A MODEL OF UNCERTAINTY CALCULATION FOR THE CALIBRATION OF AUDIOMETERS

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ABSTRACT

The goal of this paper is to present a model to calculate the uncertainty applied to the audiometers calibration process which adjusts to the limits expressed on the IEC60645-1 Standard (2001 edition) and to the specific standards for the uncertainty calculus. The most outstanding factors in the calibration process, both for aerial and bone conduction transducers, are presented and illustrated for the cases of a circumaural earphone and a bone vibrator.

INTRODUCTION

The current international standard [IEC60645-1] establishes the tolerances and the maximum uncertainties allowed in an audiometer's calibration process. Table 1 includes the expanded uncertainty (with coverage factor k = 2) for the most important parameters:

Measured Quantity	U_{max} (k = 2)
Sound pressure level (125 Hz to 4 kHz)	0,7 dB
Sound pressure level (over 4kHz)	1,2 dB
Frequency	0,5 %
Harmonic distortion	0,5 %
Force level (125 Hz to 4 kHz)	1 dB
Force level (over 4 kHz)	1,5 dB
Linearity in the HL control	0,1 dB

Table 1: Values for uncertainty specified in [IEC60645-1]

This paper's goal is to present a model that characterizes the uncertainty for the measures taken, in which the most outstanding factors that affect the calibration process are perfectly identified and which application is simple in a laboratory. Due to the length of the piece of work, only the data concerning to an aerial conduction transducer (HDA200) and to a bone conduction transducer (B71) are presented.

CONSIDERED FACTORS

The first three factors are the pressure, humidity and temperature conditions. Due to the conditions of the environment where the measurements where taken, neither the pressure nor the humidity were controlled, therefore references will be made only to the variation of measurements with the temperature since this was the only controlled factor. The second factor of influence detected during the measurement process is the assembly and the placement of the devices that are part of the measurement chain. Uncertainty components exists caused by the center of the circumaural earphone piece with the microphone used on the artificial ear AEC101.

Table 2 gathers the outstanding factors:

Component	Circumaural Earphone HDA200	Bone Vibrator B-71
$u(x_1)$: Acoustic calibrator B&K4226	✓	✓
$u(x_2)$: Acoustic calibrator. Temporal Stability.	✓	✓
$u(x_3)$: Acoustic calibrator. Dependency on temperature.	✓	✓
$u(x_4)$: Acoustic calibrator. Dependency on pressure.	✓	✓
$u(x_5)$: Acoustic calibrator. Rotation of the calibrator on the microphone.	✓	✓
$u(x_6)$: Sound Level Meter. Dependency on temperature.	✓	✓
$u(x_7)$: Sound Level Meter. Dependency on humidity.	✓	✓
$u(x_8)$: Sound Level Meter. Dependency on pressure.	✓	✓
$u(x_9)$: Sound Level Meter. Resolution.	✓	✓
$u(x_{10})$: 2559 Microphone.	✓	✓
$u(x_{11})$: AEC101 Artificial Ear. Correction factor.	✓	
$u(x_{12})$: B&K4152 Microphone	n/a	n/a
$u(x_{13})$: AMC493 Artificial Mastoid.		✓
$u(x_{14})$: B&K4093 Artificial Mastoid.		✓
$u(x_{15})$: HDA200 Dependency on Temperature,	✓	
$u(x_{16})$: HDA200 Dependency on Placement. Left earpiece.	✓	
$u(x_{17})$: HDA200 Dependency on Placement. Right earpiece.	✓	
$u(x_{18})$: DT 48 Kind A uncertainty. Left earpiece.	n/a	n/a
$u(x_{19})$: DT 48 Kind A uncertainty. Right earpiece.	n/a	n/a
$u(x_{20})$: EARTONE 3A kind A uncertainty. Right earpiece.	n/a	n/a
$u(x_{21})$: EARTONE 3A kind A uncertainty. Left earpiece.	n/a	n/a
$u(x_{22})$: B-71 Dependency on placement.		✓
$u(x_{23})$: B-71 Dependency on temperature.		✓

Table 2: Uncertainty components for the different transducers.

Aerial Conduction Transducers Results: HDA200 Circumaural Earphones.

Having all the components described in Table 2 as non correlated input components with sensibility factors equals to 1, the expression of the typical combined uncertainty for this transducer is described in the equations Eq. 1 y Eq. 2 for both the left and right earpieces.

HDA200 – Left earpiece:

$$\begin{aligned} u_c^2(y) = {} & u^2(x_1)+u^2(x_2)+u^2(x_3)+u^2(x_4)+u^2(x_5)+u^2(x_6)+u^2(x_7)+u^2(x_8)+ \\ & +u^2(x_9)+u^2(x_{10})+u^2(x_{11})+u^2(x_{15})+u^2(x_{16}) \end{aligned} \qquad \text{Eq. 1}$$

HDA200 – Right earpiece:

$$u_c^2(y) = u^2(x_1) + u^2(x_2) + u^2(x_3) + u^2(x_4) + u^2(x_5) + u^2(x_6) + u^2(x_7) + u^2(x_8) + \\ + u^2(x_9) + u^2(x_{10}) + u^2(x_{11}) + u^2(x_{15}) + u^2(x_{17}) \qquad \text{Eq. 2}$$

Moreover, applying the Welch–Satterthewaite equation, the degrees of freedom are calculated, with which the value of the coverage factor, kp, is obtained in order to determine the value of the expanded uncertainty, U, with a coverage probability of 95,45%.

Using the values for each frequency, the results in Table 3 are obtained:

Frequency (Hz)	HDA200 – Left earphone			HDA200 – Right earphone		
	$u_c(y)$ (dB)	k_p	U (dB)	$u_c(y)$ (dB)	k_p	U (dB)
125	0,276	2,000	± 0,552	0,308	2,000	± 0,616
250	0,214	2,050	± 0,439	0,252	2,000	± 0,504
500	0,181	2,000	± 0,362	0,215	2,000	± 0,430
750	0,184	2,000	± 0,368	0,259	2,000	± 0,518
1.000	0,214	2,000	± 0,428	0,214	2,000	± 0,428
1.500	0,257	2,000	± 0,514	0,196	2,000	± 0,392
2.000	0,236	2,000	± 0,472	0,258	2,000	± 0,516
3.000	0,435	2,000	± 0,870	0,409	2,000	± 0,818
4.000	0,337	2,000	± 0,674	0,289	2,000	± 0,578
6.000	0,286	2,000	± 0,572	0,211	2,000	± 0,422
8.000	0,302	2,000	± 0,604	0,240	2,000	± 0,480

Table 3: Uncertainty values for the HDA200 earphones.

From all the uncertainty contributions taken into account for these earphones, the most important one, for every frequency, is the one caused by the dependency of the response on the placement of the devices, for the left earpiece (u(x16)) as well as for the right earpiece (u(x17)), as Figure 1 and Figure 2 show.

As shown in Table 3, the results of the measurements are within the limits that the standard specifies (Table 1) except for 3 kHz, frequency at which the uncertainty contribution caused by the dependency of the response on the placement of the devices raises up to 50% for both earpieces. Therefore, and since these contributions have an A type evaluation, it is possible to reduce the values by increasing the number of measurements taken. On the other hand, since incrementing the number of measurements will produce an increment on the cost of the process, maybe these results could be assumed.

Another interesting way of expressing these uncertainty values, is to see them as a percentage of the tolerance established by the [IEC60645-1] standard, as shown on Figure 2.

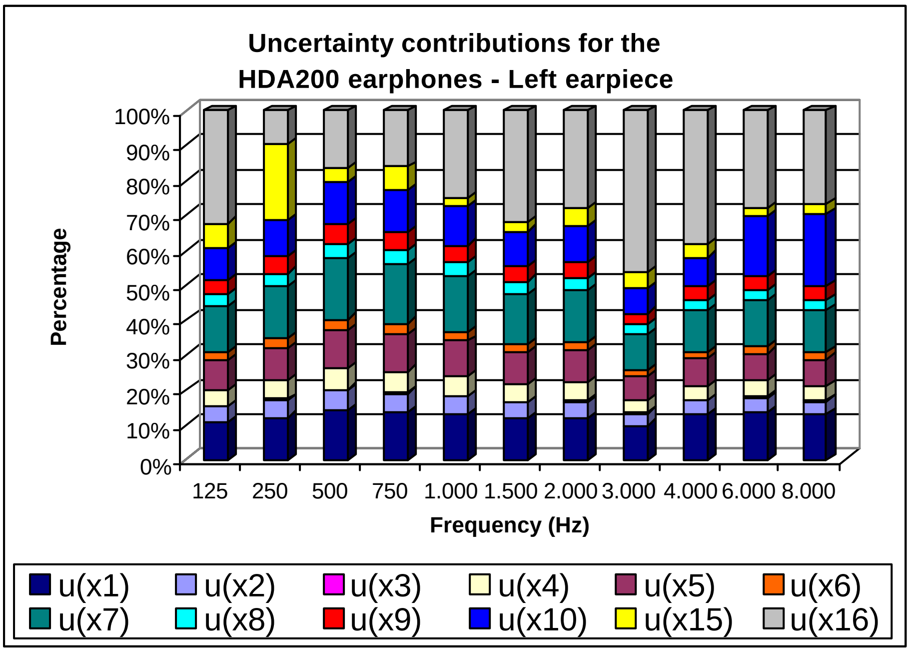

Figure 1: Uncertainty contributions for the HDA200 earphones – Left earpiece.

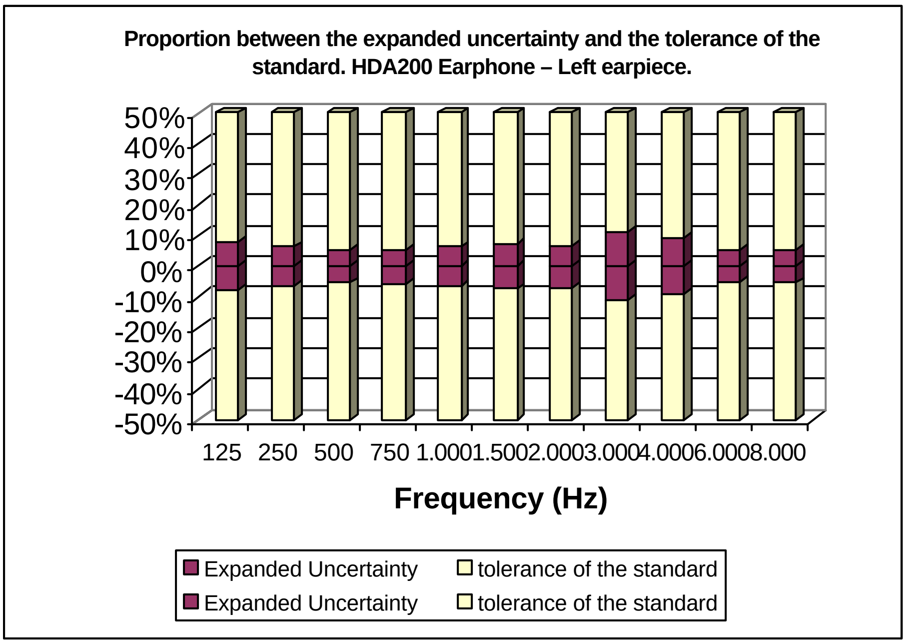

Figure 2: Proportion between the expanded uncertainty and the tolerance of the standard. HDA200 Earphone – Left earpiece.

Bone Conduction Transducers Results: B-71 Bone Vibrator.

Particularizing the expression for the case of the B-71 bone vibrator, and having the sensibility factors of value 1, the whole expression of the typical combined uncertainty for this transducer is as described in the equation Eq. 3.

$$u_c^2(y) = u^2(x_1) + u^2(x_2) + u^2(x_3) + u^2(x_4) + u^2(x_5) + u^2(x_6) + u^2(x_7) + \\ + u^2(x_8) + u^2(x_9) + u^2(x_{10}) + u^2(x_{14}) + u^2(x_{22}) + u^2(x_{23}) \qquad \text{Eq. 3}$$

Moreover, applying the Welch – Satterthewaite equation, the degrees of freedom are calculated, with which the value of the coverage factor, kp, is obtained in order to determine the value of the expanded uncertainty, U, with a coverage probability of 95,45%.

Substituting the values for each frequency, the results in Table 4 are obtained:

Frequency (Hz)	Bone vibrator B-71		
	$u_c(y)$ (dB)	k_p	U (dB)
250	0,4319	2,00	± 0,864
500	0,5433	2,25	± 1,222
750	0,4316	2,05	± 0,885
1.000	0,3309	2,00	± 0,662
1.500	0,3951	2,07	± 0,818
2.000	0,6379	2,00	± 1,276
3.000	0,8383	2,05	± 1,719
4.000	1,1756	2,13	± 2,504
6.000	0,6462	2,06	± 1,331

Table 4: Uncertainty values for the bone vibrator B-71.

Comparing these results with the values in Table 1, we can observe that for the frequencies of 500 Hz, 2 kHz, 3 kHz and 4 kHz, the results are not compliant with the specified uncertainty values in the standard. As shown in Figure 3, for these frequencies, the contributions caused by the dependency of the response on the placement of the devices (u(x22)) and the dependency of the response on the temperature (u(x23)), represents near a 50% of the whole uncertainty value. This fact is specially outstanding for the u(x23) contribution for high frequencies values. Therefore, and since this contribution has a B type evaluation, it appears as a good option to consider this dependency through a temperature variation coefficient, with which the measurements could be rectified. Moreover, and as it was stated before, the contributions with an A type evaluation (this is the case of u(x22) contribution) can be improved by increasing the number of measurements to be done.

The Figure 4 shows another way of expressing uncertainty, as a percentage of the tolerance established by the standard. As shown in the figure, uncertainty is specially outstanding for high frequencies values, raising up to 35% of the admitted tolerance. This fact reduces the margin left for calibration by the standard and therefore must be rectified as explained before in order to allow the declaration of compliance with the standard.

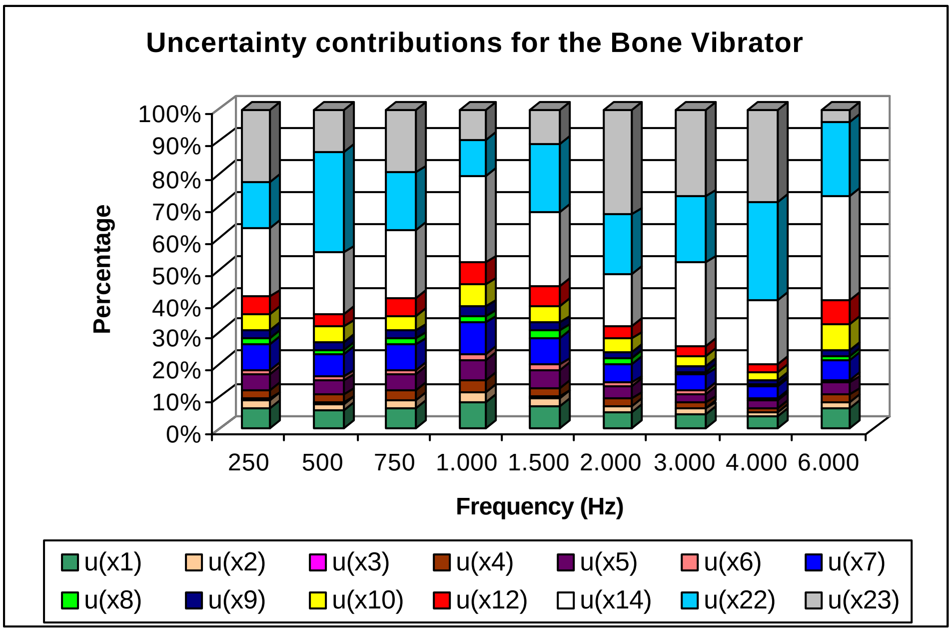

Figure 3: Uncertainty contributions for the bone vibrator B-71.

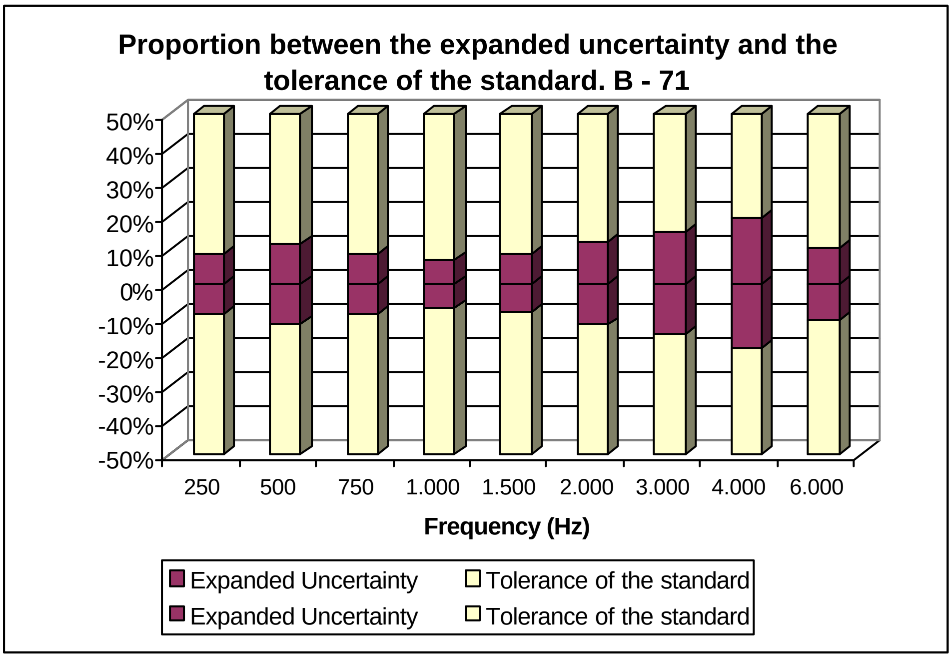

Figure 4: Proportion between the expanded uncertainty and the tolerance of the standard – Bone Vibrator B-71.

CONCLUSIONS

The obtained model for uncertainty allows to simplify the calibration of pure tone audiometers since most of the contributions have been considered using a B type evaluation, giving a coverage probability and avoiding the realization of multiple measurements during the calibration process.

In the case of the HDA200 earphone, the inclusion of the dependency of the response on the placement of the devices as a B type evaluation uncertainty contribution, will allow the operator to disregard for the relative position between the earpiece and the microphone. On the other hand, several measurements will have to be done since the dependency of the response on the temperature has been included as an A type evaluation uncertainty contribution, fact that will increase the cost of the calibration procedure.

On the contrary, in the calibration of an audiometer using bone conduction transducers, outstanding variations of the response have been observed depending on the placement of the bone vibrator on the artificial mastoids. This requires a special attention of the operator when placing the transducer on the artificial mastoids, obtaining a remarkable A type evaluation contribution. Temperature clearly affects the response of the bone conduction transducers, but not having found a linear variation coefficient this dependency has been considered through a B type evaluation contribution, fact that will require to keep the room where the calibration process is taking place in a certain temperature range.

REFERENCES AND BIBLIOGRAPHY

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