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# INFLUENCE OF THE ACOUSTIC IMPEDANCE OF HEADPHONES

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## ABSTRACT

There are obvious differences in the quality of sound reproduction of binaural signals depending on the reproduction system, particularly when headphones and crosstalk arrangements are compared. This could be caused by an inadequate headphone equalization, differences in bone conduction or the acoustical load upon the ear caused by the headphone.
In order to study the influence of the acoustical load, the acoustical impedance of headphones was measured with an impedance tube and the two-microphone-method. These results will be a basis for listening tests, where the test subjects judged loudness and localisation in dependence on free field and headphone reproduction.

## INTRODUCTION

One possible reason for the difference of perceived sound reproduced with headphones (HP) and loudspeakers is assumed to be the acoustical load on the ear caused by headphones. Differences are detectable also if the HP is perfectly equalized. In order to examine the influence of the acoustical load, the acoustic impedance of the headphone has to be measured. Accordingly 25 headphones were measured with a specially designed impedance tube.

These results were correlated with results from listening tests.

## IMPEDANCE MEASUREMENT

Measurements have been carried out with an impedance tube and the two microphone method according to ISO 10345-2 [1]. The impedance tube with an inner diameter of 10 mm allows measurements in a frequency range between 200 Hz and 12 kHz. For first listening tests a set of four out of 25 headphones were selected. Two headphones have an acoustical impedance similar to the open ear and two headphones have a maximum deviation from the open ear situation. The impedance of the headphones are related to the impedance of the open ear by subtraction, and can thus be interpreted as “additional acoustical” load caused by the headphone:

$$\underline{\Delta\zeta} = \underline{\zeta}_{HP} - \underline{\zeta}_{Pinna} \qquad (\text{with } \underline{\zeta}=\underline{Z}/\rho_0 c) \qquad \text{eq. 1}$$

Due to the subtraction, a representation of real and imaginary part is more appropriate than the representation of the magnitude (see fig. 1). Also the wearing comfort was considered. In each case headphones with a similar impedance but a different wearing comfort were selected.

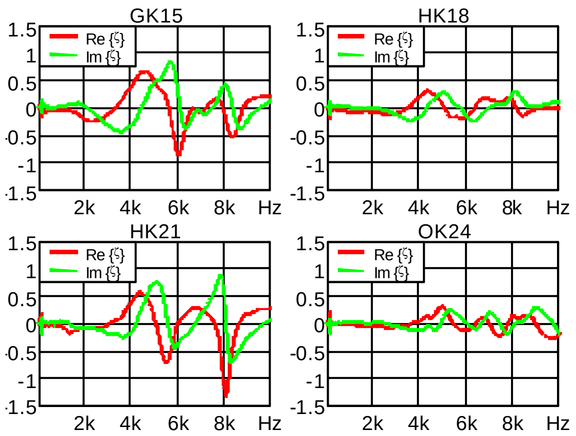



Fig. 1: Additional acoustical load on the ear of four headphones under test

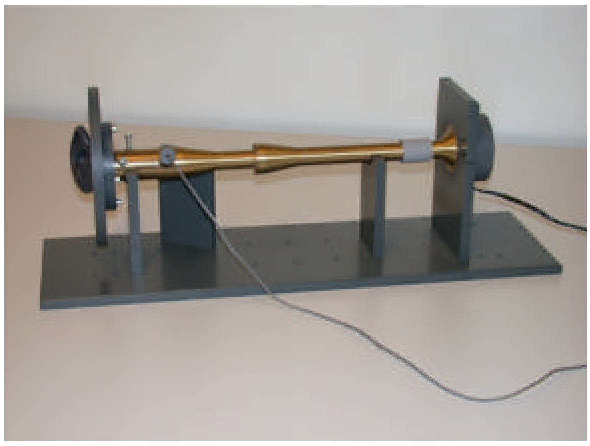


Fig. 2: Impedance tube. Note the pinna termination on the left end.

**EXPERIMENTAL SETUP**

In a preliminary listening test, the subjects should compare between different kind of reproduction techniques:

- 24 Loudspeaker (LS) array (upper hemisphere) as reference situation

- Headphones (HP)

- Crosstalk cancellation (CTC) representing an ideal open headphone

The loudspeaker arrangement consists of 12 loudspeaker in the horizontal plane and 5 loudspeaker in the median plane and up to 7 loudspeaker in various distances for example for tests about the distance hearing. The distance of the loudspeaker in horizontal and median plane to the subjects head is 2 m. The whole arrangement is placed in an anechoic room with hard floor (see fig. 3). The floor in the area between the loudspeaker was covered with absorbing material. Independently of the ratio between direct sound and floor reflections the reflections can be fully simulated with CTC or HP. Two loudspeaker in the horizontal plane (+/-60°) were used for the CTC. The subject were placed on an elevated seat with its ears on a level of 2 m. The head is fixed with a support in order to allow the subject to keep the head in one position in a comfortable way.

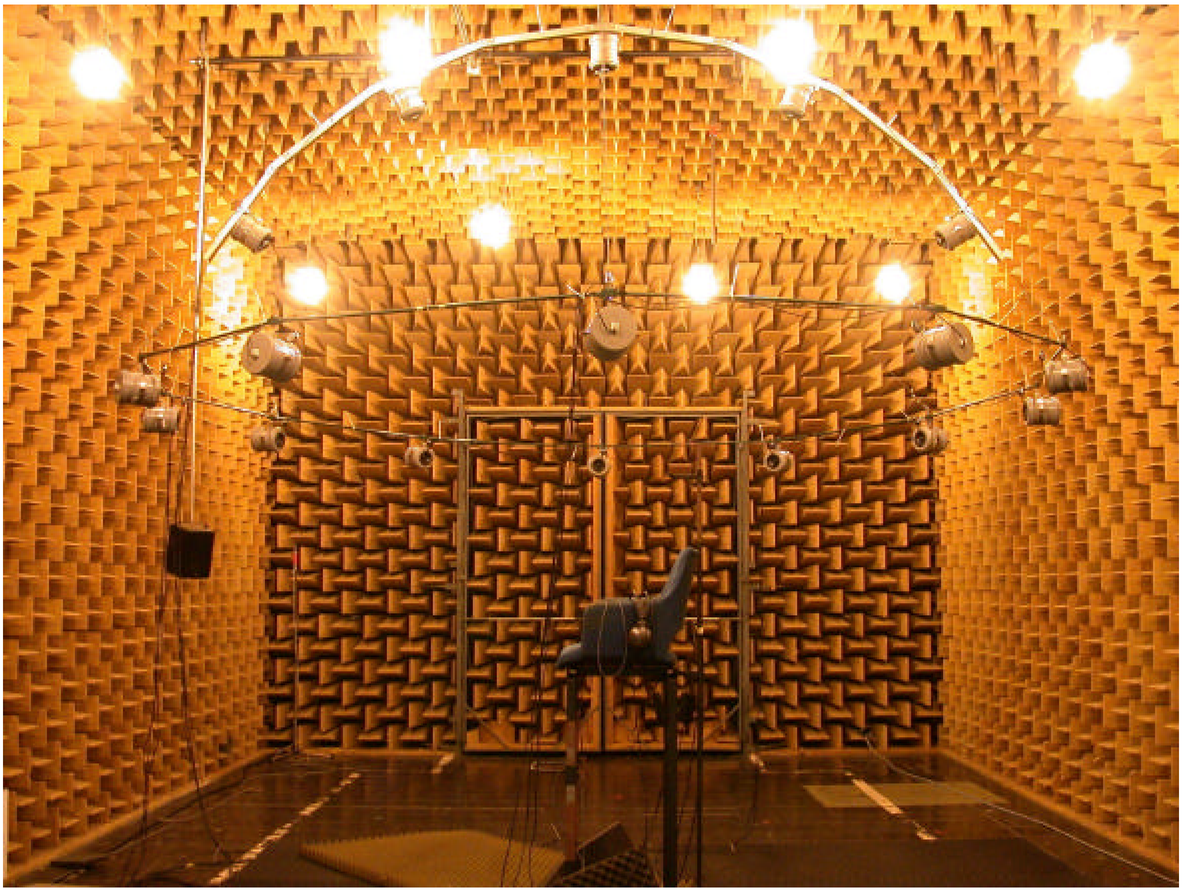


Fig. 3: Experimental setup in anechoic room

For all measurements a probe microphone was used which consists of a 60 mm bent metal tube (outer diameter 1.6 mm). The signal is measured 3 to 5 mm from the entrance of the ear canal (see fig. 4). The attenuation caused by the metal tube is ‘only’ 15 dB at 20 kHz and can be compensated without problems.

Fig. 4: Probe microphone attached to the ear

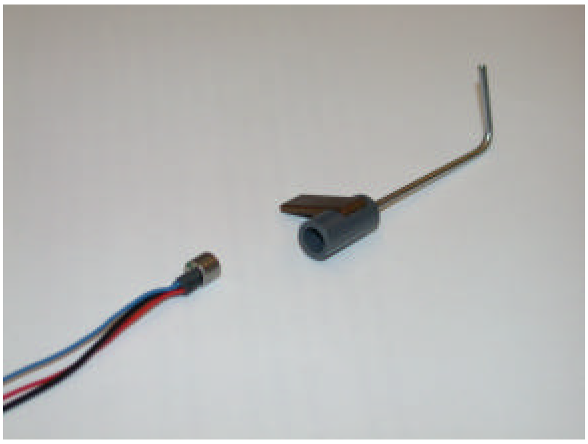


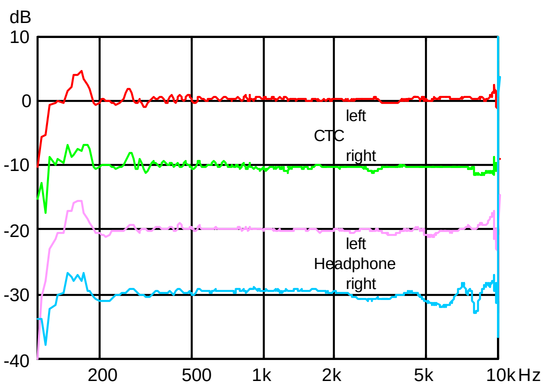
Fig. 5: Probe microphone (based on Sennheiser KE4)

## MEASUREMENT AND CALCULATION OF TEST SIGNALS

The complex signal at the eardrum must be identical, independent from the reproduction technique. That means that magnitude and phase should be identical. Accordingly the subject had to wear the probe microphone during the whole test. In the beginning of the test all HRTFs for all loudspeakers positions were measured. The whole procedure including all loudspeaker positions lasted 30s. These HRTFs were used for the calculation of the CTC filters and the headphone signals. All loudspeakers were equalized individually. While listening to the reference situation, the remaining floor reflections were audible also. So they were not removed by windowing. It is also possible to handle the reflections from the undamped floor. Only narrow dips are not equalized. The headphone transfer function (HPTF) was measured during the subject wore the headphone. From the measurements, all filters were calculated which were necessary for the convolution with any test signals. All calculations were checked immediately with measurements in order to make sure that the ear signals are identical. These measurements were repeated during the test was running in order to detect deviations caused by movements of the subjects head or the microphone. Starting from the 24 measured directions complex scenes could be generated.

## MEASUREMENTS

First of all the frequency range is limited to 10 kHz, because an insufficient suppression of dips creates tonal components. Figure 6 shows the deviation of CTC- and HP-reproduction compared to loudspeaker reproduction. Figure 7 shows the performance of the CTC.



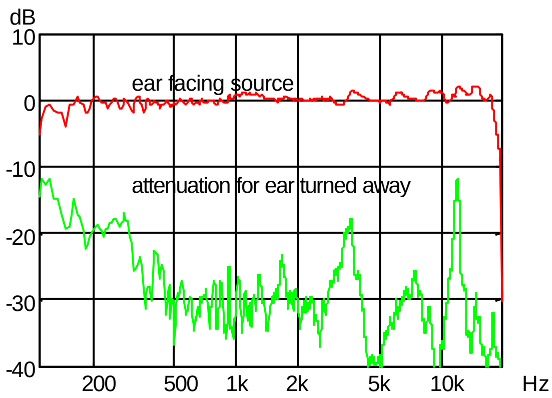




Fig. 6: Deviation of frequency response in comparison to loudspeaker reproduction.

Fig. 7: Performance of crosstalk cancellation

## LISTENING TEST

The results described here originated from preliminary tests in order to get an impression of the dimensions of the psychoacoustic effects. They are also used for the preparation of the main tests to be done.

Seven subjects participated, four of which where experienced with binaural tests. Though the headphone transfer functions (HPTF) partly changed slightly caused by repeated removement and re-fitting of the HP, an individual equalization of the HP is provided in order to keep the deviation as low as possible. So a paired comparison between HP and LS or HP and CTC is possible, starting with HP.

After multiple presentation of the test signal with HP, the signal was presented with loudspeaker or CTC for a direct comparison. The subjects were asked about parameters as follows: loudness, timbre, localization, distance (in-head localization) and apparent source width. Generally the differences where rated as being very small. Localization and source width has been judged as absolutely identical, also for sources in the median plane. If a deviation was reported, it was necessary to make a new measurement of the HPTF, which shows indeed the necessity of the individual equalization for each removal and re-fitting. Identity does not mean, however, that the absolute direction was located correctly, which does not matter in this test. The HP reproduction was perceived as quieter, nearer and brighter which can be interpreted as first trend, at least.

The comparison between CTC (interpreted as ideally open headphone) and loudspeaker shows significantly smaller differences, whereby four subjects were not able to detect any difference at all, even though this comparison allows the perception of smaller differences because the change-over is faster, and no new measurement is necessary. Also the subject did not know, which kind of reproduction was selected.

## CONCLUSION

In this study the different perception of sound reproduced with headphones or loudspeakers is related to the acoustical load of the headphone on the ear. In listening tests the influence of the acoustic load by same signals at the eardrum is studied.

The experimental setup described here is capable to present identical signals with different techniques for reproduction with very low deviations. In a preliminary test the suitability of the setup was tested.

Next step will be the measurement of absolute hearing thresholds in the different reproduction situations. The procedure for the measurement of the threshold of hearing is easier to interpret, because no direct comparison to the reference situation is needed, which requires a permanent removal and re-weiring of the headphone.

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