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PERFORMANCE TESTS OF FOUR FEDERAL AIRWAYS VOR FACILITIES

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by

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SUMMARY

Tests were conducted to determine the cause and extent of certain bearing errors observed on the VOR stations at Alma, Georgia; Columbia, South Carolina; and Elizabeth City, North Carolina. The Alma VOR was found to be operating within prescribed tolerances. The VOR at Columbia was located on an unsatisfactory site which accounted for its general poor performance. Course scalloping at the Elizabeth City VOR was excessive and accounted for its poor performance. A fourth site at Wilmington, North Carolina, was selected for comparison tests using portable VOR equipment. All tests indicated that a VOR located on this site would be a good facility.

In addition to the performance tests conducted at each site, tests also were conducted to determine the differences in the reflectivity of radio waves at omnirange frequencies of the various types of soils. A comparison of the results obtained at Wilmington and Alma, which were very similar sites, but with great differences in soil composition, confirmed a theoretical analysis, within the precision of measurement, that no difference exists in the reflection properties of these two types of soil.

INTRODUCTION

Difficulties have been experienced in siting VOR facilities along the east coast of CAA Region Two. A VOR facility which performs satisfactorily at one site may exceed established tolerances at another site having apparently similar characteristics. Since the VOR equipment is of uniform design and construction, the site is considered the sole source of the difficulties encountered.

Since great differences exist in the composition of the soils at the various sites, it was believed that these differences might be affecting the performance of the VOR facilities. It was further believed that the coefficient of reflection of radio waves at the omnirange frequencies might differ considerably for different types of soil. Such differences in the coefficient of reflection could alter the radiation patterns in the vertical plane sufficiently to produce the observed differences in VOR performance.

In view of the fact that siting is extremely important to the successful operation of a VOR, the Office of Federal Airways requested the Technical Development and Evaluation Center to investigate some of the difficulties encountered. Three of the Region Two VOR facilities, Alma, Georgia; Columbia, South Carolina, and Elizabeth City, North Carolina, were chosen for the tests because of their reported poor performance. A fourth site at Wilmington, North Carolina, was included for comparison purposes because of its apparently excellent characteristics. This report presents the findings of the investigations conducted at the four VOR facilities.

FLIGHT TESTS AND RESULTS

Wilmington, North Carolina

The Wilmington site is on black sandy loam in generally flat terrain. A medium stand of pine trees, averaging 30 feet in height have been removed within a radius of 2,000 feet from the facility. A topographical map of the site is shown in Fig. 1.

A portable VOR supplied by Region Two was used as the test facility. A theodolite-controlled flight calibration circle of six miles radius was flown to provide an accurate check on the performance of the VOR station. Figure 2 shows the results of this test. The shape of the calibration curve indicates that cross-coupling existed between the variable phase and reference phase modulations. Either faulty modulation eliminator tubes or slope detection of the reference phase modulation in the modulator can produce such cross-coupling. A calibration circle of 20 miles radius was flown about the omnirange to verify the results of the theodolite-controlled calibration and to permit a closer study of the course scalloping due to reflections. The results of the 20-mile radius calibration are shown in Fig. 3. The 6-mile and 20-mile calibration curves are similar in general shape, and the increase in magnitude of the 20-mile bearing error is attributed to inaccuracies in the check points used. Flight recordings made under theodolite control, along the airway radials 167° and 347°, failed to reveal any course scalloping. The course scalloping which appeared on the 20-mile calibration recording was analyzed for frequency and magnitude. Since the response of the course deviation indicator varies with the course scalloping frequency, it was necessary to convert the scalloping amplitude to that which would be observed as the course scalloping frequency approached zero[1]. Figure 4 is a graphic representation of the measured course scalloping frequency and amplitude and the zero-frequency amplitude for each 10° sector.

The source of course scalloping can often be isolated and attributed to prominent objects in the vicinity of the facility, such as power lines, buildings, or towers. A comparison is made between the course scalloping

[1] S. R. Anderson, T. S. Wonnell, "The Development and Testing of the Terminal VHF Omnirange," TDEC Report No. 225, Figure 22.

frequency observed and the computed course scalloping frequency of an assumed source of reflections[2]. Table I presents the results of a study of the course scalloping for this site in which the power line was the assumed source of reflections.

A single loop antenna, driven by approximately eight watts of r-f power, was elevated to a height of 59 feet above the ground on a telescoping tower. Field strength measurements were recorded in the vertical plane to determine the reflectivity of the soil for radio waves at omnirange frequencies. The resulting vertical plane pattern is shown in Fig. 5. The ratio of maximum to minimum field strength is 18.53 between elevation angles of 4° and 6°.

Alma, Georgia

This VOR facility is located on the flat sandy terrain of a former military airport. Trees which surround the facility have been removed for a radius of 2,000 feet or more from the VOR. The remaining trees average 50 feet in height. Figure 6 shows the position of the VOR in relation to the surrounding trees and other major obstructions.

Region Two had installed the VOR to serve as an enroute omnirange facility on the Atlanta-Miami airway; however, they reported that due to excessive course scalloping on the airway radials it could not be commissioned for operational use. Modernization of the facility failed to reduce the course scalloping sufficiently to fulfill established requirements.

A 6-mile radius theodolite-controlled calibration circle was flown to check the performance of the VOR. The results of this flight shown in Fig. 7 indicate an over-all bearing error spread of 2.9°, the curve having a normal octantal shape. A 20-mile radius calibration circle, using the check point method, was flown to verify previous results and to permit a close study of the course scalloping. The shape of the 20-mile radius calibration curve is similar to that of the 6-mile calibration curve, however, the over-all bearing error was 4.5° as shown in Fig. 8. A study of the course scalloping from the recordings of the 20-mile radius calibration, showed that most of the scalloping is non-sinusoidal, a characteristic of scalloping caused by trees. The analysis of the maximum course scalloping observed in each 10° sector is shown in Fig. 9. The computed zero-frequency scalloping exceeded the established maximum of ±2° in only one sector.

[2] S. R. Anderson, H. F. Keary, "VHF Omnirange Wave Reflections From Wires," TDEC Report No. 126, Appendices I, II, and III.

A field strength recording was made of the test antenna at this site to determine the reflectivity of the soil. Figure 10 shows the resulting pattern obtained from the field strength measurements in which the ratio of the maximum at 5.5° to the minimum at 3.75° is 20.25. This ratio is 9 per cent higher than the corresponding ratio measured at Wilmington. Errors introduced in making the measurements may account for the 9 per cent difference.

Columbia, South Carolina

The Columbia, South Carolina, VOR is located on leveled terrain on the side of a hill. The terrain rises to the southwest and drops off rapidly to the north. Trees, whose heights range from 5 feet to 70 feet, surround the facility at distances greater than 750 feet from the VOR; however, patches of small brush averaging 5 to 6 feet in height extend between 250 feet and 750 feet on the north side of the station. The relationship between the location of the station and the surrounding obstructions is shown in Fig. 11.

This VOR facility had been placed in operational use. However, it was reported by Region Two that, at best, its performance was marginal. Excessive bearing errors and severe scalloping on many radials were the principle deficiencies

A recording of the 6-mile radius theodolite-controlled calibration circle revealed an over-all bearing error of 3.8°. The calibration curve, shown in Fig. 12, has a quadrantal shape indicating an unbalance in the sideband amplitudes The calibration curve for the 20-mile radius circle was of the same general shape as the 6-mile radius curve, however, the over-all bearing error spread increased to 8.2° as shown in Fig. 13. The increase in magnitude of the bearing error for the 20-mile radius circle indicates that the site is responsible for the increase.

The course scalloping recorded on the 20-mile radius circle was analyzed for maximum scalloping amplitude and frequency in each 10° sector as shown in Fig. 14. The zero-frequency scalloping amplitude exceeds established minimum requirements in several sectors.

A field strength recording was made at this site using the test antenna and the resulting vertical plane pattern is shown in Fig. 15. The folding-over of the maximum between 3° and 6° elevation was caused by the falling away of the terrain north of the station.

Elizabeth City, North Carolina

The Elizabeth City, North Carolina, VOR is located on flat terrain free of obstructions for a minimum radius of 1500 feet. A dense wooded area, having trees 90 feet high, is located approximately 2250 feet from the VOR at an azimuth of 240°. Power lines, 20 to 40 feet high, enclose three sides of the site at distances of 1500 feet or more. Figure 16 shows the relationship of the VOR to the surrounding obstructions.

This VOR had been operating on a test basis because excessive course scalloping prevented commissioning of the facility for operational use. This site was formerly used for the VAR facility on the New York-Jacksonville airway.

The curve for the 6-mile radius theodolite-controlled calibration shows an over-all bearing error of 5.5° as shown in Fig. 17. The change in the shape of the calibration curve between 180° and 360° is caused by a displacement of the nulls of the horizontal field pattern, occurring at 225° and 315°. Further evidence of this condition is noted in the calibration curve for the 20-mile radius circle, shown in Fig. 18. The over-all bearing error for the 20-mile radius calibration was 6.8°. A reduction of the over-all bearing error would be possible by retuning and correct placement of the nulls of the horizontal field pattern.

The course scalloping amplitude and frequency were analyzed from the recording of the 20-mile radius circle and plotted graphically for each 10° sector as shown in Fig. 19. The zero-frequency scalloping was excessive in many sectors. Course scalloping on the recordings indicated several sources of reflection, and results of the study to determine the sources of reflection are given in Table II. A field strength recording was made with the test antenna at this site. Also, the resulting vertical plane pattern is shown in Fig. 20.

CONCLUSIONS

1. Tests conducted at the VOR sites at Alma, Georgia, and Wilmington, North Carolina, substantiated a theoretical analysis that the difference in composition of various soils does not alter the reflectivity at VOR frequencies and, therefore, the difference in amplitude of scalloping between the two stations is not caused by difference in soil composition.

2. The VOR facility at Alma, Georgia, performed within the operational limits established by the Office of Federal Airways.

3. A generally undesirable site is the principle cause of the poor performance of the VOR facility at Columbia, South Carolina.

4. All flight data obtained on the site at Wilmington, North Carolina, indicated that this was an acceptable location for a VOR facility. Rerouting the power line located 1100 feet north of the station will eliminate the major source of course scalloping.

5 Numerous reflection sources in the proximity of the VOR site at Elizabeth City, North Carolina, accounted for its poor performance.

TABLE I
SCALLOPING CHARACTERISTICS OF WILMINGTON, N. C., VOR SITE

Magnetic Bearing Degrees	Maximum Scalloping Amplitude Degrees	Scalloping Frequency Measured cps	Zero Frequency Scalloping Amplitude Degrees	d_1 Feet	$\frac{r_o}{d_1}$	ϕ Degrees	Scallop Frequency Calculated cps	Assumed Source of Scalloping
112	±.25	.6	±1.15	2260	43.7	152	.53	EW Power line
120	±.3	.44	±1.0	1760	55.2	168	.46	Located 1100' nort
125	±.4	.434	±1.3	1600	61	178	.426	
132	±.4	.357	±1.1	1440	70	192	.36	
149	±.55	.206	±.9	1220	93.4	226	.195	
199	±.6	.232	±1.15	1270	84	326	.258	
208	±.55	.266	±1.15	1440	71.5	344	.35	
213	±.4	.33	±1.0	1520	66.8	354	.388	
221	±.4	.5	±1.5	1800	55.7	10	.46	

Note: Symbols refer to TDEC Report No. 126, Appendices I, II, and III.
S. R. Anderson and H. F. Keary "VHF Omnirange Wave Reflections from Wires"

TABLE II
Course Scalloping at the VOR Facility Elizabeth City, N. C.

Magnetic Bearing Degrees	Measured Scalloping Degrees	Measured Scalloping Frequency cps	Zero Frequency Scalloping Amplitude Degrees	d_1 Feet	$\frac{r_o}{d_1}$	ϕ Degrees	Calculated Scalloping Frequency cps	Assumed Source of Scalloping
75	±.65	.135	±.76	1500	72.1	114	.148	Metal roofs of
82	±.5	.219	±.88	1500	73.9	121	.183	buildings 1500 feet
99	±1.25	.377	±3.66	1500	61.9	138	.315	from VOR at 50°
107	±.5	.416	±1.57	1500	62.3	146	.349	magnetic
117	±1.0	.461	±3.43	2700	38.3	230	.445	NE-SW power line 2500 feet east of VOR
152	±.35	.571	±1.6	2225	45.5	182	.572	East-west power line
162	±.35	.43	±1.15	1910	54.7	202	.444	1500 feet north of VOR
249	±.75	.12	±.84	1500	63.3	288	.128	Metal roofs of
256	±1.4	.161	±1.76	1500	63.7	295	.175	buildings 1500 feet
266	±1.3	.243	±2.63	1500	63.7	305	.237	from VOR at 50°
276	±1.4	.277	±2.93	1500	62.6	315	.297	magnetic
284	±1.0	.434	±3.25	1500	61.9	323	.339	
297	±.4	.421	±1.27	2350	42	49	.413	Grain elevator and
304	±.4	.425	±1.27	2350	42	56	.353	dryer 2350 feet from
314	±.3	.25	±.63	2350	38.8	66	.278	VOR at 338° magnetic
322	± 5	.17	±.65	2350	38.1	74	.193	

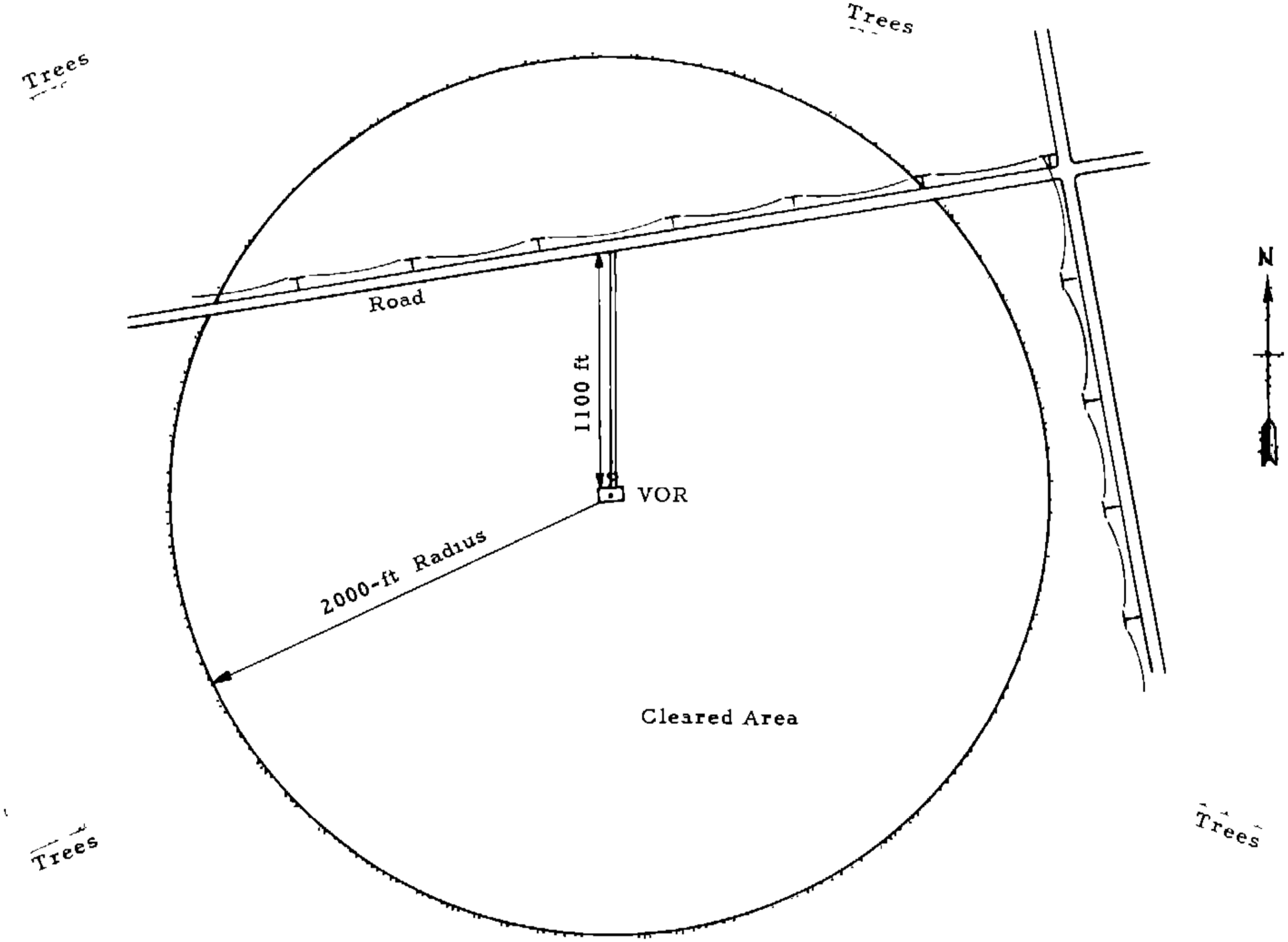

FIG 1 VOR SITE--WILMINGTON, N C

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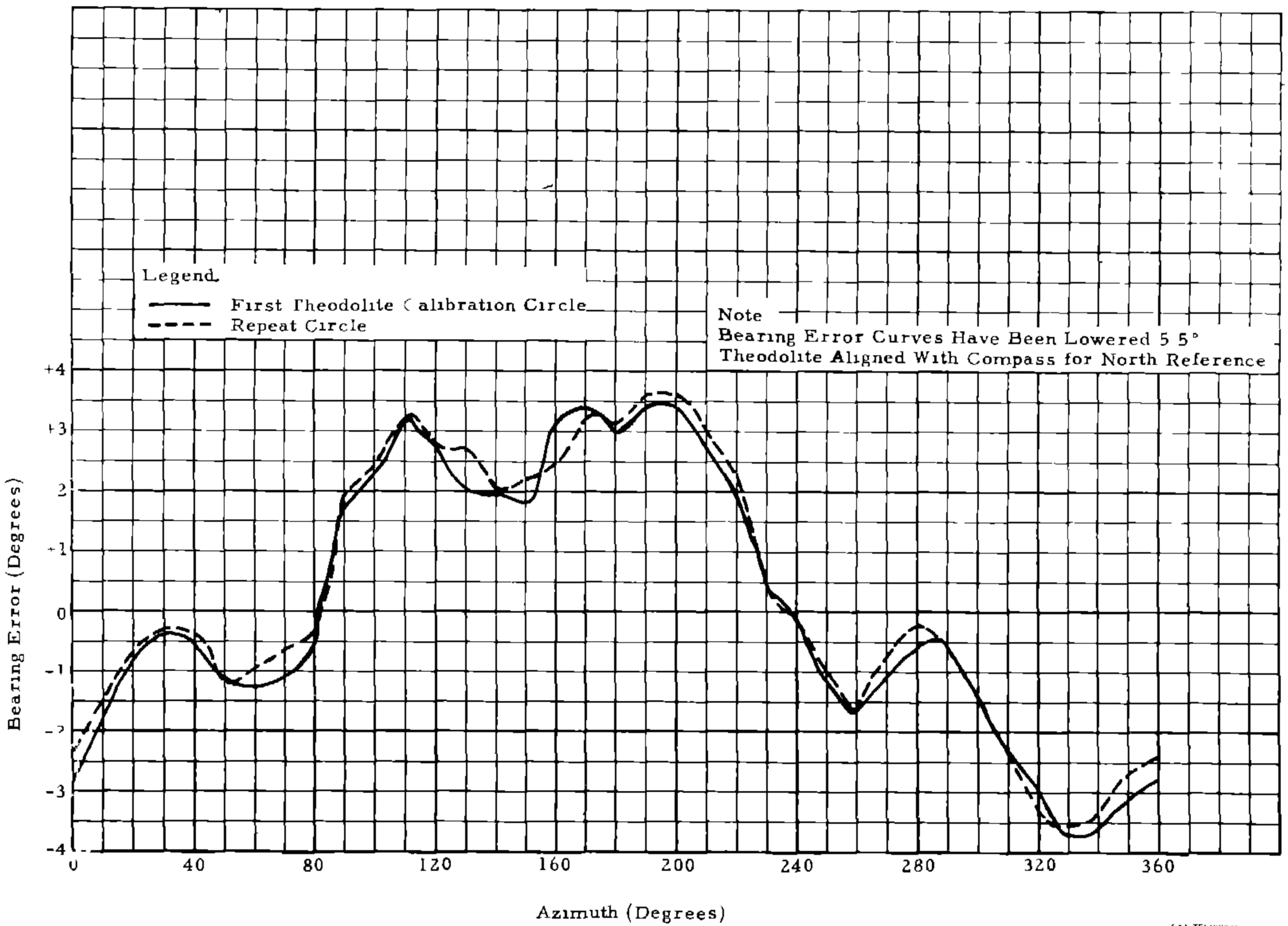

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FIG 2 SIX-MILE THEODOLITE CALIBRATION CURVE--WILMINGTON, N C

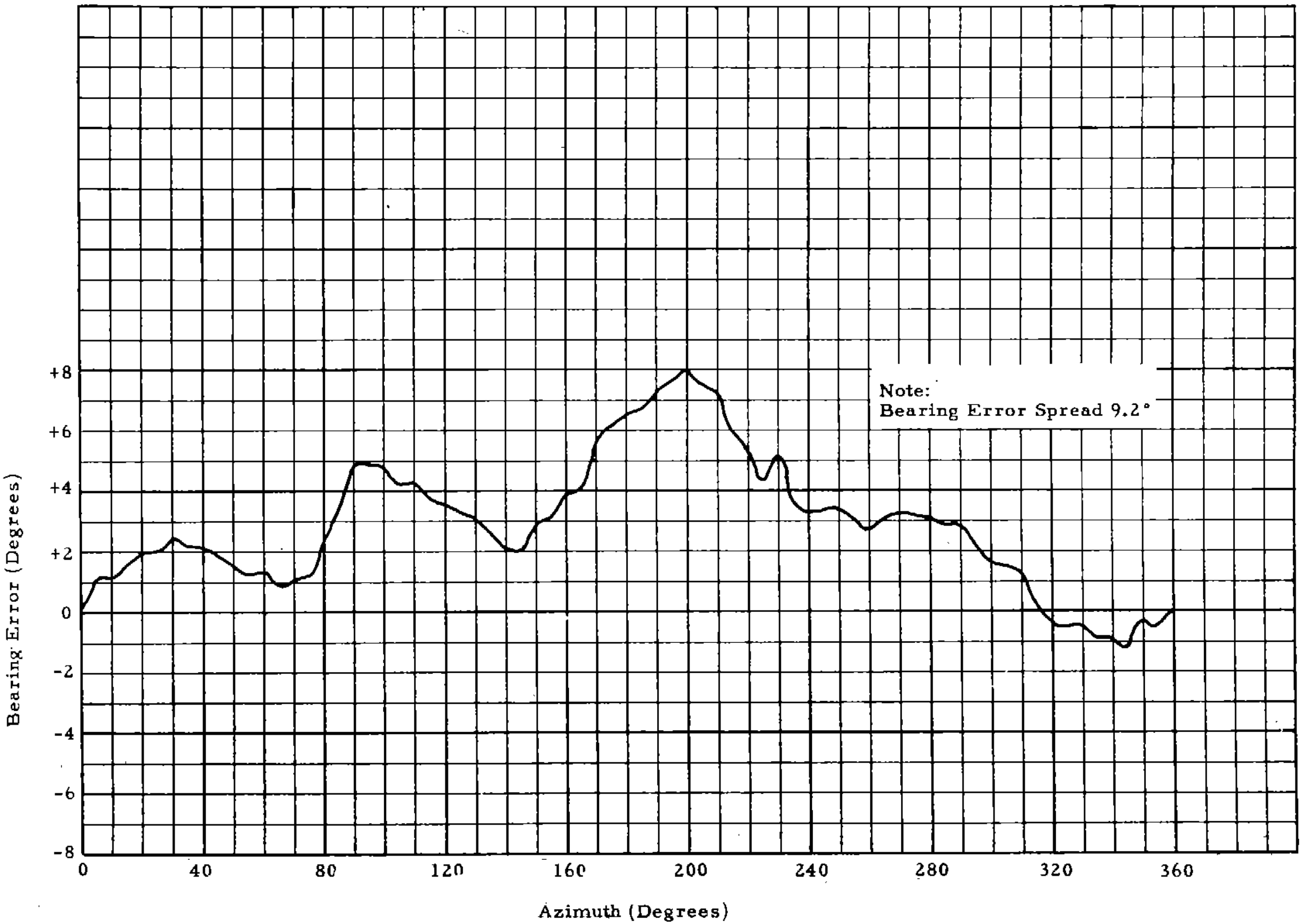

FIG. 3 TWENTY-MILE CALIBRATION CURVE--WILMINGTON, N. C.

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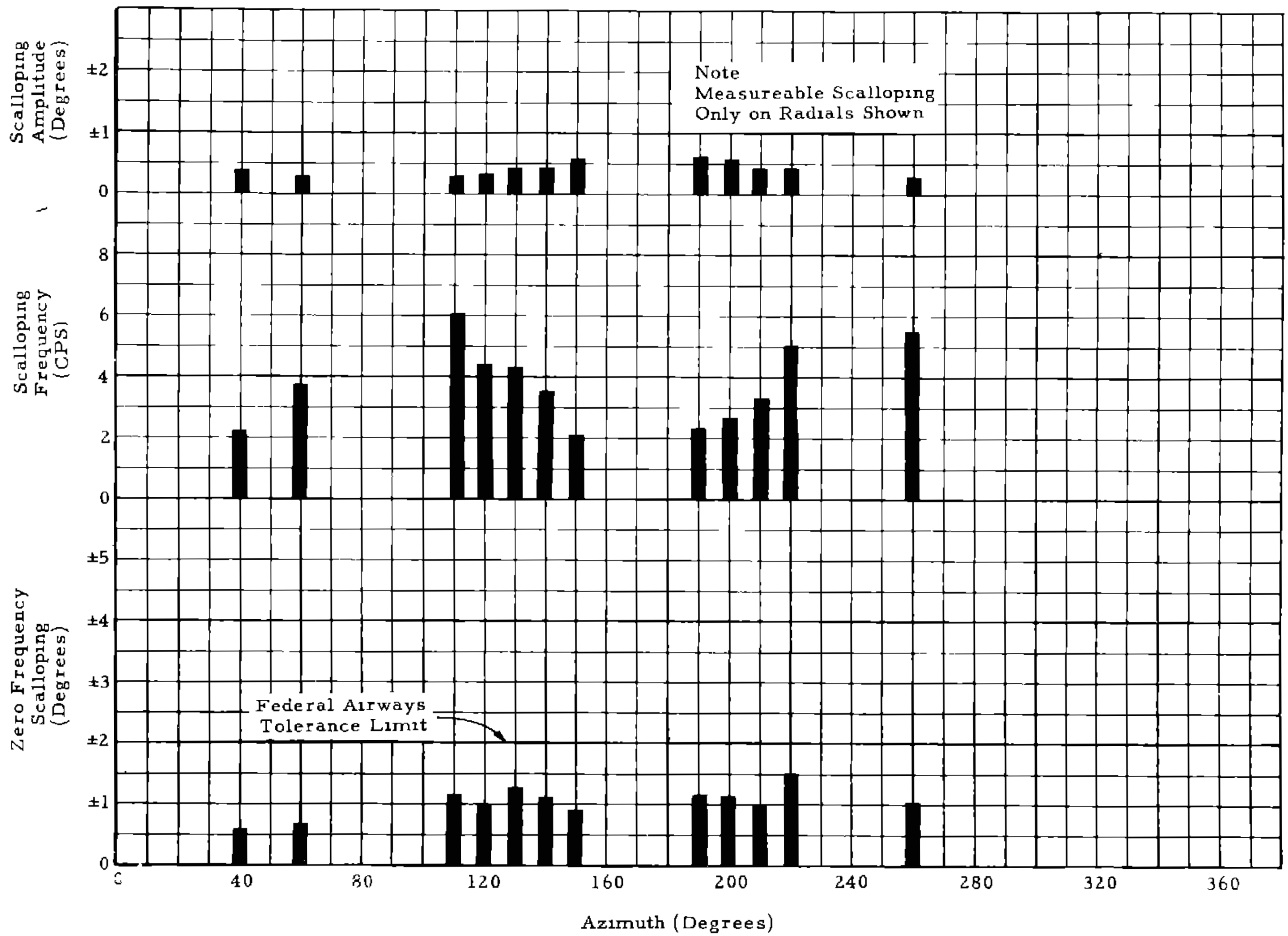

FIG 4 SCALLOPING ON 20-MILE RADIUS CALIBRATION CIRCLE--WILMINGTON, N C , VOR

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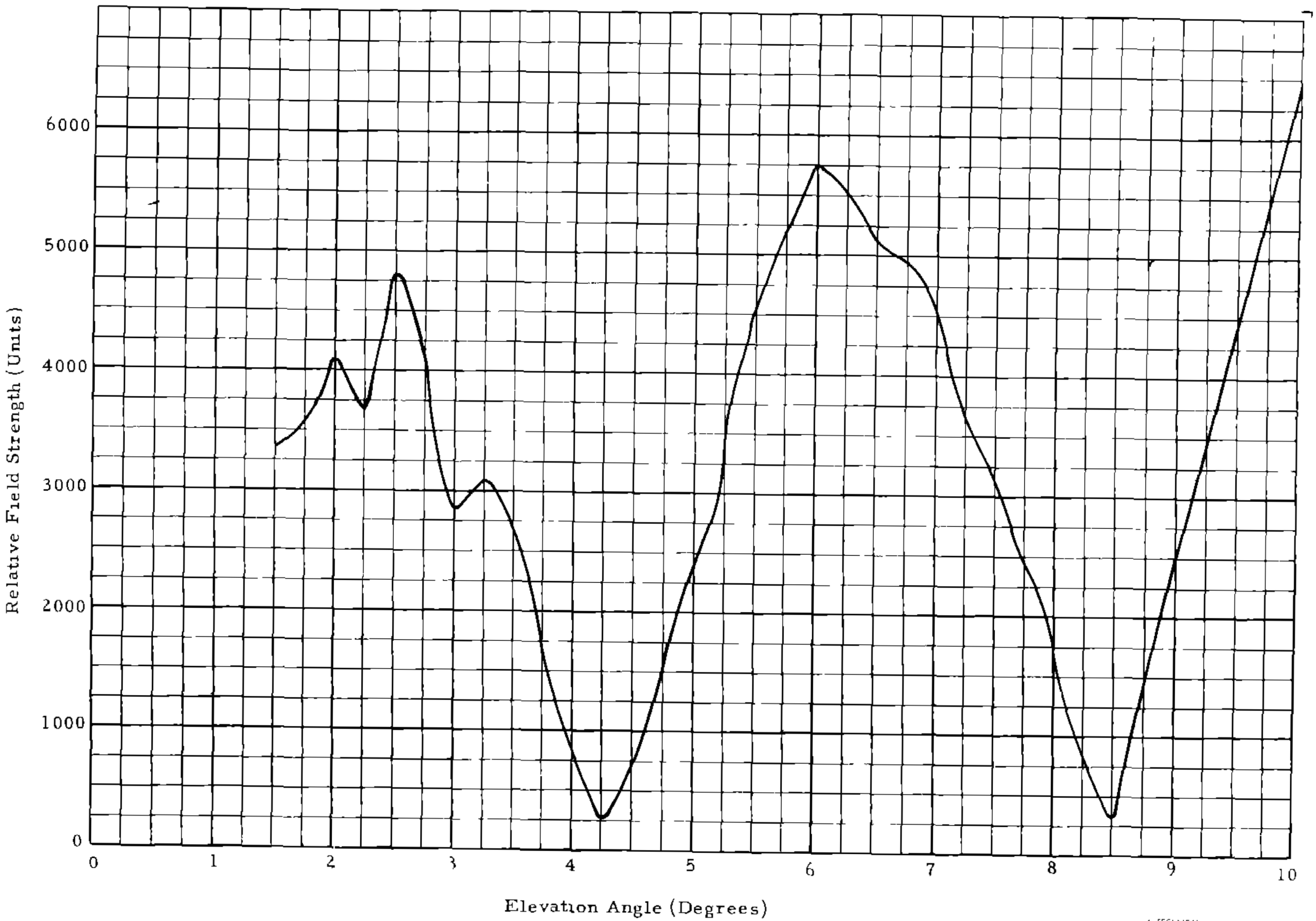

FIG 5 VERTICAL PLANE PATTERN OF LOOP ANTENNA--WILMINGTON, N C

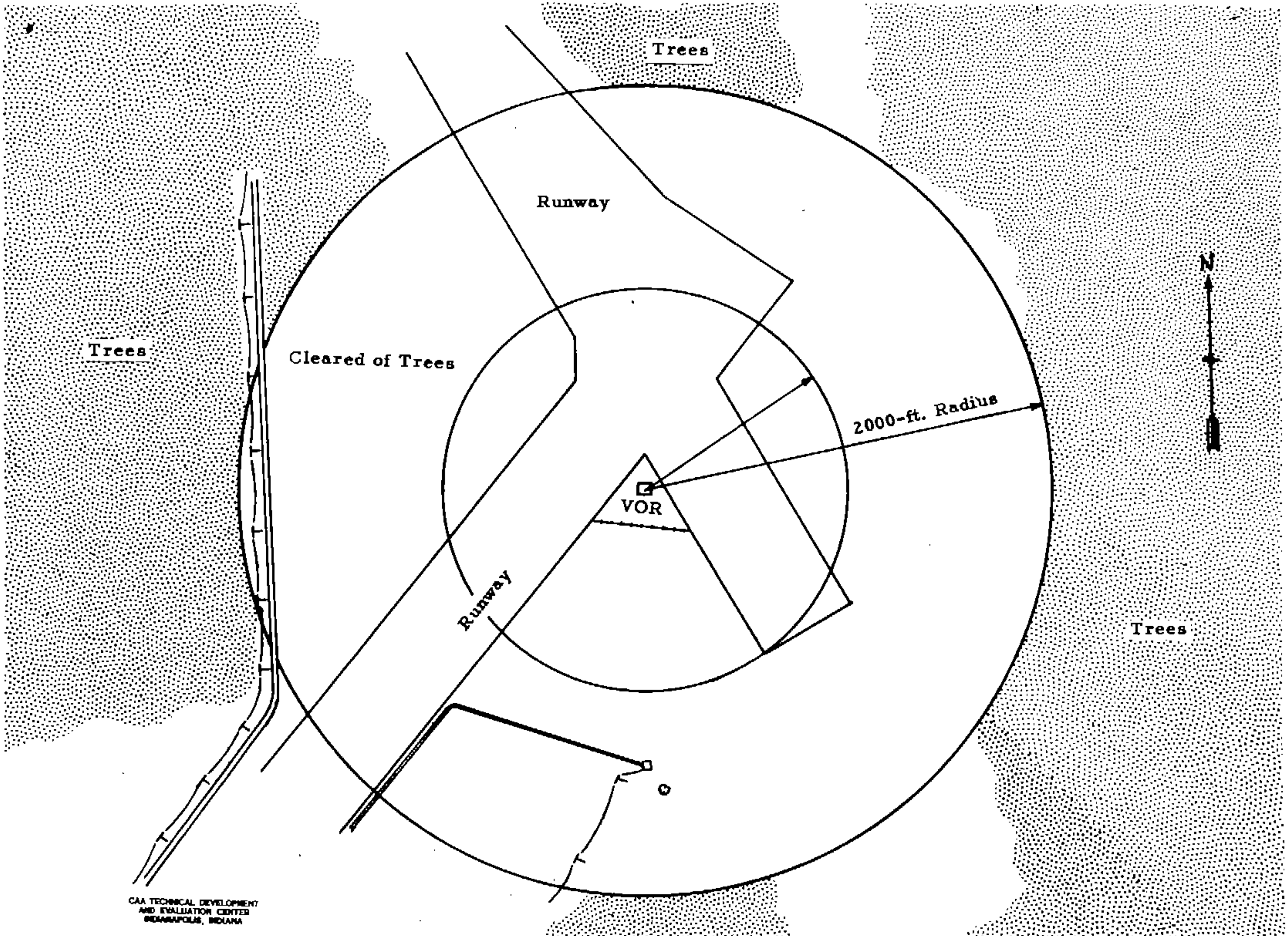

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FIG. 6 VOR SITE--ALMA, GEORGIA

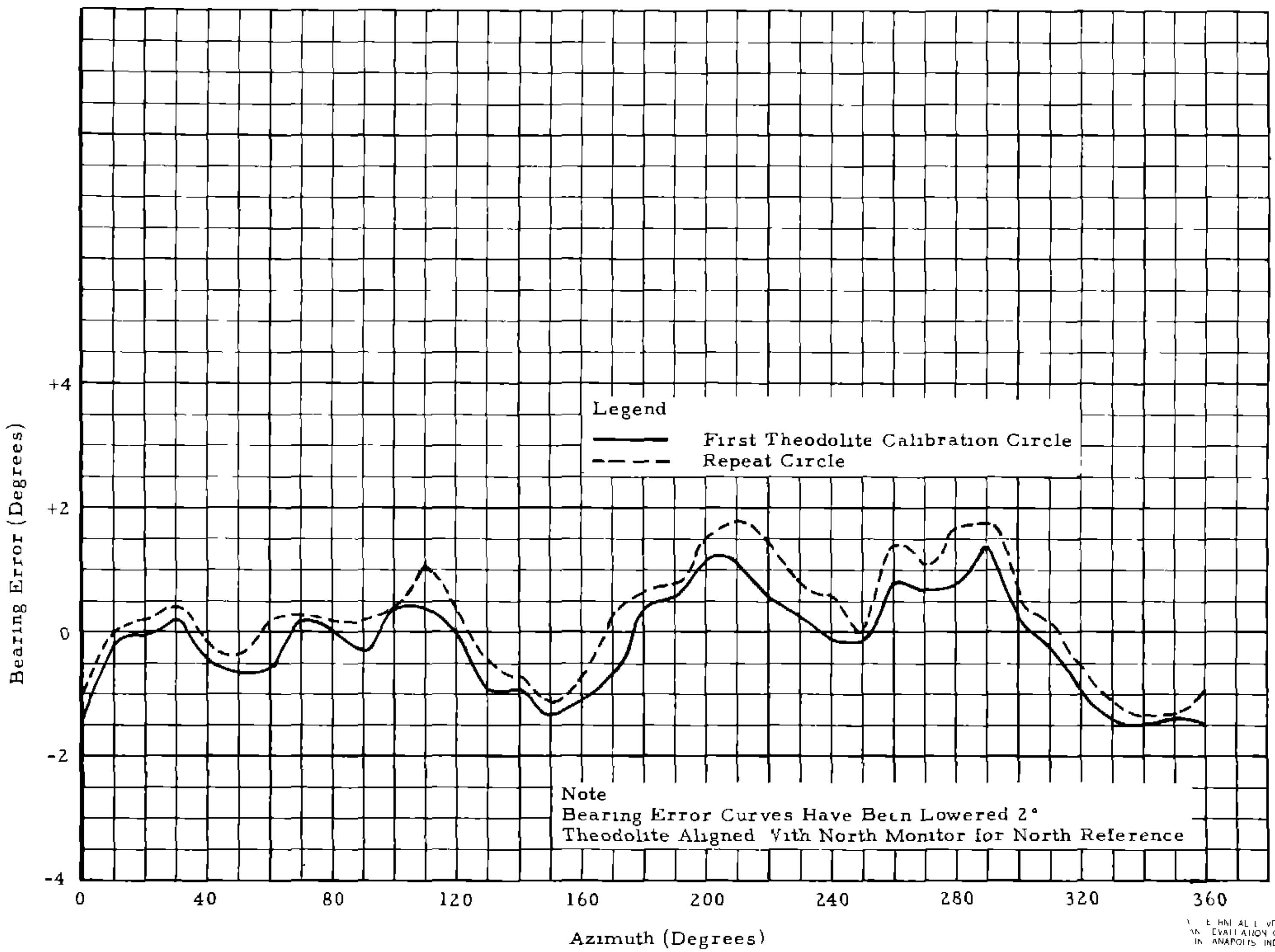

FIG 7 SIX-MILE THEODOLITE CALIBRATION CURVE--ALMA, GA

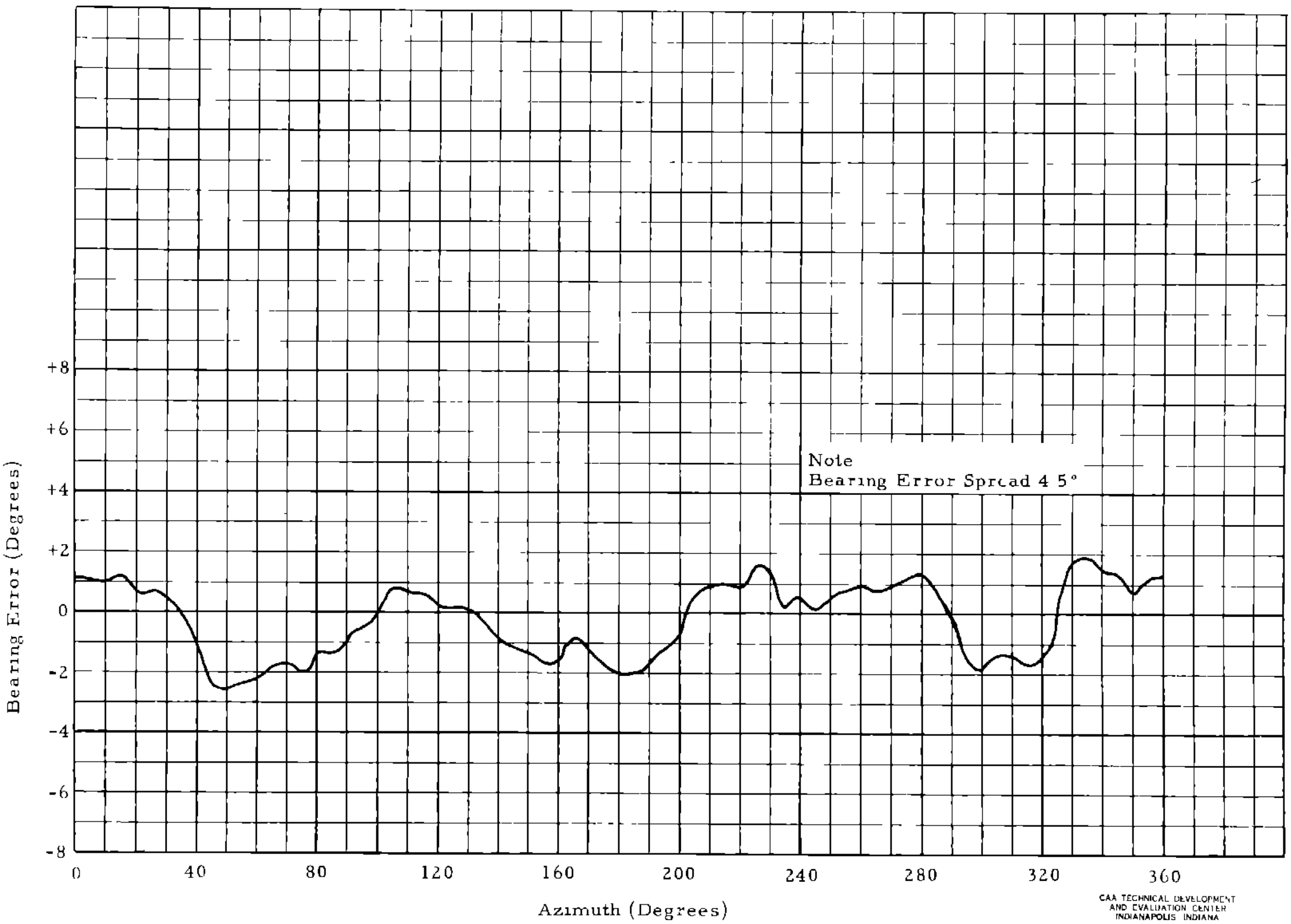

FIG 8 TWENTY-MILE CALIBRATION CURVE--ALMA, GA

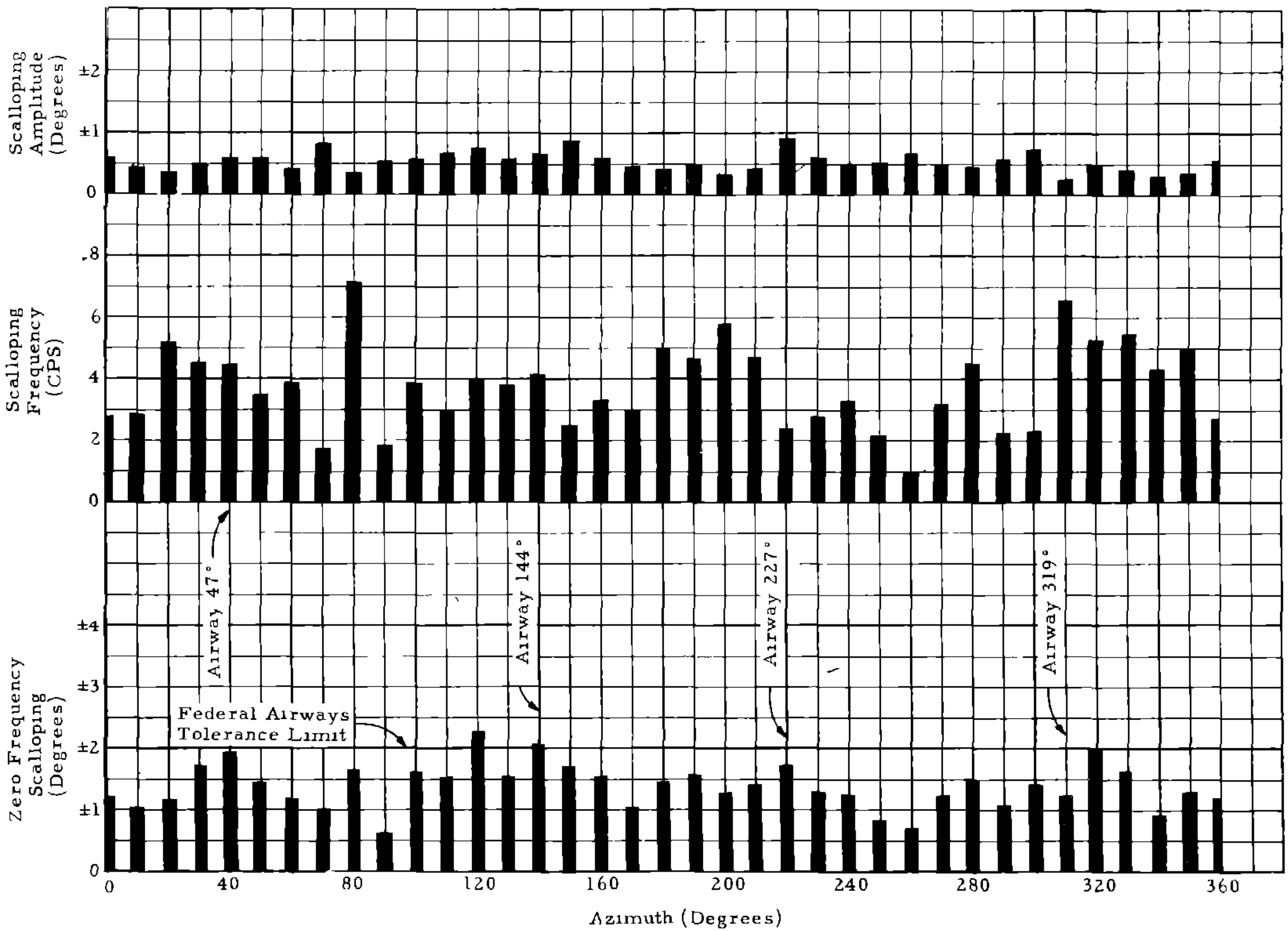

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FIG 9 SCALLOPING ON 20-MILE RADIUS CALIBRATION CIRCLE--ALMA, GA, VOR

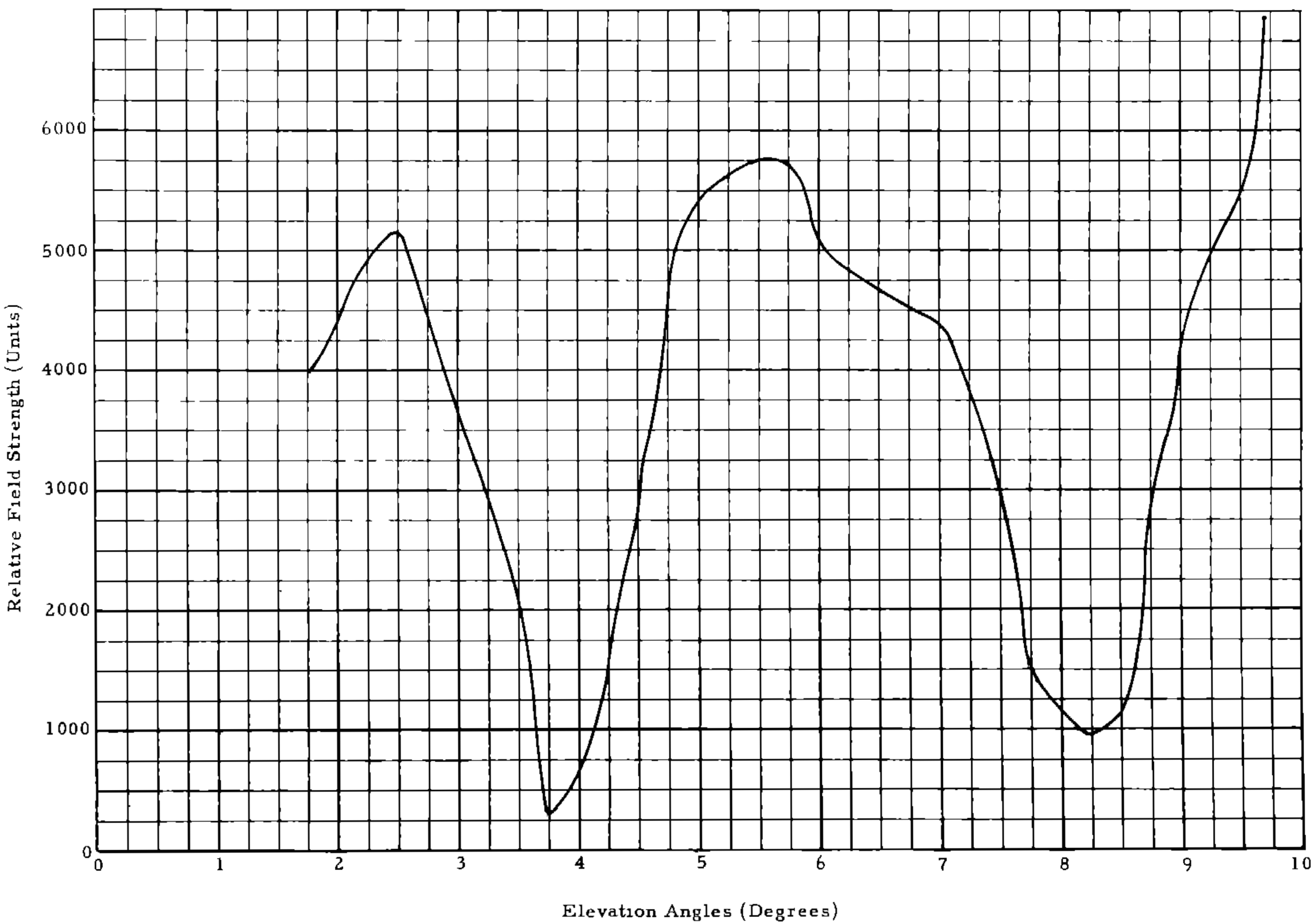

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FIG 10 VERTICAL PLANE PATTERN OF LOOP ANTENNA--ALMA, GA

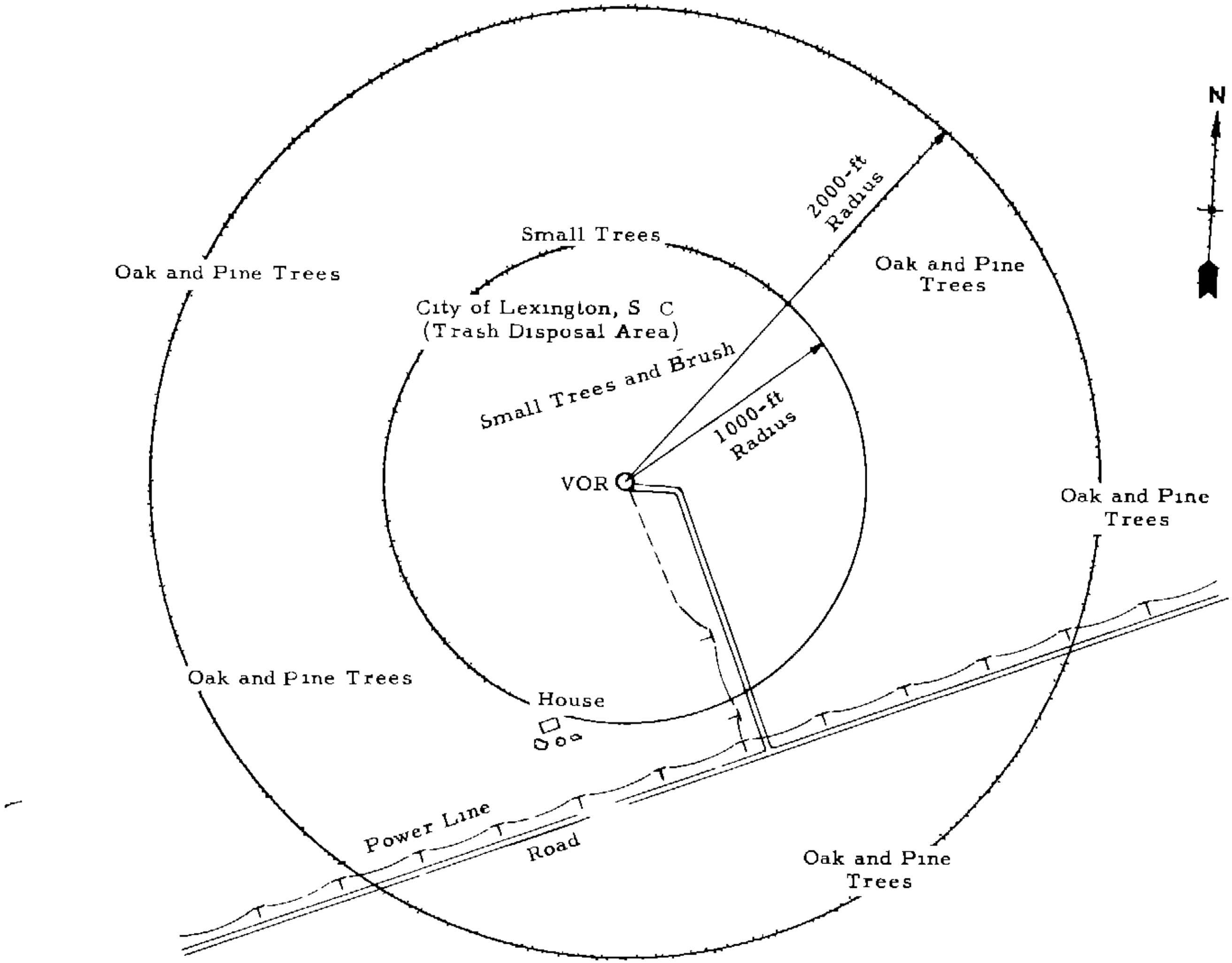

FIG 11 VOR SITE--COLUMBIA, SOUTH CAROLINA

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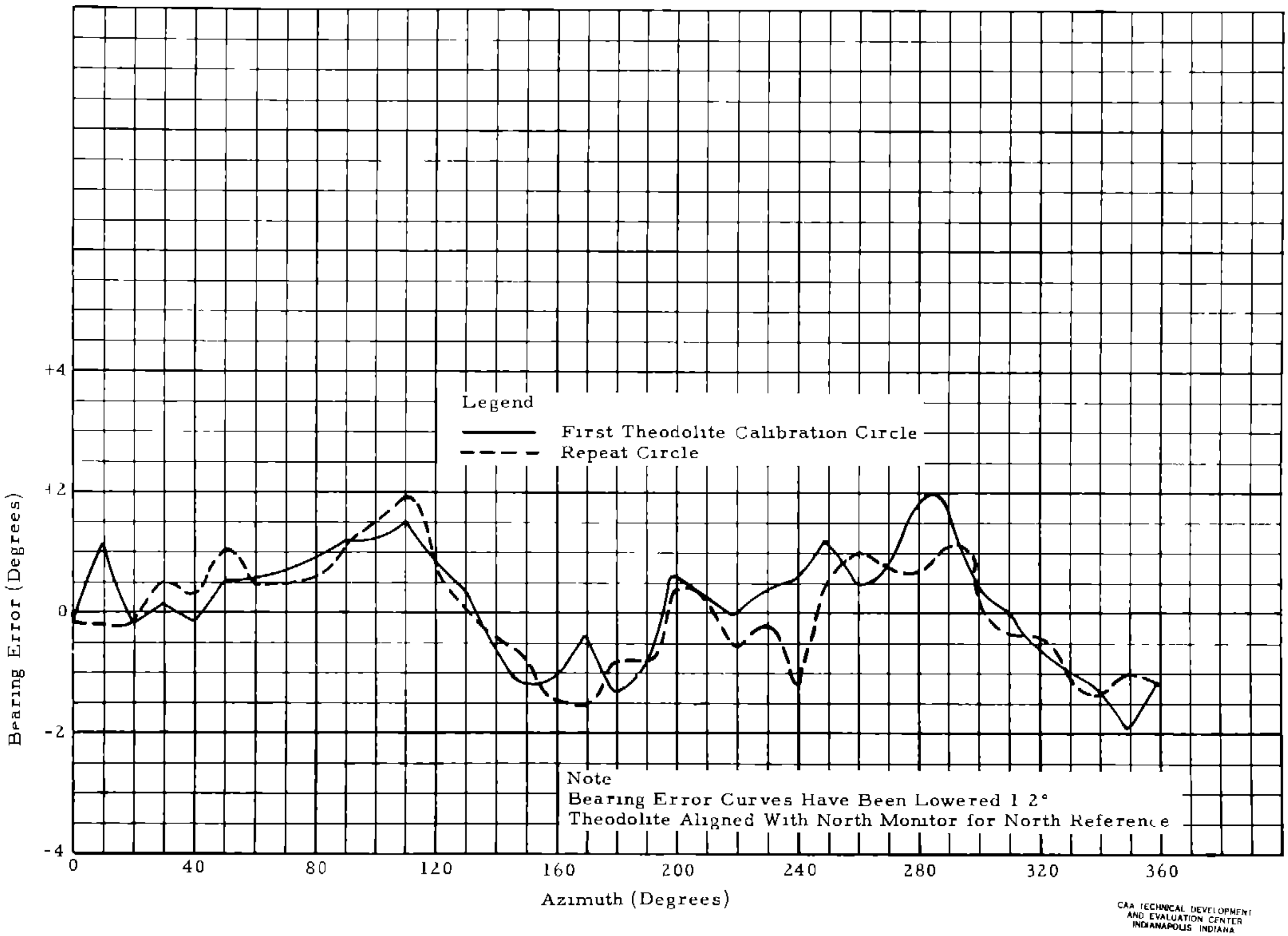

FIG 12 SIX-MILE THEODOLITE CALIBRATION CURVE--COLUMBIA, S C

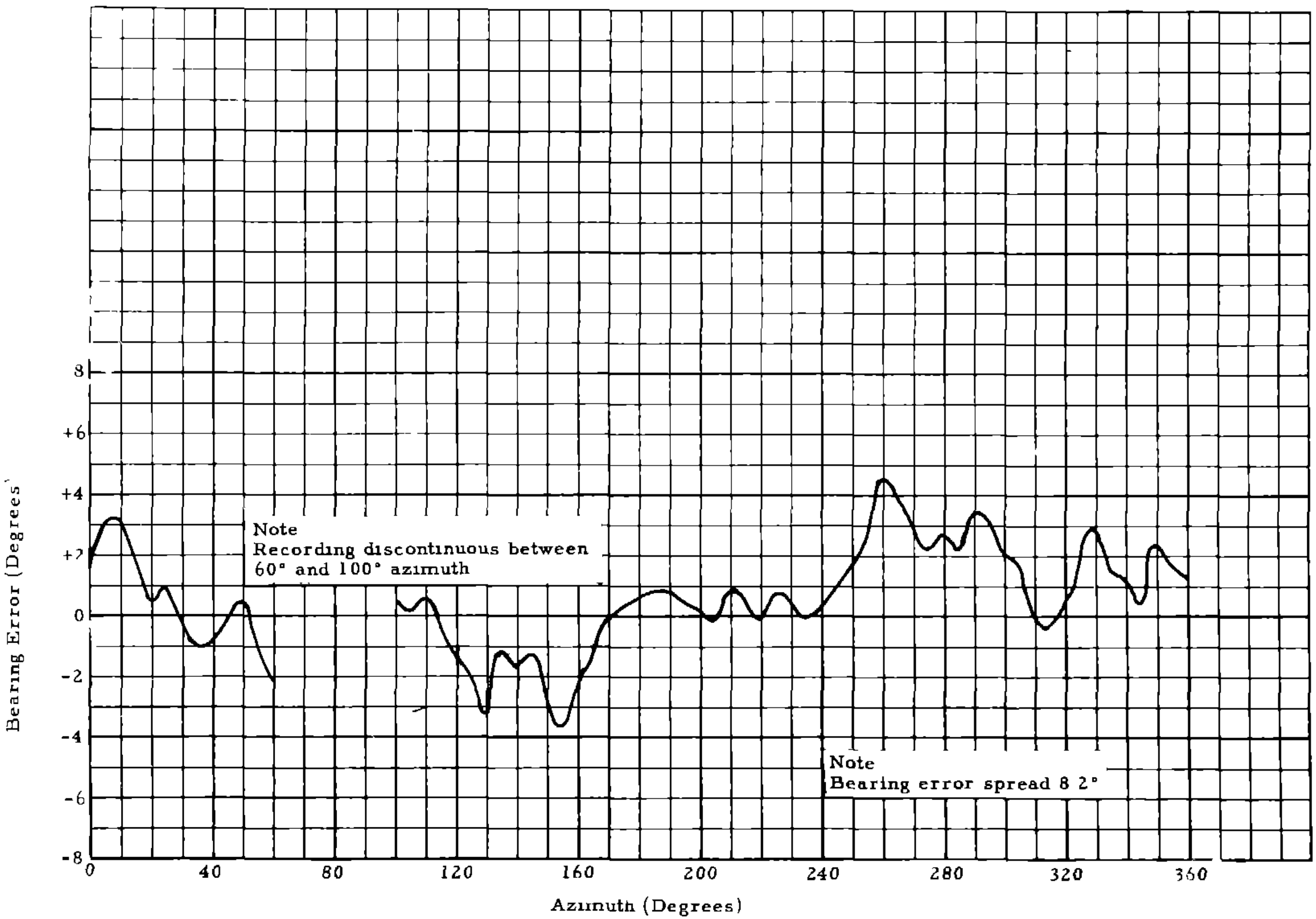

FIG 13 TWENTY-MILE CALIBRATION CURVE--COLUMBIA, S C

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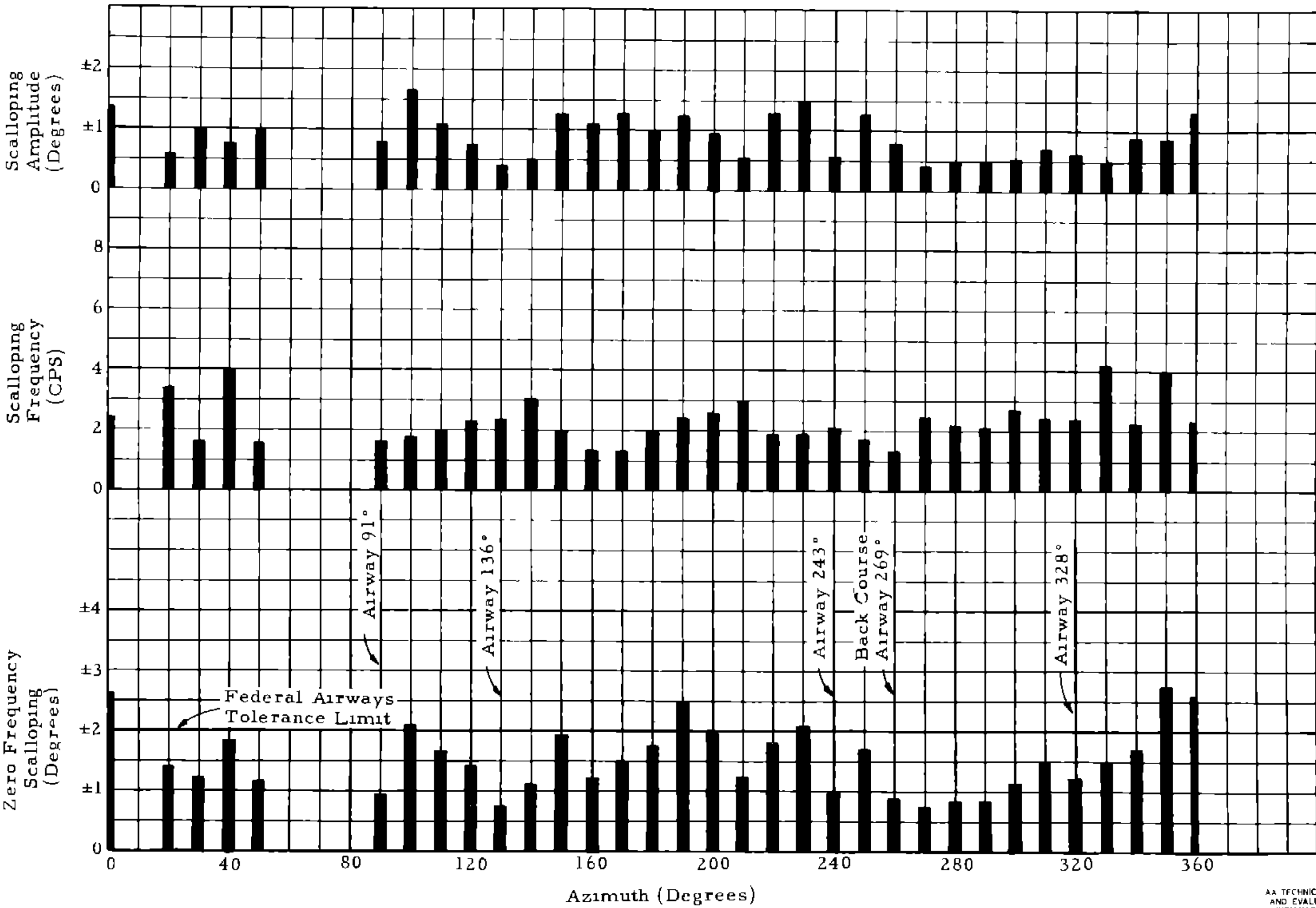

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FIG 14 SCALLOPING ON 20-MILE RADIUS CALIBRATION CIRCLF--COLUMBIA, S C , VOR

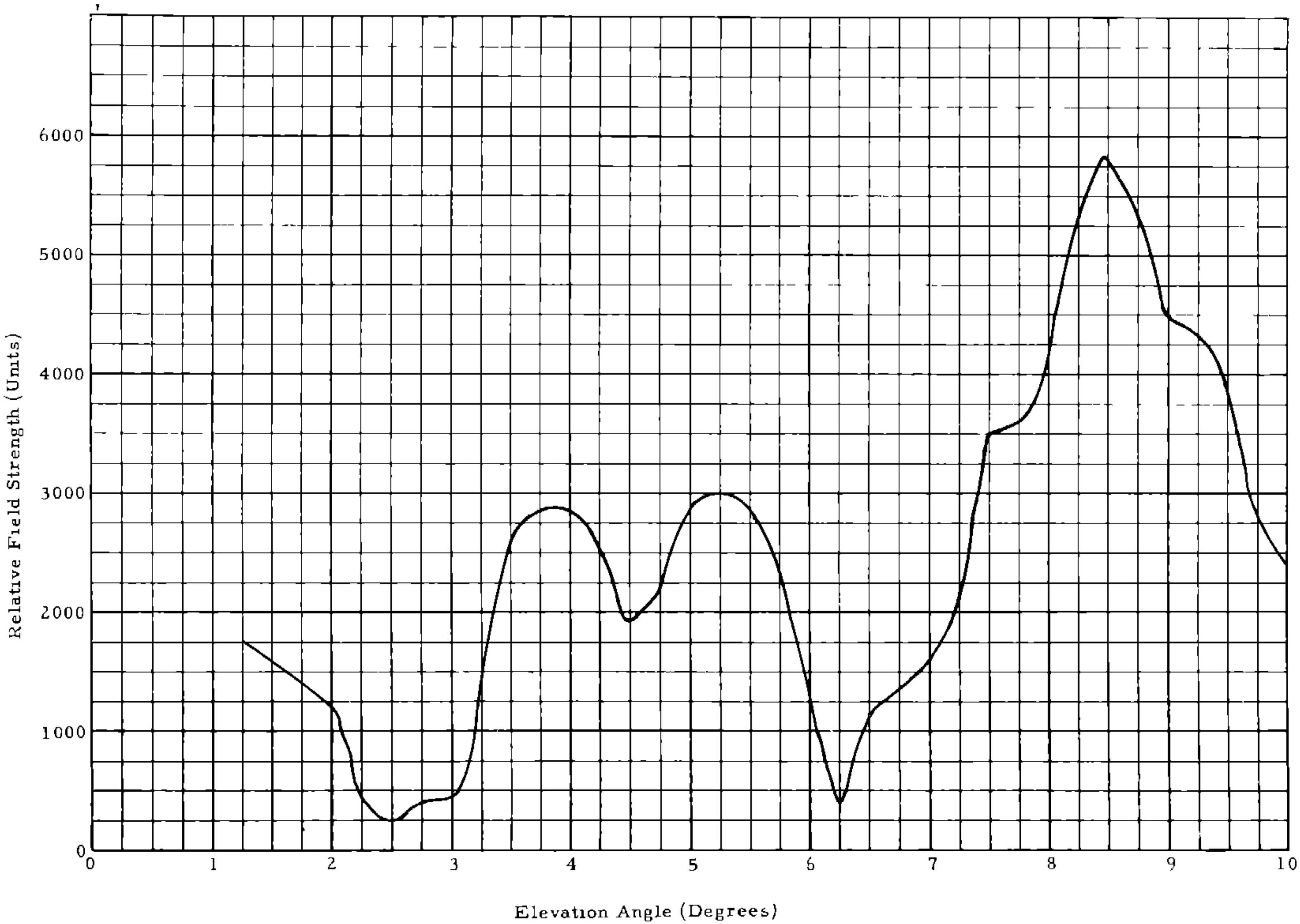

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FIG 15 VERTICAL PLANF PATTERN OF LOOP ANTENNA AT COLUMBIA, S C

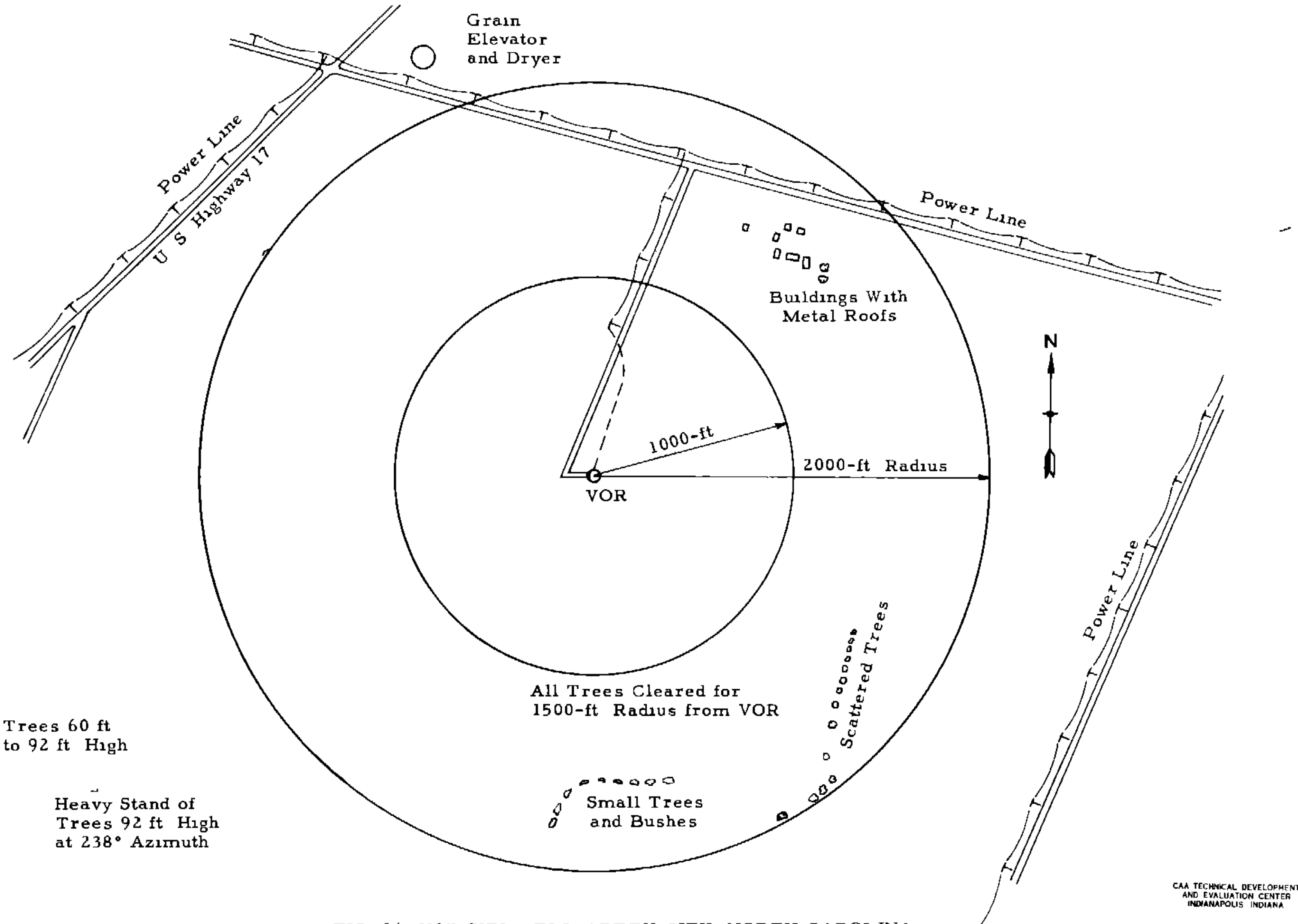

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FIG 16 VOR SITE--ELIZABETH CITY, NORTH CAROLINA

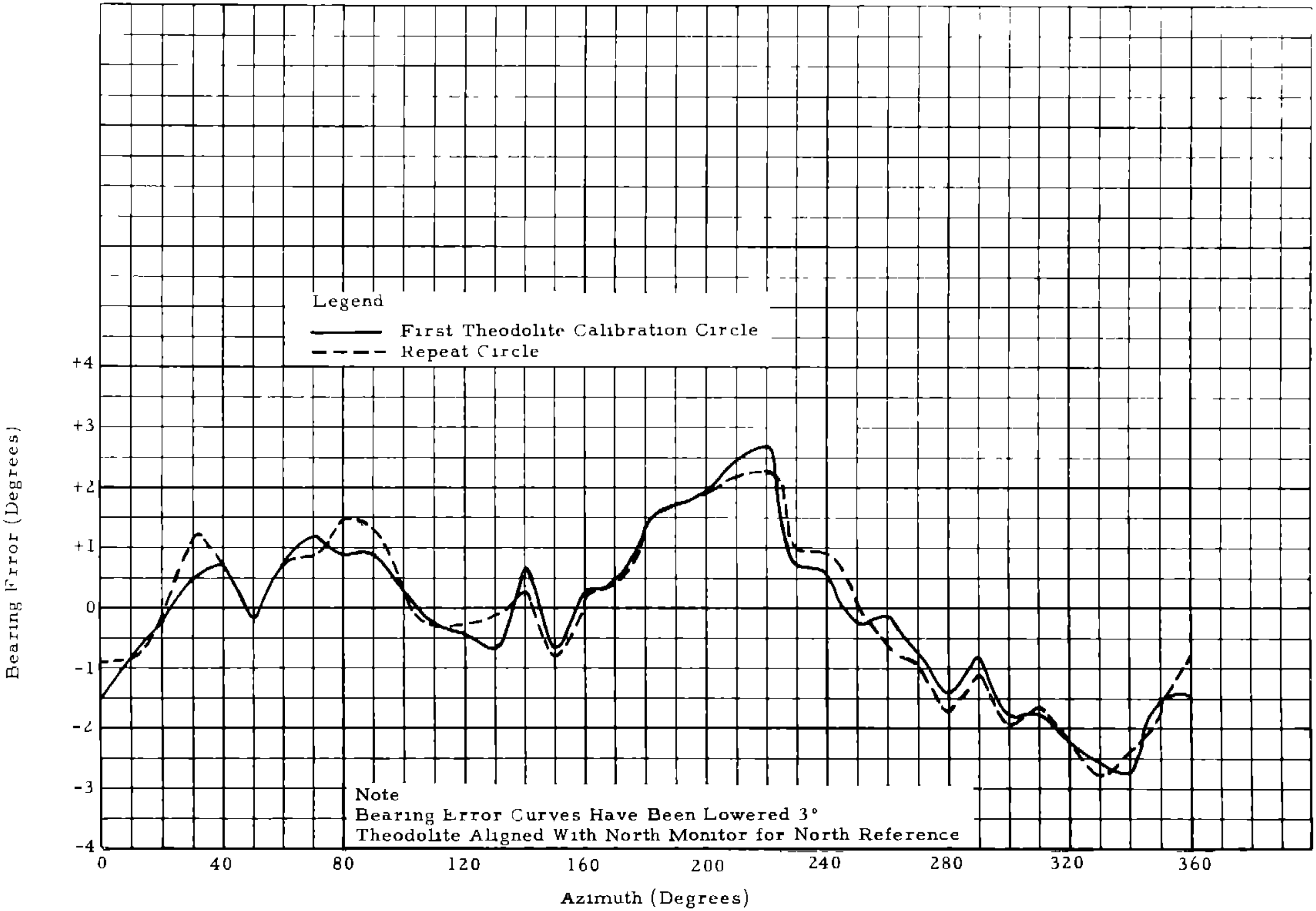

FIG 17 SIX-MILE THEODOLITE CALIBRATION CURVE--ELIZABETH CITY, N C

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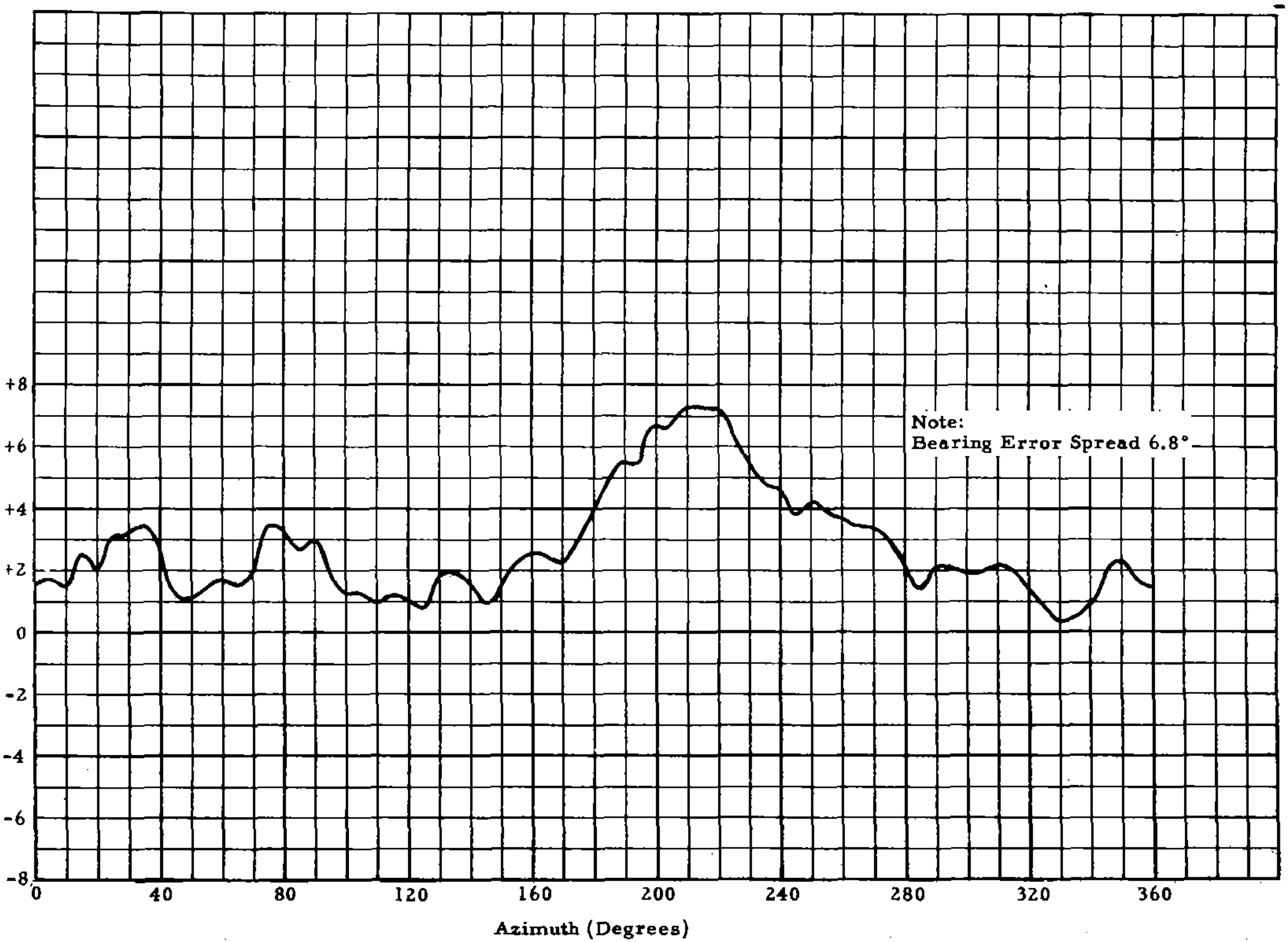

FIG. 18 TWENTY-MILE CALIBRATION CURVE--ELIZABETH CITY, N. C.

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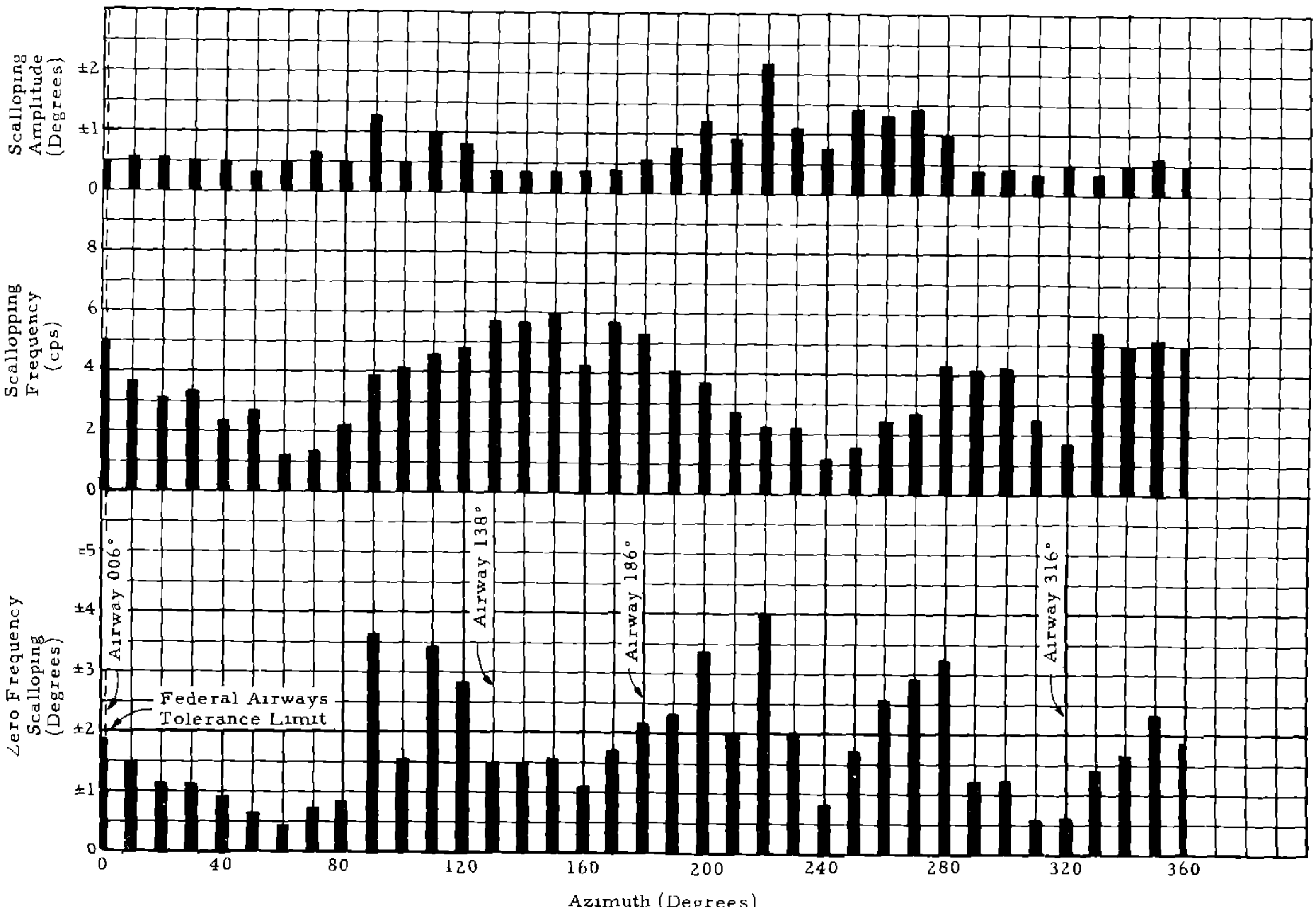

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FIG 19 SCALLOPING ON 20-MILE RADIUS CALIBRATION CIRCLE--ELIZABETH CITY, N C, VOR

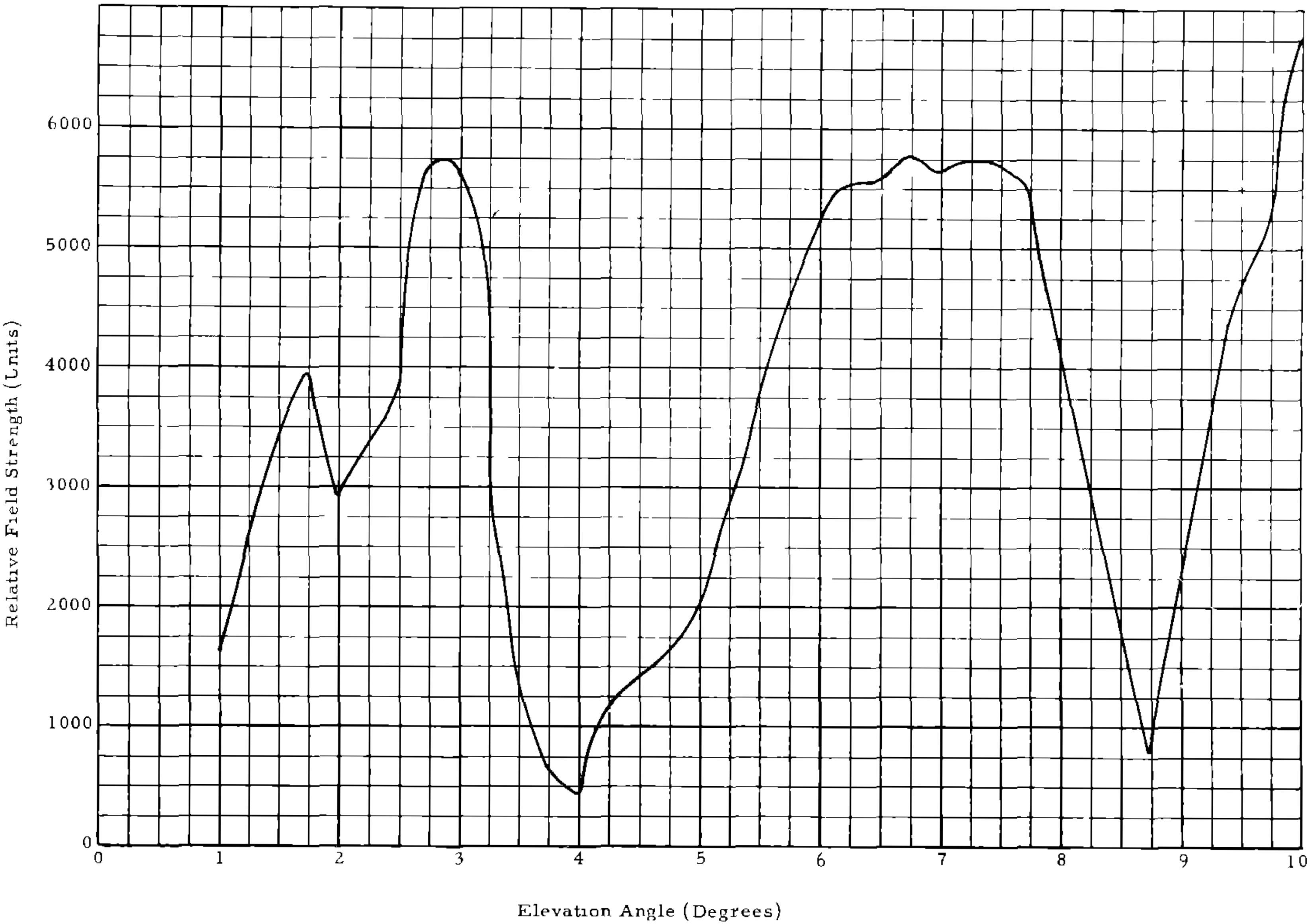

FIG 20 VERTICAL PLANE PATTERN OF LOOP ANTENNA AT ELIZABETH CITY, N C

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