RESEARCH DEPARTMENT

EXPERIMENTAL CORRELATION BETWEEN AURAL AND OBJECTIVE PARAMETERS OF ELECTRICAL NOISE.

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Drawings -
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to
G.040.14

EXPERIMENTAL CORRELATION BETWEEN AURAL AND OBJECTIVE PARAMETERS OF ELECTRICAL NOISE.

1. Introduction and Statement of the Problem.

Many types of electrical machinery cause radio interference because they make or break an electric current. The transient oscillation thus set up in neighbouring circuits may have Fourier components at audio and radio frequencies and these may be radiated or mains borne to audio or radio frequency receiving apparatus thus setting up a disturbance which, if the interference spectrum is uniform over the band of frequencies accepted by the receiver, is characterised mainly by the transmission properties of the receiver.

In order to suppress such interference it is necessary to decide subjectively how much of it is tolerable. The next step is to devise a measuring instrument capable of informing the engineer engaged in suppression of interference when he has accomplished his task. This measuring instrument should thus have such characteristics as will enable its assessment of interference to simulate that of the person for whom the transmission is arranged.

In the case of sound broadcasting it is the listener's ear which the interference measuring device must simulate. The ideal interference measuring set would thus consist of a typical receiver and loudspeaker and a human operator whose ear was tireless and never changing.

The tests to be described were undertaken with a view to ascertaining the law of variation of annoyance as the objective parameters of the interference were varied, and then the design or selection of a suitable measuring instrument.

In what follows the word loudness is invariably taken to mean the "amount" of interference in the absence of broadcast programme. The word annoyance, on the other hand, is taken to mean the "amount of disturbance" caused by the interference in the presence of programme.

The impulsive type of interference with which we shall deal usually manifests itself in the receiver output in the form of successions of damped wavetrains. The time interval between them is usually much greater than their duration because the receiver bandwidth is much greater than the frequency of interruption of the current in normal types of electrical machinery such as motor car ignition systems, electric motors, electric razors, thermostats, etc. It is thus convenient to idealise the interference into repeated Heaviside unit impulses. Such interference has only two parameters; the time integral, U, of its waveform and its recurrence frequency, P.R.F.

The output of impulsive noise from the receiver will be a function not only of U and P.R.F., but also of receiver modulation-frequency characteristic and any non-linear elements the receiver may contain. The shape of the receiver modulation-frequency characteristic has to conform to more stringent requirements than those which might be determined from impulsive interference considerations and may be taken as more or less uniform over its acceptance band. We may now summarize and say that the significant parameters of the output noise are first, the peak or maximum value proportional to U and to receiver bandwidth; secondly the duration of the noise phenomenon proportional to the reciprocal of receiver bandwidth, and thirdly the P.R.F. equal to that of the incoming interference. We have therefore to correlate annoyance with variation of each of those three parameters. The effect of peak on annoyance has been assumed a priori to be logarithmic so that we may start by measuring change of annoyance in decibels as units. This leaves bandwidth and P.R.F. as suitable variables.

2. Experimental Arrangements.

The experiments were based on a comparison between a standard noise and the noise whose parameters were varied. This method was chosen rather than working to an absolute value of annoyance because it was thought to be quicker; to restrict the "spread" or standard deviation of the listeners' results, and would require less explanation to and effort from the listener himself. Fig. 1 shews a block schematic of the method adopted. Fig. 2 is a photograph of the "listening room". By means of a P.O. Key the test listener could obtain any one of a number of noises, each adjustable in level by him, and compare them one at a time with the reference noise. The listener was allowed to adjust the level of reference noise at the start of the test provided that his adjustment brought it between the limits of "just perceptible" and "disturbing". Measured on a Tannoy Phon Meter type 800 these limits were 70 phons less 30 db and 70 phons less 60 db. The noise level of the "listening room" was about 70 phons less 34 db but this did not interfere with listening to noise levels lower than this, presumably due to spectrum difference between the test noises and the room background noise. The programme level was also set to the listeners' wishes and was invariably between 70 and 80 phons.

3. The Noises.

The programme used during annoyance tests was not specially selected but consisted of any one of the broadcast programmes existing at the time. It was conveyed to the listening room from the broadcast studio by land line and was thus in itself reasonably free from noise and amplitude or harmonic distortion.

The test noises were seventeen in number, excluding the reference noise. This consisted of random fluctuation noise in a band from 250 c/s. to 10 kc/s. The reason for the bass cut below 250 c/s. was that hum from source amplifiers at the input of the AF chain caused trouble which was cured by the insertion of a 250 c/s. high pass filter. Fig. 3a shews the spectrum. Noises one to eight were all restricted in spectrum to the band between 250 c/s. and 10 kc/s.

Noise one consisted of the output from a V.H.F. F.M. receiver with 50µS. de-emphasis due to the application to its input of unit impulses repeated at 100 p/s, Fig. 3b. The receiver was operated just below F.M/A.M. improvement threshold so that a small proportion of the output pulses had uniform rather than triangular spectra before de-emphasis, Fig. 3c. Fig. 4 is a photograph of these output pulses, some being more or less unidirectional (uniform spectrum) and others bi-directional (triangular spectrum). The amplitudes of successive output pulses have a random statistical distribution due to the random phase angles between each input pulse and a steady "wanted" carrier wave.

Noise two was the output from a V.H.F. A.M. receiver due to the same interference input as noise one. Its spectrum is shewn in Fig. 3d. Fig. 5 is a photograph of it.

Noise three was random fluctuations emerging from a V.H.F. F.M. receiver with 50 µS. de-emphasis. The spectrum is shewn in Fig. 3e.

Noise four was surface noise from a freshly cut cellulose recording disc. The disc was cut in the absence of modulation on the cutter.

Noise five was teleprinter "cross talk" obtained from a land line and recorded on a cellulose disc.

Noise six was 1000 c/s tone.

Noise seven was the same as noise one except that the P.R.F. was reduced from 100 p/s to 15 p/s.

Noise eight was the same as noise two but with a similar reduction of P.R.F.

Noises nine to seventeen were produced by feeding repeated unit impulses to a 30 c/s. to 5 kc/s. band pass filter. The reference noise also had this bandwidth when these noises were used. The test arrangement was improved so that the hum was eliminated and the 250 c/s. high pass filter was no longer needed. The upper cut-off frequency of 5 kc/s. was used in order to simulate conditions applying in the case of typical domestic broadcast receivers and also to be in close agreement with the bandwidth of a C.I.S.P.R. interference measuring set, BS727. The spectrum of noises nine to seventeen is shewn in Fig. 3f. A photograph of noise nine is shewn in Fig.6, These noises differed only in P.R.F. Table 1 gives the P.R.F. of each noise.

TABLE 1

Noise Number	P.R.F.
9	16 p/s
10	8
11	4
12	2
13	1
14	0.5
15	0.25
16	0.125
17	0.1

4. The Noise Meters.

One way in which the law of variation of annoyance with variation of the objective noise parameters may be brought to light is to employ a number of different noise meters, each one having a known behaviour with respect to noise parameter change. One might reasonably hope that one or more of the meters would closely follow the subjective results. This method was, in fact adopted. Some of the meters were preceded by aural weighting networks, these having been chosen experimentally by pilot tests not described. Table 2 gives the noise meter and weighting network combinations adopted. All noise meters were used in conjunction with preceding attenuators, the attenuation being so adjusted as to maintain constant meter reading.

TABLE 2

Noise Meter	Best Available Aural Weighting Network
a. B.B.C. Mean Square Meter.	C.C.I.F. Aural Network for Broadcast Circuits, Fig. 7.
b. G.P.O. Speech Voltmeter.	C.C.I.F. Aural Network for Broadcast Circuits.
c. B.B.C. Portable Noise Meter PNM/1	C.C.I.F. Aural Network for Broadcast Circuits. (This circuit is included inside the PNM/1)
d. V.U. Meter	7 kc/s. L.P. filter in cascade with A.S.A. weighting network Z 24.3-1944 curve B.
e. A.F. version of C.I.S.P.R. interference measuring set. Charge time:- 1 mS. Discharge times switchable:- 500 mS or 160 mS	5 kc/s. L.P. filter.
f. B.B.C. Peak Programme Meter PPM/6	New A.S.A. weighting network for Broadcast Circuits, Fig. 8.

Meter a. indicates the mean square value of any input waveform less the mean value (usually negligible or zero). This meter will read mean square values in a linear (undistorted) manner for all waveforms having crest factors not greater than 40 db.

Meter b. is similar to meter a. but is not linear for waveforms having crest factors much above 14 db.

Meter d. indicates the full-wave rectified mean value of a waveform applied to it.

Meters c., e., and f. are all based upon the same principle, namely charging a condenser through one resistor and discharging it through another. They are completely defined by the charge and discharge time constants if the waveform being measured is repeated with sufficient frequency for the indicating instrument needle to give a steady reading. This can always be assured by making both time constants large enough, and this will not effect the behaviour of the meter to varying P.R.F. These meters give characteristic curves of response against P.R.F. or bandwidth (determining pulse height and width). Both these characteristic curves are unaltered if the ratio of discharge to charge times is kept constant; but they are altered if this ratio is changed. The alteration in response characteristic against P.R.F. for a multiplication of the ratio by a number N is a translation 1/N along the P.R.F. axis, Figs. 9 and 10. The actual shape of the response against P.R.F. characteristic is constant whatever the charge or discharge times and is due to the manner in which a condenser charges and discharges. A very important practical remark results from the foregoing. It is that if a certain discharge to charge ratio is found to simulate the aural annoyance against P.R.F. over a certain range of the latter, then perfectly steady meter needle readings may be obtained, however low the P.R.F., by multiplying both charge and discharge times by a sufficiently big number. The above remarks have only been confirmed experimentally for discharge to charge time ratios greater than 10 and for values of P.R.F. less than a fifth of the circuit cut-off frequencies. These conditions are, however, eminently practical.

The significant characteristics of the meters for noise measurements are thus as given in table 3.

TABLE 3

Noise Meter	Characteristics
e	Charge time 1 mS Discharge time 160 mS or 500 mS
c	Charge time 150 mS Discharge time 1500 mS
f	Charge time 1.5 mS Discharge time 1000 mS

5. The Experiments

5.1. Annoyance and Loudness as Functions of Receiver Bandwidth. (Random Amplitude Pulses)

Impulsive interference repeated at 100 p/s was fed to a V.H.F. A.M. receiver of overall bandwidth $\pm$ (30 c/s to 25 kc/s). An unmodulated carrier was also present. The output was passed to a loudspeaker (B.T.H. Senior R.K. with internal spider. An Altec-Lansing speaker was also tried but did not alter the laws of annoyance and loudness variation) through a de-emphasis circuit of variable time constant. Programme was fed directly to the loudspeaker from a land line. The test listener was asked to equalise by means of a calibrated attenuator the annoyance and loudness of the random amplitude output pulses emerging from the different bandwidths to that from the narrowest of them. No meter was used. The results are shewn in Fig. 11.

5.2. Annoyance as a Function of P.R.F. (Random Amplitude Pulses)

This experiment was similar to the previous one except that the bandwidth was fixed at 30 c/s. to 5 kc/s, and the P.R.F. was varied. The test listener was asked to equalise again, with a calibrated attenuator, the annoyance at each P.R.F. to that obtaining when the P.R.F. was 30 p/s. The results are shewn in Fig. 12.

5.3. Annoyance as a Function of P.R.F. (Constant Amplitude Pulses).

The noises used for this test had spectra as shewn in Fig. 3f. The test listener was asked to equalise with a calibrated attenuator the annoyance of pulses at a given P.R.F. to that obtaining for a P.R.F. one octave lower. The results are shewn in Fig. 9 as ⊡. The results of six listeners were all within ± 5 db. Again no meter was used but the results are placed upon the response characteristic of meter a. at 10 p/s.

5.4. Annoyance and Loudness as Read on Different Noise Meters.

The noises used for this test were those numbered one to eight. The test listener was asked to equate annoyance and loudness to that caused by the reference noise. When the test listener had equated these properties of the noises to one another and to the reference noise, the results were measured on meters a. to f. Tables 4, 5 and 6 summarize the results.

TABLE 4 Loudness

Noise	1	2	3	4	5	6	7	8
No. of observations	18	18	28	19	19	18	9	9
Average of readings of meter a. in decibels	2.81	.805	-.125	-.105	1.6	16.6	7.71	5.83
Standard deviation in db.	4.71	2.19	.893	2.23	3.64	6.16	3.07	2.6

TABLE 5 Annoyance

Noise	1	2	3	4	5	6	7	8
No. of observations	28	28	43	27	26	25	14	14
Average readings of meter a. in decibels	-.518	-1.79	-.221	1.89	-.269	14.8	1.64	.428
Standard deviation in db.	3.07	2.74	1.07	2.87	4.84	6.67	2.9	2.32

TABLE 6 Loudness and Annoyance

Noise	1	2	3	4	5	6	7	8
No. of observations	46	46	71	46	45	44	23	23
Average readings of meter a. in decibels	.32	-.77	-.18	1.06	.523	15.2	4.03	2.54
Standard deviation in db.	4.17	2.84	.997	2.8	4.47	6.8	4.18	3.6

Of 40 people only 3 were rejected as giving results very far from the average. 6 of the listeners were women and 30 were radio engineers. The people giving most consistent results were the least familiar with acoustic and engineering problems. Engineers with most acoustic experience gave the least consistent results. Fig.13 shews the average change in meter readings between reference noise and each of the eight noises. Fig. 14 shews statistical frequency distributions of the test listeners' results on the various meters. Meter a. appears to be the most promising. This would seem to indicate that Ohm's Law of Hearing (D. Gabor, New Possibilities in Speech Transmission, J.I.E.E., Vol. 94, Part III No. 32, November 1947) applies with adequate accuracy to wide spectrum type noises; that is, the ear is insensitive to small changes of phase. It is interesting to note, in this connection, that there is very little aural difference between random amplitude pulses repeated at a sufficient rate for the individual clicks to have merged into a continuous sound and random fluctuation noise. The two energy spectra can be identical, the only difference being that all pulses are in phase at zero time whilst random fluctuation noise may be regarded as pulses having a random statistical phase distribution. There is a difference in sound (that between frying and hissing) but it is not great.

5.5. Variation of Difference in Annoyance between Random and Constant Amplitude Pulses as a Function of P.R.F.

Noises of the type nine to twelve were used on the one hand with random amplitudes, and on the other as reference noises with constant amplitudes. The test listener was asked to adjust the level of the random amplitude noise such that it caused the same annoyance as that produced by the same type of noise except that the amplitudes of successive pulses were constant. Table 7 summarizes the results of readings of meter a. upon the subjectively adjusted noises.

TABLE 7 Annoyance

Noise	9	10	11	12
No. of observations	14	18	9	8
Average readings of meter a. in decibels	.822	-.194	.778	0
Standard Deviation in db.	1.85	1.08	2.2	1.5

The meter was first "set up" on constant amplitude pulses. The average change of meter reading when connected to the output of random amplitude pulses is shewn in the Table. As in 5.4 we note that meter a. gives readings quite close to the subjective results.

5.6 Annoyance as a Function of P.R.F. (Constant Amplitude Pulses of Very Low P.R.F.)

This test is a variation and extension of test 5.3. Instead of comparing annoyance at one P.R.F. with that caused by pulses repeated at a frequency an octave lower, the annoyance of the constant amplitude pulses was compared with that of random fluctuation reference noise. The results are given in Table 8.

TABLE 8 Annoyance

Noise	9	10	11	12	13	14	15	16	17
No. of observations	10	12	14	17	18	18	17	18	8
Average readings of meter a. in decibels	.625	.25	-.054	1.22	4.33	7.06	5.93	7.25	7.23
Standard deviation in db.	2.2	1.99	2.89	2.78	4.56	6.12	8.73	7.27	7.05

These figures are also plotted in Fig. 9 as I. They are plotted in such manner as to shew the average test listener's ear in the form of a noise meter. Thus, for example, at a P.R.F. of 1 p/s. the M.S. meter a. would read 4 1/3 db higher than the human noise meter, whilst the C.I.S.P.R. meter with a discharge time of 160 mS. reads 5 db lower than it. The V.U. meter d. reads 27 db lower and the C.I.S.P.R. meter with 500 mS. discharge time reads 5 1/3 db higher than it. It may be seen from Fig. 9 that at P.R.F. below about 2 p/s. the rate of fall-off of annoyance with decrease in P.R.F. appears to increase from 3 db per octave to about 6 db per octave. This would seem to shew that the ear can store energy for about a half second but not longer. It should be stated that for P.R.F. lower than 1 or 2 p/s. none of the meters used could cope with the crest factors of the impulsive waveforms present. The method adopted was to increase the P.R.F. from that listened to by the test subject to a value of 2 p/s, allowing an increase of 3 db per octave increase of P.R.F. on meter a.

5.7. Measurement of Programme to Noise Ratios.

It seems from the foregoing that at least for the types of noises used in this series of experiments a M.S. meter indicates annoyance adequately. Thus two major experiments remain to be done. First, is it possible to measure programme loudness with a M.S. meter? If it is, secondly, measure programme to noise ratios which have been subjectively adjusted to fit certain designations.

The method adopted for the measurement and comparison of programme to noise ratios consisted in the adjustment of a speech programme to have the same loudness as a music programme, both in the presence of a random fluctuation noise background. The signal to noise ratios were then measured with meters a. and f., each measurement being done in a manner suitable to the particular instrument in use. Table 9 shews that for the three test listeners used, the M.S. meter a. gives a more constant reading of signal to noise ratio than does the peak programme meter f.

TABLE 9

	Average RMS Signal to Noise Ratio	Maximum Deviation from Average (RMS)	Average PPM Signal to Noise Ratio	Maximum Deviation from Average (PPM)
Speech	30.3 db	1.7 db	32.3 db	1.7 db
Music	30	0	26.6	-.6

5.8. Designated Programme to Noise Ratios.

Programme was adjusted to a level of 75 phons in the absence of noise. Random fluctuation noise was then switched on and each of four test listeners was asked in turn to adjust the noise level to the description given in the first column of Table 10, below.

TABLE 10

Noise level Designation	Average RMS Programme to Noise Ratio	Maximum Deviation from Average
Just perceptible	60.6 db.	3 db.
Perceptible	50	0
Slightly disturbing	42	2
Disturbing	31	1

During these tests the listener could switch programme on and off at will for cross checking purposes. Meter a. was used in this test.

5.9. Effect of Noise Level on Comparison of Annoyance of Different Types of Noise.

Test listeners were asked to adjust the levels of noises one to six so as to equate the annoyance to that caused by the random fluctuation reference noise. This experiment was undertaken for two values of the reference noise level, those corresponding with "slightly disturbing" and "disturbing". Table 11 shews the average change (taken as positive decibels for an increase) of meter readings when the reference noise was changed from "disturbing" to "slightly disturbing".

TABLE 11 Annoyance

Noise	1	2	3	4	5	6
No. of Observations	6	6	6	6	6	6
Average increase in meter reading in db when noise level decreased by 10 db	5.5	2.9	.17	2.4	8.3	-.42
Standard Deviation in db	4.86	4.58	1.07	4.77	9.00	6.56

This table would seem to indicate that the relative annoyance of impulsive noise (principally noises one, two and five) vis à vis random fluctuation noise decreased slightly with decrease in level or increase in signal to noise ratio. The standard deviations are rather large, however, so that broadly speaking one may say that for reasonably good signal to noise ratios the change in listening criterion resulted in changes of annoyance considerably less than the actual change in level. This ceases to be true for very poor signal to noise ratios. Meter c. was used in this test.

5.10. Effect of Noise Level on Comparison of Loudness of Different Types of Noise.

This experiment differed from the previous one only in that programme was not used, and that a 20 db change in reference noise level was used instead of a 10 db change. The noise levels used were 70 phons less 30 db and 70 phons less 50 db. Table 12 shews virtually no change in the relative loudness of impulsive noise vis à vis random fluctuation noise.

TABLE 12 Loudness

	Noise	1	2	3
No. of Observations		4	4	4
Average increase in meter reading in db when noise level decreased by 20 db		.63	.25	0
Standard deviation in db		1.08	2.28	1.37

6. Conclusions

The subjective effects of typical types of electrical interference have been studied, and a meter suitable for their measurement has been designed. The present meter, the M.S. meter a., is however not suitable for P.R.F. below 1 p/s emerging from a C.C.I.F. aural network because the crest factor of such pulses would exceed 40 db and the meter would depart from true M.S. readings. It is further evident from Fig. 9 that a rate of fall of annoyance per octave decrease in P.R.F. of 6 db is required for values of P.R.F. below about 2 p/s. This characteristic, could be arranged as follows: a meter of the type a. with improved crest factor characteristic followed by a de-emphasis circuit of time constant about half a second (to take the average of the noise waveform over a half second interval) followed by a "square rooting" device to the output of which would be connected a D.C. indicating instrument of time constant somewhat longer than the reciprocal of the lowest P.R.F. likely to be encountered in practice. Such a device should follow the 3 db per octave law down to a P.R.F. of about 2 p/s and then change gradually to a 6 db per octave law.

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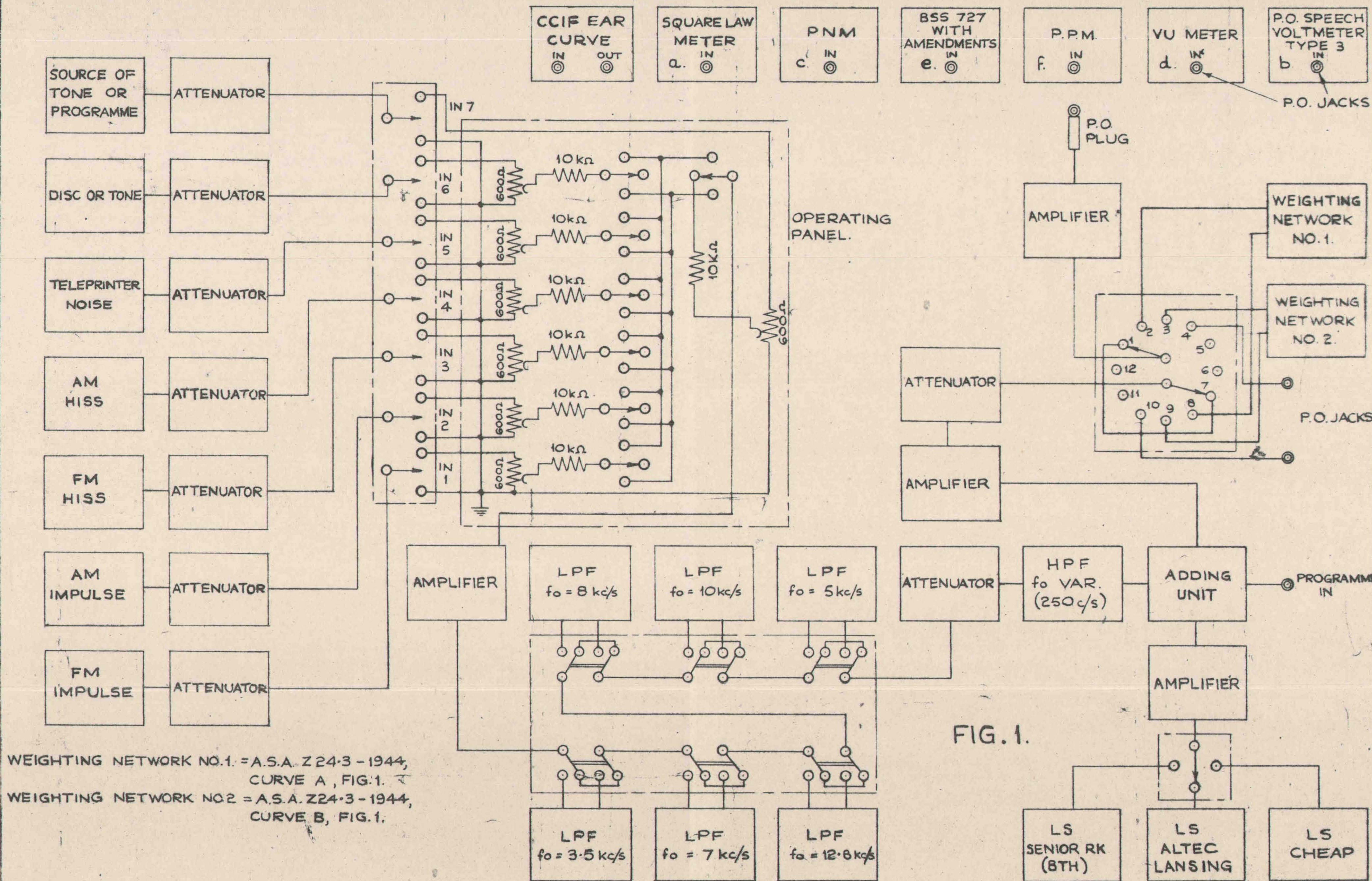

FIG. 1.

WEIGHTING NETWORK NO.1. = A.S.A. Z24·3 - 1944, CURVE A, FIG.1.

WEIGHTING NETWORK NO.2 = A.S.A. Z24·3 - 1944, CURVE B, FIG.1.

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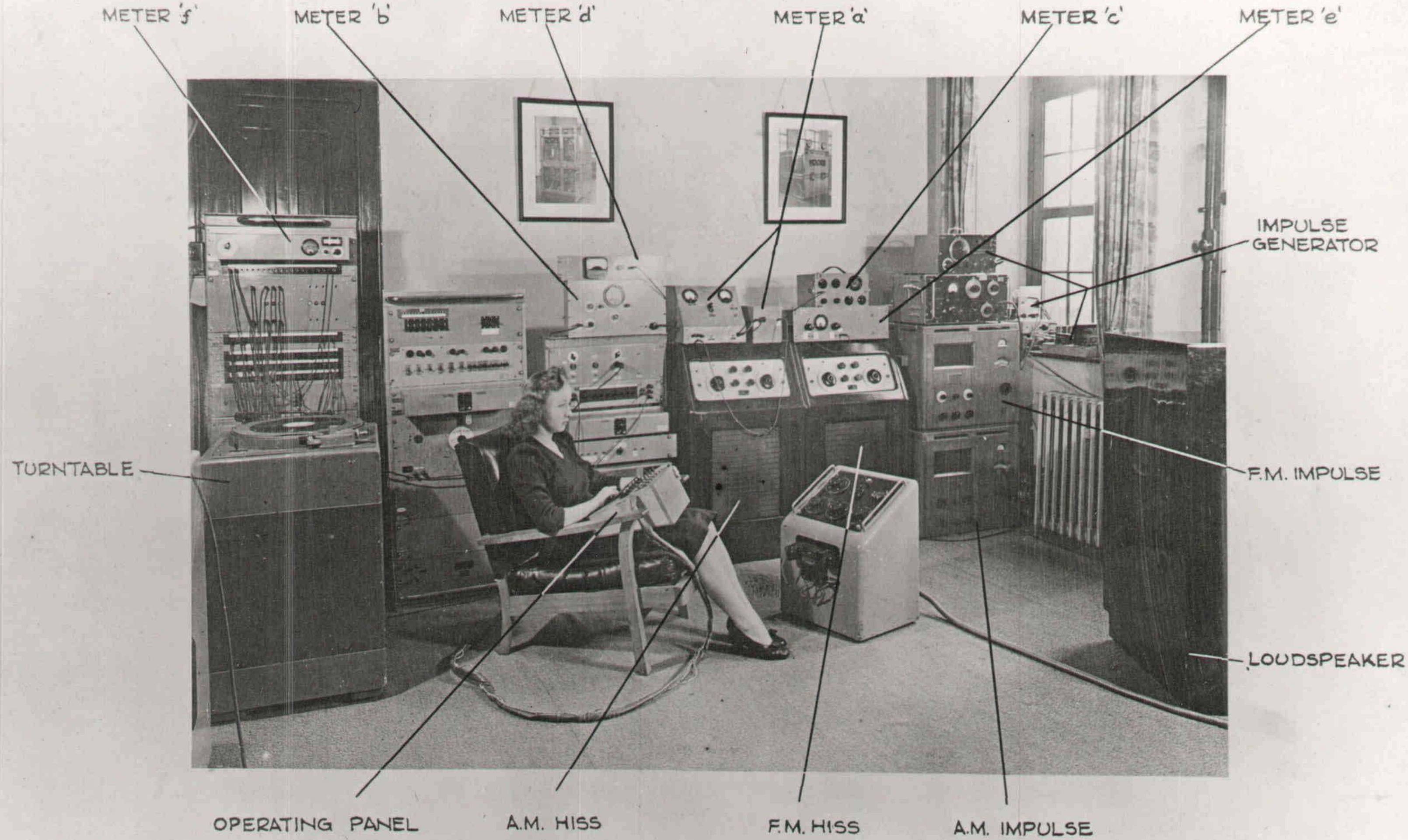

FIG. 2

THE LISTENING ROOM.

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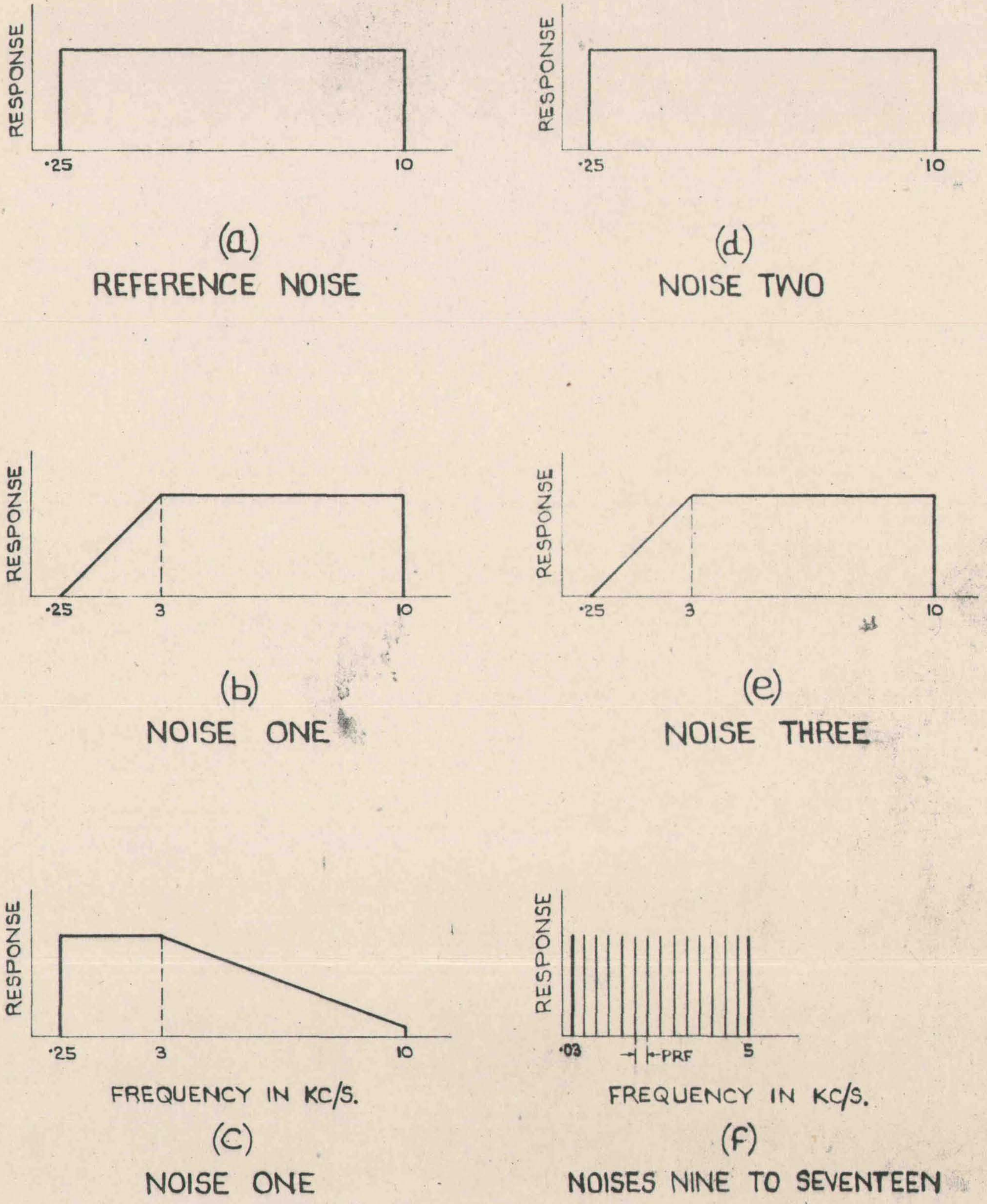

FIG. 3.

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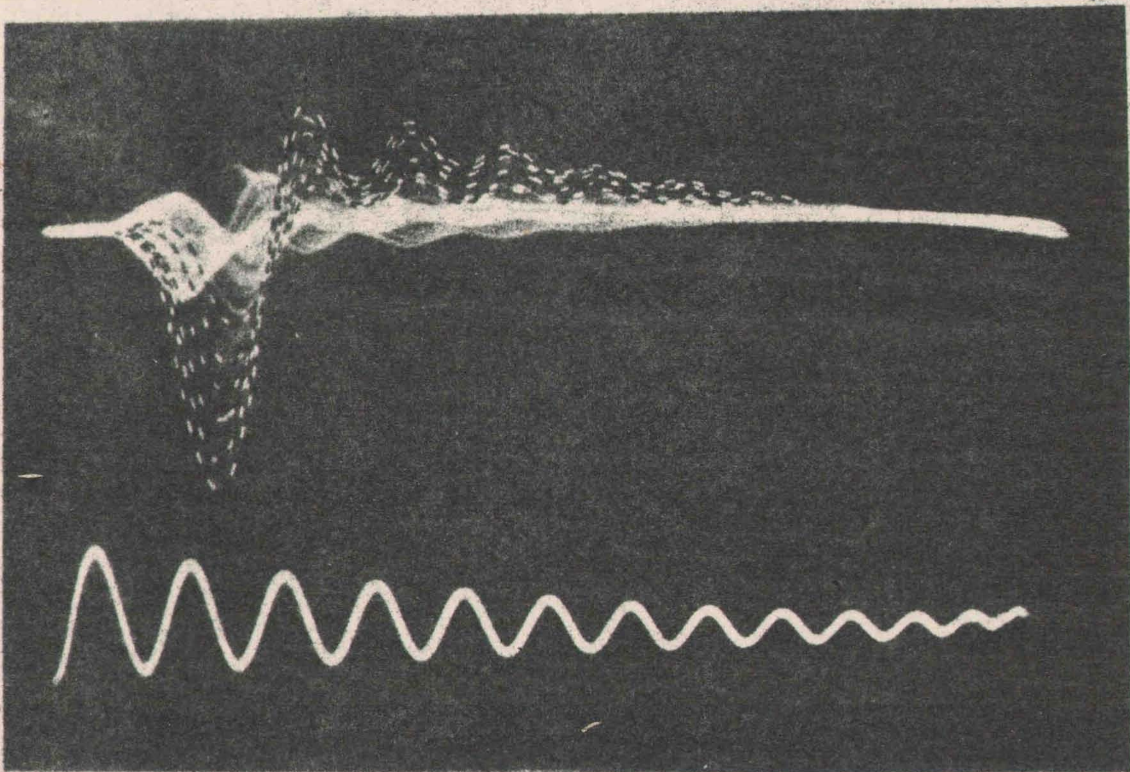

FIG. 4.

NOISE ONE. DOTTED PULSES ARE 'POPS' DUE TO OPERATION OF F.M. RECEIVER JUST BELOW IMPROVEMENT THRESHOLD. UNTOUCHED PULSES ARE 'CLICKS' TYPICAL OF F.M. RECEPTION. AMPLITUDES OF SUCCESSIVE PULSES ARE RANDOM WITH TIME DUE TO PRESENCE OF A CARRIER. 10 kc/s. TIMING WAVE SHEWN BELOW.

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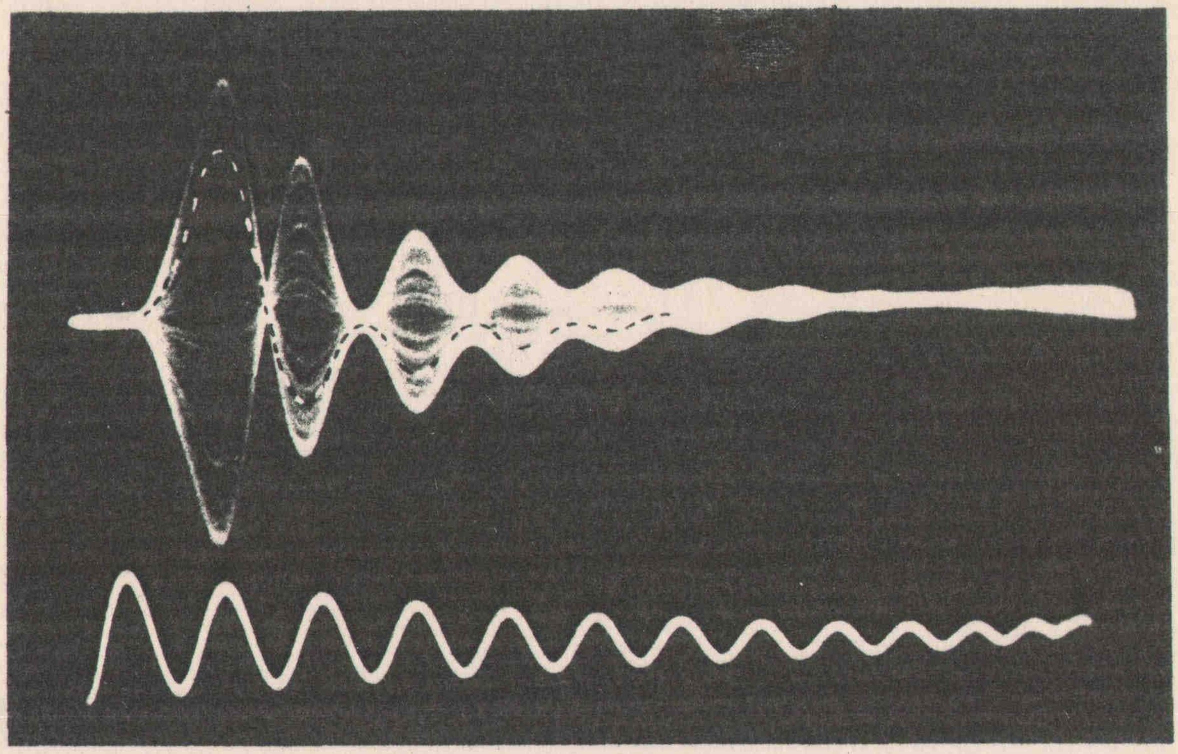

FIG.5.

NOISE TWO. TYPICAL IMPULSIVE INTERFERENCE OUTPUT FROM A.M. RECEIVER. AMPLITUDES OF SUCCESSIVE PULSES ARE RANDOM WITH TIME DUE TO PRESENCE OF A CARRIER. 10 kc/s. TIMING WAVE SHEWN BELOW.
ONE WAVETRAIN DOTTED FOR CLARIFICATION.

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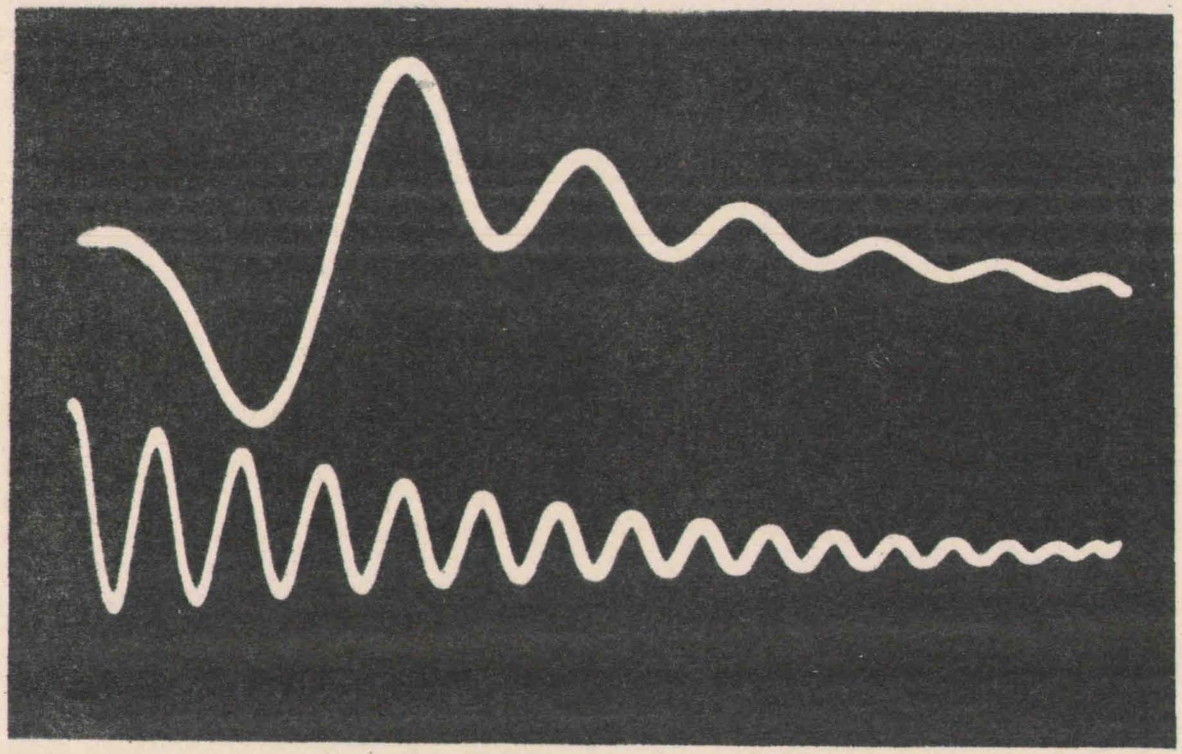

FIG. 6

NOISE NINE. IMPULSE RESPONSE OF 30 c/s. TO 5 kc/s. BAND PASS FILTER WITH 10 kc/s. TIMING WAVE BELOW.

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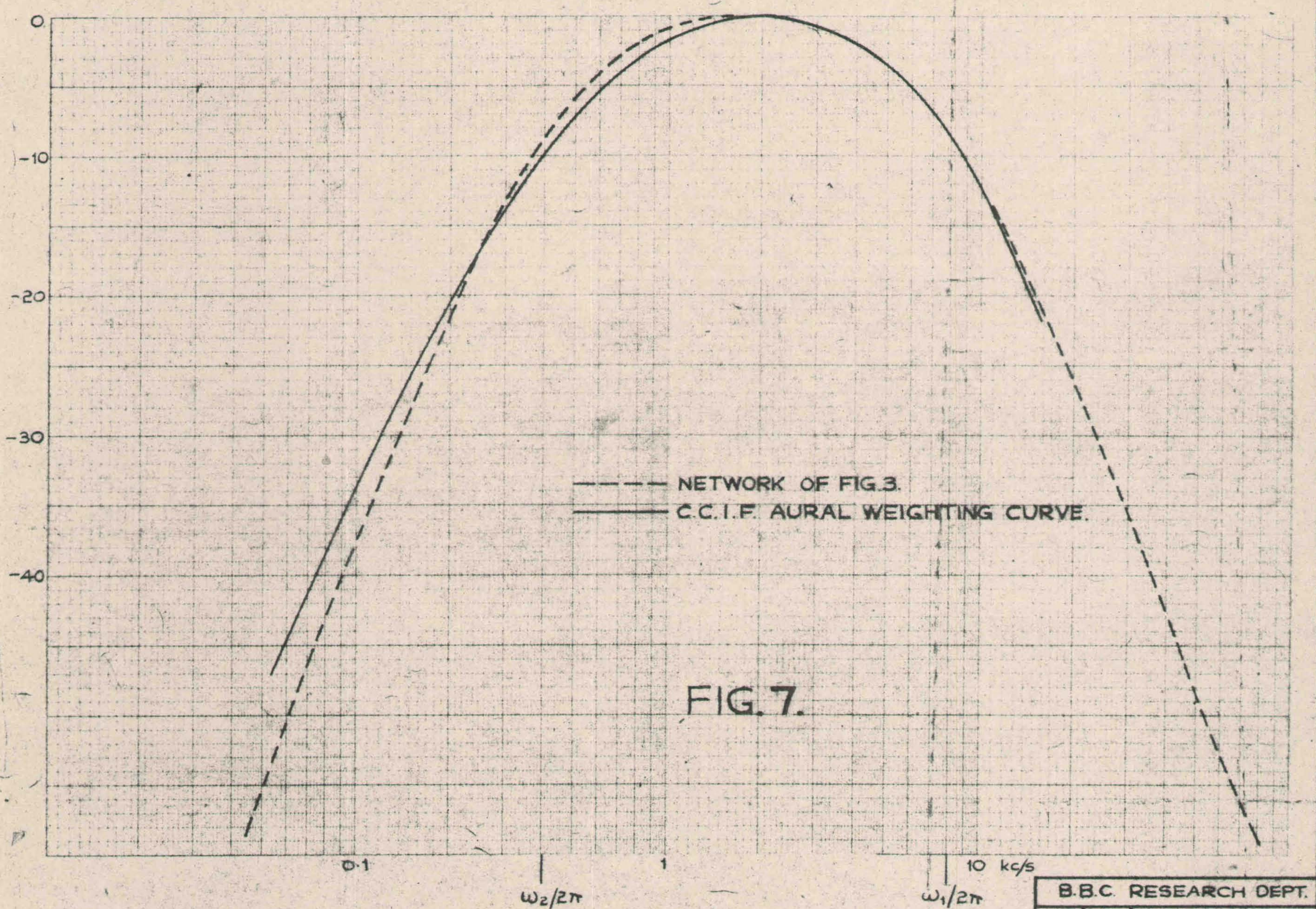

FIG. 7.

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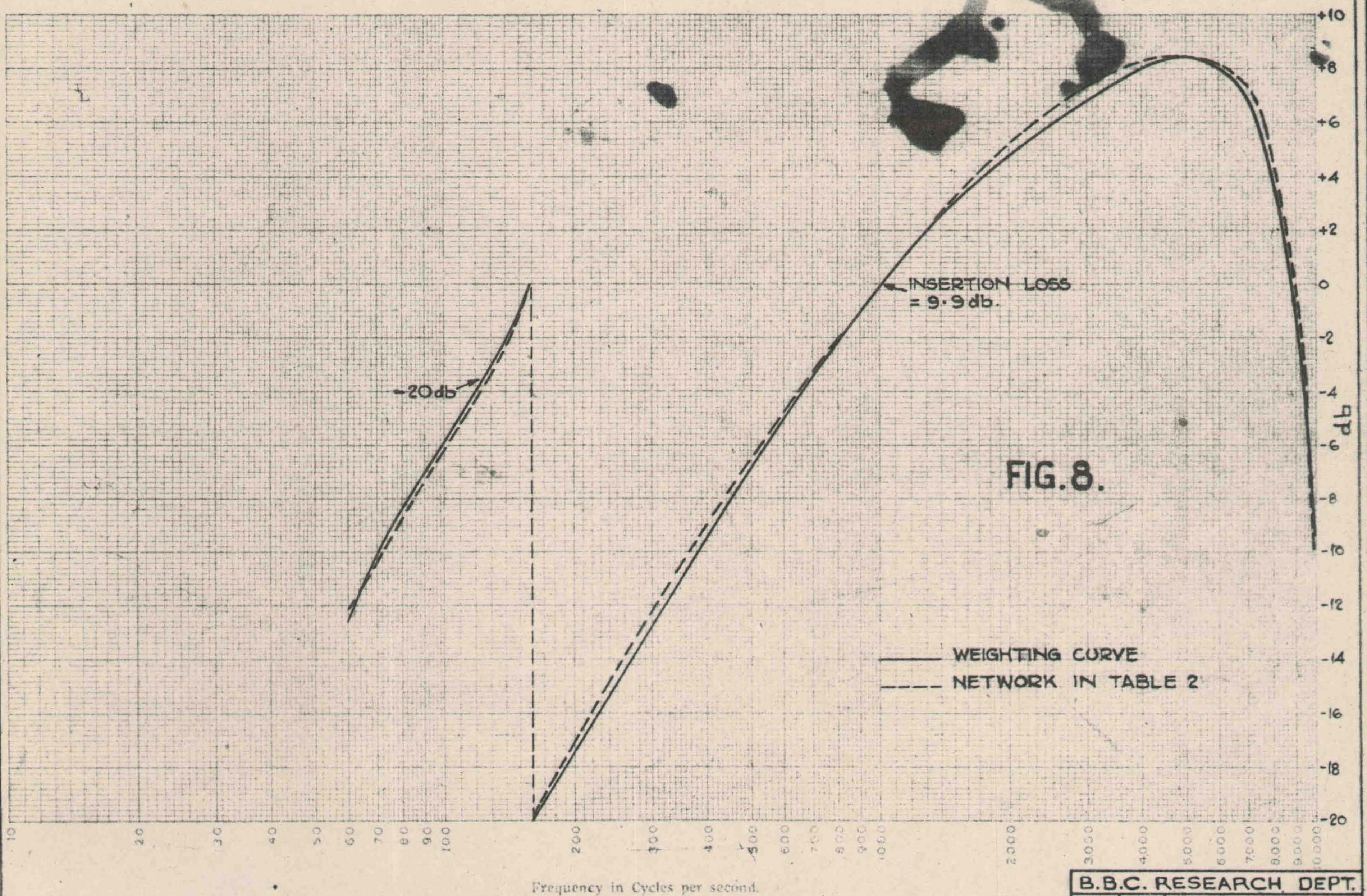

FIG. 8.

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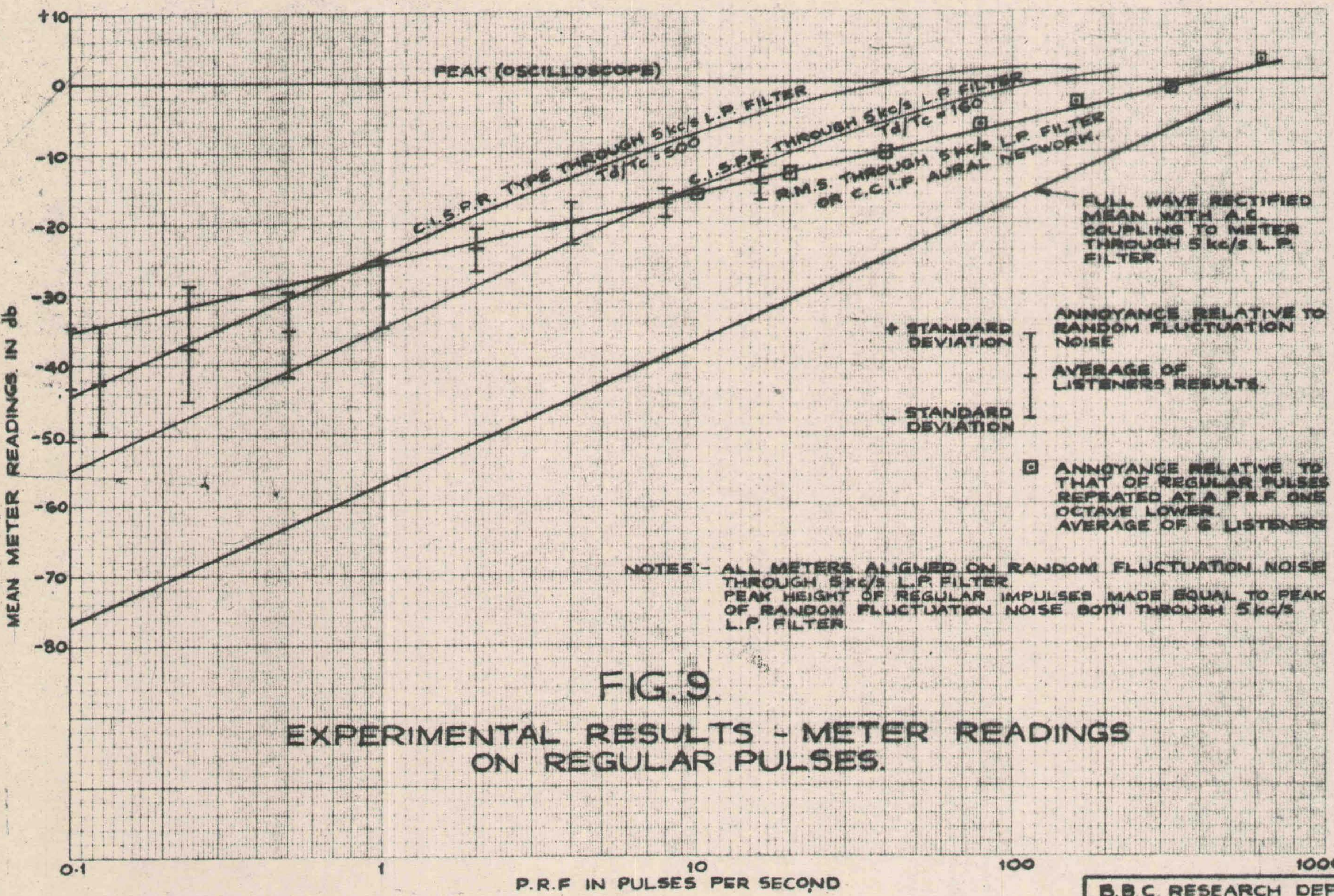

FIG. 9.

EXPERIMENTAL RESULTS - METER READINGS ON REGULAR PULSES.

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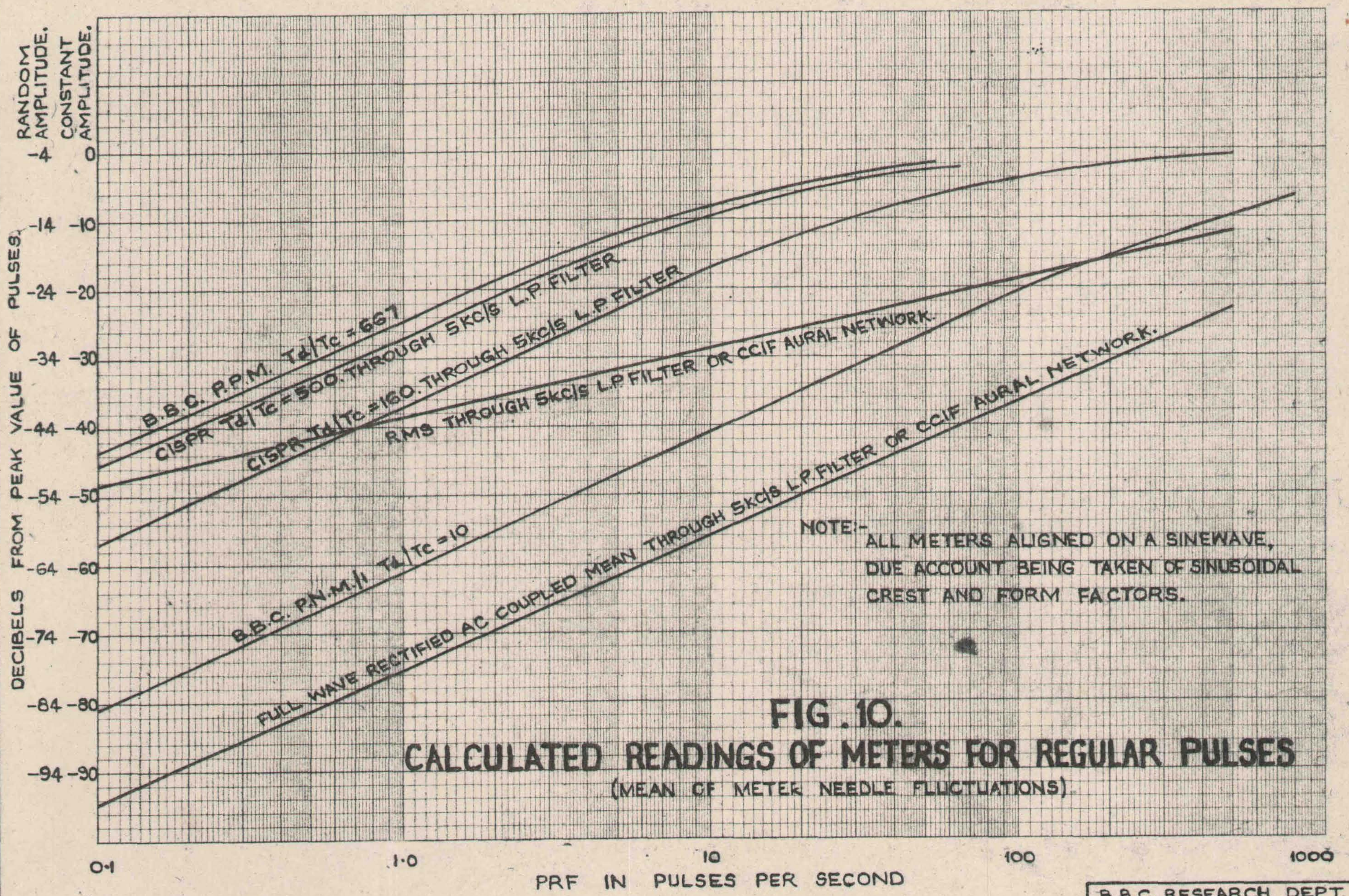

FIG. 10.
CALCULATED READINGS OF METERS FOR REGULAR PULSES
(MEAN OF METER NEEDLE FLUCTUATIONS)

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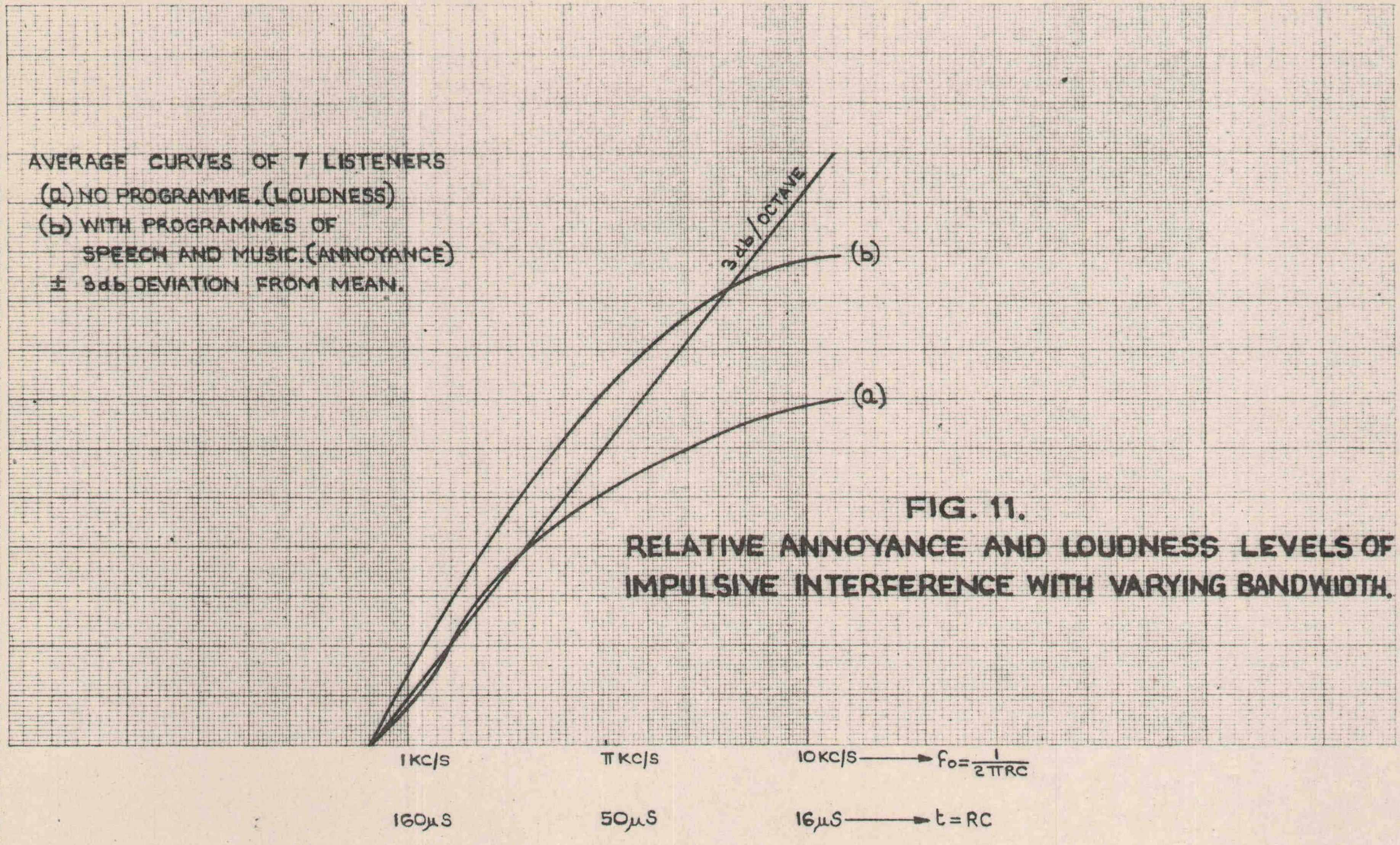

FIG. 11.

RELATIVE ANNOYANCE AND LOUDNESS LEVELS OF IMPULSIVE INTERFERENCE WITH VARYING BANDWIDTH.

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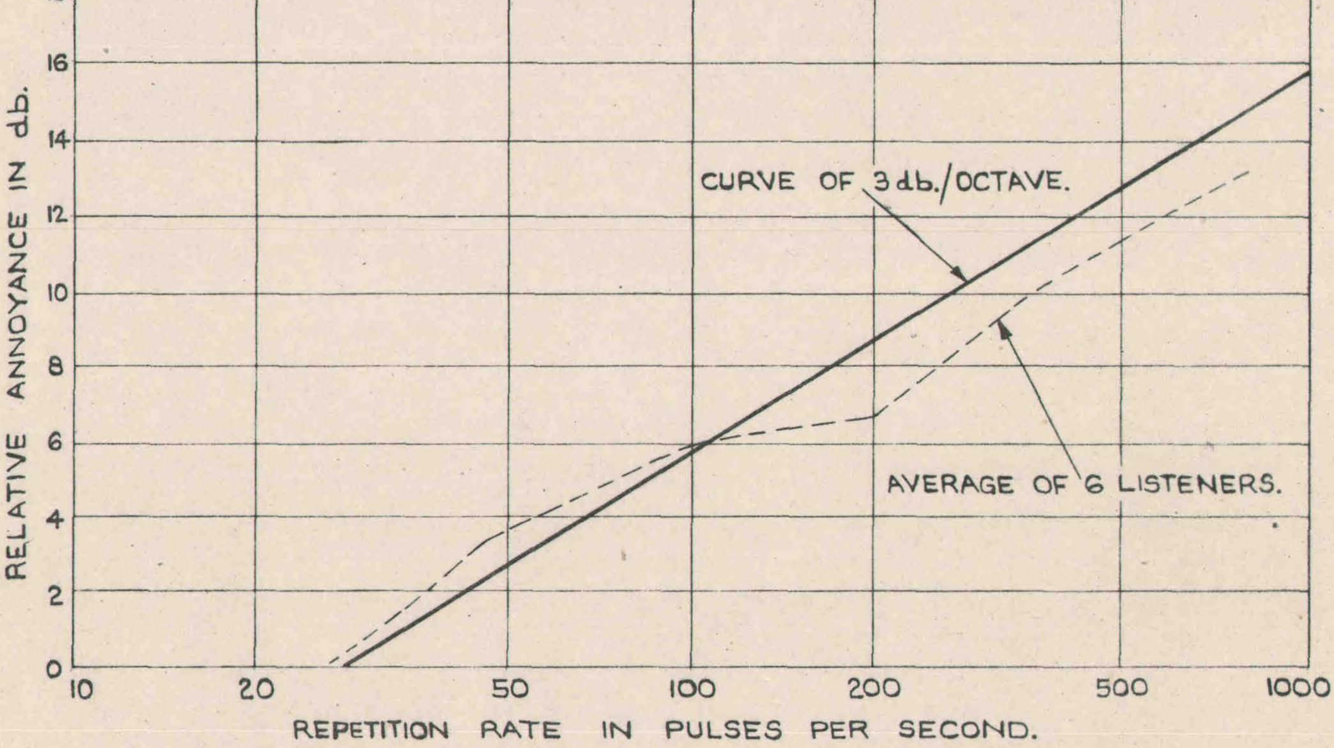

FIG.12.

RELATIVE ANNOYANCE OF IMPULSIVE INTERFERENCE OF RANDOM AMPLITUDE.

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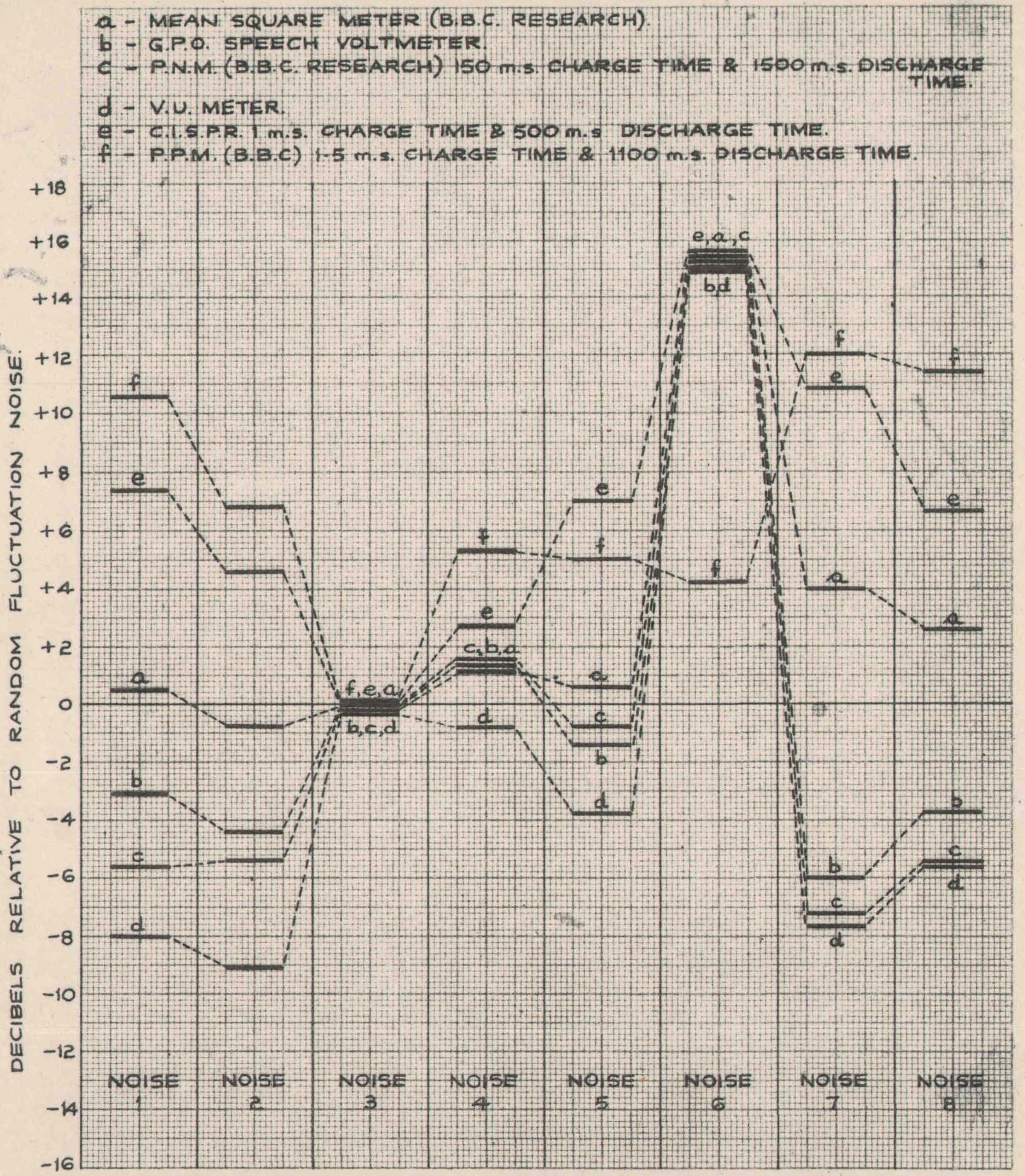

ALL METERS ALIGNED ON RANDOM FLUCTUATION NOISE.

FIG. 13.

EXPERIMENTAL RESULTS. AVERAGE READINGS FOR EACH NOISE.

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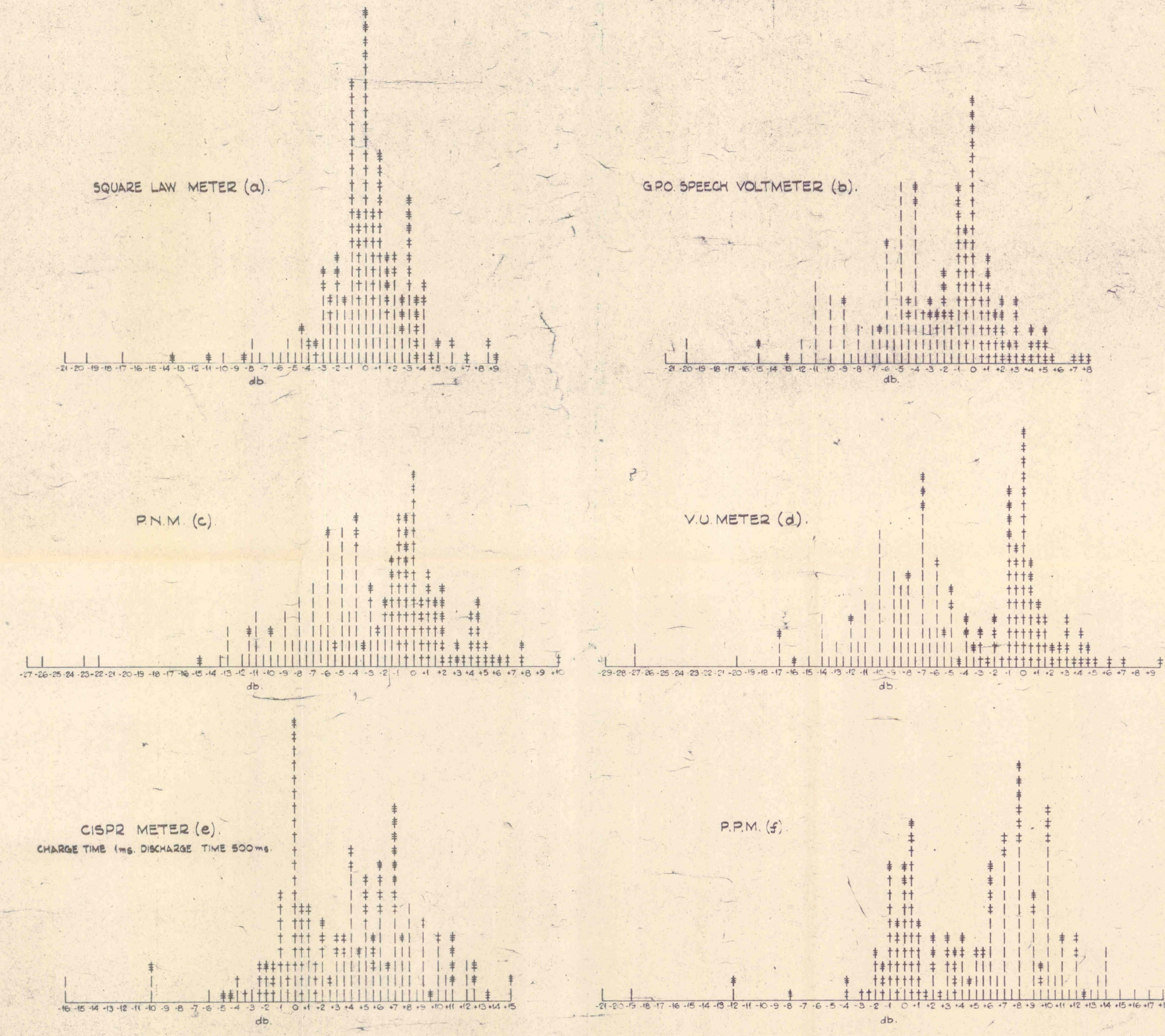

FIG. 14.
COMPARISON OF METERS (ANNOYANCE).

IMPULSIVE | NOISES 1,2,7 & 8
FM HISS † NOISE 3
DISC ‡ NOISE 4
TELEPRINTER ǂ NOISE 5

BBC

NOISE COMPARISONS

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