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Report of  
Receiver Fidelity Test  
of  
Understandability of Voice Reception  
and Necessary Frequency Band

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WASHINGTON, D. C.

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## ABSTRACT

The Bureau of Engineering has recently requested the Naval Research Laboratory to investigate the fidelity of receivers as to the reproduction of speech. Specifically, the models of receivers compared were Model RAB-1, Serial 30; Model NC-100xA, National 204J; Model HRO National; Super-Pro SP-110 Series; Hammarlund Manufacturing Company, Inc.

The percentage of understandability of voice reception was determined by placing the receivers in one room and the auditors in another. Carrier frequencies at various levels modulated by words predominating in low frequency content and words rich in high harmonics were applied to each receiver. The number of received words was then tabulated for both phones and speakers. It was found that the performance of the Model RAB receiver was equal to the other receivers compared when operated within its designed capacity. An amplifier should be used in the output of the Model RAB when using loud speakers for voice reception. Tests were conducted with filters to determine the frequency range needed for voice reception. The most satisfactory frequency band for voice recognition is the range of 150 to 5,000 cycles.

A comparison of three types of head phones was made: the Telephonics Type TH-37, CTE-49016, and the Western Electric 588A and 563A. A slightly higher percentage of words was recorded by use of Western Electric types and too, the opinion of the men was in favor of these types.

## INTRODUCTION

### Authorization

1. This work was authorized by Bureau of Engineering letter, reference (a). Other important data are listed in references (b) to (e).

- Reference: (a) BuEng.ltr. S67/46(10-26-R8) of 28 October 1938.  
(b) BuEng.ltr. S67/46(10-26-R8) of 5 December 1938.  
(c) The Sounds of Speech, by I. B. Crandall, Bell System Tech. Jour. November 1925.  
(d) Useful Numerical Consonants of Speech and Hearing by H. Fletcher, Bell Tech. Jour. August 1925.  
(e) Transmitted Frequency Range for Circuits in Broad Band Systems, by H. A. Affel, Bell System Tech. Jour. October 1937.

### Statement of Problem

2. This problem was to compare the Model RAB-1, Serial 30 with Models NC-100xA, HRO, and Super-Pro SP110 Series receivers for their fidelity as to speech using headphones and loud speakers, and to determine the transmitted frequency band necessary for understandability and voice recognition.

### Theoretical Considerations

3. The primary and most important concern in reception of speech sounds is the two properties, intelligibility and naturalness. The transmission and reproduction of sound may be conveniently considered as matters of transmitting and reproducing the several component waves. For a system to be ideal from a quality viewpoint, these components must be reproduced unchanged and no new components introduced. The requirements then for no noticeable distortion in a sound reproducing system may be stated as follows:

- (a) The reproduced sounds shall have the relative intensities of the component frequencies the same as the original sound.
- (b) The reproduced sounds shall not contain any components of frequencies not present in the original sound.

Failure to meet these two requirements is referred to as "frequency" and "non-linear" distortion, respectively.

4. It is the distortion with which we are concerned in this report. To determine the effect of distortion we have to conduct tests which will call upon the auditors to recognize sounds in the

form of words as a means of comparison of various amplifiers, in our case the four receivers. Distortion not only affects the recognizability or, commonly called, understandability of speech sounds but the tonal character or naturalness of the sounds as well. The former aspect admits of a qualitative determination by means of the so-called articulation test. The latter aspect is considerably less definite and does not appear to be very simply related to the recognizability.

5. In the articulation or understandability test, as used here, it was found convenient to collect the 36 sounds into five groups and select words characteristic of these sounds. The sounds composing each of the five groups are shown below:

Long vowels: a, ā, ē, ō, o', ū  
Short vowels: a', e, i, o, u, w, y  
Nasal consonants: l, m, n, ng, r  
Stop consonants: b, ch, d, g, h, j, k, p, t  
Fricative consonants: f, s, sh, st, th, th', v, z, zh

The speaker transmitted words of these sounds to the auditors and the number of correct words recorded over the various receivers was compared. In order to get some idea of the effort needed to listen, the auditors' opinions were solicited.

6. The frequency bands of speech sounds range from 100 to 8,000 cycles. Each of the various group of sounds does not require this whole range. The most important region is between 200 and 3300 cycles. Long vowels have the range of 200-2500 cycles, short vowels 300-3,000 cycles, nasal consonants 500-4,000 cycles, stop consonants 750-5,000 cycles. The unvoice fricative consonants (s, f, th) have their sound spectra in the upper frequency regions between 1,000 and 8,000 cycles. A woman's speech is more difficult to understand than a man's, although the long and short vowel sounds are easier to recognize when spoken by women than when spoken by men. Most of the energy is carried by the vowel sounds and at frequencies below 1,000 cycles, but the fine modulations of the vowels which produce the stop consonants and also the fricative consonants involve frequencies mostly above 1,000 cycles. For this reason, it is well to bear in mind that the importance of any frequency region for carrying the energy in speech is quite different from that carrying the intelligibility. It is found, for example, that while a system which transmits only the frequency range of 100-1600 reproduces speech which can be understood, yet it leaves much to be desired from the standpoint of naturalness.

7. Results can be obtained for speech which are good for both intelligibility and naturalness with a frequency range of 200 to 3600 cycles. However, this range may be reduced to 200-3300 with satisfactory results. There is nothing to be gained by going much below 150 cycles for speech - in fact, there is a loss in intelligibility,

but there is an appreciable difference between a lower cut-off of 175 cycles and 250 cycles. As for the upper range, there is little gain in intelligibility by going above 3500 cycles. However, there is much to be gained in the way of naturalness by going to 4,000 or 5,000 cycles.

#### Narrative of Work Done at This Laboratory

8. A broadcasting station consisting of high quality flat response transformers and amplifiers in the frequency band of 10 cycles to 20,000 cycles, and a signal generator type 605B, was set up and connected in turn to the input of the Models RAB, NC-100, HRC, and Super-Pro receivers. The output of the receivers was connected to the headphones and speakers in a distant room. Seventy Navy operators were used in the listening test, usually four at a time. One receiver was used at a time and the men recorded the words sent through each receiver at various input levels.

9. Tests were made at normal levels and at levels down to 1 microvolt input. A carrier of 1400 kilocycles was used as the input signal for obtaining the data presented in this report. A few tests were conducted on higher carrier frequencies with the same results. Any signal above 50 microvolts was considered a normal level of input. The percentage of correct words recorded at the various levels is shown in Tables 1 to 4. In addition to the headphones, three loud speakers were used on each model of receiver. One speaker was used at a time with four men recording. The phones used in the above test were the Western Electric CW-49003 type. These phones are the Navy standard high impedance type, having characteristics approximately the same as the Telephonics Type TH-37, CTE-49016.

10. A comparison of the aircraft phones, Types TH-37, CTE-49016 and the Western Electric Types 588A and 563A was made. The records show that the same man would record from 2 to 10% more words in a special word test using words rich in high harmonics on the Western Electric phones. The opinion of the men was in favor of the Western Electric types. In test using the 100 most used words in the English language as shown on Table 6 there is no appreciable difference in the percentage of words received on the Telephonics Type CTE-49016 and the Western Electric types, 588A and 563A. The words on Table 7 are rich in high harmonics and the Telephonics are not flat up to the region where these frequencies come in. The Western Electric 588A is a low impedance type of headphone. The frequency characteristics are shown in Plate 6. These phones are more sensitive in a higher frequency range than the Western Electric type CW-49003 or the Telephonics. The difference in these phones is not considered serious; a more complete investigation into the properties of these phones is now in progress, and the completion of the work on headphones as requested in reference (b) will be described in a subsequent report.

## METHODS

### (a) Circuit Diagram

11. Plate 1 shows the circuit arrangement used in the experiment. The headphones and loud speakers were arranged to plug into any one of the four receivers separately. Transformers A and B are used for matching impedances. These transformers are high quality flat response over a wide band.

### (b) Description of Experiment.

12. The four receivers to be compared, namely, the RAB, NC-100, HRO, and Super-Pro, were placed in a double screened booth, all electrical connections to and from the receivers being identical. All accessories were examined as to frequency characteristics to see that the bands were wider than those of the receivers. The reader, control operator and broadcast equipment consisting of wide band flat response amplifiers and transformers together with the signal generator and the receivers were placed in the screened booth and the four auditors were stationed in a separate room, it being impossible for the auditors to know which receiver was in use. Starting at a level of 1 microvolt input to the receivers, the speaker read off 15 words over each receiver to the auditors. This was repeated during the course of the test with many groups of four men as auditors and with various groups of words. The method was repeated at levels of 2.5, 5, 10, 25, 50, 10,000, and 100,000 microvolts using both headphones and loud speakers. In the tests using headphones, an amplifier of wide band flat response type was placed in the circuit between the phones and the receiver in use. The input impedance of the amplifier was adjusted to a normal load for the RAB. The amplifier was then adjusted to give normal output to the extra load of the head phones necessary for four auditors. All receivers worked into the same constant high resistance load. While using the loud speakers, all impedances were matched. The carrier or input voltage to the receivers was regulated by a signal generator, Type 605B. The receivers were aligned by tuning to a given signal, modulated 50% per cent at 400 cycles; with a given input voltage, the output voltage of all receivers was adjusted to a common value. Repetition of the test using 15 and 60 word groups was conducted over a period of a few weeks. Table 5 is a typical list of the words used. The percentages of correct words recorded over each receiver are found in Tables 1 to 4 inclusive. Separate tests using filters to pass frequency bands of (Plate 2 to 5) 0-1600, 0-2600, 225-1600, 225-2600, 450-2600, 200-4500, 50-8000, 225 cycles up and 450 cycles up were made. Table 3 shows the percentages of correct words recorded. The band of 225-2600 is fair for intelligence but poor for voice recognition. Plates 2-5 show the cut off characteristics of the filters. From the experience gained by these tests, it is believed that a band of 150-5,000 cycles would be very desirable and quite satisfactory for Navy use. This recommendation is made from a consideration of the physics of the sound spectra of the human voice, giving no considera-

tion to the engineering difficulties to obtain this frequency band. When the upper end of the frequency band is reduced to 3300 there is need to repeat more of the sounds as sh, st, th, f, s, v, z, zh, etc. This is an example of where both intelligibility and naturalness may be impaired. However, the band of 200 to 3300 is fair for both intelligibility and naturalness using common words as found on this page. This is slightly better than the ordinary city phone.

#### DATA OBTAINED

##### (a) Data in Tabular Form.

13. The results of the data obtained using loud speakers are found in Table 1. The table shows the percentages of correct words received by the auditors over each receiver at various input levels. Three loud speakers were used on each receiver, one at a time; the loud speakers used were those belonging to the HRO, Super-Pro, and NC-100 receivers. In most runs of 15 and 60 word groups there were four men auditing; sometimes there were only three auditors.

14. Section 1 of Table 1 shows the results of three runs on each receiver using three separate loud speakers with three men auditing and a fifteen word group. In column 1 is found the results of the RAB receiver. The opinion of the auditors in this case was that stations 1 and 4 were the most pleasant and had the best quality. These proved to be the RAB and the Super-Pro receivers. One may say the percentage of words received over each receiver is practically the same.

15. In Sections 2 and 3 of Table 1 we have the results of a different group of four auditors and two loud speakers using 60 word groups. Here too is shown a preference for the RAB and Super-Pro receivers; the percentage of correct words received is again practically the same. The above mentioned data were taken at a level of 50 microvolts input and with an amplifier in the output of the RAB receiver.

16. Section 4 was recorded with the same input level but without an amplifier in the output of the RAB. The output of the compared receiver, Super-Pro, was reduced to a slightly lower level to match the reduced level of the RAB without the amplifier. The percentage of correct words received is the same and there was about a 3 to 1 preference for the Super-Pro over the RAB. No difference could be detected in comparing the RAB with the HRO and NC-100 at this fairly low output (80 to 100 milliwatts). Section 4 shows, however, that the RAB receiver can be used at low output levels without an amplifier when the impedances are properly matched. The percentages recorded there are the results of three groups of four men each, a total of 12 men.

17. The results shown in sections 5, 6, and 7 were obtained

with an input of 100,000, 50,000, and 2.5 microvolts respectively. In these tests an amplifier was used in connection with the RAB receiver. Twenty-one men were used to get these observations.

18. Table 2 shows the results of using filters in the circuit in order to pass only part of the total frequency band passed by the receivers. These filters have a sharp cut-off as shown by plates 2 to 5 inclusive and are flat in the pass region. The percentages recorded there are based on the number of words received by eight auditors out of 240 words broadcast. In columns 4 and 6 we note that the bands of 225-2600 and 0-2600 are fairly good for understandability, but poor for voice recognition.

19. In Table 3 is recorded the results obtained by the use of head phones. A preference was shown by some auditors for the RAB and the Super-Pro receivers. Many, however, did not detect any difference. On extremely low levels the NC did not perform as well as the other three receivers. This was agreed by all. One may say of the results in Table 3 that the RAB is as good if not better than the other receivers for head phone use. Seventy men were used as auditors. The total number of words sent on each level is recorded in column 5.

20. Table 4 is a record of using filters with head phones. The filters were connected as shown in the circuit diagram. The percentages received of 240 words read are entered.

#### (b) Statement of Probable Errors

21. It is believed that the tests were conducted in such a way as to reduce the errors to a minimum. In cases where the broadcaster's enunciation was poor and all receivers' percentages were unusually low, a check against the speaker reading directly to the auditors showed that he would cause the auditors to miss a large number of words, exactly accounting for the unusually low per cent. The men and words were changed so as to give all receivers an equal chance. The auditors were changed each day to prevent familiarity with the 750 words used. Due to the nature of the test, one may consider results which are within 5% of each other as practically the same.

#### DISCUSSIONS

22. The results of the test, using percentages recorded in Table 3 on headphones and the opinion of the men auditing as an index, show that the RAB receiver, when operated within its designed capacity, is favored over the NC-100, HRO and Super-Pro receivers. This margin of favor is, however, very small, but it in the least shows the RAB to be as good as the others.

23. In the test using loud speakers, a high quality broad band flat response amplifier was used in the output of the RAB to furnish the extra power needed. The percentage of words recorded over it was the same as the records of the other receivers. When the same loud speaker was shifted from one receiver to another, many of the auditors could not distinguish any difference between the receivers. However, the author together with 14 of 21 men selected stations No. 1 and No. 4 as the best of the four stations - these preferences were the Super-Pro and the RAB receivers. The difference seemed very slight and should be taken as an index of nothing other than personal preference.

24. The test was repeated five times with the same results. By tuning to regular broadcast stations the auditors were able to duplicate their opinions of the same receivers. The chief cause of complaint in the case of the RAB receiver for voice reception, as mentioned in paragraph 1 of reference (a), is its small power output. If loud speakers are used on it without an amplifier, care must be taken to match the impedances and at best there is some distortion when using loud speakers at output levels in the neighborhood of 100 milliwatts or more. The ordinary good loud speaker requires from 25 to 350 milliwatts. The RAB receiver is designed to work at 6 milliwatts undistorted output.

25. The frequency band necessary for intelligence transmission was found to be good between 250-3500 cycles, but is not complete for voice recognition. A band of 200-3600 is much more desirable for both intelligence and voice recognition. The band recommended as the most desirable and complete is the region of 150-5000. This increase in band width over the above mentioned bands is only for the purpose of voice recognition. In some circumstances where there is low frequency noise, such as aircraft, it may be better to raise the lower cut-off to 250 cycles. In considering the wide band of 150-5000, the first thing of importance is the frequency range of the microphones and head phones. The ranges of these instruments should be increased to agree with the above band. If the expense of obtaining the band of 150-5000 is objectionable, the region of approximately 200-3600 may be adopted with the expectation of fairly good results. This is slightly better than the ordinary telephone.

#### CONCLUSIONS AND RECOMMENDATIONS

##### (a) Conclusions

26. The Model RAB receiver, when used within its designed capacity, is as satisfactory as the other receivers compared for voice reception. The Model RAB has a weight factor of 6 to 8 times the other receivers.

27. The frequency band necessary for intelligence transmission and voice recognition may be classified as follows:

150-5000 cycles, very good for both recognition and understandability.

200-3600 cycles, fair for voice recognition, good for understandability.

250-3300 cycles, not positive for voice recognition, satisfactory for understandability.

(b) Recommendations

28. When using a loud speaker on the Model RAB receiver, it is recommended that a suitable amplifier be used between the output of the RAB receiver and the loud speaker.



(Continued)

TABLE 1

Input 100,000	1 Receiver RAB			2 Receiver NC			3 Receiver HRO			No filters 4 Receiver SP		
	Speakers			Speakers			Speakers			Speakers		
	HRO	SP	NC	HRO	SP	NC	HRO	SP	NC	HRO	SP	NC
Section 5	14	15	14	12	15		13	14		14	14	
	15	14	13	13	15		14	15		15	14	
	15	14	14	14	14		14	15		14	14	
	15	14	15	14	15		15	15		15	15	
	14	13	15	14	14		15	14		15		
	13	14	14	15	12		14	14		14		
	14	14	15	15	14		15	15		15		
	14		13	10	15		15	14		15		
	95%	93.4%	94%	89%	95%		95.6%	96.6%		97.3%	95%	
Section 5	Input 50,000											
	92.8%			91.2%			93.4%			94.8%		
Section 7	Input 2.5											
	32.6%			44.5%			69%			80.5%		
Section 7	13	8		6	9		7	12		12	11	
	14	8		11	11		9	10		11	11	
	10	12		7	8		7	14		12	11	
	12	9		4	9		8	11		9	10	
	13	10		6	7		12	9		8	11	
	12	11					9	9		10	11	
							10	9				
	82.3%	64.4%		58.6%	57.3%		59%	70.5%		68.8%	71.2%	

TABLE 2  
Speakers with Filters

225 Up	450 Up	225-1600	225-2600	0-1600	0-2600	450-2000
97.5%	89.5%	67.5%	87%	57.8%	95.4%	82.5%

TABLE 3

Headphones

Microvolt Input	1 RAB	2 NC	3 HRO	4 SP	Total Words Sent
1	47.3%	37.4%	49.3%	45.5%	345
2.5	69.2%	53.2%	70.5%	67.1%	1395
5	83.3%	68.2%	80.5%	78%	1755
10	85.2%	80.8%	86.8%	85.4%	735
25	90.8%	88.1%	93.8%	94%	780
50 500 10,000 100,000	96.4%	93.7%	91.4%	96.2%	2760

TABLE 4

Headphones with Filters

	0-1600	0-2600	225-2600	450-2600
Shure 70 Crystal Mike	84.4%	96.8%	94%	90.4%
Western Electric 630A	85.3%	91.3%	95.4%	85.5%

TABLE 5

Typical List of Words

talk	beat	guy	this
top	bit	wick	free
tone	bite	lie	both
ten	but	my	tree
ton	bought	pie	fist
tool	bat	tie	hiss
teen	book	zest	pest
tap	bout	term	thirst
tip	back	cheap	team
zip	put	whiz	bake
kit	pert	then	vest
took	pool	fall	kiss
bat	by	call	tease
bait	which	ball	fizzle
bet	die	tall	chat

TABLE 6

The 100 Most Frequently Occurring Words in the English Language.

the	not	their	time	the e
of	at	there	up	two
and	this	were	do	ver
to	are	so	out	bef re
a	we	my	can	gre t
in	his	if	then	cou d
that	but	me	only	suc
it	they	what	she	fir t
is	all	would	made	upo
I	or	who	other	eve y
for	which	when	into	how
be	will	him	men	com
was	form	them	most	us
as	had	her	people	sha l
you	has	war	said	sho ld
with	one	your	many	the
he	our	any	men	lik
on	an	more	about	wel
have	been	now	over	lit le
by	no	its	some	say

TABLE 7

Special Word Test

this	zest	bait
tis	best	thin
F.S.T.	list	in
threc	fist	sin
five	pest	pat
T.V.F.	V.F.E.	thirst
sieve	tooth	seeps
fec	chap	bake
B	cheap	tease
vest	zip	team
both	vest	teen
free	tease	sister
Lee	Z	bother
asure	f	sie
that	V.V.B.	pie
save	this	thy
tree	sizzle	that
fist	fizzle	chat
kit	C.S.T.	zit
hiss	cive	kit

CIRCUIT DIAGRAM

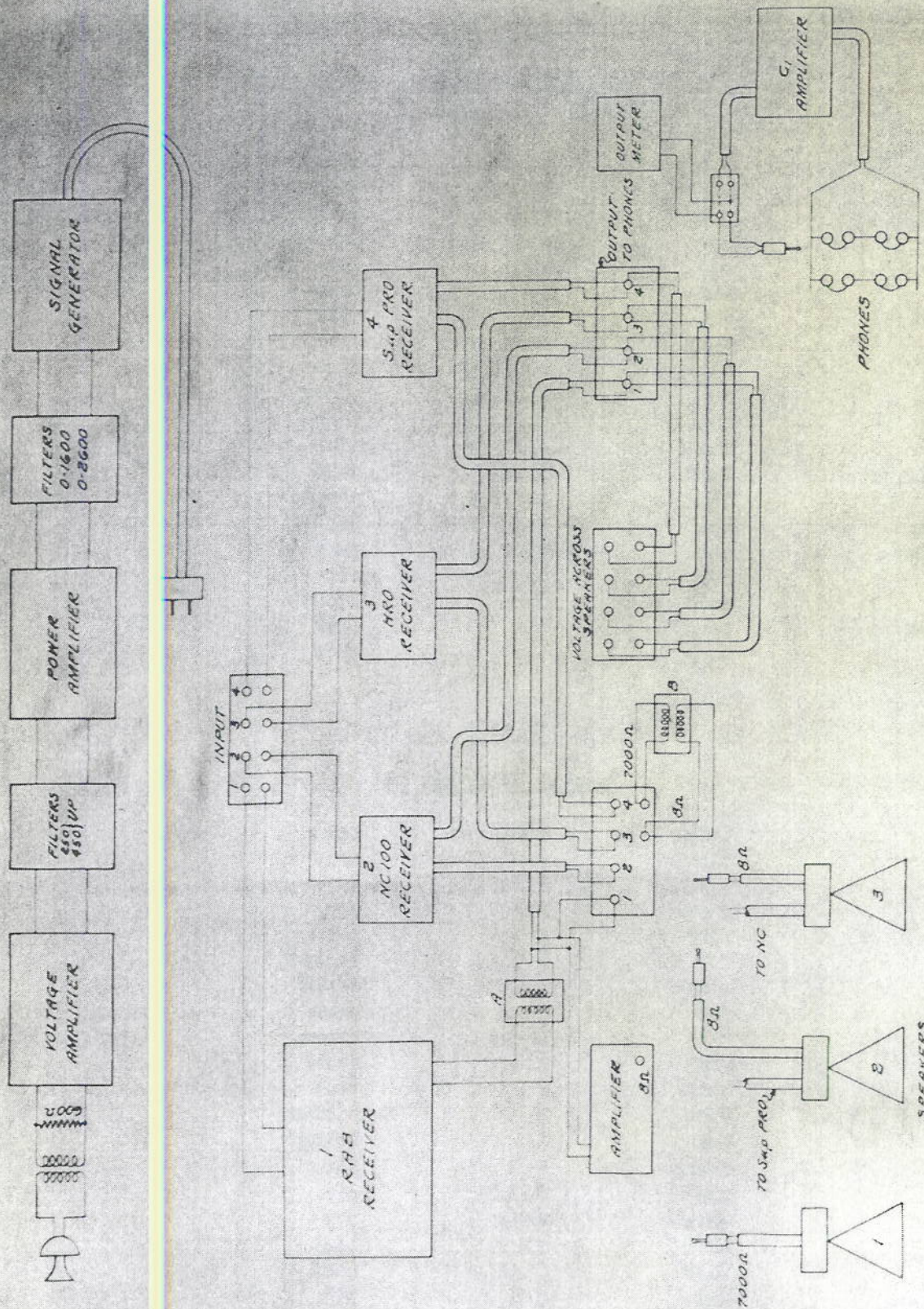
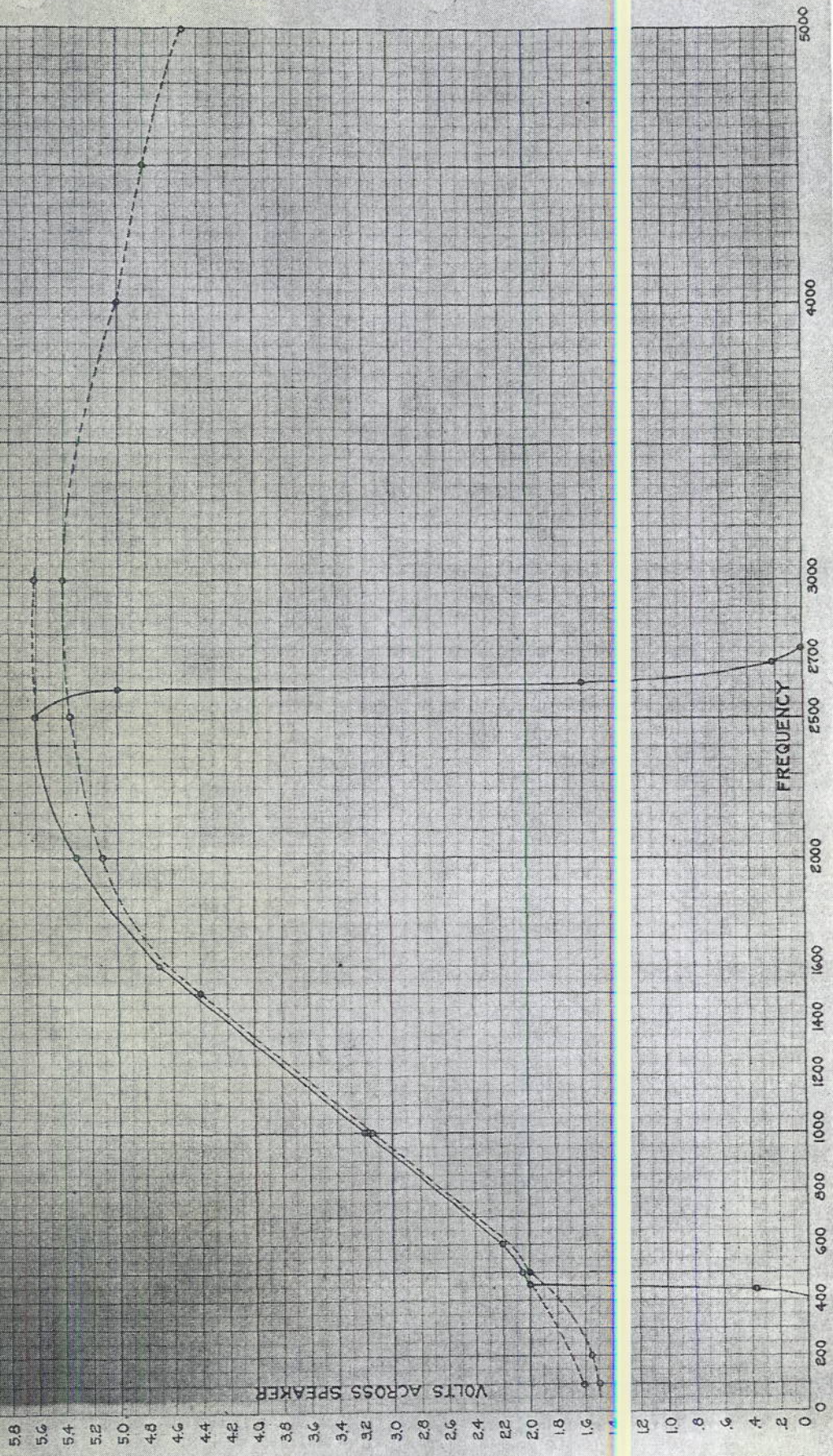
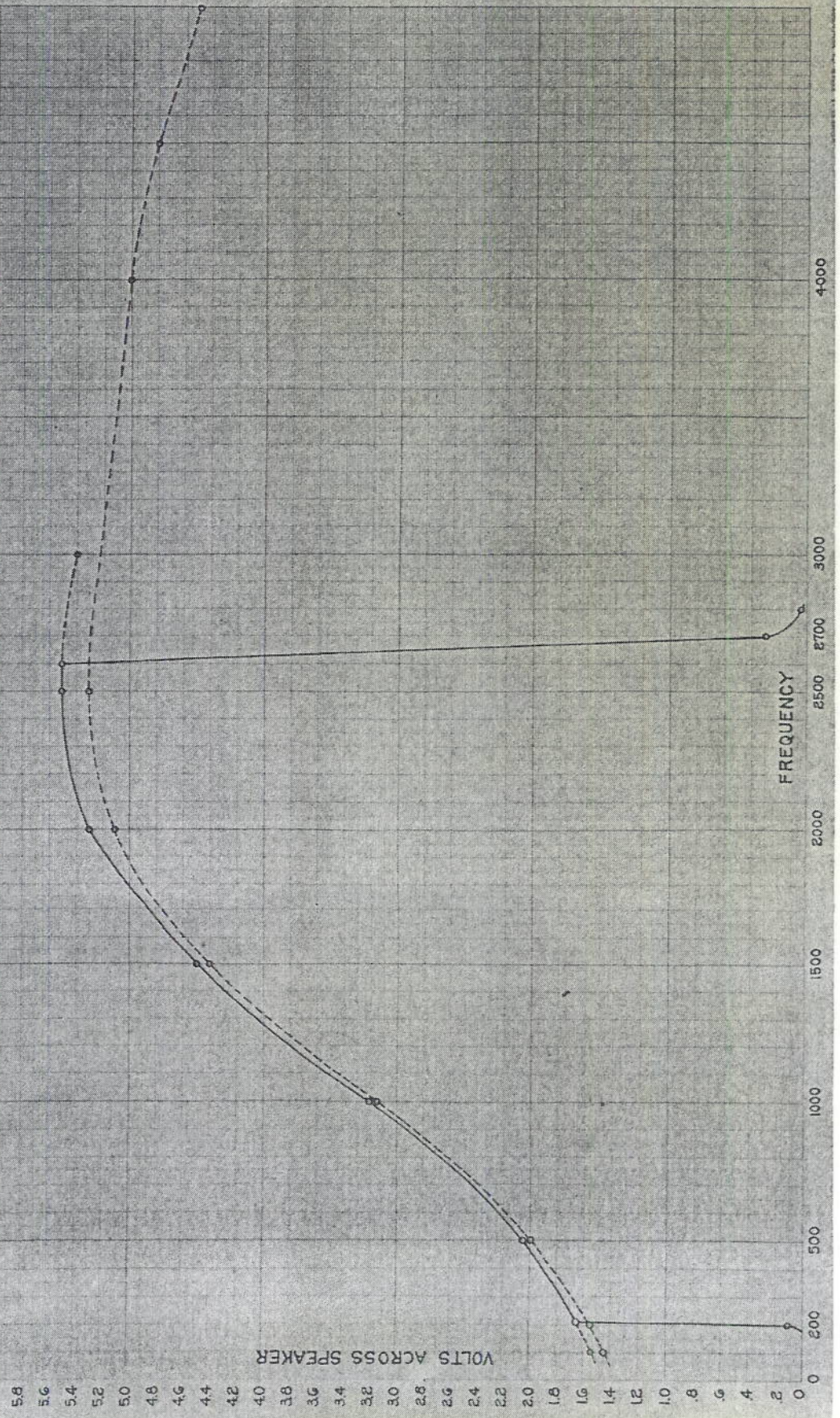


PLATE I

FREQUENCY BAND 450-2600 CYCLES  
 CHARACTERISTICS OF RECEIVER WITHOUT FILTER DENOTED BY DOTTED LINES



FREQUENCY BAND 225-2600 CYCLES  
 CHARACTERISTICS OF RECEIVER WITHOUT FILTER DENOTED BY DOTTED LINE



FREQUENCY BAND 225-1600 CYCLES  
 CHARACTERISTICS OF RECEIVER WITHOUT FILTER DENOTED BY DOTTED LINE

VOLTS ACROSS SPEAKER

FREQUENCY

5000  
4000

3000

2000

1500

1000

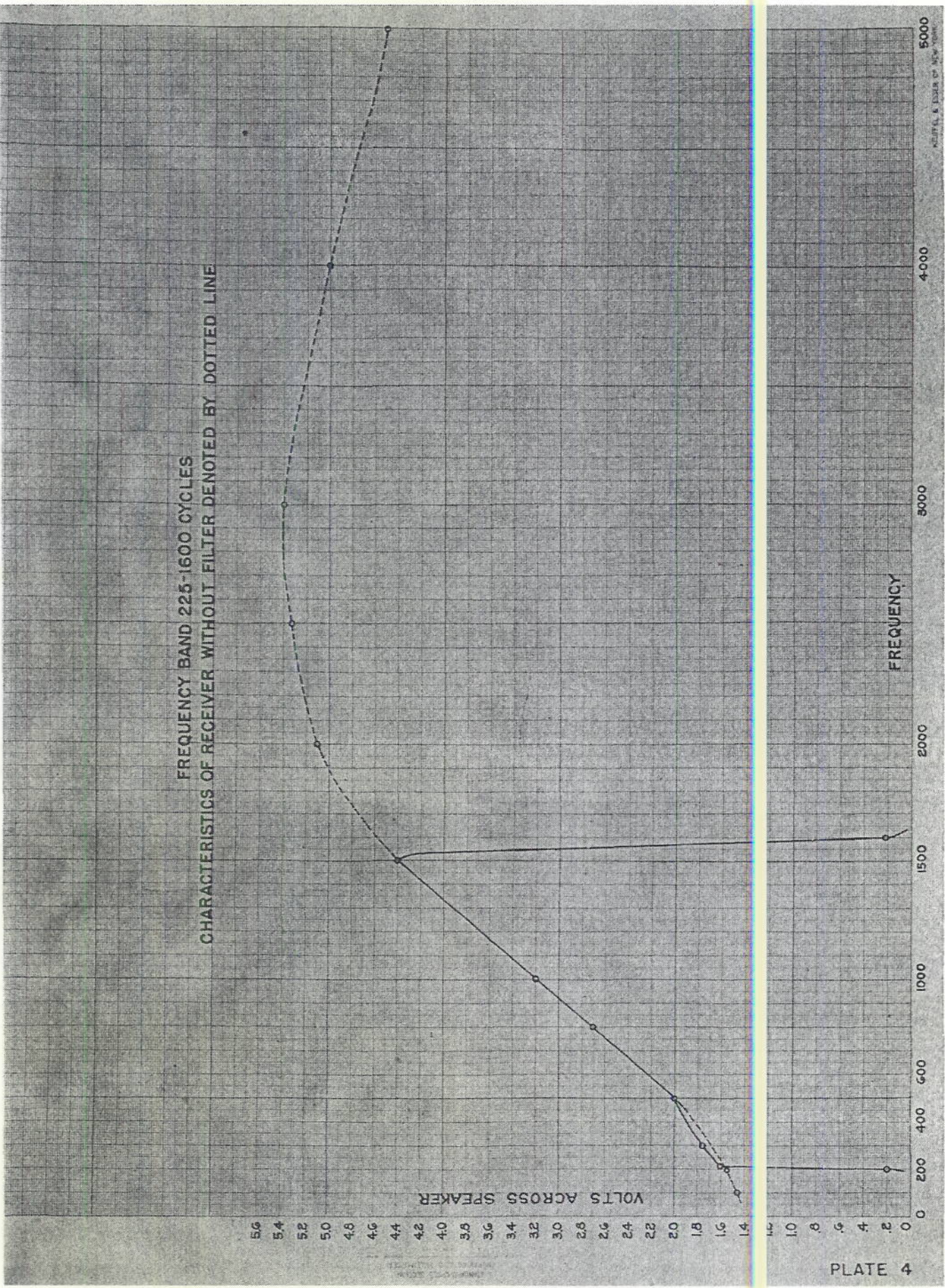
600

400

200

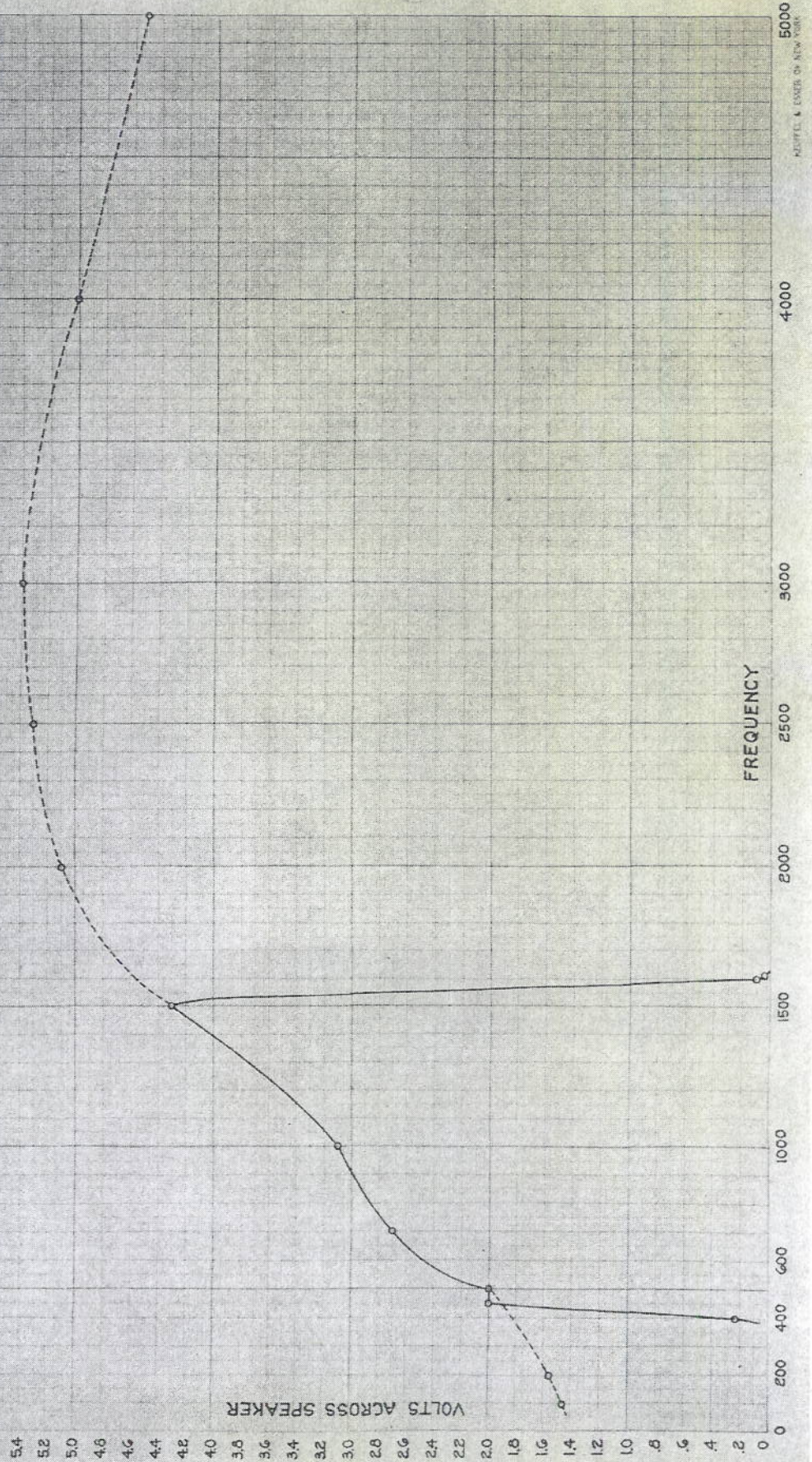
0

PLATE 4



CHARACTERISTICS OF RECEIVER WITHOUT FILTER DENOTED BY DOTTED LINE

FREQUENCY BAND 100 1000 CYCLES



# CURVES OF HEADPHONES

