# Comparison calibration of a pressure-velocity (p-v) tympanometric probe prototype

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## Introduction

Wide band p-v tympanometry can be defined as the direct measurement of the acoustic immittance of the ear, in the full audio frequency range and possibly in normal air pressure condition, through the acquisition of both pressure and velocity (p-v) signals at the ear canal entrance. To this aim, a prototype of a p-v tympanometric probe has been developed by modifying a standard one, in order to host a Knowles Electronics EK-23133-C36 microphone and a CMOS-compatible acoustic velocimeter. Such a prototype has been then calibrated by comparison with a similar p-v tympanometric probe used as a reference one, this latter hosting anyway a Microflown® match-size intensity probe. Calibration methodology and obtained results are here reported.

## Experimental setup

### Inspection of the probes under comparison

The easiest way to build a tympanometric probe based on pressure-velocity measurements is to start from a standard one. Typically, this instrument consists in a aluminium or plastic cylinder, which hosts inside a microphone (in general 1/10"), a miniaturized source and a tube linked to a pump, responsible of the static pressure variation. A first example of p-v tympanometric probe was obtained using the same chassis and substituting the microphone with a Microflown® PU Match Probe (Fig. 1a). It is then completed by a wide band sound source, in this case an in-ear phone (Fig 1b). Since it is possible to calibrate this kind p-v sensors with various methods, one of which presented in [1] by some of the present work authors, and the velocity sensor has a good sensitivity, this probe will be called reference p-v tympanometric probe from now on.

A similar procedure is used for the "low cost" tympanometric p-v probe, which mounts a new anemometric velocity sensor, based on standard CMOS technology [2, 3] and being developed within SIHT (Sogliano High Industrial Technology) Project. Figure 2 shows the velocimetric side of the printed circuit board, while the pressure microphone is housed on the rear side of the PCB. This is evident in Figure 3: clearly the sensitive axis of the velocimetric sensors is parallel to the case axis of the two probes under comparison calibration. Finally, it is worth to note that the geometry and the volume of the residual air inside the two probes are quite different: this will turn a crucial limit for the calibration via comparison.

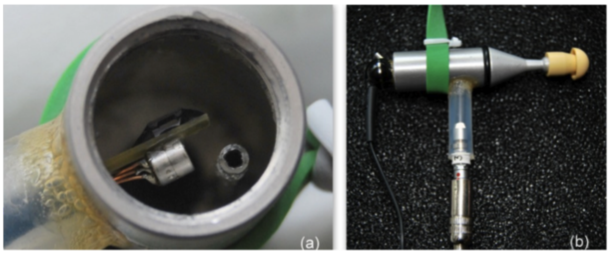


**Figure 1:** Detailed view of the reference p-v tympanometric probe based on Microflown® technology. (b) overall view; (a) housing of the sensor inside the case.

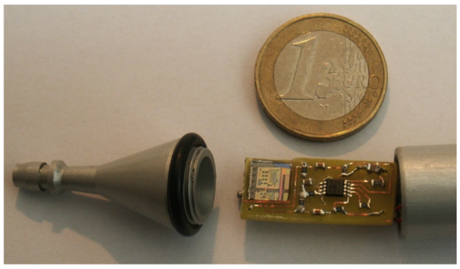

**Figure 2:** Disassembled view of the prototype of the p-v tympanometric probe based on CMOS compatible technology

### The method

Since traditional tympanometry, used at present for diagnosis, limits its working range between 100 and 1200 Hz, the first aim of the procedure is to perform a good calibration within this limited range. Of course, this is not a problem for the reference sensor, because it was already calibrated in a much wider range before the creation of the p-v tympanometric probe prototype, as extensively reported in [1]. On the other hand, the CMOS compatible sensor, because of its different shape, cannot undergo to the same method, and so it must be calibrated through a comparison procedure.

The next step consists in the choice of the reference field for the calibration process. Among standard volumes of 4 $cm^2$, 2 $cm^2$ and 0.2 $cm^2$, available at our laboratory, we chose the last one, because it doesn't have any resonance within the considered range (100-1200 Hz). Finally, impulse responses were measured for the two probes in

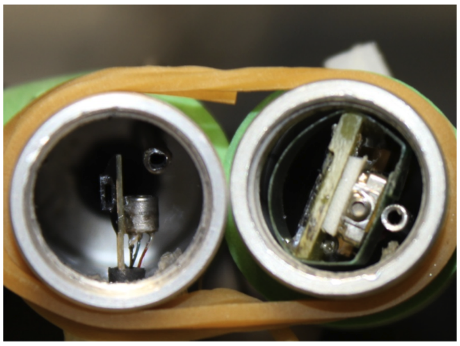

**Figure 3:** Visual comparison of the interior of the two probes. Left: the reference p-v tympanometric probe. Right: CMOS prototype is on the right.

the 0.2 $cm^2$ cavity and their respective correction curves were calculated. The procedure has been then checked by measuring the immittance function of the 2 $cm^2$ cavity with the two probes previously calibrated by comparison.

# Experimental results

## p-v responses measured in the reference field

Results of the comparison calibration executed over the 0.2 $cm^2$ air cavity are reported in Figure 4. In the Figure, blue plots are relative to the reference probe, while the red ones report calibration data of the prototype probe. Results are reported in a wider range, up to 4 kHz so making evident that a resonance occurs between 1.5 and 2 kHz, which is outside the functional range for timpanometry (100-1200 Hz).

Figure 5 shows amplitude of the specific acoustic admittance $Y(\omega) = \mathcal{F}(v)/\mathcal{F}(p)$ for both probes. Clearly, here, results from the prototype probe are uncalibrated. In fact a similar behaviour for the amplitude is found, but quite different phases.

## Checking of the comparison calibration procedure

As fully detailed in [1] the correction curve $\Gamma(\omega)$ for calibrating any p-v probe is given by the complex ratio of the reference admittance and the rough admittance measured with the p-v probe under calibration. As a check of the comparison calibration process here presented, measurements obtained with the reference probe and the calibrated prototype one are reported below.

The check has been done by comparing the admittance measured with the two probes over a 2 $cm^2$ air cavity. Plots in Figure 6 compare results obtained with the prototype probe (red) and the reference one (blue). Dashed lines represent data obtained with the prototype probe after calibration. The calibration gives satisfactory results below 700 Hz while loses its effectiveness at upper frequencies. A possible interpretation of this bad behaviour may rely on the different geometries inside the probes. In particular, the major problem is certainly due to the big difference of the inner air volumes, as clearly shown in Figure 3.

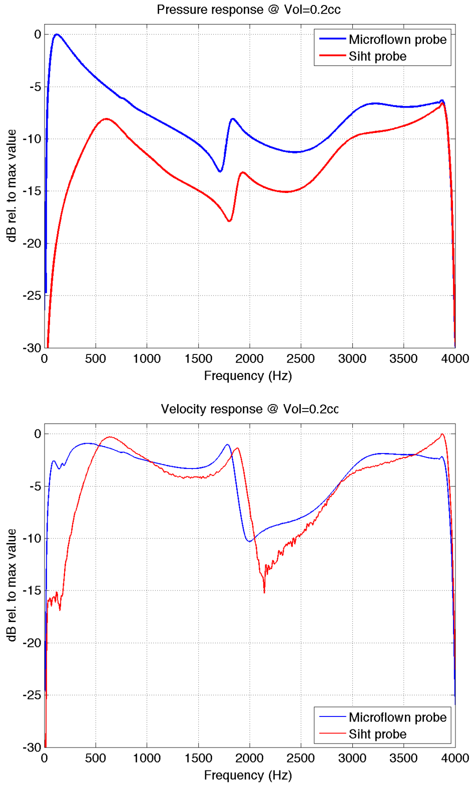


**Figure 4:** Pressure (top) and velocity (bottom) responses of the probes coupled to a 0.2 $cm^2$ volume.

# Conclusions

The comparison calibration of a CMOS-compatible prototype of a p-v tympanometric probe with a reference probe has been done by using a 0.2 $cm^2$ air cavity and the calibration process has been then checked over a standard 2 $cm^2$ air cavity.

Obtained results in the [100, 1200] Hz frequency range show that the calibration process loses its effectiveness at frequencies above 700 Hz. This is not due at all to the characteristics of the used p-v sensors but mainly to the geometrical differences in their assembly into the case of the tympanometric probes and especially to the different residual volumes of air inside them.

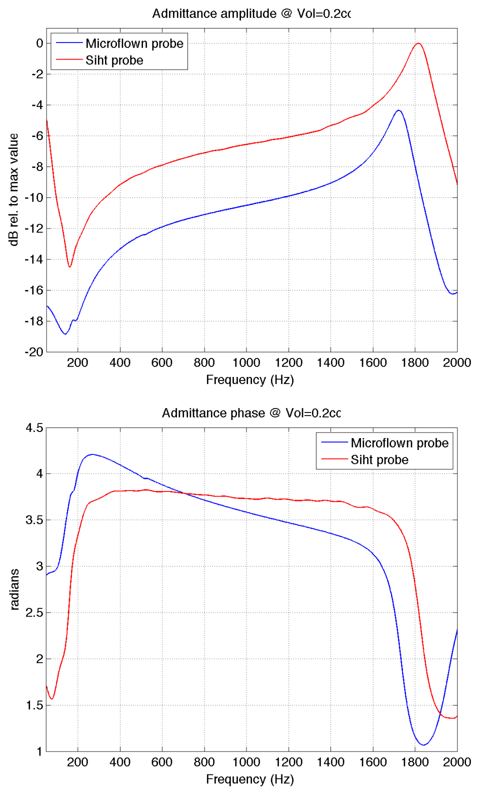


**Figure 5:** Amplitude (top) and phase (bottom) of specific admittance measured with the reference probe, compared with the same quantity measured with the prototype one (SIHT probe). Data collected with the SIHT probe are clearly uncalibrated.

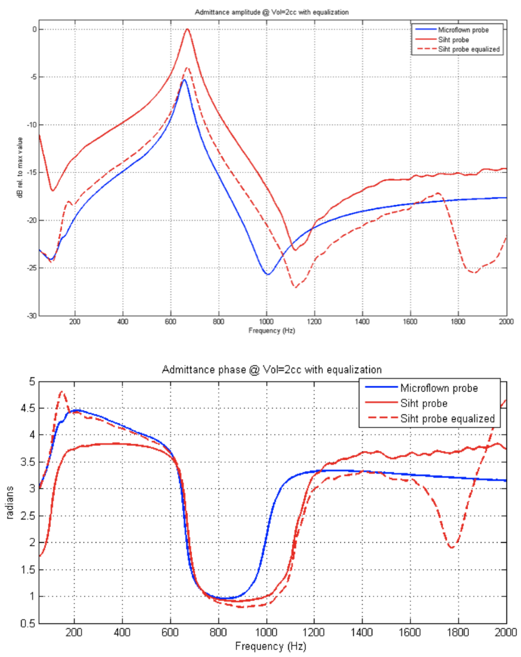


**Figure 6:** Specific admittance for a 2 $cm^2$ volume. Response of the SIHT probe before (red, continous) and after (red, dashed) the calibration is compared to the reference one (blue)

# References


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