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Performance of an Electro-Acoustic SC Tube

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NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

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NRL Report No. S-1618
Performance of an Electro-Acoustic SC Tube

20 May 1940

NRL Report No. S-1618
BuEng. Prob. U2-5C

NAVY DEPARTMENT

FR-1618

Report on

The Performance of an Electro-Acoustic SC Tube

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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Prepared by:

P. N. Arnold, Associate Physicist

L. M. Treitel, Contract Employee

Reviewed by:

H. C. Hayes, Principal Physicist
Superintendent, Sound Division

Approved by:

H. G. Bowen, Rear Admiral, U.S.N.
Director

Distribution: BuEng-C&R (10)

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Appendices

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Section I - Introduction

1. At the request of the Bureau of Engineering, the Naval Research Laboratory has constructed an electro-acoustic SC tube, and has carried out certain experiments to determine its relative merits as a subaqueous binaural direction finding device as compared with a standard acoustic SC tube of the type now in use on submarines in the Naval Service. The purpose of this report is to describe the instrument and to set forth the results of performance tests carried out at New London in the period 22 - 26 April 1940, inclusive, with submarine number 125 and the U.S.S. SEMMES cooperating.

Section II - Discussion of General Principles

2. The principles involved in the application of the binaural sense to direction finding in the SC tube need not be covered in complete detail in this report. In the acoustic SC tube, sound energy is taken from the water by a receiver of the non-resonant air bubble type and is transmitted by a vibration-insulated air-filled duct directly to the listener's ear as air-borne sound. Two receivers, one at each end of a rotatable arm, are employed, and each has its own associated transmission duct. The energy from one is led to listener's right ear, and the energy from the other to his left. By rotation of the aforementioned arm, the listener is able to center binaurally an audible noise and to determine the relative bearing of its source. In the electro-acoustic SC tube, the same type of non-resonant air bubble takes sound energy from the water, but a microphone within the bubble converts the air-borne sound energy into electrical energy. This energy is transmitted electrically, with or without selective amplification, to the observation station, and there reconverted at the listener's ear to air-borne sound by a telephone receiver. As in the all-acoustic case, two identical systems are used, one for each of the listener's ears, and the relative bearing of a sound source is determined by centering it binaurally exactly as with the acoustic SC tube. For a schematic diagram of the electro-acoustic SC tube, see Plate 1.

3. In binaurally centering an audible noise with such a device, the listener is adjusting the length of path between the sound source and one ear to equal the path length between the same source and the other ear, typical human ears being able to detect a difference of approximately 10 microseconds in the time of arrival of a given sound wave front. As the velocity of sound in sea water is 1.5×10^5 centimeters per second, a path difference in sea water of 1.5 centimeters or .6 inch is detectable by the average pair of ears. In an instrument making use of this power of the ears, it is essential that the sound energy in water incident upon the two receivers be converted to air-borne sound and presented respectively to the separate ears without the introduction of any spurious path difference or time delay. In the acoustic SC tube, this is accomplished by the use of identical receivers and identical transmission ducts for the air-borne sound. Identity in the two transmission ducts is not difficult to attain, brass tubing of the same length, wall thickness, and inside diameter being used. Both ducts are in a common housing and therefore are maintained at approximately the same temperature. Identity in the receivers is more difficult of attainment, but

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the non-resonant air bubble type has served well in practice. Being non-resonant, the air-borne sound within the receiver builds up in phase with the water-borne sound outside the rubber envelope. Receivers of the air bubble type which are resonant have been shown to be not practical, as exact identity in two such receivers is unattainable.

Section III - Description of the Electro-Acoustic SC Tube

4. In developing the electro-acoustic SC tube the non-resonant air bubble type of receiver was retained without change or experimentation except that a somewhat larger bubble was used to permit the mounting of a commercially available microphone within the envelope. Resonance was carefully avoided on the basis of experience with the acoustic SC tube.

5. Preliminary experiments were conducted by this Laboratory to ascertain the feasibility of using inexpensive microphones of the sound power telephone transmitter type for converting air-borne sound energy within the air bubble to electrical energy. The types investigated were manufactured by the Radio Corporation of America and by the Automatic Electric Company. Briefly, it was concluded that these microphones are not adapted for use in binaural listening equipment. They are relatively sensitive, but their sensitivity varies very considerably with frequency. One or more resonances occur in the audio frequency range, and, as in the case of the air bubble type of receiver discussed above, this makes the attainment of satisfactory identity between two microphones of this type practically impossible. For a curve typical of these microphones, see Plate 2. The resonances at 600 and 1200 cycles per second destroy the usefulness of this device in an equipment where phase distortion cannot be tolerated.

6. Higher quality microphones, of the type used as transducers in broadcast studios, were found to be satisfactory for use in binaural listening equipment in so far as their electro-acoustic properties were concerned. The sensitivity of such a microphone is relatively low, but it is very nearly the same (± 1 decibel) for sound energy at any frequency between 70 and 7,000 cycles per second. Being free of resonances in this frequency range, the electric wave energy builds up in phase with the air-borne sound energy within the air bubble type of receiver. Moreover, the sensitivity and frequency response characteristic of this microphone are very nearly the same for all microphones of the type as received from the manufacturer. Four different microphones of the same type (Type 633A Western Electric Company) were compared in the Laboratory by measuring their respective responses to the sound emitted by a given sound source, the frequency of which was varied. Microphones #2 and #3 of the group were found to have the same sensitivity (± 1/2 decibel) at any frequency between 100 and 1,000 cycles per second. At frequencies between 1,000 and 4,000 cycles per second, microphone #3 was approximately 1 decibel more sensitive than #2. As the human ear is not conscious of differences in sound intensity of less than 1 decibel, the similarity between these microphones was considered acceptable and they were used in the assembly of the electro-acoustic SC tube. Microphone #1 of the group was approximately 1.5 decibels more sensitive than #2, and microphone #4 was approximately 2.5 decibels more sensitive.

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The frequency characteristic of this type of microphone being nearly flat in the audio frequency range, differences in the average sensitivity of any two of the type can, in general, be compensated for very simply in the associated electrical transmission equipment.

7. The low sensitivity of the type of microphone which is suitable for use in a binaural listening device makes it necessary to employ amplification. Transmission and amplification of electric wave energy without deleterious phase or amplitude distortion in the audio frequency band is relatively a simple matter. For the electro-acoustic SC tube, two amplifiers were constructed to be as nearly alike as possible, using readily available components. Each was designed to take electric wave energy from one of the high quality microphones at a 37 ohm level, and deliver the energy amplified 70 decibels with very little phase or amplitude distortion into a 37 ohm load. The gain-frequency characteristic of each amplifier is shown in Plate 3. In Plate 4 two curves are shown, one giving as a function of frequency the tolerable relative phase distortion which may be introduced by the amplifiers and the other that actually introduced as measured in the Laboratory. In calculating the tolerable difference in the delays introduced by the two amplifiers, the quantity 5 microseconds was used. This is one-half the value detectable by a normal pair of ears. The curves of Plates 3 and 4 show the suitability of the two amplifiers for use in binaural listening equipment. Each amplifier was provided with a manually operated gain control by which slight differences in the average gains of the two amplifiers might be compensated. The amplifiers are conventional in design, and no particular efforts were made in this preliminary model to secure long term stability or a gain characteristic independent of line voltage fluctuations. The two amplifiers, however, were operated from a common power supply.

8. For converting the electric wave energy delivered by the amplifier to air-borne sound for the listener's ear, a telephone receiver was used. Ordinary, inexpensive receivers have resonances which make them unsatisfactory for use in binaural listening equipment. For the electro-acoustic SC tube, telephone receivers of the broadcast monitoring type were chosen (Type 705A Western Electric Company). Each receiver had an impedance of approximately 37 ohms and constituted a satisfactory load for one of the amplifiers described above. The response characteristics of the two telephone receivers used in the electro-acoustic SC tube are presented in Plate 5. These measurements were made in the Laboratory with artificial ear equipment. It is to be noted that these receivers were not completely free of resonance effects. They were, however, well matched and, in so far as this Laboratory is aware, were as good as any obtainable at reasonable expense.

9. Between the first and second stages of each of the amplifiers for the electro-acoustic SC tube, provision was made for the insertion of certain electric wave filters. In this manner, variations in the transmission characteristics of the amplifiers could be effected for the purpose of increasing the discrimination between the desired audible noise and undesired background noise. The filters provided were of the following types:

[redacted]

(1) Low Pass - 1,000 cycles per second cut-off frequency
(2) High Pass- " " " " " "
(3) Low Pass - 500 " " " " "
(4) High Pass- " " " " " "

The 500 c.p.s. high pass and the 1,000 c.p.s. low pass filters could be inserted in tandem to give 500 to 1,000 c.p.s. band pass selective amplification. Two of each type of filter, carefully matched, were provided, and also a ganged switch mechanism, so that the transmission characteristics of the two amplifiers were alike, to within a half decibel, for each of the possible choices of filter insertion. In Plates 6 and 7 the gain-frequency characteristic of one of the amplifiers is shown for the five different filter choices provided. The relative phase difference introduced by the two amplifiers with filters inserted was not measured for lack of time prior to the performance test of the electro-acoustic SC tube. The excellent matching of the filter pairs, however, indicates that any difference introduced in the pass bands must be small, and in practice, with the filters inserted in the amplifiers, good binaural centering of audible noises was attained.

10. For binaural operation of the electro-acoustic SC tube, the air-borne sound energies presented to the left and right ears of the listener were kept definitely separated. However, provision in this equipment was made for connecting the two telephone receivers in series and for connecting them in turn to the combined outputs of the two amplifiers, the latter either in series-aid or in series-opposition. A switch was provided to enable the listener to make these changes in connections with ease and rapidity. He was enabled thus to take bearings on a target binaurally in the normal manner or by adjusting the rotating member of the equipment for a maximum or a minimum response in the telephone receivers.

Section IV - Performance Test of the Electro-Acoustic SC Tube.

11. The U.S.S. 125 was designated to carry out the performance test of the electro-acoustic SC tube. The rotating member of the JK-SC tube assembly of the 125 was removed and replaced by one, without a JK head, which had been renovated and modified at this Laboratory. The renovation consisted of the installation of new sound transmission tubing, new vibration insulation, and new packings in the acoustic SC tube. New rubber nipples were also installed. The only modification introduced was the provision of the lead-in wires necessary for the connection of the two microphones in the outboard part of the electro-acoustic SC tube to the amplifiers within the boat. As installed, the outboard part of the electro-acoustic SC tube was mounted on the platform normally used for the JK head. This arrangement was chosen as it permitted a rapid and valid comparison of the performance of the two types of SC tube. The observer, in moving the shaft of the assembly, moved both the rotatable arm of the acoustic SC tube and that of the electro-acoustic SC tube and was able to listen to one or the other at will.

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12. Comparative performance tests of this equipment were carried out on 25 April 1940 in Long Island Sound, the U.S.S. SEMMES assisting as target ship. The 125 took a course and ran submerged at periscope depth at 4 knots. The SEMMES, having dropped astern, steamed on a parallel course at 5 knots, passing abeam at approximately 800 yards, and continuing on her course until well out of the range of the devices being tested. The limit of range and instructions to reverse course were signalled to the SEMMES by the broaching of the 125. The SEMMES steamed on the reverse course at 5 knots until again out of the range of the instruments, thus completing run #1. In runs #2 and #3 the SEMMES went through the same procedure, but at different speeds. In run #2 she steamed at 10 knots and in run #3 at 20 knots. During the course of these runs, two observers, trained in the use of binaural direction finding devices, determined the bearing of the target ship alternately each minute, one using the acoustic SC tube and the other the electro-acoustic SC tube. The bearings and time of observation were recorded. From time to time during the runs, the observers exchanged listening devices. In the control room of the 125, the bearing of the stern of the SEMMES and her approximate range, as determined by periscope, were recorded with the time of observation each minute throughout the runs. Care was taken in synchronizing the clocks used at the two observation stations.

13. These tests were conducted in Long Island Sound from Hatchet Reef Buoy to Cornfield Buoy in 150 feet of water. The wind was light and variable and the sea was calm. The per cent of clouds was estimated to be 40%. The water temperature was 38° F.

14. The results of these tests are presented in Plates 8 to 13 inclusive, in which the relative bearing of the target as determined by the periscope and by the two binaural devices, is plotted against time of observation in minutes. Approximate ranges are indicated by yardage figures adjacent to the periscope bearing curve. Note that in Plate 9 the observers using the binaural devices were misled and took bearings on a false target, a small boat not reported to them by the deck officer. Note also in Plate 11 the complete failure of the binaural observers with either instrument to locate the target. It is probable that a misunderstanding by the observers with regard to the time of the start of run was responsible for this failure. During this part of the second run the 125 changed course.

Section V - Discussion of the Performance Test

15. An appraisal of the relative merits of the acoustic SC tube and the electro-acoustic SC tube as direction finding devices on the basis of the data presented in Plates 8 to 13 inclusive must be somewhat arbitrary as both devices are far from ideal instruments. The operation of either depends to a marked degree upon the operator, the quality of his ears, his powers of concentration and auditory discrimination, and the degree of cultivation of his binaural sense. At the start it must be said that the results presented in this report are unfair to the electro-acoustic SC tube in this respect, for the two trained listeners available for the test were not equally successful with the acoustic SC tube. All target bearings reported at the longer ranges for the

[redacted]

acoustic SC tube are those observed by the more successful of the two listeners. With the electro-acoustic SC tube, either operator had substantially the same success even at the range limit of the instrument.

16. In consideration of the data presented in Plates 8 to 13 inclusive, Plates 9 and 11 are omitted except that attention is called to the fact that difficulties will arise in binaural listening if the observer is not continuously attentive and if there is more than one target. From the other plates, certain general conclusions may be drawn: (1) neither instrument is a very precise sound locator, (2) the relative bearing of a target abaft of beam may be determined more accurately by either device than that of one on the quarter, and (3) the limiting range of either device in the hands of a competent operator is substantially the same. With the target nearly abeam and at moderate range, good bearing measurements were made at the three target speeds with both instruments. The precision of measure with the target in this position is presumably somewhat better than the plotted points indicate as the relative bearings were changing quite rapidly with time and inevitable small errors in the recorded time of observation resulted in quite large differences between the actual relative bearing and the binaurally observed relative bearing.

17. On the basis of general conclusion (2) of the above paragraph, binaurally observed target bearings were divided into two groups, one for the case of the target on the quarter and the other for the case of the target abaft of beam. In each group all observed points except the two most in error were included. These were omitted as being mere guesses on the part of the listener. The results are presented in the following table:

	Acoustic SC Tube			Electro-Acoustic SC Tube		
	Max. Error	Min. Error	Avg. Error	Max. Error	Min. Error	Avg. Error
Target on the Quarter	32°	6°	21°	22°	3°	11°
Target abaft of Beam	15°	0°	7°	9°	0°	3°

Considered in this way, the electro-acoustic SC tube is quite definitely superior to the acoustic SC tube as a sound locator. The larger errors in the binaurally determined relative target bearings for the case of a target on the quarter are presumably due to the effect of the wake of the target ship.

18. The following table gives the range of the target at the time of the last relative bearing determined by the binaural observers in the various runs, and the corresponding error in the determined bearing.

	Acoustic SC Tube		Electro-Acoustic SC Tube	
	Max. Target Range	Error	Max. Target Range	Error
Target on the Quarter				
Target Speed 5 knots	1600 yards	30°	1000 yards	11°
10 knots	2000 yards	15°	1600 yards	21°
20 knots	6600 yards	13°	6000 yards	4°

[redacted]

		Acoustic SC Tube		Electro-Acoustic SC Tube	
		Max.Target Range	Error	Max.Target Range	Error
Target abaft of Beam					
Target Speed	5 knots	2600 yards	12°	2500 yards	1°
	10 knots	3600 yards	4°	5000 yards	5°
	20 knots	8500 yards	6°	6500 yards	2°

These figures taken from Plates 8 to 13 inclusive should not be accepted without qualification. The noted errors in several cases are a good deal less than should be expected from consideration of bearing measurements by the same observer with the same equipment for lesser ranges in the same run, suggesting that an element of luck entered strongly in some cases at the extreme ranges. Taking all the data into consideration and allowing for the difference between the two observers noted in paragraph 15 above, it is concluded that the range limit for the two devices is substantially the same.

19. As in all listening devices, the range of usefulness is limited by the undesired noise, in which or above which the desired noise from the target must be identified by the listener. Undesired noise in the case of the acoustic SC tube is of three types: (1) water noises of various kinds which enter the listening equipment exactly as does the desired noise from the target; (2) vibrational noise which enters principally through the acoustic transmission ducts; and (3) ambient noise at the listening station. In the electro-acoustic SC tube these three types of noise play a part and in addition there is noise introduced by the associated electrical equipment.

20. Vibrational noise is minimized in the acoustic SC tube by insulating the transmission ducts of the device against vibration with rubber spacers. This insulation was effective enough that vibrational noise was not a limiting factor in the subject test. Insulation of the microphones of the electro-acoustic SC tube against vibration was provided, and in this device also, vibrational noise was not a limiting factor.

21. Ambient noise at the listening station during this performance test was at a very low level and did not really enter as a factor. However, with normal operating activity in the forward torpedo room of a submarine ambient noise might well play an important role. With the electro-acoustic SC tube, the rubber-capped telephone receivers employed very effectively insulate the listener against the ambient noise and let him take observations in comfort without undue strain or concentration. In the case of the acoustic SC tube, the listener uses a stethescope which is not as comfortable for his ears, and which is less effective as insulation against ambient noise.

22. Water noises were the important interference in both SC tubes and limited the range of successful target bearing measurements in both cases. In the electro-acoustic SC tube, electrical noise also was of some significance. A hum, not noted in the Laboratory, appeared in the equipment as installed on the 125, presumably due to the difference in the primary source of power. This hum was of the same order of magnitude as the water noises as heard by the listener, but was of such a character

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that target noises could be identified through it if they could be identified through the water noises. It was an added impediment for the listener, however, and should be eliminated in service equipment if it is ever supplied. The amplification available in the case of the electro-acoustic SC tube was, of course, not effective in extending the useful range of the device beyond that of the acoustic SC tube as both desired and undesired noise were subjected to the same amplification.

23. In the electro-acoustic SC tube, the gain-frequency characteristic of the binaural amplifiers could be readily changed by the listener as described in paragraph 9 of this report. Curiously enough, the first of the experienced listeners, after trial, chose the low pass 500 c.p.s. cut-off frequency characteristic, whereas the second chose the high pass 500 c.p.s. cut-off frequency characteristic. In the acoustic SC tube, the higher frequencies are very much attenuated and the first trained listener, accustomed to the acoustic SC tube, was evidently biased by his experience to favor the low frequencies for binaural listening. To an inexperienced observer, the choice of the second trained listener seemed better. Discrimination against the very low frequencies was advantageous as the amplifier hum was eliminated as an interfering element. Aside from this, the higher fidelity of the electro-acoustic SC tube was definitely an advantage for the inexperienced listener. With the low frequencies only eliminated, the initiate could hear and recognize the target ship, and at near and moderate ranges could center it binaurally. The acoustic SC tube with its low-pass characteristic was useless in his hands as he could not identify the sound from the target ship. The experienced listeners made good bearing measurements on the target using each of the various choices of filter insertion in the binaural amplifiers. It is believed that a fairly wide band-pass characteristic, giving fair fidelity but eliminating the very high and the very low frequency components, is the most desirable for the average listener. Cut-off frequencies of 250 and 1500 c.p.s. are suggested as the limits of a desirable band-pass characteristic for binaural amplifiers.

24. Bearing determinations with the electro-acoustic SC tube were successfully made using both minimum and maximum telephone receiver response, as described in paragraph 10 of this report. These determinations were made with the target at rather close range when the noise from the target was well above the background of noise. The minimum settings in these cases were very definite and sharp and easy to make. The maximum settings were rather broad and less definite. The target could be located, however, at longer ranges using binaural operation of the device.

Section VI - Conclusions and Recommendations

25. The electro-acoustic SC tube as a binaural direction finding device is better than the acoustic SC tube in the following respects:

(a) It presents sound energy to the listener's ears at a comfortable level. This reduces the strain on the listener and is conducive to better results.

(b) It presents the target noise to the listener with greater fidelity than the acoustic SC tube. This is an advantage to the average listener, aiding recognition and discrimination.

[redacted]

(c) As electrical transmission and amplification are employed, a desirable frequency transmission characteristic may be readily attained in the system by means already available for communication circuits. A characteristic may be chosen which discriminates against important interfering components while preserving sufficient fidelity to yield maximum discrimination between desired target noise and undesired background noise.

(d) In performance tests, it has determined the relative bearing of a given target at various ranges with appreciably greater precision than an acoustic SC tube and has a range limit, set by water noise level, not substantially different from that of the acoustic SC tube.

(e) As telephone receivers are used at the listener's ears rather than the stethescope of the acoustic SC tube, a certain hazard to the listener is avoided. With the all-acoustic instrument there is danger of serious damage to the listener's ears if a depth charge explodes within a certain radius of the submarine due to the destructive pressure wave which is set up in such a case. Quite aside from this factor of safety introduced by the electro-acoustic device, telephone receivers are more comfortable to wear than a stethescope, and at the same time give the listener a greater degree of insulation against ambient noise at the listening station.

26. The electro-acoustic SC tube compares unfavorably with the acoustic SC tube in the following respects:

(a) It is more complicated, requiring expert maintenance and periodic performance checks with specialized auxiliary equipment.

(b) It is less rugged. The type of microphone which is adapted for use in binaural listening equipment is essentially a delicate mechanism. As constructed, it is protected against ordinary changes of hydrostatic pressure, but it is questionable whether the protection is sufficient against the rapid changes to which it might be subjected during crash dives. It is even more questionable whether it is adequately protected against damage by depth charge explosions. Further experimentation is necessary to determine the adequacy of the protection at present provided and to devise adequate protection if the existing arrangements are not satisfactory.

[redacted]

(c) The low sensitivity of the type of microphone which is adapted for use in binaural listening equipment makes amplification essential in the electro-acoustic SC tube. Its operation is therefore dependent upon the ship's power supply, of which the acoustic SC tube is completely independent.

27. Neither the electro-acoustic SC tube nor the acoustic SC tube compares favorably as a subaqueous direction finding device with other devices already in use in the Service (e.g. the JK). Either one, installed in a submarine, would be a standby instrument. Moreover, the superiority of the electro-acoustic SC tube over the acoustic SC tube lies principally in that it is easier to operate and can give results in the hands of a less well trained or gifted operator. With a well trained operator, endowed with a good power of concentration, substantially the same results can be obtained with the acoustic SC tube. In view of these facts, it is the considered opinion of this Laboratory that the substitution of an electro-acoustic SC tube for the acoustic SC tube in the Naval Service is not warranted. As a standby instrument, available for use in emergencies, the acoustic SC tube, being simple, rugged, and completely independent of the ship's power supply, is to be preferred.

28. In the course of the development and test of the electro-acoustic SC tube, certain ideas were brought forward and are noted as follows:

(a) An experienced listener in using the electro-acoustic SC tube observed that its operation and listening qualities were superior to those of the JL type of sound locating device, now in use in the Naval Service. In a comparison of these two equipments, the electro-acoustic SC tube would definitely hold an advantage from the point of view of simplicity, bulk, weight, and cost. If there are instances in the service where a rotatable sound locating device can be installed quite as well as a non-rotatable device, an experimental, comparative performance test between the JL and the electro-acoustic SC tube should perhaps be carried out in order to determine the actual performance superiority of one over the other.

(b) Inasmuch as the use of electric wave filters in the transmission systems of the electro-acoustic SC tube improved its performance, it is suggested that an all-acoustic SC tube be devised employing acoustic wave filters. In this manner, a desirable transmission characteristic might be given to the instrument, improving its performance, without affecting its inherent ruggedness and without making it dependent for operation upon the ship's power supply.

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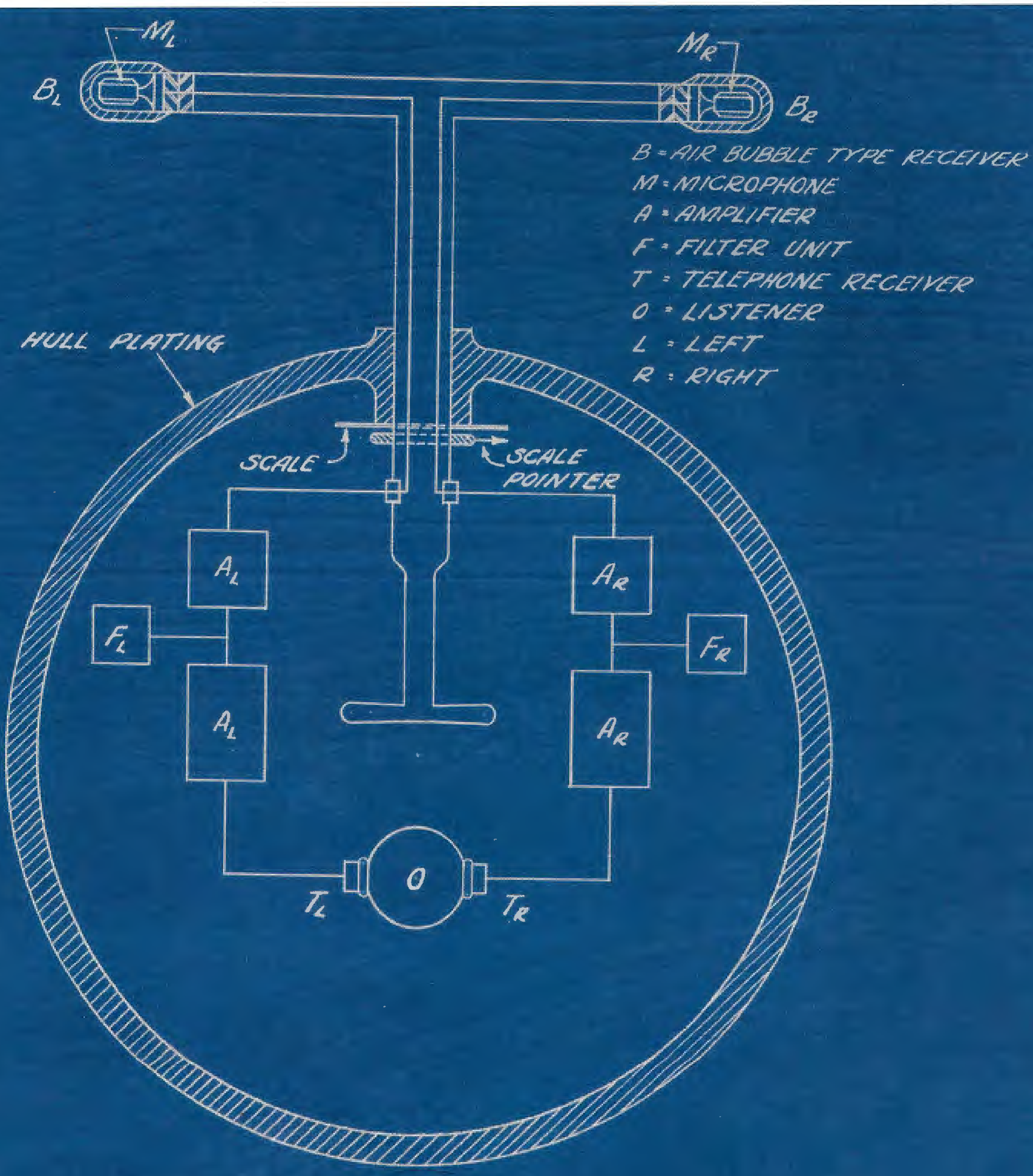
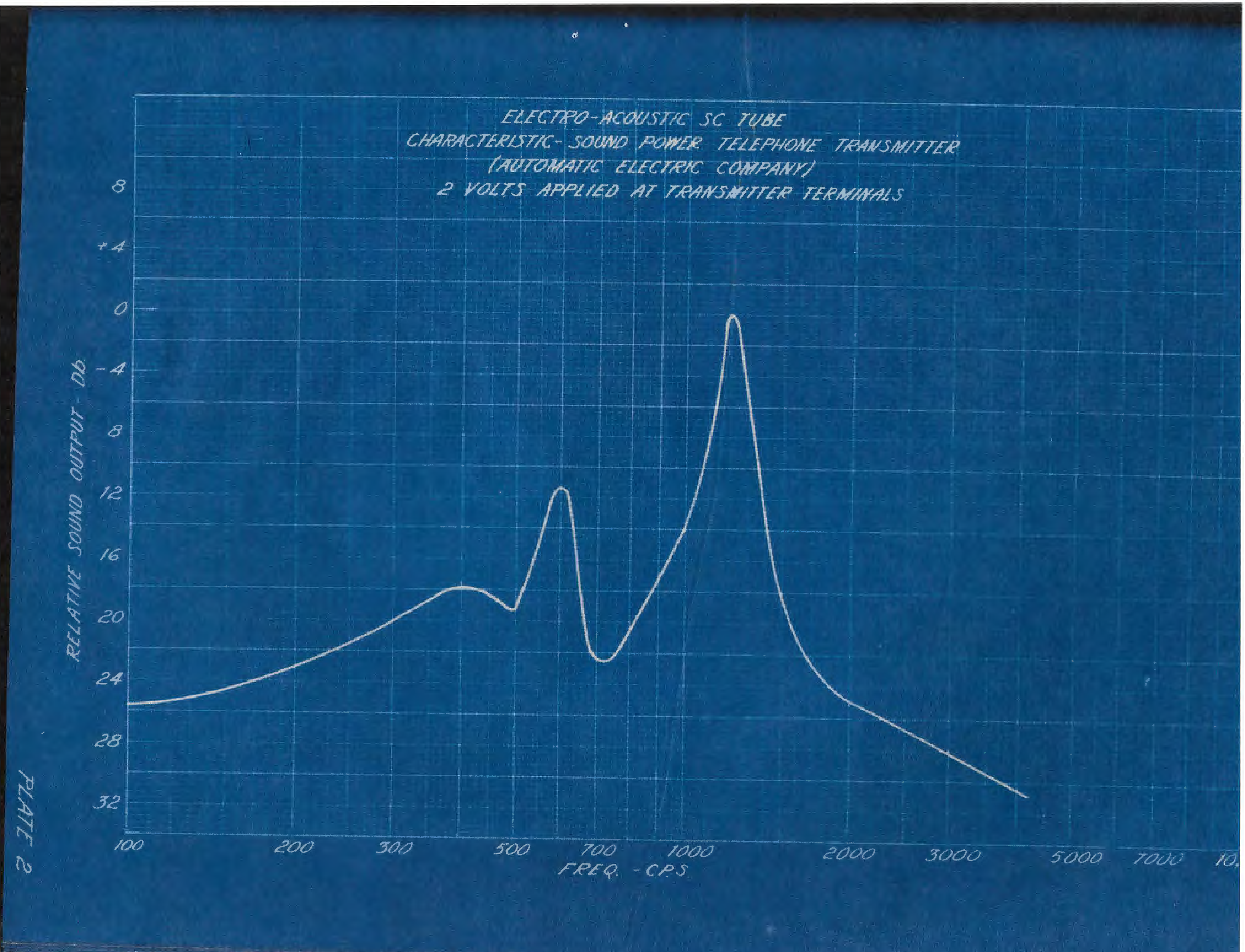


ELECTRO-ACOUSTIC SC TUBE

SCHEMATIC DIAGRAM

PLATE 1.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CHARACTERISTIC- SOUND POWER TELEPHONE TRANSMITTER
(AUTOMATIC ELECTRIC COMPANY)
2 VOLTS APPLIED AT TRANSMITTER TERMINALS
8
+4
0
-4
8
12
16
20
24
28
32
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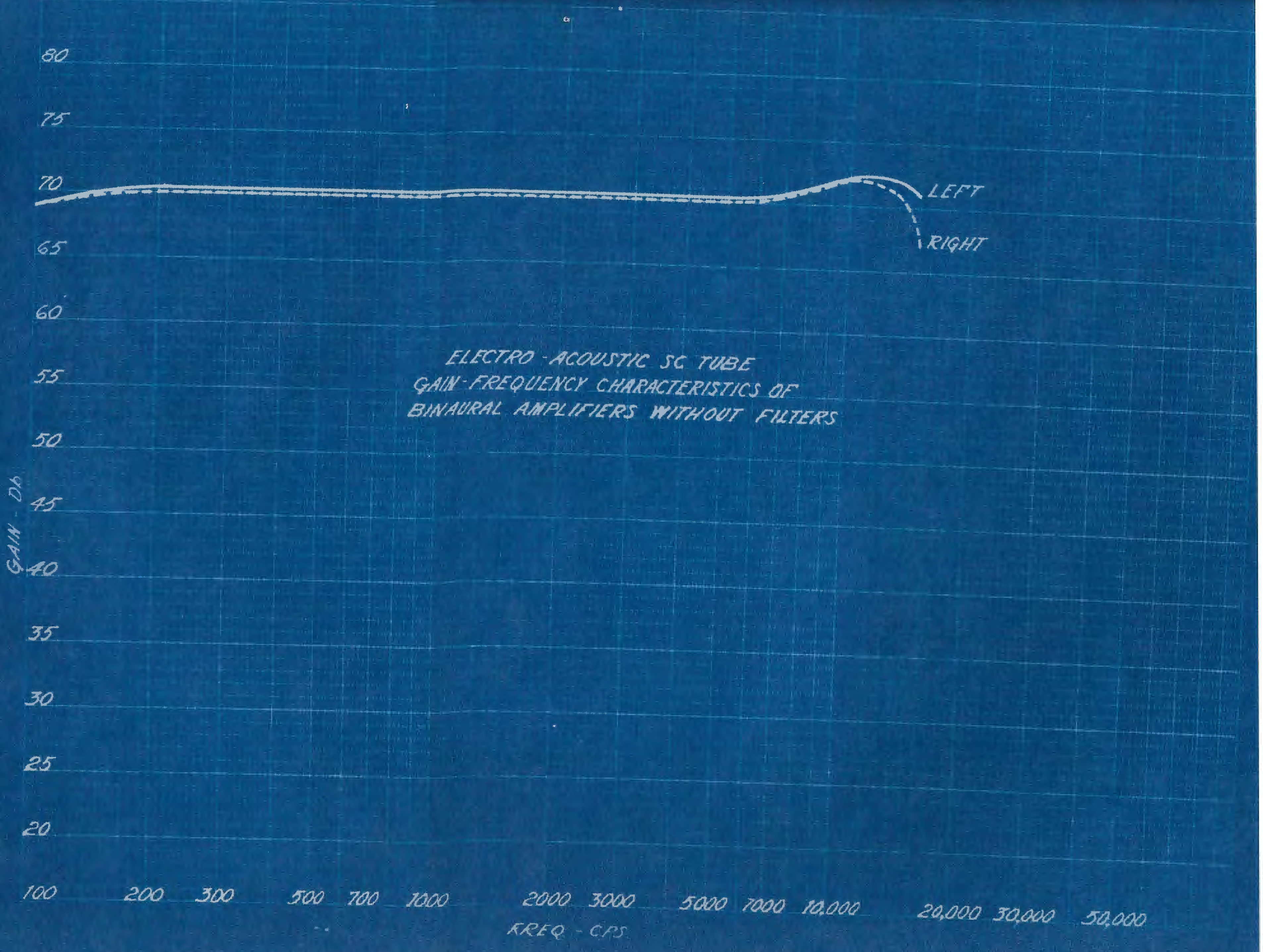
200
300
500
700
1000
2000
3000
5000
7000
FREQ. - CPS

PLATE 2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GAIN - FREQUENCY CHARACTERISTICS OF
BINAURAL AMPLIFIERS WITHOUT FILTERS
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RIGHT
GAIN - Db
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75
70
65
60
55
50
45
40
35
30
25
20
100
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300
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1000
2000
3000
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7000
10,000
20,000
30,000
50,000
FREQ - CPS

PLATE 3

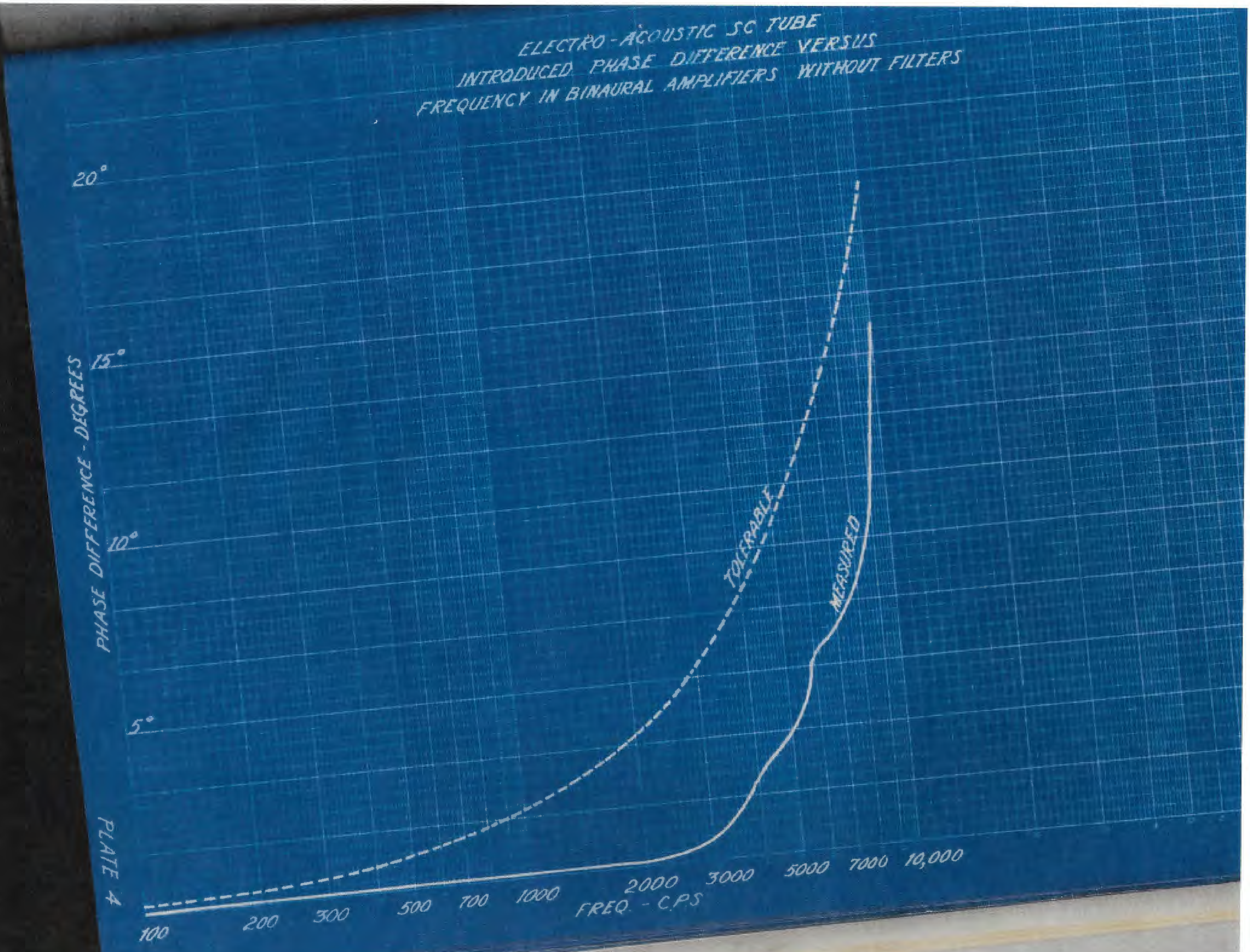
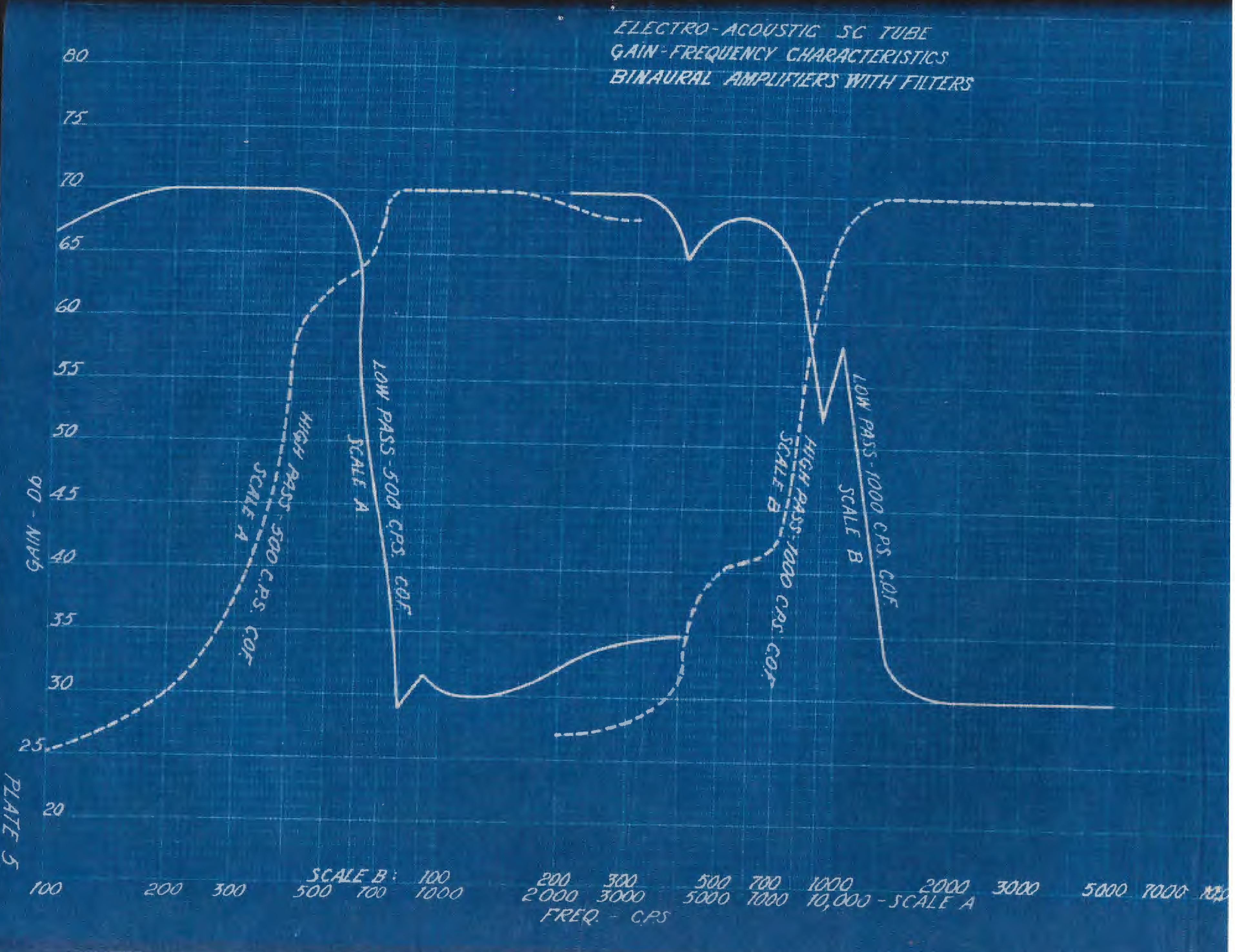

ELECTRO-ACOUSTIC SC TUBE
INTRODUCED PHASE DIFFERENCE VERSUS
FREQUENCY IN BINAURAL AMPLIFIERS WITHOUT FILTERS
PHASE DIFFERENCE - DEGREES
20°
15°
10°
5°
TOLERABLE
MEASURED
100
200
300
500
700
1000
2000
3000
5000
7000
10,000
FREQ. - C.P.S.

PLATE 4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BINAURAL AMPLIFIERS WITH FILTERS
80
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70
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60
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45
40
35
30
25
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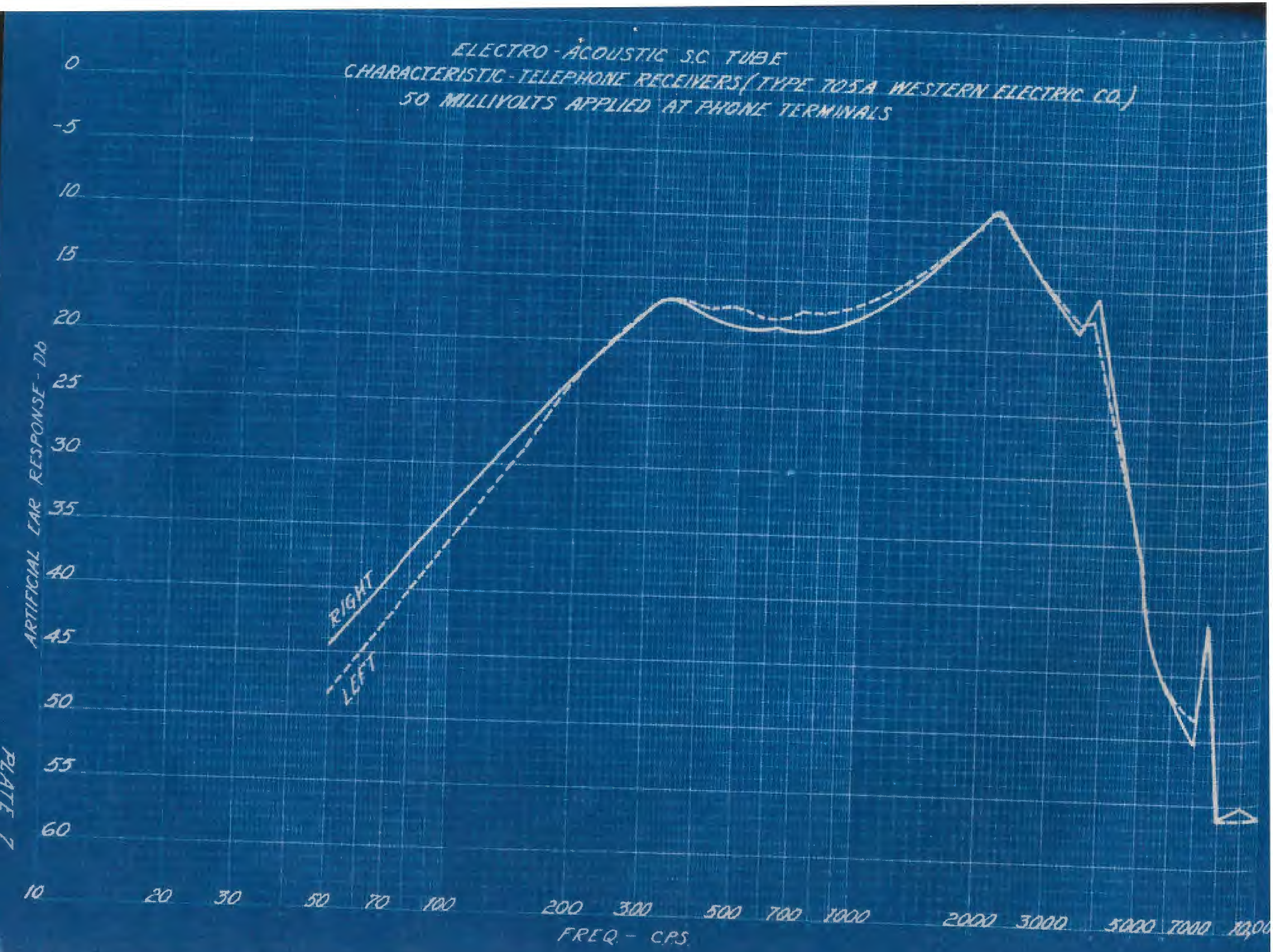
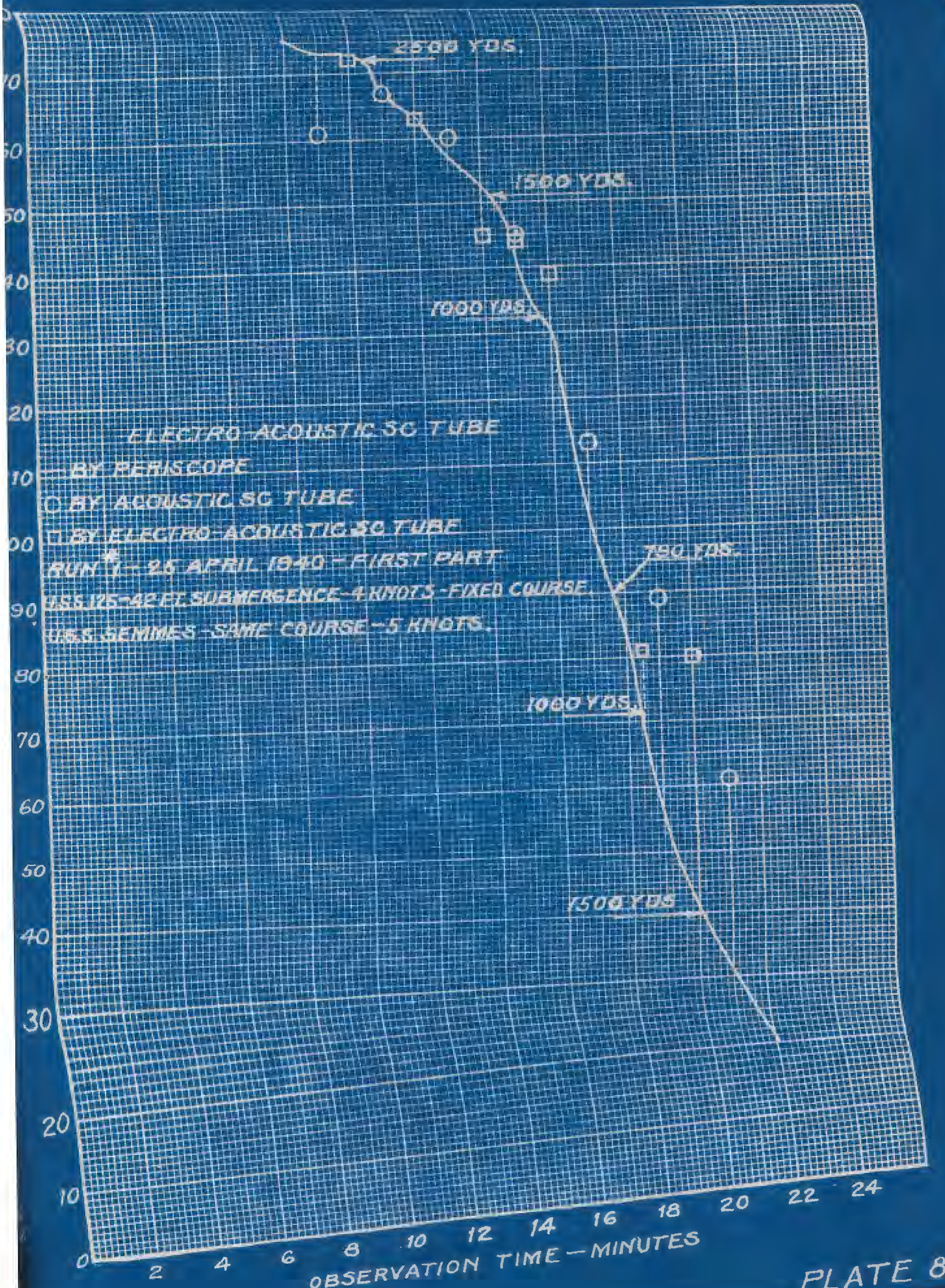
GAIN - DB
HIGH PASS-500 C.P.S. C.O.F.
SCALE A
LOW PASS-500 C.P.S. C.O.F.
SCALE A
HIGH PASS-1000 C.P.S. C.O.F.
SCALE B
LOW PASS-1000 C.P.S. C.O.F.
SCALE B
SCALE B: 100 200 300 500 700 1000
100 200 300 500 700 1000 2000 3000 5000 7000 10,000 - SCALE A
2000 3000 5000 7000 10,000
2000 3000 5000 7000
FREQ. - C.P.S.

PLATE 5



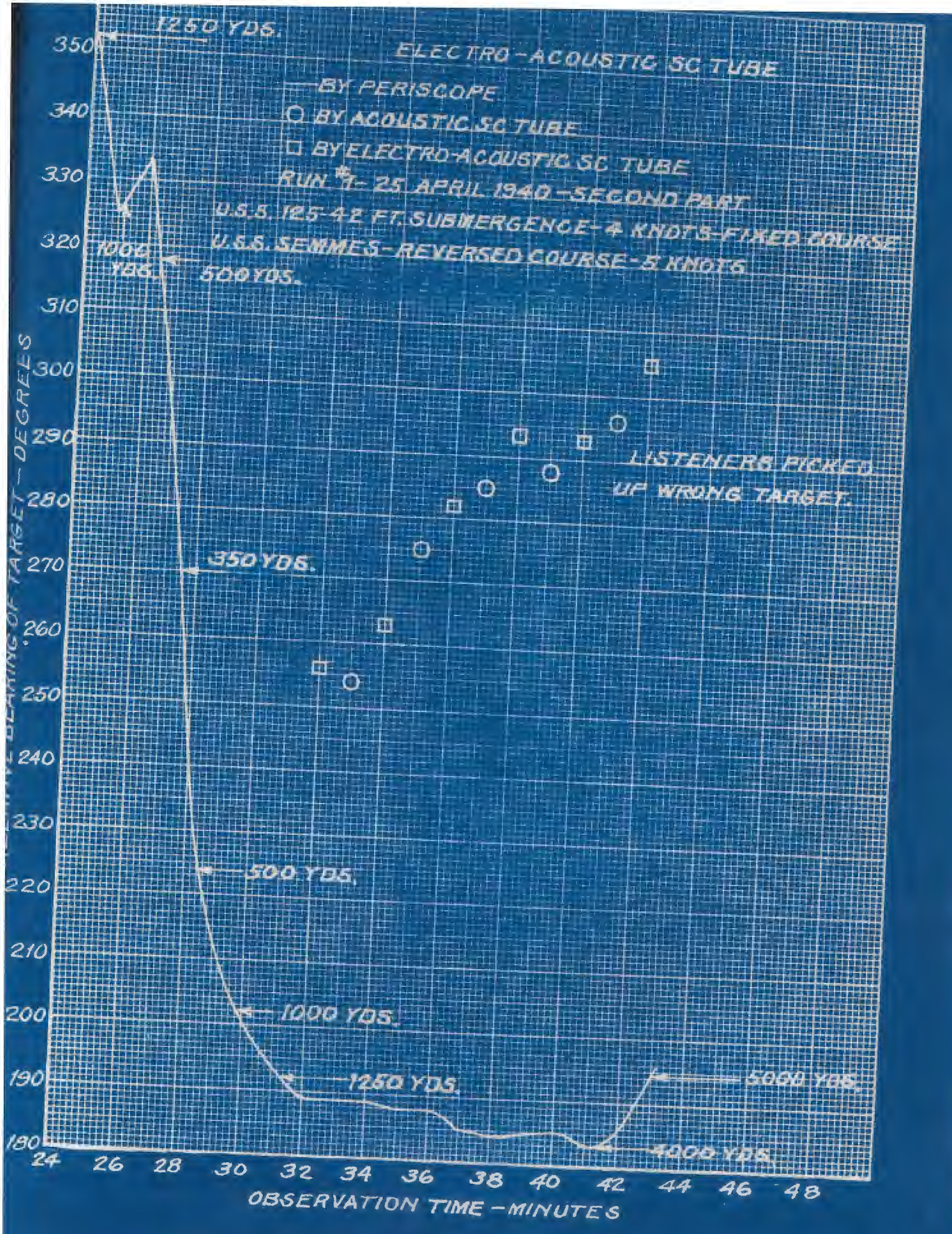
ELECTRO - ACOUSTIC S.C. TUBE
CHARACTERISTIC - TELEPHONE RECEIVERS (TYPE 705A WESTERN ELECTRIC CO.)
50 MILLIVOLTS APPLIED AT PHONE TERMINALS
ARTIFICIAL EAR RESPONSE - Db
0
-5
10
15
20
25
30
35
40
45
50
55
60
10
20
30
50
70
100
200
300
500
700
1000
2000
3000
5000
7000
10,000
FREQ. - CPS.
RIGHT
LEFT

PLATE 7



2500 YDS.
1500 YDS.
1000 YDS.
ELECTRO-ACOUSTIC SC TUBE
— BY PERISCOPE
○ BY ACOUSTIC SC TUBE
□ BY ELECTRO-ACOUSTIC SC TUBE
RUN #1 - 25 APRIL 1940 - FIRST PART
U.S.S. 125 - 42 FT. SUBMERGENCE - 4 KNOTS - FIXED COURSE
U.S.S. SEMMES - SAME COURSE - 5 KNOTS.
780 YDS.
1000 YDS.
1500 YDS.
0 2 4 6 8 10 12 14 16 18 20 22 24
OBSERVATION TIME — MINUTES

PLATE 8



ELECTRO-ACOUSTIC SC TUBE
— BY PERISCOPE
○ BY ACOUSTIC SC TUBE
□ BY ELECTRO-ACOUSTIC SC TUBE
RUN #1 - 25 APRIL 1940 - SECOND PART
U.S.S. 125-42 FT. SUBMERGENCE - 4 KNOTS - FIXED COURSE
U.S.S. SEMMES - REVERSED COURSE - 5 KNOTS
1250 YDS.
1000 YDS.
500 YDS.
350 YDS.
500 YDS.
1000 YDS.
1250 YDS.
5000 YDS.
4000 YDS.
LISTENERS PICKED UP WRONG TARGET.
BEARING OF TARGET - DEGREES
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
24
26
28
30
32
34
36
38
40
42
44
46
48
OBSERVATION TIME - MINUTES

PLATE-9

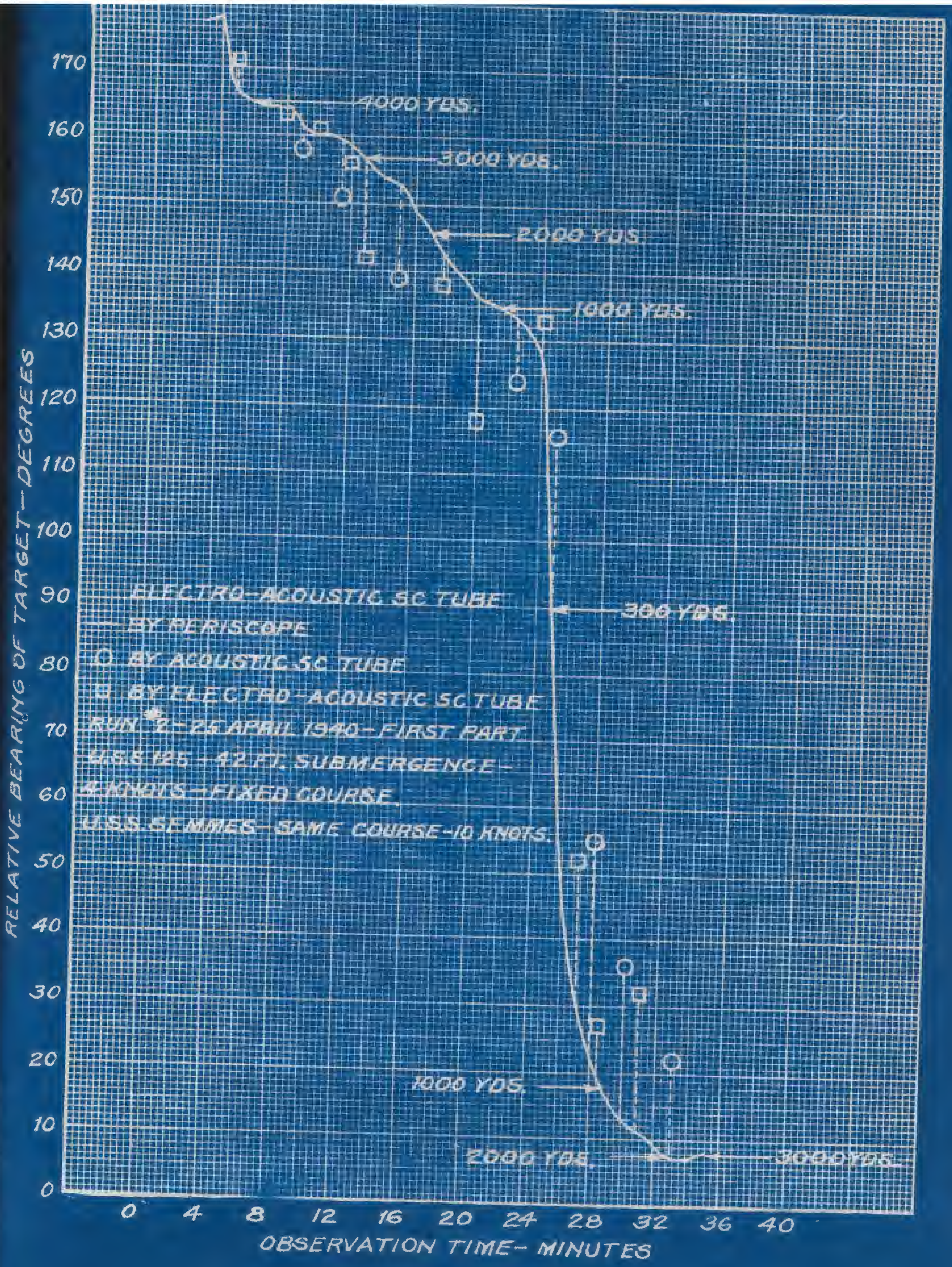
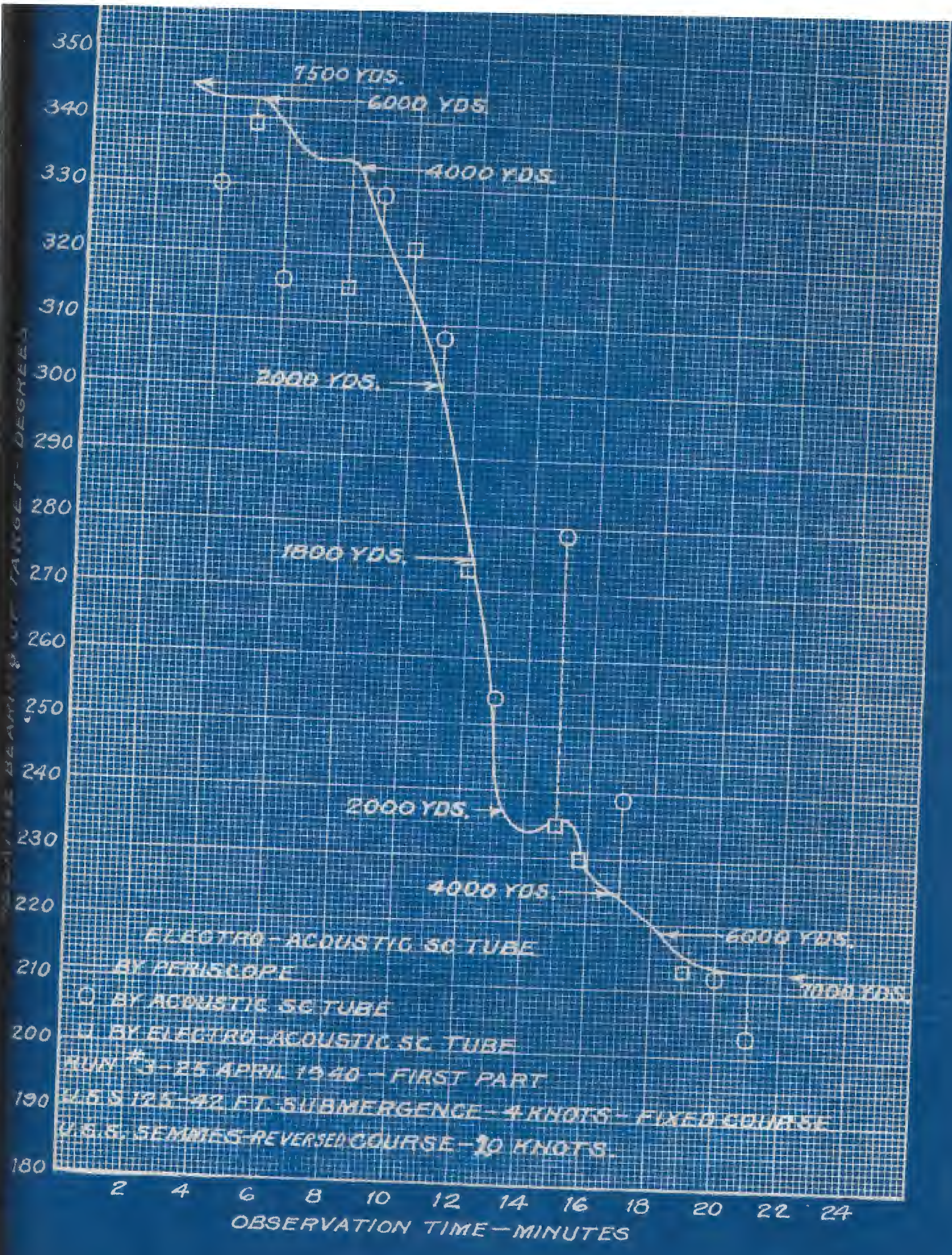

4000 YDS.
3000 YDS.
2000 YDS.
1000 YDS.
300 YDS.
1000 YDS.
2000 YDS.
3000 YDS.
ELECTRO-ACOUSTIC SC TUBE
— BY PERISCOPE
○ BY ACOUSTIC SC TUBE
□ BY ELECTRO-ACOUSTIC SC TUBE
RUN #2 - 25 APRIL 1940 - FIRST PART
U.S.S. 125 - 42 FT. SUBMERGENCE -
4 KNOTS - FIXED COURSE
U.S.S. SEMMES - SAME COURSE - 10 KNOTS.
RELATIVE BEARING OF TARGET — DEGREES
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
28
32
36
40
OBSERVATION TIME — MINUTES

PLATE 10



350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
TARGET - DEGREES
7500 YDS.
6000 YDS.
4000 YDS.
2000 YDS.
1800 YDS.
2000 YDS.
4000 YDS.
6000 YDS.
7000 YDS.
ELECTRO-ACOUSTIC SC TUBE
BY PERISCOPE
○ BY ACOUSTIC SC TUBE
□ BY ELECTRO-ACOUSTIC SC TUBE
RUN #3 - 25 APRIL 1940 - FIRST PART
U.S.S. 125 - 42 FT. SUBMERGENCE - 4 KNOTS - FIXED COURSE
U.S.S. SEMMES - REVERSED COURSE - 10 KNOTS.
2
4
6
8
10
12
14
16
18
20
22
24
OBSERVATION TIME - MINUTES

PLATE 12

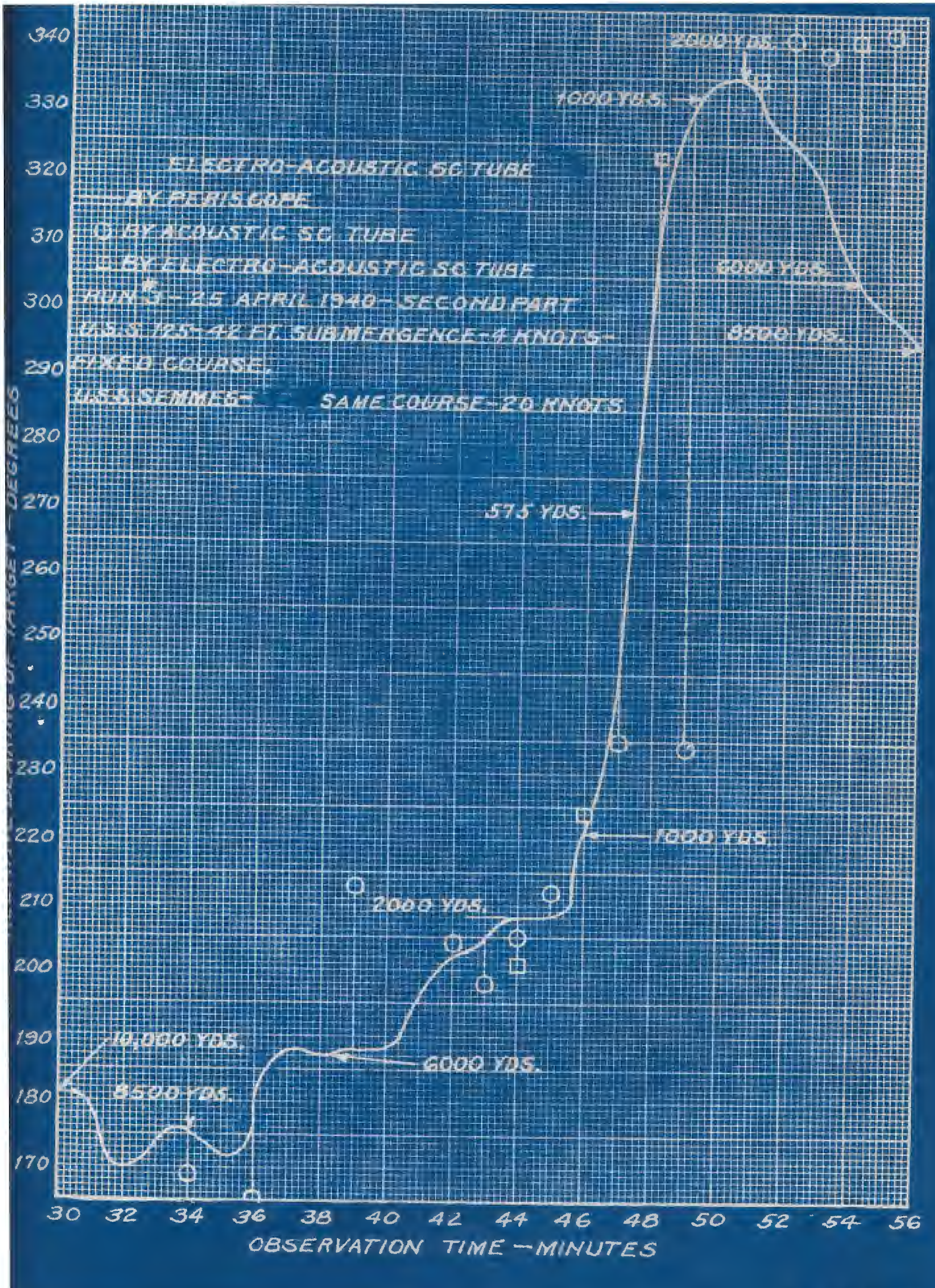

ELECTRO-ACOUSTIC SC TUBE
BY PERISCOPE
BY ACOUSTIC SC TUBE
BY ELECTRO-ACOUSTIC SC TUBE
RUN 3 - 25 APRIL 1940 - SECOND PART
U.S.S. 125 - 42 FT. SUBMERGENCE - 4 KNOTS - FIXED COURSE.
U.S.S. SEMMES - SAME COURSE - 20 KNOTS
2000 YDS.
1000 YDS.
6000 YDS.
8500 YDS.
575 YDS.
1000 YDS.
2000 YDS.
10,000 YDS.
6000 YDS.
8500 YDS.
TARGET — DEGREES
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
30
32
34
36
38
40
42
44
46
48
50
52
54
56
OBSERVATION TIME — MINUTES

PLATE 13