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Evaluation of the Lorenz VOR Antenna

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EVALUATION OF THE LORENZ VOR ANTENNA

SUMMARY

This report describes the evaluation of the Lorenz very high frequency omnirange antenna manufactured by C. Aktiengesellschaft, Stuttgart, Germany. The evaluation included ground and flight measurements of the bearing accuracy, polarization error, cone characteristics, and distance range.

Measurements were conducted at 111.8, 115.7, and 117.7 megacycles. The bearing errors were plus or minus 0.85° at the lower frequency and plus or minus 0.70° at the two higher frequencies as determined by the conventional ground calibration procedure. Portable polariscope measurements indicated maximum polarization errors of plus or minus 2.5° at 111.8 megacycles, plus or minus 1.8° at 115.7 megacycles, and plus or minus 1.4° at 117.7 megacycles.

Flight tests showed that the TO-FROM indication had ambiguities through a cone width of approximately 40° (cone elevation angle of 70°). Recordings of the course deviation indicator current indicated a cone width of 40°, which is considered good. The distance range for 5 microvolts at the receiver input was 49 miles compared to 55 miles for the four-loop omnirange, indicating that the Lorenz antenna radiation efficiency is less than that of the four-loop antenna.

INTRODUCTION

The Lorenz very high frequency omnirange (VOR) cage antenna system is the result of further work on the FTL-21A VOR spinning antenna by C. Lorenz Aktiengesellschaft, Stuttgart, Germany. The FTL-21A VOR spinning antenna was developed by the Federal Telecommunications Laboratories, Inc. Two models of the FTL VOR antenna have been evaluated at this Center; an experimental model[1] in 1950, and the improved model FTL-21A[2] in 1954. The evaluation of the Lorenz VOR antenna was conducted in the fall of 1957 at the CAA Technical Development Center (TDC), Indianapolis, Indiana.

The Lorenz VOR system is to be installed in European countries under the supervision of personnel of the CAA Office of International Cooperation. In order to obtain operational data supplementary to that available from the limited testing facilities of the manufacturer, TDC was requested to evaluate the Lorenz antenna.

Performance data were obtained by measurements on the ground and in flight. These measurements included many of those now used by the CAA in establishing, flight

[1] Thomas S. Wonnell, "Evaluation of Federal Telecommunications Laboratories Omnirange Antenna," CAA Technical Development Report No. 111, May 1950.

[2] Samuel E. Taggart, Thomas S. Wonnell, and Walter M. Ehler, "Evaluation of the FTL-21A VOR Spinning Antenna," CAA Technical Development Report No. 262, February 1955.

checking, and maintaining commissioned VOR facilities on the Federal Airways.

DESCRIPTION

The Lorenz VOR antenna is shown in Figs. 1 and 2. It consists of an upper cage assembly and a lower cage assembly. The lower cage contains an omnidirectional antenna and a rotating dipole antenna. Carrier energy, radiated by the omnidirectional antenna, is amplitude-modulated by a 9,960-cycles-per-second (cps) subcarrier which, in turn, is frequency-modulated at 30 cps. The carrier is amplitude-modulated in space by the figure-of-eight field pattern produced by the dipole antenna which rotates at 30 revolutions per second (rps). The lower cage of vertical rods serves to improve the impedance match between the antennas and free space and to reduce the radiation of vertically polarized energy. The purpose of the upper cage is to minimize errors caused by the vertically polarized radiation from the lower cage.

The omnidirectional radiator is a metal plate divided into four equal 90° sectors by radial slots as shown in Fig. 3. When these four slots are excited in phase and with equal voltages, a circular radiation pattern is obtained similar to that of a horizontally positioned loop antenna with a circumference small compared to the wavelength.

Each of the four slots is fed by a rigid coaxial line. The four coaxial lines run from the top center of the lower cage structure downward along the cage axis to the center of the omnidirectional radiator. From this point each of the rigid coaxial lines runs radially along a slot to the edge of the disc where the outer conductor is connected to the near side of the slot; the inner conductor crosses the slot and terminates in an adjustable capacitive section of rigid coaxial line which runs along the opposite edge of each slot. The rigid coaxial lines can be seen in Fig. 3. The series resonant circuit, composed of the adjustable capacitive reactance and the inductive reactance of each feeder, is bridged across each slot to produce a virtual short circuit across the slot as viewed from the spinning dipole. A two-section tunable pi-network permits matching of the omnidirectional radiator to the 60-ohm characteristic impedance of the feed cable. The pi-network for the carrier feed line is located on the under side of the antenna as shown in Fig. 4.

The rotating element is a folded dipole which is short compared with the wavelength. It is fed by a coaxial line through one-half of the dipole. The other half is equipped with a dummy cable which has no electrical function, but is used for mechanical balancing. The dipole is secured and locked to the shaft of a synchronous motor. The tone wheel and the pickup are mounted at the top bearing bracket of the motor. The coaxial line of the dipole runs through a bore along the motor shaft and through the bearing shaft to a rotating coupling fixed to the lower bearing bracket. In series with this line is a single pi-section for matching the dipole to the 60-ohm feed cable. The pi-section and connecting receptacle are located on the under side of the antenna as shown in Fig. 4. The dipole, tone wheel, and motor are protected by a plastic cover and are integrated into a single insert which is illustrated in Figs. 2 and 4. The insert is mounted in the antenna structure from below and fastened by means of wing nuts.

GROUND MEASUREMENTS

Ground measurements conducted on the Lorenz VOR antenna included calibration, space modulation, field strength, and polarization error. These measurements were made with the antenna operating on each of three frequencies 111.8 megacycles (Mc), 115.7 Mc, and 117.7 Mc. Data obtained from these measurements are shown in Table I.

The ground calibration method developed at this Center[3] was employed to obtain the bearing accuracy of the antenna. The bearing error measurements were made with the VOR field detector at the counterpoise edge and also at a distance of 200 feet from the antenna. The measuring equipment included a modified Type CA-2041 VOR field detector, a Type CA-1277 VOR monitor, a Type 2559 DuMont oscilloscope, and a Type CA-1430 reference and variable test generator. The bearing errors at the counterpoise edge and at 200 feet from the antenna are shown in Figs. 5 and 6.

Bearing errors also were measured at the receiver laboratory located at a distance of 3,725 feet from the VOR. Equipment included a ten-element Yagi receiving antenna, a Collins 51R-3 navigation receiver, and a VOR course simulator. The receiver bearing indication obtained for each 20° of antenna rotation in the horizontal plane was reproduced by applying the signal from the VOR course simulator to the receiver input. Figure 7 contains the bearing error curves obtained from the receiver laboratory data.

Coupling between the carrier antenna and the rotating sideband antenna caused a 60-cps amplitude modulation of the carrier energy. It was difficult to reduce the amplitude of the unwanted 60-cps component below 10 per cent of the level of the 30-cps amplitude modulation of the carrier. Although laboratory tests have shown that a 60-cps signal equal to 10 per cent of the 30-cps signal level injected at the detector input terminals of a Type CA-1277 VOR monitor can cause up to plus or minus 1.9° error in indicated bearings, the same percentage of the 60-cps modulation component in a signal applied to the input of a 51R-3 navigation receiver has a negligible effect on its bearing indications. This accounts in part for the large differences in the indicated bearings measured at the VOR counterpoise and at the receiver laboratory.

Minimum coupling between the carrier antenna and the rotating sideband antenna was determined by measuring the voltage across the sideband transmission line when terminated in its characteristic impedance with power supplied only to the carrier antenna. The manufacturer specified that the decoupling should be 40 decibels (db) (less than one volt of rectified voltage across the sideband transmission line) with 200 watts applied to the carrier antenna. Decoupling voltages measured on each frequency of operation are included in Table I.

[3] Robert B. Flint and William L. Wright, "Ground Calibration of the VOR," CAA Technical Development Report No. 227, October 1955.

Measurements of variable-phase (30-cps space) modulation levels were made at the receiver laboratory using a remote percentage modulation level indicator.[4] These measurements were conducted for each 20° position as the antenna was rotated through 360°. The data obtained in this series of measurements are presented in Fig. 8.

Relative field-strength measurements were made on the ground to compare the radiation efficiencies of the Lorenz VOR antenna and the four-loop VOR antenna. To obtain a direct comparison, the antennas were operated with equal power inputs on a frequency of 115.7 Mc. Relative field-strength measurements also were made with the same power input to the Lorenz antenna on 111.8 and 117.7 Mc. The instrumentation used in this series of measurements included a modified Collins 51R-3 navigation receiver, a direct-current (d-c) amplifier for amplifying the first radio-frequency (r-f) amplifier cathode current of the receiver, and an Esterline-Angus graphic recorder. Operating as a unit, the system was calibrated to indicate field strength as a function of recorder pen deflection. Receiver input voltages measured at distances of 400, 500, and 600 feet from the VOR are shown in Table I and in the curves of Fig. 9. The curves indicate the greater radiating efficiency of the four-loop antenna over the Lorenz antenna at 115.7 Mc.

Measurements of polarization error were conducted with a portable polariscope.[5] These determinations were conducted at a distance ranging from 300 to 500 feet from the VOR for each 45° interval around the station. The data obtained in this series of measurements are plotted in Fig. 10. Measurements of polarization error on 117.7 Mc indicate that complete electrical contact between the base plate and the counterpoise is required. With the antenna base plate 1/2-inch above the counterpoise, polarization errors were doubled, as illustrated in Fig. 11.

FLIGHT TESTS

In-flight measurements were conducted on the Lorenz antenna to obtain polarization errors, distance range, theodolite flight calibration, and cone characteristics. Each of these measurements was conducted on 111.8 Mc, 115.7 Mc, and 117.7 Mc. The tests were conducted in a Douglas C-47 aircraft, using a Collins 51R-3 navigation receiver, a tail-mounted V-109 receiving antenna, an airborne polariscope, and an Esterline-Angus graphic recorder. The results of these tests are contained in Table I.

Theodolite Flight Calibration.

The theodolite flight calibration is a process wherein a series of exact differences between omnirange indicated bearings and theorolite bearings

[4] John Beck and Alan L. Saunders, "A Percentage Modulation Indicator," CAA Technical Development Report No. 343, March 1958.

[5] Sterling R. Anderson and Wendell A. Law, "The Measurement of VOR Polarization Errors,' CAA Technical Development Report No. 202, May 1953.

are obtained throughout the 360° around a range station. These differences are plotted as a measured error curve. Flights were made in a counterclockwise direction at a 6-mile radius at an altitude of 1,000 feet. The measured error curves are shown in Fig. 12.

Distance Range

The distance range was measured at each of the three frequencies selected for the evaluation. At 115.7 Mc, the distance checks were made using both the Lorenz and four-loop antennas within the same two-hour period, in order to obtain a direct comparison of the respective ranges for equal power applied to the antennas under observation. Two definitions of distance range were used in these measurements.

In one method of measurement, the distance range is defined as the distance in statute miles from the station at which the course width in degrees becomes double the course width measured at 10 miles. In the second method of measurement, the distance range is defined as the distance in statute miles from the station at which the free-space attenuation of the signal has reduced the field strength to a value such that five microvolts is applied to the input terminals of the receiver.

The distance range on 115.7 Mc was greater for the four-loop antenna than for the Lorenz antenna, 62.2 compared to 59.9 miles for double course width, and 55 compared to 49 miles for 5 microvolts, indicating that the four-loop antenna is a more efficient radiator than the Lorenz antenna. The distance range for the Lorenz antenna on the other frequencies is listed in Table I.

Polarization Errors.

In flight-checking the Lorenz VOR antenna, four methods of measuring polarization error were employed. Each of the following tests was conducted on a radial near zero azimuth and at an altitude of 1,000 feet. The polarization errors measured are included in Table I.

30° Wing Rock. Heading toward the station, the aircraft is banked plus and minus 30°. The nose of the aircraft is held at a constant heading during this maneuver. The course-deviation-indicator (CDI) current is recorded and converted to degrees of course displacement.

Eight Ways Over a Ground Checkpoint: While the CDI current is being recorded, the aircraft is flown on eight different headings (cardinal and semi-cardinal) over a specific ground checkpoint. The recordings are marked as the airplane crosses the checkpoint, and the indicated bearing is compared with the magnetic bearing. The zero reference point is taken on the heading to the station.

Circle: With the airplane headed toward the station and the tests started from a ground checkpoint, a circle is flown at a constant 30° bank. The CDI current is recorded during this circular flight and converted into degrees of error from the azimuth course which was flown at the beginning of the circle. Since the aircraft changes azimuth with respect to the VOR, this deviation is computed in degrees and subtracted from the course-deviation-indicated error. Subtraction of the known deviation results in the numerical value of polarization error.

Airborne Polariscope: Polarization errors were measured on flight checks with an airborne polariscope. The airborne polariscope utilizes a crossed dipole antenna mounted on the nose of the aircraft. A 25-rpm motor drives a phase sweep in conjunction with r-f bridges to vary continuously the relative phase of the vertically and horizontally polarized components of the VOR signals. The output of the polariscope is connected to the navigation receiver and CDI recorder equipment. The recorded course from the VOR then has a "scalloping" of 0.42 cps, the amplitude of which is proportional to the ratio of vertically to horizontally polarized radiation from the VOR. The recording is made on inbound radial flights. It will indicate error attitude effect equivalent to a 45° wing rock with the optimum relative r-f phase for greatest error. The polarization errors determined by flight check are included in Table I.

Cone Measurements.

Radial flights were made across the VOR, recording the currents of the CDI and the TO-FROM indicator of the Collins 51R-3 receiver for the purpose of measuring cone width.

In order to determine the width of the cone from a recording of the CDI current, a definition of the cone must be stated so that the boundaries of the cone may be positioned on the recording. With the VOR receiver and associated recording equipment calibrated to a given recorder deviation equal to a given number of degrees of VOR course displacement, a flight track is flown directly over the VOR. When the CDI deviates more than 2°, and this deviation, as observed on the recording, is due to the normal course disturbances encountered above a VOR, the cone is considered to begin. In a similar manner, the cone ends at the 2° deflection point as the straight-line course indication is resumed on the other side of the cone. When measuring a cone in this manner, the results are referred to as a CDI cone measurement. A typical recording of a CDI cone measurement is reproduced in Fig. 13.

The TO-FROM cone width is defined in the same manner as the CDI cone width except that the cone is defined as beginning when the indication becomes erroneous and ending when the correct indication is resumed. A recording of the TO-FROM indicator current is reproduced in Fig. 14.

Field-strength measurements were made during radial flights over the VOR to obtain data for plotting the vertical plane field pattern of the antenna. The equipment used for these measurements is the same as that used in ground equipments of field strength. The vertical plane field pattern is plotted in Fig. 15.

GROUND-LEVEL TESTS

Additional tests were conducted with the Lorenz VOR antenna mounted at ground level to simulate a mountain-top installation. The purpose of the tests was to determine the diameter of the metallic counterpoise required for minimum polarization error. Since it was necessary to have access to the under side of the antenna, it was mounted at approximately ground level on a wooden platform over a pit 8 feet wide, 10 feet long, and 5 1/2 feet deep.

The counterpoise was 36 feet in diameter and constructed of wire mesh. The outside edge of the counterpoise was 8 inches below the base of the antenna. Polarization errors were measured for the counterpoise diameters of 36 feet, and with only a 40-inch antenna base plate. The 13-foot-diameter counterpoise was just large enough to cover the pit completely and prevent discontinuities. A discontinuity was introduced during measurements with the 36-foot-diameter counterpoise by removing the cover from a 2-foot-square access hatch 9 feet from the center of the antenna. For each condition, polarization errors were measured at intervals of 45° at a radius of 300 feet from the VOR throughout 360° of azimuth. The measuring equipment was the same as that described previously. The results of the measurements are plotted in Fig. 16. Curve A in Fig. 16 was used to illustrate the error with either the 13- or 36-foot-diameter counterpoise, since the errors were essentially the same at all but one azimuth.

For tests with a 9-foot-diameter counterpoise, an earth fill was made to form a continuous surface from the base of the antenna to a radius of approximately 10 feet. The wooden platform over the pit was covered to a depth of 4 inches by the earth fill and the antenna and counterpoise were mounted flush with the surface. The polarization error for this condition is shown by curve B of Fig. 16.

The results of these tests indicate that the diameter of the metal counterpoise should be not less than approximately 13 feet. A comparison of the polarization error curves obtained with the counterpoise 9 and 13 feet in diameter shows an increase in error with a counterpoise diameter less than 13 feet. The importance of a uniform counterpoise is illustrated by curve C, Fig. 16. This curve demonstrates the effect of a discontinuity in the counterpoise, such as an open manhole, near the antenna.

CONCLUSIONS

The Lorenz VOR antenna features excellent workmanship resulting in a system relatively easy to install and adjust. Pi-network sections simplify the matching of the transmission lines to the antennas.

Coupling between the carrier disc and rotating dipole antennas limits the bearing accuracy which otherwise would be possible with this type of antenna.

The polarization error probably could be reduced by adding more shorting discs to the upper cage, as was demonstrated during the evaluation of the FTL-21A VOR antenna at this Center in 1954.

The radiation efficiency of the Lorenz VOR antenna is somewhat below that of the four-loop VOR antenna.

TABLE I

EVALUATION DATA OF THE LORENZ ANTENNA

	111.8 Mc	115.7 Mc	117.7 Mc
I. Flight Tests.			
Theodolite Calibration			
A. Six-mile 1,000-Foot Orbit	±1.9°	±1.1°	±1.0°
Distance Range at 1,000-Foot Altitude			
A. Lorenz Double Course Width Distance	63.2 mi.	59.9 mi.	59.0 mi.
B. Lorenz Distance for 5 uv to Receiver	51.4 mi.	49.0 mi.	48.0 mi.
C. Four-Loop Double Course Width Distance		62.2 mi.	
D. Four-Loop Distance for 5 uv to Receiver		55.0 mi.	
Polarization Error			
A. 30° Wing Rock	±0.25°	±0.75°	±0.25°
B. Circle Test	±3.0°	±1.5°	±2.5°
C. Polariscope	±3.0°	±2.5°	±1.5°
D. Eight Ways Over a Point	±1.0°	±1.0°	±0.75°
Cone Angle			
A. TO-FROM Indication	44°	40°	44°
B. CDI Indication	38°	40°	40°
II. Ground Tests.			
Ground Calibration			
A. At Receiver Laboratory	±1.5°	±0.65°	±0.60°
B. At Counterpoise Edge	±0.85°	±0.70°	±0.70°
C. At 200 Feet	±0.70°	±0.55°	
Polarization Error			
A. Portable Polariscope	±2.2°	±1.8°	±1.4°
Relative Field Strength			
A. Lorenz Relative Field at 400 Feet	19.25 mv	12.3 mv	12.0 mv
B. Four-Loop Relative Field at 400 Feet		16.5 mv	
Space Modulation - Maximum Variation with Azimuth			
A. At Receiver Laboratory	±2.0%	±1.8%	

TABLE I (continued)

EVALUATION DATA OF THE LORENZ ANTENNA

Dipole Decoupling			
A. Rectified Voltage at Dipole Input for 200 Watts Applied to Carrier	1.9 v	1.5 v	1.5 v
Voltage Standing Wave Ratios			
A. Dipole Feed Line	1.1/1	1.15/1	1.07/1
B. Carrier Feed Line	1.07/1	1.1/1	1.1/1

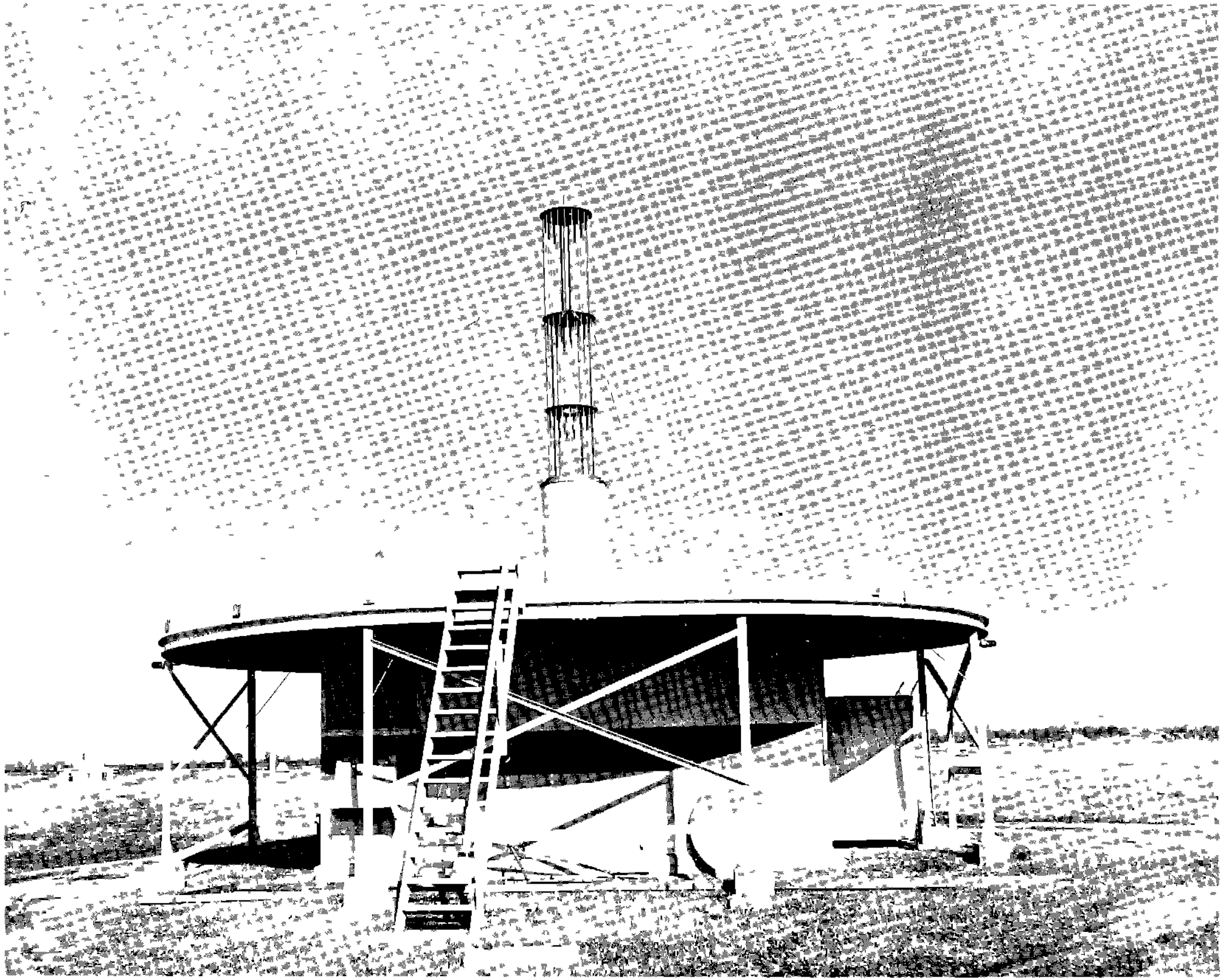


FIG. 1 THE LORENZ VOR ANTENNA

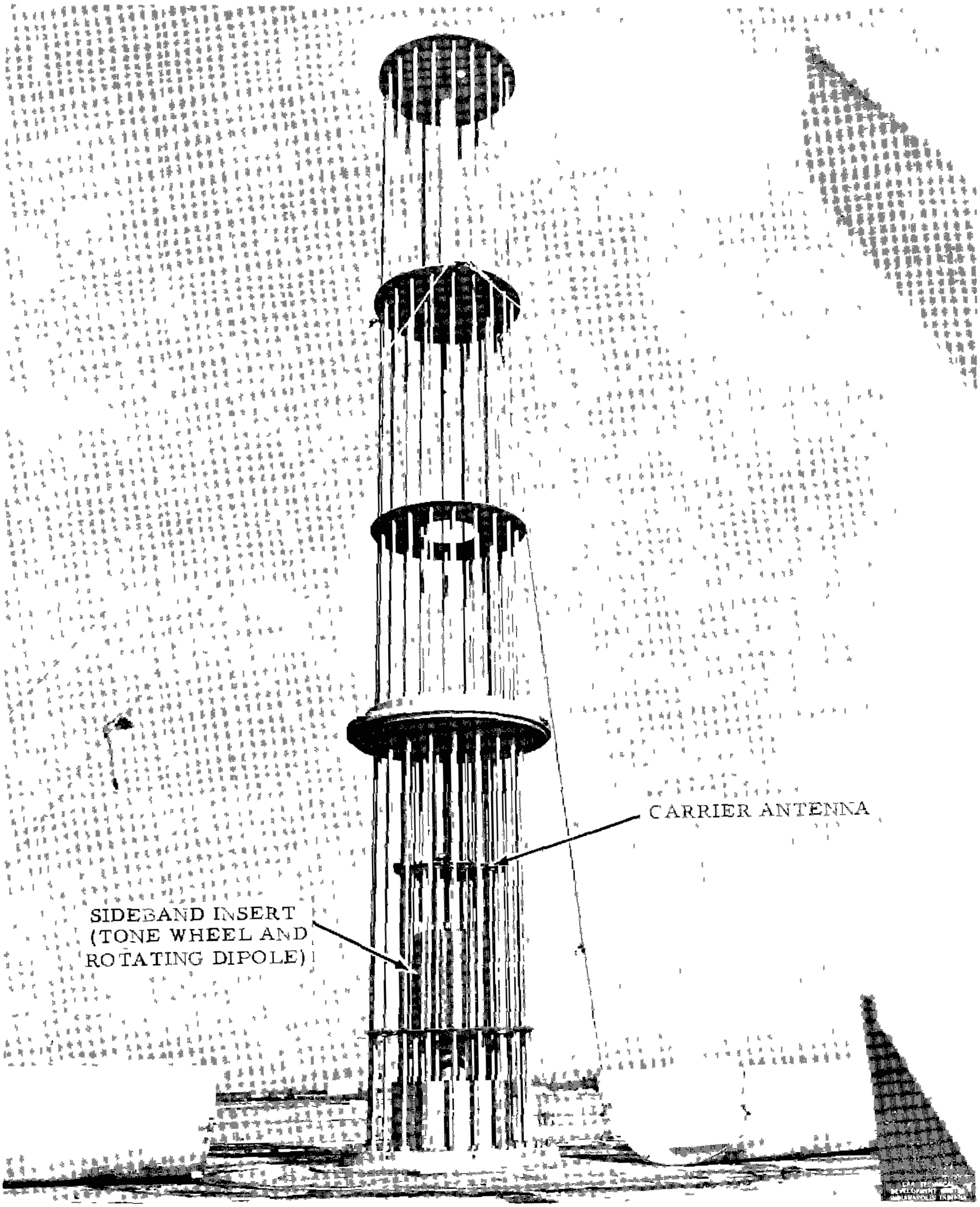


FIG. 2 THE LORENZ VOR ANTENNA WITH FIBERGLAS COVERS REMOVED

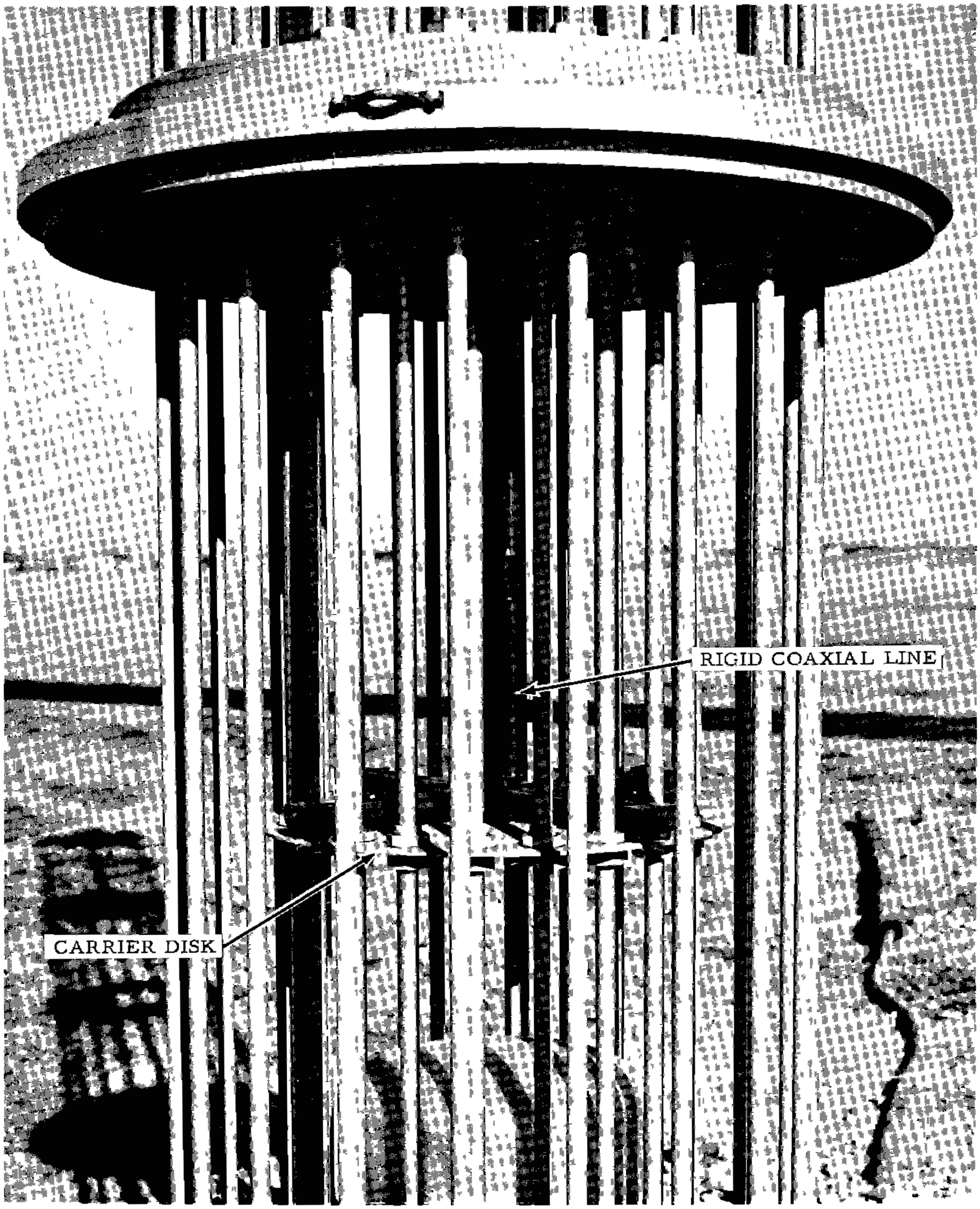


FIG. 3 CLOSE-UP OF LORENZ VOR CARRIER ANTENNA AND RIGID COAXIAL LINE FEED SYSTEM

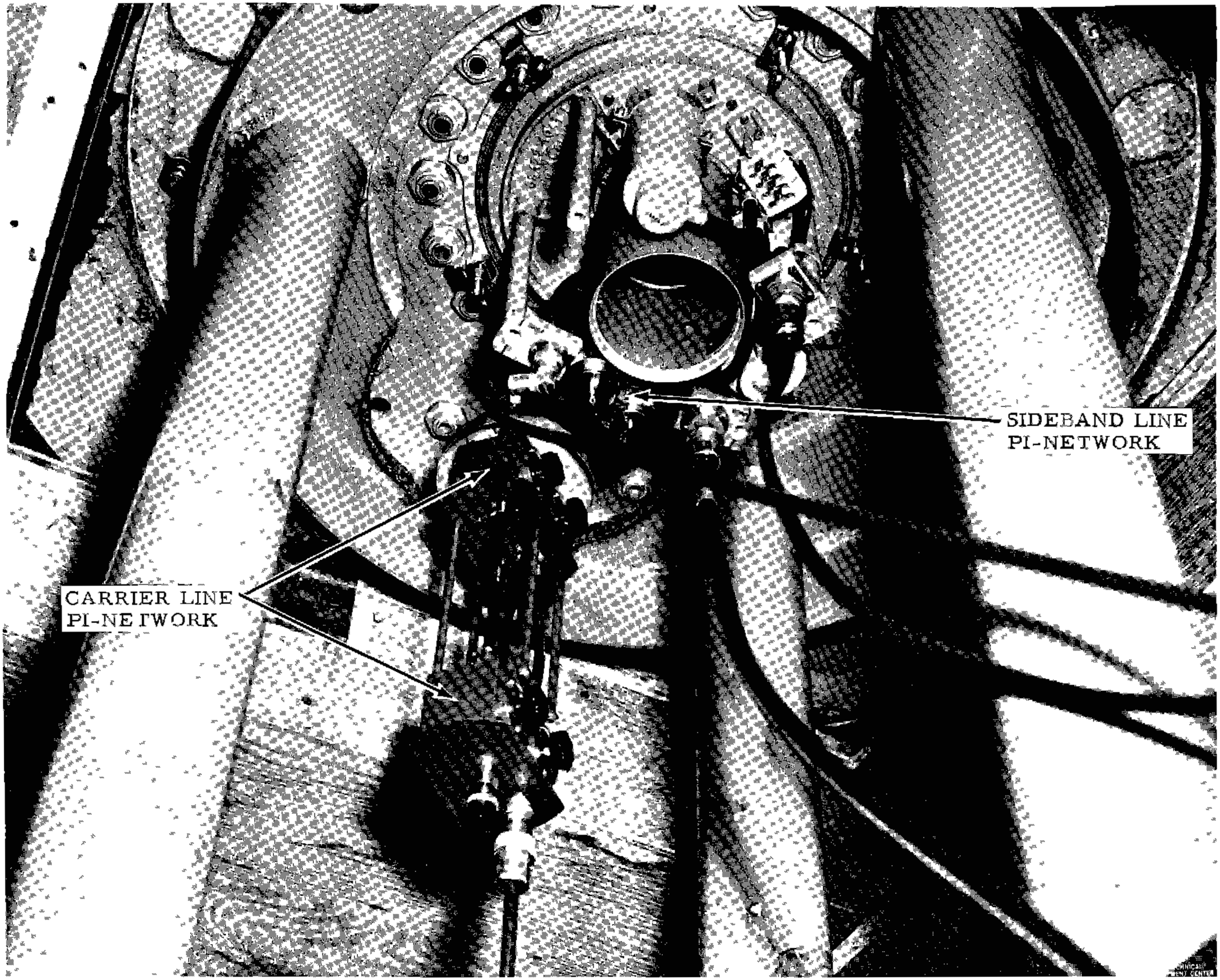


FIG. 4 UNDER SIDE OF LORENZ VOR ANTENNA

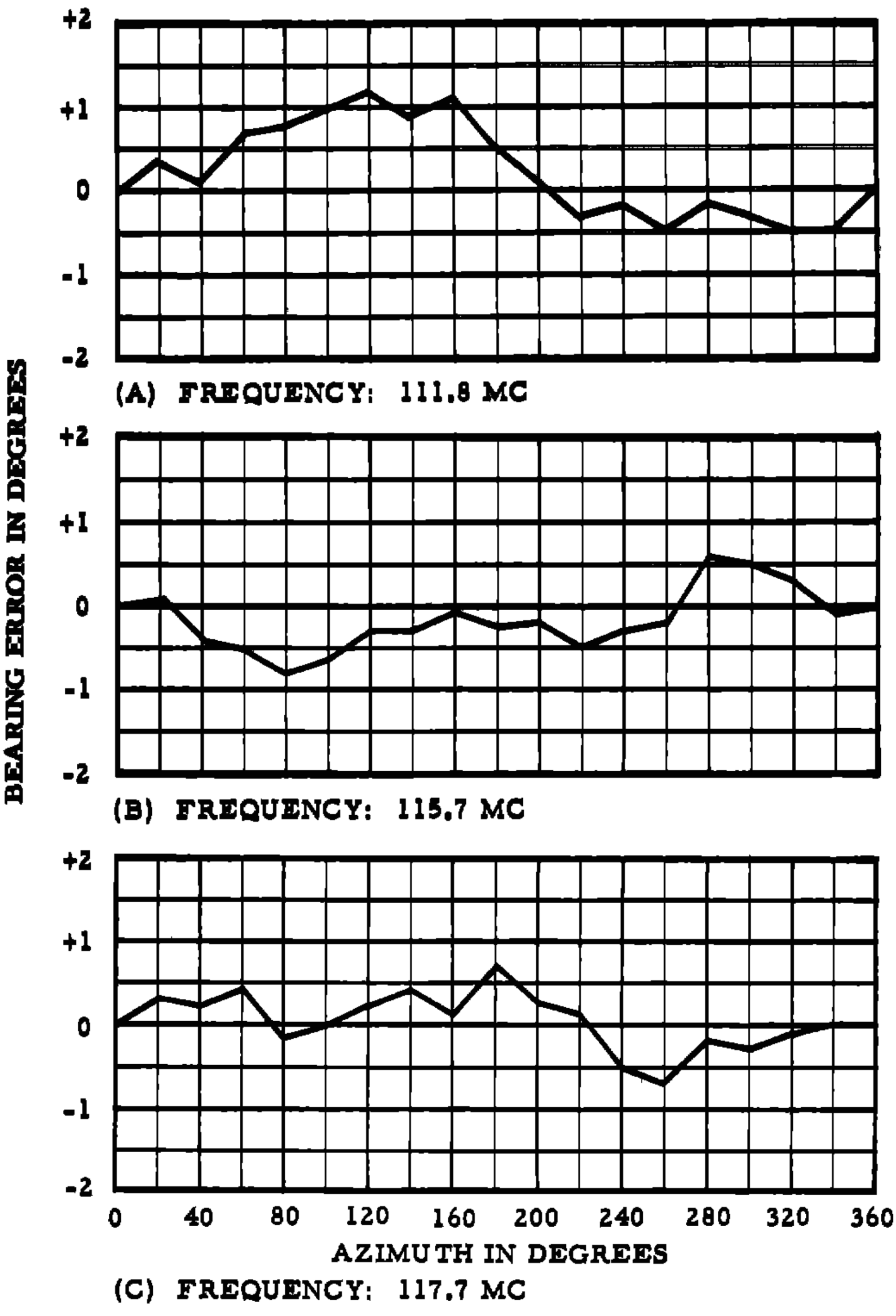


FIG. 5 GROUND CALIBRATIONS OF LORENZ VOR ANTENNA, VOR MONITOR DETECTOR AT COUNTERPOISE EDGE

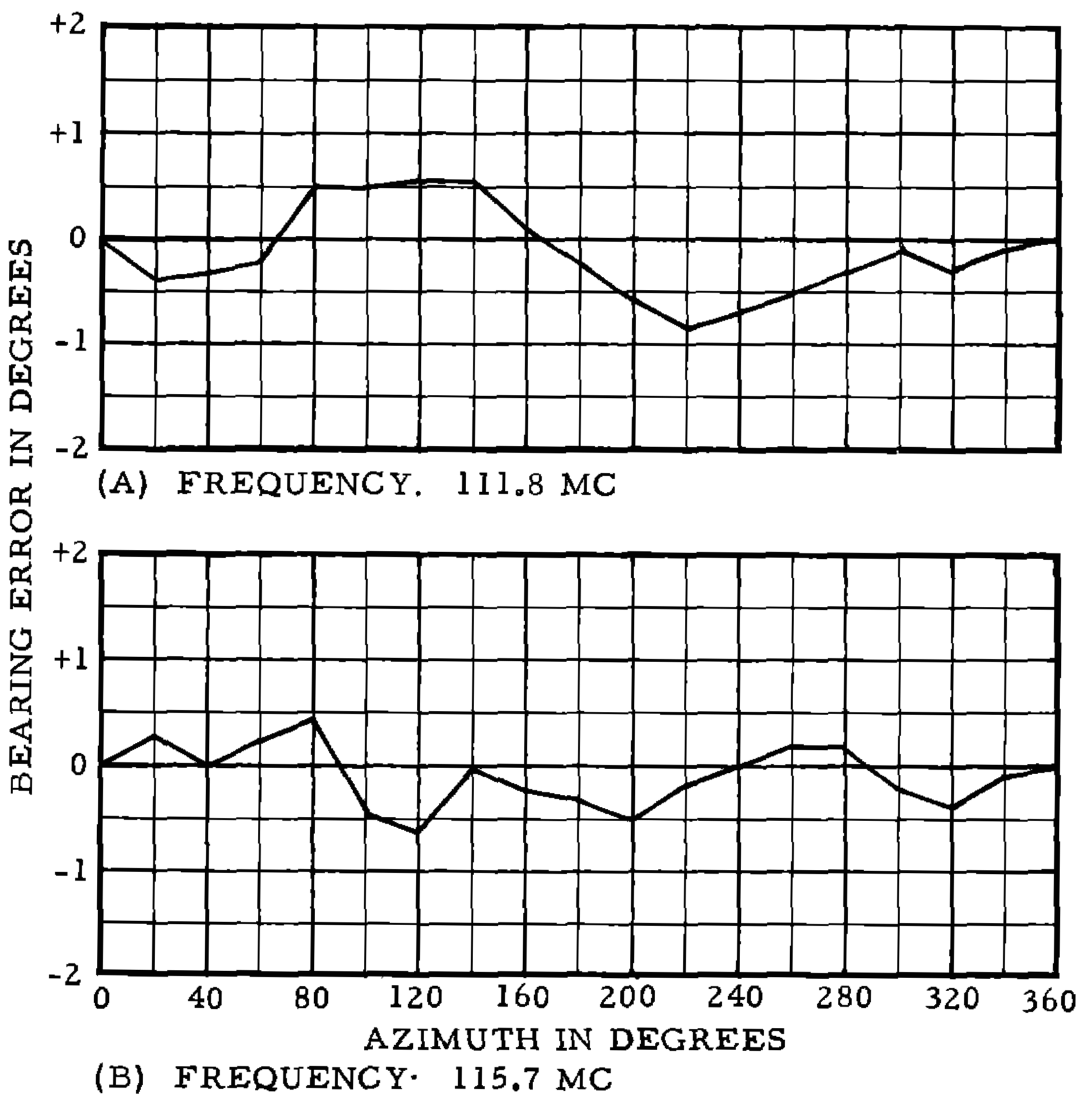


FIG. 6 GROUND CALIBRATIONS OF LORENZ VOR ANTENNA, VOR MONITOR DETECTOR AT 200-FOOT RADIUS

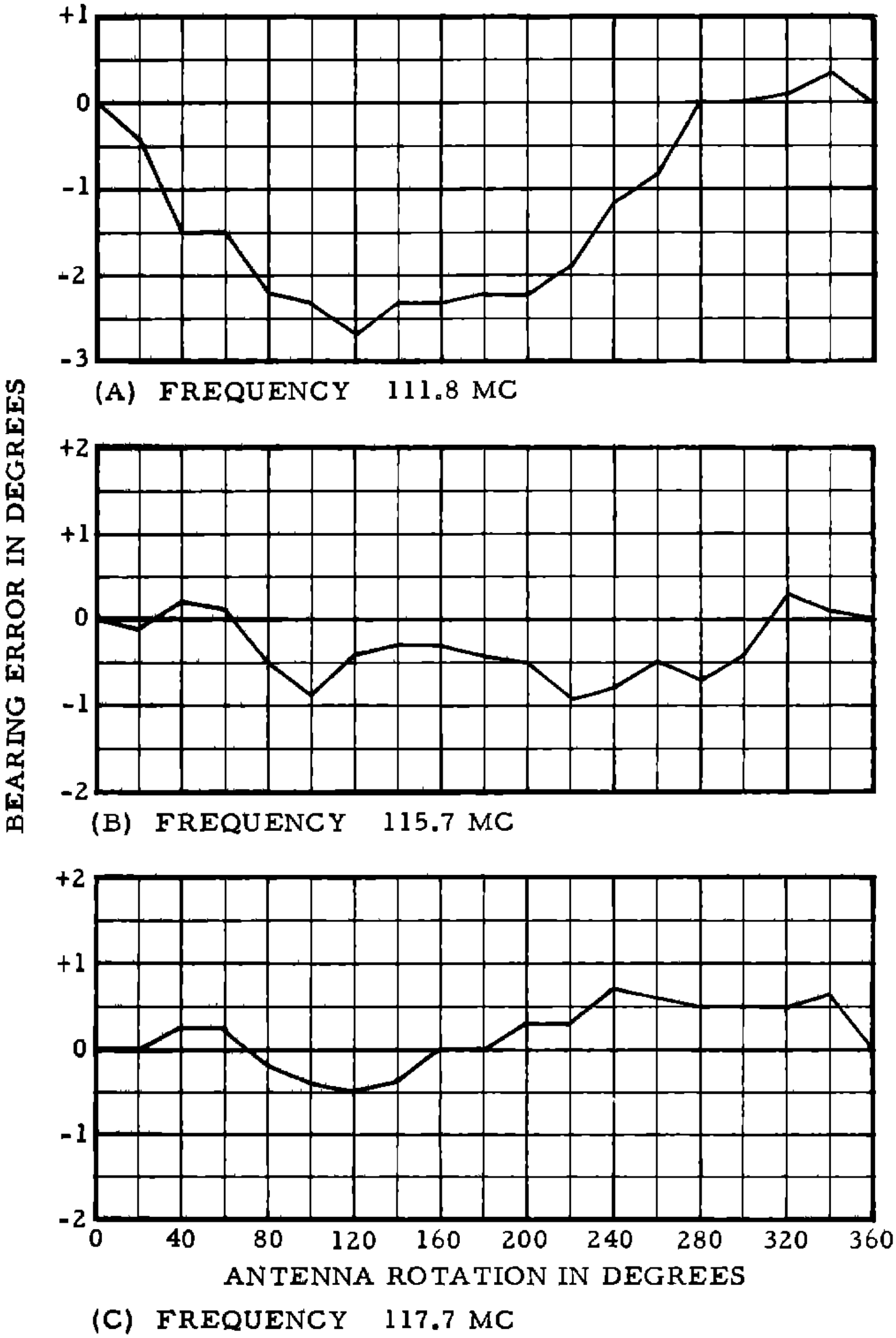
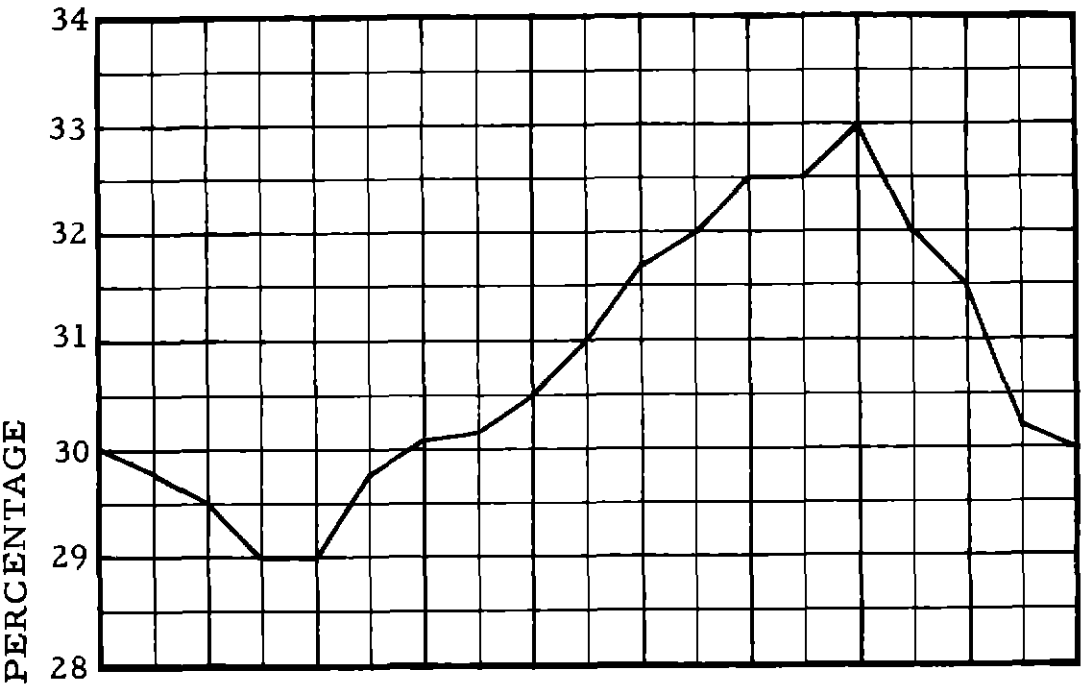
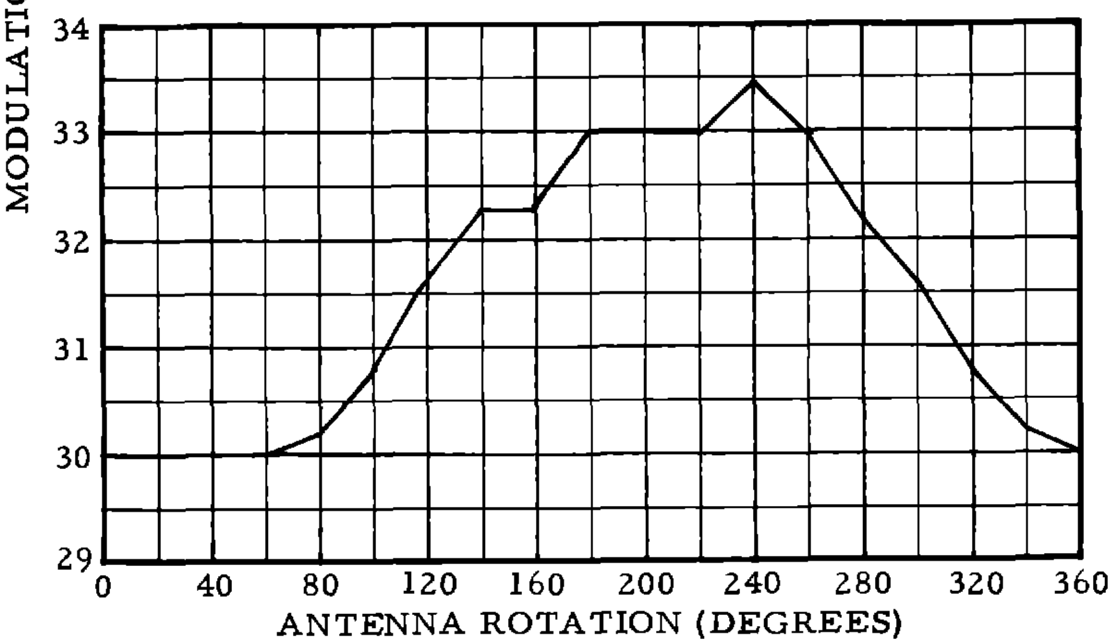


FIG. 7 RECEIVER LABORATORY CALIBRATION OF LORENZ VOR ANTENNA, ANTENNA ROTATED



A. FREQUENCY OF 111.8 MC



B. FREQUENCY OF 115.7 MC

FIG. 8 VARIATION OF SPACE MODULATION PERCENTAGE WITH AZIMUTH

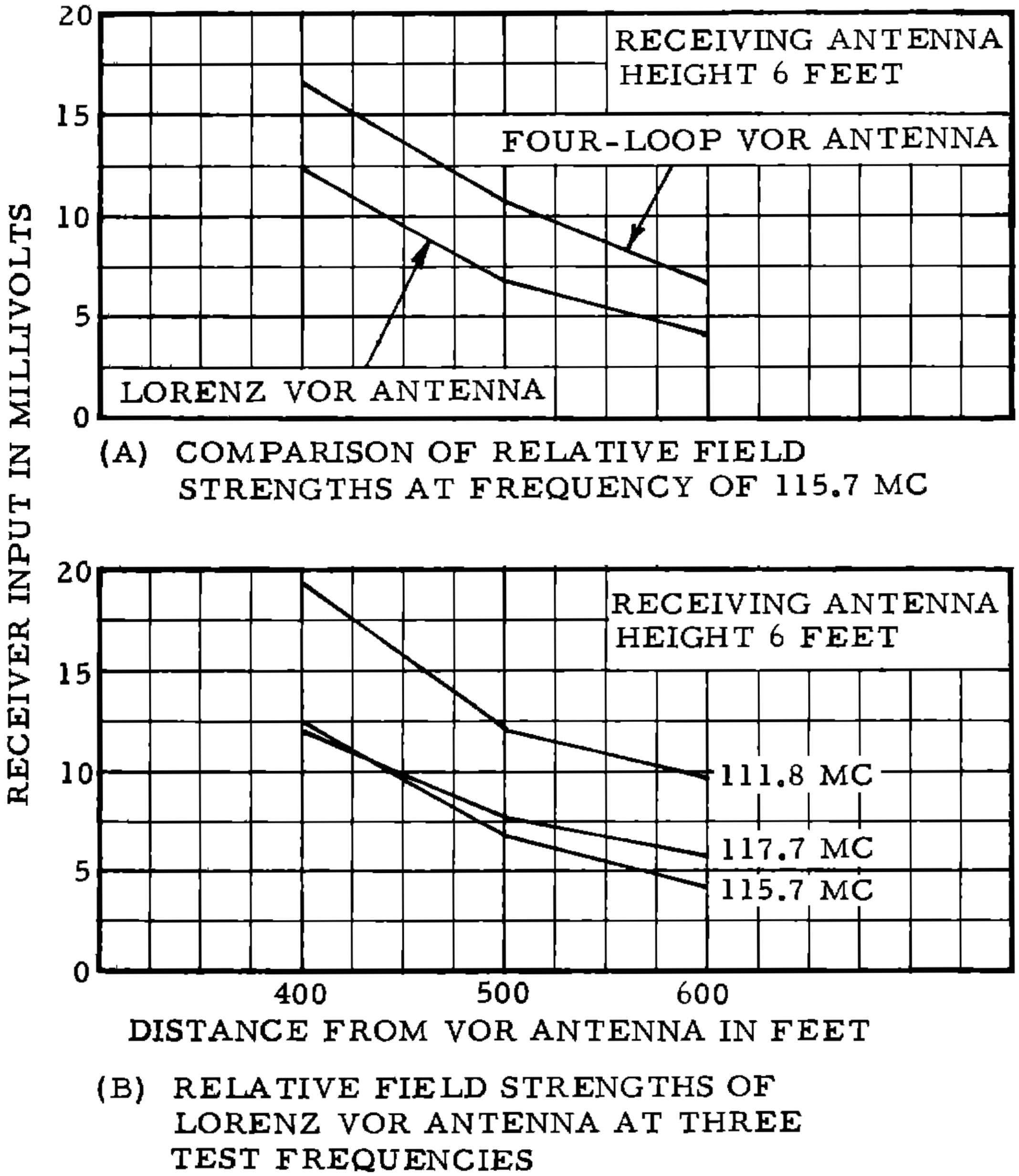


FIG. 9 RELATIVE FIELD STRENGTH MEASUREMENTS OF LORENZ AND FOUR-LOOP VOR ANTENNAS

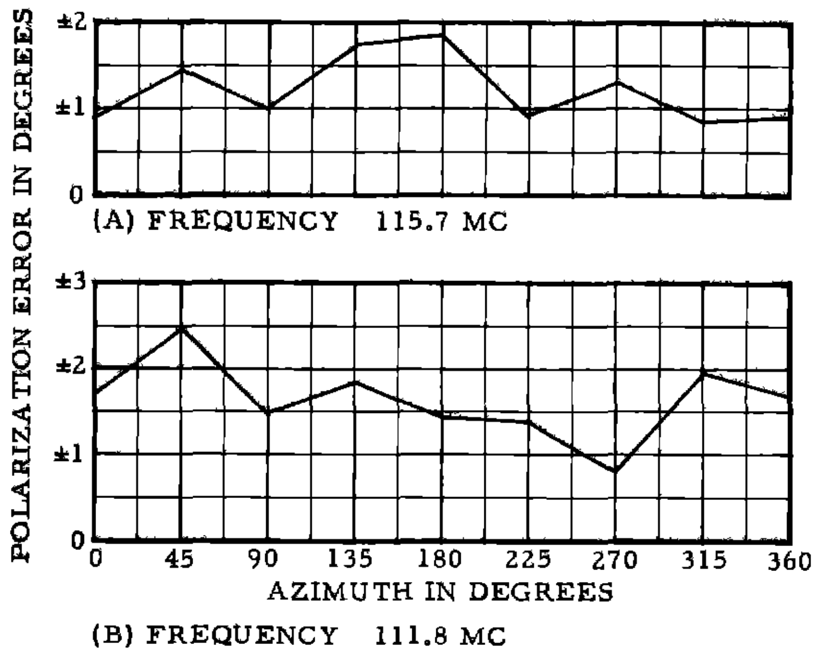


FIG. 10 POLARIZATION ERROR CURVES OF LORENZ VOR ANTENNA, GROUND CHECK

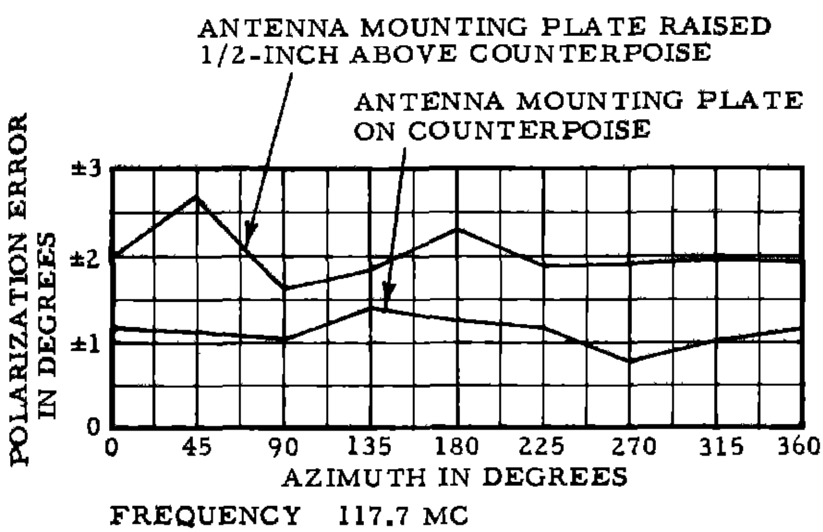


FIG. 11 POLARIZATION ERROR CURVES OF LORENZ VOR ANTENNA, GROUND CHECK

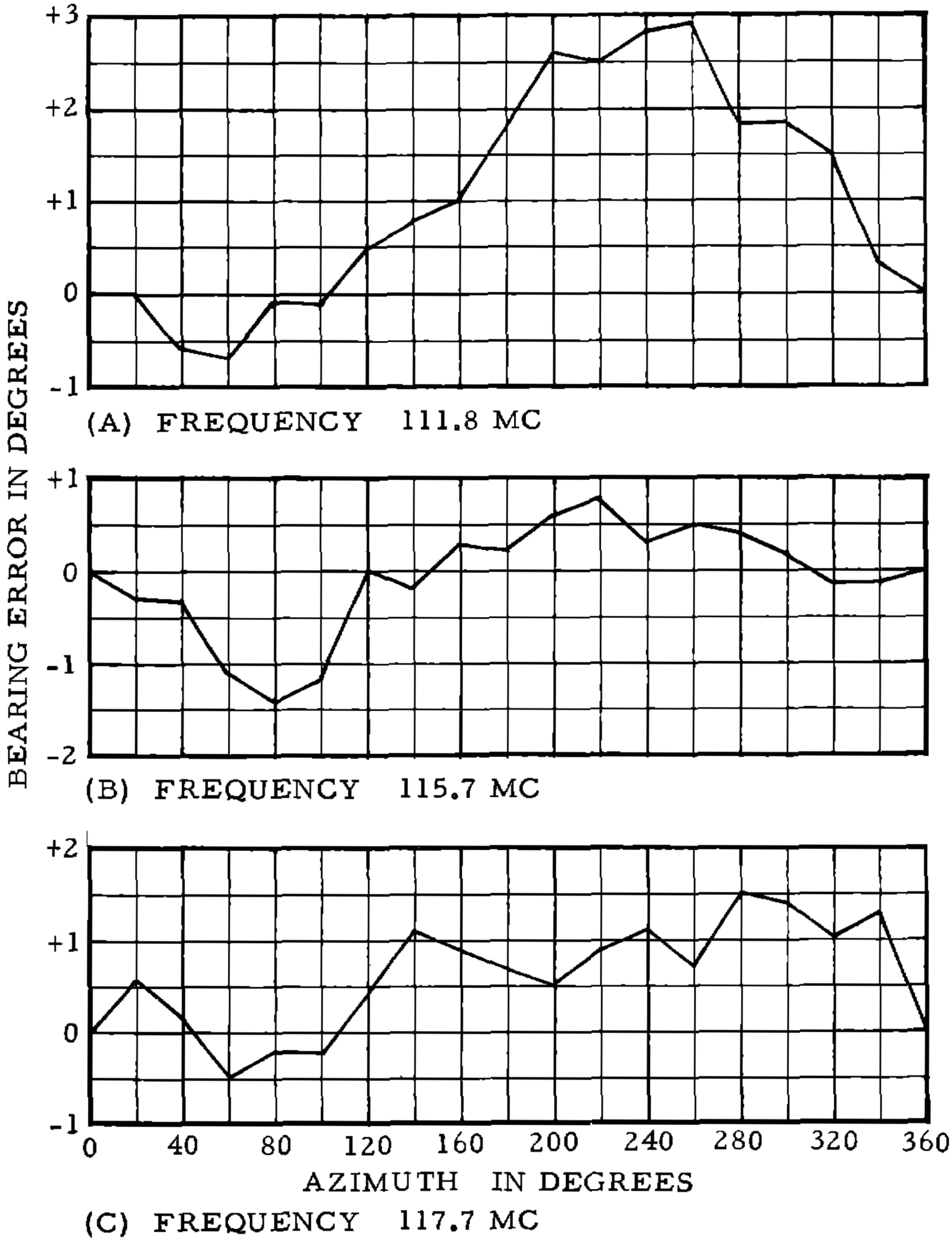


FIG. 12 THEODOLITE CALIBRATIONS OF LORENZ VOR ANTENNA, 6-MILE RADIUS

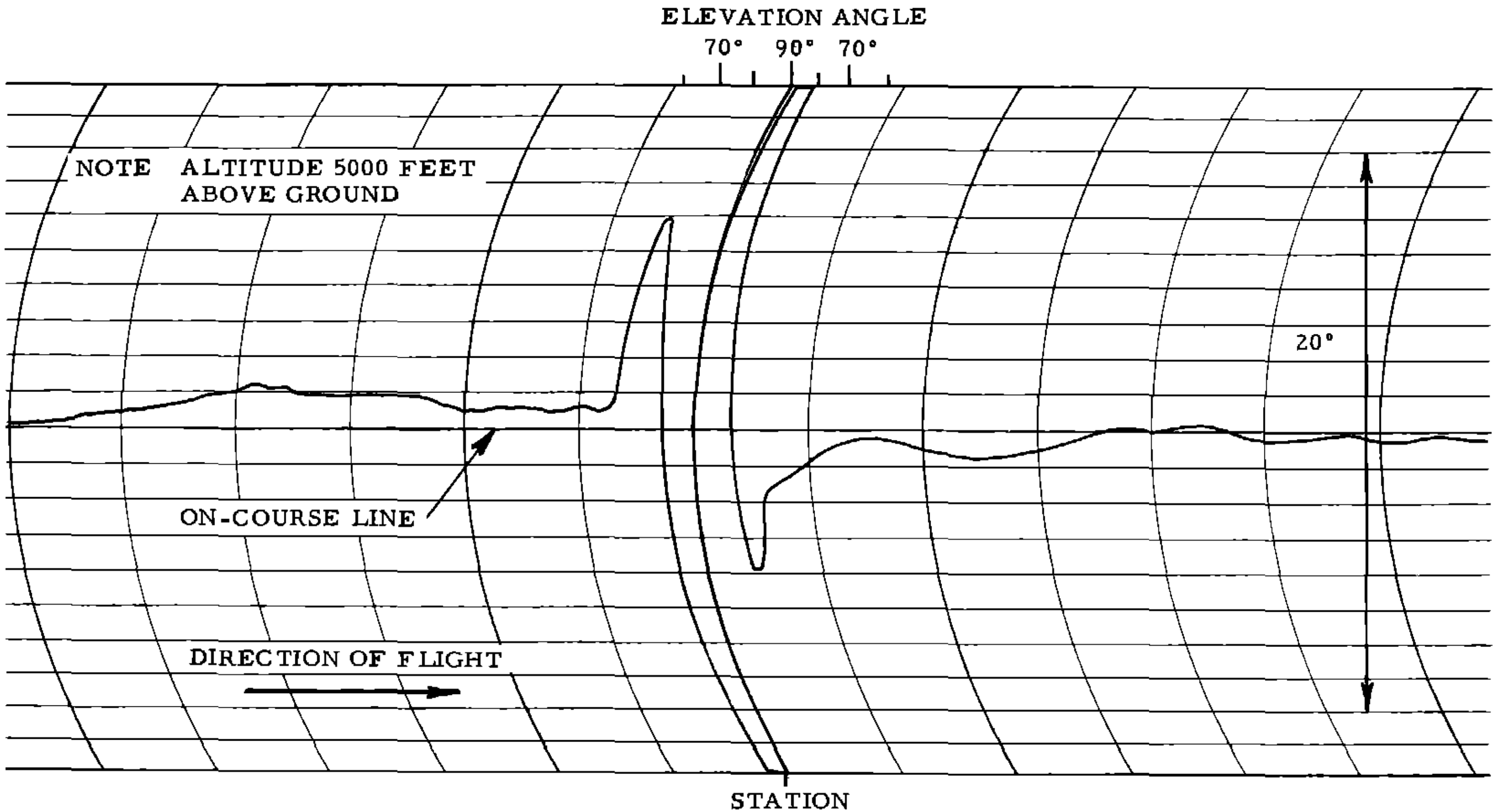


FIG. 13 COURSE DEVIATION INDICATOR RECORDING OF LORENZ VOR ANTENNA

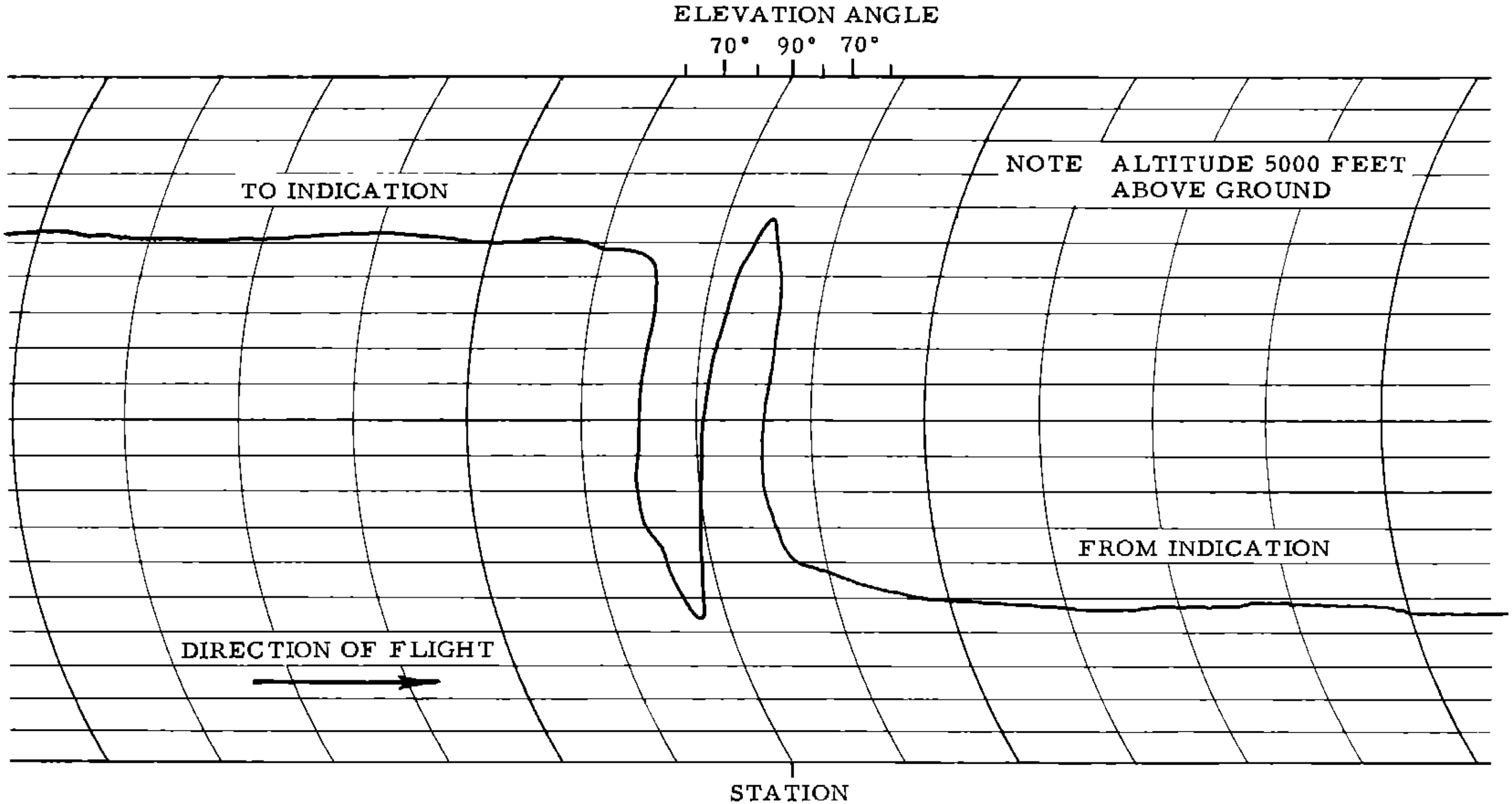


FIG. 14 TO-FROM INDICATOR RECORDING OF LORENZ VOR ANTENNA

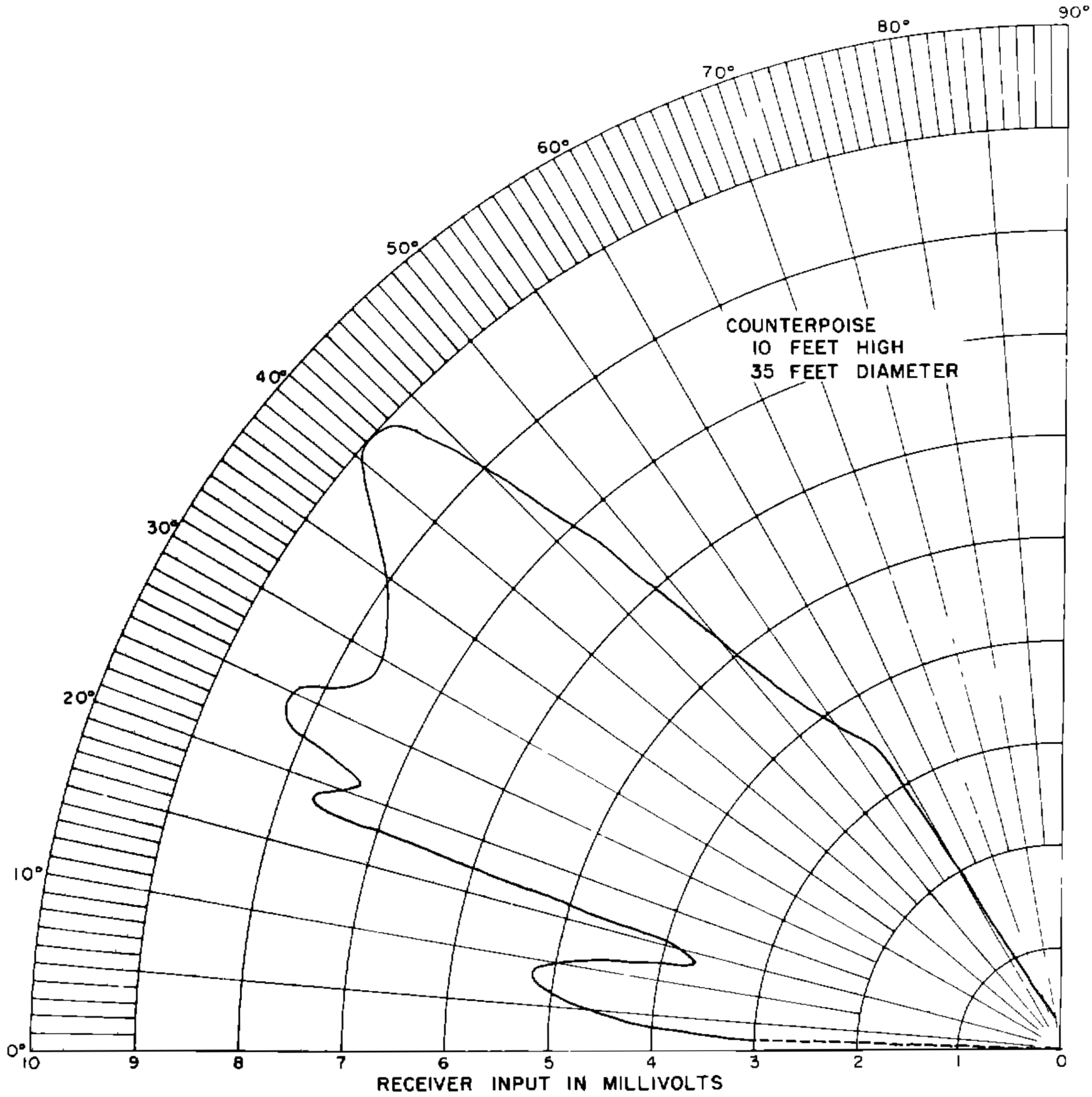


FIG. 15 LORENZ VOR ANTENNA VERTICAL PLANE FIELD PATTERN

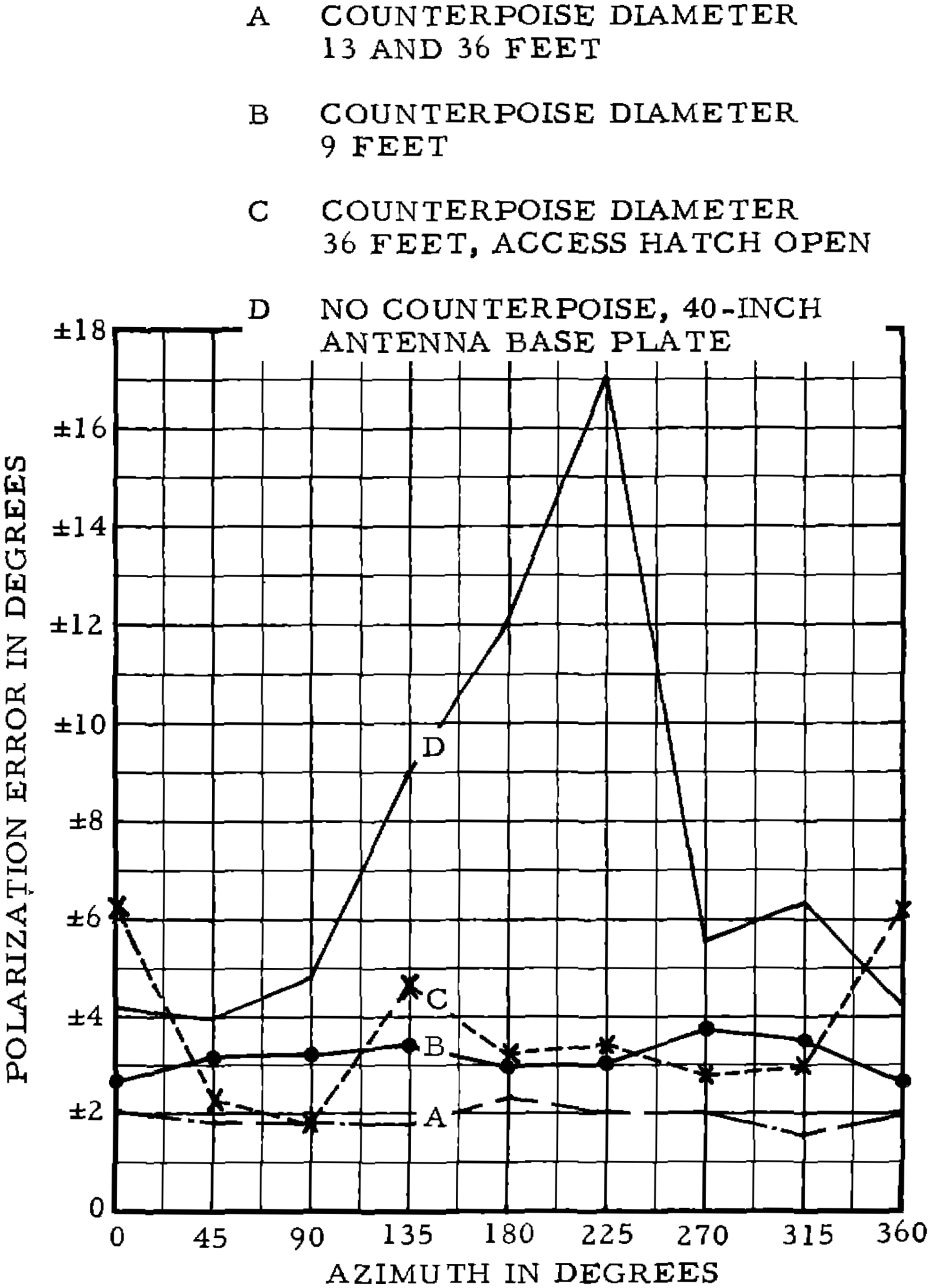


FIG. 16 POLARIZATION ERROR CURVES OF THE LORENZ VOR ANTENNA MOUNTED AT GROUND LEVEL