# PURE TONE AUDIOMETER

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**Abstract**

**Estimation of pure tone hearing threshold is a part of hearing tests conducted in order to know the sensitivity of the human auditory system. This paper presents manual audiometer implemented in Matlab which can be used to conduct such measurements. Audiometer was calibrated by means of an artificial ear and pistonphone. Modified Hughson-Westlake method [1] usually used in manual audiometry is described.**

## 1 Introduction

Pure tone threshold audiogram is a graph of the lowest signal intensity as a function of signal frequency which can the person under test hear during certain measurement conditions. The level is usually drawn as the amount of deviation from the standard threshold value (for air-conducted signals presented via earphones the threshold was published in ISO 389-8:2004 and ISO 389-5:2006 standard) and thus it is easily visible if the person's hearing is in normal range. Audiometer is the calibrated clinical device which is used for the audiogram measurement.

This paper presents software version of audiometer developed in Matlab environment. The audiometer was developed in order to conduct hearing assessment tests of subjects who will serve in psychophysical hearing tests conducted for research purposes at the Department of Radioelectronics, CTU in Prague.

## 2 Audiometer

### 2.1 GUI and Implementation

Graphical user interface of the Matlab audiometer is in the Fig. 1. This interface is controlled by a test conductor. It allows to choose the ear which is being investigated (hearing threshold is measured separately for each ear), set the pure tone frequency and level, play the sound signal, save the threshold values and save the final measured data to the file.

Graphical user interface is very simple and it was not written in GUIDE. The main body is the function called `audiometer.m`. Calling the function without parameter builds the main audiometer GUI.

Pressing the *play* button plays the sound signal via earphones. Duration of the pure tone is 2 seconds and it is generated by means of Matlab function **sin**. Onset and offset of the signal is ramped by 50 ms raised-cosine ramps. The signal is presented to the sound card by means of Matlab function **sound**. Sample frequency is 48 kHz.

The frequency and level of the signal can be set in the editable fields. Since it is convenient to quickly change the level values, two control elements (the button down and up) were placed under the level editable field. Pressing the button *down* and *up* will cause decrease and increase of the level by 5 dB respectively. The value 5 dB was chosen because it is the lowest step size which is used in the modified Hughson-Westlake method (see Fig. 3). The signal level is in dB re absolute threshold values according to ISO 389-8:2004 and ISO 389-5:2006 standard. Audiogram will thus show deviations in dB from normal hearing sensitivity to pure tones.
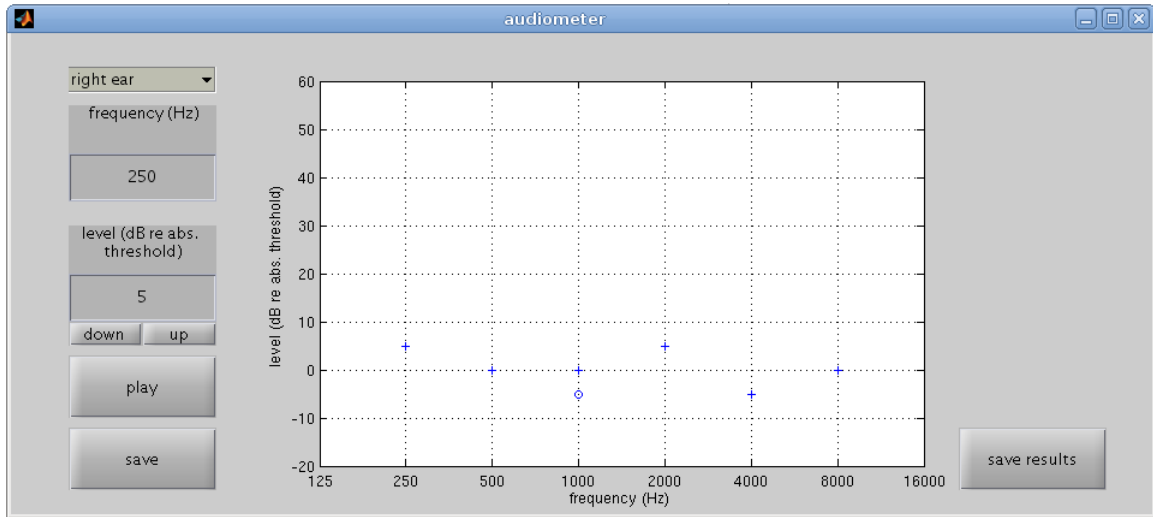
Figure 1: Graphical user interface of the pure tone audiometer

The save button will store the currently measured value of threshold. It is visualized for the right and left ear as a cross and circle mark in the graph respectively. After the measurement is done, all values can be saved to the file by pressing the button *save all*.

## 2.2 Calibration

Measurement system consists of a computer with Matlab, sound card and earphones. It is necessary to know the amplitude transfer characteristics of earphones and to know the sound pressure level of signal entering the ear. Calibration of the earphones can be done by means of an artificial ear. Microphone of the artificial ear can be calibrated by pistonphone.

Authors of this paper used sweep sine tone generated in Matlab (function **chirp**) for the earphones calibration. This signal was played via earphones and recorded to Matlab. Microphone of the artificial ear was then connected to pistonphone which generates the known value of sound pressure level at the microphone membrane. The output signal of microphone was again recorded to Matlab. Sound pressure level of the signal generated by the earphones can be easily calculated by this relationship

$$L_{earphones} = L_p - 20\log(A_p/A_{earphones}), \tag{1}$$

where $L_p$ is the known sound pressure level of pistonphone, $A_p$ is the amplitude of pistonphone signal recorded to Matlab and $A_{earphones}$ is the amplitude of earphones signal recorded to Matlab. This amplitude is generally frequency dependent (see calibration curve in the Fig .2). It is supposed that the recorded signals (both the pistonphone and earphones) were measured with the same setting of a microphone amplifier and sound card mixer. If the amplifier sensitivity was changed, the corresponding values of amplitudes in Eq. 1 must be scaled. Since we know the parameters of input sweep signal used for the earphones calibration and the values of sound pressure level as a function of signal frequency, we know how to generate a pure tone signal in Matlab which will cause desired sound pressure level at the earphones output. This is essential for the proper function of the audiometer.
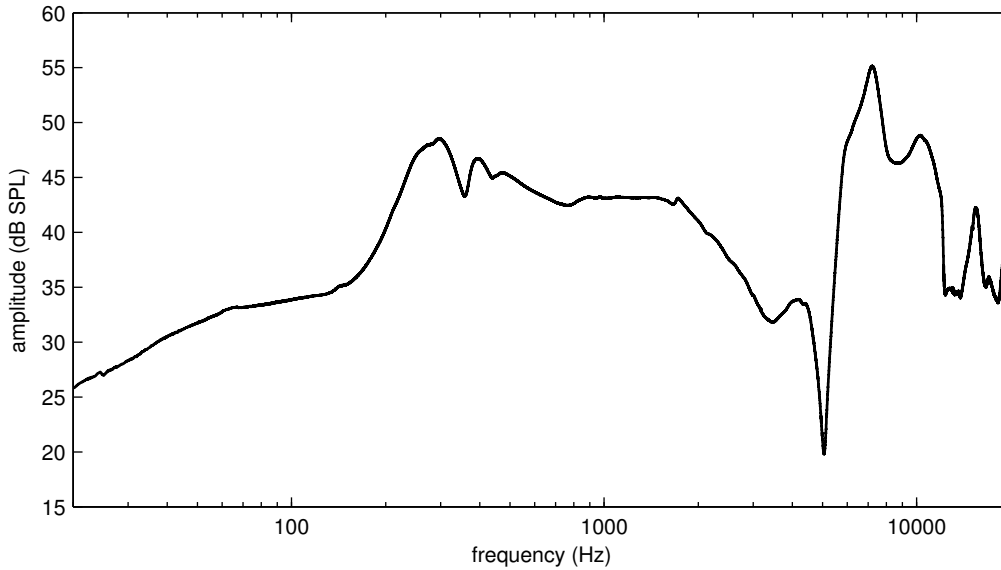
Figure 2: Calibration curve of the left earphone Sennheiser HD 280 Pro.

# 3 Audiogram measurement

## 3.1 Modified Hughson-Westlake method

This section explains methods of audiogram measurement. The procedure description was taken from the source [1] and [2]. Different procedures can be used to obtain an audiogram. Three basic groups of procedures are the method of constant stimuli, method of adjustment and method of limits.

In the method of constant stimuli the series of tones of certain frequency and level is presented to the listener who's task is to respond if he perceives the signal. If the number of responses is equal to half of the signal presentations, the signal level is set as threshold. This method is the most accurate but also the most time consuming

In the method of adjustment, the listener can control level of the signal and is instructed to set it to the just-barely heard value. If it were set to lower level, the listener would not be able to hear it at all. This just-barely heard value is taken as threshold. This method is the most inaccurate and least time consuming.

In the method of limits, the signal of certain frequency and level is presented to the listener and his response is recorded. The signal level is changed and the response is again recorded. The threshold is the lowest level where the response was at least in 50 % of the presentations. Since the accuracy of this method somewhere in the middle between the accuracy of two other methods and it is less time consuming then the method of constant stimuli, it is suitable for manual audiometry.

There are various versions of the method of limits. The mostly used procedure which will be explained here is the modified Hughson-Westlake method [1]. Flow chart of the method is in the Fig. 3. First, the signal of certain frequency is presented to the subject with clearly perceived level. In case of normal hearing it should be 40 dB above standard threshold. Subject is instructed to respond if he perceives the signal. The value of signal level is then decreased by 15 dB after each response until he stops responding. The level is then increased by 5 until the listener starts to respond again and then again decreased by 10 dB when when he stops responding. The threshold is the signal level for which the listener responds two out of three times after the level started to be incremented.
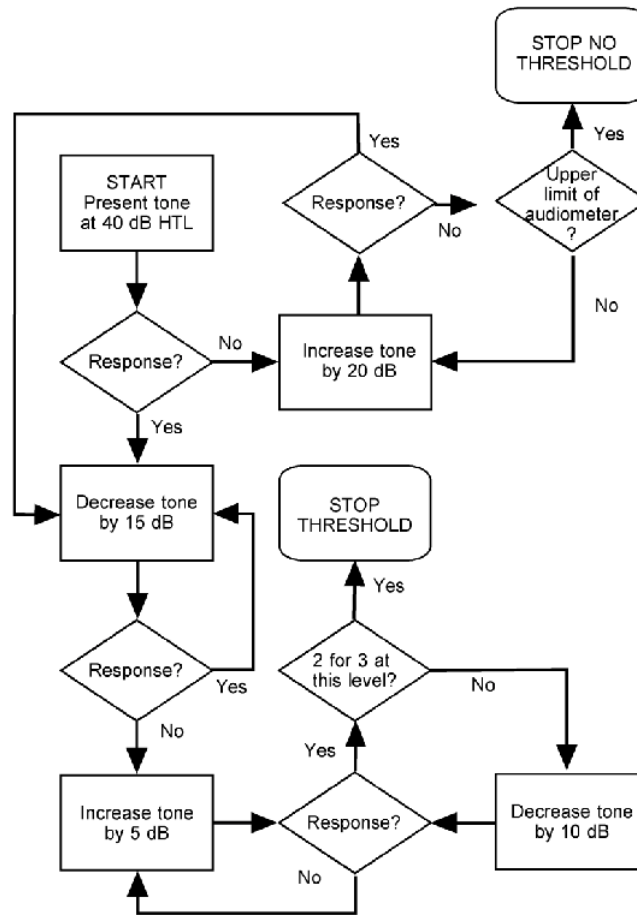
Figure 3: Modified Hughson-Westlake flow chart (adapted from [2]).

Testing for clinical purposes is done for octave frequencies from 125 Hz to 8 kHz. Half-octave frequencies 750 Hz, 1.5 kHz, 3 kHz and 6 kHz can be included too. As it was mentioned above, testing is done for each ear separately. It is convenient to start with better ear. If the better ear is not known, then the right ear is the default starting ear. The recommendation is to start with the 1 kHz tone and then measure lower frequencies. After the measurement of lower frequencies is done, set the frequency again to 1 kHz and measure the threshold again. If the both thresholds for 1 kHz agree within 5 dB, testing can continue for higher frequencies. If not, it is necessary to stop testing, re-fit the earphones and re-instruct the listener. The same sequence of testing frequencies should be used for the worse (left) ear. It is just not necessary to retest 1 kHz frequency again because the listener already showed consistency in his answers for the better (right) ear. Normal hearing range is within 20 dB re normal absolute threshold.

## 4 Conclusion

Software version of pure tone manual audiometer was implemented in Matlab. It allows to estimate the hearing threshold for pure tones. The device was realized in order to conduct hearing tests on persons who are willing to serve as subjects in psychophysical hearing tests conducted at the Department of Radioelectronics, CTU in Prague. Calibration of the audiometer (Matlab implementation, sound card, earphones) was done by means of an artificial ear and pistonphone. Modified Hughson-Westlake method which is used during pure tone audiometry was described.

## Acknowledgements

## References

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