TECHNICAL PROTOCOL FOR REGIONAL KEY COMPARISON ON LS2P MICROPHONE CALIBRATION IN PRESSURE FIELD

SIM.AUV.A-K6

June 12, 2023

National Institute of Metrology, Quality and Technology – INMETRO (Brazil)

Preface

It was agreed at the Fall Meeting of SIM MWG-9, Acoustics, Ultrasound and Vibration held online in October 2021 that a regional comparison on primary calibration of laboratory standard microphones type LS2P in pressure field should be carried to compare sensitivity measurement capabilities.

The National Institute of Metrology, Quality and Technology – INMETRO/Brazil was chosen to be the pilot laboratory. The Interamerican Metrology System – SIM and the National Institute of Standards and Technology – NIST/USA would provide the microphones to be circulated and calibrated by each participant.

This technical protocol specifies the basic procedures necessary for the comparison, but not the procedures for the microphone calibration.

Participants

The national metrology institutes below will participate in this comparison and their contact details are presented in Appendix A.

1. INMETRO, Brazil (pilot laboratory);
2. CENAM, Mexico;
3. INTI, Argentina;
4. LACOMET, Costa Rica;
5. NIST, USA;
6. NRC, Canada.

Microphones to be circulated

For this comparison, the microphones to be circulated will be two LS2P microphones, manufactured by Brüel and Kjær, type 4180 [1], serial numbers 2701981 and 3257821. These microphones require a polarizing voltage of 200 V. The stability of the microphones will be monitored by the pilot laboratory prior to and during the period of their circulation for calibration by the participants.

Transportation, check and manipulation

Each participant is responsible for the transportation of the microphones to the next one as specified in the comparison schedule. The microphones must be carefully packaged to avoid sudden shocks and prevent them from changes in sensitivity.

Each participant shall inform the pilot laboratory when the microphones are received from the previous participant and when the microphones are delivered to the next participant. This information is important to keep the circulation of the microphones under control.

Upon arrival of the microphones, the participant is requested to check if any damage has occurred to the protective package or to the microphones during transportation. If any damage is observed, then the participant shall contact the pilot laboratory.

Furthermore, careful manipulation of the microphones by properly trained staff of each participant is an essential requirement. The participant responsible for transportation of the microphone shall avoid their inappropriate manipulation by customs officers or by any other untrained person. The microphones must not be used for any other purpose than those associated with the calibration for this comparison. Sudden shocks can be caused by applying sound calibrators and pistonphones to the microphones and these actions should be avoided. No grease or similar lubricating substances shall be applied to the microphones. The microphones have a suitably flat front surface, which makes the use of grease unnecessary.

Measurements

Each participant shall determine the microphones' sensitivities by primary method in pressure field therefore this comparison will only consider measurement results obtained in such method and field. It is expected that most participants will fulfil the measurement requirements by implementing the reciprocity technique. Where the reciprocity technique is to be used, this shall be in accordance with IEC 61094-2:2009 + Amd1:2022 [2]. If the "Low frequency solution" is applied, care should be taken to avoid a discontinuity in the frequency response. The use of hydrogen-filled couplers is not recommended, but where a participant intends to use such method, the circulated microphones shall only be used as receivers.

Table 1 shows the measurands and frequency range within the scope of this comparison. It is required to determine the open-circuit pressure sensitivity modulus of each microphone and, optionally, the open-circuit pressure sensitivity phase. Appendix B shows the summary of expected measurements.

Table 1. Scope of the SIM.AUV.A-K6 comparison.

Frequency range	Sensitivity modulus	Sensitivity phase
2 Hz to 16 Hz (1/3-octave)	Optional	Optional
20 Hz to 20 kHz (1/3-octave)	Mandatory	Optional
25 kHz	Optional	Optional

Uncertainty analysis

Each participant shall submit its final results with an uncertainty budget (for sensitivity modulus and, where applicable, for sensitivity phase) to the pilot laboratory. Failure to do so will result in the exclusion of the participant since this is a CIPM requirement [3]. The ISO document "Evaluation of measurement data – Guide to the expression of uncertainty in measurement" [4] shall be used as the reference document

for the calculation of measurement uncertainty. Uncertainty budget should be based on a confidence probability of 95 % (k = 1,96).

Reporting results

The open-circuit pressure sensitivity modulus shall be reported in decibels with a reference value of 1 V/Pa.

The convention to be used for reporting the sensitivity phase is that it approaches 180º at low frequencies and is 90º at the resonance frequency of the microphone, i.e. the open-circuit pressure sensitivity phase shall be reported as positive values.

The base-10 system of frequencies specified in IEC 61260-1:2014 [5] shall be used. Accordingly, measurements shall be carried out and reported at frequencies calculated by the equations given in IEC 61260-1:2014 [5]. Appendix C lists the one-third-octave band center frequencies over the entire range of this comparison. The actual frequency that can be set during a measurement will be determined by the particular measurement system used. The effect on the measured sensitivity caused by differences between the set frequency and the calculated frequency shall be accounted by each participant in its uncertainty analysis. Any other frequencies reported by the participants will not be collated by the pilot laboratory. The frequency range of any calibration and measurement capability (CMC) that a participant intends to declare as being supported by this comparison under the mutual recognition agreement (MRA) must correspond to, or fall within, the range of data to be reported by the institute.

Results shall be corrected for the reference environmental conditions given in IEC 61094-2:2009 + Amd1:2022 (temperature: 23 ºC, static pressure: 101,325 kPa and relative humidity: 50 %) [2] using as reference the paper authored by Knud Rasmussen [6].

Moreover, it is suggested that each participant reports the following additional information: 1) front cavity depth, 2) equivalent volume, 3) front cavity volume, 4) resonance frequency, 5) loss factor for each microphone and 6) if the circulating microphones were used, or not, as a sound source (i.e. as a transmitter microphone). These additional information are for investigation purposes only. The participant shall indicate if the reported values are nominal or measured/calculated ones.

Any deviations from the recommendation in IEC 61094-2:2009 + Amd1:2022 [2] shall be reported and uncertainty components caused by these deviations shall be included in the uncertainty budget.

Each participant shall report calibration results by using a spreadsheet template sent by the pilot laboratory and the official certificate in the format that would be normally issued to a customer. It is responsibility of each participant to check that the results reported in the template are consistent with the reported in the certificates as the template data will be used as the basis for the analysis. The official certificate shall be properly signed and approved by the issuing laboratory.

The results (template and signed certificate) shall be sent to pilot laboratory by e-mail (tbmilhomem@inmetro.gov.br) within four weeks of the end of the scheduled measurement period. It is not necessary to send the printed template and certificate.

Finance

Each participant is responsible for its costs related to calibrations and, in addition, for transportation and any associated fees to deliver the microphones to the next participant. It is agreed that the receiver shall not be responsible for any payment if a door-to-door delivery service is employed by the sender. Each participant responsible for any damage to the microphones while they are under its responsibility/care, i.e. the period from date of receipt of the microphones until the date of receipt by the next participant, including the period taken for delivery of the microphones.

Timetable

The timetable of the comparison is presented in Table 2. It is essential that the microphones be transported to the next participant on time. Any change of the timetable must be justified and agreed.

Table 2 – Timetable for the SIM.AUV.A-K6 comparison.

1) Check of microphones stability	
National Metrology Institute	Period
INMETRO	May 29 to September 08, 2023
2) Circulation of the microphones	
National Metrology Institutes	Period
INMETRO	September 11 to September 29, 2023
Transportation of the microphones by previous participant to the next one	
NRC	October 23 to November 10, 2023
Transportation of the microphones by previous participant to the next one	
NIST	December 04, 2023 to January 12, 2024
Transportation of the microphones by previous participant to the next one	
INMETRO	February 05 to March 01, 2024
Transportation of the microphones by previous participant to the next one	
CENAM	March 25 to April 19, 2024
Transportation of the microphones by previous participant to the next one	
LACOMET	May 13 to May 31, 2024
Transportation of the microphones by previous participant to the next one	
INMETRO	June 24 to July 12, 2024
Transportation of the microphones by previous participant to the next one	
INTI	August 5 to August 23, 2024
Transportation of the microphones by previous participant to the next one	
INMETRO	September 16 to October 4, 2024

(continue)

3) Analysis of the reported results	
National Metrology Institute	Period
INMETRO	October 7 to December 6, 2024

Notes:

1. A period of three weeks is allocated for the microphones calibration by each participant with exception to CENAM, which is allocated a period of four weeks due to the Holy Week.
2. A period of three weeks is also allocated for the transportation of the microphones between participants. Because of the difference between customs formalities of each country, it is difficult to know how long it actually takes to clear the goods. Therefore, each participant shall consider the transportation as early as possible within the period in order to avoid any delays due to customs. It is highly recommended that each participant get in contact with the next one in advance in order to check all specific customs requirements/procedures to be fulfilled, assure a expedite export/import process and avoid unnecessary delays with the transference of the microphones.
3. INMETRO will carry out measurements in four periods during the circulation of the microphones to monitor their stability, but only the results obtained during the first period will be used for comparison with the reference values.
4. The period from December 18 to January 5 is assumed a recess period due to the holidays of Christmas and New Year and the period from February 12 to 16 is assumed a recess period due to the Carnival.

Determination of the regional key comparison reference values and the degree of equivalence

To determine the regional comparison reference values, the measurements performed with the two LS2P microphones will be analyzed separately. On the other side, to determine the degrees of equivalence, the measurements performed with the two LS2P microphones will be analyzed together. The procedure employed will follow the analysis proposed by Lars Nielsen [7, 8, 9]. In summary, for each parameter of interest and for each microphone, calculations will be made to estimate the reference values of the comparison at each frequency and to get differences between each participant's measurement results and the reference values. Then, calculations will be made to get only one degree of equivalence for each parameter at each frequency. A statistical test of consistency will be applied to identify inconsistent data. If a result is found to be anomalous, the participant in question will be notified and given three weeks to respond. Then, a Draft A Report will be prepared. The determination of the reference values is an important outcome of this project. It is expected that the analysis of the results can be conducted in the same way as used for the BIPM/CCAUV key comparison CCAUV.A-K6. The data will be analyzed by the pilot laboratory who will be responsible to identify anomalous results, notify the participant and make the reports.

Link to the key comparison CCAUV.A-K6 reference value

The link to the CIPM key comparison CCAUV.A-K6 reference value will be obtained considering the results from one, or more, of the participants that have also taken part in the CCAUV.A-K6, i.e. CENAM/Mexico, INMETRO/Brazil and NRC/Canada. To provide this link the laboratories' measurement system and procedure shall be essentially the same in both comparisons. If more than one laboratory can provide this link, the options will be analyzed. If for any reason no participant can provide a consistent and robust link for a given measurement condition, then no link will be made for this specific case.

References

[1] BRÜEL & KJÆR SOUND & VIBRATION. **Products**. Available in: <www.bksv.com>. Access in: November 26, 2021.

[2] INTERNATIONAL ELECTROTECHNICAL COMMISSION, **IEC 61094-2 + Amd1 Electroacoustics – Measurements microphones – Part 2: Primary method for pressure calibration of laboratory standard microphones by the reciprocity technique**, 2nd ed. Geneva, 2009 (including Amendment 1, 2022).

[3] CIPM MRA-D-05, **Measurement comparisons in the CIPM MRA**, Version 1.6, 2016.

[4] JOINT COMMITTEE FOR GUIDES IN METROLOGY, **Evaluation of measurement data – Guide to the expression of uncertainty in measurement**, 1st ed., 2008.

[5] INTERNATIONAL ELECTROTECHNICAL COMMISSION, **IEC 61260-1 Electroacoustics – Octave-band and fractional-octave-band filters – Part 1: Specifications**, 1st ed. Geneva, 2014.

[6] RASMUSSEN, K., **The influence of environmental conditions on pressure sensitivity of measurement microphones**, In: Brüel & Kjaer Technical Review, **1**, 1-13 (2001).

[7] NIELSEN, L., **Evaluation of measurement intercomparisons by the method of least squares**, In: DFM Report, **DFM-99-R39** (2000).

[8] NIELSEN, L., **Identification and handling of discrepant measurements in key comparisons**, In: DFM Report, **DFM-02-R28** (2002).

[9] HENRIQUEZ, V. C. and RASMUSSEN, K., **Final report on the key comparison CCAUV.A-K3**, 27-28 (2006)

Appendix A – List of contacts of the participants

Instituto Nacional de Metrologia, Qualidade e Tecnologia – INMETRO Brazil Av. Nossa Senhora das Graças, 50, Prédio 1, Xerém, Duque de Caxias, RJ, 25.250-020 Zemar Martins Defilippo Soares <zmsoares@inmetro.gov.br> Tel: +55 21 26799192 Thiago Antônio Bacelar Milhomem <tbmilhomem@inmetro.gov.br> Tel: +55 21 26799221
Centro Nacional de Metrología – CENAM Mexico Carretera a los Cués km 4.5. Municipio El Marqués CP 76246. Querétaro Andrés E Pérez Matzumoto <eperez@cenam.mx> Tel: +52 442 2110500 al 04 ext. 3569 Osvaldo Llamas Llamas <ollamas@cenam.mx> Tel : +52 442 2110500 al 04 ext. 3503
Instituto Nacional de Tecnología Industrial – INTI Argentina Av. General Paz 5445 - CP 1650 - Edificio 3 y 44 San Martín - Buenos Aires Federico Ariel Serrano <fserrano@inti.gob.ar> Tel: +54 11 4713 2826
Laboratorio Costarricense de Metrologia – LACOMET Costa Rica La Ciudad de la Investigación de la UCR, San Pedro, San José, Costa Rica Adrián Solano Mena <asolano@lacomet.go.cr> Tel: +506 4060 1061 Ext:1061
National Institute of Standards and Technology – NIST USA 100 Bureau Drive, Mail Stop 8120, Gaithersburg MD 20899 Randall Wagner <randall.wagner@nist.gov>
National Research Council Canada – NRC Canada 1200 Montreal Road, Building M-36, Ottawa, Ontario K1A 0R6 Peter Hanes <Peter.Hanes@nrc-cnrc.gc.ca> Tel: +613 998 1282

Appendix B – Summary of expected measurements

Table B.1 – Summary of expected measurements by each participant of the SIM.AUV.A-K6 comparison.

2 Hz to 16 Hz (1/3-octave)		
NMI	Sensitivity modulus	Sensitivity phase
INMETRO	x	x
CENAM	x	x
INTI		
LACOMET		
NIST		
NRC	x	x
20 Hz to 20 kHz (1/3-octave)		
NMI	Sensitivity modulus	Sensitivity phase
INMETRO	x	x
CENAM	x	x
INTI	x	
LACOMET	x	x
NIST	x	
NRC	x	x
25 kHz		
NMI	Sensitivity modulus	Sensitivity phase
INMETRO	x	x
CENAM	x	x
INTI		
LACOMET		
NIST	x	
NRC	x	x

Appendix C – The one-third-octave band center frequencies over range of this comparison

Table C.1 – The one-third-octave band center frequencies over range of this comparison.

The one-third-octave band center frequencies over range of this comparison (Hz)	
1,9953	251,19
2,5119	316,23
3,1623	398,11
3,9811	501,19
5,0119	630,96
6,3096	794,33
7,9433	1000,0
10,000	1258,9
12,589	1584,9
15,849	1995,3
19,953	2511,9
25,119	3162,3
31,623	3981,1
39,811	5011,9
50,119	6309,6
63,096	7943,3
79,433	10000
100,00	12589
125,89	15849
158,49	19953
199,53	25119