# Computer Audiometer for Hearing Testing

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## Abstract

*In this paper, we present a prototype of a simple audiometer CAUM (Computer AUdioMeter) based on a computer equipped with a standard sound card. It is a software developed under windows in order to provide a virtual instrument of a standard audiometer on computer. It has functionality to test a patient's hearing using pure tone testing and white noise masking signal.*

*The functions and performances of the prototype are evaluated by hearing tests and compared with classical AC50 audiometer.*

## 1. Introduction

Human hearing can be affected by a wide range of hearing defects. We can classify noise as the number one cause of professional invalidity of hearing organism [1]. Most of us are always exposed to several kind of noise in our professional life. Another cause of hearing defect is the age. Body functions and sensory organs deteriorate as we age. In general, the deterioration in hearing capability starts in the 20s [2].

Human hearing is also affected by hereditary phenomenon. Around one third of hearing problems present since birth are due to hereditary factors [1].

Various sicknesses from bacteria and from viruses (scarlet fever, German measles, meningitis) can damage the ear and cause more or less hearing loss.

In some cases, medicines, alcohol, smoke can harm hearing and are therefore defined as ototoxic [1].

People delay wearing hearing aids because they are not aware of the deterioration progress and get used to living with hearing difficulties [2]. Due to these various hearing defects, audiometers are necessary which can easily screen persons with hearing loss progressing at an early stage.

Audiometry is a medical technique, dealing with measurement of hearing. Given the physical dimension of a sound stimulus, it is possible to measure the response caused by that stimulus. There are different kinds of audiometers, according to their characteristics: pure-tone and speech, manual and automatic. There are also different devices that vary in complexity and in their frequency and intensity ranges [3]. The main purpose of this paper is to develop a simple version of hearing measurements software under windows able to generate sounds comparable to those generated by a real audiometer AC50. We present in this paper the acoustic characteristics of sound bases used in the development concept. Then, we explain the hearing measurements procedure used to find the Hearing Loss thresholds of patients. Finally, we present the obtained results with conclusion and future works.

## 2. Acoustic characteristics of Sound

The study of sound perception begins with a physical description of the sound itself. It is usually an attempt to discover the relationship between the human response to a sound and a precise physical characterization of that sound. It is almost a truism to say that all perceptually relevant sounds are characterized by differences in intensity across time or frequency. Intensity perception can be regarded, therefore, as one of the basic concerns of hearing research, and one that has generated a great deal of interest. Despite many decades of work in this area, the field is still progressing rapidly, and the last ten years have seen significant developments in our understanding of a very fundamental problem, how sound intensity is represented, or coded, in the auditory system.

### 2.1. Sound Pressure Level

Sounds are easily described by means of the time-varying sound pressure, $P(t)$. Compared to the magnitude of the atmospheric pressure, the temporal variations in sound pressure, caused by sound sources are extremely small. The unit of sound pressure is the PASCAL $(Pa)$ [4].

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In psychoacoustics, values of the sound pressure between $10^{-5}$ Pa (absolute threshold) and $10^{2}$ Pa (threshold of pain) are relevant. In order to cope with such a broad range of sound pressures, the Sound Pressure Level (SPL) is normally used. Sound pressure and SPL are related by the equation:

$$L = 20\log\left(\frac{P}{P_0}\right)dB \qquad (1)$$

The reference value of the sound pressure $P_0$ is standardized to $20\mu PAa$. Besides sound pressure and SPL, the sound intensity, $I$, and sound intensity level are also relevant in psychoacoustics. In plane travelling waves, sound pressure level and sound intensity level are related by the equation:

$$L = 20\log\left(\frac{P}{P_0}\right)dB = 10\log\left(\frac{I}{I_0}\right)dB \qquad (2)$$

In particular, when dealing with noises, it is advantageous to use, instead of sound intensity directly, its density, i.e., the sound intensity within a bandwidth of 1 Hz. The expression "noise power density" – although not quite correct – is also used.

## 2.2. The Perception of Loudness

Equal loudness contours are descriptions of the frequency dependence of the loudness of pure tones (Fletcher & Munson, 1933). They can be measured fairly easily by requiring listeners to match the intensity of a comparison tone of variable frequency to the intensity of a standard tone at 1 kHz [5]. An equivalent technique often used is to present a series of levels of the comparison tone and ask listeners to judge for each level whether the comparison is "louder" or "softer" than the standard. The transition level from "louder" judgments to "softer" judgments can be taken as the point of subjective equality. The loudness level (in phons) of a tone at any frequency is taken as the level ( in dB SPL ) of the 1kHz tone to which it sounds equal in loudness.

This means that, for example, any tone that has the same loudness as a 40 dB, 1 kHz tone has, by definition, a loudness of 40 phons. An equal loudness contour, then, is a line joining the levels of tones of different frequencies that have the same loudness in phons. Figure 1 shows equal loudness contours as measured by Robinson and Dadson (1956). It can be seen that, although the equal loudness contours tend to follow the absolute threshold curve at low loudness levels, at high loudness levels the contours flatten somewhat; this is the result, principally, of a steeper function relating loudness to intensity at low frequencies than at medium frequencies.

The finding that the loudness function is steeper at low than at medium frequencies is explained by loudness models mainly in terms of the increase in absolute threshold at low frequencies. It should be noted that there is currently some argument over whether the equal loudness contours derived by Robinson and Dadson accurately reflect subjective equality (Suzuki & Sone, 1994). It appears that the measurements are not free from bias and can be affected, for example, by the range of comparison levels used (Gabriel, Kollmeier, & Mellert, 1994).

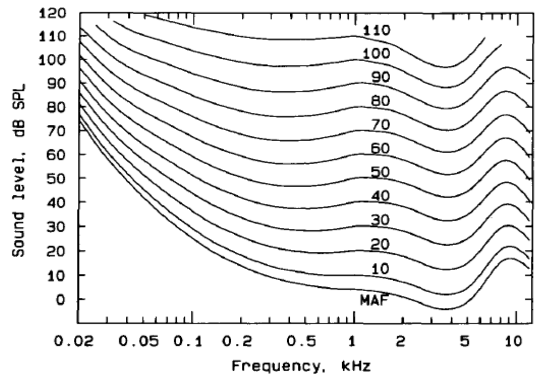



**Fig. 1:** Equal loudness contours illustrating the variation in loudness with frequency.

## 3. Pure-tone hearing-threshold measurements

The principal audiometric test entails measuring the auditory thresholds for pure tones. Results indicate the minimum SPL that evoke the minimal auditory sensation within the frequency range between 125 and 8000 Hz. International standards define the SPL threshold values for normal hearing, and after normalisation, relate them to 0 dB Hearing Loss HL .

Threshold increments up to 25 dB HL , although irrelevant for medicolegal purposes, may be valuable for diagnostic purposes [6]. Two separate measures of the hearing threshold, respectively air-conducted (through an earphone) or bone-conducted (a vibrator on the forehead or the mastoid process) stimuli, permit the distinction between two main kinds of hearing losses: conductive and sensorineural. The first show a normal bone-conducted and an elevated airconducted hearing threshold. The second show equal values of the two thresholds. There are also mixed hearing losses, which have elements of both conductive and sensorineural losses. When a marked difference exists between the hearing thresholds of the two ears, noise masking is needed for the better ear, in order to ensure that a sensation evoked in the better ear does not interfere with the sensation elicited in the worse ear.

Clinical pure-tone audiometry, such as the psychoacoustical tests, is based on a stimulus response behavioural model, which requires active cooperation and attentive attitude by the subject being tested.

Simulators, individuals with low levels of vigilance and reduced attention may give unreliable results, i.e., a hearing threshold poorer than the actual threshold or one excessively variable at retest. Three to five-year-old children can reliably perform pure-tone audiometry: Younger children can be examined by special conditioning procedures [6].

## 4. Development concept

### 4.1 Acoustic and electrical considerations

The main purpose of this project is to develop a simple software able to generate pure-tone for hearing measurements using a computer equipped with a standard sound card without any external devises. The software offers the ability to be calibrated for any sound card using the calibration tool implemented in it.

It offers a simple way with minimum cost to evaluate hearing measurements of patients at anytime and anywhere.

The idea is to estimate the power ability of a simple sound card to generate sufficient Sound Pressure Level within the frequency range between 125 and 8000 Hz by the means of specialized headphones. Using the SPLs limits of all selected frequencies, we can obtain the lowers ones by the linearization of the SPLs logarithmic values given by equation 1 and perform conversion to the corresponding voltages in order to synthesize the pure tones according to the desired SPLs.

The frequencies selected for pure tone tests are: 125Hz, 250Hz, 500Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz.

A direct solution is to measure the SPLs using a sound pressure level meter. But the precision of measurements depends on the background noise of the room where the measurements are done. We have made many tries for such experience but results were not satisfying.

The solution is to made voltage measurements across the headphone in order to obtain the corresponding SPLs. We have started by evaluating the higher limit range of the output voltage of a standard sound card for each frequency using TDH39P Telephonics headphone. The load (TH39P) used is generally complex and present a certain frequency response in the audible range. The second step is to measure the output voltage for each test frequency across the TH39P headphone of the classical calibrated audiometer AC50. These voltages give as the corresponding thresholds of the SPLs that can be generated by a computer equipped with a standard sound card. The intensities range start by 0 dB or less and end to the SPLs thresholds. These intensities can be generated using linearization operation as explained above. The SPLs limits thresholds are represented in Figure 2. The same experience is done to obtain the SPL threshold of the white noise used as a masking signal. The tests sounds (pure tones and masking signal) are synthesized at a sampling frequency of 44.1 kHz and sounded as 24 bit outputs signals.

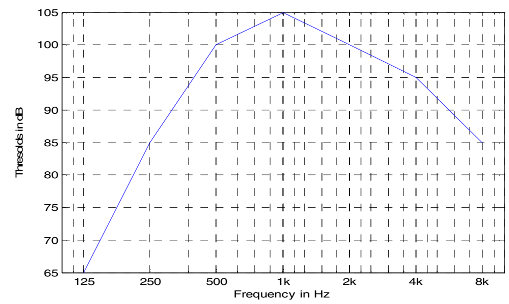



**Fig.2**: Limit thresholds of a standard card sound over frequency

### 4.2. Description

This audiometer has the following characteristics:

- Pure tone audiometer (a single frequency heard at one time).
- Frequency range: 125, 250, 500, 1000, 2000, 4000, 8000 Hz.
- Intensity range for both air and bone conduction vary for each frequency starting from 0 dB to the SPL threshold given by figure 2.
- The attenuation (or augmentation) is in 5dB steps.
- Masking white noise from 0 to 105 dB.
- Operation modes: manual.
- Patient response by hand switch.
- Test headset (TDH-39 earphones) or bone vibrator.

CAUM is a prototype version of a software Audiometer. It is designed under matlab and presented in figure 3. The software interface provides a convivial system which facilitates the task for the operators and thus the patients. All controls are mouse driven (point and click). Tests are carried out using simple orders for a better comprehension. The possibility of returning backward for repeating some tests makes possible to carry out precise evaluations. The results can be transferred to an excel file in order to be achieved.

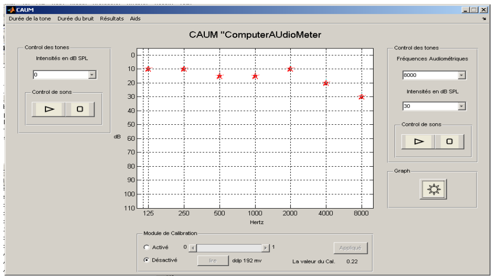
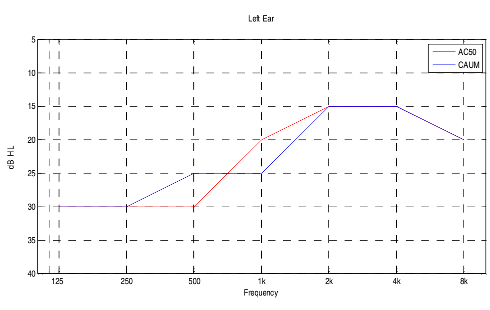


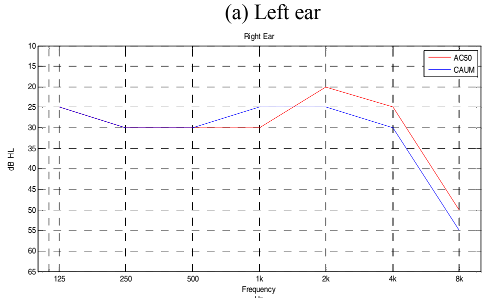

**Fig. 3**: CAUM user interface

## 4.3. Experimental tests and results

Audiometric tests have been done using CAUM on many candidates from different ages and sexes and compared to those of AC50 classical audiometer with the assistance of Dr Benia, ORL and associate researcher in CDTA. We have obtained satisfactory results for most candidates. The hearing measurements of female patient in the 40$^{th}$ age using both AC50 and CAUM audiometers are presented in figure 4.




(a) Left ear




(b) Right ear

**Fig. 4:** An example of hearing loss measurements using AC50 and CAUM audiometers

Our software presents two limitations. The first one is the background noise generally presented in a standard card sound. This noise in generally around 5 dB SPL, it can influence the perception of tone in same order. Generally these cases do not affect the clinical diagnostic since the perception of 5 dB loudness over tests frequencies is considered as high perception without hearing loss. The second limitation is its ability to generate pure tones higher than the SPLs thresholds calculated above (according to a classical Sound Card). A solution is to use a Low Noise Amplifier at the sound card output which is not the aim of our project which is to only explore the standard sound card of an ordinary computer.

## 5. Conclusion and future works

In this paper, a prototype of an audiometer for hearing testing purposes named CAUM; "Computer AUdioMeter" was developed under matlab. The CAUM audiometer has been calibrated and tested under several computers with several sound cards types. It was examined as a regulated audiometer by verifying the function and the performance compared with a calibrated AC50 classical audiometer. The results showed that there was practicable possibility to use the computer for hearing measurements. The finalised version will be tested in hospitals and evaluated by ORL specialists. The next step will be the inclusion of other clinical test of audiometry such as SISI, pulse, alternated pulse, modulation and alternated modulation. The price of the device would be much lower than that of classical audiometers providing the same variety of audiometric examinations.

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