Bilateral Comparison of LS1P Microphone Calibrations between KRISS and KIM-LIPI

APMP.AUV.A-K1.1

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June 2009

Abstract

A bilateral comparison of the pressure sensitivity calibration of an LS1P microphone has been performed between the Korea Research Institute of Standards and Science (KRISS, Korea) and the Research and Development Center for Calibration Instrumentation and Metrology (KIM-LIPI, Indonesia) in 2008. The KRISS was the pilot laboratory and the results of the KIM-LIPI have been linked to those of the CCAUV.A-K1 comparison through the KRISS. The degree of equivalence of KIM-LIPI with respect to the KCRV is given at each of the measured frequencies.

Contents

1. Introduction

A bilateral comparison of pressure sensitivity calibration of LS1P microphone has been performed between the Korea Research Institute of Standards and Science (KRISS, Korea) and Research and Development Center for Calibration Instrumentation and Metrology (KIM-LIPI, Indonesia), during July to August, 2008, with KRISS acting as the pilot laboratory.

2. Organization of Bilateral Comparison

The APMP workshop on Microphone Pressure Reciprocity Calibration and Its Uncertainty Analysis was held at the Indonesian Institute of Science (Puslit KIM-LIPI), Tangerang, Indonesia on November 19-21, 2007. During the workshop, Dr. Prem Narang, APMP TCAUV Chair, suggested the bilateral comparison of LS1P and LS2P microphones between KRISS and KIM-LIPI to ensure the mutual agreement between calibration results. It was agreed that KRISS would be the pilot laboratory and NMIA, Australia, would be the third-party for data collection and release.

3. Calibration Method

3.1 Reciprocity Calibration Method

The calibration was performed as reciprocity calibration using closed couplers at both laboratories in the nominal preferred octave frequencies from 63 Hz to 1 kHz and the nominal preferred 1/3rd octave frequencies from 1.25 kHz to 8 kHz in accordance with the International Standard IEC 61094-2:1992. The microphones were coupled in pairs using two air-filled plane wave couplers of different lengths (nominal length of 7.5 and 15 mm). The sensitivity of the microphone is obtained from the electrical transfer impedance which was measured using the computer operated automatic Reciprocity Calibration Apparatus, B&K 5998.

3.2 Microphone Parameters

KRISS

Front Cavity Depth: The depth of the microphone front cavity is measured by an optical method using a depth-focusing microscope equipped with a digital dial gauge (Mahr, Millitast 1083) to monitor the vertical displacement of the lens (focal length of 0.5 mm). The cavity depth is calculated as the difference between the digital dial gauge readings at the surface of microphone rim and at the surface of diaphragm. The front cavity depth is determined from the mean of measurements at four places.

Front Cavity Volume: The microphone front cavity volume V_F is calculated using the equation $V_F = 274.4L_F$ as given in the Technical Documentation of Reciprocity Calibration System,

B&K 9699, where L_F is the microphone front cavity depth.

Equivalent Volume: The equivalent volume is estimated by data fitting. The equivalent volume is adjusted to have the minimum difference between the measured results of the short (nominal length of 7.5 mm) and the long (nominal length of 15 mm) plane wave couplers at the frequency of 250 Hz.

Resonance Frequency and Loss Factor: The frequency response of the microphone diaphragm displacement is measured by the laser vibrometer. The microphone is coupled with a plane wave coupler, of which one of the openings is blocked by transparent optical glass. The vibration of diaphragm is assumed to be that of a simple mass-spring-damper system with a single degree of freedom. To obtain the microphone resonance frequency and loss factor, the least square fitting procedure is carried out until the best agreement is obtained between the measured and the theoretical frequency responses in the frequency range from 8000 Hz to 30000 Hz.

KIM-LIPI

Equivalent Volume: The equivalent volume is estimated by data fitting. The equivalent volume is adjusted to have the minimum difference between the measured results of the short (nominal length of 7.5 mm) and the long (nominal length of 15 mm) plane wave couplers at the frequency of 250 Hz.

Nominal values are used for the other parameters of the microphone, such as microphone front cavity depth, front cavity volume, resonance frequency, and loss factor.

Microphone parameters as well as temperature and pressure coefficients of the sensitivity for LS1P microphone are listed in Table 1.

4. Traveling Microphone

Brüel & Kjaer type 4160 microphone supplied by KRISS was circulated in this comparison.

- **Brüel & Kjær 4160, serial number 1792662**

The traveling microphone was 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. The same type of aluminum box was used in APMP.AUV.A-K1 and APMP.AUV.A-K3 key comparisons. It was transported by DHL international delivery service.

Table 1. Microphone parameters for LS1P microphone.

	KRISS	KIM-LIPI
Front cavity depth (mm)	1.981	1.950
Front cavity volume (mm^3)	543.6	555.8
Equivalent volume (mm^3)	159.6	150.0
Temperature coefficient (dB/K)	-0.0022	-0.0019
Pressure coefficient (dB/kPa)	-0.0152	-0.0153
Resonance frequency (Hz)	7.9	8.2
Loss factor	0.97	1.05

5. Calibration Schedule

The calibration schedule is shown in Table 2.

Table 2. Calibration schedule.

Id	Task name	Duration	Start	Finish
1	Initial calibration at KRISS	2 weeks	Mon 30/06/2008	Fri 12/07/2008
2	Calibration at KIM-LIPI	4 weeks	Mon 14/07/2008	Fri 09/08/2008
3	Check calibration at KRISS	2 weeks	Mon 18/08/2008	Fri 30/08/2008

6. Calibration Results and Uncertainties

All calibration results are referred to the reference environmental conditions of 23.0 ^{o}C, 101.325 kPa and 50 %RH.

The calibration results and expanded uncertainties are shown in Table 3. The first set of results is taken as the result of KRISS and the second is only referred to check the drift or damage of the artifact. The difference between two measured results at KRISS is small showing the stability of the standards during the measurements.

Table 3. Reported sensitivity levels in dB re. 1 V/Pa.

Freq. (Hz)	KRISS			KIM-LIPI	
	Sensitivity Level		Expanded Uncertainty	Sensitivity Level	Expanded Uncertainty
	1st	2nd			
63.0	-25.99	-25.99	0.04	-25.99	0.06
125.0	-26.02	-26.03	0.04	-26.03	0.06
250.0	-26.05	-26.05	0.04	-26.06	0.06
500.0	-26.06	-26.06	0.04	-26.06	0.06
1000.0	-26.02	-26.03	0.04	-26.03	0.05
1250.0	-25.99	-26.00	0.04	-26.00	0.06
1600.0	-25.93	-25.94	0.04	-25.94	0.06
2000.0	-25.85	-25.86	0.04	-25.86	0.06
2500.0	-25.73	-25.73	0.04	-25.74	0.06
3150.0	-25.54	-25.55	0.04	-25.56	0.07
4000.0	-25.30	-25.30	0.05	-25.31	0.08
5000.0	-25.09	-25.10	0.05	-25.11	0.09
6300.0	-25.28	-25.27	0.05	-25.30	0.09
8000.0	-26.76	-26.76	0.05	-26.81	0.10

7. Deviation from Linking Laboratory

The deviation $D_{KRISS-KIM/LIPI}^{APMP}$ between KRISS and KIM-LIPI is given by the following equation;

$$D_{KRISS-KIM/LIPI}^{APMP} = M_{KRISS}^{APMP} - M_{KIM/LIPI}^{APMP} \quad (1)$$

where M_{KRISS}^{APMP} and $M_{KIM/LIPI}^{APMP}$ are the arithmetic mean of the pressure sensitivity levels of the microphone measured in KRISS and KIM-LIPI, respectively.

The expanded uncertainty of the deviation is given by;

$$U^2(D_{KRISS-KIM/LIPI}^{APMP}) = U^2(M_{KRISS}^{APMP}) + U^2(M_{KIM/LIPI}^{APMP}) \quad (2)$$

where $U(M_{KRISS}^{APMP})$ and $U(M_{KIM/LIPI}^{APMP})$ are the corresponding expanded uncertainties.

Table 4 shows the difference between KRISS and KIM-LIPI for each frequency and their expanded uncertainties. Fig. 1 shows the difference between KRISS and KIM-LIPI for LS1P microphone.

8. Degrees of Equivalence

The 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. The degrees of equivalence of KRISS in the CCAUV.A-K1, that is the differences and their expanded uncertainties are listed in the Table 5.

Table 4. The differences between KRISS and KIM-LIPI and their expanded uncertainties.

Freq. (Hz)	Difference (dB)	Expanded uncertainty (dB)
63.0	0.00	0.08
125.0	0.01	0.08
250.0	0.01	0.08
500.0	0.00	0.08
1000.0	0.01	0.07
1250.0	0.01	0.08
1600.0	0.01	0.08
2000.0	0.01	0.08
2500.0	0.01	0.08
3150.0	0.02	0.09
4000.0	0.01	0.10
5000.0	0.02	0.11
6300.0	0.02	0.11
8000.0	0.05	0.12

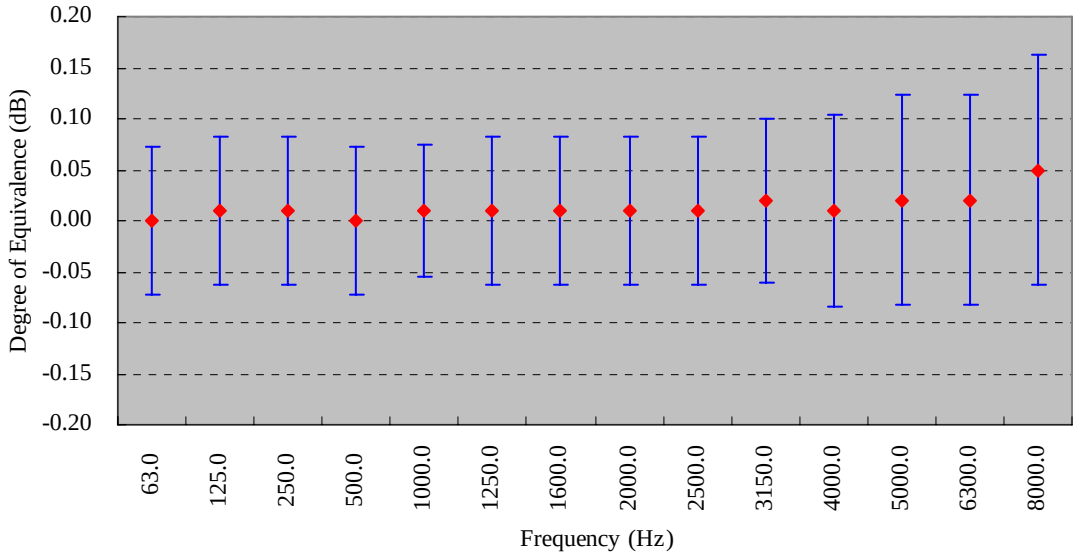

Fig. 1. Degrees of equivalence between KRISS and KIM-LIPI.

Table 5. Degree of equivalence of KRISS in the CCAUV.A-K1.

Freq. (Hz)	Difference (dB)	Expanded Uncertainty (dB)
63.0	0.00	0.03
125.0	0.00	0.03
250.0	0.00	0.03
500.0	0.00	0.03
1000.0	0.00	0.03
1250.0	0.01	0.03
1600.0	0.01	0.03
2000.0	0.01	0.03
2500.0	0.02	0.03
3150.0	0.02	0.03
4000.0	0.02	0.03
5000.0	0.02	0.03
6300.0	0.01	0.04
8000.0	0.02	0.04

To link the results of KIM-LIPI to the KCRV of CCAUV.A-K1, the correction factor between measurands of KRISS in CCAUV and APMP is introduced as follows:

$$\Delta M = M_{KRISS}^{CCAUV} - M_{KRISS}^{APMP} \quad (3)$$

The measurands M_{KRISS}^{CCAUV} and M_{KRISS}^{APMP} were measured in KRISS with the same calibration system and the method. The correlation coefficient of the measurements made in one laboratory was assumed C = 0.7 during the analysis in CCAUV.A-K3 and is applicable also here.

The correction factor has to be applied to link the results of KIM-LIPI to the KCRV of CCAUV.A-K1.

$$\begin{aligned} D_{KIM/LIPI-KCRV} &= M_{KIM/LIPI}^{APMP} + \Delta M - M_{KCRV}^{CCAUV} \\ &= M_{KIM/LIPI}^{APMP} - M_{KRISS}^{APMP} + M_{KRISS}^{CCAUV} - M_{KCRV}^{CCAUV} \\ &= D_{KRISS-KCRV}^{CCAUV} - D_{KRISS-KIM/LIPI}^{APMP} \end{aligned} \quad (4)$$

$$U^2(D_{KIM/LIPI-KCRV}) = U^2(D_{KRISS-KIM/LIPI}^{APMP}) + U^2(D_{KRISS-KCRV}^{CCAUV}) \quad (5)$$

where M_{KCRV}^{CCAUV} is the KCRV and $D_{KRISS-KCRV}^{CCAUV}$ is the difference between the KRISS and the KCRV. As the correlation coefficient between each participant and the KCRV were not reported in the CCAUV.A-K1, we have considered this part to be negligible.

Table 6 shows the degrees of equivalence of KIM-LIPI with KCRV, that is the deviations and their expanded uncertainties, and Fig. 2 illustrates them graphically.

Table 6. Degree of equivalence of KIM-LIPI with the KCRV.

Freq. (Hz)	Difference (dB)	Expanded Uncertainty (dB)
63.0	0.00	0.08
125.0	-0.01	0.08
250.0	-0.01	0.08
500.0	0.00	0.08
1000.0	-0.01	0.08
1250.0	0.00	0.08
1600.0	0.00	0.08
2000.0	0.00	0.08
2500.0	0.01	0.08
3150.0	0.00	0.09
4000.0	0.01	0.10
5000.0	0.00	0.11
6300.0	-0.01	0.12
8000.0	-0.03	0.12

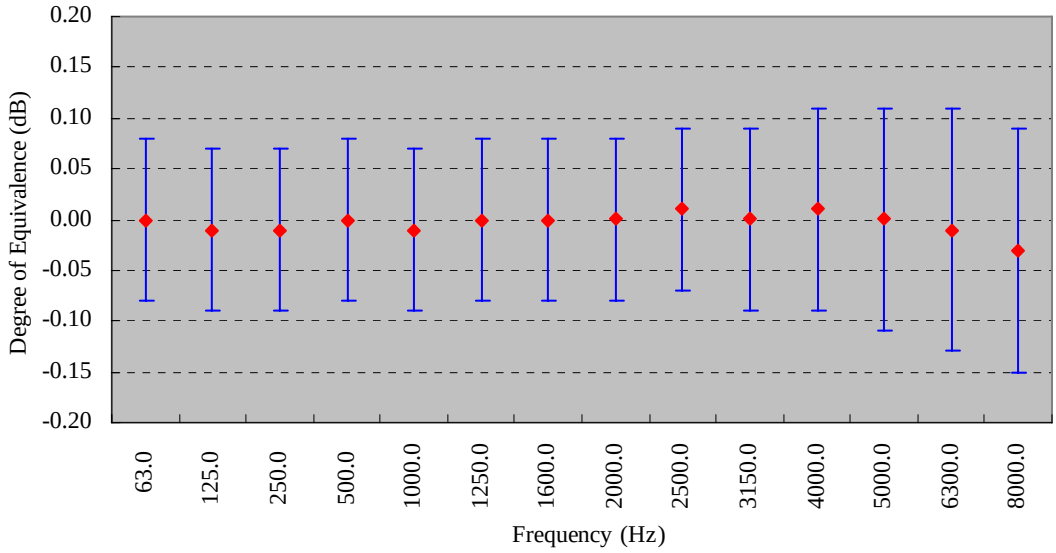

Fig. 2. Degrees of equivalence of KIM-LIPI with the KCRV.

9. Conclusion

The calibrated results for the LS1P microphone of KIM-LIPI were linked to the KCRVs of the CCAUV.A-K1 key comparison. All of the degrees of equivalence of KIM-LIPI with respect to the KCRVs have a difference of less than or equal to 0.03 dB with an expanded uncertainty less than 0.12 dB.

10. Acknowledgement

The author wishes to thank Mr. Achmad Suwandi of KIM-LIPI, Indonesia for his cooperation during the bilateral comparison and Dr. Prem Narang of NMIA, Australia for his role as a neutral third party.

11. References

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[3] R. Horiuchi, H. Takahashi, T. Fujimori, and S. Sato, “Final Report on Key Comparison APMP.AUV.A-K1,” 2007

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Appendix A. Uncertainty Budgets

The following pages show the uncertainty budgets of two participants, KRISS and KIM-LIPI for LS1P microphone.

Table A1. Uncertainty budget of LS1P microphone, KRISS

Uncertainty Budget of LS1P, KRISS														
MEASURED QUANTITY	63	125	250	500	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
Electrical Transfer Impedance	**0.0062**	**0.0061**	**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	0.0045	0.0045	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	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	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	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	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	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
Receiver Ground Shield	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	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	**0.0008**	**0.0008**	**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	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	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	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	0.0006
Coupler Surface Area	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	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	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	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
Microphone Parameters	**0.0069**	**0.0069**	**0.0070**	**0.0070**	**0.0070**	**0.0070**	**0.0071**	**0.0074**	**0.0082**	**0.0100**	**0.0134**	**0.0176**	**0.0158**	**0.0068**
Front Cavity Depth	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	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	0.0067	0.0067	0.0067	0.0067	0.0067	0.0066	0.0065	0.0063	0.0061	0.0056	0.0048	0.0035	0.0017	0.0008
Resonance Frequency	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	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	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
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	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	**0.0156**	**0.0156**	**0.0156**	**0.0156**	**0.0156**	**0.0156**	**0.0156**	**0.0156**	**0.0157**	**0.0158**	**0.0171**	**0.0084**	**0.0108**	**0.0104**
Rounding Error	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	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150	0.0150	0.0160	0.0020	0.0025	0.0031
Static Pressure Corrections	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	0.0011	0.0010	0.0010	0.0011	0.0014	0.0015	0.0018	0.0020	0.0025	0.0034	0.0051	0.0076	0.0101	0.0093
Sum	**0.0182**	**0.0182**	**0.0182**	**0.0178**	**0.0177**	**0.0178**	**0.0179**	**0.0180**	**0.0188**	**0.0197**	**0.0226**	**0.0204**	**0.0202**	**0.0140**
Expanded Uncertainty (*k*=2)	**0.0364**	**0.0364**	**0.0364**	**0.0357**	**0.0355**	**0.0357**	**0.0358**	**0.0361**	**0.0375**	**0.0395**	**0.0452**	**0.0409**	**0.0403**	**0.0280**
Stated Uncertainty	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.05**	**0.05**	**0.05**	**0.05**

Table A2. Uncertainty budget of LS1P microphone, KIM-LIPI

Uncertainty Budget of LS1P, KIM-LIPI														
MEASURED QUANTITY	63	125	250	500	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
Microphone Parameters	**0.0072**	**0.0071**	**0.0070**	**0.0070**	**0.0069**	**0.0068**	**0.0066**	**0.0064**	**0.0060**	**0.0054**	**0.0044**	**0.0036**	**0.0060**	**0.0089**
Front Depth	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0021	0.0020	0.0019	0.0017	0.0013	0.0007	0.0010	0.0004
Front Volume	0.0046	0.0044	0.0043	0.0043	0.0043	0.0042	0.0041	0.0039	0.0036	0.0033	0.0029	0.0031	0.0036	0.0083
Equiv Volume	0.0039	0.0039	0.0039	0.0039	0.0039	0.0038	0.0037	0.0036	0.0033	0.0029	0.0021	0.0010	0.0009	0.0006
Resonance Frequency	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0021	0.0020	0.0020	0.0017	0.0014	0.0010	0.0044	0.0030
Loss Factor	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0021	0.0021	0.0020	0.0020	0.0018	0.0010	0.0014	0.0007
Electrical Measurement	**0.0094**	**0.0094**	**0.0053**	**0.0040**	**0.0035**	**0.0040**	**0.0040**	**0.0040**	**0.0053**	**0.0053**	**0.0053**	**0.0053**	**0.0053**	**0.0053**
Voltage Ratio	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017
Capacitance	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
Cross Talk	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
Polarising Voltage	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	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
Receiver Ground Shield	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	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
Distortion	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
Coupler Properties	**0.0075**	**0.0065**	**0.0056**	**0.0026**	**0.0026**	**0.0026**	**0.0026**	**0.0026**	**0.0026**	**0.0026**	**0.0026**	**0.0026**	**0.0026**	**0.0026**
Length	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
Diameter	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023
Volume	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
Surface Area	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
Air Leakage	0.0070	0.0060	0.0050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ambient Conditions	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**	**0.0182**
Pcoeft Unknown	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
Static Pressure	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
Pressure Variation	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
Tcoeft Unknown	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
Microphone Temperature	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
Temperature Variation	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140
Relative Humidity	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
Mic. Rel. Humidity	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001

Physical Corrections	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0020**	**0.0130**	**0.0134**	**0.0161**	**0.0180**	**0.0200**	**0.0300**	**0.0340**	**0.0350**	**0.0370**
Radial Wave Motion Correction	0.0000	0.0000	0.0000	0.0000	0.0020	0.0130	0.0134	0.0161	0.0180	0.0200	0.0300	0.0340	0.0350	0.0370
Viscosity Losses	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
Type A and Rounding	**0.0115**	**0.0118**	**0.0142**	**0.0151**	**0.0105**	**0.0108**	**0.0108**	**0.0104**	**0.0112**	**0.0110**	**0.0106**	**0.0119**	**0.0143**	**0.0114**
Type A	0.0103	0.0107	0.0133	0.0142	0.0092	0.0095	0.0096	0.0092	0.0100	0.0098	0.0094	0.0108	0.0134	0.0103
Rounding Error	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
Combined Uncertainty, uc	**0.0257**	**0.0255**	**0.0254**	**0.0251**	**0.0226**	**0.0262**	**0.0264**	**0.0276**	**0.0292**	**0.0303**	**0.0374**	**0.0409**	**0.0428**	**0.0441**
Effective dof	87	81	44	34	81	81	79	68	59	51	29	25	26	24
k Factor	1.99	1.99	2.02	2.03	1.99	1.99	1.99	2.00	2.00	2.01	2.05	2.06	2.06	2.06
Expanded Uncertainty, U95	0.0510	0.0508	0.0511	0.0510	0.0450	0.0521	0.0525	0.0551	0.0583	0.0608	0.0765	0.0843	0.0880	0.0909
U95 Rounded to 2 dP	**0.06**	**0.06**	**0.06**	**0.06**	**0.05**	**0.06**	**0.06**	**0.06**	**0.06**	**0.07**	**0.08**	**0.09**	**0.09**	**0.10**