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Report

on

Determination of Interference Levels.

NAVAL RESEARCH LABORATORY
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WASHINGTON, D.C.

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AUTHORIZATION

1. This problem was authorized by reference (a). Other pertinent data are listed as references (b), (c) and (d).

Reference: (a) BuEng.ltr. S67/85 (9-15-R8) of 20 September 1938.
(b) "Speech and Hearing," by Harvey Fletcher, pp. 169, 137, 199, 140, 67, 79.
(c) "Acoustics," by Stewart and Lindsay, p. 222.
(d) "Masking Effect of Pure Tones," by A. A. Mayer, Phil. Mag. 11, 500 (1876).

STATEMENT OF PROBLEM

2. Briefly, the problem consisted in determining relative levels at which interfering radio-code and radio-phone signals would just preclude 100 per cent intelligibility of the desired phone or code signal, as requested in reference (a). Also it is desirable to determine at what level a code signal may be copied 100 per cent intelligible by free-hand or pencil copy, and to what level the signal must be raised when a standard Navy typewriter is substitutod for the "still" or pencil copy.

KNOWN FACTS BEARING ON THE PROBLEM

3. As suggested in reference (a), the literature does not contain information pertinent and helpful in the guidance of this investigation, but places same in a field virgin within itself. However, much useful work on threshold intensities at various frequencies both for pure tones, voice and whispers at various intensities are contained in the literature together with masking of pure tones of one frequency by a pure tone of another frequency. These were made useful in this problem through their ability to convey reference level magnitudes to a standard level of reference, known as the threshold of audibility. This level is such that when a signal frequency of 1024 cycles per second is caused to generate a sound wave whose root-mean-square value is .00052 bar (1 dyne per square centimeter) pressure in the ear canal, the sound is just audible to 72 listeners out of 102 examined (references (b) and (c)). This represents a rejection of 30 ears in 102 or 29.4 per cent of the total tested, leaving 70.6 per cent of the total tested as having normal hearing. It was on this basis various investigators agreed on the above quoted pressure as the threshold pressure (p_0) when the frequency is 1024 cycles per second.

4. It will be shown in this report after testing 50 random radio operators that it was required to classify 76 per cent of the total tested as possessing normal hearing with respect to intelligibility, which agrees well with the above figure of merit.

5. Such information as has been revealed in this report has been checked for its relation to fundamental acoustics and it is believed the data are agreeable as a whole.

THEORETICAL CONSIDERATIONS

6. The calibration of the phones used in these tests was done with the "Electric Ear," which gives their relative efficiencies.

METHOD OF TESTS

7. Plate 1 depicts the schematic diagram of the test circuit. Two piezo-electric phonographic pick-ups were employed and put in parallel with two calibrated amplifiers. The outputs of these amplifiers were placed in parallel and six sets of head phones approximating 120,000 ohms (in series) were also connected in parallel with the outputs of the amplifiers. This connection matched well enough the outputs of the two amplifiers as was evidenced when a single pick-up, say No. 1, was compared with No. 2 pick-up, and No. 2 amplifier against the vacuum tube voltmeter. When No. 1 and No. 2 pick-ups were run simultaneously through their respective amplifiers, the voltmeter registered the sum of their effective single-valued calibrations, when the input was 1000 cycles per second to each amplifier. For voice signals, this will not be true due to the effect of the harmonic content on the voltmeter.

8. Ten classes of five operators each were tested. The first test made was for ear acuity at pencil copy of 1000 cycle code signals. These signals were our standard daily weather reports, recorded for this purpose on a home recording device. In a class of five operators, each operator was tested singly at station No. 4, and his attenuation number (∝) noted. One operator served to verify the accuracy of the pencil copy by an accurate translation of the signal record, and upon an error of a letter a signal was given, and at this gesture, his attenuation number was recorded for which his copy was 100 per cent correct. No listening-in was permitted during these tests by other operators since a slight rustle of the telephone cord or phones would interfere with the operator being tested. These tests appear in Table 1.

9. A similar procedure was followed for the second test where a standard Navy typewriter was substituted for the pencil copy. These tests appear in Table 2.

10. Included in Tables 1 and 2 are two columns of information not specifically called for in this problem, one pertaining to the acoustic pressure acting in the ear canal at the signal strength indicated, and the other a decibel scale of loudness greater than the threshold of hearing. Hence the decibel scale infers a sensible degree of magnitude as to how loud is a 22 microvolt signal when energizing a standard Navy headphone of 10,260 ohms impedance. This statement may be interpreted to mean a 22 microvolt signal at 1024 cycles per second will produce in the ear canal of the operator wearing the phone an acoustical pressure of .002 bar whose loudness is ~~11.7 decibels above~~ the average intelligibility of the human ear, or is 11.7 decibels above the threshold of hearing (L_o).

11. The following tests were then made in the order indicated below with each of the five operators seated at his respective station;

shown on Plate 1.

Test No.	Signal Intelligence	Circuit	Data Sheet
4a	Voice No. 1 vs. Voice No. 2	Workable	Table 3
4e	Voice No. 1 vs. Voice No. 2	Good	Table 3
4a'	Voice No. 2 vs. Voice No. 1	Workable	Table 4
4e'	Voice No. 2 vs. Voice No. 1	Good	Table 4
4b	Voice No. 1 vs. Code No. 4	Workable	Table 5
4f	Voice No. 1 vs. Code No. 4	Good	Table 5
4c	Code No. 4 vs. Voice No. 1	Workable	Table 6
4g	Code No. 4 vs. Voice No. 1	Good	Table 6
4d	Code No. 4 vs. Code No. 3	Workable	Table 7
4h	Code No. 4 vs. Code No. 3	Good	Table 7

12. In all tests where a voice signal is indicated, the matter of 100 per cent intelligibility could be checked only through the acknowledgment of the operator being tested. Likewise, in tests where a voice signal is indicated, the voltages V_a, V_b, V_c, V_d and V_i shown in Tables 3, 4, 5 and 6 were arrived at in the following manner. The phonographic voice records were played many times and checked against a stenographic translation of the record studied and the indicated mean response of a vacuum tube voltmetor noted and recorded in r.m.s. volts on the stenographic copy as the record progressed. An average response level was then determined and it is this average response level that was selected as a reference level of the whole record. It was possible to change this reference level at will and thus the average loudness by a potentiometer control in the piezo-electric signal generator circuit. The cue-word of the text selected as representing the average response level was the word "passion". The input voice signal required for 12 phones in series was 1 volt r.m.s. Hence, for all tests the cue-word "passion" was set to register 1 volt, or 2 volts, depending whether we refer to the desired or the undesired voice signal.

13. In this way it was possible to duplicate tests for different groups to be tested. It so happened the two voices, viz., Maurice Evans, tenor, as signal voice No. 1, and John Barrymore (baritone) as signal voice No. 2, were nearly equal in response at the same cue word and average response level.

14. It must be remembered, however, the voltages are not true r.m.s. values as would be the case in a pure 1000 cycle note, due to the error in the voltmeter readings from harmonic content of the voice signal. The error may not be great and may be negligible as other factors are considered. However, it is felt that the errors are consistent due to the method used in reproducing a voice signal; consequently, the various levels indicated in the tables would not be changed materially.

DATA RECORDED DURING TESTS

15. The data recorded during tests are compiled and tabulated in Tables 1 to 7 inclusive. A resumé of the entire problem in terms of relative interference levels as referred to signal voltages is given in Table 8.

PROBABLE ERRORS

16. The probable errors in measurement are estimated as follows:

Tables 1 and 2.

V_e ± 2%, E_e ± 5%, p_e* ± 15%

V_t 2%, E_t 5%, p_t* ± 15%

Tables 3 and 4.

V_a and V_i* ± 10%

Table 5.

V_b ± 10%* V_i ± 2%

Table 6.

V_c ± 2%, V_i* ± 10%

Table 7.

V_d ± 2%, V_i ± 2%

* Note: These errors do not represent measured values but are estimates. Pressures in the ear canal may be 10 per cent less than indicated in table due to poor coupling or leakage to the ear by the phones. Voice signal voltage may or may not contain 10 per cent harmonics voltage error. Artificial pressure of holding phone to ear was not permitted other than the normal mechanical pressure supplied by head strap.

DISCUSSION

17. It is the opinion of some operators that when an interfering signal frequency is 1000 cycles per second, if the frequency of the desired signal is lowered about 50 per cent, a good copy is secured with less fatigue to the operator. This opinion seems to bear weight since the distribution of acoustical energy (the fundamental of aural intelligence) is massed principally below 500 cycles. It will be seen this is true for speech power (reference (b)) where male and female voices show a maximum energy distribution around 250 cycles.

18. This problem (reference (a)) bears a direct relation to the "masking of pure tones by pure tones" (reference (b)). In this reference, page 168, is shown graphically the result of a masking tone of 1200 cycles (interfering signal, by way of analogy) which is caused to

completely mask or obliterate pure tones of varying frequencies (desired signal frequencies). Quote (reference (b)), "It is seen that the greatest masking effect is near 1200 cycles (the desired signal frequency) which is the frequency of the masking tone." "A tone of 1250 cycles must be raised to 46 decibels above the threshold to be perceived in the presence of a 1200 cycle tone which is 60 decibels above its threshold." "Or it must be raised to within 14 decibels of the masking tone before it is perceived."

19. A photostatic copy of this masking effect is made a part of this report and designated as Plates 2 and 3.

20. The Mayer effect is seen to hold true under certain conditions and this is that a low-pitched sound completely obliterates higher pitched tones of considerable intensity and that higher pitched frequencies will never obliterate lower pitched tones. A study of this effect might lead to information quite valuable for Naval receivers.

21. In these tests no attempt was made to measure complete masking; however, we do have masking in terms of 100 per cent intelligibility. If we refer to Table 7 we see for each value of α complete masking of a 1000 cycle tone by a masking tone of 800 cycles, but attached to this is the fact that complete masking was attained at the expense of 100 per cent intelligibility. Where α is equal to zero it is seen 10 per cent of our auditors were completely masked so far as copying the desired signal at a voltage of .0416 volt when the masking voltage was .167 volt. The decibel level here is 12 decibels above the desired signal instead of 14 decibels as shown by Fletcher. The 2 decibel difference in level may well be charged to making 100 per cent copy, or error in measurements.

CONCLUSIONS

22. The data summarized in tabular form in Table 8 are recapitulated below:

(a) An interfering voice may be about 2.0 decibels above a desired voice for a workable circuit, and it should be 5.4 decibels below the desired voice for a good circuit (one voice baritone and the other tenor).

(b) An interfering voice may be about 10.4 decibels above a desired code signal for a workable circuit, and it should be not more than 5 decibels above the desired code signal for a good circuit (baritone voice and 1000 cycle code signal).

(c) An interfering code signal may be about 6.6 decibels above a desired voice for a workable circuit, and it should be about 4.4 decibels below the desired voice for a good circuit.

(d) An interfering code signal may be about 8 decibels above a desired code signal for a workable circuit, and about 3.5 decibels above the desired signal for a good circuit (one code signal frequency 1000 cycles, and the other 800 cycles).

Table 1

TESTS ON EAR ACUITY FOR PENCIL COPY.
(See Appendix 1)

Class or Line No.	α db	No. of Auditors	Per Cent Auditors	V_e 10^{-6} Volts	E_e 10^{-12} Watts	L_e db	p_e Bars	L_o db
1	31.57	10	20	22	.0242	-12.60	.0020	11.7
2	25.02	18	36	47	.1091	- 6.06	.0042	18.2
3	21.58	2	4	69	.243	- 2.58	.0063	21.7
4	19.08	8	16	93	.426	- 0.14	.0085	24.3
	Synonyms at zero level			94	.440	0	.0087	24.5
5	17.14	1	2	116	.669	+ 1.82	.0107	26.3
6	15.56	4	8	139	.966	3.42	.0129	27.9
7	13.06	3	6	185	1.725	5.94	.0172	30.4
8	11.12	2	4	232	2.68	7.85	.0214	32.3
9*	5.78	1	2	427	9.14	13.20	.0395	37.7
10*	4.68	1	2	486	11.75	14.27	.0436	38.5
		50	100%					
Less eliminated		48	96%					

* Indicates eliminated auditors (see Appendix 1).

Where

$$V_e = \frac{834 \times 10^{-6}}{\epsilon^{\mu\alpha}} \text{ r.m.s. volts.}$$

$$E_e = \frac{67.68 \times 10^{-12}}{\epsilon^{2\mu\alpha}} \text{ average watts.}$$

$$p_e = .0131 \sqrt{E_{e\mu\mu} \text{ watts}} \quad \text{bars r.m.s.}$$

$$L_o = 20 \log \frac{p_e}{p_o} \text{ decibels above } p_o.$$

p_o = .00052 bars = threshold pressure at 1024 cycles per second.

μ = 0.1151 = modulous to Naperian transmission unit system.

α = Attenuation in decibels necessary to produce the signal voltage.

Table 2

TESTS ON EAR ACUITY FOR TYPEWRITTEN COPY.
(See Appendix 2)

Class or Line No.	α db	No. of Auditors	Per Cent Auditors	V_t 10^{-6} Volts	E_t 10^{-12} Watts	L_t db	P_t Bars	L'_o db
1	25.02	1	2	47	.110	-14.13	.0043	18.4
2	19.08	7	14	93	.431	- 8.20	.0086	24.4
3	15.56	7	14	139	.963	- 4.72	.0127	27.8
4	13.06	9	18	185	1.705	- 2.24	.0171	30.3
5	11.12	8	16	232	2.682	- 0.26	.0214	32.3
	Synonyms at zero level			239	2.845	± 0.00	.0221	32.6
6	9.54	5	10	278	3.850	1.32	.0257	33.8
7	7.90	3	6	336	5.62	2.96	.0310	35.5
8	6.78	3	6	382	7.25	4.06	.0353	36.6
9	4.68	2	4	486	11.75	6.16	.0436	38.5
10*	3.98	1	2	527	13.85	6.88	.0474	39.2
11*	3.44	1	2	592	15.60	7.39	.0517	40.0
12*	2.18	1	2	655	20.95	8.67	.0600	41.2
13*	.36	1	2	800	31.85	10.49	.0739	43.0
Does not type*		1	2	---	---	---	---	---
		50	100%					
Less eliminated		45	90%					

* Eliminated auditors.　　　See Appendix 2.

The increase in level for the typewritten copy over that of the pencil copy gives a measure of the noise, distraction, etc., contributed by the typewriter and is given as follows:

$$\text{Noise contribution} = L'_o - L_o = 20 \log \frac{V_t}{V_e} = 10 \log \frac{E_t}{E_e} = 20 \log \frac{P_t}{P_e}$$

$$= 32.6 - 24.5 = 8.1 \text{ db above zero level.}$$

NOTE: The same nomenclature applies here as used in Table 1 except for subscripts. See Table 1.

Table 3

VOICE NO. 1 vs. VOICE NO. 2
(See Appendix 3)

Data recorded during tests where V_a = .0833 volts.

α db	Test No. 4a. Workable Circuit Number of Auditors			Test No. 4e. Good Circuit Number of Auditors		
		Per Cent Auditors	Volts V_i		Per Cent Auditors	Volts V_i
0	1	2	.167			
0.31	4	8	.161			
.36	2	4	.160			
.72	5	10	.151			
1.14	5	10	.146			
1.80	6	12	.134			
2.18	2	4	.129			
2.80	10	20	.120			
4.15	5	10	.101	5	10	.101
4.68	1	2	.096			
5.00	2	4	.094			
6.33	7	14	.079	10	20	.079
9.70				20	40	.053
12.08				5	10	.041
12.60				5	10	.039
13.06				5	10	.037
Totals	50	100%	6.220	50	100%	2.940
Weighted mean			.1204			.0588

Test No.	Circuit	Average Volts V_i	Level in db. above V_a	10^{-6} Watts E_i
4a	Workable	.120	3.18	.718
V_a = Signal voltage		.0833	0.00	.346
4e	Good	.059	-3.00	.173

Table 4

VOICE NO. 2 vs. VOICE NO. 1
(See Appendix 3)

Data recorded during tests where V_a = .0833 volts.

	Test No. 4a'. Workable Circuit.			Test No. 4e'. Good Circuit.		
α db	Number of Auditors	Per Cent Auditors	Volts V_i	Number of Auditors	Per Cent Auditors	Volts V_i
0	1	2	0.167			
0.08	1	2	.162			
.36	1	2	.159			
1.14	5	10	.145			
1.16	1	2	.144			
2.18	8	16	.129			
2.66	5	10	.121			
3.44	2	4	.111			
Weighted mean			.1045			
4.68	6	12	.096	5	10	.096
5.78	5	10	.085			
6.33				5	10	.079
6.78	9	18	.075			
7.90	1	2	.066			
9.54	5	10	.054			
11.12				15	30	.045
13.06				5	10	.037
15.56				15	30	.028
19.08				5	10	.019
	50	100%	5.228	50	100%	2.250
Weighted mean			.1045			.045

Test No.	Circuit	Volts V_i	L_i db.	E_i 10^{-6} Watts
4a'	Workable	.1045	1.98	.545
V_a = Signal voltage		.0833	0.00	.346
4e'	Good	.0450	-5.36	.101

Table 5

VOICE NO. 1 vs. CODE NO. 4
(See Appendix 3)

Data recorded during tests where V_b = .0416 volts.

α db	Test No.4b. Workable Circuit. Number of Auditors	Per Cent Auditors	Volts V_i	Test No.4f. Good Circuit. Number of Auditors	Per Cent Auditors	Volts V_i
0	1	2	.166			
.36	1	2	.160			
1.16	1	2	.144			
1.72	2	4	.136			
2.18	7	14	.129			
2.66	2	4	.121			
3.44	3	6	.112			
4.68	9	18	.096			
Weighted mean			.089			
5.78	1	2	.085			
6.78	8	16	.075			
7.90	3	6	.066			
9.54	4	8	.054			
11.12				5	10	.045
13.06	5	10	.037	5	10	.037
15.56				10	20	.028
				Weighted mean		.025
17.14				10	20	.023
19.08	3	6	.019	15	30	.019
22.00				5	10	.013
	50	100%	4.428	50	100%	1.270
Weighted mean			.089			.025

Test No.	Circuit	Volts V_i	db L_i	10^{-6} Watts E_i
4b	Workable	.089	6.60	.395
V_b = Signal voltage		.0416	0.00	.086
4f	Good	.025	-4.44	.031

Table 6

CODE NO. 4 vs. VOICE NO. 1
(See Appendix 3)

Data recorded during tests where V_c = .0416 volts.

∝ db	Test No. 4c. Workable Circuit. Number of Auditors	Per Cent Auditors	Volts V_i	Test No. 4g. Good Circuit. Number of Auditors	Per Cent Auditors	Volts V_i
0	9	18	.167			
.31	6	12	.160			
.72	5	10	.151			
1.14	6	12	.145			
Weighted mean			.137			
1.80	10	20	.134			
2.80	4	8	.120			
3.20	1	2	.114			
3.50	1	2	.110			
4.15	4	8	.101			
5.00	1	2	.093	10	20	.093
6.33	3	6	.079	25	50	.079
				Weighted mean		.074
9.70				15	30	.053
	50	100%	6.866	50	100%	3.700
Weighted mean			.137			.074

Test No.	Circuit	Volts V_i	db L_i	10^{-6} Watts E_i
4c	Workable	.137	10.36	.935
V_c = Signal	voltage	.0416	0.00	.086
4g	Good	.074	5.02	.273

Table 7

CODE NO. 4 vs. CODE NO. 3
(See Appendix 3)

Data recorded during tests where V_d = .0416 volts.

α	Test No. 4d. Workable Circuit.			Test No. 4h. Good Circuit.		
db	Number of Auditors	Per Cent Auditors	Volts V_i	Number of Auditors	Per Cent Auditors	Volts V_i
0	5	10	.167			
0.08	1	2	.164			
0.31	1	2	.162			
0.74	1	2	.153			
1.16	1	2	.150			
1.42	1	2	.145			
1.50	1	2	.144			
2.30	1	2	.128			
2.38	1	2	.127			
2.80	4	8	.121	5	10	.121
3.44				5	10	.111
3.70	3	6	.108			
Weighted mean			.104			
4.15	4	8	.101			
4.66	1	2	.096			
5.35	1	2	.090			
5.88	1	2	.084			
6.33	12	24	.079	5	10	.079
6.86	3	4	.075	Weighted mean		.062
8.20	3	6	.059			
9.22	2	4	.056			
9.70	3	6	.053	5	10	.053
10.87				5	10	.047
12.08				25	50	.041
	50	100%	5.211	50	100%	3.080
Weighted mean			.104			.062

Test No.	Circuit	Volts V_i	db L_i	10^{-6} Watts E_i
4d	Workable	.104	7.96	.538
V_d = Signal voltage		.0416	0.00	.086
4h	Good	.062	3.47	.191

Table 8

RELATIVE INTERFERENCE LEVELS AS REFERRED TO SIGNAL VOLTAGES.

Test No.	Desired Signal vs.	Interfering Signal	L_i db	Circuit	Interference
4c	1000 cy code	Baritone voice	10.36	Workable code level	Phone
4d	1000 cy code	800 cy code	7.96	Workable code level	Code 800 cycles
4b	Baritone voice	1000 cy code	6.60	Workable phone level	Code 1000 cycles
4g	1000 cy code	Baritone voice	5.02	Good code level	Phone
4h	1000 cy code	800 cy code	3.47	Good code level	Code 800 cycles
4a'	Tenor voice	Baritone voice	1.98	Workable phone level	Phone
4a	Baritone voice	Tenor voice	3.18	Workable phone level	Phone
	Desired Signal Level		0.00		
4e	Baritone voice	Tenor voice	-3.00	Good phone level	Phone
4e'	Tenor voice	Baritone voice	-5.36	Good phone level	Phone
4f	Baritone voice	1000 cy code	-4.44	Good phone level	Code 1000 cycles

Appendix 1

ANALYSIS OF TABLE 1.

Table of Ear Acuity for Pencil Copy.

Type of test: Reception of code signals (weather report) at a signal frequency of 1000 cycles per second.

Condition of test: Quiet room of low noise level but not sound-proofed.

Requirement of test: Copy must be 100 per cent intelligible.

Nomenclature: L = The level of reference, or zero reference level. This level is defined as one for which the weighted mean of 96 per cent of the total operators tested separates the good from the poor. Operators testing at this level suffer a hearing loss of 18.5 per cent.

L_o = The level of pressure above the threshold of audition for a signal frequency of 1024 cycles per second.

p_o = Threshold pressure in the ear canal at which a note of 1024 cycles per second is just audible;
= .00052 r.m.s. bar or .00052 r.m.s. dynes per centimeter squared.

E = Electric energy in watts expended in displacing telephone diaphragm sufficiently to produce the required acoustic energy at a given frequency.

v = R.M.S. value of a voltage applied to a single telephone receiver in order to produce the required electric power.

α = The attenuation in decibels necessary to produce the required signal voltage (v) when the applied voltage is 834×10^{-6} volts.

NOTE: The appended subscript (e) to above nomenclature defines the ear acuity test at pencil copy while the appended subscript (t) defines the ear acuity test at typewritten copy. (See Table 2.)

In analyzing data from Tables 1 and 2, an arbitrary level should be established as a reference axis by which other levels could be referred.

The requirement of all tests was 100 per cent intelligibility in order to insure the process of elimination. Intelligibility may be here defined as consisting of four major dependencies, viz.:

Intelligibility	1. Sense of feeling	Auditory sensation area
	2. Sense of hearing	
	3. Gift of concentration	Mental training and experience
	4. Ability of Interpretation	

The first two embrace the auditory sensation area of which the first is the locus of the threshold of feeling as a function of frequency, while the second is the locus of the threshold of audibility, also a function of frequency. The latter two may well constitute mental training and experience.

The data show the highest degree to which intelligibility presented itself in testing 50 random operators was contained in only 20 per cent of the total auditors tested. These auditors copied Navy code signals at a frequency of 1000 cycles per second from a minimum excess pressure in the ear canal of $p = .0020$ bar r.m.s., while the threshold of hearing at this frequency is $p_0 = .00052$ bar, thus suffering a hearing loss in per cent of 8.9 per cent, or 11.7 decibels above threshold. This 8.9 per cent loss is directly chargeable to the high degree of intelligibility indicated for 100 per cent copy. The largest group tested possessing a high degree of intelligibility is shown in Table 1, line 2. The per cent hearing loss here is 13.8 per cent on a 18.2 decibel level above the threshold. Up to this point 56 per cent of the auditors tested have been covered. An auditor suffering a hearing loss of 13.8 per cent should be known now as a very good operator since he will make a perfect copy of test signal at an excess in pressure of 0.0042 bar r.m.s. When the hearing loss is 100 per cent, total deafness is assumed.

Out of 50 auditors tested, ten different classes of operators were found, requiring 10 different powers of the test signal for 100 per cent copy. Two classes in lines 9 and 10, Table 1, were eliminated by test and personal admission of defective hearing. The weighted mean of the electric power level for the remaining 8 classes fixed 0.440×10^{-12} electric watts as a point of reference. This indicated that auditors bearing an audibility number $\alpha = 17.14$ decibels or less were defective or inexperienced. A check of the questionnaires filled out by the 10 auditors whose audibility number is shown on lines 5, 6, 7, and 8 verified the tests in that their duty previous to entrance to the school in 1938 was from one to three years under Radio Materiel, Shore, Sound, or little "Receiving Line" duties. Hence the process of elimination fixes the upper limit of good operators, as 76 per cent of the auditors tested and eliminates 6 classes of low rating. This 76 per cent of the 50 operators tested and designated as good operators, checks well with 70.6 per cent of auditors tested as having normal hearing (reference (b)). This indicates that probably 25 per cent of random operators entering any service requiring a high degree of ear acuity would be defective so far as 100 per cent intelligibility was concerned. Hence, the synonomous units required to establish the reference electric power level of 0.440×10^{-12} watts or the zero power level of reference are:

For Pencil Copy

V_E = 94.0 x 10^{-6} volts at a frequency of 1000 cycles.

when E_E = 0.440 x 10^{-12} watts of electric power = reference level.

p_E = 0.0086 bar r.m.s.

L_0 = 24.4 decibels above threshold of hearing.

$HL\%_E$ = 18.5% hearing loss.

when $Z = 10{,}260 \angle 57^\circ 10'$ Vector impedance of phones in ohms.

and P.F. = .511 = power factor of electric unit = cos 57° 10'.

Appendix 2

ANALYSIS OF TABLE 2.

Test: Code signals (weather report) at a frequency of 1000 cycles per second copied by typewriter at 100 per cent intelligibility.

In analyzing this test, the law of averages can also be used since each operator tested will require an increment in electric power over what it took for pencil copy for 100 per cent intelligibility. Thus, in using the same process of elimination as previously employed, it was found that the same auditors eliminated in Table 1 remained eliminated in Table 2 plus three other auditors, one of whom could not type at all, while the other two lacked typing experience and became confused, although both were proficient at pencil copy in their respective classes.

This gives 90 per cent of the total auditors tested as passing this test at 100 per cent intelligibility and the weighted mean of electric power for each headphone was 2.845×10^{-12} watts or 8.12 decibels above the level required for pencil copy.

Let $A = 8.12$ decibels above pencil copy to which the power must be increased to produce 100 per cent intelligibility for a typewritten copy.

Then in accordance with established nomenclature, the synonomous units required to establish the electric power level of 2.845×10^{-12} watts, or the zero power level for typewritten copy may be had as follows:

$$V_T = V_E \, \epsilon^{.115 A} = V'_e \, \epsilon^{.932} = 239.0 \times 10^{-6} \text{ volts.}$$

when $E_T = 2.845 \times 10^{-12}$ watts (electric) = reference level.

also $p_T = p_e \, \epsilon^{.115 A} = .0087 \times 2.54 = .0221$ bar r.m.s.

$$L_o' = 20 \log \frac{pt}{po} = 20 \times 1.628 = 32.6 \text{ decibels above threshold.}$$

$$= L_o + A = 24.5 + 8.1 = 32.6 \text{ decibels above threshold.}$$

$$H.L.\%_T = 24.8\% \text{ hearing loss.}$$

when $Z = 10{,}260 \, \underline{/57^\circ \, 10'}$ = vector impedance of phones in ohms.

$$P.F. = \text{Cos } 57^\circ \, 10' = .511 = \text{power factor of electric unit.}$$

Appendix 3

ANALYSIS FOR TABLES 3 to 8 INCLUSIVE.

Bureau problem request numbers 4a to 4h inclusive.

Request numbers 4a and 4e:

Desired signal = That of Maurice Evans, to be known as signal voice No. 1 or plaintiff signal.

Interfering signal = That of John Barrymore, to be known as signal voice No. 2 or defendant signal.

Subject matter = Hamlet's soliloquy "Now I am alone," Act 2 of Scene 2 from "Hamlet" by Shakespeare.

Average voice pitch = Maurice Evans - Signal voice No. 1 - tenor.

Average voice pitch = John Barymore - Signal voice No. 2 - baritone.

V_1 = R.M.S. value of the voltage applied to 12 phones in series for signal voice No. 1 voltage.

= 1 volt r.m.s.

V_2 = Same as V_1 but for signal voice No. 2 voltage.

= 2 volts r.m.s.

Then $V_a = \frac{V_1}{12} = .0833$ volts.

V_i = R.M.S. voltage of interfering signal applied across a single phone.

$$V_i = \frac{V_2}{12\,\epsilon^{\mu\alpha}} = \frac{0.1666}{\epsilon^{\mu\alpha}} \text{ r.m.s. volts.}$$

μ = 0.1151 = Modulous to naperian T.U. system.

α = The acuity attenuation (db) necessary to produce the interfering signal voltage.

Request numbers 4a' and 4e':

The reverse of request No. 4a was measured as test No. 4a' for the workable circuit and 4e' for the good circuit. The above voltages were simply reversed in terms of the desired and interfering signal, viz., signal voice No. 2 became the desired signal, while signal voice No. 1 became the interfering signal.

Request numbers 4b and 4f:

Desired signal = Signal voice No. 1.

Interfering signal = 1000 cycle code No. 4.

V_3 = R.M.S. value of the voltage applied to 12 phones in series for signal voice No. 1.

= 0.5 volt r.m.s.

V_2 = Same as V_3 but for code signal No. 4.

$$V_b = \frac{V_3}{12} = \frac{.5}{12} = .0416 \text{ volts.}$$

$$V_i = \frac{V_2}{12\,\epsilon^{u\alpha}} = \frac{0.1666}{\epsilon^{u\alpha}}$$

Request numbers 4c and 4g:

Desired signal = 1000 cycles code No. 4.

Interfering signal = Signal voice No. 1.

$$V_c = V_b = .0416 \text{ volts}$$

$$V_i = \frac{0.1666}{\epsilon^{u\alpha}}$$

Request numbers 4d and 4h:

Desired signal = 1000 cycle code No. 4.

Interfering signal = 800 cycle code No. 3.

$$V_d = V_c = V_b = .0416 \text{ volts.}$$

$$V_i = \frac{0.1666}{\epsilon^{u\alpha}}$$

NOTE: The r.m.s. voltages when referred to voice signals are not true r.m.s. values due to errors in the harmonic content of the complex voltage envelope. (See report, "Methods of Tests.") Similarly, the r.m.s. voltages of the single frequency signals are only true when applied to a telephone receiver whose impedance (reference (c)) and phase angle (θ) are equal to our standard Navy type receiver used in these tests, which requires:

$Z = 10{,}260\underline{/\theta}$ Vector impedance phase

Phase angle θ $\cos\theta = 0.511$

TEST CIRCUIT

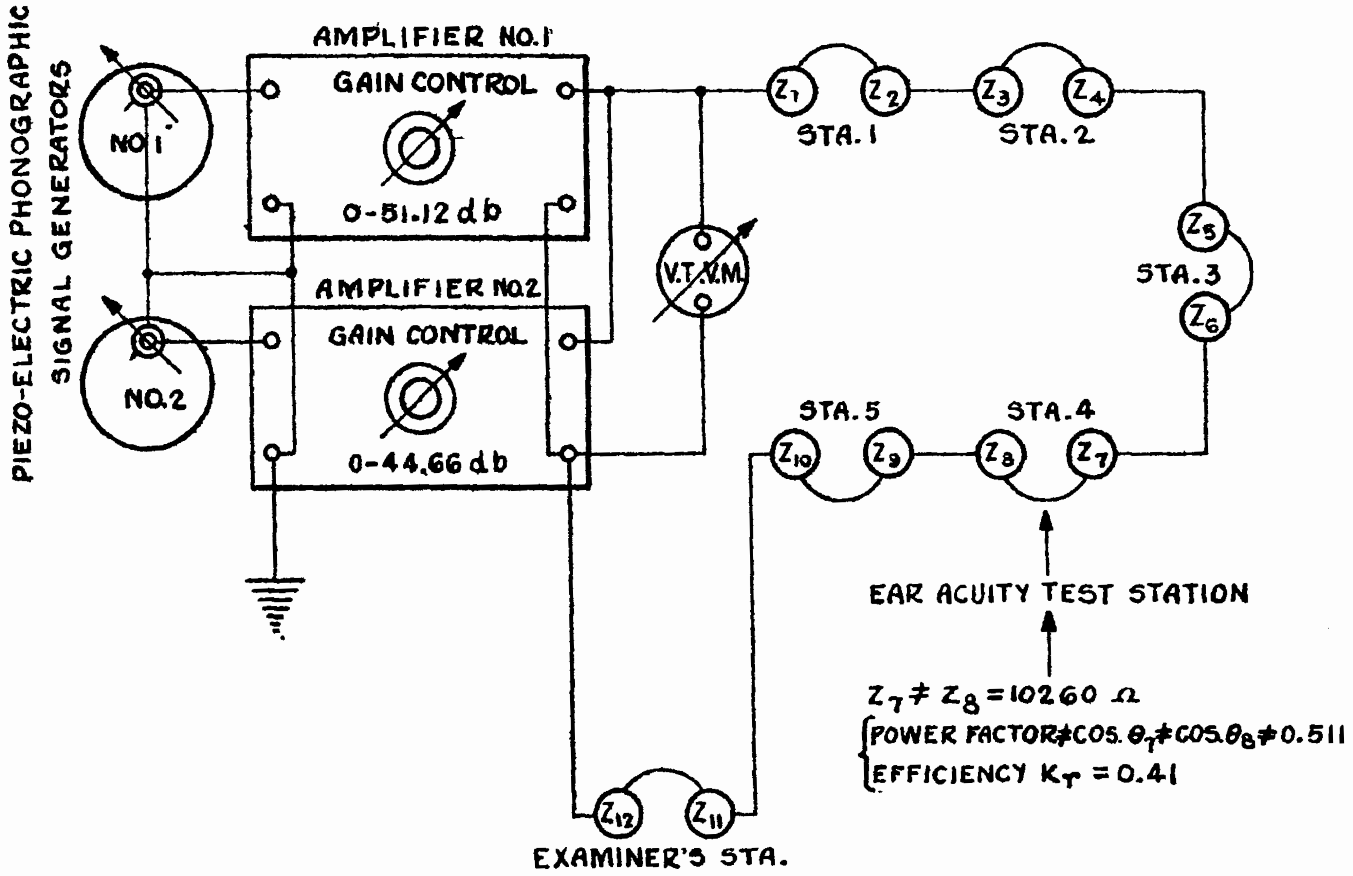

PLATE I

11. A damped telephone receiver was used for generating the pure tones. Connected to this receiver were two vacuum tube oscillators equipped with filters for eliminating any harmonics and with attenuators for supplying any magnitude of current. The attenuators were arranged so that by turning a dial the intensity level of the tone could be reduced very quickly from the maximum value to a value below the threshold. The intensity level for the threshold was determined both for the masked and the masking tones. The masking tone was then kept at a constant sensation level while the tones of other pitch were gradually increased in intensity until they were just perceptible in the presence of the masking tone. The level expressed in decibels that the masked tone was raised above its threshold value in the quiet is called the threshold shift.

The results of these measurements are shown in the curves of Fig. 86. The frequency of vibration of the masking tone is given by the number at the top of each chart and its sensation level by the number on each curve. The frequency of vibration of the masked tone is given by the abscissa and the threshold shift of the masked tone by the ordinate.

For example, in the fourth chart the masking effects of a tone having a frequency of 1200 cycles are shown. It is seen that the greatest masking effect is near 1200 cycles, which is the frequency of the masking tone. A tone of 1250 cycles must be raised to 46 db above the threshold to be perceived in the presence of a 1200-cycle tone which is 60 db above its threshold, or it must be raised to within 14 db of the masking tone before it is perceived. This corresponds to an intensity ratio between the tones of only 25. A tone of 3000 cycles, however, can be perceived in the presence of a 1200-cycle tone which is at 60 db when it is only 8 units above its threshold. This means that the intensity ratio between these two tones, under such circumstances, corresponds to 52 db or to a ratio of approximately 160,000 in intensity.

However, as the loudness of the masking tone is increased, all of the high tones must be increased to fairly large values before they can be heard. For example, the high frequencies

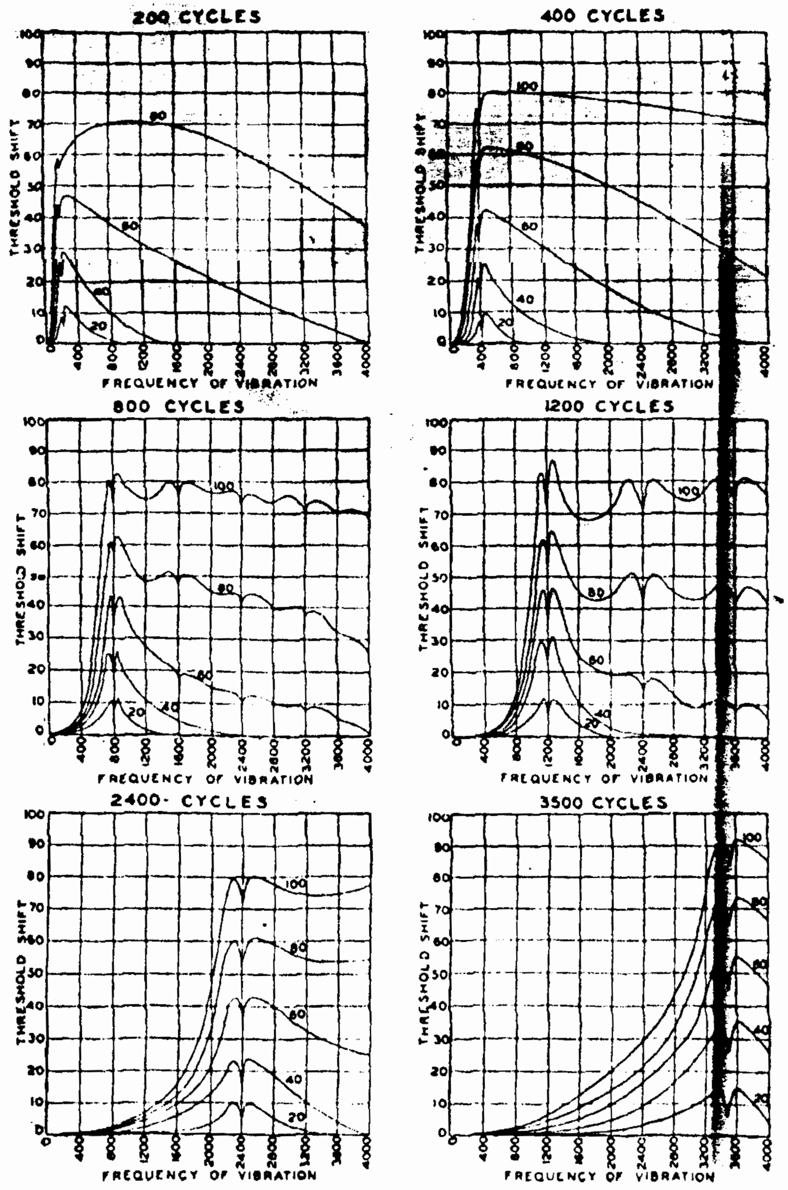

FIGURE 86.

PLATE 2A

must be raised 75 db above the threshold to be heard in the presence of a 1200-cycle tone having a sensation level of 100 db. But even for such large intensities for the masking tone, those frequencies below 300 are perceived by raising their loudness only slightly above the threshold value. It should be noticed that in all cases, those tones having frequencies near the masking frequency, whether they are higher or lower, are easily masked.

It is thus seen that Mayer's conclusion that a low-pitched sound completely obliterates higher pitched tones of considerable intensity and that higher pitched frequencies will never obliterate lower pitched tones is true only under certain circumstances. A low tone will not obliterate to any degree a high tone far removed in frequency, except when the former is raised to very high intensities. Also a tone of higher frequency can easily obliterate a tone of lower frequency if the frequencies of the two tones are near together. When the two tones are very close together in pitch, the presence of the masked tone is perceived by the beats it produces. This accounts for the sharp drop in the curves at these frequencies. A similar thing happens for those frequency regions corresponding to harmonics of the masking tone. In the charts for the 200- and 400-cycle masking tones these drops are not shown, inasmuch as they were small, but in an accurate picture they should be shown.

These results are plotted in a different way in Fig. 87. The abscissas represent the loudness of the masking tones, the frequency of which is indicated at the top of each of the charts. The amounts that the threshold of the masked tone is shifted are plotted as ordinates as in the previous figure.

For example, in the first chart the results are shown for a masking tone of 200 cycles. The curve marked 3000 indicates the masking effect of a 200-cycle tone upon a 3000-cycle tone. It is seen that the sensation level of the low-pitched tone can be raised to 55 db before it has any interfering effect upon the high-pitched tone. For higher levels than this it has a very marked effect.

PLATE 2B

It will be noticed that in nearly all of the charts the curves for different frequencies intersect. This leads to some rather interesting conclusions regarding the perception of a complex tone. If, for example, a complex tone had three frequencies of 400, 300, and 2000 cycles with levels of 50, 10, and 10, respectively, the ear would hear only the 400- and 2000-cycle

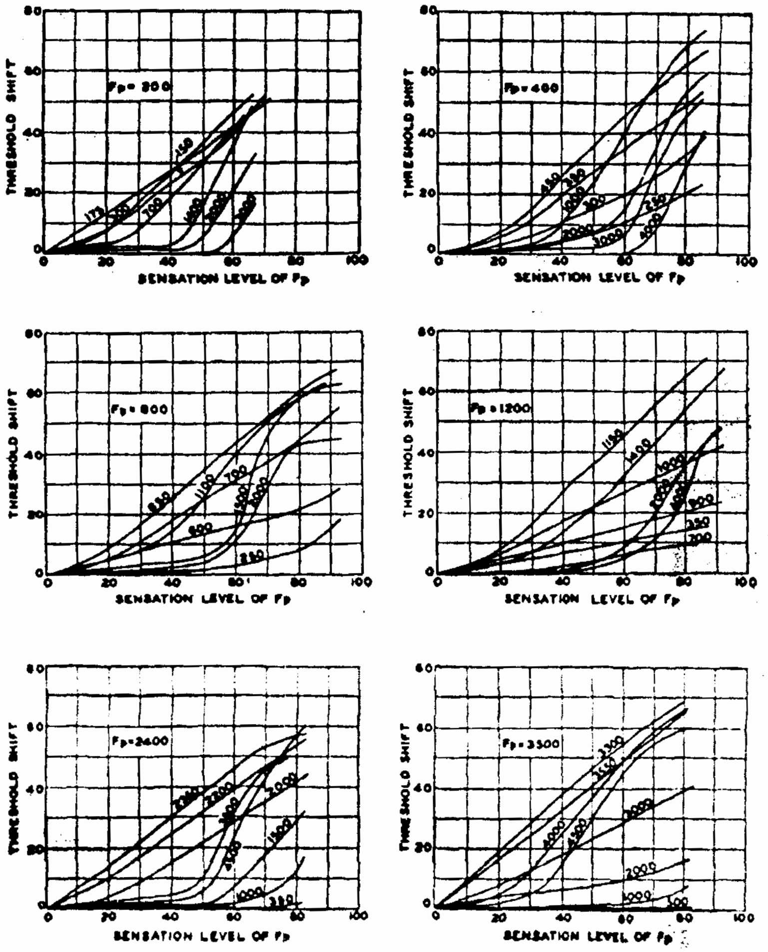

Fig. 87.—Monaural Masking.