TECHNICAL DEVELOPMENT REPORT NO. 111

EVALUATION OF FEDERAL TELECOMMUNICATION LABORATORIES OMNIRANGE ANTENNA

FOR LIMITED DISTRIBUTION

by

Thomas S. Wonnell

Electronics Division
Technical Development
May 1950

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS, INDIANA

EVALUATION OF F.T.L. OMNIRANGE ANTENNA

INTRODUCTION

This report presents the results of the evaluation of an experimental model of the Federal Telecommunication Laboratories omnirange transmitting antenna. For these tests, which were conducted at the Technical Development and Evaluation Center, the antenna was installed at the north omnirange site at the west edge of Weir Cook Airport, Indianapolis, Indiana.

At this site there is a solid circular counterpoise 34 feet in diameter and situated on a tower 15 feet above ground The radio frequency power was supplied by a Type TUN transmitter. Omnirange signals emanating from this site are subject to reflections from hangar buildings and other objects located at the airport. This produces severe scalloping on several radials about the site.

At the conclusion of these evaluation tests, the Federal antenna was removed from the counterpoise and a standard 5-loop omnirange antenna array was installed in its place. This antenna was tested for comparative data. The complete evaluation was not repeated, but ample tests were conducted to provide a direct comparison between the two antenna systems. The results of the flight tests conducted on the 5-loop antenna are listed in each case with results obtained in the same flight tests conducted on the Federal antenna.

DESCRIPTION OF F.T.L. ANTENNA

The Federal transmitting antenna is shown in Figs. 1, 2, and 3. Referring to these figures the lower antenna section G is a cylindrical structure six feet in height and is comprised of an outer cage E and an inner cage F whose lengths are determined by the position of the shorting plates C and D. The shorting plate D in the inner cage is actually the disc-type loop radiator and that of the outer cage C is a solid circular metal plate. The lower antenna section is simultaneously excited internally by a short rotating dipole B and the disc-type loop radiator D, properly phased to produce a rotating limacon field pattern. The dipole is 1/10 wavelength long and is rotated at 1,800 rpm by a 1/12 hp synchronous motor, and is used to produce the omnirange variable phase signal. It is fed by means of a capacity-coupled rotating joint of low characteristic impedance and is compensated by a series inductive stub. The impedance of the dipole is determined by the position of the shorting plates of the inner and outer cages The disc-type loop is stub-matched, and is used to produce the reference phase signal.

The upper antenna section A is a cylindrical structure of the same diameter as the lower antenna section. The upper antenna section is added to suppress the vertically polarized radiation resulting from the lower antenna section. This upper antenna section is 12 feet in height.

FLIGHT TESTS

Approximately 21 hours of flying time were devoted to flight testing the Federal rotating antenna. These tests consisted of,

(1) Polarization flight checks,
(2) Distance range checks,
(3) Theodolite orbits to measure indicated azimuth accuracy, and
(4) Cone measurement flights.

Polarization Flight Checks

In flight testing the Federal antenna three polarization tests were conducted These tests were made at an approximate distance of 20 miles from the VOR station at an altitude of 1,000 feet above ground in a Douglas C-47 aircraft using a Collins 51R-1 receiver and a tail-mounted V-109 antenna. A description and results of the tests performed follow:

1. 30° wing rock

Headed toward the station, the aircraft was banked ±30°. The nose of the airplane was held "on the point" during this maneuver The course deviation indicator current was recorded and converted to degrees of course displacement This polarization flight check was performed on eight different radials around the VOR.

Federal Antenna

Bearing from VOR (degrees)	0	45	90	135	180	225	270	315
Polarization Error (degrees)	±1/4	±1/2	±3/8	±5/8	±3/8	±1 1/2*	±1/2	±1/2

(* Note: Severe scalloping makes results at this point questionable)

5-loop Antenna

Bearing from VOR (degrees)	0	45	90	135	180	225	270	315
Polarization Error (degrees)	±3/4	±3/4	-	-	±7/8	-	±5/8	-

2 Eight ways over a ground check point

Recording the course deviation indicator current, the aircraft was flown on eight different headings ("Daisy" pattern crossing a point at every 45° heading) over a specific ground check point. The recording was marked as the airplane crossed the check point, and the indicated bearing was compared with the magnetic bearing. The zero reference point in each case was taken on the heading to the station.

Federal Antenna

Check Pt. 20 Miles From VOR (degs.)	Aircraft Heading Over Check Point(deg)								Total Heading Effect (degs)
	E	W	N	S	SE	SW	NE	NW	
0	-1/2	-1	-3/4	0	-1/4	-3/4	-1/2	-1/4	±1/2
45	-1/4	+1/2	+1/2	-1	0	0	-1/4	-1/2	±3/4
90	0	0	0	-1/4	-1	0	+1	+1/4	±1
135	-1/4	-1	+1/4	0	+1/4	0	-1/4	0	±5/8
180	+1/4	+1/4	0	+1/2	0	+1/4	+1/4	0	±1/4
225	+1 1/4	+1 1/4	+1 3/4	+1 3/4	+1 1/2	+3/4	0	+1 3/4	±7/8*
270	0	+3/4	+1/4	+1/4	+3/4	+1/2	+1/4	+1/4	±3/8
315	-1/4	+1	-1/4	+1/2	0	+3/4	-1/2	+1	±3/4

(* Note· Severe scalloping makes results at this point questionable)

5-loop Antenna

0	+1	-1/2	0	0	+1/4	+1/2	+1/2	0	±3/4
45	+3/4	+3/4	0	0	+1/2	0	+1/2	-3/4	±3/4
180	+3/4	-1	0	-1	0	-1/4	-1	+1/2	±7/8
270	0	-3/4	-1	+1/4	-1/2	-1/4	-1/4	-3/4	±5/8

3. 360° Circle

The method employed in measuring polarization error in a 360° circle was as follows.

Headed toward the VOR and starting from a ground check point, a 360° circle was flown at a constant 30° bank. The course deviation indicator current was recorded during this circle and converted into degrees of error from the azimuth course being flown at the beginning of the circle. Since the aircraft in the 360° circle was changing azimuth with respect to the VOR, this deviation was computed in degrees and subtracted from the course deviation indicated error, resulting in the numerical value of polarization error, following the removal of the receiver error.

This polarization test was conducted at an altitude of 1,000 feet above ground and at a distance of approximately 20 miles from the VOR. The results obtained on this flight check, made on four different azimuth bearings from the station, are as follows:

Federal Antenna		5-loop Antenna	
Bearing From VOR (degs.)	Polarization Error (degs.)	Bearing From VOR (degs.)	Polarization Error (degs.)
90	± 0.5	0	± 2.25
45	±0.5	45	± 2.05
315	±0.75	180	± 2.0
270	±1.0	270	± 2.2

Distance Range Flight Check

The distance range of a VOR facility is defined as the distance in statute miles from a VOR at which the course width in degrees becomes double the course width measured at ten miles from the VOR. This test is conducted at an altitude of 1,000 feet above ground.

This flight check was conducted two different times and during each of these flights the IND commissioned VOR facility having a counterpoise and power input identical to that of the north omnirange was checked for comparative results. The distance range measured on the IND VOR is in direct agreement with the distance range measured on the 5-loop array antenna installed at the north omnirange site upon completion of the Federal antenna evaluation.

The distance range flight checks were conducted on the zero radial of the north omnirange site. The results obtained are as follows:

Distance Range

Antenna	Headed North (miles)	Headed South (miles)
Federal	43.0	44.7
Federal	45.4	45.5
5-loop	62.6	60.8

Theodolite Flight Calibration

The theodolite flight calibration is a process wherein a series of exact differences between indicated and magnetic bearings is obtained through the 360° around a range station. These differences are plotted as a calibration or measured error curve. Flights were made in both clockwise and counterclockwise directions at a 6-mile radius.

The first theodolite flight calibration was invalid because of a shift of the theodolite at some time during the flight; however, the error curve obtained indicated that an error of approximately ±1° was to be expected on this antenna array. The following day the theodolite calibration flight was repeated, and the resulting error curve revealed an error of ±2.5° which exceeded considerably the error expected on the basis of the previous flight. Later that same day the ground checks on vertical polarization error were resumed, and it was discovered that the VOR courses were shifting as much as 3°. The wind velocity at this time was 40 mph with gusts up to 50 mph from a southwest direction. The error curves obtained by flight calibration at the time the 40 mph wind velocity existed are shown in Figs. 4 and 5.

In order to investigate the wind effect observed, nylon guy ropes were attached to the antenna, and three flight calibration circles were flown. During this flight the antenna was guyed as follows·

1. in a true vertical position (maximum error ±2°),
2. with antenna bending to the southeast (maximum error ±1.2°), and
3. with antenna bending to the southwest (maximum error ±0.75°).

The resulting error curves are reproduced in Fig. 6.

The final theodolite flight calibration was made with the antenna securely guyed in a vertical position. The wind velocity during this flight was reported at 15 mph from a southwest direction. The resulting error curves of two counterclockwise and two clockwise circles are shown in Figs. 7 and 8, and revealed a maximum error of ±1.1° and ±1.7°, respectively.

The error curve obtained on the theodolite flight calibration of the 5-loop antenna is shown in Fig. 9, and revealed a maximum error of ±2.5° for the clockwise circle and ±1.6° for the counterclockwise circle.

Cone Measurements

Twelve radial flights were made across the Federal antenna, recording the currents of the course deviation indicator and TO-FROM indicator of a Collins 51R-1 receiver for the purpose of measuring cone width.

In order to measure the cone of a VOR from a recording of the course deviation indicator current, a definition of the cone must be stated so that the beginning and end points of the cone may be positioned on the recording. The course deviation indicator is considered to be graduated in 10 equally spaced "dots" across the face of the instrument. When the indicator deviates beyond one dot, 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 at the point where the indicator exceeds one dot from the center position. In a similar manner, the cone ends at the one dot 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 course deviation indicator (CDI) cone measurement.

The second method of cone measurement consists of recording the current of the TO-FROM indicator. The cone is considered to begin at the point where the TO-FROM indicator deviates from the normal TO indication position and this deviation (as observed on the recording) is due to the normal change from a TO indication to a FROM indication as a result of passing over the VOR. The cone ends at the point where the transition from TO to FROM is completed. A cone angle measured using this definition and method is referred to as a TO-FROM cone measurement. In measuring the cone by the TO-FROM method, the accompanying course deviation indicator recording must be available in order to verify the fact that the radial flown passed directly over the VOR station.

It was observed immediately that the angle above ground at which the cone was entered was increased over that of a normal 5-loop omnirange antenna. With the narrowing of the cone, the problem of measurement becomes more difficult. As the cone is approached, the course becomes sharper, and the slightest deviation of the aircraft from the course results in a large displacement of the course deviation indicator. With the pilot completely aware of the existing situation and doing his utmost to stay on course, the last correction, before entering the cone proper, becomes a matter of chance with the result that approximately 25 percent of the radials flown were not suitable for cone elevation measurements. The flag alarm does not show at any time during a pass directly over the cone.

Listed below are the results of the cone measurement flight tests on the Federal antenna, together with the measurements recorded on the 5-loop antenna.

Federal Antenna

Aircraft Altitude Above Ground (feet)	Type Measurement	Cone Angle Above Ground (degs.)
2,000	TO-FROM	69.2
2,000	TO-FROM	69.9
2,000	Course Deviation Indicator (CDI)	71.7
2,000	TO-FROM	75.7
2,000	CDI	71.6
2,000	CDI	75.2
10,000	TO-FROM	75.2
10,000	CDI	77.3
10,000	TO-FROM	73.5
10,000	CDI	74.5
10,000	TO-FROM	75.2

5-loop Antenna

Aircraft Altitude Above Ground (feet)	Type Measurement	Cone Angle Above Ground (degs)
2,000	TO-FROM	49.4
2,000	TO-FROM	49 8
2,000	CDI	49.8
2,000	CDI	51.3

GROUND TESTS

Polarization Error Measurements

The polarization error of the antenna was measured in accordance with the latest procedure devised by the Center. The procedure is equivalent to tilting a dipole ±45° from the horizontal position, but with the added advantage of being able to change the radio-frequency phase between the vertical pickup as compared to the horizontal pickup. The receiving test antenna was located at a distance of approximately 1,000 feet and at zero-degree elevation.

The Federal antenna array was rotated in 20° steps, and the resulting polarization error is shown in Fig. 10. This also produced azimuth error data, and the azimuth error curve is shown in Fig. 11. The same test conducted on the 5-loop array produced the polarization error shown in Fig 12. This method of testing polarization removes the effective improvement obtained in flight by the use of Uskon cloth.

Carrier Pattern Measurement

With the loop excited alone, the Federal antenna array was rotated in 20° steps through 360°, and the relative field intensity was recorded. Fig. 13 is a polar plot of the carrier field pattern.

Figure-of-eight Pattern

Exciting the dipole alone, the entire Federal antenna was rotated in 20° steps through 360° The dipole remained stationary with respect to the antenna array during these measurements. Fig. 14 is a graph of the relative field strength through 360°.

MISCELLANEOUS OBSERVATIONS

The evaluation conducted on the Federal omnirange antenna extended over a period of six weeks. This amount of time was required because of bad weather. During the evaluation there were periods of heavy snowfall, rain, and severe icing. On three occasions high winds were recorded with velocities of 50 mph This provided the opportunity to observe the operation of the antenna during adverse weather conditions. The antenna was not sheltered during the evaluation. The rotating dipole was not in continuous operation. It was turned on each morning and off at night.

The following observations are reported:

(1) One morning following an ice storm, the spinning dipole motor was unable to attain synchronous speed. Removal of the ice remedied the situation immediately.

(2) During a heavy rain, the impedance of the reference carrier loop changed to the extent that a four-to-one standing wave voltage ratio was measured on the transmission line. The normal standing wave voltage ratio was measured at 1.1 to 1. The effect of this large increase in standing wave voltage ratio was noticed at the time the ground polarization measurements were being conducted. The normal receiver course width sensitivity was 16°. This sensitivity was checked each time the antenna was rotated 20°. While the antenna was being rotated on one occasion, a heavy rain began. The next receiver sensitivity check revealed that the course width had increased from 16° to 90° bringing a halt to the measurements at that time.

(3) Moisture did not affect the impedance of the rotating dipole at any time

(4) Course shifting was observed during high winds. This shifting consisted of slow, irregular oscillations with a period of approximately five minutes The maximum deviation equalled ±1.25°. The average deviation was ±0.5°. The exact cause of this course shifting was not determined, but tests showed that the dipole motor does not slip synchronization in high winds

(5) An attempt to duplicate the force exerted on the antenna in high winds was made by pulling on guy ropes attached to the antenna. Pulling on these guy ropes in different directions about the antenna with the force that one man can exert produced course shifts varying between 1.25° and 2°.

(6) With the excitation to the dipole removed, the 60-cps modulation of the carrier resulting from coupling between the dipole and the loop was measured and found to equal 12 percent. The FTL engineers improved this condition and the 60-cps modulation was then measured at five percent.

(7) The output of the tone wheel was observed to contain approximately ten percent AM. Furthermore, the tone-wheel output was measured at 0.07 volt ac. Normal tone-wheel output voltage is of the order of 0.5 volt ac. The 0.07-volt output is below that required for proper operation of the course monitor. The Federal engineers reported that the tone wheel in use had been damaged and some eccentricity in rotation was noticed. In order to reduce the AM of the 9.96-kc subcarrier to the ten percent figure, they were forced to increase the spacing between the pickup and the tone wheel, hence the low output. No direct error is expected from this fault, but second order errors might be introduced if the transmitting and receiving equipment are not properly aligned.

(8) The radiated field intensity of the Federal VOR antenna is less than that of a standard 5-loop VOR antenna. Immediately upon completion of the evaluation of the Federal antenna, a standard 5-loop VOR antenna array was installed at the same site. A comparative field intensity measurement revealed that the Federal antenna field intensity is down approximately four-to-one when compared with that of a standard 5-loop VOR antenna array. This was verified by obtaining equal distance ranges with the 5-loop antenna using 1/16 of the power as compared to that used with the Federal antenna.

(9) The azimuth error recorded on the ground check does not agree with the results obtained on the theodolite calibration flights. It is possible that this is due to a permanent off-vertical bearing of the antenna induced by the high winds encountered during the evaluation, or a change in the bonding of the antenna base plate with the counterpoise. These possibilities are substantiated by the results of the theodolite calibration error curves obtained when the antenna was guyed with a tension tending to pull the antenna from a vertical position. One of these error curves revealed an azimuth error of ±0.75° as compared with ±2.0° error recorded on the ground check.

CONCLUSIONS

The Federal omnirange transmitting antenna has one fundamental shortcoming. The radiated field intensity is approximately four-to-one down from the field radiated by a standard 5-loop omnirange antenna. With this exception, the Federal antenna is technically the best VOR antenna thus far evaluated at TDEC.

The polarization error is so improved over anything heretofore tested, that little advantage is to be gained with further improvement beyond this point.

The azimuth accuracy is not as good as it is reasonable to expect on a theoretical basis for this type of antenna system, yet it has greater accuracy than any antenna yet evaluated.

The antenna in its present form is not suitable for operational use. The modifications required are housing, structural reinforcement, and an improvement in the power efficiency of the carrier antenna. Following these modifications, the antenna should be placed in continuous operation for a period of time in order to determine whether these modifications correct the instability observed under adverse weather conditions during the evaluation.

The entire evaluation was conducted at one frequency, 113.9 Mc. It is important that this antenna be tested throughout the omnirange band of 112-118 Mc. It is possible that the antenna characteristics might change with frequency.

It is believed that the modifications required are not difficult problems and that the development of this new type antenna is a distinct step forward in omnirange progress.

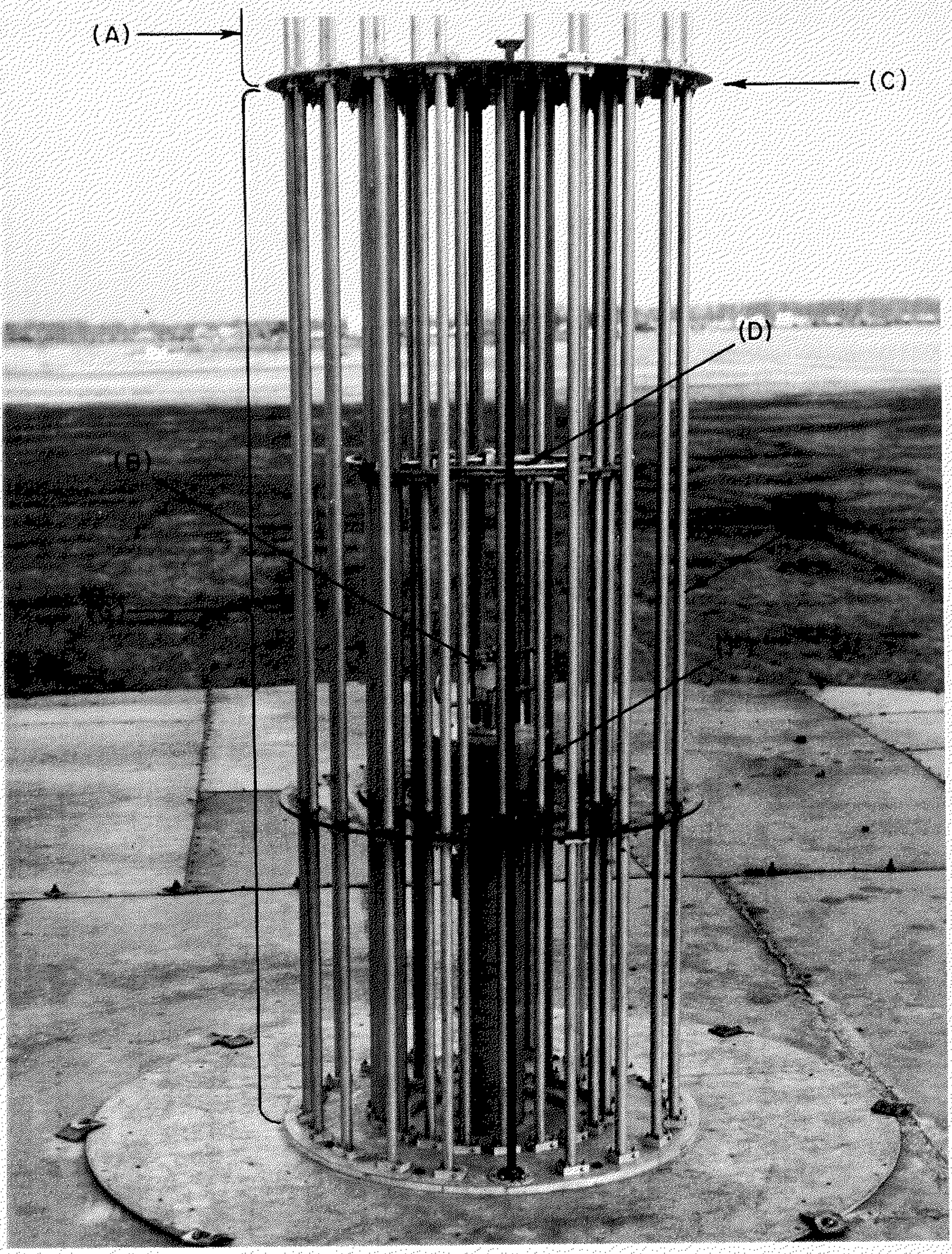
(B) ROTATING DIPOLE

(D) DISC-TYPE LOOP RADIATOR

(E) OUTER CAGE

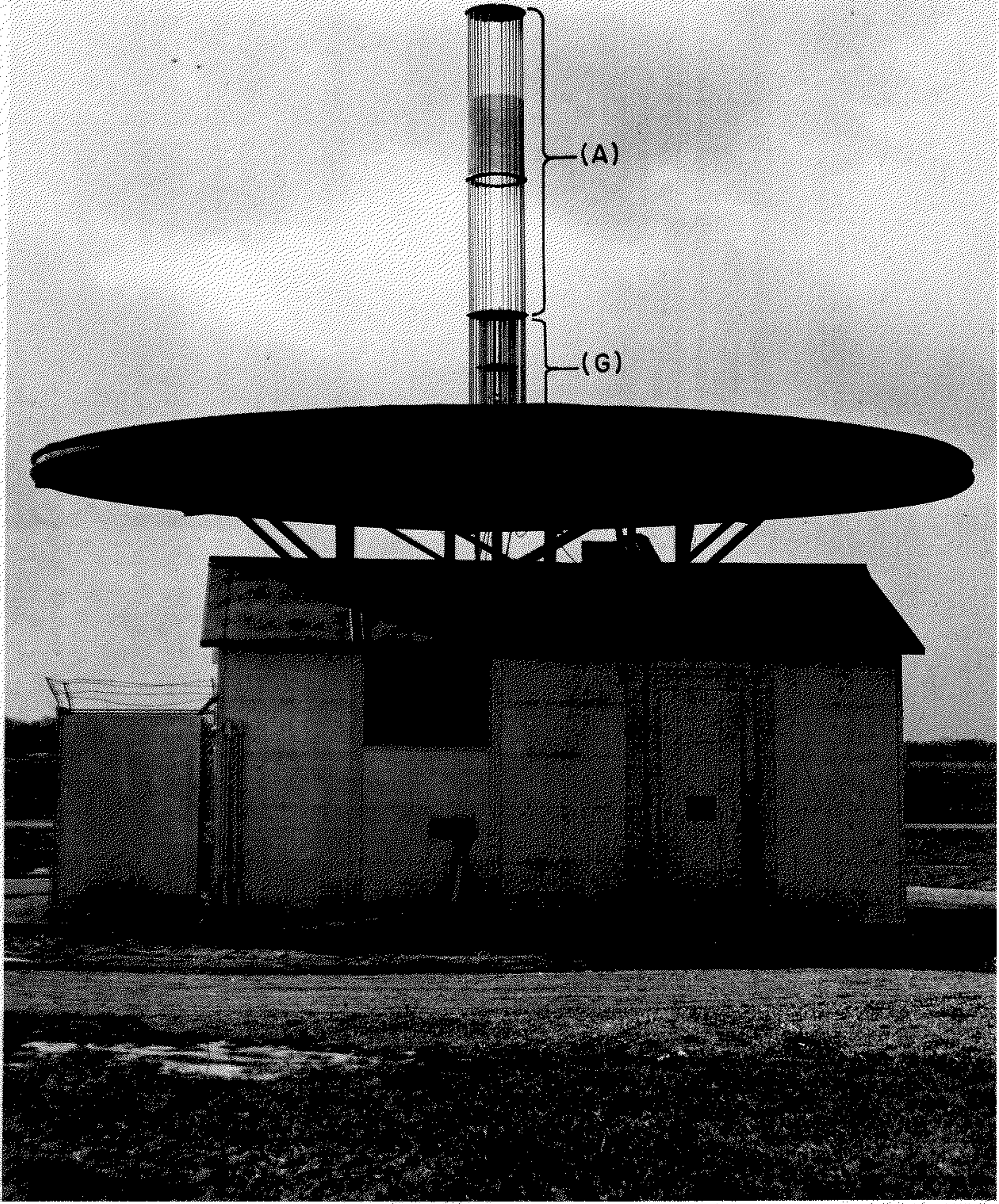
(F) INNER CAGE

FIG. 1 FTL OMNIRANGE ANTENNA



(A) UPPER ANTENNA SECTION
(B) ROTATING DIPOLE
(C) SHORTING PLATE
(D) DISC-TYPE LOOP RADIATOR
(E) OUTER CAGE
(F) INNER CAGE
(G) LOWER ANTENNA SECTION

FIG. 2 FTL OMNIRANGE ANTENNA



(A) UPPER ANTENNA SECTION

(G) LOWER ANTENNA SECTION

FIG. 7 ETL OMNIRANGE ANTENNA

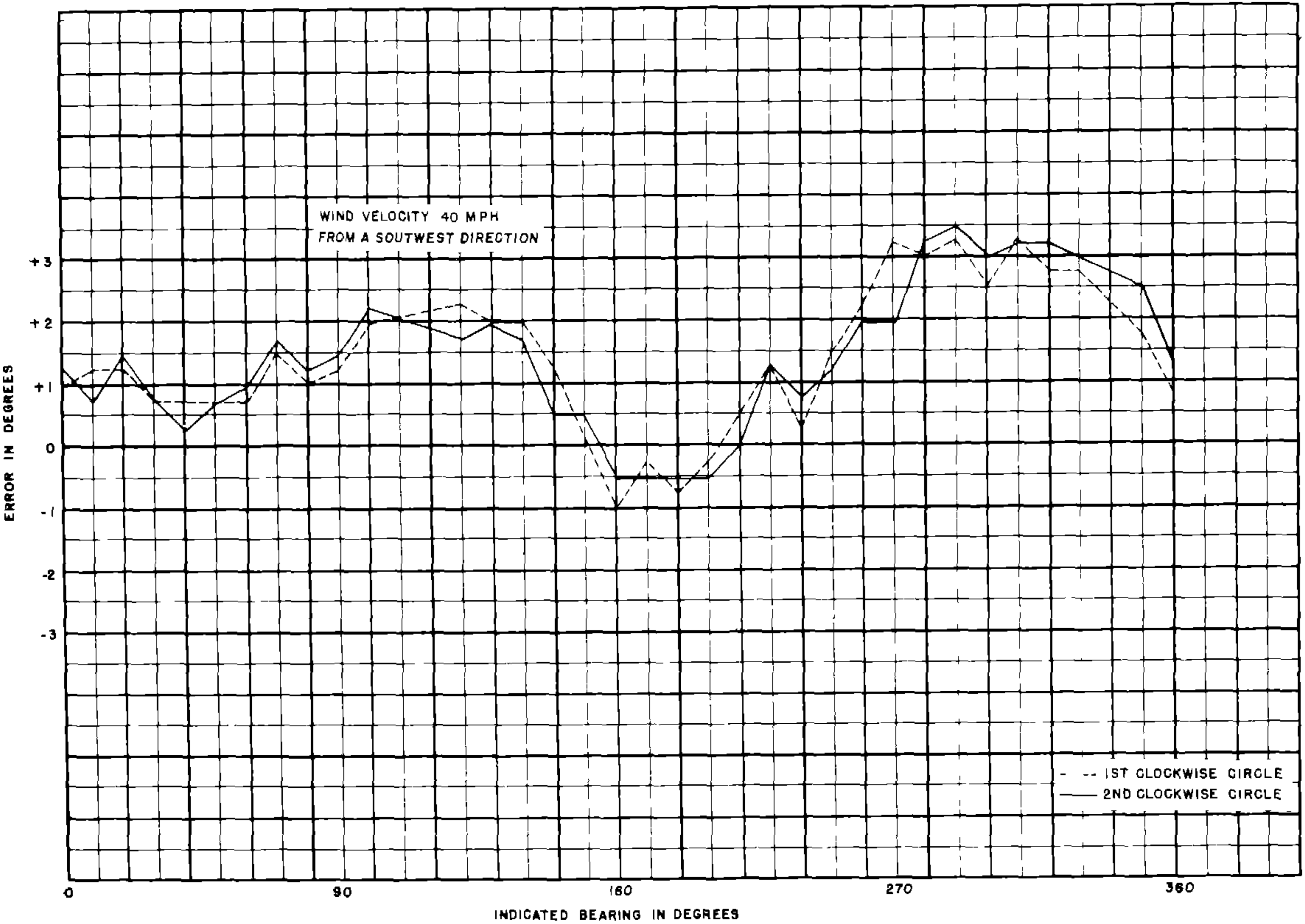


FIG 4 THEODOLITE FLIGHT CALIBRATION ERROR CURVE OF FTL OMNIRANGE TRANSMITTING ANTENNA (RECEIVER ERROR REMOVED)

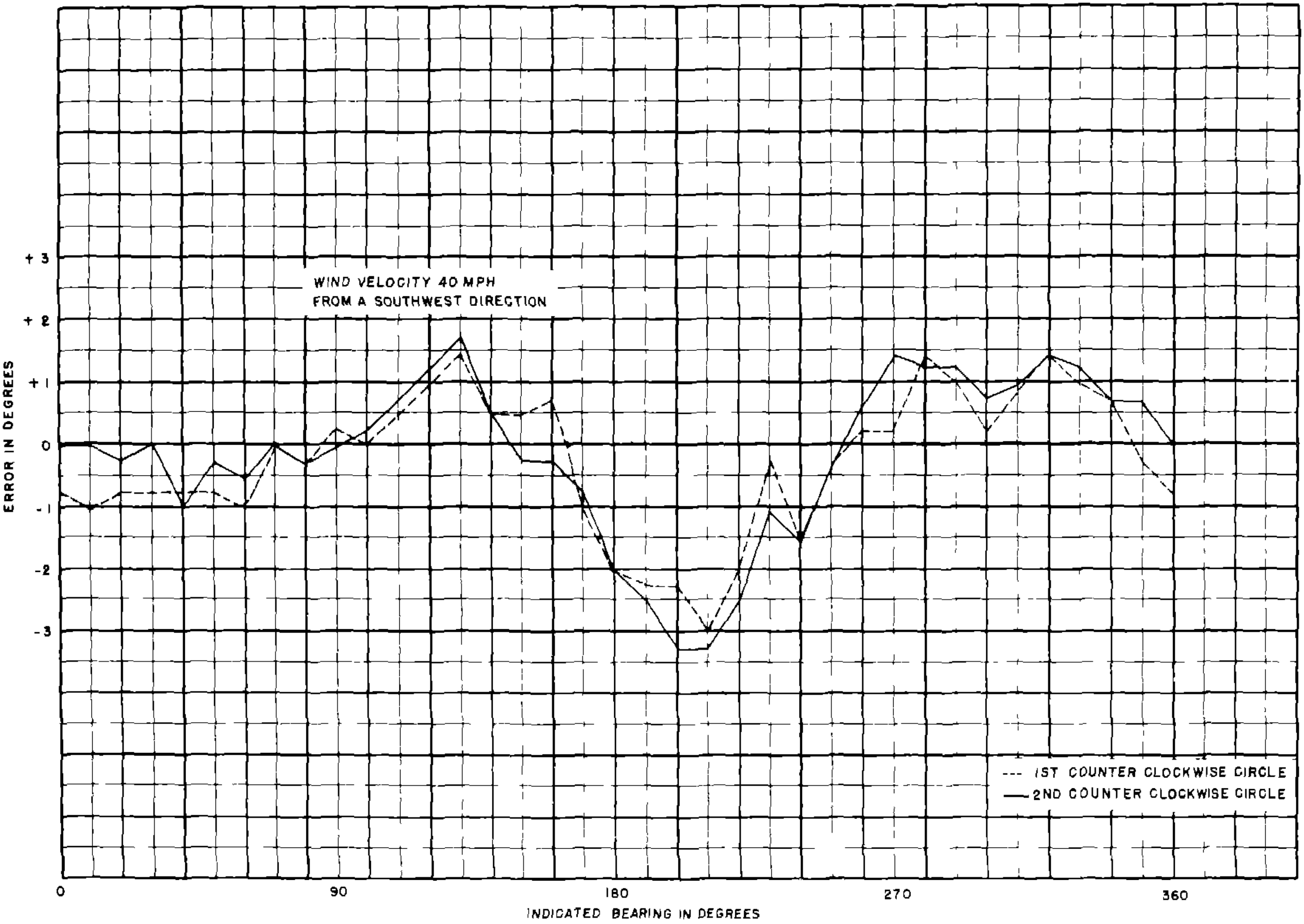


FIG 5 THEODOLITE FLIGHT CALIBRATION ERROR CURVE OF FTL OMNIRANGE TRANSMITTING ANTENNA (RECEIVER ERROR REMOVED)

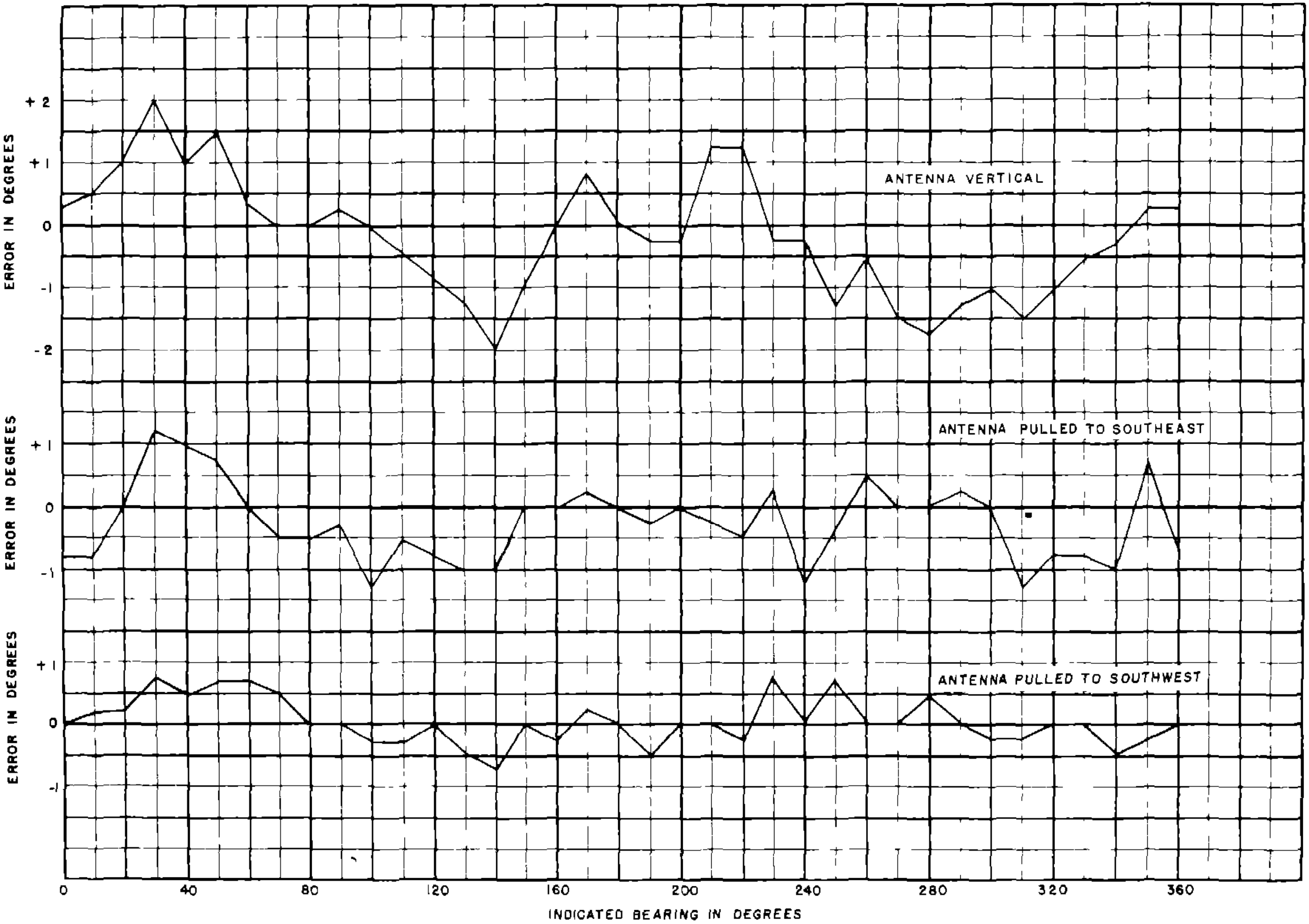


FIG 6 THEODOLITE FLIGHT CALIBRATION ERROR CURVE OF FTL OMNIRANGE TRANSMITTING ANTENNA (RECEIVER ERROR REMOVED)

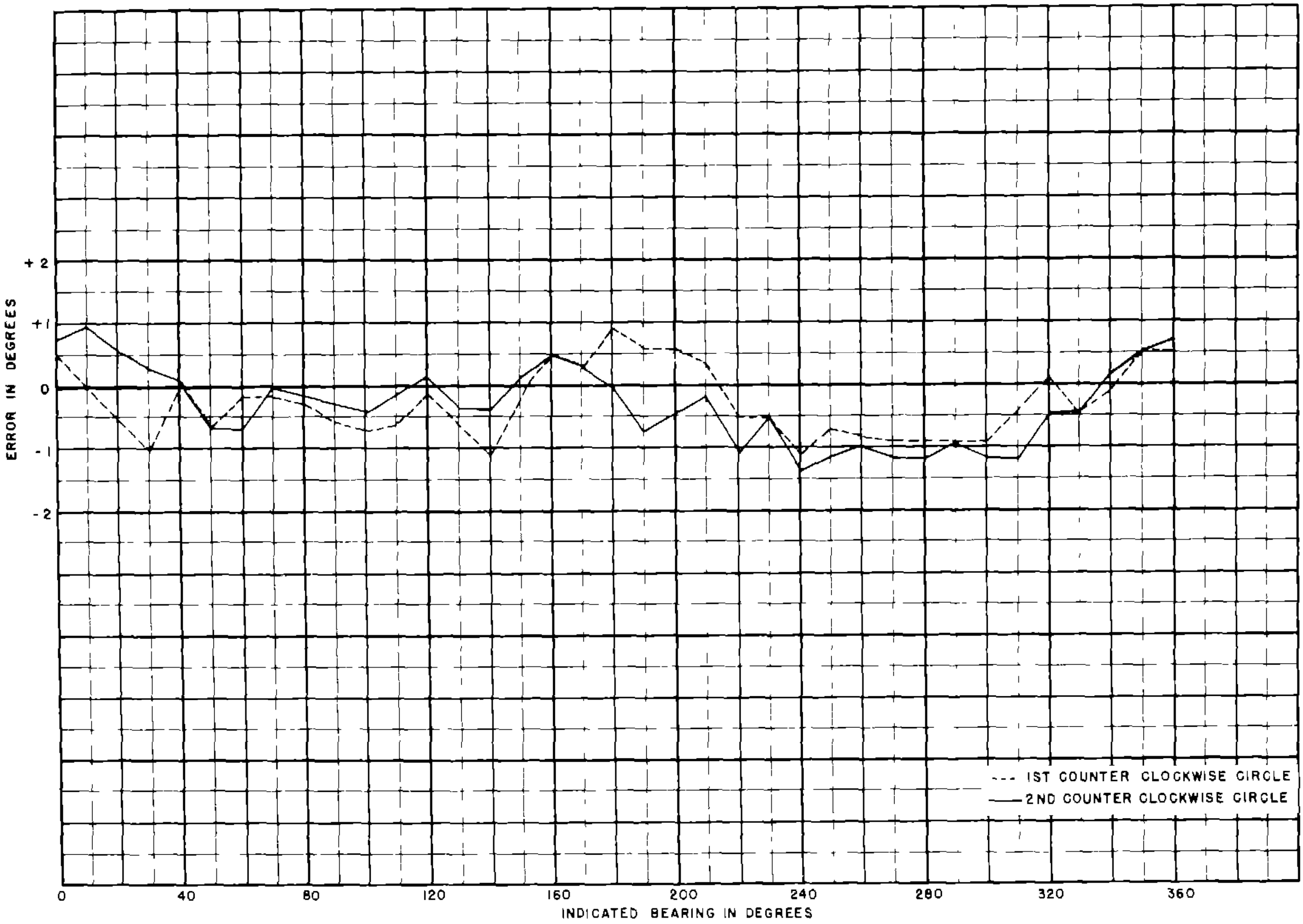


FIG 7 THEODOLITE FLIGHT CALIBRATION ERROR CURVE OF FTL OMNIRANGE TRANSMITTING ANTENNA (RECEIVER ERROR REMOVED)

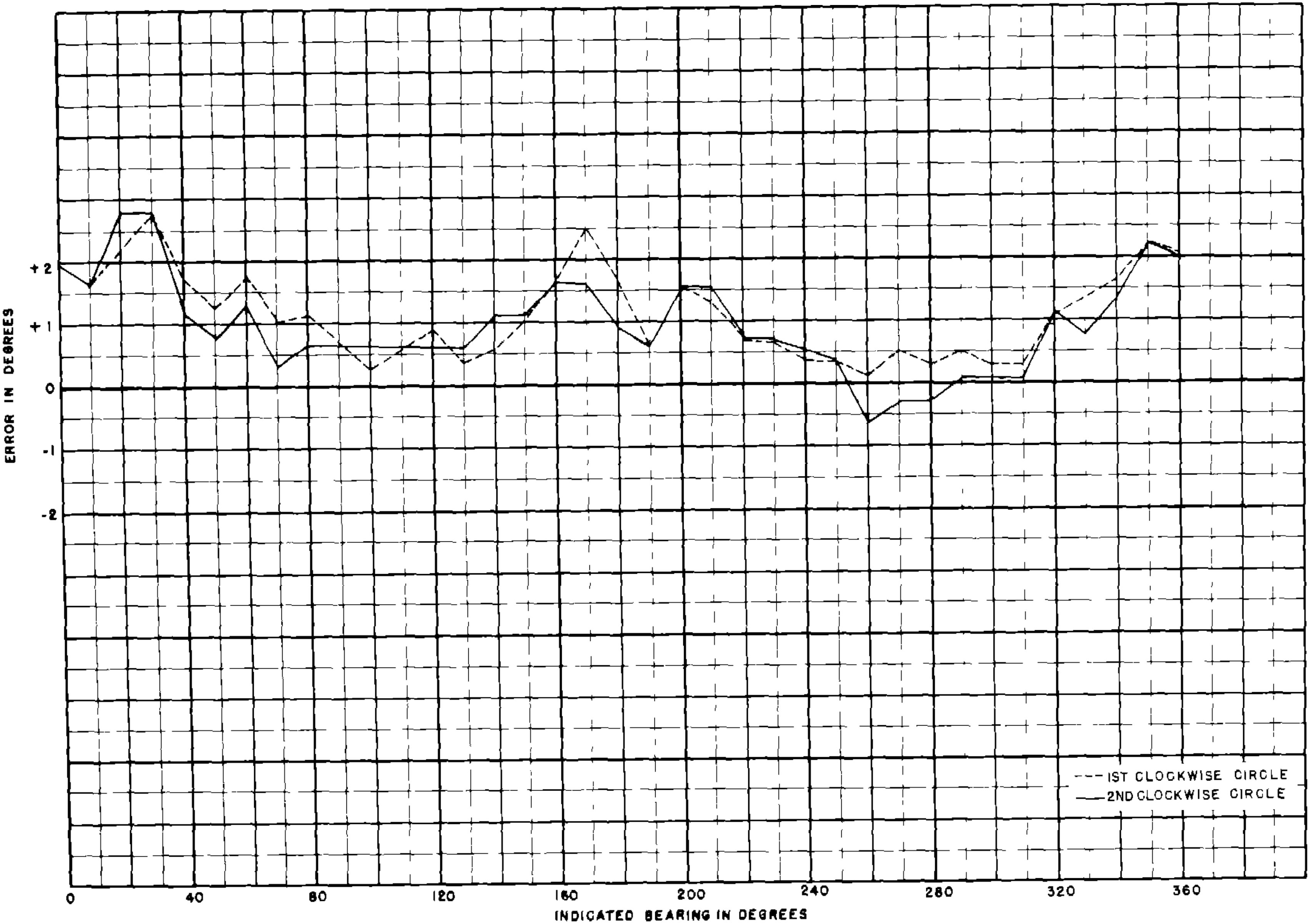


FIG 8 THEODOLITE FLIGHT CALIBRATION ERROR CURVE OF FTL OMNIRANGE TRANSMITTING ANTENNA (RECEIVER ERROR REMOVED)

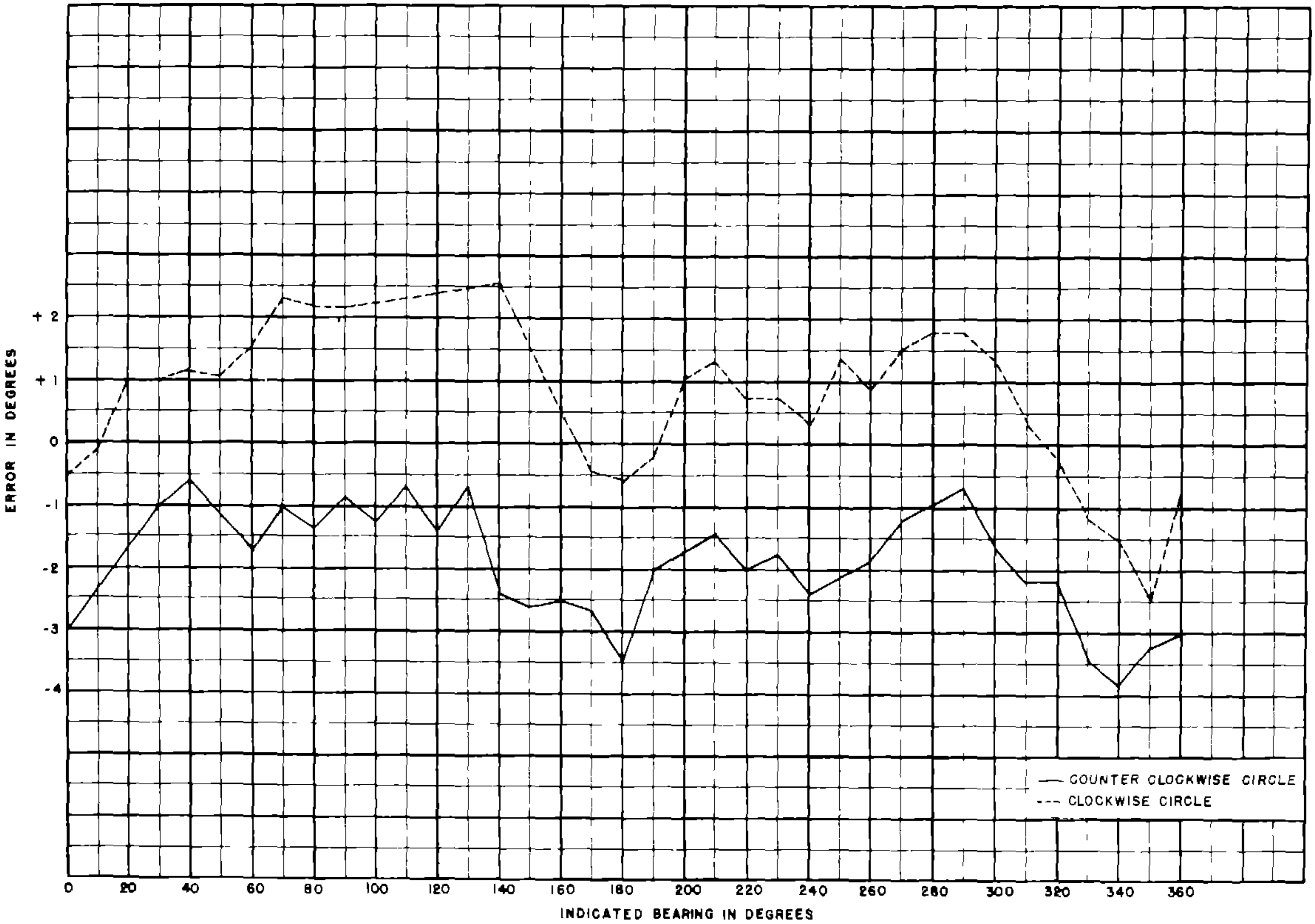


FIG 9 THEODOLITE FLIGHT CALIBRATION ERROR CURVE OF STANDARD 5 LOOP OMNIRANGE TRANSMITTING ANTENNA (RECEIVER ERROR REMOVED)

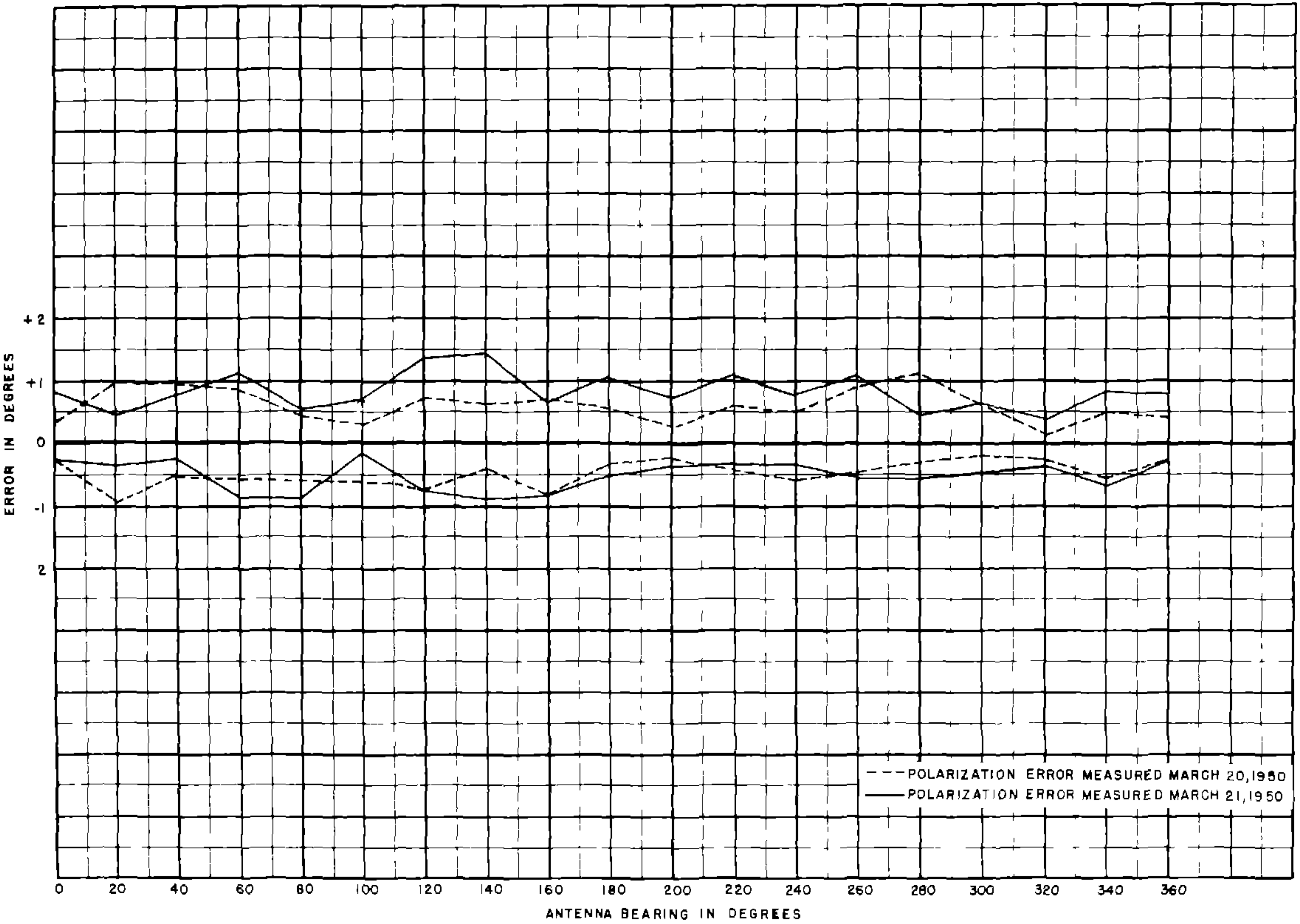


FIG 10 POLARIZATION ERROR CURVES OF FTL OMNIRANGE TRANSMITTING ANTENNA, GROUND CHECK

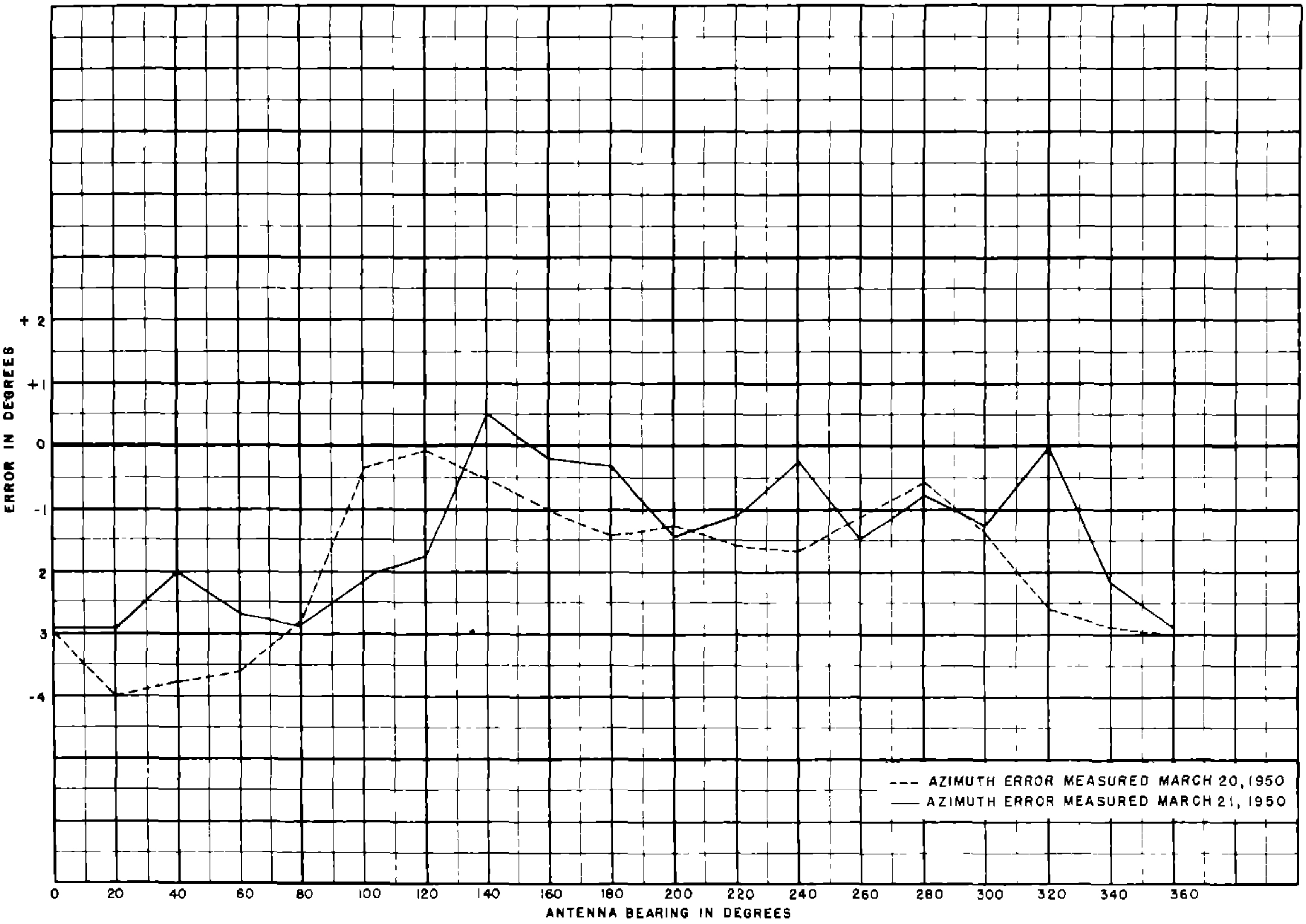


FIG 11 AZIMUTH ERROR CURVE OF FTL OMNIRANGE TRANSMITTING ANTENNA, GROUND CHECK (RECEIVER ERROR REMOVED)

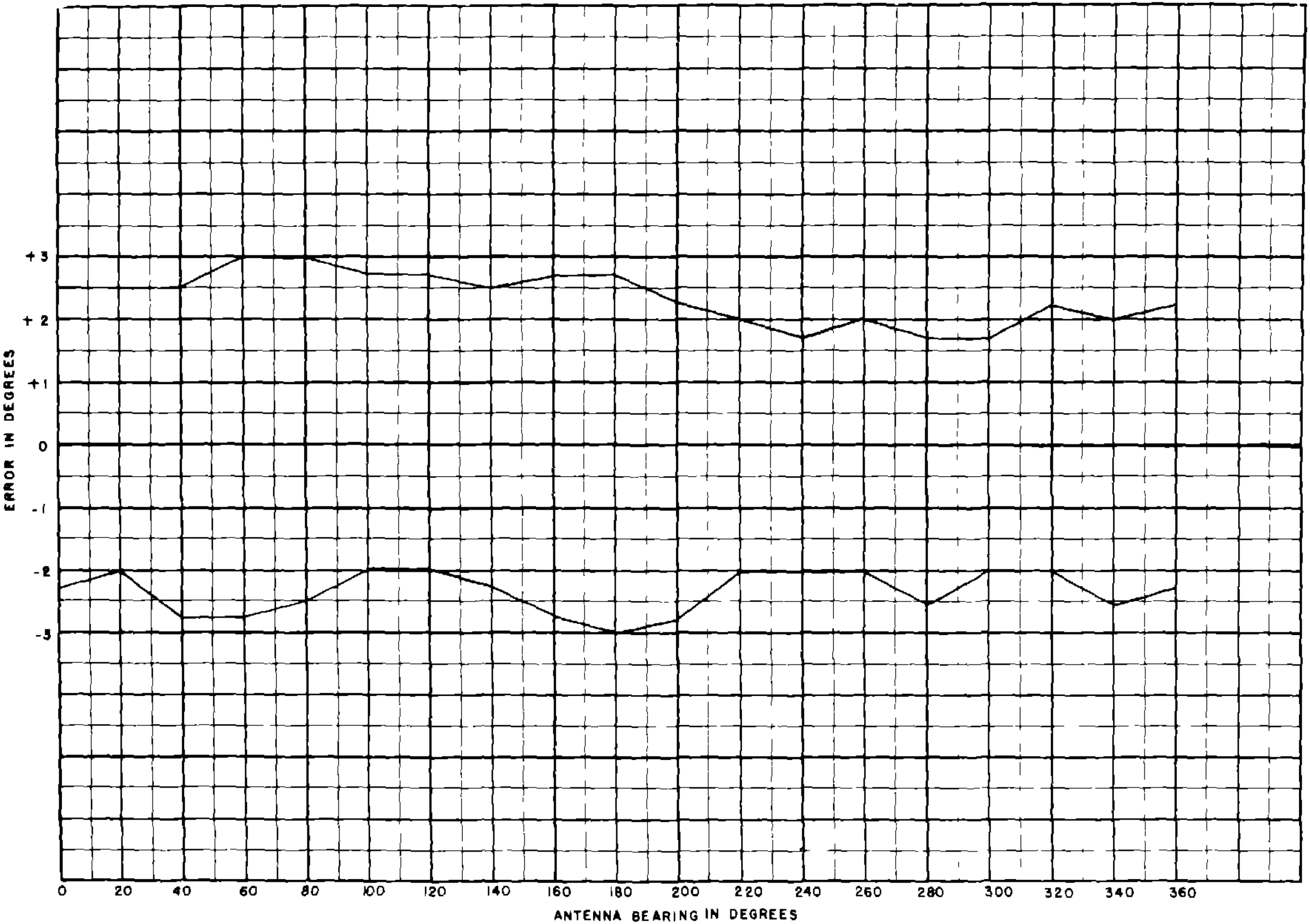


FIG 12 POLARIZATION ERROR CURVE OF STANDARD 5 LOOP OMNIRANGE ANTENNA, GROUND CHECK

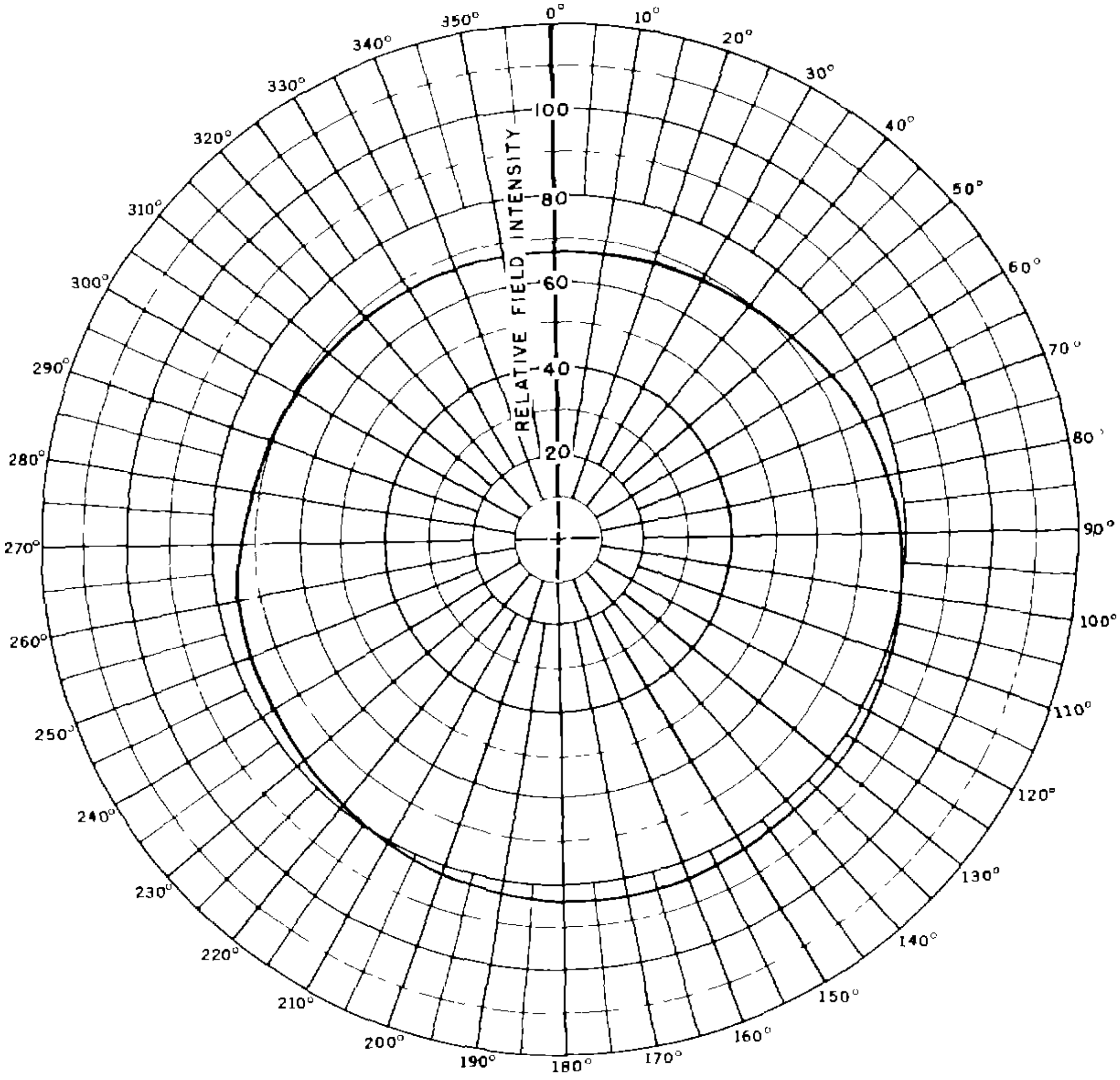


FIG 13 FTL OMNIRANGE TRANSMITTING ANTENNA POLAR PLOT OF CARRIER FIELD PATTERN

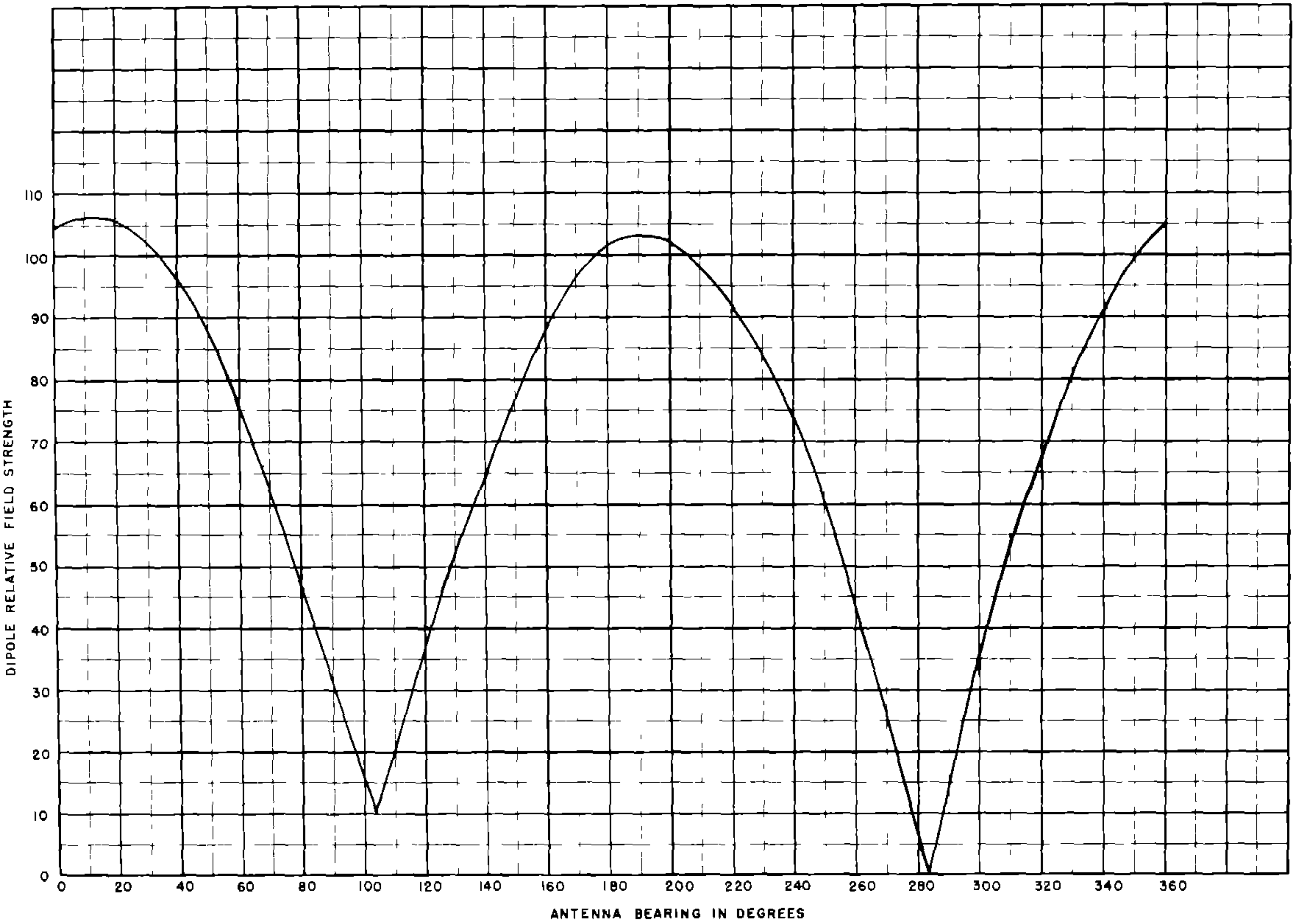


FIG 14 FTL OMNIRANGE TRANSMITTING ANTENNA
SIDEBAND FIGURE OF EIGHT PATTERN