The Effect of Frequency Tolerance on Audiometer Accuracy

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SUMMARY

Investigations into the methods used to calibrate audiometers reveal that the 6 000 Hz frequency is particularly liable to yield inconsistent results when calibrated in the usual way. It is shown that the TDH39 telephone receiver which is usually calibrated on a 9A coupler in accordance with the International Standards Organization recommendation R389 will depend to a considerable extent on the precise frequency used and may differ by as much as 7 db when the frequency is varied but still retained within the specified tolerance limits.

A new telephone receiver, the TDH50, is much less sensitive to frequency variation. It is shown that this receiver should be calibrated with the same threshold figures as the TDH39.

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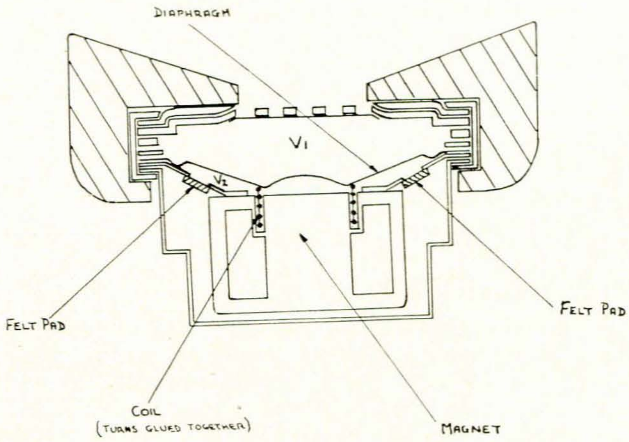

Fig. 1. A TDH39 receiver.

Hearing and hearing loss are assessed by means of an audiometer. Such an instrument consists essentially of a generator, an amplifier, an attenuator and a transducer which is designed to present the sound to the subject being tested. The transducer can be either a loudspeaker, in which case the sound is presented in a free field, or it can be a telephone receiver. The latter is usually used for diagnostic purposes because it can distinguish between the two ears, which the free-field audiometer cannot do to the same extent.

The calibration of a free-field audiometer presents no great difficulty because it is easy to measure the sound intensity at a particular spot with a calibrated microphone. The presentation of sounds through a telephone receiver, however, raises considerable problems. Sounds from a telephone receiver are not necessarily judged in the same way as sounds in a free field.[1] Also, when the receiver is placed upon the ear it produces a sound pressure on the tympanic membrane which depends not only upon the volume enclosed by the receiver but also on positioning, pressure and other factors.

THE TELEPHONE RECEIVER AS A SOURCE OF SOUND

Fig. 1 shows the cross-section of a typical moving coil telephone receiver (TDH39) as used in an audiometer. The basic problem is to relate the voltage applied to the moving coil of the receiver to the threshold of hearing of a normal person at the test frequencies.

In order to simplify comparisons between various receivers a number of artificial ears have been described and standardized. These are compared in a recommendation issued by the International Standards Organization referred to as ISO R389. In this recommendation a number of receivers are compared on the 9A coupler and recommended values of normal hearing threshold are given for these receivers when calibrated on that coupler.

Fig. 2 shows the equivalent circuit diagram for the TDH39 receiver simplified to bring out the elements mainly responsible for its behaviour at the frequencies used in audiometry. The following 3 main resonance frequencies are caused by the interaction of the inertances with various capacitances (volumes):

1. The resonance caused by the inertance of the diaphragm in series with the capacitances V_1 and V_2 frequency of resonance of about 3 500 Hz. Because the acoustic capacitance is equal to $\frac{V}{\rho c}$ this point of resonance will depend to some extent on the air pressure and temperature.

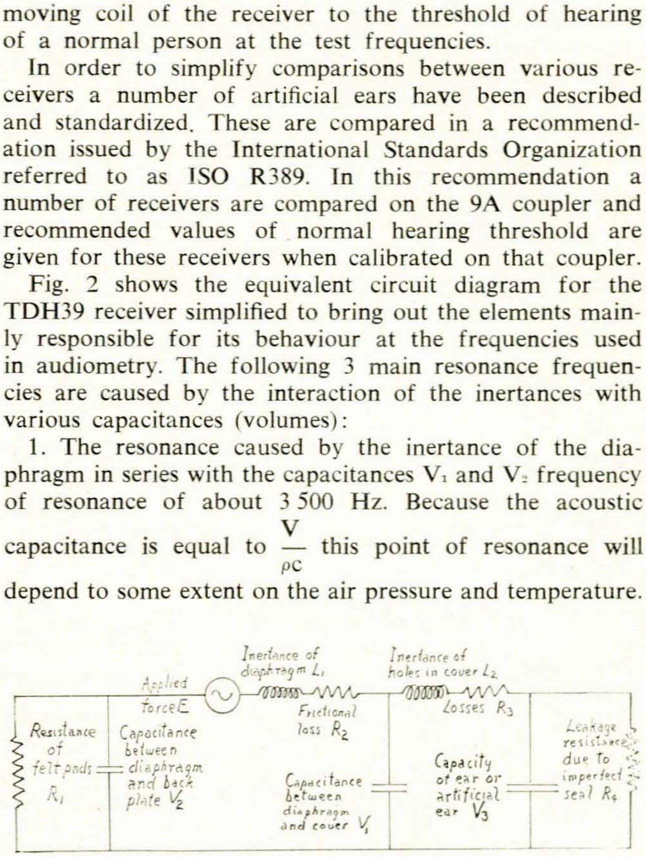

Fig. 2. A simplified schematic circuit of the receiver and the ear.

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2. The resonance caused by the inertance of the holes in the cover plate L_2 with the capacitance of the ear or artificial ear V_3. The frequency of this resonance will of course depend on the size of this volume, the particular ear or artificial ear that is used in the test and on the particular earcap that is being used. It will also depend on temperature. A typical frequency with a 6-cc ear is about 6 000 Hz.

3. The resonance caused by the inertance of the diaphragm and the capacitance of the ear or artifical ear V_3. This would also be affected by the barometric pressure and by the size of the ear cavity. This resonance is at 500 Hz.

In addition to the resonance, which can be ascribed to lumped circuit elements, resonances associated with the length of the external auditory meatus also play a part at higher frequencies.

Fig. 3 shows a record of the response of a TDH39 receiver on a 9A coupler (6 cc). The 3 resonance points are clearly shown. Two records have been made, one without an earcap with the receiver placed directly on the coupler, the other with an MX41/AR earcap, as prescribed by the International Standards Organization. It can be seen that resonance 2 is shifted from 6 361 Hz to 5 742 Hz, which corresponds to the increase in volume due to the earcap. The other resonances are only shifted to a small extent.

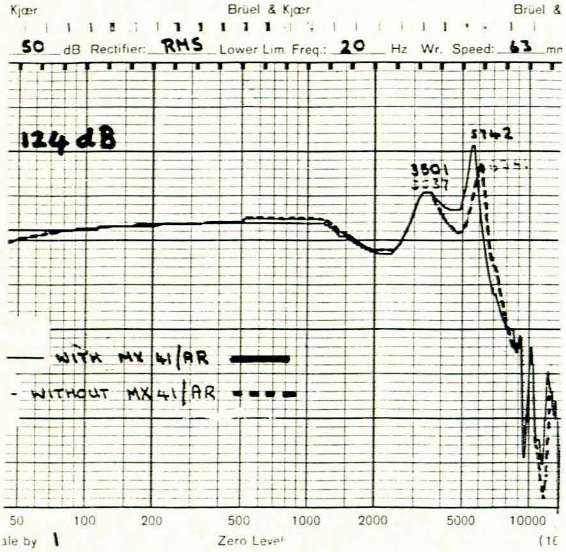


Fig. 3. Response of the TDH39 receiver on a type 9A coupler with and without earcap type MX41/AR.

THE EFFECT OF RESONANCE ON CALIBRATION

The resonances at 500 Hz and at 3 500 Hz are fairly well damped and therefore do not have a sharp peak. For this reason they do not affect calibration figures to any great extent. However, the resonance at about 6 000 Hz is much sharper and will depend considerably on the volume enclosed by the earpiece on the ear or artificial ear which is being used. This results in a much greater dispersion in any tests carried out at this frequency. Thus Brinkman[2] reports a standard deviation of 6,2 db at 6 000 Hz compared with 3,7 db at 1 000 Hz. Because the resonance point is likely to be close to 6 000 Hz it is probable that the precise frequency of the audiometer will have a considerable influence on the results both in calibration and in use.

The increased standard deviation of the threshold at 6 000 Hz could also be due to larger variations in the actual threshold of individuals at this frequency but the possibility of the variations being in part due to the proximity of the resonance cannot be overlooked.

THE PROBE MICROPHONE AS A METHOD OF ASSESSING THE EFFECTS OF RESONANCE

A probe microphone was inserted in an earcap and used to determine the precise point of resonance for various conditions. This probe measures the pressure at the entrance to the external auditory meatus (actually in the centre in front of the receiver). It is assumed that this measurement will be directly related to the pressure on the drum.

THE EFFECT OF FREQUENCY

Fig. 4 shows the response of the probe microphone on the artificial ear and Figs 5 and 6 show the responses of the same probe microphone on different human ears. It can be seen that the particular resonance point under consideration can vary from 5 600 to 6 000 Hz. If the audiometer under consideration generates a frequency of 6 180 Hz (still within the 3% tolerance according to IEC 177), then the calibration for this frequency could have a value of say 50 mV for a level of 75,5 db on the artificial ear for the telephone earpiece concerned. If, on the other hand, the frequency was 5 820 Hz (which is

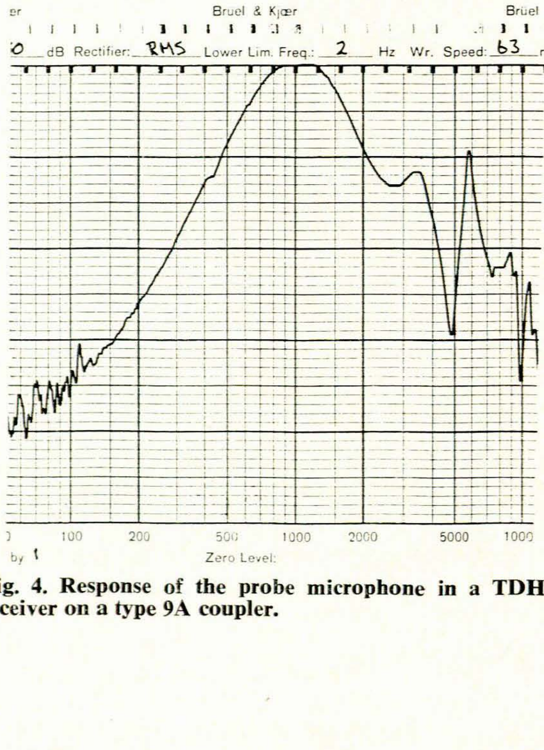


Fig. 4. Response of the probe microphone in a TDH39 receiver on a type 9A coupler.

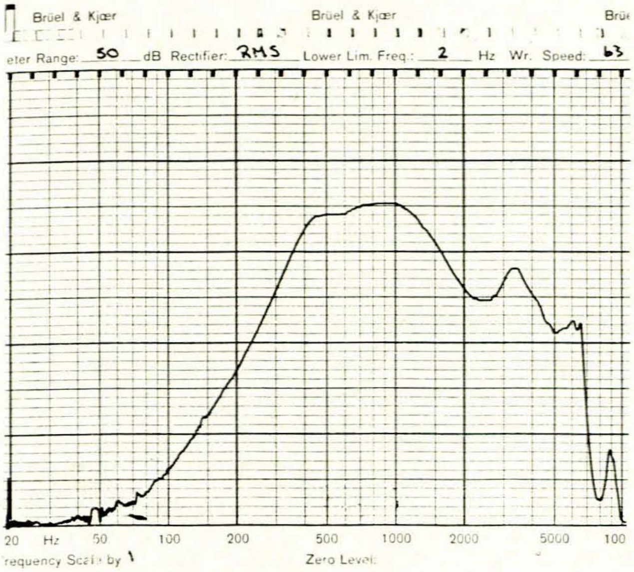


Fig. 5. Response of the probe microphone in the cavity of a TDH39 receiver on a person with a small external auditory meatus.

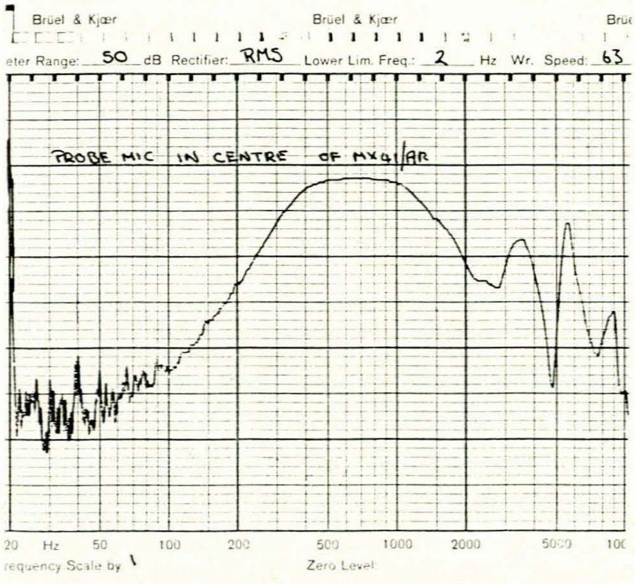


Fig. 6. Response of the probe microphone in the cavity of a TDH39 receiver on a person with a large external auditory meatus.

also within the prescribed tolerance) the calibration voltage would then be only 22 mV for the same output on the artificial ear.

If the ear under test had precisely the same resonance as the artificial ear, then this discrepancy would be of no consequence but if the resonance is different, as in Fig. 5, then it would make a difference of 7 db in the test (in the example there is practically no difference in the sensitivity, as measured by the probe, at the two frequencies). Assuming the subject, the artificial ear as well as the telephone receiver to be the same, but only the audiometer frequency to be different (but still within the tolerance), the assessment of hearing loss could differ by as much as 7 db. Thus it appears that with the present standards, the frequency tolerances permitted are too large. It can be argued that 7 db is not a very large discrepancy. In fact it is seldom possible to determine hearing loss to an accuracy better than ±5 db. Nevertheless, it is obviously desirable that standardizing methods should be more accurate.

AN IMPROVED RECEIVER WHICH DAMPS OUT THE RESONANCE AT 6 000 Hz

When the TDH39 receiver is used, the accuracy of the assessment of hearing at 6 000 Hz is dependent to a considerable extent on the precise frequency. Even if the tolerance on the value of this frequency were improved a considerable variation would still be caused by the differences in the volume enclosed by the receiver when placed on the ears of different individuals. It is therefore most desirable that steps should be taken to reduce the resonance at 6 000 Hz. This has been achieved in the TDH50 receiver. A response curve taken on the type 9A coupler is shown in Fig. 7. Examination of this curve shows that the resonance at 6 000 Hz is no longer as prominent and is reduced in frequency to about 5 000 Hz. In fact at 5 000 Hz a considerable amount of damping has been added so that it is no longer necessary to increase the accuracy of the frequency used if variation in the assessment of hearing loss is to be avoided.

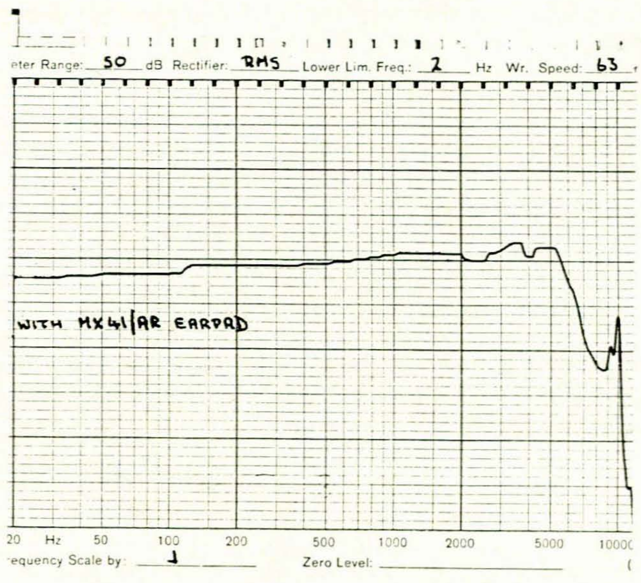


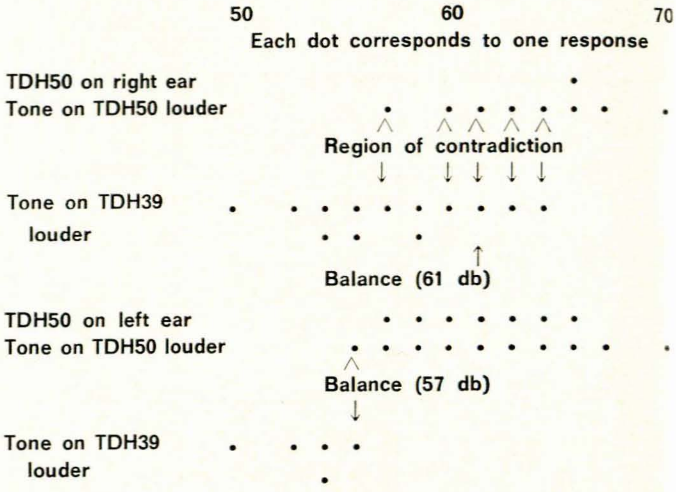
Fig. 7. Response of a TDH50 receiver on a 9A coupler with earcap type MX41/AR.

CALIBRATION OF THE TDH50 RECEIVER

An important practical question arises concerning the calibration figures for the TDH50 receiver. Are these figures the same as for the TDH39 receiver or is it necessary to redetermine the threshold calibration figures for the new receiver? At all frequencies below 6 000 Hz it is to be expected that the TDH50 receiver will have the same characteristics as the TDH39 receiver because the external physical dimensions are the same. Resonances below 6 000 Hz are also well damped in both receivers. It is therefore most unlikely that at these frequencies the calibration figures will vary between the two receivers.

As an interim measure it was considered desirable to establish the difference (if any) between them. The comparison was carried out by means of a loudness balance test using the method of constant stimuli as described by Churcher and King[1] and Guelke and Helm.[3] In the first instance the one receiver was placed on the right ear and the other on the left. Both receivers were calibrated and the TDH39 receiver was maintained at a steady level, corresponding to 60 db HTL on the audiometer. The TDH50 receiver was supplied with varying voltages corresponding to 50 - 70 db HTL and the same calibration figures as for the TDH39 were used. The subject was presented with the two tones from each receiver one after the other, each lasting 2 seconds, and was requested to signal by pressing a button once if the first tone was judged louder and twice if the second tone was judged louder. By presenting a number of tones of different intensities in the one receiver a 'region of contradiction' was established. The balance was taken to be the point at which as many contradictory judgements were recorded below as above this value.

Fig. 8 shows the method of recording the judgements and the way in which the point of loudness balance was determined. The schedule was arranged so that 2 presentations were given at 1-db intervals over the region where balance was expected. The order of presentation was reversed to eliminate any possible time effects. The receivers were then changed to the opposite ears and the balance was repeated. If both receivers had the same effect on the ear and if the subject had ears of equal sensitivity, then both balances should have occurred at the same level in both cases. If the subject's ears were not equally sensitive, then the balance should have been as much above the level of the point of equality when, say, the TDH50 receiver was on the right ear as it was below that level on the left ear. Any differences observed could then be attributed to the behaviour of the receivers themselves. In this way the TDH50 receiver was compared with the TDH39 receiver. The results of this comparison are given in Table I.



On changing receivers to opposite ears perfectly balanced receivers should balance at as many decibels below/above 60 db as the first balance was above/below 60 db. In this case the 2nd balance should have been at 59 db. The discrepancy between the two receivers is $\frac{57 - 59}{2}$ db = −1 db (for this test).

Fig 8. Comparison of ear receivers TDH39 and TDH50 by subjective loudness balance at frequency of 6 000 Hz. The TDH39 receiver was maintained at 60 db above the threshold (75,5 db SPL, ISO calibration, 9A coupler). The level of the TDH50 receiver was, as indicated, above 15,5 db, as measured on the SPL 9A coupler.

In order to assist subjects as far as possible in the reliability of their judgements the following details of the presentation were adopted: A light signal was presented to the subject immediately prior to each presentation. This was done to enable the subject to concentrate on the presentation concerned but to relax during the intervening periods. The first presentations in each series were chosen to be well away from the balance point so as to make the first few judgements easy for the subject to assist him or her to gain confidence. A positive judgement was insisted upon — the subject had to choose one presentation as the louder, and the judgement 'equally loud' was not accepted. Consecutive presentations in which the tone varied only 1 or 2 db were avoided. As stated previously, the order of presentation was changed in such a way that every level in the region of balance

TABLE I. MEAN THRESHOLDS (db ABOVE μPA)

				TDH50 compared with TDH39	
Frequency (Hz)	TDH39 on 9A coupler (ISO R389)	TDH39 on 9A coupler	SD	Balance	Estimated reliability
250	**25,5**	**23,5**	**4,5**	**−1,5**	**1,5**
500	**11,5**	**9,5**	**3,7**	**−1,0**	**1,0**
1 000	**7,0**	**6,0**	**3,7**	**−0,5**	**1,0**
2 000	**9,0**	**6,5**	**4,7**	**−1,0**	**1,0**
4 000	**9,5**	**8,5**	**4,6**	**−0,5**	**1,0**
6 000	**15,5**	**14,5**	**6,2**	**−1,5**	**2,0**

TABLE II. RECORD OF BALANCE TEST*

TDH39 on right ear, TDH50 on left ear			TDH39 on left ear, TDH50 on right ear		
TDH50 level db	Order of presentation	Response 1 or 2 louder	TDH50 level db	Order of presentation	Response 1 or 2 louder
50	39 - 50	1	50	50 - 39	2
70	50 - 39	1	70	39 - 50	2
55	50 - 39	2	55	39 - 50	1
65	39 - 50	2	65	50 - 39	1
60	50 - 39	1	60	39 - 50	2
63	39 - 50	2	63	50 - 39	1
59	39 - 50	1	59	50 - 39	1
62	50 - 39	2	62	39 - 50	2
58	39 - 50	2	58	50 - 39	1
64	50 - 39	1	64	39 - 50	2
61	50 - 39	2	61	39 - 50	2
57	39 - 50	1	57	50 - 39	1
62	39 - 50	2	62	50 - 39	1
59	50 - 39	2	59	39 - 50	2
56	50 - 39	2	56	39 - 50	1
61	39 - 50	2	61	50 - 39	1
64	39 - 50	2	64	50 - 39	1
58	50 - 39	2	58	39 - 50	2
63	50 - 39	2	63	39 - 50	2
57	50 - 39	2	57	39 - 50	1
60	39 - 50	1	60	50 - 39	1
56	39 - 50	1	56	50 - 39	2

* Frequency: 6 000 Hz; TDH39 at 60 db HTL (75,5 SPL on 9A coupler); TDH50 level indicated above 15,5 db SPL on 9A coupler.

was presented twice but that the order of presentation was reversed during the second series.

Table II gives the result of a typical series as recorded in Fig. 8.

RESULTS AND CONCLUSIONS

The investigation shows that a disadvantage of the TDH39 ear receiver, which is used in a large number of audiometers, is its sensitivity to the precise frequency of the 6 000 Hz tone. This is due to a very sharp resonance which occurs at this frequency. The TDH50 receiver which is now on the market, succeeds in damping this particular resonance and is therefore more suitable for use in audiometers. Balance tests indicate that the differences between the threshold figures for the TDH39 and TDH50 receivers measured on the 9A coupler are inside the limits of reliability for the experiments concerned and less than the known variations that are reported from different laboratories on the threshold determinations themselves. It should therefore be acceptable to use the same ISO figures for the TDH50 as for the TDH39 for the present. An independent direct determination of thresholds for use with the TDH50 receiver is, however, desirable. This would eliminate any residual uncertainty as well as the reliance on the TDH39 figures, which are themselves of limited reliability.

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