

# **EUROMET PROJECT 399**

## **An international comparison of sound pressure standards**

Richard Barham

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AN INTERNATIONAL COMPARISON OF SOUND PRESSURE STANDARDS

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**ABSTRACT**

An international comparison of primary standards for sound pressure, by the calibration of laboratory standard microphones, has taken place between fourteen institutes within Euromet. A 'three-pilot' structure was adopted. These three laboratories first exchanged microphones between themselves and subsequently with three or four other laboratories each. A reference value has been defined which allows any two laboratories to compare results. Results for type LS1 microphones were within a range of  $\pm 0.15$  dB and for LS2a microphones were within a range of  $\pm 0.06$  dB, for all frequencies up to 10 kHz and 20 kHz respectively. This project now becomes a regional comparison alongside the worldwide CCAUV key comparisons that are underway or completed. Results for LS1P microphones from this comparison have been linked to CCAUV.A-K1.

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by Dr. B Zeqiri, Authorised by Director, Quality of Life Division

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## 1. INTRODUCTION

Direct realisation of the primary standards for sound pressure in air cannot provide the accuracy required to meet the needs for acoustical measurement. By international agreement therefore, pressure sensitivity of laboratory standard microphones determined by the reciprocity method, provide the basis for primary standards. The sensitivity is measured in units of volts per pascal, but usually quoted in decibels relative to 1V/Pa. IEC 61094-1 specifies the acoustical and geometrical properties of two types of laboratory standard microphone, referred to as type LS1 and type LS2a. These types of microphone have a similar construction and differ mainly in their size. LS1 microphones are nominally 25 mm in diameter and LS2 microphone are 12.6 mm in diameter. They used to be referred to as 'one-inch' and 'half-inch' microphones respectively, although the nomenclature introduced in IEC 61094-1<sup>1</sup> makes such historically based references unnecessary. The calibration principle, though not the methodology, is described in detail in IEC 61094-2<sup>2</sup>.

An international comparison to compare results of microphone calibrations has been organised within Euromet. The project was agreed in September 1998 and the measurements took place over a eight month period ending May 1999. The results have been reported within Euromet, but until now, no widely available publication has been produced.

The main reason for this is that since this project was conceived, the CCAUV has been formed. The consultative committee has the remit for formalising comparisons between laboratories worldwide, using a systematic series of key, regional and supplementary comparisons. Although this project was completed just as CCAUV was being formed, it was decided to give it the status of a regional comparison and ultimately link its results to appropriate key comparisons. Consequently the project has become known as EUROMET.A-K1. Since the formation of CCAUV, a worldwide key comparison on the calibration of type LS1 has been completed<sup>3</sup>. A further key comparison on the calibration of type LS2a is in progress.

This report will therefore briefly describe the comparison, present the results and provide data for type LS1 microphones that has been linked to the key comparison reference value.

## 2. THE PROTOCOL AND ORGANISATION OF THE COMPARISON

Fifteen laboratories agreed to participate in the comparison as shown in Table 1. However LNE, France, were unable to provide any results before the completion of the measurement phase of the project and had to withdraw. Participants had the option of calibrating either type LS1 or type LS2a microphones, or one of each type. Given the large number of participants and the timescale proposed for the project, the traditional round-robin arrangement was not viable. Instead the comparison was built up from a coordinated series of bilateral comparisons, where two laboratories exchanged microphones and compared results.

NPL, DPLA and PTB formed a nucleus for the project, where DPLA and PTB each exchanged microphones with NPL. These three laboratories in turn exchanged microphones with four other laboratories independently. Each laboratory was asked to supply two microphones for the project. Those that chose to, contributed one type LS1 and one type LS2 microphone. Others chose to calibrate two examples of the same type of microphones.

Participant	Acronym	Country	Microphones exchanged	Exchanged with
National Physical Laboratory	NPL	UK		-
Physikalische-Technische Bundesanstalt	PTB	Germany	2 LS1, 2 LS2	NPL
Danish Primary Laboratory for Acoustics	DPLA	Denmark	2 LS1, 2 LS2	NPL
Czech Metrological Institute	CMI	Czech Rep.	2 LS1	NPL
Institute National de Metrology	INM	France	1 LS1, 1 LS2	NPL
Telecom Engineering	TE	Finland	1 LS1, 1 LS2	NPL
Central Office of Measures	GUM	Poland	2 LS2	NPL
Instituto Electrotecnico Nazionale	IEN	Italy	1 LS1, 1 LS2	PTB
Slovenky Metrologicky Ustav	SMU	Slovak Rep.	2 LS1	PTB
Orszagos Meresugyi Hivatal	OMH	Hungary	2 LS1	PTB
National Metrology Institute	UME	Turkey	2 LS1	PTB
Instituto de Acustica	IA	Spain	1 LS1, 1 LS2	DPLA
Swiss Federal Office of Metrology	OFMET	Switzerland	1 LS1, 1 LS2	DPLA
Swedish National Testing and Research Institute	SP	Sweden	1 LS1, 1 LS2	DPLA
Bundesamt fur Eich-und Vermessungswesen	BEV	Austria	1 LS1, 1 LS2	DPLA

Table 1. Participants in the comparison

The protocol required the pressure sensitivity of the microphones to be determined according to IEC 61094-2, and the results and uncertainties to be reported by the issue of the participant's usual calibration certificate. A summary of their uncertainty calculation was also requested.

The advantages of this three-pilot approach were that measurements could be made by a number of participants in parallel, one laboratory was not over-burdened, and the stability of the microphones became less of an issue because it was only transferred between two laboratories. The disadvantage was that many different microphones were used, each having an arbitrary sensitivity. Some means of comparing any two laboratories, regardless of their position in the structure of the comparison, therefore needed to be developed.

### 3. DETERMINATION OF A REFERENCE VALUE

The results from the comparison need to be considered in two ways. First, it is necessary and interesting to consider the comparison as an exercise in its own right. Ultimately though, the results have much greater value by being linked to the key comparison reference value. However, in order to perform this linking, the results must first be referred to a reference value derived from this comparison alone. Initially then, the results for this regional comparison are considered in isolation.

The measurements that have been made result in values for the pressure sensitivities of the microphones used, but these absolute figures have no significance beyond characterising the particular microphone. What is important is that this data provides a means for comparing the performance of the two laboratories that calibrated the microphones. It is now necessary to find some way of removing the dependence on particular microphones and enabling results from any two laboratories to be compared, the complex structure of the comparison notwithstanding.

The process begins by defining an initial reference point for the three pilot laboratories. Both PTB and DPLA exchanged microphones with NPL, so in both cases a difference in the microphone

sensitivity at each frequency can be calculated. The initial reference value at each frequency was then taken to be one-third the sum of these differences. It is then the case that the mean deviation from this reference value at each frequency, across these three laboratories is zero.

For each of the other laboratories it is then possible to determine the difference in the sensitivities of the microphones exchanged with the relevant pilot laboratory and therefore relate their results to the initial reference point. With all participating laboratories related to the same reference point it is then possible to compare data from any two. However, the reference point is currently only defined in terms of the performance of the three core laboratories and should be re-determined so that the mean deviation across all laboratories is zero at each frequency. This is achieved by calculating the grand mean deviation from the initial reference point at each frequency, and adjusting the results of each participant by this amount, so that the resulting new grand mean deviation becomes zero at each frequency. These adjusted results then specify the performance of each participant relative to the defined reference point for the comparison, which by design has a value of zero. Notice that shifting the initial reference point as describe does not alter the results of one participant relative to another's.

#### **4. RESULTS AND DISCUSSION**

Although the comparison started with 15 participants, INM (France) were unable to take part in the measurements and withdrew. In addition TE (Finland) completed their measurements but reported their results without associated uncertainties. These results have therefore been excluded, but are reproduced in Annex B for information.

Nevertheless this was a large-scale comparison involving 14 participants and 32 microphones, producing 1060 individual measurement results each with an associated uncertainty. This report does not therefore aim to overwhelm by presenting all of this data and the interim results of the data reduction process. Instead the main results, emerging from the process described in the previous section are presented.

Table 2 and Table 3 show the results of the comparison in terms of the deviation from the reference value that has been established. The results are also plotted in Figure 1 and Figure 2.

The results for type LS2a microphones shown in Figure 2, deserve comment. The calibration of type LS2a microphones is technically more demanding than type LS1 microphones, yet the relative level of agreement that has been obtained would suggest otherwise. However, only a subset of the participants opted to take part in the LS2a comparison. These laboratories might be regarded as the ones that have longer experience in reciprocity measurements and may have had earlier opportunities to compare their performance. It might therefore be expected that this smaller set of laboratories might reach closer agreement in their measurements.

Lab <i>i</i> Frequency (Hz)	NPL		IA		DPLA		BEV		SP		IEN		PTB		UME		OFMET		SMU		OMH		CMI	
	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$
63	-0.01	0.03	0.02	0.05	-0.03	0.04	-0.02	0.06	0.00	0.05	-0.02	0.05	0.00	0.03	0.03	0.05	-0.04	0.03	0.02	0.04	0.03	0.07	-	-
125	0.00	0.03	-0.02	0.04	-0.01	0.03	0.00	0.03	0.01	0.04	0.00	0.05	0.02	0.03	0.03	0.05	-0.02	0.03	0.01	0.04	0.04	0.07	-0.03	0.03
250	0.00	0.03	-0.03	0.04	-0.01	0.03	-0.01	0.03	0.01	0.04	-0.01	0.05	0.02	0.03	0.03	0.05	-0.01	0.03	0.01	0.04	0.04	0.07	-0.04	0.03
500	0.00	0.03	-0.01	0.04	-0.01	0.03	-0.01	0.03	0.00	0.04	0.00	0.05	0.02	0.03	0.02	0.05	-0.02	0.03	0.02	0.04	0.02	0.07	-0.03	0.03
1000	0.00	0.03	0.00	0.04	-0.01	0.03	-0.01	0.03	0.01	0.04	-0.02	0.05	0.01	0.03	0.05	0.05	-0.02	0.03	0.01	0.04	0.00	0.07	-0.04	0.03
1250	0.00	0.03	-	-	-0.01	0.03	-0.02	0.03	0.01	0.04	-0.03	0.05	0.00	0.03	0.04	0.05	-	-	0.00	0.04	-0.01	0.07	-	-
1600	0.01	0.03	-	-	0.00	0.03	-0.01	0.03	0.00	0.04	-0.03	0.05	0.01	0.03	0.06	0.05	-0.02	0.03	0.01	0.04	0.00	0.07	-	-
2000	0.01	0.03	-	-	-0.01	0.03	-0.02	0.03	0.00	0.04	-0.02	0.05	0.02	0.03	0.07	0.05	-0.04	0.03	0.02	0.04	0.00	0.07	-	-
2500	0.00	0.04	-	-	-0.01	0.03	-0.02	0.03	-0.01	0.04	-0.02	0.05	0.01	0.03	0.05	0.05	-	-	0.02	0.04	-0.02	0.07	-	-
3150	0.01	0.04	-	-	0.00	0.03	-0.02	0.03	0.00	0.05	-0.02	0.05	0.02	0.03	0.02	0.05	0.00	0.03	-	-	-0.01	0.07	-	-
4000	0.01	0.04	-	-	0.01	0.03	-0.02	0.03	0.00	0.05	-0.03	0.05	0.02	0.03	0.02	0.05	0.00	0.03	-	-	-0.02	0.07	-	-
5000	0.01	0.05	-	-	0.02	0.04	-0.03	0.04	0.00	0.06	-0.03	0.05	0.03	0.06	0.03	0.10	-	-	-	-	-0.03	0.07	-	-
6300	0.03	0.05	-	-	0.02	0.05	-0.06	0.05	0.01	0.07	-0.03	0.05	0.05	0.06	-0.01	0.10	0.01	0.05	-	-	-0.03	0.07	-	-
8000	0.03	0.05	-	-	0.00	0.06	-0.09	0.06	0.03	0.10	0.04	0.05	0.05	0.06	-0.03	0.10	-0.01	0.04	-	-	-0.04	0.07	-	-
10000	0.03	0.09	-	-	-0.04	0.12	-0.06	0.12	0.12	0.20	-0.03	0.08	0.02	0.06	0.02	0.10	-0.06	0.04	-	-	-	-	-	-

Table 2. Results for type LS1 microphones.



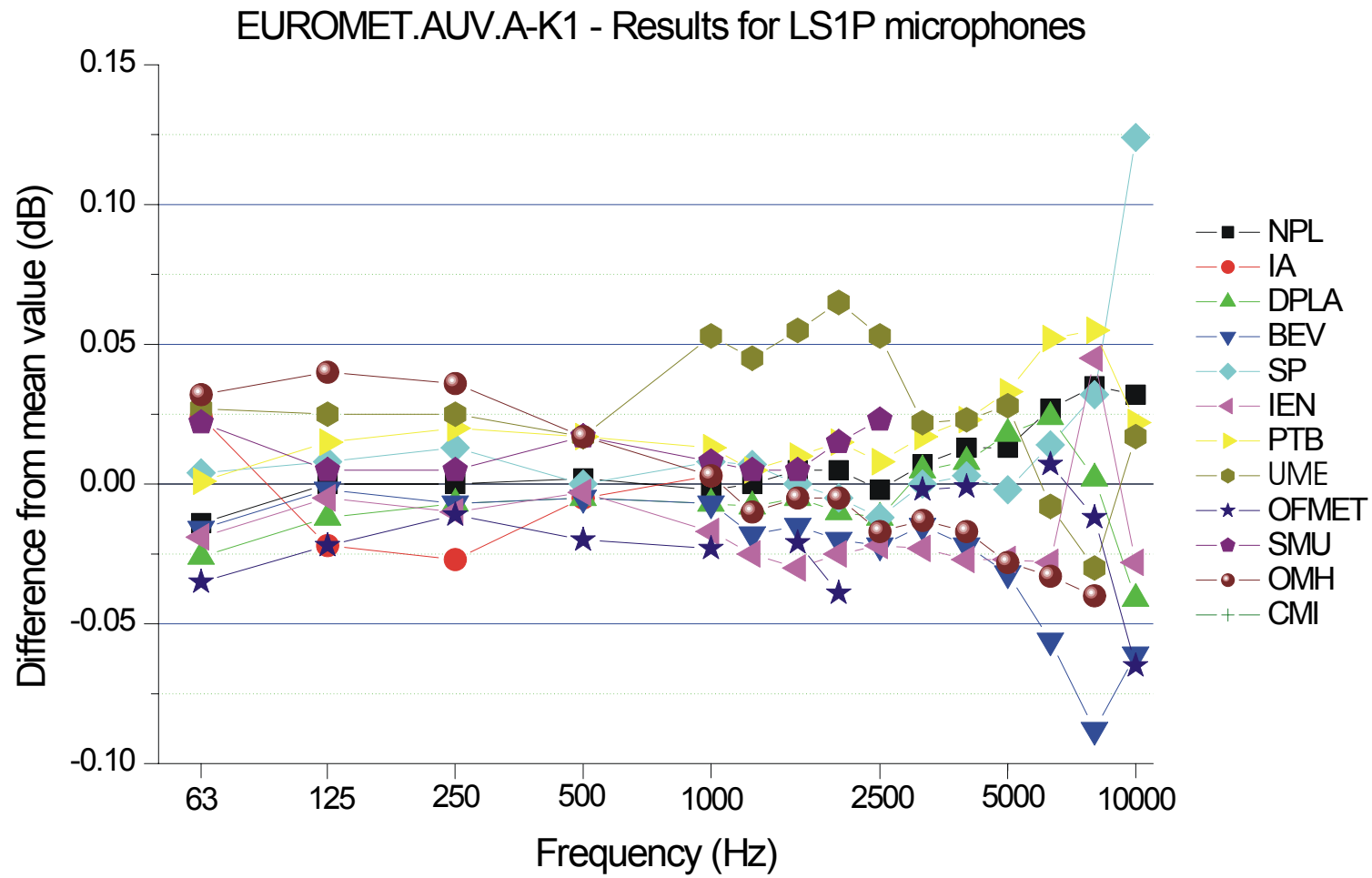


Figure 1. Graph of results for type LS1 microphones.

Lab <i>i</i> Frequency (Hz)	NPL		DPLA		BEV		SP		IEN		PTB		OFMET		GUM	
	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$
63	-0.01	0.05	0.00	0.05	-0.01	0.05	-0.01	0.08	0.01	0.05	0.01	0.06	-0.01	0.04	0.01	0.05
125	-0.02	0.05	0.00	0.04	-0.01	0.05	0.00	0.06	0.00	0.05	0.01	0.06	0.00	0.03	0.00	0.05
250	-0.02	0.05	0.00	0.04	-	-	-0.01	0.05	0.00	0.05	0.00	0.06	0.00	0.03	0.00	0.05
500	-0.01	0.05	0.01	0.04	0.00	0.05	0.00	0.05	0.01	0.05	0.00	0.06	0.00	0.03	0.01	0.05
1000	-0.02	0.05	0.00	0.04	-0.01	0.05	0.00	0.05	0.02	0.05	0.00	0.06	-0.01	0.03	0.01	0.05
2000	-0.01	0.05	0.01	0.04	-0.01	0.05	-0.01	0.05	0.01	0.05	-0.01	0.06	0.00	0.03	0.01	0.05
4000	-0.01	0.05	0.01	0.04	0.00	0.05	0.00	0.05	0.00	0.05	-0.02	0.06	0.00	0.03	0.00	0.05
5000	-0.01	0.05	0.01	0.04	0.00	0.06	0.00	0.05	0.00	0.05	-0.02	0.09	-	-	0.01	0.05
6300	-0.01	0.05	0.01	0.04	-0.01	0.06	0.00	0.06	-0.02	0.05	-0.01	0.09	0.01	0.04	0.02	0.05
8000	-0.01	0.06	0.02	0.04	0.00	0.07	0.01	0.06	-0.04	0.05	-0.01	0.09	0.01	0.04	0.01	0.06
10000	-0.01	0.07	0.02	0.06	0.00	0.09	0.01	0.08	-0.06	0.08	-0.01	0.09	0.02	0.04	0.02	0.07
12500	-0.01	0.08	0.01	0.06	-0.03	0.11	-0.01	0.10	-	-	-0.02	0.09	0.02	0.07	0.02	0.08
16000	-0.02	0.09	0.01	0.08	-0.03	0.14	-0.05	0.12	-	-	-0.01	0.09	-0.01	0.06	0.04	0.09
20000	-0.04	0.17	-0.01	0.12	-0.05	0.15	-0.03	0.20	-	-	-0.03	0.09	-0.03	0.05	0.04	0.17

Table 3. Results for type LS2a microphones

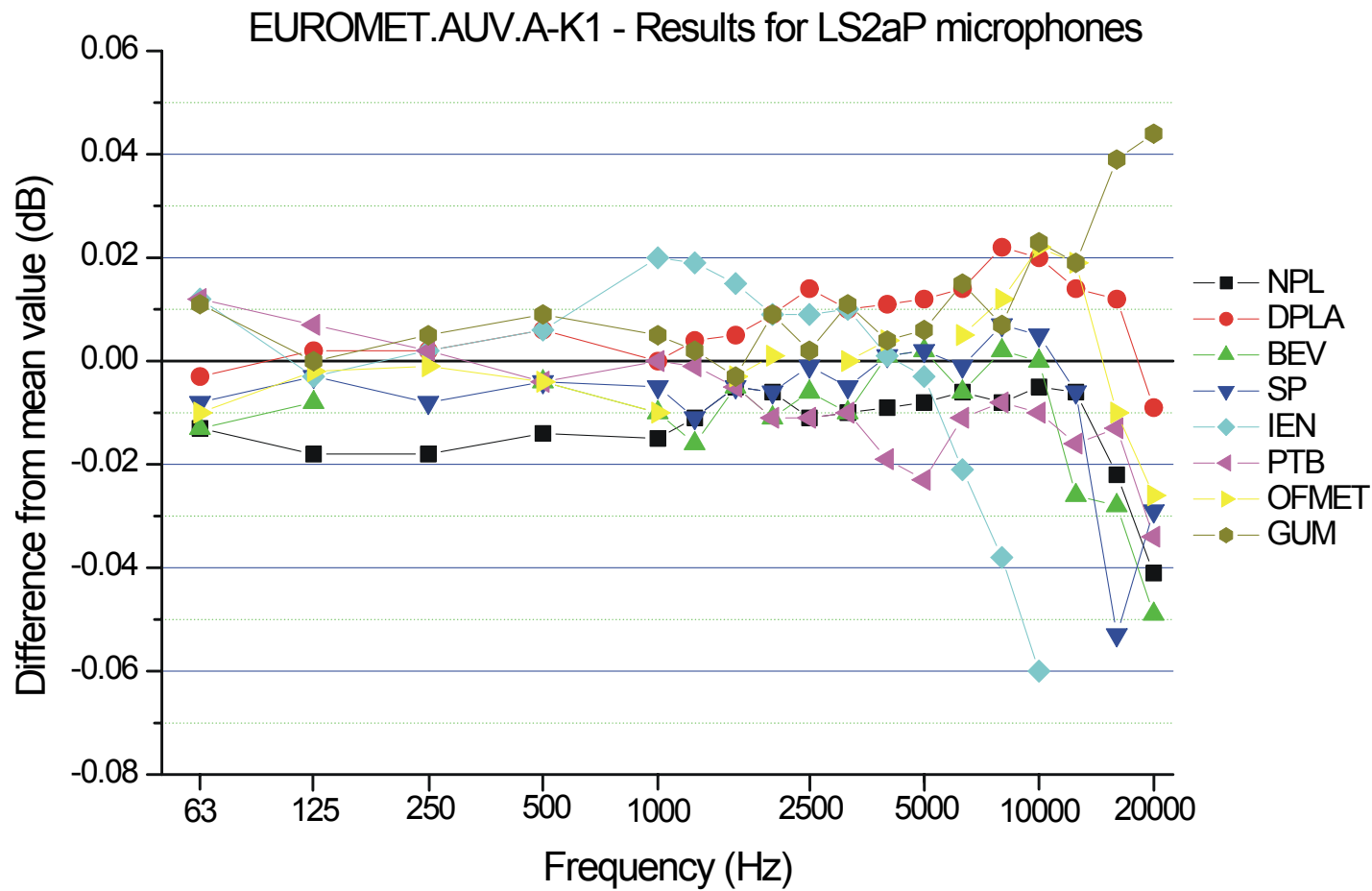


Figure 2. Graph of results for type LS2a microphones

**5. LINKING RESULTS TO THE KEY COMPARISON REFERENCE VALUE**

Key comparison CCAUV.A-K1 was concerned with the calibration of type LS1 microphones, and has established a key comparison reference value (KCRV) for these microphones<sup>3</sup>. Key comparison CCAUV.A-K3 is in progress and will do the same for type LS2a microphones in due course. Using the results of those laboratories that took part in both the key and regional comparisons, it is possible to link the results of all participants in the regional comparison to the KCRV.

NPL, DPLA and PTB are the laboratories that can now provide this link for type LS1 microphones. Once a KCRV is established for type LS2a microphones, these same laboratories and GUM will be used to provide the link for these microphones.

The process involves calculating the average result of the linking participants at each frequency, in each comparison. The difference between this average result from the key comparison and regional comparison then provides a ‘linking factor’ which is used to convert the results based on the regional comparison reference value so they become relative to the KCRV. The NPL/DPLA/PTB average results for the two comparisons and the ‘linking factor’ are shown on Table 3

Frequency (Hz)	Average value of results from NPL/DPLA/PTB in EUROMET.A-K1 (dB)	Average value of results from NPL/DPLA/PTB in CCAUV.A-K1 (dB)	Difference (CCAUV - EUROMET) (dB)
63	-0.013	0.008	0.021
125	0.001	0.005	0.004
250	0.005	0.004	-0.001
500	0.005	0.003	-0.001
1000	0.002	0.009	0.007
1250	-0.001	0.012	0.014
1600	0.003	0.013	0.009
2000	0.004	0.011	0.007
2500	-0.002	0.013	0.015
3150	0.010	0.012	0.002
4000	0.014	0.014	-0.001
5000	0.021	0.016	-0.005
6300	0.034	0.019	-0.015
8000	0.031	0.010	-0.021
10000	0.004	-0.006	-0.010

Table 4. Mean results of the ‘linking’ participants leading to the ‘linking factor’

Annex A shows the results for type LS1 microphone relative to the KCRV. These have been obtained simply by adding the ‘linking factor’ to the data shown in Table 2<sup>†</sup>. The results for type LS2a microphones shown in Annex A is the same as that in Table 3.

<sup>†</sup> It is not sensible to show data in Table 1 and Table A1 with a precision any greater than 2 decimal places. However all calculations have been carried out with greater precision to maintain accuracy. This extends to the results from some participants, particularly the pilot laboratories whose data are produced from a statistical calculation. Because of this, there may be an apparent discrepancy of 0.01dB between data in Table 1 and the corrected data in Table A1. This is a result of the rounding process used to show the results in these tables.

Annex A also gives the degrees of equivalence with the KCRV for type LS1 microphones and with the regional comparison reference value for type LS2a microphones. Since the reference value in both cases is zero, the degrees of equivalence have the same value as the result. The difference is found in the uncertainty which includes a component for both the result and the reference value.

Finally Annex A gives the degrees of mutual equivalence between laboratories in the determination of the pressure sensitivity of each type of microphone at 250 Hz.

The linking process can be validated by comparing the performance of the linking laboratories in the two key comparisons against the KCRV in both cases. This is illustrated in Figure 3. Differences are seen to be typically less than 0.01 dB which is close to the resolution of many measurement systems and significantly lower than the measurement uncertainty. This is evidence that the linking process yields reliable results across EUROMET.A-K1 and CCAUV.A-K1 and that the performance of the linking laboratories is consistent and unchanging, especially given that the time interval between the two comparisons was as much as two years.

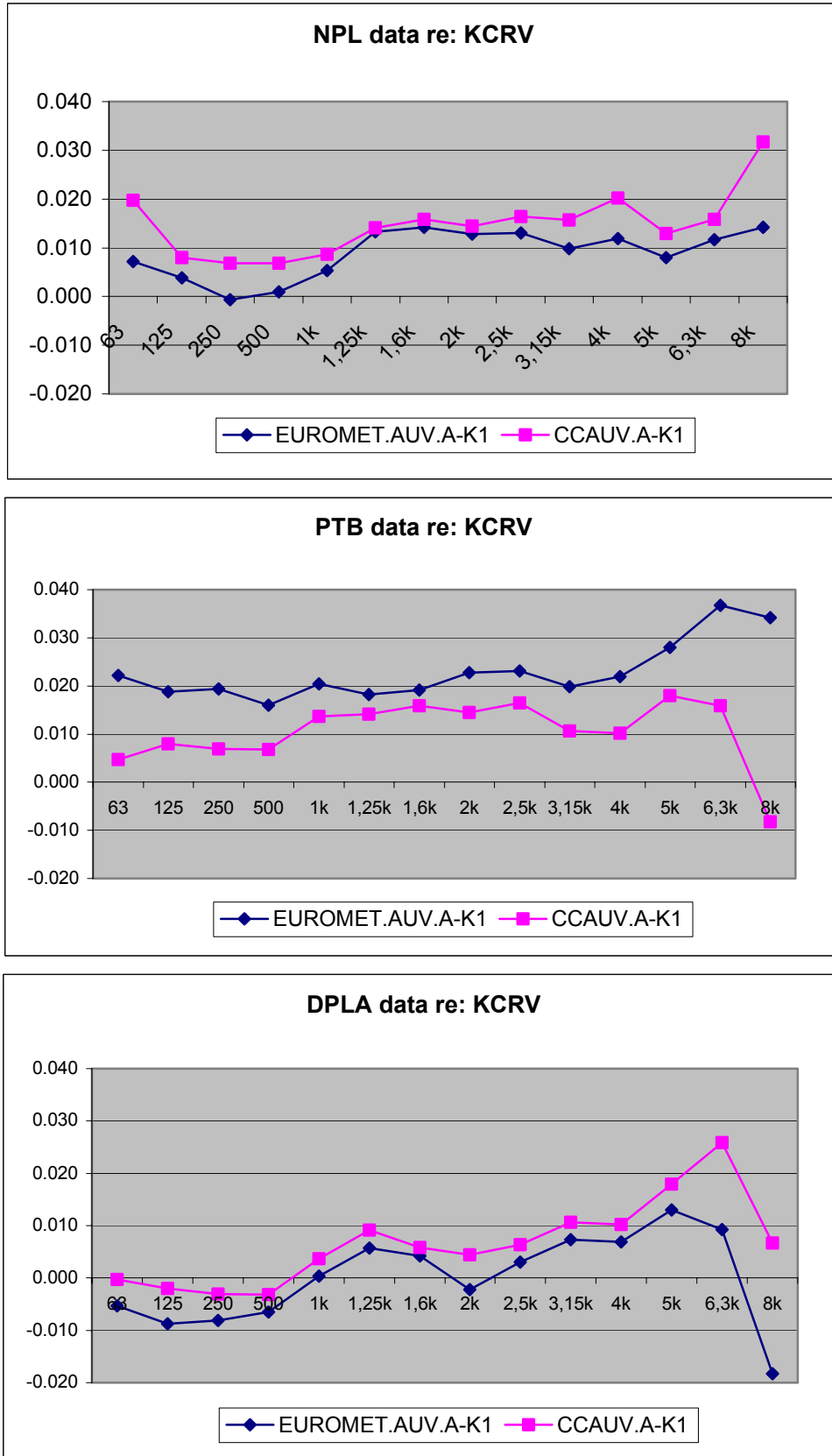


Figure 3. Performance of linking laboratories in regional and key comparisons relative to the KCRV

## 6. CONCLUSIONS

The 'three-pilot' structure of this comparison proved an efficient mechanism for the number of participants involved. It added a degree of complication to the analysis of the data, but the final form of the results show clearly the performance of each laboratory.

The results for type LS1 microphones were consistent within  $\pm 0.1$  dB for all frequencies up to 10 kHz, with the exception of one participant at 10 Hz. Furthermore, 8 of the 13 laboratories reported results consistent within  $\pm 0.05$  dB for all frequencies up to 10 kHz.

For LS2a microphones results from all 9 participants were within a range of  $\pm 0.06$  dB for all frequencies up to 20 kHz. Interestingly, all participant produced results in the range  $\pm 0.02$  dB for all frequencies up to 6.3 kHz

The results for the type LS1 microphones now allows a further 10 Euromet laboratories to be linked to the KCRV in the BIPM database (see [www.bipm.org](http://www.bipm.org)).

## 7. ACKNOWLEDGEMENT

The author gratefully acknowledges the financial support of the National Measurement System Directorate of the UK Department of Trade and Industry for the work carried out in this project by NPL. The efforts of Duncan Jarvis in setting up and coordinating this project, Mark Jiggins in developing the database to hold and analyse the data, and all of the national measurement institutes that provided data for this project are also gratefully acknowledged.

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3. R. Barham. Report on key comparison CCAUV.A-K1. NPL Report CAIR 02 (2003).

### ANNEX A. RESULTS AND DEGREES OF EQUIVALENCE

The following results are presented in the preferred format for entry into the key comparison database. However only data for the type LS1P microphone are intended for the database at present. As such, data for Instituto de Acustica, Spain have been omitted from these tables because they are not recognised as an NMI or delegated laboratory.

Lab <i>i</i> Frequency (Hz)	NPL		DPLA		BEV		SP		IEN		PTB		UME		OFMET		SMU		OMH		CMI		KCRV	
	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>i</sub></i>	<i>2u<sub>i</sub></i>	<i>M<sub>ref</sub></i>	<i>u<sub>ref</sub></i>
	dB		dB		dB		dB		dB		dB		dB		dB		dB		dB		dB		dB	
63	0.01	0.03	-0.01	0.04	0.00	0.06	0.02	0.05	0.00	0.05	0.02	0.03	0.05	0.05	-0.01	0.03	0.04	0.04	0.05	0.07	-	-	0.00	0.01
125	0.00	0.03	-0.01	0.03	0.00	0.03	0.01	0.04	0.00	0.05	0.02	0.03	0.03	0.05	-0.02	0.03	0.01	0.04	0.04	0.07	-0.03	0.03	0.00	0.01
250	0.00	0.03	-0.01	0.03	-0.01	0.03	0.01	0.04	-0.01	0.05	0.02	0.03	0.02	0.05	-0.01	0.03	0.00	0.04	0.03	0.07	-0.04	0.03	0.00	0.01
500	0.00	0.03	-0.01	0.03	-0.01	0.03	0.00	0.04	0.00	0.05	0.02	0.03	0.02	0.05	-0.02	0.03	0.02	0.04	0.02	0.07	-0.04	0.03	0.00	0.01
1000	0.01	0.03	0.00	0.03	0.00	0.03	0.02	0.04	-0.01	0.05	0.02	0.03	0.06	0.05	-0.02	0.03	0.02	0.04	0.01	0.07	-0.03	0.03	0.00	0.01
1250	0.01	0.03	0.01	0.03	0.00	0.03	0.02	0.04	-0.01	0.05	0.02	0.03	0.06	0.05	-	-	0.02	0.04	0.00	0.07	-	-	0.00	0.01
1600	0.01	0.03	0.00	0.03	-0.01	0.03	0.01	0.04	-0.02	0.05	0.02	0.03	0.06	0.05	-0.01	0.03	0.01	0.04	0.00	0.07	-	-	0.00	0.01
2000	0.01	0.03	0.00	0.03	-0.01	0.03	0.00	0.04	-0.02	0.05	0.02	0.03	0.07	0.05	-0.03	0.03	0.02	0.04	0.00	0.07	-	-	0.00	0.01
2500	0.01	0.04	0.00	0.03	-0.01	0.03	0.00	0.04	-0.01	0.05	0.02	0.03	0.07	0.05	-	-	0.04	0.04	0.00	0.07	-	-	0.00	0.01
3150	0.01	0.04	0.01	0.03	-0.01	0.03	0.00	0.05	-0.02	0.05	0.02	0.03	0.02	0.05	0.00	0.03	-	-	-0.01	0.07	-	-	0.00	0.01
4000	0.01	0.04	0.01	0.03	-0.02	0.03	0.00	0.05	-0.03	0.05	0.02	0.03	0.02	0.05	0.00	0.03	-	-	-0.02	0.07	-	-	0.00	0.01
5000	0.01	0.05	0.01	0.04	-0.04	0.04	-0.01	0.06	-0.03	0.05	0.03	0.06	0.02	0.10	-	-	-	-	-0.03	0.07	-	-	0.00	0.01
6300	0.01	0.05	0.01	0.05	-0.07	0.05	0.00	0.07	-0.04	0.05	0.04	0.06	-0.02	0.10	-0.01	0.05	-	-	-0.05	0.07	-	-	0.00	0.01
8000	0.01	0.05	-0.02	0.06	-0.11	0.06	0.01	0.10	0.02	0.05	0.03	0.06	-0.05	0.10	-0.03	0.04	-	-	-0.06	0.07	-	-	0.00	0.02

Table A1 – Reported results for type LS1 microphones relative to the KCRV.



Lab <i>i</i>	Frequency (Hz)	NPL		DPLA		BEV		SP		IEN		PBT		UME		OFMET		SMU		OMH		CMI	
		$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$	$D_i$ dB	$U_i$
	63	0.01	0.04	-0.01	0.04	0.00	0.06	0.02	0.05	0.00	0.05	0.02	0.04	0.05	0.05	-0.01	0.04	0.04	0.04	0.05	0.07	-	-
	125	0.00	0.04	-0.01	0.04	0.00	0.04	0.01	0.04	0.00	0.05	0.02	0.04	0.03	0.05	-0.02	0.03	0.01	0.04	0.04	0.07	-0.03	0.04
	250	0.00	0.04	-0.01	0.04	-0.01	0.04	0.01	0.04	-0.01	0.05	0.02	0.04	0.02	0.05	-0.01	0.03	0.00	0.04	0.03	0.07	-0.04	0.04
	500	0.00	0.04	-0.01	0.04	-0.01	0.04	0.00	0.04	0.00	0.05	0.02	0.04	0.02	0.05	-0.02	0.03	0.02	0.04	0.02	0.07	-0.04	0.04
	1000	0.01	0.04	0.00	0.04	0.00	0.04	0.02	0.04	-0.01	0.05	0.02	0.04	0.06	0.05	-0.02	0.03	0.02	0.04	0.01	0.07	-0.03	0.04
	1250	0.01	0.04	0.01	0.04	0.00	0.04	0.02	0.04	-0.01	0.05	0.02	0.04	0.06	0.05	-	-	0.02	0.04	0.00	0.07	-	-
	1600	0.01	0.04	0.00	0.04	-0.01	0.04	0.01	0.04	-0.02	0.05	0.02	0.04	0.06	0.05	-0.01	0.03	0.01	0.04	0.00	0.07	-	-
	2000	0.01	0.04	0.00	0.04	-0.01	0.04	0.00	0.04	-0.02	0.05	0.02	0.04	0.07	0.05	-0.03	0.04	0.02	0.04	0.00	0.07	-	-
	2500	0.01	0.04	0.00	0.04	-0.01	0.04	0.00	0.04	-0.01	0.05	0.02	0.04	0.07	0.05	-	-	0.04	0.04	0.00	0.07	-	-
	3150	0.01	0.04	0.01	0.04	-0.01	0.04	0.00	0.05	-0.02	0.05	0.02	0.04	0.02	0.05	0.00	0.04	-	-	-0.01	0.07	-	-
	4000	0.01	0.04	0.01	0.04	-0.02	0.04	0.00	0.05	-0.03	0.05	0.02	0.04	0.02	0.05	0.00	0.04	-	-	-0.02	0.07	-	-
	5000	0.01	0.05	0.01	0.04	-0.04	0.04	-0.01	0.06	-0.03	0.05	0.03	0.06	0.02	0.10	-	-	-	-	-0.03	0.07	-	-
	6300	0.01	0.05	0.01	0.05	-0.07	0.05	0.00	0.07	-0.04	0.05	0.04	0.06	-0.02	0.10	-0.01	0.05	-	-	-0.05	0.07	-	-
	8000	0.01	0.06	-0.02	0.07	-0.11	0.07	0.01	0.11	0.02	0.06	0.03	0.07	-0.05	0.11	-0.03	0.06	-	-	-0.06	0.08	-	-

The degree of equivalence of each laboratory with respect to the reference value is given by a pair of numbers:

$D_i = (M_i - M_{ref})$  and  $U_i$ , its expanded uncertainty ( $k = 2$ ),  $U_i^2 = 2^2(u_i^2 + u_{ref}^2)$ , both expressed in dB

The reference value and its uncertainty has been defined by key comparison CCAUV.A-K1

No KCRV is available at 10 kHz, so no degrees of equivalence can be calculated at this frequency

Table A2 – Degrees of equivalence with the KCRV for type LS1 microphones

Lab *j* →

Lab <i>i</i> ↓	$D_i$	$U_i$
	dB	
NPL	0.00	0.03
DPLA	-0.01	0.03
BEV	-0.01	0.03
SP	0.01	0.04
IEN	-0.01	0.05
PTB	0.02	0.03
NMI	0.03	0.05
OFMET	-0.01	0.03
SMU	0.01	0.04
OMH	0.04	0.07
CMI	-0.04	0.03

NPL	DPLA	BEV	SP	IEN	PTB	UME	OFMET	SMU	OMH	CMI											
$D_{ij}$	$U_{ij}$	$D_{ij}$	$U_{ij}$	$D_{ij}$	$U_{ij}$	$D_{ij}$	$U_{ij}$	$D_{ij}$	$U_{ij}$	$D_{ij}$	$U_{ij}$										
dB		dB		dB		dB		dB		dB											
		0.01	0.04	0.01	0.04	-0.01	0.05	0.01	0.06	-0.02	0.04	-0.03	0.06	0.01	0.04	-0.01	0.05	-0.04	0.08	0.04	0.04
-0.01	0.04			0.00	0.04	-0.02	0.05	0.00	0.06	-0.03	0.04	-0.03	0.06	0.00	0.04	-0.01	0.05	-0.04	0.08	0.03	0.04
-0.01	0.04	0.00	0.04			-0.02	0.05	0.00	0.06	-0.03	0.04	-0.03	0.06	0.00	0.04	-0.01	0.05	-0.04	0.08	0.03	0.04
0.01	0.05	0.02	0.05	0.02	0.05			0.02	0.06	-0.01	0.05	-0.01	0.06	0.02	0.05	0.01	0.06	-0.02	0.08	0.05	0.05
-0.01	0.06	0.00	0.06	0.00	0.06	-0.02	0.06			-0.03	0.06	-0.04	0.07	0.00	0.06	-0.02	0.06	-0.05	0.09	0.03	0.06
0.02	0.04	0.03	0.04	0.03	0.04	0.01	0.05	0.03	0.06			-0.01	0.06	0.03	0.04	0.02	0.05	-0.02	0.08	0.06	0.04
0.03	0.06	0.03	0.06	0.03	0.06	0.01	0.06	0.04	0.07	0.01	0.06			0.04	0.06	0.02	0.06	-0.01	0.09	0.06	0.06
-0.01	0.04	0.00	0.04	0.00	0.04	-0.02	0.05	0.00	0.06	-0.03	0.04	-0.04	0.06			-0.02	0.05	-0.05	0.07	0.03	0.04
0.01	0.05	0.01	0.05	0.01	0.05	-0.01	0.06	0.02	0.06	-0.02	0.05	-0.02	0.06	0.02	0.05			-0.03	0.08	0.04	0.05
0.04	0.08	0.04	0.08	0.04	0.08	0.02	0.08	0.05	0.09	0.02	0.08	0.01	0.09	0.05	0.07	0.03	0.08			0.07	0.08
-0.04	0.04	-0.03	0.04	-0.03	0.04	-0.05	0.05	-0.03	0.06	-0.06	0.04	-0.06	0.06	-0.03	0.04	-0.04	0.05	-0.07	0.08		

Regional comparison EUROMET.A-K1

MEASURAND : Normalised sensitivity level at 250 Hz

NOMINAL VALUE: 0 dB

**Key comparison reference value: there is no single reference value for this comparison,**

The degree of equivalence of each laboratory with respect to the reference value is given by a pair of numbers:

$D_i = (M_i - M_{ref})$  and  $U_i$ , its expanded uncertainty ( $k = 2$ ),  $U_i^2 = 2^2(u_i^2 - u_{ref}^2)$ , both expressed in dB

The degree of equivalence between two laboratories is given by a pair of numbers:

$D_{ij} = M_i - M_j$  and  $U_{ij}$ , its expanded uncertainty ( $k = 2$ ),  $U_{ij}^2 = 2^2(u_i^2 + u_j^2)$ , both expressed in dB

Table A3 – Degrees of mutual equivalence for type LS1 microphones

The following results for type LS2 microphones are not valid for entry to the key comparison database. No KCRV has yet to be established for these microphones.

Lab <i>i</i> Frequency (Hz)	NPL		DPLA		BEV		SP		IEN		PTB		OFMET		GUM	
	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$	$M_i$ dB	$2u_i$
63	-0.01	0.05	0.00	0.05	-0.01	0.05	-0.01	0.08	0.01	0.05	0.01	0.06	-0.01	0.04	0.01	0.05
125	-0.02	0.05	0.00	0.04	-0.01	0.05	0.00	0.06	0.00	0.05	0.01	0.06	0.00	0.03	0.00	0.05
250	-0.02	0.05	0.00	0.04	-	-	-0.01	0.05	0.00	0.05	0.00	0.06	0.00	0.03	0.00	0.05
500	-0.01	0.05	0.01	0.04	0.00	0.05	0.00	0.05	0.01	0.05	0.00	0.06	0.00	0.03	0.01	0.05
1000	-0.02	0.05	0.00	0.04	-0.01	0.05	0.00	0.05	0.02	0.05	0.00	0.06	-0.01	0.03	0.01	0.05
2000	-0.01	0.05	0.01	0.04	-0.01	0.05	-0.01	0.05	0.01	0.05	-0.01	0.06	0.00	0.03	0.01	0.05
4000	-0.01	0.05	0.01	0.04	0.00	0.05	0.00	0.05	0.00	0.05	-0.02	0.06	0.00	0.03	0.00	0.05
5000	-0.01	0.05	0.01	0.04	0.00	0.06	0.00	0.05	0.00	0.05	-0.02	0.09	-	-	0.01	0.05
6300	-0.01	0.05	0.01	0.04	-0.01	0.06	0.00	0.06	-0.02	0.05	-0.01	0.09	0.01	0.04	0.02	0.05
8000	-0.01	0.06	0.02	0.04	0.00	0.07	0.01	0.06	-0.04	0.05	-0.01	0.09	0.01	0.04	0.01	0.06
10000	-0.01	0.07	0.02	0.06	0.00	0.09	0.01	0.08	-0.06	0.08	-0.01	0.09	0.02	0.04	0.02	0.07
12500	-0.01	0.08	0.01	0.06	-0.03	0.11	-0.01	0.10	-	-	-0.02	0.09	0.02	0.07	0.02	0.08
16000	-0.02	0.09	0.01	0.08	-0.03	0.14	-0.05	0.12	-	-	-0.01	0.09	-0.01	0.06	0.04	0.09
20000	-0.04	0.17	-0.01	0.12	-0.05	0.15	-0.03	0.20	-	-	-0.03	0.09	-0.03	0.05	0.04	0.17

Table A4 – Reported results for type LS2a microphones relative to the regional comparison reference value.

Lab *j* ⇨

Lab <i>i</i> ↓	<b><i>D<sub>i</sub></i></b>	<b><i>U<sub>i</sub></i></b>
	dB	
NPL	-0.02	0.05
DPLA	0.00	0.04
SP	-0.01	0.05
IEN	0.00	0.05
PTB	0.00	0.06
OFMET	0.00	0.03
GUM	0.00	0.05

NPL		DPLA		SP		IEN		PTB		OFMET		GUM	
<i>D<sub>ij</sub></i>	<i>U<sub>ij</sub></i>	<i>D<sub>ij</sub></i>	<i>U<sub>ij</sub></i>	<i>D<sub>ij</sub></i>	<i>U<sub>ij</sub></i>	<i>D<sub>ij</sub></i>	<i>U<sub>ij</sub></i>	<i>D<sub>ij</sub></i>	<i>U<sub>ij</sub></i>	<i>D<sub>ij</sub></i>	<i>U<sub>ij</sub></i>	<i>D<sub>ij</sub></i>	<i>U<sub>ij</sub></i>
dB		dB		dB		dB		dB		dB		dB	
		-0.02	0.06	-0.01	0.07	-0.02	0.07	-0.02	0.08	-0.02	0.06	-0.02	0.07
0.02	0.07			0.01	0.06	0.00	0.06	0.00	0.07	0.00	0.05	0.00	0.06
0.01	0.06	-0.01	0.06			-0.01	0.07	-0.01	0.08	-0.01	0.06	-0.01	0.07
0.02	0.07	0.00	0.06	0.01	0.07			0.00	0.08	0.00	0.06	0.00	0.07
0.02	0.07	0.00	0.07	0.01	0.08	0.00	0.08			0.00	0.07	0.00	0.08
0.02	0.08	0.00	0.05	0.01	0.06	0.00	0.06	0.00	0.07			-0.01	0.06
0.02	0.06	0.00	0.06	0.01	0.07	0.00	0.07	0.00	0.08	0.01	0.06		

**Regional comparison EUROMET.A-K1**

**MEASURAND : Normalised sensitivity level at 250 Hz**  
**NOMINAL VALUE: 0 dB**

**Regional comparison reference value: there is no single reference value for this comparison,**

**The degree of equivalence of each laboratory with respect to the reference value is given by a pair of numbers  $D_i = (M_i - M_{ref})$  and  $U_i$ , its expanded uncertainty ( $k = 2$ ),  $U_i^2 = 2^2(u_i^2 - u_{ref}^2)$ , both expressed in dB**

**The degree of equivalence between two laboratories is given by a pair of numbers:  $D_{ij} = M_i - M_j$  and  $U_{ij}$ , its expanded uncertainty ( $k = 2$ ),  $U_{ij}^2 = 2^2(u_i^2 + u_j^2)$ , both expressed in dB**

Table A5 – Degrees of mutual equivalence for type LS2a microphones

### ANNEX B. REPORTED RESULTS FOR TELECOM ENGINEERING (FINLAND)

These results were reported without associated uncertainty data and have therefore had to be excluded from the main analysis. They are included here for information.

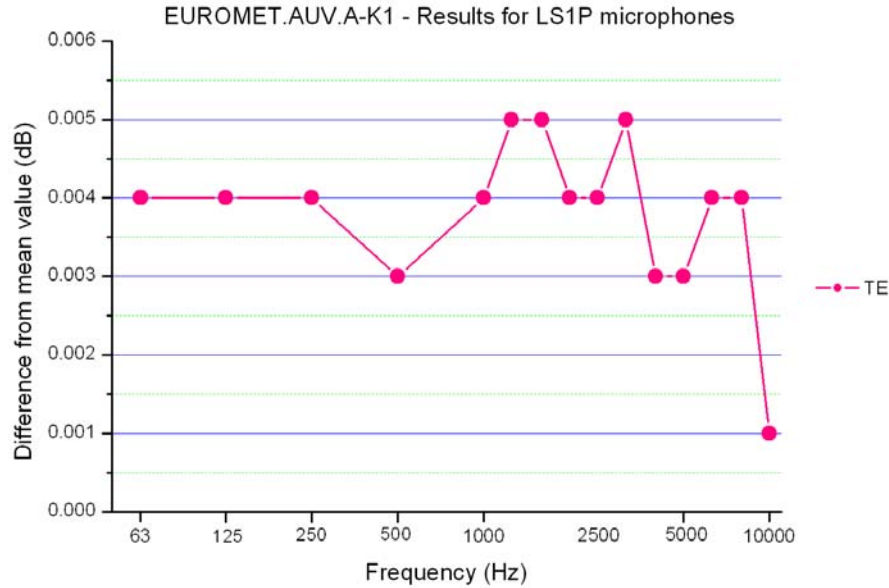


Figure B1. Graph of results for type LS1 microphones relative to the regional reference value for TE

Lab <i>i</i>	⇒	TE	
Frequency (Hz)	↓	$M_i$	$2u_i$
		dB	
	63	0.00	-
	125	0.01	-
	250	0.01	-
	500	0.00	-
	1000	0.01	-
	1250	0.00	-
	1600	0.01	-
	2000	0.00	-
	2500	0.00	-
	3150	0.00	-
	4000	-0.01	-
	5000	-0.02	-
	6300	0.00	-
	8000	-0.01	-
	10000	0.01	-

Lab <i>i</i>		TE	
Frequency (Hz)		$D_i$	$U_i$
		dB	
	63	0.02	-
	125	0.01	-
	250	0.00	-
	500	0.00	-
	1000	0.01	-
	1250	0.02	-
	1600	0.01	-
	2000	0.01	-
	2500	0.02	-
	3150	0.01	-
	4000	0.00	-
	5000	0.00	-
	6300	-0.01	-
	8000	-0.02	-

	TE	
	$D_{ij}$	$U_{ij}$
	dB	
NPL	-0.01	-
IA	-0.04	-
DPLA	-0.02	-
BEV	-0.02	-
SP	0.00	-
IEN	-0.02	-
PTB	0.01	-
NMI	0.01	-
OFMET	-0.03	-
SMU	-0.01	-
OMH	0.06	-
CMI	-0.05	-

Table B1 – Results, degree of equivalence and degree of mutual equivalence for TE, for type LS1 microphones.

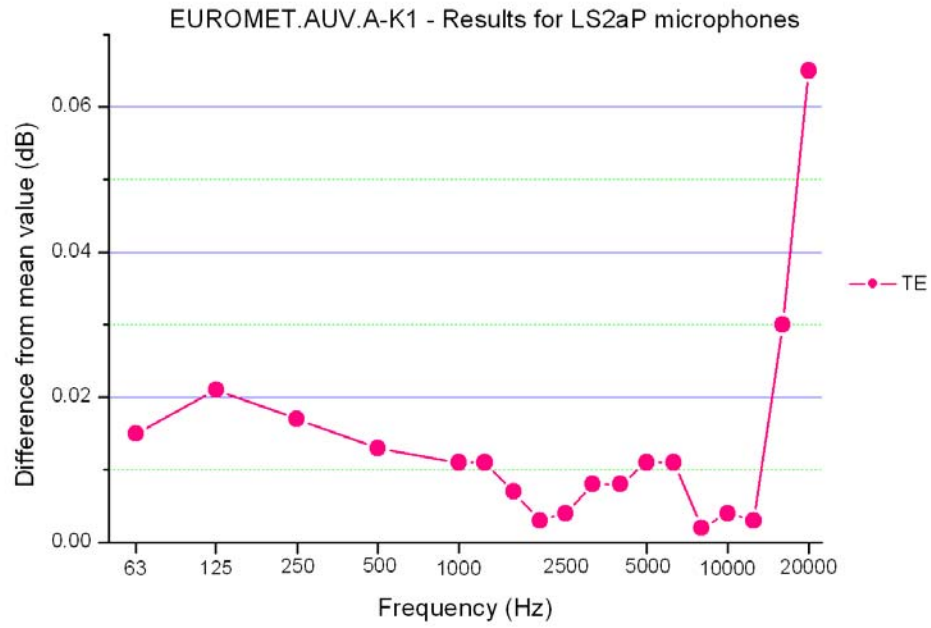


Figure B2. Graph of results for type LS2a microphones for TE

Lab <i>i</i>	⇒	TE	
Frequency (Hz)	⇓	$M_i$	$2u_i$
		dB	
	63	0.01	-
	125	0.02	-
	250	0.02	-
	500	0.01	-
	1000	0.01	-
	2000	0.00	-
	4000	0.01	-
	5000	0.01	-
	6300	0.01	-
	8000	0.00	-
	10000	0.00	-
	12500	0.00	-
	16000	0.03	-
	20000	0.06	-

	TE	
	$D_{ij}$	$U_{ij}$
	dB	
NPL	-0.03	-
DPLA	-0.02	-
SP	-0.03	-
IEN	-0.02	-
PTB	-0.02	-
OFMET	-0.02	-
GUM	-0.01	-

Table B2 – Results and degree of mutual equivalence for TE, for type LS2a microphones.