

# Primary calibration of measurement microphones in the world: state of art

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**Abstract.** This paper presents an overview of state of art of measurement microphones primary calibration in the world with emphasis on Brazil practices. Initially, pressure field calibration is summarized being discussed mainly the couplers used to create pressure field conditions. After that, free-field calibration is presented being commented especially the anechoic chambers used to create free-field conditions. Concluding, it is showed diffuse-field calibration that is being investigated. It is presented, in particular, the reverberant chambers used to create diffuse-field conditions.

## 1. Introduction

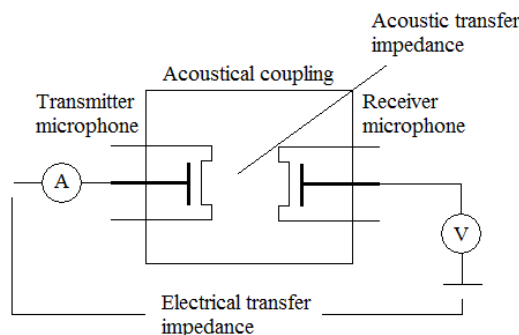
Calibration of a measurement microphone commonly consists in determining its sensitivity (modulus and phase) as a function of frequency, i.e., determining the ratio between the incident sound pressure and the emerging voltage as a function of frequency.

Primary calibration of measurement microphones usually is performed by the reciprocity method using three microphones. Following this method, the microphones are acoustically coupled in pairs and using one of them as sound source (transmitter microphone) and other as sound receiver (receiver microphone), the electrical and acoustic transfer impedances are determined (figure 1). Thus, from the determined impedances for each pair of microphones, the sensitivity of each microphone is calculated [1-3].

Such as sensitivity changes according to the sound field, three theoretical sound fields were established for calibration purposes: pressure field, free-field and diffuse-field [1]. Therefore, a microphone must be calibrated in a sound field similar to that where it is expected to operate.

The motivation of this paper is to present an overview of state of art of measurement microphones primary calibrations in the world with emphasis on Brazil practices.





**Figure 1.** Primary calibration of measurement microphones.

## 2. Pressure field primary calibration

Pressure field reciprocity calibration is performed as stated by the international standard IEC 61094-2 [2]. It is performed in acoustic couplers and, according to International Bureau of Weights and Measures (BIPM), thirteen National Metrology Institutes (NMIs) are recognized for their accomplishment, being eleven along with the 1992 edition and two along with the 2009 edition [4]. The 2009 edition presents a significant change compared to the earlier edition: it presents a solution to heat conduction effect at low frequencies ("low frequency solution") and another solution that includes heat conduction effect and viscous losses at high frequencies ("broad-band solution") while the 1992 edition only presents one solution for heat conduction effect that applies to all frequency range [2,5]. The 2009 edition was tested for the first time in the CCAUV.A-K5 key comparison [6], whose results were presented in 2014 [7]. Brazil, through Inmetro, is recognized for its accomplishment to perform this calibration as stated by the 1992 edition and took part in the CCAUV.A-K5.

Pressure field calibration was tested in four key comparisons conducted by the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV) of the International Committee for Weights and Measures (CIPM): CCAUV.A-K1, CCAUV.A-K2, CCAUV.A-K3 and CCAUV.A-K5, being CCAUV.A-K5 the most recent. Inmetro also took part in the CCAUV.A-K1 and CCAUV.A-K3 [7].

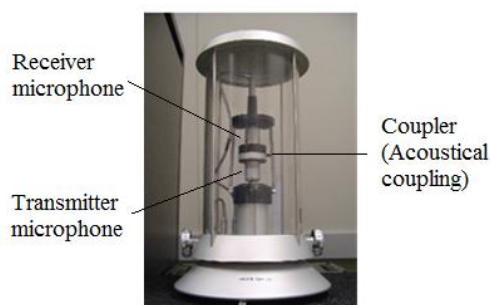
Twelve NMIs took part in the CCAUV.A-K5: NPL from United Kingdom, DPLA from Denmark, GUM from Poland, NIM from China, Inmetro, Cenam from Mexico, Inrim from Italy, Nmisa from South Africa, Kriss from Republic of Korea, NRC from Canada, Vniiftri from Russia Federation and NMIJ from Japan. The standards circulated among the institutes were two 1-inch laboratory standard microphones designed for pressure field. Their sensitivity (modulus and phase) were calibrated in the frequency range from 2 to 10000 Hz (being phase optional and range 2-20 Hz for modulus optional as well). The measurements took place between January 2011 - July 2012 and the final report was presented in 2014 [6].

In this comparison, NPL and GUM used a single coupler for the acoustical coupling. NPL used a 2 cc coupler and GUM used a 1.5 cc coupler without capillary tubes. NMIJ used two plane wave couplers, but it did not specify their volumes. Kriss and Viniiftri used two plane wave couplers, one 2 cc and other 4 cc. DPLA and NRC used four different plane wave couplers, but they did not specify their volumes being the couplers used by NRC did not have capillary tubes. NIM, Inrim and Nmisa also used four plane wave couplers. NIM used couplers with nominal volumes of 1.5, 2, 2.7 and 4 cc. The couplers used by Inrim were 1.2, 1.5, 2 and 2.7 cc and the ones used by Nmisa were 1, 1.5, 2 and 2.7 cc without capillary tubes. Cenam used five plane wave couplers with nominal volumes of 1.2, 1.5, 2, 2.7 and 4 cc being the three largest used in measurements below 40 Hz and the three smallest used in measurements from 20 Hz [6].

Regarding the effect on sensitivity due to the heat conduction, NPL, Inrim, Nmisa and NRC used the broad-band solution specified in the standard. GUM used the low frequency solution. DPLA

combined the low frequency and the broad-band solution and, in order to minimize fluctuations on the microphones responses, a gradual transition between two solutions was made [6].

Inmetro used four plane wave couplers whose volumes were 1.2, 1.6, 3 and 5 cc and used the broad-band solution [6]. Figure 2 shows a picture of the setup for pressure field reciprocity calibration in Inmetro.



**Figure 2.** Setup for pressure field reciprocity calibration in Inmetro.

Results, showed in the final report [6], do not indicate a relationship between the number of couplers and a good performance or between the heat conduction solution used and a good performance.

### 3. Free-field primary calibration

Free-field reciprocity calibration is performed in anechoic chambers. It was performed as stated by the international standard IEC 61094-3 [3] and, according to BIPM, three NMIs are recognized for their accomplishment [4]. It was tested in only one key comparison conducted by CCAUV, the CCAUV.A-K4, and only the sensitivity modulus was measured [7]. Brazil also is recognized for its accomplishment to perform the free-field calibration.

Seven NMIs took part in the CCAUV.A-K4: DFM from Denmark, Cenam, Kriss, NMII, LNE from France, PTB from Germany and Inmetro. Two ½-inch laboratory standard microphones designed for pressure field were calibrated in the frequency range from 1 to 40 kHz (40 kHz optional). The measurements took place from February 2007 - February 2008 and the results were presented in 2010 [8].

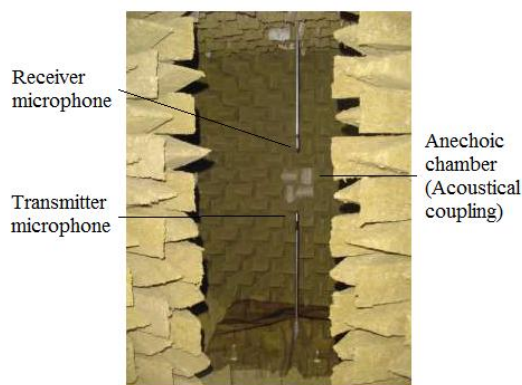
In this comparison, DFM used a small anechoic chamber of 3.6 m<sup>3</sup> volume. Kriss and PTB, in turn, used a little higher anechoic chamber: 12 m<sup>3</sup> and 15 m<sup>3</sup> volume respectively. NMII used a large anechoic chamber of 547 m<sup>3</sup> volume, however, to compensate low signal-to-noise ratio at frequencies below 5 kHz it used, as transmitter microphone, microphones with higher sensitivity than the microphones of key comparison, which were used only as receiver microphone [8].

LNE determined the electrical and acoustic transfer impedances using three distances between transmitter and receiver microphones. The distances were 250, 300 and 350 mm. Cenam and NMII used four distances between the microphones. Cenam used distances of 160, 189, 220 and 250 mm, while NMII used distances of 100, 150, 200 and 250 mm being the three lowest used for the range 1-5 kHz and the three highest for the range 6.3-40 kHz. Kriss used five distances between microphones: 100, 150, 200, 250 and 300 mm [8].

Inmetro used a small anechoic chamber of 2.8 m<sup>3</sup> volume and determined the electrical and acoustic transfer impedances using four distances between microphones: 170, 200, 240 and 300 mm [8]. At present, Inmetro measures at only the distance of 300 mm because it uses an innovative signal processing technique that eliminates the needs to calculate the average on space [9]. This technique

was checked in the CCAUV.A-K4. Figure 3 shows a picture of the setup for free-field reciprocity calibration in Inmetro.

Results, showed in the final report [8], do not indicate a relationship between the anechoic chamber volume and a good performance or between the number of distances used and a good performance.



**Figure 3.** Setup for free-field reciprocity calibration in Inmetro.

#### 4. Diffuse-field primary calibration

Diffuse-field reciprocity calibration is performed in reverberant chambers but it is not consolidated, i.e., there is no international standard that deals with this subject and no key comparison was conducted by the CCAUV [7]. Four NMIs are researching this calibration: DPLA/DFM [10], NPL [11], PTB [12] and Inmetro [13].

NPL measured in a reverberation chamber of  $330 \text{ m}^3$  volume while DPLA/DFM measured in a short reverberation chamber of  $2 \text{ m}^3$  and lastly PTB measured in a very short reverberation chamber of  $0.23 \text{ m}^3$  [10-12].

NPL measured voltage, current and reverberation time in three positions, far enough away from all boundary surfaces, for determining the electrical and acoustic transfer impedances. In this context, “far enough away” means that the distance should be much greater than the diffuse-field distance which is the distance where the direct sound energy density equals the average energy density. DPLA/DFM, in turn, measured in sixteen positions representing spatially independent points, i.e., they should be spaced at least by half a wavelength. On the other, PTB measured in twenty-five spatial combinations result of a 5x5 used positions montage [10-12].

No research [10-13] presented satisfactory results yet, i.e., with adequate accuracy and precision (standard deviation).

Inmetro is measuring in a small reverberation chamber of  $2 \text{ m}^3$  with different diffusers (hanging diffusers, panels, and/or boundary diffusers also known as volume diffusers, spherical caps) and measuring in sixteen and thirty-two spatial combinations (result of a 4x4 and 4x8 used positions montage). Figure 4 shows a picture of the experimental arrangement for diffuse-field reciprocity calibration in Inmetro.



**Figure 4.** Experimental arrangement for diffuse-field reciprocity calibration in Inmetro.

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