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EVALUATION OF THE MELPAR VOR GROSS ERROR DETECTOR

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SUMMARY

This report presents the evaluation of the Melpar Gross Error Detector conducted at the Technical Development and Evaluation Center of the Civil Aeronautics Administration, Indianapolis, Indiana. The purpose of the equipment as proposed is to detect gross errors in the VOR system.

The accuracy of the bearing observations of the gross error detector and omnibearings on flight checks was determined by comparing them to the magnetic bearing of ground check points. The maximum errors measured on the aural bearings were +6.0° and -1.0° after installation and deteriorated to +13° and -10° at the completion of three weeks operation. The maximum bearing error of the VOR station on ground checks was less than ±1.0° before the gross error detector was installed and ±1.9° after the equipment was installed. The maximum indicated gross errors observed on flight tests were +3° and -5°.

Further development of the gross error detector equipment would be necessary before the system accuracy would be satisfactory for operational use. The system introduces added complexity and errors to the VOR and has 180° ambiguity of the aural bearings.

INTRODUCTION

An experimental model VOR gross error detector[1] developed by Melpar, Inc. was installed at the Tilden experimental VOR site of the Technical Development and Evaluation Center of the Civil Aeronautics Administration, Indianapolis, Indiana. This station uses a four-loop antenna system[2].

The purpose of the gross error detector is to enable the pilot to determine errors or failures in the VOR system. This actually involves the addition of an aural omnirange to the VOR station. In the model equipment the pilot listens to voice bearing announcements with respect to North. These voice announcements of 10° intervals are nondirectionally transmitted and partially masked except during the null by a slowly rotating figure-of-eight tone of 1020 cps (or other suitable audio frequency). The pattern rotates 180° in approximately 30 seconds.

[1] Vernon I. Weihe, "A Suggested Modification of VHF Omnirange to Eliminate Gross Errors," RTCA Paper 126-52/RE-22, May 26, 1952.

[2] S. R. Anderson, H. F. Keary, W. L. Wright, "The Four-Loop VOR Antenna," Technical Development Report No.

To determine the ground reference bearing of his aircraft with respect to the VOR station being received, the pilot must listen until the null moves through his bearing. He mentally notes the spoken number at the time the tone fades to zero. The gross error is then determined by comparing the aural and visual bearings.

In order that the VOR voice and code identification may be time-shared with the gross error detector, a cam-operated switch on the slow moving goniometer driveshaft provides this function. The voice is recorded on a magnetic drum which is geared to rotate at twice the speed of the goniometer and only identifies 180° of rotation of the tone figure-of-eight pattern. During the identification of the null from 0° to 180°, the other null is moving from 180° to 360° resulting in an unresolved 180° ambiguity.

This report presents the evaluation and operational tests of the Melpar Gross Error Detector.

DESCRIPTION

The necessary modification of the VOR ground station for installation of the Melpar Gross Error Detector is illustrated in Fig. 1. In order to obtain both visual and aural courses from the VOR it was necessary to provide a means for simultaneous feed to the loops from the two signal sources. This was done by placing two additional balanced bridges in the sideband feed circuits. The VOR goniometer outputs were fed to the bridges at points 1 and 5 and the aural goniometer outputs were fed at points 3 and 7. Twenty-watt, 52-ohm resistive loads were connected at points 4 and 8. The NW-SE sideband and the NE-SW sideband lines were connected to points 2 and 6, respectively.

Excitation for the sideband generator was obtained from the modulation eliminator output. Plate and screen power was supplied to the sideband generator from the modulator, which was driven by a 1020-cps oscillator. The output of the sideband generator consists of sideband energy only (carrier frequency ±1020 cps). The output of the sideband generator is applied to the 1-rpm goniometer. Each diagonal pair of loops is driven from an output of the goniometer and produces a figure-of-eight pattern in space, which rotates at a speed of 1 rpm.

Voice announcement of the aural null indication is recorded on a 12-1/2-inch diameter magnetic drum which rotates at 2 rpm. The magnetic pickup amplifier is connected to the voice and code identification input of the VOR. A cam-operated switch controls a relay which turns the aural equipment on for 200° rotation of the 1 rpm goniometer and the identification for the remaining 160°.

Fig. 2 illustrates more clearly how the aural figure-of-eight pattern and voice bearing announcements are time-shared with the normal identification of the VOR. Figures 3 and 4 show two views of the equipment as installed at the VOR.

MEASUREMENTS

Tests were conducted to determine the accuracy of the VOR with the Melpar Gross Error Detector installed, and the accuracy of the Melpar equipment. The tests included ground measurements of the course deviation indicator readings to determine bearing errors, and flight tests to determine the accuracy and feasibility of the aural indications. Changes in the operating conditions resulting from the addition of the Melpar equipment are included.

Measurements taken one mile from the VOR at 180° show a scalloping effect on the course deviation indicator with rotation of the aural goniometer when it is connected to the added bridges as shown in Fig. 5A. This course variation is caused by the varying impedance presented by the rotating goniometer to the added bridges. The bridges do not have perfect isolation, and this varying impedance causes reflections of normal VOR sideband energy in the lines connecting the aural goniometer to the bridges. The net effect is an unbalance in the VOR sideband lines which changes with rotation of the aural goniometer.

A course deviation indicator variation of ±1.75° was the minimum obtained by adjusting the line lengths from the aural goniometer to the new bridges. A further reduction in course shift was effected by placing 52-ohm resistive loads in parallel with the outputs of the aural goniometer. The course variations were reduced to ±0.65° as shown in Fig. 5B, but were not noticeable by the observers during flight since the frequency was only 2 cpm. Variations of this effect with azimuth are shown in Fig. 6.

Measurements of operating conditions are shown in Table I. The addition of the Melpar equipment caused a 27.5 per cent (1.4 db) loss in carrier power. This did not materially decrease the distance range of the VOR, however, and is further discussed in the flight tests section of this report.

TABLE I

Equipment Measurements

Conditions	Normal	With Gross Error Detector
Carrier power output referred to normal VOR	100 %	72.5 %
9960 cps modulation on modulation eliminator output (60 ma cathode current)	2 %	5 %
9960 cps modulation on modulation eliminator output (70 ma cathode current)		2 %
Modulation eliminator power divider position	34	69
20 per cent of 1000 cps space modulation		
Sideband generator grid current, I_g		6 ma
Sideband generator cathode current, I_k (per tube)		14 ma
Total output of aural goniometer		2.8 w
Total input to bridges from slow goniometer		1.2 w
Loss in lines from aural goniometer to bridges		0.2 w
Total power input to 52-ohm stabilizing loads		1.4 w
Power input to VOR goniometer	4 w	8 w
Power input to sideband generator		10 w
Total power taken from modulation eliminator	4 w	18 w

The residual 10 kc modulation on the output of the modulation eliminator was increased from 2 to 5 per cent with the addition of the Melpar equipment, but can be reduced to 2 per cent by adjusting the bias control to increase the modulation eliminator cathode current from a normal 60 ma to 70 ma. The evaluation tests were conducted at a cathode current of 60 ma.

The additional power taken from the modulation eliminator by the sideband generator and the bridge balancing loads must be made up by the higher power divider setting. The resultant increased plate dissipation of the modulation eliminator diodes would probably reduce their life expectancy. Extensive tests would have to be made to determine:

1. If the present modulation eliminator would continue to supply this power without increased maintenance.

2. The effect of paralleling the two 52-ohm loads presented by the regular VOR goniometer and sideband generator to the 52-ohm output of the modulation eliminator.

The sideband generator is operated at the same power as in localizer service and should perform satisfactorily. The effects of sideband generator tuning and phasing on the indicated null position were investigated and results tabulated in Table II.

TABLE II

Effects of Sideband Generator Tuning and Phasing On Null Position

Plate Dial	Null Shift (deg)	S.B. Generator Monitor (ma)
3.89	+3/4	0.38
3.87	+1/4	0.39
3.83 (normal)	0	0.40
3.79	-1/4	0.39
3.77	-1/2	0.38

Null Shift (deg)	S.B. Generator Phaser
+1-3/4	50
+3/4	25
0	15 (normal)
-1/4	5

Grid tuning of sideband generator produced no shift.

Sideband 2 phaser was left at the normal setting of 47 for the following conditions:

S.B.1 Phaser	Course Shift Gross Error Detector (deg)	Course Shift VOR (deg)
67	-2-1/4	-1.0
47 (normal)	0	0
27	+4-3/4	+1.0

From the foregoing data, it can be seen that insofar as the tuning and phasing of the sideband generator are concerned, the Melpar equipment is relatively stable but is affected more than the VOR by sideband line phasing changes or misadjustments. These changes were investigated at the north monitor pickup and found to have different effects at various azimuths around the station.

The bearing error curves of the nulls produced by the rotating aural figure-of-eight patterns are illustrated in Fig. 7. The displacement of the nulls was partly due to direct radiation from the sideband generator. This fault is a development problem and was not investigated further Figure 8 illustrates the shift which occurred in the null positions after the equipment had operated three weeks. This shift was not apparent from daily meter readings, but was disclosed by subsequent checks of aural bearing errors.

The curves in Fig. 9 illustrate the change in the bearing error curve of the station when the aural goniometer was stopped. The maximum errors were observed with the aural goniometer stopped at 45° and 270°. Figure 10 illustrates the effect on the bearing error when the power to the Melpar equipment was cut off. The aural goniometer was stopped on 135° for this test.

FLIGHT TESTS

Several flight tests were conducted on the gross error detector installed at the Tilden VOR operating on a frequency of 114.8 Mc. The tests consisted of checks on accuracy, and null width with distance observations. The accuracy test was conducted by flying over a ground check point and observing the audio bearing and omnibearing, and comparing these with the magnetic bearing of the check point. The check points selected were approximately 20 miles from the VOR. The data obtained are listed in Table III.

TABLE III

VISUAL, AURAL, AND GROSS ERROR MEASUREMENTS

Check Point	Magnetic Bearing (deg)	Receiver Error Plus Station Error (deg)	Aural Bearing Error (deg)	Indicated Gross Error (deg)
OBSERVER #1				
1	42	+1.0	+3.0	-2
2	19.75	-1.75	+0.25	-2
3	354.2	+2.8	+0.8	+2
4	322.7	+1.3	+2.3	-1
5	308.8	-0.8	+1.2	-2
6	287.5	+1.0	+2.5	-1.5
7	227.4	-1.4	+2.6	-4
8	220	-1.0	0	-1
9	197	+1.0	+3.0	-2
10	186	-2.5	-1.0	-1.5
11	164.5	-1.5	-4.5	+3
12	140	+1.0	0	+1
13	126	-0.5	-1.0	+0.5
14	106	-2.0	-1.0	-1
15	83	-2.0	-3.0	+1
OBSERVER #2				
1	42	-1.0	+3.0	-4
2	19.75	-1.75	+1.25	-3
3	354.2	+0.8	+1.8	-1
4	322.7	-1.7	+2.3	-4
16	26	-1.0	0	-1
OBSERVER #3				
1	42	-1.0	-2.0	+1
2	19.75	-1.75	+0.25	-2
3	354.2	+0.8	+0.8	0
4	322.7	-1.8	+2.3	-4
16	26	-1.0	-5.0	+4
OBSERVER #4				
12	140	-2.0	+3.0	-5
11	164.5	+0.5	+4.5	-4
10	186	+2.0	+4.0	-2
9	197	+2.0	+3.0	-1
8	220	+2.0	0	+2
OBSERVER #5				
12	140	-2.0	0	-2
11	164.5	+0.5	+3.5	-3
10	186	+2.0	+5.0	-3
9	197	+2.0	0	+2
8	220	+2.0	+2.0	0

The indicated gross errors from the data in Table III range from +3° to-5° for 35 observations by five observers. The results of the observations are plotted on Fig. 7. They show some correlation with the aural null positions measured with a vacuum tube voltmeter, however, Fig. 11 shows the accuracy with which those observers were able to judge the null position. The difference between the measured null and observed null positions is the psychological error of the observer. These data were not sufficiently complete to draw definite conclusions; but they do indicate the presence of a psychological lag of about 2°.

The distance range check conducted on the Tilden VOR, with and without the gross error detector, resulted in a range of 58 miles for the normal VOR and 56 miles with the gross error detector. The distance range is defined here as the distance in miles from the VOR at which the course width becomes double the course width measured at ten miles from the station.

The null-width distance test consisted of flying a radial away from the VOR at an altitude of 1,000 feet above ground and estimating by ear the gross error detector null width in degrees with voice announcements as a reference. The data obtained are listed in Table IV. The null widths shown are for 10 per cent and 20 per cent 1020 cps space modulation.

TABLE IV

Aural Null Width Measurements

Distance from VOR (Miles)	Null Width	
	10 per cent (deg)	20 per cent
30	20	10
39	30	15
45	40	20
50	60	35
52	70	50
56	80	70
58	100	100

From the above data and as a result of flight experience, it is believed that the usable distance range of the aural equipment is approximately 70 per cent of that of the VOR.

Space modulation by the masking tone greater than 20 per cent was not used because only 40 per cent modulation was available for both voice bearing announcements and masking tone. It is believed that 20 per cent voice modulation is the minimum usable level.

MODIFICATIONS

The original magnetic tape contained a 600-cps tone at the 5° point between each of the 10° voice announcements. Early observations disclosed that these tones between voice bearing announcements were distracting and did not add to the accuracy of the aural observations; hence, they were removed.

A proposed modification to eliminate the 180° ambiguity of the gross error detector system was to combine a circular pattern with the rotating figure-of-eight to produce a cardioid pattern with only one null. Besides the power loss and additional complication of another rf bridge circuit, the null produced by this cardioid would be much wider than those of the figure-of-eight. Figure 12 shows a comparison of the null widths of the two systems. Using the typical null width of 20°, it is seen that with the same noise level a cardioid pattern null width would be 100°.

CONCLUSIONS

The gross error detector operated as intended and no installation difficulty was encountered. The major deficiencies of the equipment are as follows:

1. The addition of this equipment introduced a maximum course variation of ±0.85° at 2 cycles per minute and also introduced the possibility of large errors caused by failures in the gross error equipment.

2. The maximum aural error of the equipment is ±10°.

3. The voice bearing announcements are of poor quality because of the slow tape speed of 1.3 inches per second and could undoubtedly be improved by a higher tape velocity or by a sound on film method.

4 The usable aural service distance range was approximately 70 per cent of the visual service range.

5. The equipment has an unresolved 180° ambiguity.

6 The system utilizes the voice channel of the VOR which normally is employed for CAA ground-to-air communications with civil aircraft. While the channel can be shared between the gross error system service and voice communications, frequent use of the voice communication channel would render the gross error system difficult and discouraging to use.

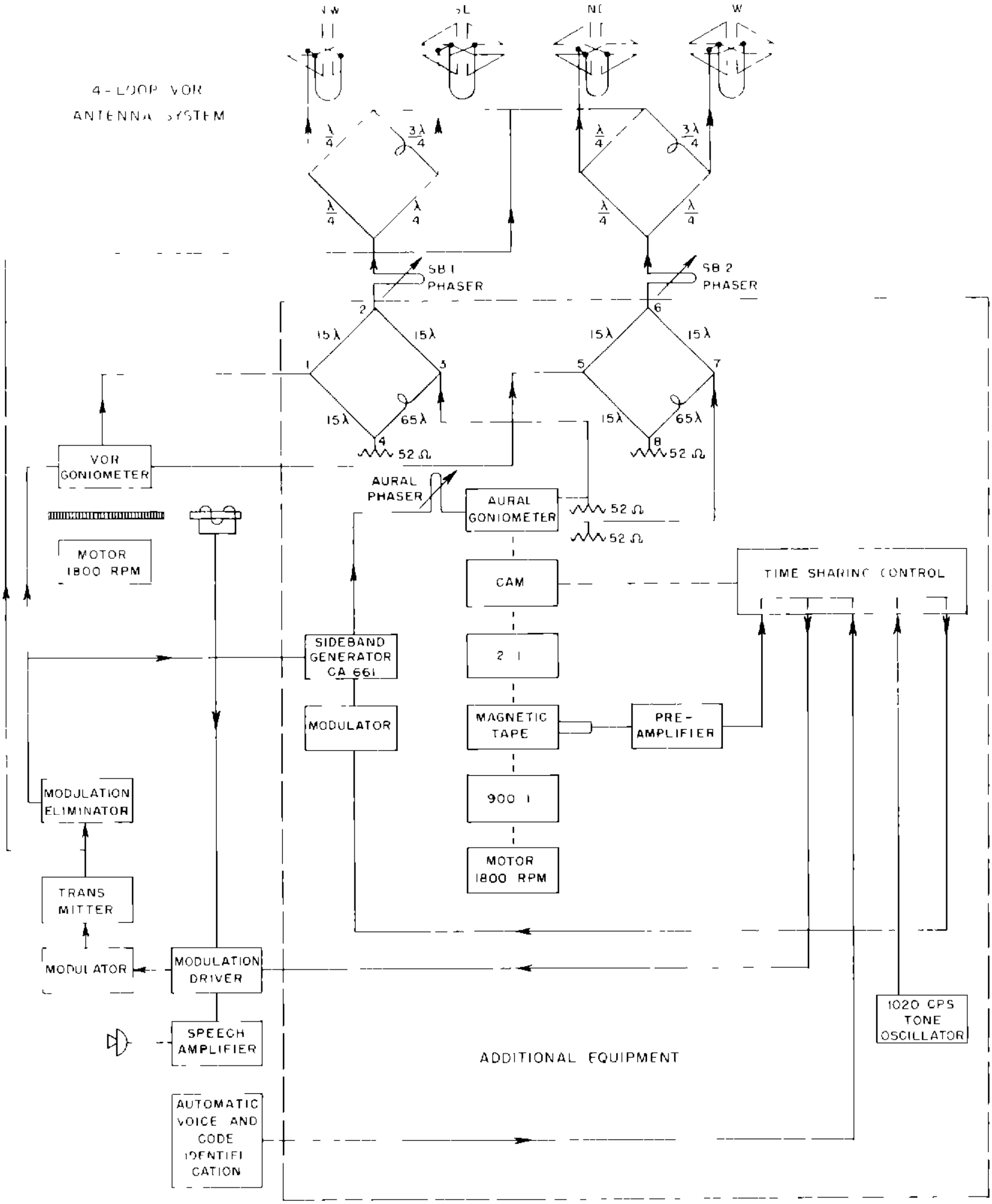
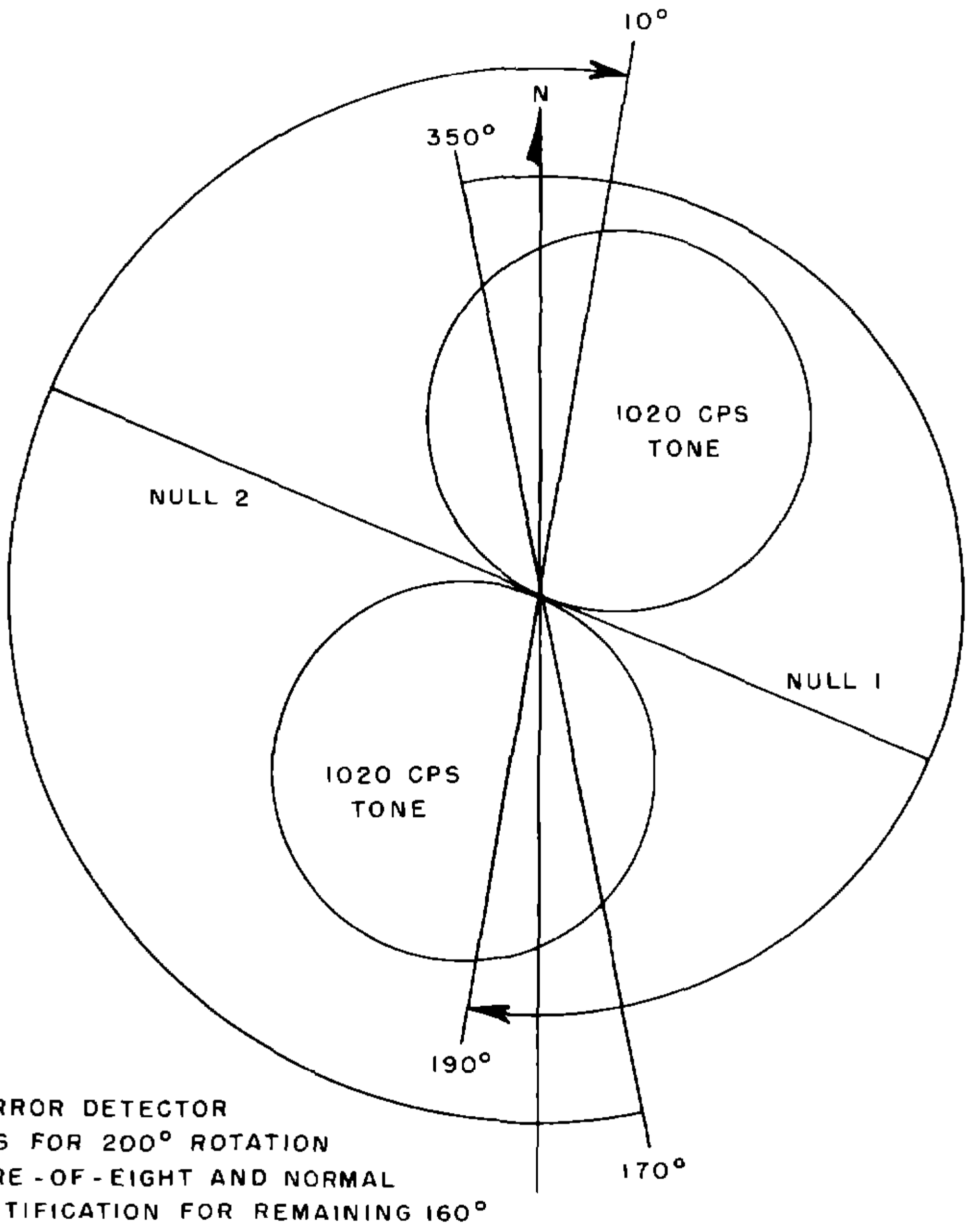


FIG 1 BLOCK DIAGRAM OF VOR WITH GROSS ERROR DETECTOR



NOTE
GROSS ERROR DETECTOR
OPERATES FOR 200° ROTATION
OF FIGURE-OF-EIGHT AND NORMAL
VOR IDENTIFICATION FOR REMAINING 160°

FIG 2 TIME-SHARING DIAGRAM

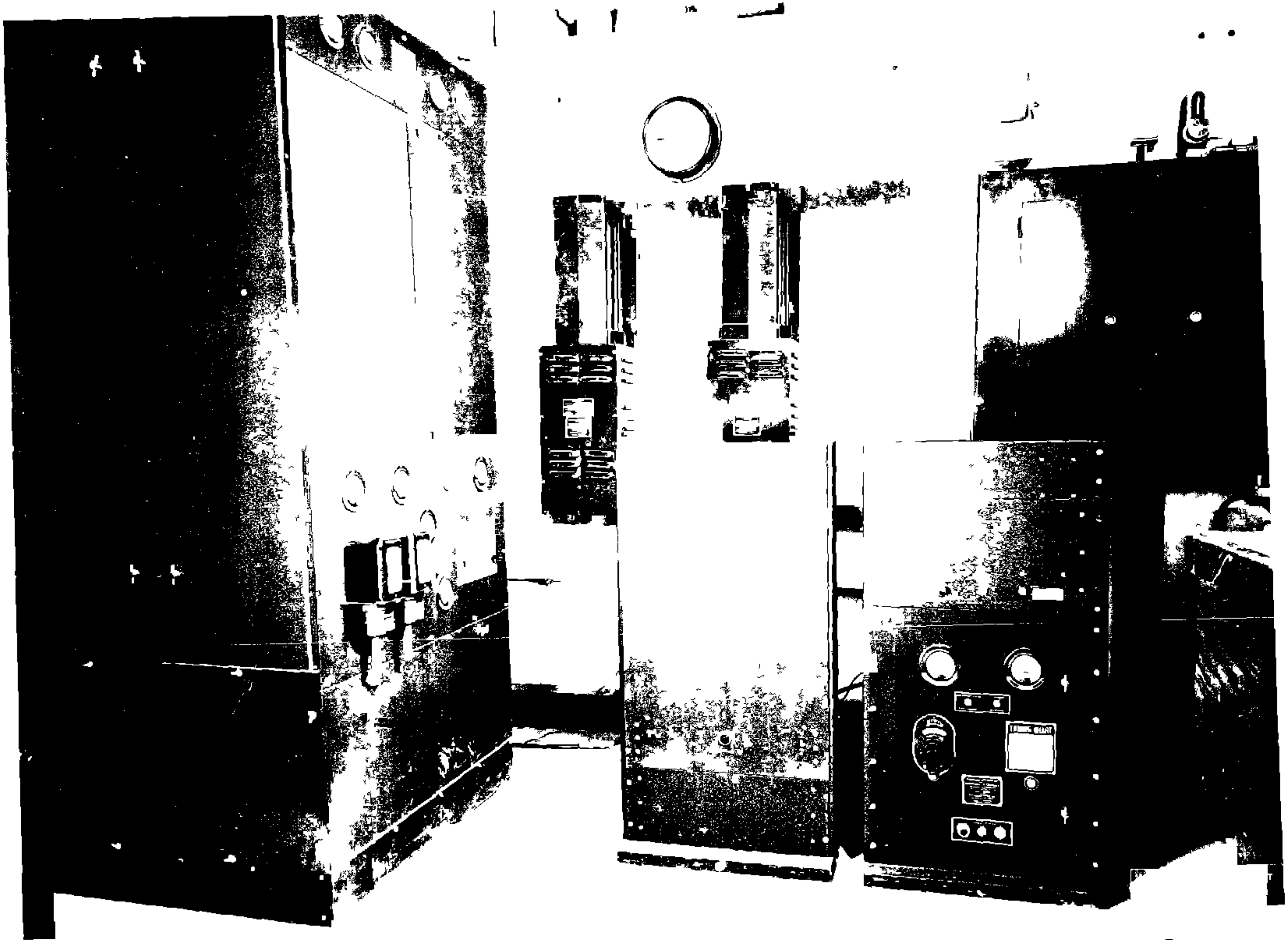


FIG 3 GROSS ERROR DETECTOR EQUIPMENT INSTALLED AT TILDEN VOR

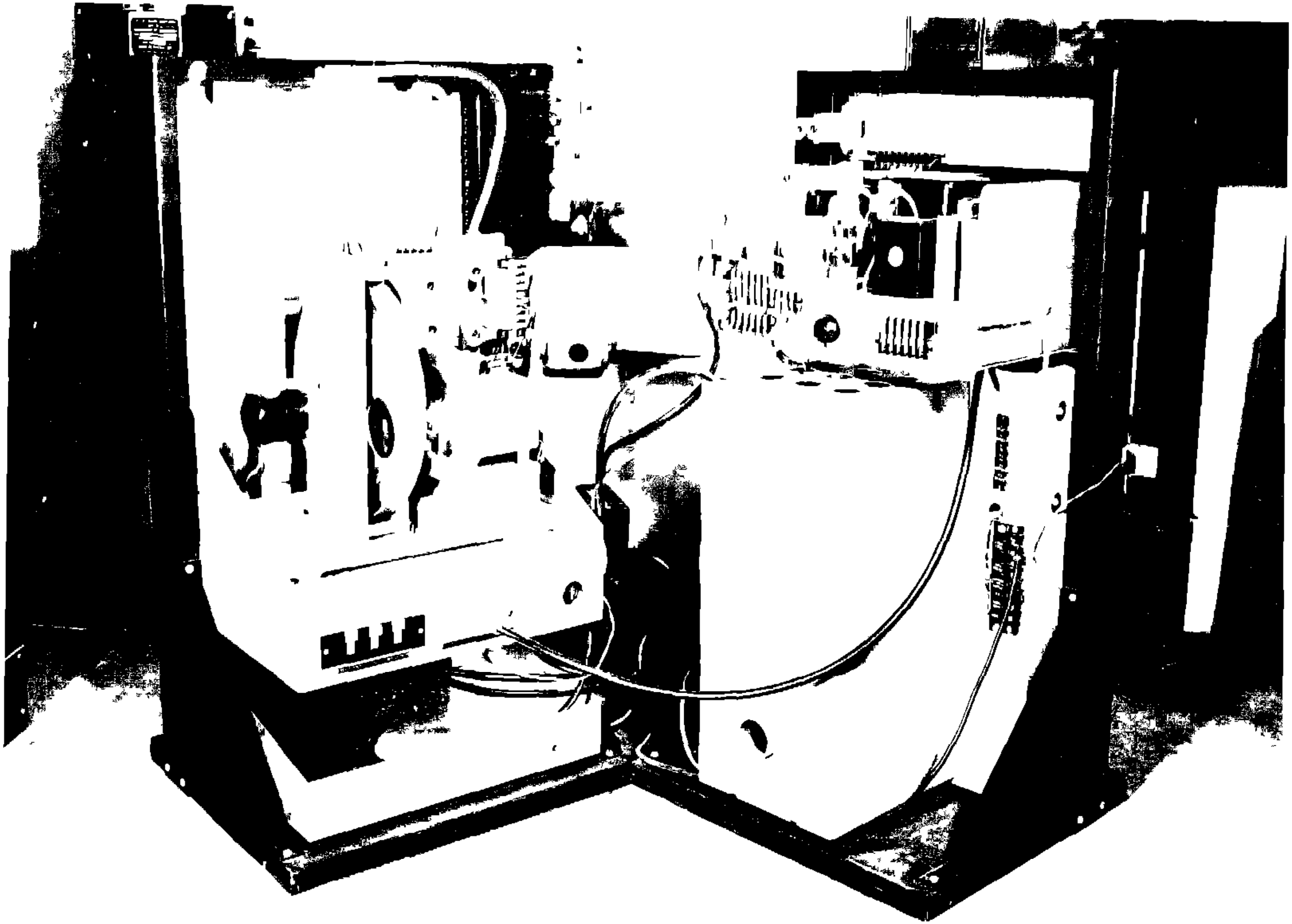
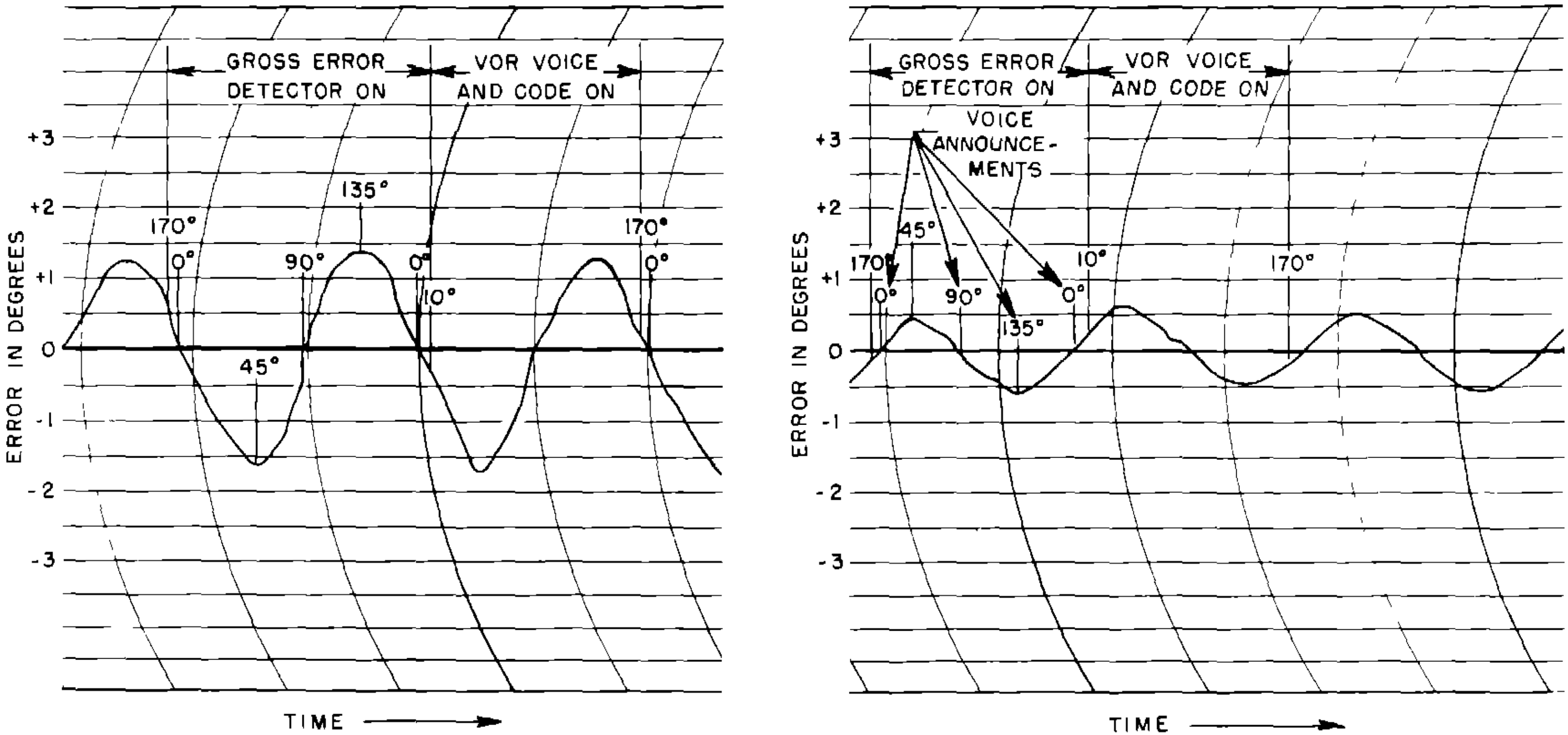


FIG 4 REAR VIEW OF GROSS ERROR DETECTOR EQUIPMENT

NOTE
RECORDING MADE WITH COLLINS 51R2 RECEIVER
LOCATED ONE MILE AT 180 DEGREES



(A) WITHOUT 52-OHM STABILIZING LOADS

(B) WITH 52-OHM STABILIZERS

FIG 5 COURSE VARIATION CAUSED BY AURAL GONIOMETER

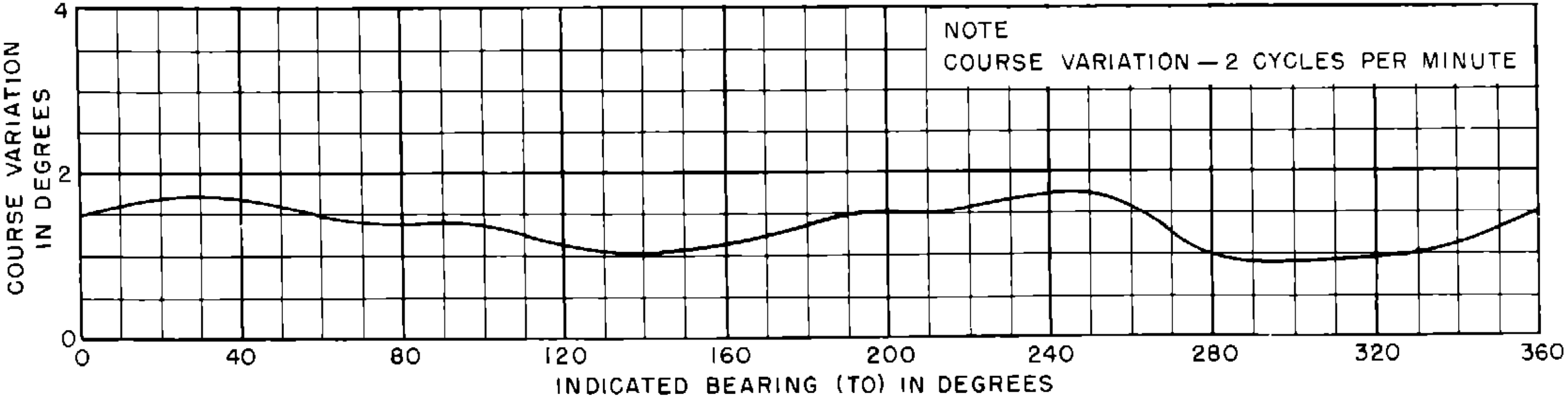


FIG 6 VARIATION INTRODUCED ON VISUAL COURSE BY THE GROSS ERROR DETECTOR (TILDEN VOR MARCH 20, 1953)

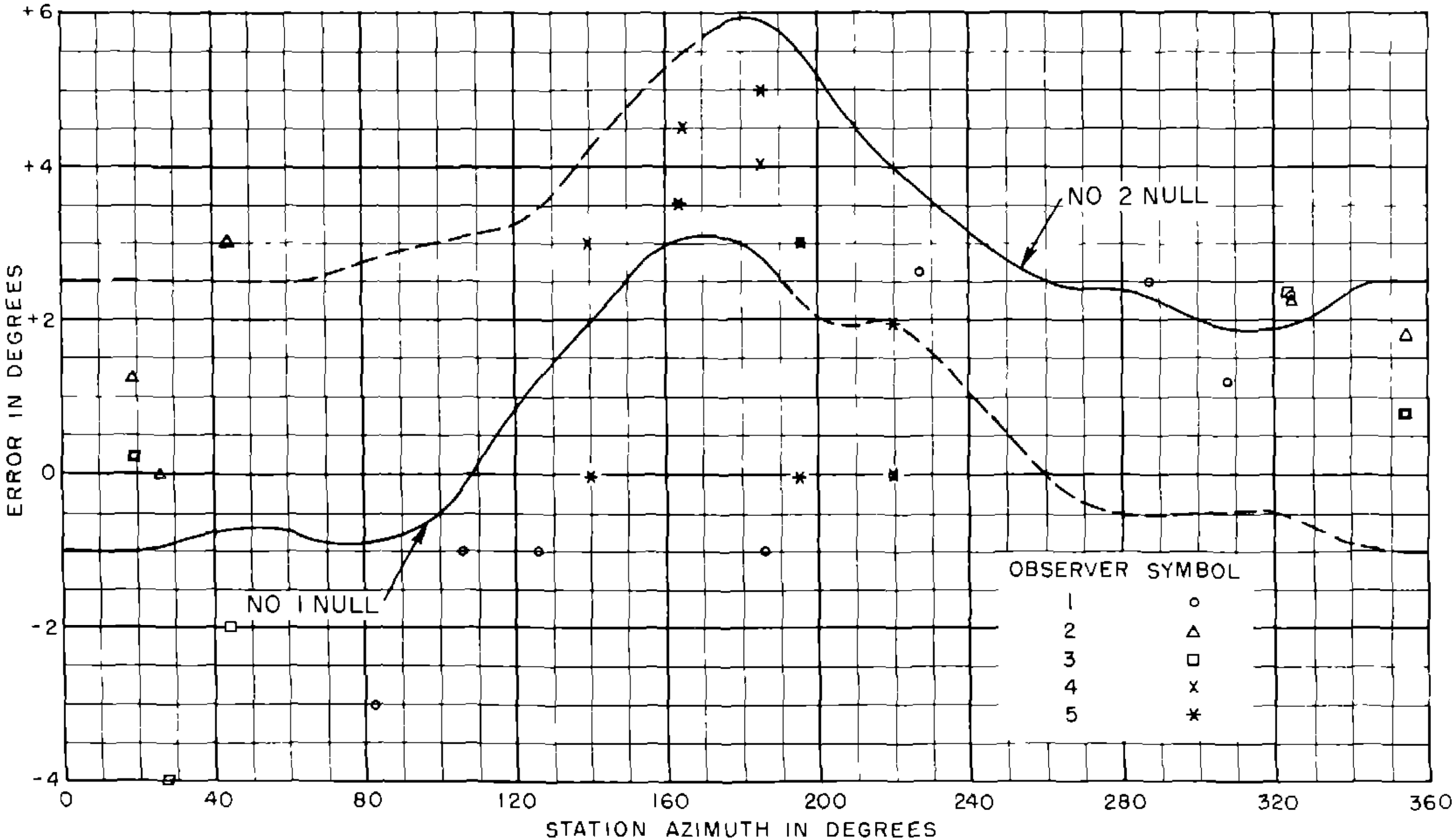


FIG 7 ERROR CURVES OF THE NULLS PRODUCED BY THE ROTATION OF THE AURAL FIGURE-OF-EIGHT PATTERN AND OBSERVATIONS OF AURAL BEARINGS ON FLIGHT TESTS (TILDEN VOR MARCH 16, 1953)

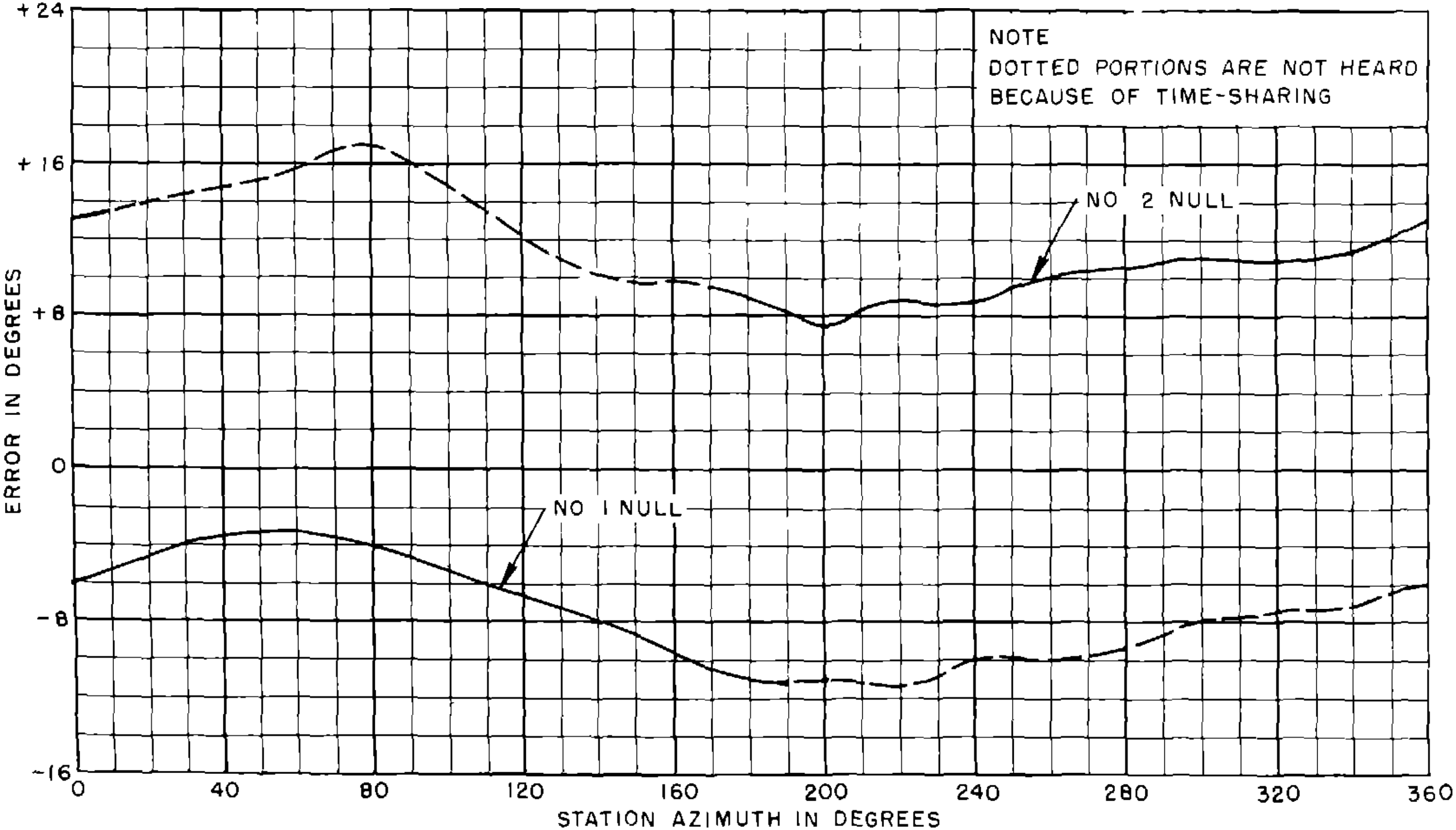


FIG 8 ERROR CURVES OF THE NULLS PRODUCED BY THE ROTATING AURAL FIGURE-OF-EIGHT PATTERN (TILDEN VOR APRIL 6, 1953)

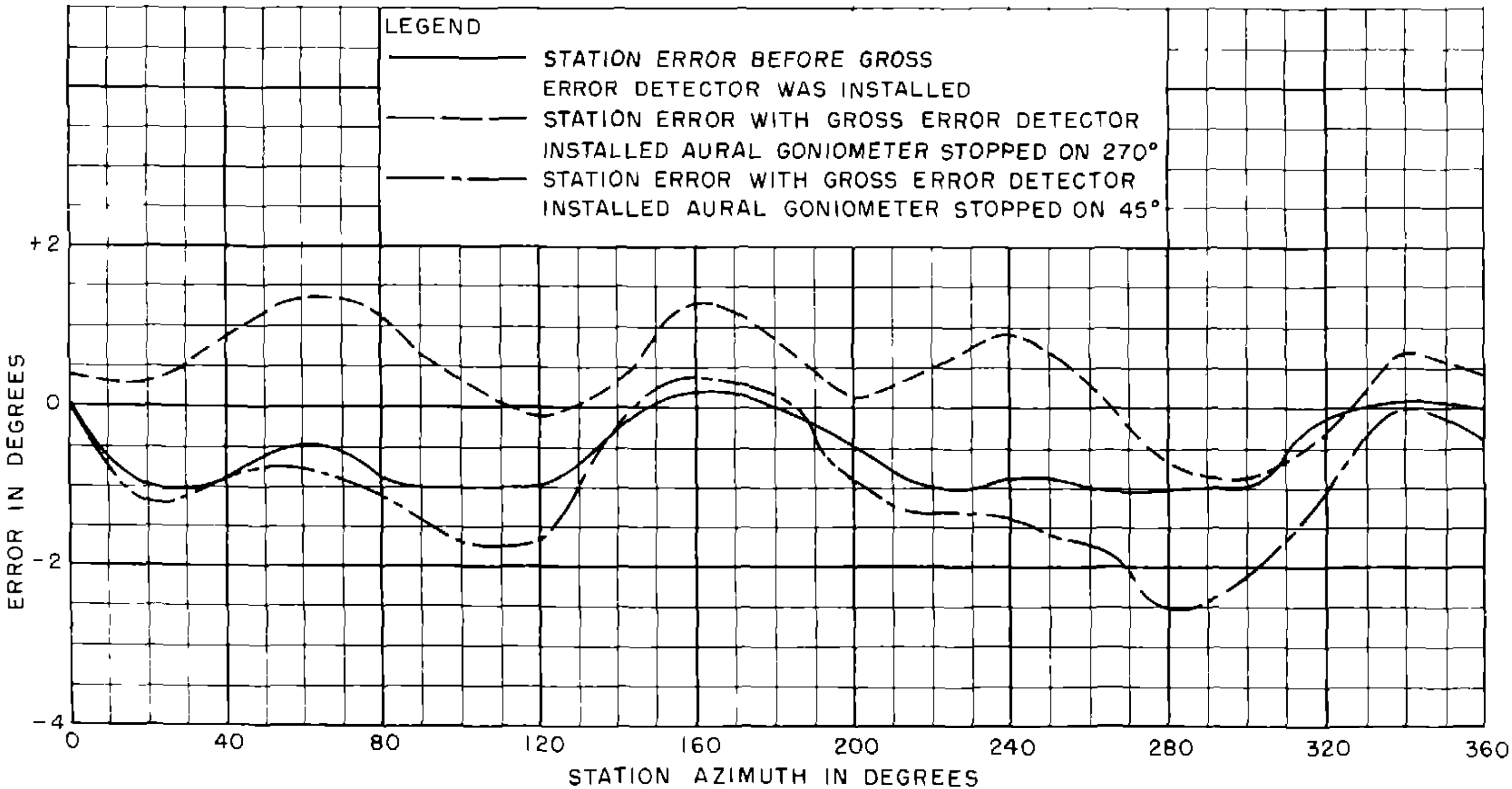


FIG 9 BEARING ERROR CURVES OF STATION ILLUSTRATING MAXIMUM POSSIBLE ERRORS IN CASE THE AURAL GONIOMETER STOPS ROTATING (TILDEN VOR APRIL 6, 1953)

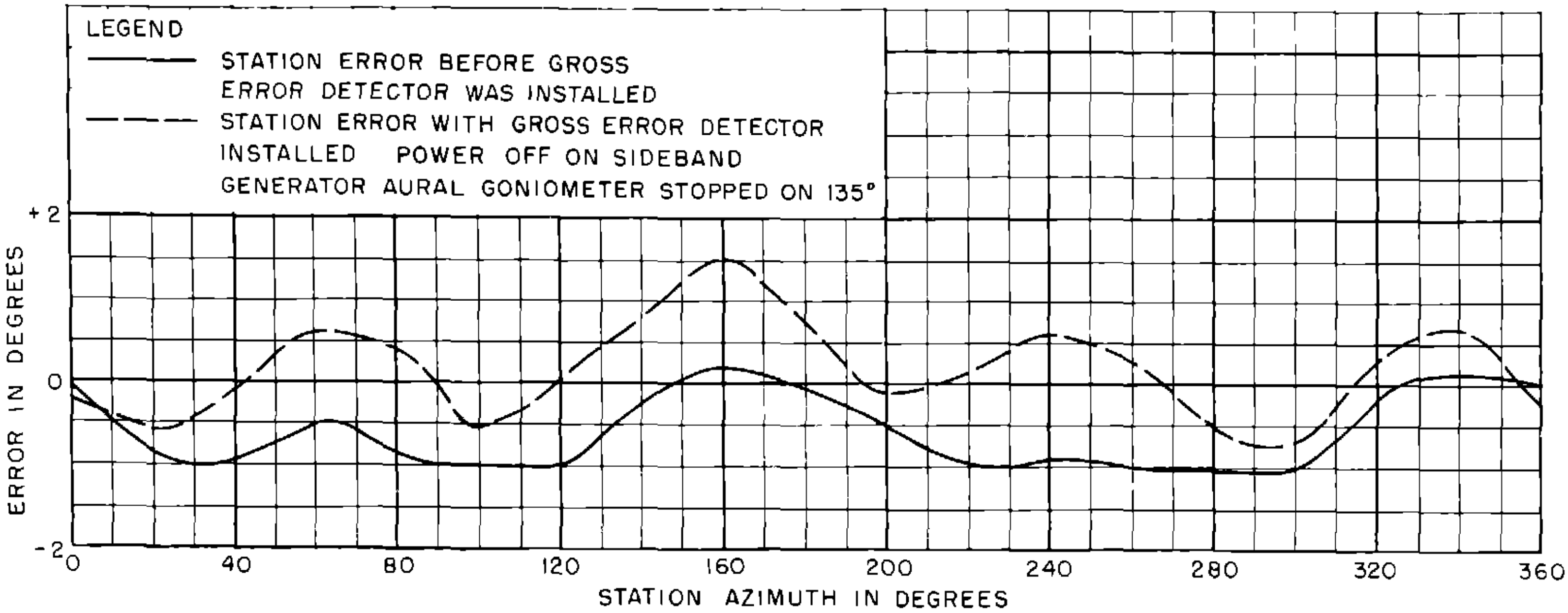


FIG 10 BEARING ERROR CURVES OF STATION ILLUSTRATING THE ERROR IN THE EVENT OF A POWER FAILURE TO GROSS ERROR DETECTOR (TILDEN VOR APRIL 6, 1953)

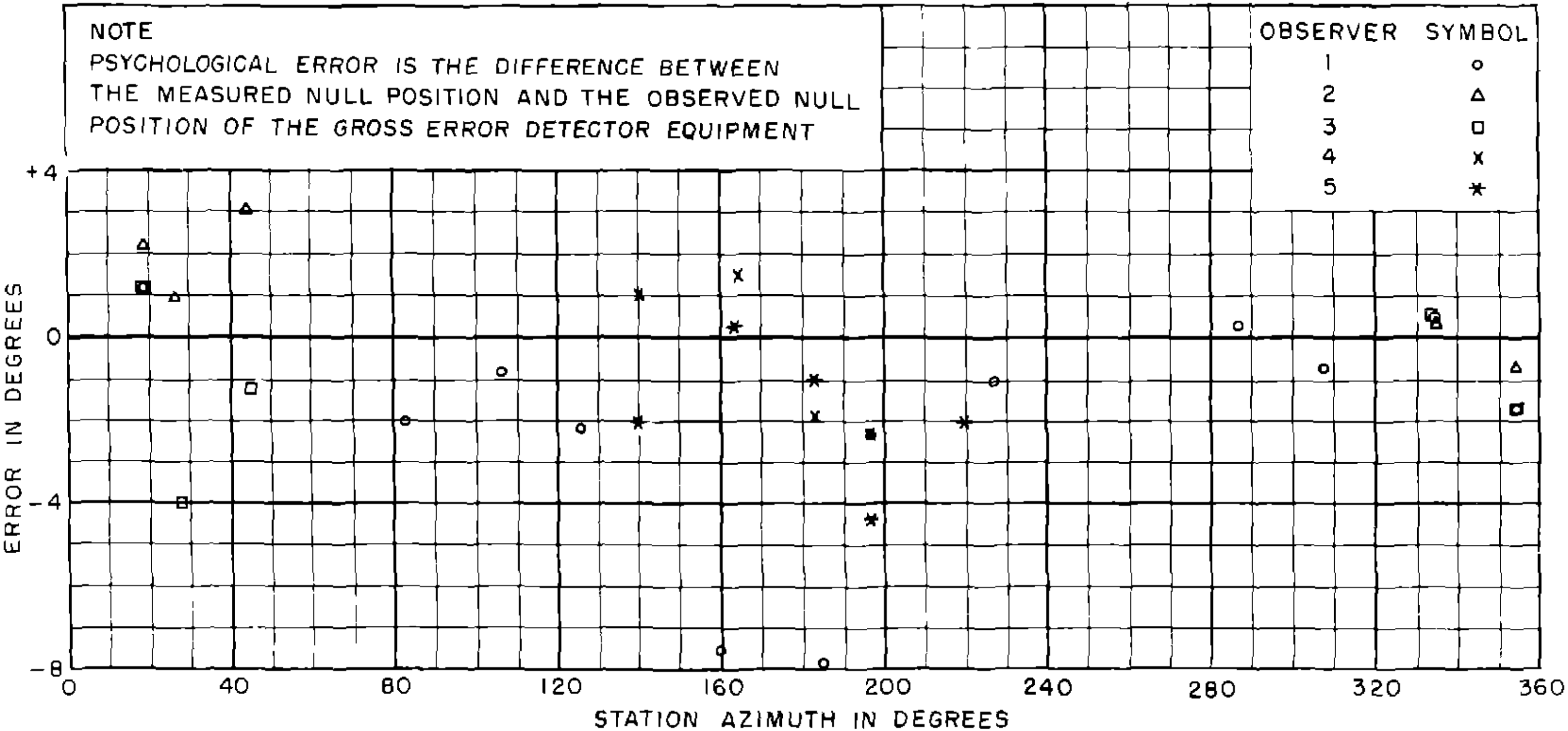


FIG 11 PSYCHOLOGICAL ERROR VERSUS STATION AZIMUTH

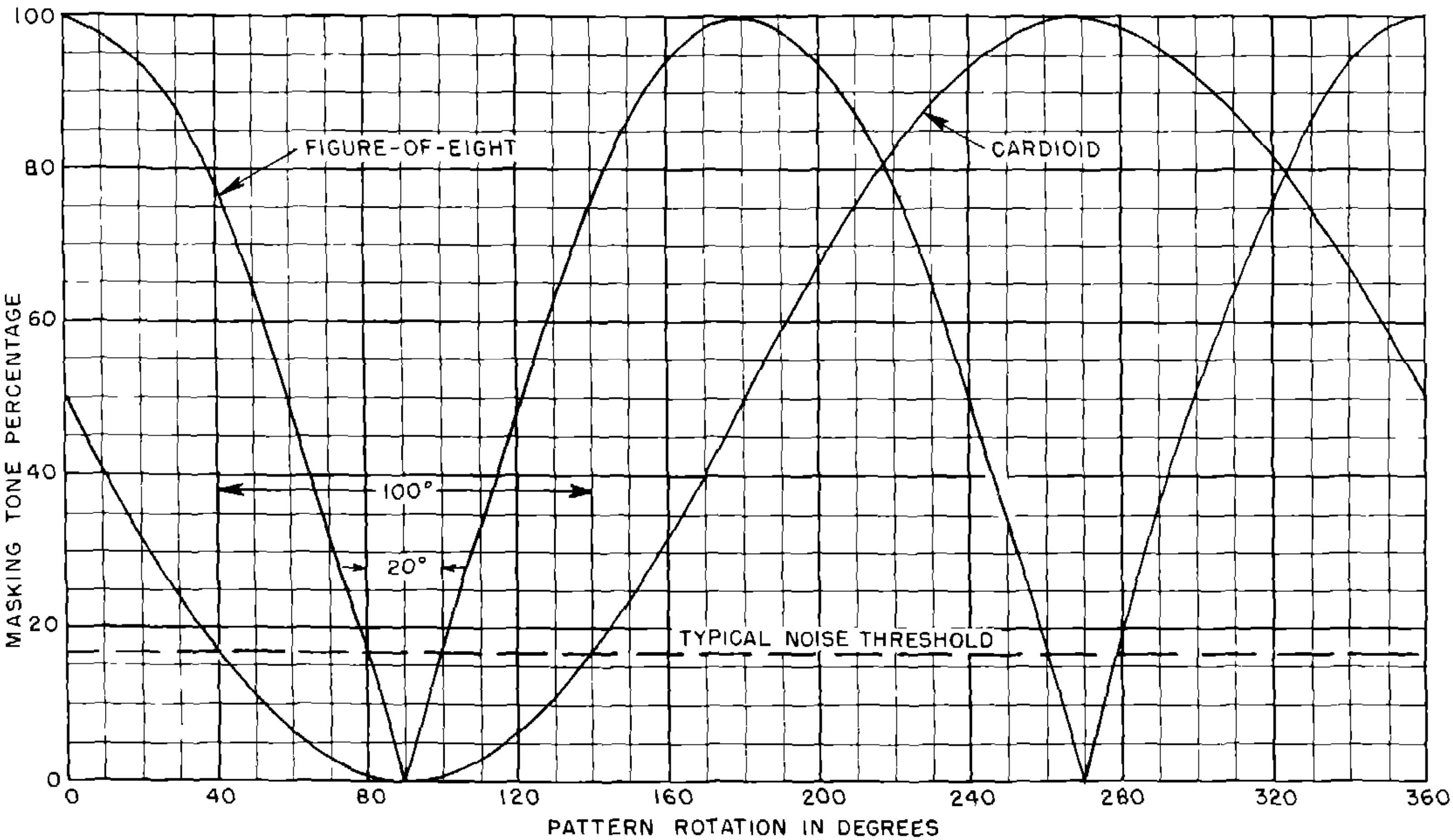


FIG 12 NULL COMPARISON OF FIGURE-OF-EIGHT AND CARDIOID FOR GROSS ERROR DETECTOR