FINAL REPORT ON THE KEY COMPARISON EUROMET.AUV.A-K3

June 2006

CCAUV Approved September 2006

ISTITUTO NAZIONALE DI RICERCA METROLOGICA
&
THE DANISH PRIMARY LABORATORY FOR ACOUSTICS

Knud Rasmussen
Danish Primary Laboratory for Acoustics
Kgs. Lyngby
Denmark

Tel +45 4525 3937
Fax +45 4588 0577
Email: kr@oersted.dtu.dk

Claudio Guglielmone
INRiM
Strada delle Cacce 91, Torino
Italy
Tel +39 011 39319626
Fax +39 011 3919621
Email: guglielm@inrim.it

Contents

Introduction

The need for a comparison of laboratory standard microphones type LS2aP was agreed during the EUROMET TC AUV “Sound in air” SC and contact persons meeting in Warsaw, held in May 2002. The goal of the comparison is to complement on a regional scale the CCAUV.A-K3 comparison, in order to be able to demonstrate the equivalence of acoustical pressure standards of European NMIs. The EUROMET TC AUV presented a project N° 674 for the comparison and it was agreed that IEN would be the pilot laboratory with technical assistance given by DPLA. A Technical Protocol was distributed in September 2003 and measurements started in November 2003. Draft A was prepared in January 2005 and finally approved in May 2005 at TC AUV EUROMET meeting in Torino. The CCAUV approved this final report and the degrees of equivalence in September 2006.

1. Participants

The following laboratories participated in the comparison:

BEV, Austria	Metas, Switzerland
CEM, Spain	Mikes, Finland
CMI, Czech Republic	NMi, The Netherlands (1)
DPLA, Denmark	SP, Sweden
IEN, Italy	
(now INRIM)	

Contact details are in Appendix

(1) Due to problems in the measuring instruments, NMi withdrew from the comparison

2. Measurements phase

Two LS2aP microphones have been circulated for this comparison. They are Brüel & Kjær type 4180 microphones serial numbers 1395456 and 1627783. One of the microphones (SN 1395456) changed its sensitivity during a return trip to DPLA and then remained stable in the new sensitivity condition until the end of the comparison. The timetable has been followed without problems but an equipment failure prevented one of the laboratories from performing the measurements in time. The same laboratory was allowed to calibrate the circulating standards at the end of the scheduled period. Unfortunately, new management policies prevented the laboratory to redo the measurements. The laboratory was therefore excluded from the comparison.

A more general problem arose form the interpretation of the technical protocol: many laboratories used the exact frequencies and not the standardised nominal octave and third octave frequency values of ISO 266, as required by the protocol. It must be said that the protocol itself could have been more explicit for the frequency selection, and this experience will be useful for the development of new protocols. The frequency mismatch between results of different laboratories creates a problem for obtaining a reference value (for DRAFT A report only) and comparing the results. Fortunately the pilot laboratory calibrated the standards at many more frequencies than those required by the protocol, and some interpolation can be performed. During the elaboration of the Draft A Report, it was decided to interpolate the data at exact frequencies. A similar approach had been adopted for the corresponding CCAUV comparison.

3. Stability of the standards

The standard laboratory microphones used in this comparison are two of the four used in the corresponding CCAUV.A.K-3 comparison, and in the CCAUV comparison they were estimated stable. In this EUROMET comparison one of the microphones drifted in a measurable way.

The change in the sensitivity of microphone 4180 SN 1395456 occurred during the return trip from CEM laboratory. In figure 1 the difference in sensitivity is shown versus frequency. The change was computed on the mean of the calibrations at DPLA before (3 measurements) and after (4 measurements) the change.

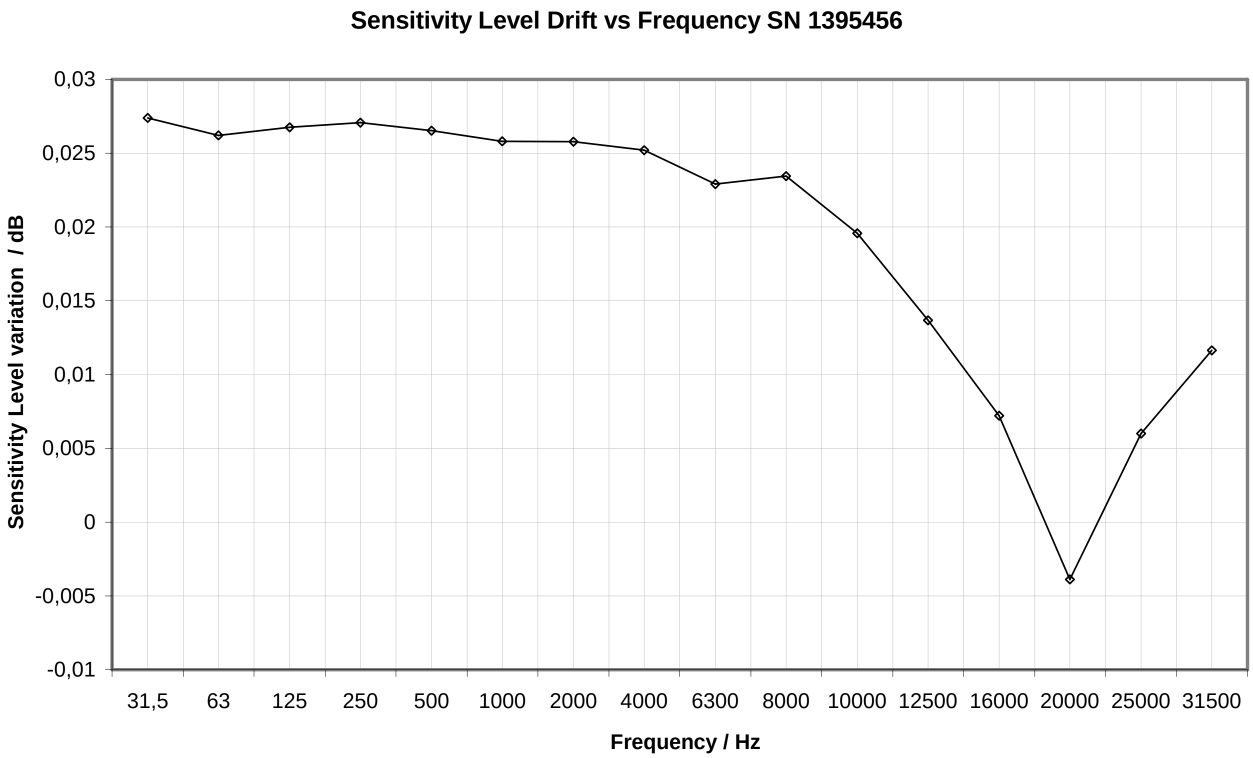

Figure 1. Change in sensitivity of standard microphone SN 1395456 as a function of frequency.

In figure 2, the drift is shown as a function of time at two frequencies. Only the data of the pilot laboratory are reported.

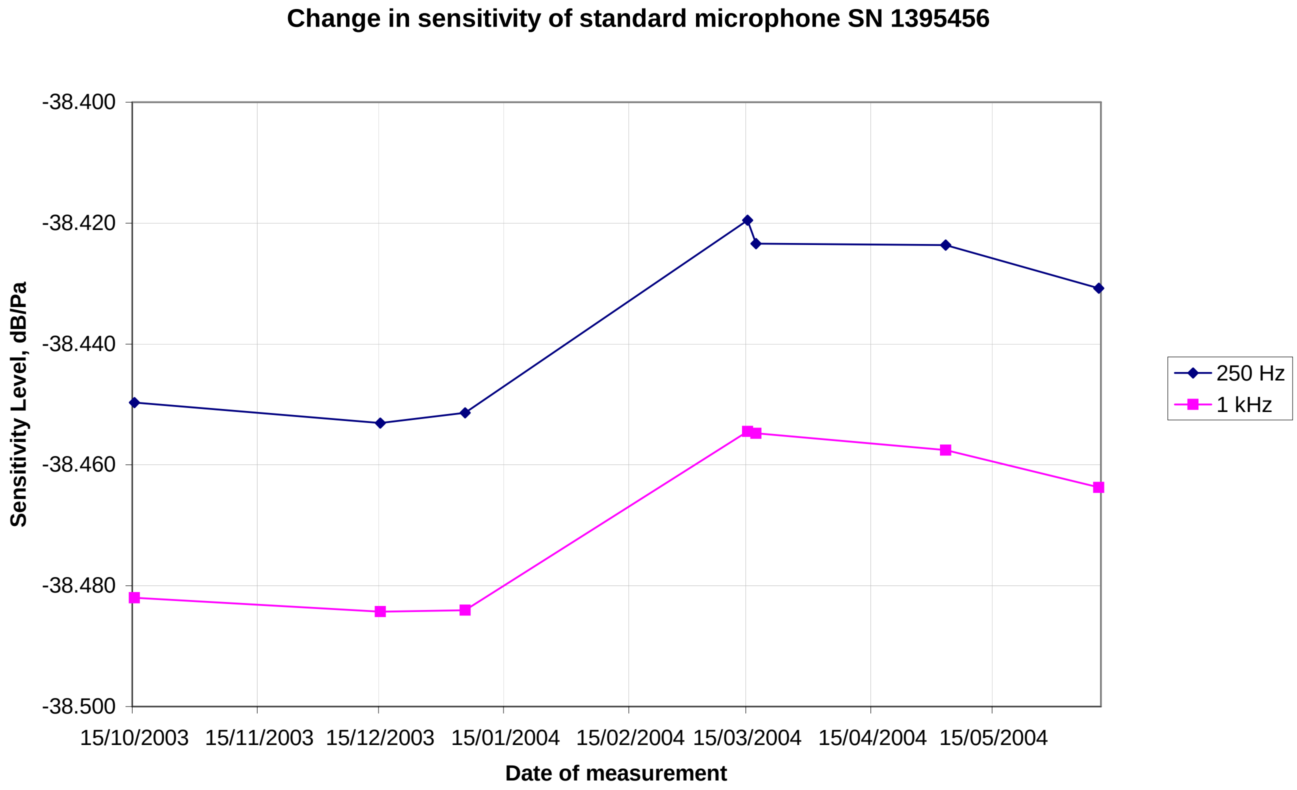

Figure 2. Change in sensitivity of standard microphone SN 1395456 as a function of time

The graph suggests that a sudden change in sensitivity has happened during the circulation, and that the minor variations before March 15 and after the "jump" are normally related to laboratory repeatability and reversible instabilities of the standard.

The difference to the behaviour of microphone SN 1627783, reported in figure 3, is evident. This kind of instability is typical of condenser microphones, and reflects a permanent change in some mechanical characteristic of the device (most likely diaphragm tension or distance between it and backplate), triggered by a mechanical or thermal shock. The microphone may then be stable in the new condition, and it is the case that occurred here. The data of this "unstable" standard can therefore be used, but the approaches used in polynomial approximation of the drift, typical for generalise least squares estimations and suitable for standards like masses, are problematic here. A reasonable proposal is to use the data from the pilot lab, and use the difference shown in figure 1 to correct the data of all measurements after the jump in sensitivity. In the analysis of the results the validity of this approach will be evaluated.

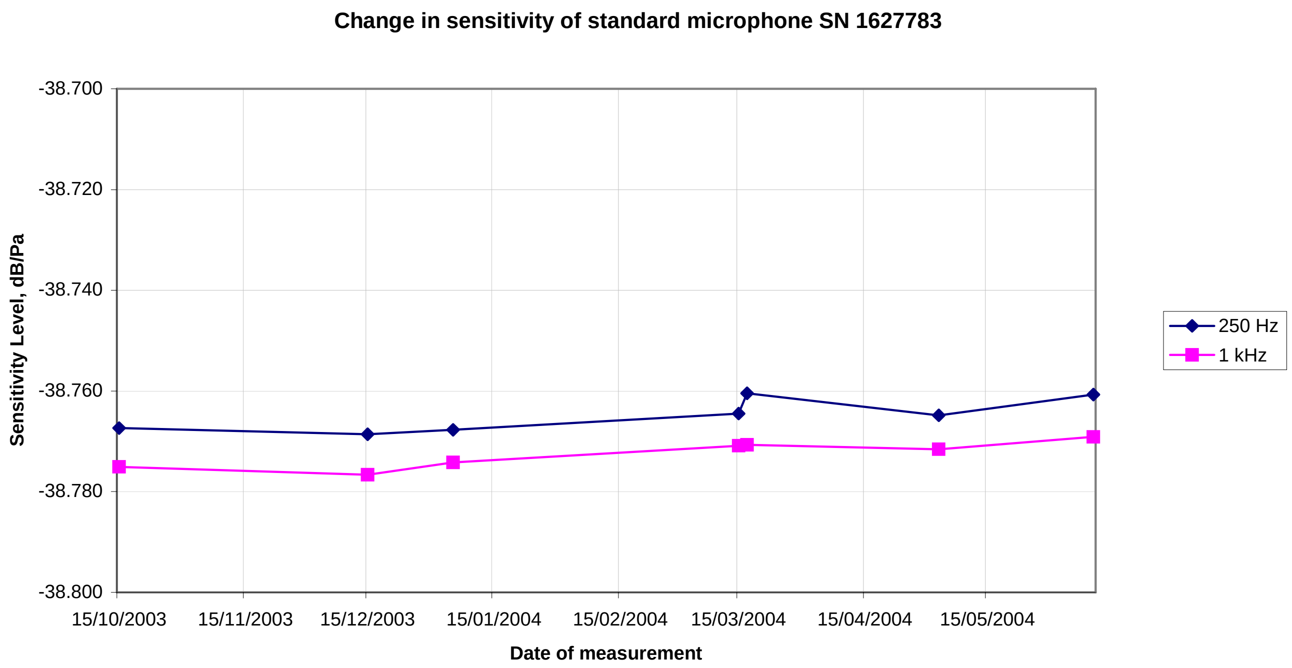

Figure 3. Change in sensitivity of standard microphone SN 1627783 as a function of time

4. Results from the laboratories

4.1 Results

In the following tables the results of all laboratories and the declared uncertainties are reported. The DPLA results are the first measurements, for model **4180 SN 1395456** a sensitivity change has been detected.

Table I. Results for circulating standard microphone **4180 SN 1627783** first part

	DPLA		IEN			BEV			CMI		
Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95
Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB
31.5	-38.725	0.08	31.5	-38.69	0.08	31.5	-38,720	0.03	31.62	-38.92	0.08
63	-38.736	0.04	63	-38.71	0.05	63	-38,736	0.03	63.1	-38.82	0.06
125	-38.752	0.03	125	-38.73	0.05	125	-38,750	0.02	125.89	-38.82	0.06
250	-38.767	0.03	250	-38.74	0.05	250	-38,763	0.02	251.19	-38.81	0.06
500	-38.774	0.03	500	-38.75	0.05	500	-38,771	0.02	501.19	-38.81	0.06
1000	-38.775	0.03	1000	-38.76	0.05	1000	-38,772	0.02	1000	-38.81	0.06
2000	-38.751	0.03	2000	-38.74	0.05	2000	-38,748	0.02	1995.26	-38.79	0.06
4000	-38.645	0.03	4000	-38.63	0.05	4000	-38,642	0.02	3981.07	-38.69	0.06
6300	-38.447	0.03	6300	-38.44	0.05	6300	-38,444	0.03	6309.57	-38.51	0.07
8000	-38.273	0.03	8000	-38.27	0.05	8000	-38,254	0.04	7943.28	-38.36	0.08
10000	-38.078	0.03	10000	-38.07	0.08	10000	-38,071	0.04	10000	-38.17	0.09
12500	-37.939	0.04	12500	-37.94	0.1	12500	-37,915	0.05	12589.25	-38.06	0.1
16000	-38.213	0.05	16000	-38.2	0.1	16000	-38,197	0.08	15848.92	-38.29	0.1
20000	-39.425	0.08	20000	-39.44	0.15	20000	-39,394	0.10	19952.63	-39.45	0.17
25000	-41.721	0.14	25000	-41.68	0.2	25000	-41,700	0.14	25118.87	-41.68	0.25
31500	-44.462										

Table II. Results for circulating standard microphone **4180 SN 1627783** second part

	Metas			CEM			Mikes			SP	
Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95
Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB
31.62	-38.684	0.046	31.62	-38.744	0.05	31.5	-38.78	0.579	31.5	-38.713	0.1
63.1	-38.708	0.046	63.1	-38.757	0.04	63	-38.744	0.0284	63	-38.720	0.08
125.89	-38.727	0.038	125.89	-38.77	0.04	125	-38.746	0.0258	125	-38.732	0.05
251.19	-38.743	0.036	251.19	-38.782	0.04	250	-38.76	0.0258	250	-38.744	0.05
501.19	-38.755	0.036	501.19	-38.79	0.04	500	-38.766	0.0283	500	-38.752	0.05
1000	-38.759	0.036	1000	-38.792	0.04	1000	-38.769	0.03	1000	-38.751	0.05
1995.26	-38.739	0.036	1995.26	-38.769	0.04	2000	-38.749	0.0442	2000	-38.729	0.05
3981.07	-38.636	0.034	3981.07	-38.665	0.04	4000	-38.644	0.0432	4000	-38.623	0.05
6309.57	-38.443	0.032	6309.57	-38.47	0.04	6300	-38.446	0.0437	6300	-38.427	0.06
7943.28	-38.278	0.036	7943.28	-38.305	0.04	8000	-38.275	0.0448	8000	-38.256	0.06
10000	-38.077	0.041	10000	-38.105	0.04	10000	-38.075	0.0505	10000	-38.060	0.08
12589.25	-37.941	0.045	12589.25	-37.97	0.04	12500	-37.948	0.0554	12500	-37.928	0.1
15848.92	-38.186	0.047	15848.92	-38.218	0.05	16000	-38.207	0.0633	16000	-38.226	0.12
19952.63	-39.404	0.063	19952.63	-39.481	0.08	20000	-39.351	0.0754	20000	-39.426	0.2
25118.87	-41.794	0.0163	25118.87	-41.716	0.14	25000			25000	-41.727	0.3

Table III. Results for circulating standard microphone **4180 SN 1395456** first part

	DPLA		IEN			BEV			CMI		
Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95
Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB
31.5	-38.367	0.08	31.5	-38.33	0.08	31.5	-38.347	0.03	31.62	-38.39	0.08
63	-38.397	0.04	63	-38.37	0.05	63	-38.380	0.03	63.1	-38.42	0.06
125	-38.427	0.03	125	-38.4	0.05	125	-38.409	0.02	125.89	-38.45	0.06
250	-38.450	0.03	250	-38.43	0.05	250	-38.434	0.02	251.19	-38.48	0.06
500	-38.471	0.03	500	-38.45	0.05	500	-38.454	0.02	501.19	-38.5	0.06
1000	-38.482	0.03	1000	-38.47	0.05	1000	-38.466	0.02	1000	-38.51	0.06
2000	-38.465	0.03	2000	-38.45	0.05	2000	-38.447	0.02	1995.26	-38.5	0.06
4000	-38.340	0.03	4000	-38.33	0.05	4000	-38.324	0.02	3981.07	-38.38	0.06
6300	-38.087	0.03	6300	-38.08	0.05	6300	-38.073	0.03	6309.57	-38.14	0.07
8000	-37.856	0.03	8000	-37.85	0.05	8000	-37.825	0.04	7943.28	-37.93	0.08
10000	-37.575	0.03	10000	-37.57	0.08	10000	-37.561	0.04	10000	-37.66	0.09
12500	-37.334	0.04	12500	-37.34	0.1	12500	-37.318	0.05	12589.25	-37.44	0.1
16000	-37.595	0.05	16000	-37.59	0.1	16000	-37.593	0.08	15848.92	-37.66	0.1
20000	-39.059	0.08	20000	-39.09	0.15	20000	-39.062	0.09	19952.63	-39.11	0.17
25000	-41.779	0.14	25000	-41.78	0.2	25000	-41.821	0.13	25118.87	-41.85	0.25
31500	-44.701										

Table IV. Results for circulating standard microphone **4180 SN 1395456** second part

	Metas			CEM			Mikes			SP	
Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95	Frequency	Pressure Sensitivity Level	U95
Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB	Hz	dB re 1 V/Pa	dB
31.62	-38.332	0.046	31.62	-38.365	0.05	31.5	-38.325	0.0579	31.5	-38.335	0.1
63.1	-38.371	0.046	63.1	-38.395	0.04	63	-38.348	0.0284	63	-38.353	0.08
125.89	-38.402	0.038	125.89	-38.424	0.04	125	-38.377	0.0258	125	-38.377	0.05
251.19	-38.43	0.036	251.19	-38.449	0.04	250	-38.404	0.0259	250	-38.402	0.05
501.19	-38.453	0.036	501.19	-38.47	0.04	500	-38.426	0.0284	500	-38.423	0.05
1000	-38.468	0.036	1000	-38.482	0.04	1000	-38.437	0.03	1000	-38.433	0.05
1995.26	-38.452	0.036	1995.26	-38.466	0.04	2000	-38.419	0.0443	2000	-38.418	0.05
3981.07	-38.331	0.034	3981.07	-38.344	0.04	4000	-38.295	0.0443	4000	-38.294	0.05
6309.57	-38.079	0.032	6309.57	-38.093	0.04	6300	-38.04	0.0444	6300	-38.043	0.06
7943.28	-37.856	0.036	7943.28	-37.87	0.04	8000	-37.806	0.0464	8000	-37.813	0.06
10000	-37.564	0.041	10000	-37.582	0.04	10000	-37.52	0.0535	10000	-37.533	0.08
12589.25	-37.322	0.045	12589.25	-37.348	0.04	12500	-37.293	0.059	12500	-37.308	0.1
15848.92	-37.544	0.047	15848.92	-37.579	0.05	16000	-37.543	0.0638	16000	-37.608	0.12
19952.63	-39.011	0.063	19952.63	-39.123	0.08	20000	-38.946	0.0734	20000	-39.125	0.2
25118.87	-41.851	0.0163	25118.87	-41.901	0.14	25000			25000	-41.948	0.3

4.2 Correction for frequency realignment

The results of CMI, Metas and CEM must be interpolated to nominal frequencies in order to be used for linking this comparison to the CCAUV one. In the following table the corrections and an estimate of the additional uncertainty due to the standard deviation associated with the determination of the slopes used for the linear interpolation, are reported. It should be noted that the units for uncertainties are thousandth of dB. Some additional uncertainty should be accounted for at higher frequencies (20 kHz and 25 kHz) due to the possibly limited validity of a linear interpolation in that frequency range of the pressure response. The additional uncertainty pertaining to the frequency realignment is negligible compared to the combined uncertainty and will not be accounted for in the following analysis.

The correction *C* is defined as follows:

$$C = [f_{nom} - f_{exact}] \cdot slope \quad [\text{dB}]$$

where:

$$slope = [(\text{DPLA sensitivity at } f_{nom}+1/12 \text{ octave}) - (\text{DPLA sensitivity at } f_{nom}-1/12 \text{ octave})] / [(f_{nom}+1/12 \text{ octave} - (f_{nom}-1/12 \text{ octave})]$$

f_{nom} = nominal frequency [Hz]

f_{exact} = exact frequency [Hz]

Table V. Corrections for frequency realignment

From exact Frequency Hz	To nominal frequency Hz	Correction to nominal frequencies for SN 1627783, dB	additional uncertainty dB 10^{-3}	Correction to nominal frequencies for SN 1395456, dB	additional uncertainty dB 10^{-3}
31.62	31.5	0.00007	0.04	0.00019	0.06
63.1	63	0.00004	0.03	0.00007	0.03
125.89	125	0.00018	0.01	0.00022	0.01
251.19	250	0.00004	0.07	0.00019	0.07
501.19	500	0.00002	0.02	0.00005	0.02
1000	1000	0.00000	0.00	0.00000	0.00
1995.26	2000	0.00016	0.01	0.00016	0.01
3981.07	4000	0.00132	0.02	0.00166	0.02
6309.57	6300	-0.00094	0.01	-0.00125	0.01
7943.28	8000	0.00573	0.08	0.00800	0.08
10000	10000	0.00000	0.00	0.00000	0.00
12589.25	12500	-0.00109	0.07	-0.00395	0.07
15848.92	16000	-0.02705	0.23	-0.03212	0.23
19952.63	20000	-0.01897	0.22	-0.02361	0.22
25118.87	25000	0.05568	0.33	0.06316	0.33

Table VI. Corrected values for CMI, Metas and CEM.

	CMI		Metas		CEM	
Nominal	SN 1395456	SN 1627783	SN 1395456	SN 1627783	SN 1395456	SN 1627783
Hz	dB re 1V / Pa	dB re 1V / Pa	dB re 1V / Pa	dB re 1V / Pa	dB re 1V / Pa	dB re 1V / Pa
31.5	-38.390	-38.920	-38.332	-38.684	-38.365	-38.744
63	-38.420	-38.820	-38.371	-38.708	-38.395	-38.757
125	-38.450	-38.820	-38.402	-38.727	-38.424	-38.770
250	-38.480	-38.810	-38.430	-38.743	-38.449	-38.782
500	-38.500	-38.810	-38.453	-38.755	-38.470	-38.790
1000	-38.510	-38.810	-38.468	-38.759	-38.482	-38.792
2000	-38.500	-38.790	-38.452	-38.739	-38.466	-38.769
4000	-38.378	-38.689	-38.329	-38.635	-38.342	-38.664
6300	-38.141	-38.511	-38.080	-38.444	-38.094	-38.471
8000	-37.922	-38.354	-37.848	-38.272	-37.862	-38.299
10000	-37.660	-38.170	-37.564	-38.077	-37.582	-38.105
12500	-37.444	-38.061	-37.326	-37.942	-37.352	-37.971
16000	-37.692	-38.317	-37.576	-38.213	-37.611	-38.245
20000	-39.134	-39.469	-39.035	-39.423	-39.147	-39.500
25000	-41.787	-41.624	-41.788	-41.738	-41.838	-41.660

4.3 Correction for sensitivity drift

The drift of microphone B&K 4180 SN 1395456 has been calculated according to the data in table VII. The mean of four measurements of the pilot laboratory before the sensitivity shift, and of three measurements after the shift have been used to evaluate the difference. The standard deviation of the results of the pilot laboratory is reported, and it is reasonable to assume that no additional uncertainty for this correction needs to be applied.

Table VII. Values for the correction of the change of sensitivity of microphone B&K 4180 SN 1395456

Frequency Hz	Drift dB	SD of Pilot Laboratory, dB
31.5	0.027	0.00074
63	0.026	0.00230
125	0.027	0.00121
250	0.027	0.00172
500	0.027	0.00110
1000	0.026	0.00125
2000	0.026	0.00110
4000	0.025	0.00161
6300	0.023	0.00167
8000	0.023	0.00273
10000	0.020	0.00299
12500	0.014	0.00409
16000	0.007	0.01462
20000	-0.004	0.00733
25000	0.006	0.00356
31500	0.012	0.00074

The correction of the drift has been applied to the results of Mikes and SP, the two laboratories that received the microphones after the sensitivity shift occurred.

4.4 Corrected results

In table VIII the results for microphone SN 1627783, corrected to nominal frequencies, are reported.

Table VIII. Laboratory results for microphone SN 1627783
corrected to nominal frequencies.
Sensitivity levels, dB re 1V / Pa

1627783	DPLA	IEN	BEV	CMI	Metas	CEM	Mikes	SP
Date	15-ott	05-nov	20-nov	03-dic	15-gen	01-mar	29-mar	28-apr
Hz	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa
31.5	-38.725	-38.690	-38.720	-38.920	-38.684	-38.744	-38.780	-38.713
63	-38.736	-38.710	-38.736	-38.820	-38.708	-38.757	-38.744	-38.720
125	-38.752	-38.730	-38.750	-38.820	-38.727	-38.770	-38.746	-38.732
250	-38.767	-38.740	-38.763	-38.810	-38.743	-38.782	-38.760	-38.744
500	-38.774	-38.750	-38.771	-38.810	-38.755	-38.790	-38.766	-38.752
1000	-38.775	-38.760	-38.772	-38.810	-38.759	-38.792	-38.769	-38.751
2000	-38.751	-38.740	-38.748	-38.790	-38.739	-38.769	-38.749	-38.729
4000	-38.645	-38.630	-38.642	-38.689	-38.635	-38.664	-38.644	-38.623
6300	-38.447	-38.440	-38.444	-38.511	-38.444	-38.471	-38.446	-38.427
8000	-38.273	-38.270	-38.254	-38.354	-38.272	-38.299	-38.275	-38.256
10000	-38.078	-38.070	-38.071	-38.170	-38.077	-38.105	-38.075	-38.060
12500	-37.939	-37.940	-37.915	-38.061	-37.942	-37.971	-37.948	-37.928
16000	-38.213	-38.200	-38.197	-38.317	-38.213	-38.245	-38.207	-38.226
20000	-39.425	-39.440	-39.394	-39.469	-39.423	-39.500	-39.351	-39.426
25000	-41.721	-41.680	-41.700	-41.624	-41.738	-41.660		-41.727

In table IX, the results for microphone SN 1395456, corrected to nominal frequencies, and for sensitivity level drift (Mikes and SP laboratories only) are reported.

Table IX. Laboratory results for microphone SN 1395456
corrected to nominal frequencies and for sensitivity level drift .
Sensitivity levels, dB re 1V / Pa

1395456	DPLA	IEN	BEV	CMI	Metas	CEM	Mikes	SP
Date	15-ott	05-nov	20-nov	03-dic	15-gen	01-mar	29-mar	28-apr
Hz	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa	dB re 1 V/Pa
31.5	-38.367	-38.330	-38.347	-38.390	-38.332	-38.365	-38.352	-38.362
63	-38.397	-38.370	-38.380	-38.420	-38.371	-38.395	-38.374	-38.379
125	-38.427	-38.400	-38.409	-38.450	-38.402	-38.424	-38.404	-38.404
250	-38.450	-38.430	-38.434	-38.480	-38.430	-38.449	-38.431	-38.429
500	-38.471	-38.450	-38.454	-38.500	-38.453	-38.470	-38.453	-38.450
1000	-38.482	-38.470	-38.466	-38.510	-38.468	-38.482	-38.463	-38.459
2000	-38.465	-38.450	-38.447	-38.500	-38.452	-38.466	-38.445	-38.444
4000	-38.340	-38.330	-38.324	-38.378	-38.329	-38.342	-38.320	-38.319
6300	-38.087	-38.080	-38.073	-38.141	-38.080	-38.094	-38.063	-38.066
8000	-37.856	-37.850	-37.825	-37.922	-37.848	-37.862	-37.829	-37.836
10000	-37.575	-37.570	-37.561	-37.660	-37.564	-37.582	-37.540	-37.553
12500	-37.334	-37.340	-37.318	-37.444	-37.326	-37.352	-37.307	-37.322
16000	-37.595	-37.590	-37.593	-37.692	-37.576	-37.611	-37.550	-37.615
20000	-39.059	-39.090	-39.062	-39.134	-39.035	-39.147	-38.942	-39.121
25000	-41.779	-41.780	-41.821	-41.787	-41.788	-41.838		-41.954

5. Microphone acoustical impedance

Microphone parameters used in the calculations are reported in table X. A rather good agreement is shown, but the comparison was not intended to examine this aspect of microphone calibration and the data are reported for information only.

Table X . Results of the measurements of microphone electro mechanical parameters.

4180 SN 1627783											
		DPLA	CMI	CEM	BEV	Metas	SP	Mikes	IEN	Mean	SD
Front cavity volume	mm^3	31.7	30.657	31.2	32	31.91	31.6	30.06	31.7	31.353	0.6772
Cavity depth	mm	0.469	0.46	0.455	0.46	0.49	0.471	0.45473	0.46	0.465	0.0117
Equivalent Volume	mm^3	8.5	9.3	8.6	9	8.55	9.19	9	8.8	8.868	0.3019
Resonance frequency	kHz	22.7	22.5	22	22.5	22.21	22	20.184	21.2	21.912	0.8375
Loss factor		1.05	1.15	1.05	1.05	1.06	1.05	1.08	1.07	1.070	0.0342
4180 SN 1395456											
Front cavity volume	mm^3	34.6	33.503	34.9	35.5	34.32	35.5	34.55	34.73	34.700	0.6470
Cavity depth	mm	0.514	0.504	0.508	0.505	0.477	0.504	0.50005	0.507	0.502	0.0110
Equivalent Volume	mm^3	9.3	9.3	8.4	9.2	9.7	9.19	9.4	9.4	9.236	0.3741
Resonance frequency	kHz	21.2	22.5	22	21	22.18	22	19.161	20.6	21.330	1.0923
Loss factor		0.98	1.15	1.05	1	1.06	1.05	1.0096	1.03	1.041	0.0520

6. Analysis of the results

6.1 Linking EUROMET.AUV.A-K3 to CCAUV.A-K3

A regional comparison should not try to calculate a key comparison reference value (KCRV), unless for internal purposes [1]. In Draft A Report for EUROMET.AUV.A-K3 comparison, such an attempt was made and the un-weighted mean and the median were used as estimators [2].

The method chosen for calculating the degrees of equivalence of the laboratories in this report is the generalized least square method, as suggested in point 9 of reference [1]. This choice has two main reasons:

1) There are two travelling standards, one likely drifting;
2) A method based on the generalized least squares approach has been applied in the analysis of the corresponding CCAUV.A-K3 comparison.

The approach used in this analysis of the results is the method proposed by reference [3] for linking international comparisons. But as noted in paragraph 3, the drift, or more appropriately "jump", in sensitivity of one of the standards, has been dealt with in a different way.

The model used in reference [3] can be expressed in the form:

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{e} \qquad (1)$$

where:

$\mathbf{y}$ $= (y_1 \ldots . y_g)^T$ is a column vector of the results

$\mathbf{X}$ is the design matrix $g \times h$

$\boldsymbol{\beta} = (\beta i \ldots \beta_h)^t$ is a column vector of the unknowns

$\mathbf{e} = (e_1 \ldots e_g)$ is a vector of random errors or disturbances.

Each row of $\boldsymbol{X}$, except the last, represents one of the comparison measurements (EUROMET or CCAUV, 28 + 1 in the present case), and there is a corresponding result in the vector $\boldsymbol{y}$. The last row of $\boldsymbol{X}$ and the last value of $\boldsymbol{y}$ are related to the constraint.

In reference [3] it is shown that the approximation $\hat{\boldsymbol{\beta}}$ of best linear unbiased estimate $\tilde{\boldsymbol{\beta}}$ can be expressed as:

$$\hat{\boldsymbol{\beta}} = \hat{\mathbf{C}}\mathbf{X}^{\mathbf{T}}\boldsymbol{\Phi}^{-1}\mathbf{y} \qquad (2)$$

where $\hat{\mathbf{C}}$ is the uncertainty matrix defined as:

$$\hat{\mathbf{C}} = (\mathbf{X}^{\mathbf{T}}\boldsymbol{\Phi}^{-1}\mathbf{X})^{-1} \qquad (3)$$

The matrix $\hat{\boldsymbol{\Phi}}$ is a symmetric $g \times g$ matrix, whose diagonal elements are the variances associated with each measurement result (standard uncertainty squared). Off diagonal elements allow for correlation between measurements, in our case, following the analysis of the CCAUV.A-K3 comparison, a correlation coefficient of 0,7 was chosen for measurements made by the same laboratory, while measurements of different laboratories were considered essentially uncorrelated.

In the following, standard 1 will designate microphone B&K 4180 SN 1627783, and standard 2 microphone B&K 4180 SN 1395456.

The result vector $\mathbf{y}$ is formed as follows:

$y_1 \ldots y_8$ are the measurements results on travelling standard 1 in EUROMET.AUV-K3;

$y_9 \ldots y_{16}$ are the measurements results on travelling standard 2 in EUROMET.AUV-K3;

y_{17} is the deviation of DPLA from KCRV as determined in CCAUV.A-K3;

y_{18} is the constraint , difference from KCRV is forced to 0.

The design matrix $\mathbf{X}$ has the form:

$$\mathbf{X}=\begin{bmatrix}1&0&0&0&0&0&0&0&1&0&0\\0&1&0&0&0&0&0&0&1&0&0\\0&0&1&0&0&0&0&0&1&0&0\\0&0&0&1&0&0&0&0&1&0&0\\0&0&0&0&1&0&0&0&1&0&0\\0&0&0&0&0&1&0&0&1&0&0\\0&0&0&0&0&0&1&0&1&0&0\\0&0&0&0&0&0&0&1&1&0&0\\1&0&0&0&0&0&0&0&0&1&0\\0&1&0&0&0&0&0&0&0&1&0\\0&0&1&0&0&0&0&0&0&1&0\\0&0&0&1&0&0&0&0&0&1&0\\0&0&0&0&1&0&0&0&0&1&0\\0&0&0&0&0&1&0&0&0&1&0\\0&0&0&0&0&0&1&0&0&1&0\\0&0&0&0&0&0&0&1&0&1&0\\1&0&0&0&0&0&0&0&0&0&1\\0&0&0&0&0&0&0&0&0&0&1\end{bmatrix}$$

Columns 1 to 8 are relative to the eight laboratories that took part in the comparison, columns 9 and 10 are for the two standards, in any case no local reference value is needed. Column 11 is for the link.

Rows 1 to 8 are relative to the 8 measurements on standard 1, rows 9 to 16 are relative to measurements on standard 2. The last two rows are for the link (deviation of linking laboratory from CCAUV KCRV) and for the constraint.

One the laboratories did not provide a result at 25 kHz, therefore at 25 kHz $\mathbf{X}$ has 10 columns instead of 11 and 16 rows instead of 18.

The degrees of equivalence are calculated from $\hat{\boldsymbol{\beta}}$ and $\hat{\mathbf{C}}$. The deviations are obtained from $\beta_1 \ldots \beta_8$ and the uncertainty U_i of the deviations are:

$$U_i = k\sqrt{\hat{\mathbf{C}}_{ii}} \tag{4}$$

where k is the coverage factor, it has been assumed k=2.

6.2 Drift of the standards

The change of the sensitivity of one of the microphones was clearly visible in a preliminary analysis of the data.

An attempt has been made to model the drift of the standards with a polynomial model, according to reference [3].

The sensitivity s of the microphone i is expressed as a function of time t as:

$$s_i(t) = s_i^{'} + a_i t + b_i t^2 + c_i t^3 \tag{5}$$

In the design matrix $\mathbf{X}$ three columns for standard 1, with t, t^2 and t^3 and three columns for standard 2 are added, on the rows relative to the respective measurements. The time t reflects the measurements date, as the spacing of the measurements in this comparison is not constant. The analysis included all measurements from the pilot laboratory only, for a total of 14 results and $\mathbf{X}$ in this case has 16 rows.

In figures 4 and 5 the behaviour of the two standard microphones, calculated according to (5), without any a priori correction for the drift is reported.

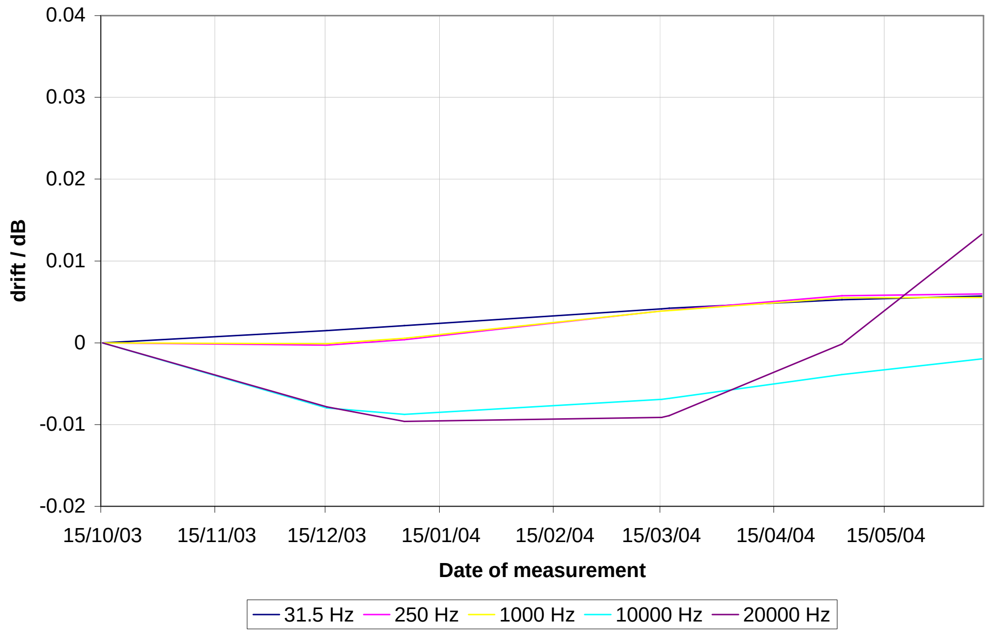

Figure 4. Drift of microphone B&K 4180 SN 1627783 during the comparison: polynomial fit.

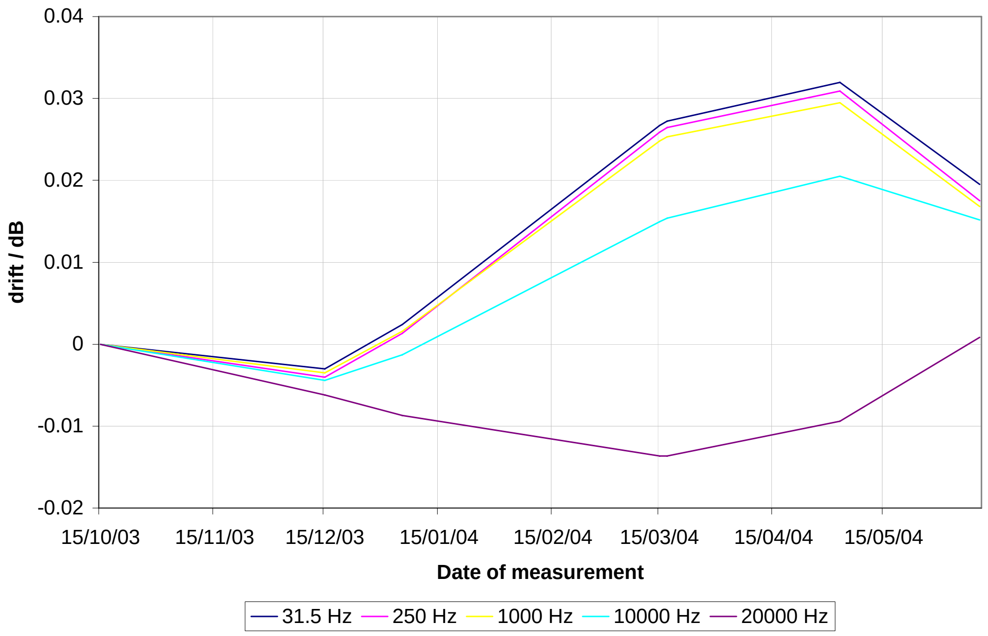

Figure 5. Drift of microphone B&K 4180 SN 1395456 during the comparison: polynomial fit, no correction applied to data.

In figure 6, the data for microphone B&K 4180 SN 1395456, calculated on the measurement data corrected for the shift in sensitivity as described in 4.3, is reported.

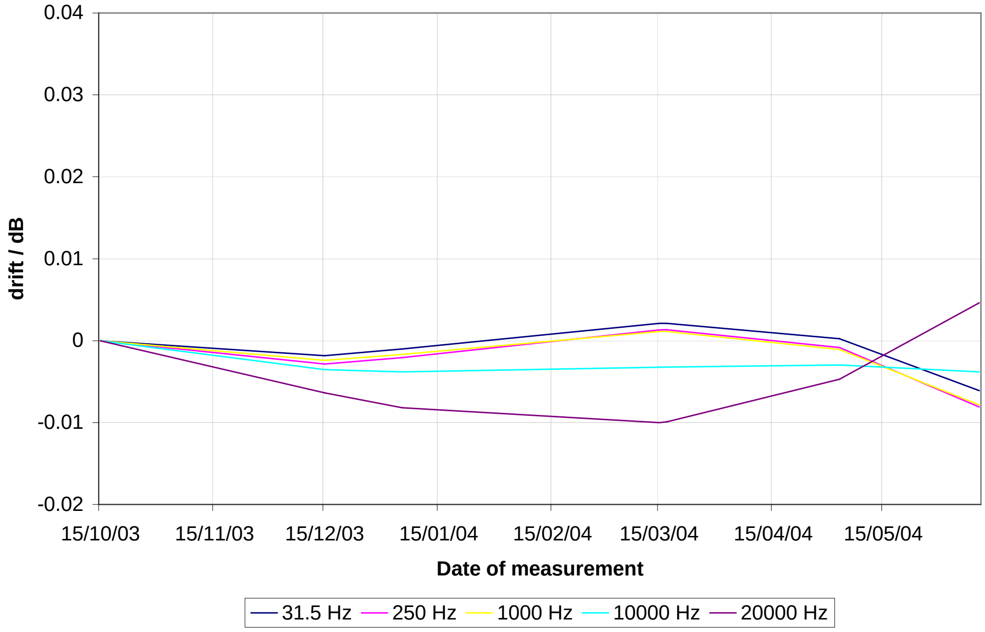

Figure 6. Drift of microphone B&K 4180 SN 1395456 during the comparison: polynomial fit, correction applied to data.

The comparison of figure 5 and figure 6 shows that the applied correction as reported in figure 6 seems to work well, while the polynomial fit in figure 5 is not able to follow the shift in sensitivity accurately. It is in fact reasonable to assume that, given the typical behaviour of standard laboratory microphones, the sensitivity change is essentially a step function, and a polynomial function of degree 3 is not able to follow it accurately.

7. Degrees of equivalence

The degrees of equivalence have been calculated from (2) and (3) for deviations and their uncertainties respectively. The data from CCAUV.A.K3 Draft B report [4] have been used for the calculations. In particular, the deviations of the linking laboratory, DPLA, and their uncertainty from the KCRV were used in the calculations.

In table XI the deviations of the measurements, directly derived from $\hat{\boldsymbol{\beta}}$ after solving equation (2) are reported. The same data is reported in graphical form in figure 7.

In table XII are reported the uncertainties of the deviations of table XI, derived from the diagonal elements of $\hat{\mathbf{C}}$ with a coverage factor of 2.

The inter laboratory degrees of equivalence are reported for the frequencies of 250 Hz and 1000 Hz in tables XIII to XVI. The data are calculated from $\hat{\boldsymbol{\beta}}$. The deviation $D_{i,j}$ of laboratory *i* from laboratory *j* is:

$$D_{i,j} = \beta_i - \beta_j \qquad (4)$$

and its uncertainty $U_{i,j}$ is again obtained from $\hat{\mathbf{C}}$ using the formula:

$$U_{i,j} = k\sqrt{C_{ii} + C_{jj} - 2C_{ij}} \qquad (5)$$

where *k* is the coverage factor, it has been assumed $k = 2$.

Table XI. Degrees of equivalence per laboratory and per frequency: deviations, expressed in dB.

	DPLA	IEN	BEV	CMI	Metas	CEM	Mikes	SP
Hz	Deviations, dB							
31.5	-0.005	0.031	0.007	-0.114	0.033	-0.013	-0.025	0.003
63	-0.002	0.024	0.006	-0.056	0.025	-0.012	0.005	0.015
125	-0.003	0.022	0.007	-0.048	0.023	-0.010	0.012	0.019
250	-0.004	0.020	0.006	-0.040	0.018	-0.011	0.009	0.018
500	-0.004	0.019	0.006	-0.036	0.015	-0.011	0.009	0.018
1000	-0.004	0.010	0.006	-0.035	0.011	-0.012	0.009	0.020
2000	-0.004	0.010	0.007	-0.040	0.009	-0.013	0.008	0.018
4000	-0.003	0.009	0.006	-0.044	0.007	-0.014	0.007	0.018
6300	0.001	0.007	0.009	-0.059	0.005	-0.015	0.013	0.021
8000	-0.002	0.002	0.023	-0.076	0.002	-0.018	0.010	0.016
10000	-0.003	0.004	0.008	-0.091	0.003	-0.020	0.017	0.018
12500	0.000	-0.004	0.020	-0.116	0.002	-0.025	0.009	0.012
16000	0.010	0.018	0.018	-0.091	0.019	-0.015	0.035	-0.007
20000	0.015	-0.008	0.029	-0.044	0.028	-0.066	0.110	-0.017
25000	-0.002	0.018	-0.013	0.042	-0.015	-0.001	-	-0.093

Table XII. Degrees of equivalence per laboratory and per frequency: uncertainties of the deviations, expressed in dB.

	DPLA	IEN	BEV	CMI	Metas	CEM	Mikes	SP
Hz	Uncertainty, dB							
31.5	0.082	0.093	0.063	0.093	0.071	0.073	0.078	0.108
63	0.042	0.055	0.041	0.063	0.052	0.047	0.040	0.080
125	0.032	0.052	0.030	0.060	0.042	0.044	0.033	0.052
250	0.032	0.052	0.030	0.060	0.041	0.044	0.033	0.052
500	0.032	0.052	0.030	0.060	0.041	0.044	0.035	0.052
1000	0.032	0.052	0.030	0.060	0.041	0.044	0.036	0.052
2000	0.032	0.052	0.030	0.060	0.041	0.044	0.047	0.052
4000	0.032	0.052	0.030	0.060	0.039	0.044	0.046	0.052
6300	0.033	0.052	0.037	0.069	0.038	0.044	0.047	0.060
8000	0.033	0.052	0.044	0.078	0.041	0.044	0.048	0.060
10000	0.034	0.078	0.045	0.087	0.046	0.045	0.053	0.078
12500	0.044	0.098	0.057	0.098	0.053	0.049	0.061	0.098
16000	0.055	0.101	0.085	0.101	0.060	0.062	0.071	0.118
20000	0.088	0.153	0.113	0.170	0.087	0.098	0.095	0.195
25000	0.152	0.215	0.170	0.256	0.111	0.170	-	0.298

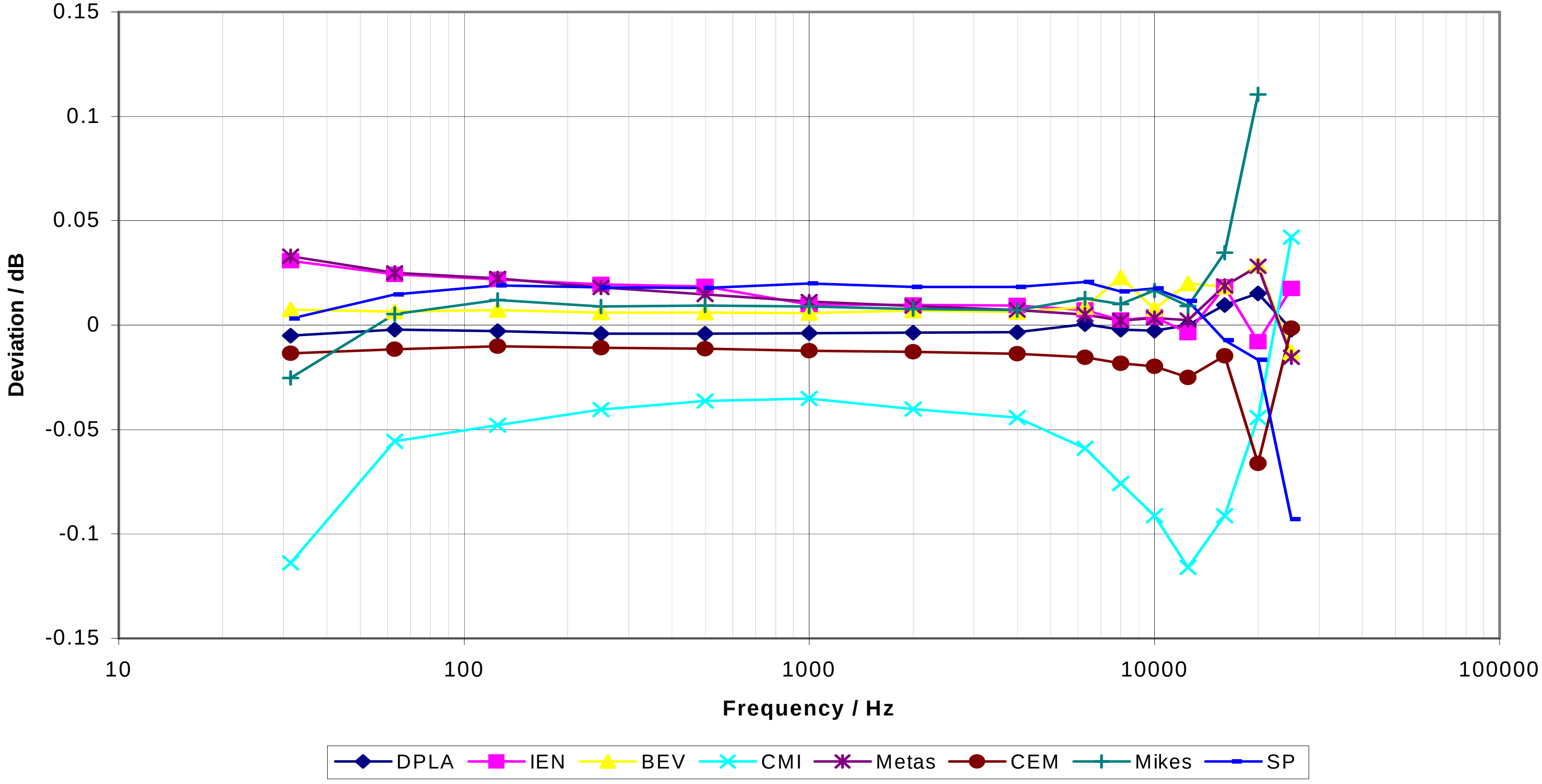

Figure 7. Deviations from KCRV as a function of frequency.

Table XIII. Inter laboratory degrees of equivalence at 250 Hz, deviations dB

250 Hz	DPLA	IEN	BEV	CMI	Metas	CEM	Mikes	SP
DPLA	-	-0.024	-0.010	0.036	-0.022	0.007	-0.013	-0.022
IEN	0.024	-	0.014	0.060	0.001	0.030	0.011	0.002
BEV	0.010	-0.014	-	0.046	-0.012	0.017	-0.003	-0.012
CMI	-0.036	-0.060	-0.046	-	-0.058	-0.030	-0.049	-0.058
Metas	0.022	-0.001	0.012	0.058	-	0.029	0.009	0.000
CEM	-0.007	-0.030	-0.017	0.030	-0.029	-	-0.020	-0.029
Mikes	0.013	-0.011	0.003	0.049	-0.009	0.020	-	-0.009
SP	0.022	-0.002	0.012	0.058	0.000	0.029	0.009	-

Table XIV. Inter laboratory degrees of equivalence at 250 Hz, uncertainty dB

250 Hz	DPLA	IEN	BEV	CMI	Metas	CEM	Mikes	SP
DPLA	-	0.054	0.033	0.062	0.043	0.046	0.036	0.054
IEN	0.054	-	0.050	0.072	0.057	0.059	0.052	0.065
BEV	0.033	0.050	-	0.058	0.038	0.041	0.030	0.050
CMI	0.062	0.072	0.058	-	0.065	0.066	0.060	0.072
Metas	0.043	0.057	0.038	0.065	-	0.050	0.041	0.057
CEM	0.046	0.059	0.041	0.066	0.050	-	0.044	0.059
Mikes	0.036	0.052	0.030	0.060	0.041	0.044	-	0.052
SP	0.054	0.065	0.050	0.072	0.057	0.059	0.052	-

Table XV. Inter laboratory degrees of equivalence at 1000 Hz, deviations dB

1 kHz	DPLA	IEN	BEV	CMI	Metas	CEM	Mikes	SP
DPLA	-	-0.014	-0.010	0.031	-0.015	0.008	-0.013	-0.024
IEN	0.014	-	0.004	0.045	-0.001	0.022	0.001	-0.010
BEV	0.010	-0.004	-	0.041	-0.006	0.018	-0.003	-0.014
CMI	-0.031	-0.045	-0.041	-	-0.047	-0.023	-0.044	-0.055
Metas	0.015	0.001	0.006	0.047	-	0.023	0.002	-0.009
CEM	-0.008	-0.022	-0.018	0.023	-0.023	-	-0.021	-0.032
Mikes	0.013	-0.001	0.003	0.044	-0.002	0.021	-	-0.011
SP	0.024	0.010	0.014	0.055	0.009	0.032	0.011	-

Table XVI. Inter laboratory degrees of equivalence at 1000 Hz, uncertainties dB

1 kHz	DPLA	IEN	BEV	CMI	Metas	CEM	Mikes	SP
DPLA	-	0.054	0.033	0.062	0.043	0.046	0.039	0.054
IEN	0.054	-	0.050	0.072	0.057	0.059	0.054	0.065
BEV	0.033	0.050	-	0.058	0.038	0.041	0.033	0.050
CMI	0.062	0.072	0.058	-	0.065	0.066	0.062	0.072
Metas	0.043	0.057	0.038	0.065	-	0.050	0.043	0.057
CEM	0.046	0.059	0.041	0.066	0.050	-	0.046	0.059
Mikes	0.039	0.054	0.033	0.062	0.043	0.046	-	0.054
SP	0.054	0.065	0.050	0.072	0.057	0.059	0.054	-

8. References

[1] Brief guidelines for linking RMO key comparisons to the CIPM KCRV. CCAUV/04-27, BIPM 26 May 2004

[2] DRAFT A REPORT EUROMET.AUV.A-K3, January 2005

[3] C.M. Sutton. Analysis and linking of international measurement comparison. *Metrologia* **41** (2004) 272- 277.

[4] V. Cutanda Henriquez, K. Rasmussen. Report on the Key Comparison CCAUV.A-K3 Draft B. January 2006

Appendix
List of contact persons

BEV: Merita Sinojmeri BEV Department: Acoustics, frequency, time Arltgasse 35 1160 Wien Austria Tel: +43 1 49110 390 Fax: +43 1 49208 875 E-mail: m.sinojmeri@metrologie.at	**IEN:** Claudio Guglielmone Istituto Elettrotecnico Nazionale (IEN) Galileo Ferraris Strada Delle Cacce 91 I-10135 Torino Italy Tel: +390 11 3919 626 Fax: +390 11 346 384 E-mail: guglielm@ien.it
CEM: Carmen Casal Sobrino Centro Espanol de Metrologia (CEM) Department: Laboratorio de Acustica Calle Del Alfar 2 28760 Tres Cantos Madrid Spain Bus: +34 91 807 4825 Bus Fax: +34 91 807 4807 E-mail: ccasal@cem.es	**METAS:** **At time of the comparison:** Fabienne Berthod Swiss Federal Office of Metrology & Accreditation (METAS) Lindenweg 50 3003 Bern-Wabern Switzerland Tel: +41 31 32 34 750 Fax: +41 31 32 33 210 E-mail: fabienne.berthod@metas.ch **Now :** Dr. Christian Hof Tel: + 41 31 32 34 750 Fax: +41 31 32 33 210 E-mail: christian.hof@metas.ch
CMI: Michal Bartos Czech Metrology Institute (CMI) V Botanice 4 15072 Praha 5 The Czech Republic Tel: +420 2 5731 46 90 Fax: +420 2 5732 80 77 E-mail: mbartos@cmi.cz	**MIKES:** Kari Ojasalo Centre for Metrology and Accreditation (MIKES) Department: Electricity Group P.O. Box 9 (Tekniikantie 1) 02151 Espoo Finland Tel: +358 010 6054 423 Fax: + 358 010 6054 498 E-mail: kari.ojasalo@mikes.fi
DPLA: Knud Rasmussen Danish Primary Laboratory of Acoustics Acoustic Technology Oersted Institute, DTU Building 352 2800 Kgs. Lyngby Denmark Tel: +45 4525 3937 Fax: +45 4588 0577 Email: kr@oersted.dtu.dk	**NMI:** Paul van Kan Nederlands Meetinstituut (NMi) Postbus 654 Schoemakerstraat 97 2600 AR Delft The Netherlands Tel: + 31 152 691 673 Fax: + 31 152 612 971 E-mail: pvankan@nmi.nl

	SP: Hakan Andersson Swedish National Testing & Research Institute (SP) PO Box 857 SE-50115 Boras Sweden Tel: +46 33 16 54 23 Fax: +46 33 13 83 81 E-mail: hakan.andersson@sp.se