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18 February 1944
RADAR CROSS SECTION OF
SHIP TARGETS, II
By
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Report No. R-2232
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SERIAL No. 50

Report on

RADAR CROSS SECTION
OF SHIP TARGETS, II



NAVAL RESEARCH LABORATORY
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ABSTRACT

In this report, the measurement of radar cross section of ships is discussed. To reduce the measurements to quantitative values, a system of standard targets of calculable radar cross section is employed. The measurement technique is described in detail. Numerical data are given for combat ships of various types for frequencies extending from 200 Mc/s to 3000 Mc/s. The data are examined in accordance with a simplified analysis given in a preceding report, and found to give satisfactory agreement.

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INTRODUCTION

1. The work reported here has been conducted under the authorization of NRL Problem No. S411R-S.

2. The purpose of the work accomplished under the above problem which is reported here is to determine quantitative values of the radar cross sections of ships of various categories. This information is needed in determining the effectiveness of radar countermeasures, in judging the ranges at which detection by enemy radar is likely to occur, as well as in judging the operational efficiency of radars in use against ship targets.

3. Heretofore, there has been no accepted definition of radar cross section for ship targets. This situation is due to the more complicated phenomena entering into reflections from surface targets. A surface target, such as a ship, is not illuminated uniformly by the radar beam, due to interference between direct and reflected rays. The echo, which is the resultant of the fields scattered by all portions of the target, depends on the way in which the illumination is distributed over the target. This distribution depends, among other things, on the height of the radar antenna and the range.

4. In NRL Report RA 3A 213A "Radar Cross Section of Ship Targets", a simplified analysis of ship echoes has been presented. From that analysis, it was found that the variation of received signal with range could be divided into two zones, called there the near and far zones. The equations defining the near and far zone radar cross sections given there are

Far Zone:

$$(1) \quad \sigma_f = 4\pi R^2 \left(\frac{R}{h_1}\right)^4 \frac{W_r}{W_o}$$

Near Zone:

$$(2) \quad \sigma_n = 4\pi R^2 \frac{W_r}{W_o}$$

where

R = Range

h_1 = Height of radar antenna

W_r = Power density received at radar antenna

W_o = Free-space power density at target

5. In the far zone, the received power (field intensity) varies as the inverse eighth (fourth) power of the range, while in the near zone, the received power (field intensity) varies as the inverse fourth (second) power of the range. In the far zone, the received power increases as the fourth power of the radar antenna height, while in the near zone the antenna height does not affect the received signal power.

6. In the report referred to, some experimental data substantiating the theory were presented. The data presented in this report conform to the theoretical expectations, and thus lend further support to the assumptions underlying the analysis.

METHODS OF MEASUREMENT

(a) Measurement in Terms of Standard Targets.

7. The magnitude of the echo received from a target depends on its range and radar cross section, as well as on the system characteristics of the radar (i.e., transmitter peak power, antenna gain, transmission line and TR losses, etc.); for surface targets in the far zone, the height of the radar antenna enters also. Thus, one way in which the radar cross section of the target could be determined would be to measure the magnitude of the received echo, together with all of the system characteristics. This is a tedious and difficult procedure, involving the separate measurement of a number of quantities, and becomes impracticable for routine work. A much simpler and more rapid method is to compare the magnitude of the echo with that from a reference target of known radar cross section. This requires only the determination of the relative values of two echo levels, thus canceling out the system characteristics. By measuring the echo from the reference target at sufficiently frequent intervals, changes in the performance of the radar can be detected and their effect cancelled through the comparative measurement. The latter procedure of comparing the target with a standard is the one that has been employed in the work reported here.

8. The reference targets used as "standards" consist of flat sheets or corner reflectors, depending on the frequency of the radar set. For a flat sheet illuminated uniformly, the radar cross section is

$$(3a) \quad (\sigma)_{\square} = 4\pi \frac{A^2}{\lambda^2}$$

while for a square corner reflector oriented to give the triple reflection,

$$(3b) \quad (\sigma)_{\oplus} = 12\pi \frac{d^4}{\lambda^2}$$

where d is the length of a side of the square. For a triangular corner reflector having the same length of side, the value of is $1/9$ as great,

$$(3c) \quad (\sigma)_{\triangle} = \frac{4}{3}\pi \frac{d^4}{\lambda^2}$$

9. The power density of the echo received from such a "standard" target could then be computed in the following way, if no ground-reflection took place:

$$(4) \quad W_r = \frac{W_o}{4\pi R^2} \sigma_o,$$

$$= \frac{P_t G}{(4\pi R^2)^2} \sigma_o.$$

where

P_t = transmitted peak power

G = antenna gain

In general, however, a ground-reflected ray exists and gives rise to interference lobes. This can be taken into account by changing the incident and received power densities by a factor F^2 (F is the ratio of the actual field intensity at the target to the free-space field at the same range). The power density of the received echo is then modified to

$$(5) \quad W_r = \frac{P_t G F^4}{(4\pi R^2)^2} \sigma_o.$$

In order for this expression to hold, however, it is necessary that the target illumination be substantially uniform (see NRL Report RA 3A 212A, "The Determination of the Coefficient of Reflection of Radio Waves at the Ground by Means of Radar Observations.") This is assured (a) by making the vertical extent of the target small compared with the height above water of the first maximum, and (b) by installing the target near the height where the first maximum of field intensity occurs, in which region the variation of received echo with height is least.

10. To simplify calculation, the radar cross sections of the standard targets have been expressed as equivalent free-space values by incorporating the factor F^4 with σ_o in (5) to form a new value

$$(6) \quad \sigma_o' = \sigma_o F^4$$

so that

$$(7) \quad W_r = \frac{P_t G}{(4\pi R^2)^2} \sigma_o'.$$

11. At first a low-lying raft, anchored about 2500 yards out in Chesapeake Bay, was used to support the standard target. This was found to give fairly consistent results for a short time after orienting the target broadside to the radar, even though it gave bobbing echoes due to rocking of the raft and target by the waves. A more fundamental difficulty arose when it was found that changes of tide turned the raft sufficiently so that the target was no longer oriented properly, and thus could not be relied upon as a "standard" unless checked for orientation before and after each run. This, of course, was not practicable.

12. To overcome this difficulty, a system of piles have been driven into the bottom of the bay to form supports for permanent targets. Each support consists of three piles arranged in tripod fashion, converging just above the surface. A center pole is fastened to these and supports the target at the appropriate height above the water. By tilting this pole slightly toward or away from the radar, it was found possible to reduce the echo from the support to a negligible value.

13. The tide level in Chesapeake Bay near the NRL Annex is less than 2 feet, and has been recorded during the latest runs. No allowance for tide or waves has yet been deemed necessary, however.

14. In order to obtain some sort of check on the reliability of the "standard", different sized targets of the same form have been intercompared and checked against the theoretical relations (3a-c). In this way, one large square corner reflector was found to be deformed sufficiently to give a large discrepancy from the calculated value. To admit an additional check, the mounts for the reflectors are now being modified so as to permit rotation about a vertical axis. This will allow the directive pattern of the reflector to be measured and compared with the theoretical pattern.

15. As indicated by experience, improvements have been made in the set of standard targets used during the course of the ship measurement program. Wherever possible, the earlier reflectors were compared with the later ones before being replaced. In this way, the earlier data could be corrected, where necessary. The data presented in this report are based on the best estimates of the radar cross sections of the standard targets now in use.

16. One of the reference targets which has long been in use is Sharps Island Lighthouse, at range 14,700 yards, and probable effective height of 40 ft. (a double-reflection corner reflector was installed at this height to give a stronger echo).

The lighthouse has the disadvantage that its echo is dependent to some extent on weather conditions which affect atmospheric refraction. However, since ship echoes at comparable ranges are similarly affected, the lighthouse echo provides a convenient reference for judging refraction conditions. As an example of the variations encountered, the lighthouse echo appears to have varied as much as 10 decibels during a 24-hour period, providing that other factors remained constant.

17. The standard target system in use at present is shown in Table I.

Table I

Radar	Frequency	Polarization	Antenna Height	Reflector	Reflector Height	Range	σ_b^1
SC-2	200 Mc/s	H	110 ft.	6'X6'sheet	24 ft.	3600 yds.	6.5 sq.
SK	200	H	117	" " "	"	3620	8.2 meters
Mk 5	400	H	113	" " "	"	3610	500
HD (simulated) Wurzburg	560	V	113	" " "	"	3620	2890
Mk 4	700	H	116	" " "	"	3620	8460
Mk 12	970	H	126	" " "	"	3700	23,100
SF	3060	H	137	1 ft. square corner	8.5	3900	420
SG-1	3060	H	137		"	3900	420

(b) Measurement of Echo Amplitude.

18. Since the use of reference targets eliminates the system characteristics of the radar, it is necessary only to determine the ratio of the ship target to standard target echoes. This has been accomplished in either of two ways: (1) by use of a pulsed signal generator, (2) by calibrating the gain-control dial of the radar receiver and recording dial settings. The first method is more desirable by far, and is used whenever appropriate signal generator equipment is available. However, since as many as seven different radars have been used simultaneously in the more recent tests, the calibrated gain control has had to be resorted to on some of the sets, due to lack of a sufficient number of signal generators to go around.

19. Where pulsed signal generators are employed, the signal generator echo is introduced into the receiver by means of a high impedance connection, which introduces a loss of about 20 decibels in the signal generator echo, but does not affect the target echo perceptibly. The amount of this loss can be determined very easily, but does not enter into the comparative measurement of ship and standard target.

20. The echo from a ship fades up and down in rhythm with the rolling and pitching motion of the ship. The data of principal interest are the values of the maximums to which the varying echoes rise. Due to the statistical nature of the fading, the maximum value attained depends on the time interval over which the observation extends. For ships, this has usually been taken to be in the order of 30 seconds. The maximum is read either (1) by visually matching the height of signal generator pip to that of the echo maximum, or (2) by adjusting the receiver gain control so that the maximum echo pip just reaches a reference mark on the A scope, and then adjusting the signal generator pip to the same reference mark, or (3) by reading the gain-control dial after adjusting as in (2).

21. By interspersing frequent measurements of standard target echo, the measurements can be reduced to a quantitative basis.

22. At short ranges, within about 5,000 yards, some of the radars are subject to a variable loss due to TR recovery. This has been allowed for either by measuring the TR recovery characteristic (this is readily done with the pulsed signal generator) directly after a run, or by swinging the antenna off the target and bringing the signal generator pip into the same range as the target.

(c) Maneuvering of Ship.

23. Since the echo from a ship depends markedly on its aspect toward the radar, information has been sought on the radar cross sections for the principal aspects. Bow aspects were obtained by steaming directly toward the station, and stern aspect by the reverse course. To obtain data on broadside aspects, the ship executed slow ($\approx 5-8$ minutes) tight circles at selected ranges. By taking readings of maximum pip heights during 30-second intervals, values of the principal maxima of the aspect diagram were obtained. The largest of these maxima were labeled "broadside" aspect; they almost always corresponded closely to the broadside position, as nearly as could be judged.

24. On the radial runs, a convenient ship speed has been found to be about 12 knots. This is a suitable compromise which allows a sufficient number of readings to be taken, without prolonging the run unduly. Runs are taken out to maximum range, and in as close as the ship's draft and depth of the bottom permit. Due to the nature of the bottom, the course is broken up into two legs, (1) a "far" run down the bay starting from about 10,000 yards, and (2) a "near" run across the bay from about 3000 out to 12,000 yards. Ships drawing 30 feet or over cannot maneuver closer than about 8000 yards, however.

25. Due to the limitations of water depth in the bay, it was not possible to bring the larger vessels in close enough to obtain data on the near zone radar cross sections on the lower frequencies. Fortunately, however, vessels in this category should rarely close to such short ranges, so that it is considered that data have been obtained in most cases for the ranges of tactical interest.

DATA OBTAINED.

26. The nature of the data obtained from the tests is illustrated by Figs. 1-21. These show the plots of all the measured points obtained for a cruiser-carrier of the Independence class on six radars of different frequencies, lying between 200 Mc/s and 3060 Mc/s. The received signal, expressed in decibels, is plotted against range on a logarithmic scale, providing, in effect, a log-log plot. Through the experimental points there have been drawn straight lines having slopes corresponding to R^{-8} variations of received power for the far zone, and, in those cases where the indication was quite definite, lines having slopes corresponding to R^{-4} for the near zone.

27. The fit of these lines to the measured points is satisfactory in almost all cases. This is particularly true for the lower frequencies. For the higher frequencies, the pip fades more violently and the maximums occur in brief flashes, making it difficult to determine the amplitude of the maximum accurately. As a result, the measurements obtained on the higher frequencies show progressively greater amounts of scatter.

28. The method of computing the radar cross section from the plotted data follows directly from (1), (2) and (7). For the far zone, the power density received from the ship is given by (1):

$$(8) \quad (W_r)_f = \frac{W_0}{4\pi R^2} \left(\frac{h_1}{R}\right)^4 \sigma_f = \frac{P_t G}{(4\pi R^2)^2} \left(\frac{h_1}{R}\right)^4 \sigma_f.$$

R = range of ship

The power density received from the standard target is given by (7):

$$(9) \quad (W_r)_\Delta = \frac{P_t G}{(4\pi R_\Delta^2)^2} \sigma_0'.$$

R_Δ = range of standard target

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The ratio of (8) to (7) is

$$(10) \quad \frac{(W_r)_f}{(W_r)_s} = \left(\frac{R_s}{R}\right)^4 \left(\frac{h_1}{R}\right)^4 \frac{\sigma_f}{\sigma_o'}$$

so that

$$(11) \quad \sigma_f = \frac{(W_r)_f}{(W_r)_s} \cdot \left(\frac{R}{R_s}\right)^4 \left(\frac{R}{h_1}\right)^4 \sigma_o'$$

$\frac{(W_r)_f}{(W_r)_s}$ is the ratio of the signal received from the ship at range R to that from the standard target at range R_s . This ratio can be read directly off the graphs as a difference in decibels. Smoothed values corresponding to the R^{-8} lines have been used here in evaluating the measured data.

29. An easy way of applying (11) to the evaluation of σ_f from the plotted data is to employ the following procedure. The ratio of σ_f to σ_o' is, from (11),

$$\frac{\sigma_f}{\sigma_o'} = \frac{(W_r)_f}{(W_r)_s} \cdot \left(\frac{R}{R_s}\right)^4 \left(\frac{R}{h_1}\right)^4$$

Expressing this in db gives

$$(12) \quad \text{db } \sigma_f/\sigma_o' = \text{db}_{\text{ship}} - \text{db}_{\text{tgt}} + 4\text{db}_{R/R_s} + 4\text{db}_{R/h_1}$$

To make matters easy, the value of db_{ship} is read off the appropriate graph at a range in yards equal to 100-times the value of antenna height in feet. The last term of (12) is then equal to 99.08 db. The standard target db is also read directly off the curve. The third and remaining term is easily read off on a slide rule, so that (12) can be evaluated by simple addition of the db-values.

30. In a way similar to that followed above the expression for the near zone radar cross section is found to be

$$(13) \quad \sigma_n = \frac{(W_r)_n}{(W_r)_s} \left(\frac{R}{R_s}\right)^4 \sigma_o'$$

Values of σ_o' and R_s are listed in Table I.

31. σ_n can be evaluated in terms of db in the same manner described for σ_f in paragraph 29. If the value of db_{ship} is read off at the range R_s of the standard target, the value of $(R/R_s)^4$ becomes unity; the ratio of σ_n to σ_0' , expressed in db, is then the difference between the db_{ship} and db_{tgt} values.

32. Data of the type shown in Figs. 1-18 have also been obtained on a battleship, a destroyer, a destroyer escort, an LST, and an LCT. The number of frequencies on which measurements were made was not the same in all cases, depending on availability of calibrated radars suitable for this type of work. The values of σ_f and σ_n are deduced from the measurements and tabulated in Tables II and III, respectively.

33. In addition to the more complete measurements on the ships listed above, some fragmentary measurements have been obtained on several other combat ships which were not made available directly for cross section measurements. The information obtained is summarized in Table IV. These values should be considered as provisional, however, due to the small number of measurements available.

34. The data obtained at 3060 Mc/s on the CVL (using the SF radar) require some explanation. As explained in paragraph 24, the courses executed consisted of two legs, one down bay for the longer ranges, the other across bay for the shorter ranges. For the down bay run, the view of the SF radar was partially obscured by the antenna of the Mark 4 radar mounted on the Mark 37 director. In order to determine whether this produced a reduction in signal, a test was made several days later with a 75-foot motor launch as target: Readings of received signal were taken for various ranges on the down bay course, and again at similar ranges across bay. Each group of measured points fell very smoothly on an R^{-8} line, with the across bay values 10 db above those from the down bay run. Accordingly, the CVL measurements made on the SF on the down bay legs were raised by 10 db. The fit of the two sets of points after this correction was made is poor (Figs. 19-21); in fact, the fit of the uncorrected data (Figs. 16-18) is rather good. The 10 db correction may not apply entirely to the CVL runs, since there was some variation in heading on the down bay runs, these having been made at night. Due to the better fit obtained with the uncorrected data, these have been used in deducing the radar cross sections. The results, therefore, must remain in question.

35. An interesting result was obtained by chance during the destroyer and destroyer escort measurements. Some of the runs on these ships were repeated on the day following the first tests. [Note: This is usually not possible, since the ships are made available for the tests for a 24-hour period only, and other types

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TABLE II
 Values of σ_f in Square Meters
 Frequency in Mc/s

Ship	Aspect	200	400	560	700	970	3060
DE	bow	$3.7 \cdot 10^{10}$	$9.2 \cdot 10^{11}$		$1.4 \cdot 10^{13}$		$8.5 \cdot 10^{16}$
	stern	$1.9 \cdot 10^{11}$	$9.2 \cdot 10^{11}$		$5.1 \cdot 10^{12}$		$5.4 \cdot 10^{16}$
	broadside	$6.6 \cdot 10^{11}$	$1.1 \cdot 10^{13}$	$1.5 \cdot 10^{14}$	$2.9 \cdot 10^{13}$		$1.5 \cdot 10^{18}$
DD	bow	$2.4 \cdot 10^{11}$	$3.3 \cdot 10^{12}$		$2.9 \cdot 10^{12}$		$5.4 \cdot 10^{16}$
	stern	$5.8 \cdot 10^{10}$			$2.2 \cdot 10^{13}$		$1.3 \cdot 10^{17}$
	broadside	$5.7 \cdot 10^{11}$	$2.9 \cdot 10^{13}$	$7.5 \cdot 10^{13}$	$6.9 \cdot 10^{13}$		$1.3 \cdot 10^{18}$
BB (New York)	bow	$1.4 \cdot 10^{12}$	$3.3 \cdot 10^{14}$		$4.8 \cdot 10^{15}$		$1.0 \cdot 10^{16}$
	stern	$2.5 \cdot 10^{12}$			$1.2 \cdot 10^{15}$		
	broadside	$1.9 \cdot 10^{13}$	$5.1 \cdot 10^{14}$	$3.3 \cdot 10^{15}$	$5.7 \cdot 10^{15}$		$6.1 \cdot 10^{17}$
LST	bow	$4.2 \cdot 10^{10}$			$2.0 \cdot 10^{12}$		$1.7 \cdot 10^{15}$
	stern	$2.6 \cdot 10^{10}$			$5.2 \cdot 10^{12}$		$1.3 \cdot 10^{15}$
	broadside	$9.4 \cdot 10^{10}$			$1.0 \cdot 10^{14}$		$1.5 \cdot 10^{17}$
LCT	bow	$1.2 \cdot 10^8$			$6.6 \cdot 10^9$		
	stern	$2.1 \cdot 10^8$			$6.6 \cdot 10^9$		
	broadside	$4.3 \cdot 10^8$			$7.4 \cdot 10^{10}$		
CVL	bow	$1.3 \cdot 10^{11}$	$1.6 \cdot 10^{14}$	$5.4 \cdot 10^{13}$	$5.5 \cdot 10^{13}$	$5.6 \cdot 10^{14}$	$2.8 \cdot 10^{16}$
	stern	$5.5 \cdot 10^{11}$	$4.3 \cdot 10^{13}$	$7.9 \cdot 10^{13}$	$5.5 \cdot 10^{13}$	$4.2 \cdot 10^{14}$	$7.7 \cdot 10^{15}$
	broadside	$6.1 \cdot 10^{12}$	$1.2 \cdot 10^{16}$	$1.8 \cdot 10^{15}$	$3.4 \cdot 10^{15}$	$7.8 \cdot 10^{15}$	$7.5 \cdot 10^{16}$

TABLE III

Values of σ_n in Square Meters

Ship	Aspect	Frequency in Mc/s		
		400	700	3060
CVL	bow	$7.2 \cdot 10^4$	$3.0 \cdot 10^4$	$1.3 \cdot 10^6$
	stern	$1.0 \cdot 10^4$	$2.9 \cdot 10^4$	$9.4 \cdot 10^5$
	broadside	$1.2 \cdot 10^6$	$8.5 \cdot 10^6$	$9.4 \cdot 10^6$
LST	bow			$2.1 \cdot 10^4$
	stern			$2.4 \cdot 10^4$
	broadside			$1.2 \cdot 10^7$

TABLE IV

Tentative Values of σ_f in Square Meters

Ship	Aspect	Frequency in Mc/s	
		200	700
BB-62 (New Jersey)	bow	$7 \cdot 10^{12}$	$4 \cdot 10^{15}$
CV-12 (Hornet)	bow	$4 \cdot 10^{14}$	$5 \cdot 10^{14}$
	stern	$4 \cdot 10^{14}$	$2 \cdot 10^{14}$
	circle	$6 \cdot 10^{14}$	$5 \cdot 10^{15}$
SS-256 (Hake)		$1 \cdot 10^{12}$	

of tests have to be fitted into this period as well. These ships, together with the battleship, all arrived together a day in advance of that scheduled, and so were available for two days.] It happened that on the second day propagation conditions were abnormal, giving extreme ranges. The measurements, however, still conformed to an R^{-8} slope in the far zone (within the horizon), but were about 10 db higher than those on the previous day, on which conditions were considered normal.

36. Due to the great number of figures that would be required to show the measurements made on all the ships, only those for the CVL have been shown here. The data for this particular ship were chosen for illustration because of the large number of radars with which measurements were made. (Measurements were also made with an X-band set, but have not been included because of the absence of suitable calibration data.) The data for the other ships, for the most part, conform quite well to the R^{-4} and R^{-8} slopes corresponding to the near and far zones. It will be noted that near the horizon in the far zone the measured points consistently curve below the R^{-8} lines. This is to be expected, since the R^{-8} variation was deduced for a flat earth, and should exceed the measured values in the region where the earth's curvature screens part of the ship.

37. In many cases, measurements did not extend into short enough ranges to determine the transition from the R^{-8} to the R^{-4} slopes. Hence, it is necessary to specify the least range to which calculations of echo amplitudes may be extended with certainty. This least range, furthermore, is a function of antenna height. The values are given in Table V.

38. Where values of both σ_f and σ_n are given for a ship, a value of received echo can be calculated, for any range, from each, using eqs. (21a) and (21b) of Report RA 3A 213A. The smaller of the two values of received echo is then the appropriate one to use.

CONCLUSIONS

39. From the general agreement between the measurements of signal variation with range with the type of variation deduced from the simple theory given in Report RA 3A 213A, it is concluded that the definitions of radar cross sections for ship targets in the far and near zones given by (1) and (2) can be considered as applying satisfactorily to the ship target problem. The values of σ_f and σ_n thus deduced, coupled with known radar system characteristics, can then be used to calculate the maximums of the echoes which may be expected at various ranges, except near the horizon. The values of σ_f and σ_n depend on the aspect of the ship as seen from the radar, so that the values appropriate to the aspect considered should be employed.

TABLE V

Least Range (in Yards) to Which Values
of σ_f May be Applied

Antenna Heights as Listed in Table I. For Other Antenna
Heights, Least Range May be Assumed Approximately Proportional
to Antenna Height.

Ship	Aspect	Frequency in Mc/s					
		200	400	560	700	970	3060
BB (New York)	bow	< 5000	< 8000	< 8000	< 8000		9000
	stern	"	5000	8000	8000		10000
	broadside	"	5000	7000	8000		
CVL-30	bow	"	8300	7000	8000	12000	13000
	stern	"	9600	7000	8000	13000	15000
	broadside	"	12000	9000	6000	13000	14000
DD	bow	"	5000	3500			15000?
	stern	"	"	"			"
	broadside	"	"	"			"
DE	bow	"	"	"			"
	stern	"	"	"			"
	broadside	"	"	"			"
LST	bow	"			6000		
	stern	"			6000		
	broadside	"			6000		
LCT	bow	"			3500		
	stern	"			3000		
	broadside	"			4000		

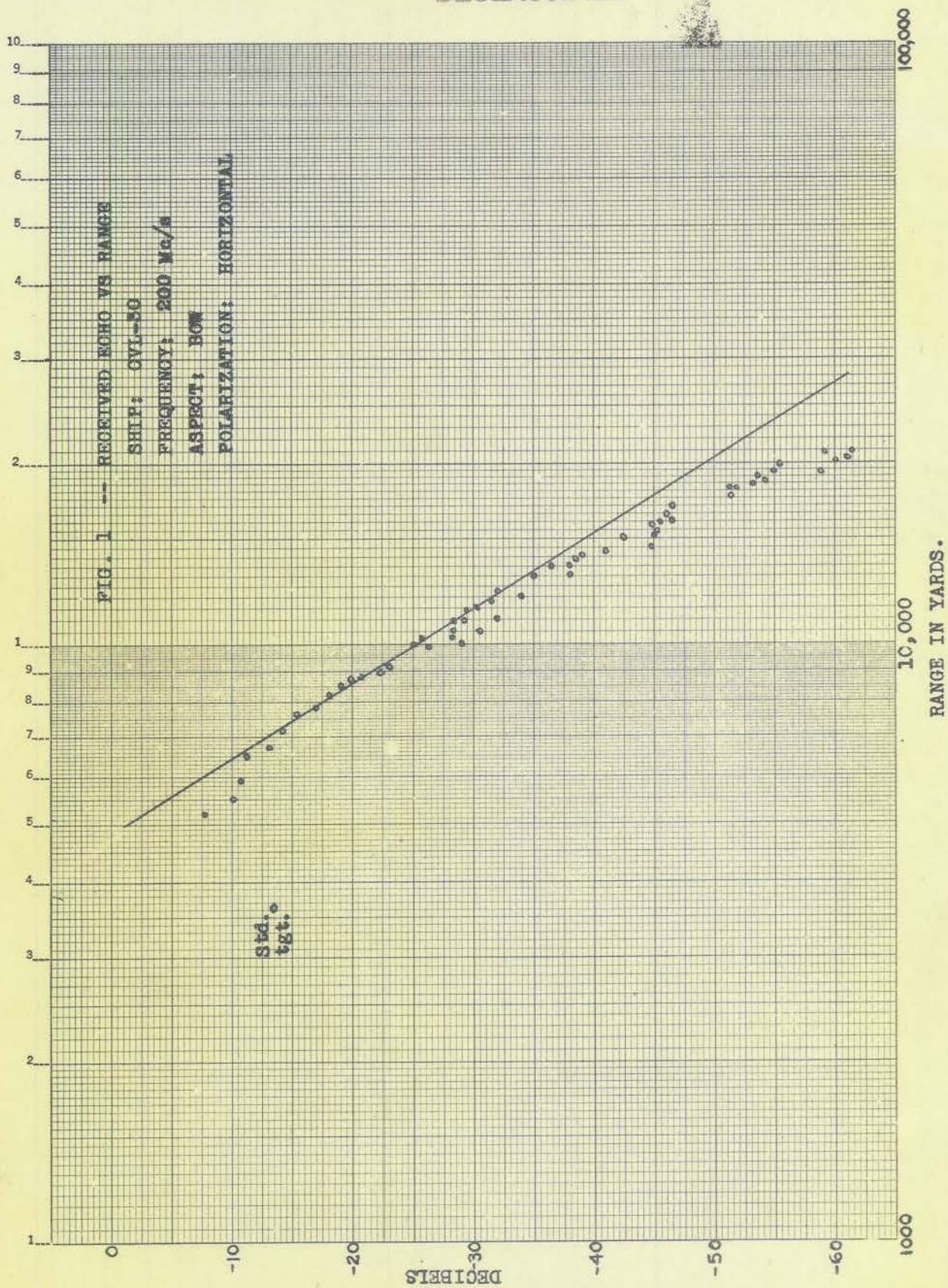
40. Near the horizon, the echoes are weaker than predicted by the R^{-8} slope, due to the curvature of the earth. In a later report it is hoped to extend the theory to provide the necessary corrections, so that the data may be applied to the determination of maximum ranges.

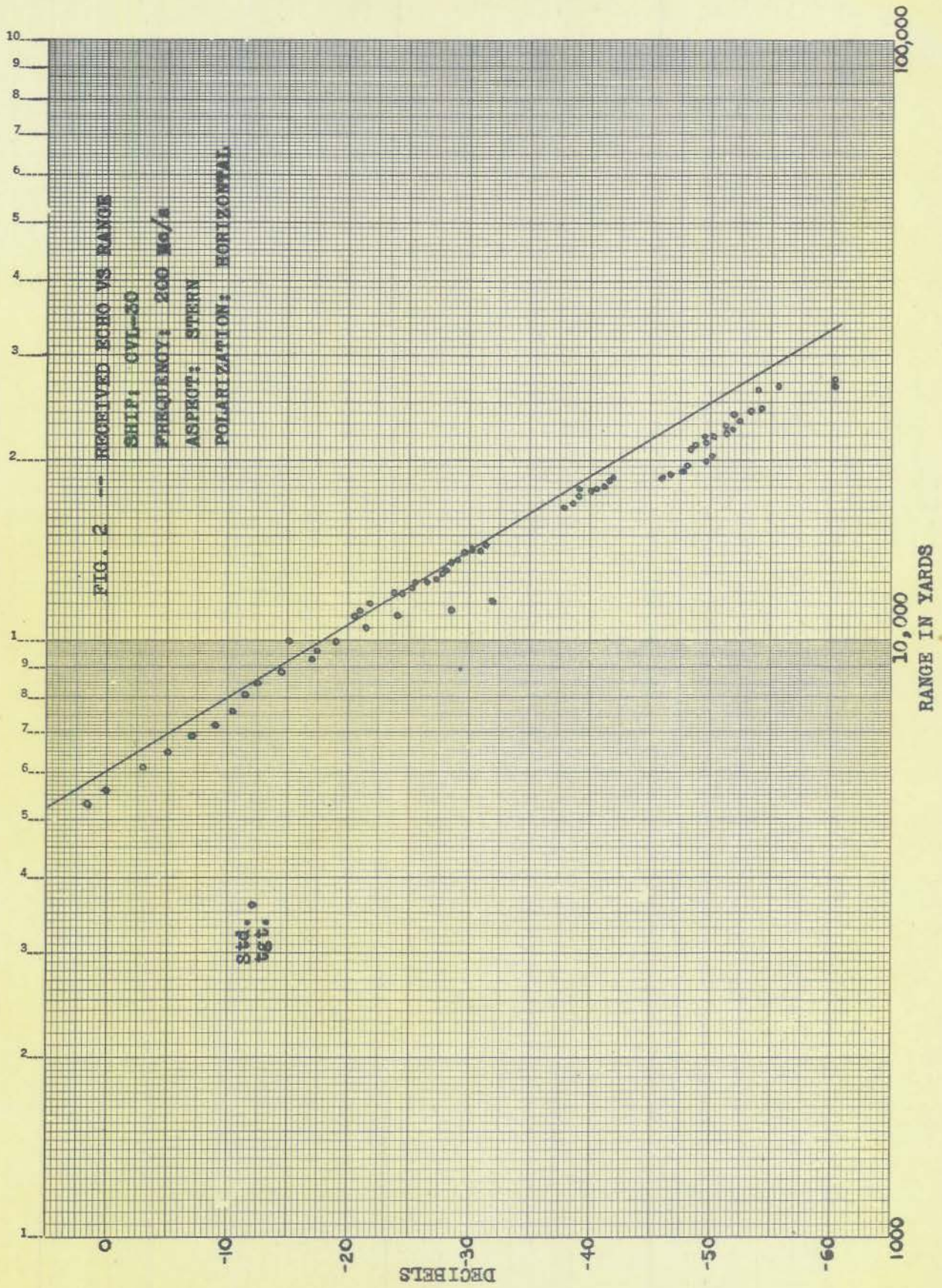
APPENDIX

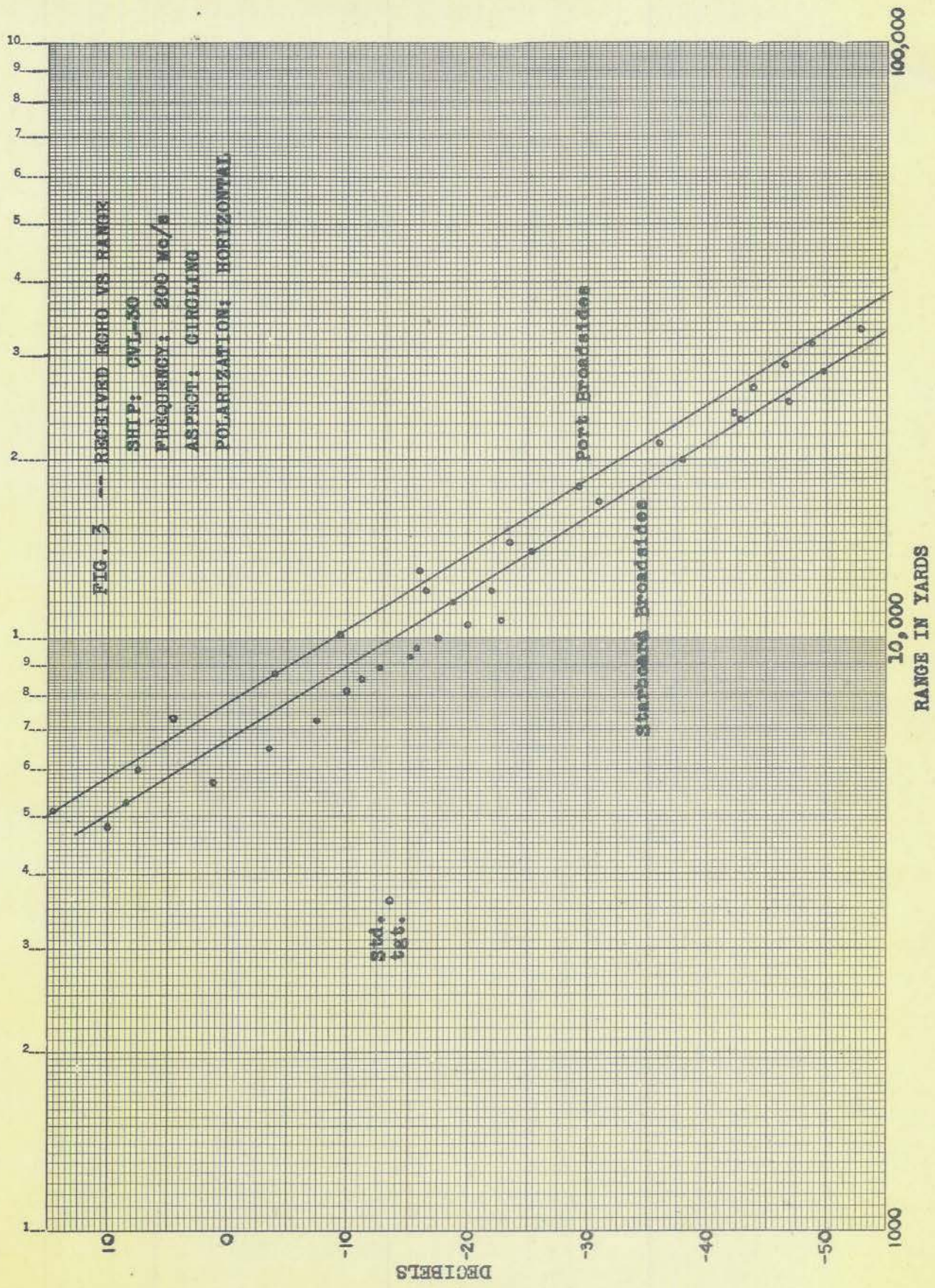
CORRECTION NOTICE

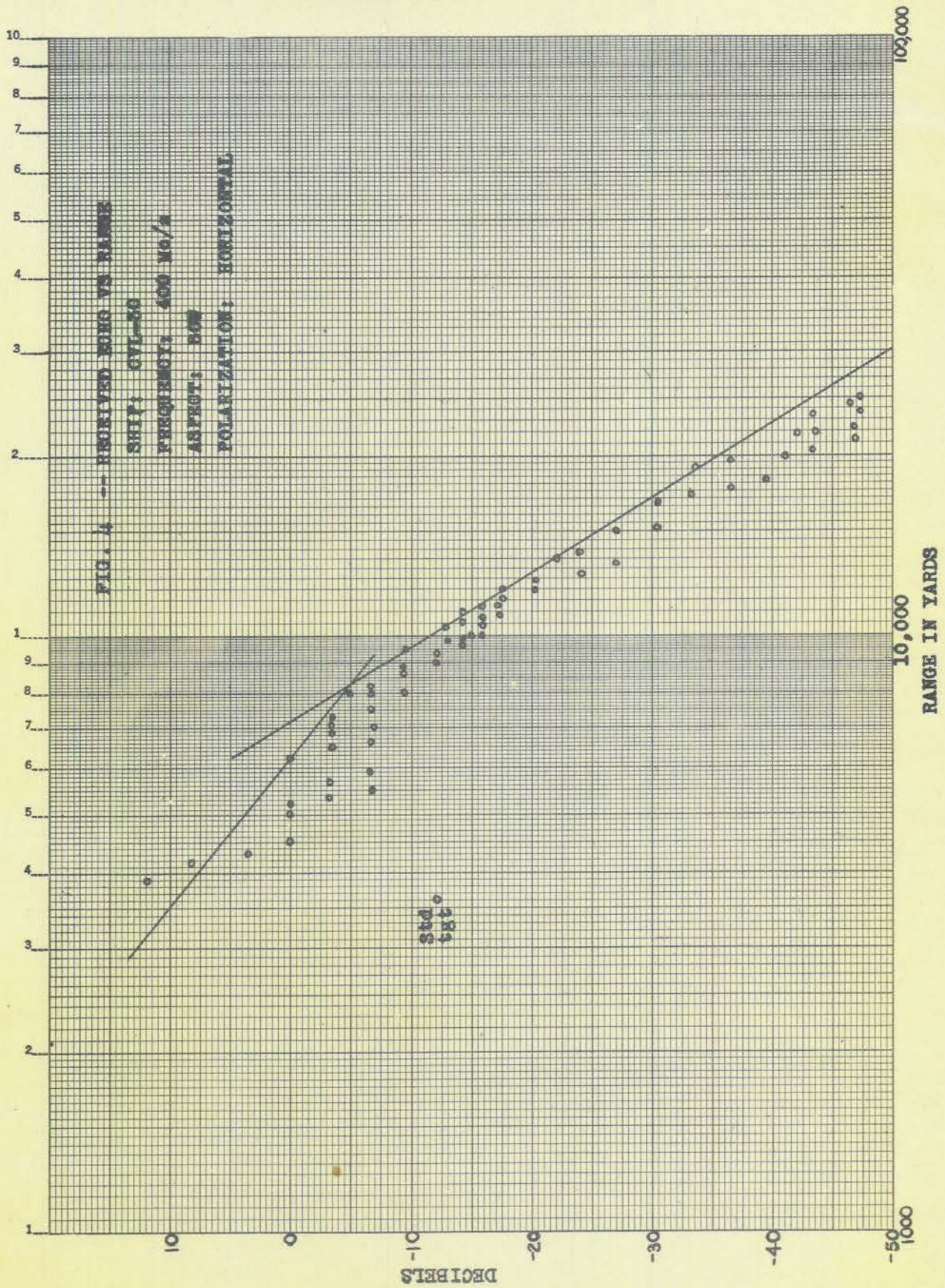
41. In NRL Report RA 3A 213A, equation (22) for the radar cross section of a cylindrical target does not contain the correct numerical factor. This equation should read

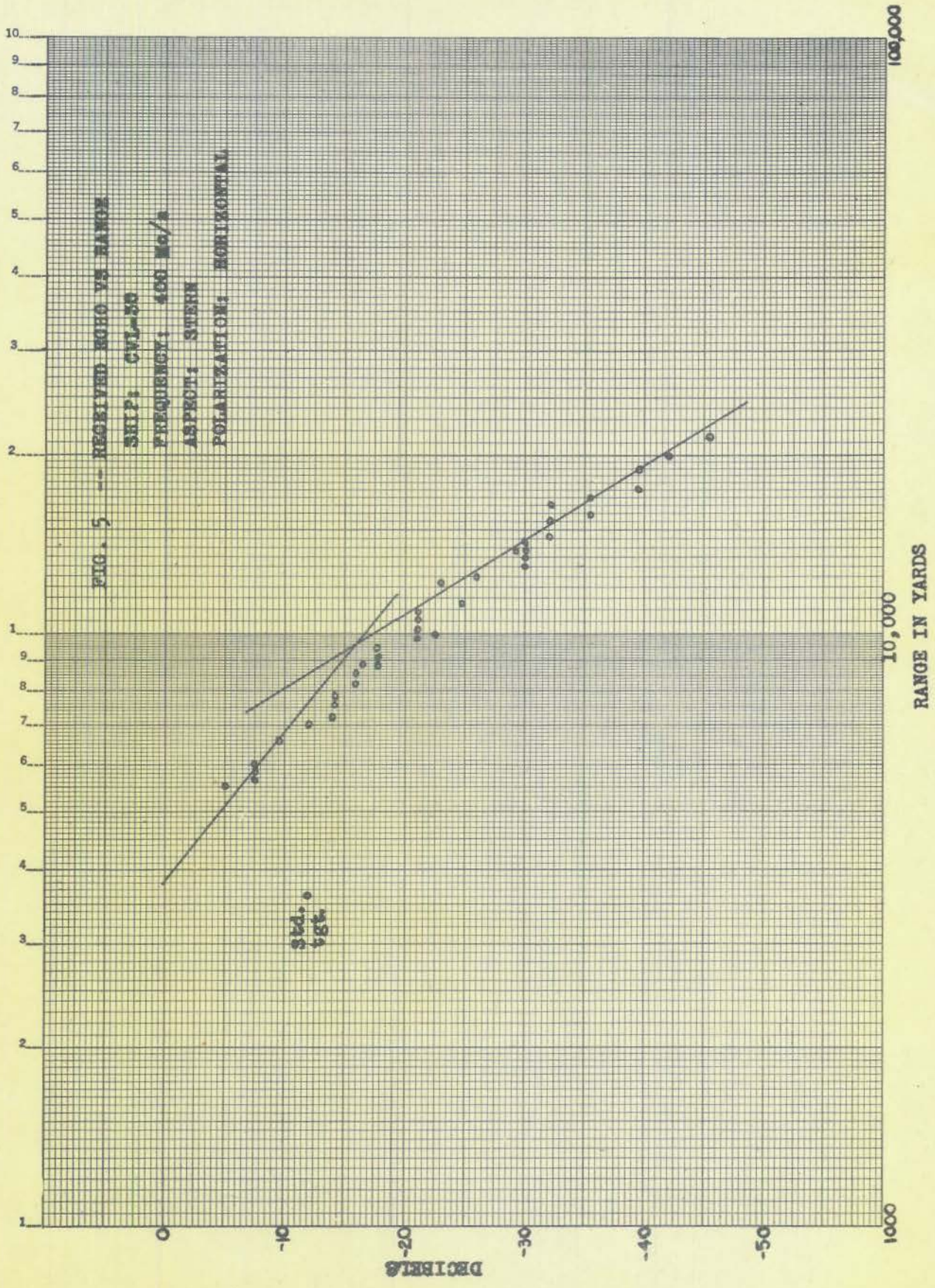
$$\sigma_0 = \pi H^2 \frac{d}{\lambda} .$$



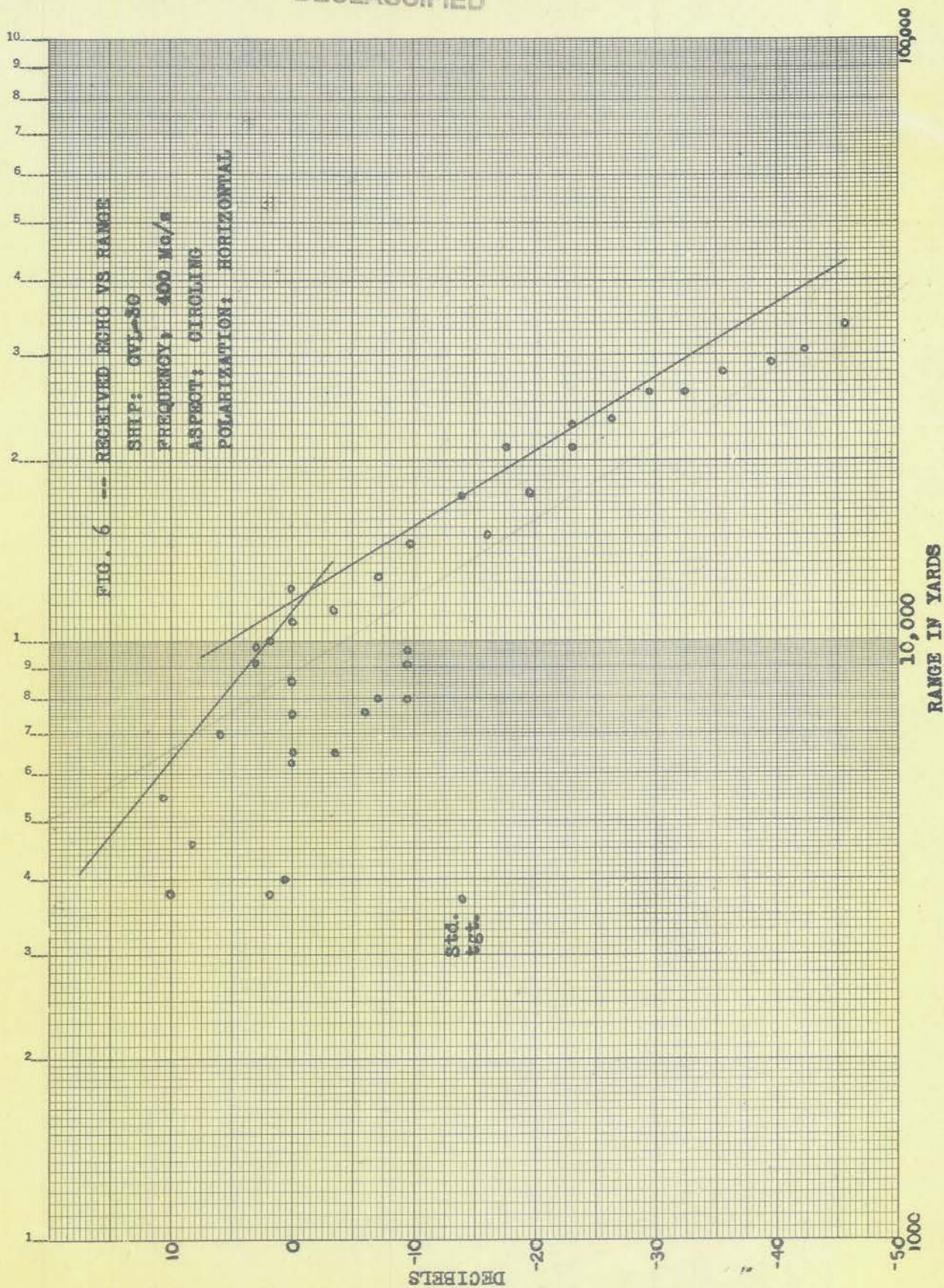




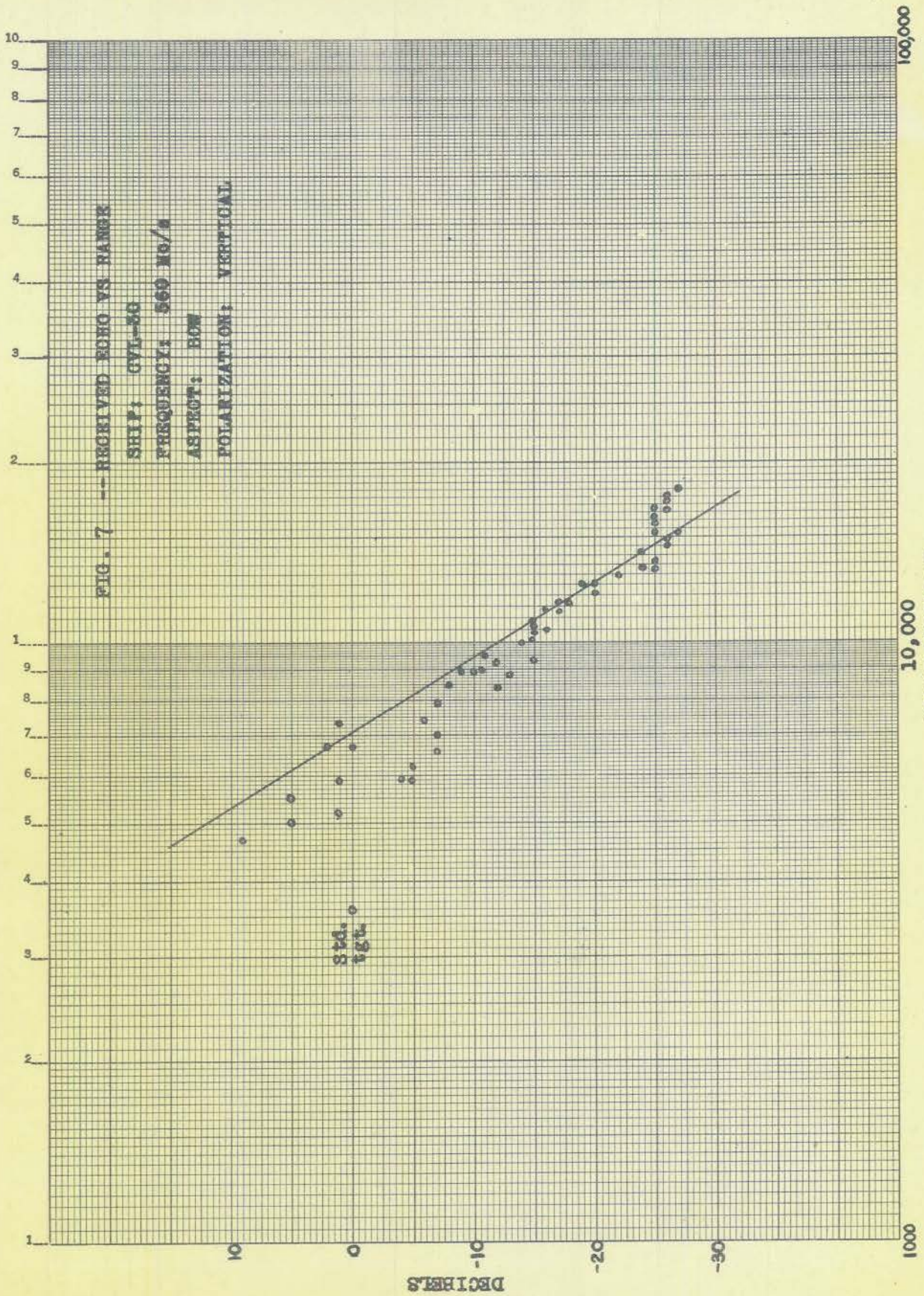


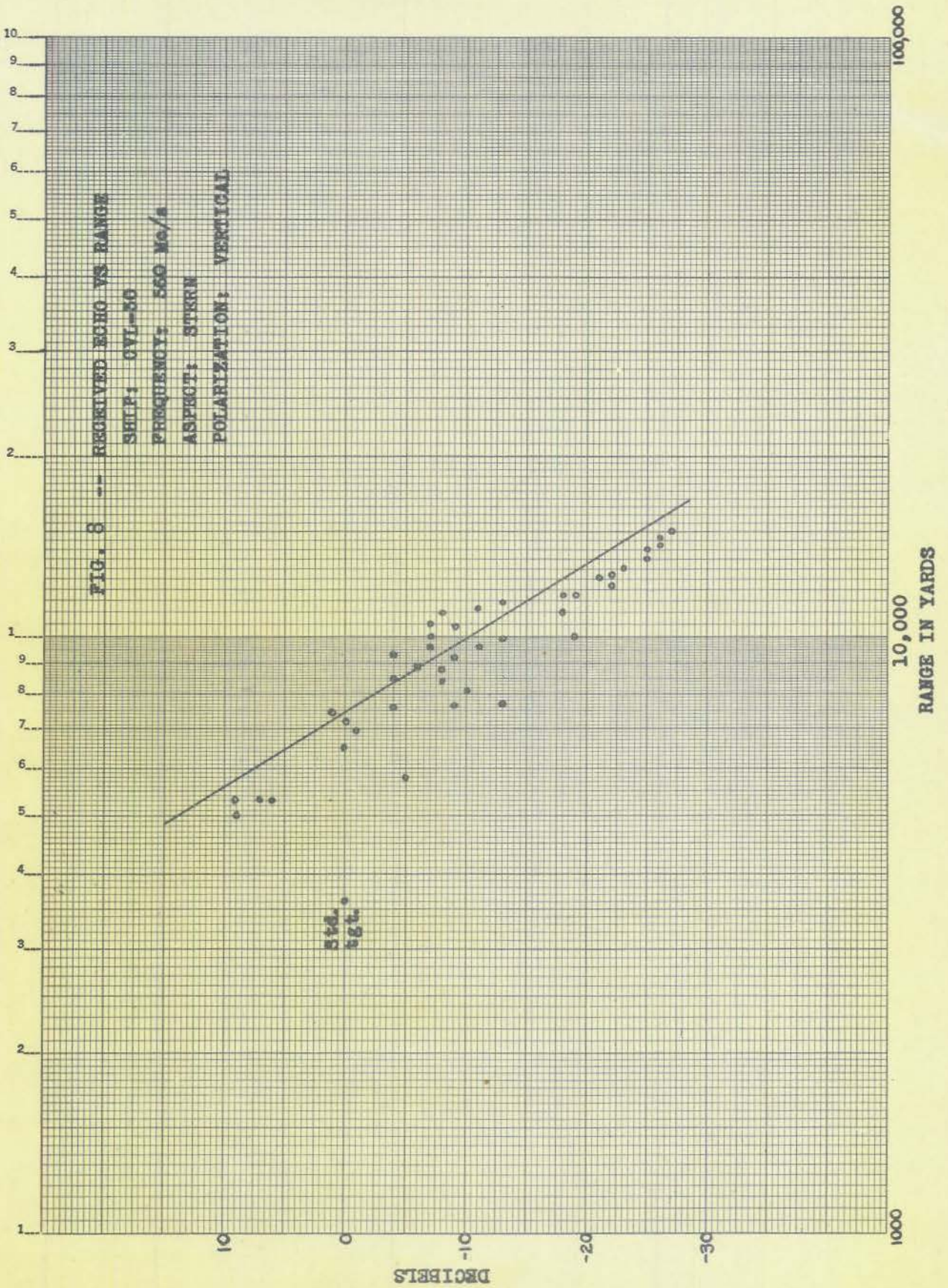


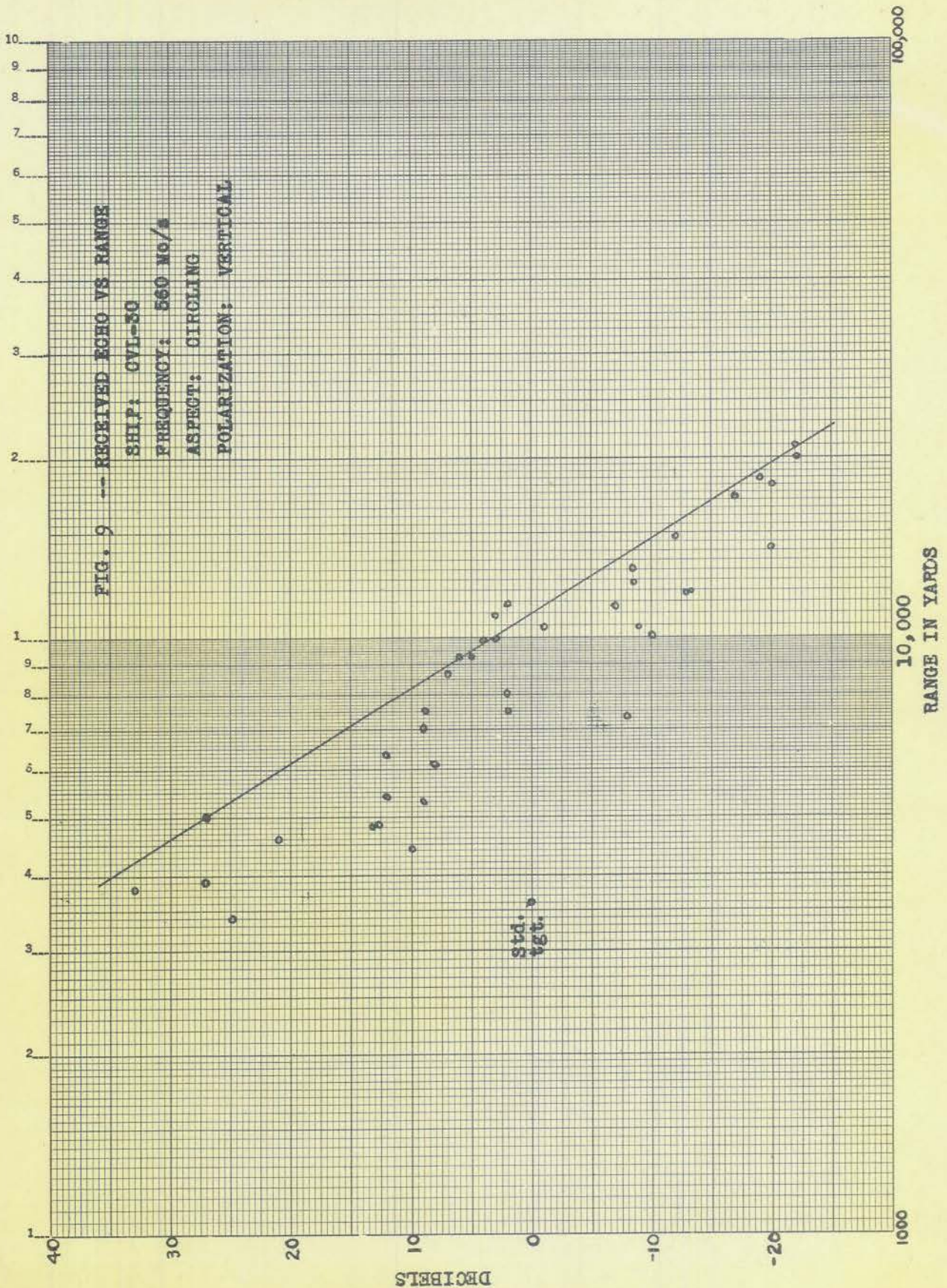
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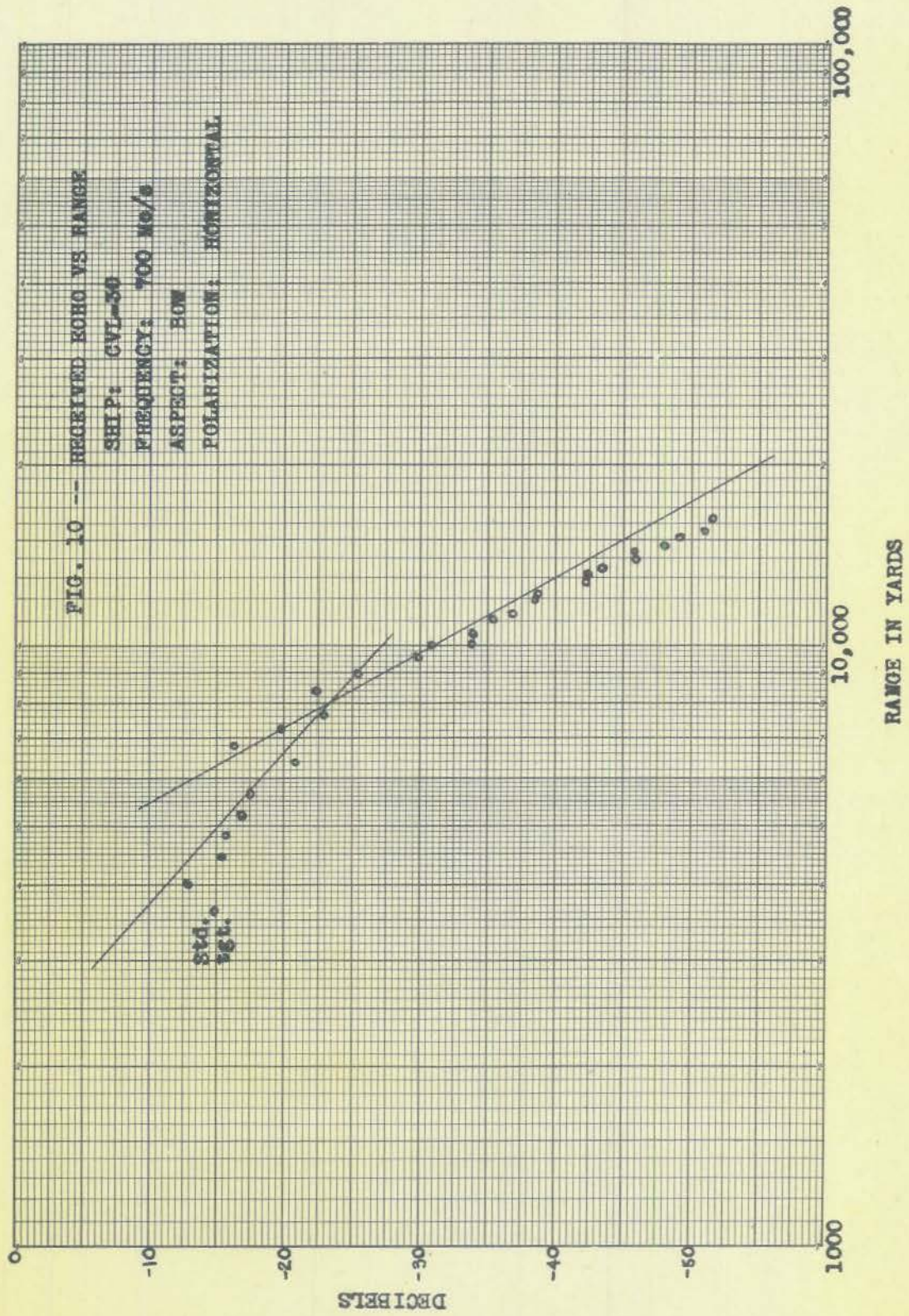


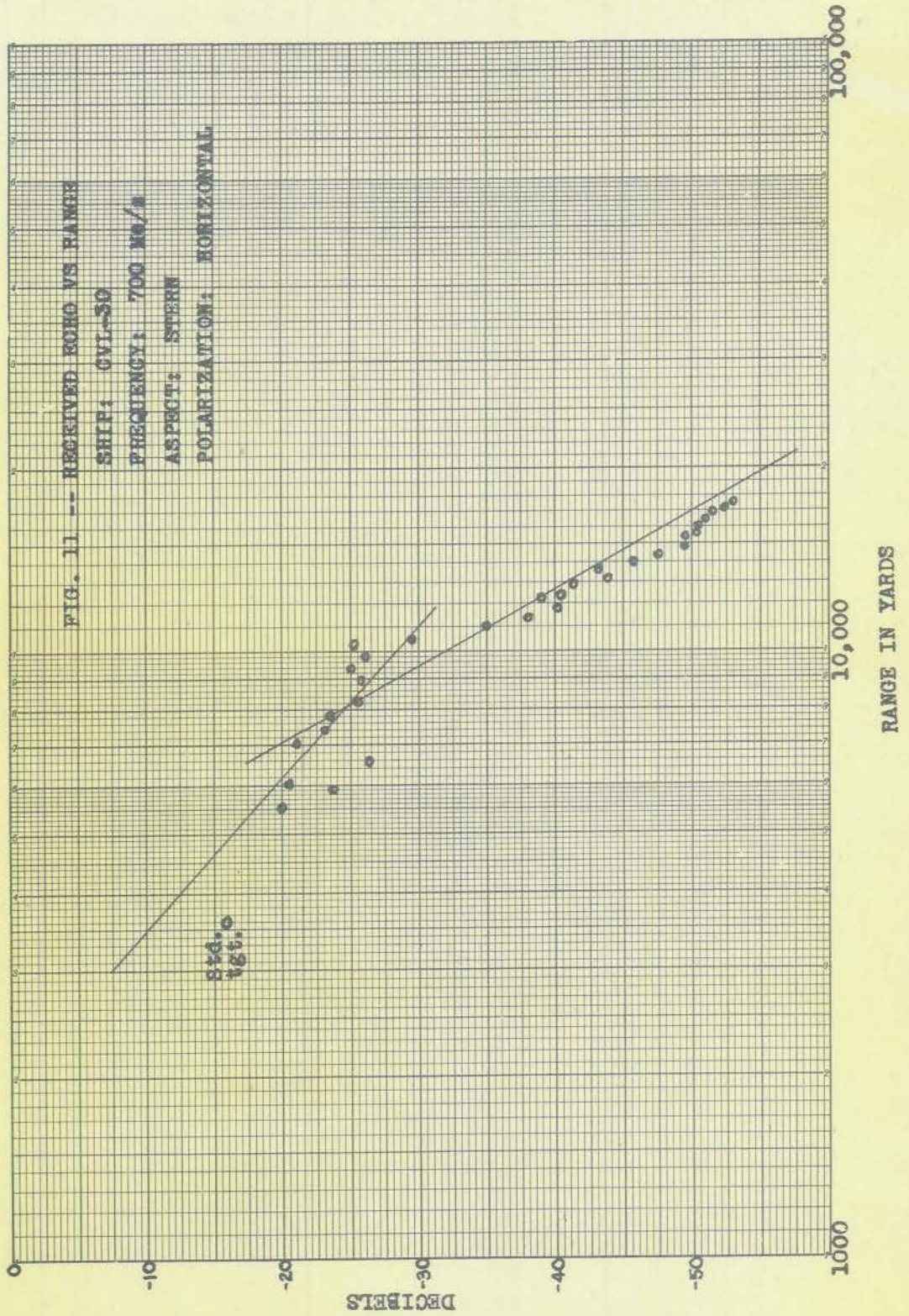
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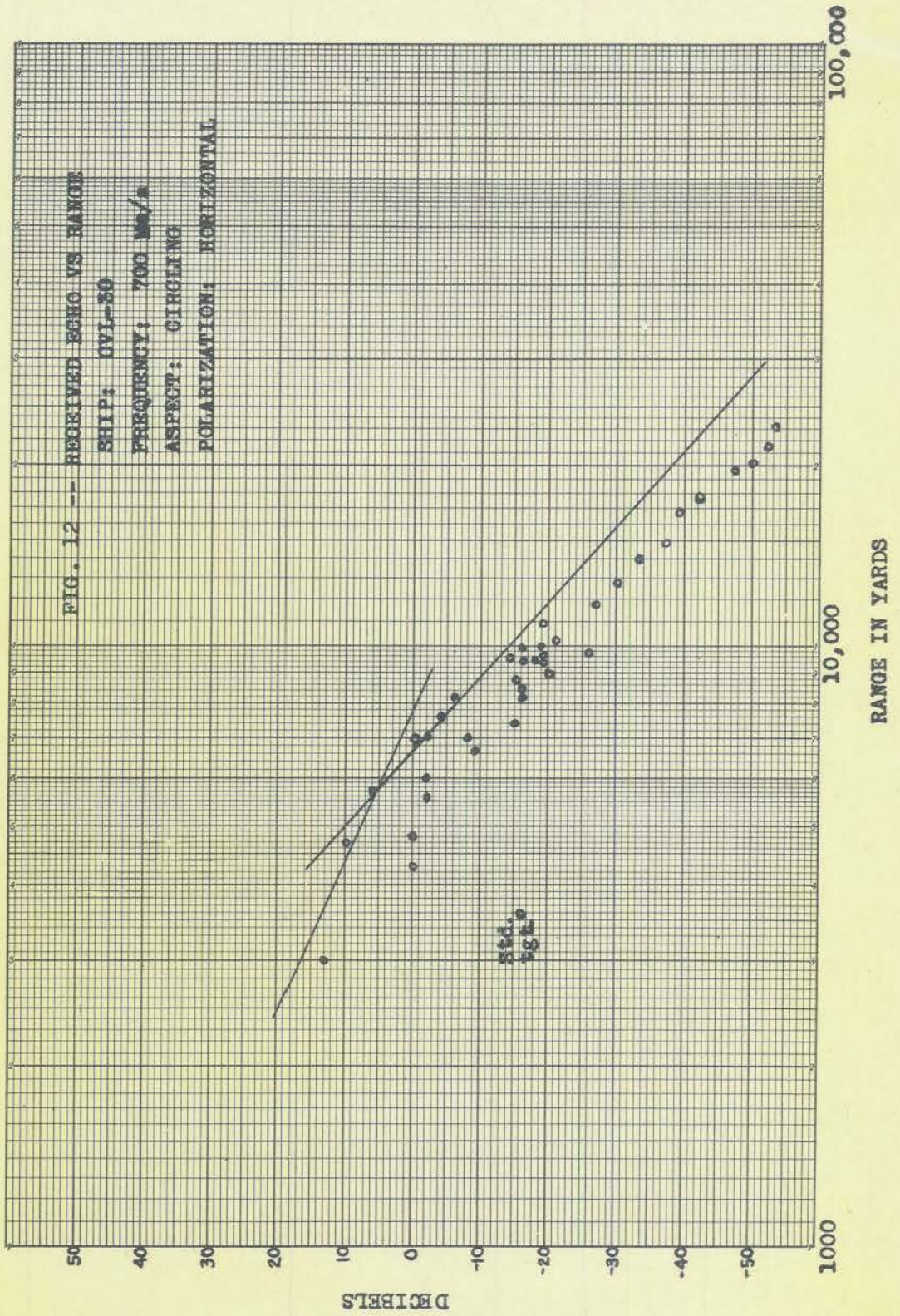




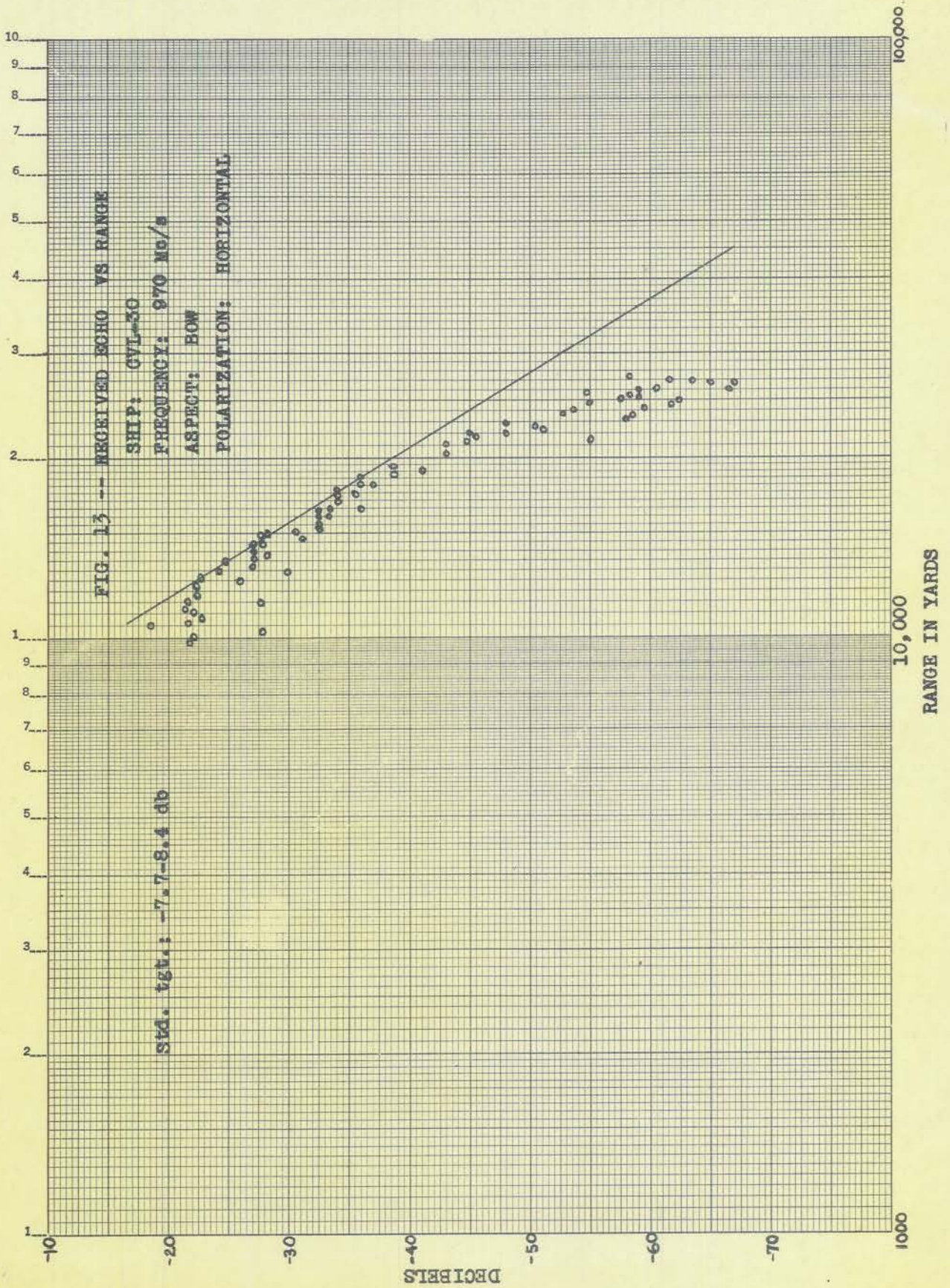




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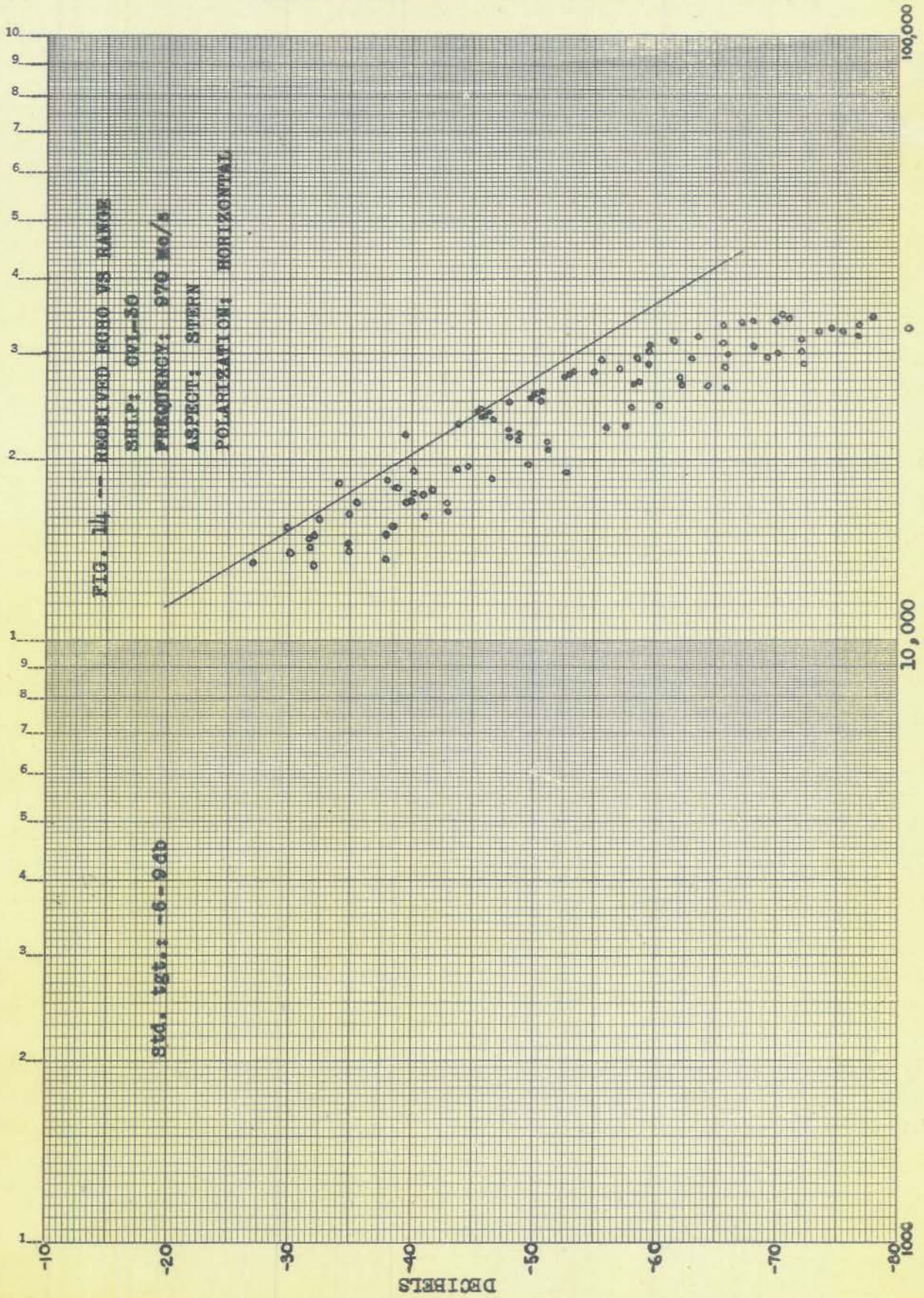


FIG. 14 -- RECEIVED ECHO VS RANGE

