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VOR POLARIZATION TESTS

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SUMMARY

This report presents the results of polarization tests conducted on a standard 5-loop omnirange antenna array in accordance with ICAO specifications, which establish standards for an omnirange antenna. The results of other tests are also presented in this report

Tests were made with the receiver dipole located four wavelengths from the base of the 5-loop array at an elevation angle of 40°. Data were obtained for the array elevated 8 inches above ground, and also for an omnirange installation where the antenna is located on top of a 30-foot steel tower with 35-foot diameter counterpoise.

The data obtained for the 5-loop array elevated 8 inches above ground with the dipole located at a distance of eight wavelengths and elevation angle of 40° showed maximum polarization errors of $+2.0^\circ$ and -6.5° for a $\pm 45^\circ$ rotation of the dipole in the horizontal plane.

The 5-loop array installed on top of a 30-foot tower with counterpoise shows a polarization error that varies with direction at the specified distance of four wavelengths and elevation angle of 40°. The maximum polarization error observed for a $\pm 45^\circ$ rotation of the dipole in the horizontal plane at any bearing of the 5-loop array was $+4.25^\circ$ and -6.0°.

At a distance of approximately 3500 feet from an array mounted on a 15-foot tower without counterpoise, with a dipole elevation angle less than 1°, the maximum polarization error for a $\pm 45^\circ$ rotation of the dipole in the vertical plane was found to be $+3.2^\circ$, -2.1° with no Uskon cloth, and $+0.25^\circ$, -0.3° with Uskon cloth.

INTRODUCTION

While the omnirange antenna is designed to radiate horizontally polarized energy, tests have demonstrated that the system radiates a vertically polarized component also, which will in general produce omnibearing indications which are at phase quadrature with true bearing information. Errors caused by such vertically polarized radiations are termed polarization errors.

If an aircraft equipped with a navigation receiver flies over a fixed ground check point at a number of different headings, the indicated omnibearing may be found to vary with heading. The aircraft has only one correct omnibearing when over the ground check point and it is independent of heading; consequently, the change in the omnibearing with heading is one form of polarization error and is referred to as push-pull error. The name comes from early navigational aids work where the course was observed to be pushed ahead of the aircraft or pulled toward the aircraft when flying across a course.

The aircraft receives primarily the signal from the horizontally polarized wave, however, as the heading is changed, the ratio of vertically to horizontally polarized pickup varies, producing different omnibearing indications when over a ground check point.

Polarization errors in general vary with the type of aircraft and with the location of the receiving antenna on the aircraft.

Another form of polarization error occurs when an aircraft departs from level flight, such as banking. Under these conditions, the indicated bearing may change even though the direction from the station is unchanged This type of polarization error is generally referred to as attitude error.

Polarization errors at low angles have been reduced to a negligible amount in the omnirange system through the use of Uskon cloth. This cloth which has an rf resistance of 377 ohms per square, envelops the group of four sideband pedestals in a single layer. The cloth is insulated from the pedestals with strips of insulating material.

EQUIPMENT

The equipment used in conducting polarization tests consisted of a dipole pickup unit with detector and amplifier (see Fig. 11), an omnirange monitor equipped with azimuth selector (see Fig. 12), and a standard 5-loop omnirange antenna whose base plate was elevated approximately 8 inches above ground (see Fig. 13). Also, an ARC-15 navigation receiving equipment with a dipole antenna was used for tests made at distances greater than eight wavelengths.

A 55-foot wood pole, set in a concrete and steel casing, and capable of rotation on its axis through a 360° angle served to elevate the receiver dipole at any desired angle (between 0 and 40°) with respect to the base of the 5-loop array. See Fig. 13. The pole was equipped with a 360° calibrated scale to indicate the angle of rotation.

The dipole was elevated to any desired height on the pole by means of a rope track which introduced a small error due to the dipole being offset from the exact center of the pole. This error was accounted for in all measurements.

In order to remove any doubt as to the effect of offset error, special provisions were made to rotate the dipole on its axis when measurements were made at the specified distance of four wavelengths at an angle of 40° (for example, see Fig. 14), corresponding to a vertical height of 22 1/4 feet and a horizontal distance of 26 feet between the base of the 5-loop array and the base of the wood pole.

Polarization tests conducted at a standard VHF omnirange included the measuring equipment described above and also a 50-foot plywood mast with special arrangements for rotating the dipole on its axis through a 360° angle at a height of 52 feet. This is shown in Fig. 14.

TESTS AND DISCUSSION

The curves, Figs. 1 to 8, present the results of the polarization tests conducted with the equipment described previously. The following is a brief discussion of each figure.

Fig 1. The directions of greatest polarization error do not in all cases line up with any particular part of the array. The 0° array angle is in the direction of the cross-over point of the two figure-of-eight patterns. This places the 40° - 90° maximum in the null of one figure-of-eight pattern, the other maximum, 300° - 340°, is in the null of the other figure-of-eight pattern. The other null directions, 135° and 225°, are not directions of maximum (or minimum) polarization error. No definite source of polarization error is apparent.

Fig. 2. The 1 and 6, 2 and 5, and 3 and 4 dipole orientations are each two parallel orientations where the resulting pairs of curves should be identical. It is believed that polarization errors are probably small compared to other errors causing the curves to change with small displacements of the dipole around the supporting wooden pole. Theoretically, the polarization error should decrease with a decrease of dipole height when measured by turning the receiver dipole in the horizontal plane. This is the case except for the 4-foot point of curve 3.

Fig. 3. This figure shows that the 40° angle at four wavelengths is in a critical region The curves of each pair 1 and 6, 5 and 2, and 3 and 4 indicate by their similarities that the polarization

error is large compared to other errors at least in the region 22 - 29 feet. The Fig. 2 curves appear to be in a similar region to the zone 29 - 32 feet of Fig. 3.

Fig 4. Varying the distance to the dipole from four to eight wavelengths at a constant elevation angle of 40° substantially decreases the polarization error.

Fig. 5. This set of data agrees with theory in that when the receiver dipole is in the $\theta = \pm 90^{\circ}$ positions, arrived at by traveling in opposite directions along a given curve, the same polarization error is measured. The amount of this error is approaching 90°.

Fig. 6. These curves appear very significant because of the quadrantal shape. The maximum polarization error obtained under these conditions was $+4.3^{\circ}$ and -6.0°.

Fig. 7 These curves were obtained by testing a commissioned VOR station using Uskon cloth. The dipole pickup antenna was moved around the antenna array instead of rotating the array.

Fig. 8. These data were taken to determine the effects of the Uskon cloth when measured at a low elevation angle while rotating the dipole in the vertical plane. An ARC-15 receiver and dipole antenna were used for these tests at a distance of 3500 feet.

Additional tests were made at a low elevation angle on the commissioned VOR station at Brownsburg, Indiana, by using portable receiving equipment at a distance of approximately 2000 feet.

Test Position 1 Bearing 316° to station

		Rotating Dipole in Horizontal Plane		Rotating Dipole in Vertical Plane	
Dipole Antenna Position	Horizontal	45° L turn	45° R turn	45° L tilt	45° R tilt
Error in degrees	0	-0.13	+0.17	-0.08	-0.08

Test Position 2 Bearing 345° to Station

Dipole Antenna Position	Horizontal	Rotating Dipole in Horizontal Plane		Rotating Dipole in Vertical Plane	
		45° L turn	45° R turn	45° L tilt	45° R tilt
Error in Degrees	0	+0.14	-0.09	-0.14	-0.09

Figs. 9 and 10. These two figures present a conception of the polarization phenomena of the omnirange. The vector E_H is the intended radiated electric field strength. This vector contains the correct bearing information, horizontally polarized, i.e., parallel to the xy plane and perpendicular to r, and is large compared with E_1. E_1 is perpendicular to r and E_H, and contains incorrect bearing information which often is in quadrature with the true bearing. Note that E_1 must be perpendicular to r but it may assume other angles than 90° with E_H.

It is evident from Fig. 9 that, since E_1 may be represented by its components E_{V1} and E_{H1}, a dipole rotated in the horizontal plane, at the angle of elevation $\theta = 40°$, will receive a sample of E_{H1} and E_H, thereby making possible an evaluation of the VOR array.

Also evident, Fig. 10, is the fact that no sample of E_1 will be obtained, if the receiver dipole is confined to various positions in the horizontal plane. Consequently, for small elevation angles, the receiver dipole must be rotated in the vertical plane to sample both E_1 and E_H.

It is believed that, for a study of antenna polarization errors, tests should be conducted at an elevation angle of 40° and, the receiver dipole should be turned $\pm 45°$ in the horizontal plane. The polarization error should also be measured at a small elevation angle by turning the receiver dipole $\pm 45°$ in the vertical plane, normal to the line joining the VOR array and the receiver dipole, to account for the region used most of the time by aircraft flying the VOR. The distance between the receiver dipole and the VOR array should be approximately eight wavelengths at the 40° elevation angle and 1000 feet or more at small elevation angles.

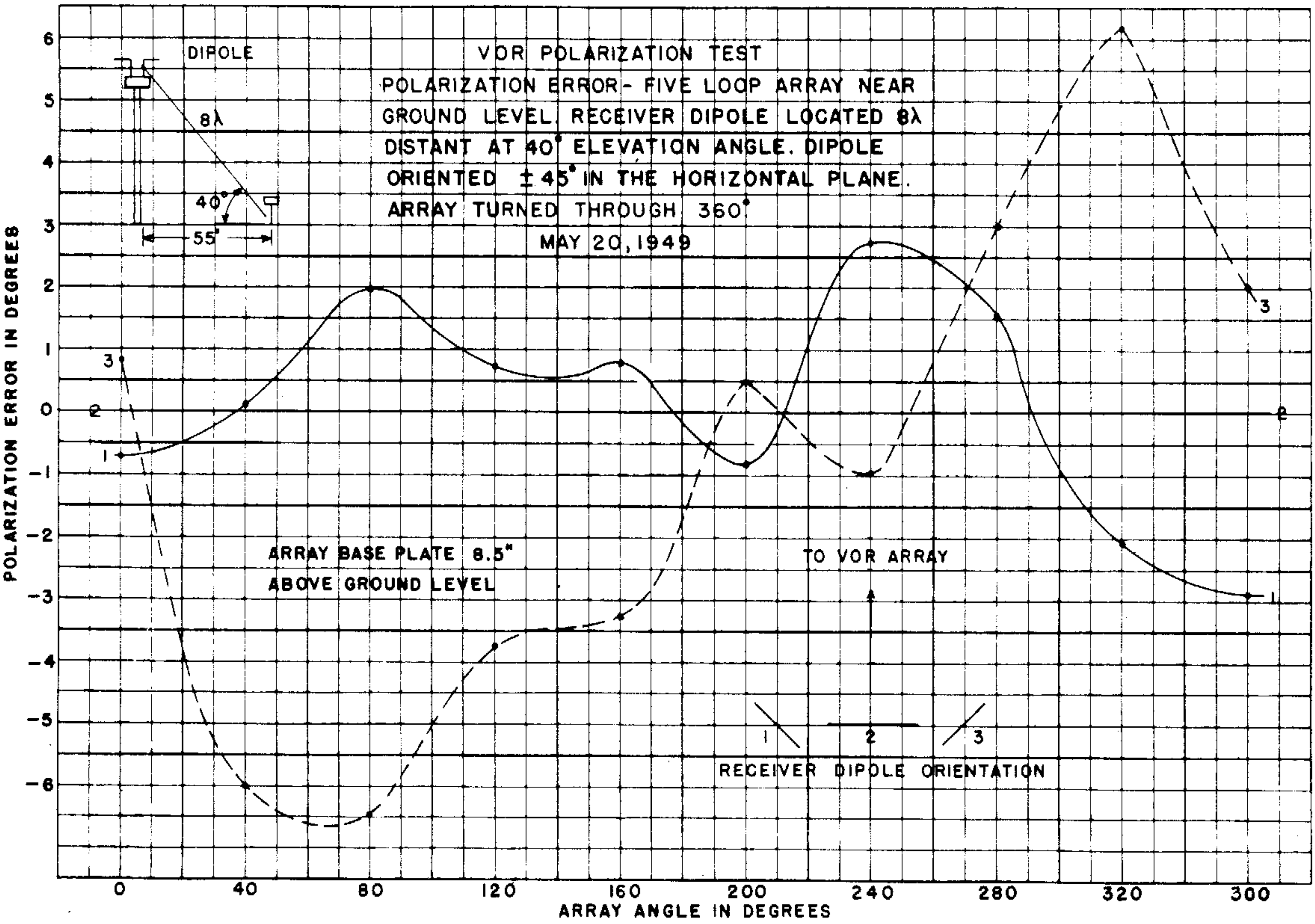
Flight tests made at low angles of elevation confirm polarization tests made on the ground at distances of 1000 feet or more.

CONCLUSIONS

A VOR array may be ground tested for polarization error by:

1) Locating a receiver dipole at a distance of eight wavelengths, at a 40° elevation angle, and placing the dipole in the normal and $\pm 45^\circ$ positions in the horizontal plane.

2) Locating a receiver dipole 1000 feet or more at a small elevation angle, and placing the dipole in the positions horizontal and $\pm 45^\circ$ in the vertical plane, while it is held normal to the line joining the VOR array and the dipole.



VOR POLARIZATION TEST
POLARIZATION ERROR- FIVE LOOP ARRAY NEAR GROUND LEVEL. RECEIVER DIPOLE LOCATED 8λ DISTANT AT 40° ELEVATION ANGLE. DIPOLE ORIENTED ±45° IN THE HORIZONTAL PLANE. ARRAY TURNED THROUGH 360°
MAY 20, 1949
DIPOLE
8λ
40°
55°
ARRAY BASE PLATE 8.5" ABOVE GROUND LEVEL
TO VOR ARRAY
RECEIVER DIPOLE ORIENTATION
1
2
3
POLARIZATION ERROR IN DEGREES
ARRAY ANGLE IN DEGREES

FIG. 1

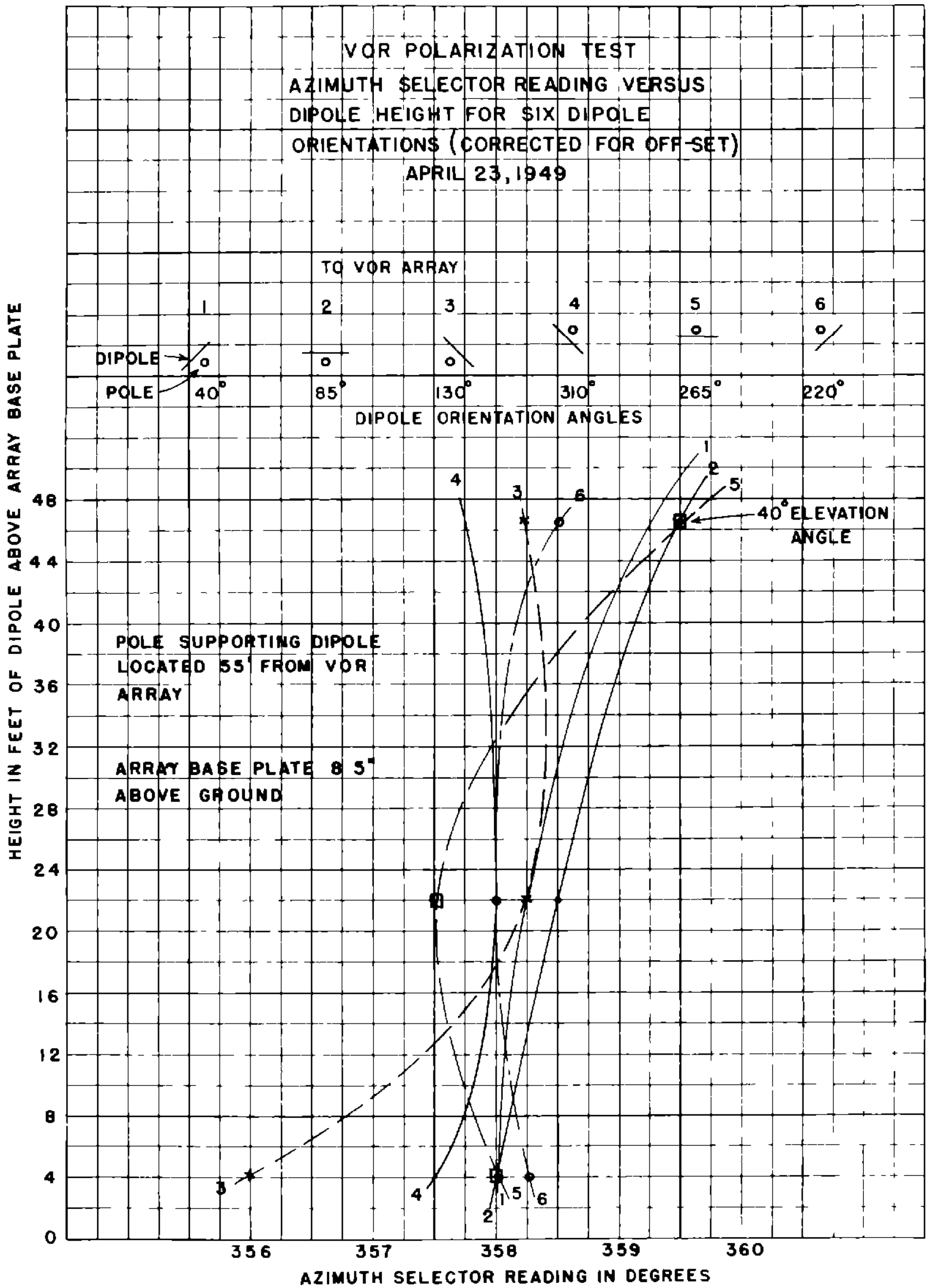
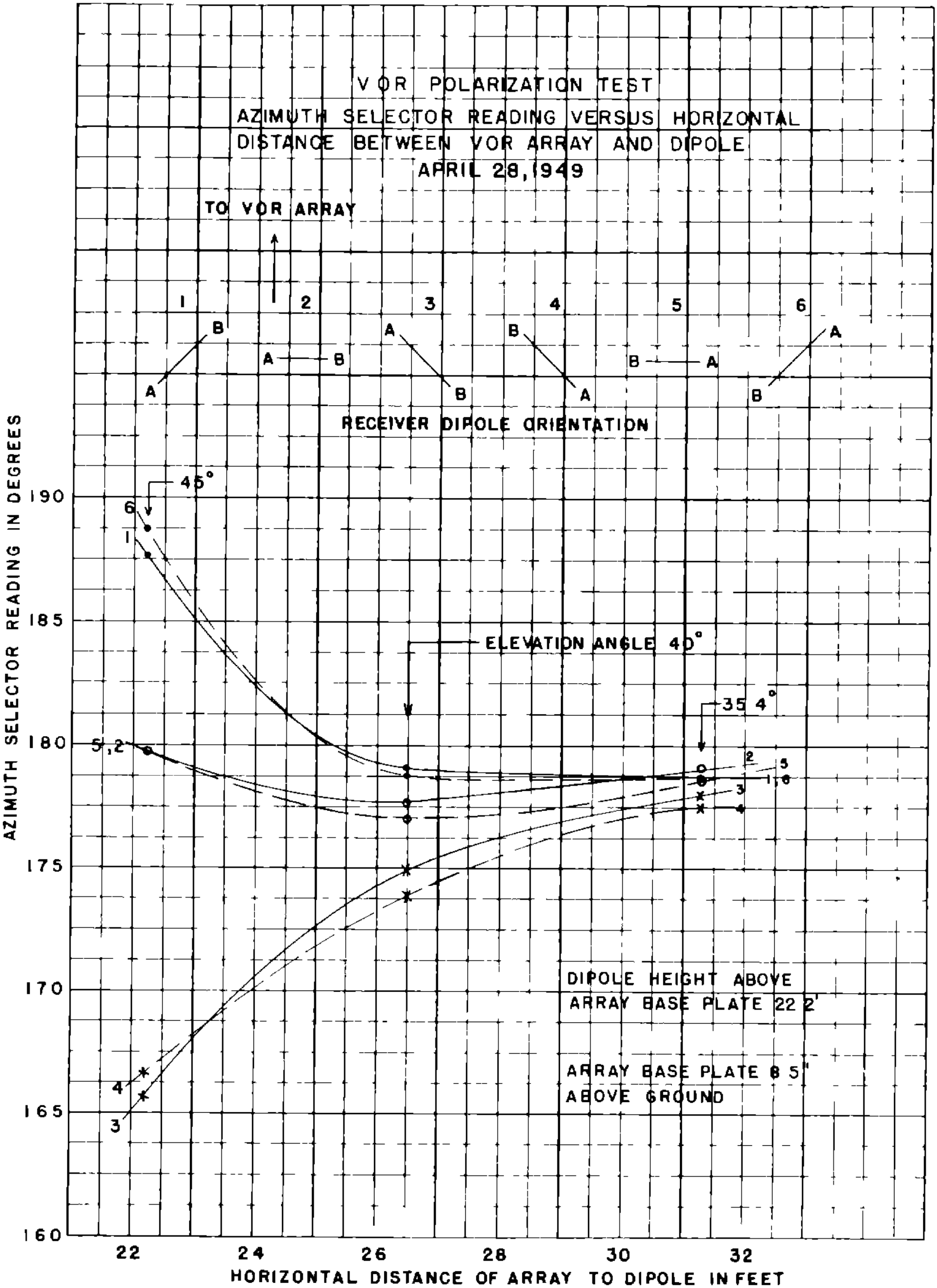

VOR POLARIZATION TEST
AZIMUTH SELECTOR READING VERSUS
DIPOLE HEIGHT FOR SIX DIPOLE
ORIENTATIONS (CORRECTED FOR OFF-SET)
APRIL 23, 1949
TO VOR ARRAY
1
2
3
4
5
6
DIPOLE
POLE
40°
85°
130°
310°
265°
220°
DIPOLE ORIENTATION ANGLES
40° ELEVATION
ANGLE
POLE SUPPORTING DIPOLE
LOCATED 55' FROM VOR
ARRAY
ARRAY BASE PLATE 8.5"
ABOVE GROUND
HEIGHT IN FEET OF DIPOLE ABOVE ARRAY BASE PLATE
0
4
8
12
16
20
24
28
32
36
40
44
48
356
357
358
359
360
AZIMUTH SELECTOR READING IN DEGREES

FIG 2



VOR POLARIZATION TEST
AZIMUTH SELECTOR READING VERSUS HORIZONTAL
DISTANCE BETWEEN VOR ARRAY AND DIPOLE
APRIL 28, 1949
TO VOR ARRAY
1 2 3 4 5 6
A B
RECEIVER DIPOLE ORIENTATION
45°
ELEVATION ANGLE 40°
35 4°
5,2
1,6
DIPOLE HEIGHT ABOVE
ARRAY BASE PLATE 22 2'
ARRAY BASE PLATE 8 5"
ABOVE GROUND
AZIMUTH SELECTOR READING IN DEGREES
160 165 170 175 180 185 190
22 24 26 28 30 32
HORIZONTAL DISTANCE OF ARRAY TO DIPOLE IN FEET

FIG 3

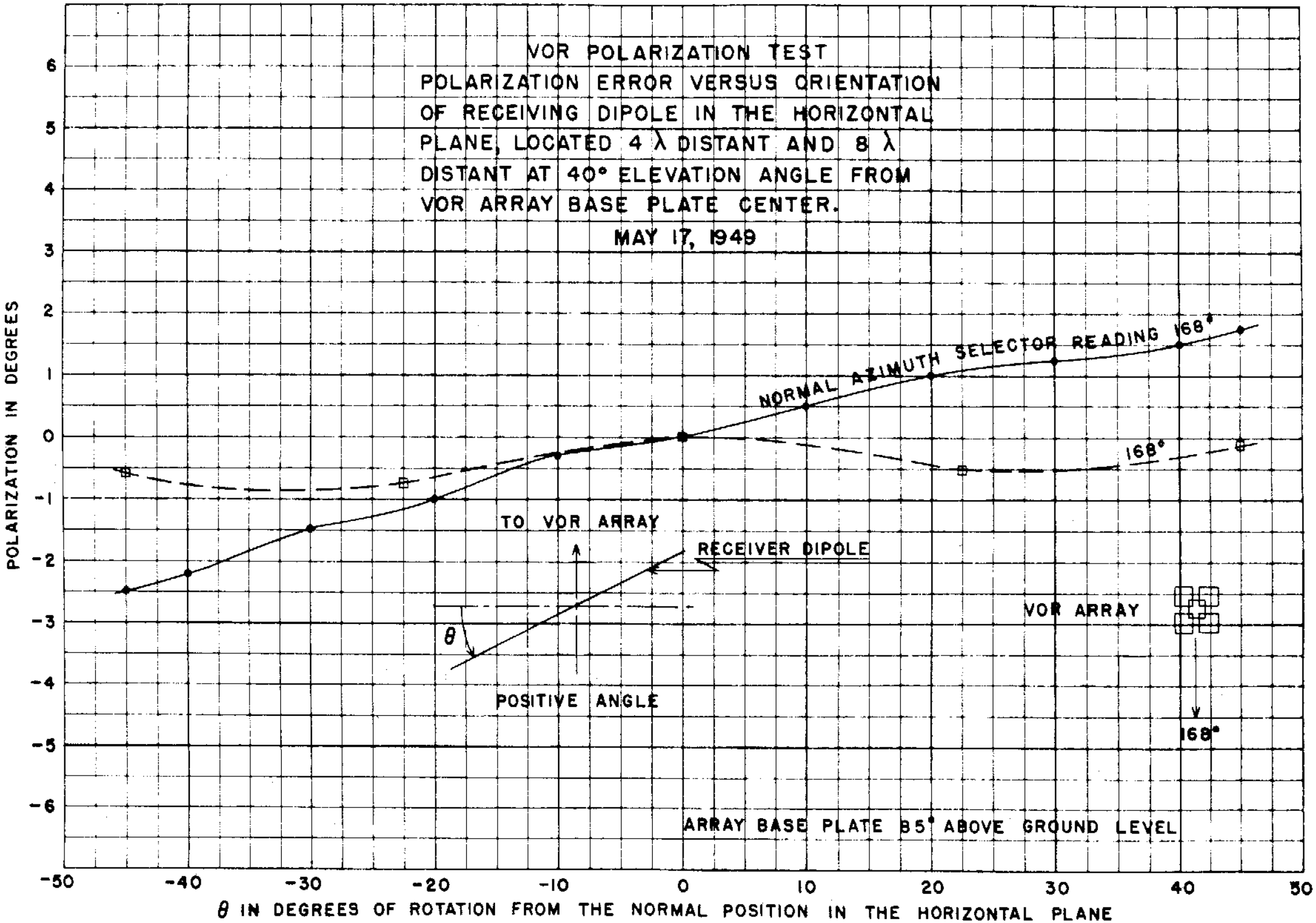

VOR POLARIZATION TEST
POLARIZATION ERROR VERSUS ORIENTATION OF RECEIVING DIPOLE IN THE HORIZONTAL PLANE, LOCATED 4 λ DISTANT AND 8 λ DISTANT AT 40° ELEVATION ANGLE FROM VOR ARRAY BASE PLATE CENTER.
MAY 17, 1949
NORMAL AZIMUTH SELECTOR READING 168°
168°
TO VOR ARRAY
RECEIVER DIPOLE
θ
POSITIVE ANGLE
VOR ARRAY
168°
ARRAY BASE PLATE 85' ABOVE GROUND LEVEL
POLARIZATION IN DEGREES
θ IN DEGREES OF ROTATION FROM THE NORMAL POSITION IN THE HORIZONTAL PLANE
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-50
-40
-30
-20
-10
0
10
20
30
40
50

FIG. 4

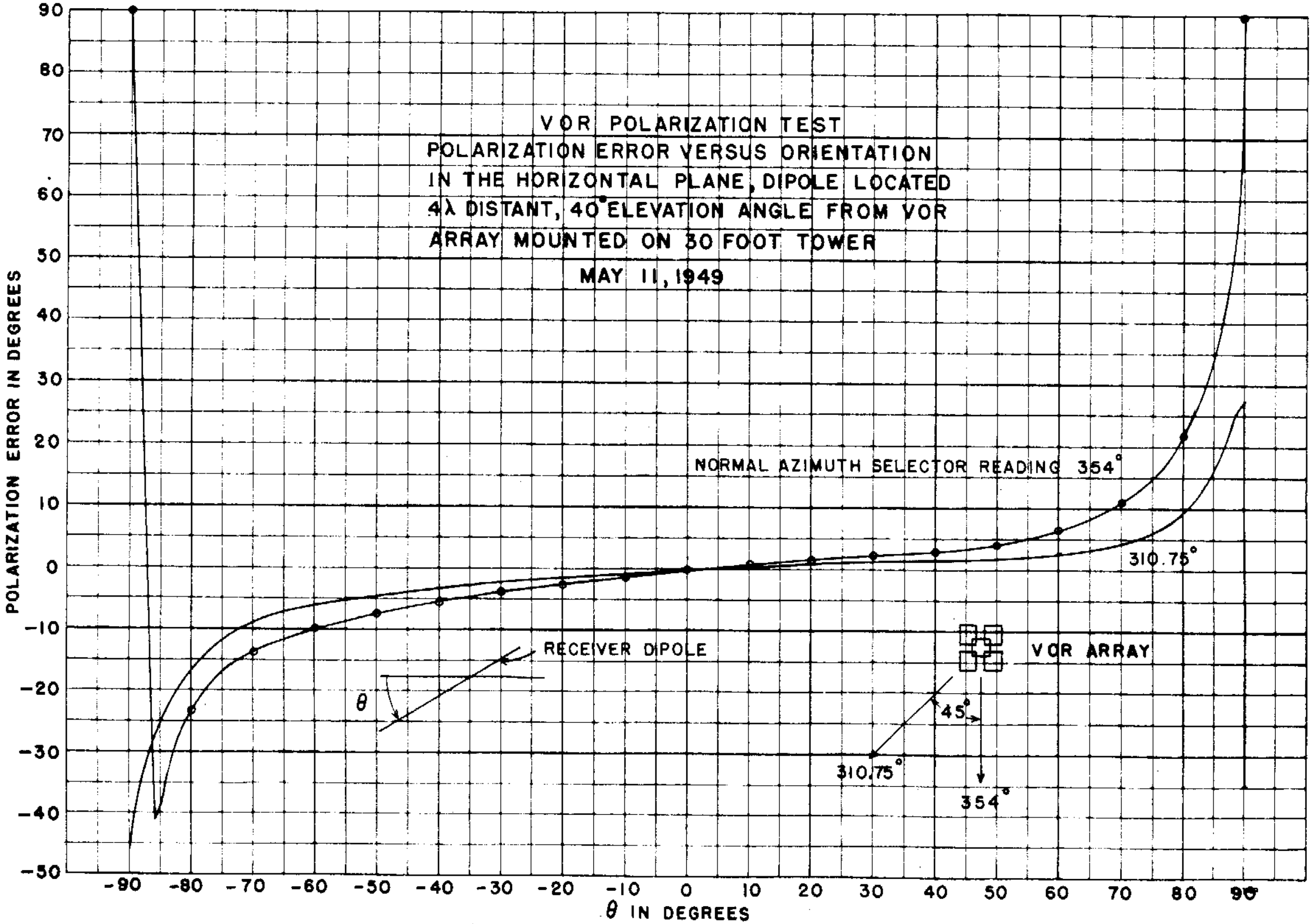

VOR POLARIZATION TEST
POLARIZATION ERROR VERSUS ORIENTATION
IN THE HORIZONTAL PLANE, DIPOLE LOCATED
4λ DISTANT, 40° ELEVATION ANGLE FROM VOR
ARRAY MOUNTED ON 30 FOOT TOWER
MAY 11, 1949
NORMAL AZIMUTH SELECTOR READING 354°
310.75°
RECEIVER DIPOLE
θ
VOR ARRAY
45°
310.75°
354°
POLARIZATION ERROR IN DEGREES
θ IN DEGREES

FIG. 5

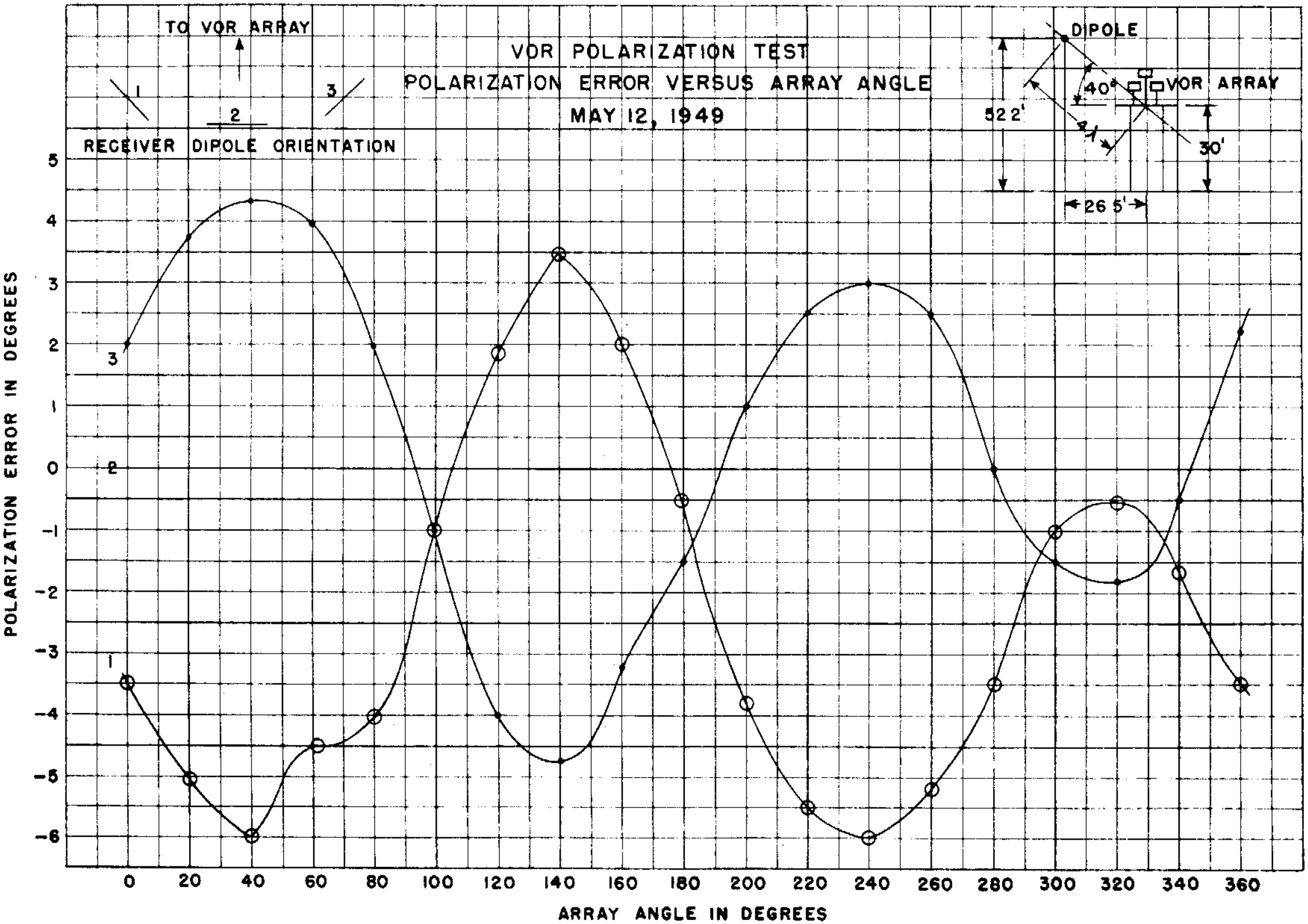

VOR POLARIZATION TEST
POLARIZATION ERROR VERSUS ARRAY ANGLE
MAY 12, 1949
TO VOR ARRAY
RECEIVER DIPOLE ORIENTATION
DIPOLE
VOR ARRAY
40°
52 2'
30'
26 5'
POLARIZATION ERROR IN DEGREES
ARRAY ANGLE IN DEGREES

FIG. 6

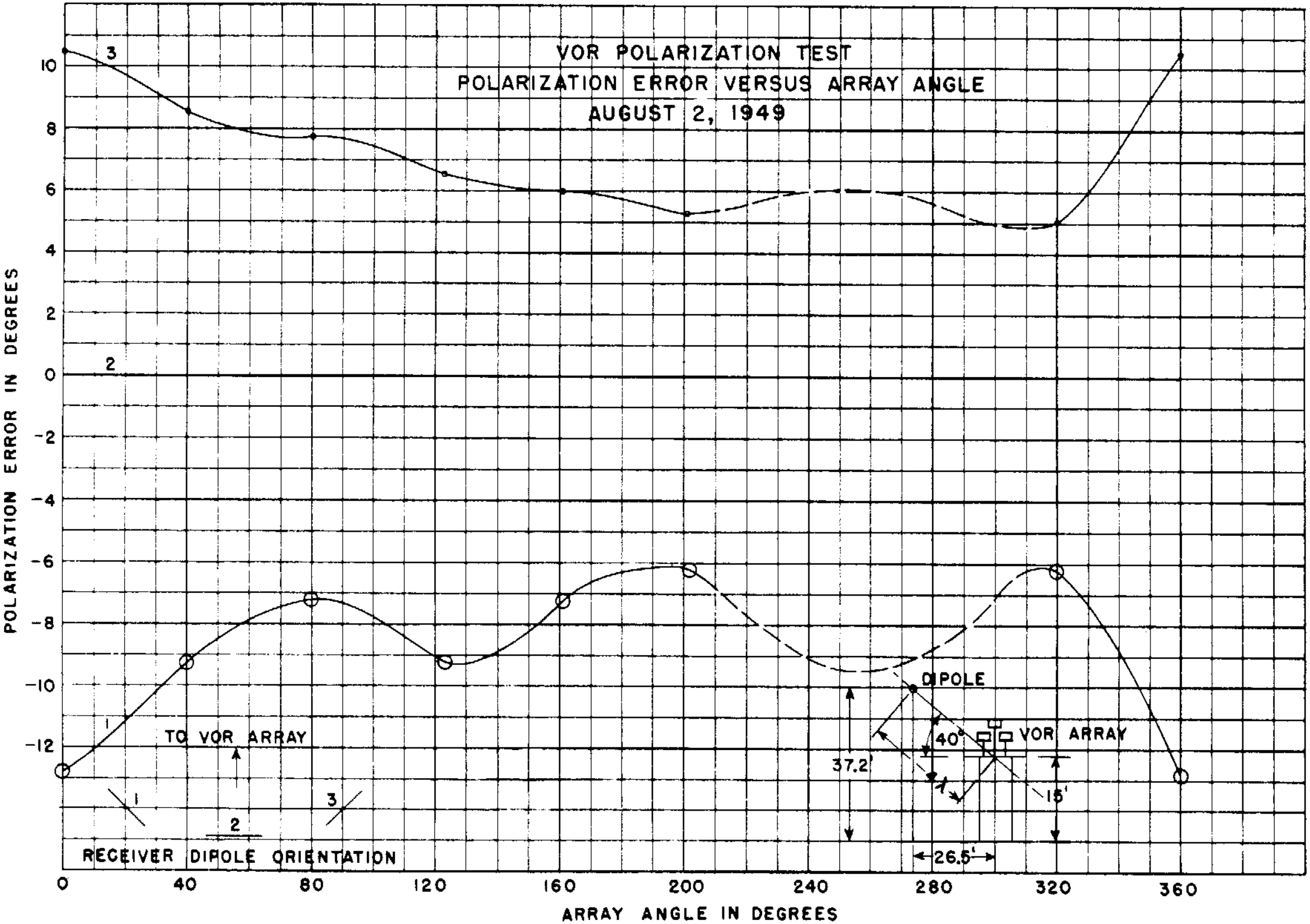

VOR POLARIZATION TEST
POLARIZATION ERROR VERSUS ARRAY ANGLE
AUGUST 2, 1949
POLARIZATION ERROR IN DEGREES
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
3
2
1
TO VOR ARRAY
1
2
3
RECEIVER DIPOLE ORIENTATION
DIPOLE
40°
VOR ARRAY
37.2'
15'
26.5'
0
40
80
120
160
200
240
280
320
360
ARRAY ANGLE IN DEGREES

FIG. 7

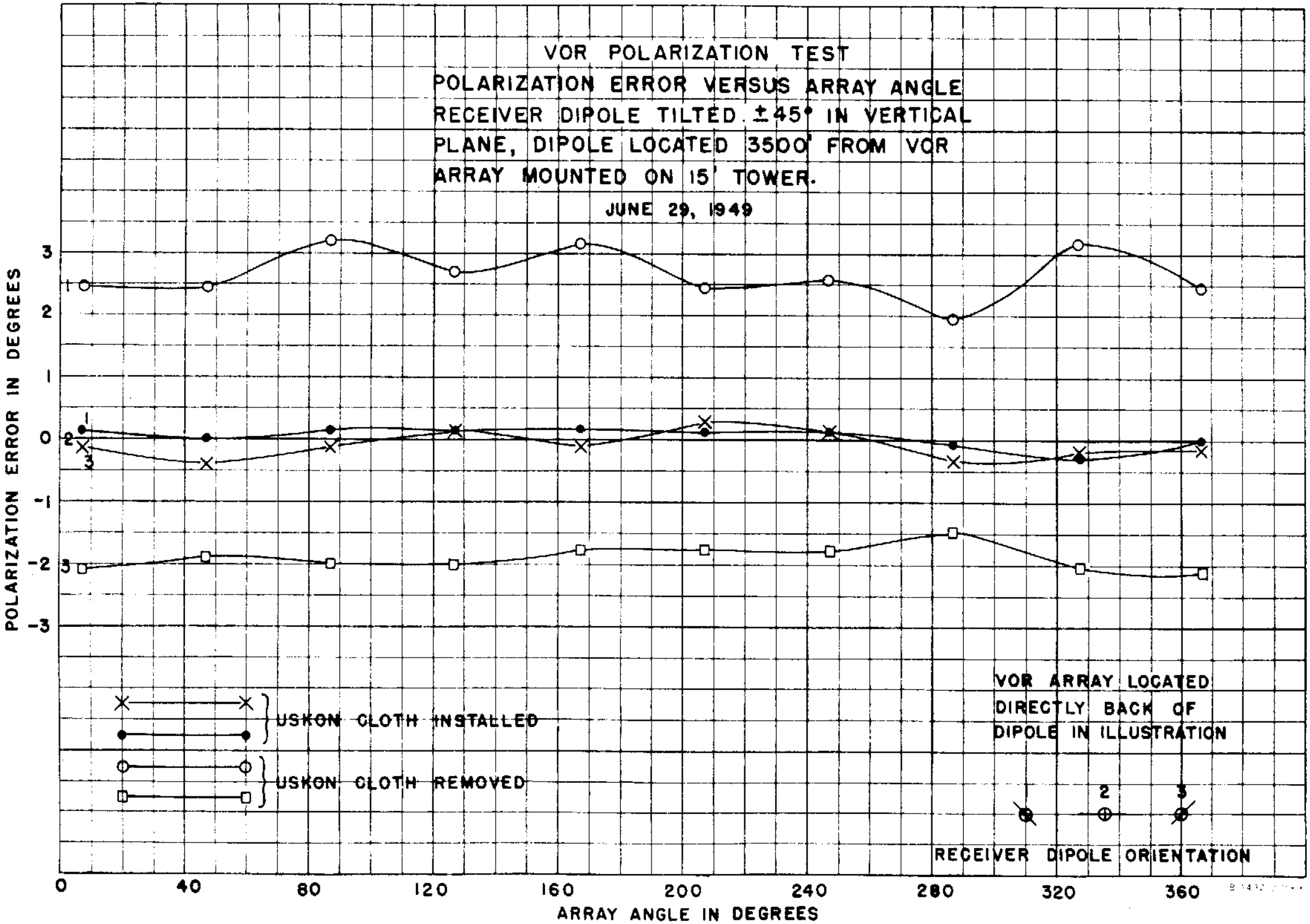

VOR POLARIZATION TEST
POLARIZATION ERROR VERSUS ARRAY ANGLE
RECEIVER DIPOLE TILTED ±45° IN VERTICAL PLANE, DIPOLE LOCATED 3500' FROM VOR
ARRAY MOUNTED ON 15' TOWER.
JUNE 29, 1949
POLARIZATION ERROR IN DEGREES
3
2
1
0
-1
-2
-3
USKON CLOTH INSTALLED
USKON CLOTH REMOVED
VOR ARRAY LOCATED DIRECTLY BACK OF DIPOLE IN ILLUSTRATION
1
2
3
RECEIVER DIPOLE ORIENTATION
0
40
80
120
160
200
240
280
320
360
ARRAY ANGLE IN DEGREES

FIG. 8

VOR POLARIZATION TEST

DISPLAY OF HORIZONTALLY POLARIZED AND VERTICALLY POLARIZED FIELD VECTORS AT AN ELEVATION ANGLE OF 40°

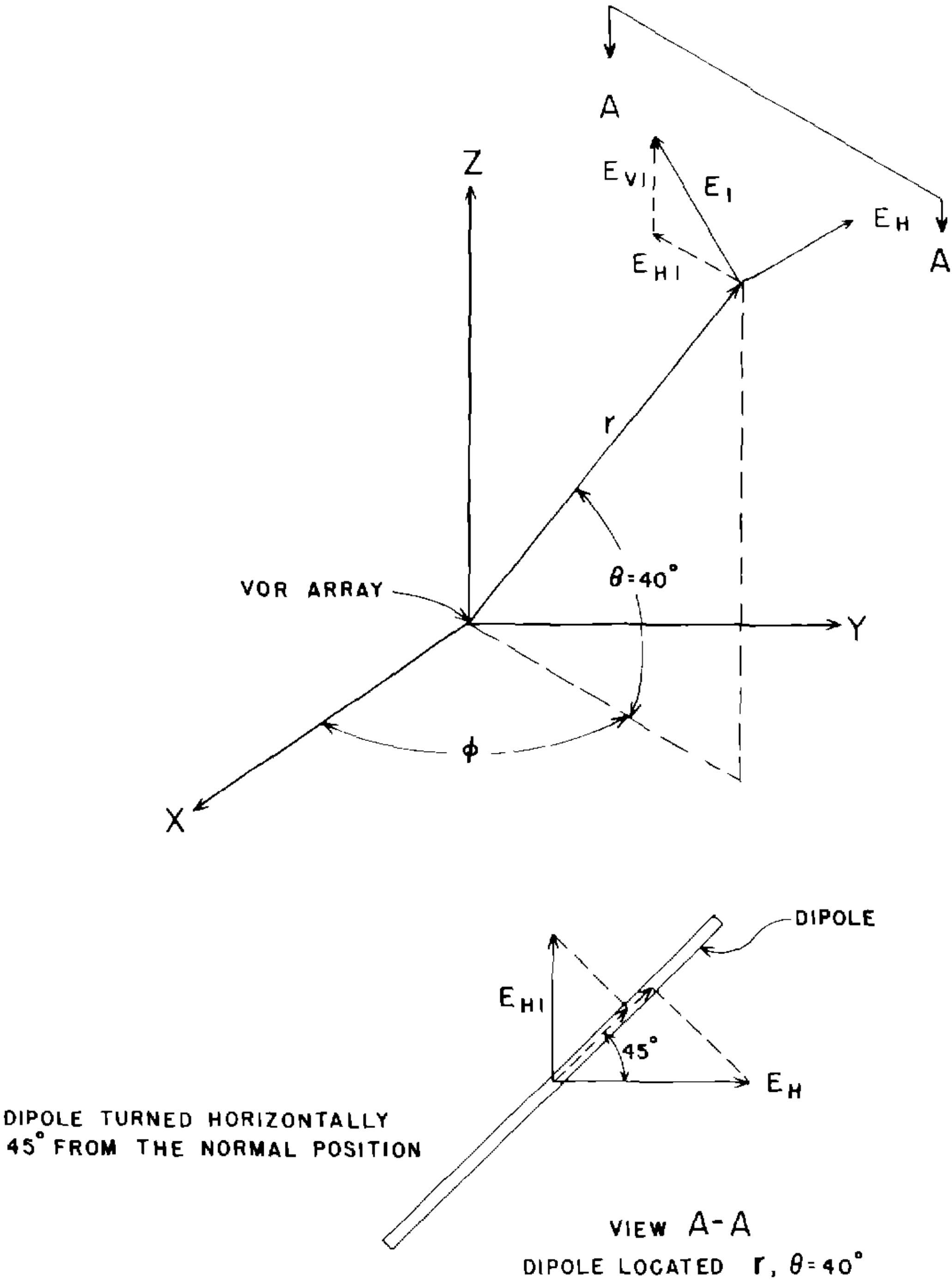


FIG 9

VOR POLARIZATION TEST

DISPLAY OF HORIZONTALLY POLARIZED AND VERTICALLY POLARIZED FIELD VECTORS AT AN ELEVATION ANGLE OF 0°

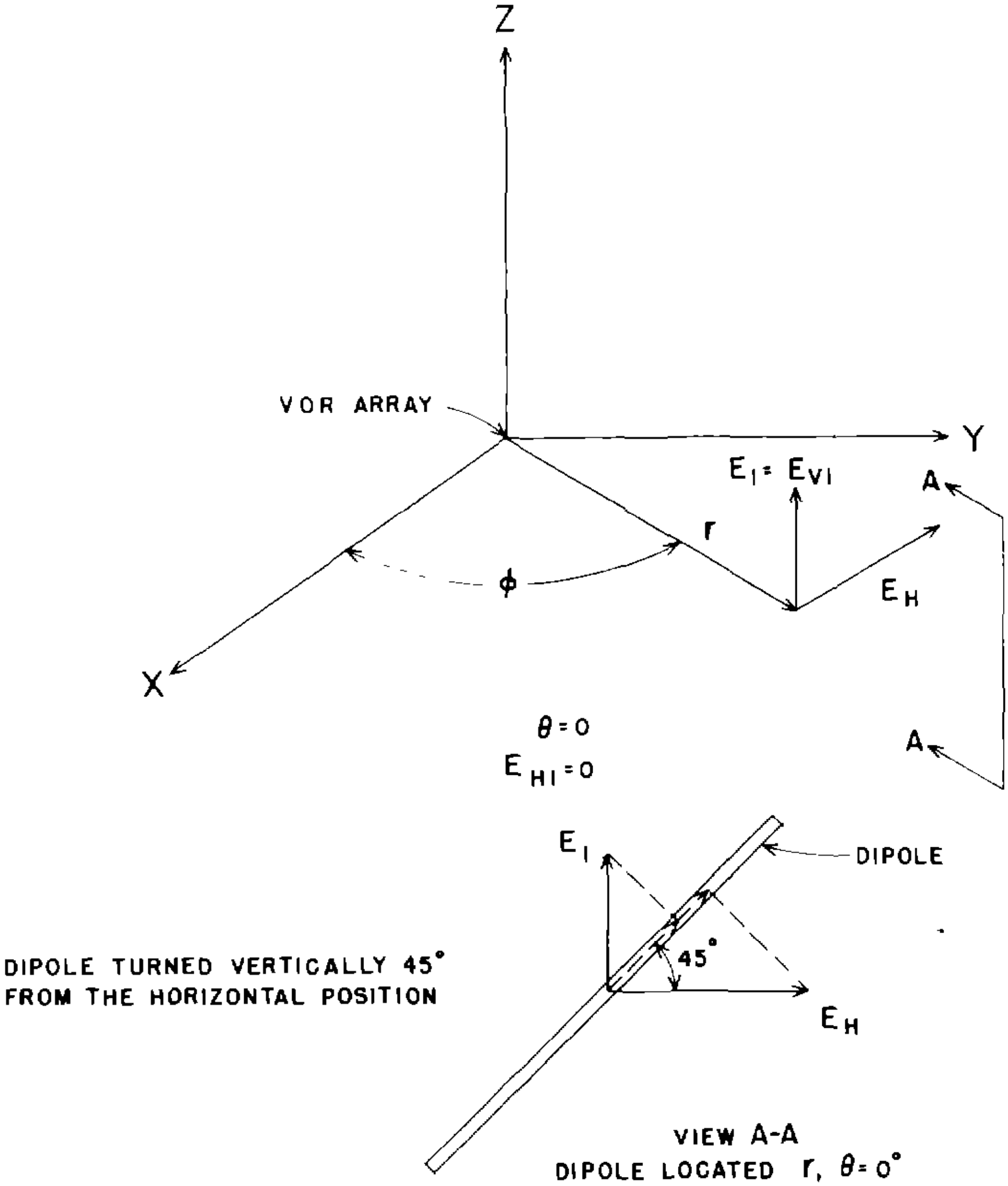


FIG 10

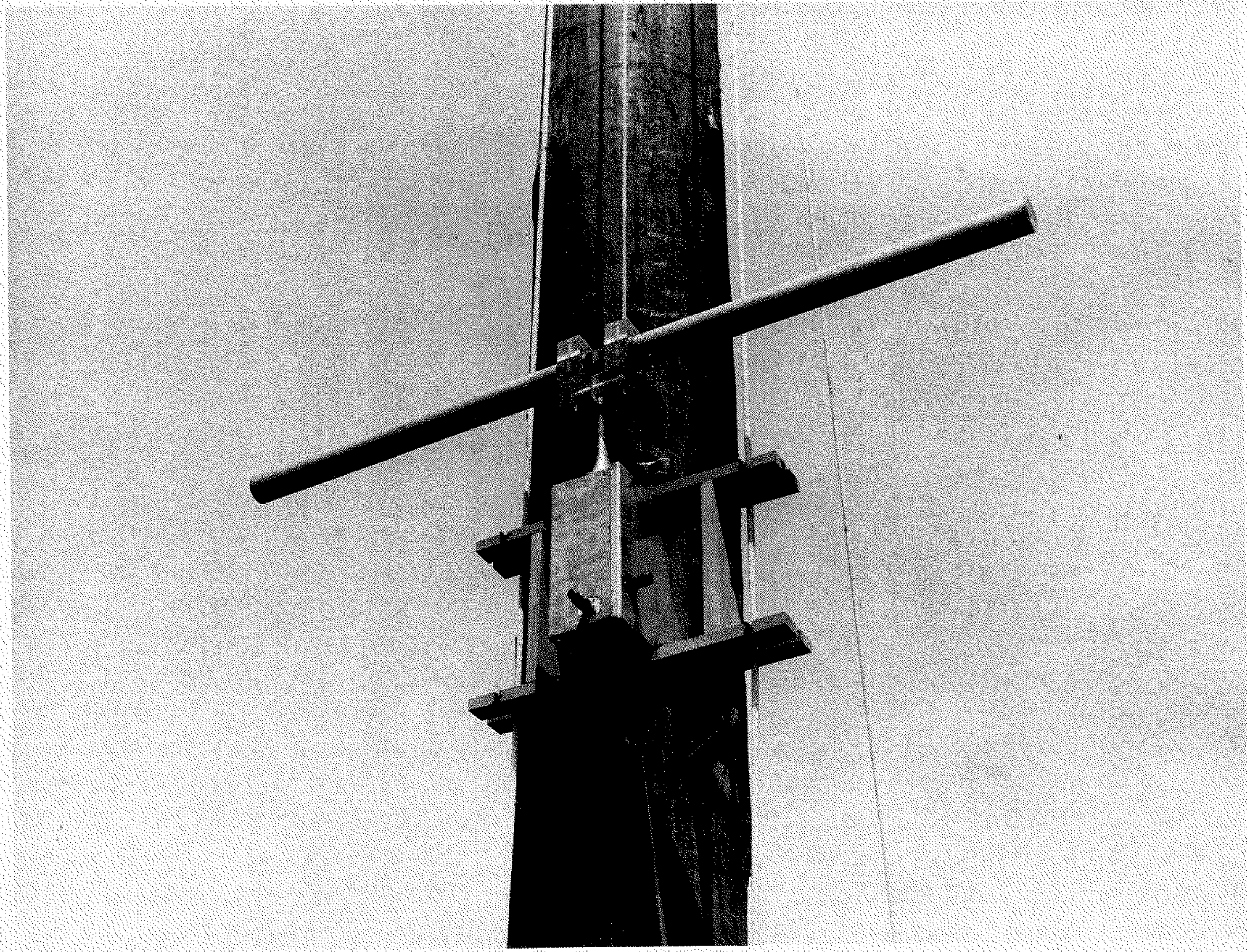


FIG. 11

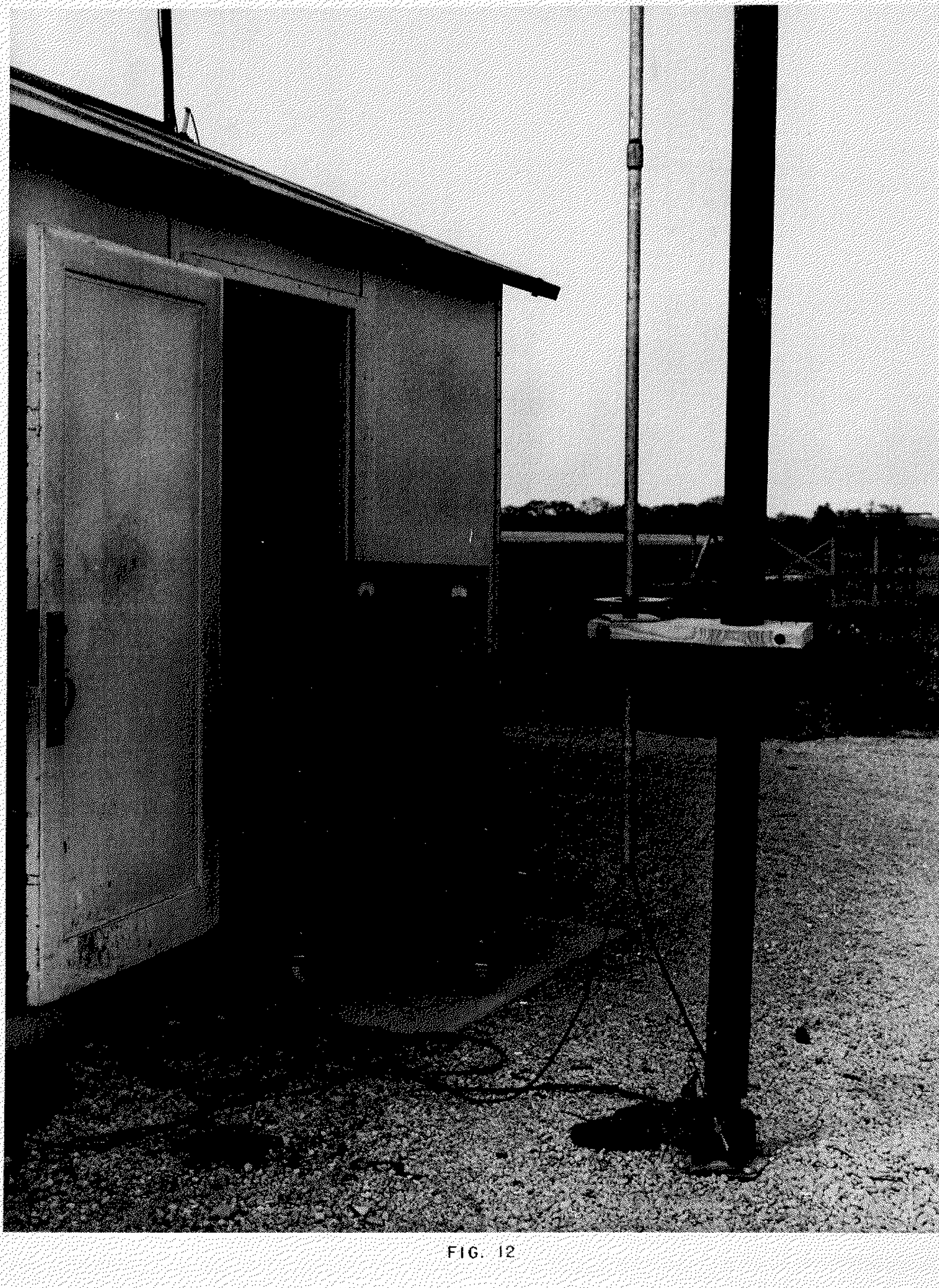


FIG. 12

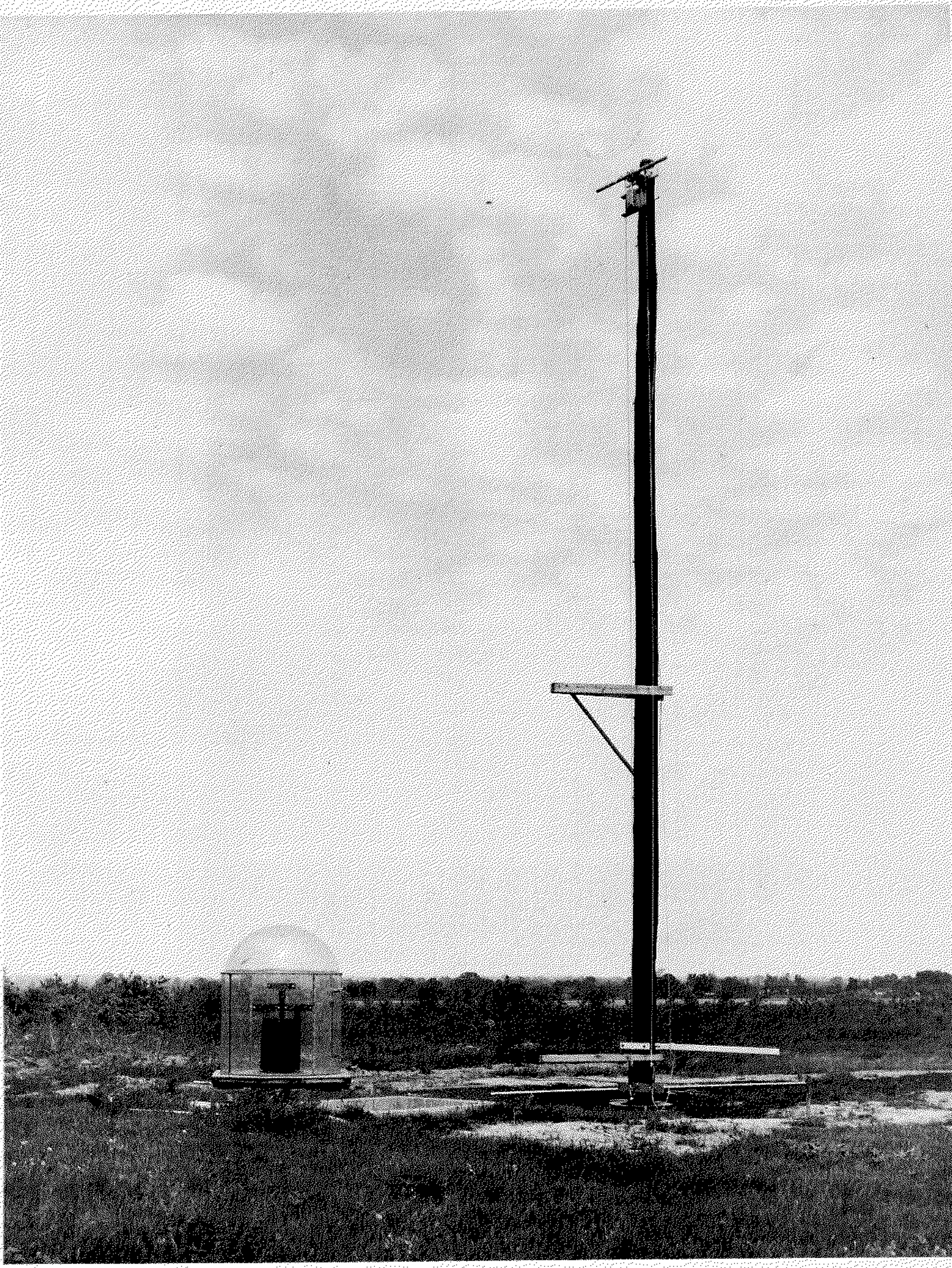


FIG. 13

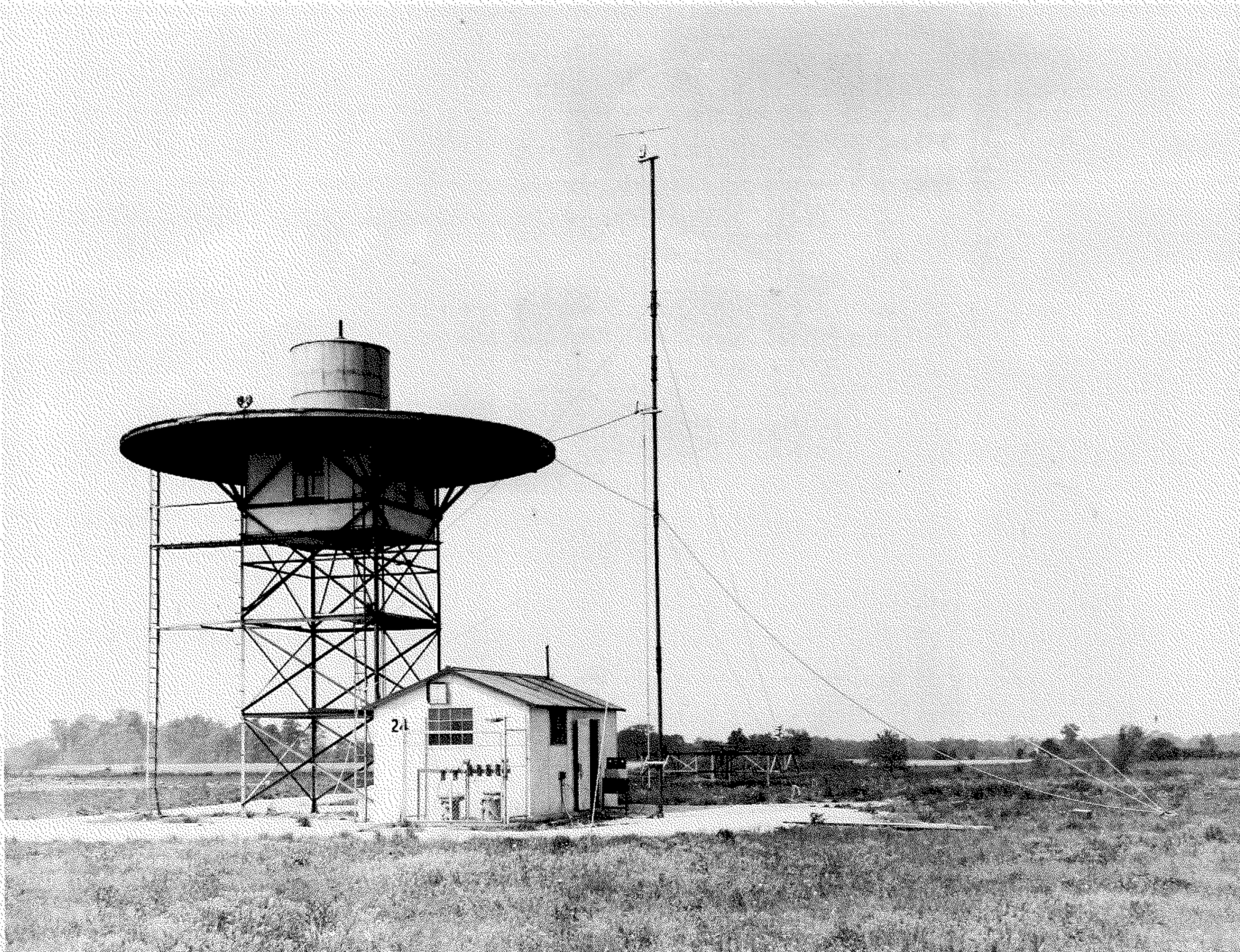


FIG. 14