REPORT NO. S-1404

DATE 5 October 1937

SUBJECT

Report on

Sound Research and Development

with Particular Reference
to
Tests on the U.S.S. SEMMES

on July 6 - 28, 1937

by

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NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

[illegible] October 1937

NRL Report No. [illegible]-14[illegible]4
BuEng. Prob. [illegible]

NAVY DEPARTMENT

[redacted] BUREAU OF ENGINEERING

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NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text - 38 Tables - 10 Plates - 53

Authorization: BuEng let.C-S68(11-27-W6) of 5 Dec.1936.

Date of Tests: July 6 - 28, 1937.

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Section I

INTRODUCTION

The present report deals with two sound problems; first, "Sound Research and Improvement," and second, "Reduction of Sound Generated by Naval Vessels." Under the first it describes the progress made in echo detection equipment during the past three years and under the second, it covers briefly the sound analysis work done on the S-20, the SEMMES, and on propeller models and discusses certain deductions therefrom as to the sources of the underwater sound generated by Naval vessels and their contribution to the general background of noise picked up by the echo detection apparatus.

Section II

SOUND TEST PROGRAM ON U.S.S. SEMMES, July 6 - 28, 1937

(1) Outline of Test Program

Definite knowledge of the present status of these two closely related problems has resulted from a sound test program carried out on the SEMMES in the New London area during the period July 6 - 28, 1937. A brief outline of this program follows:

(a) Test both as sound transmitters and sound receivers the following types of transceivers:

(1) QC-5. Submarine Signal Company production model. A 24 kilocycle magnetostriction transceiver. Radiating face diameter 14 inches. Housed in spherical case.

(2) QC-5B. Submarine Signal Company test model. A 17.5 kilocycle magnetostriction transceiver. Radiating face diameter 16 inches. Housed in spherical case.

(3) XQB. Old Naval Research Laboratory type. A rochelle salt transceiver. Radiating face diameter 14.5 inches. A broadly tuned transceiver designed to operate over frequency range 17 - 35 kilocycles. Housed in spherical case.

(4) XQB. New Naval Research Laboratory type. A rochelle salt transceiver, broadly tuned to operate over frequency range 17 - 30 kilocycles. Housed in a semi-streamlined cylindrical case. Rectangular shaped radiating area of dimensions 16 inches by 16 inches.

(5) XQC. New Naval Research Laboratory type. An untuned magnetostriction transceiver. Designed to operate over the frequency range 15 - 40 kilocycles. Active elements flattened nickel tubes. Designed primarily for detecting propeller sounds. Housed in non-streamlined case.

(6) XQD. New Naval Research Laboratory type operating on pure electrodynamic principles. Mechanically tuned to 22.8 kilocycles. Radiating face diameter 17 inches. Housed in non-streamlined case.

NOTE: In addition to the above six types, the SEMMES had test data on two other transceivers developed by the Submarine Signal Company, one a 24 kilocycle magnetostriction having radiating face diameter of 15 inches which we label QC-7 and the other a QB of the same radiating area. The sound generated by these can be roughly calculated in absolute units through their rating by the SEMMES as compared with the QC-5. Such computed ratings are included in Table I which follows later.

(b) Compare each type transceiver with QC-5 for detecting a submarine by echo under various operating conditions. Determine limiting echo range for each type.

(c) Make underwater sound analysis of SEMMES at the following locations; D-2 tubes, Main Sound Room, and Forward Sound Room, using D-2 type receivers in all three locations, and in addition using the QC-5 mounted in one well of the Main Sound Room.

(2) Transceiver Tests

(a) Test Procedure - Transceivers

The procedure followed for testing the several types of transceivers both as transmitters and receivers depends on the use of a standard crystal receiver calibrated to measure in absolute units the pressure amplitude of the impinging sound waves. This measurement permits computation of the sound intensity through the well known relation:

$$I = p^2/2\rho c$$

where I is the sound energy flowing through a unit area at the location of the receiver,

p, the pressure amplitude of the sound waves meeting the receiver,

ρ, the density of the sound conducting medium and

c, the velocity of the sound waves.

Since both (ρ) and (c) are known, a measurement of (p) permits determination of the intensity.

It may be noted that this report is the first, in this country at least, to record measurements of the absolute intensity of underwater sound signals. The technique and importance of such measurements are considered later under the heading "DISCUSSION" as are also the discrepancies between the ratings of the several transceivers from routine measurements made by the SEMMSS and from the test measurements made by Naval Research Laboratory personnel using somewhat different technique and apparatus.

The standard procedure for testing sound transmitters by the SEMMSS' personnel is as follows:

(a) The transmitter is mounted in one well of the main sound room and directed toward a type D-2 receiver which periscopes to a depth about [illegible] feet below the keel through an opening on the starboard side of the keel. Its location is about 160 feet astern of the transceiver under test. The transceiver is oriented about the azimuth to the point where the D-2 gives maximum response. The D-2 then lies on the axis of the sound beam.

(b) The transceiver is energized at different frequencies by tuning the driver consecutively to different known frequencies and the D-2 response in decibels or millivolts recorded for each frequency. The so-called "Intensity-Frequency Curve" results from plotting D-2 response as ordinates against corresponding signal frequency as abscissae. The maximum ordinate of this curve gives the resonant frequency and its breadth gives the sharpness of mechanical tuning of the transceiver.

(c) The driver is set at the resonant frequency of the transceiver and the response of the D-2 recorded for increasing power input to the transceiver. The so-called "Intensity-Power Curve" results from plotting D-2 response as ordinates against corresponding power input as abscissae. Safety precautions usually require that the power input be kept within the linear range of this curve.

(d) The power input to the transceiver is held constant at the resonant frequency and the response of the D-2 recorded against bearing as the transceiver is rotated step by step about the azimuth. The so-called "Beam Width Curve" is given by plotting the D-2 response as ordinates against corresponding azimuth bearing as abscissae. It shows the angular distribution of the sound energy and hence the directive selectivity of the transceiver. This plot is preferably made in polar coordinates.

This procedure is subject to criticism on the grounds that the response of the D-2 receiver results from both the direct and hull-reflected sound to which it is exposed. The phase relation between these two components at the receiver determines whether they add or subtract. It changes with the pitch of the signal and probably to some extent with changing turbulent conditions along the two sound paths underneath the ship.

The Naval Research Laboratory tests avoided the interference of hull reflections by mounting the receiver in the second well of the main sound room, thereby giving an athwart ship sound path between transmitter and receiver of 4-1/2 feet. Since the line of centers of the lowered transmitter and receiver lies about 2 feet below the keel, the sound beam in no case spreads sufficiently to strike the hull and reflect on the receiver. The Naval Research Laboratory tests employed the calibrated crystal receiver instead of the D-2 to permit reducing the measurements to absolute units.

The beam width curves (Intensity vs Direction) taken athwart ship lack discrimination because of the small cross section of the beam at this short range as compared with the sectional area of the receiver. To better illustrate the beam characteristics of the several types of transceivers, such curves were taken at a range of about 60 feet by using the D-2 of the forward sound room as a receiver.

Thus, it will be seen, the testing of a transceiver as a sound transmitter requires the experimental determination of three curves:

(a) Intensity vs Frequency - Power input held constant. This curve gives the resonant frequency of the transceiver and by showing the sharpness of resonance determines the degree of its mechanical selectivity.

(b) Intensity vs Power Input - at resonant frequency. The slope of this curve is a measure of the acoustical efficiency of the transceiver and hence indicates the power limit to which the transceiver should be exposed. From the standpoint of both safety and economy, the power should never greatly exceed the linear range of this curve and normally should be kept within this limit.

(c) Intensity vs azimuth. Resonant frequency and constant power. This curve shows the angular distribution of the transmitted sound and hence the directive selectivity.

Such curves follow in the above order for each of the six transceivers tested.

(b) <u>Presentation of Data for Transceivers</u>

Plates 1, 2, and 3 pertain to the QC-5. Plate 1 gives a resonance frequency of 14.6 kilocycles and mechanical selectivity of 61.

<u>NOTE:</u> The mechanical selectivity is herein defined as the ratio of the resonant frequency to the width in cycles of the Intensity vs Frequency Curve at an intensity level 3 decibels below the maximum.

Plate 2 holds linear well beyond the "High Power" setting of the driver. Points 1 and 2 on the curve correspond to "Low Power" and "High Power" settings of the QC-5 driver. The axial intensity in milliwatts per square centimeter at the 4-1/2 foot athwart ship range is 7.9 for "Low Power" and 38 for "High Power." The Naval Research Laboratory 1 kilowatt driver was used to develop this curve and to assure against damage by overheating at the higher powers, the key was closed only during the brief interval required to read the meter.

Plate 3 shows a beam width of 20 degrees. The intensity of the first lobe is 15.5 decibels below the axial intensity.

The beam width is herein taken as the angle subtended between the two first minima, one to the right and the other to the left of the beam axis. From theoretical considerations this angle is related to the frequency and dimensions of the radiating face in accordance with the equation:

$$2\,\theta = 2\,\sin^{-1}\left\{0.61\ \frac{V}{N \cdot R}\right\} = 2\,\sin^{-1} 0.61\,\frac{\lambda}{R},$$

where θ is half the angular beam width,
V, the velocity of sound
N, the frequency of the sound signal and
R, the radius of the circular radiating face,
V/N, the wavelength λ.

Theory also predicts that the difference between the axial intensity and that of the first lobe should approximate 17 decibels.

These theoretical deductions follow from two assumptions: first, that all parts of the circular radiating face oscillate with equal amplitude and phase (like the end of a driven piston) and second, that the circular radiating face is centered in a plane baffle of large area (similar to a piston fitted into a hole in a wall of large dimensions) which prevents any of the radiated sound from penetrating the region back of the plane containing the radiating face.

The heavy sound-impervious casing of the transceiver serves in a practical way to replace the theoretical baffle and therefore the transceiver beam-pattern agrees closely with the theoretical if the whole radiating face oscillates with uniformity of amplitude and phase. As a result, a comparison of the theoretical and experimental beam widths shows whether or not the radiating face, as a whole, is operating with proper coordination of amplitude and phase to give the maximum concentration of sound energy along the beam axis. The information given by such comparisons will be covered later. It may be stated, however, that the theoretical beam width of the QC-5 computes to be 25.1 degrees.

The assembled information derived from these three QC-5 curves is:

(1) Resonance frequency - 27.6 kilocycles per second.
(2) Mechanical selectivity - 61
(3) Beam width (theor.) - 25.1 degrees
(4) Beam width (exp.) - 30 degrees
(5) Intensity of first lobe 15.5 decibels below axial intensity.
(6) Axial intensity at 4-1/2 ft. range (low power) - 7.9 milliwatts per sq.cm.
Axial intensity at 4-1/2 ft. range (high power) - 39.0 milliwatts per sq.cm.

Such data, derived from the experimental curves for each type of transceiver, are assembled in columns 4, 6, 10, 11, 12, and 22 of Table 1, which contains all the data pertaining to or derived from the transmitting tests.

Columns 1 and 2 of this table give respectively the direct current and resistance for the different transceivers. From these the d.c. power used for polarizing is computed and tabulated in column 3. These columns are blank in case of the rochelle salt transceivers since they do not require polarization.

Column 4 gives the Mechanical Resonance Frequency (F_o); column 5, labeled ΔF, gives the width in cycles of the Intensity vs Frequency Curve 3 decibels below the point of maximum intensity. The ratio $F_o/\Delta F$ gives the Mechanical selectivity or Sharpness of Mechanical tuning as tabulated in column 6. Non-resonant receivers are not mechanically selective.

Columns 7, 8, and 9 give respectively the sound wave length (λ) and transceiver face dimensions needed for computing (2θ) the theoretical beam width as tabulated in column 10 and which may be compared with the corresponding experimental width of column 11. Column 12 gives the ratio of the maximum intensity of the first side lobe to that along the beam axis and 13 gives this ratio in decibels for ready comparison with the theoretical value of 17 decibels.

Columns 14 to 19 inclusive have to do with the a-c power supplied to the transceivers, giving respectively the a-c current; a-c voltage across the transceiver terminals; a-c volt-ampere product; a-c impedance in ohms; power factor when sufficient data were available; and finally the a-c power in watts wherever the power factor could be determined.

The input a-c power in watts, column 19, divided into the total sound output, column 20, gives the acoustical efficiency recorded in column 21. The acoustical efficiency of the QC and RS types is indefinite. The values recorded were obtained by using volt-ampere product in place of a-c power and as a result these values are too small because the power factor, which multiplied into the volt-ampere product gives the a-c power, cannot exceed unity. All that can be claimed for these types is that their acoustical efficiency is not less than the values given.

Columns 22, 23, and 24 give the axial sound intensity in milliwatts or microwatts per square centimeter for the respective ranges 4-1/2 feet, 160 feet, and 3000 feet. The intensities for the 3000 foot and 160 foot ranges, columns 23 and 24 respectively, are computed from the measured values at 4.5 feet by use of a theoretical relation between axial intensity and range which assumes no attenuation in transit and no surface reflections.

Column 25 gives the ratio of the total sound output of the several transceivers operated at various power input to the total sound generated by the QC-5 operated at "high power."

Columns 26 and 27 give the ratio of the axial intensity of the several transceivers, operated at various power input to the axial intensity of the QC-5 operated at "high power." This ratio proves to be practically independent of range but it may be noted that the Naval Research Laboratory results recorded in column 27 are for the same range, 160 feet, as for those taken by the SEMMES and recorded in column 26. As stated above, the figures given by the SEMMES can be criticised on the ground that the receiver was exposed to both direct and reflected components of the sound beam. This may account for the lack of agreement.

The overall directivity of an echo detecting system using any of the transceivers tested is high because its directive properties come into play both on transmission of the signal and reception of the echo and, as a result, the echo is heard only when the axis of the sound beam is directed very approximately at the target. Thus the echo effectiveness of a transceiver is largely determined by the axial intensity of its signals. Column 27, therefore, rates the several transceivers in accordance with their echo ability in terms of that of the QC-5 operated at "high power." These ratings are assembled in Table 2 together with those of two other models - labeled respectively QC-7 and QB, developed by the Submarine Signal Company and previously tested on the SEMMES.

(c) Discussion of Various Transceivers

QC-5

The QC-5 experimental beam width (2θ) is 30 degrees while the theoretical value is only 25.1 degrees. Inserting the measured value of θ in the beam width formula,

$$\sin \theta = 0.61 \; \lambda/R,$$

gives the effective radius (R). In other words, it gives the radius of a circular area which, oscillating at equal amplitude and phase, would generate the same width of beam. Inserting 15° for θ and 2.495" for λ, as recorded in column 7, Table I, the effective value of R proves to be 5.88" as compared with the actual radius of 7". The percent of the total face area that is effective is therefore

$$\frac{\text{effective area}}{\text{face area}} = \frac{\pi \, \overline{5.88}^2}{\pi \, \overline{7}^2} = 0.706$$

which means that about 70% of the face area is active and the other 30% is ineffective. The ratio of the inactive to the active area is 0.42. The symmetry of the beam pattern (see Plate 3) indicates that the actual radiating area is circular in form. This leads to the conclusion that the radiating area is centered in the face with a radius equal to 5.88 inches and the inactive portion consists of the surrounding ring-shaped area of 1.12 inches radial width.

Consideration of the mechanical design lends credence to this conclusion for the active tube elements are arranged in checkerboard spacing over the circular face and this necessarily imposes unequal plate loading on the outer elements - those located next to the circular boundary. These elements with their non-uniform plate load will have a different resonant frequency from those on the central portions of the plate where the loading per tube is uniform. If this difference is more than the coupling can pull into phase, as appears probable, the outer portions of the circular plate area will become relatively inactive.

Failure of any transceiver to utilize the whole face area is a serious matter for it not only reduces the total sound output in proportion to the ratio of the inactive to the active area but it further reduces the axial intensity of the sound it does radiate by spreading it over a wider beam.

In case of the QC-5 the inactive area reduces the sound output by about 40% and in addition makes the axial intensity of this weakened signal about 35% less than it would be if the sound were radiated uniformly from the whole plate area. This fault of the QC-5 can doubtless be improved through properly directed research. If it were entirely overcome the axial intensity would be increased to about 1.9 times its present value.

The suppression of the first lobe to 15.5 decibels below the axial intensity is quite satisfactory.

QC-5B

The experimental beam width of 29.6° at "high power" agrees well with the theoretical value of 29.5° and the suppression of the first lobe to 14 decibels below the axial intensity is satisfactory. The whole face area at this low frequency, 17.5 kilocycles, appears to oscillate with proper coordination of amplitude and phase. The total sound radiated (high power) is 72 watts as compared with 27 watts for the QC-5. The QC-5, if improved to get equally good phasing, uniform amplitude, and equal face area as compared to the QC-5B, would be superior to it. It is doubtful if this could be accomplished with the present rectangular arrangement of the driving elements.

As these two transceivers stand, it is probable that comparative echo tests would slightly favor the QC-5B. It would be a mistake, however, to conclude that the lower frequency is more favorable for echo detection. Any superiority the QC-5B may show is due to failure of the QC-5 to function properly rather than to the excellence of the QC-5B. For despite the fact that it properly utilizes its whole face area, the sound output per unit area is about 7% less than that from the active area of the QC-5, and its wide beam necessarily reduces the axial intensity.

Improvement in the Submarine Signal Company's QC type of transceiver, as regards transmission, would appear to lie in: (a) making the resonant frequency at least 24 kilocycles; (b) increasing the face area as much as possible; and (c) improve the design so that the whole face area will radiate more effectively.

NRL Electrodynamic Type XQD

The theoretical beam width proves to be 20.7°, while the experimental, as taken on the SMMMSS, is 17° and as measured on the sound barge is 18.2°. The intensity of both the first and second lobe is only 8.5 decibels below the axial intensity. The effective face radius computed from the 17° beam width is 10.3 inches and from the Naval Research Laboratory beam width 9.6 inches. The diameter of the face is 17 inches and of the face plus the flange is 19.5 inches.

Thus the effective diameter derived from the Naval Research Laboratory beam width measurement taken at a range of 30 feet in comparatively open water is 19.2 inches or practically equal to that of the face and supporting flange. The effective face diameter resulting from the SSMMSS measurement is 20.6 inches which is more than an inch greater than the maximum diameter of the transceiver.

Since the retaining flange is bolted against a rubber gasket and not rigidly against the massive case, it could possibly oscillate and radiate a considerable amount of energy. Under such conditions the active diameter might be equivalent to the face plus the flange as indicated by the 18.1° measurement. But no plausible explanation has been found to account for an effective diameter greater than that of the transceiver other than the possibility that the beam widths measured on the SMMMSS, where the receiver is exposed to both direct and reflected components, are not very accurate and presumably too narrow.

This transceiver shows an undesirable amount of radiation in both the first and second lobes, but despite this the test data give it a beam radiation of 272 watts as compared with about 25 watts for the QC-5 at "high power." Its measured axial intensity was 12 times that of the QC-5, measured at maximum power and at a lower power input, Mr. Horne's measurement gives it a factor of 4 over the QC-5.

This transceiver proves to have several favorable features: (a) its acoustical efficiency holds constant up to high power input; (b) the resonant frequency is constant and independent of the power input; (c) its resonance frequency and mechanical selectivity is practically the same for both transmission and reception. It will be seen that the QC types do not embody these favorable features. These improved characteristics are especially valuable in echo work.

This new type of transceiver, which is still in the developmental stage, gives excellent promise of supplying most of the requirements of a tuned or mechanically selective transceiver. It remains to effect a better angular distribution of its radiated energy, which will probably result from a study of the flange mounting, and provide a streamlined housing.

NRL Non-Resonant Magnetostriction

This transceiver at 24 kilocycles gives a theoretical beam width of 23.1° against a measured width of 21.5°. This device houses within the case free of flange and radiates through a plane rubber diaphragm that gives no measurable distortion to the angular sound distribution. The amplitude and phasing of all portions must approach the theoretical uniformity for the device is thoroughly non-resonant. Yet the beam width as measured on the SEMMES is 1.6° less than the theoretical. Here again it looks as though the beam width measurements made on the SEMMES are too narrow. The first lobe is only 7 decibels below the axial intensity. The relatively high intensity of the first lobe is probably caused by partial absorption of the radiation about the perimeter of the face by the cork mounting and the low sensitivity can be ascribed to buckling of the 0.010 inch material of the radiating face. The SEMMES gives this transceiver a rating of 0.01 which differs radically from 0.5 computed from Laboratory measurements. In the opinion of this Laboratory, its performance is about midway between the "high power" and "low power" ratings of the QC-5.

This transceiver comes nearest to being mechanically non-resonant over the workable supersonic frequency range of any thus far tested. As such it should serve well for detecting propeller sounds and by proper design can be made a fairly good non-resonant transmitter, particularly if it employs one of the alloys of higher magnetostrictive sensitivity. However, there is reason to doubt that it can be made to equal the non-resonant QB types.

New NRL XQB Rectangular Face and Cylindrical Case

The theoretical beam width at 24 kilocycles is 17.7° and the measured is 19.5°. Here the curved rubber window of the cylindrical housing was expected to spread the sound beam to about 21°. Either the index of refraction taken for the rubber is too large or the SEMMES measurement makes the angle of spread too small. The suppression of the intensity of the first lobe to 14.3 decibels below the axial intensity is satisfactory.

This transceiver is broadly tuned, mechanically, at 21 kilocycles. It radiates 88 watts at this frequency when energized by 861 volts a.c. across the transceiver. At 24 kilocycles and this same a.c. voltage it radiates 57 watts. The device is designed to take 1500 volts and after the echo tests were completed it was energized to this voltage at 23.6 kilocycles for the SEMMES to make comparative measurements with the QC-5. From these measurements and the Laboratory tests of the QC-5, the sound output of the XQB computes to 77 watts. No measurement of the output at 1500 volts and resonance frequency of 21 kilocycles has been made. If the sound output at this frequency remains proportional to the power input, the total sound radiated would be about 260 watts. This would nearly equal the performance of the electrodynamic. Thus, it will be noted, the rating of 3.6 at the optimum frequency follows from the low input voltage of 861 while the ratings of 3 and 4 are for the respective frequencies of 24 and 23.6 kilocycles. The rating for 1500 volts at the resonant frequency of 21 kilocycles should be about 10. (See Plate 19 for linearity at 21 kilocycles.)

The tests show that this broadly tuned rochelle salt type of transceiver is capable of transmitting an intense signal with the energy properly distributed between the central beam and the adjacent lobes. Its acoustical efficiency at 21 kilocycles is 14%, using volt amperes in place of power. The impedance of these transceivers is highly reactive and the power factor is probably not greater than 50%. Thus the acoustical efficiency must approximate 30%. This means that with equal power input this new XQB generates a signal with axial intensity from 8 to 10 times that of the QC-5.

(3) Receiver Performance Tests

(a) Theory and Presentation of Data

The procedure for testing a transceiver as a sound receiver consists of mounting the transceiver in one well of the main sound room, the calibrated standard receiver in the other well and receiving on both signals of various intensity and frequency transmitted from a D-2 type transceiver mounted in the forward sound room. The intensity of the signal in terms of pressure amplitude of the sound waves is determined by means of the standard receiver and this divided into the e.m.f. that the signal generates in the transceiver is a measure of its sensitivity as a receiver. Herein e.m.f. is measured in microvolts and pressures in bars (dynes per square centimeter). Thus the receiving sensitivity of the transceivers tested is expressed as microvolts per bar.

The sensitivity varies with the frequency of the signal and when plotted against frequency gives the "Sensitivity vs Frequency Curve" which furnishes complete data for rating the receiver. Such a curve follows for each of the several transceivers tested at New London (Plates 27 to 35). The highest point of this curve gives the maximum sensitivity and this occurs at the resonant frequency of the transceiver <u>when acting as a receiver</u>. The ratio of the resonant frequency (f_o) to Δf, the width of the curve in cycles at 3 decibels below maximum intensity, gives the mechanical selectivity or sharpness of mechanical tuning. The non-resonant transceivers have no appreciable mechanical selectivity.

The selectivity factor becomes of prime importance under the conditions that prevail on ships of the screen because it measures the ability of the receiver to filter out the intense echo-masking local noise. Mechanically tuning a transceiver improves its acoustical efficiency as a transmitter, but this is not extremely important for the efficiency of the XQB is fully double that of any of the mechanically tuned types. A transceiver is designed for mechanical resonance primarily to make it an insensitive receiver of local disturbing noises and, therefore, mechanical selectivity is the most important single factor defining the effectiveness of a resonant receiver. Plate 27, which will be explained under "Discussion", shows graphically the comparative mechanical selectivity of the three resonant transceivers, QC-5, QC-5B, and XQD, acting as receivers.

The curve of Plate 29 refers to the QC-5. The maximum sensitivity occurs at 24.1 kilocycles. This is the resonant frequency (f_o). The band width (Δf) at 3 decibels below maximum is 1.61 kilocycles, making the mechanical selectivity, $f_o/\Delta f$ equal 15. Such data is obtained from a similar curve for each transceiver tested. These and other pertinent data are assembled in Table 5.

Here column 1 gives the polarization or field current. The crystal types do not require polarization. Column 2 gives the sensitivity in microvolts per bar at open circuit at the resonant frequency given in column 3. Column 4 gives the band width (Δf) and column 5 the mechanical selectivity.

Column 6 gives the resonant frequency of the transceivers when used as transmitters and column 7 gives the maximum receiving sensitivity at these frequencies. Column 8 gives the impedance in ohms of the various receivers and column 9 gives the square root of the impedance. This latter figure is used to compute the sensitivity of each type when its voltage pick-up is transformed ideally to match some definite fixed impedance. The ratio of these sensitivities to that of the QC-5 are recorded in column 10. These numbers give the sensitivity rating of the several receivers in terms of the QC-5 taken as unity.

(b) Discussion

Echo detection utilizes the transceiver both for sending the signal and receiving its echo. Except for a slight shift of frequency by the Doppler Effect, the echo to be received has the same pitch as the signal, and since the efficiency of a mechanically tuned transceiver for both transmission and reception is a maximum at the resonant frequency, it becomes important that the resonant frequency when transmitting should be the same as when receiving. A comparison of the data of columns 3 and 6 shows that the QC-5 resonates at 24.1 kilocycles when used as a receiver and at 23.6 kilocycles when used as a transmitter - a difference of 500 cycles. Similarly, the QC-5B shows a difference of 400 cycles. The electrodynamic shows no definite measurable difference although the receiving resonance, 23.6+ kilocycles, was judged to be slightly higher than the transmitting resonance marked 23.6 kilocycles.

This weakness shown by both QC types may be inherent in the magnetostriction transceiver due to the difference in the magnetic field conditions within the resonating nickel tubes when they serve respectively for transmitting and receiving. The electrodynamic type appears to be free from this weakness.

Column 5 gives 15 and 11 respectively for the mechanical selectivity of the QC-5 and QC-5B as compared with 147 for the electrodynamic. Yet as transmitters, the corresponding values are 61 and 46 as compared with 118 for the electrodynamic. Herein lies the greatest weakness of the QC types. Their mechanical selectivity is too low for best efficiency as receivers, where mechanical selectivity is of prime importance. They show practically none as compared with 147 for the electrodynamic.

The relative mechanical selectivity of these three types of receivers is shown graphically on Plate 27 where the three curves represent respectively the three intensity vs frequency curves with their maximum intensity plotted at the same common point and their abscissae expressed in terms of percent of the resonant frequency. Their relative mechanical selectivity may be regarded as the inverse of their breadth along the minus 3 D.B. level. Plate 28 likewise shows the relative selectivity for echo reception. This handicaps the QC types where the resonant frequency differs for transmission and reception.

Normally a transceiver shows somewhat sharper mechanical tuning under the low intensities involved in reception than under the high transmission intensities. This proves true for the electrodynamic and would probably prove true for both the QC-5 and QC-5B if the approaching plane sound waves were not distorted by flectural waves set up in the 1/16 inch hemispherical shield.

Column 10 rates the transceivers as receivers in accordance with their sensitivity. The QC-5 is lowest of the three resonant types, the QC-5B has about two times and the electromagnetic better than four times its sensitivity. None of the resonant types are as sensitive for general sound reception as the non-resonant rochelle salt types.

(c) <u>Old Receivers and Comments on Future Development</u>

<u>Non-Resonant Transceivers</u>

The new XQB has about twice the sensitivity of the old XQB model. This progress has resulted from the researches of the past three years directed toward improving the rochelle salt transceiver.

<u>Resonant Transceivers</u>

The XQD, in its present undeveloped state, proves to have 4.3 times the sensitivity of the QC-5 and what is much more important its mechanical selectivity is 10 times that of the QC-5. This progress has resulted from researches of the past three years directed toward the development of an entirely new type of resonant supersonic transceiver.

<u>Future Development - Receivers</u>

The QC-5 and associated QC types can probably be made more sharply tuned - more mechanically selective - by modifying the present hemispherical shield and possibly by making the transmitting and receiving resonance frequencies more nearly equal.

The XQD has all the mechanical selectivity it can stand without responding to "shock excitation" but it can be increased somewhat as can also its sensitivity. The most obvious procedure for improving its transmitting properties is to strengthen the d-c field. This will automatically increase its receiving sensitivity.

The new XQB probably represents about the limit that can be expected of a non-resonant receiver. It is an excellent receiver of propeller sounds but cannot compete with the best resonant types for receiving c.w. signals or their echoes in the presence of an intense noise background because of its lack of mechanical selectivity. It appears probable, however, that this lack of mechanical selectivity can be supplied by a mechanical filter in a properly designed amplifier. Such an amplifier could be of the inverted superheterodyne type having the mechanical filter embodied in one of its intermediate stages. Such a combination could serve for echo reception fully as effectively as the best resonant transceivers and perhaps more so, for the XQB (new) probably generates as intense a signal as the XQD and its receiving sensitivity is fully four times greater. Its present effectiveness for detecting propeller sounds would be restored by turning a switch that shunts out the mechanical filter. Substantial future progress should result from such further development of the new XQB equipment.

This may perhaps be a proper place to discuss briefly future developments in supersonic drivers. Test data collected on the sound barge have indicated that better discrimination between surface echoes and target echoes can be had by using raw 60 cycle a.c. plate voltage on the power tubes of the driver. This scheme was tested briefly on the SEMMES with favorable results. This kind of drive energizes the transceiver 60 times per second so long as the key is closed and each exposure to power lasts 1/120 of a second rising from zero to maximum power in one-half of this period or 1/240 second. In case of a 24 kilocycle transceiver it will make 100 oscillations during this period. If its tuning is too sharp it may not build up to maximum amplitude in this short period. The XQB, however, lends itself excellently to this kind of drive because being non-resonant its amplitude of oscillation follows the amplitude of the driving voltage. It requires no building up time and therefore can be operated with raw a.c. of any frequency that may prove to be most advantageous. Future progress may result from further investigation of the use of raw a.c. in place of the present high d.c. plate voltage. The engineering advantages offered by such a driver will warrant its use if such investigation only demonstrates that it does not weaken the installation acoustically.

SECTION III

DISCUSSION OF OLDER TYPE TRANSCEIVERS AND COMPARISON WITH MODERN TRANSCEIVERS.

Development of the standard receiver has made possible an accurate comparison of all types of submarine sound transmitters through a determination of their sound output in absolute units. A comparison of the QC-5 as a standard with other types that have been developed within the past four years serves to show the progress that has been made during this period. Such comparisons follow and are grouped in Table 3 to show the progress made in the two general types of transceivers, non-resonant and resonant.

Non-Resonant Transceivers

NRL Old Type XQB - Spherical Case. This transceiver represents the state of development of the rochelle salt supersonic transmitter when the work resulting in the new XQB transceiver was started early in 1935. It is broadly resonant at 22 kilocycles and gives measured beam width of 33.5° as compared with a theoretical width of 25.9°. This departure is probably due to non-uniformity of crystals and to failure to anchor the crystals uniformly to their backing plate. Although this abnormal spreading of the sound beam reduces the axial intensity to about 62% of what it would otherwise be, it still equals 91% of that given by the QC-5 operated at "high power."

Submarine Signal Company QB. The axial intensity of this QB supplied by the Submarine Signal Company, as determined from test measurements previously made on the SEMMES, is also 91% of that given by the QC-5 and, therefore, identical with that given by the Naval Research Laboratory old type XQB.

Comparison of the axial intensity (8 to 10) for the new Naval Research Laboratory XQB with 0.91 for the Submarine Signal Company QB and the Naval Research Laboratory old XQB gives a measure of the improvement made in non-resonant sound transmitters during the past three years. This progress has resulted entirely from the research and developmental work of the Naval Research Laboratory where, in addition to this progress which is confined entirely to rochelle salt transceivers an entirely new type employing magnetostrictive material has been developed to the point where preliminary tests show it compares favorably with the earlier rochelle salt models. This may develop into a superior detector of propeller sounds.

Resonant Transceivers

General Radio Company XQC. This is the first type of

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transceiver supplied to the Navy under contract. The complete installation, including driver and receiver amplifier, was placed on the U.S.S. HAMILTON and tested by Lt. Comdr. Dodge in the Spring of 1933 with favorable results. This same type of transceiver was also supplied later on a contract with the RCA Victor Company. The original transceiver (XQC-1) tested on the HAMILTON has since been tested on the Sound Barge where its sound output could be reduced to absolute units for comparison with the QC-5 and other later types of transceivers. The experimental beam width is 25° as compared with 23° for the theoretical and the intensity of the first lobe is 14 decibels below the axial intensity. Thus the angular distribution of the transmitted sound agrees very closely with the theoretical - much closer in fact than does the sound output of the QC-5. Its axial intensity at 150 feet proves to be 1.2 as compared with unity for the QC-5 operated at "high power."

This transceiver has one feature that might prove of practical value; namely, it has two distinct resonant frequencies. This results from making the oscillating head substantially a half wave length thick. The head and attached nickel tubes together comprise a coupled system similar in principle to the coupled circuit radio transmitter. Such systems have two resonant frequencies, with their separation dependent on the "coefficient of coupling." The intensity vs frequency curve of the XQC-1 gives respectively 24.5 kilocycles and 29.2 kilocycles as the two resonant frequencies; 1.2 and 0.94 as the respective axial intensity in terms of the QC-5, and 30 and 47 as the mechanical selectivity.

The Naval Research Laboratory XQC is the only resonant magnetostriction transceiver that the Sound Division has developed to the point where it could be tested in open water. Another type employing the half wave vented head and quite similar to the General Radio XQC was partially developed before the General Radio Company contracted to develop a magnetostriction transceiver. When it was discovered that this company was also developing the vented head type, the Laboratory, to avoid duplication of effort, stopped this work and started development of the present "so-called" Naval Research Laboratory XQC.

This transceiver employs a square radiating face 10.5 inches on a side. It is energized by 81 nickel tubes uniformly spaced over the back of the face plate. It resonates at 21 kilocycles, has mechanical selectivity of 25, and axial intensity of 1.5 as compared with 1 for the QC-5. Its measured and theoretical beam widths are in good agreement which indicates that its whole face area radiates effectively. It gives a total sound output of 68 watts as compared with 35 for the QC-5 despite the fact that its face area is only 71% that of the QC-5. It radiates 0.124 watts per sq.cm. of face area as compared with 0.033 for the QC-5. The intensity of the first lobe is 12 D.B. below the axial intensity as compared with 15.5 for the QC-5.

The Naval Research Laboratory XQA represents the Laboratory's last model of the quartz-steel transceiver. It was duplicated by the Washington Yard and installed on several destroyers and submarines. This transceiver has a circular radiating face 14.75 inches in diameter. Its resonant frequency is 29.8 kilocycles, mechanical selectivity 27, theoretical beam width 18.9°, measured beam width 31°, total sound radiation 45 watts, intensity of first lobe 22 D.B. below that along the beam axis, and its axial intensity is 2.4 times that of the QC-5.

The wide discrepancy between the theoretical and measured beam width indicates that the active radiating area is confined to a circle of about 4.6 inches radius centered in the face. This means that only 40% of the face area radiates effectively. Yet this small area radiates 30% more sound energy than does the QC-5. If the total face area oscillated with proper coordination of amplitude and phase the total sound radiated would be about 112 watts. This would result in narrowing the beam to about 19° and the axial intensity would then become about 15 times that of the QC-5 operated at "high power." This would exceed the XQD which, as it stands, gives an axial intensity 12 times that of the QC-5.

It is interesting, at this point, to consider the axial intensity of a quartz-steel transceiver with radiating face 24 inches in diameter, such as there is some reason to believe is employed by the British Navy. If the whole face area radiates as effectively as the active portion of the present Naval Research Laboratory XQA and the wave length is such as to give a 12° beam width, its axial intensity would be about 38 times that of our QC-5; and, if as is rumored, the British transceiver uses crystals 6.25 mm thick as compared with our 5 mm and employs proportionately higher voltage to drive the crystals, its axial intensity will then be about 60 times that of our QC-5.

The above data derived from measurement of the sound radiated by the older types of transceivers are collected in Table 5. Table 6a gives the axial intensity at 160 ft. of all transceivers tested - both old and new. They are listed in the order of their superiority in terms of the axial intensity of the QC-5 operated at "high power."

SECTION IV

COURSE OF FUTURE DEVELOPMENT OF TRANSCEIVERS

The main intent back of the Navy's transceiver developmental program has been, and still is, to increase the signal strength and thereby raise the echo intensity with respect to the masking background. Two questions naturally arise in connection with this work; first, what is the maximum possible sound output from a transceiver and second, what proportion of this maximum output does each of the various types of transceivers generate.

The answer to the first question has been known through the theoretical relation;

$$I = p^2/2\rho c,$$

where I represents the sound energy radiated per unit of face area,

p the pressure of the sound conducting medium against the radiating face,

ρ the density of the medium, and

c the velocity of sound.

The curve of Plate 21, computed from this equation, gives as abscissae the maximum watts of sound energy that can be radiated per square centimeter of face area and as ordinates, depth of transceiver submergence in feet. Taking 12 feet as the average depth of submergence on destroyers, the maximum sound radiation per square centimeter of face area is 0.61 watt. Radiation beyond this amount would produce cavitation.

The second question is now answered for the first time through determination of the total sound output by means of the standard receiver. The radiated energy in watts divided by the face area in square centimeters gives the average radiation per unit area and this divided by 0.61 gives the percent that the radiated energy per unit area is of the maximum possible. Such data are assembled in Table 4. It shows that the "high power" output of the QC-5 must be increased by a factor of 17 and that of the QC-5B by a factor of 11 to give the maximum possible output while the increase factor for the electrodynamic and the new XQB is 3 and 4 respectively.

Unless some entirely new type of transceiver is developed, which at this time appears improbable, future progress must depend on the ability of the present types to handle several times the present input power with safety and without serious loss of acoustical efficiency. Their relative ability to do this can be predicted from a study of their "Intensity vs Power" curves which are assembled in Plate [illegible]. The question to be answered is - which, if any, of these curves can be extended to the 0.61 watt level.

The acoustical efficiency of the QC-5 begins to fall off noticeably when the power input (volt x amperes) is increased by a factor of 5 above its "high power" value. It therefore appears certain that it can not handle 17 times its present power. Therefore, it is concluded that the 24 kilocycle QC type of transceiver supplied by the Submarine Signal Company cannot be made to radiate the maximum of 0.61 watt per square centimeter.

No opportunity was afforded to develop the Intensity vs Power Curve for the QC-5B beyond the two power values supplied by its own driver. But past researches dealing with the oscillating energy generated by nickel tubes driven magnetostrictively have shown in all cases that their efficiency starts falling off more and more rapidly when the power input is raised beyond rather definite limits and in the light of this work it appears certain that the QC-5B could not handle 11 times its present "high power" input and, therefore, cannot be made to give maximum radiation.

The acoustical efficiency of the new XQB shows a gradual decline with increase of power when driven at 24 kilocycles, but when driven at its resonant frequency of 21 kilocycles, it remains constant up to 861 volts across the transceiver which is as far as the test was carried. If this curve remains linear, the maximum possible radiation will be reached at about 2500 volts. The transceiver should be able to handle this voltage safely when used for transmitting short signals but under prolonged closed key conditions the crystals might be damaged by overheating. This voltage can be safely used if the driver is provided with a proper time-release protecting relay. Thus there is a possibility that the new XQB can generate the maximum of 0.6 watt per sq.cm. But whether it can or not it represents about the best that can be expected from the QB type of transceiver.

The Intensity vs Power holds strictly linear for the XQD, the electrodynamic, up to 2.1 kilowatts, the maximum to which it has been exposed. Probably this experimental model cannot handle three times this amount of power and therefore cannot be made to radiate the maximum 0.61 watt per sq.cm. But when the condition causing the high intensity of the first and second lobes is found and corrected, it is probable that part of this wasted energy will be added to the sound beam with the result that the radiation per square centimeter will be raised and the axial intensity increased. There is reason to believe that a transceiver of this type can now be designed to give the maximum radiation.

The QA type of transceiver, as shown by the above recorded tests, should not be overlooked. If it can be developed to radiate as effectively over its whole face area as it does over the central portion it will at least equal the present dynamic, and with the improved methods and apparatus that have been perfected for analyzing transceivers it may be possible to develop the QA type to give maximum output.

Finally, it may be noted that these beam type sound transmitters may concentrate the sound energy along the beam axis to intensities greater than the radiation per unit face area. Theory predicts axial intensities as great as 4 times the intensity at the radiating face. It may, therefore, prove that cavitation along the beam axis will prevent effective utilization of the maximum possible radiation per unit area at the transceiver face. However, the linearity of the Intensity vs Power curve for the electrodynamic gives proof that such effects have not set in for intensity one-third the maximum. Moreover, these predicted high intensity points along the beam axis all fall within the short range given by R^2/λ, where R is the radius of the radiating face and λ is the signal wave length, and it is quite possible that slight cavitation at these points would "heal over" and not materially affect the axial intensity at the relatively long echo ranges. Thus it appears probable that the power limiting factor will prove to be face cavitation and not cavitation along the axis of the sound beam.

SECTION V

STUDIES OF ECHO AND PROPELLER SOUND DETECTION

(1) Introduction

The ability of the QC-5, the new XQB, and the XQD electrodynamic installations to detect the R-10 by both echo and propeller sound detection was compared during test runs in Long Island Sound and Block Island Sound areas. The test data, as taken by Lt. Comdr. M.E. Curts, Lt. Charles F. Horne, Jr., and Lt. D. C. Beard follow:

(2) Test Data

(a) XQB and QC-5

20 July a.m. R-10 bearing approximately 55-60 relative distance 450 yards (on surface) (speed 10 knots). Echo heard about 25% of time on both XQB superior as listener although propellers of submarines heard at all times on QC-5.

NOTE: With QC-5 trained on own propellers (SEMMES) the propellers of SEMMES made no more noise than the submarines. (Our propellers not heard 15° off of bearing.)

10:00 - Submarine opens to 1800 yards; good reliable echoes on XQB - also on QC-5; also each hears propellers of submarine. XQB better. Speed of SEMMES - 9 knots.

10:20 - 2400 yards - no good on echo on either - listens OK on XQB; not on QC-5. SEMMES' speed - 12 knots.

10:45 - 2100 yards - 12 knots. XQB gets about 35%, QC-5 - 20% of echoes: XQB hears propeller OK; QC-5 propeller unheard.

11:00 - 1800 yards - 12 knots - 70% echoes on each.
1700 yards - 12 knots - 100% echoes on each.
1500 yards - 12 knots - 100% echoes on each.

20 July p.m. Submarine down, speed 3 knots. Submarine propeller noise down 10 dbs.

XQB - listens excellent } 2000 yards
QC-5 listens no good }

Submarine up, QC-5 listens OK at 2000 - speed 5 knots.

2800 yards - XQB and QC-5 echo OK - listen OK on both.
3000 yards - No echoes on either.

21 July a.m. Operating off Block Island in supposedly favorable waters.

Time	Range	XQBHP	XQBLP	QC-5
0800	300 5 knots	Listen=L - OK Echo =R - OK	L - OK R - OK	L - OK R - OK
0830	300 5 knots	L - OK R - OK	L - OK R - OK	L - OK R - OK

Discrimination on all better than yesterday.

Time	Range	XQBHP	XQBLP	QC-5
0840	1500 5 knots	L - OK R - OK	L - OK R - OK	L - OK R - OK
0850	2100 5 knots	L - OK R - OK	L - OK R - OK	L - OK R - OK
0910	3000 -	Unheard		
1030	Submarine down			

Maximum range (echo) each - 2300 yards

21 July p.m. Took power level measurement, sensitivity, noise receiver vs speed. XQB picked up lobster pot - no damage.

(b) XQD and QC-5. At 1700 picked up submarine on both XQD and QC-5 and followed it out on both with echoes to 1920 yards at which time lost it. Noted that XQD and QC-5 are about equal as listeners. XQD has good discrimination at low speeds.

22 July a.m.

R-10 Surface - Speed 8 knots
SEMMES " " 8 knots

						Discrimination
	QC-5	1100 yards		Echo OK	Listens OK	OK
	XQD	1100 yards	1 kw	" "	" NG	OK
	QC-5	1200		" "	" OK	OK
	XQD	1200	1 kw	" "	" NG	OK
75° t	QC-5	1700		" "	" OK	OK
	XQD	1700	1 kw	" "	" NG	OK
	QC-5	2200		" "	" OK	OK
	QC-5	2460		2/5	" OK	NG
	XQD	2460	1-1/2 kw	2/5	" NG	NG
	QC	2660		2/5	" OK	NG
	XQD	2660	"	2/5	" NG	NG
	QC	2260		4/5	" OK	
	XQD	2260	"	4/5	" NG	

XQD - Not streamlined and its poorness as a listener may very possibly be due to background of water noises.

22 July p.m. Tried raw 60 cycles a.c. on plate of XQD with excellent results. It appears to be just as good, if not better, than d.c. and has many engineering advantages. Ranges on neither XQD nor QC-5 as good as in morning. Discrimination of echo better on both and best on XQD.

During the evening the SEMMES took comparative intensity measurements between the QC-5 and the XQD, receiving these signals on the D-2 mounted in the aft sound room. These data together with similar measurements made by the SEMMES on other types of transceivers are as follows:

		(db)	Power ratio to QC-5
QC-5	(Sub.Sig. production model)	72	1
QC	19" (Sub.Sig. trial gear)	76/79	3/1
QB	19" (" " " "	70	6/10
XQB	NRL (new) rochelle cylindrical	78-80	4/1
XQB	NRL (old) " spherical	70	6/10
XQD	NRL (new) electrodynamic	78	4/1
XQC	NRL (new) flattened nickel	48	1/120

(3) Discussion

(a) XQB and QC-5

The test data is too limited and conflicting to warrant drawing many definite conclusions. The forenoon tests of 20 July indicate that the new XQB is definitely superior to the QC-5 as a detector of propeller sounds. Propellers were heard up to 1800 yards on both but better on the XQB. Beyond this range the QC-5 lost the propellers while the XQB was still hearing them clearly at the maximum range of 2400 yards with the SEMMES steaming at 12 knots.

The echo tests also favor the XQB which received about 35% of the echoes at 2100 yards as against 20% for the QC-5. This proved to be about the maximum range for both.

The afternoon tests again showed the superiority of XQB for detecting propeller sounds. During these tests the R-10 proceeded at 3 knots submerged. Under these conditions the intensity of her propeller sounds is about 10% that of the forenoon tests. At range 2000 yards, the XQB "listens excellently" and the QC-5 "does not listen." However, when the submarine surfaced and proceeded at 5 knots, the QC-5 could pick up the more intense propeller sounds at 2000 yards and both followed by echo and propeller detection to 2800 yards. At 3000 yards both lost the R-10.

The next forenoon operations were transferred to the Block Island area in supposedly more favorable water. Both devices followed the R-10 by echo and propeller sound detection to 2100 yards and neither could make contact at 3000 yards. When the R-10 submerged at 10:30 the maximum echo range on each was 1300 yards. This completed the comparative tests between the QC-5 and the new XQB.

(b) <u>XQD and QC-5</u>

The XQD was installed in place of the XQB during the afternoon. The R-10 was picked up by echo on both the QC-5 and XQD and followed out to and lost at 1920 yards.

Comparison detection tests were carried out the next day between the QC-5 and the XQD with both the SEMMES and R-10 on the surface at 8 knots. The results are consistent. Both devices followed the target by echoes to 2260 yards, the maximum range attempted. The QC-5 heard the propellers at all ranges and the XQD failed to hear them at any range. It is probable that, as in case of the previous range tests, both devices would have lost the echo at about 3000 yards had the tests been carried to greater ranges.

(c) <u>General</u>

These tests, as a whole, give the following somewhat definite information:

(a) The XQB is a better detector of propeller sounds (listener) than is the QC-5 and the QC-5 is better than the XQD. A comparison of the directivity, sensitivity, and mechanical selectivity of these receivers not only gives this information but also tells how much better one type is than the other.

(b) Comparative echo tests between the QC-5 and the XQB show that both lose the target at the same range. This also proves true for the QC-5 and the XQD at 1920 yards and it can be confidently stated that the same would have happened on the last tests if the range had been extended to something like 3000 yards. These results appear to show that the range-penetrating ability is the same for all three types and, therefore, give no information regarding the intensity of their respective signals. In fact, these range tests indicate that the signal strength is the same for all three types of transceivers.

Such comparative test data can be and in the past has been misleading. The methods and procedure followed in this report for testing and rating transceivers are simple and reliable.

It may be stated that the development of the standard receiver now makes it possible for the first time to prepare definite specifications for underwater sound gear and accurately to determine whether or not the apparatus supplied meets the specifications. This alone should result in improved sound equipment. This compares with Naval radio practice in which we do not test (accept) transmitters according to range, but according to performance in standard dummy antennas.

The reason the echo tests gave equal range for all three transceivers irrespective of their widely different signal intensity is readily explained. The temperature of the water in the Long Island and Block Island areas decreases with depth during the summer months. Such descending temperature gradients can be expected in any area where the temperature of the overlying air averages higher than the temperature of the water. Under such conditions the velocity of the sound waves decreases with depth and therefore the top of the horizontally projected sound beam has a slightly higher velocity than the bottom. This vertical decrease in velocity across the beam warps it downward from the horizontal and at some fairly definite range it passes beneath the target. When this range is reached, no echo is returned no matter what may be the intensity of the transmitted signal.

The maximum range of echo detection is defined by the relation:

$$S = 53 \frac{\sqrt{H} + \sqrt{h}}{\sqrt{10\, T_{gr} - .0058}}$$

where (S) is the maximum echo range in yards, (H) is the depth of submergence of the submarine in feet, (h) is the depth of submergence of the transceiver in feet and (T_{gr}) is the drop in temperature degrees Centigrade per foot depth. In other words, it is the vertical temperature gradient and the formula assumes it to hold constant from the surface to the depth (H) of the submarine. While this assumption of constant gradient never holds strictly true in practice, nevertheless the above expression gives a close approximation in most areas.

The curve of Plate 36 gives a plot of this equation under the condition of 100 feet submergence for the submarine and 1[illegible] feet for the transceiver. The factor (10) in the denominator is the change in sound velocity in feet per second per degree Centigrade change of temperature and the constant 0.0058 represents the gain in sound velocity per foot depth caused by the resulting increase in pressure. The pressure effect is so small in comparison with that caused by temperature that it can usually be neglected.

This curve shows that the echo range is very dependent on the temperature gradient. A temperature variation as small as 1° C in a depth of a hundred feet reduces the maximum echo range to about 1500 yards, while 6° C gives scarcely 500 yards. It may, therefore, be expected that the maximum echo range over a large portion of the ocean areas during some portion of the year will be determined by the temperature gradient in accordance with the above range equation. Under such conditions this equation offers the best known means for determining the spacing between ships in the submarine screen.

Over most ocean areas there are certain seasons of the year when the temperature gradient is zero or negative. Under these conditions the echo range is largely dependent on the rate of absorption and scattering of the sound signal by the medium. The maximum range is then determined by the intensity of the signal. The more intense the signal the farther it can travel before becoming too much attenuated to be heard. This is one reason why transceiver development should be carried to the point of maximum sound output of 0.6 watt per unit of radiating area.

Another argument for increasing the signal intensity to a maximum is that the echo range is not definite. In general, 100% echoes are received out to some moderate range beyond which the fraction of received echoes gets smaller and smaller but even a relatively weak signal occasionally carries to great range. Within this "twilight zone", the percentage of echoes received increases with the signal intensity. Here increased signal intensity serves more to increase the reliability than the range of detection.

(4) Conclusion

A brief discussion of the five curves of Plate 37 completes the portion of this report dealing primarily with the testing and rating of transceivers. The ordinates of all the curves are expressed in decibels (db) and for curves 1 - 4 inclusive they measure the intensity of the received echo. In case of curve 5 they measure on the same scale the intensity of the local noise background. The abscissae of curves 1 to 4 are expressed at the bottom of the sheet as echo-range in yards and for curve 5 they are expressed at the top of the sheet as speed in knots.

The five points on curve 3 represent experimental data taken by the SEMMES in the Guantanamo area using the QC-5B transceiver. They represent the intensity of echoes from the S-20 at different respective ranges. These were used to determine the constants of the theoretical equation,

$$I_x = \frac{I_o}{4x^2} \mathcal{E}^{-2\alpha x}$$

where I_o is the transmitted intensity, I_x is the echo intensity at range (x) and (α) is the absorption coefficient. Curve 3 plotted from this equation gives the echo intensity of signals transmitted by the QC-5B as a function of the range. The results of the New London tests rates the QC-5B as 1.6 against the standard QC-5 as unity. This places curve 1, which corresponds to the QC-5, 2 decibels below curve 3. Curve 4 is computed for the QC-5B on the assumption that it radiates the maximum possible sound; i.e., 0.6 watt per sq.cm. of face area. Curve 2 refers to the electrodynamic transceiver. Its ordinates are 1/3 those of curve 4 and thus this curve lies 4.8 decibels below this maximum curve.

The main purpose of the Laboratory's transceiver developmental program has been, and still is, to raise the "Intensity vs Range Curve" to coincidence with the curve 4. The reason becomes obvious when it is understood that the echo can be heard only so long as its intensity is at least equal to that of the noise background. If its intensity falls below that of the background the echo will be "masked." Therefore, given any definite background intensity (say, +20 decibels) the maximum echo range is given by the intersection of this intensity level on the range vs intensity curve of the transceiver. The QC-5 gives an echo range of 1000 yards as against about 2500 yards for the electrodynamic. If the electrodynamic were developed to give a signal about three times its present intensity, which is the maximum shown by curve 4, the echo range would be extended to about 3200 yards.

Thus the height of the curve 2 above that of curve 1 represents the progress made in transceiver development in the past three years. The difference in height between curves 2 and 4 represents the progress that is still possible.

Curve 3 gives the intensity of the noise background picked up by the QC-5 mounted in the main sound room on the SEMMES as a function of the ship's speed in knots. This curve will probably be modified somewhat when a more careful and accurate sound analysis is made of the sound generated by the SEMMES. But the point to note is that a noise vs speed curve similar to curve 3 exists for each sound-equipped ship of the Navy and that its character is an important factor in determining the range of echo detection. To illustrate, suppose the speed of the SEMMES is 15 knots. The intensity of the noise background is 20 decibels. This would limit the echo range of the QC-5 to 1000 yards. If this background could be reduced to 10 decibels it would result in increasing the echo range to 2000 yards.

The same increase in echo range results from either raising the echo intensity vs range curve any definite number of decibels or from lowering the background vs speed curve by the same number of decibels. The maximum decibels remaining to be gained by raising the echo intensity vs range curve, as stated, is 4.8 decibels while the maximum decibels possible to gain by lowering the background vs speed curve of the SEMMES may amount to as much as 50 decibels at speeds above 20 knots. The main purpose of the problem "Reduction of Sound Generated by Naval Vessels" is to lower the "Background Intensity vs Speed Curve." Herein lies the most promise of future progress in submarine sound detection. The remainder of this report deals with this problem.

SECTION VI

REDUCTION OF SOUND GENERATED BY NAVAL VESSELS

(1) Introduction

The maximum detection range of a sound target may be measured by the ratio:

$$\frac{\text{Intensity of sound received from target}}{\text{Intensity of received local sound}}$$

For practical operating conditions this ratio must always approximate unity. In case of echo detection it becomes possible to increase this so-called Signal-Background ratio by both increasing the value of its numerator and decreasing its denominator. Increasing the intensity of the transmitted signal increases the echo intensity of the sound received from the target. But in case of propeller-sound detection we have no control over the intensity of an enemy ship's propeller sounds and hence over the numerator of this ratio. The range of propeller-sound detection is, therefore, determined solely by the intensity of the received local or ambient noise.

Section V of this report, which deals solely with echo detection, discusses the relative response sensitivity of various transceivers to the local ambient noise and shows that it is determined by their directive and mechanical selectivity. The narrower the sound beam and the sharper the mechanical tuning the lower will be the background intensity. It also shows that these two selective factors have each been carried to the approximate practical limit.

Yet the background within the speed range required of ships in the screen - Curve 5, Plate 37 - is still too great to permit reliable detection to the ranges required by screen tactics. The intensity of the received local ambient noise must be reduced still farther. Since it cannot be done through transceiver design, it must be accomplished through weakening or eliminating the local sound sources which cause the background. This second part of the present report deals with a program of sound tests carried out on the U.S.S. SEMMES for the purpose of locating these sources. They must be located before they can be reduced or eliminated.

(2) Noise Analysis on the U.S.S. SEMMES

There are three primary sources of the general background noise that may be picked up by the sound gear while the ship is under way. The noise may come from:

(a) the propellers,
(b) the turbulence around the hull or the transceiver,
(c) mechanical vibrations of the hull or transceiver supporting structure, directly transmitted through that structure to the transceiver.

The noises produced by any or all of these sources are undetermined functions of the design and speed of the ship and of the sea conditions. The noises picked up by the transceiver are inter-related functions of the design, frequency, selectivity, relative bearing, and type of mounting of the transceiver. The problem during this period was to take such data as would give evidence of the relative importance of factors (a), (b), and (c) under different operating conditions, to develop a technique that would be applicable to future more elaborate studies, to compare service data with previous model tests, and to indicate the direction that future noise reduction work should take.

(a) Non-directive Noise Studies

The first study was made by installing a D-2 tube and a Boonton amplifier in each of the forward, main, and after sound rooms and listening by three experienced listeners in rotation as the ship's speed was varied from 0 to 20 knots. Due to the low sensitivity of the D-2, which is a non-resonant and non-directive pick-up, satisfactory measurements could not be made on the output meters but a summary of the important qualitative data is shown in Table 1a.

(b) Directive Noise Studies

For this work the QC-5 and QC-5B magnetostriction transceivers were used as receivers. An attenuation box was used ahead of a Boonton amplifier and the impedance was matched to the transceiver. Attenuation was inserted in the decibel box to keep the output meter reading constant. This was checked by substituting a standard signal generator for the transceiver and measuring the microvolts necessary to give standard output through the same attenuation. The QC-5, 23.8 kilocycles, was installed in the starboard well and the QC-5B, 17.2 kilocycles, in the port well. Only one tube was lowered during measurements, except that one run at each speed was made on the starboard tube with both tubes down, to determine the noise generated by the turbulence around the port tube. Readings were taken on each 20° relative bearing and the cardinal points were checked. The depth of the water was 25 to 40 fathoms and sea conditions were almost perfect. The results are shown in Figs. 1a, 2a, and 3a.

Study of Fig. 1a shows an approximately linear decrease of noise with speed from 25 to 21 knots and a more rapid decrease to 20 knots for any particular bearing. For any particular speed there is a general increase of noise with relative bearing from 0° to 180° but the increase is not uniform. A comparison of the intensities on symmetrical bearings is made in Table 2a showing that the inboard side averages 2 decibels noisier than the outboard side at 25 knots and 1 decibel noisier at 20 knots. This appears to be due to turbulence along the keel.

Comparison of Fig. 1a and Fig. 3a shows the right hand sides to be quite similar, but the left hand side of Fig. 3a is distorted. This effect is shown in Table 3a to reach 5 db on bearing 270 at 25 knots and is due to the turbulence caused by the port transceiver being dragged through the water. The distance between centers of the two tubes is 4 feet 11 inches.

Fig. 2a shows a marked difference in type from Fig. 1a. The QC-5B is a larger transceiver than the QC-5 with a lower resonant frequency. The beam widths are about the same but the QC-5B is somewhat more sensitive. The noise level curve is low and fairly uniform on all bearings up to 22 knots but at 25 knots it approximates the QC-5 in shape and values.

(c) <u>Separation of the Effects of Propeller Noise and Turbulence Noise.</u>

From available data, curves can be plotted showing the total noise as a function of speed from 16 to 25 knots on bearings 0° to 180° relative. See dashed curves, Fig. 4a. It is assumed that the turbulence around the forward part of the ship and around the transceiver is independent of the means of propulsion; that is, whether the ship is driven by the propellers or by its own inertia. The ship therefore was driven at a steady speed of 25 knots and the noise level accurately established on a given bearing, then the power was suddenly cut off and the noise level recorded against time as the ship decelerated. Readings were taken at approximately one second intervals until the noise decreased to the lowest measurable level. Zero time was the last steady state reading before the noise started to decrease. To plot the noise level against knots it is necessary to have the deceleration curve of the ship. From the known mass of the ship and the effective horse power as a function of speed, it can be shown that

$$V_t = \frac{V_0}{1 + .00036\, V_0\, t}$$

where V_t is the velocity at any time t, V_o is the initial velocity in feet per second, and t is the time in seconds. The curve of the above equation is plotted in Fig. 5a. Since for $t = 0$, $V_t = V_o$, zero time may be taken corresponding to any initial speed on the curve. This assumes that the effect of the propellers is completely eliminated at zero time. This is not quite true for the inertia of the turbines continues to drive the propellers for a short interval, after which they are rotated as a water turbine at decreasing rate for a period of about 7 minutes. During this deceleration period the propeller sound is of low intensity, as proven by measurements on the D-4 tube in the after sound room. Using the deceleration curve for the transposition, the noise level is plotted as a function of speed during deceleration. See solid curves of Fig. 4a.

The outstanding features of the curves of Fig. 4a are the differences in the levels for 0° and 180° bearings and the rates at which the decelerating curves separate from the driven curves on the different bearings.

Neglecting, for reasons explained below, the effect of mechanical vibrations of the ship or transceiver support, we may say that the noise level on the decelerating curve is due to turbulence and on the driven curve the noise is due to turbulence plus the propellers. Expressed mathematically,

$$(1) \qquad DB_t = 10 \log I_t \, ,$$

where I_t is the intensity of the background due to turbulence about the transceiver and its mount and DB_t is the value of I_t in decibels. Likewise,

$$(2) \qquad DB_d = 10 \log (I_t + I_p),$$

where I_t and I_p are respectively the background intensity due to turbulence about the transceiver and to noise generated by the propellers. It follows that,

$$(3) \quad DB_d - DB_t = 10 \log \left\{ \frac{I_t + I_p}{I_t} \right\} = 10 \log \left\{ 1 + \frac{I_p}{I_t} \right\}$$

Also,

$$(4) \quad DB_{t \sim 180} - DB_{t \sim 0} = 10 \log \frac{I_{t \sim 180}}{I_{t \sim 0}}$$

where the subscripts (t ~ 180) and (t ~ 0) refer respectively to (turbulence at bearing 180) and (turbulence at bearing 0).

The values of DB_t are taken from the experimental intensity versus speed curve when decelerating and of DB_d from the corresponding curve obtained when the ship is driven.

From the curves of Fig. 4a and the above equations, Table 4a has been prepared showing the ratios of the intensities of propeller noise to turbulence noise, and the ratios of propeller ahead and astern, and of turbulence ahead and astern.

The ratios of propeller noise to turbulent noise on 0° and 180° bearings are plotted in Fig. 6a.

It should be remembered that the above data were taken with the QC-5 transceiver which has a resonant frequency of 23.8 kilocycles and a directivity and selectivity shown by the data in the first part of the report. The absolute values would be different for another transceiver and therefore too general conclusions are not warranted by the present limited data, though the trends seem clearly indicated.

Fig. 6a shows that the propellers make the major proportion of the noise at speeds under 20 knots. At 21 to 22 knots, propellers and turbulence are about equal (the driven and decelerating curves are 3 decibels apart) and between 22 and 23 knots the turbulence dominates. It is important to distinguish between absolute values and ratios. At the lower speeds, although the propellers produce the major portion of the noise, the absolute level is so low that it may not seriously interfere with echo ranging but it is still an adverse factor in listening to the propeller noise from a distant target ship. On 0° bearing the absolute value of the propeller noise is less than on 180°, but the turbulence is also much less on 0° than on 180°, so the ratio on 0° is greater than on 180°. It is also probable that considerable propeller noise is reflected from the waves ahead of the ship or the bow wave, like the surface echoes in echo ranging, and may strike the face of the transceiver on 0° bearing.

When a spherical transceiver is drawn through the water, the turbulence will always be greater astern than forward, and the noise picked up on 0° bearing, where the face of the transceiver is towards the minimum turbulence, will be less than on 180° bearing, where the face of the transceiver is towards the maximum turbulence. Also since this turbulence is near the face of the transceiver, it not only produces a high noise level but partially shields the transceiver from the propeller noise, hence the lower ratios of propellers to turbulence on 180° bearing.

(d) <u>Effects of Mechanical Vibrations of the Ship or the Transceiver Supporting Structure.</u>

On 22 July 1937 the SEMMES listened on both sonic and supersonic gear to the noise from the R-10 under different operating conditions. The data agree with similar tests on the S-20. References: Report No. S-1199 of 25 September 1935; Report S-1282 of 17 June 1936. The following conclusions seem warranted:

(1) The average sound output is not consistently or materially different when running on the surface on engines or motors at the same r.p.m.

(2) At zero r.p.m. the noise drops to the ambient level which was 4 db at the time of the tests. For 218 r.p.m., 5 knots, the noise is 26 db above the ambient level, corresponding to an intensity ratio of 400:1.

(3) No difference could be detected in the noise level from the R-10 at 500 yards range when lying to with both engines stopped and when charging batteries with both engines.

This is because the charging noise does not rise above the general background level on the listening ship. Also, no bearings could be obtained by listening to the noise on either sonic or supersonic while the R-10 was lying to at 500 yards and charging batteries with both engines.

The evidence is conclusive that, when listening at a distance, the noise produced by vibrations of the hull is negligible compared to that produced by the propellers. When listening on the same ship, however, conditions may be different due to the shorter range and to the fact that vibrations may be transmitted directly through the ship's structure to the transceiver. This was shown during the tests of the "Aircraft Detector for Submarines" where propeller vibrations were transmitted through the ship and periscope to the microphone at its tip until the microphone was sound insulated for the low frequency vibrations. On the SEMMES this type of vibration does not seem to cause serious interference as far as can be determined by listening with the transceiver raised and shielded in supporting structure. This is the reason that only propellers and turbulence were considered as major sources of noise in the above analysis.

During a test on the PHELPS there was definite evidence of vibration of the transceiver supporting tube that raised the background above the propeller or turbulence noise beyond a certain speed. The effect was believed to be due to chattering of the spider which is the lower bearing for the transceiver tube. This type of noise interference can be eliminated by proper design and workmanship on the transceiver support.

(e) Correlation of Noise and Turbulence

The data accumulated during the past five years show that turbulence causes noise in the water. Tests have been made on the operating ship, on distant target ships, on model propellers, and on experimental equipment in the Laboratory. Tests have also shown both on model propellers and on ships, that when cavitation, which is an extreme form of turbulence, begins there is a rapid increase in the noise level. This is also shown by the differences between a flat face and a spherical transceiver when the noise is measured as a function of speed and bearing. The quantitative data on which these statements are based have been fully presented in numerous previous reports.

(f) Value of Noise Reduction

In any receiving system involving listening, the most important factor is the signal-noise ratio. This factor can be improved (a) by increasing the signal strength and (b) by decreasing the background noise level. The first section of the report has shown that transceivers are now approaching the maximum radiation limit imposed by cavitation; therefore, reduction in noise level is the obvious method for further improvement. This can be done either by reducing the intensity at the source or by shielding against it, or by both methods operating together.

(g) Conclusions

The brief sound analysis of the SEMMES appears to show that the background of noise picked up by the transceiver is due to two local sound sources: (a) the propellers and (b) turbulence about the transceiver housing; and that the ratio of (a) to (b), which is large at the lowest speeds, increases gradually with speed and becomes unity at about 22 knots. It follows that reduction of the transceiver noise background on ships of the screen, where the speed is relatively high, will require treatment of both of these local sound sources, while for patrol ships operating at slower speed it may only be necessary to reduce the propeller sounds.

Two researches are already under way that should result in reducing these two disturbing sources - one directed toward

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the development of a noiseless propeller for submarines and the other toward the development of a sound transparent shield having sufficient strength and rigidity to serve for a streamlined housing about a transceiver. Improvement in underwater sound detection in the near future will depend to a large extent upon the progress made on these two problems.

PROJECTOR	POLARIZATION OR FIELD CURRENT AMPS. - D.C.	D.C. RESISTANCE-OHMS	D.C. POWER - WATTS	MECHANICAL RESONANCE f_0 - FREQUENCY - Kc/Sec.	BAND WIDTH Δf - FREQUENCY - Kc/Sec.	MECHANICAL SELECTIVITY $f_0/\Delta f$	WAVE LENGTH IN SEA WATER CENTIMETERS	AREA OF RADIATING FACE SQUARE CENTIMETERS	RADIUS OF RADIATING FACE CENTIMETERS	$2\theta°$ ($= 2 \sin^{-1} .61 \frac{\lambda}{R}$)	MEASURED BEAM WIDTH $2\theta°$ - DEGREES	INTENSITY OF MAX. SEC. LOBE / INTENSITY OF MAIN BEAM	DITTO IN DECIBELS	A.C. CURRENT INPUT AMPERES (RMS)	PROJECTOR TERMINAL A.C. VOLTAGE (RMS)	A.C. VOLT - AMPERE PRODUCT	A.C. IMPEDANCE - OHMS	POWER FACTOR	A.C. POWER - WATTS	TOTAL SOUND OUTPUT WATTS	ACOUSTIC EFFICIENCY SOUND OUTPUT / A.C. POWER INPUT X 100	AXIAL SOUND INTENSITY AT 54" MW/cm^2	AXIAL SOUND INTENSITY (IDEAL) AT 160' MW/cm^2	AXIAL SOUND INTENSITY (IDEAL) AT 3000' MW/cm^2	TOTAL SOUND OUTPUT RATIO TO 90-5 "HP"	AXIAL INTENSITY AT 3000' (IDEAL) RATIO TO 90-5 "HP"	AXIAL INTENSITY AT 160' (IDEAL) RATIO TO 90-5 "HP"	INTENSITY RATIO AT 160' BY MR. HORNE	[illegible]
90-5	5.4	8.0	234	23.65	.387	61	6.34	993	17.8	25.1°	30°	.028	-15.5	1.09	132	143	121	?	?	7	>5%	8	7	.020	.21	.21	.21		"LOW POWER" (BEAM WIDTH)
SUBMARINE SIGNAL COMPANY	5.4	8.0	234	23.6	.452	52	6.35	993	17.8	25.2°	X	X	X	2.15	204	439	95	?	?	33	>7%	39	34	.097	1	1	1	1	"HIGH POWER" (MR. HORNE'S COMPARISON BASE)
CASE:- SPHERICAL - 17" DIAM.	5.4	8.0	234	23.6	X	X	6.35	993	17.8	25.2°	X	X	X	4.00	415	1660	104	?	?	98	>6%	115	102	.288	3.0	3.0	3.0		LINEARITY LIMIT
WINDOW:- NON-CORROSIVE STEEL (1/16")	5.4	8.0	234	23.6	X	X	6.35	993	17.8	25.2°	X	X	X	6.00	585	3500	98	?	?	139	>4%	163	144	.410	4.2	4.2	4.2		MAXIMUM POWER APPLIED
90-5B	6.0	7.6	274	17.6	.382	46	8.52	1295	20.3	29.6°	29.5°	.040	-14.0	1.30	167	217	128	?	?	19	>8%	17	15	.042	.58	.43	.44		"LOW POWER" (BEAM WIDTH)
SUBMARINE SIGNAL COMPANY	6.0	7.6	274	17.5	.374	47	8.57	1295	20.3	29.8°	X	X	X	2.30	267	615	116	?	?	73	>12%	63	55	.156	2.2	1.6	1.6		"HIGH POWER"
CASE:- SPHERICAL - 19" DIAM.																													
WINDOW:- NON-CORROSIVE STEEL (1/16")																													
XOD (NEW) ELECTRODYNAMIC	4.0	40	640	23.6	X	X	6.35	1460	21.6	20.7°	X	X	X	16	222	3550	13.9	.555	1970	168	8.5%	254	256	.726	5.1	7.5	7.5		MAXIMUM POWER APPLIED 4.0 A. FIELD CURRENT
NAVAL RESEARCH LABORATORY	4.4	40	775	23.6	X	X	6.35	1460	21.6	20.7°	X	X	X	14.5	202	2930	13.95	.566	1660	172	10.3%	260	262	.744	5.2	7.7	7.7	4	POWER APPLIED FOR MR. HORNE'S COMPARISON MEASUREMENT
CASE:- CYLINDRICAL (H) - 19½" DIAM.	5.0	40	1000	23.6	X	X	6.35	1460	21.6	20.7°	X	X	X	16	224	3585	14.0	.585	2100	272	12.9%	412	416	1.180	8.2	12	12		MAXIMUM POWER APPLIED 5.0 A. FIELD CURRENT
WINDOW:- NONE	4.0	40	640	23.6	.200	118	6.35	1460	21.6	20.7°	17°	.141	- 8.5	3	41.7	125	13.9	.555	69.3	5.9	8.5%	9.0	9.1	.026	.18	.27	.27		LOW POWER (BEAM WIDTH)
XOG (NEW) MAGNETOSTRICTION (NON-RESONANT)	6.0	4.3	155	20.0	N.R.	N.R.	7.50	1140	19.0	27.8°	X	X	X	2	378	756	189	.530	400	21	5.2%	21	18	.051	.64	.53	.53		MAXIMUM POWER APPLIED
NAVAL RESEARCH LABORATORY	6.0	4.3	155	24.0	N.R.	N.R.	6.25	1140	19.0	23.1°	21.5°	.200	- 7.0	2	450	900	225	.566	510	11	2.1%	14	13	.037	.33	.38	.38	.01	MAXIMUM POWER APPLIED (BEAM WIDTH) MR. HORNE'S COMPARISON POINT
CASE:- CYLINDRICAL (H) - 17" DIAM.																													
WINDOW:- RUBBER																													
XQB (NEW) ROCHELLE SALT	X	X	X	21.0	N.R.	N.R.	7.14	1700	"23.3"	20.2°	X	X	X	.73	861	629	1130	?	?	88	>14%	121	124	.352	2.7	3.6	3.6		MAXIMUM POWER APPLIED
NAVAL RESEARCH LABORATORY	X	X	X	24.0	N.R.	N.R.	6.25	1700	"23.3"	17.7°	19.5°	.037	-14.3	.75	861	646	1150	?	?	57	>9%	94	104	.297	1.7	3.1	3.1		MAXIMUM POWER APPLIED (BEAM WIDTH)
CASE:- CYLINDRICAL (V) - 19½" DIAM.	X	X	X	23.6	N.R.	N.R.	6.35	1700	"23.3"	18.0°	X	X	X	1.3	≈1500	≈1950	≈1150	?	?	(77)	>4%	(124)	(137)	(.389)	(2.3)	(4.0)	(4.0)	4	POWER [illegible] COMPARISON MEASUREMENT
WINDOW:- RUBBER	X	X	X																										
XCB (OLD) ROCHELLE SALT	X	X	X	17.0	N.R.	N.R.	8.82	1100	18.6	33.7°	X	X	X	1.5	315	469	208	?	?	10	>2.1%	7.2	6.1	.017	.30	.18	.18		[illegible]
NAVAL RESEARCH LABORATORY	X	X	X	22.0	N.R.	N.R.	6.91	1100	18.6	25.9°	33.5°	.013	-19.0	1.5	316	474	210	?	?	31	[illegible]	35	31	.083	.94	.41	.41		[illegible]
CASE:- SPHERICAL - 17" DIAM.	X	X	X	29.0	N.R.	N.R.	5.17	1100	18.6	19.6°	25.4°	.079	-11.0	1.5	295	442	197	?	?	11	[illegible]	19	18	.042	[illegible]	.54	[illegible]		[illegible]
WINDOW:- RUBBER	X	X	X																										

TABLE 1

Table 2

Test Data - Modern Sound Transmitters

Transceiver	Relative Axial Sound Intensity at 160' (Ratio to QC-5 "HP")
QC-5 Submarine Signal Company "High Power" 23.6 kc/s	1
QC-5B Submarine Signal Company "High Power" 17.5 kc/s	1.6
XQD Naval Research Laboratory Max. power applied 23.6 kc/s	12
XQC Non-Resonant N.R.L. Max. power applied 20 kc/s	.53
XQB (New) Naval Research Laboratory Max. power applied 21 kc/s Estimated 1500 volts	4 10
XQB (Old) Naval Research Laboratory Max. power applied 22 kc/s	.91
QC-? Submarine Signal Company "High Power" 24 kc/s	3.5
QB Submarine Signal Company (Power not specified) 24 kc/s	.91

COLUMN	1	2	3	4	5	6	7	8	9	10	11
PROJECTORS NOW CONSIDERED OBSOLETE BY BU. OF ENG.	RESONANT FREQUENCY f_o KILOCYCLES PER SECOND	BAND WIDTH Δf KILOCYCLES PER SECOND	MECHANICAL SELECTIVITY $\frac{f_o}{\Delta f}$	THEORETICAL BEAM WIDTH ANGULAR DEGREES	MEASURED BEAM WIDTH ANGULAR DEGREES	MAXIMUM SECONDARY LOBE DECIBELS BELOW AXIAL INTENSITY	TOTAL SOUND OUTPUT WATTS	FACE RADIATION IN WATTS PER Cm^2.	AXIAL INTENSITY AT 160'(IDEAL) MICROWATTS PER Cm^2.	TOTAL SOUND OUTPUT RATIO TO QC-5 "HP"	AXIAL INTENSITY AT 160'(IDEAL) RATIO TO QC-5 "HP"
XQA - NAVAL RESEARCH LABORATORY FACE DIAMETER - - - - $14\frac{3}{4}$" WINDOW - - - - - - - None CURRENT (A.C.- - - 1.5 A. (D.C.- - - None	29.8	[1.1]	[27]	18.9°	31°	22	45	.041	83	1.4	2.4
XQC - NAVAL RESEARCH LABORATORY FACE AREA - - - - $10\frac{1}{2}$ x $10\frac{1}{2}$ WINDOW- - - - - - Nons CURRENT (A.C. - - 2 Amp. (D.C. - - 7 Amp.	21	.83	25	31.1°	32°	12	88	.124	51	2.7	1.5
XQC-1 - GENERAL RADIO COMPANY FACE DIAMETER - - $14\frac{3}{4}$" WINDOW- - - - - - None CURRENT (A.C. - - .39 Amp. (D.C. - - 1.3 Amp.	24.5	[.90]	[27]	23.0°	23°	14	33	.030	40	1	1.2
XQC-1 - GENERAL RADIO COMPANY FACE DIAMETER - - $14\frac{3}{4}$" WINDOW- - - - - - None CURRENT (A.C. - - .50 Amp. (D.C. - - 1.3 Amp.	29.2	[.57]	[51]	19.2	19.5	16	18	.016	32	.55	.94

TABLE 3

Table 4

Modern and Obsolete Types of Transmitters -

Data Showing the Percent Their Radiation

is of the Maximum Possible.

Transceiver	Watts Radiated per Sq.Cm.	% of Max.	Increase Factor for Max.Output
QC-5 Submarine Signal Company "High Power" 23.6 kcs/s	.035	6%	17
QC-5B Submarine Signal Company "High Power" 17.5 kc/s	.056	9%	11
XQD Naval Research Laboratory Max.power applied 23.6 kc/s	.186	31%	3
XQC Non-Resonant Nav.Res.Lab. Max.power applied 20 kc/s	.018	3%	33
XQB (New) Naval Res.Lab. Max.power applied (861V.) 21 kc/s	.052	9%	11
1500 V. (Estimate) 21 kc/s	(.162)	27%	4
XQB (Old) Nav.Res.Lab. Max.power applied 22 kc/s	.028	5%	20
XQA Naval Research Laboratory Optimum Power 29.8 kc/s	.041	7%	14
XQC Resonant Nav.Res.Lab. Optimum Power 21 kc/s	.124	20%	5
XQC-1 General Radio Company Optimum Power 24.5 kc/s	.030	5%	20
Optimum Power 29.2 kc/s	.016	3%	33

Table 6

Test Ratings of Both Modern and Obsolete Types

Sound Transmitters

Transceiver	Relative Axial Sound Intensity at 180' (Ratio to QC-5 "HP")
XQD Naval Research Laboratory Max. power applied 23.6 kc/s	12
XQB (New) Naval Research Laboratory Max.power applied (861 V.) 21 kc/s Estimated for 1500 volts	4 10
XQA Naval Research Laboratory Optimum power 29.8 kc/s	2.4
QC-5B Submarine Signal Company "High Power" 17.5 kc/s	1.8
XQC Resonant Nav.Res.Lab. Optimum Power 21 kc/s	1.6
XQC-1 General Radio Company Optimum power 24.5 kc/s	1.2
QC-5 Submarine Signal Company "High Power" 23.6 kc/s	1
XQB (Old) Naval Research Laboratory Max.power applied 22 kc/s	.01
XQC Non-Resonant Nav.Res. Lab. Max. power applied 20 kc/s	.53

Table 1a

Noise on D-2 Transceiver and Boonton Amplifier

Condition	Sound Rooms Forward	Main	Aft
Speed at which propeller turns can first be definitely counted	12 kts	8 kts	5 kts
Speed for measurable level	-	18 "	12 "
Speed at which propeller rhythm disappears and becomes "static"	22 "	20 "	12 "
Intensity of sharp peaks above average noise	5-10 db	5-10 db	10-15 db

NOTES: (a) The port propeller was much noisier than the starboard.

(b) When listening in the after sound room there is an increase in sound when the propellers are accurately synchronized.

(c) The noise increased about 6 db when the frequency was changed from 15 to 20 kilocycles but this was partly receiver sensitivity.

(d) Raising the D-2 tube had little effect until the transceiver was almost completely housed.

(e) The intensity and duration of the sharp peaks were increased by roll or pitch of the ship.

8	9	10
Internal Impedance - Ohms	$\sqrt{\text{Internal Impedance}}$	Relative Sensitivity (Ratio to QC-5) (with ideal step-up circuits)
125	11.2	1
125	11.2	2.3
14	3.74	4.3
189	13.8	.48
225	15.0	.67
272	16.5	.38
1500	38.7	19
1400	37.4	14
240	15.5	8.0
220	14.8	2.4

TABLE 5

COLUMN	1	2	3	4	5	6	7
RECEIVERS	Polarization or Field Current Amperes - D.C.	Maximum Open Circuit Sensitivity Microvolts per Bar	Resonant Frequency - f_0 Kilocycles per Second	Band Width - Δf Kilocycles per Second	Mechanical Selectivity - $f_0/\Delta f$	Transmitting Frequency Kilocycles per Second	Open Circuit Sensitivity Microvolts per Bar
QC-5 Magnetostriction Submarine Signal Co.	5.4	12.6	24.2	1.61	15	23.6	11.2
QC-5B Magnetostriction Submarine Signal Co.	6.0	27.8	17.1	1.52	11	17.5	26.0
XQD (New) Electrodynamic Naval Research Laboratory	5.0	17.2	23.65	.16	147	23.6	16.2
XQC (New) Magnetostriction (Non-Resonant) Naval Research Laboratory	4.5					20	6.6
Ditto	4.5	10.0	24			24	10.0
Ditto	4.5					29	6.2
XQB (New) Rochelle Salt Naval Research Laboratory		>1300	<15			21	750
Ditto						24	509
XQB (Old) Rochelle Salt Naval Research Laboratory		124	22			22	124
Ditto						29	36

Table 2a

Comparison of Symmetrical Bearings

QC-5 24 kilocycles in Starboard Well Port Tube Up

Bearings	DB Difference 25 knots	20 knots
20 - 340	-1	+1
40 - 320	-1	0
60 - 300	-2	0
80 - 280	-5	-5
90 - 270	-1	-1
100 - 260	-3	-5
120 - 240	+1	0
140 - 220	-2	+1
160 - 200	-1	+2
	Avg -2	-1

Table 3a

Effect of Turbulence from Port Tube

when listening on QC-5 in Starboard Well

Bearing	Difference in decibels between lowered and raised positions 25 knots	20 knots
300	+2	0
280	+1	0
270	+5	+4
260	+5	+2
240	+2	0

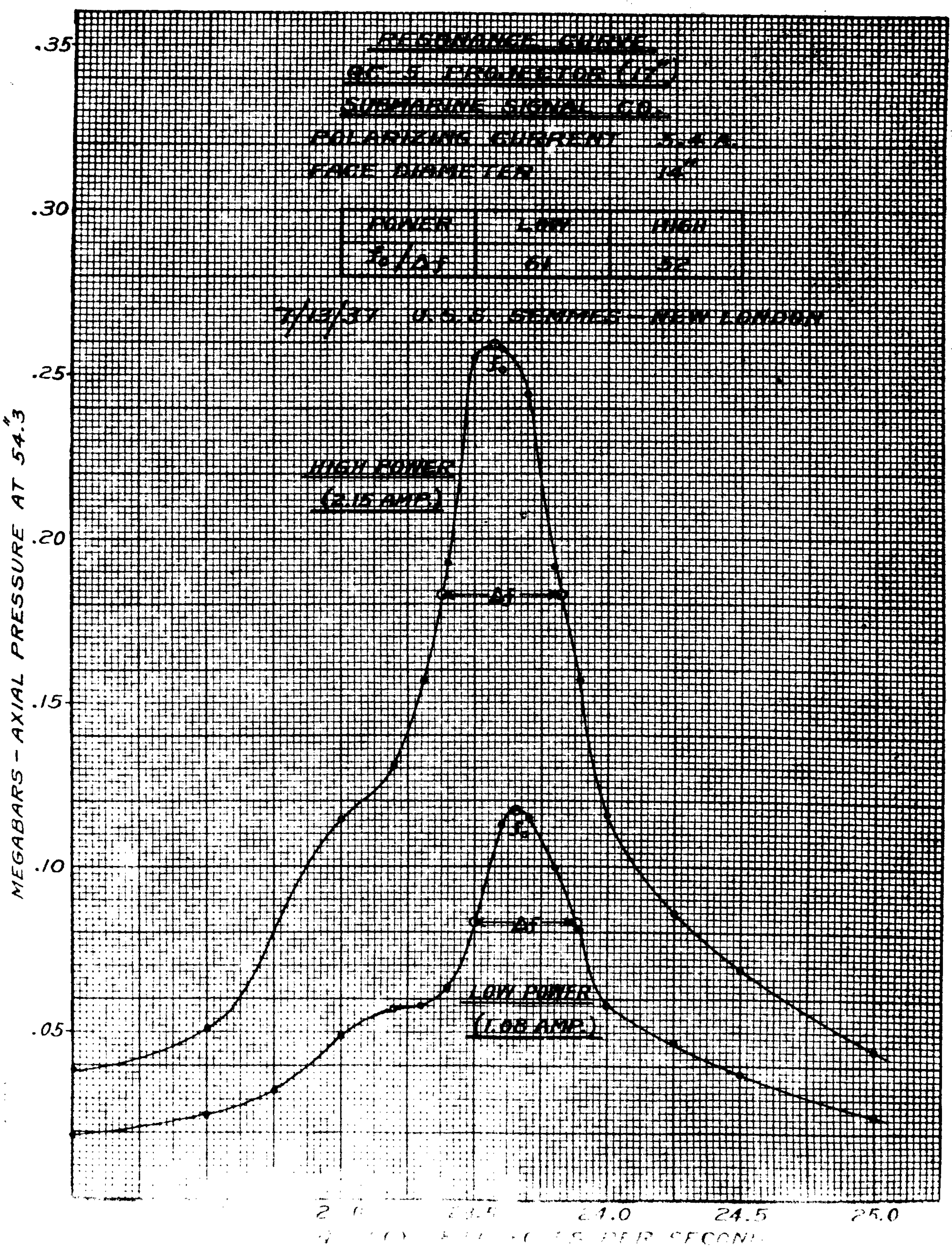
Table 4a

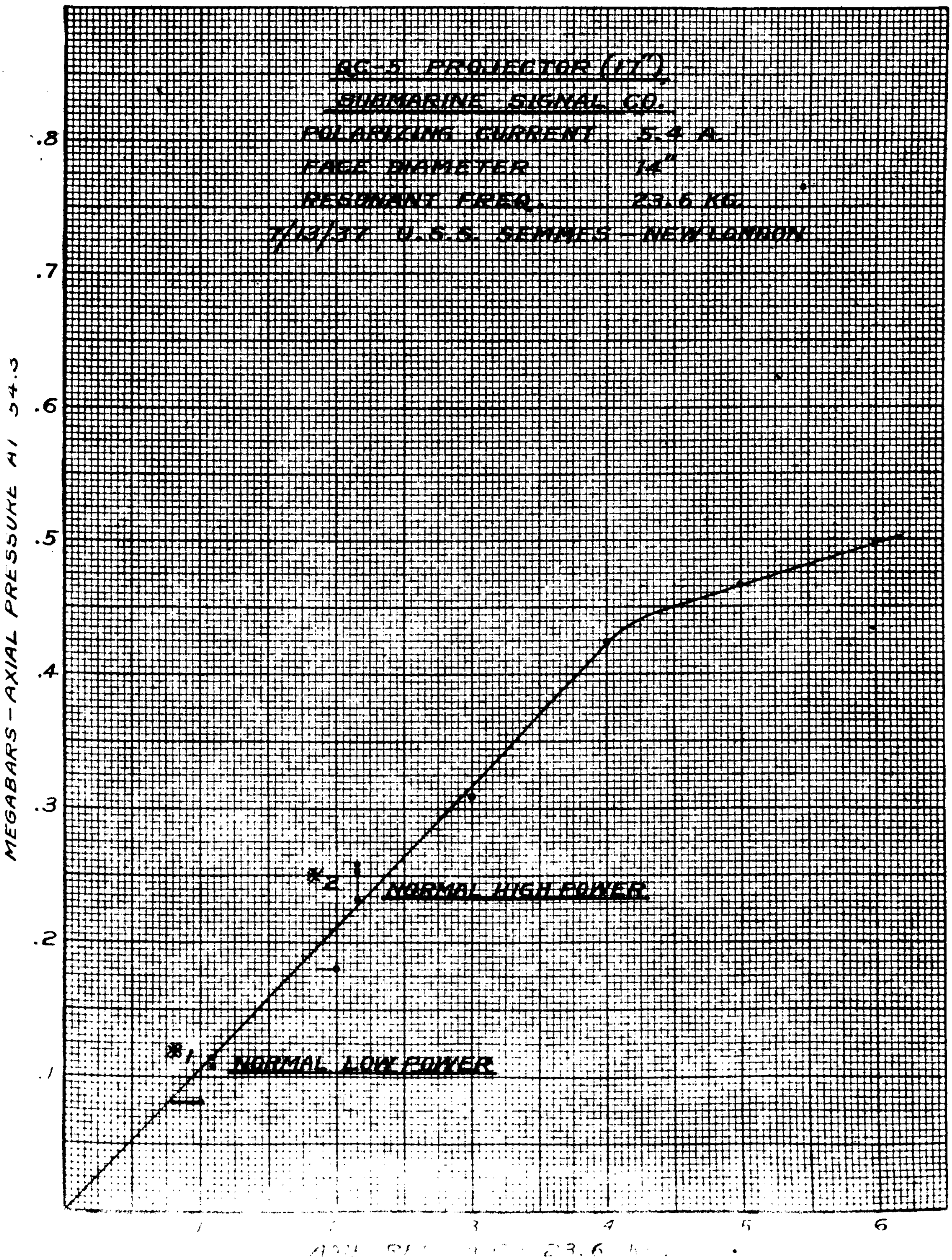
Ratios of Propeller and Turbulence Noises

Speed	Bearing	Observed DBt	Observed DBa	Calculated Ratios: Propellers/Turbulence	Calculated Ratios: Propellers Astern/Ahead	Calculated Ratios: Turbulence Astern/Ahead
16 kts	0	-2.0	15.5	28.4		
	180	12.5	25.5	1[illegible].6	1[illegible].5	[illegible]
18	0	15.0	27.0	14.9		
	180	32.5	38.0	[illegible].3	1[illegible]	5[illegible].4
20	0	27.0	33.5	2.5		
	180	44.5	48.5	1.5	[illegible]4.0	56.4
22	0	35.0	37.5	1.8		
	180	55.0	56.0	1.03	57	100.0
23	0	38.0	39.0	0.76		
	180	58.0	58.5	0.12	46	100.0

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D.C.

DATE




PROJECTOR
SUBMARINE SIGNAL CO.
POLARIZING CURRENT 5.4 A.
FACE DIAMETER 14"
RESONANT FREQ. 23.6 KC.
7/13/37 U.S.S. SEMMES - NEW LONDON
*2 NORMAL HIGH POWER
*1 NORMAL LOW POWER
MEGABARS - AXIAL PRESSURE AT
.8
.7
.6
.5
.4
.3
.2
.1
1
2
3
4
5
6
23.6

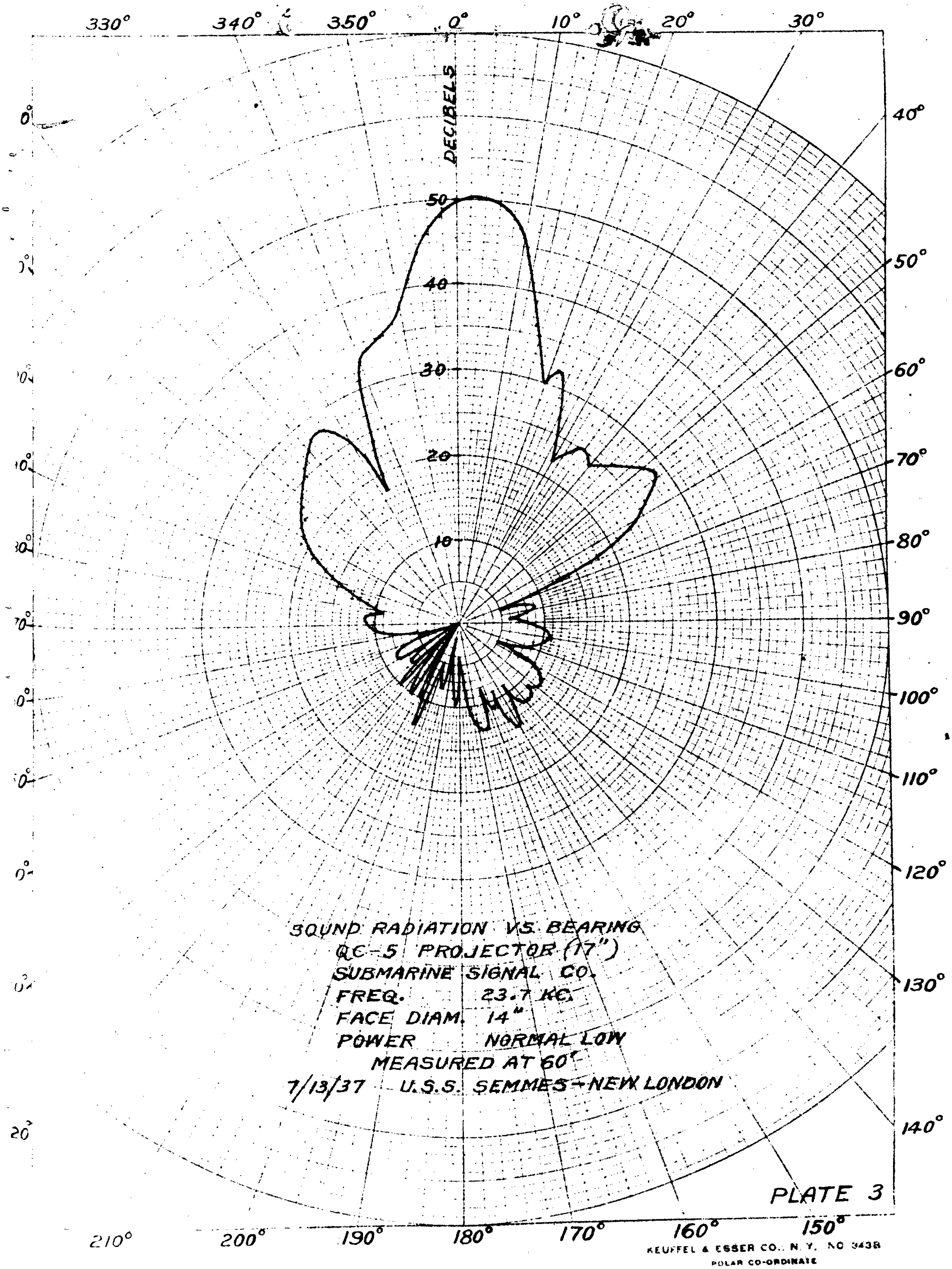

SOUND RADIATION VS. BEARING
QC-5 PROJECTOR (17")
SUBMARINE SIGNAL CO.
FREQ. 23.7 KC.
FACE DIAM. 14"
POWER NORMAL LOW
MEASURED AT 60'
7/13/37 U.S.S. SEMMES - NEW LONDON
DECIBELS
10
20
30
40
50
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
330°
340°
350°
KEUFFEL & ESSER CO., N. Y. NO 343B
POLAR CO-ORDINATE

PLATE 3

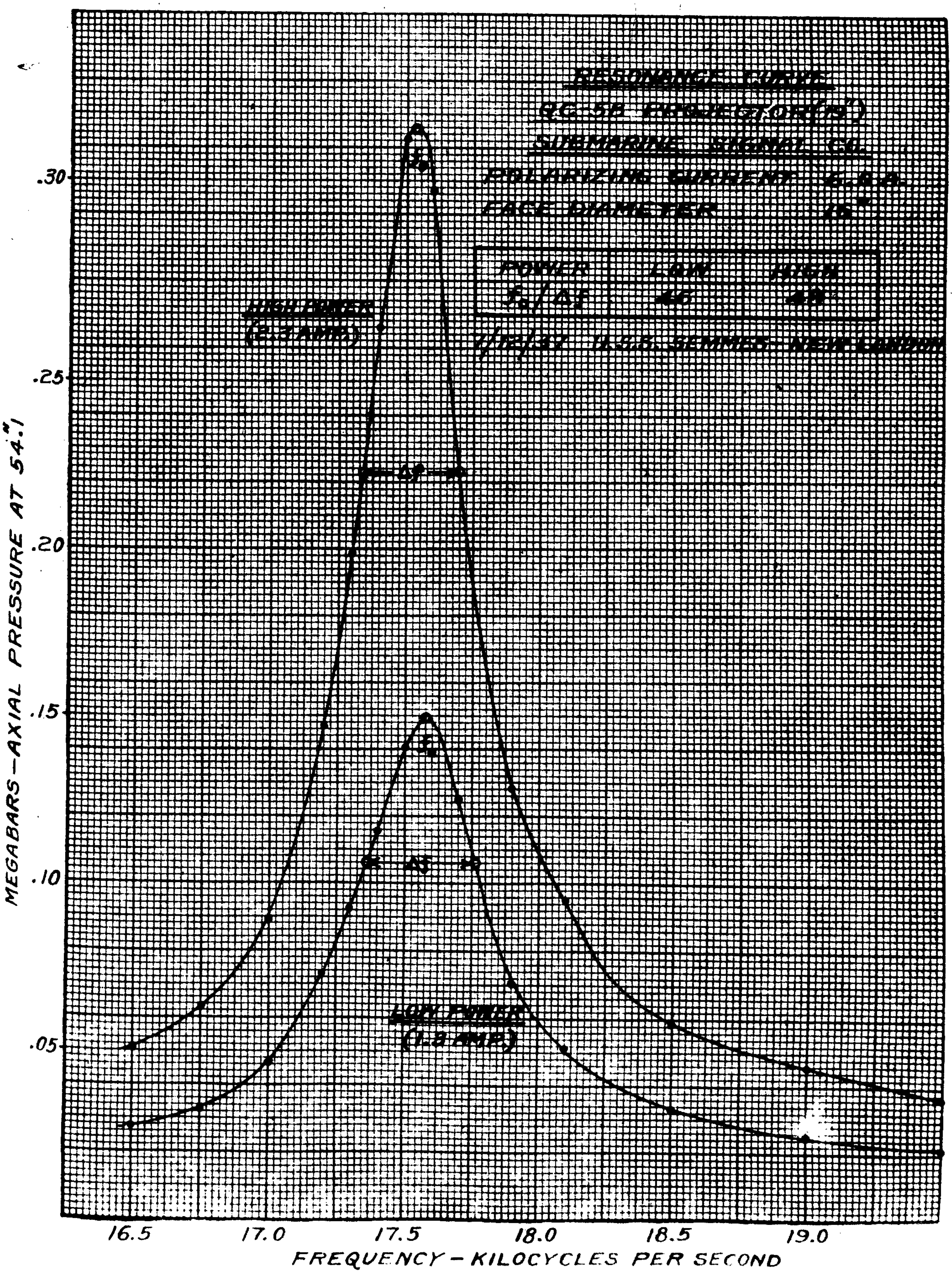

RESONANCE CURVE
SUBMARINE SIGNAL CO.
POWER
LOW
HIGH
HIGH POWER
LOW POWER
.30
.25
.20
.15
.10
.05
MEGABARS–AXIAL PRESSURE AT 54.1"
16.5
17.0
17.5
18.0
18.5
19.0
FREQUENCY – KILOCYCLES PER SECOND

PLATE 4

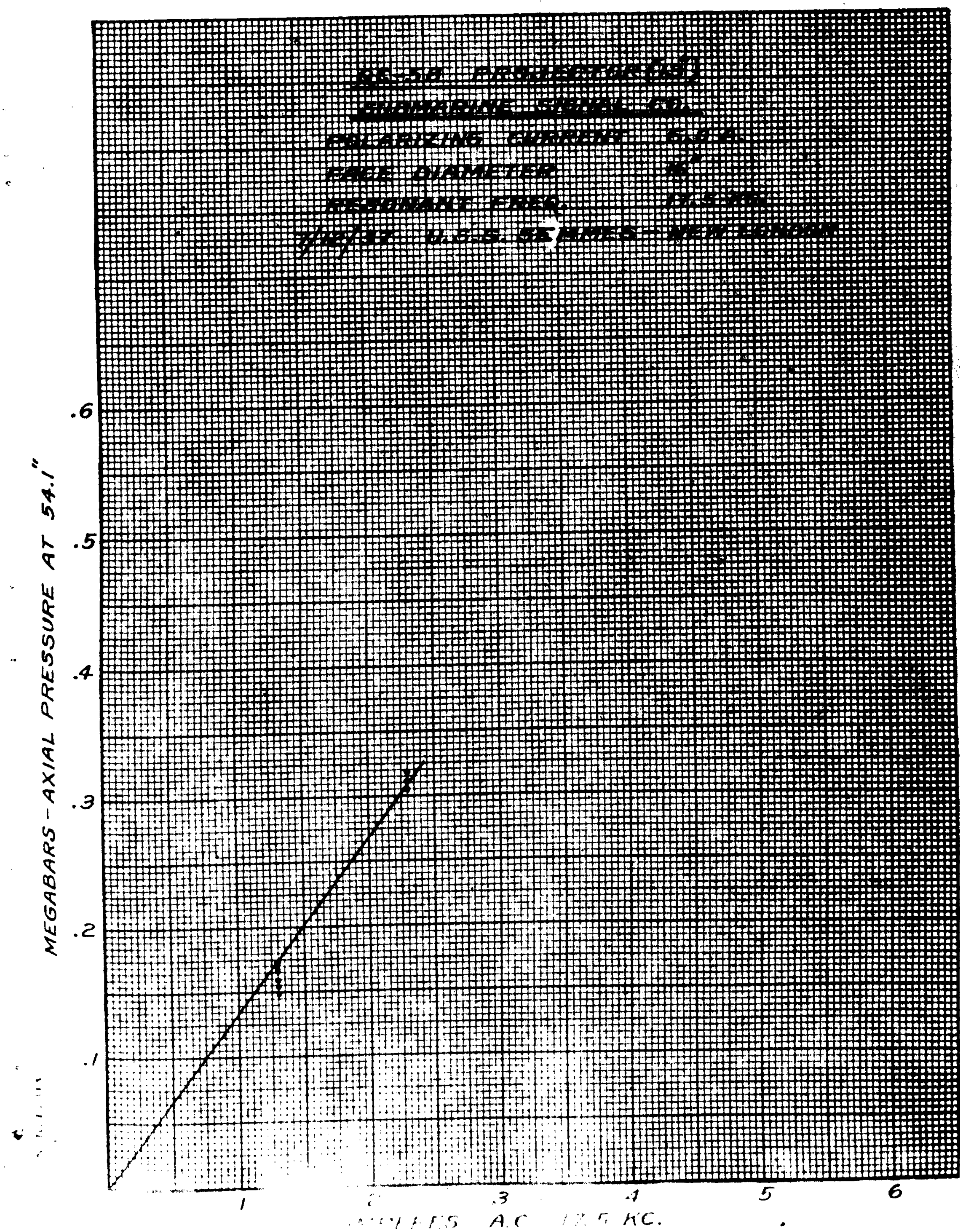

POLARIZING CURRENT
FACE DIAMETER
RESONANT FREQ.
MEGABARS - AXIAL PRESSURE AT 54.1"
.1
.2
.3
.4
.5
.6
1
2
3
4
5
6
KC.

PLATE 5

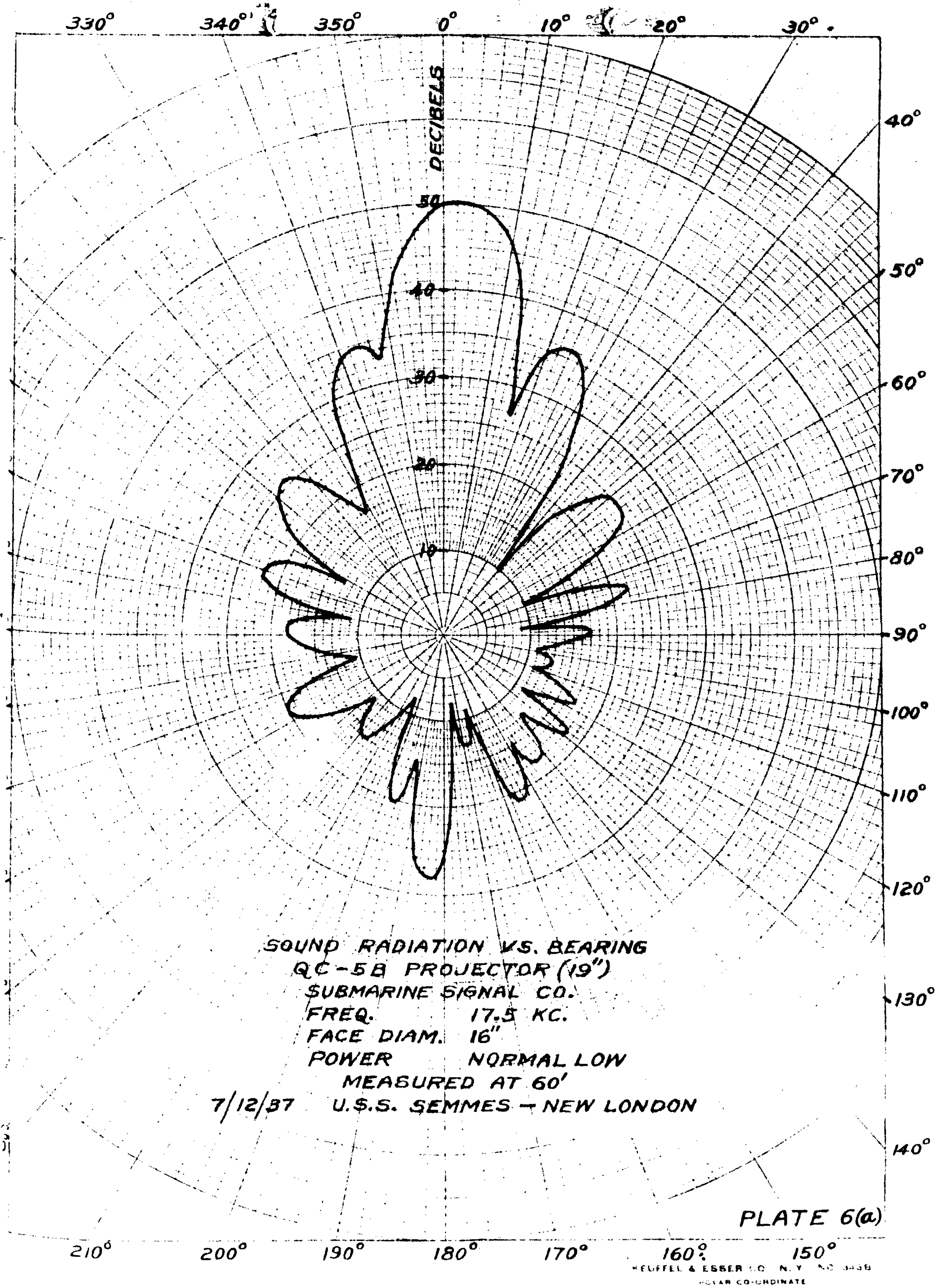

330° 340° 350° 0° 10° 20° 30°
40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140°
210° 200° 190° 180° 170° 160° 150°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
QC-5B PROJECTOR (19")
SUBMARINE SIGNAL CO.
FREQ. 17.5 KC.
FACE DIAM. 16"
POWER NORMAL LOW
MEASURED AT 60'
7/12/37 U.S.S. SEMMES – NEW LONDON
KEUFFEL & ESSER CO. N.Y.
POLAR CO-ORDINATE

PLATE 6(a)

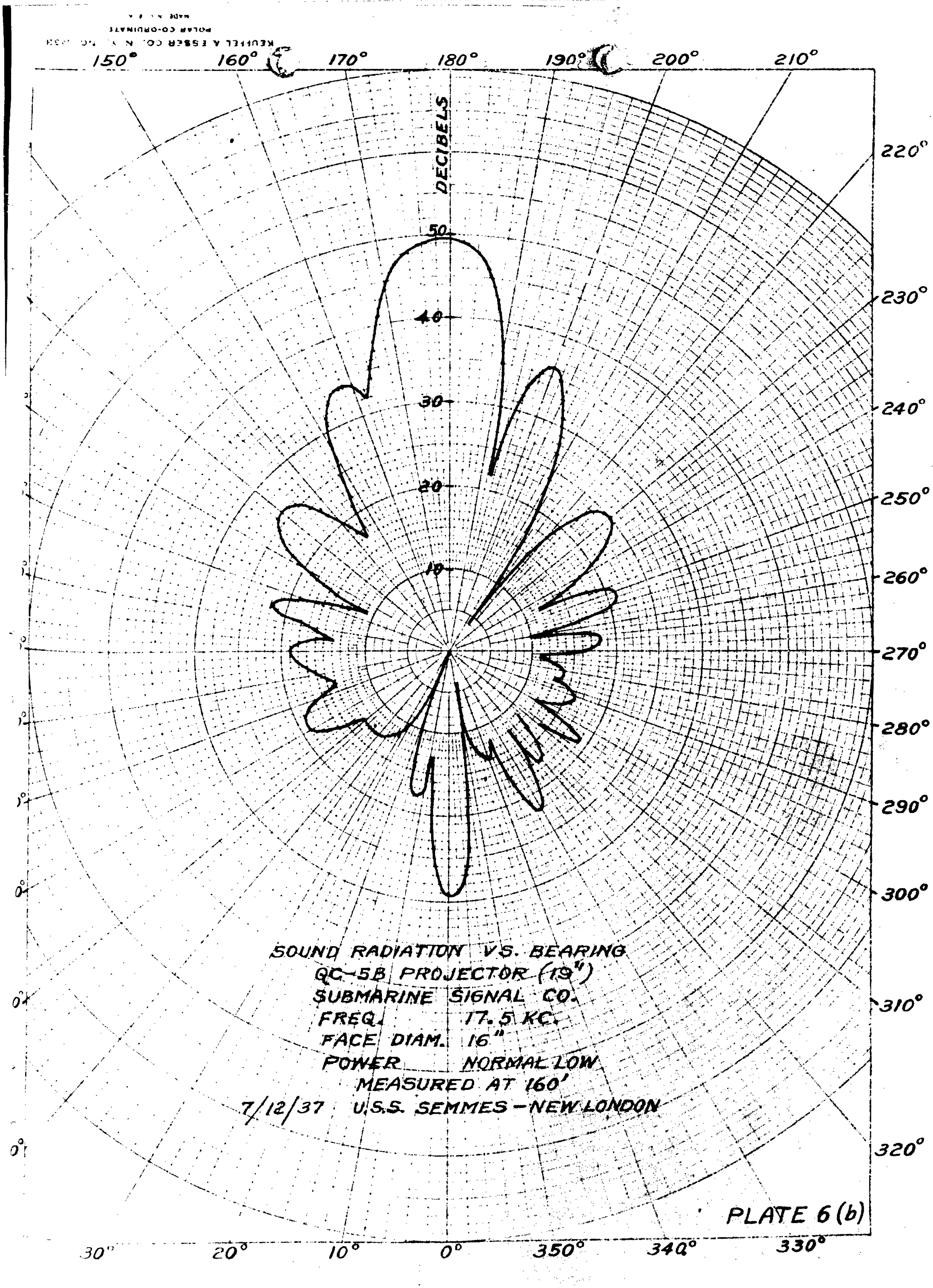
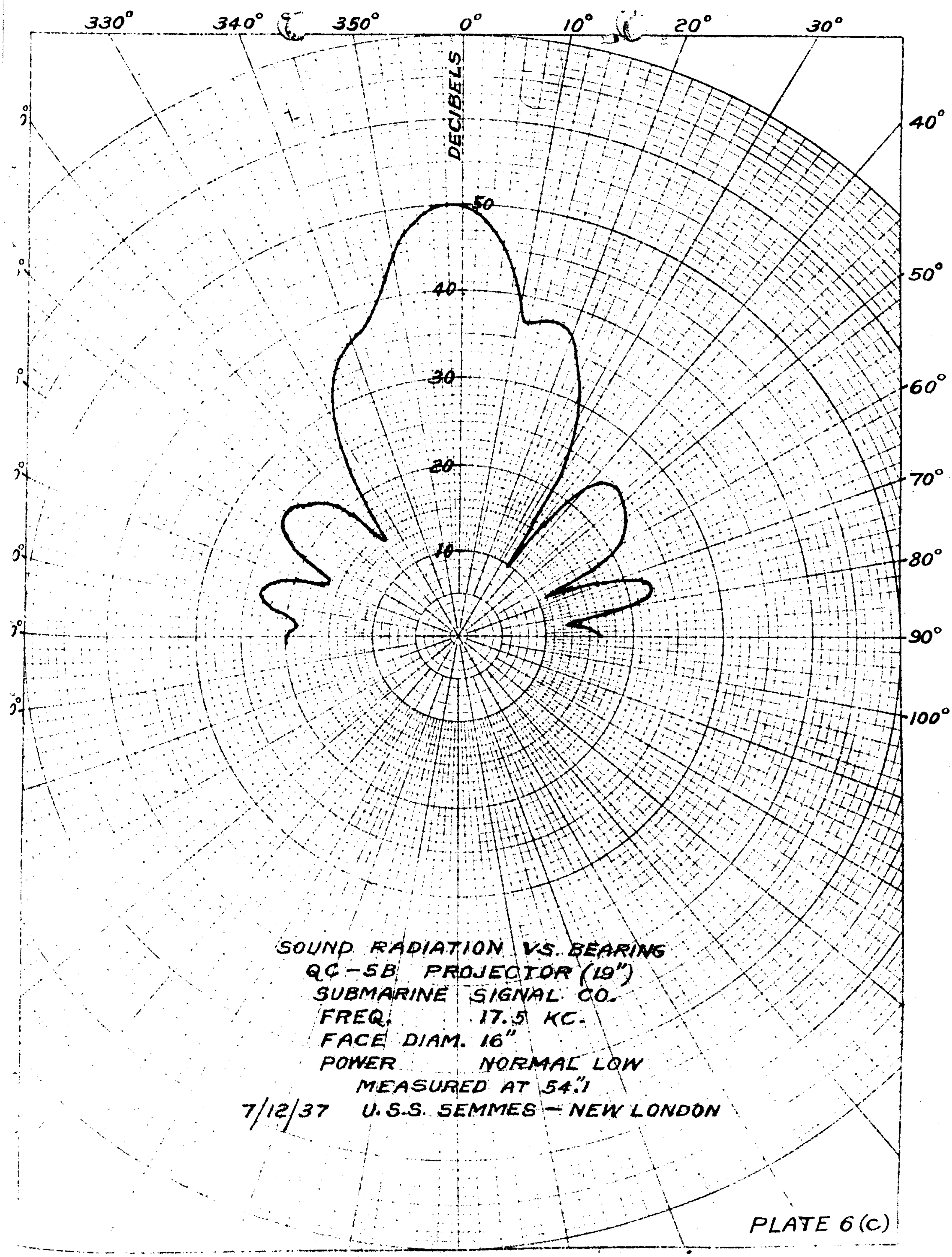

150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°
0°
10°
20°
30°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
QC-5B PROJECTOR (19")
SUBMARINE SIGNAL CO.
FREQ. 17.5 KC.
FACE DIAM. 16"
POWER NORMAL LOW
MEASURED AT 160'
7/12/37 U.S.S. SEMMES—NEW LONDON

PLATE 6 (b)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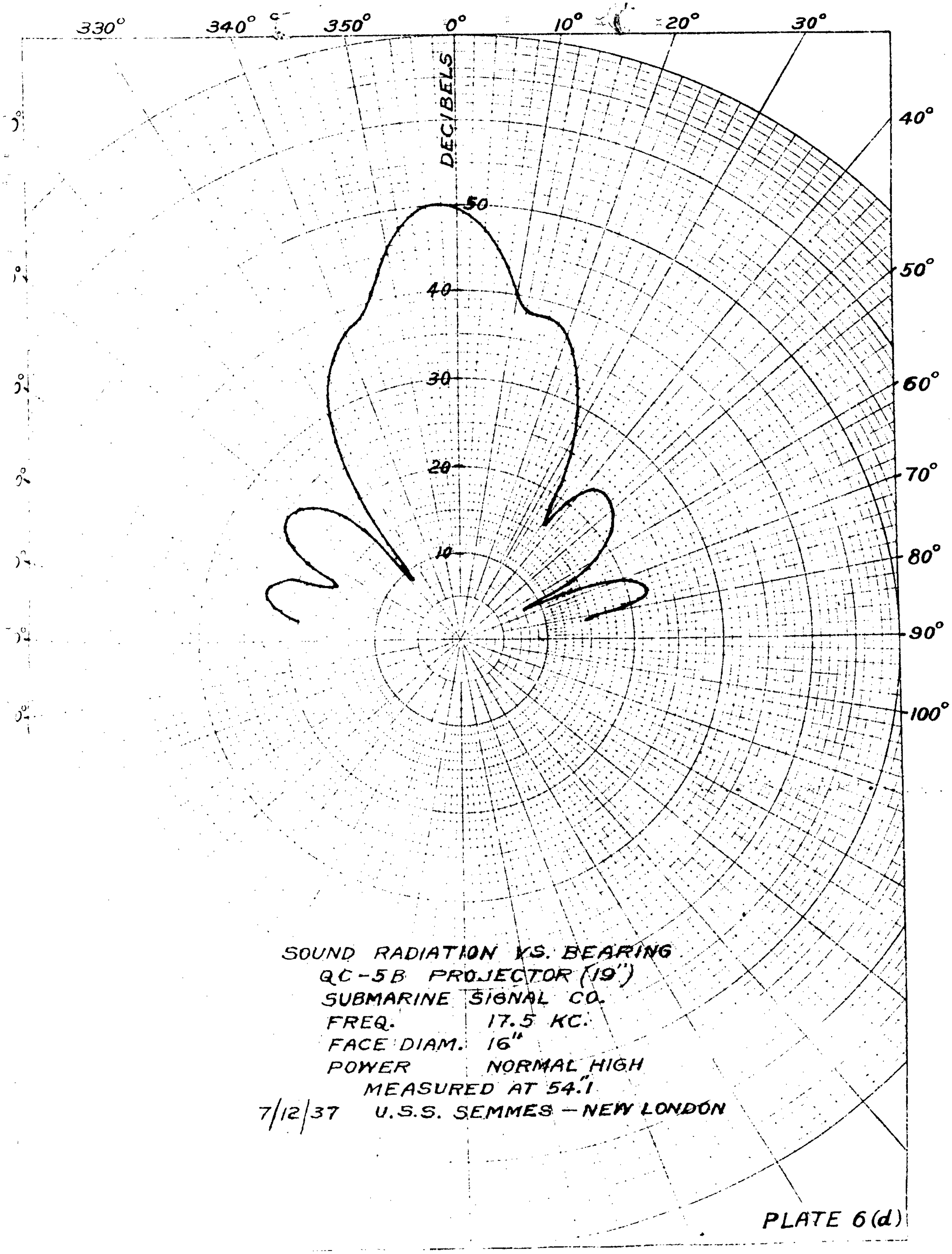
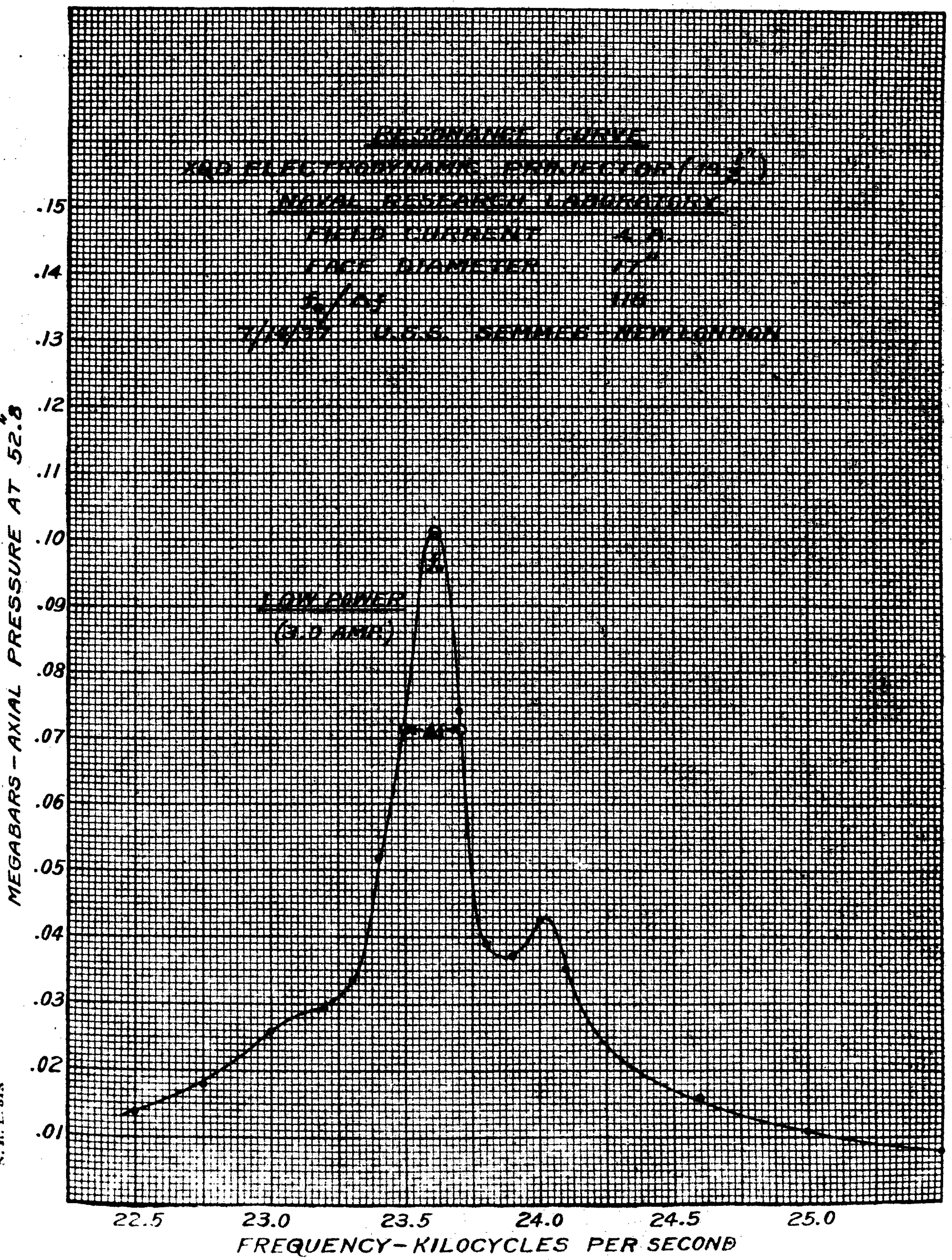
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
QC-5B PROJECTOR (19")
SUBMARINE SIGNAL CO.
FREQ. 17.5 KC.
FACE DIAM. 16"
POWER NORMAL LOW
MEASURED AT 54'.1
7/12/37 U.S.S. SEMMES – NEW LONDON

PLATE 6 (c)



SOUND RADIATION VS. BEARING
QC-5B PROJECTOR (19")
SUBMARINE SIGNAL CO.
FREQ. 17.5 KC.
FACE DIAM. 16"
POWER NORMAL HIGH
MEASURED AT 54.1
7/12/37 U.S.S. SEMMES – NEW LONDON

PLATE 6(d)


RESONANCE CURVE
NAVAL RESEARCH LABORATORY
FIELD CURRENT 4 A.
FACE DIAMETER 17"
7/14/37 U.S.S. SEMMES - NEW LONDON
LOW POWER
(3.0 AMP.)
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
22.5
23.0
23.5
24.0
24.5
25.0
MEGABARS - AXIAL PRESSURE AT 52.8"
FREQUENCY - KILOCYCLES PER SECOND

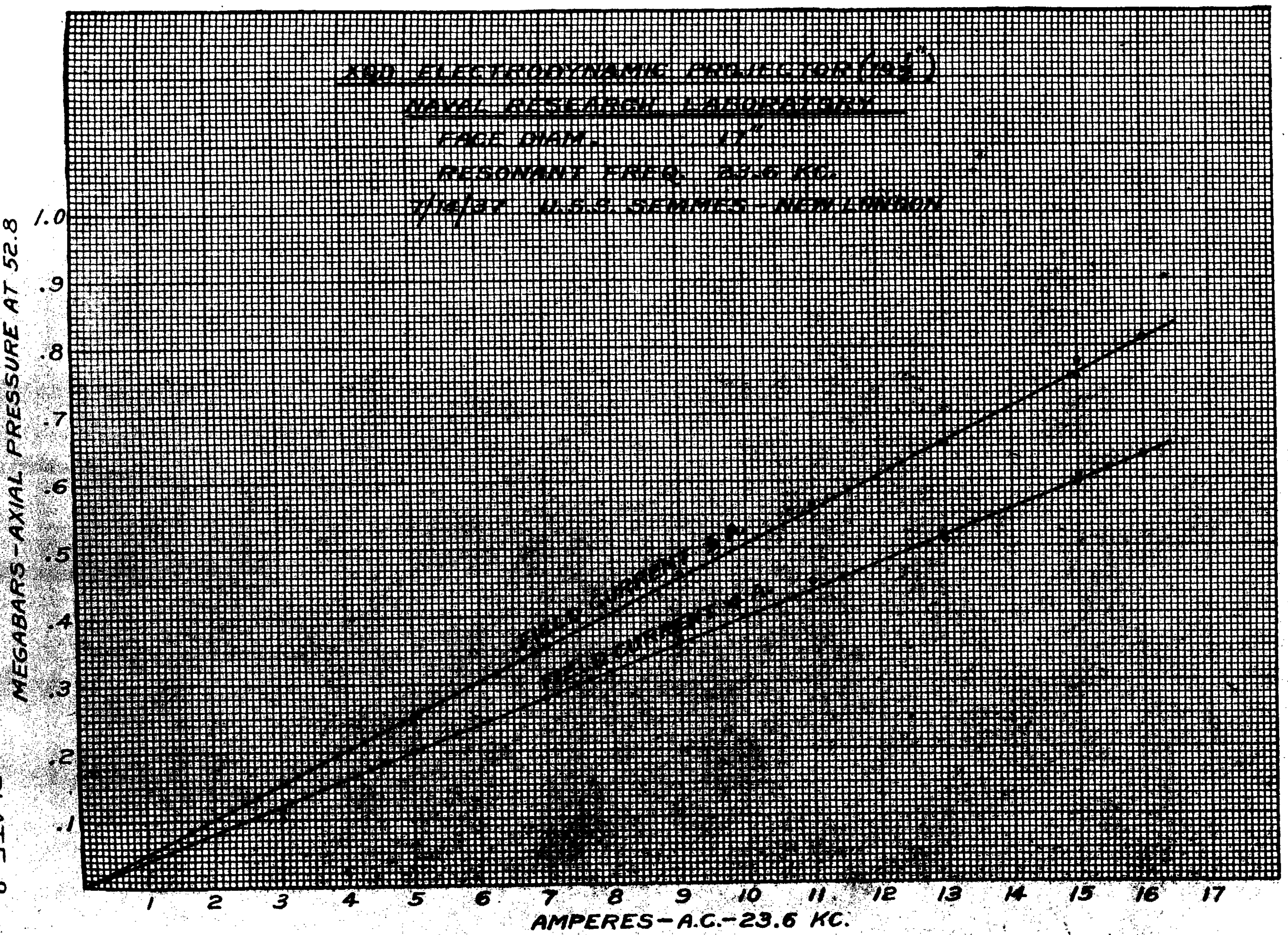
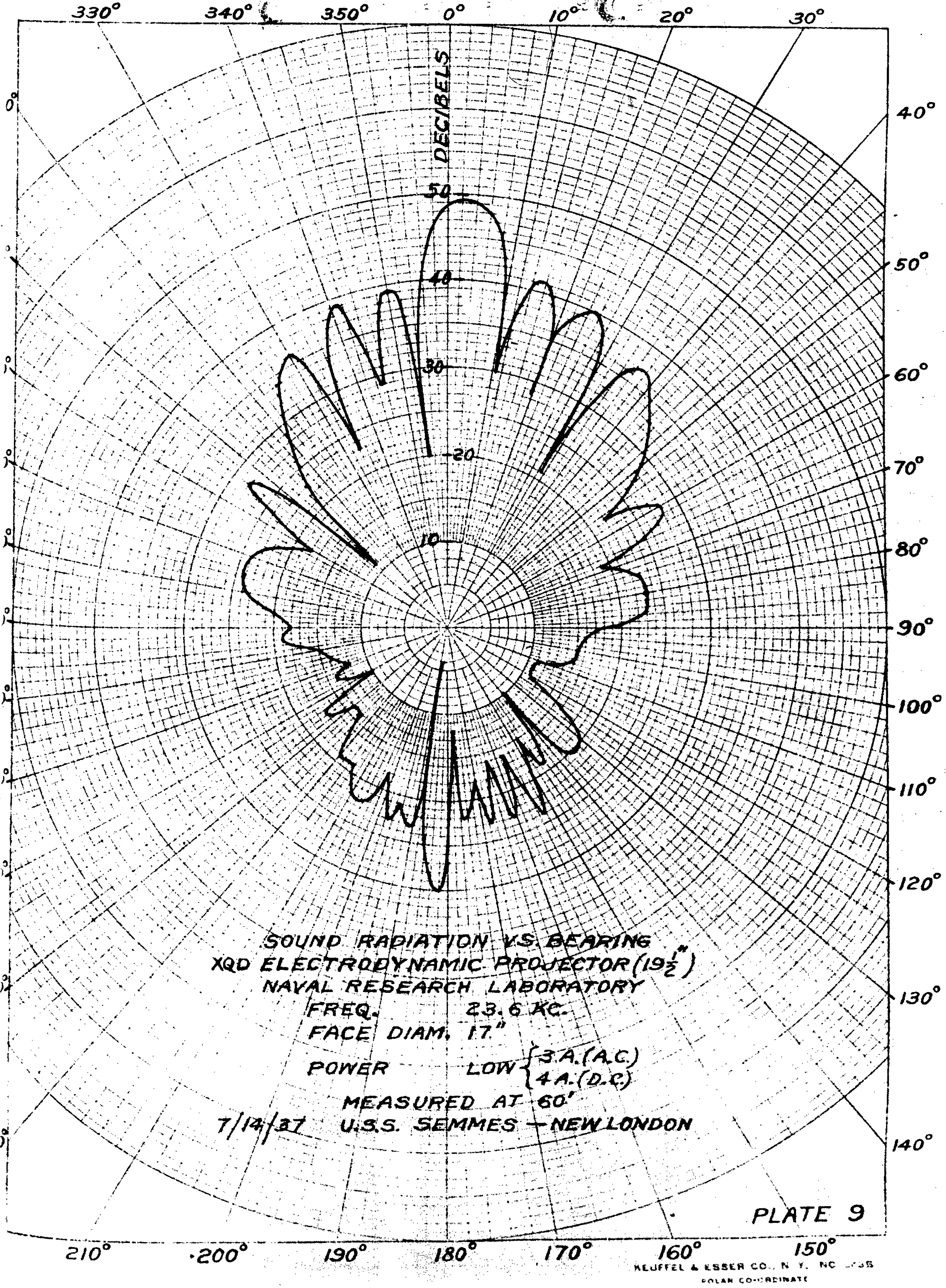

XBD ELECTRODYNAMIC PROJECTOR
NAVAL RESEARCH LABORATORY
FACE DIAM. 17"
RESONANT FREQ. 23.6 KC.
7/14/37 U.S.S. SEMMES - NEW LONDON
MEGABARS-AXIAL PRESSURE AT 52.8"
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
AMPERES-A.C.-23.6 KC.

PLATE 8



330°
340°
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10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
XQD ELECTRODYNAMIC PROJECTOR (19½")
NAVAL RESEARCH LABORATORY
FREQ. 23.6 KC.
FACE DIAM. 17"
POWER LOW {3 A. (A.C.) 4 A. (D.C.)
MEASURED AT 60'
7/14/37 U.S.S. SEMMES — NEW LONDON
PLATE 9
KEUFFEL & ESSER CO., N. Y.
POLAR CO-ORDINATE

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

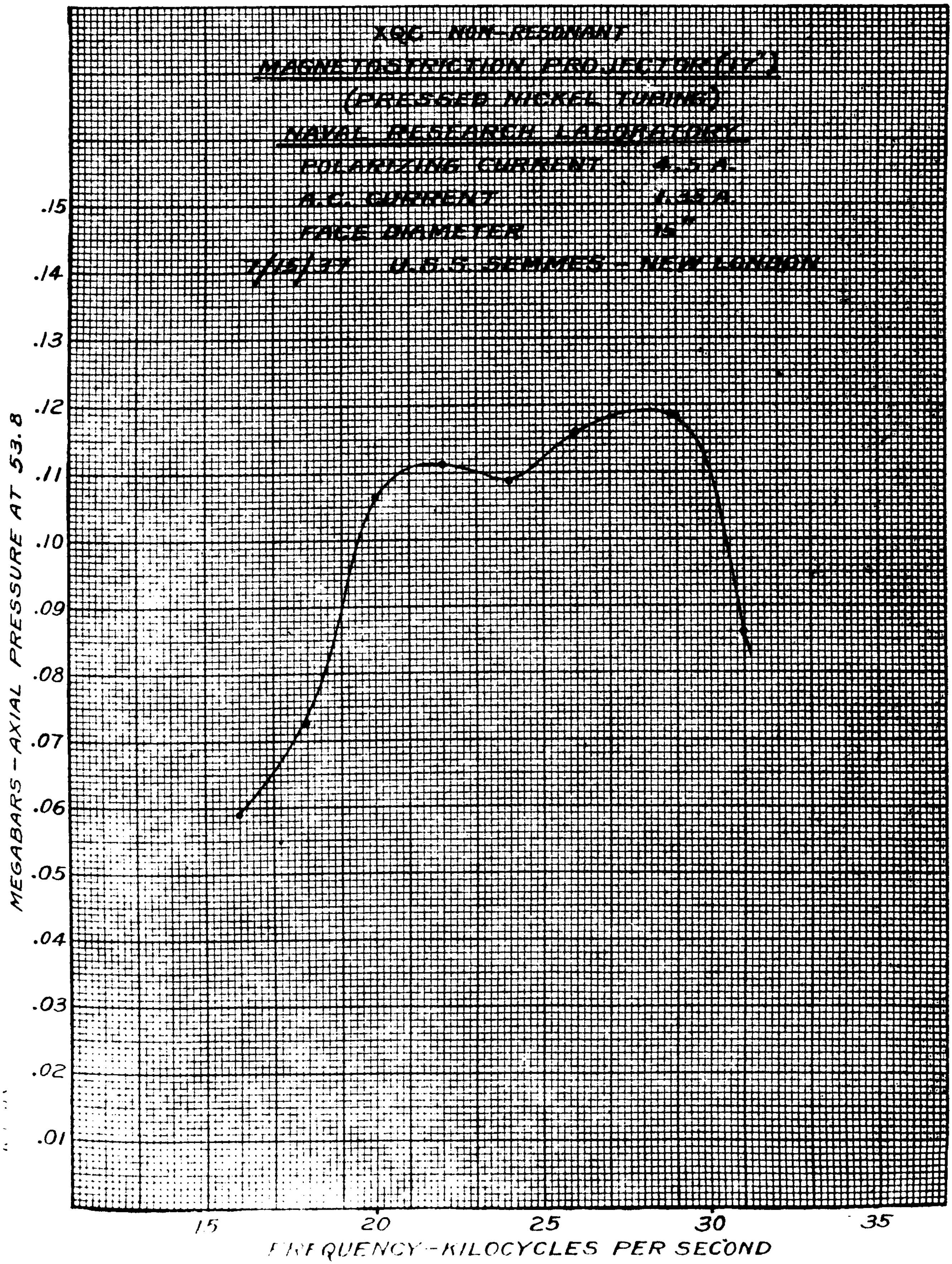
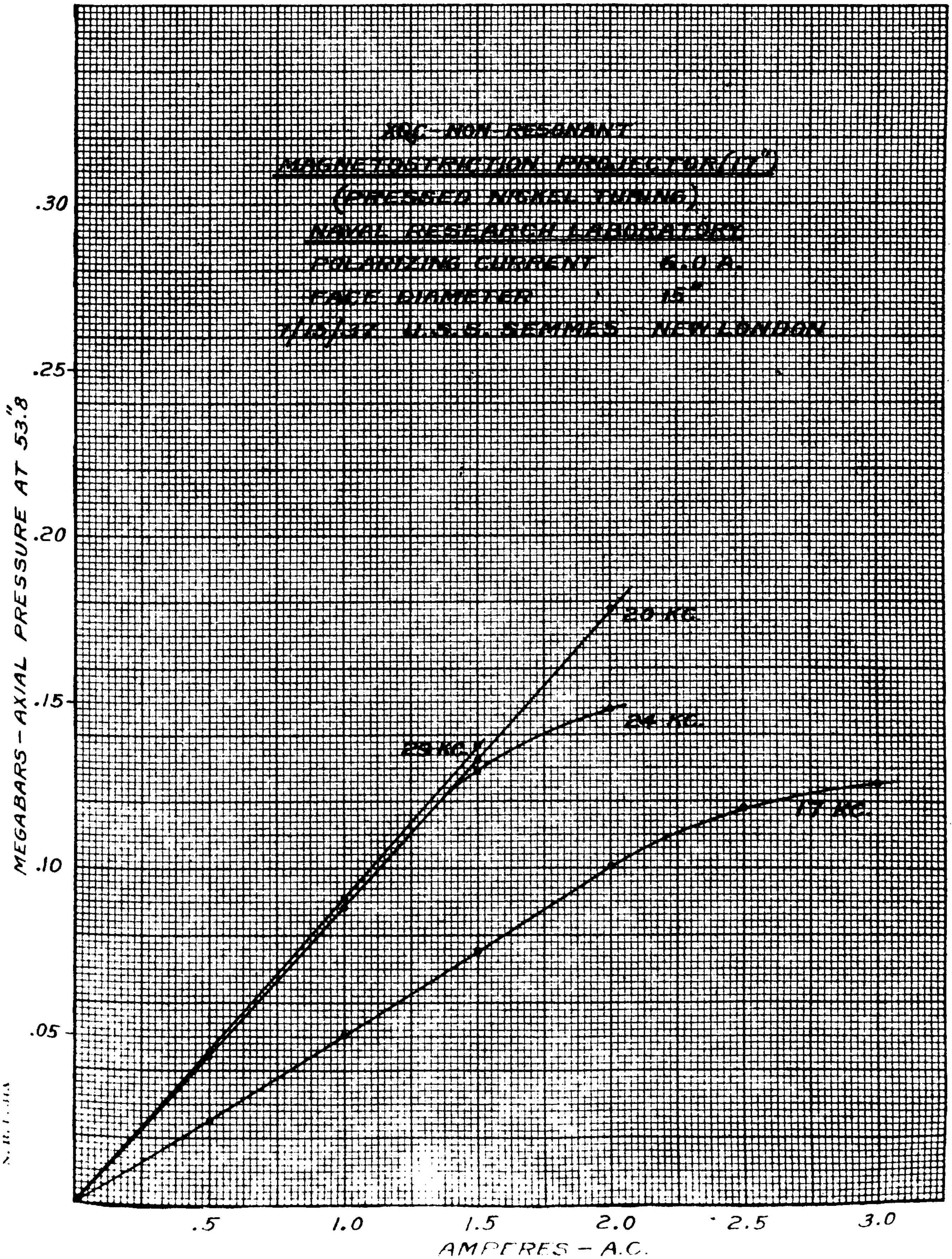
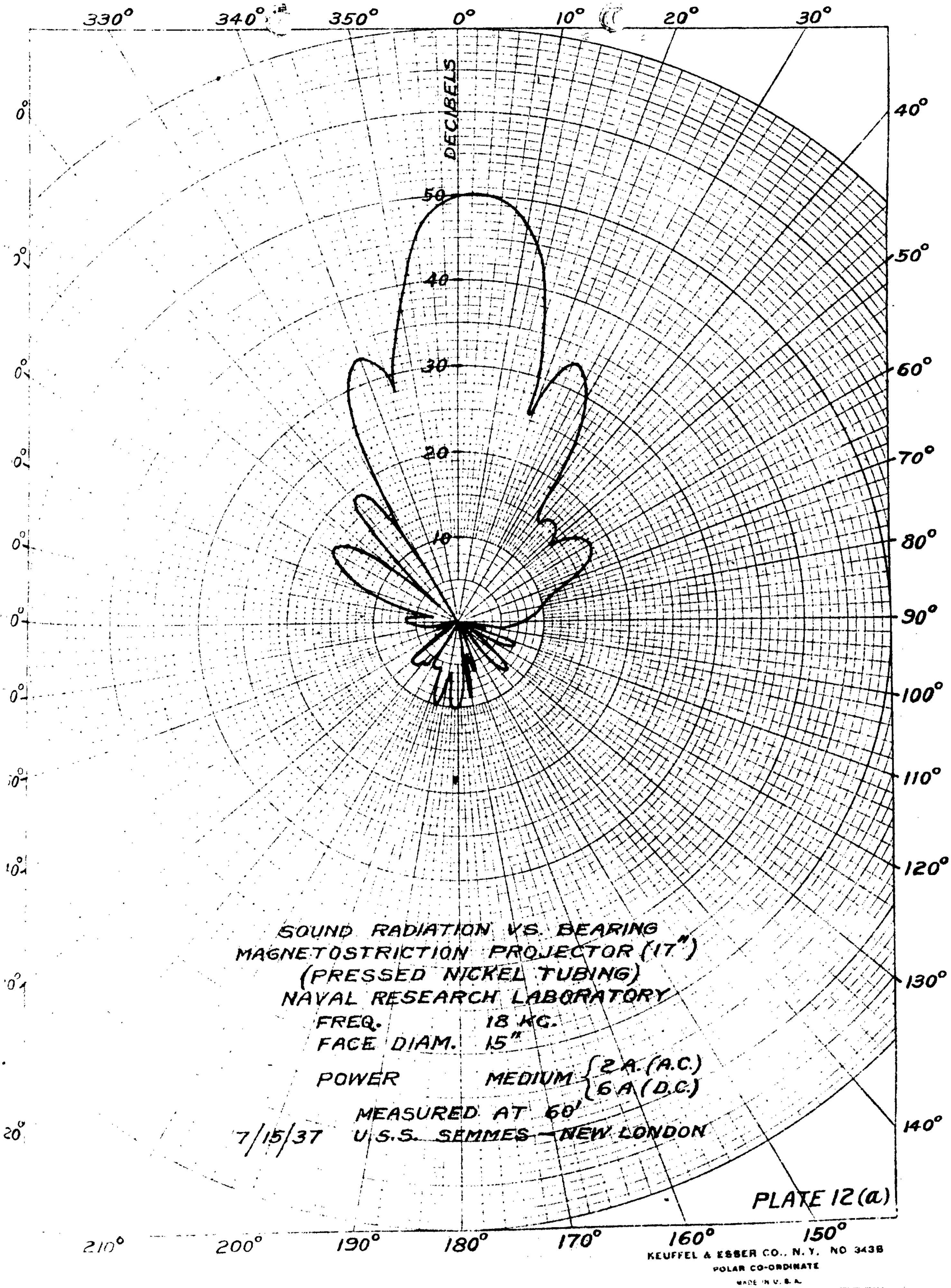


PLATE 10


XRC NON-RESONANT
MAGNETOSTRICTION PROJECTOR (17")
(PRESSED NICKEL TUBING)
NAVAL RESEARCH LABORATORY
POLARIZING CURRENT 6.0 A.
FACE DIAMETER 15"
7/15/37 U.S.S. SEMMES NEW LONDON
20 KC.
24 KC.
29 KC.
17 KC.
MEGABARS - AXIAL PRESSURE AT 53.8"
.30
.25
.20
.15
.10
.05
.5
1.0
1.5
2.0
2.5
3.0
AMPERES - A.C.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30°
40°
50°
60°
70°
80°
90°
100°
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120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
MAGNETOSTRICTION PROJECTOR (17")
(PRESSED NICKEL TUBING)
NAVAL RESEARCH LABORATORY
FREQ. 18 KC.
FACE DIAM. 15"
POWER MEDIUM { 2 A. (A.C.) 6 A (D.C.)
MEASURED AT 60'
7/15/37 U.S.S. SEMMES — NEW LONDON
KEUFFEL & ESSER CO., N.Y. NO 343B
POLAR CO-ORDINATE
MADE IN U.S.A.

PLATE 12(a)

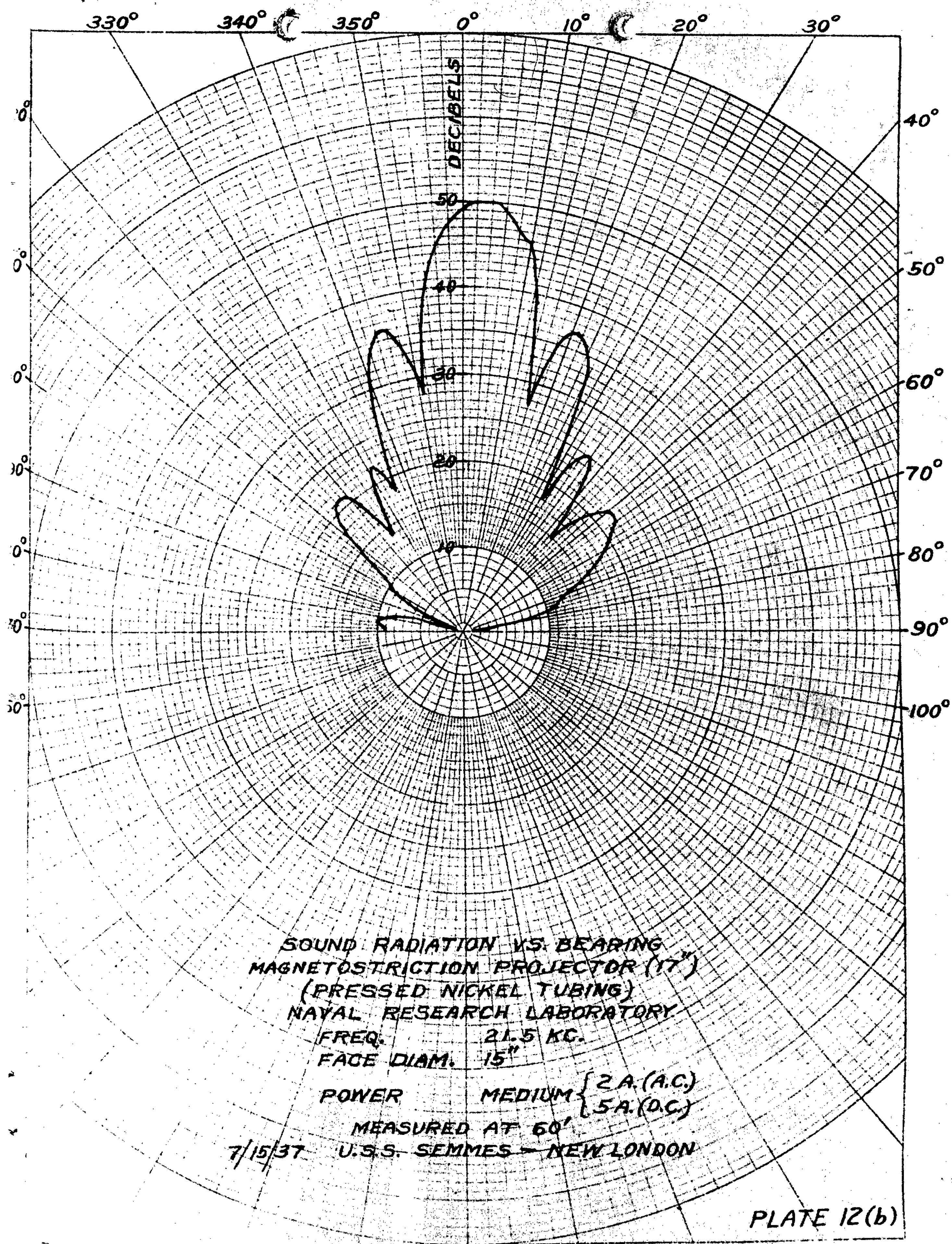

330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
MAGNETOSTRICTION PROJECTOR (17")
(PRESSED NICKEL TUBING)
NAVAL RESEARCH LABORATORY
FREQ. 21.5 KC.
FACE DIAM. 15"
POWER MEDIUM { 2 A. (A.C.) / 5 A. (D.C.)
MEASURED AT 60'
7/15/37 U.S.S. SEMMES – NEW LONDON

PLATE 12(b)

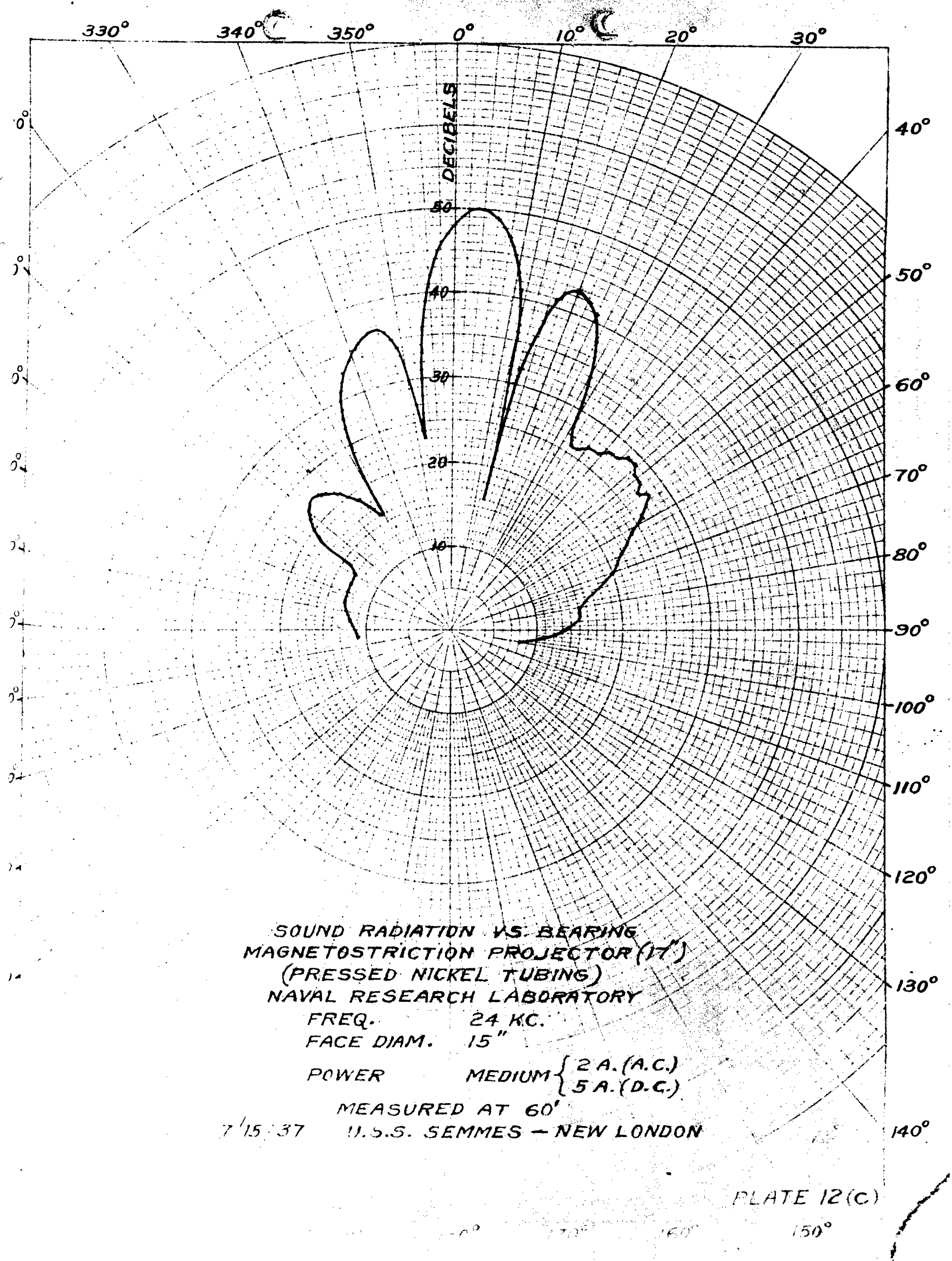

330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
MAGNETOSTRICTION PROJECTOR (17")
(PRESSED NICKEL TUBING)
NAVAL RESEARCH LABORATORY
FREQ. 24 KC.
FACE DIAM. 15"
POWER MEDIUM { 2 A. (A.C.) 5 A. (D.C.)
MEASURED AT 60'
7/15/37 U.S.S. SEMMES — NEW LONDON

PLATE 12(c)

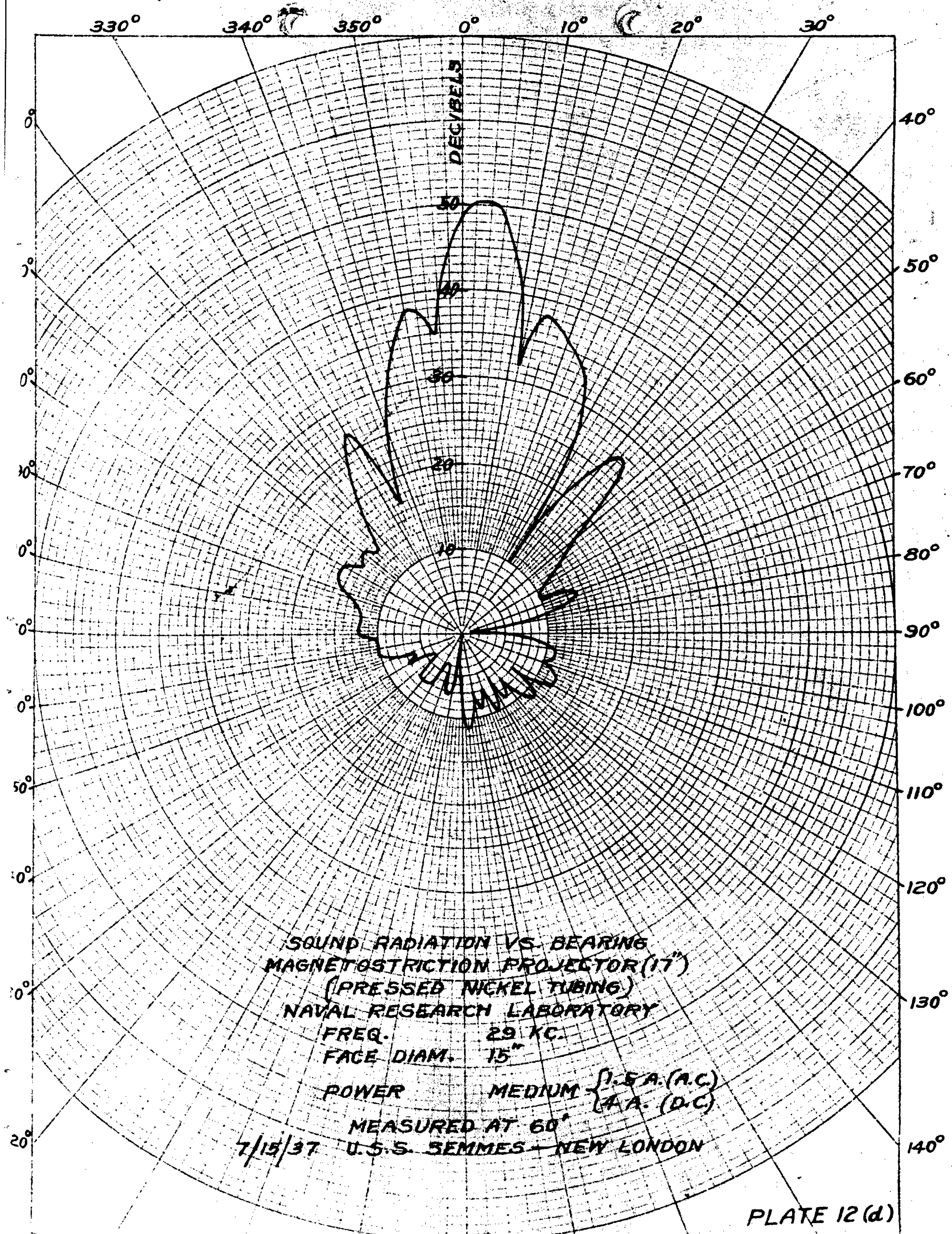


PLATE 12 (d)

KEUFFEL & ESSER CO., N.Y. NO 343B
POLAR CO-ORDINATE
MADE IN U.S.A.

TE

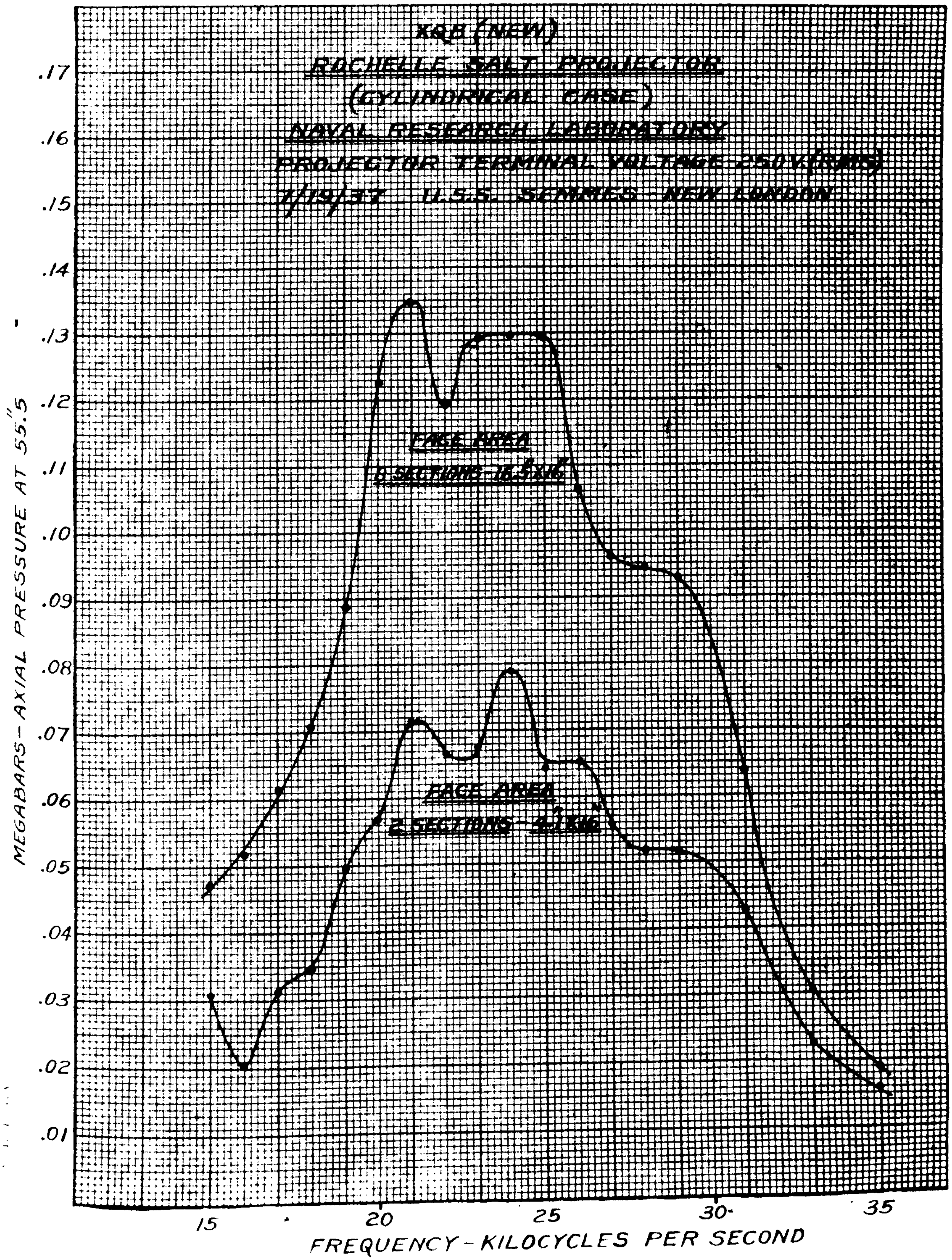

XQB (NEW)
ROCHELLE SALT PROJECTOR
(CYLINDRICAL CASE)
NAVAL RESEARCH LABORATORY
PROJECTOR TERMINAL VOLTAGE 250V.(RMS)
7/19/37 U.S.S. SEMMES NEW LONDON
FACE AREA
6 SECTIONS –
FACE AREA
2 SECTIONS –
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
MEGABARS – AXIAL PRESSURE AT 55.5"
15
20
25
30
35
FREQUENCY – KILOCYCLES PER SECOND

PLATE 13

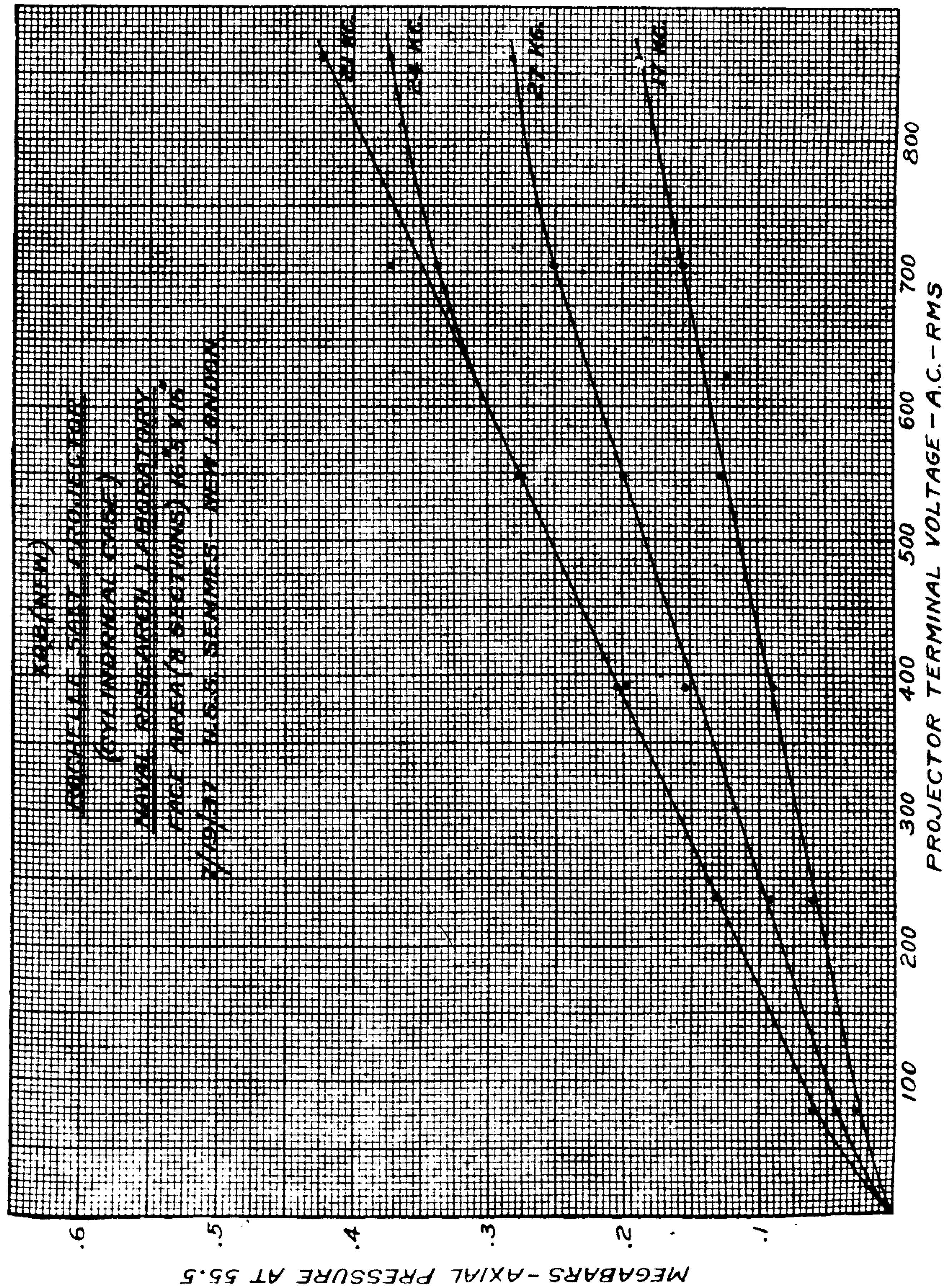
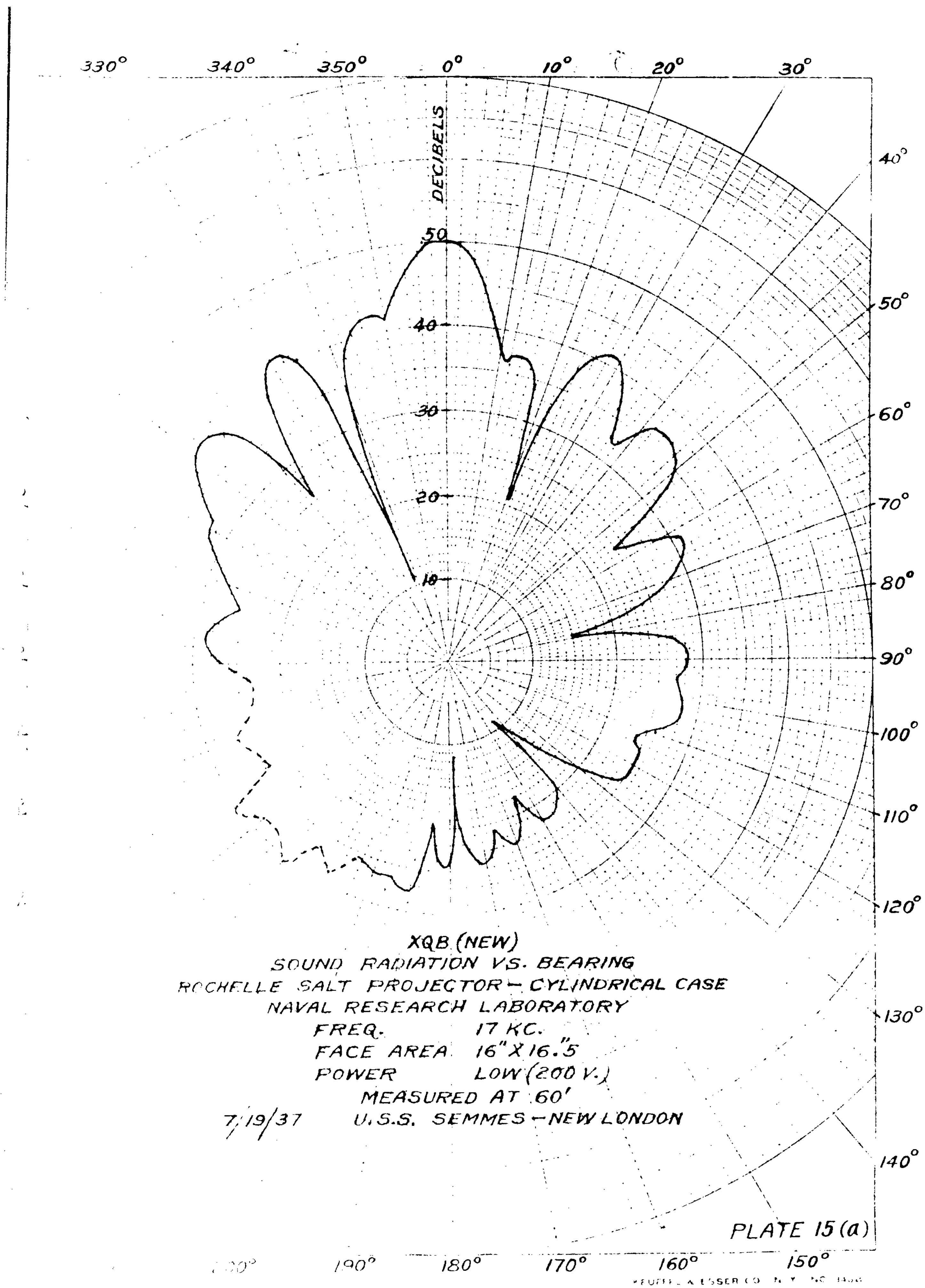
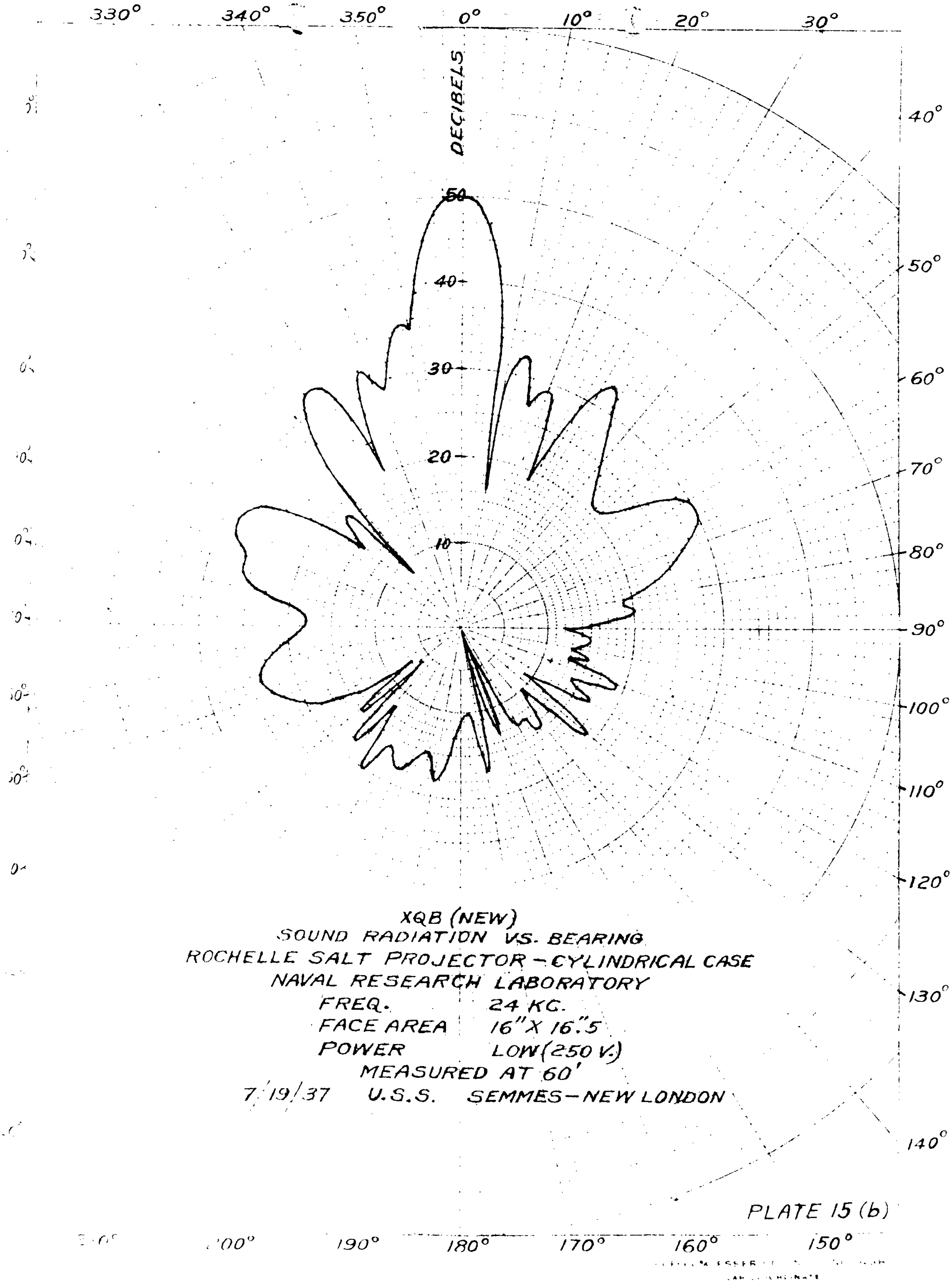

X9B (NEW)
ROCHELLE SALT PROJECTOR
(CYLINDRICAL CASE)
NAVAL RESEARCH LABORATORY
FACE AREA (8 SECTIONS) 16.5 X 16
7/19/37 U.S.S. SEMMES - NEW LONDON
21 KC.
24 KC.
27 KC.
17 KC.
100
200
300
400
500
600
700
800
PROJECTOR TERMINAL VOLTAGE - A.C. - RMS
.1
.2
.3
.4
.5
.6
MEGABARS - AXIAL PRESSURE AT 55.5"

PLATE 14



XQB (NEW)
SOUND RADIATION VS. BEARING
ROCHELLE SALT PROJECTOR — CYLINDRICAL CASE
NAVAL RESEARCH LABORATORY
FREQ. 17 KC.
FACE AREA 16" X 16.5"
POWER LOW (200 V.)
MEASURED AT 60'
7/19/37 U.S.S. SEMMES — NEW LONDON

PLATE 15 (a)



XQB (NEW)
SOUND RADIATION VS. BEARING
ROCHELLE SALT PROJECTOR – CYLINDRICAL CASE
NAVAL RESEARCH LABORATORY
FREQ. 24 KC.
FACE AREA 16" X 16".5
POWER LOW (250 V.)
MEASURED AT 60'
7/19/37 U.S.S. SEMMES – NEW LONDON

PLATE 15 (b)

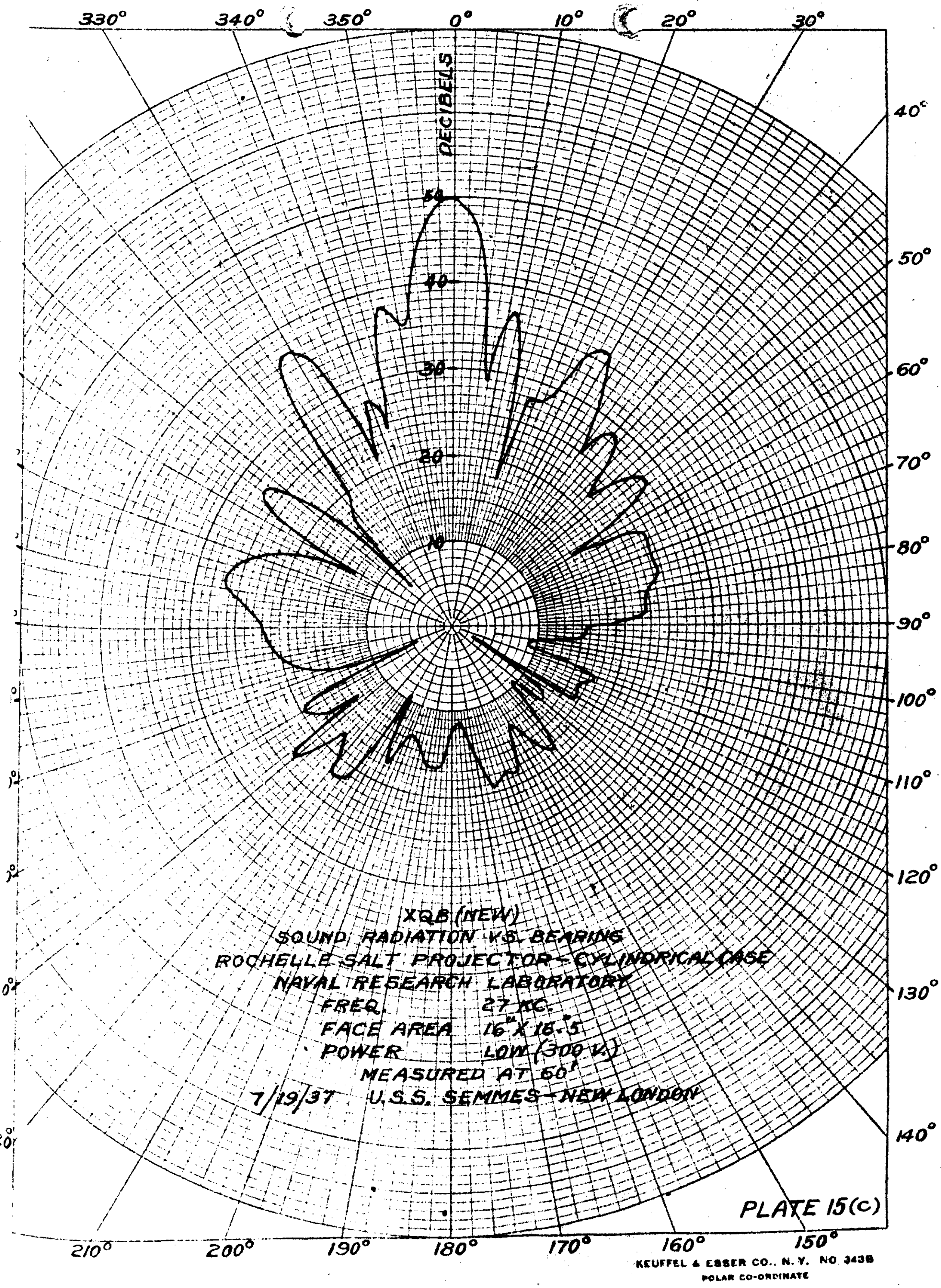

330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
DECIBELS
50
40
30
20
10
XQB (NEW)
SOUND RADIATION VS. BEARING
ROCHELLE SALT PROJECTOR - CYLINDRICAL CASE
NAVAL RESEARCH LABORATORY
FREQ. 27 KC.
FACE AREA 16" X 16.5
POWER LOW (300 V.)
MEASURED AT 60'
7/19/37 U.S.S. SEMMES - NEW LONDON
KEUFFEL & ESSER CO., N.Y. NO. 343B
POLAR CO-ORDINATE
MADE IN U.S.A.

PLATE 15(c)

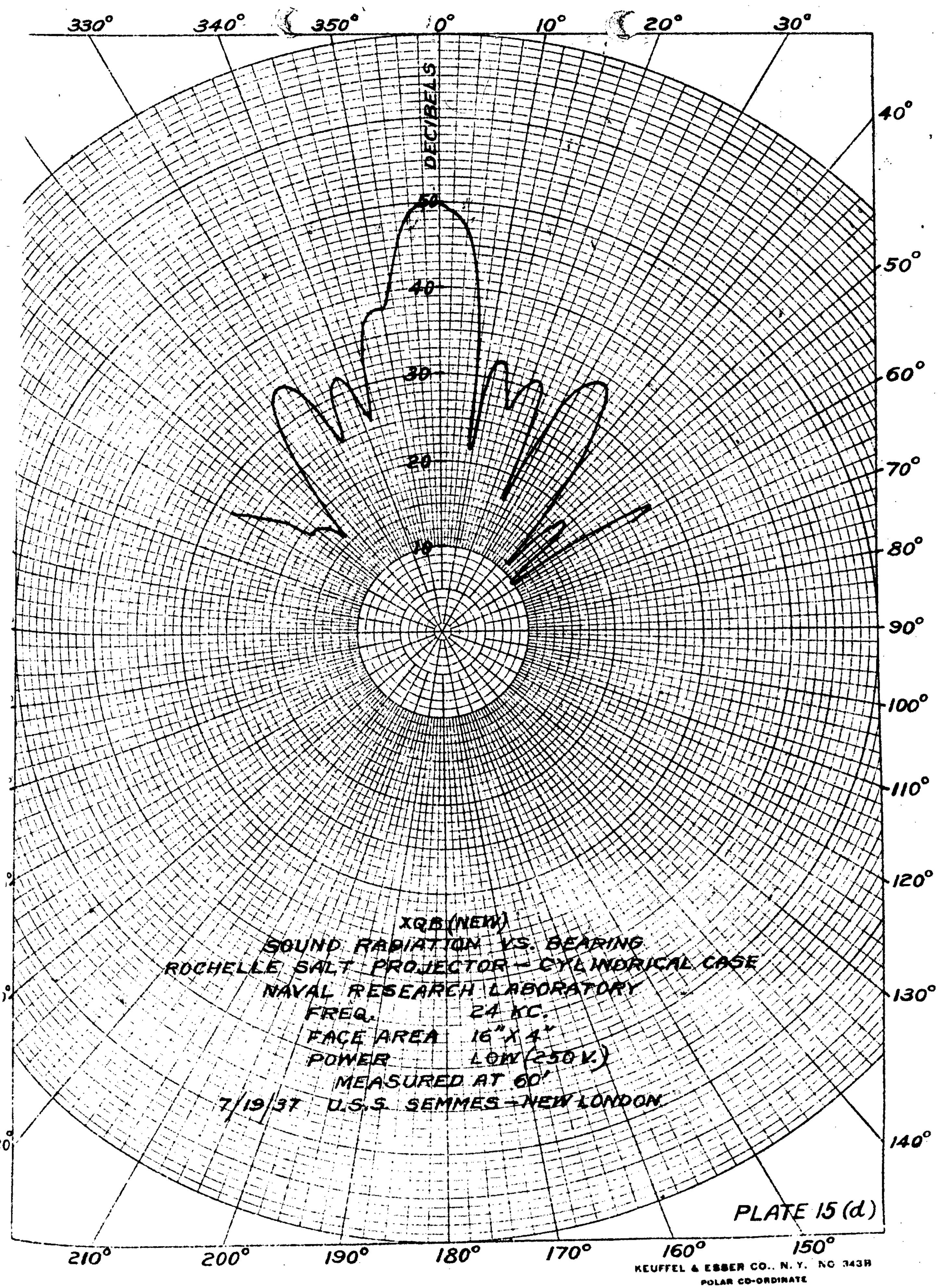

XQB (NEW)
SOUND RADIATION VS. BEARING
ROCHELLE SALT PROJECTOR — CYLINDRICAL CASE
NAVAL RESEARCH LABORATORY
FREQ. 24 KC.
FACE AREA 16" X 4"
POWER LOW (250 V.)
MEASURED AT 60'
7/19/37 U.S.S. SEMMES — NEW LONDON
DECIBELS
10
20
30
40
50
330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
KEUFFEL & ESSER CO., N. Y. NO 343B
POLAR CO-ORDINATE
MADE IN U. S. A.

PLATE 15 (d)

DATE

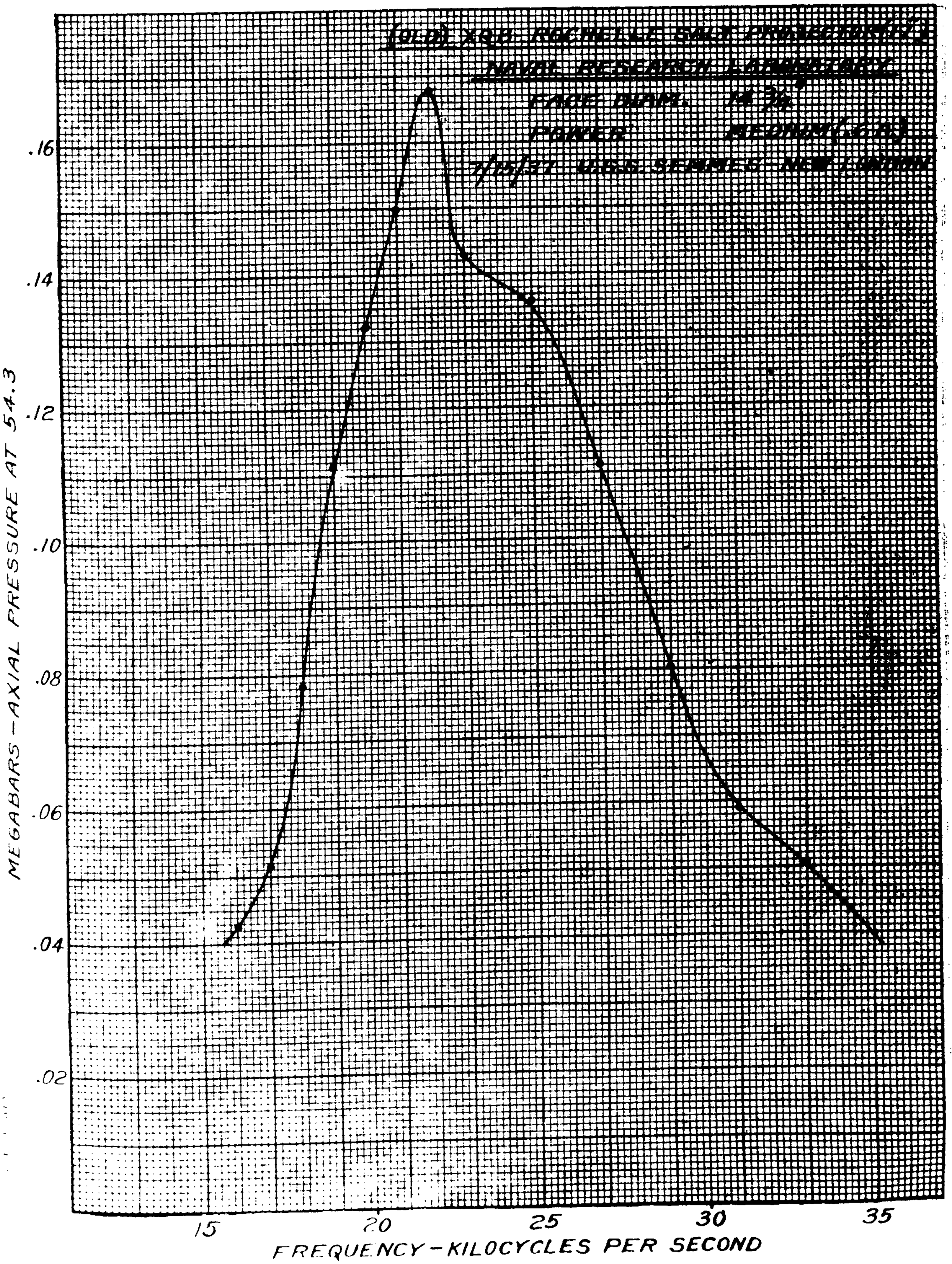


PLATE 16

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

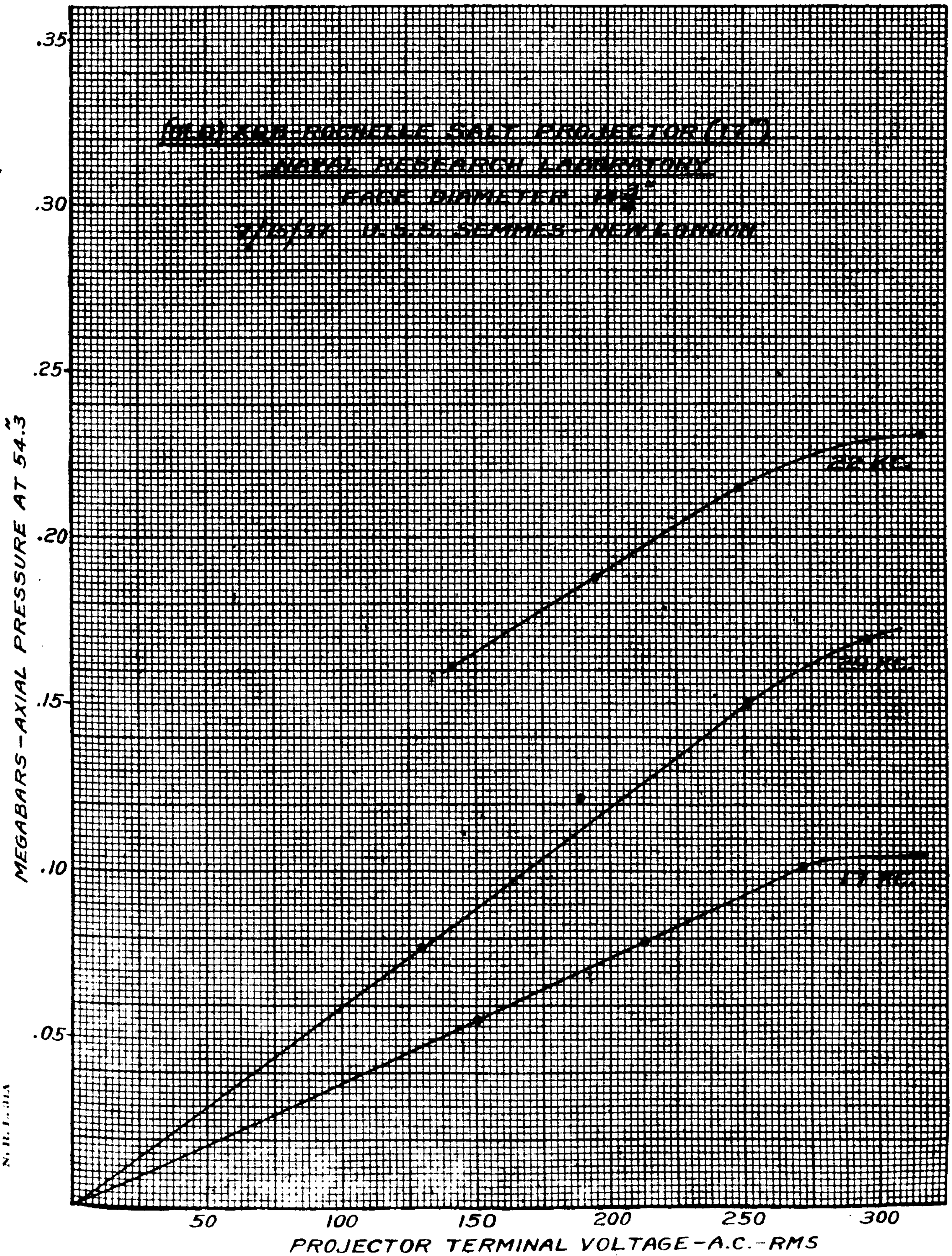


PLATE 17

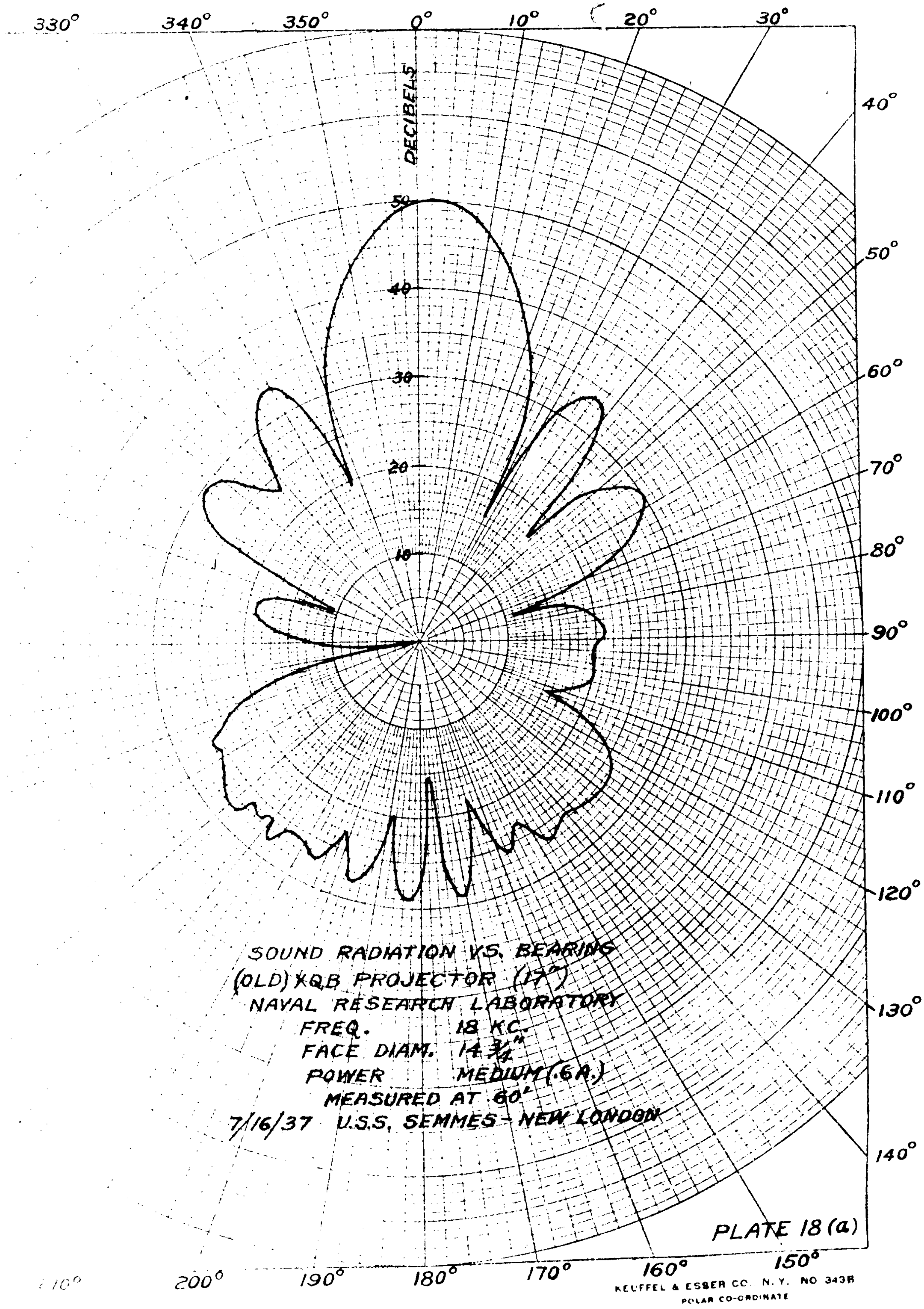

330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
(OLD) XQB PROJECTOR (17")
NAVAL RESEARCH LABORATORY
FREQ. 18 KC.
FACE DIAM. 14 3/4"
POWER MEDIUM (.6A.)
MEASURED AT 60'
7/16/37 U.S.S. SEMMES - NEW LONDON
KEUFFEL & ESSER CO. N.Y. NO 343B
POLAR CO-ORDINATE

PLATE 18 (a)

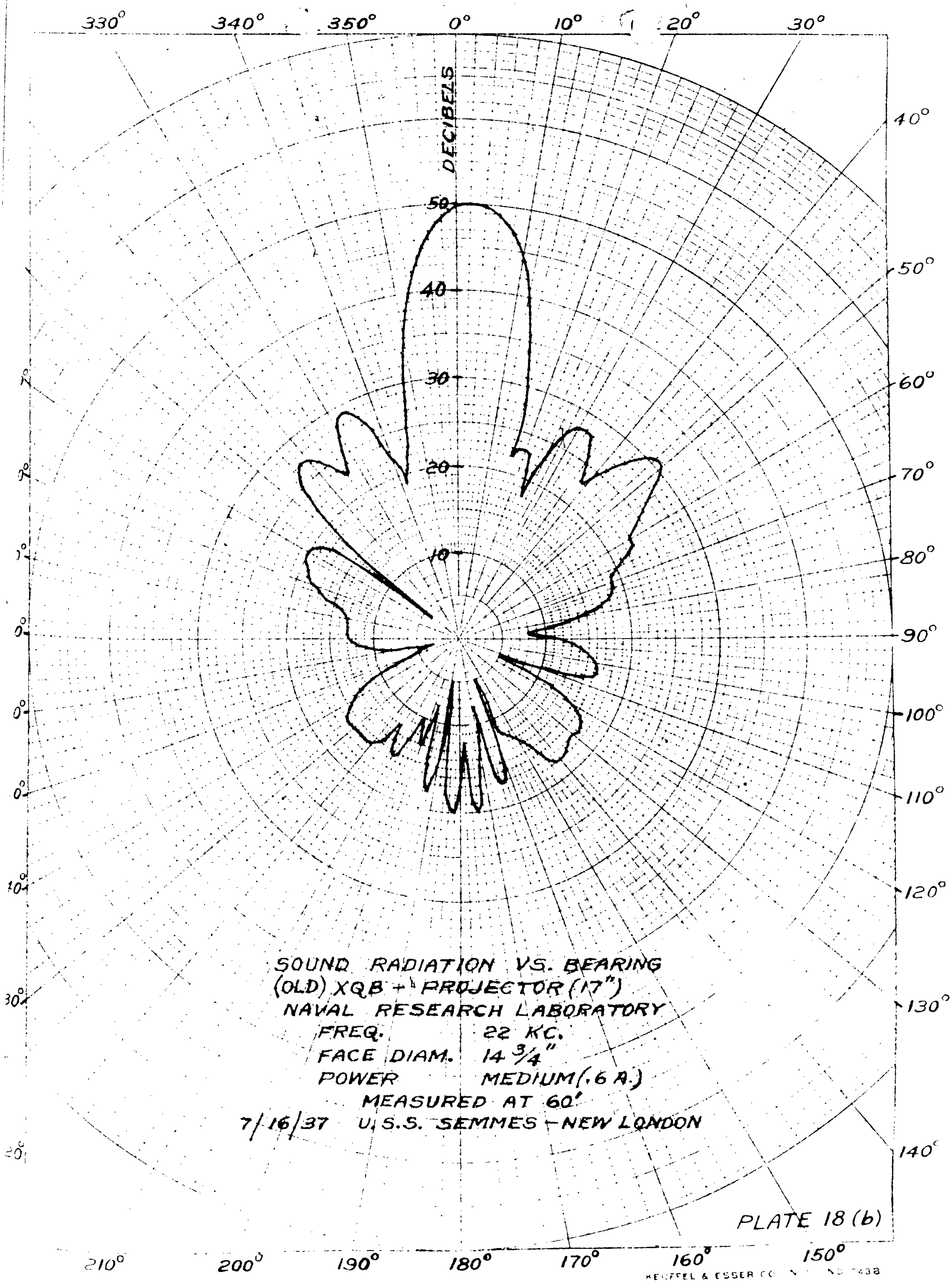

330° 340° 350° 0° 10° 20° 30°
40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140°
150° 160° 170° 180° 190° 200° 210°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
(OLD) XQB + PROJECTOR (17")
NAVAL RESEARCH LABORATORY
FREQ. 22 KC.
FACE DIAM. 14 3/4"
POWER MEDIUM (.6 A.)
MEASURED AT 60'
7/16/37 U.S.S. SEMMES - NEW LONDON

PLATE 18 (b)

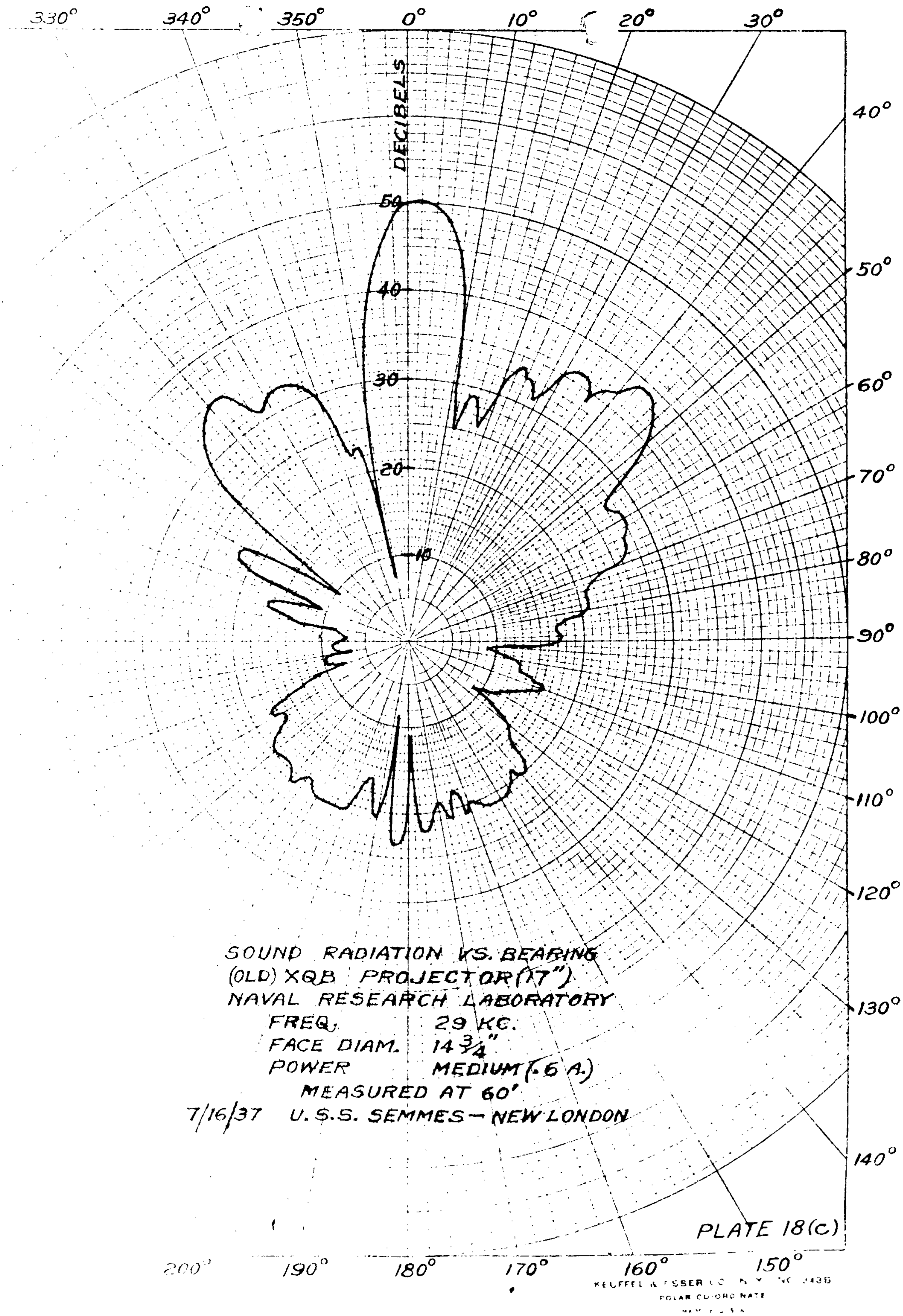
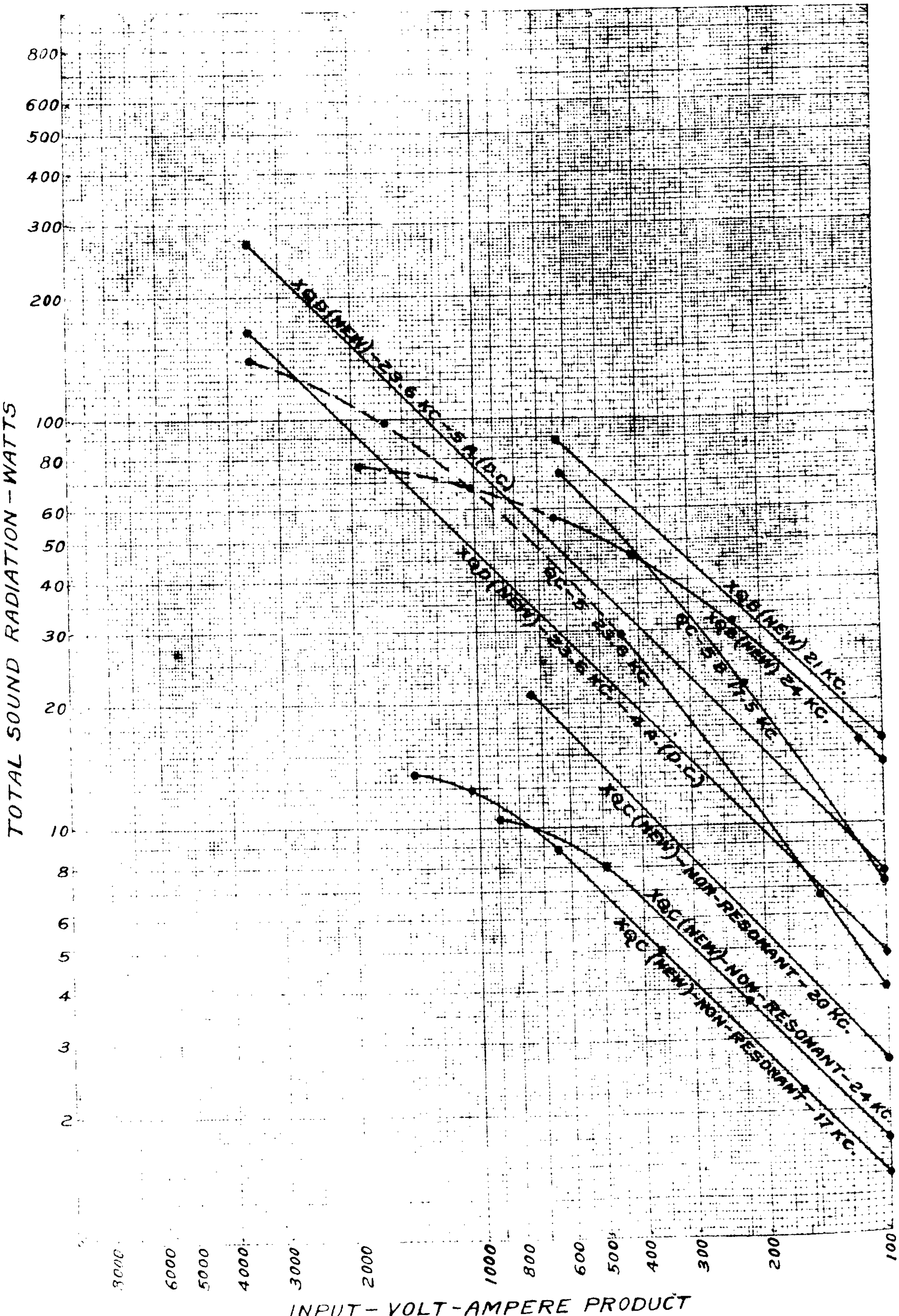

330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS. BEARING
(OLD) XQB PROJECTOR (17")
NAVAL RESEARCH LABORATORY
FREQ. 29 KC.
FACE DIAM. 14 3/4"
POWER MEDIUM (.6 A.)
MEASURED AT 60'
7/16/37 U.S.S. SEMMES — NEW LONDON

PLATE 18(c)



TOTAL SOUND RADIATION - WATTS
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
6000
5000
4000
3000
2000
1000
800
600
500
400
300
200
100
INPUT - VOLT-AMPERE PRODUCT
XQB(NEW)-23.6 KC.-5 A.(D.C.)
XQB(NEW)-23.6 KC.-4 A.(D.C.)
QC-5 23.8 KC.
XQB(NEW) 21 KC.
XQB(NEW) 24 KC.
QC-5 B 17.5 KC.
XQC(NEW)-NON-RESONANT-20 KC.
XQC(NEW)-NON-RESONANT-24 KC.
XQC (NEW)-NON-RESONANT-17 KC.

PLATE 19

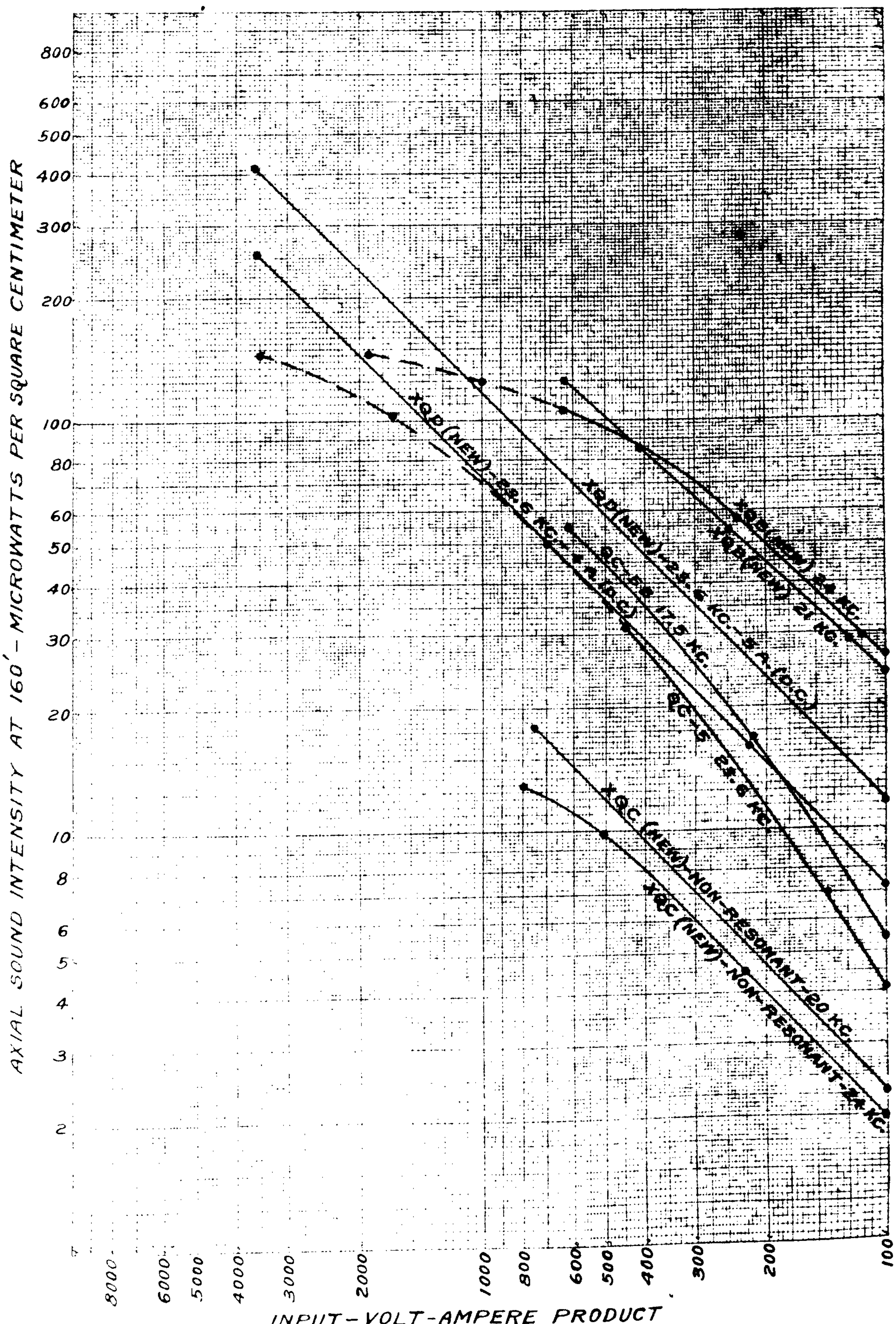

AXIAL SOUND INTENSITY AT 160' - MICROWATTS PER SQUARE CENTIMETER
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
8000
6000
5000
4000
3000
2000
1000
800
600
500
400
300
200
100
INPUT - VOLT - AMPERE PRODUCT
XQB (NEW) 24 KC.
XQB (NEW) 21 KC.
XQD (NEW) - 23.6 KC. - 5 A. (D.C.)
QC-5B 17.5 KC.
XQD (NEW) - 23.6 KC. - 4 A. (D.C.)
QC-5 23.6 KC.
XQC (NEW) - NON-RESONANT - 20 KC.
XQC (NEW) - NON-RESONANT - 24 KC.

PLATE 20

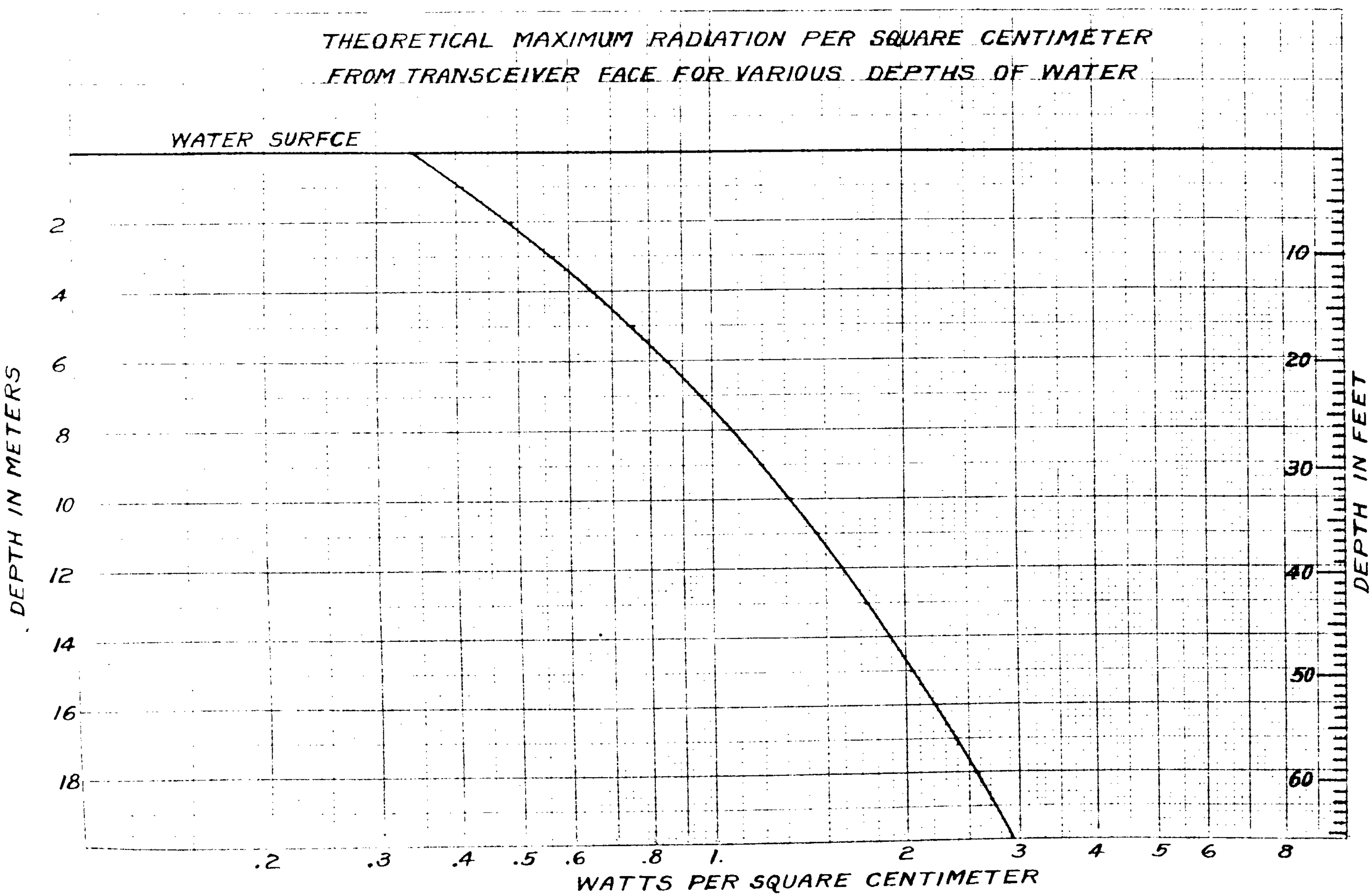

THEORETICAL MAXIMUM RADIATION PER SQUARE CENTIMETER
FROM TRANSCEIVER FACE FOR VARIOUS DEPTHS OF WATER
WATER SURFCE
DEPTH IN METERS
2
4
6
8
10
12
14
16
18
DEPTH IN FEET
10
20
30
40
50
60
.2
.3
.4
.5
.6
.8
1.
2
3
4
5
6
8
WATTS PER SQUARE CENTIMETER

PLATE 21

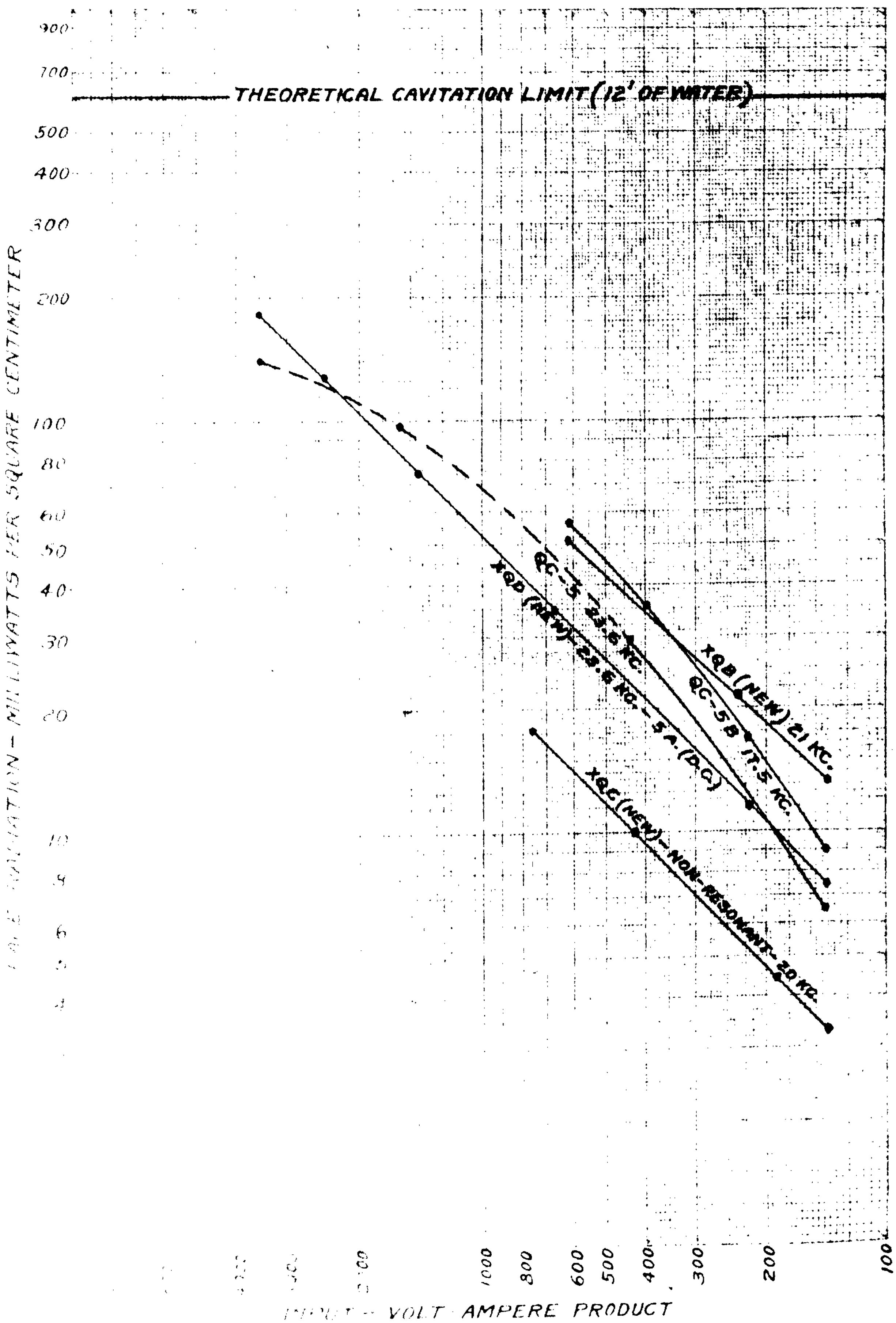

THEORETICAL CAVITATION LIMIT (12' OF WATER)
XQB (NEW) 21 KC.
QC-5B 17.5 KC.
QC-5 23.6 KC.
XQD (NEW) 23.6 KC. – 5 A. (D.C.)
XQC (NEW) – NON-RESONANT – 20 KC.
MILLIWATTS PER SQUARE CENTIMETER
VOLT AMPERE PRODUCT
900
700
500
400
300
200
100
80
60
50
40
30
20
10
8
6
4
1000
800
600
500
400
300
200
100

PLATE 22

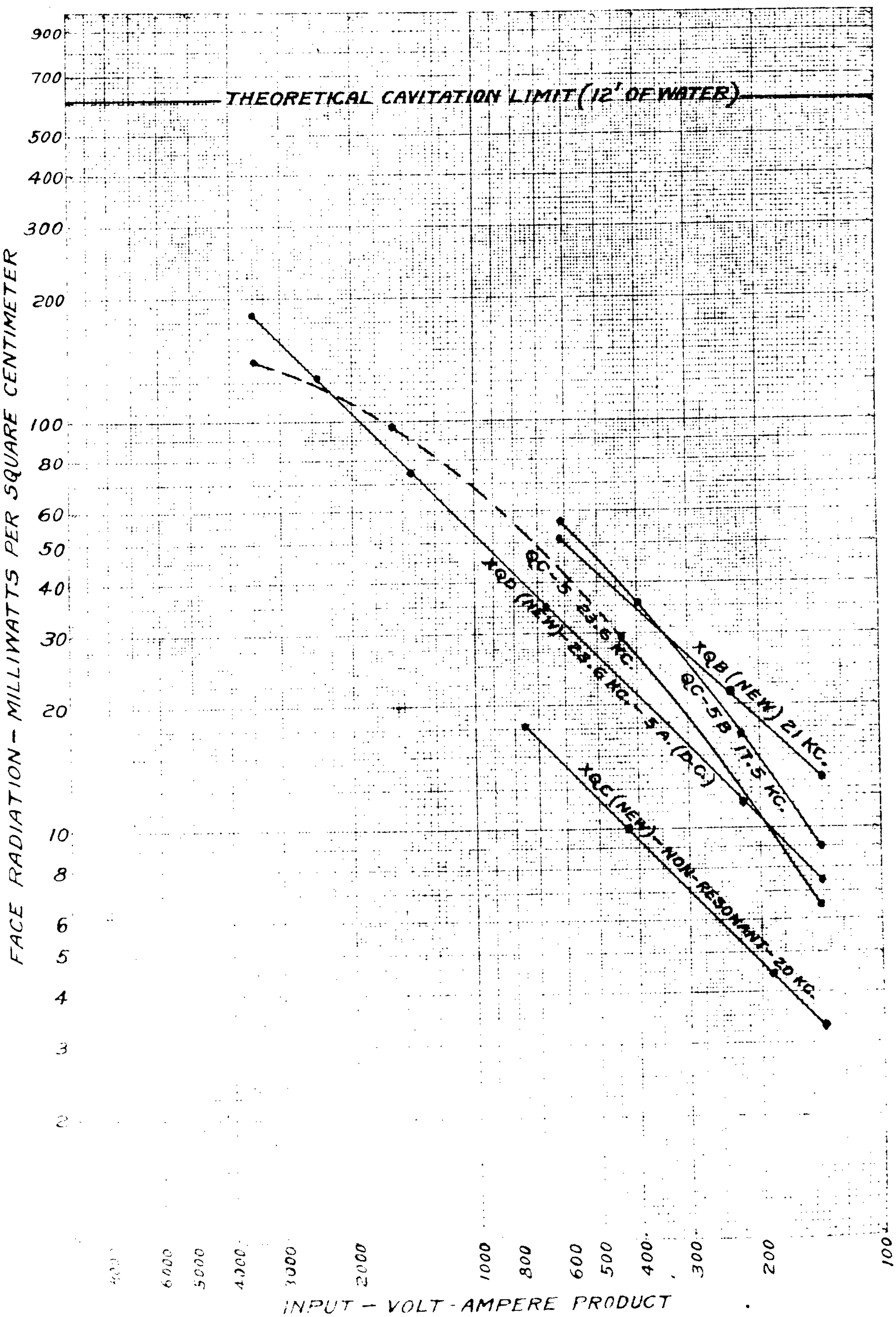

THEORETICAL CAVITATION LIMIT (12' OF WATER)
FACE RADIATION - MILLIWATTS PER SQUARE CENTIMETER
INPUT - VOLT-AMPERE PRODUCT
QC-5 23.6 KC.
XQD (NEW) 23.6 KC. - 5 A. (D.C.)
XQB (NEW) 21 KC.
QC-5 B 17.5 KC.
XQC (NEW) - NON-RESONANT - 20 KC.
900
700
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
6000
5000
4000
3000
2000
1000
800
600
500
400
300
200
100

PLATE 22

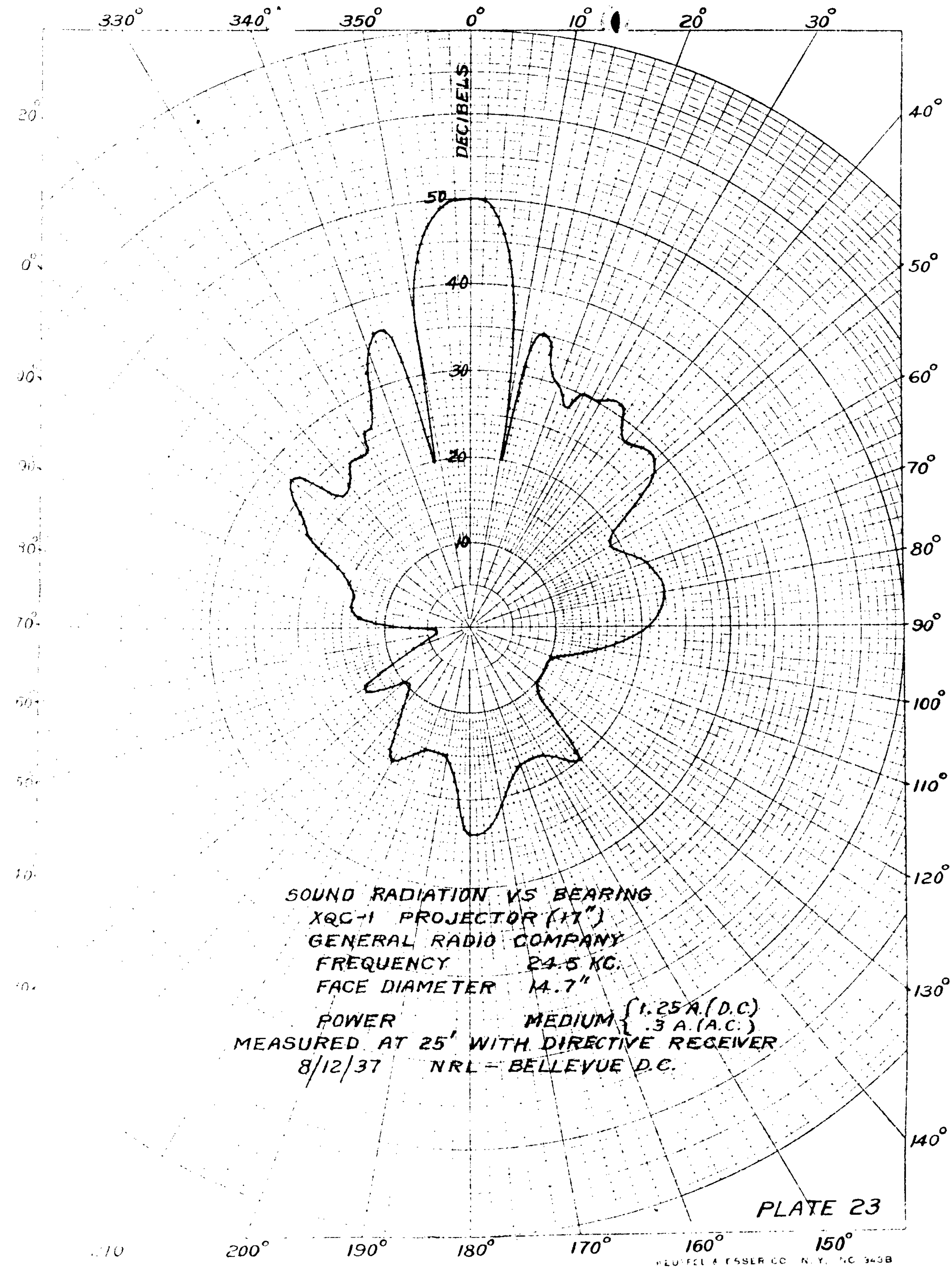
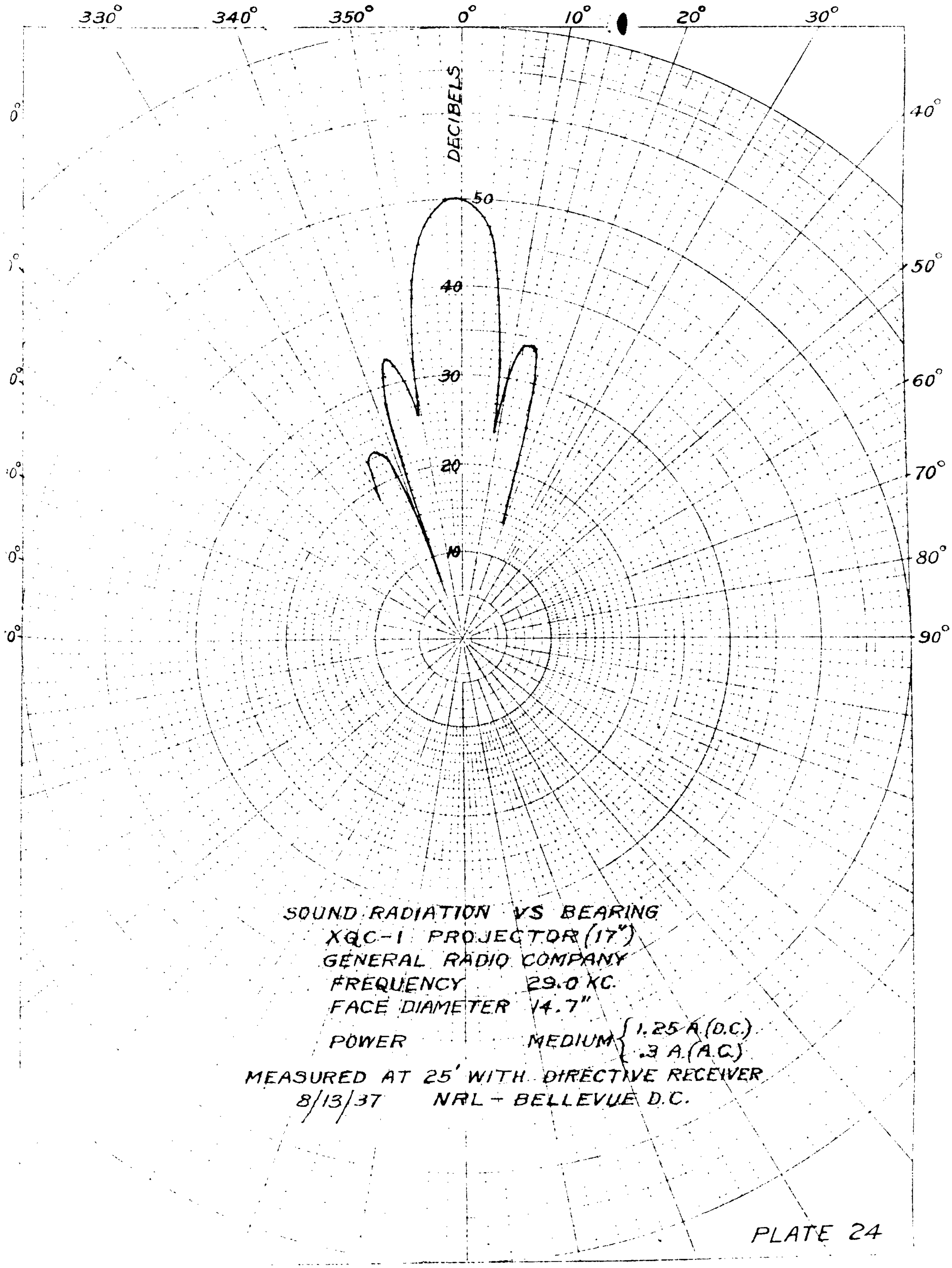
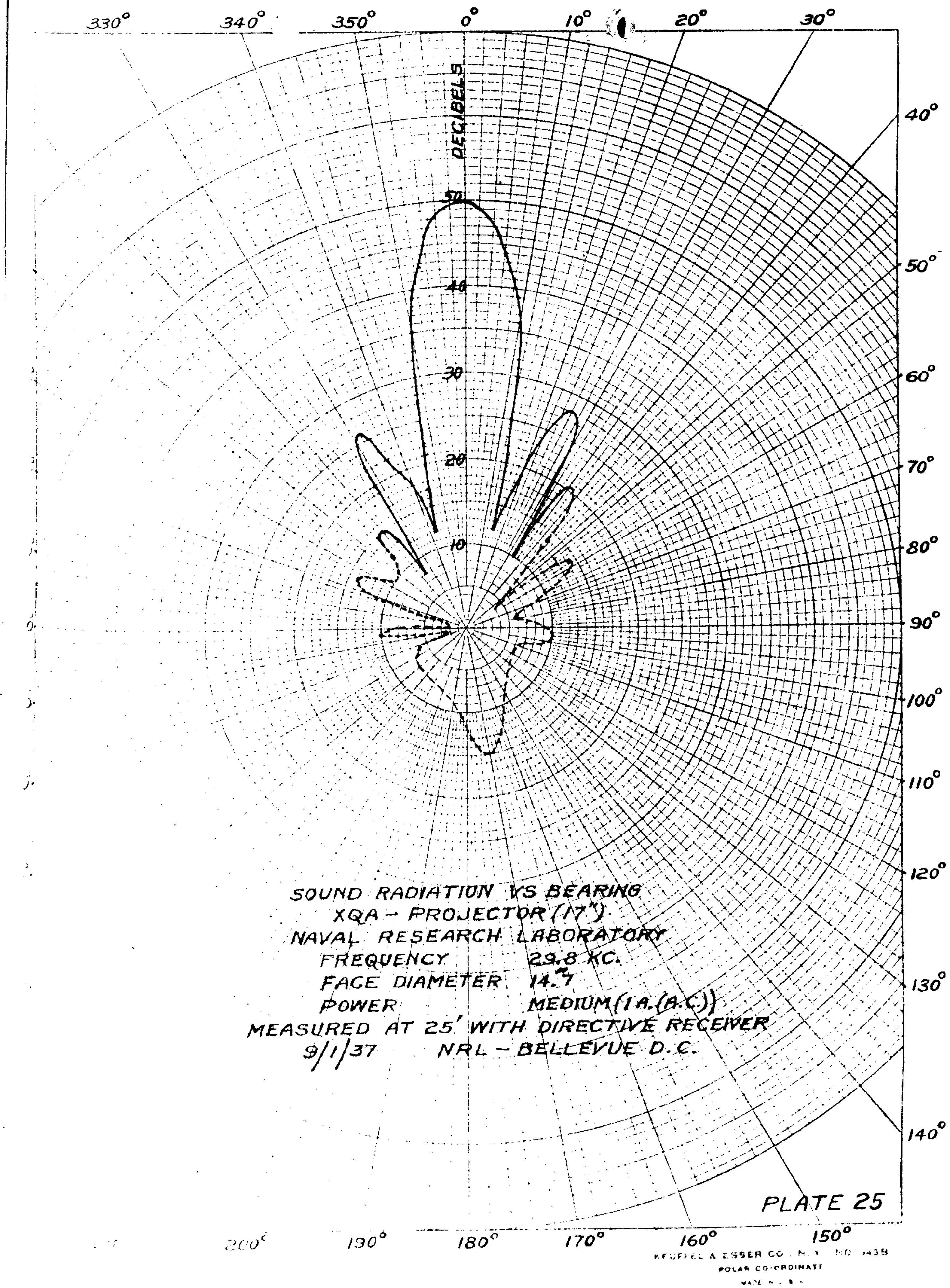

DECIBELS
50
40
30
20
10
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
330°
340°
350°
SOUND RADIATION VS BEARING
XQC-1 PROJECTOR (17")
GENERAL RADIO COMPANY
FREQUENCY 24.5 KC.
FACE DIAMETER 14.7"
POWER MEDIUM { 1.25 A. (D.C.)
.3 A. (A.C.)
MEASURED AT 25' WITH DIRECTIVE RECEIVER
8/12/37 NRL - BELLEVUE D.C.

PLATE 23

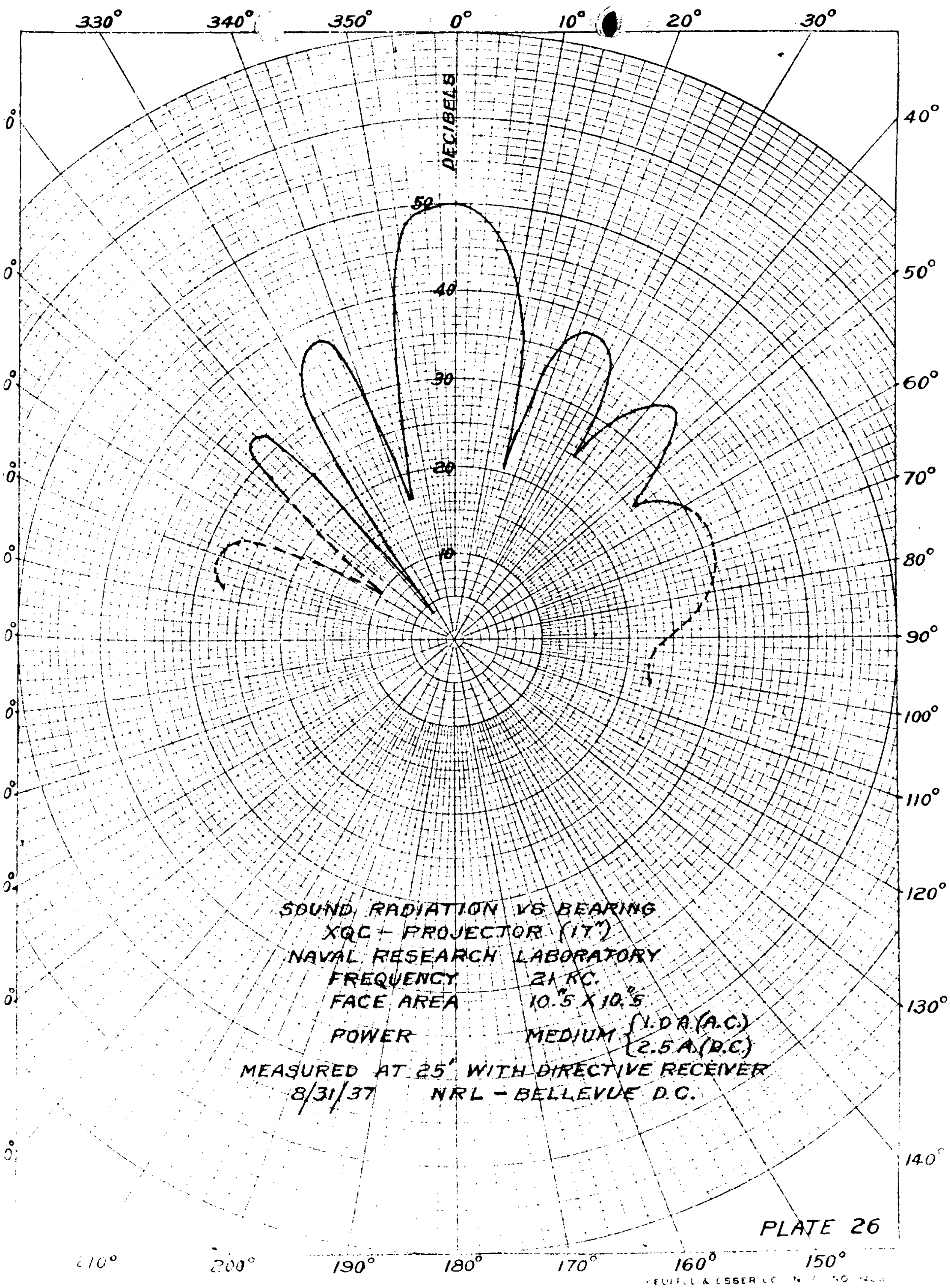


SOUND RADIATION VS BEARING
XQC-1 PROJECTOR (17")
GENERAL RADIO COMPANY
FREQUENCY 29.0 KC.
FACE DIAMETER 14.7"
POWER MEDIUM { 1.25 A. (D.C.) / .3 A. (A.C.) }
MEASURED AT 25' WITH DIRECTIVE RECEIVER
8/13/37 NRL - BELLEVUE D.C.

PLATE 24



330° 340° 350° 0° 10° 20° 30°
40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140°
150° 160° 170° 180° 190° 200°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS BEARING
XQA - PROJECTOR (17")
NAVAL RESEARCH LABORATORY
FREQUENCY 29.8 KC.
FACE DIAMETER 14.7"
POWER MEDIUM (1 A. (A.C.))
MEASURED AT 25' WITH DIRECTIVE RECEIVER
9/1/37 NRL - BELLEVUE D.C.
PLATE 25
POLAR CO-ORDINATE



330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
DECIBELS
50
40
30
20
10
SOUND RADIATION VS BEARING
XQC - PROJECTOR (17")
NAVAL RESEARCH LABORATORY
FREQUENCY 21 KC.
FACE AREA 10.5" X 10.5"
POWER MEDIUM {1.0 A. (A.C.) 2.5 A. (D.C.)
MEASURED AT 25' WITH DIRECTIVE RECEIVER
8/31/37 NRL - BELLEVUE D.C.

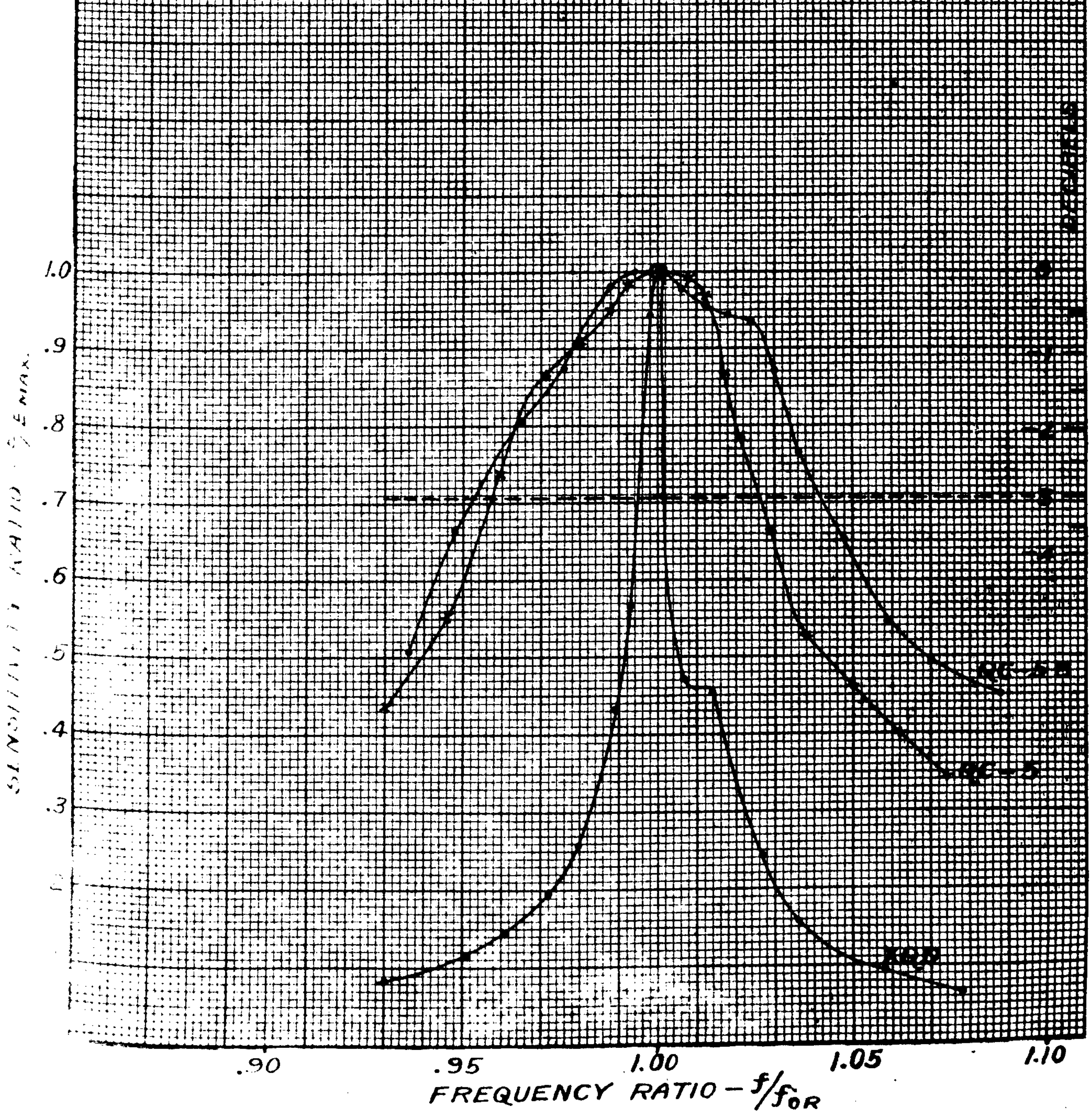
PLATE 26

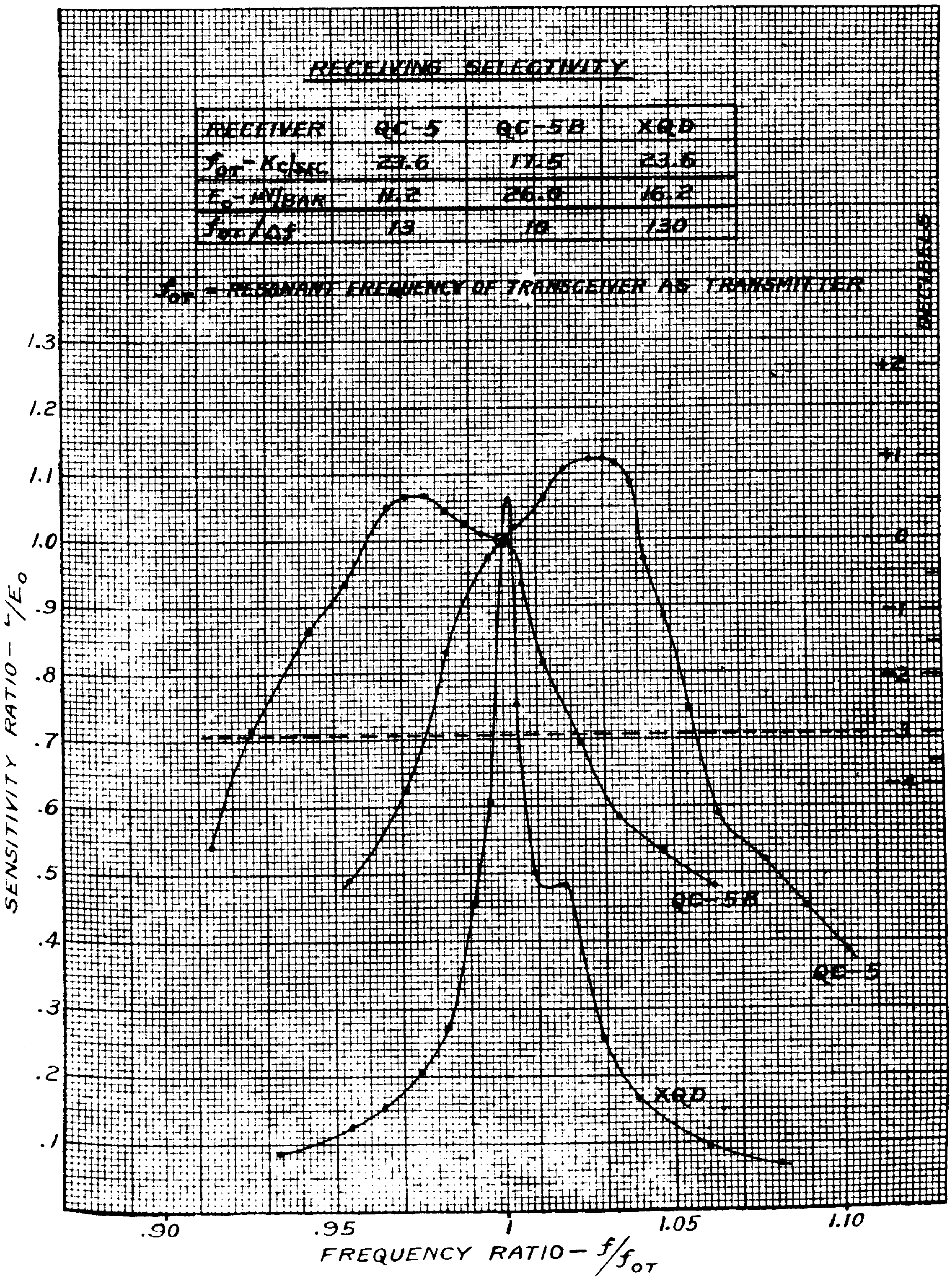
DATE

RECEIVING SELECTIVITY

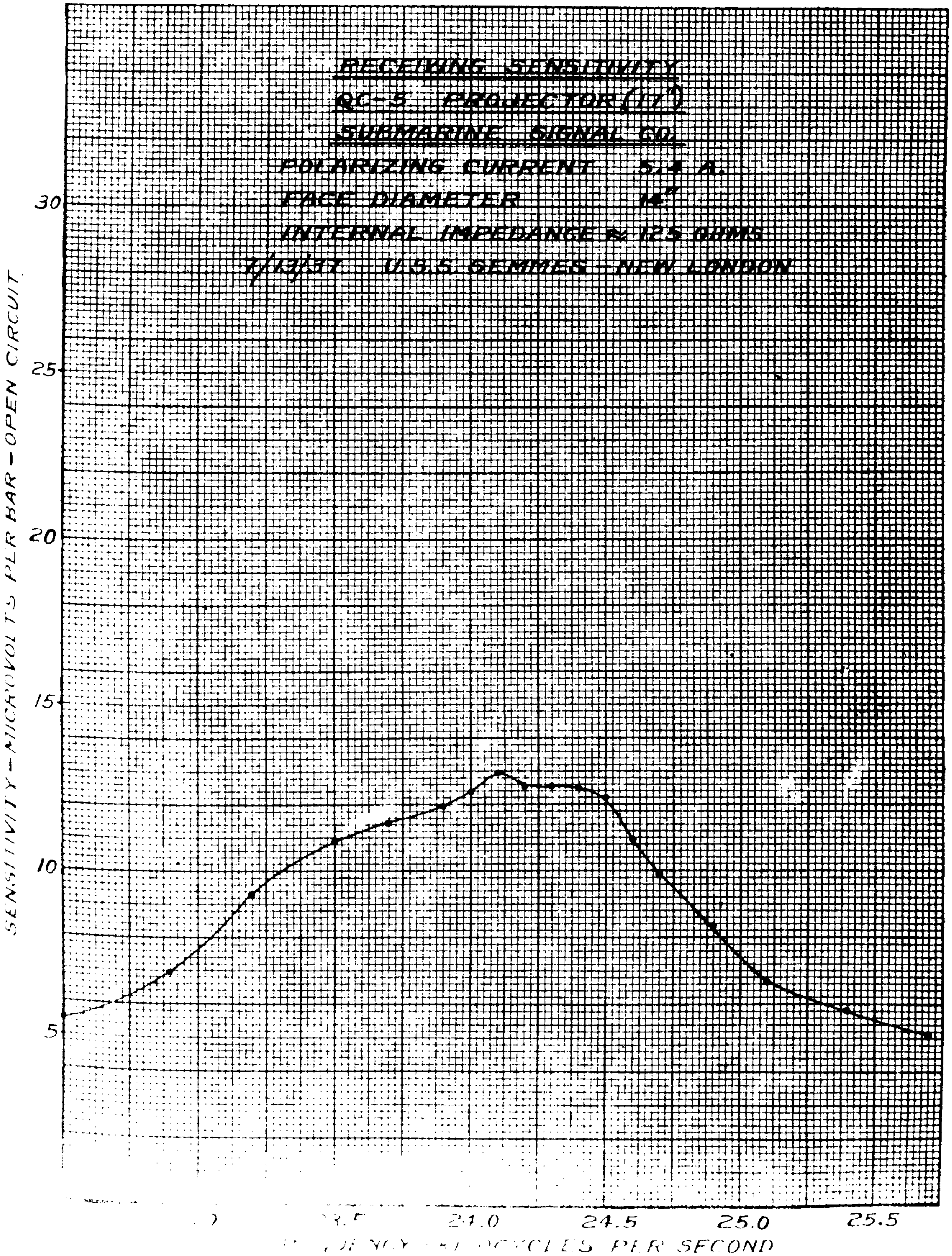
RECEIVER	QC-5	QC-5B	XQR
f_{OR} - Kc/sec	24.2	17.1	23.65
E_{MAX} µV/cm	12.6	27.8	17.2
$f_{OR}/\Delta f$	15	11	150

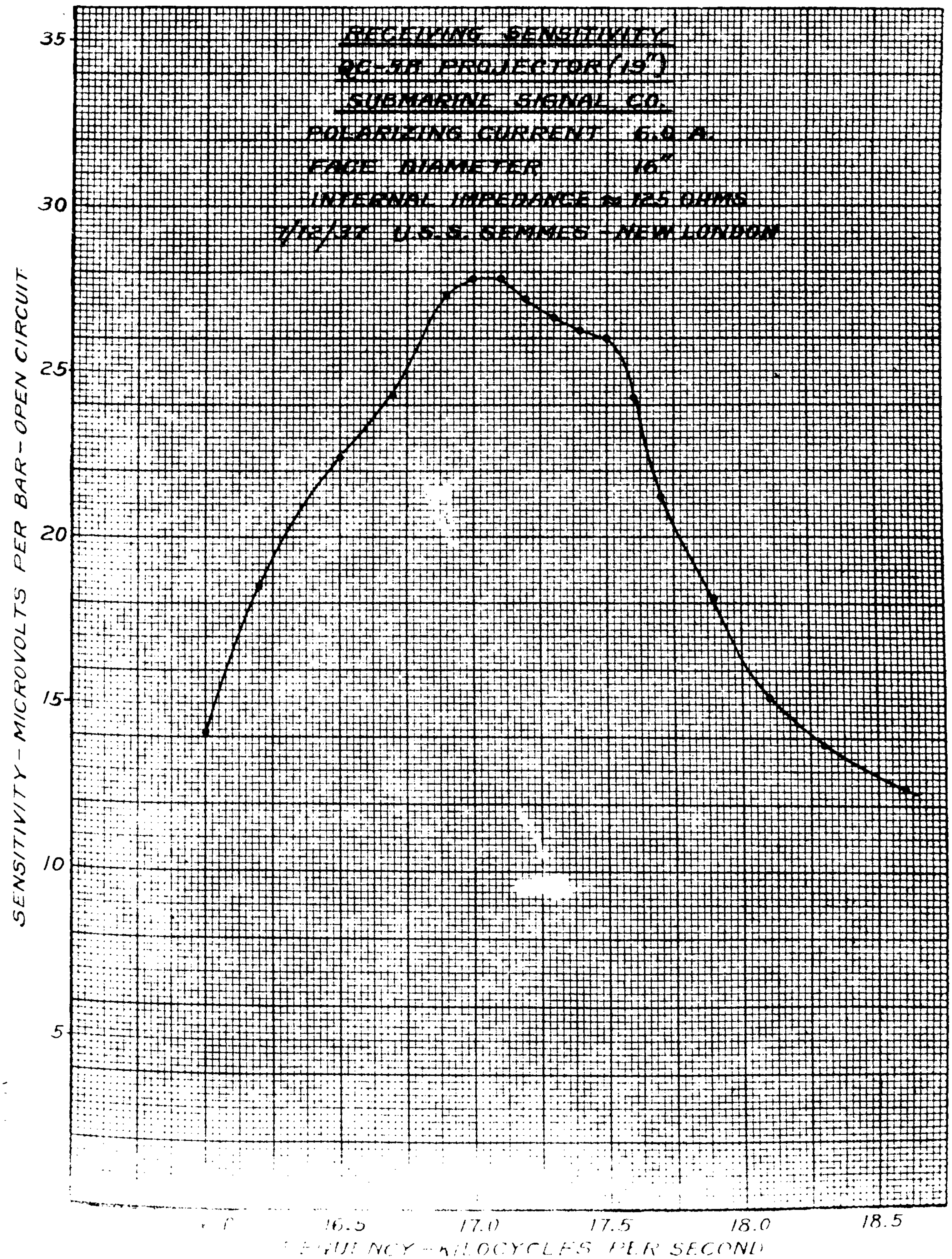
f_{OR} = RESONANT FREQUENCY OF TRANSCEIVER AS RECEIVER




RECEIVING SELECTIVITY
RECEIVER | QC-5 | QC-5B | XQD
f_{OT} - Kc/SEC | 23.6 | 17.5 | 23.6
E_o - µV/BAR | 11.2 | 26.8 | 16.2
$f_{OT}/\Delta f$ | 13 | 10 | 130
f_{OT} = RESONANT FREQUENCY OF TRANSCEIVER AS TRANSMITTER
DECIBELS
+2
+1
0
-1
-2
-3
-4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
SENSITIVITY RATIO – E/E_o
QC-5B
QC-5
XQD
.90
.95
1
1.05
1.10
FREQUENCY RATIO – f/f_{OT}

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.




RECEIVING SENSITIVITY
QC-5R PROJECTOR (19")
SUBMARINE SIGNAL CO.
POLARIZING CURRENT
FACE DIAMETER 16"
INTERNAL IMPEDANCE ≈ 125 OHMS
7/12/37 U.S.S. SEMMES - NEW LONDON
35
30
25
20
15
10
5
16.5
17.0
17.5
18.0
18.5
SENSITIVITY - MICROVOLTS PER BAR - OPEN CIRCUIT
KILOCYCLES PER SECOND

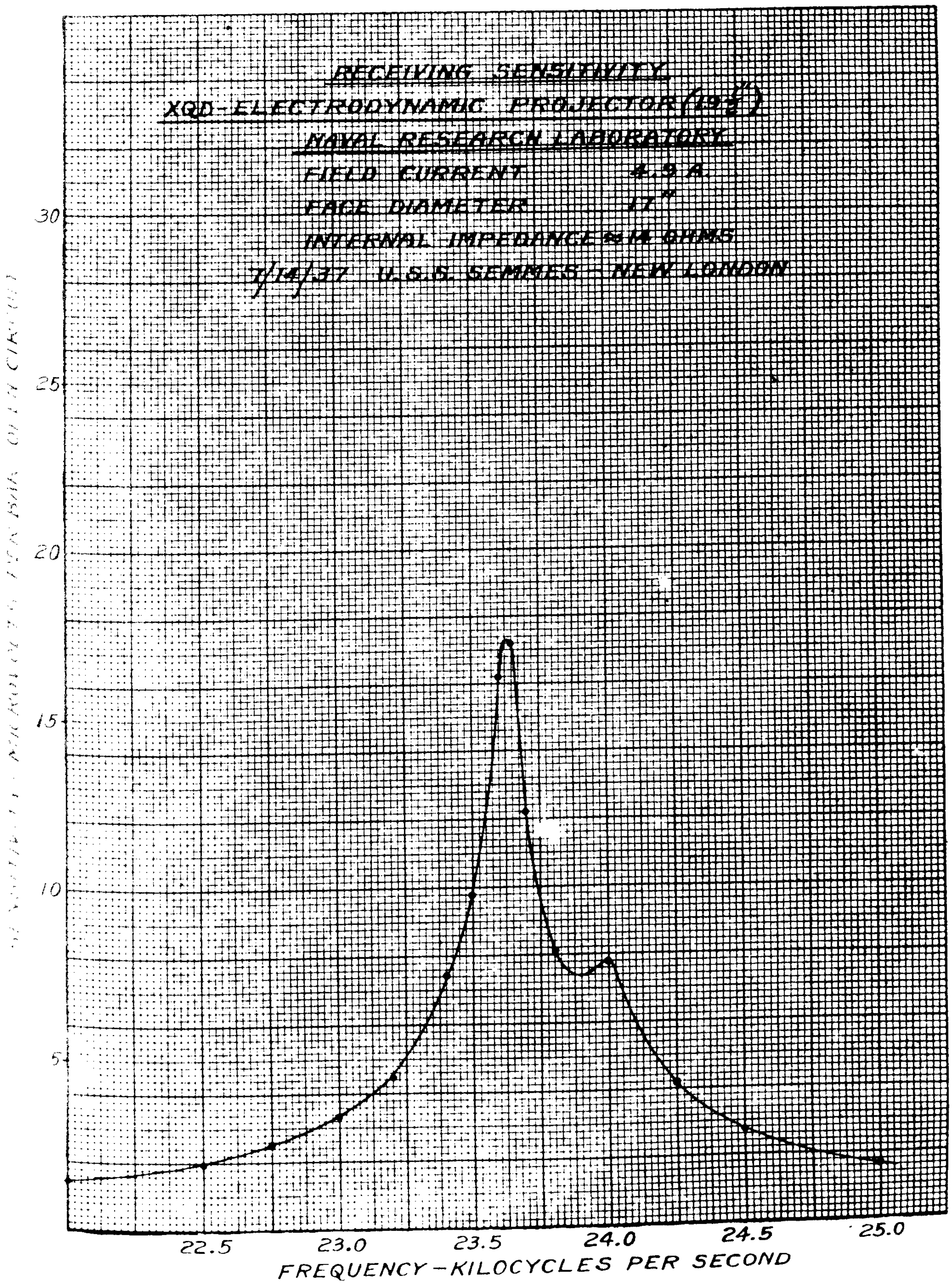

RECEIVING SENSITIVITY
XQD-ELECTRODYNAMIC PROJECTOR (19½")
NAVAL RESEARCH LABORATORY
FIELD CURRENT 4.9 A.
FACE DIAMETER 17"
INTERNAL IMPEDANCE ≈ 14 OHMS
7/14/37 U.S.S. SEMMES - NEW LONDON
30
25
20
15
10
5
22.5
23.0
23.5
24.0
24.5
25.0
FREQUENCY - KILOCYCLES PER SECOND

PLATE 31

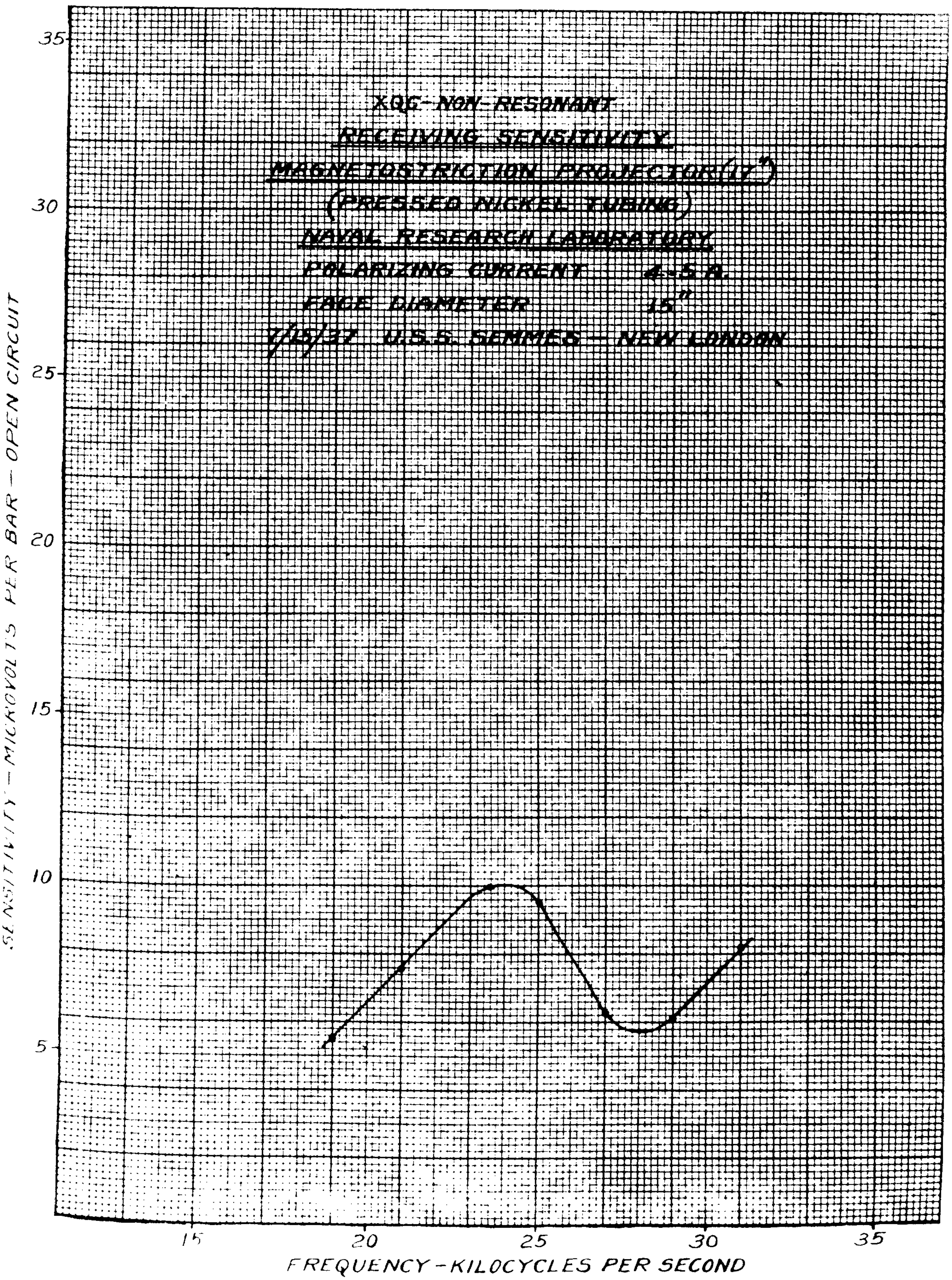
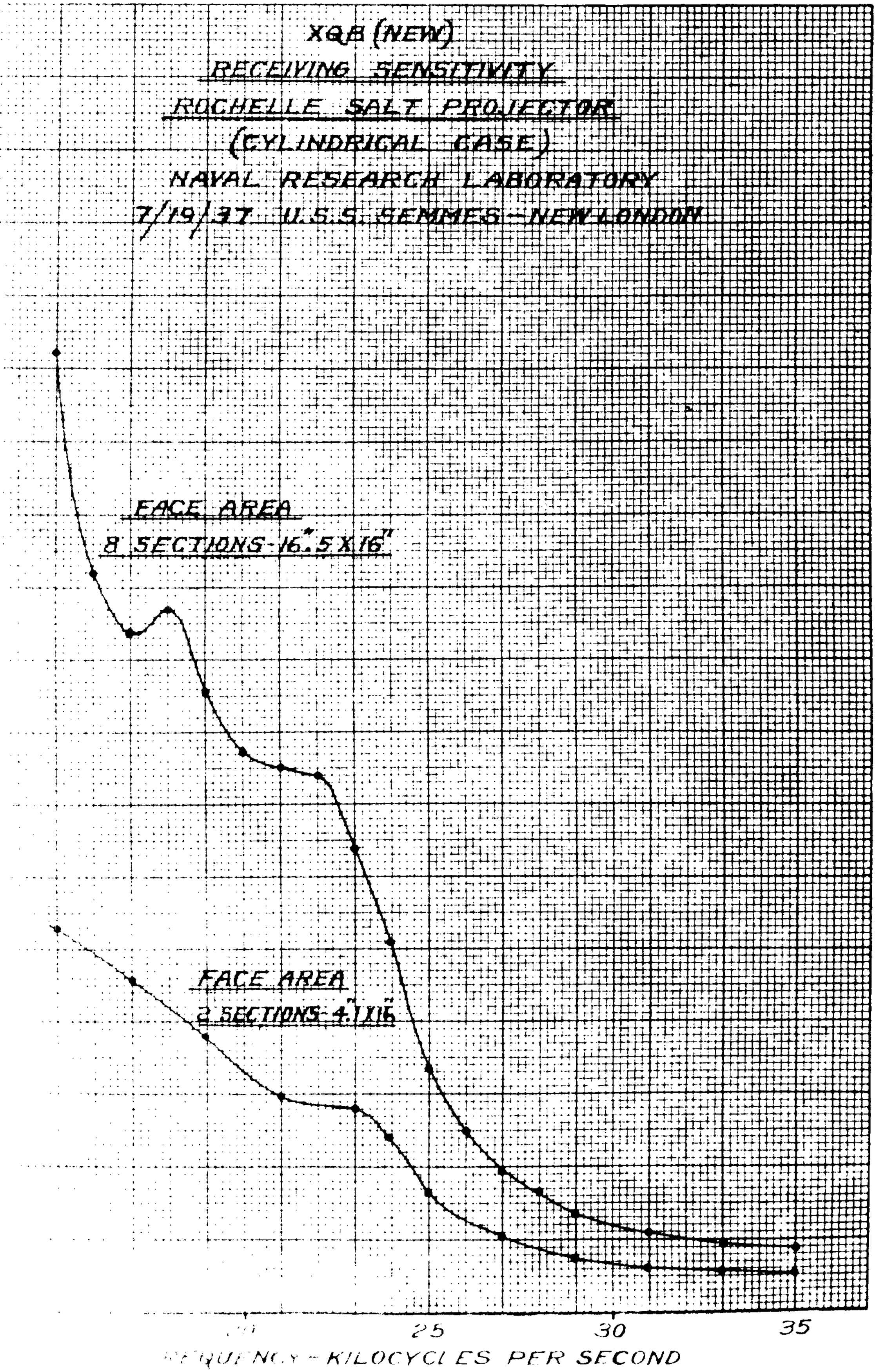

XQG - NON - RESONANT
RECEIVING SENSITIVITY
MAGNETOSTRICTION PROJECTOR (17")
(PRESSED NICKEL TUBING)
NAVAL RESEARCH LABORATORY
POLARIZING CURRENT 4.5 A.
FACE DIAMETER 15"
7/15/37 U.S.S. SEMMES - NEW LONDON
SENSITIVITY - MICROVOLTS PER BAR - OPEN CIRCUIT
35
30
25
20
15
10
5
15
20
25
30
35
FREQUENCY - KILOCYCLES PER SECOND

PLATE 32


XQB (NEW)
RECEIVING SENSITIVITY
ROCHELLE SALT PROJECTOR
(CYLINDRICAL CASE)
NAVAL RESEARCH LABORATORY
7/19/37 U.S.S. SEMMES - NEW LONDON
FACE AREA
8 SECTIONS-16".5 X 16"
FACE AREA
2 SECTIONS-4".1 X 16"
25
30
35
KILOCYCLES PER SECOND

RESEARCH LABORATORY

DATE

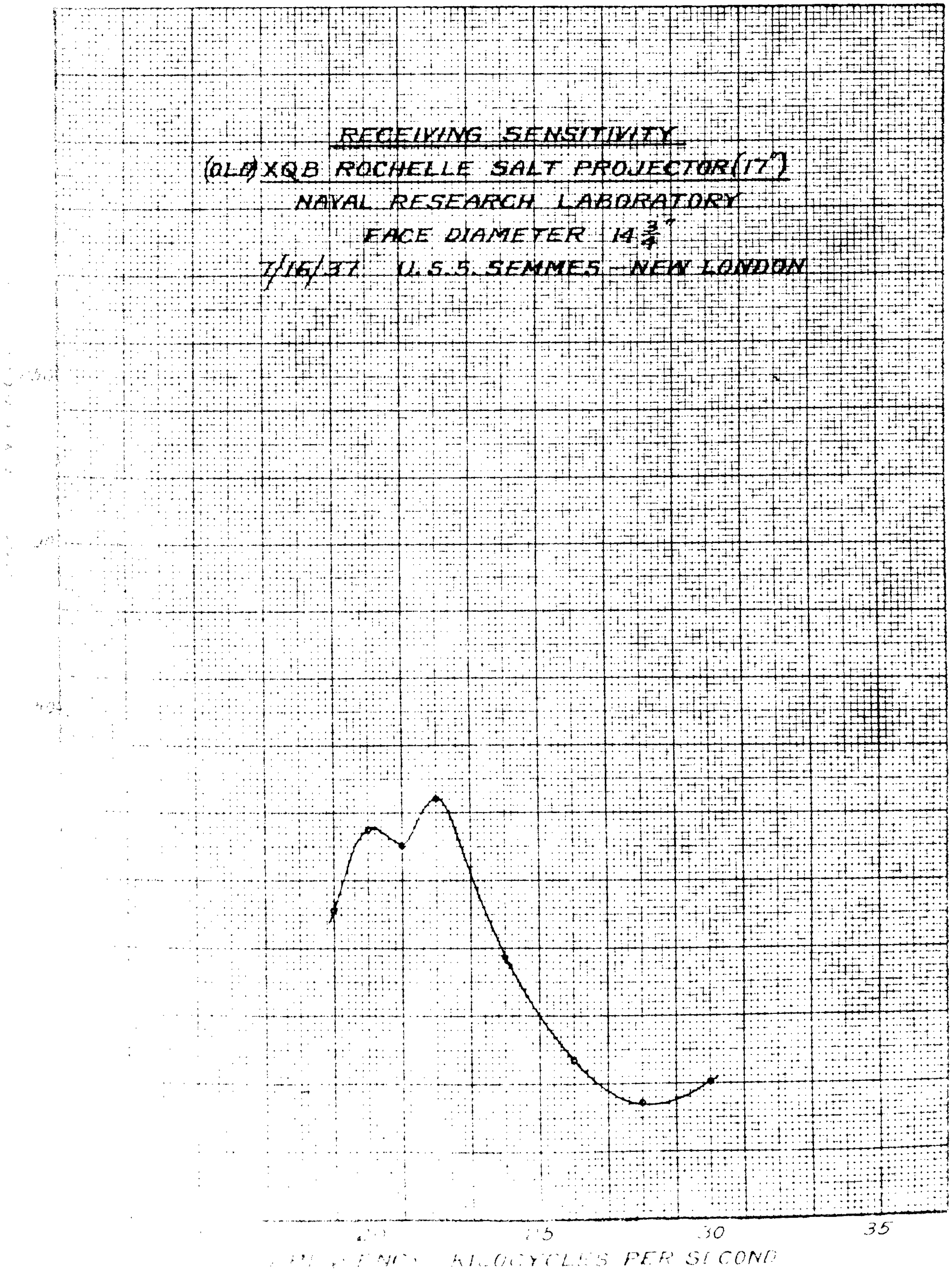


PLATE 34

RECEIVING SENSITIVITY (OPEN CIRCUIT) VS FREQUENCY

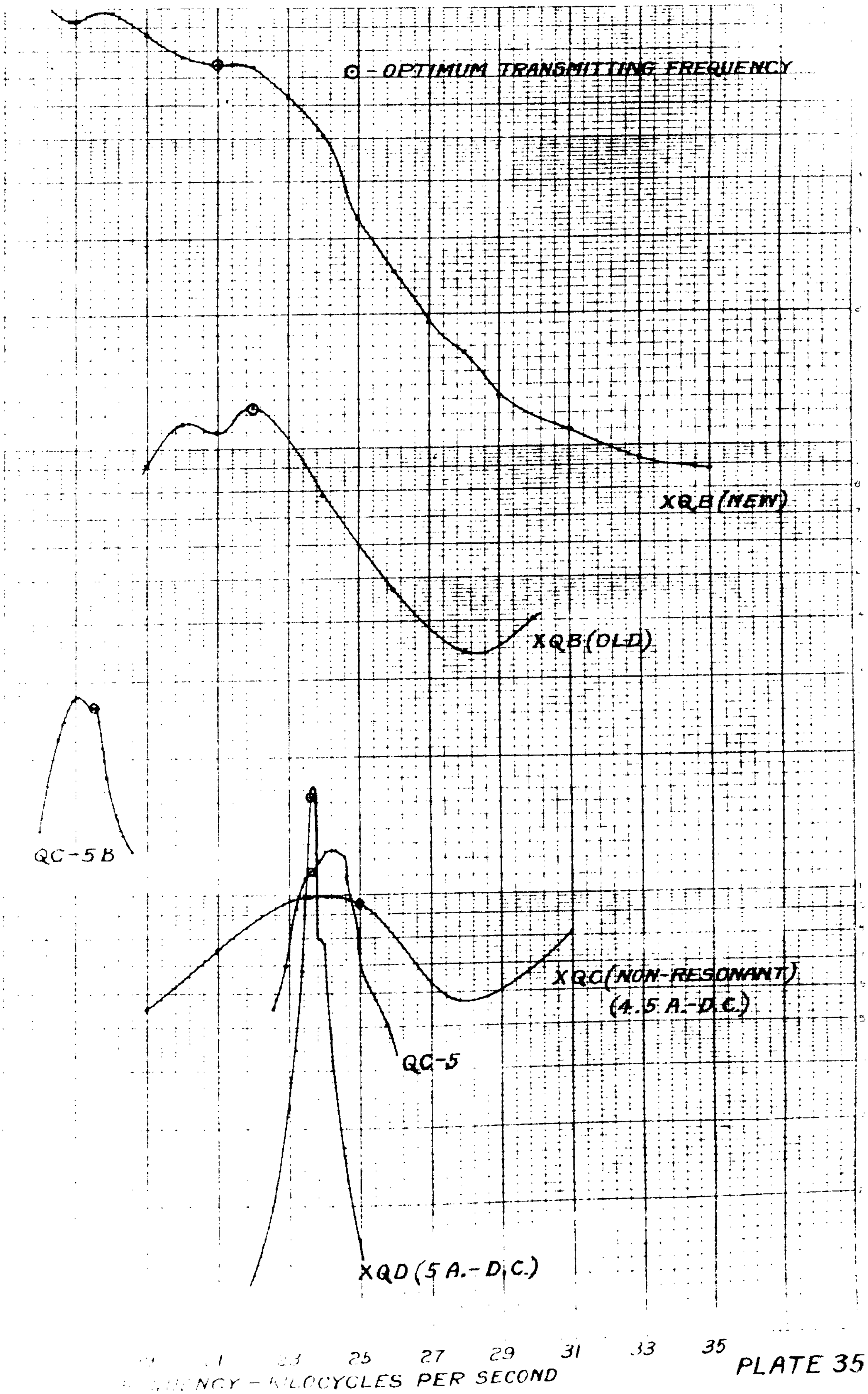


PLATE 35

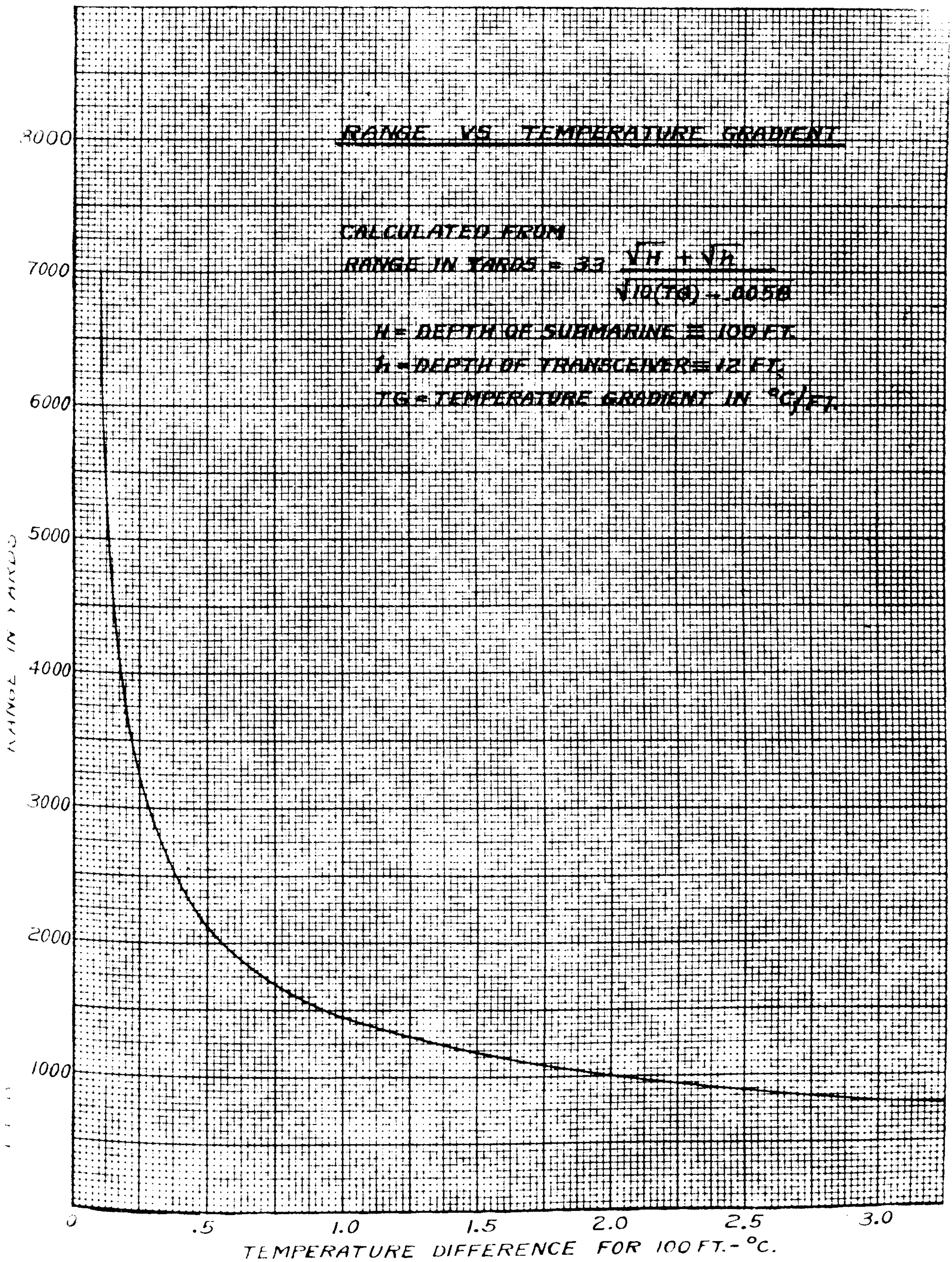
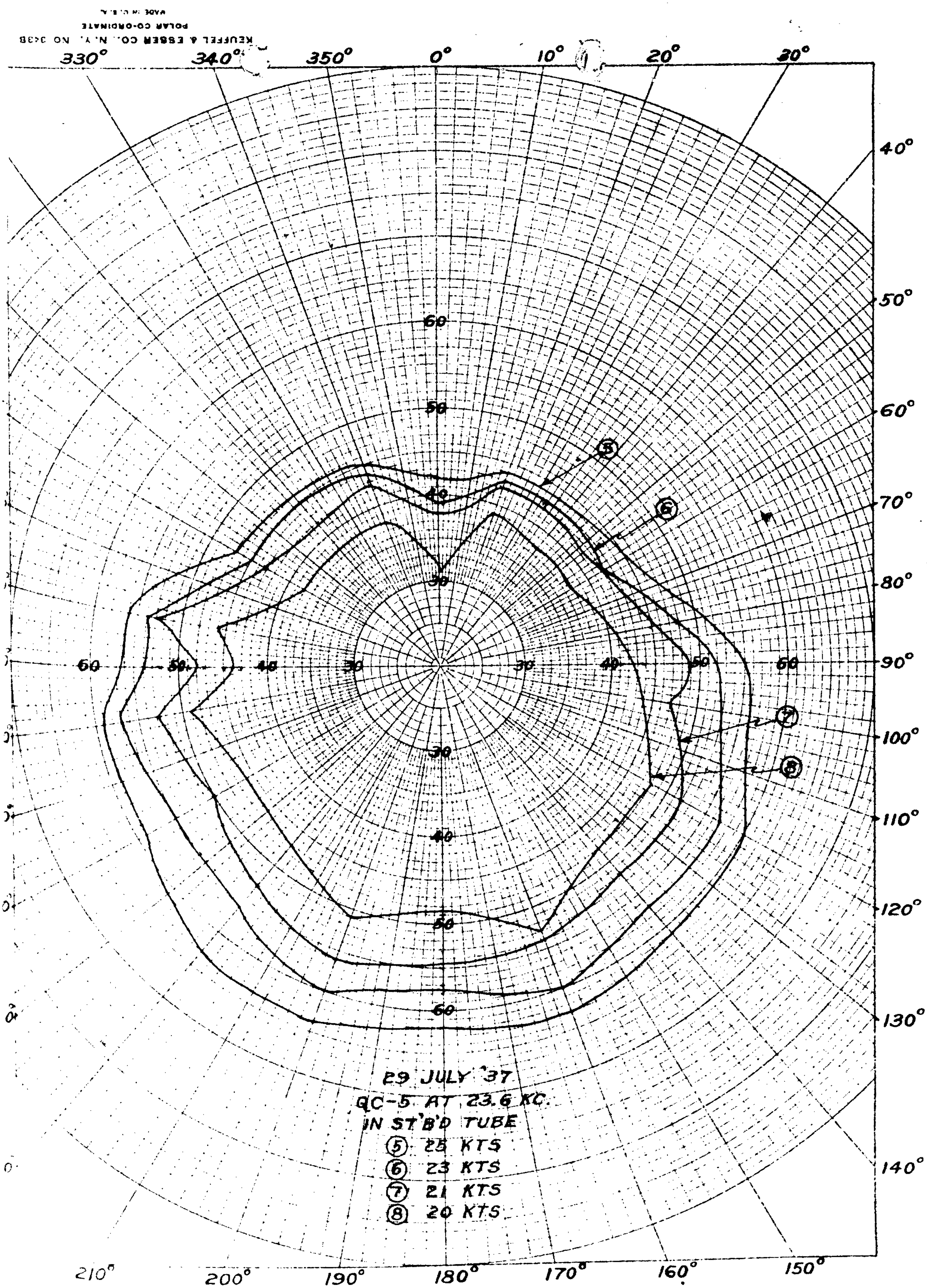
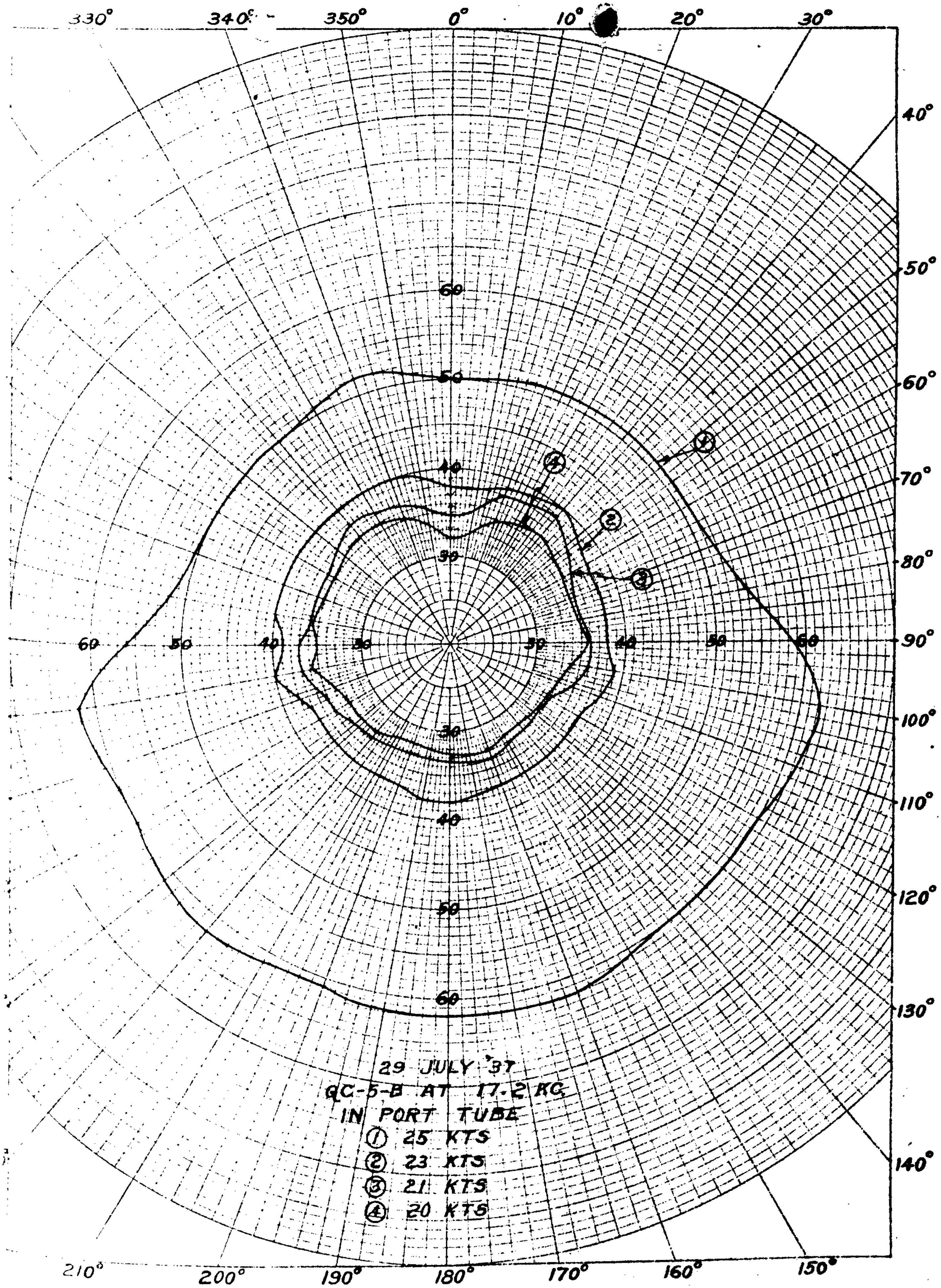

RANGE VS TEMPERATURE GRADIENT
CALCULATED FROM
RANGE IN YARDS = 3.3 $\frac{\sqrt{H} + \sqrt{h}}{\sqrt{10(TG) + .0058}}$
H = DEPTH OF SUBMARINE ≡ 100 FT.
h = DEPTH OF TRANSCEIVER ≡ 12 FT.
TG = TEMPERATURE GRADIENT IN °C/FT.
RANGE IN YARDS
8000
7000
6000
5000
4000
3000
2000
1000
0
.5
1.0
1.5
2.0
2.5
3.0
TEMPERATURE DIFFERENCE FOR 100 FT. - °C.

PLATE 36



KEUFFEL & ESSER CO., N.Y. NO. 3438
POLAR CO-ORDINATE
MADE IN U.S.A.
330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
60
50
40
30
5
6
7
8
29 JULY '37
QC-5 AT 23.6 KC.
IN ST'B'D TUBE
5 25 KTS
6 23 KTS
7 21 KTS
8 20 KTS

FIG. 1a



330°
340°
350°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
60
50
40
30
29 JULY '37
QC-5-B AT 17.2 KC
IN PORT TUBE
① 25 KTS
② 23 KTS
③ 21 KTS
④ 20 KTS

FIG. 2a

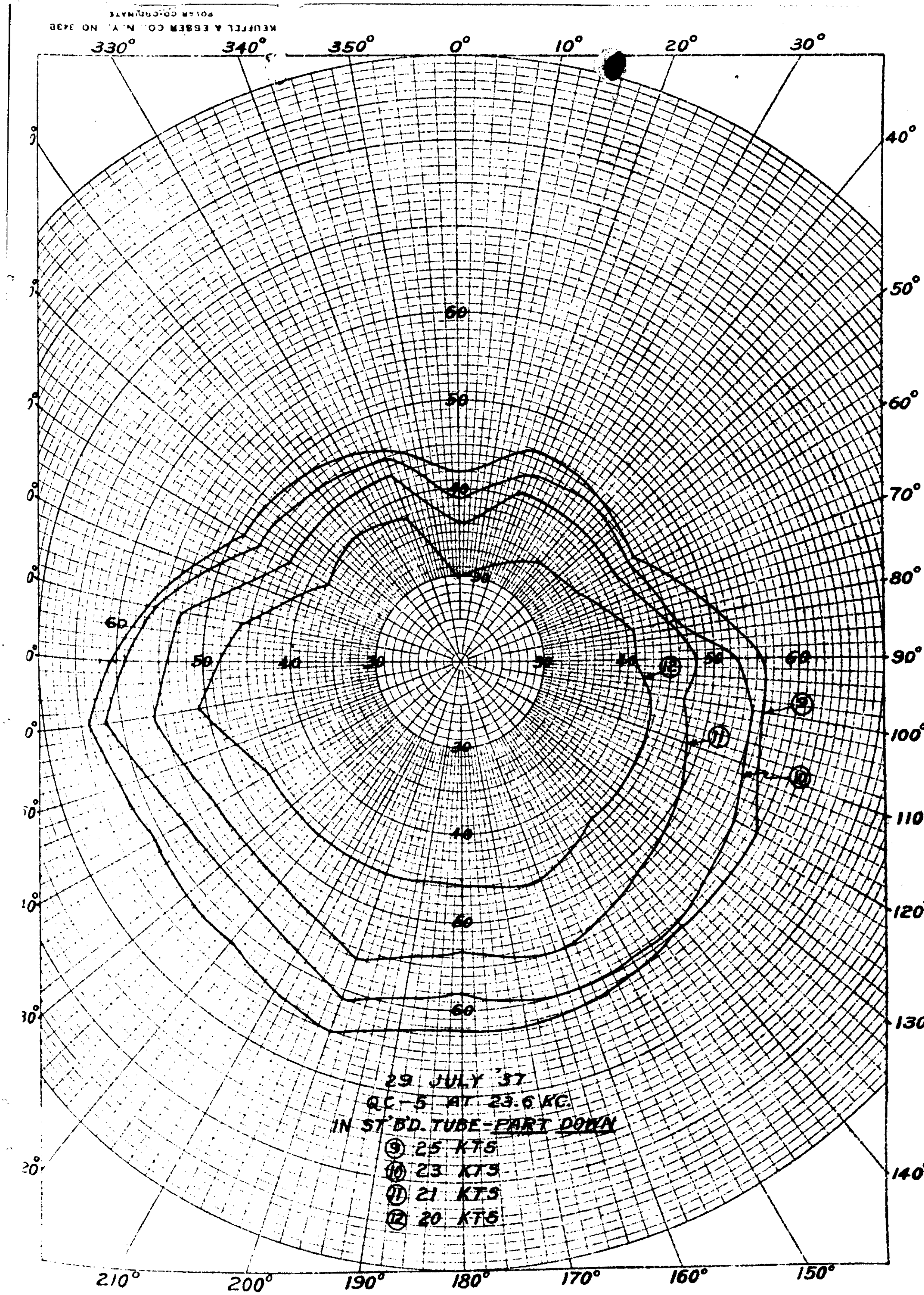

29 JULY '37
QC-5 AT 23.6 KC.
IN ST'BD. TUBE-PART DOWN
⑨ 25 KTS
⑩ 23 KTS
⑪ 21 KTS
⑫ 20 KTS

FIG. 3a

DATE

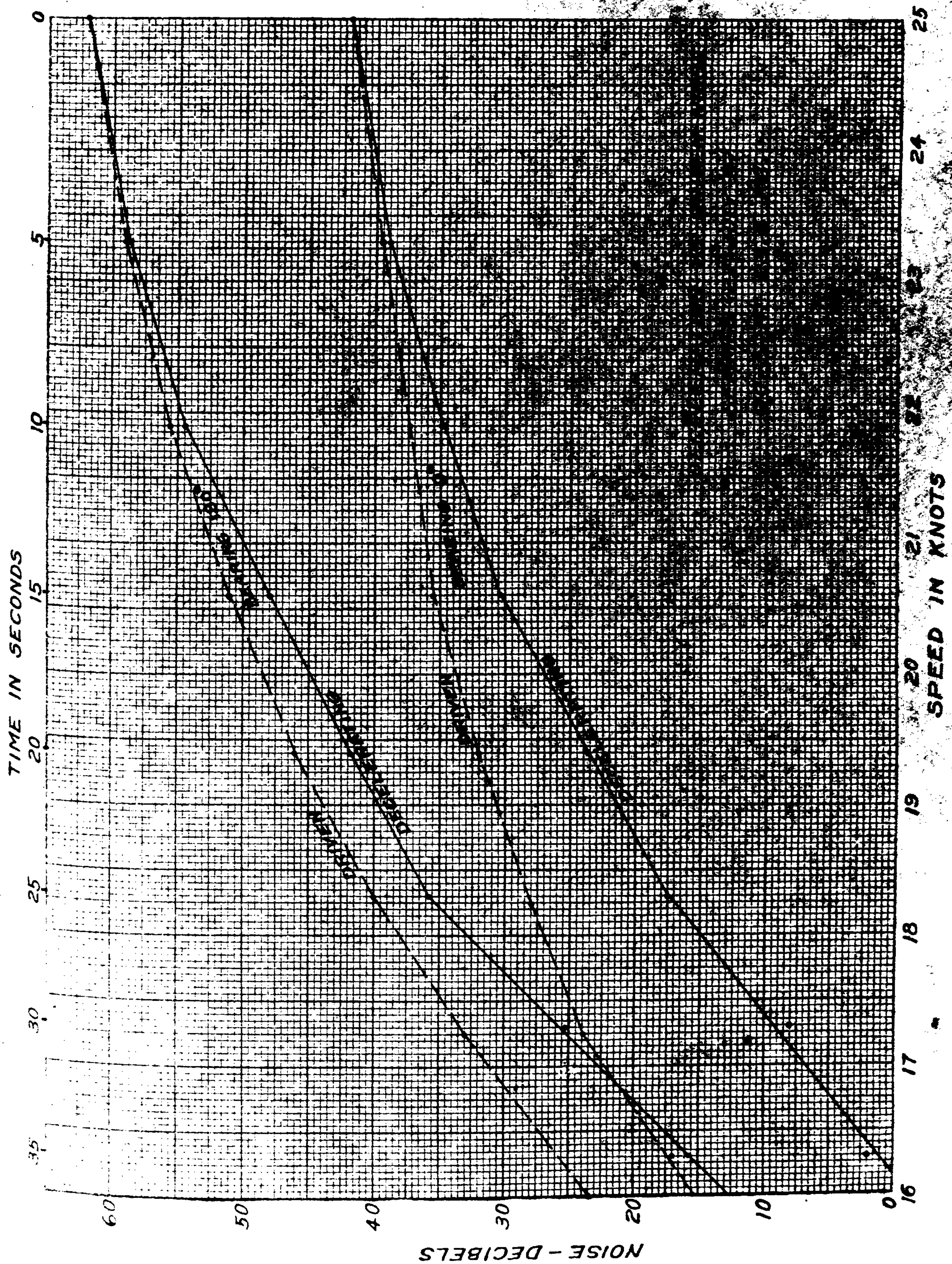
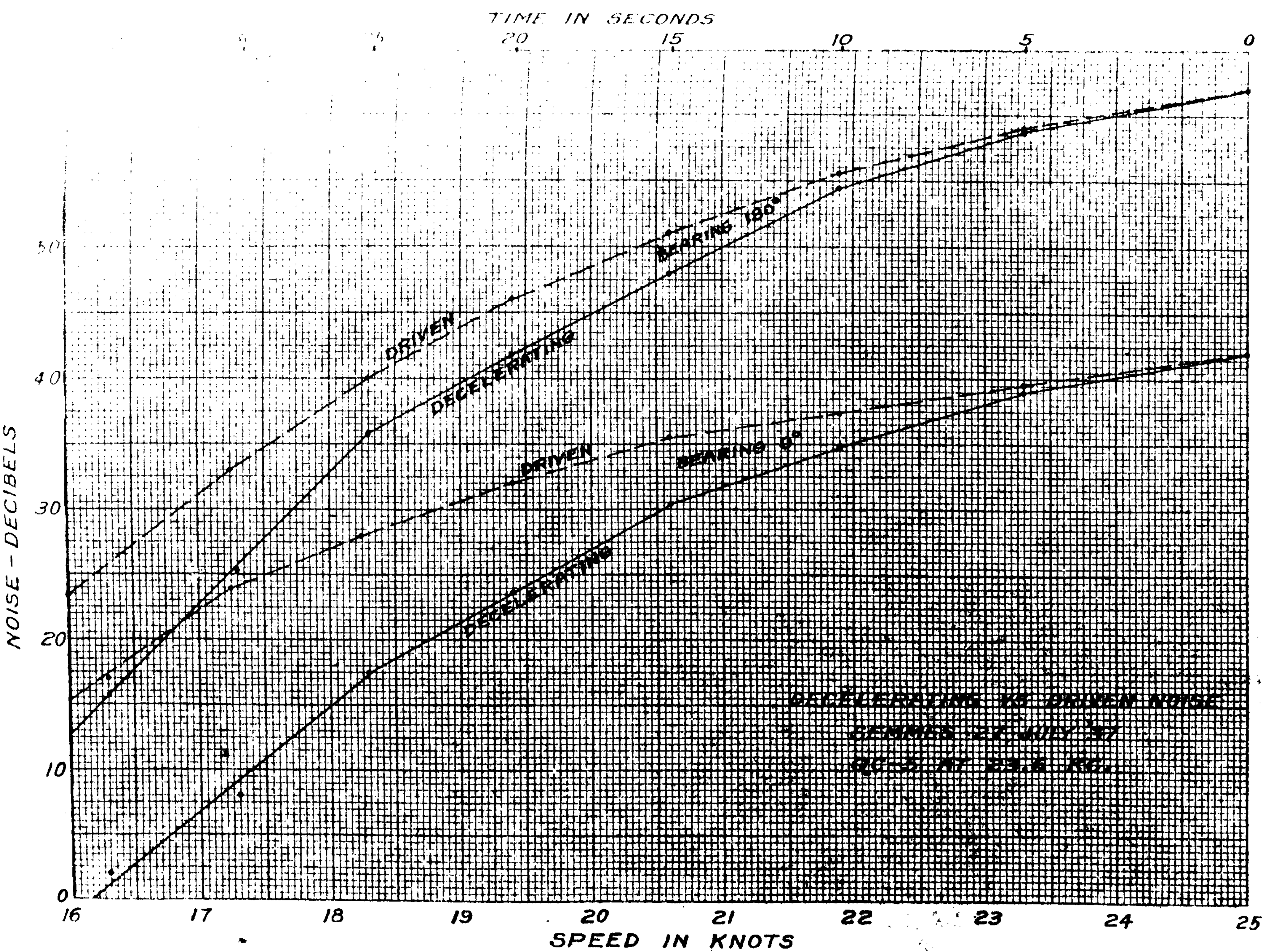


FIG. 4a



TIME IN SECONDS
0
5
10
15
20
NOISE - DECIBELS
10
20
30
40
50
SPEED IN KNOTS
16
17
18
19
20
21
22
23
24
25
DRIVEN
DECELERATING
BEARING 180°
DRIVEN
BEARING 0°
DECELERATING
DECELERATING VS DRIVEN NOISE

FIG. 4a

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DATE

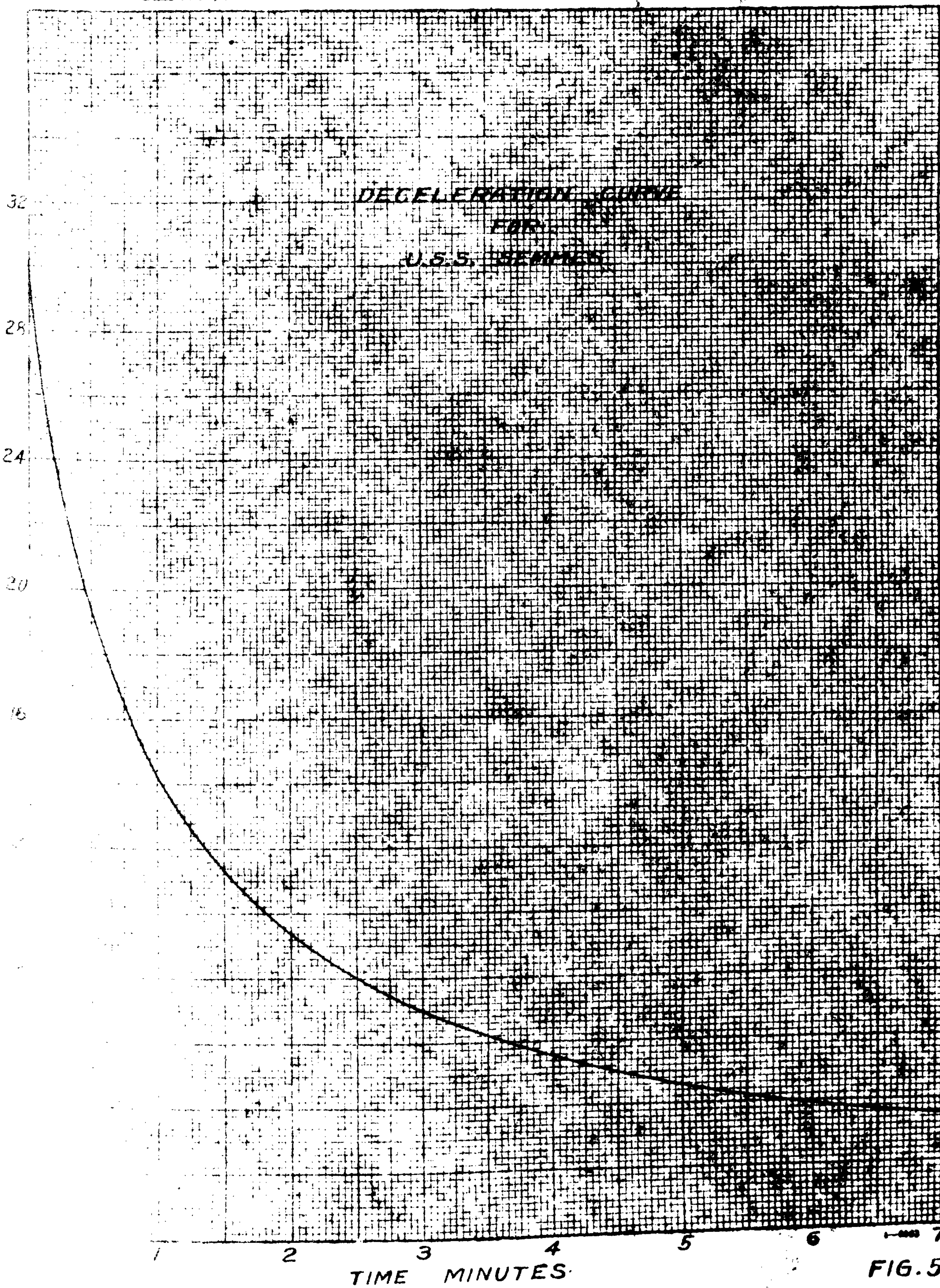

FIG. 5a