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# EVALUATION OF THE ALFORD SLOTTED-CYLINDER VOR ANTENNA

FOR LIMITED DISTRIBUTION

by

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# EVALUATION OF THE ALFORD SLOTTED-CYLINDER VOR ANTENNA

## SUMMARY

This report describes tests made on two Alford slotted-cylinder VOR antennas. The two antennas were alike except for minor modifications. Figure-of eight patterns were obtained and were plotted along with theoretically ideal curves.

Numerous tests were made to measure the bearing error and the effects of weather on the slotted-cylinder antenna. The bearing stability was compared with that of the TDEC four-loop array. Flight and ground tests were made to determine the polarization error, and the results were compared with similar tests on other types of VOR antennas. The size and characteristics of the cone above the station were determined by flight checks, and the distance range of the slotted-cylinder antenna was compared with that of the four-loop array.

The evaluation of the slotted-cylinder antenna was divided into two phases. Phase I shows a comparison of characteristics of this antenna and other VOR antennas. Phase II applies to a period of normal operation for one of the antennas. The factors involved in installing the antenna or changing its operating frequency also are discussed.

## INTRODUCTION

Since the original development of the CAA VHF omnirange, a number of different antenna systems have been conceived and built by various individuals and organizations. Attempts have been made to increase accuracy and stability, to reduce the size of the cone above the station, and to decrease the physical size of the antenna structure. One type of slotted-cylinder antenna was tested in 1948. At the present time several VOR antennas are being developed, but test data on most of these were not available at the time of the preparation of this report.

Two slotted-cylinder VOR antennas, developed by Andrew Alford, were obtained by the Air Navigation Development Board and forwarded to this Center for evaluation. All of the evaluation was conducted at two sites at the Weir Cook Airport at Indianapolis, Indiana. During the evaluation, data were obtained which could be used for direct comparison with other antennas tested.

The basic antenna is a metal cylinder 14 inches in diameter, 84 inches long, and mounted with the axis of the cylinder vertical. Four narrow vertical slots, 48 inches long are equally spaced around the cylinder and are protected from the weather by pressed fiber glass covers.

The uniform circular radiation pattern of the carrier is produced by feeding the four slots in phase. The carrier is amplitude-modulated by a 9.96-kc subcarrier which in turn is frequency-modulated by a 30-cps signal. This provides the reference phase. Diagonally opposite slots are fed in pairs to produce the figure-of-eight radiation patterns of the sidebands. Each of the two sideband slot pairs are fed carrier energy that has been stripped of all modulation. This carrier energy is supplied to the sidebands through a capacity goniometer which maintains a 90° rf phase displacement between the sidebands. A synchronous motor driving the goniometer causes the sidebands to produce a rotating figure-of-eight pattern at the rate of 30 cps. The rotating figure-of-eight pattern combines with the carrier in space to produce the variable phase modulation.

Two antennas, designated Serial No. 3 and Serial No. 4, were used in this evaluation. Both antennas had been adjusted at the factory to operate on 112.3 Mc.

## TEST EQUIPMENT

A 12-foot diameter counterpoise was located at one of the sites. The transmitter was sheltered in a building beneath the supporting tower when the counterpoise was elevated 10 feet above the ground. The transmitter shelter was moved horizontally 50 feet from the counterpoise when tests were conducted at ground level. A 35-foot diameter circular counterpoise supported 10 feet above the ground by a standard VOR building comprised the second site. A view of this installation is shown in Fig. 1. A rotatable pedestal extended from the floor of the VOR shelter to the level of the counterpoise. This provided a means of mounting the antenna so that it could be rotated, and the angle of rotation could be read accurately from an azimuth ring within the shelter. The rotating mechanism and the azimuth ring are shown in Fig. 2. Two monitors were installed along a common radial of the VOR and located approximately 100 feet and 3000 feet from the transmitting antenna.

## TESTS AND OBSERVATIONS

In January 1953 preliminary flights of antenna No. 3 indicated a wide cone with erroneous TO-FROM information above the station. After a conference with the manufacturer, it was agreed that lowering the antenna so that the centers of the slots would be 48 inches above the counterpoise instead of 72 inches, would improve the cone. This modification improved the TO-FROM indication to the extent that, instead of several fluctuations of the pointer, a single TO-FROM indication was observed.

VSWR Measurements

The No. 3 antenna was mounted at the north VOR site on a solid counterpoise 35 feet in diameter and 10 feet above the ground. A Type TUQ transmitter rated at 50 watts output at this frequency, and later a Type TUN transmitter developing 160 watts of rf power, were used to drive this antenna.

The No. 3 and No. 4 antenna voltage standing-wave ratios (VSWR) measured at two different times for the three RG-10/U inputs are given in Table I. The voltage standing-wave ratios for a four-loop antenna are also included.

TABLE I
VSWR Measurements

| | Alford No. 3 Jan. 1953 | Alford No. 3 June 1953 | Alford No. 4 | Typical 4-loop |
|---|---|---|---|---|
| Carrier | 1.15 | 1.17 | 1.26 | 1.10 |
| Sideband #1 | 1.05 | 1.30 | 1.52 | 1.13 |
| Sideband #2 | 1.08 | 1.36 | 1.36 | 1.16 |

Data were obtained and curves were drawn demonstrating the rate of change of VSWR with frequency. Figure 3 shows two sets of these curves. One set is for an Alford slotted cylinder adjusted to a frequency of 112 3 Mc, while the other set is for the same antenna adjusted to a frequency of 116.0 Mc. Figure 4 is a set of the same type of curves for a four-loop antenna adjusted to a frequency of 115.7 Mc. It may be seen from these curves that the sideband VSWR's of the slotted cylinder are more critical with respect to frequency than the carrier VSWR's and are also more critical than either sideband or carrier VSWR's for the four-loop array. From Fig. 3 it is also apparent that the minimum VSWR does not occur at the same frequency for the slotted-cylinder carrier as for the sidebands. In the case where the antenna was adjusted at 116 Mc, the minima for the two sidebands do not occur at the same frequency.

Horizontal-Plane Patterns

Figure 5 is a set of horizontal-plane patterns of radiation intensity from pairs of slots of the No. 3 antenna. Sine and cosine curves are also shown for comparison purposes as the theoretically desirable shape. Figure 6 presents the horizontal-plane pattern of the figure-of-eight, the theoretical sine and cosine curves, and a plot of carrier field intensity. It should be noted here that each pair of slots has its own nulls spaced 180° apart but that the nulls of one pair of slots are 88° from the nulls of the other pair of slots. Theoretically, this injects a 2° error in the bearing-error curve, and this error can be removed only by shifting the nulls to the normal 90° displacement.

The figure-of-eight radiation patterns of the slot pairs must be equal in size and shape, hence, the following method was used to compare the radiation efficiency of slot pair No. 1 and No. 3 to slot pair No. 2 and No. 4. Various lengths of attenuating cable were inserted in one or the other of the sideband feed lines until a minimum in bearing-error spread was obtained. This assured that most of the unbalance in the figure-of-eight sizes had been equalized, whether the unbalance was due to unequal r-f voltages fed to the slot pairs or to unequal radiation efficiencies. The two sideband feed lines, including the attenuating section, were interchanged at the antenna, and another bearing-error curve was obtained. Since the bearing-error spread remained the same, the attenuating sections were therefore equalizing an unbalance in voltages supplied to the antenna. Had the attenuating sections equalized an unbalance in radiation efficiency, the interchange of lines would have placed a low-voltage feed line on a pair of slots with poor radiation efficiency and the unbalance in figure-of-eight sizes would have been accentuated, producing a sizable increase in bearing-error spread. This test produced an equal bearing-error spread for both configurations of feed lines, indicating excellent balance in figure-of-eight size from each pair of slots for the Serial No 3 antenna when in a thoroughly dry condition. Later, the characteristics of this antenna changed, after which the figure-of-eight patterns shown in Fig. 5 were obtained. One lobe of each figure-of-eight pattern differed in magnitude by three per cent from its opposite lobe. This situation could not be remedied by external means but only by adjustments within the antenna. The adjustments were so inaccessible that no attempts were made to make any internal corrections.

## Bearing-Error Measurements

Bearing errors were measured at fixed locations with either a standard VOR receiver at a distance of 3000 feet, or with a monitor located 100 feet from the VOR. The antenna was rotated on a pedestal and bearings were read every 20°. The angular setting of the VOR antenna from a north reference line was accurately read from the pedestal azimuth ring which is shown in Fig. 2. This setting could be relied on to 0.1°. This method assured that interfering reflections from buildings would produce a constant fixed error for all angular positions of the antenna. Flight calibrations of the bearing error required more time to complete. They showed the combination of the station error plus the siting error.

One current method used to determine the transmitted bearing utilizes a standard Collins 51R-2 or equivalent receiver with a bearing selector having 1° detents. A 150-0-150 microammeter is substituted for the course deviation indicator. By noting the bearing selector setting and the scale reading of the microammeter, these conditions can be repeated when the receiver input is connected to the Collins 479-S phase standard, and a corrected bearing can be read from it. This method removes the receiver error, and the bearing error obtained is that transmitted from the VOR. A secondary method consists of detecting the radiated signal to obtain the VOR variable phase and applying this 30-cps signal to the horizontal plates of an oscilloscope, and a 30-cps signal from a Bendix Type CA 1430 phase-standard signal generator to the vertical plates of the oscilloscope. The resulting Lissajous figure may then be rotated by changing either the phase of the signal from the phase-standard signal generator or the variable phase transmitted from the VOR. The phase-standard motor and the goniometer motor are both synchronous and are driven from the same 60-cps power line. This provides a common time base for both the goniometer and the Type CA 1430 phase standard. By proper phasing of the signal from the phase standard relative to the variable phase transmitted from the VOR, one side of the Lissajous figure may be superimposed upon the other. This straight-line pattern becomes a sensitive indication of phase relation between the transmitted variable phase and the signal from the phase standard. With good oscilloscopes of high gain and constant phase shift within the oscilloscope amplifiers, the repeatability is 0.1°. If the VOR antenna array is not moved, the phase standard may be readjusted several times to produce the straight-line pattern on the oscilloscope, and the phase-standard reading will vary by not more than ±0.1°. One disadvantage of this system is that no use is made of the reference phase transmitted by the VOR; consequently, any changes occurring in the reference phase are not detected. Hence, if the actual bearing error of the VOR station is required, the first method is used. The second method is faster and more practical when one is interested only in changes of shape of the bearing-error curve.

<u>Effect of Weather on Bearing Accuracy</u>

The first weather effects investigated were those produced by a heavy, wet snowfall that coated one side of the antenna, primarily one slot. This coating of snow was 3/4 inch thick. Figure 7 is a plot of the error curve observed under these conditions along with a normal error curve taken with no snow coating. From these curves, it appears that a snow coating on one slot cover has little or no effect on the bearings transmitted from the antenna.

An ice coat 3/8 inch thick was next applied to the No. 4 slot and bearing errors were observed. Figure 8 is a photograph of this ice coating. A bearing-error curve, plotted with a normal curve is shown in Fig. 9. As in the case with the snow coating, the ice had little or no effect on the bearings transmitted. The total difference between the normal curve and the curve with an ice-coated slot is only 0.4°.

Tests were then conducted to determine the effects of water, such as a driving rain, blowing against the antenna. This condition was simulated by spraying water under pressure from a garden hose against the antenna. Curve A of Fig. 10 shows the bearing error of the station with a dry antenna, and Curve B shows the bearing error 30 minutes later after spraying the No. 4 slot with water. The bearing-error spread increased from 2.3° to 4.4°. The night after this test was performed, a heavy rain again wet the antenna. The next morning the bearing-error spread had increased to 7.6°, as shown in Curve C of Fig. 10.

The No. 4 antenna was also susceptible to moisture; however, the resulting moisture effects were different in this case. Curve A of Fig. 11 was obtained when the antenna was known to be wet inside, but with attenuating sections in one of the sideband lines to obtain the small 2.1° bearing error spread. Curve B was obtained after three days of dry weather. The bearing-error spread increased to 6° and changed to a quadrantal shape, indicating a change in figure-of-eight sizes.

A pressed fiber glass dome-shaped VOR antenna shelter of the type in use on the Federal Airways was installed after being modified to accommodate the additional height of the slotted-cylinder antenna. Little change in the total spread of the bearing-error curve was observed after three weeks operation during rain and high humidity although the location of the bearing-error maximum shifted with respect to azimuth.

Upon learning the effect of water on the bearing error, the manufacturer proposed sealing the metal seams of the antenna with a rubber compound to prevent the admittance of water. The effect of heavy rain was greatly reduced by sealing the antenna, but a slow change in the bearing error was still evident. The bearing-error Curve A of Fig. 12 was obtained on June 3 after several days of dry weather; and, so far as could be observed, the antenna was thoroughly dry. This bearing-error curve has a spread of 2.2°. On July 16, the bearing-error Curve B of Fig. 12 was obtained. At this time the antenna had been under a waterproof shelter for one week, and warm, dry air had been blown through the antenna with the slot covers removed for five hours. The bearing-error curve could change from 2.2° to 5° for some reason other than moisture within the antenna.

For comparison purposes, the following observations were made on a four-loop antenna.

1. The VSWR measurements made in July 1952, at the carrier and two sideband inputs of the Indianapolis TVOR four-loop array, indicate no appreciable change since stubbing the lines, 12 months previously.

2. The Indianapolis TVOR has used a four-loop antenna since 1950. The bearing was measured at the Center continuously from November 21, 1952, to February 6, 1953 An instability of approximately ±0.25° was noted for this period with the exception of November 25, when a change of ±10 75° was noted, and January 3 and 4, when a ±0.5° change occurred. It is believed that contact changes in the sideband phasers account for these variations.

3. Between December 15, 1952, and May 4, 1953, the bearing of the Federal Airways VOR at Indianapolis, Indiana, was measured twice daily at this Center. The readings varied by ±0.25° from a mean value of 137.7[illegible] during this period, with the exception of the approximate interval from March 1 to April 1, when the readings varied ±0.25° from a mean of 137.25°.

## Polarization Errors

Omnirange systems are designed to radiate horizontally polarized energy. Some vertically polarized radiation containing false information is normally present and steps are usually taken to keep this radiation at an absolute minimum. Tests were conducted to determine the magnitude of polarization error in the Alford antenna. The method and equipment used in the ground measurement of the polarization error are presented in another report[1]. Results of these tests are presented in Table II, together with comparison data obtained with other VOR antenna systems.

TABLE II
Polariscope Measurements of Polarization Error

| Type Antenna | Polarization-Error Total Spread in Direction of Maximum Error (degrees) |
|---|---|
| Alford slotted-cylinder No. 3 on 35-foot diameter counterpoise | 3.8 |
| Alford slotted-cylinder No. 4 on 12-foot diameter counterpoise | 2.2 |
| Alford slotted-cylinder No. 4 on 35-foot diameter counterpoise | 2.6 |
| TDEC four-loop on 12-foot diameter counterpoise with polarizer | 2.2 |
| TDEC four-loop on 35-foot diameter counterpoise with polarizer | 1.6 |
| TDEC five-loop on 35-foot diameter counterpoise with Uskon cloth | 6.0 |
| Federal Telecommunication Labs. spinning antenna | 2.1 |

From Table II it is evident that the slotted antenna compared quite favorably with other antenna systems with respect to polarization error. The polarization error was unusually uniform in all directions from the antenna.

Table III presents some results of flight checks[2] to determine polarization error of the slotted antenna in comparison with other antenna systems.

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

[2] Thomas S. Wonnell, "Mountain-Top VOR Site Flight Tests," CAA TD Report No. 139, March 1951.

TABLE III
Aircraft Measurements of Polarization Error

| Type Antenna | Bearing Error: 30° Wing Rock (degrees) | Eight Ways Over a Point (degrees) | 360° Circle (degrees) |
|---|---|---|---|
| Federal Telecommunication Labs. spinning antenna | ±0.62 | ±1.0 | ±0.5 |
| Four-loop antenna | ±0.5 | ±0.6 | ±0.7 |
| Alford slotted No.3 at ground level | ±0.65 | ±0.5 | ±1.8 |
| Alford No.3 on 35-foot diameter counterpoise 10 feet high | ±0.15 | ±0.3 | ±1.5 |
| Five-loop array with Uskon cloth | ±0.87 | ±0.8 | ±2.1 |

This Table also indicates that the slotted-cylinder antenna mounted on a 35-foot diameter counterpoise compared favorably with other antennas as regards polarization error.

## Width of Cone

The method commonly used to define cone width failed in the case of the slotted-cylinder antenna because of the exceptionally low signal level within the cone. Normally, as a flight is made across the cone above a four-loop array, rapid fluctuations of the CDI denote the interior of the cone. Occasionally, one or two rapid appearances of the flag will occur. A normal flight through the cone above the slotted cylinder caused the flag to show partially from the time the angle of elevation of the aircraft was 45° to the horizontal until the aircraft passed over the station and out again to an angle of elevation of 45° on the other side. The signal level was so low that instead of the CDI fluctuating, it became almost stationary at the on-course position. Actual measurements on a recording with angular indications derived from a theodolite located at the station showed that the flag appeared when the aircraft was at an elevation of 44° to the horizon.

## TO-FROM Cone Measurements

A recording of the TO-FROM indication as the aircraft is flown directly over the station provides useful information for evaluating the cone transmitted by a VOR antenna. Figure 13a is typical of the recordings obtained when the slotted-cyclinder antenna was mounted on a 35-foot diameter counterpoise 10 feet high. Figure 13b is a typical recording obtained when the antenna was on a 12-foot diameter counterpoise 10 feet high. TO-FROM recordings made on the cone above a four-loop array mounted on a 12-foot diameter counterpoise 10 feet high and on a 35-foot diameter counterpoise 10 feet high are shown in Figs. 13c and 13d, respectively. Recordings 13a and 13b were both obtained from the cone above the No. 4 antenna, but 13e was from the No. 3 antenna. The multiple crossovers associated with the No. 3 antenna were practically eliminated in the No. 4 antenna This improvement was brought about by adjusting the voltage distribution across the slots so that the carrier and sideband maxima coincided at the center of each slot. It should also be pointed out that, with the antenna on a 35-foot diameter counterpoise, the TO-FROM crossover was gradual as compared to the rapid TO-FROM crossover of the four-loop array. This indicated that the cone above the slotted cylinder was broad. With the slotted-cylinder antenna on a 12-foot diameter counterpoise, the crossover was sharper and more defined with a suggestion of the build-up that is present in the case of the four-loop array just before the crossover. On the 12-foot diameter counterpoise, there was some tendency toward a low clearance as the crossover was approached. The opinion that there was a broad cone of low signal above the slotted-cylinder antenna was confirmed by the test data.

Distance Range

The distance range[3] for the slotted-cylinder antenna was 56 miles, which is the same as that for the four and five-loop arrays for the same amount of power supplied from the transmitter. The antenna was mounted on a 35-foot diameter counterpoise 10 feet high and fed with a 160-watt transmitter.

Cross Coupling

Data are furnished in Table IV to show a comparison of carrier to sideband isolation in the Alford antenna and in the four-loop antenna. The measurements were made with the station operating normally except that no power was fed to the modulation eliminator, its input being left open. Power was then supplied to the carrier input only, while the carrier and the two sideband voltages were measured.

TABLE IV
Measurements of Carrier to Sideband Isolation

| | Alford Antenna (volts) | Four-Loop Antenna (volts) |
|---|---|---|
| Carrier | 100 | 100 |
| Sideband #1 | 1.67 | 1.4 |
| Sideband #2 | 2.54 | 1.5 |

[3] Ibid.

## Adjustments Necessary to Change Frequency

A change in frequency is much more easily accomplished with the slotted-cylinder antenna than with the four-loop array. To change frequency it is only necessary to determine two numbers corresponding to the desired frequency from a chart supplied with the antenna. These two numbers are scale settings for two sliding adjustments inside the antenna near its base. Figure 14 shows these two scales with the slot cover removed as would be necessary in order to make the adjustments. The slotted-cylinder antenna utilizes three frequency divisions to cover the VOR band. A pair of operating shunts, fitted with N-type coaxial fittings, are provided for each frequency division. In contrast, the four-loop array requires carefully cut lengths of line in the bridges as well as matching stubs of the correct length at the three antenna inputs. These line lengths can be determined from graphs of previous tests. The loop-antenna system divides the VOR band into two parts. A different set of loop antennas are required for each of the two frequency divisions.

## Effect of Unbalance Between Sidebands

Equipment employing carrier and sideband lines 60 feet in length was used for all tests of Phase I. This prevented the irregularities in the equipment from entering into the tests. A number of changes were made before entering on the Phase II testing. The sideband and carrier lines were shortened to approximately 10 feet in length. A Type TUN transmitter producing 160 watts of r-f power was used in place of the Type TUQ transmitter which produces 50 watts of output power.

Figure 16a is a diagram of the equipment associated with the antenna. The 12-1/2-inch length of RG-21/U attenuation cable was added externally at TDEC to equalize the radiated energy of the sidebands because the lobes of the sideband figure-of-eight patterns were not of equal amplitudes. The antenna was rotated about a fixed axis and the sideband energy was measured with a calibrated field meter to obtain the relative field strength. Table V gives the maximum field strength readings of the sideband figure-of-eight patterns without attenuation cable in sideband No. 1. It was intended to operate the antenna for the operational evaluation with a minimum bearing error. Some of the antenna defects were given detailed analysis in other sections of this report. Figure 17 is the bearing error curve with the attenuation cable in the sideband No. 1 feed line.

TABLE V
Relative Field Strengths Without Attenuation Cable

| Sideband | Bearing (degrees) | Relative Field Strength |
|---|---|---|
| No. 1 | 143 | 98.5 |
| | 322 | 95.0 |
| No. 2 | 47 | 93.7 |
| | 230 | 97.0 |

After the 12-1/2 inches of attenuation line had been placed in the No. 1 sideband line, the relative field strengths listed in Table VI were measured.

TABLE VI
Relative Field Strengths With Attenuation Cable

| Sideband | Bearing (degrees) | Relative Field Strength |
|---|---|---|
| No. 1 | 143 | 96.2 |
| | 322 | 97.9 |
| No. 2 | 47 | 98.5 |
| | 230 | 95.1 |

From the relative field data in Tables V and VI, it is possible to have bearing errors of maximum value at the four cardinal points as given in Table VII

TABLE VII
Possible Errors Due to Sideband Unbalance

| Without RG-21/U In Sideband No. 1 | | With 12-1/2 inches RG-21U In Sideband No.1 |
|---|---|---|
| Bearing (degrees) | Possible Error (degrees) | Possible Error (degrees) |
| 0 | -0.1 | +0.20 |
| 90 | +1.4 | -0.62 |
| 180 | -0.82 | -0.40 |
| 270 | -0.85 | +0.82 |

It was necessary to isolate any changes in the antenna from possible changes in the associated equipment. A number of measurements were made, at which time the position and serial numbers of test equipment were recorded, to obtain a set of reference voltages. The sideband lines were terminated in 51.5-ohm dummy loads as shown in Fig 16b. The voltages delivered by the goniometer to the sideband lines were measured at the dummy loads with a General Radio Company vacuum tube voltmeter using an r-f probe. Sideband No. 1 read 9.1 volts and sideband No. 2 read 9.3 volts. The desired ratio of the sideband voltages, 1.02, was noted. In the next step the concentric line phasers and the attenuation cable were removed, leaving the goniometer terminated in the dummy loads through the sideband lines. The voltages, measured at the dummy loads, were each found to be 9.35 volts, indicating that the goniometer was delivering a balanced voltage at each sideband output. Under these known conditions, the antenna was placed in operation with the phasers and attenuation line in place as shown in Fig.,16a.

The station operated normally for about six weeks when a fault occurred. The bearing error curve changed from an over-all spread of 4 2° to an over-all spread of 8.6°. Minor changes had occurred during this interval, but these were not considered sufficient to merit investigation. The test procedure employed in establishing the reference conditions was followed to determine the cause of this sudden shift in bearing error. The sideband lines were connected to the dummy loads as shown in Fig. 16b, and the sideband voltages were measured Sideband No. 1 measured 7 1 volts, and sideband No. 2 measured 7.7 volts, a ratio of 1.084 The next step was to remove the attenuation cable and the phasers and make another measurement with the goniometer terminated in dummy loads through the sideband lines only, as shown in Fig. 16c. The sideband No. 1 voltage was 8 1 volts, and the sideband No. 2 voltage measured 8.15 volts, a ratio of 1.008. The attenuation line was replaced, and the sideband voltages were measured to determine if the attenuation line was at fault. The voltage at sideband No. 1 now measured 7.6 volts and at sideband No 2 it measured 7.8 volts, a ratio of 1.027, which is essentially the same as the original measurements. The RG-21/U attenuation cable, which was originally suspected as being at fault, produced an unbalanced sideband voltage ratio of 0.007. An over-all error of less than 0.2° could be attributed to this unbalance. The attenuation cable and fittings were tested for loose or intermittent connections, but no faults could be detected.

The evidence then indicated that the Alford concentric line phasers might be at fault. The plating on the exterior of the phasers caused the threads of the locking nuts to bind Although the phasers were not disassembled, it appeared possible that part of the plating on the interior of the phasers might have flaked or become loose, and thereby produced a variable conductivity.

The phasers and the attenuation cable were removed from the sideband lines, and the station was placed in operation with the connections as shown in Fig. 16d. It was desired to keep all external modifications and equipment at a minimum to insure reliable evaluation of the antenna The sideband lines were trimmed to equal electrical lengths by pruning each line to provide the same r-f phase relationship with the carrier line. A single trombone-type phaser was inserted in the carrier line to permit the adjustment of the r-f phase displacement between the carrier and sidebands.

The bearing error, Curve (a) of Fig. 18 shows the calibration of the antenna when placed in operation as described above and as shown in Fig. 16d. The bearing error, Curve (b) of Fig. 18, shows the calibration of the antenna after 30 days of continuous operation. A comparison of the two curves indicates that there was still a small instability in the antenna that could not be accounted for at this time.

## MISCELLANEOUS OBSERVATIONS

The No. 3 antenna carrier feed developed a short circuit. This short circuit was traced to a faulty piece of RG-10/U cable. A photograph of the cross section of the cable at the point where the fault occurred is shown in Fig 15.

When first examined, the No. 4 antenna also exhibited a short circuit on the carrier feed line. Investigation disclosed that a broken Riv-Nut had lodged between the plate where the carrier feed branches to the four slots and the bulkhead that is a structural part of the antenna.

## CONCLUSIONS

The installation of the Alford slotted-cylinder antenna is easily accomplished. Three independent adjustments are required to change the antenna for any frequency in the VOR band. Two slot covers must be removed to make any frequency adjustments; therefore it is important that these covers be sealed to prevent any moisture from getting inside the antenna after the frequency adjustments have been completed.

Polarization error was not excessive when the antenna was mounted on either a 35-foot or a 12-foot diameter counterpoise.

The distance range of the signal radiated was 56 miles at 1,000 feet altitude. This is the same as that of the four-loop array, for equal r-f power input.

The cone above the station is quite wide and "soft" compared to that of the four-loop array, resulting in a slow, indefinite TO-FROM crossover. Antenna No. 4 did not produce any erroneous information, but Antenna No. 3 did show multiple crossovers.

Ice and snow coatings had a negligible effect on the bearing accuracy.

The most serious defect of the antenna without a shelter was its bearing instability. Moisture entering the interior of the antenna caused the bearing error to change from ±1.0° to ±4.0°. Changes of lesser degree could take place, depending upon the amount of moisture entering the antenna.

A slow change in bearing error of ±2.0° for antenna No. 3 using a CAA VOR antenna shelter could not be definitely correlated with weather changes. Tests indicated that both the magnitude of the figure-of-eight patterns and the location of the nulls changed over a period of time.

Tests conducted during Phase II of the tests using the CAA VOR antenna shelter indicated that the greater part of the instability experienced was caused by the Alford concentric line phasers. After eliminating the instability produced by the phasers, a bearing instability of ±0.5° still remained.

The antenna components in general were not easily accessible and replacement or repair would be most difficult in the field, even if the parts were available. Many types of faults would require the return of the antenna to the manufacturer for correction.

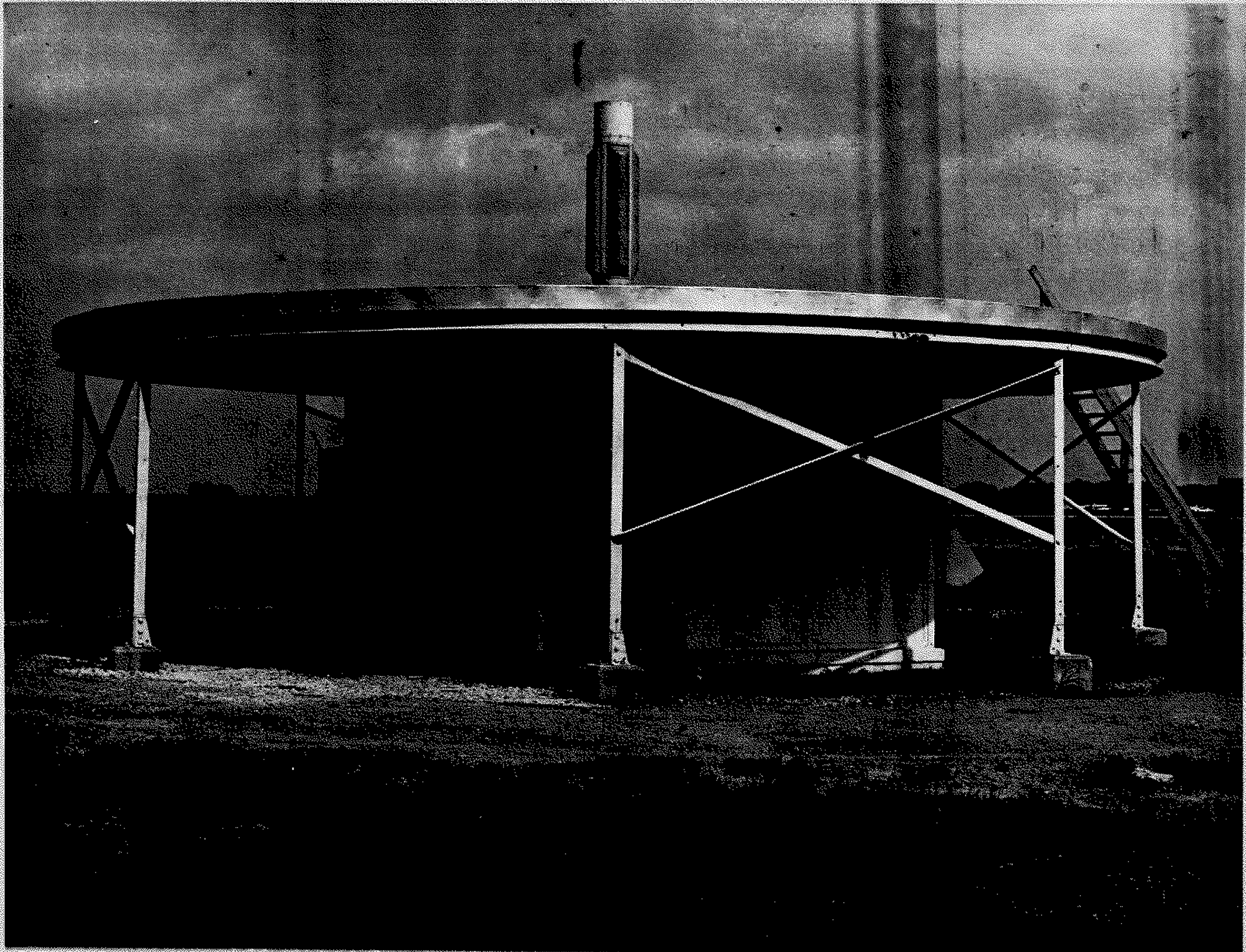


FIG. I ALFORD SLOTTED ANTENNA ON 35-FT. DIAMETER COUNTERPOISE

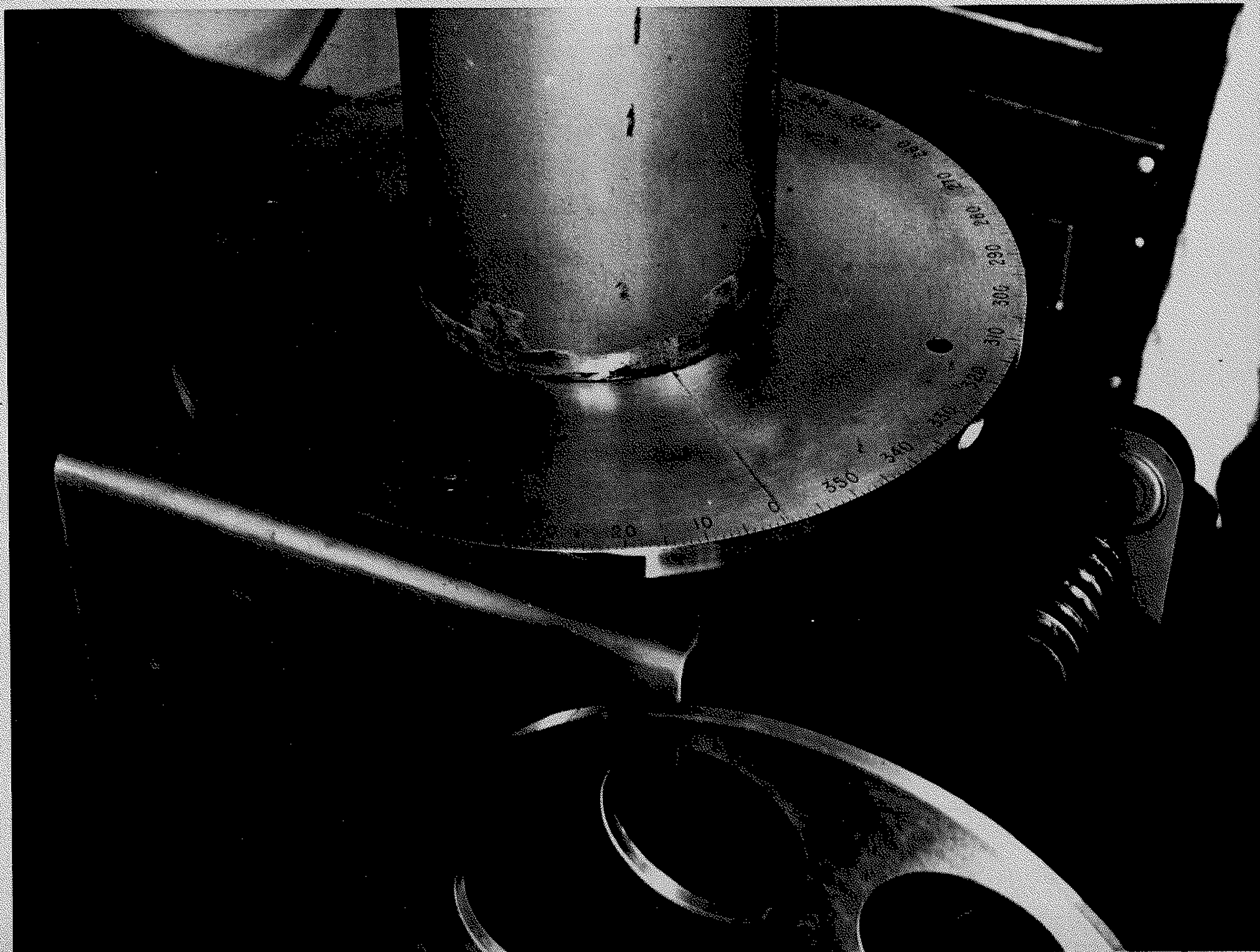



FIG. 2 AZIMUTH RING

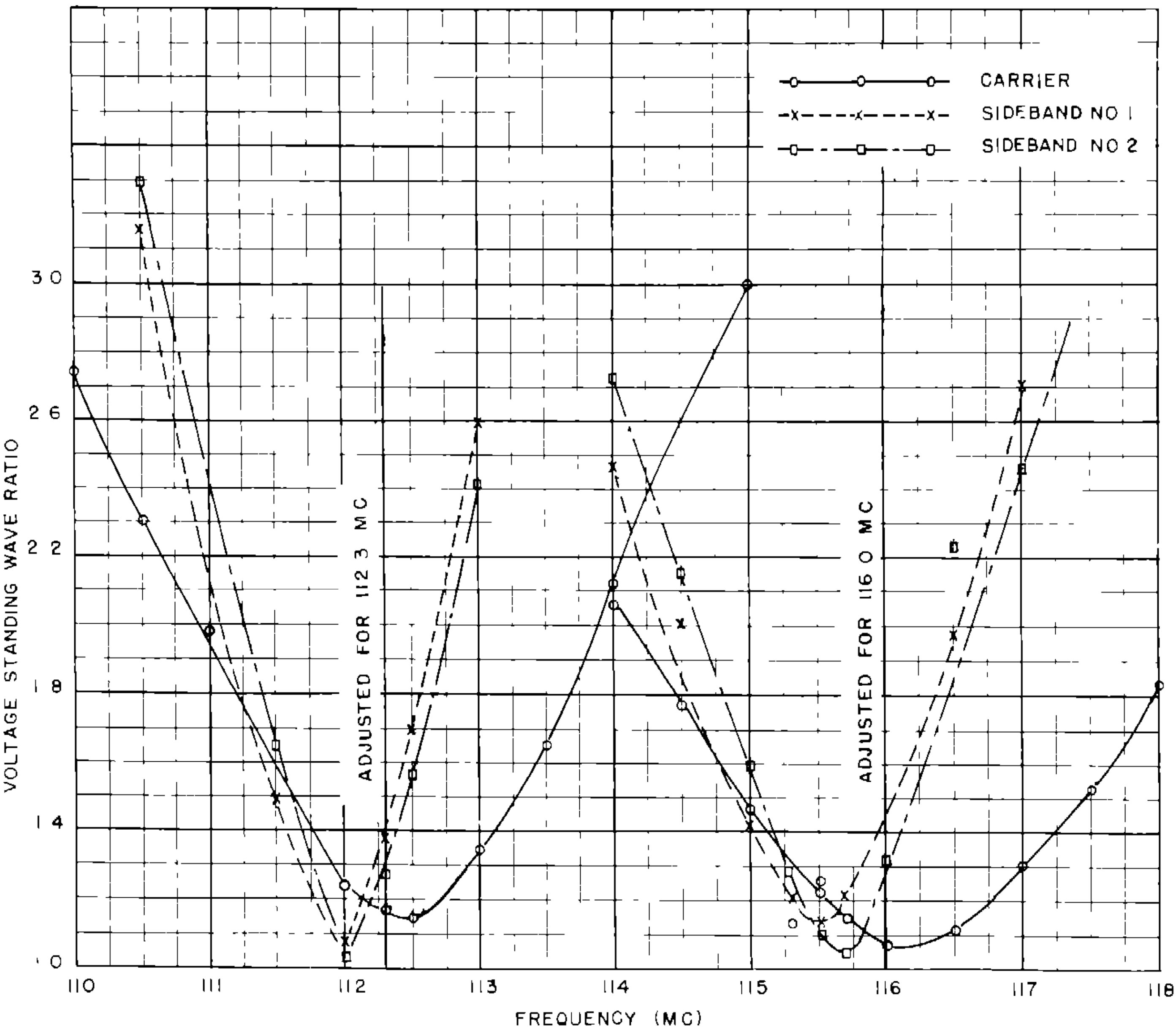



FIG 3 VOLTAGE STANDING WAVE RATIO VS FREQUENCY WHEN ADJUSTED AS NOTED (ALFORD SLOTTED CYLINDER ANTENNA NO 3)

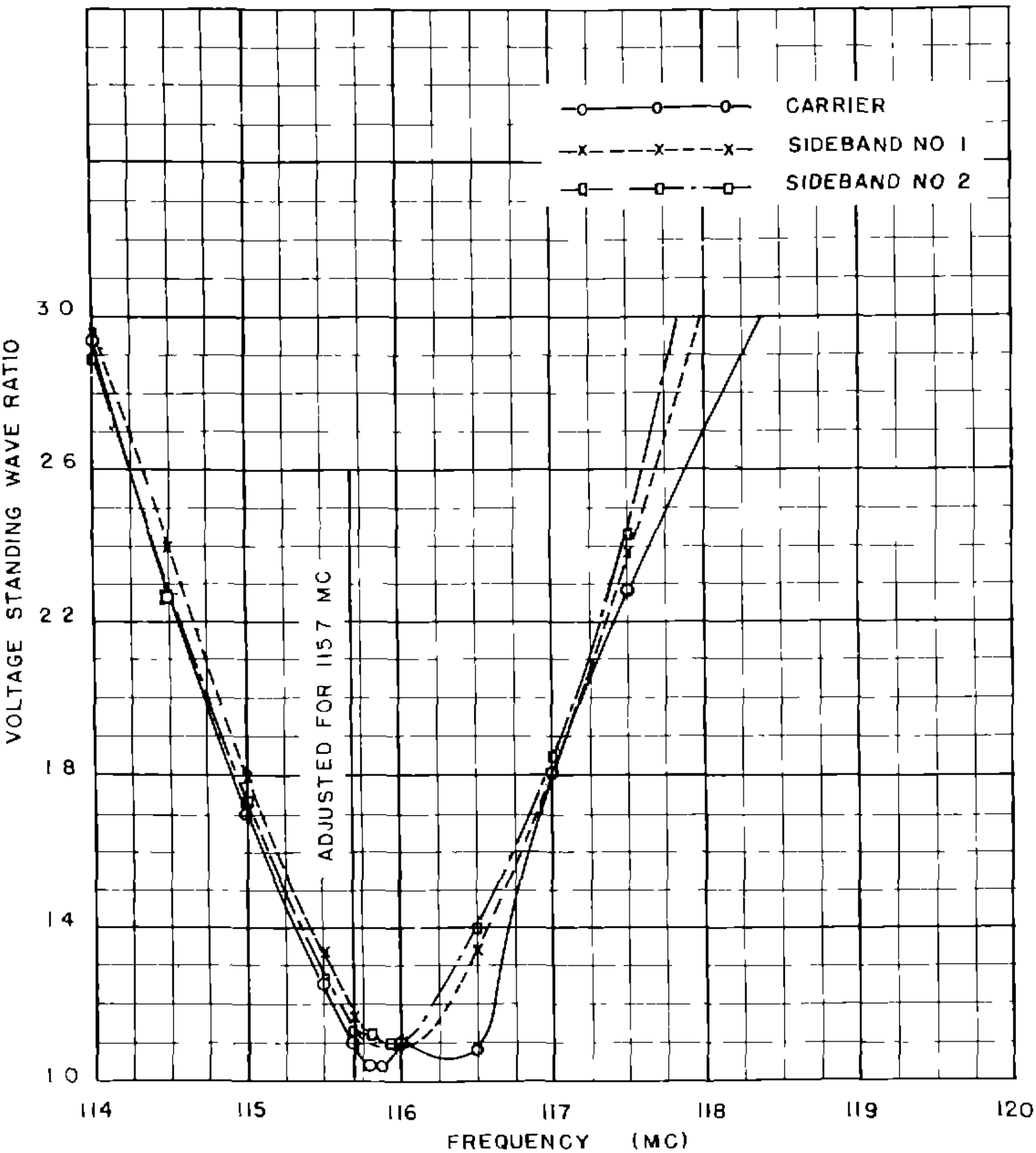



FIG 4 VOLTAGE STANDING WAVE RATIO VS FREQUENCY WHEN ADJUSTED AS NOTED (4-LOOP VOR ANTENNA)

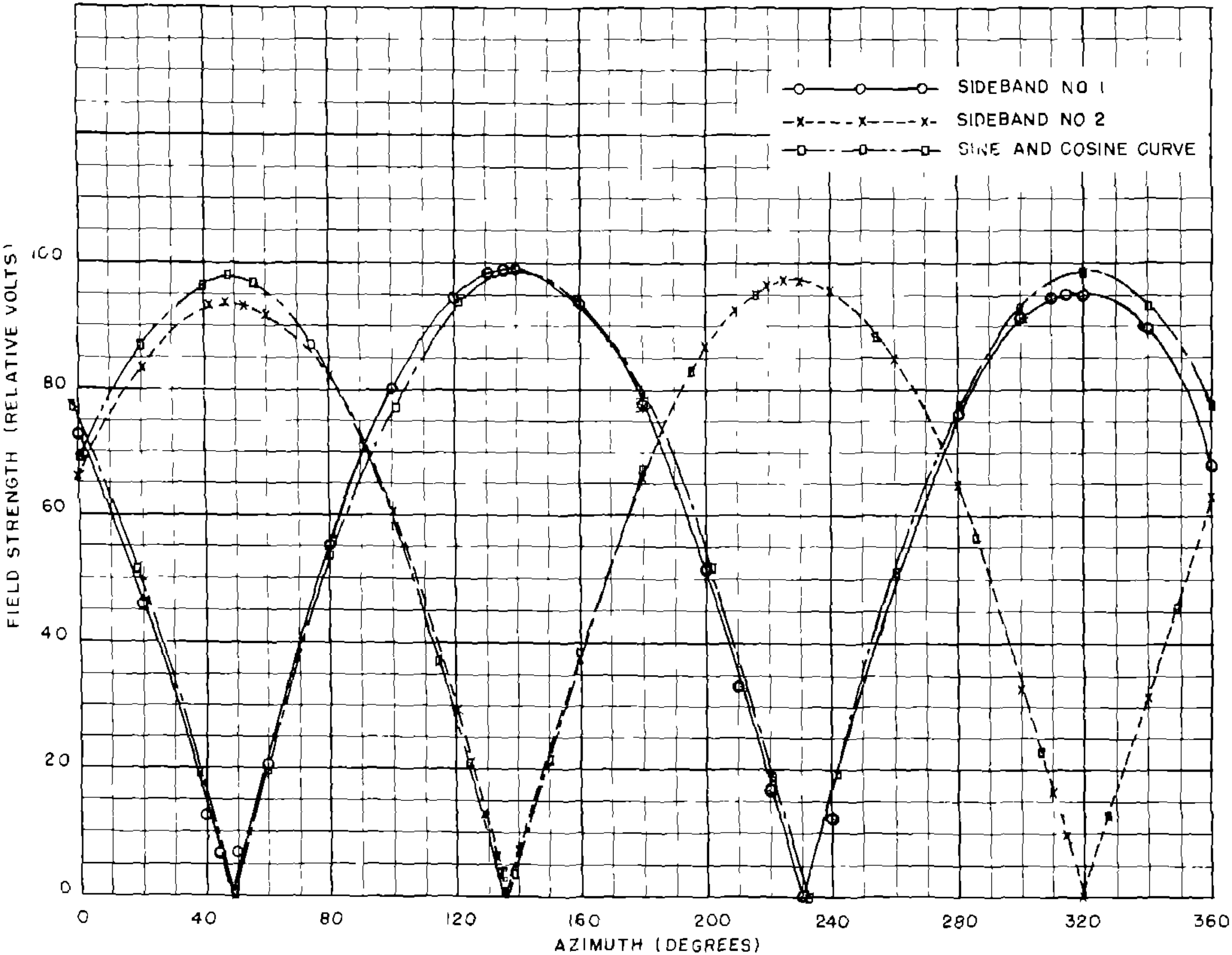



FIG 5 FIGURE OF-EIGHT PATTERNS WITH SINE AND COSINE CURVES FOR ALFORD SLOTTED CYLINDER ANTENNA NO 3 (SNOW COATED SLOT)

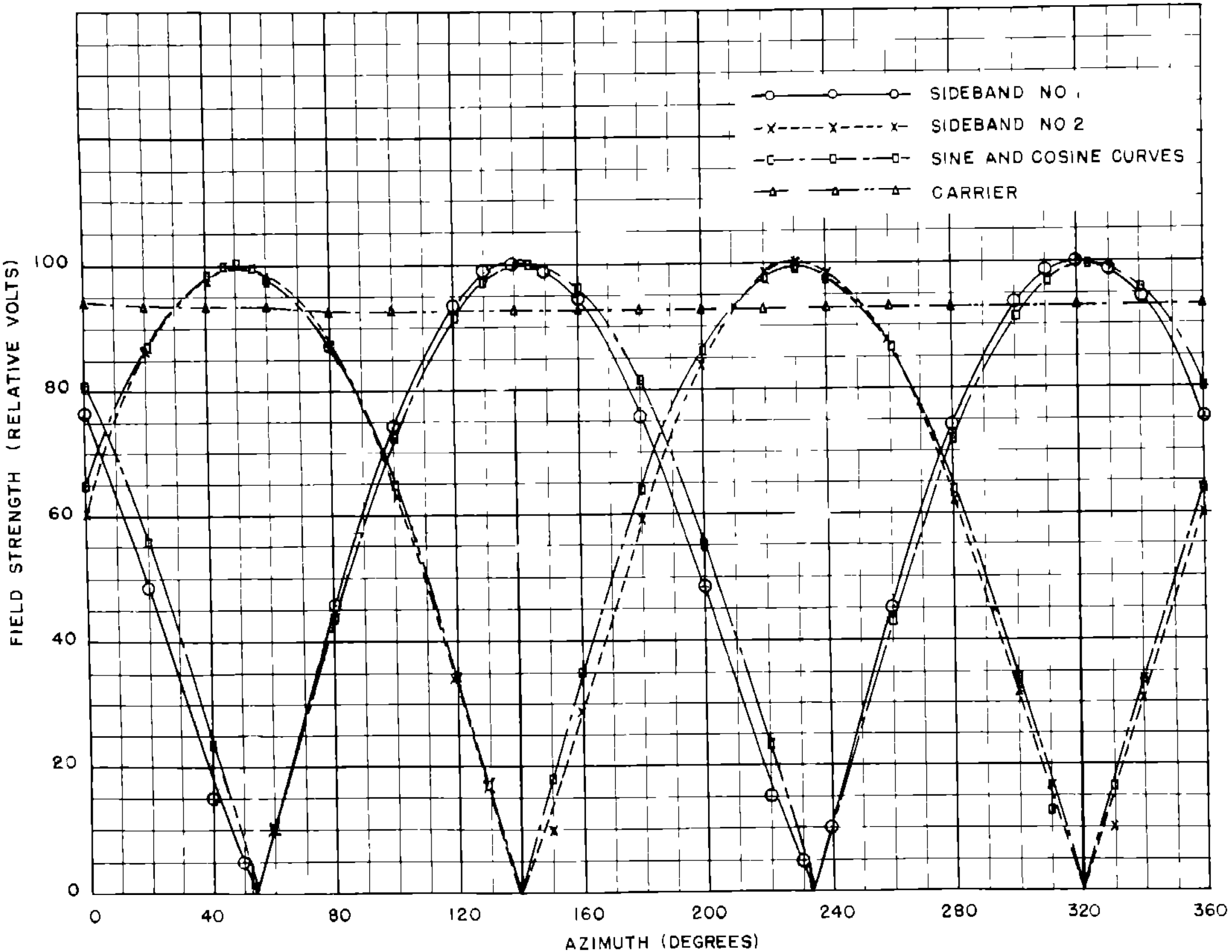



FIG 6 FIGURE-OF-EIGHT PATTERNS WITH SINE AND COSINE CURVES FOR ALFORD SLOTTED CYLINDER ANTENNA NO 4

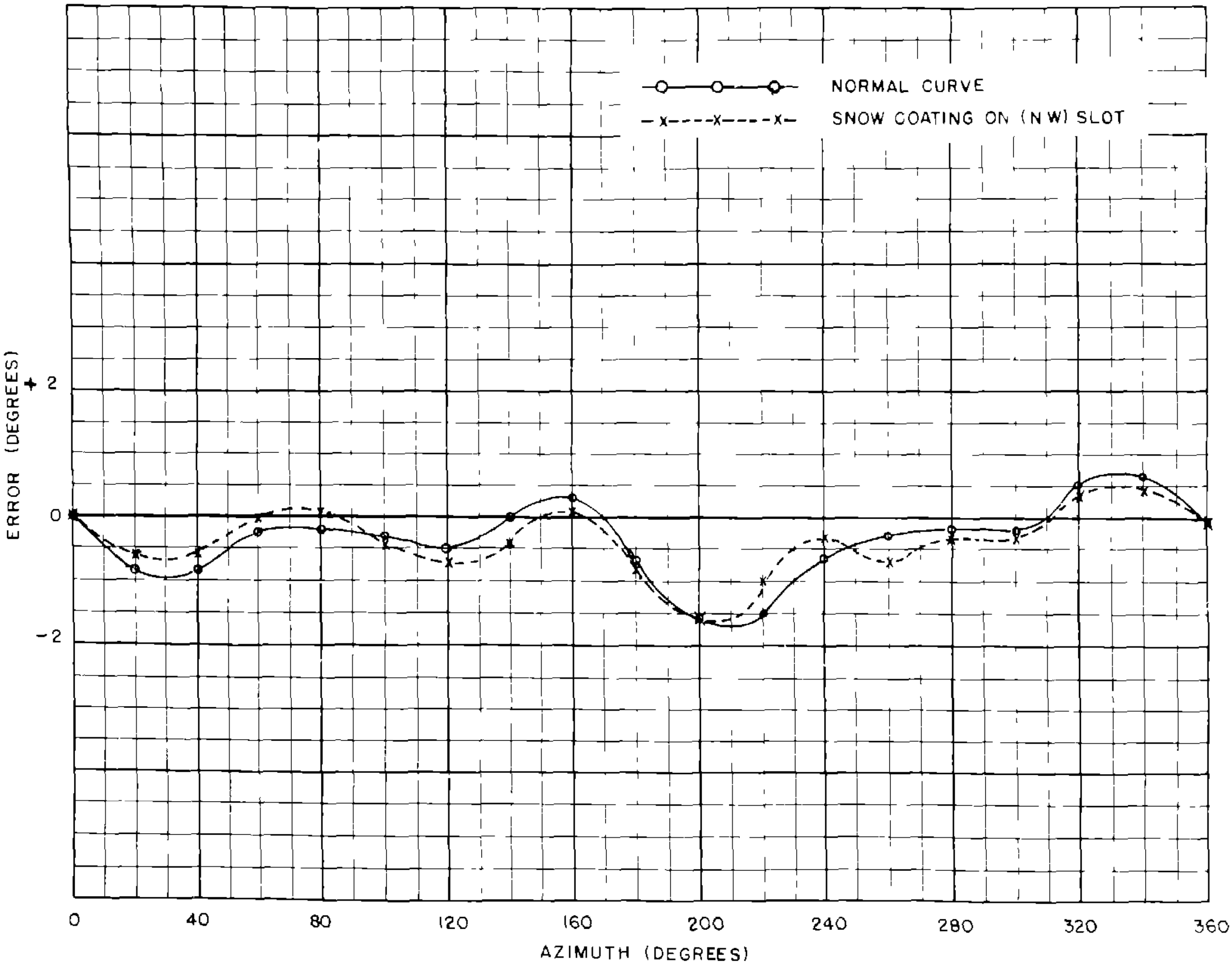



FIG 7 BEARING-ERROR CURVES FROM ALFORD SLOTTED CYLINDER ANTENNA NO 3

FIG. 8 ICE COATING ON ALFORD SLOTTED ANTENNA

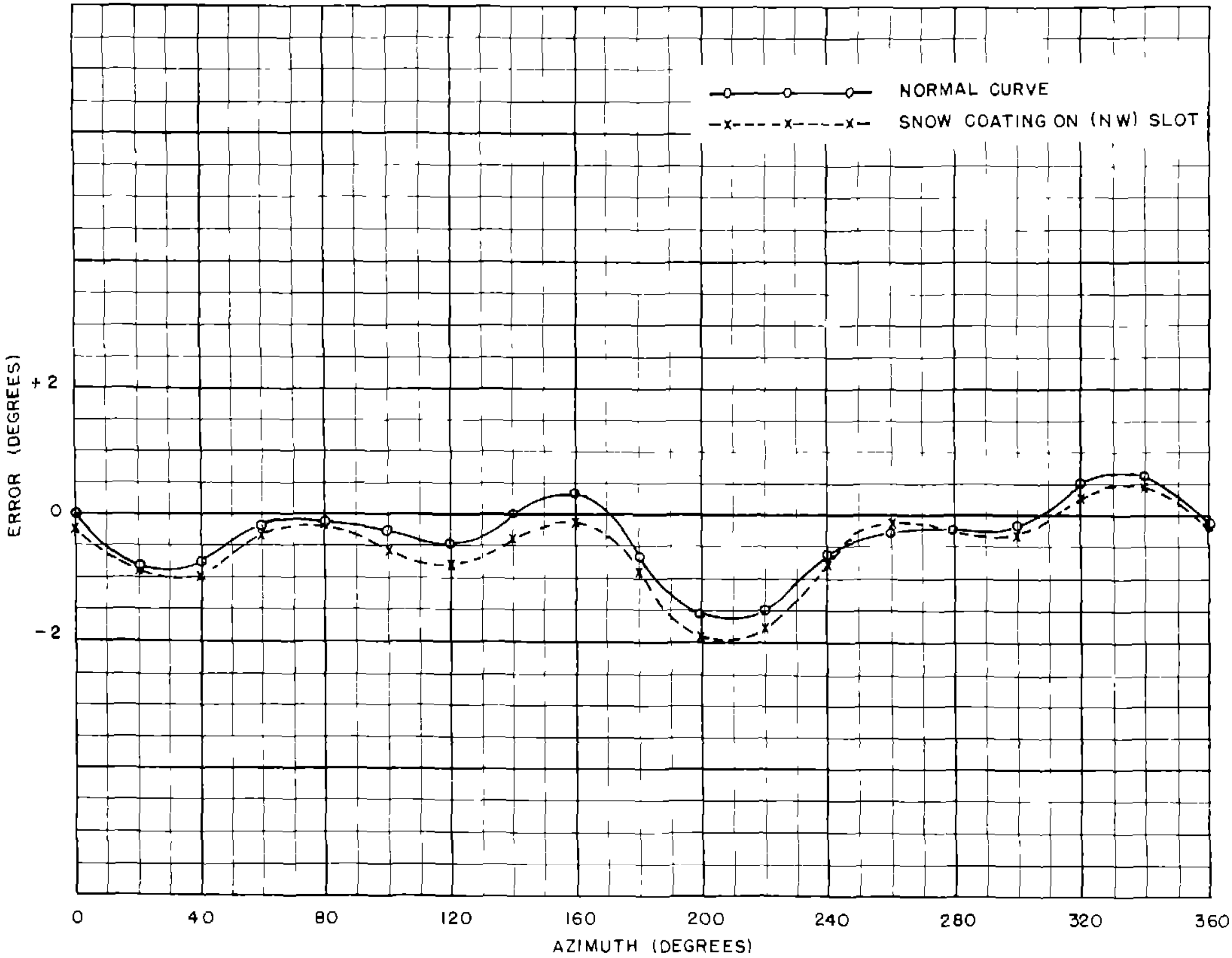



FIG 9 BEARING-ERROR CURVES FROM ALFORD SLOTTED CYLINDER ANTENNA NO 3

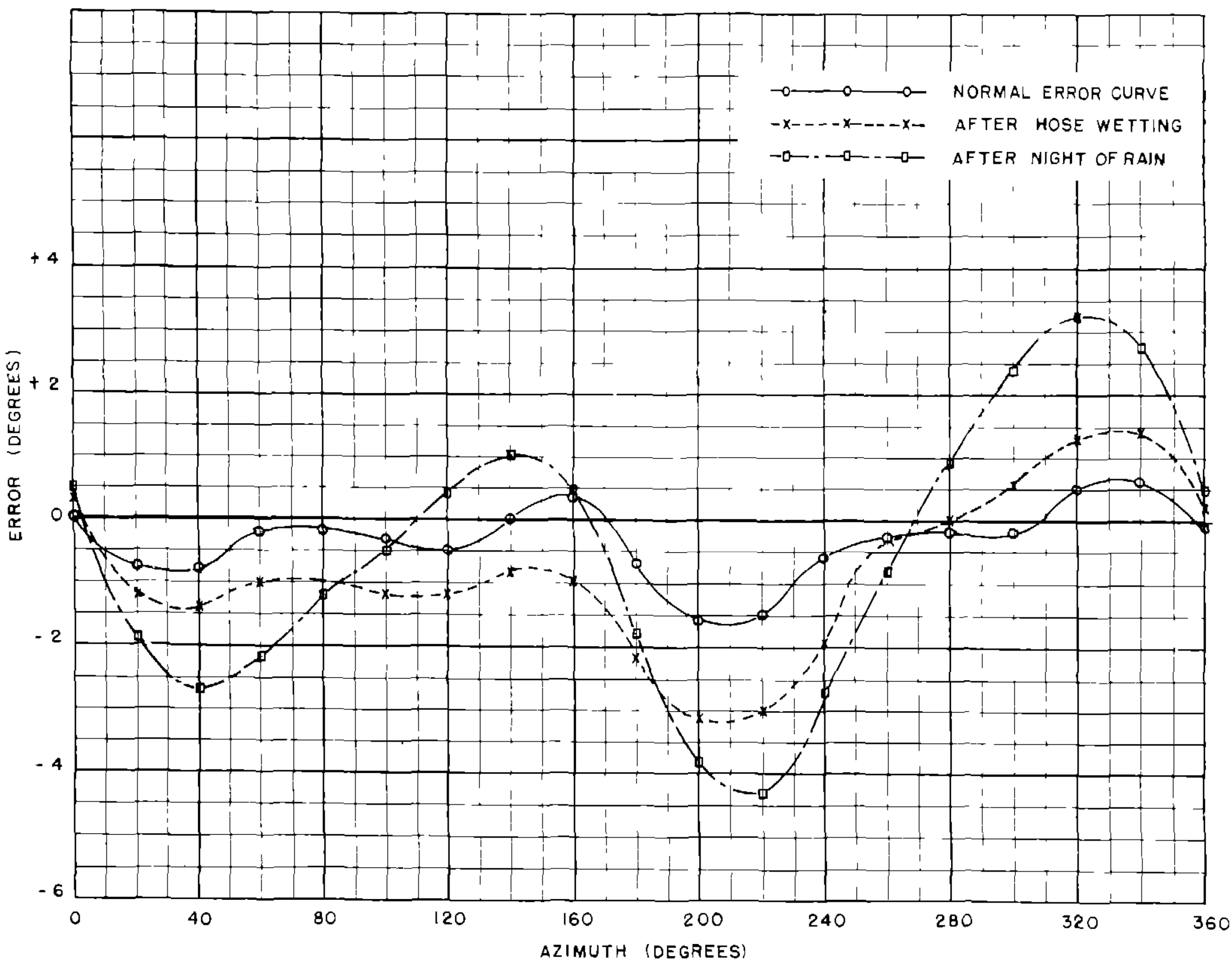



FIG 10 BEARING-ERROR CURVES SHOWING EFFECT OF WATER ON ALFORD SLOTTED CYLINDER ANTENNA NO 3

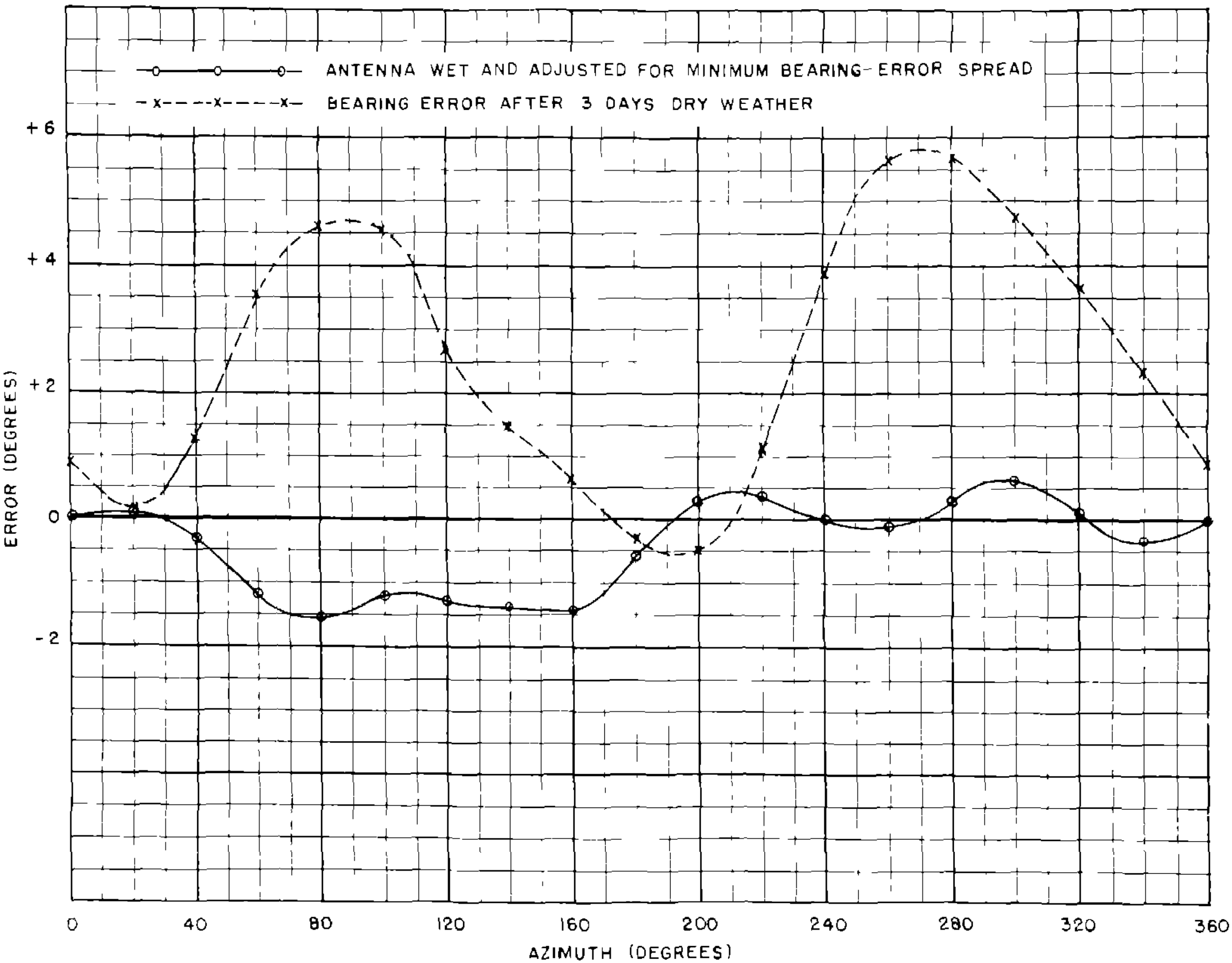



FIG 11 BEARING-ERROR CURVES FOR ALFORD SLOTTED CYLINDER ANTENNA NO 4

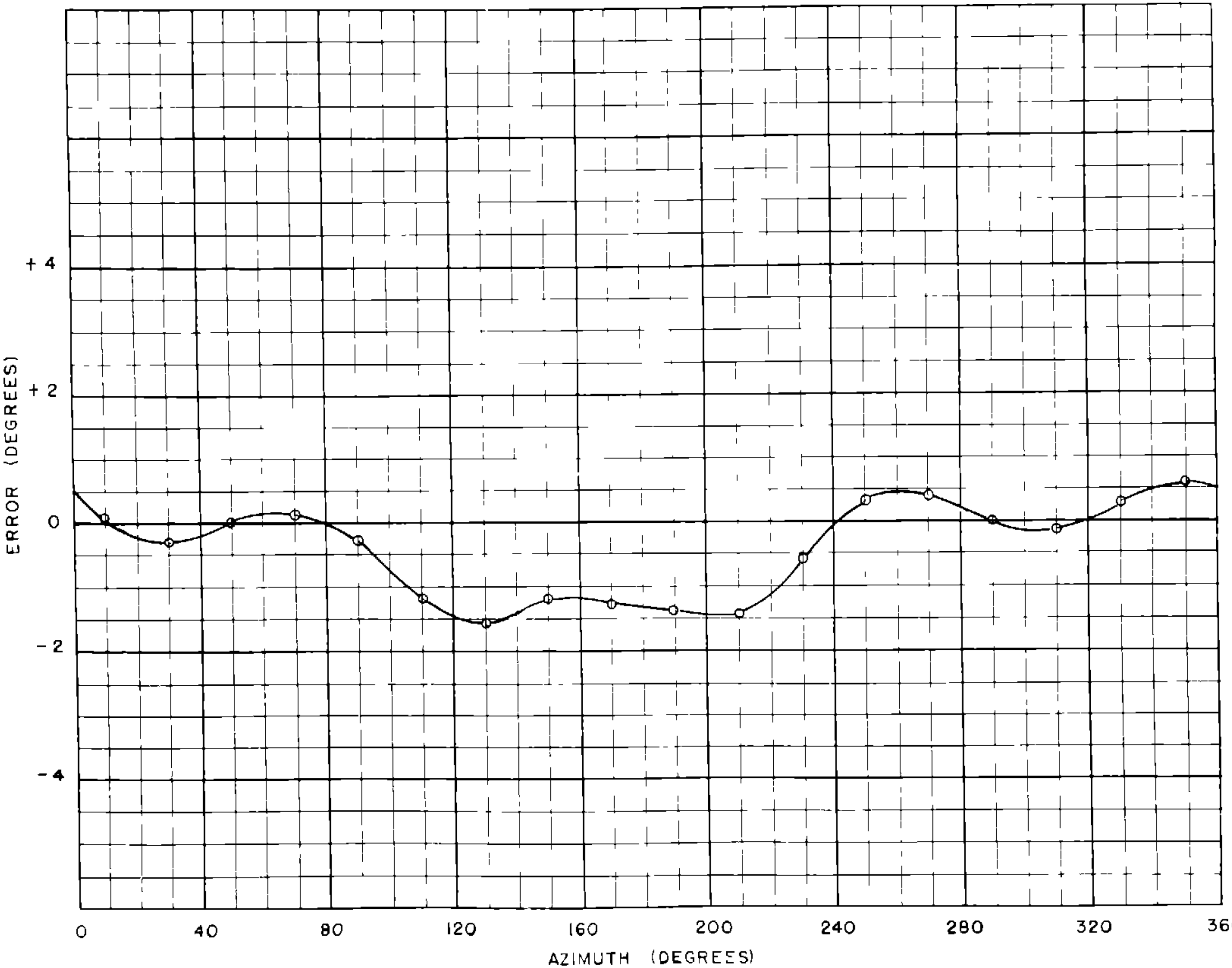



FIG 12a NORMAL BEARING-ERROR CURVE FOR ALFORD SLOTTED CYLINDER ANTENNA NO 4 JUNE 3, 1953

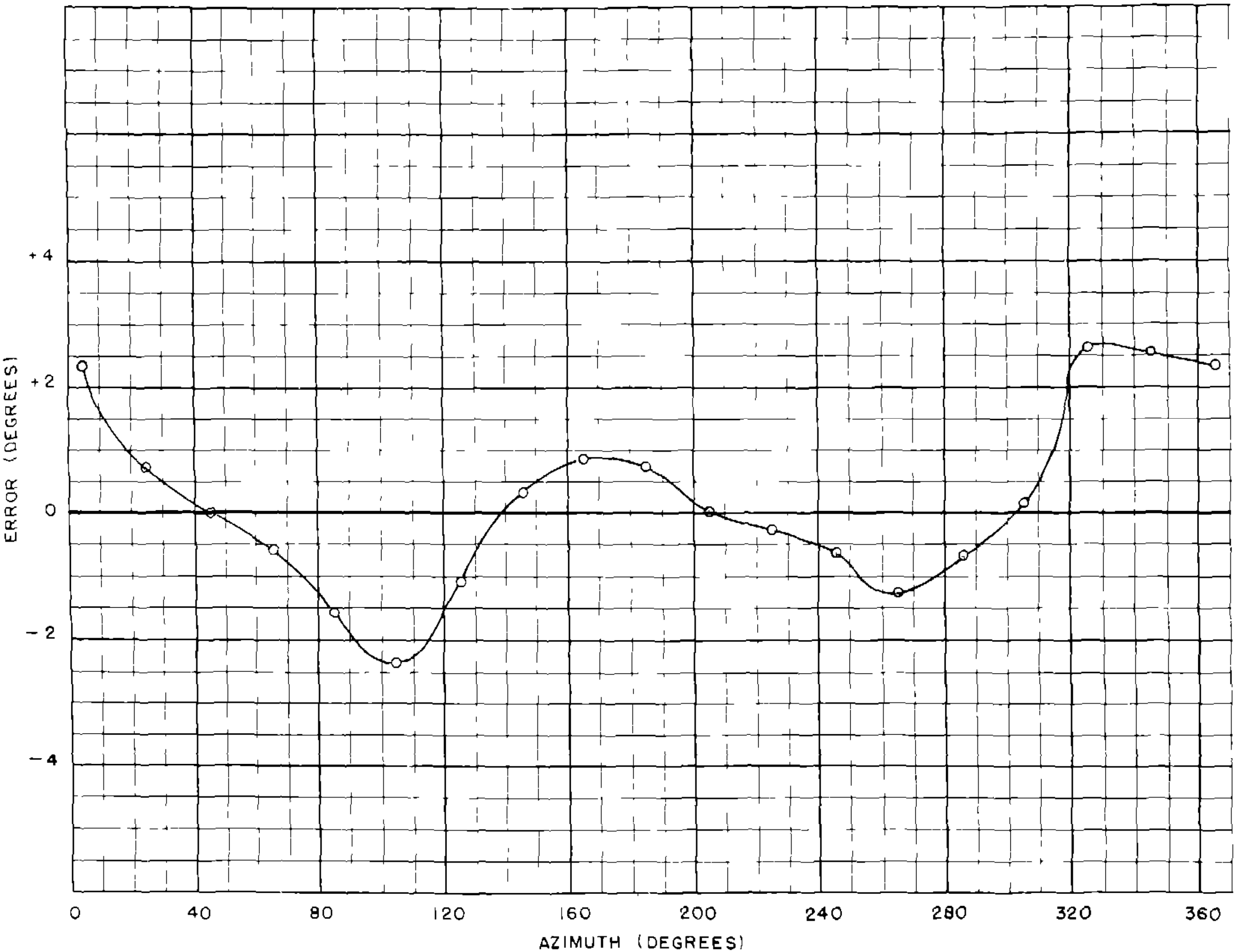
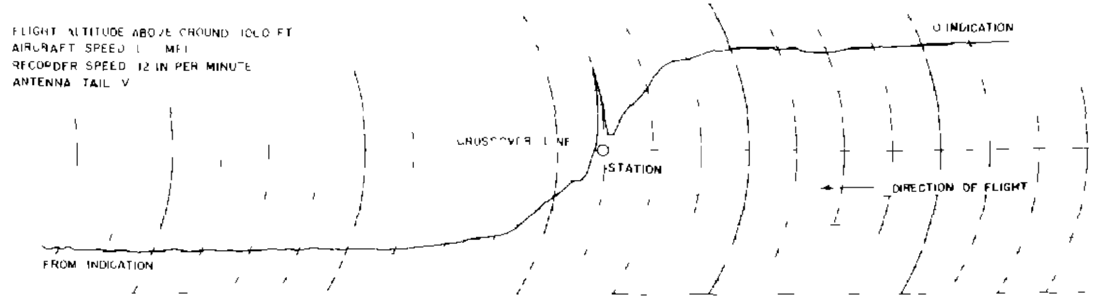
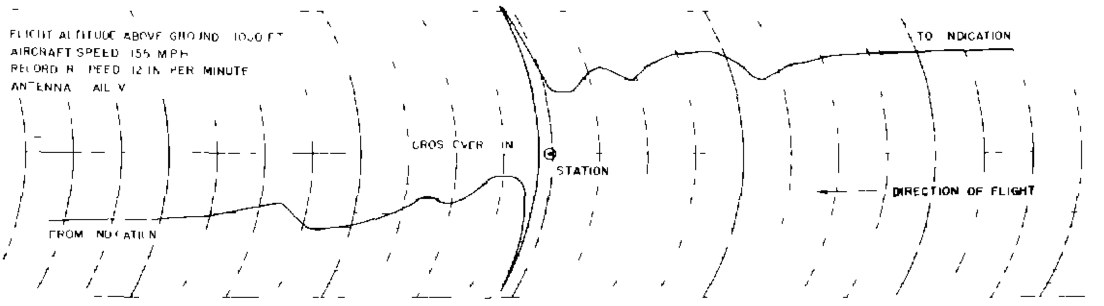


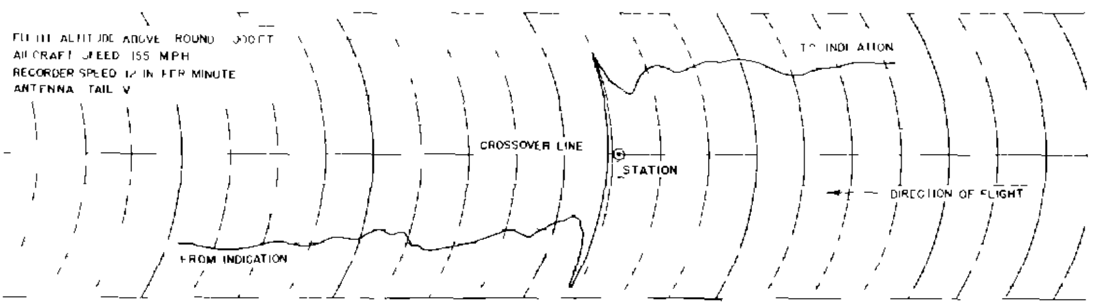

FIG 12b NORMAL BEARING-ERROR CURVE FOR ALFORD SLOTTED CYLINDER ANTENNA NO 4 JULY 16, 1953



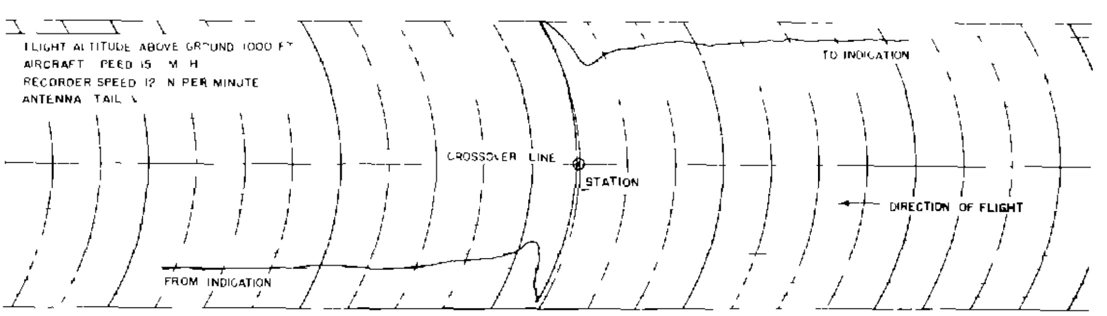

(A) ALFORD SLOTTED CYLINDER ANTENNA NO 4
ON 35 FT DIA COUNTERPOISE 10 FT HIGH



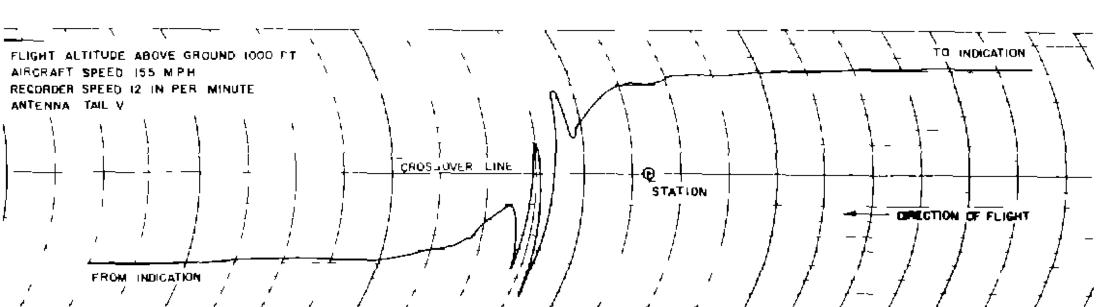

(B) ALFORD SLOTTED CYLINDER ANTENNA NO 4
ON 12 FT DIA COUNTERPOISE 10 FT HIGH




(C) FOUR LOOP ANTENNA ON 12 FT DIA COUNTERPOISE




(D) TILDEN FOUR LOOP ANTENNA ON 35 FT DIA COUNTERPOISE




(E) ALFORD SLOTTED CYLINDER ANTENNA NO 3
ON 35 FT DIA COUNTERPOISE 10 FT HIGH

FIG 13 TO FROM INDICATOR RECORDINGS OF ALFORD SLOTTED
CYLINDER ANTENNAS AND FOUR LOOP ANTENNA ARRAYS

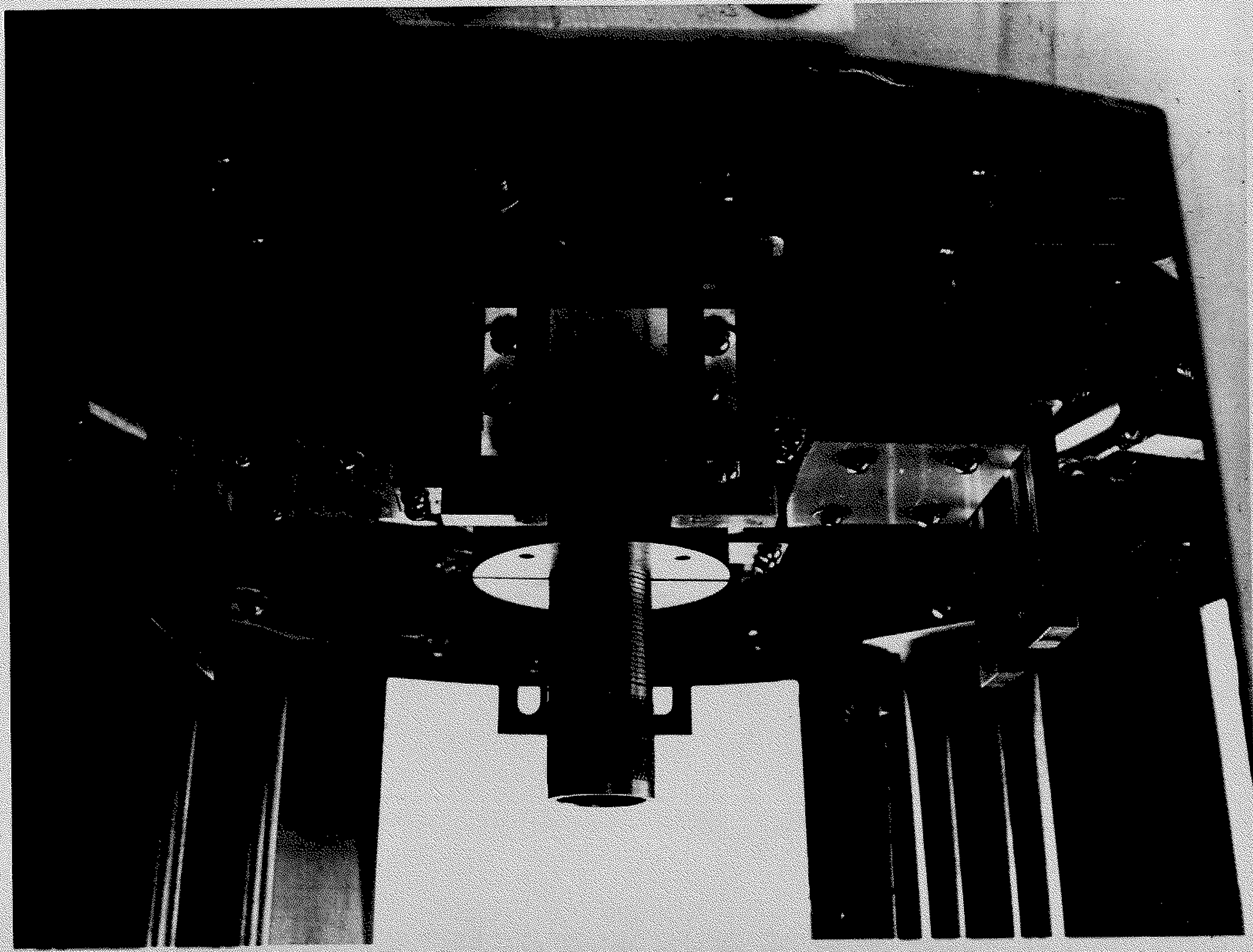


FIG. 14 FREQUENCY-CHANGING CONTROLS

FIG. 15 SHORTED RG/8U CABLE

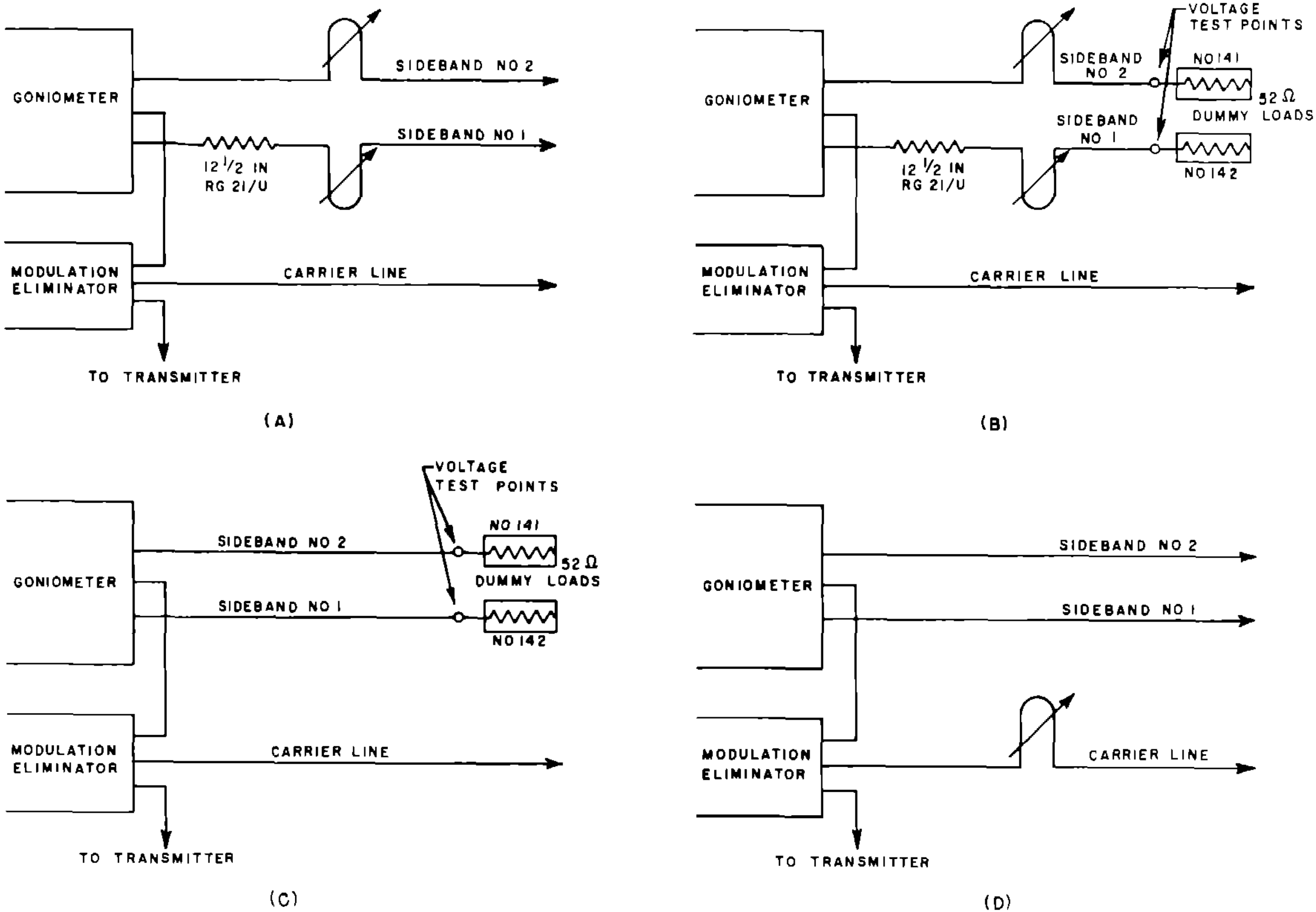



FIG 16 ANTENNA CABLING

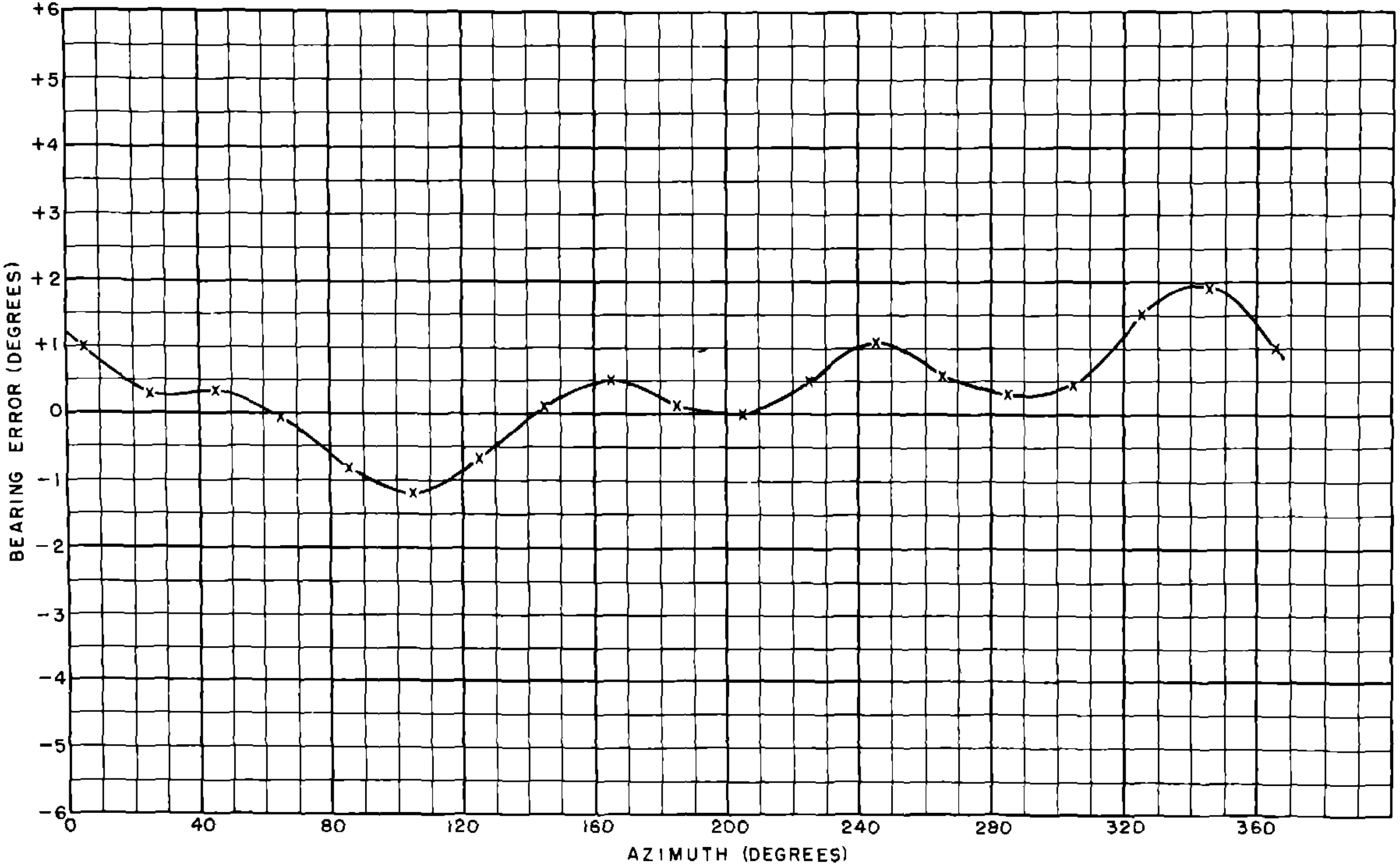



FIG 17 ALFORD TYPE 2602 SLOTTED VOR ANTENNA SERIAL NO 4 BEARING ERROR, SEPTEMBER 24, 1953

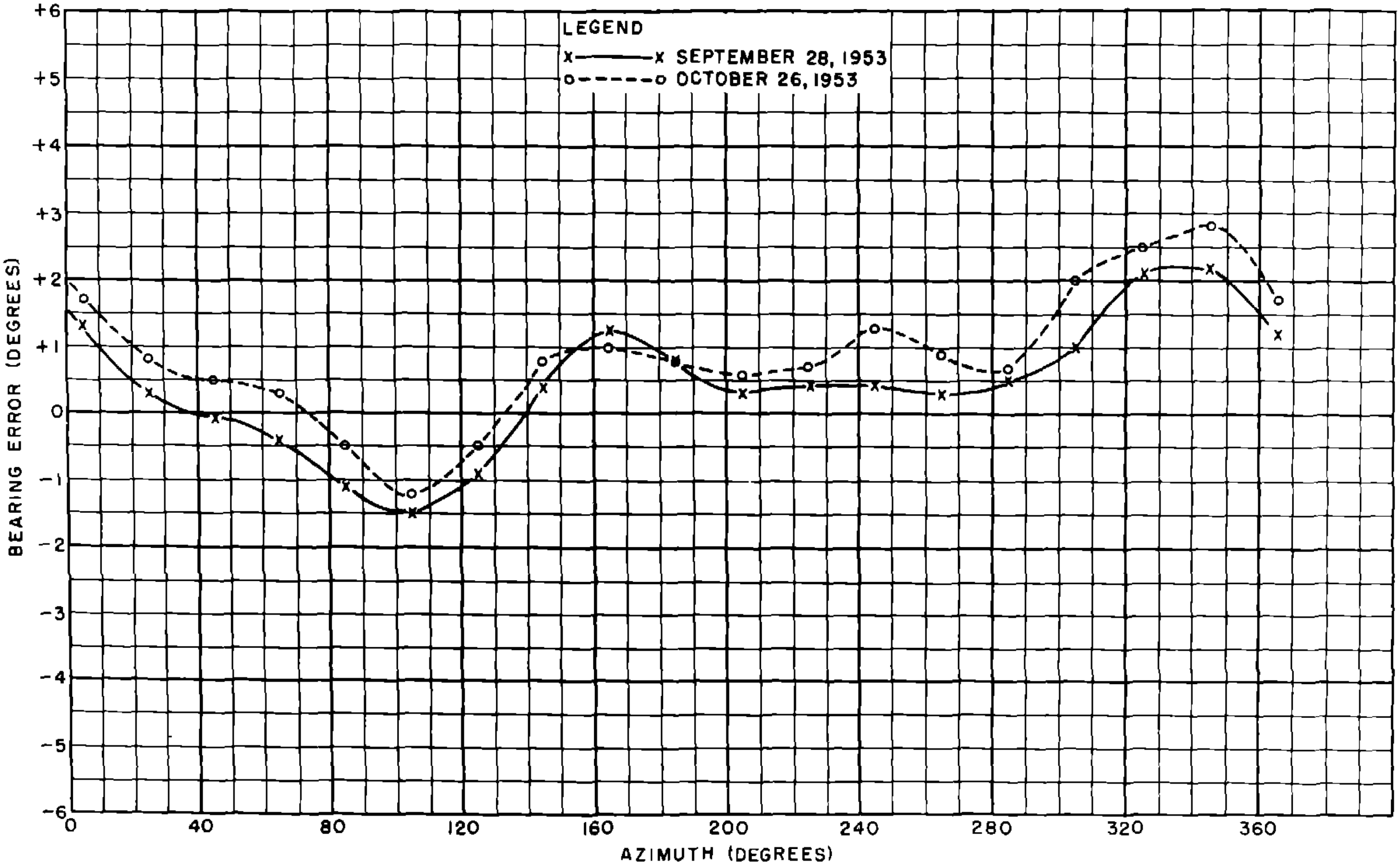



FIG 18 ALFORD TYPE 2602 SLOTTED VOR ANTENNA SERIAL NO 4 BEARING ERROR