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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report on

Development of Electrodynamic Type

of

Underwater Sound Projector

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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SECTION I

INTRODUCTION

1. This report covers the progress to date on Sound Problem U2-1C, Develop Electrodynamic Type of Underwater Sound Projector. All told, four models of this type of projector have been constructed. The first was a simple design employing a single ring and magnetic gap that served for studying the eddy current and hysteresis losses generated by the required high frequency currents. The second carried eight concentric rings and gaps and served for studying the conditions necessary for securing uniformity of amplitude and phase over the sound radiating surface. Neither of these models were tested outside of the Laboratory.

2. Model XQD-3 was designed in the light of information gained from Models 1 and 2. This was tested on the SEMMES in comparison with the standard QC-5 projector during the period July 6 - 28, 1937. The test results, as reported to the Bureau of Engineering in NRL Report No. S-1404 dated 5 October 1937, showed that the electrodynamic generated an intense and highly directive sound beam and that its sensitivity and selectivity as a receiver were somewhat superior to the magnetostriction types tested. However, it proved to have one serious weakness in that the intensity of secondary maxima was so high that an unskilled operator might mistake their response for that of the main beam. Also, the back radiation was undesirably high and tests indicated that the acoustical efficiency could be improved.

3. The design of Model XQD-4 resulted from developmental work directed toward shifting energy from the secondary maxima into the main sound beam and toward improving the acoustical efficiency. For comparison purposes, performance data of the QC-5 and XQD-3, as given in Report No. S-1404, are included with performance tests of the Model XQD-4.

SECTION II

SOUND TEST PROGRAM ON THE SEMMES: December 11 - 17, 1938

4. The test program carried out by the SEMMES during the period December 11 - 17 consisted largely of determining the effectiveness of the XQD-4 as a transmitter and receiver of underwater supersonic sound signals. The present report covers only this part of the test program.

5. As explained in the October report, the testing of a projector as a sound transmitter requires the experimental determination of three curves:

(a) Intensity vs Frequency - Constant Power Input. This curve gives the resonant frequency of the transmitter and 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 transmitter and hence indicates the upper power limit to which it should be exposed. From the standpoint of both safety and economy, the power should not exceed the linear range of this curve.

(c) Intensity vs Azimuth - At Resonant Frequency and Constant Power Input. This curve shows the angular distribution of the transmitted sound and hence the directive selectivity.

Such curves follow in the above order for XQD-4 and standard QC-5 projectors.

SECTION III

TRANSMISSION PERFORMANCE TESTS

6. The three curves of Plate 1 show the resonant frequency and the sharpness of mechanical tuning of the XQD-4 and the standard QC-5. The resonant frequency of the XQD-4 is 24.35 kilocycles whether the d-c coils are energized by 4 or 8 amperes. The resonant frequency of the QC-5 (high power) is 23.6 kilocycles. The mechanical selectivity, defined as the resonant frequency (f_o) divided by the width (Δf) of the resonance curve 3 decibels down from the peak, is 125 for the XQD-4 at both values of the field current and 52 for the QC-5. The XQD-4 curves were taken at low power and therefore do not show maximum sound intensity.

7. The three curves of Plate 2 show the relation between the intensity of sound radiation at the projector face and the volt-ampere input for the QC-5, the XQD-3, and the XQD-4, operated at resonance. In the case of the QC-5 the polarization is normal, and in the cases of the electrodynamic projectors the field currents are adjusted to the highest practical value. Two sets of ordinates are employed, one giving directly the sound radiation at the projector face in milliwatts per square centimeter and the other the relative sound radiation at the face in decibels below 1 watt per square centimeter. The theoretical limit, set by cavitation, to the radiation of sound at the face of a projector submerged 12 feet is also indicated on the plate.

8. The slope of the XQD-4 curve is constant, thereby showing that its acoustical efficiency is independent of power input up to 1.9 kilowatts, the highest power that was available for these tests. This projector was designed to handle safely 2.5 kilowatts when operated intermittently as for signalling. When so energized, the signal intensity should be about 1 decibel from the cavitation limit for this projector, if mounted on a destroyer where its depth of submergence approximates 12 feet.

9. The curves of Plate 3 show the relation between the axial sound intensity at 160 feet and the volt-ampere input for the three

projectors operated at resonance, and those of Plate 4 show the relation between the total sound output and the volt-ampere input. Curves for the electrodynamic projectors operated at lower d-c field currents are included for comparison purposes. These curves (in conjunction with power factor values given in Plate 9) show that the sound power output of the XQD-4 for a corresponding power input is 3 decibels above that of the XQD-3. Thus the developmental work leading to the XQD-4 has resulted in raising the acoustical efficiency from about 13% for the XQD-3 to 26% for the XQD-4.

10. The two curves of Plate 5 show the angular distribution of sound generated by the XQD-3 and XQD-4. The broken line refers to the XQD-3. The first "side bands" (the two ears adjacent to the main beam) which are distinct and intense on the XQD-3 pattern have shrunk and coalesced with the main beam on the XQD-4 pattern, the prominent second and third order side bands of the XQD-3 have shrunk to noticeably smaller dimensions on the XQD-4 pattern, and the back radiation from XQD-4 is 10 decibels less than from XQD-3. Thus the developmental work leading from the XQD-3 to the XQD-4 has resulted in concentrating into the main sound beam a larger percent of the total sound generated and has materially reduced the back radiation.

11. The two curves of Plate 6 give the angular distribution of the sound generated by the XQD-4 and the QC-5. The solid line refers to the XQD-4.

12. The measured beam width of the XQD-4 varies between 19.5 and 20 degrees on several patterns taken with different power input. This agrees to within the experimental error with the computed beam width of 20.1 degrees. Such agreement indicates that the radiating face oscillates with very approximate uniformity of amplitude and phase, or, in other words, the radiating face oscillates like the end surface of a piston.

SECTION IV

RECEIVER PERFORMANCE TESTS

13. The three curves of Plate 7 show the characteristics of the XQD-4 and the QC-5 when used as receivers of cw signals. The ordinates are expressed as microvolts per bar of pressure amplitude. The sensitivity of the XQD-4 varies rapidly with frequency, reaching a sharp maximum at 24.3 kilocycles. This is the same frequency at which transmission is most efficient. The mechanical selectivity is 128 and practically independent of the field excitation.

14. The sensitivity of the QC-5 is low in comparison with the XQD-4 and varies less rapidly with change of frequency. Its mechanical selectivity is 15 and the frequency of maximum sensitivity is 24.2 kilocycles, a value about 500 cycles higher than the frequency of most efficient transmission.

15. The curves of Plate 8 serve to measure the decrease of noise background effected by the higher mechanical selectivity of the XQD-4. The ordinates are proportional to the intensity of the background noise picked up at frequencies off resonance to that

at resonance. The response of each type of receiver to the background is proportional to the area under its respective curve. The area of the QC-5 curve is 2.15 times that of the XQD-4. Therefore, the background intensity picked up on the XQD-4 is 3.32 decibels below that picked up by the QC-5.

SECTION V.

ASSEMBLED DATA

16. The two tables of Plate 9 give all the data and computed results pertaining to the QC-5, the XQD-3 and the XQD-4 for comparison purposes. The upper or larger table refers to their use as transmitters and the smaller one to their use as receivers. The data of the last column of the two tables give a measure of the relative effectiveness of the three devices. Calling the QC-5 high power signal intensity unity, then as transmitters operated at a 2 kilowatt level, the XQD-3 will rate 12 and the XQD-4 will rate 23. Calling the QC-5 receiving sensitivity unity, the XQD-3 and the XQD-4 will rate 4.3 and 11.8 respectively.

SECTION VI

DISCUSSION OF VARIOUS POINTS

A. Rating of Projectors as Transmitters and Receivers.

17. The practice of rating submarine sound transmitters and receivers in terms of the performance of the QC-5 as a standard has not been followed in the present report. It is proposed to discontinue this practice and to rate receivers in terms of decibels below a volt per bar in conformity with Bell Telephone practice in rating microphones and to rate transmitters in terms of decibels below one watt of sound power per square centimeter at a range of 160 feet, the range between the wells of the main and after sound rooms of the SEMMES. It may later become necessary to change this range to conform with a different arrangement of apparatus for making acceptance tests of commercial equipment. Such scales are provided on the right hand margin of Plates 1 and 3 for the transmitters and of Plate 7 for the receivers.

B. Relative Effectiveness of XQD-4 and QC-5 Projectors.

18. Plate 3 shows that the XQD-4 operated at a 2 kilowatt level generates a sound signal 13.6 decibels more intense than does the QC-5. Plate 7 shows that the XQD-4 can detect an echo 14.1 decibels weaker than can the QC-5. This gives the XQD-4 an apparent overall superiority of 27.7 decibels.

19. But advantage cannot be taken of all this gain under normal operating conditions on surface ships where the noise background is far above the minimum intensity that can be received on even the QC-5. The 13.6 decibel gain on transmission is real because it returns an echo that is this number of decibels more intense than an echo from the QC-5. Plate 8 shows that the XQD-4 because of its higher mechanical selectivity is less responsive by 3.3 decibels to the local noise background than is the QC-5. This 3.3 decibel

gain is real because it reduces by this amount the background against which the echo is received and this is equivalent to increasing the signal strength by 3.3 decibels.

20. Thus the real gain of the XQD-4 over the QC-5 when used on ships in the screen is limited to about 17 decibels. There is also the advantage that it requires less amplification by about 14 decibels than does the QC-5. Some use can probably be made of the greater receiving sensitivity of the XQD-4 when it is used on a submerged submarine where the local noise background is low or when used on harbor patrol ships where listening can be done at low speeds. Of course, it can be utilized on ships of the screen in proportion as the local noise background is reduced.

C. Limits of Mechanical Selectivity.

21. The pitch of an echo reflected from a submerged target of any kind usually differs from that of the transmitted signal due to the Doppler effect. This pitch difference, which is numerically equal to twice the rate of change of range in terms of signal wave-length, may become as great as $\pm$ 300 c.p.s. when the searching ship steams at 20 knots. It has been considered necessary to make the mechanical resonance of a projector as broad as the Doppler effect in order that it may always be sensitive as a receiver of its signal echoes. This sets a definite and relatively low limit for the mechanical selectivity and thereby reduces the possible transmitting efficiency.

22. The mechanical tuning of the XQD-4 was deliberately broadened for this reason. But after noting that its mechanical selectivity resulted in lowering the background noise several decibels below that of the less sharply resonant QC-5, the question arose as to whether the lowered noise background caused by still sharper mechanical tuning and increased signal strength would not more than compensate for the resulting lack of sensitivity for off-resonance echo reception. The following analysis answers this question in the affirmative for a projector of the electrodynamic type.

23. It can be shown that for a projector of the electrodynamic type where the internal mechanical dissipation is very low and the acoustical efficiency (sound output divided by a-c power input) is low to moderate, the efficiency varies approximately inversely as the first power of the decrement (Δ) or band width (Δf).

$$\therefore \text{ Efficiency} = \frac{K}{\Delta} \qquad \text{Original assumption.}$$

If P is the a-c power input to the projector, then the intensity I_o of the outgoing signal becomes

$$I_o = P \times \text{Efficiency} = \frac{K \cdot P}{\Delta} \tag{1}$$

Let subscript 1 apply to a sharply resonant XQD.
Let subscript 2 apply to a broadly resonant XQD.

Then $\frac{(I_o)_1}{(I_o)_2} = \frac{\Delta_2}{\Delta_1} = \frac{\Delta f_2}{\Delta f_1}$, assuming the same power is (2)

available for application to the two projectors. It follows that

$$\frac{(I_r)_1}{(I_r)_2} = \frac{\Delta f_2}{\Delta f_1} \qquad (3)$$

, where $(I_r)_1$ and $(I_r)_2$ represent the intensity of the echoes from the sharply tuned and the broadly tuned XQD respectively. These echoes must compete with the noise level since noise and echo are both converted into electrical energy by the projectors for the amplifier. Let S_1 and S_2 be the conversion constants at resonance of the two projectors

Then $\frac{(I_r)_1 S_1}{(I_r)_2 S_2} = \frac{E_1}{E_2}$ where E_1 and E_2 represent the desired signal intensities applied to the amplifier by the sharply tuned and the broadly tuned XQD respectively.

But, $\frac{N_1}{N_2} = \frac{\Delta_1 S_1}{\Delta_2 S_2} = \frac{\Delta f_1 S_1}{\Delta f_2 S_2}$ where (N_1) and (N_2) represent (4)

respectively the intensity of the noise applied to the amplifier by the sharply and broadly tuned XQD

Therefore, $\frac{\frac{E_1}{N_1}}{\frac{E_2}{N_2}} = \left(\frac{\Delta_2}{\Delta_1}\right)^2 = \left(\frac{\Delta f_2}{\Delta f_1}\right)^2$ approximately.

This expression supposes that the echo is pitched to the resonance frequency of the XQD in both cases. There is no Doppler effect present. When the echo returns at a shifted frequency due to the Doppler effect, the response of the XQD applied to the amplifier is affected but the noise response remains the same. In case of the XQD-4, which is a velocity type of detector,

$$e_o = K \cdot v = \frac{K \cdot F}{r + j(m\omega - 1/s\omega)} \qquad (5)$$

where (e_o) is the open circuit terminal voltage and (v) is the velocity of motion in the vibrating system.

$$|e_o|^2 = \frac{K^2F^2}{r^2+(m\omega - \frac{1}{s\omega})^2} = \frac{K^2F^2}{r^2+m^2\omega^2\left[1-(\frac{\omega o}{\omega})^2\right]^2} = \frac{K^2F^2}{r^2+m^2\omega^2\left(\frac{(\omega-\omega_o)(\omega+\omega_o)}{\omega^2}\right)}$$

$$\therefore\ |e_o|^2 = \frac{K^2F^2}{r^2 + m^2\ (2\Delta\omega)^2} \qquad \frac{K^2F^2/4\ m^2}{\Delta^2 + (\Delta\omega)^2} \qquad (6)\ (7)$$

where, $\omega - \omega_o = \Delta\omega$ $\omega + \omega_o = 2\omega$ approx. $\Delta = \frac{r}{2m}$

But,

$\Delta = \pi\ (f_h - f_1)$ where f_h and f_1 are the quadrantal frequencies at the -3 decibel points of resonance curve.

$$\Delta\omega = 2\pi\ (f - f_o) = 2\pi\Delta f$$

where (Δf) is the Doppler shift.

Wherefore,

$$|e_o|^2 = \frac{K^2F^2/4\ m^2}{\pi^2(f_h-f_1)^2 + 4\pi^2(\Delta f)^2} \qquad (8)$$

Hence,

$$\frac{|e_o|^2\Delta f}{|e_o|^2\ \text{res.}} = \frac{(f_h - f_1)^2}{(f_h-f_1)^2 + 4(\Delta f)^2} = \frac{1}{1 + 4\ \frac{(\Delta f)^2}{(f_h-f_1)^2}} \qquad (9)$$

This is the ratio of the off resonance signal (echo) to the on resonance echo or signal. Hence,

$$\frac{E_1/N_1}{E_2/N_2} = \left(\frac{\Delta f_2}{\Delta f_1}\right)^2 \times \frac{1 + 4\left(\frac{\Delta f}{\Delta f_2}\right)^2}{1 + 4\left(\frac{\Delta f}{\Delta f_1}\right)^2} = \frac{\left(\frac{\text{Intensity of Echo}}{\text{Noise}}\right)_1}{\left(\frac{\text{Intensity of Echo}}{\text{Noise}}\right)_2} \qquad (10)$$

where (Δf) represents the amount the echo frequency departs from the resonance frequency of the XQD.

The above expression simplifies to:

$$\frac{E_1/N_1}{E_2/N_2} = \frac{\left(\frac{\Delta f_2}{\Delta f_1}\right)^2 + 4\left(\frac{\Delta f}{\Delta f_1}\right)^2}{1 + 4\left(\frac{\Delta f}{\Delta f_1}\right)^2}$$

Singe (Δf_2) is greater than (Δf_1) by initial assumption, it follows that

$$\frac{E_1}{N_1} > \frac{E_2}{N_2}$$ for all Doppler effects. The two ratios approach equal values for very large values of (Δf).

The conclusion is that it is disadvantagous to broaden the mechanical response of a projector of the XQD type. Increasing its mechanical selectivity increases the signal vs noise ratio and at the same time increases its acoustical efficiency.

D. Improvement Limits of the XQD Projector.

24. The developmental work leading from the XQD-3 to the XQD-4 has resulted in marked improvement in signal strength, receiving sensitivity and concentration of sound in the main beam. The question arises as to whether there is promise of still further improvement.

25. The improvement of the XQD-4 over the XQD-3 is largely due to increasing the magnetic flux density through the circular gaps. This has been accomplished despite the fact that the gaps of XQD-4 are wider by 0.0075 inch. The present gap can probably be narrowed by at least 0.005 inch because the oscillating head and magnet are each turned out during one setting in the lathe and can, therefore, be given close tolerances even under quantity production conditions. This will increase the field strength about 4% and therefore increase the acoustical efficiency by 8 percent. If experience proves that the signal vs noise ratio for reception of echoes is improved by sharpening the mechanical tuning even though their pitch has been shifted by the Doppler effect,then some further gain can be secured because, as stated, the tuning of the XQD-4 was deliberately dulled. Sharpening the mechanical tuning (raising the mechanical selectivity) gives a twofold gain, since it improves the signal vs noise ratio by reducing the noise background and at the same time increases the echo intensity by improving the acoustical efficiency.

26. These improvements may be expected in a new design and a study of the sound field in relation to the amplitude and phase relations of the radiating face which is under way may lead to a further concentration of the sound into the main beam. These im-

provements should raise the acoustical efficiency from 26 to about 36 percent. However, they will not materially increase the signal intensity beyond the present maximum which it is believed will reach cavitation limits when full power is used. But they will materially reduce the power required to generate a signal of such intensity and they will result in improved reception because of increased signal vs noise ratio.

SECTION VII

CONCLUSIONS

27. The test performance of the XQD-4, as reported herein, shows that the development of the electrodynamic type of projector has been carried to the point where its present operating limits cannot be materially extended. The power required to drive it, however, can be reduced something like 30 percent through increasing by obvious means, its overall acoustical efficiency.

28. Tests under approximate service conditions prove that this type of projector offers the following advantages for echo detection purposes over other types that we have tested.

(a) It generates signals approximating cavitation amplitude and therefore many times more powerful than does its nearest competitor. Its correspondingly stronger echoes make for improvement in both reliability and range of detection.

(b) Its high mechanical selectivity reduces its response to the local noise and increases its response to the echoes, thereby giving a higher ratio of signal to noise than other types thus far tested.

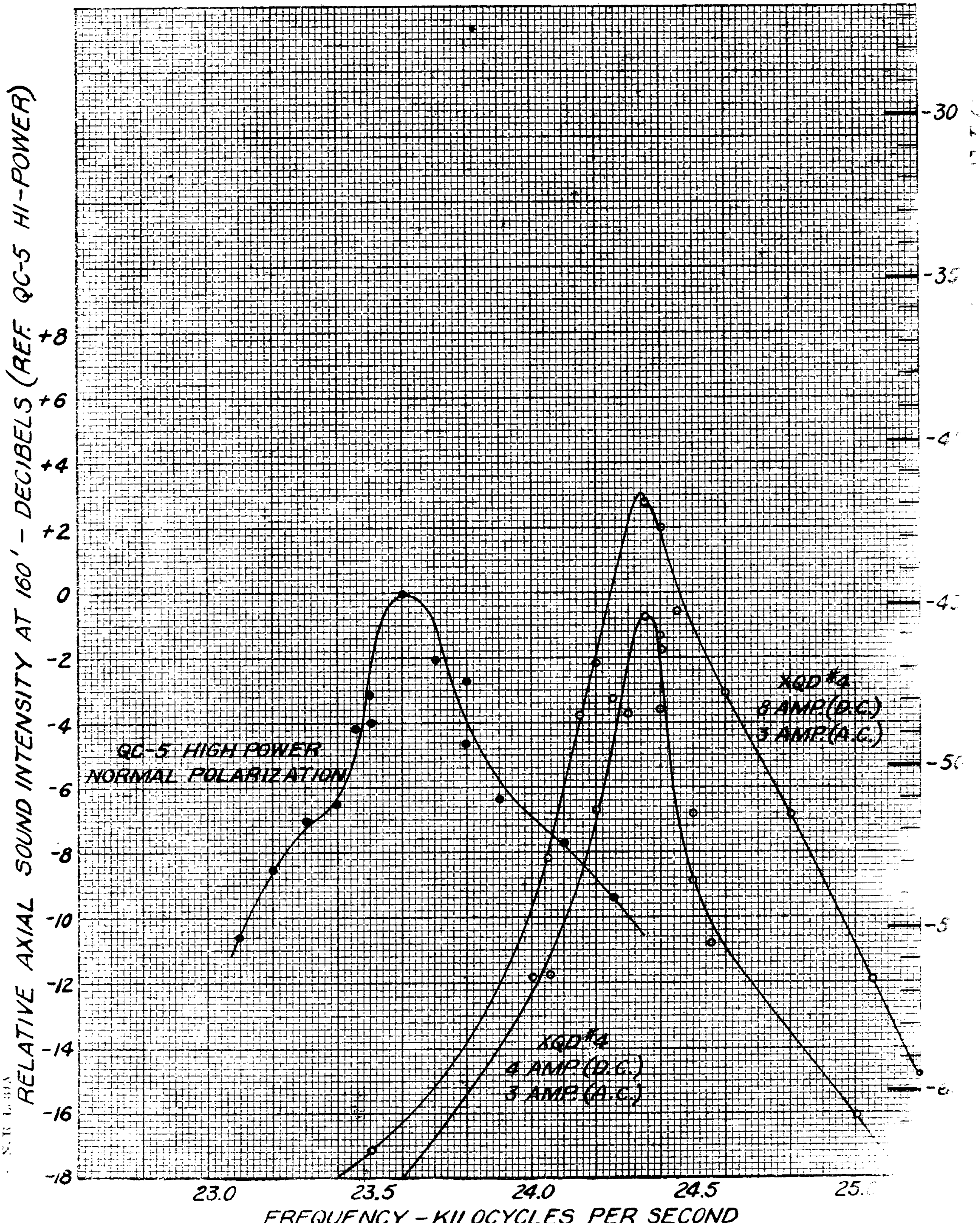
(c) Its polarizing d-c circuit is physically separate from its a-c circuit. This permits the attainment of an extremely low internal noise at very low filtration cost.

(d) It is simple and rugged and lends itself to commercial production at a relatively low cost.

(e) It is free of patent restrictions.

BELLEVUE, D. C.

DATE



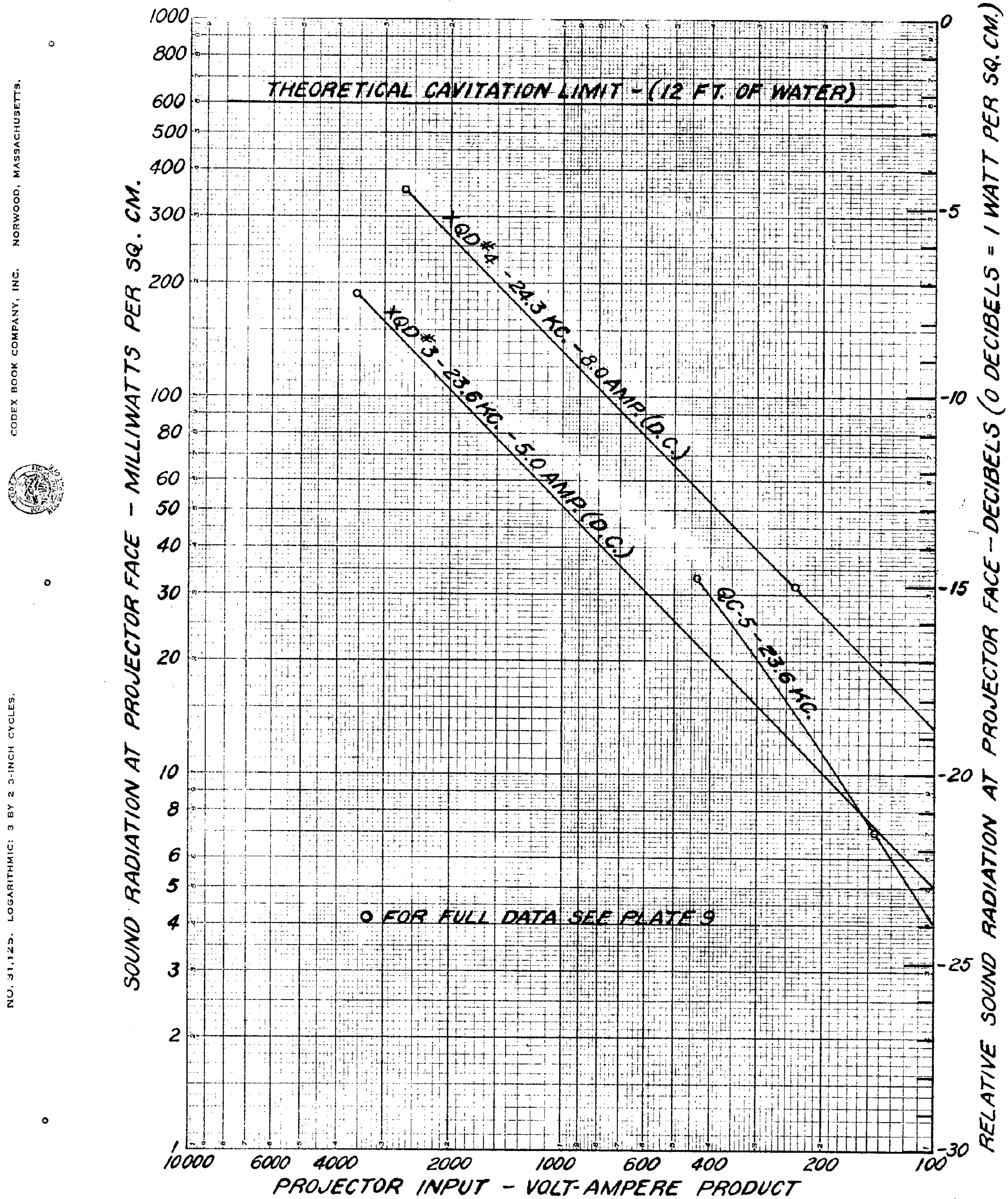

THEORETICAL CAVITATION LIMIT - (12 FT. OF WATER)
XQD*4 - 24.3 KC. - 8.0 AMP. (D.C.)
XQD*3 - 23.6 KC. - 5.0 AMP. (D.C.)
QC-5 - 23.6 KC.
o FOR FULL DATA SEE PLATE 9
SOUND RADIATION AT PROJECTOR FACE - MILLIWATTS PER SQ. CM.
RELATIVE SOUND RADIATION AT PROJECTOR FACE - DECIBELS (0 DECIBELS = 1 WATT PER SQ. CM.)
PROJECTOR INPUT - VOLT-AMPERE PRODUCT
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
10000
6000
4000
2000
1000
600
400
200
100
0
-5
-10
-15
-20
-25
-30
NO. 31,125. LOGARITHMIC: 3 BY 2 3-INCH CYCLES.
CODEX BOOK COMPANY, INC. NORWOOD, MASSACHUSETTS.

PLATE 2

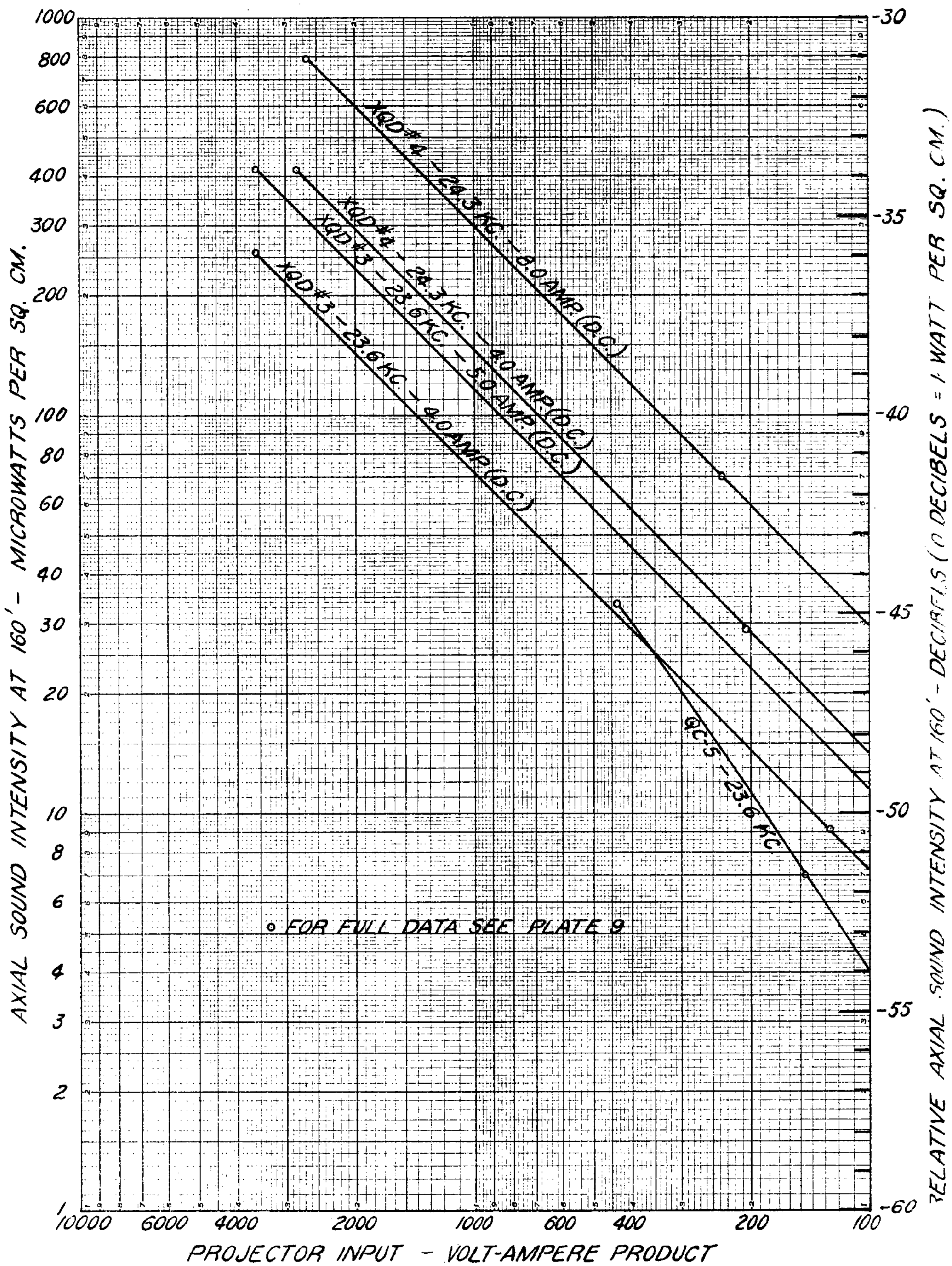
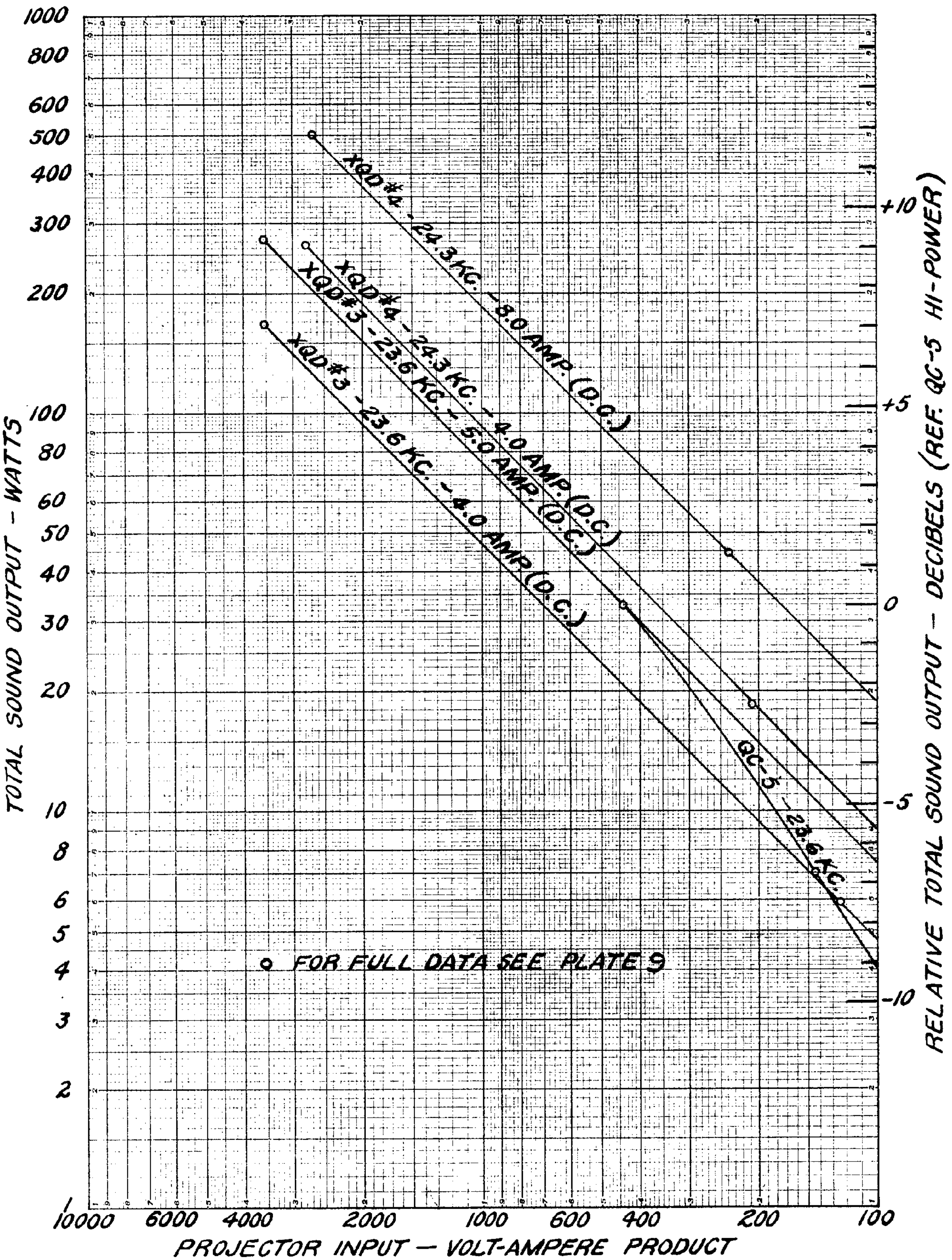

AXIAL SOUND INTENSITY AT 160' - MICROWATTS PER SQ. CM.
RELATIVE AXIAL SOUND INTENSITY AT 160' - DECIBELS (0 DECIBELS = 1 WATT PER SQ. CM.)
PROJECTOR INPUT - VOLT-AMPERE PRODUCT
1000
800
600
400
300
200
100
80
60
40
30
20
10
8
6
4
3
2
1
-30
-35
-40
-45
-50
-55
-60
10000
6000
4000
2000
1000
600
400
200
100
XQD#4 - 24.3 KC. - 8.0 AMP. (D.C.)
XQD#4 - 24.3 KC. - 4.0 AMP. (D.C.)
XQD#3 - 23.6 KC. - 5.0 AMP. (D.C.)
XQD#3 - 23.6 KC. - 4.0 AMP. (D.C.)
QC-5 - 23.6 KC.
o FOR FULL DATA SEE PLATE 9

PLATE 3



TOTAL SOUND OUTPUT - WATTS
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
RELATIVE TOTAL SOUND OUTPUT - DECIBELS (REF. QC-5 HI-POWER)
+10
+5
0
-5
-10
XQD#4 - 24.3 KC. - 8.0 AMP. (D.C.)
XQD#4 - 24.3 KC. - 4.0 AMP. (D.C.)
XQD#3 - 23.6 KC. - 5.0 AMP. (D.C.)
XQD#3 - 23.6 KC. - 4.0 AMP. (D.C.)
QC-5 - 23.6 KC.
o FOR FULL DATA SEE PLATE 9
10000
6000
4000
2000
1000
600
400
200
100
PROJECTOR INPUT — VOLT-AMPERE PRODUCT

PLATE 4

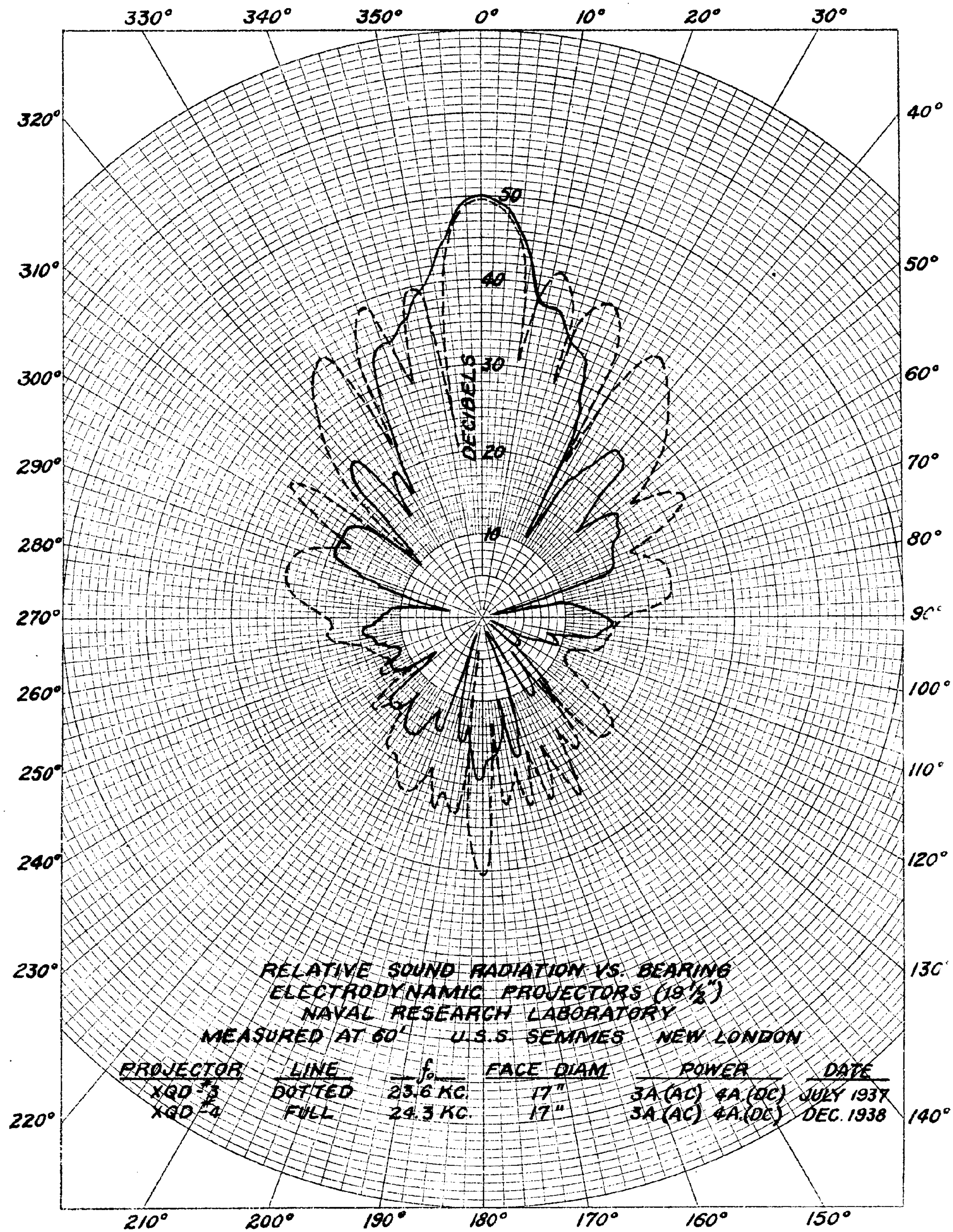

RELATIVE SOUND RADIATION VS. BEARING
ELECTRODYNAMIC PROJECTORS (18½")
NAVAL RESEARCH LABORATORY
MEASURED AT 60' U.S.S. SEMMES NEW LONDON
PROJECTOR | LINE | f₀ | FACE DIAM | POWER | DATE
XGD #3 | DOTTED | 23.6 KC. | 17" | 3A (AC) 4A (DC) | JULY 1937
XGD #4 | FULL | 24.3 KC. | 17" | 3A (AC) 4A (DC) | DEC. 1938
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°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°

PLATE 5

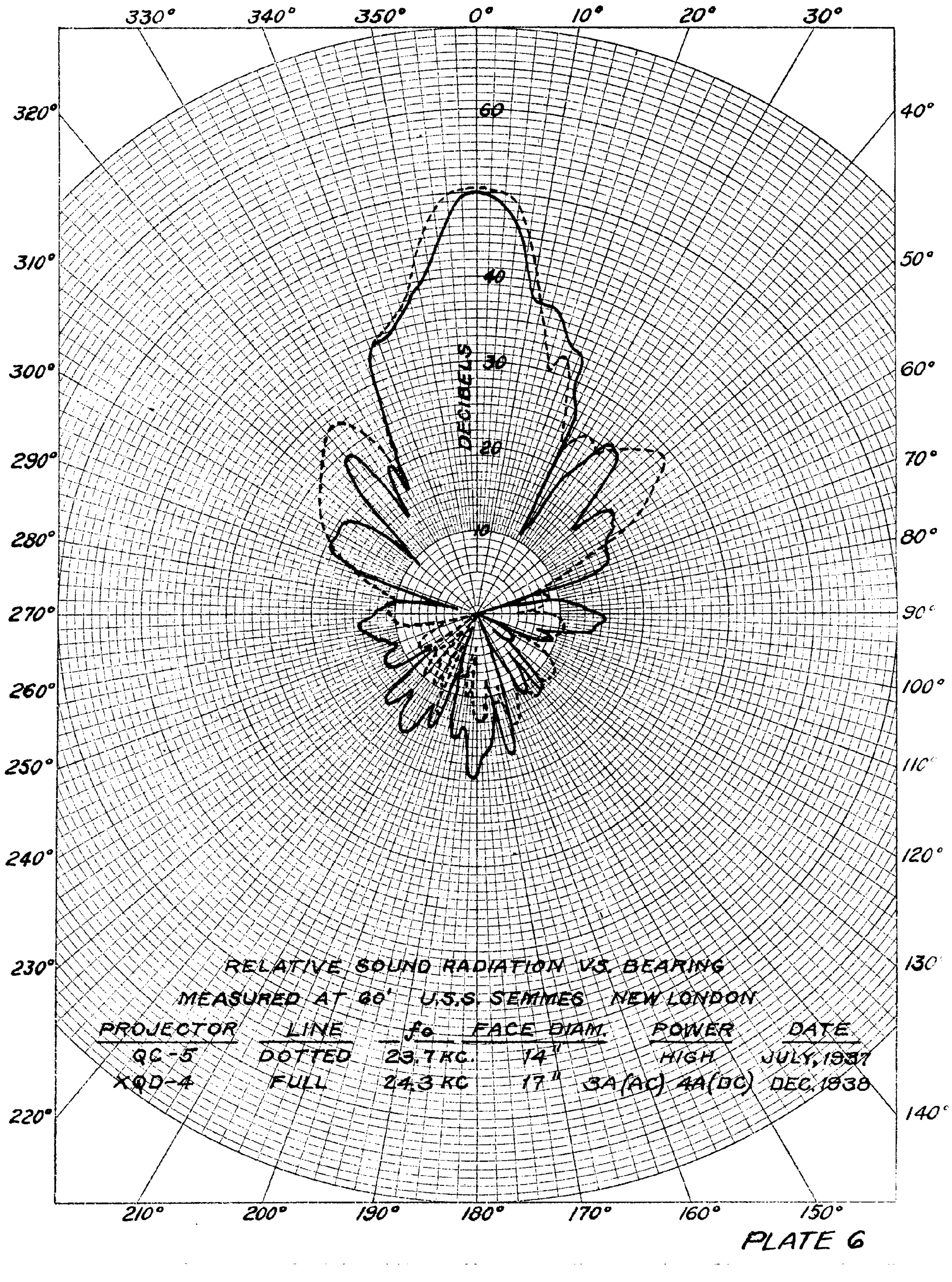
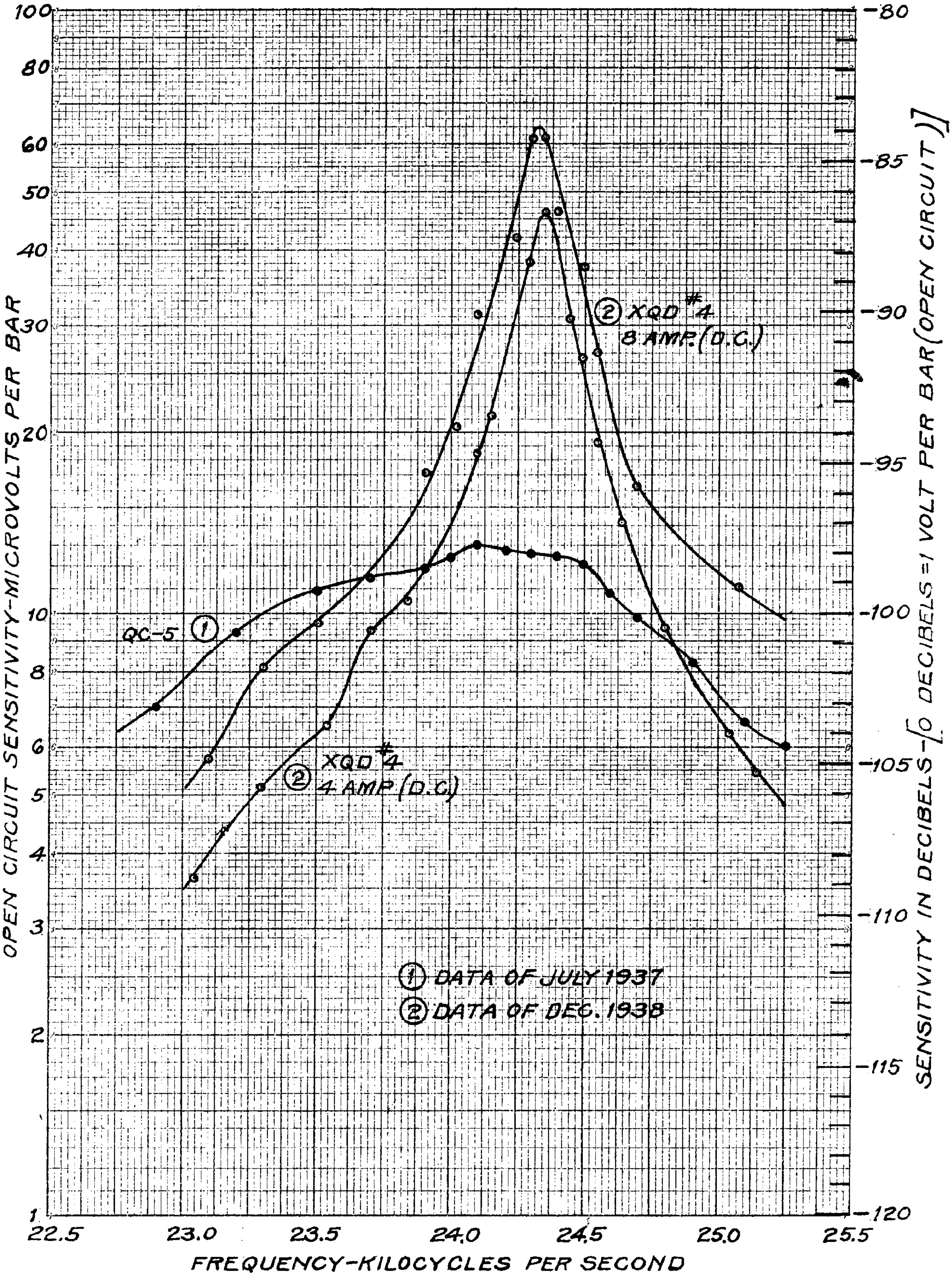

RELATIVE SOUND RADIATION VS. BEARING
MEASURED AT 60' U.S.S. SEMMES NEW LONDON
PROJECTOR LINE fo FACE DIAM. POWER DATE
QC-5 DOTTED 23.7 KC. 14" HIGH JULY, 1937
XQD-4 FULL 24.3 KC 17" 3A(AC) 4A(DC) DEC. 1938
DECIBELS
10
20
30
40
60
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°

PLATE 6



OPEN CIRCUIT SENSITIVITY-MICROVOLTS PER BAR
SENSITIVITY IN DECIBELS-[0 DECIBELS=1 VOLT PER BAR(OPEN CIRCUIT)]
FREQUENCY-KILOCYCLES PER SECOND
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
-80
-85
-90
-95
-100
-105
-110
-115
-120
22.5
23.0
23.5
24.0
24.5
25.0
25.5
(2) XQD #4
8 AMP.(D.C.)
QC-5 (1)
(2) XQD #4
4 AMP (D.C.)
(1) DATA OF JULY 1937
(2) DATA OF DEC. 1938

PLATE 7

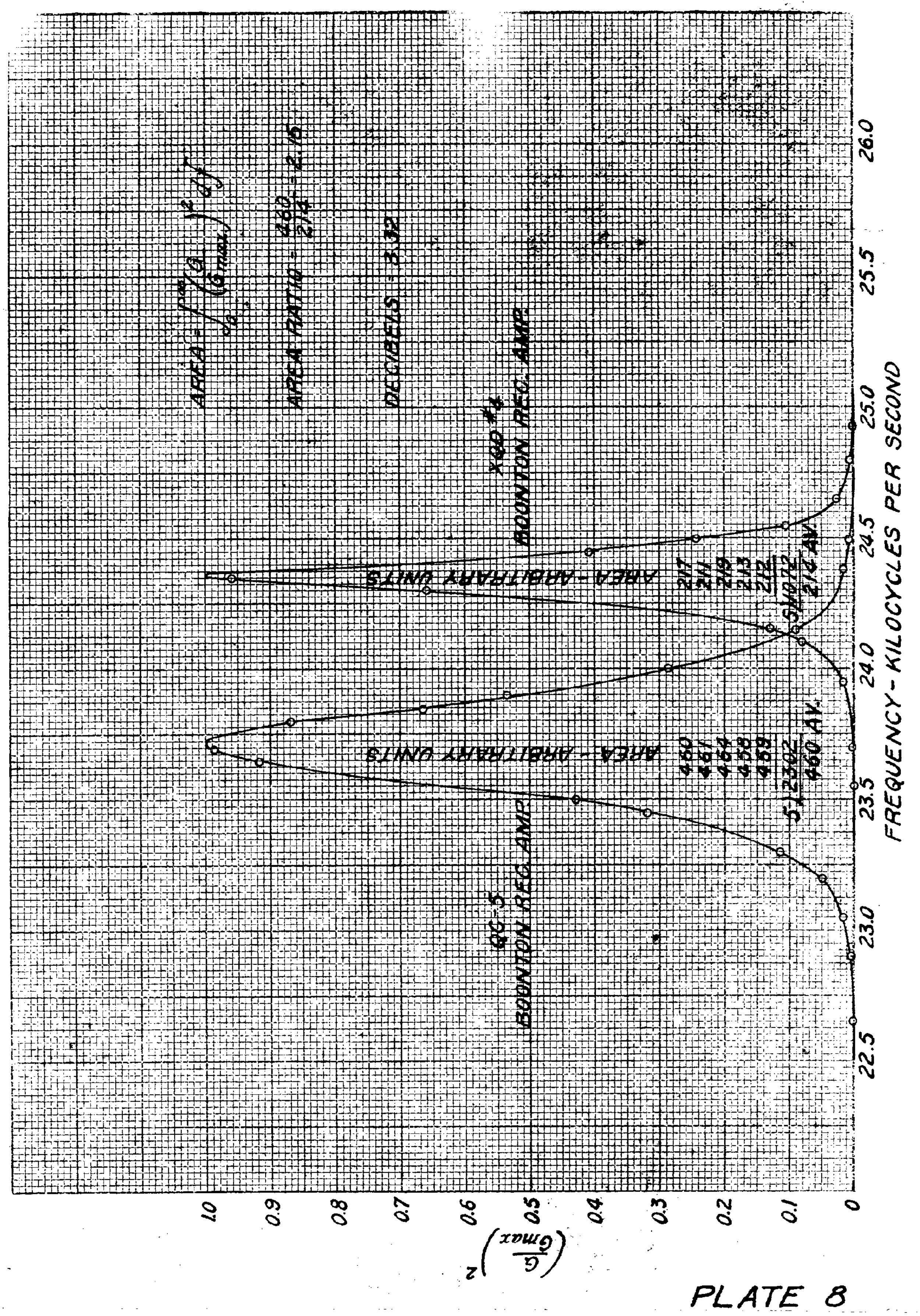

AREA = $\int_0^\infty \left(\frac{G}{G_{max}}\right)^2 df$
AREA RATIO = $\frac{460}{214}$ = 2.15
DECIBELS = 3.32
XQD #4
BOONTON REC. AMP.
AREA - ARBITRARY UNITS
217
211
219
213
212
5)1072
214 AV.
QC-5
BOONTON REC. AMP.
AREA - ARBITRARY UNITS
460
461
464
458
459
5)2302
460 AV.
22.5
23.0
23.5
24.0
24.5
25.0
25.5
26.0
FREQUENCY - KILOCYCLES PER SECOND
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$\left(\frac{G}{G_{max}}\right)^2$

PLATE 8

COLUMN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
PROJECTOR	POLARIZATION OR FIELD CURRENT AMPERES - D.C.	D.C. RESISTANCE OHMS	D.C. POWER WATTS	MECHANICAL RESONANCE f_o - FREQUENCY - KC./SEC.	BAND WIDTH Δf - FREQUENCY - KC./SEC.	MECHANICAL SELECTIVITY $f_o/\Delta f$	WAVELENGTH IN SEA WATER λ_o - CENTIMETERS	RADIUS OF RADIATING FACE R - CENTIMETERS	CALCULATED BEAM WIDTH $2\theta^o = 2 \sin^{-1} .61 \lambda_o/R$	MEASURED BEAM WIDTH $2\theta^o$ - DEGREES	INTENSITY OF MAX. SIDE LOBE / INTENSITY OF MAIN BEAM	DITTO IN DECIBELS	A.C. CURRENT INPUT AMPERES - R.M.S.	TERMINAL A.C. VOLTAGE VOLTS - R.M.S.	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 × 100	AREA OF RADIATING FACE SQUARE CENTIMETERS	FACE RADIATION PER UNIT AREA WATTS PER SQ. CM.	AXIAL SOUND INTENSITY AT 54" MW/CM²	AXIAL SOUND INTENSITY (IDEAL) AT 150' μW/CM²	AXIAL SOUND INTENSITY (IDEAL) AT 5000' μμW/CM²	TOTAL SOUND OUTPUT RATIO TO SC-5 - HI-POWER	AXIAL INTENSITY AT 5000' (IDEAL) RATIO TO SC-5 - HI-POWER	AXIAL INTENSITY AT 150' (IDEAL) RATIO TO SC-5 - HI-POWER	
JULY 1937	5.4	8.0	234	23.6^{5}	.387	61	6.34	17.3	24.1°	30°	.023	-15.5	1.09	132	144	121	?	?	7	> 5%	993	.007	8	7	.020	.21	.21	.21	a
SC-5 SUBMARINE SIGNAL CO. CASE:- SPHERICAL - 17" DIAM. WINDOW:- NON-CORROSIVE STEEL (1/16")	5.4	8.0	234	23.6	.452	52	6.35	17.3	24.2°				2.15	204	439	95	?	?	33	> 7%	993	.033	39	34	.097	1	1	1	b
JULY 1937	4.0	40	640	23.6	.200	118	6.35	21.6	20.7°	17°	.141	-8.5	3	41.7	125	13.9	.555	69.3	5.9	8.5%	1460	.004	9.0	9.1	.026	.18	.27	.27	c
XRD #3 NAVAL RESEARCH LABORATORY CASE:- CYLINDRICAL (H) - 19½" D. WINDOW:- NONE	4.0	40	640	23.6			6.35	21.6	20.7°				16	222	3550	13.9	.555	1970	163	8.5%	1460	.115	254	256	.726	5.1	7.5	7.5	d
	5.0	40	1000	23.6			6.35	21.6	20.7°				16	224	3585	14.0	.586	2100	272	13%	1460	.186	412	416	1.180	8.2	12	12	e
DECEMBER 1938	4.0	18	288	24.3^{5}	.155	157	6.16	21.6	20.1°	20°	.056	-12.5	3	69.3	208	23.1	.625	130	18$^{.5}$	14%	1420	.013		29	.082^{5}	.56	.85	.85	f
XRD #4 NAVAL RESEARCH LABORATORY CASE:- SPHERICAL - 19½" D. WINDOW:- RUBBER (2")	8.0	18	1152	24.3^{5}	.195	125	6.16	21.6	20.1°	19.5°	.063	-12.0	3	79.5	238	26.5	.734	175	44$^{.6}$	25.5%	1420	.031^{5}		70	.199	1.35	2.0^{5}	2.0^{5}	g
	4.0	18	288	24.3^{5}			6.16	21.6	20.1°				11	254	2794	23.1	.625	1740	263	15%	1420	.185		410	1.16^{5}	8	12	12	h
	8.0	18	1152	24.3^{5}			6.16	21.6	20.1°				10	265	2650	26.5	.734	1950	500	25.5%	1420	.352		750	2.25	15	23	23	i

COLUMN	1	2	3	4	5	6	7	8	9	10	11	12	13
RECEIVER	POLARIZATION OR FIELD CURRENT AMPERES - D.C.	D.C. RESISTANCE OHMS	D.C. POWER WATTS	MECHANICAL RESONANCE f_o - FREQUENCY - KC./SEC.	BAND WIDTH Δf - FREQUENCY - KC./SEC.	MECHANICAL SELECTIVITY $f_o/\Delta f$	MAXIMUM OPEN CIRCUIT SENSITIVITY MICROVOLTS PER BAR	OPTIMUM TRANSMITTING FREQUENCY KILOCYCLES PER SECOND	OPEN CIRCUIT SENSITIVITY AT OPTIMUM TRANSMITTING FREQUENCY MICROVOLTS PER BAR	RELATIVE OPEN CIRCUIT SENSITIVITY AT OPTIMUM TRANSMITTING FREQUENCY (REFERENCE SC-5)	INTERNAL IMPEDANCE OHMS	(INTERNAL IMPEDANCE)$^{\frac{1}{2}}$ (OHMS)$^{\frac{1}{2}}$	RELATIVE SENSITIVITY WITH IDEAL STEP-UP CIRCUITS AT OPTIMUM TRANSMITTING FREQUENCY (REFERENCE SC-5)
SC-5 SUBMARINE SIGNAL CO.	5.4	8	234	24.2	1.61	15	12.6	23.6	11.2	1	125	11.2	1
XRD #3 NAVAL RESEARCH LAB.	5.0	40	1000	23.6^{5}	.16	147	17.2	23.6	16.2	1.4^{5}	14	3.74	4.3
XRD #4 NAVAL RESEARCH LAB.	4.0	18	288	24.3^{5}	.19	128	42.6	24.3^{5}	42.6	3.8	23	4.80	8.9
XRD #4 NAVAL RESEARCH LAB.	8.0	18	1152	24.3^{5}	.19	128	60.9	24.3^{5}	60.9	5.4	26^{5}	5.15	11.8

NOTES

a LOW POWER - BEAM WIDTH - RESONANCE.
b HIGH POWER - NORMAL - BEAM WIDTH - RESONANCE.

c LOW POWER - BEAM WIDTH - RESONANCE.
d HIGH POWER - MAXIMUM APPLIED - 4.0 A. FIELD CURRENT.
e HIGH POWER - MAXIMUM APPLIED - 5.0 A. FIELD CURRENT.

f LOW POWER - BEAM WIDTH - RESONANCE - 4.0 A. FIELD CURRENT.
g LOW POWER - BEAM WIDTH - RESONANCE - 8.0 A. FIELD CURRENT.
h HIGH POWER - MAXIMUM APPLIED - 4.0 A. FIELD CURRENT.
i HIGH POWER - MAXIMUM APPLIED - 8.0 A. FIELD CURRENT.

PLATE 9