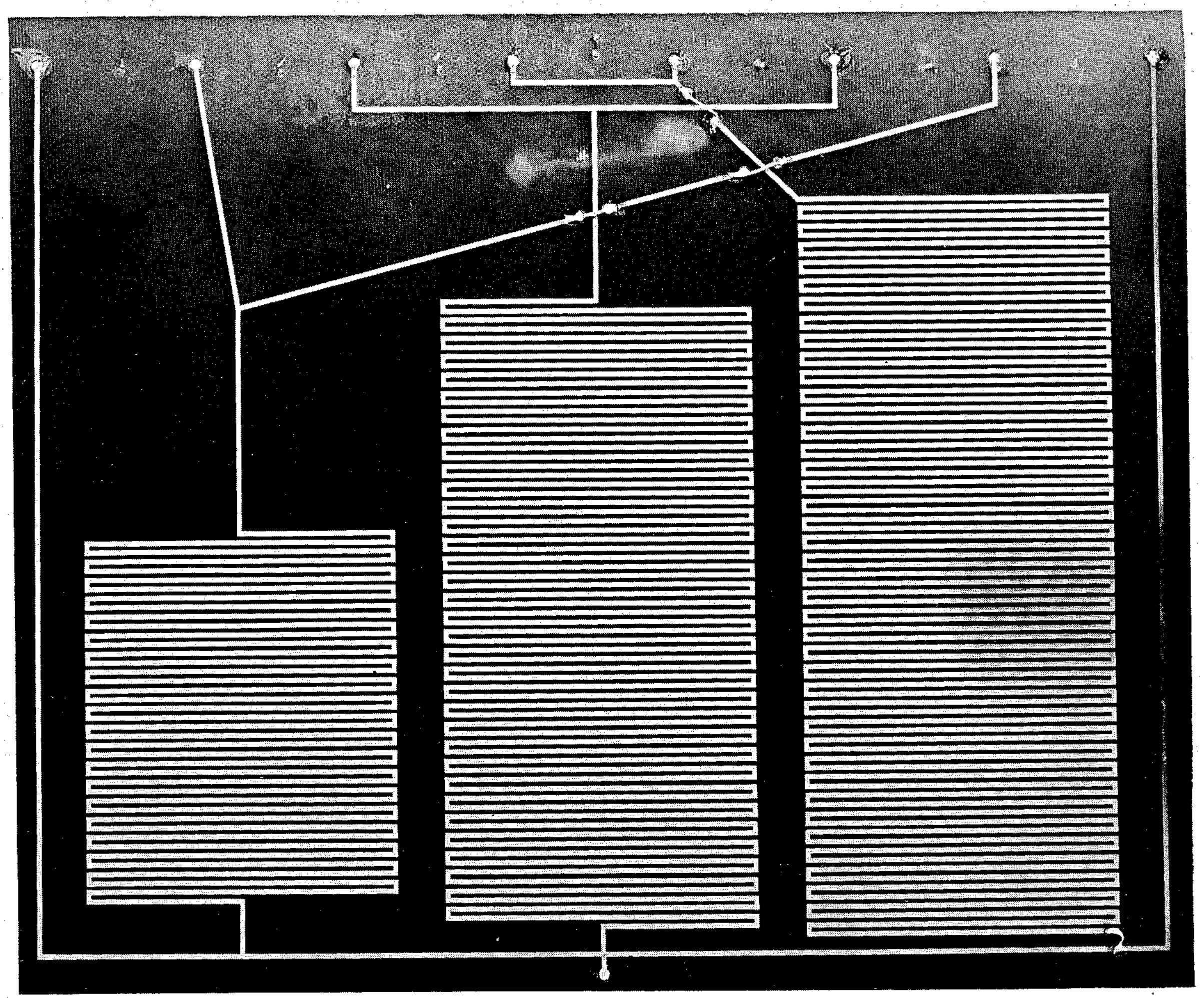

Figure 17 - Printed circuit delay line

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[redacted]

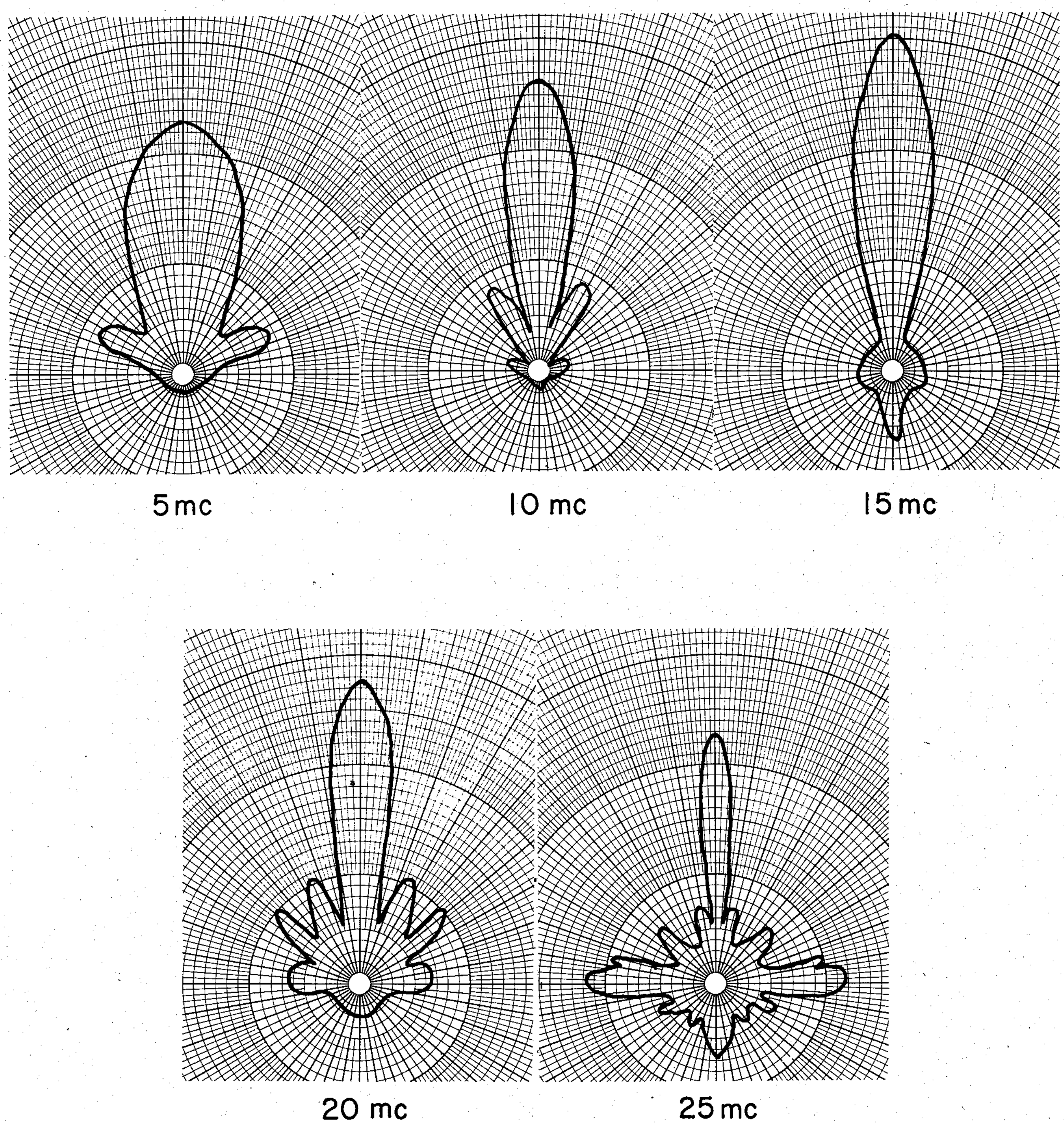

Figure 18 - Fixed beam antenna patterns

[redacted]

[redacted]

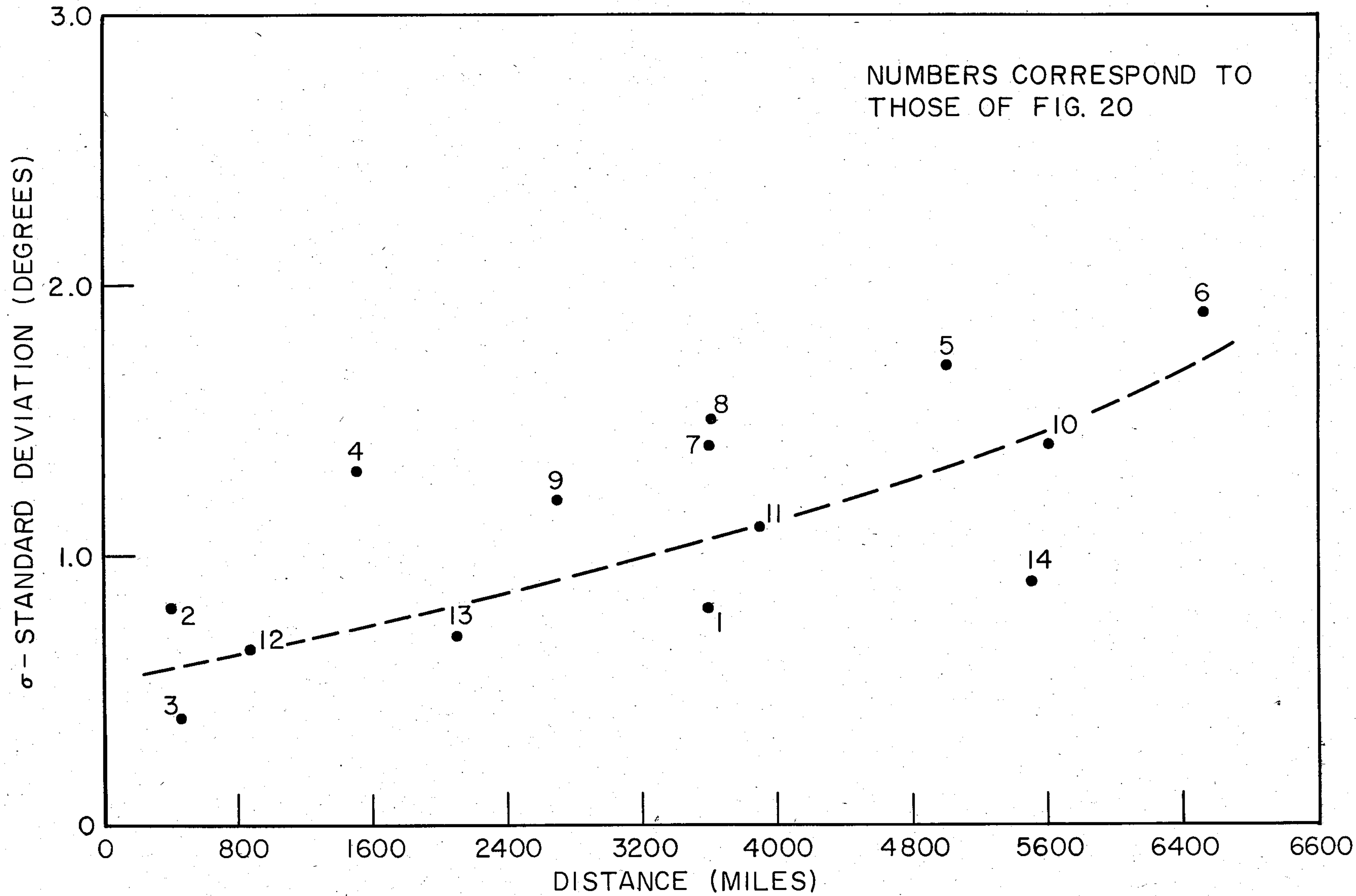

Figure 19 - Standard deviation for bearing-wander

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	Frequency MCS.	Station and Location	Distance (approximate) Miles	Standard Deviation σ
1	4.789	Teletype (England)	3600	.8
2	6.070	CFRB (Toronto, Canada)	400	.8
3	7.335	CHU (Ottawa, Canada)	460	.4
4	9.734	Dominican Republic	1500	1.3
5	11.770	Moscow	5000	1.7
6	11.972	Radio Brazzaville, Fr. AF.	6500	1.9
7	12.095	BBC England	3600	1.4
8	15.070	BBC England	3600	1.5
9	15.115	HDJB Quito, Equador	2700	1.2
10	15.235	Radio Moscow (in Southern Russia)	5000-6000	1.4
11	15.296	Voice of America, Tangiers	3900	1.1
12	17.820	Canadian CBC (CKNC)	870	.65
13	17.905	Windward Islands	2100	.7
14	21.665	Middle East	5500	.9

Figure 20 - Stations used for bearing-wander test

[redacted]