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Final report on the

Supplementary comparison

EURAMET.AUV.A-S2

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Summary

The Supplementary comparison EURAMET.AUV.A-S2 has been carried out under the auspices of the Consultative Committee on Acoustics, Ultrasound and Vibration (CCAUV) of the International Bureau of Weights and Measures (BIPM). This comparison is concerned with secondary free-field methods of microphone calibration, particularly the methods described in the International Standard IEC 61094-8 (2012). The participating NMI's are BEV (Austria), DFM (Denmark), INMETRO (Brazil), INRiM (Italy), LNE (France), NPL (UK) and PTB (Germany). The role of Pilot laboratory was undertaken by LNE (France). The measurements took place between February 2014 and June 2016. Two WS2 microphones were circulated. This report includes the measurement results from the participants, information about their calibration methods, and the analysis leading to the assignation of equivalence degrees.

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1 Contents

2 Introduction

The EURAMET.AUV.A-S2 is a Supplementary comparison realised under the auspices of the CCAUV-BIPM.

The standards circulated among the laboratories were two WS2 microphones of the type Brüel & Kjær 4191. The microphones had to be calibrated using a secondary free-field method, particularly the method described in the International Standard IEC 61094-8 (2012) in the frequency range from 500 Hz to 20 kHz (optionally up to 25 Hz and/or 40 kHz).

Eight national measurement institutes took part and the LNE (France) piloted the project. The participants are listed in Table 1. The measurements took place between February 2014 and June 2016. Two WS2 microphones were circulated. This report includes the measurement results from the participants, information about their calibration methods, and the analysis leading to the assignation of equivalence degrees. It is worth noting that NPL asked to withdraw their data from the comparison.

Table 1 : List of participating institutes

Participant (in order of participation)	Acronym	Country	Country code
Laboratoire National de Métrologie et d'Essais	LNE	France	FR
Bundesamt für Eich-und Vermessungswesen	BEV	Austria	AT
Danish Fundamental Metrology	DFM	Denmark	DK
Instituto Nacional de Metrologia, Normalização e Qualidade Industrial	INMETRO	Brazil	BR
Istituto Nazionale di Ricerca Metrologica	INRiM	Italy	IT
Physikalisch-Technische Bundesanstalt	PTB	Germany	DE
National Physical Laboratory	NPL	United Kingdom	UK

3 Comparison protocol

The technical protocol for the Supplementary comparison EURAMET.AUV.A-S2 was approved by all participants. It specified the determination of the free-field sensitivities of two WS2 microphones according to IEC 61094-8 (2012), at actual environmental conditions.

The microphones were circulated as travelling standards to each participant in turn, who were asked to calibrate them by their normal method (as might be offered to a customer) and report the results in their usual calibration certificate format. If necessary, additional information was requested, particularly any variation from the requirements of IEC 61094-8 (2012) with an estimate of its likely effect on the results and a summary of the uncertainty calculation.

Table 2 shows the measurand and frequency ranges within the scope of the comparison. Participants were asked to complete the mandatory elements and it was agreed that the optional elements could be covered partially. Each laboratory was asked to determine the open-circuit free-field sensitivity level of each reference microphone.

The first participant received the microphones in February 2014 and the final participant completed their measurements in June 2016.

Table 2 Scope of the comparison.

Frequency range	Sensitivity level
25 Hz – 500 Hz	Optional
500 Hz – 20 kHz	Mandatory
20 kHz – 40 kHz	Optional

4 Stability of travelling standards

Two WS2 microphones, Brüel & Kjær 4191, serial numbers 2114351 and 2114352, were supplied by LNE and circulated among the participants. LNE has monitored the microphones since the beginning of the comparison. The monitoring consisted of pressure reciprocity calibrations.

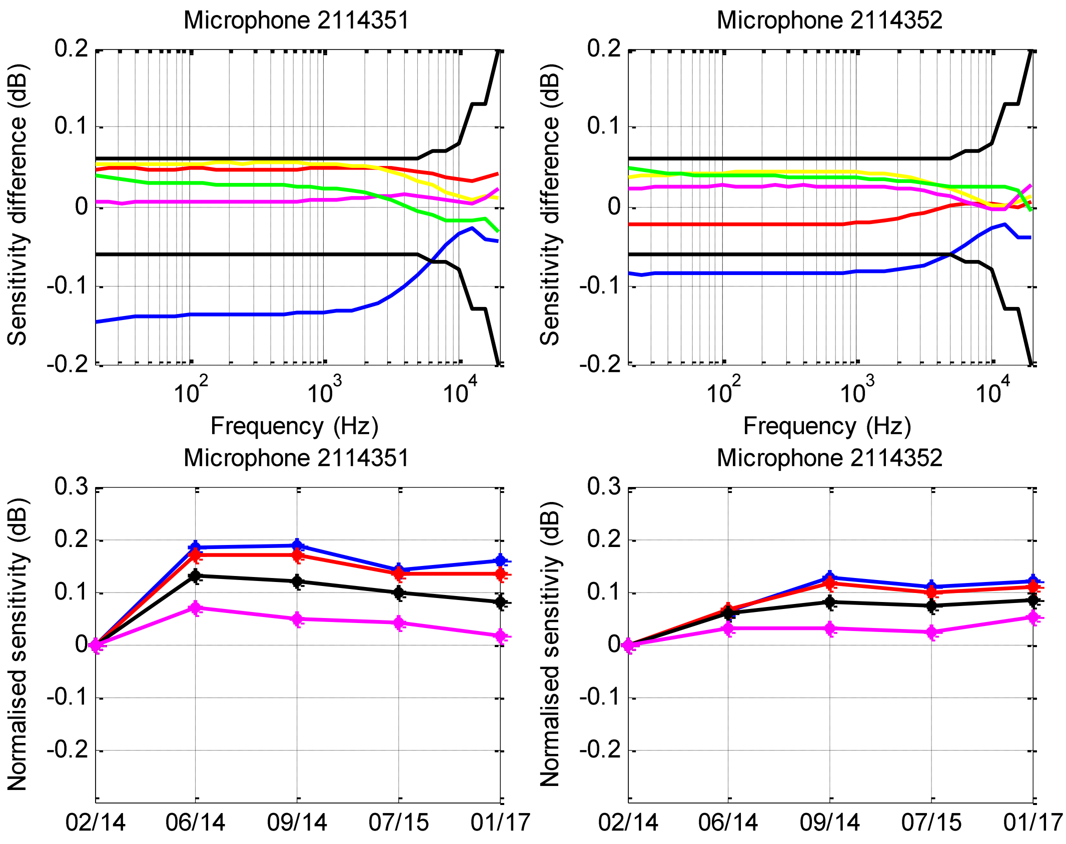

Figure 1: Upper charts: Difference of the sensitivity level obtained at each calibration at LNE with respect to their common average for each microphone as a function of frequency (LNE's uncertainty bounds are shown). Lower charts: Changes in the sensitivity level of the microphones as a function of time. The sensitivity level has been normalized to the level of the first measurement. Blue line: 1 kHz; red line 2 kHz; black line 5 kHz; and magenta line 10 kHz.

Figure 1 shows LNE's results of the control calibrations for some selected frequencies during the comparison span. Figure 1 also shows the difference with respect to a common average for the two microphones over the whole frequency range.

It is worth noting that a drift of the microphones sensitivities occurred at the beginning of the comparison, mainly for the microphone 2114351. However, the uncertainty bounds presented here are the ones of the reciprocity calibration for WS2 microphones which are lower than the uncertainties reported by the laboratories for secondary free-field calibration of microphones. Thereby, it was at first decided to analyse the data without taking account these drifts.

5 Calibration methods and reported results

5.1 Calibration methods

A description of the calibration methods and the reporting of results of each laboratory is given below as submitted by each laboratory. No editing of the contents but a small amount of reformatting has been performed.

5.1.1 LNE

a) Measurement procedure

Measurements were made in accordance with the standard IEC 61094 8:2012 from 158.49 Hz to 39811 Hz.

Measurements were made using the experimental setup described in Figure 2. The microphones are connected sequentially to the preamplifier mounted on the end of a long rod (having both the same section), which can moves up and down along the vertical axis. Measurements were made at different distances between the source and the microphone (5 distances between 80 and 120 cm). A monitor microphone is used to detect the source variations between the 2 steps of the calibration. The source, an Electro-Voice 2” driver DH2T-8 is flush-mounted in the floor of the semi-anechoic room of the LNE. This test room has a working volume of 110m^3, a cut-off frequency of 120 Hz and a linear background noise less than 30 dB (>2 kHz). Electric signals are conditioned by a B&K Nexus amplifier and a specific insert voltage box. The analyzer B&K PULSE 3560C provides the electrical sinusoidal signal to the source and performs the electrical measurements. The environmental conditions are measured during the measurement.

The reference microphone used is a laboratory standard microphone B&K 4180 (serial number 2412865) with a free-field sensitivity previously determined by the pressure reciprocity method in the frequency range 158.49 to 1584.9 Hz (adding the free-field corrections from the standard IEC 61094-7) and the free-field reciprocity method in the frequency range 1995.3 to 39811 Hz.

No signal processing was used to clean disturbances.

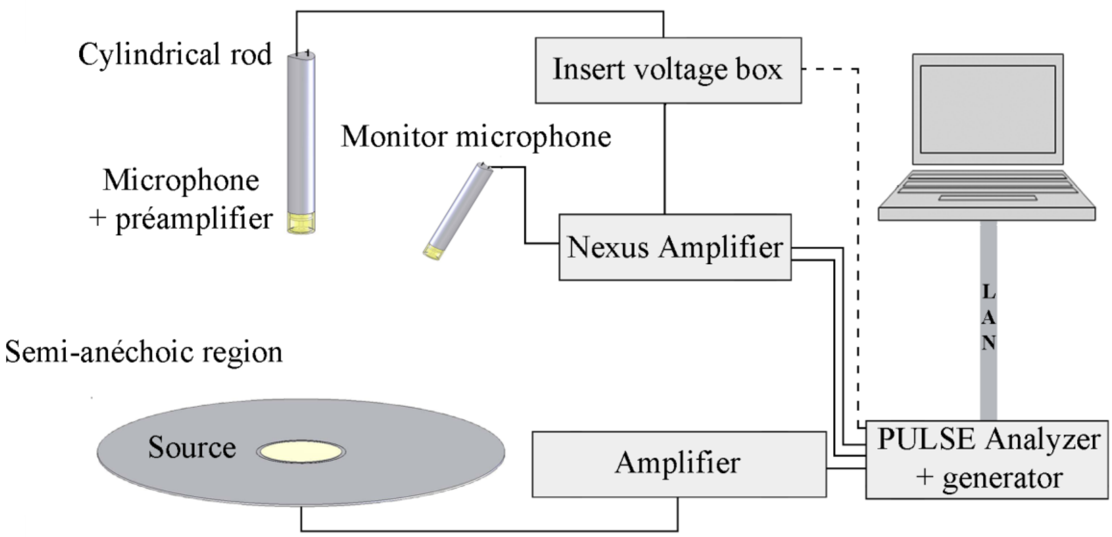

Figure 2: Experimental setup used for the secondary free-field calibration of microphones.

b) Calibration results

The results are given in the reports P121273/16 and P121273/17 respectively for the microphones 2114351 and 2114352.

Results are reported at the actual environmental conditions.

c) Condensed uncertainty budget

The uncertainty budget was determined in accordance with the Guide to the Expression of Uncertainties in Measurement. Uncertainty of measurement are reported using a coverage factor of *k=2*.

A condensed uncertainty budget is given in Annex A. The uncertainty budget includes all components listed in the Table 2 of the standard IEC 61094 8:2012.

5.1.2 BEV

a) General principle

For this comparison the two test microphones (TM) were calibrated against a reference microphone (RM) in a free-field environment in accordance to IEC 61094-8:2012. The measurements were done in the following sequence:

RM-TM-RM-TM-RM-TM

Test frequencies were set due to the comparison protocol. The frequency range is 25,1 Hz to 25,1 kHz. At each sequence the sound source successively sent signals at the chosen frequencies (in Hz):

25,1 - 31,6 - … - 25118,9 - 25,1 - 31,6 - … - 25118,9 - 25,1 - 31,6 - … - 25118,9

The microphone responses were recorded accordingly.

Only the microphones were exchanged between sequences. This means no changes in positioning and instrumentation. All measurements were done without the microphone protection grids.

b) Instrumentation

Reference microphone

A Brüel & Kjær 4180 (SN 2341440) condenser microphone was used as reference standard. The cartridge capacitance is 20,5 pF and the polarisation voltage is 200 V. This standard was calibrated according to IEC 61094-2:2009:

f Hz	S_0 dB re 1V/Pa	$U(S_0)$ dB re 1V/Pa
25,119	-38,3260	0,04
31,623	-38,3300	0,04
39,811	-38,3406	0,04
50,119	-38,3457	0,04
63,096	-38,3431	0,04
79,433	-38,3442	0,04
100,000	-38,3529	0,04
125,893	-38,3562	0,04
158,489	-38,3581	0,04
199,526	-38,3604	0,04
251,189	-38,3620	0,04
316,228	-38,3646	0,04
398,107	-38,3664	0,04
501,187	-38,3673	0,04
630,957	-38,3678	0,04
794,328	-38,3668	0,04
1000,000	-38,3666	0,04
1258,925	-38,3612	0,04
1584,893	-38,3566	0,04
1995,262	-38,3432	0,04
2511,886	-38,3278	0,04
3162,278	-38,2949	0,04
3981,072	-38,2606	0,04
5011,872	-38,1890	0,04
6309,573	-38,1079	0,04
7943,282	-37,9717	0,05
10000,000	-37,8478	0,05
12589,254	-37,7716	0,05
15848,932	-38,0911	0,10
19952,623	-39,3159	0,10
25118,864	-41,7707	0,10

Calibration results of the reference microphone B&K 4180

Test microphones

Two Brüel & Kjær 4191 (SN 2114351; SN 2114352) condenser microphones were provided for testing. The cartridge capacitance is 18,9 pF and 18,7 pF, respectively. The polarisation voltage is 200 V.

Sound source

A Visaton B200 loudspeaker (SN 1350) was used as sound source for all frequencies.

Test signal

The sinusoidal test signal was generated with a Stanford DS 360 (SN 61022) amplified by a Brüel & Kjær 2712 (SN 484792). The sound pressure level was kept at about 75 dB at a distance of 150 cm for most frequencies. For low frequencies the sound pressure level decreased to 60 dB at 150 cm.

Test space

The anechoic room has a volume of (l x w x h): 875 x 675 x 450 cm^3. The walls are made of rectangular cones with a base area of 26 x 26 cm^2 and a depth of 90 cm. The tips area is 3,2 x 26 cm^2.

Figure 3: Wall of anechoic room.

Signal processing

All microphones were connected to a Brüel & Kjær 2639 (SN 1816994, 0,2 pF input capacitance) preamplifier prior to a Brüel & Kjær 2610 (SN 833420) measuring amplifier. The internal high pass filter (22,4 Hz) was used. Voltage measurements were done with a Keithley 2001 (SN 620324).

Environmental conditions

The environmental conditions during the calibration were:

Temperature: 22 °C ± 1 °C
Pressure: 994 mbar ± 5 mbar
Humidity: 35 %RH ± 5 %RH

Distances

Loudspeaker and microphone were mounted on stands at a distance of 150 cm in the anechoic room. The height of the acoustical centres above ground was 175 cm. The distances of the loud speaker to the walls were 200 cm (see simple sketch below).

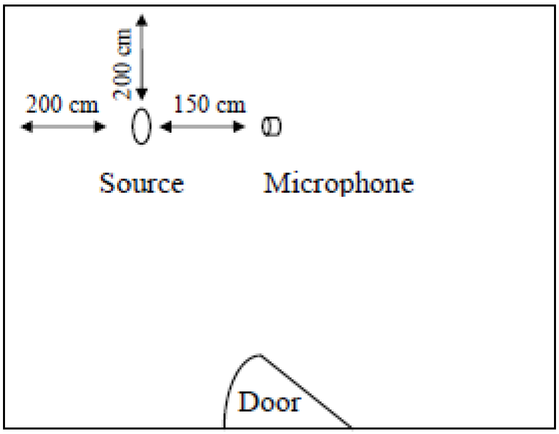

Figure 4: Measurement setup.

5.1.3 DFM

Method

Sequential comparison in a free-field with three different reference microphones according to the internal procedure Q2KAL702 *Free-field calibration of microphones*. Traceability of the reference microphones is ensured by following the primary method described in the International Standard IEC 61094-3:1995.

The microphone has been preconditioned 12 hours at 23°C.

The reported measurement uncertainty I is given as the standard uncertainty multiplied with a coverage factor of *k=2*, which for a normal distribution corresponds to a coverage probability of approximately 95%. The standard uncertainty has been calculated in accordance with the ISO GUM. Particulars of the budget are given in the above mentioned procedure.

Reference microphones

Manufacturer & type	Brüel & Kjær type 4180	Brüel & Kjær type 4180	Brüel & Kjær type 4180	Brüel & Kjær type 4180	Brüel & Kjær type 4180
Serial number	1395456	1395455	1503926	1503930	1526170
Certificate	AIM1301	AIM1301	AIM1301	AIM1301	AIM1301
Calibration date	2013-07-19	2013-07-19	2013-07-18	2013-07-18	2013-07-18

Comments

The microphones were measured without their protection grid on.

The sound source is placed 90 cm from the microphones.

Calibration conditions, microphone s/n 2114351

Static pressure (kPa): 100.57 ± 0.75
Temperature (°C): 22.6 ± 0.4
Relative humidity (%): 43 ± 2
Polarisation voltage (V): 200.00 ± 0.04

Calibration conditions, microphone s/n 2114352

Static pressure (kPa): 100.59 ± 0.74
Temperature (°C): 22.8 ± 0.3
Relative humidity (%): 45 ± 2
Polarisation voltage (V): 200.00 ± 0.04

5.1.4 INMETRO

The reference microphone and the microphone under test were sequentially exposed to essentially the same sound pressure (sequential excitation). The stability of sound source was previously verified and no important changes of its output were observed; only a small variation was detected and taken as the standard uncertainty of the stability of the sound source. Also no important changes on environmental conditions were observed during each measurement and a standard uncertainty regarding the environmental conditions was taken into account in uncertainty budget calculation.

As test space was used an anechoic chamber of around 125 m^3 of volume. To establishing the free-field were used this anechoic chamber in combination with the time selective technique. In the TST the window function used were a rectangular window with Hanning slopes of different sizes at the right and the left side. It was used two different windows sizes according to the frequency range of interest, being the shorter one (total size of 24.8 ms) for higher frequencies (upper 250 Hz) and the longer one (71.0 ms) for lower frequencies (below 250 Hz).

The sound source consists of a coaxial loudspeaker (BMS 15CN682) fitted in an enclosure (50 l, 38.3 cm x 38.3 cm x 38.3 cm).

As reference microphone was used a half inch laboratory standard microphone. It was calibrated by the reciprocity technique in pressure field (IEC 61094-2) for the frequency range from 25 Hz to 800 Hz and in free-field (IEC 61094-3) for the frequency range from 1 kHz to 40 kHz.

As the output of the sound source stability was quite good it was not used a monitor microphone.

The test signal were two swept-sine being one for the frequency range from 15 Hz to 890 Hz and the other one for the range from 860 Hz to 42 kHz. The amplitude of each swept-sine was kept constant but was given emphasis in lower frequencies by decreasing the velocity that swept-sine is played.

The microphones were mounted on a semi-infinite cylindrical rood (1.5 m) having the same diameter as the body of the microphone, the distance between the microphones and the sound source during the calibration was 1 m and they are positioned in the reference direction. The microphone under test was calibrated without its protection grid and it was fed with the polarization voltage specified by the manufacturer.

The final results represent the arithmetic mean of the sensitivities and were not corrected to the reference environmental conditions. The expanded uncertainties were stated as the combined uncertainties multiplied by the coverage factor *k=2* which corresponds to a coverage probability of approximately 95%. A summary of the uncertainty calculation is presented in Annex A.

5.1.5 INRiM

Dates of measurement and dispatching.

Microphones were received on April 7, 11 April in the acoustic laboratory, and sent to NPL on April 28.

After delivery, the microphone were pressure calibrated and found in perfect working condition.

Measurement phase took place form April 12 to April 26.

Environmental conditions during measurements.

Environmental conditions were within the following ranges:

	Minimum value	Maximum value
Static Pressure/ kPa	97,546	99,484
Humidity / %	34	50
Temperature / °C	20,2	21,8

Measurement environment (test space).

Figure 5: Microphone mounting (detail).

All measurement took place in the hemi-anechoic room in INRiM acoustic department. The room dimensions are 6.5 width x11 length x5.5 height m^3 at wedge tips . The lower cut-off frequency is about 90 Hz. The sound source is mounted flush with the floor. Two sources were used::

1. A 1” soft dome tweeter for measurements from 500 Hz to 20 kHz (in fig 6, on the floor).
2. A 6” cone loudspeaker for 25 Hz to 500 Hz measurements.

The microphones were mounted on a ½” carbon fibre rod protruding from the ceiling, as shown in Figure 5 and Figure 6. The length of the rod is 4 m, at 1.5 m there is a small discontinuity due to wires that hold the rod stable in place. The positioning of the microphones has been checked by means of two laser levels crossing at the microphone tip and source centre, see Figure 6, in order to improve repeatability.

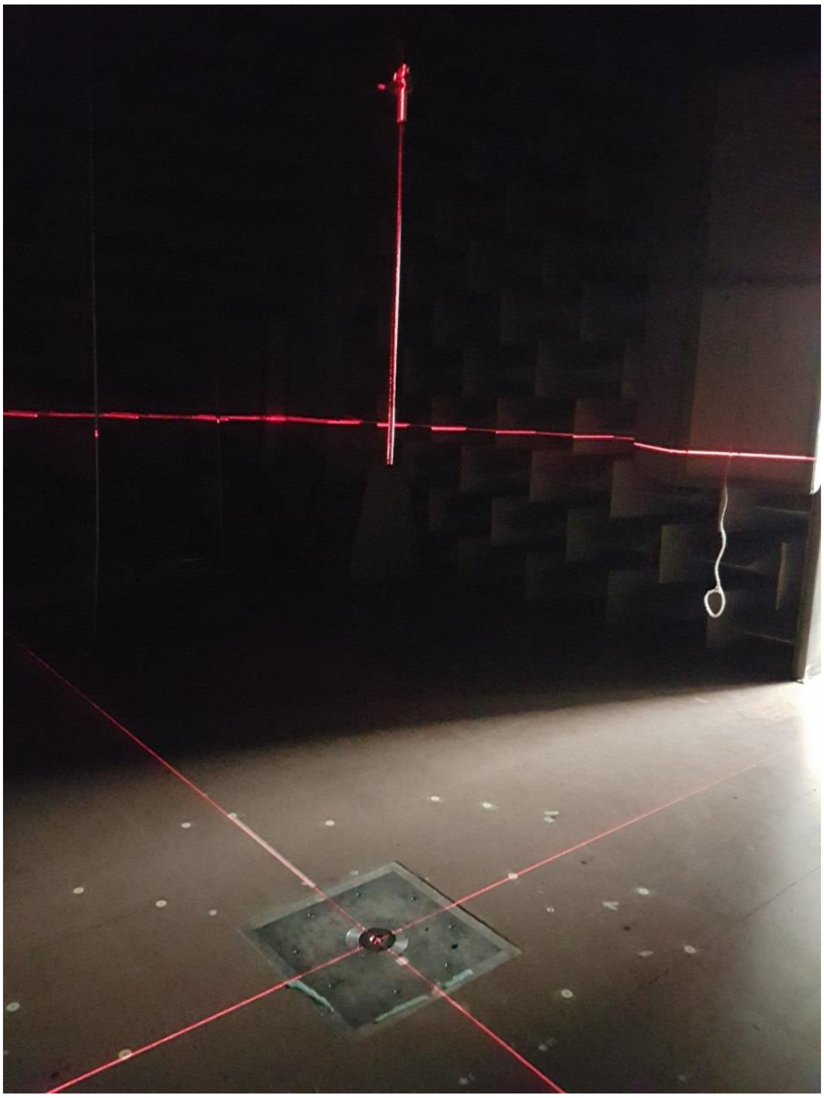

Figure 6: Microphone mounting and alignment.

Instrumentation and measurement in detail.

The following instruments and reference standard have been used:

- LS2p reference microphone B&K 4180, SN 2412892
- Microphone power supply G.R.A.S. 12AK, SN 21184
- Microphone Preamplifier B&K 2673, SN 2495320
- Frequency analyser ONO SOKKI DS300, SN 16210228001R
- Barometer Ruska 6200, SN 50348
- Termo-hygrometer TESTO 615, SN 00297909
- Audio amplifier Rotel RA-05 SE

The reference microphone was calibrated at INRiM by pressure reciprocity. Data from IEC TS 61094 part 7 have been used to calculate the free field response of the reference microphone.

The method chosen is comparison by sequential excitation: after 30' warming time for the sound source, the reference microphone is mounted on the preamplifier and the transfer function between the output of the preamplifier and the loudspeaker driving voltage is measured by a 8192 lines FFT and sampling frequency of 64 kHz by means of an ONO SOKKI DS300 frequency analyser. The driving signal is a random noise, with an amplitude of 1 Vrms for the high frequency source and 2.83 Vrms for the low frequency source.

After the reference microphone, each of the two WS2 microphones under test, with the grid removed, is measured in the same way as the reference. The stabilising time for polarisation voltage is 10'. After the measurement, the reference microphone is mounted again to verify source stability.

For the 500 Hz to 20 kHz frequency range, over 10 measurements, at distances between the microphone and the source ranging from 1 to 1.4 m, have been performed. The gain of the insert voltage preamplifier has been evaluated by measuring the transfer function between the injected signal and the preamplifier output: it must be said that the difference in gain between the reference microphone and test microphones is well within the uncertainty of measurement. The applied gain correction has no practical influence.

For the 25 to 500 frequency range, only 3 measurement have been performed, at the distance of 1.1 and 1.3 m. Below approximately 90 Hz the field cannot be considered of plane progressive waves, but the measurement has been anyway carried out to compare the results with other methodologies in the comparison. Probably for a WS2 microphone, the difference between pressure and free field response below 500 Hz is lower that the uncertainty of measurement of the present exercise at INRiM. In any case below 100 Hz the measurement method deviates from IEC 61094 part 8 requirements.

The signal processing to remove reflections has been performed according to the following steps:

- Measurement of transfer function between microphone output and source driving voltage.
- Inverse Fourier transform to obtain impulse response.
- Windowing with a Tukey window with α=0.5, length 10 ms leading, 5 ms trailing with reference to impulse peak position (100 and 100 ms for 25 Hz to 500 frequency range, but obviously not all reflection were removed in this case).
- Direct Fourier transform to obtain cleaned transfer function.
- Calculation of the sensitivity of the test microphone from the difference between test and reference microphones cleaned transfer functions plus free field corrected response of reference microphone.

Values at the exact frequencies of the protocol have been calculated by polynomial interpolation.

No correction has been made for environmental influence on test and reference microphone sensitivities, only temperature was considered in the pressure to free field correction of reference microphone.

Uncertainty of measurement

The main components of uncertainty considered are:

- Pressure calibration of reference microphone, data from calibration certificate
- Pressure to FF correction of reference microphone, from IEC TS 61094 part 7. No data for uncertainty is available below 1 kHz for LS2p microphones, data has been extrapolated.
- Repeatability of measurement, that takes into account both source stability and position repeatability. Therefore no additional uncertainty components for these effect have been considered, as they have an high, but unknown, degree of correlation with repeatability.
- Acoustic centre variation has been considered of minor effect as the distances between source and microphone are greater than 1 m and neglected.
- The effect of windowing also is considered to be negligible compared to major components, as the same window has been applied to similar impulse responses.
- Low frequency measurement are affected by the quality of the field, deviating from plane progressive waves: a rough estimation has been deduced by differences at various measurement distances with WS2 sequential comparison calibrations, but this component is tentative and needs more investigations.

In Annex A, the values of the components at some frequencies are reported, with Welch-Satterthwaite test values WS and coverage factor *k*:

5.1.6 PTB

The measurement was performed according to IEC 61094-8:2012.

The actual environmental conditions during the measurements were (given as mean value with double standard deviation in brackets): temperature 23.1 (±0.5) °C, humidity 46.9 (± 3) %, static pressure 100.39 (± 1.5) kPa. The results reported were NOT corrected for environmental conditions. The given uncertainties are valid for climatic variations of ±1 °C, ±5 % and ±50 mbar.

The measurements were performed in the large anechoic room of PTB. The source was a Beyma loudspeaker, the test signal consisted of pure tones at each of the measured frequencies. The measurement distance between the loudspeaker and the microphone was about 1 m. The substitute-voltage procedure was used, a time selective method was not applied. The reference microphone was a LS2 microphone of type B&K 4180 which was calibrated by pressure reciprocity method and free-field reciprocity method.

Calibration conditions

Static pressure (mbar):	100.39 ± 1.5
Temperature (°C):	23.1 ± 0.5
Relative humidity (%):	46.9 ± 3

Calculation of measurement uncertainty

The calculation of the uncertainty of measurement is performed according to the "Guide to the expression of uncertainty in measurement" (GUM 1995). The overall measurement uncertainty is given as the expanded uncertainty ($k = 2$) with a coverage probability of 95%. The uncertainty budget is reported Annex A for the example of the calibrated microphone B&K 4191 s/n 2114351.

6 Collation of results and uncertainties

Each laboratory reported their results after their own measurement round. No data were removed from the calculation of the reference values.

The open-circuit, free-field sensitivity levels and uncertainties reported by each laboratory for each microphone at each frequency are given in Table 3 and Table 4. The sensitivity levels are given in dB re 1 V/Pa and uncertainties in dB.

Table 3: Free-field sensitivity levels M_{ff} in dB re 1 V/Pa and expanded uncertainties in dB of the microphone 2114351 as declared by the participant laboratories.

Frequency (Hz)	LNE		BEV		DFM		INMETRO		INRIM		PTB	
	M_{ff}	U *k=2*	M_{ff}	U *k=2*	M_{ff}	U *k=2*	M_{ff}	U *k=2*	M_{ff}	U *k=2*	M_{ff}	U *k=2*
25.119	-	-	-37.969	0.265	-	-	-37.975	0.250	-37.910	0.203	-38.048	0.300
31.623	-	-	-37.966	0.247	-	-	-37.950	0.200	-37.911	0.201	-38.053	0.300
39.811	-	-	-38.137	0.253	-	-	-37.951	0.200	-37.913	0.198	-38.038	0.300
50.119	-	-	-38.093	0.244	-	-	-37.954	0.150	-37.916	0.197	-38.036	0.300
63.096	-	-	-38.121	0.243	-	-	-37.953	0.150	-37.919	0.188	-38.017	0.300
79.433	-	-	-38.078	0.243	-	-	-37.956	0.150	-37.923	0.184	-38.000	0.300
100.00	-	-	-38.100	0.243	-	-	-37.964	0.150	-37.928	0.179	-37.992	0.200
125.89	-	-	-38.187	0.247	-	-	-37.966	0.150	-37.933	0.175	-37.979	0.200
158.49	-38.139	0.200	-38.116	0.243	-	-	-37.972	0.150	-37.940	0.168	-37.972	0.200
199.53	-38.143	0.170	-38.118	0.243	-	-	-37.983	0.150	-37.949	0.165	-37.973	0.200
251.19	-38.175	0.160	-38.110	0.245	-38.066	0.110	-37.991	0.150	-37.959	0.168	-37.981	0.200
316.23	-38.163	0.150	-38.141	0.243	-38.068	0.110	-37.995	0.150	-37.971	0.162	-37.981	0.200
398.11	-38.180	0.150	-38.167	0.244	-38.073	0.110	-38.009	0.150	-37.985	0.170	-37.997	0.200
501.19	-38.181	0.150	-38.159	0.256	-38.083	0.110	-38.020	0.150	-38.000	0.093	-37.998	0.200
630.96	-38.187	0.150	-38.166	0.256	-38.089	0.110	-38.036	0.150	-38.017	0.082	-38.018	0.200
794.33	-38.194	0.150	-38.177	0.256	-38.097	0.110	-38.055	0.150	-38.036	0.074	-38.045	0.200
1000.0	-38.203	0.150	-38.187	0.257	-38.104	0.110	-38.034	0.200	-38.054	0.071	-37.998	0.200
1258.9	-38.216	0.150	-38.205	0.253	-38.119	0.110	-38.008	0.200	-38.073	0.074	-38.008	0.200
1584.9	-38.229	0.150	-38.219	0.259	-38.127	0.110	-38.035	0.200	-38.092	0.084	-38.033	0.200
1995.3	-38.209	0.140	-38.187	0.268	-38.139	0.110	-38.075	0.200	-38.114	0.102	-38.085	0.200
2511.9	-38.198	0.140	-38.236	0.274	-38.162	0.110	-38.103	0.200	-38.143	0.121	-38.115	0.200
3162.3	-38.253	0.140	-38.268	0.278	-38.211	0.110	-38.137	0.200	-38.189	0.134	-38.185	0.200
3981.1	-38.314	0.140	-38.332	0.277	-38.293	0.110	-38.219	0.200	-38.261	0.132	-38.258	0.200
5011.9	-38.421	0.140	-38.415	0.272	-38.355	0.110	-38.394	0.200	-38.366	0.120	-38.371	0.200
6309.6	-38.491	0.140	-38.477	0.285	-38.463	0.110	-38.489	0.200	-38.489	0.126	-38.502	0.300
7943.3	-38.588	0.140	-38.522	0.306	-38.558	0.110	-38.607	0.200	-38.586	0.180	-38.615	0.300
10000	-38.646	0.140	-38.517	0.371	-38.610	0.110	-38.759	0.250	-38.593	0.278	-38.691	0.300
12589	-38.571	0.140	-38.372	0.492	-38.566	0.110	-38.689	0.300	-38.481	0.345	-38.580	0.400
15849	-38.449	0.140	-38.256	0.439	-38.492	0.120	-38.604	0.500	-38.347	0.256	-38.519	0.400
19953	-38.608	0.150	-38.511	0.411	-38.712	0.120	-38.787	0.500	-38.607	0.184	-38.704	0.400
25119	-39.416	0.160	-39.383	0.420	-39.582	0.130	-39.566	0.500	-	-	-39.660	0.500
31623	-41.014	0.170	-	-	-41.103	0.200	-41.135	0.500	-	-	-41.280	0.500
39811	-43.755	0.200	-	-	-43.756	0.200	-43.854	0.600	-	-	-44.102	0.500

Table 4: Free-field sensitivity levels M_{ff} in dB re 1 V/Pa and expanded uncertainties in dB of the microphone 2114352 as declared by the participant laboratories.

Frequency (Hz)	LNE		BEV		DFM		INMETRO		INRIM		PTB	
	M_{ff}	U *k=2*	M_{ff}	U *k=2*	M_{ff}	U *k=2*	M_{ff}	U *k=2*	M_{ff}	U *k=2*	M_{ff}	U *k=2*
25.119	-	-	-37.862	0.258	-	-	-37.885	0.250	-37.827	0.203	-37.920	0.300
31.623	-	-	-37.852	0.249	-	-	-37.871	0.200	-37.829	0.201	-37.929	0.300
39.811	-	-	-37.868	0.254	-	-	-37.865	0.200	-37.831	0.198	-37.925	0.300
50.119	-	-	-37.918	0.244	-	-	-37.877	0.150	-37.833	0.197	-37.926	0.300
63.096	-	-	-37.933	0.243	-	-	-37.874	0.150	-37.836	0.188	-37.914	0.300
79.433	-	-	-37.912	0.244	-	-	-37.884	0.150	-37.840	0.184	-37.908	0.300
100.00	-	-	-37.958	0.243	-	-	-37.890	0.150	-37.845	0.179	-37.903	0.200
125.89	-	-	-37.937	0.246	-	-	-37.903	0.150	-37.851	0.175	-37.908	0.200
158.49	-38.001	0.200	-37.972	0.243	-	-	-37.909	0.150	-37.858	0.168	-37.908	0.200
199.53	-38.029	0.170	-37.995	0.243	-	-	-37.918	0.150	-37.866	0.165	-37.914	0.200
251.19	-38.041	0.160	-38.025	0.245	-37.934	0.110	-37.929	0.150	-37.876	0.168	-37.926	0.200
316.23	-38.039	0.150	-38.022	0.243	-37.938	0.110	-37.935	0.150	-37.888	0.162	-37.927	0.200
398.11	-38.055	0.150	-38.053	0.244	-37.946	0.110	-37.950	0.150	-37.902	0.170	-37.942	0.200
501.19	-38.062	0.150	-38.042	0.256	-37.957	0.110	-37.959	0.150	-37.917	0.093	-37.943	0.200
630.96	-38.068	0.150	-38.050	0.256	-37.966	0.110	-37.976	0.150	-37.933	0.082	-37.962	0.200
794.33	-38.076	0.150	-38.059	0.257	-37.969	0.110	-37.999	0.150	-37.949	0.075	-37.987	0.200
1000.0	-38.084	0.150	-38.048	0.257	-37.975	0.110	-37.979	0.200	-37.966	0.071	-37.941	0.200
1258.9	-38.095	0.150	-38.076	0.254	-37.987	0.110	-37.944	0.200	-37.981	0.074	-37.946	0.200
1584.9	-38.105	0.150	-38.093	0.259	-37.992	0.110	-37.967	0.200	-37.996	0.085	-37.969	0.200
1995.3	-38.081	0.140	-38.084	0.270	-37.999	0.110	-38.002	0.200	-38.012	0.102	-38.014	0.200
2511.9	-38.069	0.140	-38.107	0.274	-38.017	0.110	-38.021	0.200	-38.034	0.122	-38.038	0.200
3162.3	-38.117	0.140	-38.129	0.278	-38.057	0.110	-38.040	0.200	-38.071	0.134	-38.098	0.200
3981.1	-38.170	0.140	-38.184	0.277	-38.132	0.110	-38.119	0.200	-38.133	0.132	-38.159	0.200
5011.9	-38.276	0.140	-38.274	0.273	-38.188	0.110	-38.275	0.200	-38.228	0.120	-38.259	0.200
6309.6	-38.344	0.140	-38.348	0.282	-38.293	0.110	-38.366	0.200	-38.344	0.126	-38.374	0.300
7943.3	-38.441	0.140	-38.383	0.307	-38.391	0.110	-38.422	0.200	-38.440	0.180	-38.481	0.300
10000	-38.514	0.140	-38.370	0.372	-38.458	0.110	-38.600	0.250	-38.458	0.278	-38.575	0.300
12589	-38.468	0.140	-38.297	0.491	-38.447	0.110	-38.587	0.300	-38.374	0.345	-38.486	0.400
15849	-38.374	0.140	-38.175	0.439	-38.407	0.120	-38.559	0.500	-38.275	0.256	-38.452	0.400
19953	-38.557	0.150	-38.499	0.410	-38.660	0.120	-38.753	0.500	-38.576	0.184	-38.679	0.400
25119	-39.427	0.160	-39.409	0.414	-39.579	0.130	-39.593	0.500	-	-	-39.697	0.500
31623	-41.192	0.170	-	-	-41.286	0.200	-41.342	0.500	-	-	-41.479	0.500
39811	-44.055	0.200	-	-	-44.098	0.200	-44.096	0.600	-	-	-44.411	0.500

7 Method for the analysis of the results

7.1 Degrees of equivalence

The methodology used in this report for the analysis of the results is based on the methodology used for the analysis of international Key Comparisons [2, 3].

The linear model of the comparison is $E(y) = X \cdot a$, where a is a vector of parameters of the model, $E(y)$ the expectations of the measurements and X is the design matrix. In our case, the model takes the form in equation (1).

$$\begin{bmatrix} E(y_{11}) \\ \vdots \\ E(y_{15}) \\ E(y_{21}) \\ \vdots \\ E(y_{25}) \\ E(y_{31}) \\ \vdots \\ E(y_{35}) \\ E(y_{41}) \\ \vdots \\ E(y_{45}) \\ E(y_{51}) \\ \vdots \\ E(y_{55}) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix}. \tag{1}$$

$E(y_{ij})$ stands for the the i-th sensor being measured by the j-th laboratory in the loop. The parameters a_i are the values of the five sensors to be estimated. The model can take into account the instability of the sensors. However, in this report the sensors are considered stable and no correction is made.

The input data for the model are the measurement results y_i and the covariance matrix Σ. The covariance matrix has in its main diagonal the uncertainties claimed by the participants. The off-diagonal elements of Σ are only non-zero when they represent the covariance of measurements by the same laboratory. In this analysis, a high degree of correlation is assumed for measurements made by the same laboratory. However, total correlations affect the least squares calculation in the sense that measurements are linked with no uncertainties, making minimization unsolvable [3]. With all these considerations, a correlation value of 0.7 is chosen, somewhat arbitrarily, for the results presented here.

The estimated values of the standards $\hat{y}$ and their covariance matrix $V(\hat{y})$ are obtained using:

$$\hat{y} = X \cdot \hat{a}, \tag{2}$$

$$V(\hat{y}) = X \cdot V(\hat{a}) \cdot X^T ,$$

where,

$$\hat{a} = \left(X^T \cdot \Sigma^{-1} \cdot X \right)^{-1} \cdot X^T \cdot \Sigma^{-1} \cdot y$$
$$C = V(\hat{a}) = \left(X^T \cdot \Sigma^{-1} \cdot X \right)^{-1} . \quad (3)$$

The degrees of equivalence D_{ii} per laboratory are obtained using:

$$D_{ii} = A^T (y - \hat{y}),$$
$$V(D_{ii}) = A^T V(y - \hat{y}) A , \quad (4)$$

where A is an averaging matrix. The inter-laboratory degrees of equivalence can be estimated using:

$$D_{ij} = D_{ii} - D_{jj} ,$$
$$V\left(D_{ij}\right) = u_{ii} + u_{jj} - u_{ij} - u_{ji} , \quad (5)$$

7.2 Equivalence and consistence of results

The participating laboratories are supposed to be measuring the same item and their results are assumed to be drawn from a normal distribution. This hypothesis is tested by means of an observed χ^2 distributed estimator, the so-called 'chi-squared test' as described in [4]. The degrees of freedom of the χ^2 distribution are $v = n - k$, where n is the number of measurements (12 for most cases) and k the number of standards (2 microphones). To accept the hypothesis with a significance of 5%, the probability $P\{\chi^2(v) > \chi^2_{obs}\}$ has to be larger than 5%.

During the course of the comparison, any anomalous results need to be identified by the pilot laboratory. Any laboratory whose results show deviations judged to be irregular must be contacted in order to have an opportunity to revise their results.

a) Identifying discrepant measurements

Once all data was collected, and the participants reported any problem with their measurement, the analysis method in [4] was implemented. This method uses the normalized deviations that were calculated for every frequency and measurement. The method assumes that the normalized deviations are distributed as N(0,1). Therefore, if the modulus of a particular normalized deviation is greater than 2, the corresponding measurement can be considered discrepant with a significance of 5 %.

b) Handling of discrepant measurements

If a measurement has been judged to be discrepant, it should be excluded from the least squares calculation of the reference values. Otherwise the calculated reference values cannot be considered to be proper estimates of the SI values of the quantities represented by the circulated objects. If there is a discrepant measurement y_{ij} in a supplementary comparison and the uncertainty assigned to this measurement is very small, the supplementary comparison reference value will be attracted to this discrepant result. As a consequence the remaining results might appear to be discrepant as well even if they are mutually consistent. Since one discrepant measurement will always have a value $|d_{ij}|$ larger than the values $|d_{kj}|$, i≠k of two or more mutually consistent values, the value y_{ij} with the larger value $|d_{ij}|$ should be excluded first. A repeated least squares adjustment of the reference values will then show if there are further discrepant results.

The procedure of excluding discrepant results one by one can be summarized as follows:

1. Identify the result y_{ij} with the largest value $|d_{ij}|>2$ in the (reduced) set of results.
2. Exclude the result y_{ij} from the reduced set of results.
3. Repeat the least squares adjustment of reference values for the reduced set of results.
4. If the results in the reduced set are not mutually consistent, continue at point 1.

It has to be emphasized, that the discrepant results are excluded only from the calculation of the reference values and not from the supplementary comparison as such. It is therefore still necessary to calculate the deviations of the discrepant results from the reference values and the uncertainties of these deviations. Reference [4] gives a detailed explanation of the procedure.

8 Results

8.1 Reference values

The reference values are listed in Table 5. These values were obtained using the procedure described in the previous section. No discrepant results were found and no results have been excluded from the determination of the reference values. It is worth noting that NPL asked to withdraw their data from the comparison.

Table 5: Reference values for the comparison. Free-field sensitivity levels in dB re 1V/Pa and expanded uncertainties U (*k=2*) in dB.

Frequency (Hz)	4191.2114351		4191.2114352	
	Sensitivity (dB ref 1V/Pa)	U(*k=2*) (dB)	Sensitivity (dB ref 1V/Pa)	U(*k=2*) (dB)
25.119	-37.962	0.123	-37.864	0.123
31.623	-37.956	0.114	-37.862	0.114
39.811	-37.988	0.114	-37.863	0.114
50.119	-37.977	0.101	-37.878	0.101
63.096	-37.979	0.100	-37.878	0.100
79.433	-37.971	0.099	-37.879	0.099
100.00	-37.980	0.092	-37.891	0.092
125.89	-37.990	0.092	-37.894	0.092
158.49	-38.009	0.083	-37.919	0.083
199.53	-38.023	0.080	-37.938	0.080
251.19	-38.049	0.064	-37.947	0.064
316.23	-38.054	0.063	-37.952	0.063
398.11	-38.067	0.064	-37.967	0.064
501.19	-38.056	0.055	-37.960	0.055
630.96	-38.063	0.053	-37.969	0.053
794.33	-38.075	0.050	-37.980	0.051
1000.0	-38.082	0.051	-37.984	0.051
1258.9	-38.097	0.052	-37.995	0.052
1584.9	-38.116	0.055	-38.010	0.055
1995.3	-38.135	0.058	-38.023	0.058
2511.9	-38.158	0.061	-38.038	0.062
3162.3	-38.208	0.063	-38.078	0.063
3981.1	-38.281	0.063	-38.144	0.063
5011.9	-38.379	0.061	-38.234	0.061
6309.6	-38.481	0.064	-38.331	0.064
7943.3	-38.576	0.069	-38.418	0.069
10000	-38.633	0.074	-38.490	0.074
12589	-38.567	0.078	-38.457	0.078
15849	-38.459	0.081	-38.380	0.081
19953	-38.658	0.079	-38.613	0.079
25119	-39.516	0.095	-39.522	0.094
31623	-41.070	0.122	-41.252	0.122
39811	-43.785	0.133	-44.101	0.133

8.2 Degrees of equivalence per laboratory

The degrees of equivalence per laboratory were determined as mentioned in the previous section (equation (4)). Figure 7 below shows average deviation in dB per laboratory as a function of frequency. Table 6 present the degrees of equivalence and their uncertainties in tabular form.

The degrees of equivalence calculated for the frequencies, 251.19 Hz, 1000.0 Hz, 3981.1 Hz, 15849 Hz and 39811 Hz are shown in Figure 8 to Figure 12.

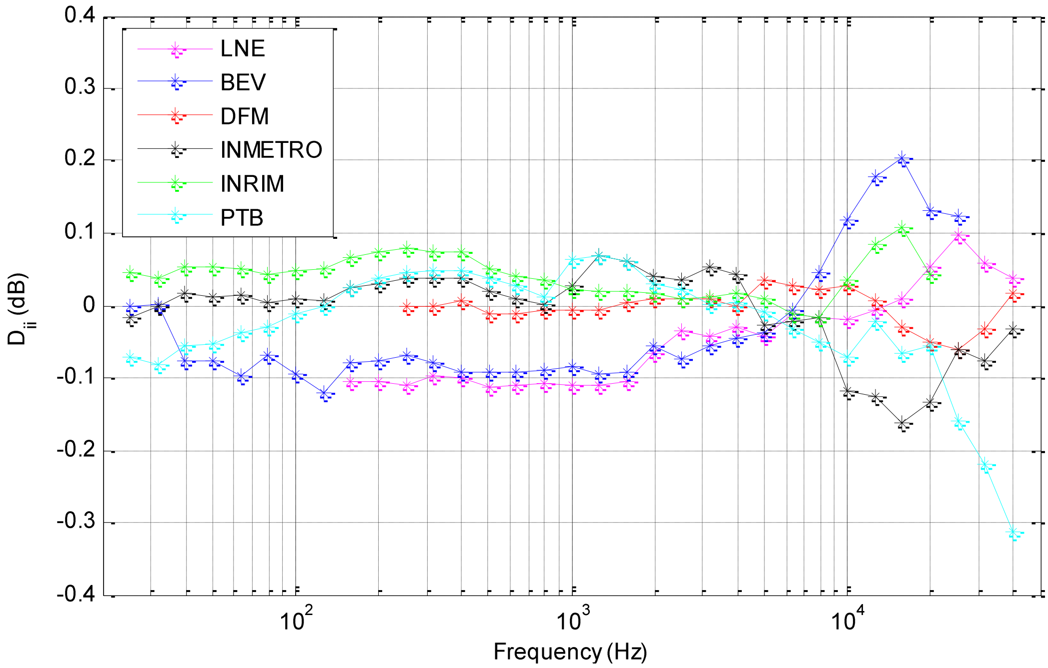

Figure 7: Degrees of equivalence per laboratory as function of frequency (deviations).

Table 6: Degrees of equivalence per laboratory as function of frequency: deviations (dB) and uncertainties *k=2* (dB).

Frequency (Hz)	LNE		BEV		DFM		INMETRO		INRIM		PTB	
	D_{ii}	U *k=2*	D_{ii}	U *k=2*	D_{ii}	U *k=2*	D_{ii}	U *k=2*	D_{ii}	U *k=2*	D_{ii}	U *k=2*
25.119	-	-	-0.002	0.213	-	-	-0.017	0.201	0.045	0.149	-0.071	0.252
31.623	-	-	0.000	0.203	-	-	-0.002	0.152	0.039	0.153	-0.082	0.256
39.811	-	-	-0.077	0.209	-	-	0.018	0.152	0.054	0.149	-0.056	0.256
50.119	-	-	-0.078	0.205	-	-	0.012	0.102	0.053	0.156	-0.054	0.260
63.096	-	-	-0.099	0.205	-	-	0.015	0.103	0.051	0.147	-0.037	0.261
79.433	-	-	-0.070	0.205	-	-	0.005	0.104	0.043	0.143	-0.029	0.261
100.00	-	-	-0.094	0.207	-	-	0.008	0.109	0.049	0.141	-0.012	0.164
125.89	-	-	-0.120	0.211	-	-	0.008	0.109	0.050	0.137	-0.001	0.164
158.49	-0.106	0.168	-0.080	0.211	-	-	0.024	0.115	0.065	0.135	0.024	0.168
199.53	-0.105	0.138	-0.076	0.212	-	-	0.030	0.117	0.073	0.133	0.037	0.169
251.19	-0.110	0.135	-0.070	0.218	-0.002	0.082	0.038	0.125	0.080	0.143	0.044	0.175
316.23	-0.098	0.125	-0.078	0.216	0.000	0.083	0.038	0.125	0.073	0.138	0.049	0.175
398.11	-0.100	0.125	-0.093	0.217	0.007	0.083	0.038	0.125	0.074	0.145	0.048	0.175
501.19	-0.113	0.129	-0.093	0.231	-0.012	0.088	0.018	0.129	0.049	0.069	0.037	0.177
630.96	-0.111	0.129	-0.092	0.231	-0.011	0.089	0.010	0.129	0.041	0.058	0.026	0.178
794.33	-0.107	0.130	-0.091	0.232	-0.006	0.090	0.000	0.130	0.035	0.050	0.011	0.178
1000.0	-0.111	0.130	-0.085	0.233	-0.007	0.090	0.026	0.178	0.023	0.046	0.063	0.178
1258.9	-0.110	0.130	-0.094	0.229	-0.007	0.090	0.070	0.178	0.019	0.049	0.069	0.178
1584.9	-0.104	0.129	-0.093	0.233	0.003	0.088	0.062	0.177	0.019	0.059	0.062	0.177
1995.3	-0.066	0.117	-0.057	0.242	0.010	0.086	0.041	0.176	0.016	0.077	0.030	0.176
2511.9	-0.035	0.116	-0.074	0.246	0.008	0.084	0.036	0.175	0.010	0.097	0.022	0.175
3162.3	-0.042	0.115	-0.056	0.250	0.009	0.083	0.054	0.175	0.013	0.109	0.001	0.175
3981.1	-0.029	0.115	-0.045	0.249	0.000	0.083	0.044	0.175	0.016	0.107	0.004	0.175
5011.9	-0.042	0.116	-0.038	0.245	0.035	0.084	-0.028	0.176	0.009	0.095	-0.009	0.176
6309.6	-0.012	0.115	-0.007	0.255	0.028	0.083	-0.022	0.175	-0.011	0.100	-0.032	0.270
7943.3	-0.017	0.112	0.045	0.276	0.023	0.079	-0.017	0.173	-0.016	0.153	-0.051	0.269
10000	-0.018	0.109	0.118	0.335	0.028	0.075	-0.118	0.220	0.036	0.247	-0.071	0.268
12589	-0.008	0.107	0.178	0.448	0.006	0.071	-0.126	0.267	0.085	0.310	-0.021	0.362
15849	0.008	0.105	0.204	0.398	-0.030	0.081	-0.162	0.455	0.109	0.224	-0.066	0.361
19953	0.053	0.117	0.130	0.371	-0.051	0.083	-0.135	0.455	0.044	0.153	-0.056	0.361
25119	0.097	0.119	0.123	0.374	-0.061	0.082	-0.060	0.453	-	-	-0.159	0.453
31623	0.058	0.110	-	-	-0.033	0.146	-0.077	0.447	-	-	-0.218	0.447
39811	0.038	0.138	-	-	0.016	0.138	-0.032	0.539	-	-	-0.314	0.444

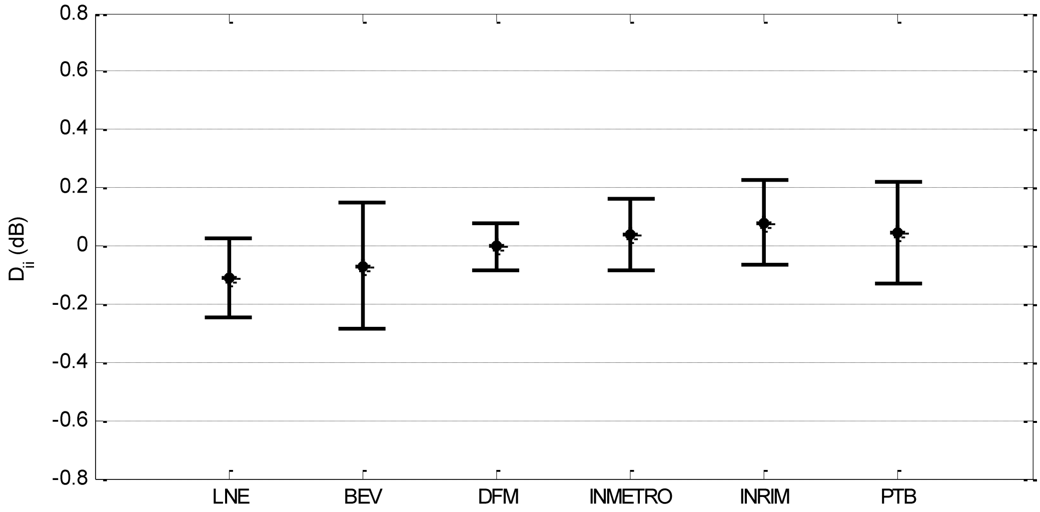

Figure 8: Degrees of equivalence and uncertainty (*k=2*) in dB – 251.19 Hz

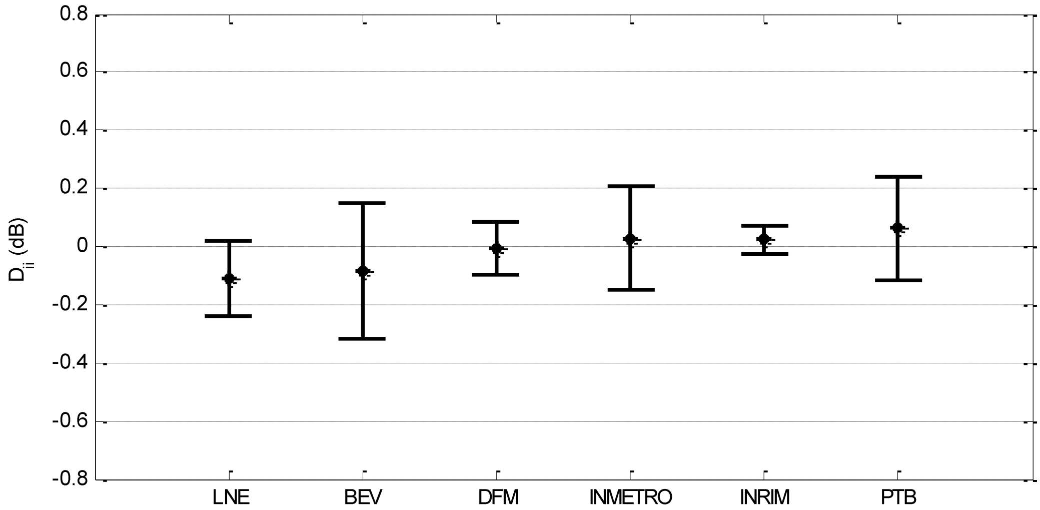

Figure 9: Degrees of equivalence and uncertainty (*k=2*) in dB – 1000.0 Hz

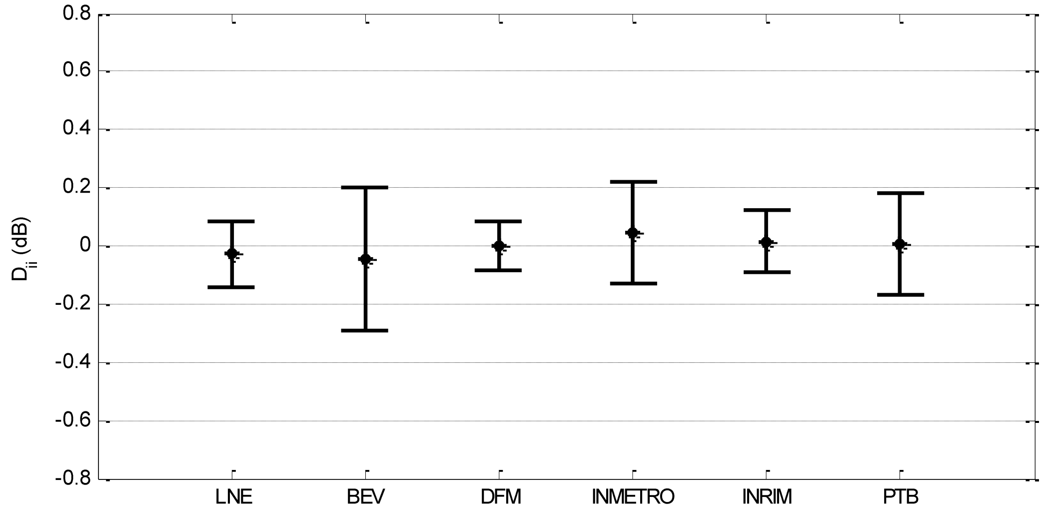

Figure 10: Degrees of equivalence and uncertainty (*k=2*) in dB – 3981 Hz

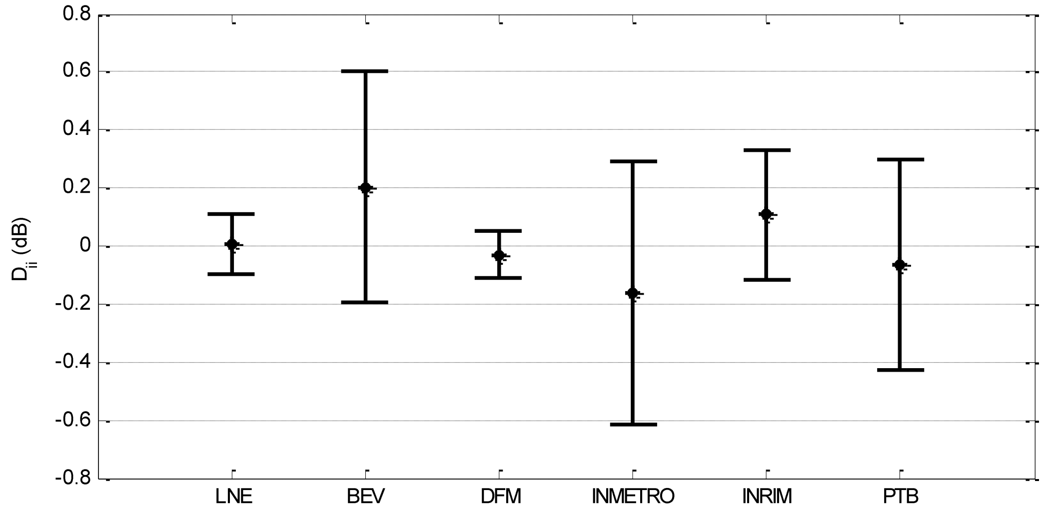

Figure 11: Degrees of equivalence and uncertainty (*k=2*) in dB – 15849 Hz

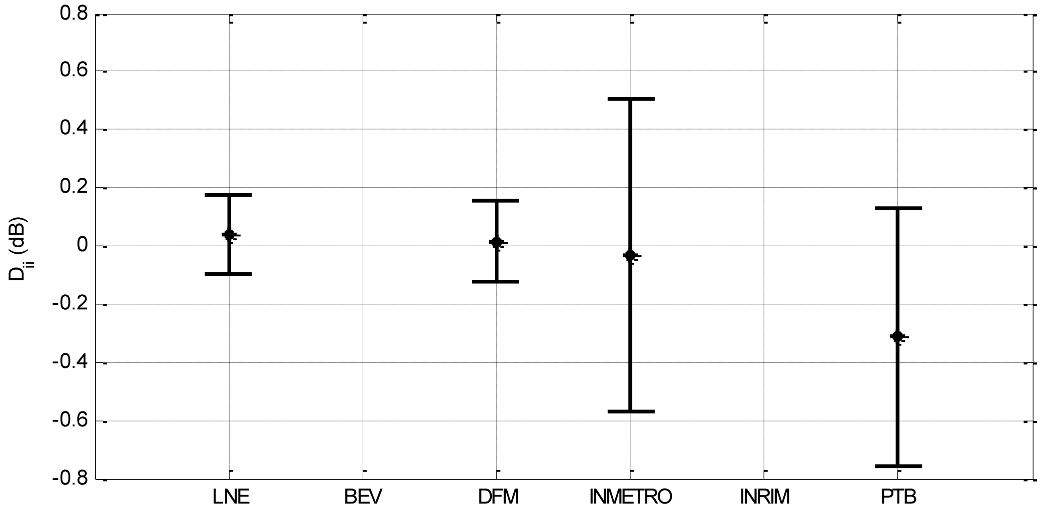

Figure 12: Degrees of equivalence and uncertainty (*k=2*) in dB – 39811 Hz

Table 7 shows the results of the χ^2 test applied to the comparison results for a correlation value of 0.7. In general, this test has been considered satisfactory.

Table 7 : Results of the χ^2 test as described in [4]. The correlation used in the calculations is 0.7.

Frequency (Hz)	$P\{\chi^2(v) > \chi^2_{obs}\}$ **(%)**
25.12	99.6
31.62	99.4
39.81	71.9
50.12	93.5
63.10	89.1
79.43	96.3
100.00	96.0
125.89	60.0
158.49	87.5
199.53	84.6
251.19	81.9
316.23	84.1
398.11	83.6
501.19	78.1
630.96	82.2
794.33	84.6
1000.00	84.1
1258.93	81.9
1584.89	87.5
1995.26	98.5
2511.89	99.7
3162.28	99.7
3981.07	99.9
5011.87	99.8
6309.57	100.0
7943.28	100.0
10000.00	99.2
12589.25	99.7
15848.93	98.5
19952.62	98.7
25118.86	87.2
31622.78	94.3
39810.72	88.7

8.3 Degrees of equivalence inter-laboratory

Table 8 to Table 12 contain the inter-laboratory degrees of equivalence of this comparison.

Table 8: Inter-laboratory degrees of equivalence at 251.19 Hz. The upper triangle contains the differences (dB); the lower triangle contains the uncertainties *k=2* (dB).

251.19 Hz	LNE	BEV	DFM	INMETRO	INRIM	PTB
LNE	-	-0.040	-0.108	-0.148	-0.191	-0.155
BEV	0.270	-	-0.067	-0.108	-0.150	-0.114
DFM	0.179	0.248	-	-0.040	-0.083	-0.047
INMETRO	0.202	0.265	0.171	-	-0.043	-0.006
INRIM	0.214	0.274	0.185	0.208	-	0.036
PTB	0.236	0.292	0.210	0.230	0.241	-

Table 9: Inter-laboratory degrees of equivalence at 1000.0 Hz. The upper triangle contains the differences (dB); the lower triangle contains the uncertainties *k=2* (dB).

1000.0 Hz	LNE	BEV	DFM	INMETRO	INRIM	PTB
LNE	-	-0.026	-0.104	-0.137	-0.134	-0.174
BEV	0.275	-	-0.078	-0.111	-0.108	-0.148
DFM	0.171	0.258	-	-0.033	-0.030	-0.070
INMETRO	0.230	0.300	0.210	-	0.004	-0.037
INRIM	0.153	0.246	0.121	0.196	-	-0.041
PTB	0.230	0.300	0.210	0.261	0.196	-

Table 10: Inter-laboratory degrees of equivalence at 3981.1 Hz. The upper triangle contains the differences (dB); the lower triangle contains the uncertainties *k=2* (dB).

3981.1 Hz	LNE	BEV	DFM	INMETRO	INRIM	PTB
LNE	-	0.016	-0.029	-0.073	-0.045	-0.033
BEV	0.286	-	-0.045	-0.089	-0.061	-0.049
DFM	0.164	0.275	-	-0.044	-0.016	-0.004
INMETRO	0.225	0.315	0.210	-	0.028	0.040
INRIM	0.177	0.283	0.158	0.221	-	0.011
PTB	0.225	0.315	0.210	0.261	0.221	-

Table 11: Inter-laboratory degrees of equivalence at 15849 Hz. The upper triangle contains the differences (dB); the lower triangle contains the uncertainties *k=2* (dB).

15849 Hz	LNE	BEV	DFM	INMETRO	INRIM	PTB
LNE	-	-0.196	0.038	0.170	-0.100	0.074
BEV	0.425	-	0.233	0.366	0.095	0.270
DFM	0.170	0.420	-	0.132	-0.138	0.036
INMETRO	0.479	0.613	0.474	-	-0.270	-0.096
INRIM	0.269	0.469	0.261	0.518	-	0.174
PTB	0.391	0.548	0.385	0.590	0.438	-

Table 12: Inter-laboratory degrees of equivalence at 39811 Hz. The upper triangle contains the differences (dB); the lower triangle contains the uncertainties *k=2* (dB).

39811 Hz	LNE	BEV	DFM	INMETRO	INRIM	PTB
LNE	-	-	0.022	0.070	-	0.352
BEV	-	-	-	-	-	-
DFM	0.261	-	-	0.048	-	0.329
INMETRO	0.583	-	0.583	-	-	0.282
INRIM	-	-	-	-	-	-
PTB	0.496	-	0.496	0.720	-	-

9 Conclusions

The aim of the Supplementary comparison EURAMET.AUV.A-S2 is to establish reliable equivalence between National Metrology Institutes for free-field calibration of Working Standard microphones of the type WS2. The initial plans involved seven participants. However, NPL asked to be removed from the comparison.

Two WS2 microphones were circulated among the participants and calibrated using a secondary free-field method based on the International Standard IEC 61094-8 (2012). All participants reported the open-circuit free-field sensitivities.

The reported sensitivities have been analysed using a least-squares technique similar to the one used in the Key Comparison CCAUV.A-K4.

The degrees of equivalence provided in the previous sections shown that the drifts of the sensitivities of the microphones reported in Section 4 can be considered as not significant given the uncertainties reported by the participant laboratories. Thereby, it is not necessary to recalculate the degrees of equivalent by taking into account these drifts in the analysis.

All laboratories were included in the estimation of the reference values and the results of the comparison are satisfactory, leading to the demonstration of the equivalence of the calibrations.

10 References

[1] Technical Protocol. Comparison of secondary free-field calibration of WS2 microphones (EURAMET.AUV.A-S2).

[2] S. Barrera-Figueroa. L. Nielsen. K. Rasmussen. A. E. Pérez Matzumoto and J. Noé Razo Razo. Final Report on the Key Comparison CCAUV.A-K4. Centro Nacional de Metrología. México. Danish Primary Laboratory for Acoustics. Denmark.

[3] V. Cutanda Henriquez. K. Rasmussen. Final report on the Key Comparison CCAUV.A-K3. Centro Nacional de Metrología. México. Danish Primary Laboratory for Acoustics. Denmark.

[4] L. Nielsen. Identification and handling of discrepant measurements in key comparisons. Danish Institute of Fundamental Metrology. DFM-01-R28. 2002.

Appendix A - Uncertainty budgets

a) LNE

Frequency (Hz)	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000	25000	31500	40000

Components of type B uncertainties in dB*1000

Reference microphone sensitivity	31	35	35	39	39	41	41	41	41	44	44	35	35	35	35	35	35	35	35	35	35	40	45	50	70
Reference microphone sensitivity drift	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Effective distance	14	14	14	14	14	14	15	15	15	15	15	15	15	15	15	15	15	16	16	17	19	21	24	29	34
Voltage ratio	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Source stability	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Air absorption	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2
Environmental corrections	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.6	11.6	11.7	11.8	12.0	12.5	12.7	11.8	15.5	22.3	22.3	22.3	22.3
Polarization voltage	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Disturbances	79	56	47	35	29	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Rounding of results	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9

Components of type A uncertainties in dB*1000

Repeatability	46.2	40.4	34.6	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9

Expanded uncertainty in dB (k=2)	0.200	0.168	0.156	0.147	0.141	0.141	0.141	0.141	0.141	0.143	0.143	0.133	0.134	0.134	0.134	0.134	0.134	0.134	0.135	0.135	0.137	0.147	0.155	0.164	0.194
Declared values in dB (k=2)	**0.20**	**0.17**	**0.16**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.15**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.15**	**0.16**	**0.17**	**0.20**

b) BEV

Measurement model

For each frequency the measurement model equation is:

(1) $$S_{0,t} = S_{0,r} + \Delta_{ff,r} + \lg\left(\frac{V_t}{V_r}\right)$$

Where:

$S_{0,t}, S_{0,r}$ …sensitivities of TM and RM, respectively

V_t, V_r …measured voltages of TM and RM, respectively

$\Delta_{ff,r}$ …free field correction of RM calculated according to IEC 61094-7:2006

Measurement uncertainty

The measurement uncertainty was calculated for each frequency and microphone. The included sources of uncertainty are listed below:

1. Calibration of the reference microphone: see 2.1 (Gauss distribution)
2. Repeatability of the reference microphone: For each frequency the repeatability was simply calculated as the uncertainty of the mean of all 9 measured sound pressure levels. (Student distribution)
3. Repeatability of the test microphone: For each frequency the repeatability was simply calculated as the uncertainty of the mean of all 9 measured sound pressure levels. (Student distribution)
4. Uncertainty due to different capacitances of RM and TM. The uncertainty was calculated with the following formula (rectangular distribution):

   $$u_c = \frac{20}{\sqrt{3}}\left(\lg\left(\frac{C_{RM}}{C_{RM}+C_I}\right) - \lg\left(\frac{C_{TM}}{C_{TM}+C_I}\right)\right)$$

   C_{RM}, C_{TM}, C_I …capacitance of RM, TM and Preamplifier, respectively
5. Uncertainty due to positioning and field non-uniformity (rectangular distribution)
6. Uncertainty due to sound source stability (rectangular distribution).
7. Uncertainties due to air temperature calculated for RM and TM according to the manufactures specifications (rectangular distribution).
8. Uncertainties due to pressure calculated for RM and TM according to the manufactures specifications (rectangular distribution).

9. Uncertainty due to free field correction of RM calculated according to IEC 61094-7:2006 (Gauss distribution).

Uncertainties due to polarisation voltage. rounding or non-linearity in signal processing were omitted. The following tables list the uncertainty values:

	Uncertainty contribution (k=1) dB re 1V/Pa									
f Hz	1	2	3	4	5	6	7	8	9	U dB re 1V/Pa
25,12	0,0200	0,0322	0,0427	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2652
31,62	0,0200	0,0119	0,0183	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2466
39,81	0,0200	0,0332	0,0154	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2535
50,12	0,0200	0,0062	0,0131	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2444
63,10	0,0200	0,0062	0,0043	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2432
79,43	0,0200	0,0085	0,0033	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2434
100,00	0,0200	0,0033	0,0027	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2429
125,89	0,0200	0,0163	0,0179	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2475
158,49	0,0200	0,0017	0,0016	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2428
199,53	0,0200	0,0034	0,0019	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2428
251,19	0,0200	0,0138	0,0106	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2452
316,23	0,0200	0,0015	0,0011	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2427
398,11	0,0200	0,0099	0,0041	0,0041	0,1155	0,0289	0,0016	0,0104	0,0058	0,2437
501,19	0,0200	0,0022	0,0016	0,0041	0,1155	0,0289	0,0016	0,0104	0,0416	0,2564
630,96	0,0200	0,0014	0,0022	0,0041	0,1155	0,0289	0,0016	0,0104	0,0416	0,2564
794,33	0,0200	0,0033	0,0015	0,0041	0,1155	0,0289	0,0016	0,0104	0,0416	0,2564
1000,00	0,0200	0,0105	0,0032	0,0041	0,1155	0,0289	0,0016	0,0104	0,0416	0,2573
1258,93	0,0200	0,0035	0,0042	0,0041	0,1155	0,0289	0,0016	0,0104	0,0365	0,2534
1584,89	0,0200	0,0017	0,0038	0,0041	0,1155	0,0289	0,0016	0,0104	0,0453	0,2590
1995,26	0,0200	0,0093	0,0023	0,0041	0,1155	0,0289	0,0016	0,0104	0,0563	0,2680
2511,89	0,0200	0,0034	0,0116	0,0041	0,1155	0,0289	0,0016	0,0104	0,0631	0,2744
3162,28	0,0200	0,0044	0,0044	0,0041	0,1155	0,0289	0,0016	0,0104	0,0679	0,2782
3981,07	0,0200	0,0044	0,0087	0,0041	0,1155	0,0289	0,0016	0,0104	0,0666	0,2773
5011,87	0,0200	0,0046	0,0061	0,0041	0,1155	0,0289	0,0016	0,0104	0,0613	0,2721
6309,57	0,0200	0,0215	0,0254	0,0041	0,1155	0,0289	0,0016	0,0104	0,0676	0,2855
7943,28	0,0250	0,0199	0,0147	0,0041	0,1155	0,0289	0,0016	0,0104	0,0890	0,3063
10000,00	0,0250	0,0103	0,0050	0,0041	0,1155	0,0289	0,0016	0,0104	0,1390	0,3708
12589,25	0,0250	0,0239	0,0175	0,0041	0,1732	0,0289	0,0016	0,0104	0,1677	0,4923
15848,93	0,0500	0,0116	0,0112	0,0041	0,1732	0,0289	0,0016	0,0104	0,1203	0,4390
19952,62	0,0500	0,0158	0,0252	0,0041	0,1732	0,0289	0,0016	0,0104	0,0887	0,4109
25118,86	0,0500	0,0308	0,0371	0,0041	0,1732	0,0289	0,0016	0,0104	0,0907	0,4196

Uncertainties for B&K 4191, SN 2114351.

	Uncertainty contribution (k=1) dB re 1V/Pa									
f Hz	1	2	3	4	5	6	7	8	9	U dB re 1V/Pa
25,12	0,0200	0,0322	0,0296	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2580
31,62	0,0200	0,0119	0,0258	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2493
39,81	0,0200	0,0332	0,0183	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2543
50,12	0,0200	0,0062	0,0116	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2442
63,10	0,0200	0,0062	0,0055	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2433
79,43	0,0200	0,0085	0,0077	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2438
100,00	0,0200	0,0033	0,0033	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2429
125,89	0,0200	0,0163	0,0118	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2461
158,49	0,0200	0,0017	0,0030	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2429
199,53	0,0200	0,0034	0,0010	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2429
251,19	0,0200	0,0138	0,0064	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2447
316,23	0,0200	0,0015	0,0019	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2428
398,11	0,0200	0,0099	0,0055	0,0047	0,1155	0,0289	0,0016	0,0104	0,0058	0,2438
501,19	0,0200	0,0022	0,0021	0,0047	0,1155	0,0289	0,0016	0,0104	0,0416	0,2565
630,96	0,0200	0,0014	0,0026	0,0047	0,1155	0,0289	0,0016	0,0104	0,0416	0,2565
794,33	0,0200	0,0033	0,0050	0,0047	0,1155	0,0289	0,0016	0,0104	0,0416	0,2567
1000,00	0,0200	0,0105	0,0023	0,0047	0,1155	0,0289	0,0016	0,0104	0,0416	0,2573
1258,93	0,0200	0,0035	0,0049	0,0047	0,1155	0,0289	0,0016	0,0104	0,0365	0,2535
1584,89	0,0200	0,0017	0,0041	0,0047	0,1155	0,0289	0,0016	0,0104	0,0453	0,2590
1995,26	0,0200	0,0093	0,0150	0,0047	0,1155	0,0289	0,0016	0,0104	0,0563	0,2697
2511,89	0,0200	0,0034	0,0032	0,0047	0,1155	0,0289	0,0016	0,0104	0,0631	0,2735
3162,28	0,0200	0,0044	0,0054	0,0047	0,1155	0,0289	0,0016	0,0104	0,0679	0,2783
3981,07	0,0200	0,0044	0,0061	0,0047	0,1155	0,0289	0,0016	0,0104	0,0666	0,2771
5011,87	0,0200	0,0046	0,0145	0,0047	0,1155	0,0289	0,0016	0,0104	0,0613	0,2734
6309,57	0,0200	0,0215	0,0119	0,0047	0,1155	0,0289	0,0016	0,0104	0,0676	0,2820
7943,28	0,0250	0,0199	0,0179	0,0047	0,1155	0,0289	0,0016	0,0104	0,0890	0,3070
10000,00	0,0250	0,0103	0,0138	0,0047	0,1155	0,0289	0,0016	0,0104	0,1390	0,3718
12589,25	0,0250	0,0239	0,0101	0,0047	0,1732	0,0289	0,0016	0,0104	0,1677	0,4914
15848,93	0,0500	0,0116	0,0106	0,0047	0,1732	0,0289	0,0016	0,0104	0,1203	0,4390
19952,62	0,0500	0,0158	0,0186	0,0047	0,1732	0,0289	0,0016	0,0104	0,0887	0,4095
25118,86	0,0500	0,0308	0,0137	0,0047	0,1732	0,0289	0,0016	0,0104	0,0907	0,4139

Uncertainties for B&K 4191, SN 2114352.

c) DFM

The uncertainty of the free-field sensitivity level of a WS microphone, $L_{M,DUT}$ can be determined using the following model:

$$L_{M,DUT} = L_{M,Ref} + C_M + C_d + C_{Env} + C_{Rep}.$$

where $L_{M,Ref}$ is the free-field sensitivity level of the reference microphone, C_M is the voltage ratio level, C_d is the correction due to acoustic distance, C_{Env} is the correction due to deviations from reference conditions, and C_{Rep} is the correction due to reproducibility. Hence these are the sources of uncertainty. The table below contains the uncertainty budget for the free-fieid sensitivity level of WS2 microphones.

Uncertainty budget for free-field sensitivity of WS2 and WS3 microphones using reference microphones Brüel & Kjær type 4180.

Frequency (kHz)	0.25	0.5	1	5	10	15	20	25	30	35	40
Components of type B in dB*1000											
Acoustic centre (2.5 mm @ 650 mm)	30	30	30	30	30	30	30	30	30	30	30
Environmental correction	1	1	1	1	2	4	5	17	25	35	40
Polarising voltage	2	2	2	2	2	2	2	2	2	2	2
Rounding	5	5	5	5	5	5	5	5	5	5	5
Sum $u_B = \sqrt{\sum u_{B,i}^2 / 3}$	18	18	18	18	18	18	18	20	23	27	30
Components of type A in dB*1000											
Sensitivity of reference microphone	35	35	35	35	40	40	45	50	60	60	60
Voltage ratio	20	20	20	20	20	20	20	20	20	20	20
Allowed reproducibility	30	30	30	30	30	30	50	50	50	60	60
Sum $u_A = \sqrt{\sum u_{A,i}^2}$	50	50	50	50	54	54	58	62	70	87	87
Expanded uncertainty *k* = 2 (dB) $U = \left(\sqrt{\sum u_A^2 + u_B^2}\right) \cdot k$	0.11	0.11	**0.11**	**0.11**	**0.11**	**0.11**	**0.12**	**0.13**	**0.15**	**0.18**	**0.18**

d) INMETRO

Uncertainty calculation from 25 to 630 Hz.

Source of Uncertainty	Frequency (Hz) 25	31,5	40	50	63	80	100	125	160	200	250	315	400	500	630	ν_i	Distribuition
LS2p microphone calibration	0,030	0,030	0,030	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	50	normal
rmsd	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,005	0,009	0,016	0,027	0,030	Infinite	rectangular
Insertion voltage	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	Infinite	rectangular
Non-linearity CMF22	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	Infinite	rectangular
Repeatability	0,069	0,048	0,045	0,034	0,028	0,027	0,027	0,025	0,025	0,027	0,027	0,027	0,027	0,028	0,028	4	normal
Rounding (0,01 dB)	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	Infinite	rectangular
Temperature, humidity, pressure (dB)	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	Infinite	rectangular
Position of acoustic center	0,008	0,008	0,008	0,008	0,008	0,010	0,010	0,012	0,013	0,015	0,015	0,017	0,018	0,020	0,020	Infinite	rectangular
Stability of sound source	0,045	0,040	0,038	0,038	0,036	0,035	0,033	0,031	0,028	0,026	0,025	0,025	0,025	0,025	0,025	Infinite	rectangular
Polarization voltage	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	Infinite	rectangular
Time-sective technique	0,045	0,045	0,044	0,041	0,040	0,039	0,038	0,033	0,020	0,015	0,009	0,005	0,002	0,000	0,000	Infinite	rectangular
Combined uncertainty	0,100	0,084	0,081	0,072	0,067	0,066	0,064	0,060	0,053	0,051	0,050	0,050	0,052	0,058	0,059	***	***
ν_{eff}	17	37	41	77	128	136	123	124	73	50	44	46	53	69	76	***	***
Coverage factor, k	2,11	2,03	2,02	1,99	1,98	1,98	1,98	1,98	1,99	2,01	2,02	2,01	2,01	2,00	1,99	***	***
Expanded uncertainty	**0,21**	**0,17**	**0,16**	**0,14**	**0,13**	**0,13**	**0,13**	**0,12**	**0,11**	**0,10**	**0,10**	**0,10**	**0,10**	**0,12**	**0,12**	***	***
Reported expanded uncertainty	**0,25**	**0,20**	**0,20**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**		

Uncertainty calculation from 800 to 20000 Hz.

Source of Uncertainty	Frequency (Hz) 800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000	ν_i	Distribuition
LS2p microphone calibration	0,025	0,065	0,060	0,056	0,052	0,052	0,047	0,046	0,046	0,057	0,064	0,075	0,095	0,095	0,100	50	normal
rmsd	0,043	0,050	0,041	0,031	0,023	0,018	0,074	0,042	0,070	0,025	0,048	0,038	0,027	0,212	0,160	Infinite	rectangular
Insertion voltage	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	Infinite	rectangular
Non-linearity CMF22	0,002	0,002	0,002	0,003	0,003	0,004	0,005	0,005	0,005	0,007	0,010	0,012	0,015	0,015	0,015	Infinite	rectangular
Repeatability	0,025	0,030	0,025	0,024	0,031	0,024	0,023	0,021	0,014	0,021	0,031	0,049	0,048	0,030	0,035	4	normal
Rounding (0,01 dB)	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	Infinite	rectangular
Temperature, humidity, pressure (dB)	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,017	0,017	0,017	0,025	0,045	Infinite	rectangular
Position of acoustic center	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,021	0,021	0,021	0,023	0,025	0,026	0,028	0,028	Infinite	rectangular
Stability of sound source	0,025	0,027	0,031	0,033	0,030	0,028	0,029	0,029	0,029	0,029	0,029	0,029	0,031	0,033	0,062	Infinite	rectangular
Polarization voltage	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	Infinite	rectangular
Time-sective technique	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	Infinite	rectangular
Combined uncertainty	0,066	0,094	0,086	0,080	0,075	0,071	0,098	0,076	0,093	0,076	0,096	0,107	0,119	0,240	0,209	***	***
ν_{eff}	175	142	155	143	85	108	559	245	770	130	147	63	69	1812	805	***	***
Coverage factor, k	1,97	1,98	1,98	1,98	1,99	1,98	1,96	1,97	1,96	1,98	1,98	2,00	2,00	1,96	1,96	***	***
Expanded uncertainty	**0,13**	**0,19**	**0,17**	**0,16**	**0,15**	**0,14**	**0,19**	**0,15**	**0,18**	**0,15**	**0,19**	**0,21**	**0,24**	**0,47**	**0,41**	***	***
Reported expanded uncertainty	**0,15**	**0,20**	**0,20**	**0,20**	**0,20**	**0,20**	**0,20**	**0,20**	**0,20**	**0,20**	**0,20**	**0,25**	**0,30**	**0,50**	**0,50**		

Uncertainty calculation from 25000 to 40000 Hz.

	Frequency (Hz)				
Source of Uncertainty	**25000**	**31500**	**40000**	ν_i	**Distribuition**
LS2p microphone calibration	0,105	0,115	0,130	50	normal
rmsd	0,180	0,190	0,210	50	normal
Insertion voltage	0,003	0,003	0,003	Infinite	rectangular
Non-linearity CMF22	0,015	0,020	0,050	Infinite	rectangular
Repeatability	0,040	0,049	0,052	4	normal
Rounding (0,01 dB)	0,003	0,003	0,003	Infinite	rectangular
Temperature, humidity, pressure (dB)	0,080	0,100	0,120	Infinite	rectangular
Position of acoustic center	0,028	0,030	0,030	Infinite	rectangular
Stability of sound source	0,074	0,086	0,098	Infinite	rectangular
Polarization Voltage	0,003	0,003	0,003	Infinite	rectangular
Time-sective technique	0,000	0,000	0,000	Infinite	rectangular
Combined uncertainty	0,241	0,265	0,302	***	***
ν_{eff}	139	160	179	***	***
Coverage factor, k	1,98	1,97	1,97	***	***
Expanded uncertainty	**0,48**	**0,52**	**0,60**	***	***
Reported expanded uncertainty	**0,50**	**0,50**	**0,60**		

e) INRiM

Main uncertainty components

Frequency	Repeatability	Field deviation from FF	Reference pressure calibration	uc	U95	WS	k
Hz	dB	dB	dB	dB	dB		
25,11886	0,022	0,093	0,032	0,101	0,203	437,154	2,01
31,62278	0,022	0,091	0,032	0,1	0,201	385,522	2,01
39,81072	0,023	0,09	0,032	0,098	0,198	330,564	2,01
50,11872	0,023	0,088	0,032	0,097	0,197	274,197	2,02
63,09573	0,024	0,086	0,023	0,093	0,188	195,824	2,02
79,43282	0,026	0,084	0,023	0,091	0,184	148,864	2,02
100	0,027	0,08	0,023	0,088	0,179	107,678	2,02
125,8925	0,029	0,076	0,023	0,085	0,175	73,858	2,05
158,4893	0,031	0,072	0,023	0,082	0,168	48,017	2,05
199,5262	0,033	0,067	0,023	0,078	0,165	29,723	2,1
251,1886	0,036	0,06	0,023	0,074	0,168	17,741	2,25
316,2278	0,039	0,054	0,023	0,071	0,162	10,46	2,28
398,1072	0,042	0,046	0,023	0,067	0,17	6,324	2,52

Frequency	Repeatability	Pressure to FF	Reference pressure calibration	uc	U95	WS	k
Hz	dB	dB	dB	dB	dB		
501,1872	0,005	0,039	0,023	0,046	0,093	55438,42	2
630,9573	0,004	0,033	0,023	0,041	0,082	59642,25	2
794,3282	0,004	0,028	0,023	0,037	0,074	70412,68	2
1000	0,003	0,026	0,023	0,035	0,071	89494,55	2
1258,925	0,003	0,028	0,023	0,037	0,074	112413,8	2
1584,893	0,004	0,034	0,023	0,042	0,084	129119,8	2
1995,262	0,004	0,044	0,023	0,051	0,102	132831,6	2
2511,886	0,006	0,055	0,023	0,06	0,121	121388,7	2
3162,278	0,007	0,062	0,023	0,067	0,134	96817,63	2
3981,072	0,007	0,061	0,023	0,066	0,132	66194,02	2
5011,872	0,007	0,054	0,023	0,06	0,12	41516,94	2
6309,573	0,008	0,057	0,023	0,063	0,126	35375,62	2
7943,282	0,01	0,086	0,023	0,09	0,18	60275,76	2
10000	0,013	0,134	0,032	0,139	0,278	146231,2	2
12589,25	0,013	0,167	0,042	0,172	0,345	333542,9	2
15848,93	0,015	0,12	0,042	0,128	0,256	50104,05	2
19952,62	0,017	0,078	0,045	0,092	0,184	8524,088	2

f) PTB

explanation	reading of voltage level of microphone to test	reading of voltage level of reference microphone	uncertainty of reference sensitivity	roundoff error in reference calibration chart	drift of reference sensitivity since last calibration	temperature drift between reference and dut measurement	static pressure drift between reference and dut measurement	humidity drift between reference and dut measurement	variation of microphone positioning between reference and dut measurement	polarisation voltage instability between reference and dut measurement	drift of air absorption between reference and dut measurement	roundoff error of result	reproducibility of final result	overall uncertainty of measurement		nominal overall uncertainty of measurement
sensitivity coefficient	1	1	1	1	1	1	1	1	1	1	1	1	1			
distribution	rectangular	rectangular	normal	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular	rectangular	normal	rectangular	normal			
weighting	0.577	0.577	1	0.577	0.577	0.577	0.577	0.577	0.577	0.577	1	0.577	1			
uncertainty in dB (k=1)	0.03	0.03	freq. dep.	0.005	0.03	0.01	0.05	0.005	0.02	0.005	freq. dep.	0.025	freq. dep.			
frequency in Hz	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=1)	unc. in dB (k=2)	nominal uncertainty (k=2)
25.119	0.0173	0.0173	0.0190	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0000	0.0144	0.1158	0.1261	0.2522	0.3
31.623	0.0173	0.0173	0.0190	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0000	0.0144	0.1136	0.1241	0.2482	0.3
39.811	0.0173	0.0173	0.0190	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0000	0.0144	0.0980	0.1100	0.2200	0.3
50.119	0.0173	0.0173	0.0190	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0000	0.0144	0.0850	0.0986	0.1971	0.3
63.096	0.0173	0.0173	0.0190	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0000	0.0144	0.0635	0.0808	0.1616	0.3
79.433	0.0173	0.0173	0.0190	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0000	0.0144	0.0539	0.0734	0.1469	0.3
100.00	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0001	0.0144	0.0416	0.0785	0.1570	0.2
125.89	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0001	0.0144	0.0348	0.0751	0.1503	0.2
158.49	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0001	0.0144	0.0266	0.0717	0.1434	0.2
199.53	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0001	0.0144	0.0247	0.0710	0.1420	0.2
251.19	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0001	0.0144	0.0197	0.0695	0.1389	0.2
316.23	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0001	0.0144	0.0156	0.0684	0.1368	0.2
398.11	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0001	0.0144	0.0142	0.0681	0.1362	0.2

501.19	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0003	0.0144	0.0136	0.0680	0.1359	0.2
630.96	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0005	0.0144	0.0121	0.0677	0.1354	0.2
794.33	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0006	0.0144	0.0133	0.0679	0.1358	0.2
1000.0	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0007	0.0144	0.0135	0.0680	0.1359	0.2
1258.9	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0007	0.0144	0.0152	0.0683	0.1366	0.2
1584.9	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0005	0.0144	0.0141	0.0681	0.1362	0.2
1995.3	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0005	0.0144	0.0122	0.0677	0.1354	0.2
2511.9	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0016	0.0144	0.0142	0.0681	0.1362	0.2
3162.3	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0034	0.0144	0.0177	0.0690	0.1380	0.2
3981.1	0.0173	0.0173	0.0480	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0061	0.0144	0.0258	0.0717	0.1434	0.2
5011.9	0.0173	0.0173	0.0485	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0104	0.0144	0.0302	0.0742	0.1483	0.2
6309.6	0.0173	0.0173	0.0980	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0168	0.0144	0.0346	0.1150	0.2299	0.3
7943.3	0.0173	0.0173	0.0980	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0263	0.0144	0.0359	0.1171	0.2342	0.3
10000	0.0173	0.0173	0.0980	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0396	0.0144	0.0544	0.1275	0.2551	0.3
12589	0.0173	0.0173	0.1542	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0568	0.0144	0.0841	0.1903	0.3807	0.4
15849	0.0173	0.0173	0.1634	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0762	0.0144	0.0574	0.1947	0.3894	0.4
19953	0.0173	0.0173	0.1749	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0918	0.0144	0.0597	0.2114	0.4229	0.4
25119	0.0173	0.0173	0.1802	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.1059	0.0144	0.1113	0.2413	0.4825	0.5
31623	0.0173	0.0173	0.1904	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.1013	0.0144	0.0399	0.2242	0.4483	0.5
39811	0.0173	0.0173	0.2193	0.0029	0.0173	0.0058	0.0289	0.0029	0.0115	0.0029	0.0593	0.0144	0.0623	0.2401	0.4801	0.5