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A Bilateral Comparison of LS2P Microphone Pressure Sensitivity between the KRISS and the KIM-LIPI

APMP.AUV.A-K3.1

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Abstract

A bilateral comparison of pressure sensitivity calibration of an LS2P 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, with KRISS acting as the pilot laboratory. The results have been linked to the CCAUV.A-K3 comparison with degrees of equivalence for the KIM-LIPI.

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Contents

1. Introduction

A bilateral comparison of pressure sensitivity calibration of LS2P 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 31.5 Hz to 4 kHz and the nominal preferred 1/3rd octave frequencies from 6.3 kHz to 25 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 4.7 and 9.4 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 $V_F = 69.3L_F$ 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 4.7 mm) and the long (nominal length of 9.4 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 4.7 mm) and the long (nominal length of 9.4 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

Bruel & Kjaer type 4180 microphone supplied by KRISS was circulated in this comparison.

- Brüel & Kjær 4180, serial number 2341431

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 LS2P microphone.

	KRISS	KIM-LIPI
Front cavity depth /mm	0.478	0.5
Front cavity volume /mm^3	33.1	34.0
Equivalent volume /mm^3	9.9	8.6
Temperature coefficient /(dB/K)	-0.0010	-0.0012
Pressure coefficient /(dB/kPa)	-0.0052	-0.0055
Resonance frequency /Hz	20.5	22.0
Loss factor	1.02	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 difference between two measured results at KRISS is small. Therefore, 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.

7. Degree of Equivalence

The degree of equivalence $D^{APMP}_{KRISS-KIM/LIPI}$ between KRISS and KIM-LIPI consists of two components, the difference and the uncertainty of the difference, the former being given by the following equation;

$$D^{APMP}_{KRISS-KIM/LIPI} = M^{APMP}_{KRISS} - M^{APMP}_{KIM/LIPI} \quad (1)$$

where M^{APMP}_{KRISS} and $M^{APMP}_{KIM/LIPI}$ are the pressure sensitivity levels of KRISS and KIM-LIPI, respectively.

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			
31.5	-38.72	-38.72	0.08	-38.74	0.09
63.0	-38.73	-38.73	0.05	-38.74	0.07
125.0	-38.73	-38.73	0.05	-38.75	0.06
250.0	-38.74	-38.74	0.04	-38.75	0.06
500.0	-38.74	-38.74	0.04	-38.75	0.06
1000.0	-38.73	-38.73	0.04	-38.75	0.06
2000.0	-38.71	-38.71	0.04	-38.73	0.06
4000.0	-38.60	-38.59	0.04	-38.62	0.06
6300.0	-38.40	-38.39	0.04	-38.43	0.06
8000.0	-38.21	-38.21	0.04	-38.25	0.06
10000.0	-37.99	-37.99	0.05	-38.02	0.06
12500.0	-37.78	-37.78	0.06	-37.81	0.07
16000.0	-37.87	-37.88	0.07	-37.90	0.08
20000.0	-38.89	-38.90	0.10	-38.98	0.12
25000.0	-41.33	-41.34	0.20	-41.43	0.17

The expanded uncertainty of the difference is given by;

$$U^2(D^{APMP}_{KRISS-KIM/LIPI}) = U^2(M^{APMP}_{KRISS}) + U^2(M^{APMP}_{KIM/LIPI}) \quad (2)$$

where $U(M^{APMP}_{KRISS})$ and $U(M^{APMP}_{KIM/LIPI})$ are the expanded uncertainties of KRISS and KIM-LIPI, respectively.

Table 4 shows the degrees of equivalence between the KRISS and the KIM-LIPI. Fig. 1 shows the degree of equivalence between KRISS and KIM-LIPI for LS2P microphone.

8. Link of the KIM-LIPI to the CCAUV KCRV

For the CCAUV.A-K3, four KCRV were calculated, since four standards were circulated. The KCRVs and the expanded uncertainties for the KRISS calibrated artifacts are listed in Table 5.

Table 4. The degree of equivalence between the KRISS and the KIM-LIPI

Freq. / Hz	Difference *D* /dB	Expanded uncertainty, *U* /dB
31.5	0.02	0.13
63.0	0.01	0.09
125.0	0.02	0.08
250.0	0.01	0.08
500.0	0.01	0.08
1000.0	0.02	0.08
2000.0	0.02	0.08
4000.0	0.02	0.08
6300.0	0.03	0.08
8000.0	0.04	0.08
10000.0	0.03	0.08
12500.0	0.03	0.10
16000.0	0.03	0.11
20000.0	0.09	0.16
25000.0	0.10	0.27

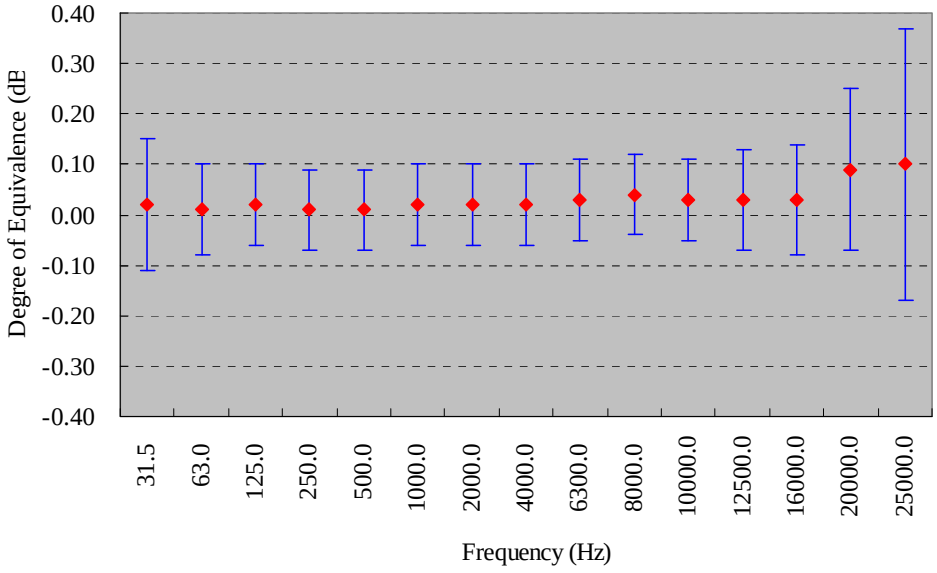

Fig. 1. Degree of equivalence between KRISS and KIM-LIPI.

Table 5. Key comparison reference values and the expanded uncertainties.

Freq. / Hz	KCRV /dB [1395456]	KCRV /dB [1627783]	Expanded Uncertainty /dB
31.5	-38.367	-38.725	0.019
63.0	-38.402	-38.740	0.013
125.0	-38.430	-38.753	0.012
250.0	-38.451	-38.766	0.012
500.0	-38.472	-38.773	0.012
1000.0	-38.481	-38.775	0.012
2000.0	-38.464	-38.753	0.012
4000.0	-38.335	-38.649	0.012
6300.0	-38.084	-38.456	0.013
8000.0	-37.850	-38.285	0.013
10000.0	-37.567	-38.091	0.016
12500.0	-37.328	-37.955	0.019
16000.0	-37.579	-38.223	0.024
20000.0	-39.073	-39.444	0.036
25000.0	-41.760	-41.714	0.061

Table 6 shows the degree of equivalence of the KRISS with the KCRV.

Table 6. Degree of equivalence of the KRISS with the KCRV.

Freq. / Hz	DoEq. / dB	Expanded Uncertainty / dB
31.5	-0.001	0.053
63.0	0.008	0.035
125.0	0.009	0.025
250.0	0.008	0.026
500.0	0.009	0.026
1000.0	0.008	0.026
2000.0	0.009	0.026
4000.0	0.016	0.025
6300.0	0.016	0.025
8000.0	0.019	0.025
10000.0	0.017	0.034
12500.0	0.014	0.043
16000.0	-0.001	0.051
20000.0	0.023	0.066
25000.0	0.066	0.176

A link between KIM-LIPI and KCRV for CCAUV KC can be established via the KRISS-KCRV comparison result. The degrees of equivalence of KIM-LIPI with the KCRV are given by the following equations;

$$D_{KIM/LIPI-KCRV} = M^{APMP}_{KIM/LIPI} - M^{APMP}_{KRISS} + M^{CIPM}_{KRISS} - M^{CIPM}_{KCRV}$$

$$= -D^{APMP}_{KRISS-KIM/LIPI} + D^{CIPM}_{KRISS-KCRV} \quad (3)$$

$$U^2(U_{KIM/LIPI-KCRV}) = U^2(D^{APMP}_{KRISS-KIM/LIPI}) + U^2(D^{CIPM}_{KRISS-KCRV}) \quad (4)$$

where M^{CIPM}_{KRISS} and M^{CIPM}_{KCRV} are the pressure sensitivity levels of the KRISS and the KCRV, $D^{CIPM}_{KRISS-KCRV}$ and $U(D^{CIPM}_{KRISS-KCRV})$ are the degree of equivalence of KRISS with the KCRV in CCAUV.A-K3.

Table 7 shows the degrees of equivalence of the KIM-LIPI with the KCRV, and Fig. 2 illustrates these graphically.

Table 7. Degree of equivalence of the KIM-LIPI with the KCRV.

Freq. / Hz	Difference *D* /dB	Expanded Uncertainty *U* /dB
31.5	-0.02	0.14
63.0	0.00	0.10
125.0	-0.01	0.09
250.0	0.00	0.09
500.0	0.00	0.09
1000.0	-0.01	0.09
2000.0	-0.01	0.09
4000.0	0.00	0.09
6300.0	-0.01	0.09
8000.0	-0.02	0.09
10000.0	-0.01	0.09
12500.0	-0.02	0.11
16000.0	-0.03	0.12
20000.0	-0.07	0.17
25000.0	-0.03	0.28

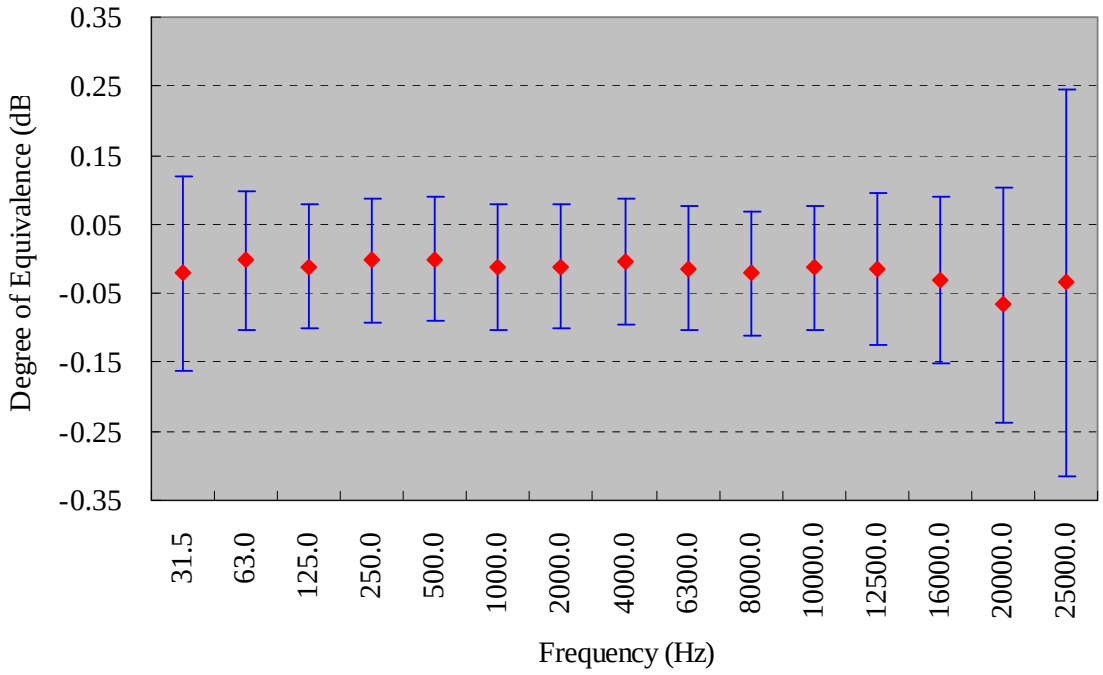

Fig. 2. Degree of equivalence of the KIM-LIPI with the KCRV.

9. Conclusion

The calibrated results for the LS2P microphone of the KIM-LIPI were linked to the KCRVs of the CCAUV.A-K3 key comparison through the results of the KRISS. All of the differences between the KIM-LIPI results and the respective KCRVs are less than $\pm$0.04 dB except the one at the frequency of 20 kHz that is 0.07 dB. Each result agrees well within the expanded uncertainties.

10. Acknowledgement

The authors wish to thank Dr Prem Narang of NMIA, Australia for his role as a neutral third party.

11. References

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Appendix A. Uncertainty Budgets

The following pages show the uncertainty budgets of the two participants, the KRISS and the KIM-LIPI for the LS2P microphone.

Table A1. Uncertainty budget of LS2P microphone, KRISS

Uncertainty Budget of LS2P, KRISS															
MEASURED QUANTITY	31.5	63	125	250	500	1000	2000	4000	6300	8000	10000	12500	16000	20000	25000
Electrical Transfer Impedance	**0.0309**	**0.0099**	**0.0098**	**0.0061**	**0.0049**	**0.0045**	**0.0050**	**0.0061**	**0.0061**	**0.0061**	**0.0077**	**0.0108**	**0.0108**	**0.0108**	**0.0108**
Series Impedance	0.0306	0.0090	0.0089	0.0044	0.0026	0.0017	0.0026	0.0044	0.0044	0.0044	0.0044	0.0087	0.0087	0.0087	0.0087
Voltage Ratio	0.0024	0.0021	0.0020	0.0020	0.0020	0.0020	0.0021	0.0021	0.0021	0.0021	0.0052	0.0052	0.0052	0.0052	0.0052
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	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	0.0009
Distortion	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0005	0.0006	0.0006	0.0004	0.0003	0.0011	0.0000	0.0000
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	0.0001
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	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	0.0003
Coupler Properties	**0.0114**	**0.0040**	**0.0019**	**0.0015**	**0.0014**	**0.0014**	**0.0014**	**0.0014**	**0.0015**	**0.0015**	**0.0016**	**0.0018**	**0.0024**	**0.0037**	**0.0075**
Coupler Length	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0003	0.0005	0.0009	0.0017	0.0037
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	0.0000
Coupler Volume	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0014	0.0014	0.0014	0.0013
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	0.0000
Static Pressure	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
Temperature	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0003	0.0005	0.0009	0.0016	0.0028	0.0061
Relative Humidity	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0003	0.0004	0.0006	0.0009	0.0019
Microphone Parameters	**0.0077**	**0.0078**	**0.0079**	**0.0079**	**0.0080**	**0.0080**	**0.0079**	**0.0077**	**0.0076**	**0.0076**	**0.0077**	**0.0069**	**0.0072**	**0.0273**	**0.0624**
Front Cavity Depth	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0006	0.0009	0.0015	0.0024	0.0043	0.0076	0.0168
Front Cavity Volume	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0035	0.0035	0.0036	0.0036	0.0033
Equivalent Volume	0.0069	0.0070	0.0071	0.0071	0.0072	0.0072	0.0071	0.0068	0.0061	0.0053	0.0041	0.0023	0.0004	0.0004	0.0099
Resonance Frequency	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0004	0.0009	0.0018	0.0023	0.0037	0.0254	0.0455
Loss Factor	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0012	0.0027	0.0039	0.0049	0.0043	0.0025	0.0051	0.0378
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	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	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	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**	**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	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	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	0.0000

Processing of Results	**0.0168**	**0.0168**	**0.0168**	**0.0168**	**0.0168**	**0.0168**	**0.0168**	**0.0169**	**0.0171**	**0.0175**	**0.0188**	**0.0214**	**0.0273**	**0.0350**	**0.0482**
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	0.0029
Repeatability of Measurements	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0170	0.0230	0.0300	0.0400
Static Pressure Corrections	0.0011	0.0011	0.0011	0.0011	0.0012	0.0012	0.0011	0.0009	0.0003	0.0006	0.0020	0.0032	0.0004	0.0107	0.0261
Temperature Corrections	0.0009	0.0008	0.0008	0.0008	0.0008	0.0009	0.0012	0.0021	0.0035	0.0051	0.0083	0.0123	0.0143	0.0143	0.0059
Sum	**0.0378**	**0.0214**	**0.0211**	**0.0196**	**0.0193**	**0.0192**	**0.0193**	**0.0196**	**0.0197**	**0.0201**	**0.0218**	**0.0250**	**0.0303**	**0.0458**	**0.0799**
Expanded Uncertainty (*k*=2)	**0.0755**	**0.0428**	**0.0421**	**0.0392**	**0.0386**	**0.0384**	**0.0386**	**0.0392**	**0.0395**	**0.0402**	**0.0435**	**0.0501**	**0.0606**	**0.0917**	**0.1598**
Stated Uncertainty	**0.08**	**0.05**	**0.05**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.05**	**0.06**	**0.07**	**0.10**	**0.20**

Table A2. Uncertainty budget of LS2P microphone, KIM-LIPI

Uncertainty Budget of LS2P, KIM-LIPI															
MEASURED QUANTITY	31.5	63	125	250	500	1000	2000	4000	6300	8000	10000	12500	16000	20000	25000
Microphone Parameters	**0.0141**	**0.0110**	**0.0087**	**0.0075**	**0.0070**	**0.0066**	**0.0062**	**0.0058**	**0.0058**	**0.0063**	**0.0075**	**0.0140**	**0.0163**	**0.0166**	**0.0424**
Front Depth	0.0134	0.0094	0.0067	0.0047	0.0033	0.0023	0.0014	0.0004	0.0018	0.0034	0.0057	0.0082	0.0113	0.0122	0.0161
Front Volume	0.0037	0.0051	0.0049	0.0053	0.0055	0.0056	0.0055	0.0053	0.0052	0.0051	0.0048	0.0113	0.0117	0.0112	0.0386
Equiv Volume	0.0025	0.0025	0.0025	0.0026	0.0026	0.0026	0.0025	0.0023	0.0018	0.0013	0.0004	0.0011	0.0001	0.0002	0.0043
Resonance Frequency	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0004	0.0006	0.0002	0.0004	0.0004	0.0024
Loss Factor	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0003	0.0001	0.0007	0.0003	0.0007	0.0050
Electrical Measurement	**0.0307**	**0.0094**	**0.0094**	**0.0053**	**0.0040**	**0.0035**	**0.0040**	**0.0053**	**0.0053**	**0.0053**	**0.0053**	**0.0092**	**0.0092**	**0.0092**	**0.0092**
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	0.0017
Capacitance	0.0306	0.0090	0.0089	0.0044	0.0026	0.0017	0.0026	0.0044	0.0044	0.0044	0.0044	0.0087	0.0087	0.0087	0.0087
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	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	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	0.0001
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	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	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	0.0001
Coupler Properties	**0.0112**	**0.0086**	**0.0078**	**0.0071**	**0.0050**	**0.0050**	**0.0050**	**0.0050**	**0.0050**	**0.0050**	**0.0050**	**0.0050**	**0.0050**	**0.0050**	**0.0050**
Length	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018
Diameter	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047
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	0.0000
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	0.0000
Air Leakage	0.0100	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	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0222**	**0.0223**	**0.0223**
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	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	0.0000
Pressure Variation	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	0.0025
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	0.0100
Microphone Temperature	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	0.0008	0.0018
Temperature Variation	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191	0.0191

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	0.0050
Mic. Rel. Humidity	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	0.0002	0.0005
Physical Corrections	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0010**	**0.0020**	**0.0030**	**0.0050**	**0.0100**	**0.0150**	**0.0200**
Radial Wave Motion Correction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0020	0.0030	0.0050	0.0100	0.0150	0.0200
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	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	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	0.0000
Type A and Rounding	0.0132	0.0132	0.0117	0.0118	0.0119	0.0116	0.0118	0.0120	0.0112	0.0112	0.0102	0.0144	0.0200	0.0397	0.0533
Type A	0.0122	0.0122	0.0105	0.0107	0.0108	0.0104	0.0107	0.0109	0.0100	0.0100	0.0089	0.0135	0.0193	0.0394	0.0531
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	0.0050
Combined Uncertainty, uc	**0.0440**	**0.0309**	**0.0292**	**0.0277**	**0.0269**	**0.0266**	**0.0267**	**0.0270**	**0.0266**	**0.0268**	**0.0268**	**0.0321**	**0.0370**	**0.0518**	**0.0751**
Effective dof	80	78	97	83	74	75	73	72	80	83	94	62	39	12	12
k Factor	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2	2.2
Expanded Uncertainty, U95	0.0876	0.0615	0.0580	0.0552	0.0537	0.0530	0.0532	0.0537	0.0530	0.0533	0.0532	0.0642	0.0748	0.1132	0.1631
U95 Rounded to 2 dP	**0.09**	**0.07**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.07**	**0.08**	**0.12**	**0.17**