FINAL REPORT ON KEY COMPARISON APMP.AUV.A-K1

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Ryuzo Horiuchi, Hironobu Takahashi, Takeshi Fujimori and Sojun Sato

National Metrology Institute of Japan
National Institute of Advanced Industrial Science and Technology
(NMIJ, AIST)

Abstract

A regional key-comparison APMP.AUV.A-K1 has been carried out for the pressure sensitivity of laboratory standard microphones. The National Metrology Institute of Japan (NMIJ) piloted this project. Two LS1P microphones were circulated through nine national metrology institutes and calibrated in the frequency range from 63 Hz to 8 kHz. Deviations from the mean value are below ±0.05 dB for all the frequencies. Results have been linked to CIPM key-comparison CCAUV.A-K1 by introducing a correction factor. For every participant, degree of equivalence with a key comparison reference value is within corresponding expanded uncertainty.

1. Introduction

This is the final report for the regional key-comparison APMP.AUV.A-K1 on the pressure sensitivity of laboratory standard microphones. It has been approved by the participants and subsequently by CCAUV, and it is publicly available now.

This report includes calibration results from the participants, a linking model to CIPM key-comparison CCAUV.A-K1 [1] and degrees of equivalence with a key comparison reference value. National Metrology Institute of Japan (NMIJ) provided the report as a pilot laboratory.

2. Protocol

The basis of this key-comparison was pressure calibration of laboratory standard microphones. Two LS1P microphones were supplied by NMIJ.

A technical protocol instructed participants to submit uncertainty budget prior to the key-comparison and then to report the sensitivity in the frequency range from 63 Hz to 8 kHz and at the reference environmental conditions in their usual certificate forms. Additional information was requested on any deviation from the requirements of IEC 61094-2, together with the estimated uncertainty.

Nine national metrology institutes took part in the project, as listed in Table 1.

Table 1 Participants in the key-comparison APMP.AUV.A-K1

Participant (in alphabetical order)	Acronym	Economy
Center for Measurement Standards Industrial Technology Research Institute	CMS/ITRI	Taiwan
Korea Research Institute of Science and Standards	KRISS	Korea
National Institute of Metrology	NIM	China
National Institute of Metrology (Thailand)	NIMT	Thailand
National Measurement Institute*	NMIA	Australia
National Metrology Laboratory SIRIM Berhad	NML/SIRIM	Malaysia
National Physical laboratory	NPLI	India
Standards and Calibration Laboratory	SCL	Hong Kong
National Metrology Institute of Japan	NMIJ	Japan

*NML/CSIRO has been re-organised as National Measurement Institute.

2.1. Circulation of the microphones

In the field of acoustics, this is probably the first key-comparison that permitted international delivery services as a transportation means of the microphones. Therefore NMIJ paid the closest attention to their container. They were packaged in an aluminum box padded with cushioning material and containing small holes in the outside casing to avoid sudden shocks and to minimize extreme changes in temperature or pressure, which could cause an irreversible change in the sensitivity or degrade the stability of the microphones. This carrying arrangement had been tested in advance to make sure that the sensitivity would be sufficiently stable during the comparison. NMIJ also recommended a reliable shipping agency that had handled other kinds of traveling standards before.

Microphones were circulated from April 2004 to February 2005 and returned to NMIJ for a check calibration each time two participants completed their calibrations. The circulation proceeded just as planned due to the participants' cooperation.

2.2. Measurement frequencies

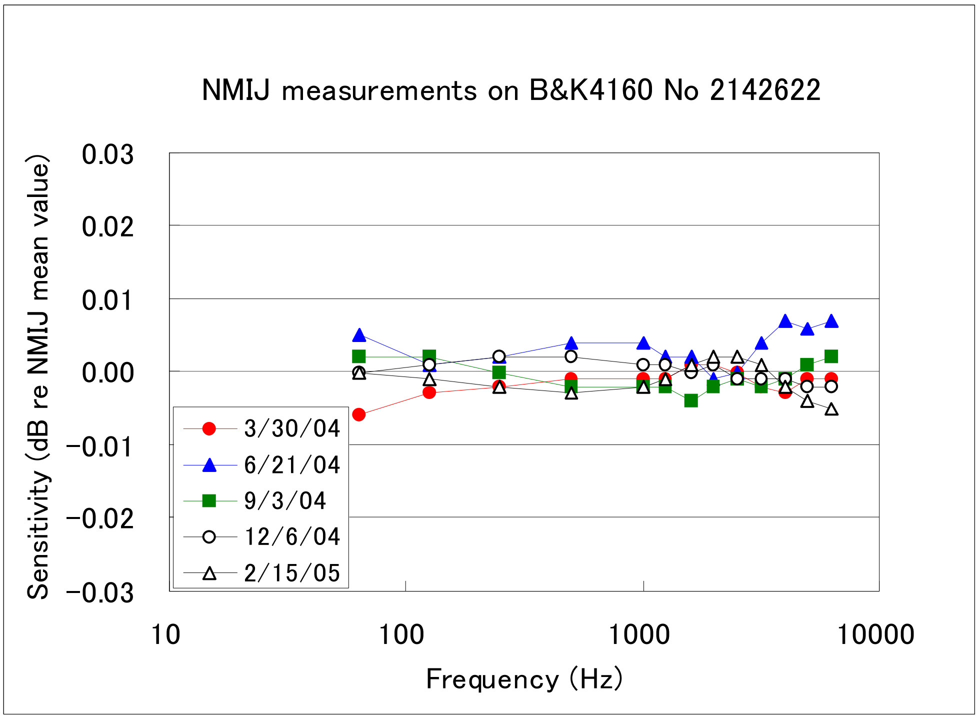
The protocol specified to calibrate the microphones at the nominal frequencies, as in the CCAUV.A-K1. An experience on CIPM key-comparison CCAUV.A-K3 taught that the set of frequencies to be used should be specified clearly [2] and this improvement seemed considerably effective in this key-comparison. However for the laboratory that still expressed the sensitivity at exact frequencies, nominal frequencies correction was applied as will be discussed later.

3. Travelling standards

NMIJ regularly monitored the stability of the microphones on their return to the pilot laboratory. Fig. 1 shows the deviation of each calibration from the average value at NMIJ. Observed changes over the period are mostly within 0.01dB and well below the uncertainty quoted by NMIJ, thus confirming that the microphones had an acceptable level of stability during the circulation.

Therefore the very first measurement from NMIJ was used as the reported NMIJ result for this key-comparison. This practice follows previous CCAUV key-comparisons.

Fig. 2 also gives the temporal variation of the sensitivities at 250 Hz. For reference, results declared by the participants are included. There appears to be little remarkable correlation between the stability of the microphones and the results from participants.



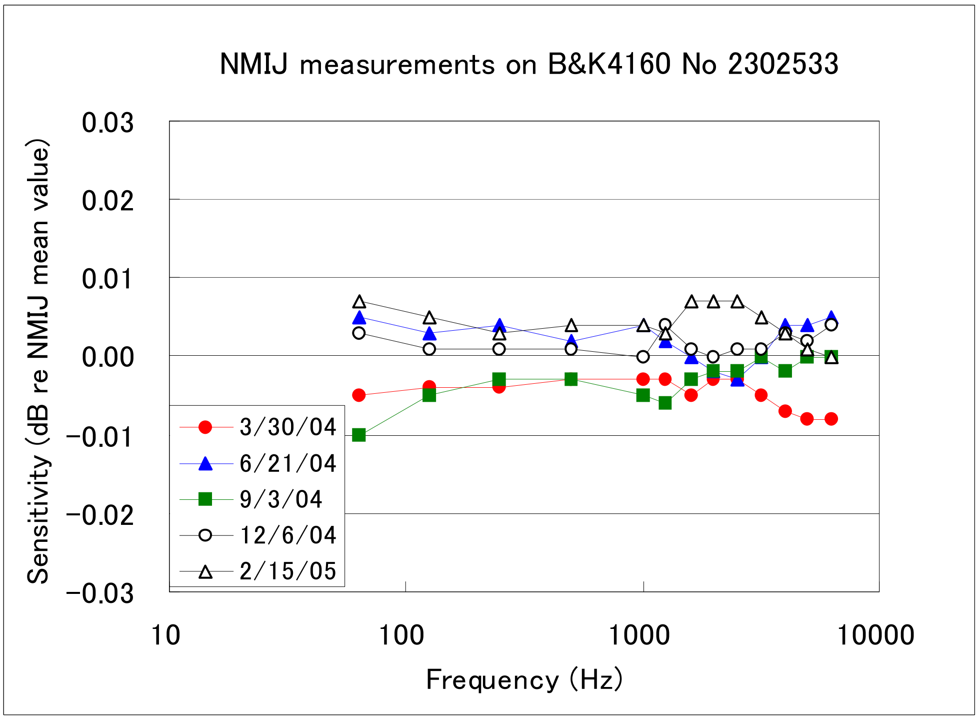
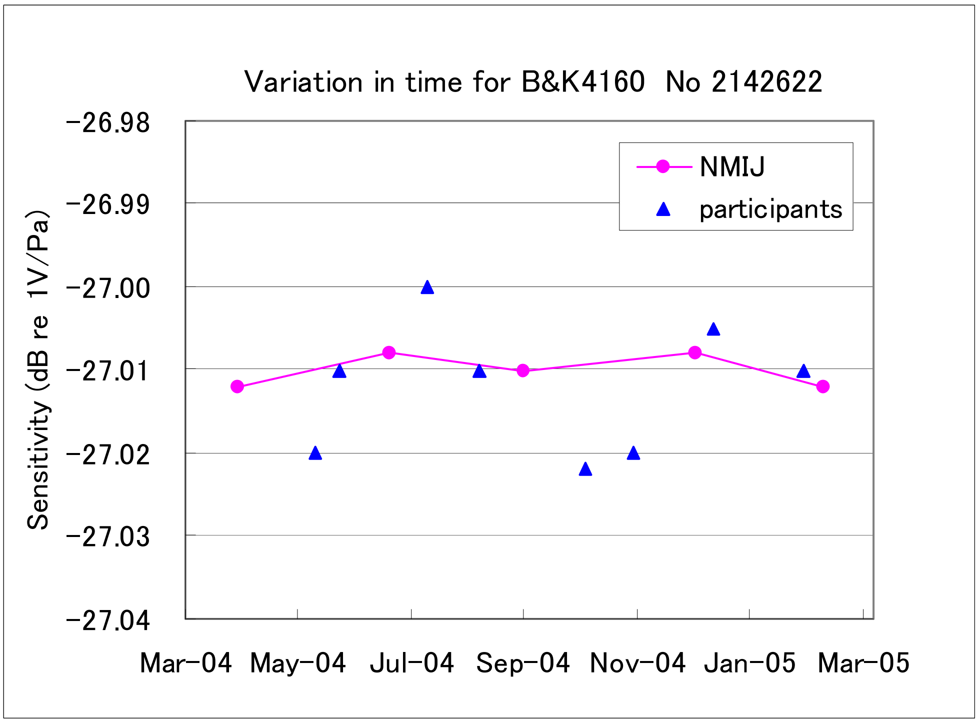


Fig. 1 NMIJ measurements during APMP.AUV.A-K1



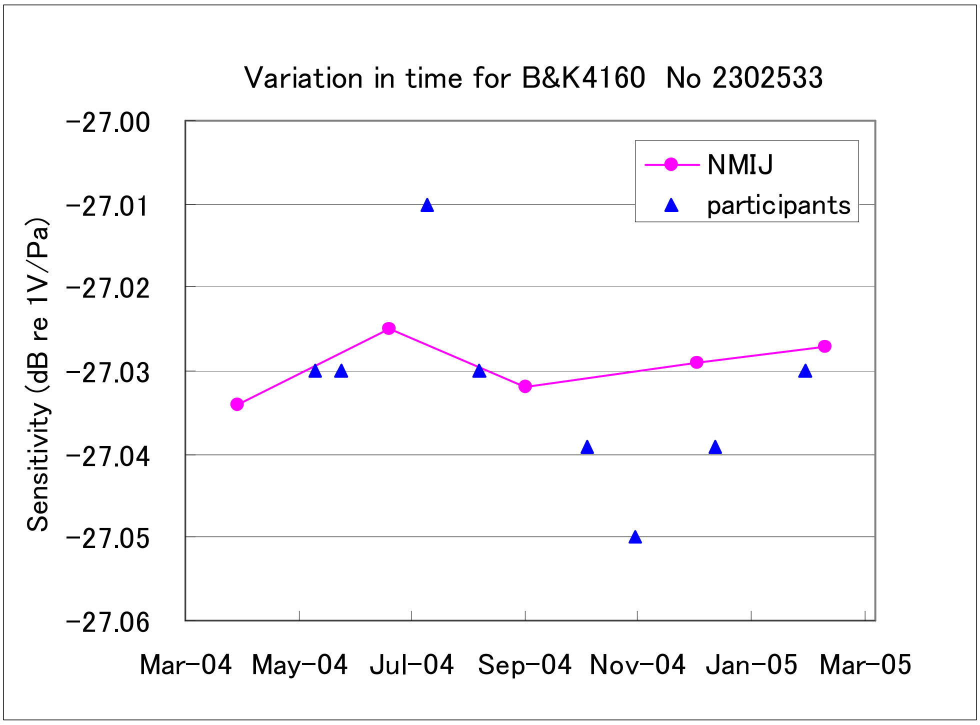


Fig. 2 Sensitivity variation during APMP.AUV.A-K1 at 250 Hz

4. Methodologies

The protocol required that the calibration method should be based on IEC 61094-2, but this standard does not mention any specific equipment to be used. The following description records methodologies and facilities used in this key-comparison by each participant. Any variation from the requirements of IEC 61094-2 was also included if declared.

NMIJ - NMIJ uses a reciprocity calibration system that they developed for laboratory standard microphones. In this system, firstly the voltage transfer function between an input terminal of a transmitter microphone and an output terminal of a receiver microphone is measured by using an insert voltage technique. Then the transmitter's capacitance is separately measured in comparison with reference capacitance. The electrical transfer impedance is determined using the voltage transfer function and the transmitter's capacitance.

In the system, a large-volume coupler (cavity volume of 19.62 cm^3) is used and gas in the cavity is exchanged from air to hydrogen in the frequency range above 1.6 kHz. The contacting surfaces between the microphones and the coupler are sealed with grease to prevent leakage of hydrogen and sound out of the cavity. Two capillary tubes are attached to the coupler to replace air with hydrogen and to equalize the static pressure inside and outside of the coupler.

CMS/ITRI - Take two reference microphones and one microphone to be calibrated by selecting two microphones a group to carry out the calibration, one being as the transmitting microphone and the other as the receiving microphone during calibration. Place the microphones separately into the cavity coupler and measuring the ration of voltage attenuation, then will obtain three individual sets of sensitivity equation to solve the sound pressure sensitivity of microphone by reciprocity method.

KRISS - The calibration is performed by a reciprocity calibration according to IEC 61094-2 using three reciprocal microphones. The microphones are coupled in pairs with two plane-wave couplers of different length (nominal length: 4.7 mm and 9.4 mm).

The receiver microphone is connected to a preamplifier B&K type

2673/WH 3291 with insert voltage facilities and the transmitter microphone is connected to a similar housing but with grounded shield.

The electrical current through the transmitter is measured as the voltage across the 4.7 nF capacitor connected in series with the transmitter. The measuring instruments are: Sine Generator B&K 1051, Digital Multimeter Wavetek 1281 and 1/3 Octave band Pass Filter B&K 1617. The measurements are made at discrete frequencies controlled via computer.

During the calibrations the coupler and the microphones are located under a cylindrical bulb of volume of about 20 liter and the cylindrical bulb is again enclosed by the acryl box with dimensions of 650 mm(W) x 859 mm(H) x 700 mm(D). The static pressure is measured by a Multifunction Pressure Indicator, Druck DPI 145, the temperature and the relative humidity are measured by Testo 650.

The front cavity depths of the microphones are measured by the Video Measuring Scope, Nikon, VMH-300N. The equivalent volume is determined by fitting the final results for the two couplers in the frequency range up to about 2 kHz. Nominal values are assumed for the resonance frequency and the loss factor of the microphone diaphragm.

NIM - Conform with the Reference documents IEC 61094-2 Primary method for pressure calibration of laboratory standard microphones by the reciprocity technique NIM carried out six complete measurements. The Reciprocity calibration system and the computer software MP.EXE determined the open-circuit pressure sensitivity of the microphones. The front cavity depth of the microphones was determined by using an optical method, and then calculates the front volume. The loss factor, pressure coefficient and temperature coefficient we used were the typical values of the microphone. Equivalent volume was determined by analysis the measurement curve using the software MP.EXE. Two wave couplers were used during measurements and coupler parameters we used were also the typical values.

NIMT - NIMT used the reciprocity calibration system. In this system, the voltage transfer function was measured using the insert voltage technique. The transmitter current was determined by measuring the voltage across a calibrated capacitance connected in series with the transmitter.

Two plain wave couplers (cavity volume was 3.098 cm^3 and 5.135 cm^3, respectively) were used, filled with air at all measurement frequencies. The microphones were set into the coupler without using grease on the assumption that leakage of air and sound was negligible. Capillary tube correction was not applied because a needle bung was fitted with each coupler instead of the capillary tube. The needle bung was attached to the coupler to equalize the static pressure and to act as an acoustic seal. No corrections were applied.

NMIA - Pressure sensitivity by the reciprocity technique using 3 type LS1P laboratory standard microphones according to IEC 61094-2. The measurement data was analysed using the computer software MP.exe Microphone Pressure Sensitivity calibration program. The software flag for the correction for radial wave motion was set to "cal" so that the corrections were applied. The results are the mean of 3 sets of measurements obtained from microphone triads.

The Front Cavity Volume, Equivalent Volume and Resonance Frequency were determined by data fitting. The Front Cavity Depth was measured using a microscope fitted with an electronic depth gauge and the Damping Factor was determined from the ratio of the sensitivities where they are at a maxima and in the vicinity of 1000 Hz where they level out.

NML/SIRIM - Absolute Calibration method using Reciprocity Calibration System according to IEC 61094-2:1992. The open circuit sensitivities of the microphones are obtained by using a combination of reciprocity calibration and insert voltage techniques. The microphones are acoustically coupled in pairs by the air enclosed in a coupler. There are 2 couplers (short and long) used in this measurement with precisely determined dimensions. For each pair of microphone, one microphone is used as a sound source (transmitter), and the other as a receiver. Included with the system are two PC programs, one to control measurements and the other to handle the sensitivity calculations according to IEC Standard.

NPLI - The condenser microphones were calibrated by absolute method in the frequency range 31.5 Hz to 8.0 kHz using plane wave couplers. Using three standard microphones in successive pairs the open-circuit voltage sensitivities of the microphones were obtained by using a combination of reciprocity calibration and insert voltage technique. The microphones were acoustically coupled in pairs by the air enclosed in a coupler. For each pair, one microphone was used as a sound source (Transmitter) and the other as a receiver. The task was to measure the electrical transfer impedance U_R/i_T where U_R is the open circuit voltage of the receiver microphone and i_T is the current through the transmitter microphone. The current through the transmitter microphone was found by measuring the voltage across a reference capacitor connected in series with the microphone. The measurements were controlled by PC software running on the Windows platform. For each frequency five sets of measurements were made and the measurement data were stored in a text file along with microphone identification and ambient parameters. Using these information the calculation programme calculates the sensitivities of the three microphones in accordance with IEC-61094-2. Also the sensitivities valid at reference ambient conditions (Room Temperature T = 23°C, Static Pressure P_s = 101.325 kPa and Relative Humidity RH = 50%) were calculated through the use of built-in microphone correction data. To increase the accuracy repeated calibrations were made using different couplers, thus allowing the determination of the total volume along with other microphone parameters by an iterative process giving convergent results.

SCL - The open circuit pressure sensitivity of the microphone was determined by reciprocity technique in accordance with international standard IEC 61094-2(1992). A long plane wave and a short plane wave coupler were used in the measurement. For frequency 63 Hz to 2000 Hz, both the long and short couplers were used. The measurement results reported in the certificate for the frequency range from 63 Hz to 2000 Hz was the average of the two results. For frequencies above 2000 Hz, only the short plane wave coupler was used.

5. Results

The pressure sensitivities of the two microphones determined by each participant are shown in Table 2. They are presented with two or three decimals, depending on the way they were reported. Table 3 gives the associated measurement uncertainties.

Table 2 (a) Pressure sensitivity (dB re 1 V/Pa) for B&K 4160 No. 2142622

Freq. (Hz)	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
63	-26.96	-26.97	-26.972	-26.96	-26.96	-26.96	-26.98	-26.954	-26.95
125	-26.98	-27.00	-27.002	-26.99	-26.99	-26.99	-27.00	-26.985	-26.99
250	-27.00	-27.02	-27.022	-27.01	-27.01	-27.01	-27.02	-27.005	-27.01
500	-27.01	-27.02	-27.029	-27.01	-27.01	-27.01	-27.03	-27.011	-27.02
1000	-26.99	-27.00	-27.004	-26.99	-26.99	-26.99	-27.01	-26.987	-27.00
1250	-26.96	-26.97	-26.980	-26.97	-26.97	-26.97	-26.98	-26.962	-26.98
1600	-26.92	-26.93	-26.938	-26.92	-26.92	-26.93	-26.94	-26.921	-26.94
2000	-26.86	-26.87	-26.876	-26.86	-26.86	-26.86	-26.88	-26.861	-26.88
2500	-26.77	-26.78	-26.783	-26.77	-26.77	-26.77	-26.78	-26.769	-26.80
3150	-26.63	-26.64	-26.643	-26.63	-26.63	-26.63	-26.64	-26.631	-26.67
4000	-26.44	-26.45	-26.451	-26.44	-26.44	-26.45	-26.45	-26.446	-26.48
5000	-26.27	-26.28	-26.294	-26.27	-26.27	-26.27	-26.26	-26.281	-26.32
6300	-26.31	-26.33	-26.341	-26.32	-26.31	-26.29	-26.30	-26.334	-26.36
8000	-27.29	-27.28	-27.283	-27.27	-27.26	-27.23	-27.24	-27.285	-27.29

Table 2 (b) Pressure sensitivity (dB re 1 V/Pa) for B&K 4160 No. 2302533

Freq. (Hz)	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
63	-26.98	-26.98	-26.991	-26.98	-26.98	-26.98	-27.01	-26.993	-26.98
125	-26.99	-27.01	-27.021	-27.01	-27.01	-27.01	-27.04	-27.021	-27.01
250	-27.01	-27.03	-27.039	-27.03	-27.03	-27.03	-27.05	-27.039	-27.03
500	-27.03	-27.03	-27.044	-27.03	-27.03	-27.03	-27.06	-27.044	-27.04
1000	-27.00	-27.00	-27.012	-27.00	-27.00	-27.00	-27.02	-27.012	-27.01
1250	-26.97	-26.97	-26.984	-26.97	-26.97	-26.97	-26.99	-26.983	-26.99
1600	-26.92	-26.93	-26.934	-26.92	-26.92	-26.93	-26.95	-26.934	-26.94
2000	-26.85	-26.85	-26.862	-26.85	-26.85	-26.85	-26.87	-26.862	-26.87
2500	-26.74	-26.74	-26.752	-26.74	-26.74	-26.74	-26.76	-26.755	-26.77
3150	-26.58	-26.58	-26.585	-26.58	-26.57	-26.58	-26.59	-26.588	-26.61
4000	-26.34	-26.35	-26.347	-26.34	-26.33	-26.35	-26.34	-26.354	-26.38
5000	-26.10	-26.11	-26.125	-26.11	-26.09	-26.10	-26.09	-26.118	-26.15
6300	-26.05	-26.08	-26.083	-26.07	-26.04	-26.03	-26.04	-26.076	-26.11
8000	-26.99	-26.98	-26.975	-26.97	-26.95	-26.92	-26.92	-26.975	-26.98

Table 3 Declared expanded uncertainties at k=2 (dB)

Freq. (Hz)	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
63	0.04	0.03	0.05	0.04	0.04	0.04	0.07	0.05	0.05
125	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.05	0.04
250	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04
500	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04
1000	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04
1250	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04
1600	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04
2000	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04
2500	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04
3150	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04
4000	0.04	0.04	0.05	0.04	0.04	0.04	0.07	0.04	0.04
5000	0.06	0.04	0.06	0.04	0.04	0.05	0.07	0.05	0.05
6300	0.06	0.04	0.06	0.04	0.06	0.06	0.07	0.06	0.06
8000	0.06	0.04	0.06	0.06	0.06	0.07	0.07	0.06	0.06

Every participant declared the same uncertainties for each microphone. Detailed uncertainty budgets for the participants are reproduced in Appendix C.

Microphone parameters are listed in Table 4, and temperature and pressure coefficients of the sensitivity in Table 5. Every participant submitted the same coefficients for each microphone. These coefficients are frequency dependent, but most of the participants reported just a single value. In this case, the pilot regarded the reported coefficients as the values at 250 Hz, if not specified. Furthermore, information on the couplers used in the key-comparison is described in Table 6.

Any corrections to the reported results are described in Appendices A and B.

Table 4 (a) Microphone parameters for B&K4160 No. 2142622

	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
Front cavity volume (mm^3)	537.0	541.3	534	543	541	530.00	535	537.3	535
Front cavity depth (mm)	1.95	1.973	1.967	1.939	1.99	1.95	1.95	1.950	1.97
Equivalent volume (mm^3)	141.0	134.5	138	136.0	139	148.0	139.6	143.0	136
Resonance freq. (kHz)	8.2	8.2	8.2	8.2	8.8	8.2	8.4	8.2	8.2
Loss factor	1.05	1.01	1.05	1.05	1.04	1.05	1.05	1.05	1.05

Table 4 (b) Microphone parameters for B&K4160 No. 2302533

	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
Front cavity volume (mm^3)	537.0	542.8	540	543	537	530.00	535	536.2	535
Front cavity depth (mm)	1.95	1.978	1.987	1.938	1.97	1.95	1.95	1.950	1.97
Equivalent volume (mm^3)	143.0	137.5	134	136.0	142	148.0	137.6	139.5	136
Resonance freq. (kHz)	8.2	8.2	8.2	8.2	9.0	8.2	8.4	8.2	8.2
Loss factor	1.05	1.01	1.05	1.05	1.04	1.05	1.05	1.05	1.05

Table 5 (a) Temperature coefficients in pressure sensitivity (dB/K)

Freq. (Hz)	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
63	−	−	−	-0.002	−	−	−	−	-0.003
125	−	−	−	-0.002	−	−	−	−	-0.003
250	-0.002	-0.001907	-0.0020	-0.002	-0.002	-0.003	-0.002	-0.002	-0.003
500	−	−	−	-0.002	−	−	−	−	-0.003
1000	−	−	−	-0.003	−	−	−	−	-0.003
1250	−	−	−	-0.003	−	−	−	−	-0.003
1600	−	−	−	-0.003	−	−	−	−	-0.003
2000	−	−	−	-0.004	−	−	−	−	-0.004
2500	−	−	−	-0.005	−	−	−	−	-0.006
3150	−	−	−	-0.007	−	−	−	−	-0.007
4000	−	−	−	-0.010	−	−	−	−	-0.010
5000	−	−	−	-0.013	−	−	−	−	-0.014
6300	−	−	−	-0.016	−	−	−	−	-0.018
8000	−	−	−	-0.013	−	−	−	−	-0.016

Table 5 (b) Pressure coefficients in pressure sensitivity (dB/kPa)

Freq. (Hz)	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
63	−	−	−	-0.02	−	−	−	−	-0.015
125	−	−	−	-0.02	−	−	−	−	-0.015
250	-0.016	-0.01524	-0.0152	-0.02	-0.016	-0.016	-0.016	-0.016	-0.015
500	−	−	−	-0.02	−	−	−	−	-0.015
1000	−	−	−	-0.02	−	−	−	−	-0.015
1250	−	−	−	-0.01	−	−	−	−	-0.014
1600	−	−	−	-0.01	−	−	−	−	-0.014
2000	−	−	−	-0.01	−	−	−	−	-0.013
2500	−	−	−	-0.01	−	−	−	−	-0.012
3150	−	−	−	-0.01	−	−	−	−	-0.009
4000	−	−	−	-0.01	−	−	−	−	-0.006
5000	−	−	−	0.00	−	−	−	−	-0.002
6300	−	−	−	0.00	−	−	−	−	0.002
8000	−	−	−	-0.01	−	−	−	−	-0.004

Table 6　Information on the couplers

(a) short plane-wave coupler

	CMS/ ITRI	KRISS	NIM	NIMT	NMIA[1]	NML/ SIRIM	NPLI	SCL	NMIJ[2]
Diameter (mm)	18.6	18.606	−	18.6	18.6	18.6252	−	18.6	18.60, 42.92, 18.60
Length (mm)	7.5	7.497	−	7.5	7.5	7.5003	−	7.5	0.80, 12.53, 0.80
Freq. Range (Hz)	20 to 12.5 k	−	−	20 to 12.5 k	up to 10 k	20 to 12.5 k	−	63 to 8 k	63 to 8 k

(b) long plane-wave coupler

	CMS/ ITRI	KRISS	NIM	NIMT	NMIA[1]	NML/ SIRIM	NPLI	SCL	NMIJ[2]
Diameter (mm)	18.6	−	−	18.6	18.6	18.6011	−	18.6	
Length (mm)	15	−	−	15.0	15.0	15.0067	−	15	
Freq. Range (Hz)	20 to 7 k	−	−	20 to 7 k	up to 6.3 k	20 to 7 k	−	63 to 2 k	

(c) capillary tube

	CMS/ ITRI	KRISS	NIM	NIMT[3]	NMIA[3]	NML/ SIRIM	NPLI	SCL	NMIJ
Number	1	−	−	none	none	none	−	none	2
Inner diameter (mm)	0.335	−	−				−		0.5
Length (mm)	50	−	−				−		100

1: NMIA applied radial wave-motion correction.

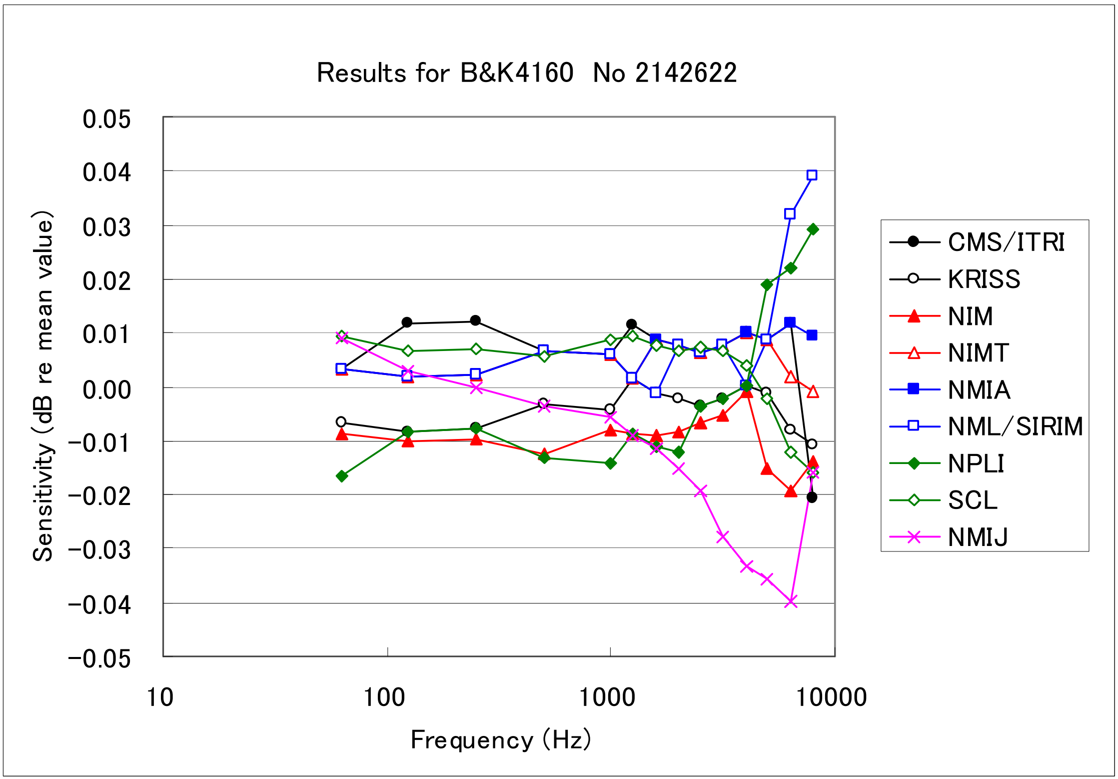
2: NMIJ used a large-volume coupler.

3: NIMT and NMIA used a needle bung instead of a capillary tube.

For each of the two microphones and at each of the frequencies, the mean value of the pressure sensitivity level was determined from all the submitted data. Fig. 3 shows the results of individual participant expressed as the difference from this mean value.

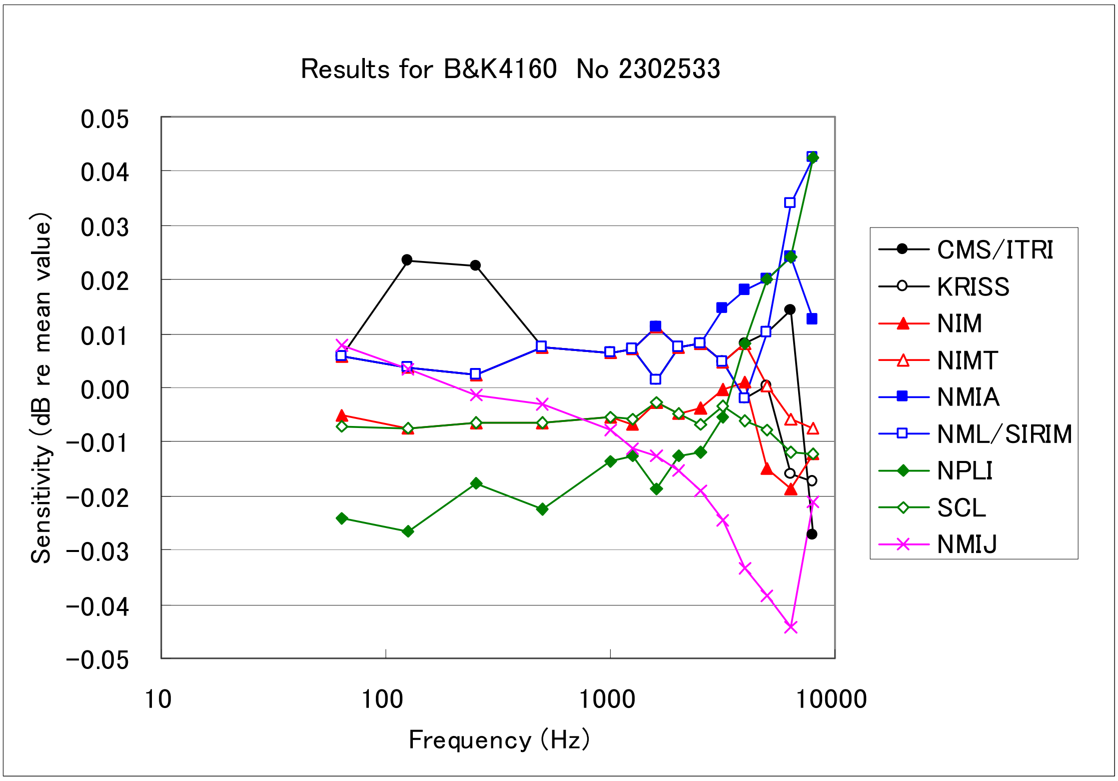
Fig. 3 indicates that the trend for each participant is mostly common to both microphones, as observed in the CCAUV.A-K1. Therefore the average difference for the two microphones was taken to specify the performance of each participant and presented in Fig. 4.

The uncertainty in the mean value of the sensitivity for each microphone is estimated to be equal to the original uncertainty in the sensitivity because full correlation was assumed between the measurements made by the same laboratory and because every participant declared the same uncertainties for each microphone.



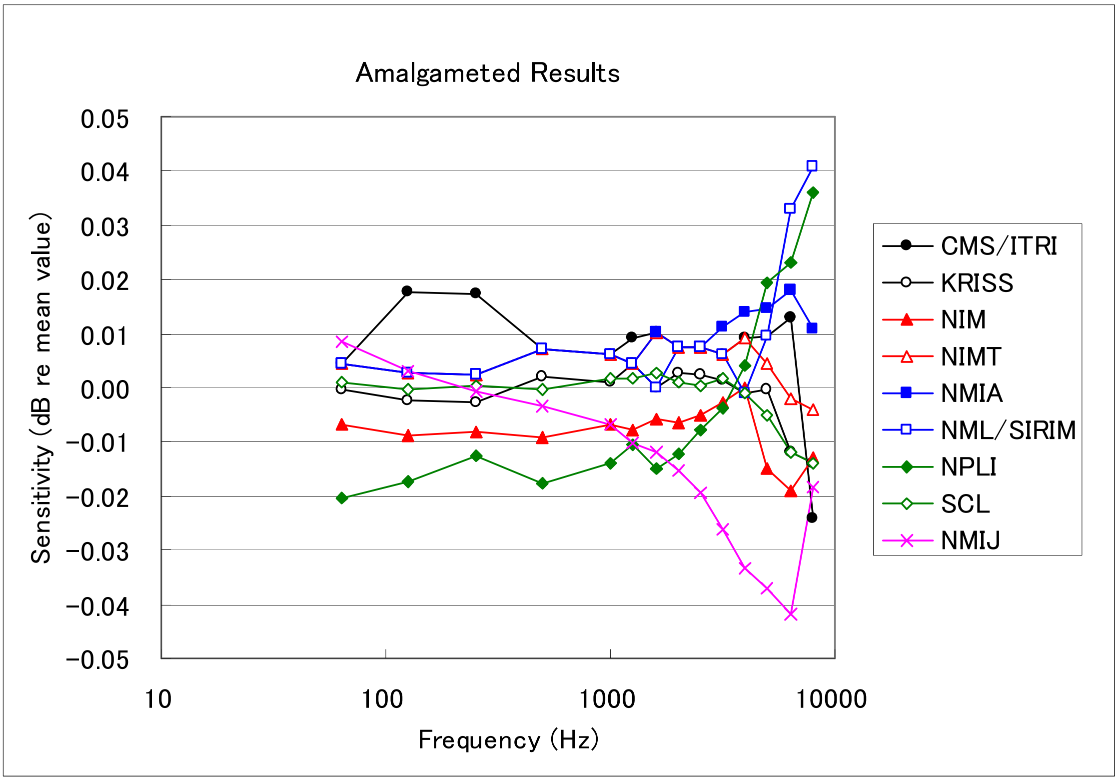
Freq. (Hz)	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
63	0.00	-0.01	-0.01	0.00	0.00	0.00	-0.02	0.01	0.01
125	0.01	-0.01	-0.01	0.00	0.00	0.00	-0.01	0.01	0.00
250	0.01	-0.01	-0.01	0.00	0.00	0.00	-0.01	0.01	0.00
500	0.01	0.00	-0.01	0.01	0.01	0.01	-0.01	0.01	0.00
1000	0.01	0.00	-0.01	0.01	0.01	0.01	-0.01	0.01	-0.01
1250	0.01	0.00	-0.01	0.00	0.00	0.00	-0.01	0.01	-0.01
1600	0.01	0.00	-0.01	0.01	0.01	0.00	-0.01	0.01	-0.01
2000	0.01	0.00	-0.01	0.01	0.01	0.01	-0.01	0.01	-0.02
2500	0.01	0.00	-0.01	0.01	0.01	0.01	0.00	0.01	-0.02
3150	0.01	0.00	-0.01	0.01	0.01	0.01	0.00	0.01	-0.03
4000	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	-0.03
5000	0.01	0.00	-0.02	0.01	0.01	0.01	0.02	0.00	-0.04
6300	0.01	-0.01	-0.02	0.00	0.01	0.03	0.02	-0.01	-0.04
8000	-0.02	-0.01	-0.01	0.00	0.01	0.04	0.03	-0.02	-0.02

Fig. 3 (a) Sensitivity deviations from the mean value for B&K4160 No 2142622 (dB)



Freq. (Hz)	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
63	0.01	0.01	-0.01	0.01	0.01	0.01	-0.02	-0.01	0.01
125	0.02	0.00	-0.01	0.00	0.00	0.00	-0.03	-0.01	0.00
250	0.02	0.00	-0.01	0.00	0.00	0.00	-0.02	-0.01	0.00
500	0.01	0.01	-0.01	0.01	0.01	0.01	-0.02	-0.01	0.00
1000	0.01	0.01	-0.01	0.01	0.01	0.01	-0.01	-0.01	-0.01
1250	0.01	0.01	-0.01	0.01	0.01	0.01	-0.01	-0.01	-0.01
1600	0.01	0.00	0.00	0.01	0.01	0.00	-0.02	0.00	-0.01
2000	0.01	0.01	0.00	0.01	0.01	0.01	-0.01	0.00	-0.02
2500	0.01	0.01	0.00	0.01	0.01	0.01	-0.01	-0.01	-0.02
3150	0.00	0.00	0.00	0.00	0.01	0.00	-0.01	0.00	-0.02
4000	0.01	0.00	0.00	0.01	0.02	0.00	0.01	-0.01	-0.03
5000	0.01	0.00	-0.01	0.00	0.02	0.01	0.02	-0.01	-0.04
6300	0.01	-0.02	-0.02	-0.01	0.02	0.03	0.02	-0.01	-0.04
8000	-0.03	-0.02	-0.01	-0.01	0.01	0.04	0.04	-0.01	-0.02

Fig. 3 (b) Sensitivity deviations from the mean value for B&K4160 No 2302533 (dB)



Freq. (Hz)	CMS/ ITRI	KRISS	NIM	NIMT	NMIA	NML/ SIRIM	NPLI	SCL	NMIJ
63	0.00	0.00	-0.01	0.00	0.00	0.00	-0.02	0.00	0.01
125	0.02	0.00	-0.01	0.00	0.00	0.00	-0.02	0.00	0.00
250	0.02	0.00	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00
500	0.01	0.00	-0.01	0.01	0.01	0.01	-0.02	0.00	0.00
1000	0.01	0.00	-0.01	0.01	0.01	0.01	-0.01	0.00	-0.01
1250	0.01	0.00	-0.01	0.00	0.00	0.00	-0.01	0.00	-0.01
1600	0.01	0.00	-0.01	0.01	0.01	0.00	-0.01	0.00	-0.01
2000	0.01	0.00	-0.01	0.01	0.01	0.01	-0.01	0.00	-0.02
2500	0.01	0.00	-0.01	0.01	0.01	0.01	-0.01	0.00	-0.02
3150	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	-0.03
4000	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	-0.03
5000	0.01	0.00	-0.01	0.00	0.01	0.01	0.02	0.00	-0.04
6300	0.01	-0.01	-0.02	0.00	0.02	0.03	0.02	-0.01	-0.04
8000	-0.02	-0.01	-0.01	0.00	0.01	0.04	0.04	-0.01	-0.02

Fig. 4 Deviations from the mean value in amalgamated results (dB)

6. Linking model for the CCAUV.A-K1

Our goal is to establish a linkage between the results of the APMP.AUV.A-K1 and those of the CCAUV.A-K1. NMIJ proposes the methodology necessary for this link in the following [3]. Two laboratories (NMIJ and KRISS) participated in both key-comparisons and play important parts as linking laboratories. NMIA also took part in both key-comparisons but was not included in the linking laboratories. This is because NMIA used different equipments in the two key-comparisons (NMIA used a 3-port coupler in the CCAUV.A-K1) and we cannot estimate absolute correlation between the NMIA results in the APMP.AUV.A-K1 and those in the CCAUV.A-K1.

6.1. Definition of symbols

Measurands in the CCAUV.A-K1 and APMP.AUV.A-K1 are denoted by X and Y, respectively. Both are the pressure sensitivity level averaged for the two B&K 4160s, but all of the four microphones have the different serial numbers.

Values x_i and $u(x_i)$ denote the best estimate and the associated standard uncertainty for the CCAUV.A-K1 participant i (i = 1 to M, M being the number of participants for the CCAUV.A-K1). In the same way, values y_j, $u(y_j)$ and the number of participants N for the APMP.AUV.A-K1 are defined.

G = {1,.., L} ($L \le \min(M, N)$) is the index set of the linking laboratories. In our case, L is equal to two.

6.2. Key comparison reference value

KCRV (Key comparison reference value) for the CCAUV.A-K1 was determined at each of the specified frequencies, from the arithmetic mean of all results and normalized to zero decibels. This mean is expressed as

$$\overline{x} = \frac{1}{M} \sum_{i=1}^{M} x_i \tag{1}$$

The corresponding standard uncertainty is calculated based on a propagating law of the measurement uncertainties.

$$u^2(\overline{x}) = \frac{1}{M^2} \sum_{i=1}^{M} u^2(x_i) \tag{2}$$

6.3. Correction factor between the two measurands

Both key-comparisons did not use the identical transducers. However, the experience on the two key-comparisons clearly shows that the normalized KCRV are independent of the traveling standards and useful to reproduce the performance of the participants.

Therefore the pilot proposes correction factor between the two measurands as follows. Firstly, the arithmetic mean of the results in the linking laboratories for the CCAUV.A-K1 and the associated standard uncertainty are

$$\overline{x_l} = \frac{1}{L}\sum_{i=1}^{L} x_i \tag{3}$$

$$u^2(\overline{x_l}) = \frac{1}{L^2}\sum_{i=1}^{L} u^2(x_i) \tag{4}$$

Similarly for the APMP.AUV.A-K1, just the measurand has to be replaced.

$$\overline{y_l} = \frac{1}{L}\sum_{j=1}^{L} y_j \tag{5}$$

$$u^2(\overline{y_l}) = \frac{1}{L^2}\sum_{j=1}^{L} u^2(y_j) \tag{6}$$

Then a simple correction factor r is introduced.

$$r = \overline{x_l} - \overline{y_l} \tag{7}$$

Standard uncertainty in the correction factor is formulated considering the correlation between the two terms in the right side of Eq. (7) because the same linking laboratories measured them.

$$u^2(r) = u^2(\overline{x_l}) + u^2(\overline{y_l}) - \frac{2C}{L^2}\sum_{i=1}^{L} u(x_i)u(y_i) \tag{8}$$

where C is a correlation coefficient between x_i and y_i but assumed to be independent of laboratories. Values of $C \geq 0.5$ result in less than 0.001 dB difference in $u(r)$. Therefore full correlation is assumed in this report. (In the following description, every correlation between the terms concerned is taken into account if necessary.)

6.4. Degrees of equivalence to KCRV

For the linking laboratories, degrees of equivalence to the KCRV in the CCAUV.A-K1 and the associated standard uncertainty were

$$d_i = x_i - \overline{x} \tag{9}$$

$$u^2(d_i) = (1 - \frac{2}{M})u^2(x_i) + u^2(\overline{x}) \tag{10}$$

On the other hand, the correction factor has to be applied for the APMP.AUV.A-K1 participants except linking laboratories.

$$d_j = y_j + r - \overline{x} \tag{11}$$

$$u^2(d_j) = u^2(y_j) + (1 - \frac{L}{M})u^2(r) + \frac{L}{M}(u^2(\overline{y_l}) - u^2(\overline{x_l})) + u^2(\overline{x}) \tag{12}$$

Table 7 shows the degrees of equivalence to KCRV and the corresponding uncertainty in each participant. Fig. 5 especially illustrates the degrees of equivalence to KCRV at 250 Hz and 1 kHz.

6.5. Degree of equivalence between two NMIs

Among the participants i and j for the CCAUV.A-K1, mutual equivalence and the associated standard uncertainty were

$$d_{ij} = d_i - d_j = x_i - x_j \tag{13}$$

$$u^2(d_{ij}) = u^2(x_i) + u^2(x_j) \tag{14}$$

These two formulas can be similarly applied to the participants i and j for the APMP.AUV.A-K1.

$$d_{ij} = y_i - y_j \tag{15}$$

$$u^2(d_{ij}) = u^2(y_i) + u^2(y_j) \tag{16}$$

If one laboratory i participated just in the CCAUV.A-K1 and the other j just in the APMP.AUV.A-K1, the equations should be

$$d_{ij} = x_i - r - y_j \tag{17}$$

$$u^2(d_{ij}) = u^2(x_i) + u^2(r) + u^2(y_j) \tag{18}$$

Table 8 shows the degree of mutual equivalence between two participants and the corresponding uncertainty at 250 Hz.

Table 7 Degrees of equivalence to KCRV (left) and associated uncertainty (right) (dB)

Freq. (Hz)	NMIJ		KRISS		NMIA		CMS/ITRI		NIM		NIMT		NML/SIRIM		NPLI		SCL	
63	0.01	0.05	0.00	0.03	0.00	0.04	0.00	0.04	-0.01	0.05	0.00	0.04	0.00	0.04	-0.02	0.07	0.00	0.05
125	0.00	0.04	0.00	0.03	0.00	0.04	0.02	0.04	-0.01	0.05	0.00	0.04	0.00	0.03	-0.02	0.07	0.00	0.05
250	-0.01	0.04	0.00	0.03	0.00	0.04	0.01	0.04	-0.01	0.05	0.00	0.04	0.00	0.03	-0.02	0.07	-0.01	0.04
500	-0.01	0.04	0.00	0.03	0.00	0.04	0.00	0.04	-0.01	0.05	0.00	0.04	0.00	0.03	-0.02	0.07	0.00	0.04
1000	-0.01	0.04	0.00	0.03	0.00	0.04	0.00	0.04	-0.01	0.05	0.00	0.04	0.00	0.03	-0.02	0.07	0.00	0.04
1250	-0.02	0.04	0.01	0.03	0.00	0.04	0.01	0.04	-0.01	0.05	0.00	0.04	0.00	0.03	-0.01	0.07	0.00	0.04
1600	-0.01	0.04	0.01	0.03	0.01	0.04	0.01	0.04	-0.01	0.05	0.01	0.04	0.00	0.03	-0.01	0.07	0.00	0.04
2000	-0.02	0.04	0.01	0.03	0.01	0.04	0.01	0.04	0.00	0.05	0.01	0.04	0.01	0.03	-0.01	0.07	0.00	0.04
2500	-0.03	0.04	0.02	0.03	0.01	0.04	0.01	0.04	0.00	0.05	0.01	0.04	0.01	0.03	0.00	0.07	0.00	0.04
3150	-0.03	0.04	0.02	0.03	0.02	0.04	0.01	0.04	0.00	0.05	0.01	0.04	0.01	0.03	0.00	0.07	0.01	0.04
4000	-0.04	0.04	0.02	0.03	0.02	0.04	0.02	0.04	0.01	0.05	0.02	0.04	0.01	0.04	0.01	0.07	0.01	0.04
5000	-0.05	0.05	0.02	0.03	0.02	0.04	0.02	0.06	-0.01	0.06	0.01	0.04	0.02	0.05	0.03	0.07	0.00	0.05
6300	-0.06	0.06	0.01	0.04	0.02	0.06	0.01	0.06	-0.02	0.06	0.00	0.04	0.03	0.06	0.02	0.07	-0.01	0.06
8000	-0.05	0.06	0.02	0.05	0.01	0.07	-0.02	0.07	-0.01	0.07	0.00	0.07	0.04	0.08	0.04	0.08	-0.01	0.07

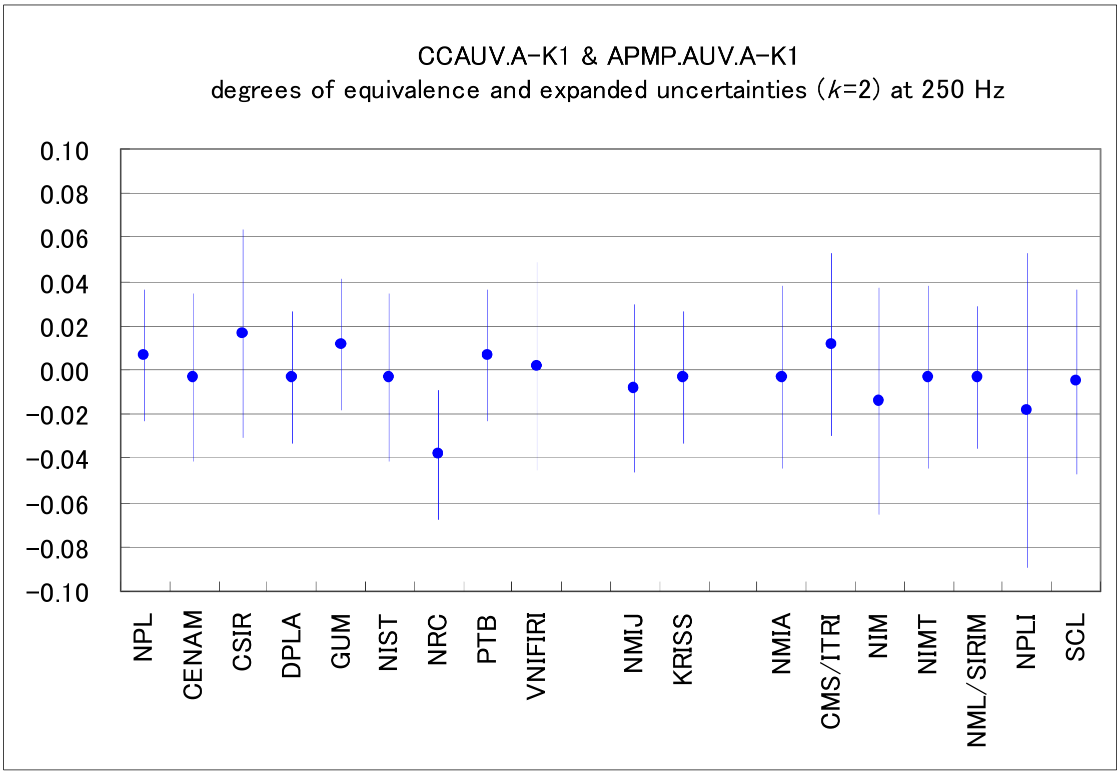


Fig. 5(a) Degrees of equivalence and expanded uncertainties (k=2) at 250 Hz (dB)

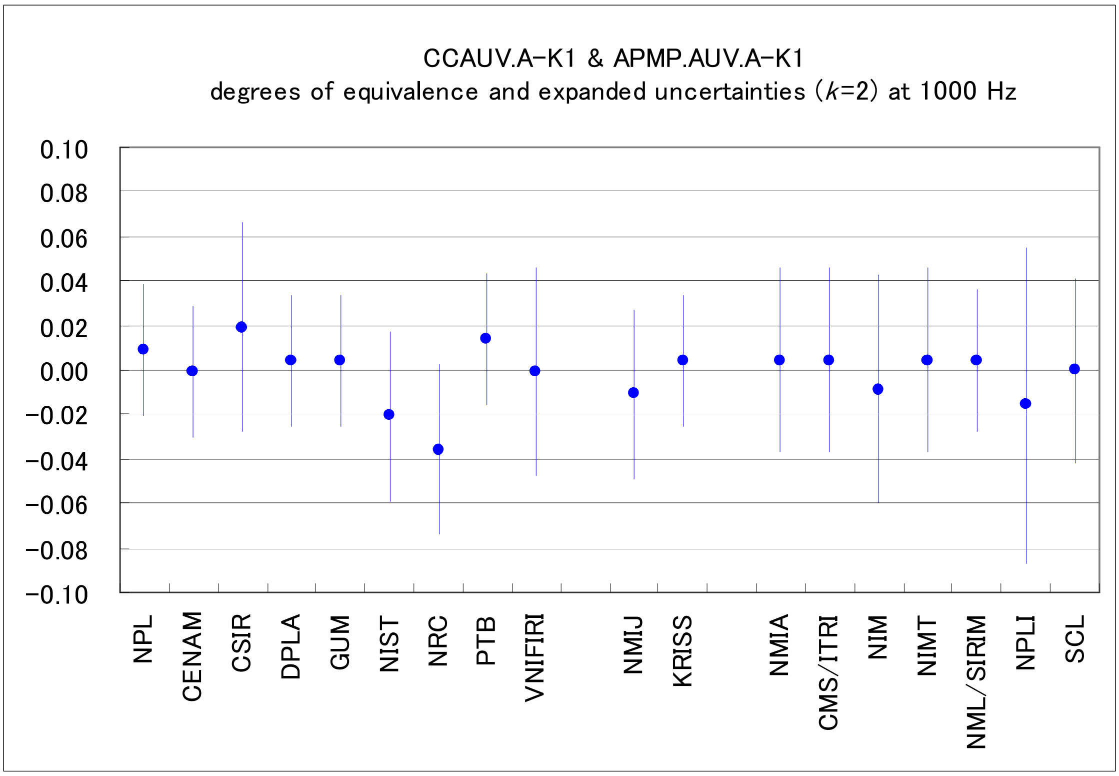


Fig. 5(b) Degrees of equivalence and expanded uncertainties (k=2) at 1000 Hz (dB)

Table 8 Degree of mutual equivalence between two participants (left) and associated uncertainty (right) at 250 Hz (dB)

	NMIJ		KRISS		NMIA		CMS/ITRI		NIM		NIMT		NML/SIRIM		NPLI		SCL	
NMIJ			-0.01	0.05	-0.02	0.06	-0.02	0.06	0.01	0.06	0.00	0.06	0.00	0.05	0.01	0.08	0.00	0.06
KRISS	0.01	0.05			-0.02	0.05	-0.02	0.05	0.01	0.06	0.00	0.05	0.00	0.04	0.01	0.08	0.00	0.05
NMIA	0.02	0.06	0.02	0.05			-0.02	0.06	0.01	0.06	0.00	0.06	0.00	0.05	0.01	0.08	0.00	0.06
CMS/ ITRI	0.02	0.06	0.02	0.05	0.02	0.06			0.03	0.06	0.02	0.06	0.02	0.05	0.03	0.08	0.02	0.06
NIM	-0.01	0.06	-0.01	0.06	-0.01	0.06	-0.03	0.06			-0.01	0.06	-0.01	0.06	0.00	0.09	-0.01	0.06
NIMT	0.00	0.06	0.00	0.05	0.00	0.06	-0.02	0.06	0.01	0.06			0.00	0.05	0.01	0.08	0.00	0.06
NML/ SIRIM	0.00	0.05	0.00	0.04	0.00	0.05	-0.02	0.05	0.01	0.06	0.00	0.05			0.01	0.08	0.00	0.05
NPLI	-0.01	0.08	-0.01	0.08	-0.01	0.08	-0.03	0.08	0.00	0.09	-0.01	0.08	-0.01	0.08			-0.01	0.08
SCL	0.00	0.06	0.00	0.05	0.00	0.06	-0.02	0.06	0.01	0.06	0.00	0.06	0.00	0.05	0.01	0.08		

6.6. Validity of linking model

The linking procedure can be confirmed by comparing the performance of the linking laboratories in both key-comparisons. Fig. 6 illustrates degrees of equivalence to the KCRV in the two key-comparisons, demonstrating that the performance of the linking laboratories is well reproduced and gives reliable process to link the results of APMP.AUV.A-K1 with those of CCAUV.A-K1.

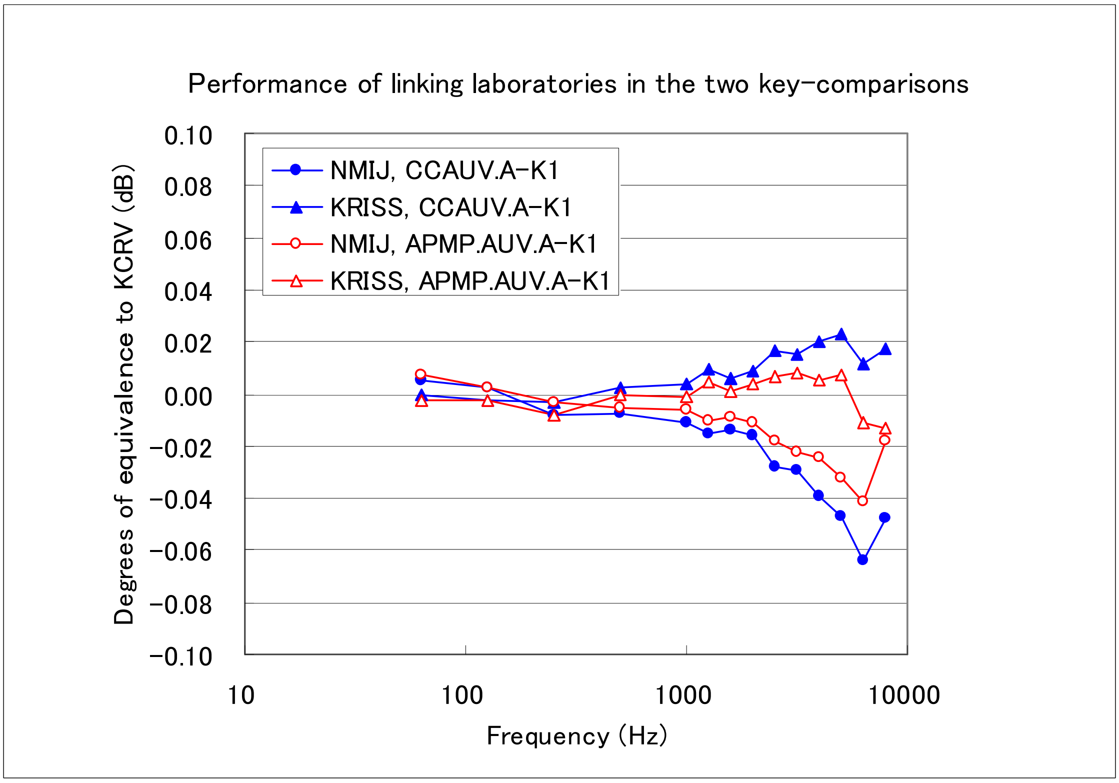


Fig. 6 Performance of linking laboratories in the two key-comparisons

7. Conclusion

NMIJ reported results of the regional key-comparison APMP.AUV.A-K1 as a pilot laboratory. Results from the participants are consistent within ±0.05 dB for all the frequencies and has been linked to the key comparison reference value in the CIPM key-comparison CCAUV.A-K1.

Acknowledgement

The authors gratefully acknowledge all the participating institutes for their thorough cooperation and fruitful discussion.

References

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[3] G. Ratel, C. Michotte, Y. Hino: BIPM comparison BIPM.RI(II)-K1.Co-58 of the activity measurements of the radionuclide ^{58}Co and the links for the 2000 regional comparison APMP.RI(II)-K2.Co-58, *Metrologia* 40 (2003) *Tech. Suppl.* 06006

Appendix A. Nominal frequencies correction

NPLI reported the results in the exact frequencies. Therefore the pilot made additional measurements in the frequencies that were 1/12 octave higher (lower) than the nominal frequencies and by using plane-wave couplers to meet the methodology of NPLI. Correction factors estimated by NMIJ for the nominal frequencies are listed in Table A1 (All the NPLI results in this report have been already corrected for the nominal frequencies). This method follows the methodology applied in the CCAUV.A-K3.

Table A1 Correction of sensitivity for the nominal frequencies (dB)

Nominal Freq.(Hz)	NPLI's Reported Freq.(Hz)	B&K4160 No 2142622	B&K4160 No 2302533
63	63.10	0.000	0.000
125	125.89	0.000	0.000
250	251.19	0.000	0.000
500	501.19	0.000	0.000
1000	1000.00	0.000	0.000
1250	1258.93	-0.001	-0.001
1600	1584.89	0.002	0.003
2000	1995.26	0.001	0.001
2500	2511.89	-0.002	-0.003
3150	3162.28	-0.003	-0.003
4000	3981.07	0.004	0.005
5000	5011.87	-0.001	-0.002
6300	6309.57	0.002	0.002
8000	7943.28	-0.053	-0.054

Correction factor [dB] = (nominal frequency f_0 to be used [Hz] − exact frequency f_e reported [Hz]) * slope [dB/Hz]

where

slope = (NMIJ sensitivity at (f_0 + 1/12 octave) [dB] − NMIJ sensitivity at (f_0 − 1/12 octave) [dB]) / ((f_0 + 1/12 octave [Hz]) − (f_0 − 1/12 octave [Hz]))

The uncertainty in this correction factor is considered as follows. The comparison of Tables 3 and A1 shows that the correction factor is much smaller than the measurement uncertainty in the sensitivity declared by NPLI within the frequency range except 8 kHz and has negligible contribution to the uncertainty in the sensitivity. Therefore only at 8 kHz, the uncertainty in the correction factor is examined.

The uncertainty in the sensitivity difference among the close frequencies is presumably caused by the components which have no correlation between these frequencies. In the NMIJ calibration system, such a component corresponds to the measurement in the electrical transfer impedance. Then the uncertainty in the correction factor is estimated to be 0.003 dB multiplied by $(f_0 - f_e) / ((f_0 + 1/12 \text{ octave}) - (f_0 - 1/12 \text{ octave}))$ and negligible, too. As a result, no correction was applied to the uncertainty reported by NPLI.

Appendix B. Handling of unusual data

The pilot was tasked with identifying anomalous results and providing the participants concerned with the opportunity to review their data.

No written guidance is given on the criteria to be used to judge if the results should be considered anomalous. To find anomalous data, NMIJ compared the sensitivity difference from the averaged value with the associated measurement uncertainty. The pilot contacted NML/SIRIM in this respect.

NML/SIRIM replied that the deviation was caused by a mistake in the sensitivity calculation and submitted revised data as shown in Table B1. While the original sensitivity was averaged for the two couplers (short and long couplers) at all the frequencies, revised data are different from the original data in that the result at 8 kHz was calculated by using only short coupler data.

NML/SIRIM made the above action after the distribution of the Draft A. However, all the participants approved the revised data at NML/SIRIM, considering that anomaly in the original data would be probably caused not by the technical performance but by a simple mistake. Therefore the revised data were used for NML/SIRIM in this report.

Table B1 (a) Pressure sensitivity at NML/SIRIM for No. 2142622 (dB)

Freq. (Hz)	Data by short coupler only	Data by long coupler only	Original data	Revised data
63	-26.96	-26.96	-26.96	no change
125	-26.99	-26.99	-26.99	no change
250	-27.01	-27.01	-27.01	no change
500	-27.01	-27.01	-27.01	no change
1000	-26.99	-26.99	-26.99	no change
1250	-26.96	-26.97	-26.97	no change
1600	-26.93	-26.93	-26.93	no change
2000	-26.86	-26.86	-26.86	no change
2500	-26.77	-26.77	-26.77	no change
3150	-26.63	-26.63	-26.63	no change
4000	-26.46	-26.44	-26.45	no change
5000	-26.29	-26.25	-26.27	no change
6300	-26.35	-26.24	-26.29	no change
8000	-27.23	-26.85	-27.04	-27.23

Table B1 (b) Pressure sensitivity at NML/SIRIM for No. 2302533 (dB)

Freq. (Hz)	Data by short coupler only	Data by long coupler only	Original data	Revised data
63	-26.98	-26.99	-26.98	no change
125	-27.01	-27.01	-27.01	no change
250	-27.03	-27.03	-27.03	no change
500	-27.03	-27.04	-27.03	no change
1000	-27.00	-27.00	-27.00	no change
1250	-26.97	-26.98	-26.97	no change
1600	-26.93	-26.93	-26.93	no change
2000	-26.85	-26.86	-26.85	no change
2500	-26.74	-26.74	-26.74	no change
3150	-26.58	-26.57	-26.58	no change
4000	-26.36	-26.34	-26.35	no change
5000	-26.12	-26.08	-26.10	no change
6300	-26.09	-25.98	-26.03	no change
8000	-26.92	-26.56	-26.74	-26.92

Appendix C. Uncertainty budgets

Here are reproduced uncertainty budgets from the participants. In the four laboratories (NIM, NML/SIRIM, NPLI and SCL), the calibration certificates differed from the corresponding uncertainty budgets in the declared uncertainties for all or part of frequencies. The pilot adopted values on the uncertainty budgets in this report.

NMIJ:

Uncertainty budget of pressure sensitivity for type 4160 microphones

(For simplicity, values shown should be multiplied by 10^{-3}; for example, “5” means 0.005 dB.)

Component	Type	Distribution	Explanation	63	125	250	500	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k	6.3k	8k
u_{v1}	B	Rectangular	Cross-talk on u_v	1	1	1	1	1	1	1	1	1	1	1	1	1	1
u_{v2}	B	Rectangular	FFT analyzer linearlity on u_v	1	1	1	1	1	1	1	1	1	1	1	1	1	1
u_{v3}	B	Rectangular	Standard attenuator on u_v	1	1	1	1	1	1	1	1	1	1	1	1	1	1
u_{v4}	A	Normal	Sound leakage on u_v	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{v5}	A	Normal	Repeatability on u_v	3	2	2	2	3	3	3	4	4	4	6	8	9	8
u_v	A	Normal	Combined VTF	3	2	2	2	3	3	3	4	4	4	6	8	9	8
u_{c1}	B	Rectangular	FFT analyzer linearlity on u_c	1	1	1	1	1	1	1	1	1	1	1	1	1	1
u_{c2}	B	Rectangular	Reference capacitance on u_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{c3}	A	Normal	Microphone attachment on u_c	2	2	2	2	2	2	2	2	2	2	2	2	2	2
u_{c4}	B	Rectangular	Stray capacitance on u_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{c5}	A	Normal	Repeatability on u_c	2	2	2	2	2	2	2	2	2	2	2	2	2	2
u_c	A	Normal	Combined transmitter capacitance	3	3	3	3	3	3	3	3	3	3	3	3	3	3
u_g	A	Normal	Specific-heat ratio	2	2	2	2	2	2	2	2	2	2	2	2	2	2
u_{pres}	A	Normal	Static pressure	1	1	1	1	1	1	1	1	1	1	1	1	1	1
u_{vol}	A	Normal	Cavity volume	16	16	16	16	16	16	16	16	16	16	16	16	16	16
u_{h1}	A	Normal	Measurement environmental conditions on u_h	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{h2}	A	Normal	Cavity dimensions on u_h	0	0	0	0	0	0	0	0	0	0	0	1	1	1
u_{h3}	A	Normal	Capillary tube dimensions on u_h	4	3	2	0	0	0	0	0	0	0	0	0	0	0
u_{h4}	A	Normal	Microphone parameters on u_h	3	3	3	3	3	3	3	3	3	3	3	2	1	0
u_h	A	Normal	Combined coupler correction factor	5	4	4	3	3	3	3	3	3	3	3	2	1	1
u_{p_temp}	A	Normal	Pressure dependency of pressure sensitivity	0	0	0	0	0	1	1	1	1	1	1	2	2	1
u_{p_pres}	A	Normal	Temperature dependency of pressure sensitivity	0	0	0	0	0	0	0	0	1	1	1	1	1	3
u_{p_f}	B	Rectangular	Frequency	0	0	0	0	0	0	0	0	0	0	0	0	0	0
u_{p_b}	A	Normal	Polarization voltage	1	1	1	1	1	1	1	1	1	1	1	1	1	1
u_{p_m}	A	Normal	Microphone instability	15	15	15	15	15	15	15	15	15	15	15	15	15	15
u_{p_r}	B	Rectangular	Rounding error	1	1	1	1	1	1	1	1	1	1	1	1	1	1
u_p			Combined pressure sensitivity	18	18	18	18	18	18	18	18	18	18	18	19	19	19
U_p (k=2)			Expanded pressure sensitivity	36	36	35	35	35	35	35	36	36	36	36	37	38	38
			Stated uncertainty	50	40	40	40	40	40	40	40	40	40	40	50	60	60

UNCERTAINTY BUDGET (CMS/ITRI, Taiwan)

Microphone：LS1P microphone

Frequency Range：63 ~ 4000 Hz

Symbol	Source of uncertainty, x_i	Estimated uncertainty	Unit	Prob. Distr.	Divisor Factor	Type A/B	Std Uncertainty $u(x_i)$	Unit	Sensitivity Coeff. c_i	Unit	Uncertainty component $\|c_i u(x_i)\|$	Unit	D.o.f. $\nu(x_i)$
$Cor_{R,,n}$													
$u_{meas,deviation}$	Voltage ratio correction	0.0052	dB	Normal	2	B	0.003	dB	1.732	-	0.005	dB	∞
$u_{meas,specification}$	Voltage ratio, accuracy	0.0026	dB	Rect.	1.732	B	0.002	dB	1.732	-	0.003	dB	12.5
Cor_{CV}													
$V_{coup,specification}$	Coupler volume correction	7	mm^3	Rect.	1.732	B	4.042	mm^3	0.001	dB/mm^3	0.004	dB	12.5
Cor_{Ps}													
$P_{s,deviation}$	Static pressure correction	2	hPa	Normal	2	B	1.000	hPa	-0.004	dB/hPa	0.004	dB	∞
Cor_C													
$C_{traceability}$	Capacitance correction	0.005	nF	Normal	2	B	0.002	nF	-0.924	dB/nF	0.002	dB	∞
$S_{ref.}$													
Cor_{HW}	Heat conduction correction	0.011	dB	Normal	2	B	0.006	dB	1	-	0.006	dB	∞
k	Ratio of specific heats	0.007	dB	Normal	2	B	0.004	dB	1	-	0.004	dB	∞
$P_{s,error}$	Static pressure	2	hPa	Normal	2	B	1.000	hPa	0.0002	dB/hPa	0.0002	dB	∞
T_{error}	Ambient temperature	1	℃	Normal	2	B	0.500	℃	0.006	dB/℃	0.003	dB	∞
H_{errot}	Ambient humidity	5	%	Normal	2	B	2.500	%	0.0002	dB/%	0.001	dB	∞
$L_{F,error}$	Microphone Cavity depth	0.01	mm	t	1	A	0.010	mm	-0.4	dB/mm	0.004	dB	4
$M_{P,repeat}$	Repeatability	0.01	dB	t	1	A	0.010	dB	1	-	0.010	dB	4
Effective degrees of freedom, ν_{eff}		62					Coverage factor, k				2		
Combined standard uncertainty, u_c		0.02				dB	Expanded uncertainty, U				0.04		dB

UNCERTAINTY BUDGET

Microphone : LS1P microphone

Frequency Range : 5000 ~ 8000 Hz

Symbol	Source of uncertainty, x_i	Estimated uncertainty	Unit	Prob. Distr.	Divisor Factor	Type A/B	Std Uncertainty $u(x_i)$	Unit	Sensitivity Coeff. c_i	Unit	Uncertainty component $\|c_i u(x_i)\|$	Unit	D.o.f. $\nu(x_i)$
$Cor_{R,,n}$													
$u_{meas,deviation}$	Voltage ratio correction	0.0052	dB	Normal	2	B	0.003	dB	1.732	-	0.005	dB	∞
$u_{meas,specification}$	Voltage ratio, accuracy	0.0026	dB	Rect.	1.732	B	0.002	dB	1.732	-	0.003	dB	12.5
Cor_{CV}													
$V_{coup,specification}$	Coupler volume correction	5	mm³	Rect.	1.732	B	2.887	mm³	0.002	dB/mm³	0.006	dB	12.5
Cor_{Ps}													
$P_{s,deviation}$	Static pressure correction	2	hPa	Normal	2	B	1.000	hPa	-0.004	dB/hPa	0.004	dB	∞
Cor_{C}													
$C_{traceability}$	Capacitance correction	0.005	nF	Normal	2	B	0.002	nF	-0.924	dB/nF	0.002	dB	∞
$S_{ref.}$													
Cor_{HW}	Heat conduction correction	0.011	dB	Normal	2	B	0.006	dB	1	-	0.006	dB	∞
k	Ratio of specific heats	0.007	dB	Normal	2	B	0.004	dB	1	-	0.004	dB	∞
$P_{s,error}$	Static pressure	2	hPa	Normal	2	B	1.000	hPa	0.0002	dB/hPa	0.0002	dB	∞
T_{error}	Ambient temperature	1	℃	Normal	2	B	0.500	℃	0.0084	dB/℃	0.004	dB	∞
H_{errot}	Ambient humidity	5	%	Normal	2	B	2.500	%	0.0003	dB/%	0.001	dB	∞
$L_{F,error}$	Microphone Cavity depth	0.01	mm	t	1	A	0.010	mm	-1	dB/mm	0.010	dB	4
$M_{P,repeat}$	Repeatability	0.02	dB	t	1	A	0.020	dB	1	-	0.020	dB	4
Effective degrees of freedom, ν_{eff}		19					Coverage factor, k				2		
Combined standard uncertainty, u_c		0.03				dB	Expanded uncertainty, U				0.06		dB

KRISS:

Uncertainty Budget for LS1P

MEASURED QUANTITY	Symbol	Unc.	Unit	63	125	250	500	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
Electrical Transfer Impedance				0.0099	0.0098	0.0061	0.0049	0.0045	0.0049	0.0049	0.0050	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061
Series Impedance	C	Table	nF	0.0090	0.0089	0.0044	0.0026	0.0017	0.0026	0.0026	0.0026	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044
Voltage Ratio	VR	Table		0.0021	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021
Cross-talk		Meas.		0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035
Inherent Noise		Meas.		0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009
Distortion		Meas.		0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0006	0.0006
Frequency	f	Table	Hz	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Reveiver Ground Shield		B&K		0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Transmitter Ground Shield		B&K		0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Coupler Properties				0.0019	0.0010	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0009	0.0010	0.0013	0.0018
Coupler Length	lcoup	0.0010	mm	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0003	0.0004
Coupler Diameter	dcoup	0.0015	mm	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Coupler Volume	Vcoup	0.4266	mm3	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
Coupler Surface Area	Scoup	0.1362	mm2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Static Pressure	Ps	0.0137	kPa	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006
Temperature	T	0.1733	K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0002	0.0004	0.0006	0.0009	0.0015
Relative Humidity	RH	1.9370	%	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0003	0.0004	0.0005
Coupler Leakage		Table		0.0017	0.0007	0.0003	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Microphone Parameters				0.0032	0.0033	0.0033	0.0033	0.0034	0.0035	0.0039	0.0046	0.0061	0.0086	0.0127	0.0173	0.0157	0.0068
Front Cavity Depth	Lf	0.0025	mm	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0002	0.0003	0.0005	0.0008	0.0013	0.0022
Front Cavity Volume	Vf	0.6860	mm3	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0019	0.0019
Equivalent Volume	Veq	1.0624	mm3	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0026	0.0025	0.0024	0.0023	0.0019	0.0014	0.0007	0.0003
Resonance Frequency	fo	510	Hz	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0005	0.0011	0.0025	0.0058	0.0110	0.0126	0.0052
Loss Factor	D	0.0800		0.0000	0.0000	0.0000	0.0002	0.0008	0.0013	0.0022	0.0033	0.0051	0.0077	0.0110	0.0131	0.0091	0.0033
Additional Heat Conduction Caused by Front Cavity Thread				0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Polarizing Voltage	Uo	0.0064	V	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Imperfection of Theory				0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Heat Conduction Theory				0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Adding of Excess Volume				0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Radial Wave Motion				0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Processing of Results				0.0063	0.0063	0.0063	0.0063	0.0063	0.0062	0.0062	0.0061	0.0061	0.0059	0.0056	0.0063	0.0071	0.0083
Rounding Error		0.0050	dB	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029
Repeatability of Measurements		Table		0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045	0.0055	0.0065	0.0075
Static Pressure Corrections		Table		0.0032	0.0032	0.0032	0.0032	0.0031	0.0030	0.0029	0.0027	0.0027	0.0023	0.0015	0.0004	0.0004	0.0020
Temperature Corrections		Table		0.0011	0.0011	0.0011	0.0012	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0009	0.0007	0.0003	0.0006
Sum				0.0123	0.0121	0.0094	0.0087	0.0085	0.0087	0.0088	0.0092	0.0106	0.0121	0.0152	0.0194	0.0184	0.0125
Expanded Uncertainty (k=2)				0.0247	0.0243	0.0188	0.0174	0.0169	0.0174	0.0177	0.0183	0.0211	0.0243	0.0304	0.0388	0.0367	0.0250
Stated Uncertainty				0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04

NIM:

dB

range	63Hz~8000Hz
Polarize Voltage	0.0005
Voltage Ratio	0.0004~0.0007
Cross Talk	0.0025
Noise	0.0001
Distort	0.0001
Frequency	0
Coupler Length	0~0.0016
Coupler Diameter	0
Coupler Surface Area	0
Coupler Volume	0.0020~0.0022
Coupler Leakage	0~0.0011
Microphone Front Length	0~0.004
Diaphragm Resonance Frequencies	0~0.0085
Diaphragm Damp Factor	0~0.0062
Series Capacitance	0.002~0.0050
Static Pressure	0.0015
Temperature	0~0.0056
Relative Humidity	0.0003~0.0012
Result Rounding	0.0005
Microphone Sensitivity Correction for Static Pressure	0.0011~0.0050
Microphone Sensitivity Correction for Static Temperature	0.0057~0.0065

NIMT:

Uncertainty components of the Pressure Sensitivity level for LS1P Microphone (Unit quoted in dB)
Date 14-05-2004

Frequency (Hz)	63	125	250	500	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
$U_{Pol.V}$	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
$U_{PCorr.}$	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0046	0.0046	0.0045	0.0045	0.0045	0.0045
$U_{Tcorr.}$	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0007	0.0007	0.0009	0.0011	0.0012	0.0010
$U_{RH.Corr.}$	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
$U_{HWcf.}$	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100
U_{P}	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
$U_{Spec.H}$	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
$U_{Cap.}$	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
$U_{Elect.Para.}$	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073
$U_{Coupler}$	0.0032	0.0031	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030
$U_{mic..}$	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0200
$U_{A\ Repeat}$	0.0008	0.0007	0.0004	0.0005	0.0003	0.0003	0.0003	0.0003	0.0003	0.0005	0.0007	0.0009	0.0012	0.0020
Combined Standard Uncertainty	0.0176	0.0176	0.0175	0.0175	0.0175	0.0175	0.0175	0.0175	0.0175	0.0175	0.0175	0.0175	0.0176	0.0251
Expanded Uncertainty (k=2)	0.0352	0.0351	0.0351	0.0351	0.0351	0.0351	0.0351	0.0351	0.0350	0.0350	0.0350	0.0351	0.0351	0.0502
Reported Uncertainty (dB)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.06

NMIA:

2/04/2004

Uncertainty Estimates				Uncertainty Components (dB) - LS1P Microphones CSIRO NML 1/04/2004												Meldrum/Bell	
Component	Symbol	u	Unit	31.5	63	125	250	500	1000	2000	4000	6300	8000	10000	Dof	Distrib'n	Source
Electrical measurements				31.5	63	125	250	500	1k	2k	4k	6.3k	8k	10k			
Series Z	C	0.001	nFd	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019	30	Rect	NML
Voltage ratio	Vr	4E-05	V	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	30	Rect	NML
Frequency	f	500	Hz	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	30	Rect	NML
Noise		300	V	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	9	Normal	NML
distortion	D	0.20%	ratio	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	30	Rect	B&K
Cross talk			ratio	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	30	Rect	B&K
Polarising V	Pv	3mV	V	0.0020	0.0010	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	30	Rect	NML
Elect u				*0.005*	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*	*0.004*	30		
DOF				*111*	*93*	*84*	*84*	*84*	*84*	*84*	*84*	*84*	*84*	*84*	30		
Coupler dimensions																	
Length	Cl	0.006	mm	0.0100	0.0050	0.0030	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	30	Normal	NML
Diameter	Cd	0.004	mm	0.0050	0.0020	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0020	0.0030	30	Normal	NML
Volume	Cv	#####	mm^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	30	Normal	NML
Area	CA	#####	mm^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	30	Normal	NML
Coupler u				*0.011*	*0.005*	*0.003*	*0.002*	*0.002*	*0.002*	*0.002*	*0.002*	*0.002*	*0.003*	*0.004*			
DOF				*44*	*39*	*37*	*44*	*44*	*44*	*44*	*44*	*44*	*60*	*52*			
Microphone parameters																	
Front depth	Fd	0.01	mm	0.0022	0.0016	0.0011	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0007	0.0006	30	Normal	NML
Total Volume	Vt	20	mm^3	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150	0.0200	0.0200	0.0200	0.0300	0.0300	30	Normal	NML
Front volume	Fv	40	mm^3	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	30	Normal	NML
Equiv volume	Ve	3	mm^3	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0070	0.0100	0.0130	30	Normal	NML
Resonance freq	Fr	500	Hz	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0007	0.0010	0.0050	0.0060	0.0090	30	Normal	NML
Loss factor	d	0.2	ratio	0.0010	0.0010	0.0010	0.0010	0.0010	0.0020	0.0030	0.0040	0.0060	0.0070	0.0080	30	Rect	NML
MicPar u				0.007	0.007	0.007	0.007	0.007	0.007	0.008	0.008	0.012	0.015	0.018			
DOF				*74*	*69*	*66*	*65*	*65*	*71*	*81*	*91*	*112*	*93*	*87*			
Ambient Conditions																	
Static Pressure	Pamb	0.08	hPa	0.0026	0.0026	0.0026	0.0026	0.0025	0.0025	0.0026	0.0027	0.0028	0.0080	0.0100	30	Triangula	NML
Drift in pressure	Pdrift	0.1	hPa	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	30	Rect	NML
Pcoeft unknown	Pcoeft	25%	dB/hPa	0.0086	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	30	Rect	NML
Mic Temperature	Tmic	0.3	DegC	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0080	0.0100	30	Normal	NML
Tcoeft unknown	Tcoeft	50%	IB/DegC	0.0072	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	30	Rect	NML
Humidity Meas't	RH%	).6%RH	%	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	30	Normal	NML
EnviroConds u				*0.012*	*0.005*	*0.005*	*0.005*	*0.005*	*0.005*	*0.005*	*0.005*	*0.005*	*0.011*	*0.014*			
DOF				*78*	*64*	*64*	*64*	*63*	*63*	*64*	*65*	*66*	*63*	*62*			
Measurement Limitations																	
Theory limitations			dB	0.0015	0.0013	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	8	Normal	NML
Rounding u		0.01	dB	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	30	Rect	NML
Type A	uA		dB	0.0020	0.0020	0.0010	0.0010	0.0010	0.0010	0.0010	0.0020	0.0040	0.0050	0.0080	3	Normal	NML
Combined Uncertainty, uc				0.019	0.012	0.011	0.010	0.010	0.011	0.011	0.011	0.014	0.020	0.025			
EffDoff				193	232	219	206	205	215	227	230	165	166	124			
k factor				2	2	2	2	2	2	2	2	2	2	2			
U95				**0.038**	**0.024**	**0.022**	**0.021**	**0.021**	**0.021**	**0.022**	**0.023**	**0.029**	**0.040**	**0.051**			
U95 rounded to 2 dP				**0.04**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**	**0.04**	**0.05**			
Stated Uncertainty				**0.08**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.06**	**0.06**	**0.08**			

LS1P 9699 U95 LS1P Uncertainty Analysis

NML/SIRIM:

Uncertainty Budget for LS1P Microphones (Bruel & Kjaer 4160)

Input Parameter	Symbol	Unit	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz	6300 Hz	8000 Hz
Static Pressure	Ps1, Ps2, Ps3	kPa	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0017	0.0017
Temperature	T1, T2, T3	K	0.0002	0.0001	0.0001	0.0001	0.0002	0.0002	0.0003	0.0003	0.0003	0.0015	0.0015	0.0015	0.0056	0.0056
Relative Humidity	RH1, RH2, RH3	%	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0005	0.0005	0.0005	0.0012	0.0012
Amb. Conditions			0.0016	0.0016	0.0016	0.0016	0.0016	0.0016	0.0017	0.0017	0.0017	0.0022	0.0022	0.0022	0.0060	0.0060
Coupler Length	lcoup	mm	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0004	0.0004	0.0004	0.0016	0.0016
Coupler Diameter	dcoup	mm	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000
Coupler Volume	Vcoup	mm3	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0022	0.0022
Coup. Surf. Area	Scoup	mm2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Coupler Leakage	-	-	0.0011	0.0003	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Coupler			0.0023	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0027	0.0027
Mic. Front Length	La	mm	0.0001	0.0000	0.0001	0.0001	0.0002	0.0002	0.0003	0.0003	0.0003	0.0010	0.0010	0.0010	0.0040	0.0040
Mic. Front Length	Lax	mm	0.0015	0.0008	0.0004	0.0002	0.0004	0.0004	0.0005	0.0005	0.0005	0.0008	0.0008	0.0008	0.0010	0.0010
Eqv. And Front Vol	Veoa, Va	mm3	0.0082	0.0082	0.0082	0.0082	0.0081	0.0081	0.0078	0.0078	0.0078	0.0066	0.0066	0.0066	0.0030	0.0030
Diaphragm Res.	foa	Hz	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0004	0.0004	0.0056	0.0056	0.0056	0.0170	0.0170
Diaph. Damp. Fac.	Da	-	0.0000	0.0000	0.0000	0.0002	0.0010	0.0010	0.0036	0.0036	0.0036	0.0124	0.0124	0.0124	0.0040	0.0040
Microphones			0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	0.0086	0.0086	0.0086	0.0152	0.0152	0.0152	0.0182	0.0182
Series Cap.	C	pF	0.0029	0.0024	0.0018	0.0018	0.0018	0.0018	0.0021	0.0021	0.0021	0.0024	0.0024	0.0024	0.0027	0.0027
Volt. Ratio, DVM	VRab, VRac, VRbc	-	0.0012	0.0012	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0012	0.0012	0.0012	0.0012	0.0012
Volt. Ratio, Cr-talk	VRab, VRac, VRbc	-	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Volt. Ratio, Noise	VRab, VRac, VRbc	-	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Volt. Ratio, Distort.	VRab, VRac, VRbc	-	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Frequency	f	ppm	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
Pol. Voltage	Uo	V	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042
Electrical Parameters			0.0058	0.0056	0.0053	0.0053	0.0053	0.0053	0.0054	0.0054	0.0054	0.0056	0.0056	0.0056	0.0057	0.0057
Reproducibility	Mp	dB	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0120	0.0120	0.0120	0.0120	0.0150
Result Rounding	Mp	dB	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
Uncertainty at Measurement Conditions		dB	0.0153	0.0152	0.0151	0.0151	0.0150	0.0150	0.0153	0.0153	0.0153	0.0210	0.0210	0.0210	0.0240	0.0256
Sensitivity Correction for Static Pressure		dB	0.0008	0.0008	0.0008	0.0008	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0097	0.0097
Sensitivity Correction for Temperature		dB	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0036	0.0053	0.0053
Uncertainty at Reference Conditions		dB	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
Reported Uncertainty at Ref Conditions		dB	**0.04**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**

NATIONAL PHYSICAL LABORATORY, NEW DELHI, INDIA

UNCERTAINTY BUDGET FOR MICROPHONE

Quantity and Description	Relative expanded uncertainty (dB)	Probability distribution model	Factor	Sens.Co-efficient	Relative Contribution (dB)
Correlated components					
(U/i) Transfer electrical impedance which include, accuracy of capacitor, resolution of capacitor, Resolution of voltmeter (voltage ratio)	0.05	Normal (2* σ)	½	1	0.025
P_s Ambient Pressure	0.004	Normal	½	1	0.002
$V + V_e$ Volume of coupler, equivalent and front cavity volume	0.04	Normal	½	1	0.02
Polarisation voltage	0.0008	Normal	½	1	0.004
Microphone sensitivity co-efficient for temperature and pressure to reference conditions	0.004	Normal	½	1	0.002
ϒ Specific heat ratio	0.004	Normal	½	1	0.002
Uncorrelated components					
(U/i) Transfer electrical impedance	0.003	Rectangular	1/√3	1	0.0017
ϒ Specific heat ratio	0.006	Rectangular	1/√3	1	0.0035
P_s Ambient Pressure	0.002	Rectangular	1/√3	1	0.001
$V + V_e$ coupler volume microphone cavity volume, equivalent volume and microphone constant	0.01	Rectangular	1/√3	1	0.006
ΔH Heat conduction	0.02	Rectangular	1/√3	1	0.01
Polarisation voltage	0.002	Rectangular	1/√3	1	0.001
W Wave motion	0.002	Rectangular	1/√3	1	0.001

Combined relative uncertainty (Coverage factor k = 2)

$$U_{rel,95}(M) = \frac{U_{95}(M)}{|M|} = 0.069 \text{ dB}$$

$$\simeq 0.07 \text{ dB}$$

SCL:

Uncertainty budget for SCL, Hong Kong

Uncertainty in 0.001 dB															
Uncertainty Components		Frequency (Hz)													
Description	Type	63	125	250	500	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
Coupler dimensions	B	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Microphone parameters	B	8	8	8	8	8	8	8	8	8	8	8	8	10	10
Voltage ratio	B	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Electrical impedance	B	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Frequency	B	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ambient pressure	B	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Ratio of specific heats	B	9	9	8	8	8	8	8	8	8	8	8	5	5	5
Heat conduction correction	B	9	7	7	7	6	6	6	6	6	6	6	3	3	3
Capillary tube correction	B	6	6	6	6	3	3	3	3	3	3	3	3	3	3
Wave motion correction	B	0	0	0	0	5	5	5	5	5	5	5	13	17	20
Polarizing voltage	B	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Corrections to reference conditions	B	5	5	5	5	5	5	5	5	5	5	5	6	8	10
Repeatability	A	12	10	5	5	5	5	5	5	5	5	5	10	10	10
Combined standard uncertainty		24.0	22.3	20.2	20.2	19.8	19.8	19.8	19.8	19.8	19.8	19.8	23.6	27.2	29.8
Expanded uncertainty (k=2)		48.0	44.7	40.3	40.3	39.6	39.6	39.6	39.6	39.6	39.6	39.6	47.2	54.4	59.6
Expanded Uncertainty (Rounded)		50	50	40	40	40	40	40	40	40	40	40	50	60	60