# INPUT ACOUSTIC IMPEDANCE OF THE AUDITORY SYSTEM MEASUREMENTS

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## 1. Introduction

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Measuring middle ear input impedance is of fundamental importance both from the point of view of the basic research and from the point of view of clinical diagnosis [1]. As regards the first aspect, characterization of the "input / output" middle ear's amplification factor is crucial for deconvolving inside otoacoustic signals cochlear transfer function from that of the middle ear. From a clinical point of view, it is essential for a correct diagnosis to be able to separate trasmissive problems, linked to the middle ear, from that caused by cochlear pathologies.

The measure of input impedance of the middle ear can be carried out using a probe consisting of a miniaturized microphone and loudspeaker inserted into the ear canal. The technique described in the literature [2] [4] consists in modeling the system probe + inner ear as a Thevenin equivalent circuit in which the characteristics impedance and Thevenin pressure of the probe have been characterized using a calibration system. The calibration, namely the characterization of the Thevenin parameters of the probe, is carried out using waveguides of known length whose impedance is derived by mathematical modeling as a function of the geometric parameters [3].

The solution of a least-squares problem allows to obtain the best fitting of the Thevenin parameters of the probe. The same measure of input impedance of the middle ear may also be effected by means of an intensimetric probe able to simultaneously measure pressure and velocity inside the ear canal. In this work measures of input impedance of the middle ear are made with both techniques described above. In particular, for the velocity measures was used a Microflown anemometer miniaturized probe. The measurements obtained by the two independent techniques were systematically compared finding a satisfactory agreement.

### Materials and methods

We used two different electro-acoustic transducers: a standard probe being part of the acquisition system for otoacoustic emissions ILO292 (Otodynamics Ltd.), subsequently referred to as probe ILO, consisting of two speakers and a microphone, and a Microflown miniaturized air speed probe, consisting of a microphone and a MEMS anemometer.

Both probes are connected to appropriate amplifiers and equalizers, in turn connected to an acquisition system based on Labview platform by National Instrument, which allows both acquisition and generation of synchronized signals. Labview software also permits accurate analysis of data collected. The system works at a sampling frequency of 50 kHz and  measurements are made by stimulating the system by clicks.

### Indirect measurement

At present, the last methodology proposed in the literature (Keefe [2]) for the measurement of impedance of the ear is accomplished with an indirect typology of measure. Using an analogy with electrical circuits we can apply the Thevenin-Norton theorem, in this way ILO probe can be schematized as a pressure generator fully characterized in terms of pressure $P_0$ and equivalent “Thevenin” impedance $Z_0$. In series to this generator is applied the impedance Z of the load, being the input impedance of the ear.

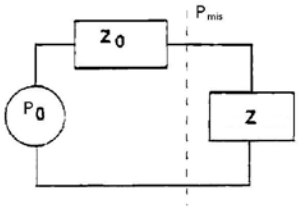



Figure 1a

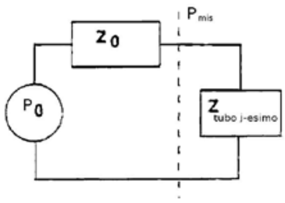



Figure 1b

Figure 1: Thevenin equivalent circuit for measuring  ear’s impedance (Fig.1a). The same circuit used to determine ILO probe Thevenin parameters (Fig.1b)

The result is a pressure divider:

(1) $$P_{mis} = \frac{Z}{Z + Z_0} P_0 \quad \text{[Pa]}$$

Where $P_{mis}$ is the pressure measured by the microphone of the probe ILO or the pressure at the ends of the ear understood as an element of the Thevenin equivalent circuit. From (1) once we known the Thevenin parameters of probe $P_0$ and $Z_0$ it is immediate to obtain the value of the impedance Z of the ear,. To determine the latter we used the same methodology as described in [2]. The probe was connected in series with loads of known impedance, these loads consisting in tubes of diameter equal to 8mm and of different length whose impedance can be calculated analytically. For the analytical expression having been used formulas of another work of Keefe [3] and the corresponding approximations that make possible to take account both of dissipative phenomena due to the viscosity of the fluid and to phenomena of thermal exchange with the walls of the same tube.

The analytical calculation was compared with numerical simulations obtained using Comsol Multiphysics. The comparison is well summarized by the graphs in Figure 2 where two analytical models, the first described in [3], is compared with the corresponding simulation. In the simulations was used a thermoacoustic  model with the bulk viscosity equal to 2/3 of the dynamic viscosity. The figure refers to a tube of 24 cm length.

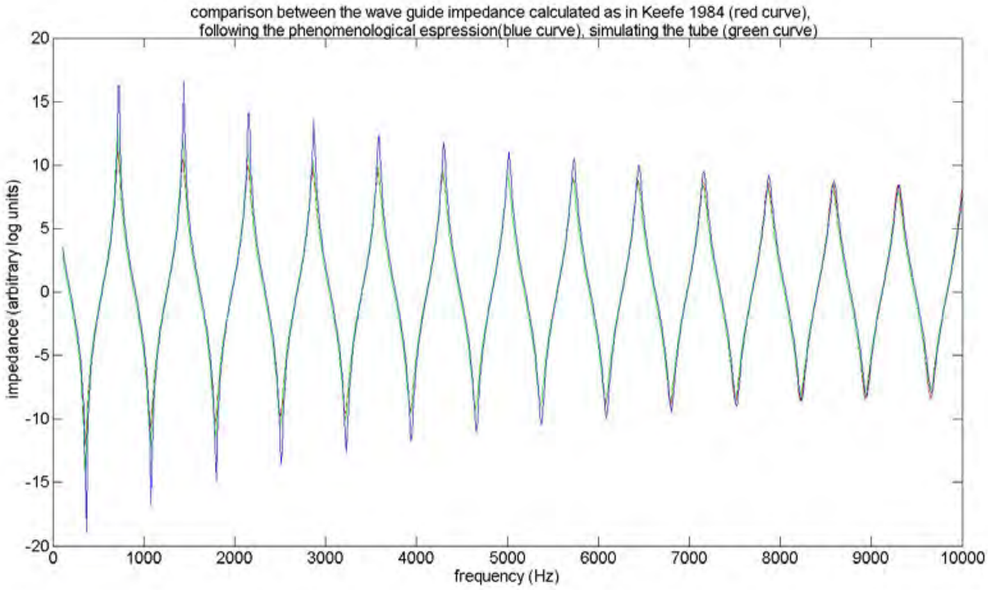
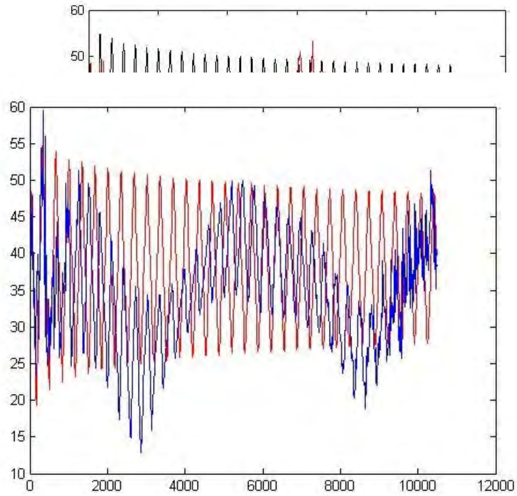



Figure 2: Comparison between the wave guide impedance as in Keefe [3], the curve calculated following the phenomenological expression, and that simulating the tube by finite elements method.

## 2. Direct measurement

The novelty of the proposed method compared with the so-called indirect method, consists of a direct measurement of the input impedance of the ear employing the particular speed probe of Microflown, this probe allowing a simultaneous measurement of pressure and speed [5]. As the source of stimulus signals have been used loudspeakers of the ILO probe. The complete probe is housed inside an opportune cavity, and measures were made by coupling the cavity to some waveguides in order to characterize its behavior.

In the result relative to a tube of 50.6 cm length, one can observe a sort of modulation of amplitude of the impedance measured with respect to the theoretical one, and also a shift of the resonance peaks This modulation is the same regardless of the load (tube of variable length) applied at the ends of the cavity, and allows to assume a resonance effect in accordance to the Helmholtz resonator model. The shift of the resonance peaks can be corrected in the first approximation by considering the system cavity + tube as a single waveguide. By applying the well-known transfer matrix, pressure and velocity can be obtained at the point of interest (mouth of the inlet hose) compared with the data at the measurement point (probe). In figure 3a is shown the comparison between theoretical impedance of a tube of 50 cm length and impedance measured by the intensimetric probe accommodated in the cavity previously described. The shift of the resonance peaks has been corrected through the application of the suitable transfer matrix. The resonance peak responsible for the amplitude modulation has been rented and the measured impedance was corrected to obtain the result of Figure 3b. As it can be seen the measured impedance, suitably corrected, is in good agreement with the known impedance by analytical way. The correction procedure has been applied to direct measurements of input impedance of the ear.



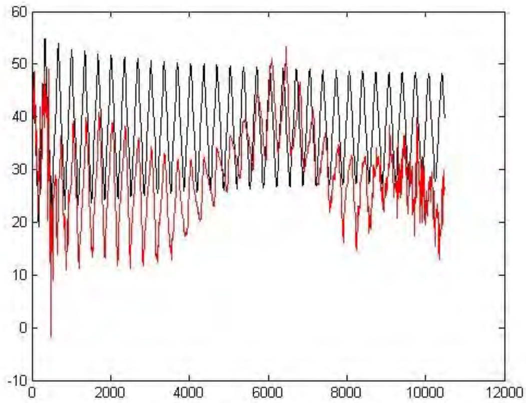




Fig. 3A

Fig. 3B

Fig. 3A. Impedance amplitude of a 50,6 cm length tube. Fig. 3B. Peaks shifting corrected by applying transfer matrix.

## 2 Direct measurement of the input impedance of the ear

By means of direct and indirect methods previously described were performed measures the input impedance of the ear of a subject. The result of the comparison between the two methods is shown in the graph below.

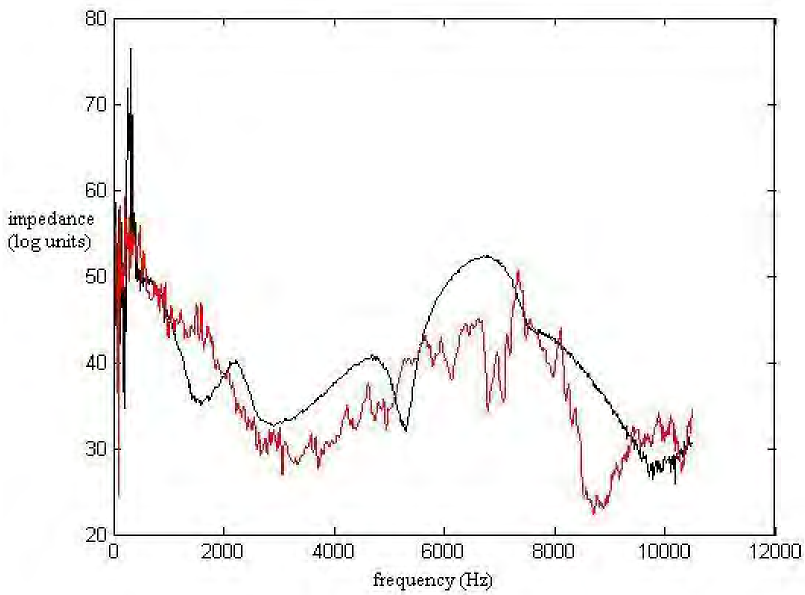


Figure 4. Right ear's imput impedance of Subject n°1 misured by direct method (black curve) and by Thevenin equivalent circuit (red curve).

The impedance in Fig.4 is expressed as 20*log10 the value of the relationship between pressure and volumetric velocity and is normalized to the reference value

$Z_r$ = 105 kg m-4 s.

## 5. Conclusions.

The comparison between the two methods till now described, the first, indirect measurement of the impedance generator via Thevenin equivalent, and the second, being a direct measurement via air speed probe and pressure, show the goodness of the direct method as well as a good interchangeability between the two methodologies. This good result is also supported by the simulations of models through Comsol, as described in Appendix A.

## 6. Appendix A

In Fig.6 is shown the comparison between the direct experimental measurement of the impedance of a tube of 16 cm total length and the simulation obtained by the finite element calculation. It is clearly visible the minimum of impedance due to the cavity within which is housed the air speed probe.

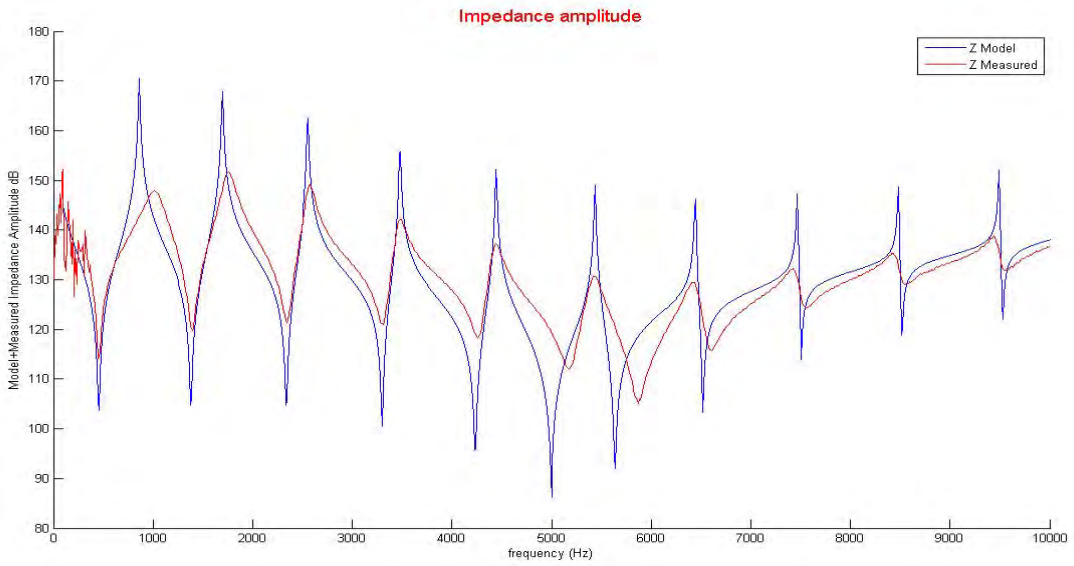



Figure 6a: Comparison between Impedance amplitude of a 16 cm length tube measured with direct method and calculated by finite element method.

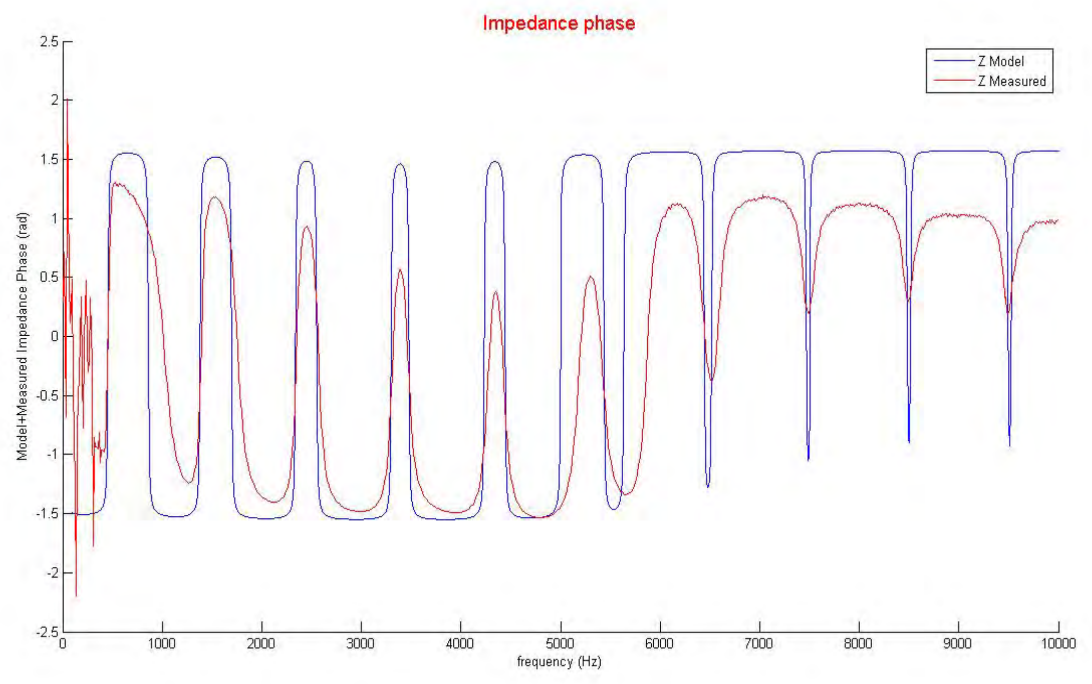



Figure 6b: The same comparison as fig. 6a referring to Impedance Phase.

## References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