EURAMET Project 1056

Inter-laboratory comparison on measurement of free-field response of a sound level meter.

Final Report

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1. Introduction

EURAMET project 1056 aims at comparing methods for SLM free field response determination actually used at some NMI and manufacturers facilities. The scope is to support IEC 62585 "Methods to determine corrections to obtain free-field response of a sound level meter" with technical evidence and verification of the proposed uncertainty budgets.

Norsonic provided a special version of their type 140 SLM, without internal electronics and with an AC output directly from the microphone preamplifier. In this way, all possible drifts are minimised and the possibility of different instrument set up is avoided.

Every laboratory was required to use its standard procedure for the measurement: therefore different measurement techniques were used. They may be divided in two main groups:

- Sequential sinusoidal excitation in a full anechoic room, without any signal processing techniques; the effect of reflections may be reduced by performing a spatial average repeating the measurements in different positions in the anechoic room.
- Techniques that use echo removal in room that may be either anechoic, semi anechoic or non anechoic rooms.

There are some implications in the use of different techniques, the main being the long time required by sequential sinusoidal excitation. Therefore in the protocol laboratories using this technique were allowed to report data at a reduced number of frequencies.

The participants were required to determine the free field response and the difference between pressure response and free field response at 1 kHz. Optionally pressure response, actuator response and free field microphone response could be submitted. Unfortunately, only pressure response and microphone free field response were submitted by enough laboratories to be used for a simplified data analysis. Pressure responses have been measured with different methods and are not directly comparable. Therefore the main interest is in SLM free field response, and will be the focus of the analysis. This exercise is not a formal intercomparison, even if the result will be analysed using the conventional tools of key comparison evaluation.

The results are presented in table and graphs that display the following data:

- reference value, obtained as a weighted mean of the results, the results of each participant is divided by its declared uncertainty squared (weight), the sum normalised by the sum of the weights. This obviously gives more influence to laboratories declaring lower uncertainties.
- Degree of equivalence, that is the difference between the result of the participant and the reference value, associated with the uncertainty of the equivalence, obtained from the square root of the sum of the squares of the uncertainty of the reference value and of the uncertainty of the participant's result.
- Value of χ^2 test. This value is used to verify if the weighted mean is a valid estimator of the reference value (it should be greater than 0,05). In this exercise the aim is only to show the consistency of the results among different laboratories and techniques in various regions of the frequency range. No attempt has been made to use another estimator in case of failure of χ^2 test, as it is beyond the scope of this project.

For equations and in depth explanations refer to [1]. This project is the first among EURAMET laboratories, aimed at give more confidence to participating laboratories, and may the base for organising a formal intercomparison, following IEC 62585 standard.

2. Object of tests

- Norsonic type 140 SLM serial n° 77351, adapted for the project by removing internal electronics, unfiltered AC output form preamplifier available.
- Norsonic type 1225 SERIAL n° 98455 condenser microphone, 200 V polarisation, on Norsonic type 1209 preamplifier SERIAL n° 126682

A Brüel & Kjær Type 4231 SERIAL n° 1761718 acoustical calibrator was supplied for pressure calibration at 1 kHz. The calibrator was calibrated at the pilot laboratory, and calibration data was used by the participants.

3. General considerations

Many laboratories provided data of absolute sensitivity of SLM, as suggested by the protocol. However, the preamplifier of the Norsonic SLM is not suitable for insert voltage measurement. The absolute sensitivity may then be affected by the preamplifier gain and the value of the microphone power supply voltage. One laboratory determined the gain of the preamplifier, another measured the gain in the reference microphone preamplifier, many others included the preamplifier gain in the uncertainty. Obviously, the gain is compensated in the comparison of pressure and free field response if the same measurement equipment is used for the evaluation of pressure to free field correction, as suggested in the appendixes of the IEC 62585 standard. The most interesting data for verification of are therefore the relative frequency responses and the correction between free field and pressure response, which are the data needed in the relevant IEC 62585 standard.

A further complication is the lack of detailed knowledge of the environmental sensitivities of the microphone under test: data is available for most of the reference microphones used in the tests, but it may be actually better not to correct the sensitivity of the reference microphone, assuming that the microphone under test has a similar behaviour. As seen from the stability test, this assumption may be not fully confirmed.

4. Results

4.1 Correction a 1 kHz

One important result required in the standard is the difference between free field and pressure response at 1 kHz. It has been determined by using the supplied Brüel & Kjær Type 4231 sound calibrator or by comparing the pressure and free field responses at 1 kHz. The results are reported in table 4.1.1 and in figure 4.1.1 and 4.1.2. Apparently, there is a difference on the results between laboratories that used the supplied calibrator and laboratories that compared the pressure and free field response. The uncertainty in the sound calibrator calibration may have played a role. The weighted mean method [1] has been used to calculate reference value, uncertainties and degrees of equivalence. χ^2 test gave a value of 0,74. The weighted mean is therefore a valid estimator, χ^2 test value being > 0,05.

Table 4.1.1 Free Field Correction

Laboratory	Correction	Declared Uncertainty	Method	Notes on Uncertainty
	dB	dB		
INRiM	-0,09	0,16	Free Field and Pressure Response 1094-5 Closed Coupler	0,14 FF +0,06 P
Norsonic	-0,08	0,22	Free Field and Pressure Response 1094-5 jig	0,2 FF+0,09 P
DPLA	0,05	0,14	Calibrator	
IA	-0,17	0,4	Calibrator	
Metas	0,05	0,22	Calibrator	0,2 FF +0,09 P
NPL	0,05	0,2	Calibrator	
BEV	0,06	0,47	Calibrator	Estimated from quoted SD and number of measurements as Type A uncertainty
Weighted Mean	-0,0067	0,0773	χ^2 Test=0,74	

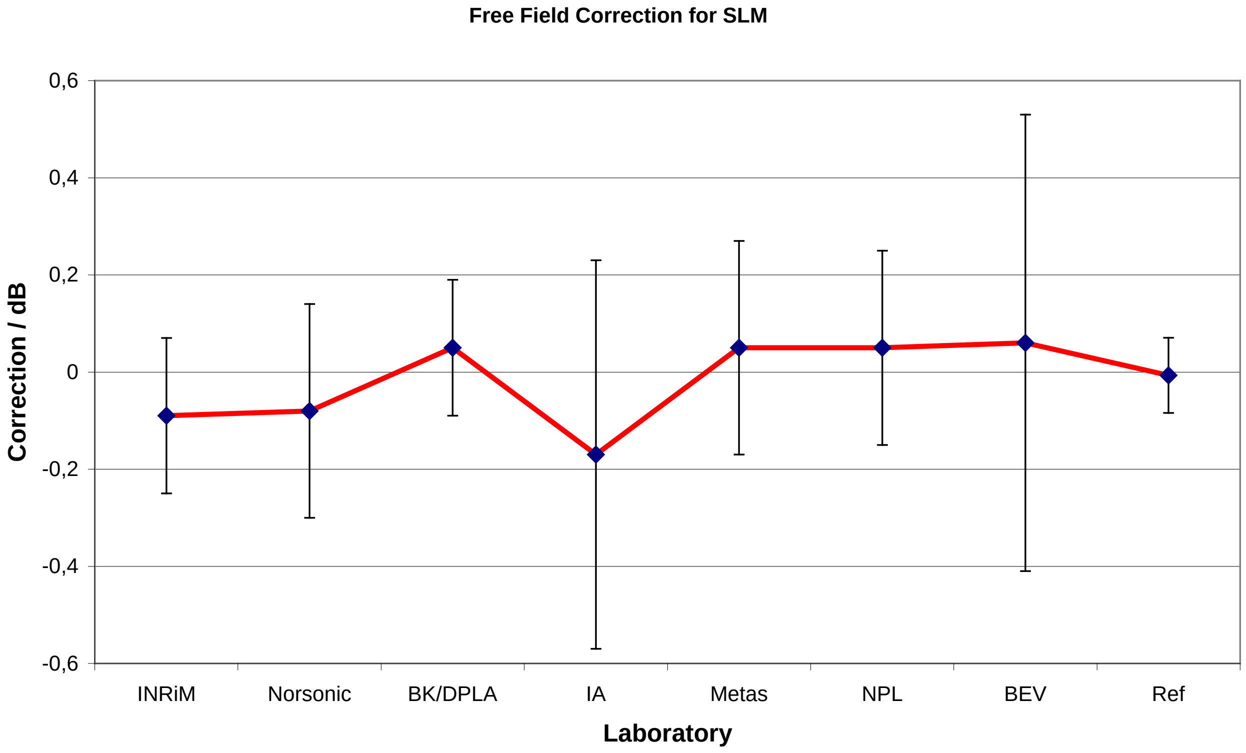

Figure 4.1.1 . Free Field correction at 1 kHz for SLM under test

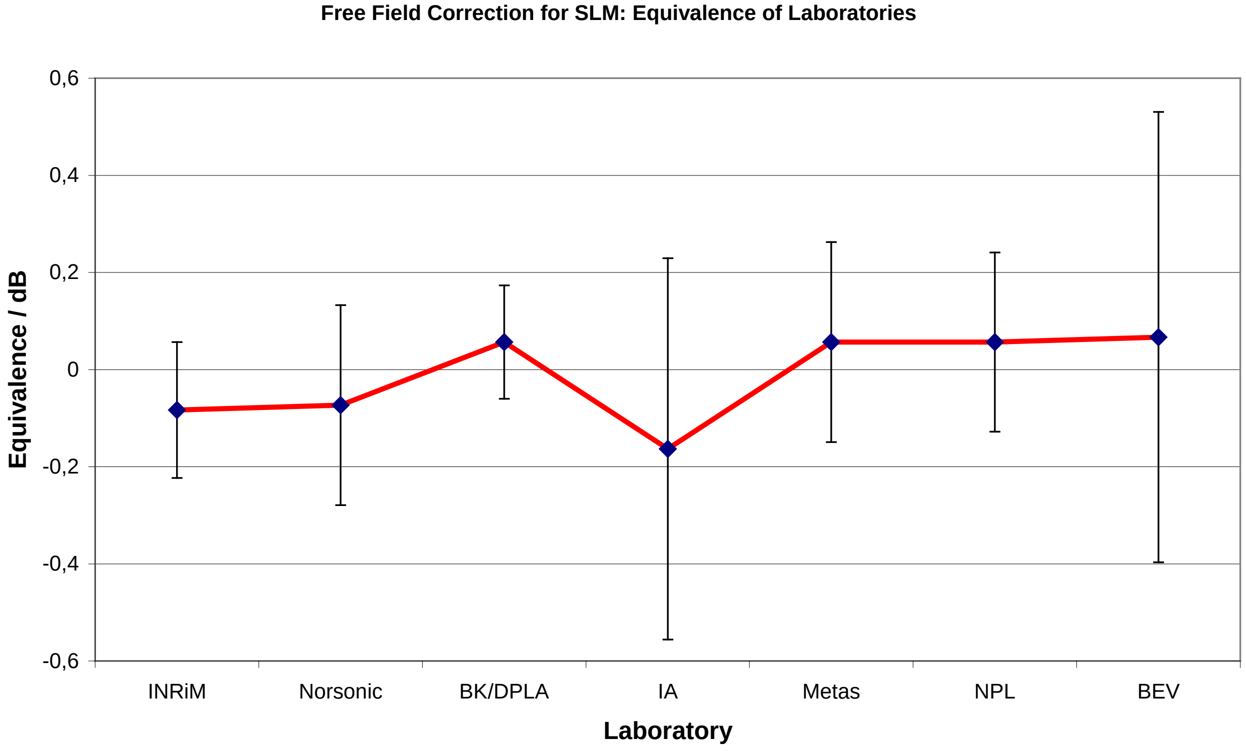

Figure 4.1.2. Degrees of equivalence of laboratories.

4.2 Free Field response

The measure of the free field response is the most complicated passage for the evaluation of the free field correction. The participants used different techniques and different measurement environments. Some determined the response relative to 1 kHz, others the absolute sensitivity vs. frequency. For comparison purposes, data will presented as response relative to 1 kHz. There could be many reasons to use a different normalisation value, i.e. the average in a frequency band around 1 kHz, and the agreement for some laboratory may improve. However, since this frequency band has not been previously agreed, it has been chosen to keep normalisation as simple as possible.

Data will be presented mostly in the format of graphs, as the large number of 1/12 octave frequencies makes tables difficult to read.

Two categories of measurement techniques have been identified: traditional measurements in anechoic room with sinusoidal excitation of the sound source (sinusoidal in figure captions), and measurements that, in different ways, eliminate the effects of reflections and do not require a free field facility (ER in captions). NPL measured with sinusoidal steady state signals in anechoic room, but reduced the effect of parasitic reflection by performing measurement at different position and making therefore a form of spatial average. The results are therefore presented all together and separated according to measurement technique. An important point is the way the SLM is mounted in the measurement setup: INRiM and NPL used a similar mounting method (a rod in the screw attachment in the SLM), Norsonic, DPLA and other used methods that are less prone to cause alterations in the frequency response. Data show evidence that mounting system is relevant and should be clearly indicated in the standard.

The first analysis takes all laboratories into consideration, and is performed at a reduced number of frequencies, the ones that are common to every participant. IA measured approximately at 1/3 octave intervals, and sets the reduced number of frequencies. Please note that the scale of degree of equivalence in graphs of individual laboratories are different.

Table 4.2.1 Reference value and degrees of equivalence

Frequency	Reference value	U_{95}	Degree of equivalence / dB						
Hz	dB	dB	INRiM	Norsonic	DPLA	IA	Metas	NPL	BEV
63,1	0,14	0,05	0,02	0,01	-0,12	-0,08	-0,07	-0,05	0,44
125,9	0,14	0,05	0,02	0,00	-0,12	-0,05	-0,06	-0,11	0,28
251,2	0,13	0,07	0,02	0,01	-0,09	-0,03	-0,02	-0,08	0,36
501,2	0,19	0,06	-0,07	0,02	0,01	-0,02	-0,01	-0,05	0,20
1000,0	0,00	0,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1258,9	-0,13	0,06	0,04	-0,01	0,01	-0,05	-0,15	-0,08	0,07
1584,9	0,22	0,06	-0,04	0,02	0,04	0,10	-0,05	0,02	0,05
1995,3	0,36	0,06	0,00	-0,04	-0,04	-0,12	0,08	-0,01	0,23
2511,9	-0,10	0,07	0,12	0,03	-0,03	-0,10	-0,16	0,09	-0,07
3162,3	0,14	0,07	0,00	0,11	0,01	0,20	-0,25	0,03	0,20
3981,1	0,15	0,07	-0,04	0,12	0,05	0,39	-0,48	0,03	0,64
5011,9	0,50	0,08	0,07	-0,01	-0,14	-0,06	0,25	0,12	0,38
6309,6	0,10	0,08	0,03	0,33	0,03	0,14	-0,68	0,01	0,19
7943,3	0,46	0,09	-0,01	0,38	0,03	0,68	-0,61	0,20	0,12
10000,0	0,76	0,10	0,15	0,41	-0,07	-0,32	-0,88	0,35	0,36
12589,3	0,77	0,12	0,04	0,35	-0,06	0,37	-0,13	0,15	0,63
14125,4	0,79	0,14	0,12	0,35	-0,04	-0,25	-0,33	0,33	0,14
15848,9	1,06	0,14	0,03	0,19	-0,02	0,18	-0,64	0,19	0,99
17782,8	0,78	0,14	0,13	0,33	0,21	-0,24	-0,86	0,26	-0,86
19952,6	0,12	0,15	0,07	0,24	0,19	0,22	-1,48	0,39	0,78

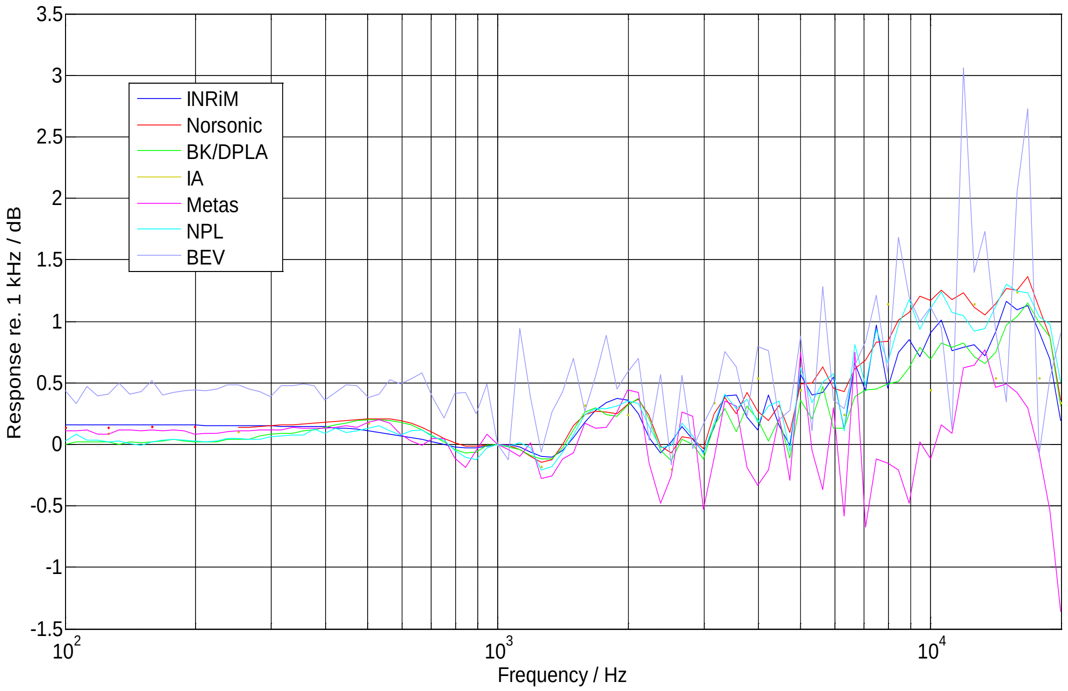

Figure 4.2.1. SLM Free Field response, normalised at 1 kHz , all laboratories.

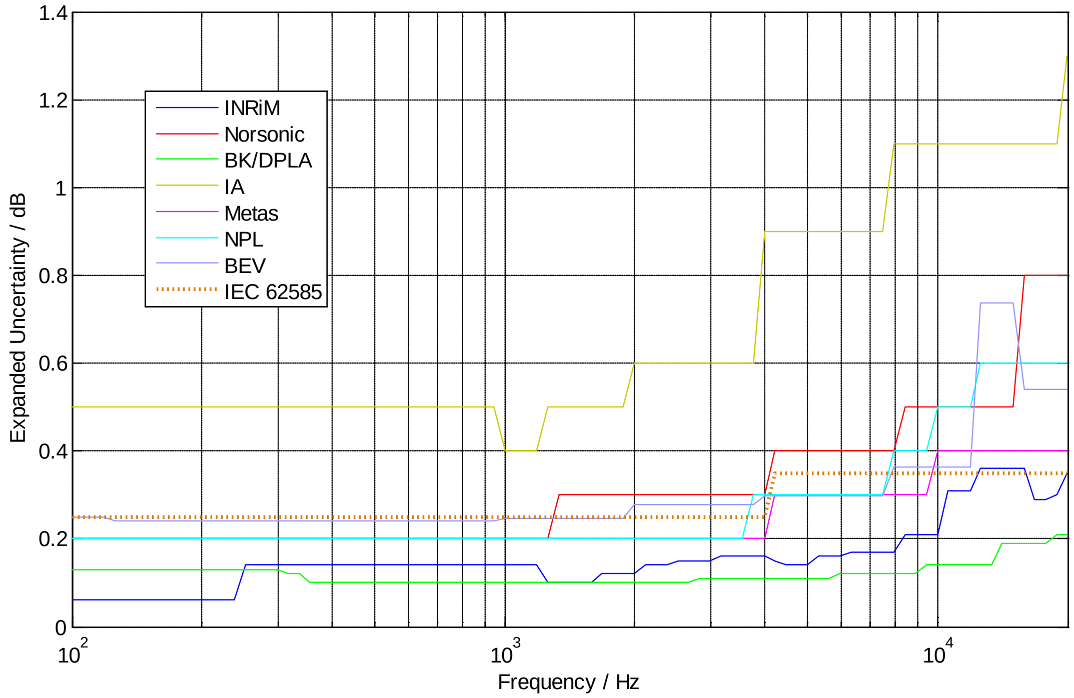

Figure 4.2.2. Declared uncertainty for SLM Free Field response measurement.

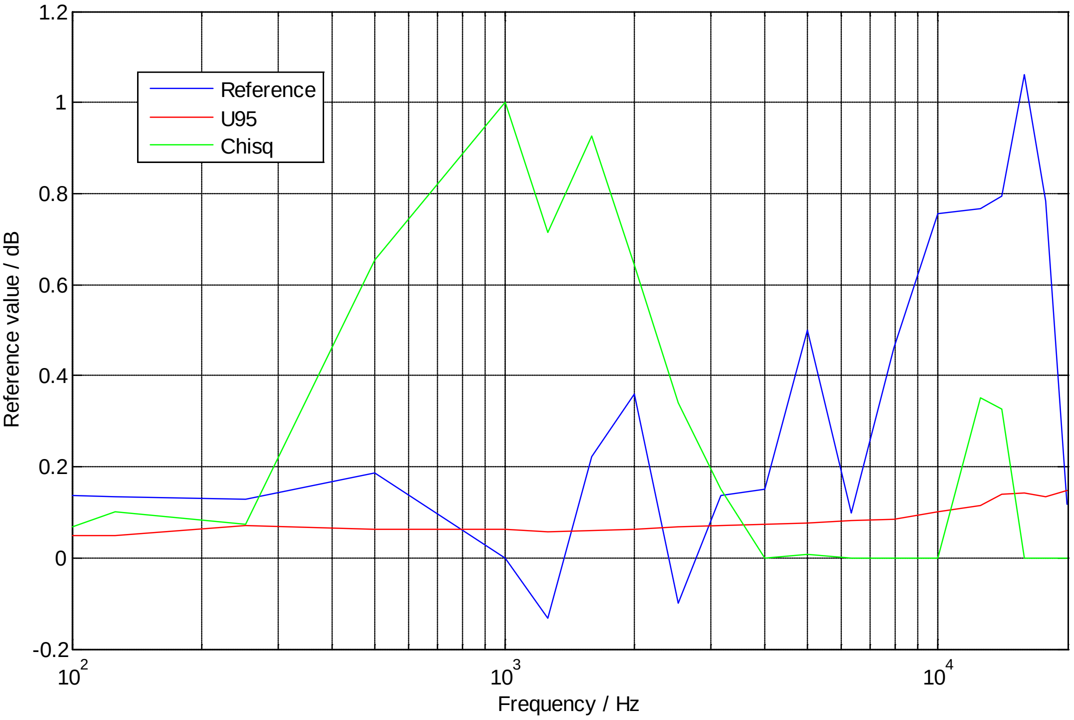

Figure 4.2.3. Reference value and expanded uncertainty. χ^2 test scale is adimensional.

As can be seen in figure 4.2.3, the consistency check fails at frequencies above 3 kHz. As this exercise is not a formal intercomparison, further analysis was considered unnecessary.

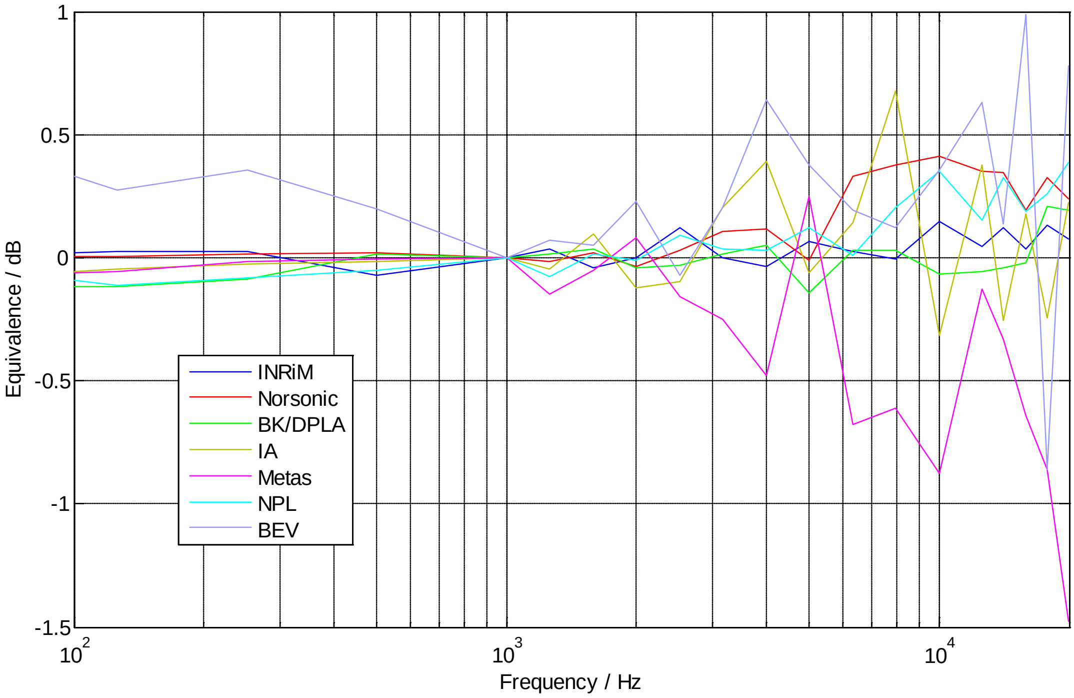

Figure 4.2.4. Degrees of equivalence of all laboratories.

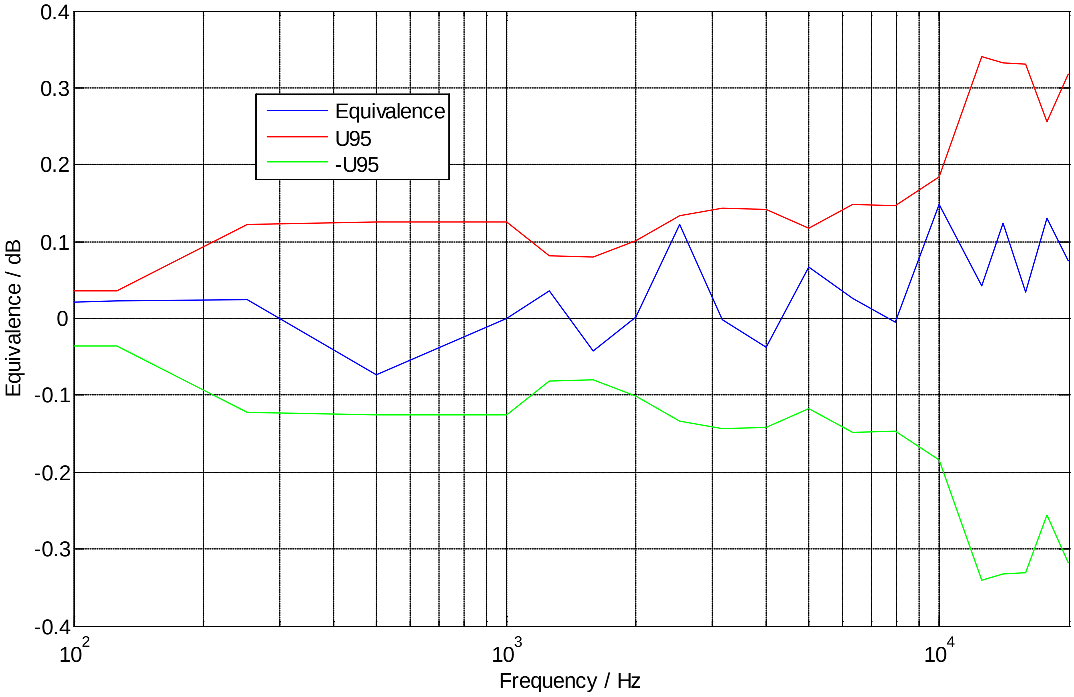

Figure 4.2.5. Degree of equivalence of INRiM.

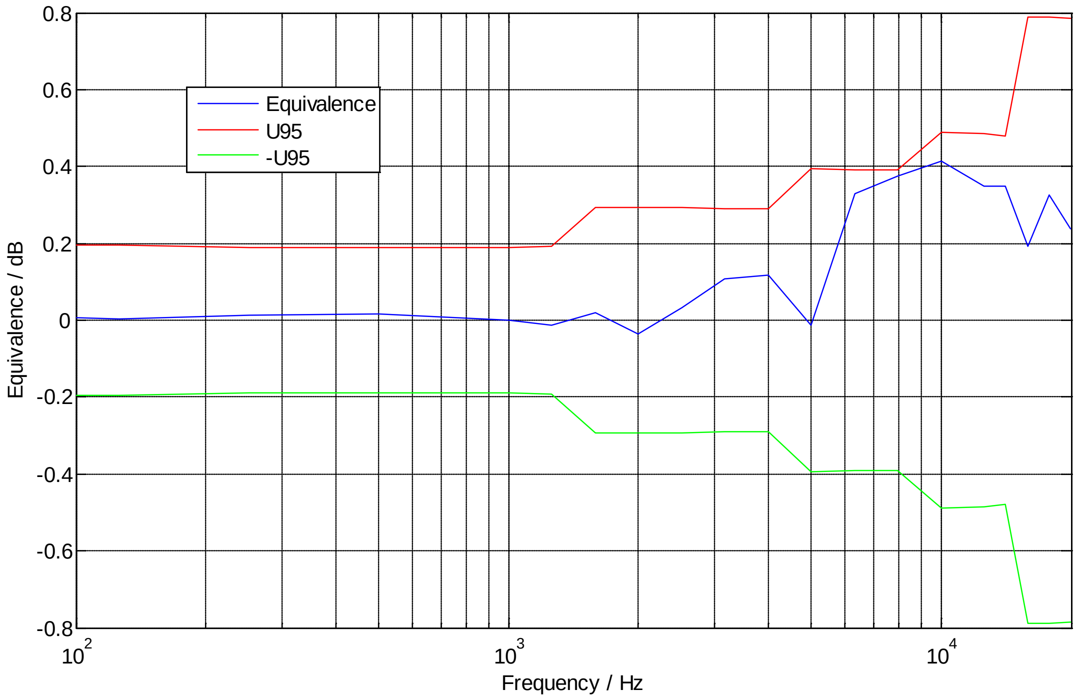

Figure 4.2.6. Degree of equivalence of Norsonic.

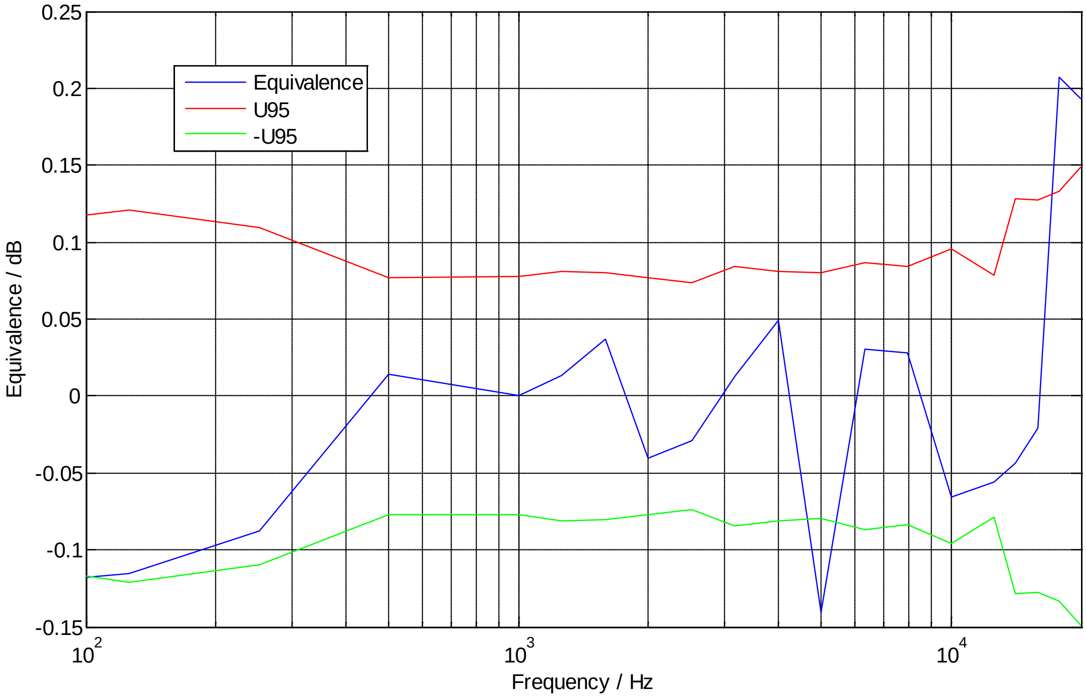

Figure 4.2.7. Degree of equivalence of DPLA.

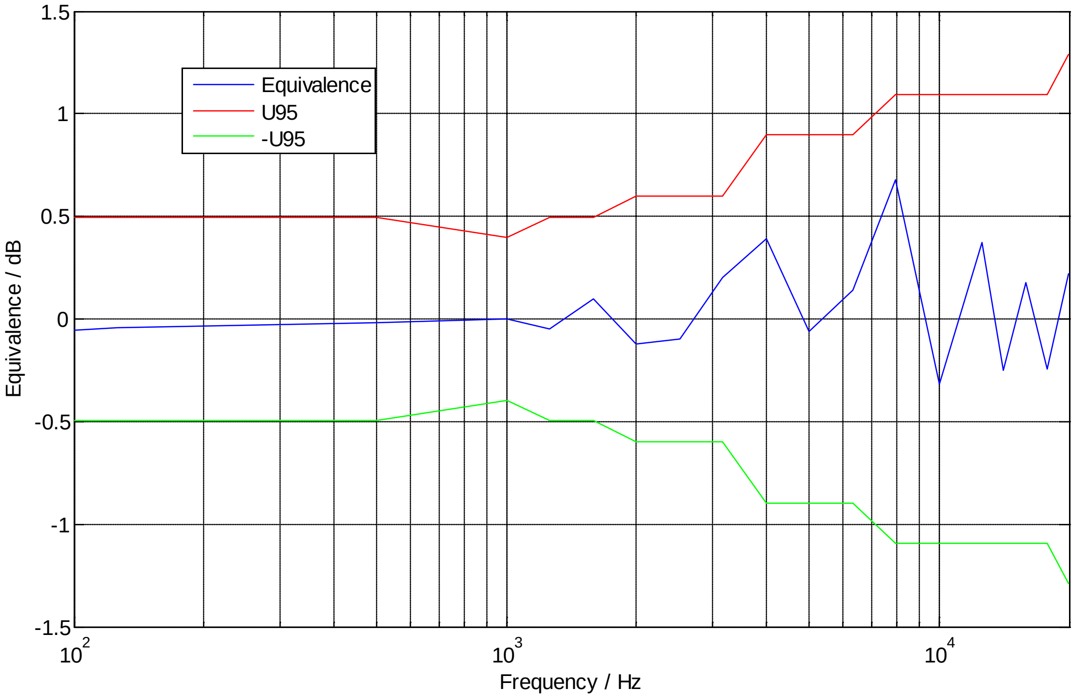

Figure 4.2.8. Degree of equivalence of IA.

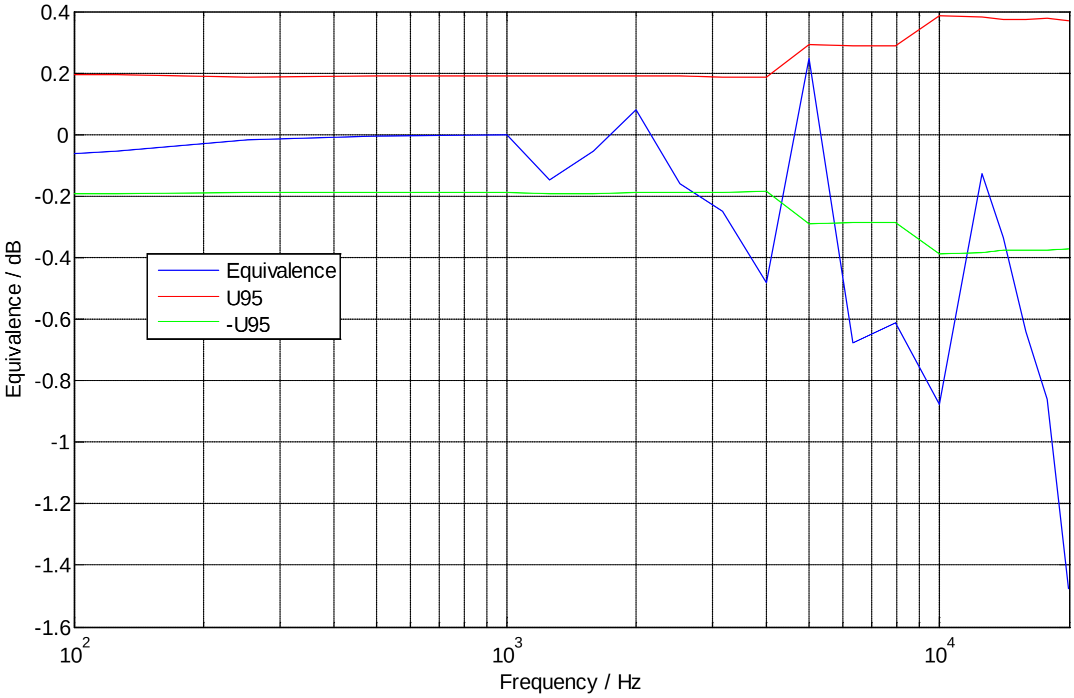

Figure 4.2.9. Degree of equivalence of Metas.

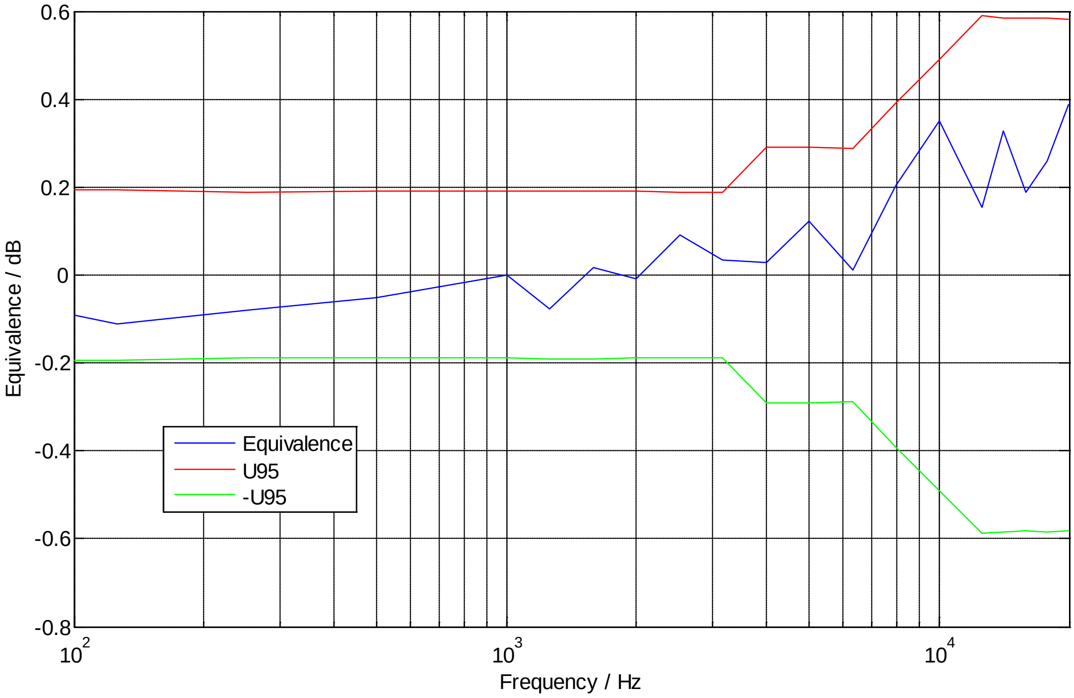

Figure 4.2.10. Degree of equivalence of NPL.

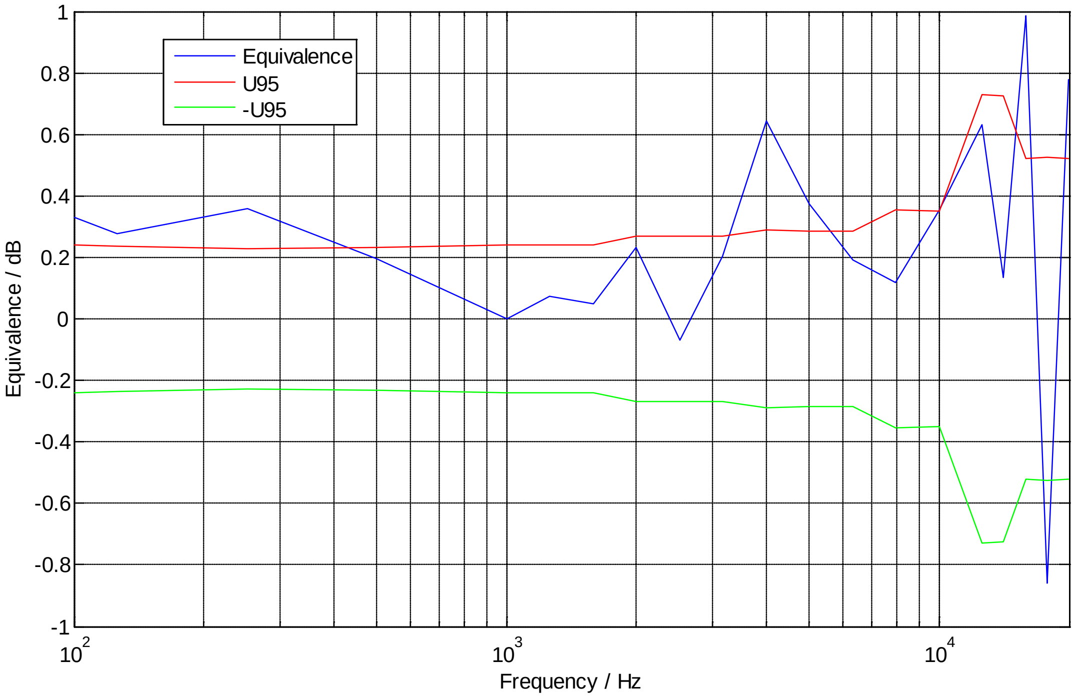

Figure 4.2.11. Degree of equivalence of BEV.

Another analysis is performed on the six laboratories that performed the measurements at (almost) all frequencies. In practice all laboratories except IA, that measured at 1/3 octave intervals.

The χ^2 test fails at individual frequencies, especially above 3 kHz, as is shown in figure 4.2.12.

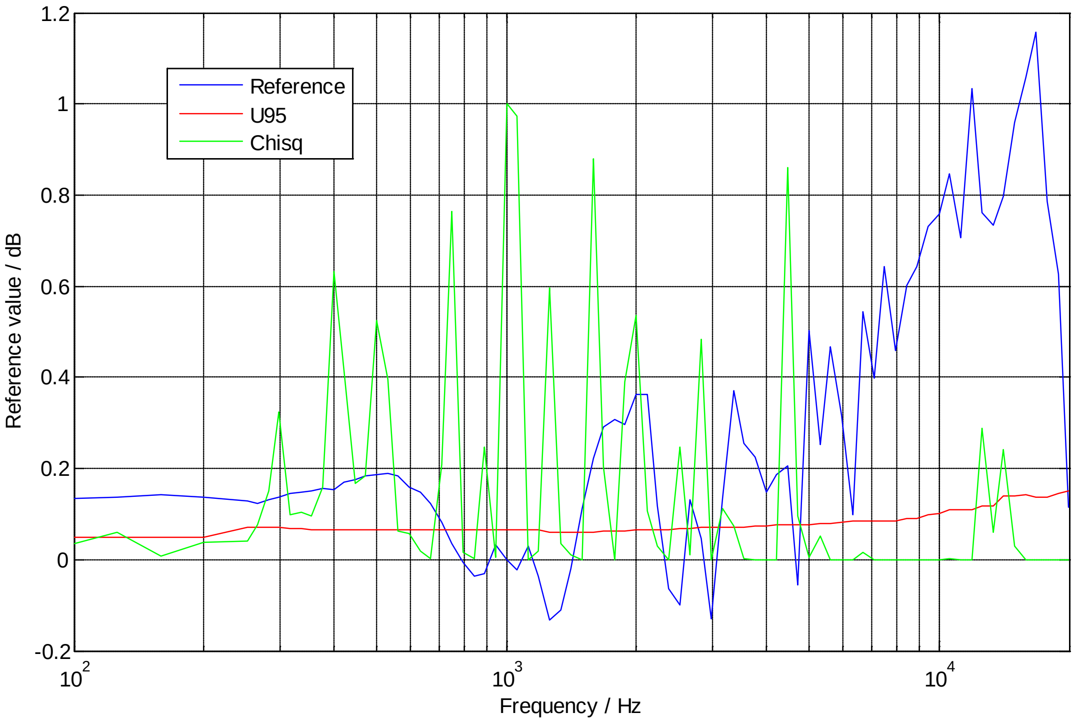

Figure 4.2.12. Reference values, 6 laboratories. χ^2 test scale is adimensional.

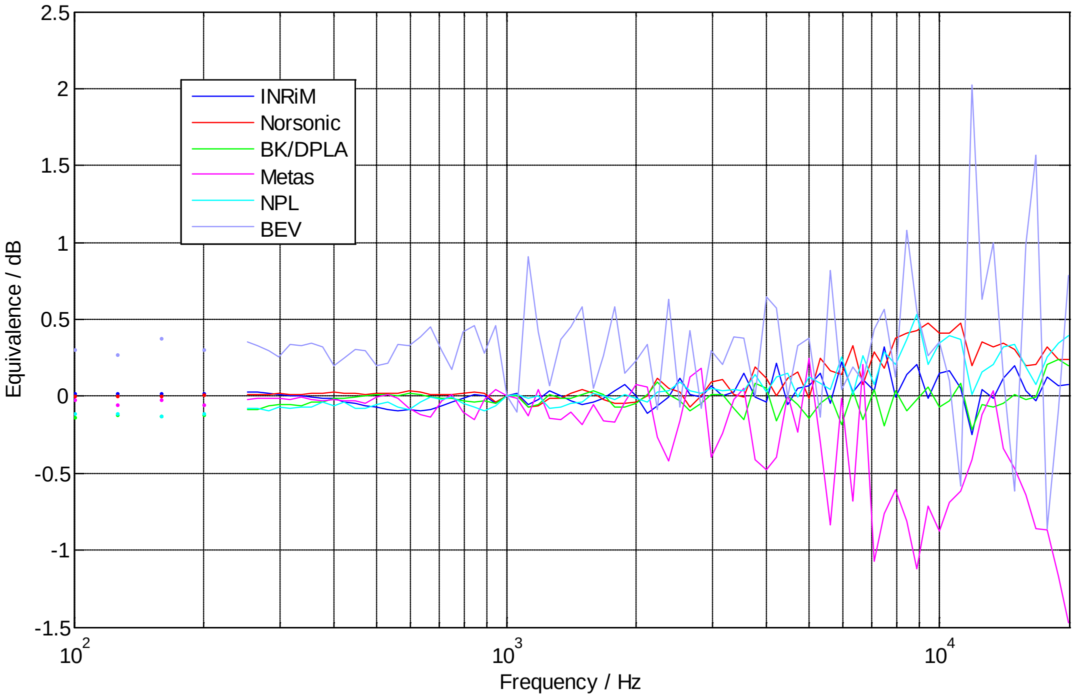

Figure 4.2.13. Degrees of equivalence, 6 laboratories.

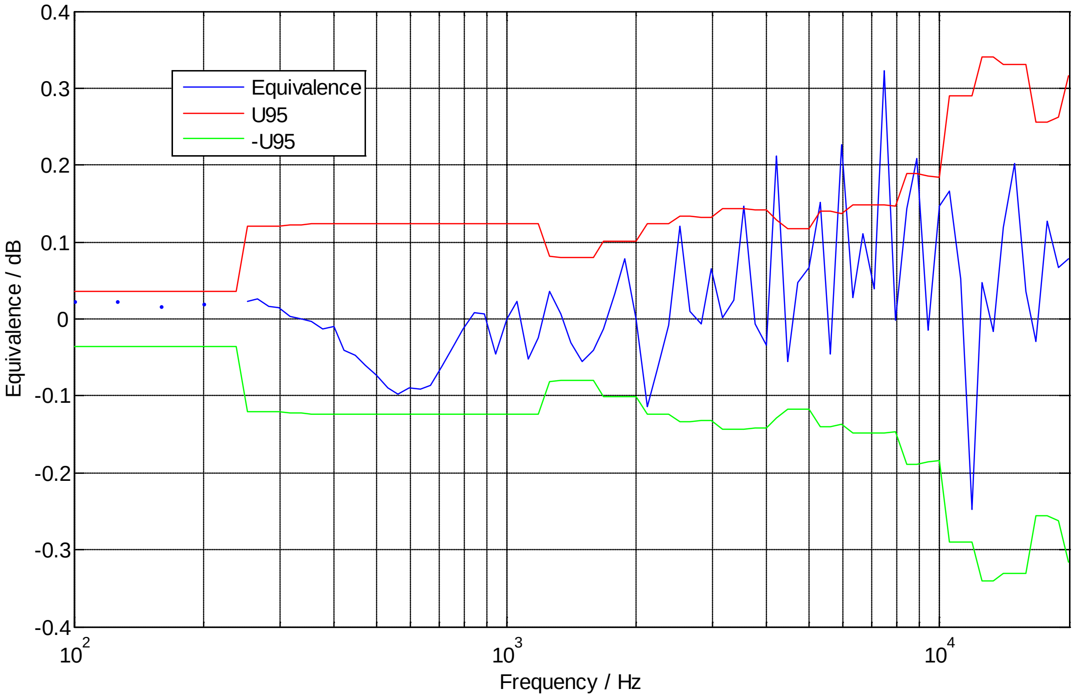

Figure 4.2.14. Degree of equivalence INRiM.

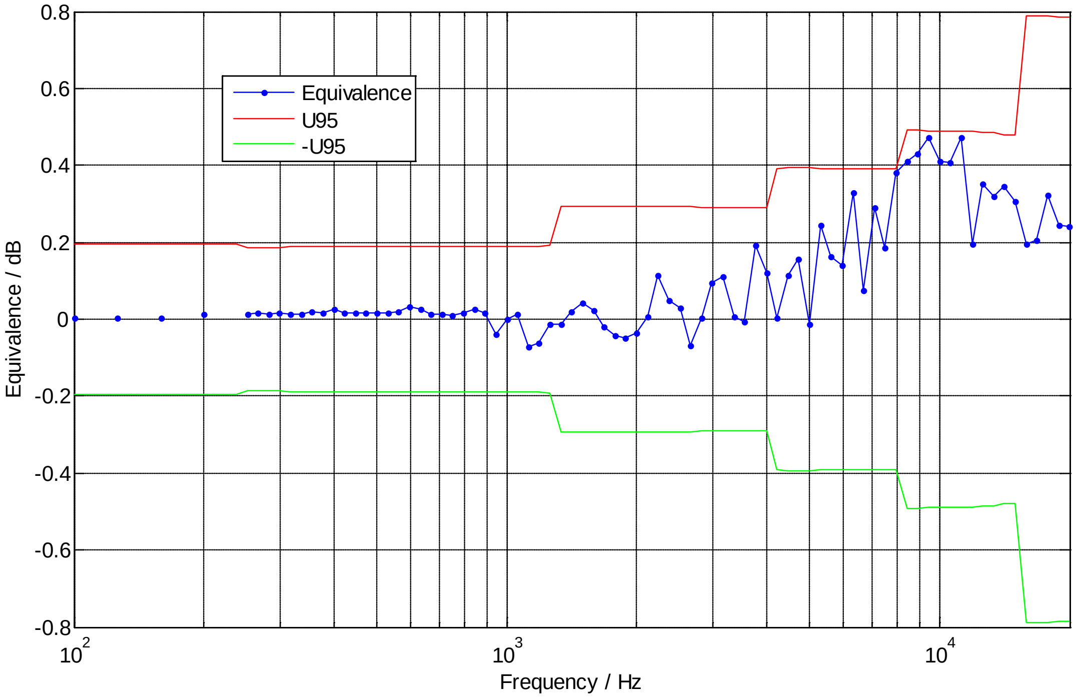

Figure 4.2.15. Degree of equivalence Norsonic.

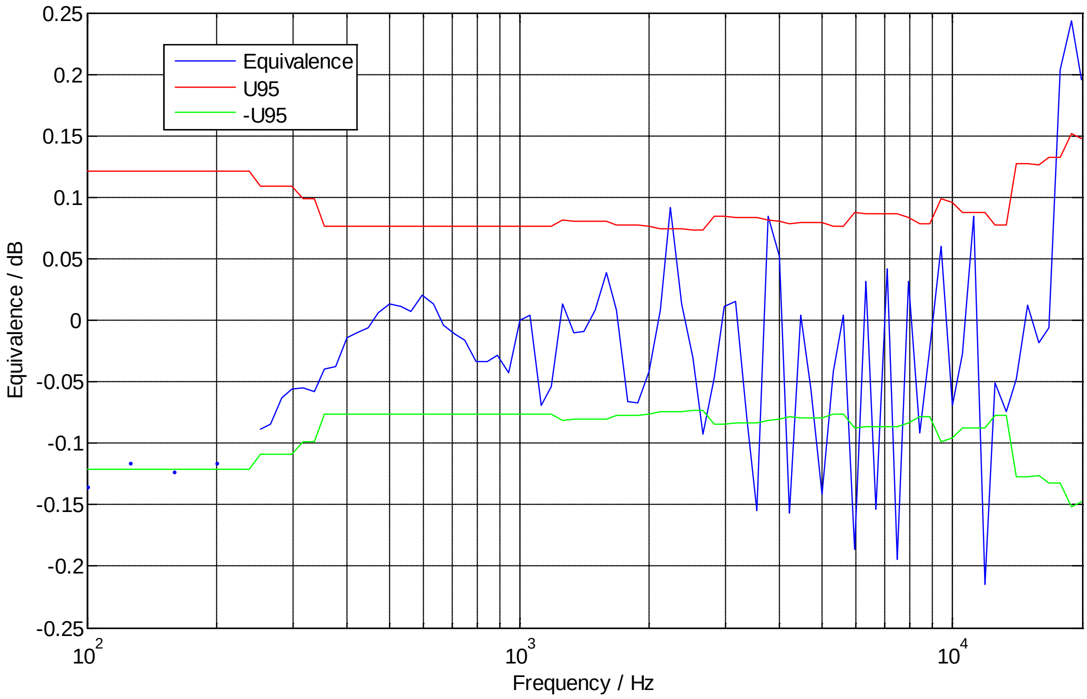

Figure 4.2.16. Degree of equivalence DPLA.

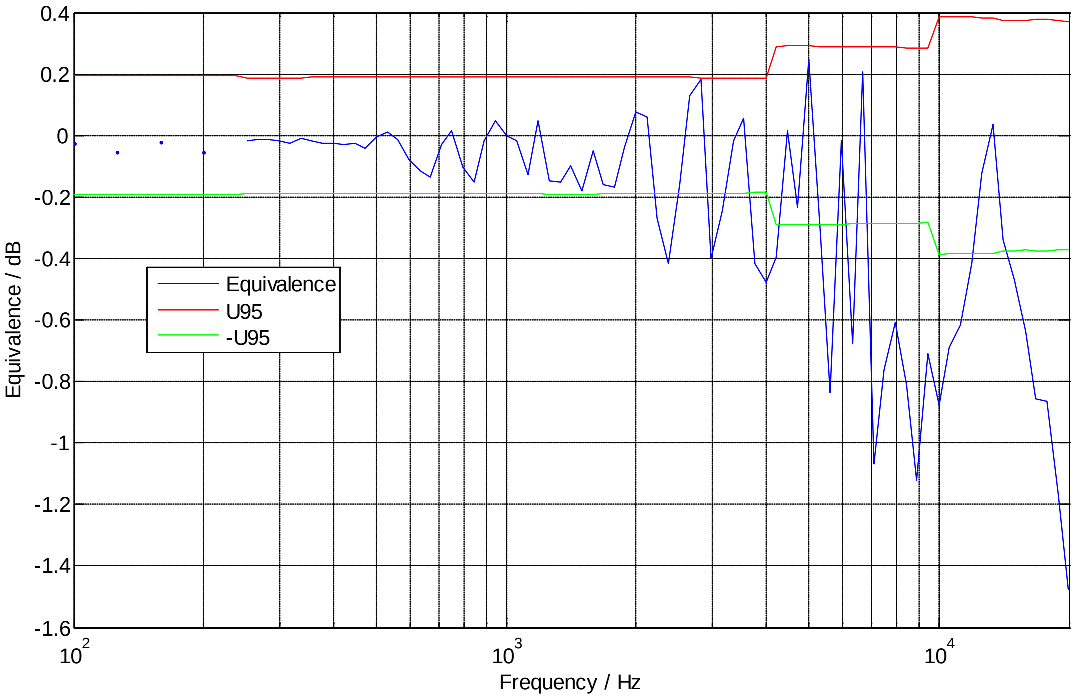

Figure 4.2.17. Degree of equivalence Metas.

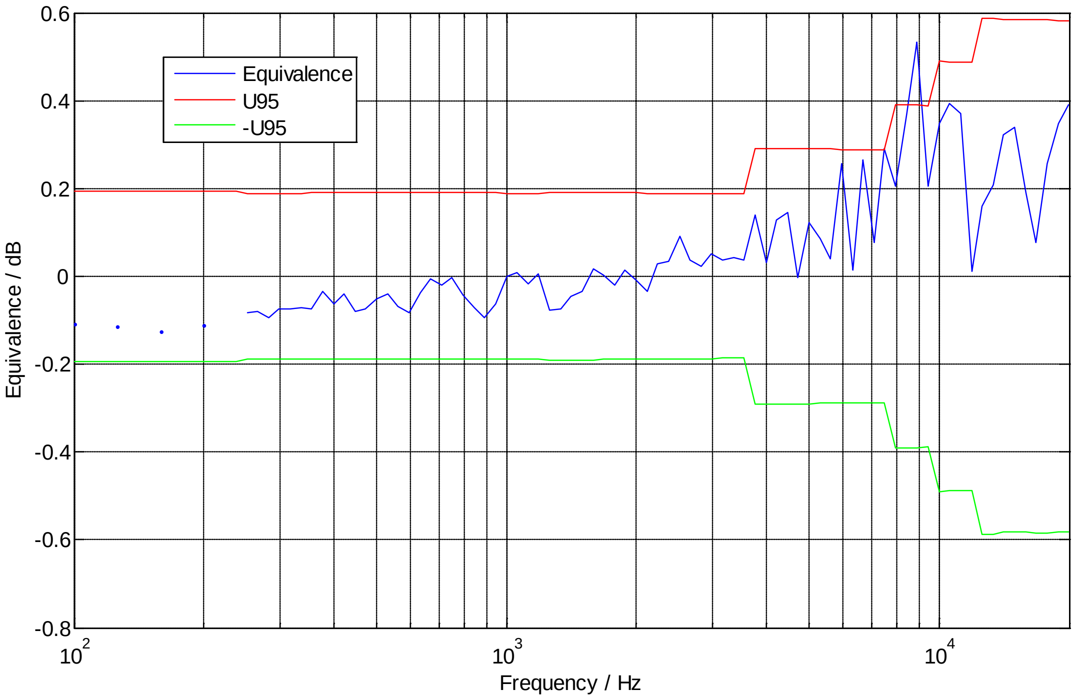

Figure 4.2.18. Degree of equivalence NPL.

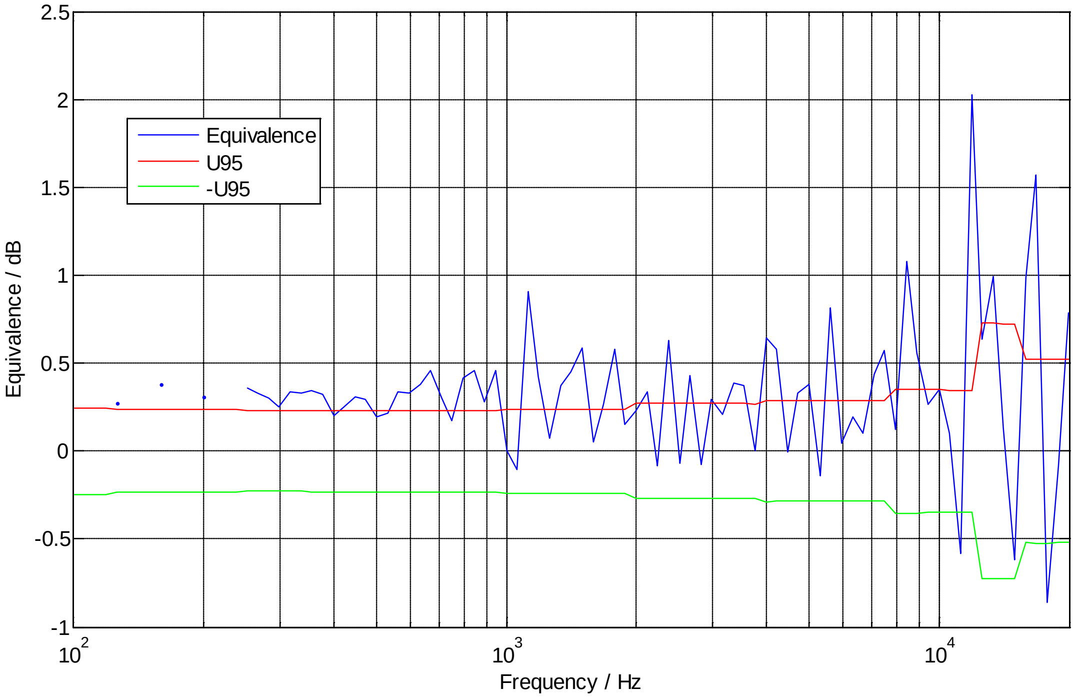

Figure 4.2.19. Degree of equivalence BEV.

Another analysis will consider only laboratories that applied some kind of reduction of the effects of the reflections in the measurement room. There are four laboratories involved, INRiM, Norsonic, DPLA and NPL.

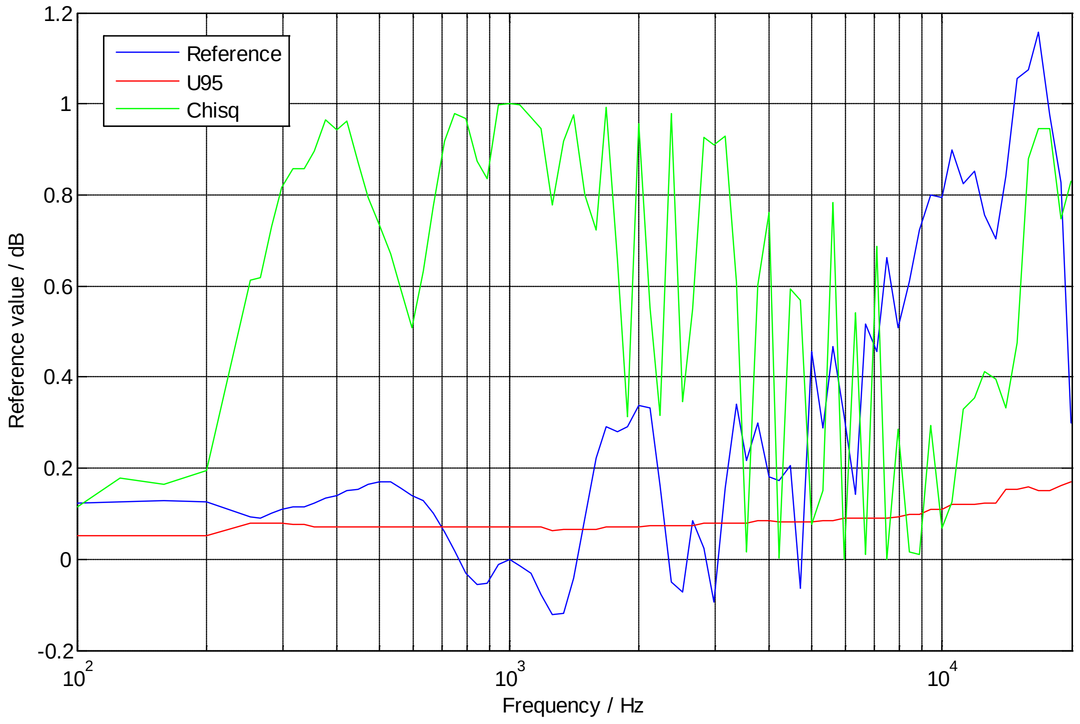

Figure 4.2.20. Reference values, ER laboratories only. χ^2 test scale is adimensional.

The χ^2 test is satisfactory up to 3 kHz and above 10 kHz: between 3 and 10 kHz there is a possible influence of different mounting fixtures and temperature dependence or instability of microphone response. At low frequencies, the four laboratories used different measurement methods.

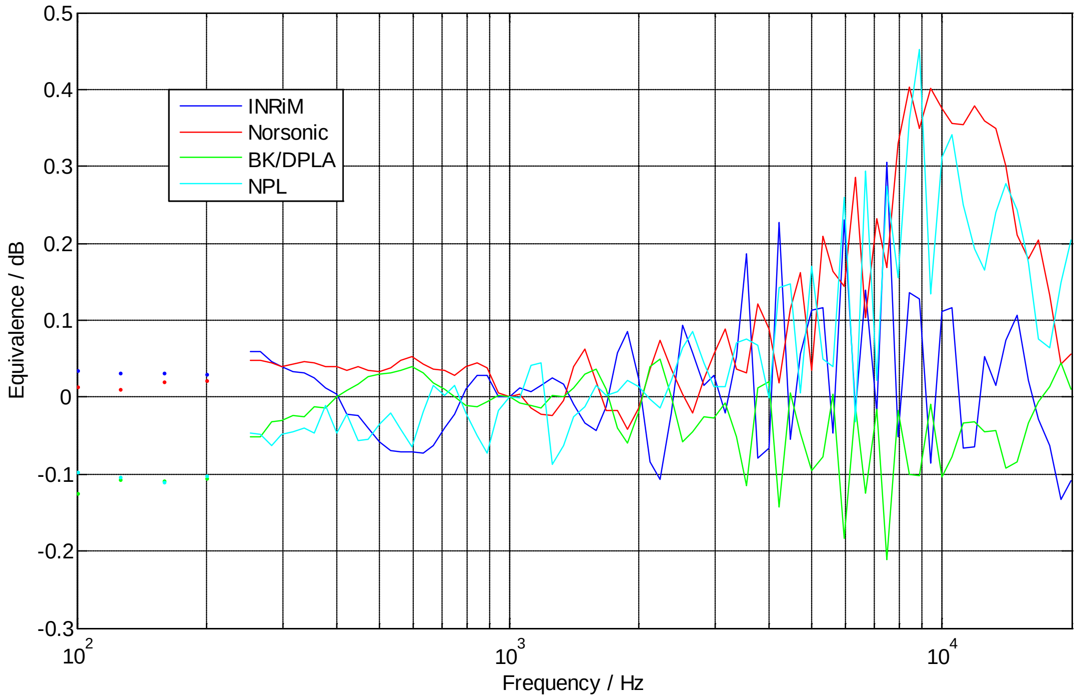

Figure 4.2.21. Degrees of equivalence of ER laboratories.

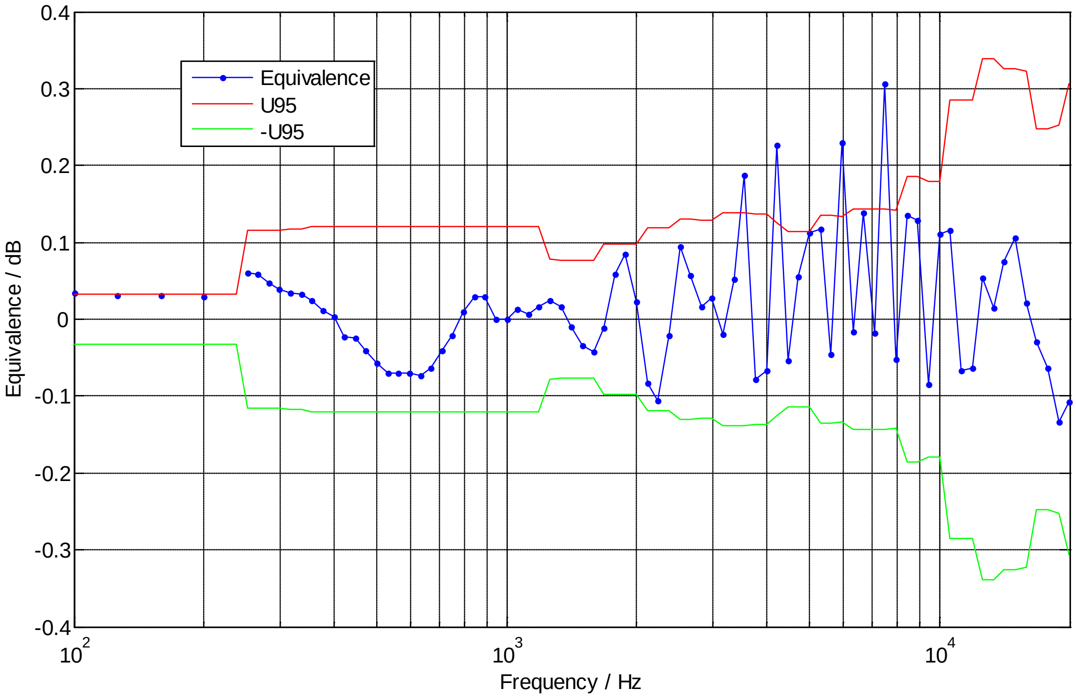

Figure 4.2.22. Degree of equivalence INRiM.

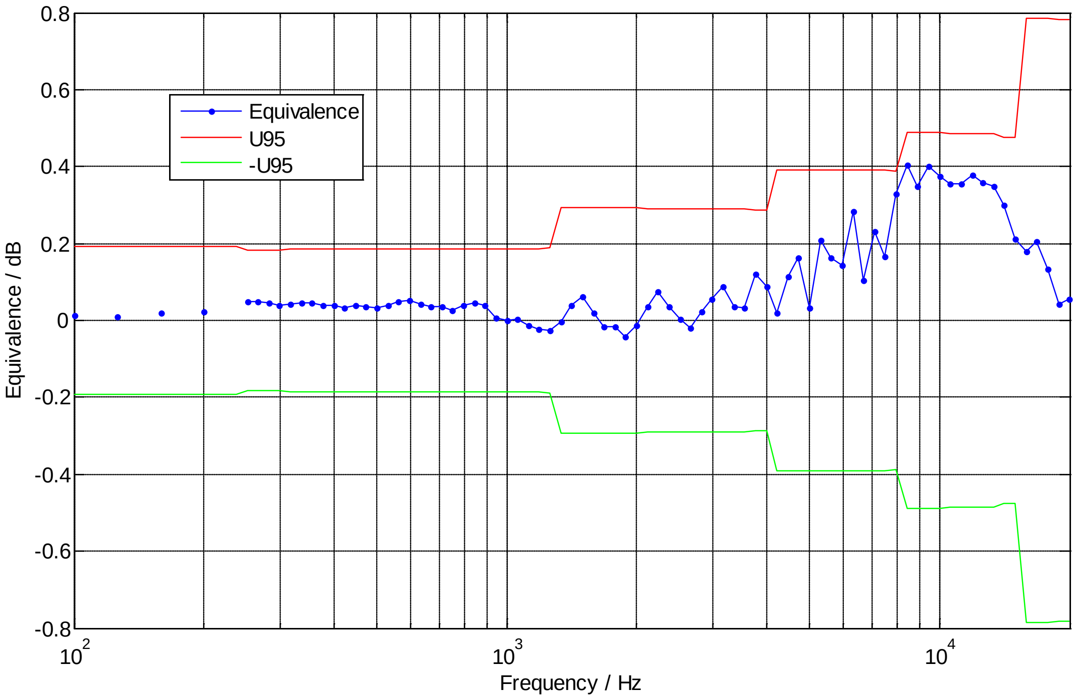

Figure 4.2.23. Degree of equivalence Norsonic.

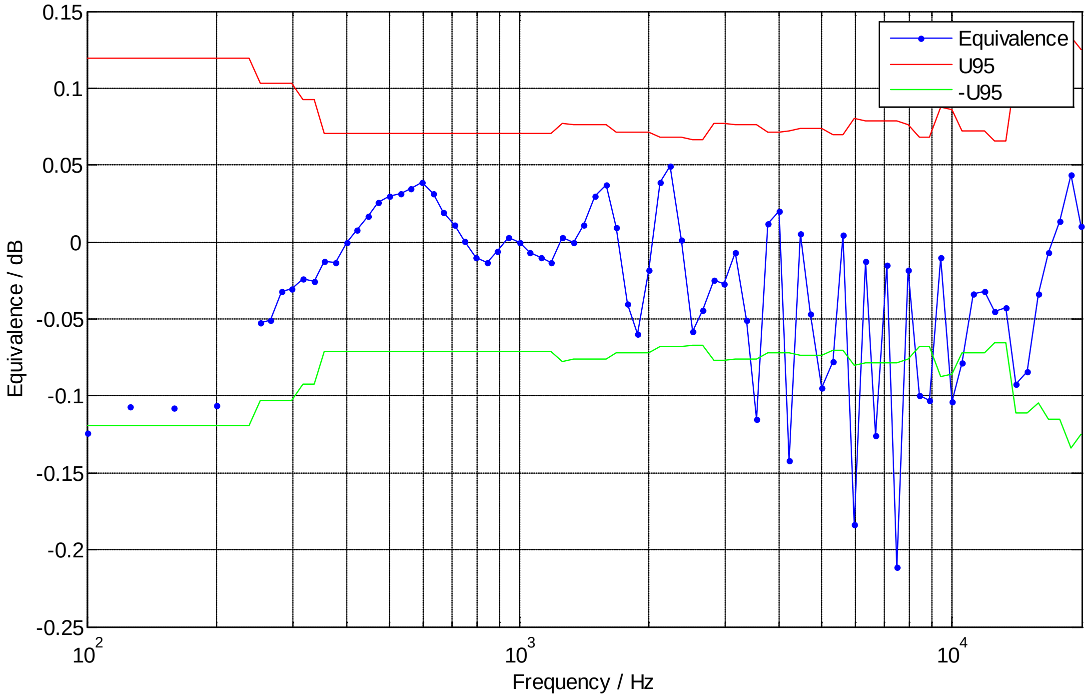

Figure 4.2.24. Degree of equivalence DPLA.

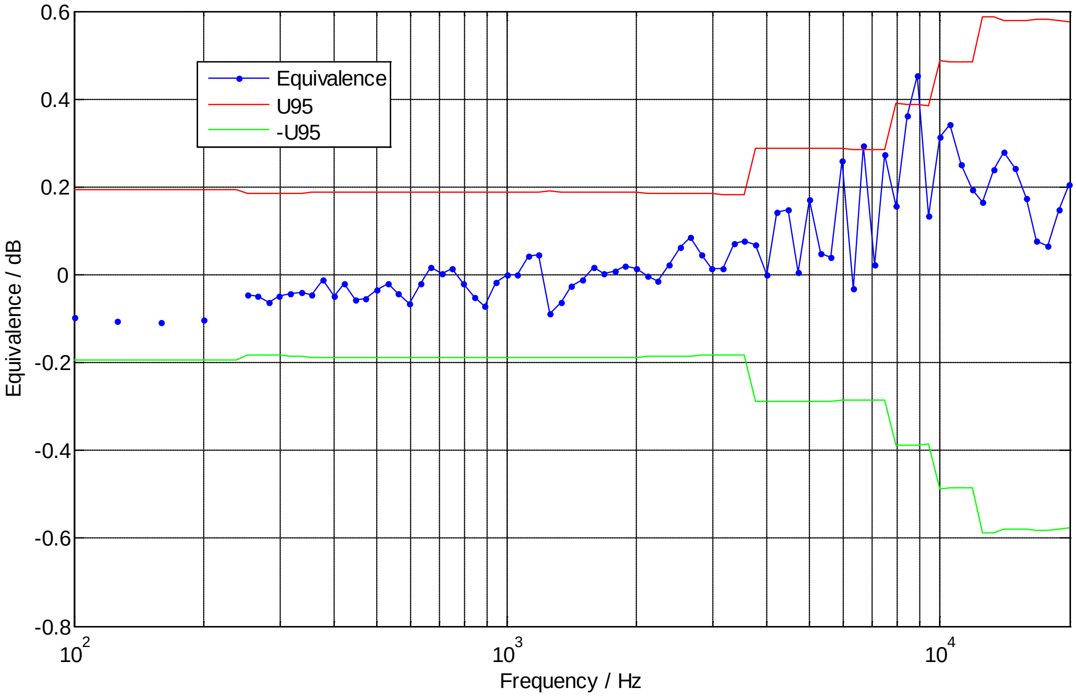

Figure 4.2.25. Degree of equivalence NPL.

As can be seen in figures 4.2.1 to 4.2.25, the results are rather variable.

The weighted mean approach gives a prevalence to laboratories that declare the lowest uncertainty and may be questioned if there is not a great experience about the effective uncertainty, as it is possible in this case. There is a possibility that some laboratories underestimated their uncertainty, but it is more likely that the dispersion of the results is linked to the design of the experiment, that allowed (too?) much freedom in SLM mounting and in other details, as the main scope was to assess the actual situation. The reflections from different positions of the mounting rod (two configurations were prevalent, one attached to bottom of the SLM, the other on the rear) are the probable culprit of the rapid variations of the equivalence at frequencies above 2 kHz.

Figure A.1 shows the influence of the mounting rod (difference of the free field response of a SLM suspended by wires and same SLM with a mounting rod on bottom) and the degree of equivalence of INRiM. The frequency resolution of the rod influence is different, but a correlation is nonetheless visually apparent.

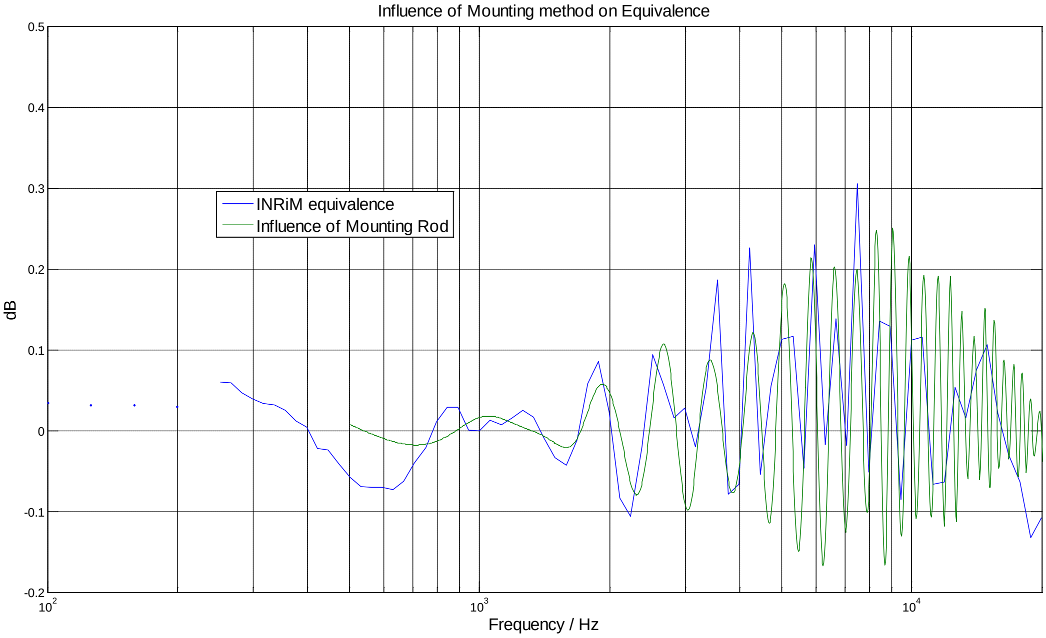

Figure A.1 Influence of mounting rod (data courtesy DPLA) and INRiM degree of equivalence.

Low frequencies measurements have been carried out using different approaches and this fact may explain a greater than expected dispersion of results: this point needs definitely to be investigated in a future project.

In particular INRiM, and to a lesser degree Norsonic, switched to pressure response at a too high frequency. The figure A.2 below, courtesy of DPLA/B&K, shows the results of a calculated body influence for a SLM of dimensions similar to the SLM under test. There is a clear rise of response at frequencies around 500-600 Hz, and a similar shape is present in the response of laboratories that performed measurements at low frequencies in anechoic room or with simulation of low frequency free field (DPLA). It is clear that pressure response should be used only below 200 Hz and INRiM should revise its measurement procedure. The equivalence at frequencies below 700 Hz must be viewed in the light of these considerations.

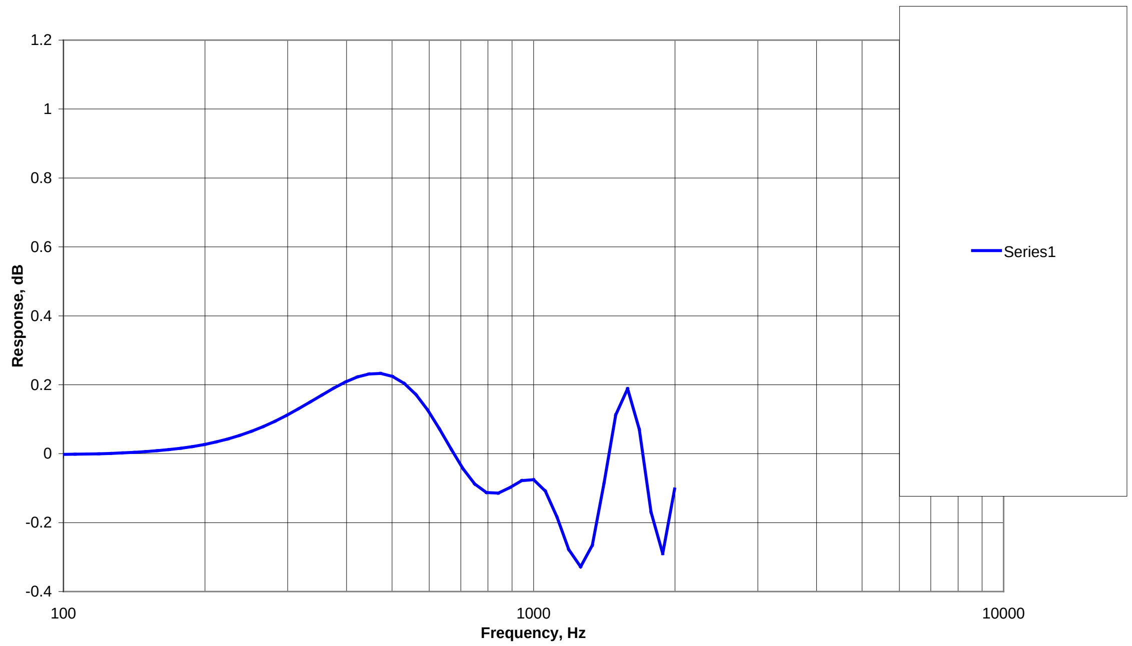

Figure A.2 Calculated influence of SLM body on free field response (courtesy of DPLA/B&K).

DPLA and INRiM declared uncertainties lower than the requirement of the IEC 62585 standard, NPL was aligned with the standard, and Norsonic uncertainties were higher. What happens if we repeat the calculations assigning to all laboratories the IEC 62585 uncertainties? The answer is in fig. 4.2.26 to 4.2.30. In fig. 4.2.26 we note that the consistency test is valid at all frequencies. All laboratories degrees of equivalence are within the uncertainty limits. INRiM and DPLA measured at about 20°C (DPLA actually carried out some measurements at 23 °C, and made averages correcting for speed of sound), Norsonic and NPL around 23 °C, and there is a clear difference in the response around 5 to 15 kHz. It is to be expected that with a microphone less sensitive to temperature effects, or to other effects that change its sensitivity (diaphragm tension?), the results in this frequency range would be better.

The uncertainty values proposed in the IEC 62585 standard are therefore reasonable and can be achieved, at least with techniques for the reduction of the effect of reflections.

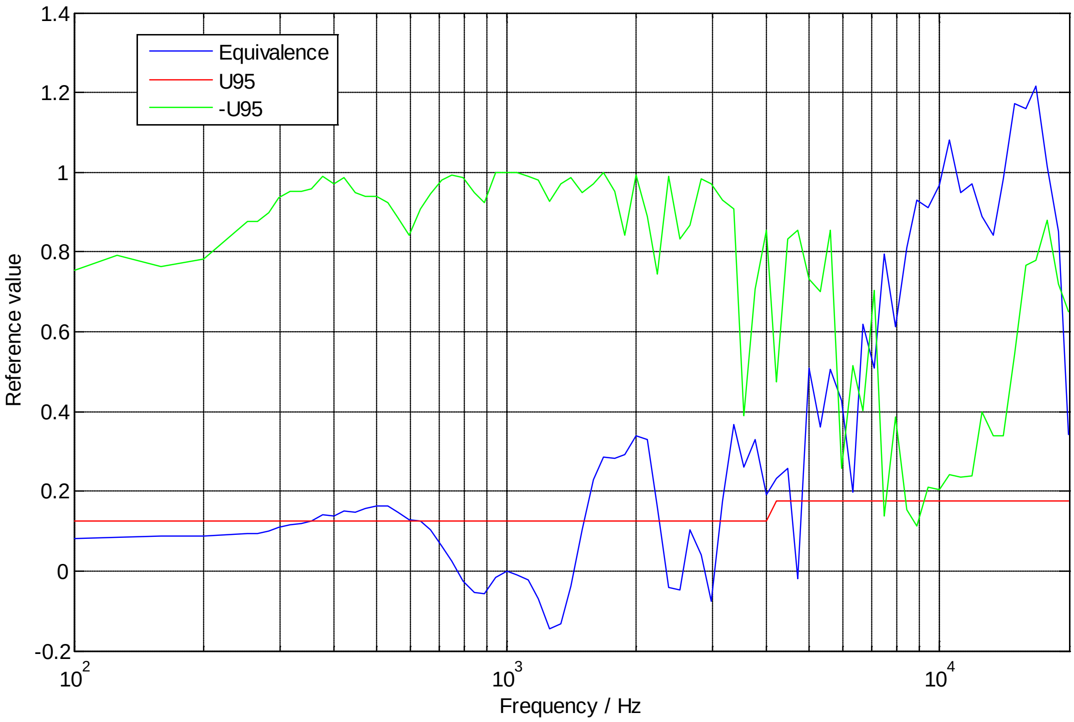

Figure 4.2.26. Reference values, ER laboratories only, uncertainty forced to IEC 62585 values. χ^2 test scale is adimensional.

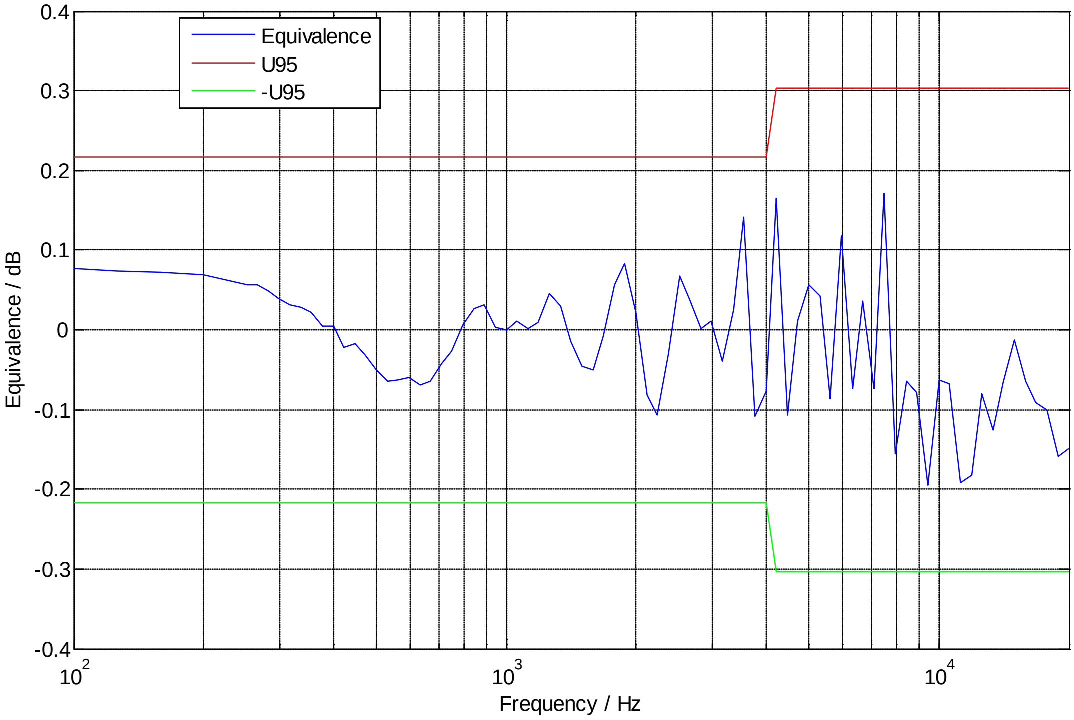

Figure 4.2.27. Degree of equivalence INRiM.

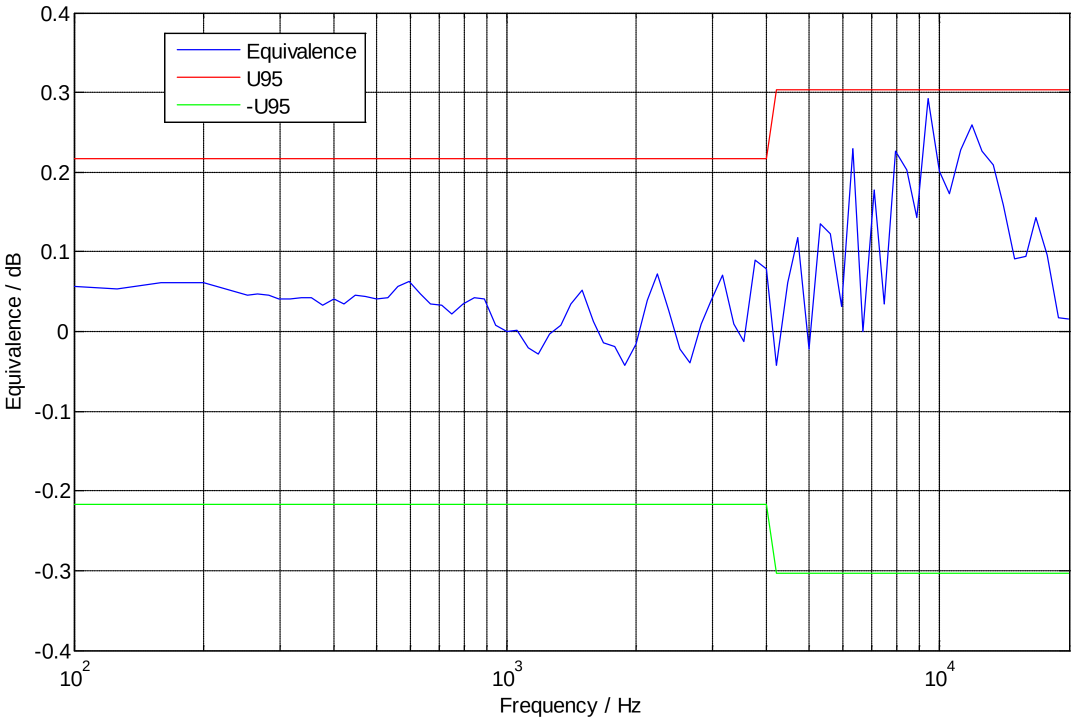

Figure 4.2.28. Degree of equivalence Norsonic.

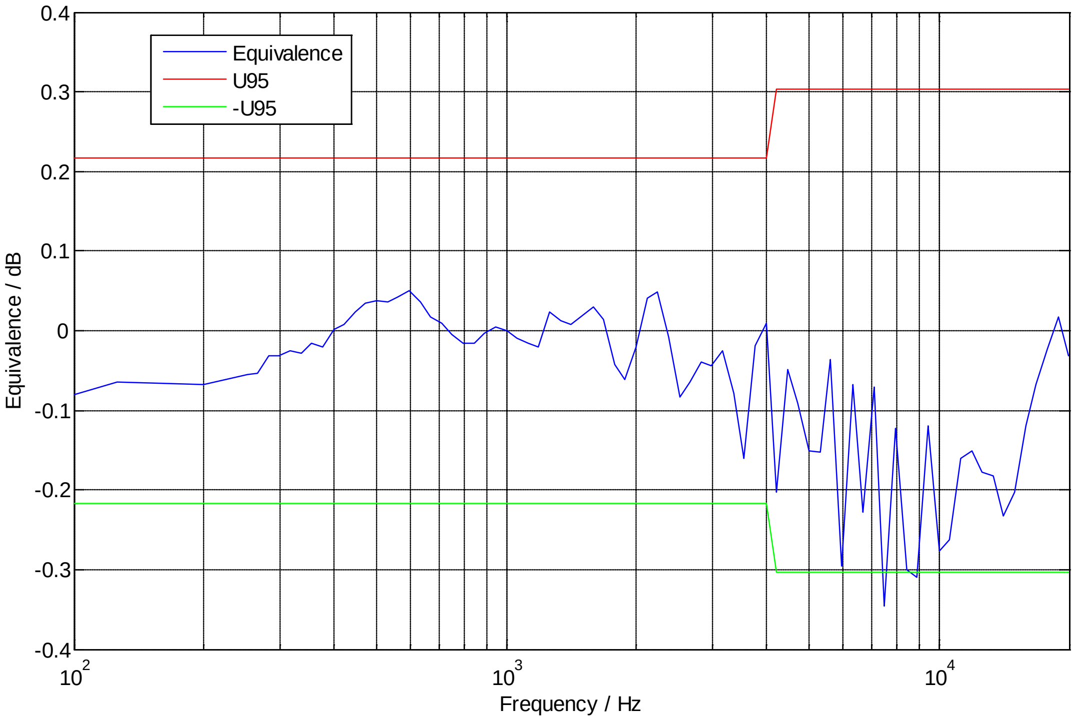

Figure 4.2.29. Degree of equivalence DPLA.

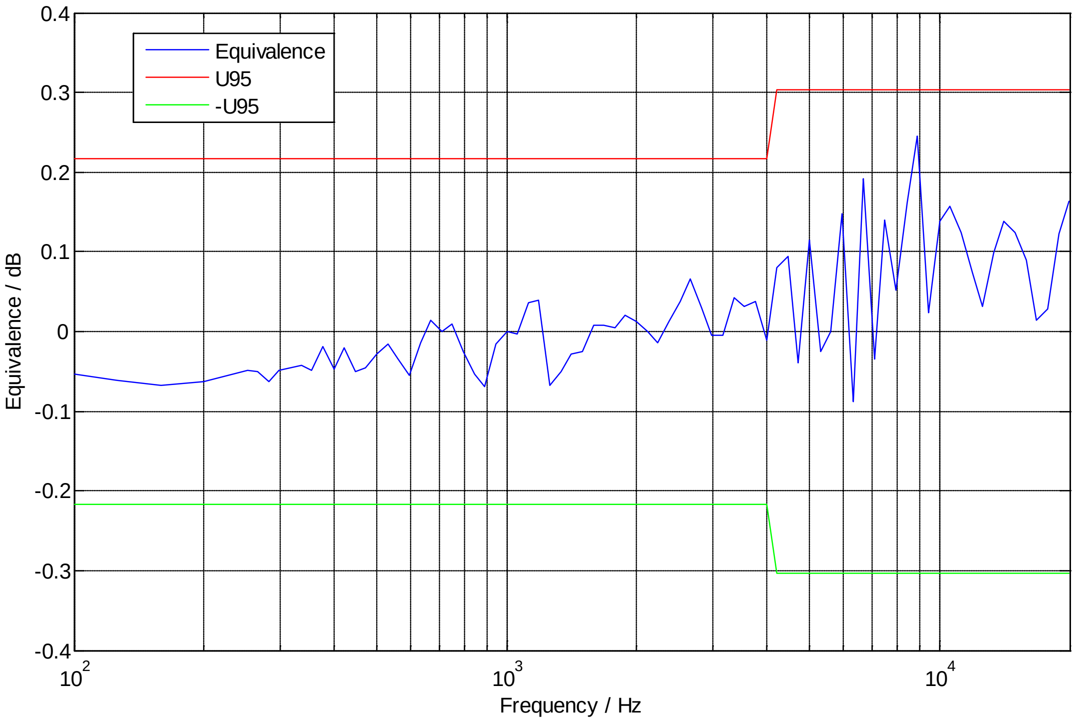

Figure 4.2.30. Degree of equivalence NPL.

4.3 Microphone Free Field response

The Norsonic 1225 condenser microphone response in free field was measured by a number of laboratories. Same considerations made for the SLM free field response apply, and data will be presented as responses relative to 1 kHz. In this case, different preamplifiers were used by laboratories (DPLA determined the gain of the two preamplifiers types used), so that absolute values are difficult to compare. The lowest frequency of measurement was not equal for all laboratories, and laboratories using impulse response techniques carried out measurement below 2-300 Hz using different methods. At frequencies below 500 Hz, for laboratories that used time windowing of the impulse response, the ripples caused by the window may be the cause of the spread of the results.

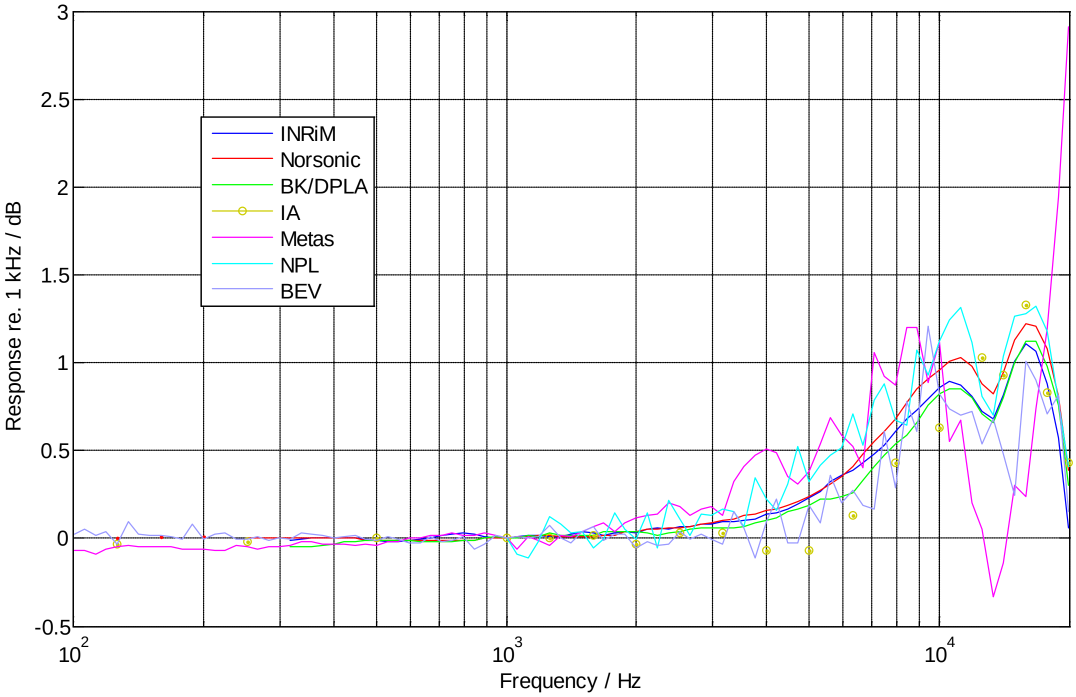

Figure 4.3.1. Microphone Free Field Response re. 1 kHz, all laboratories.

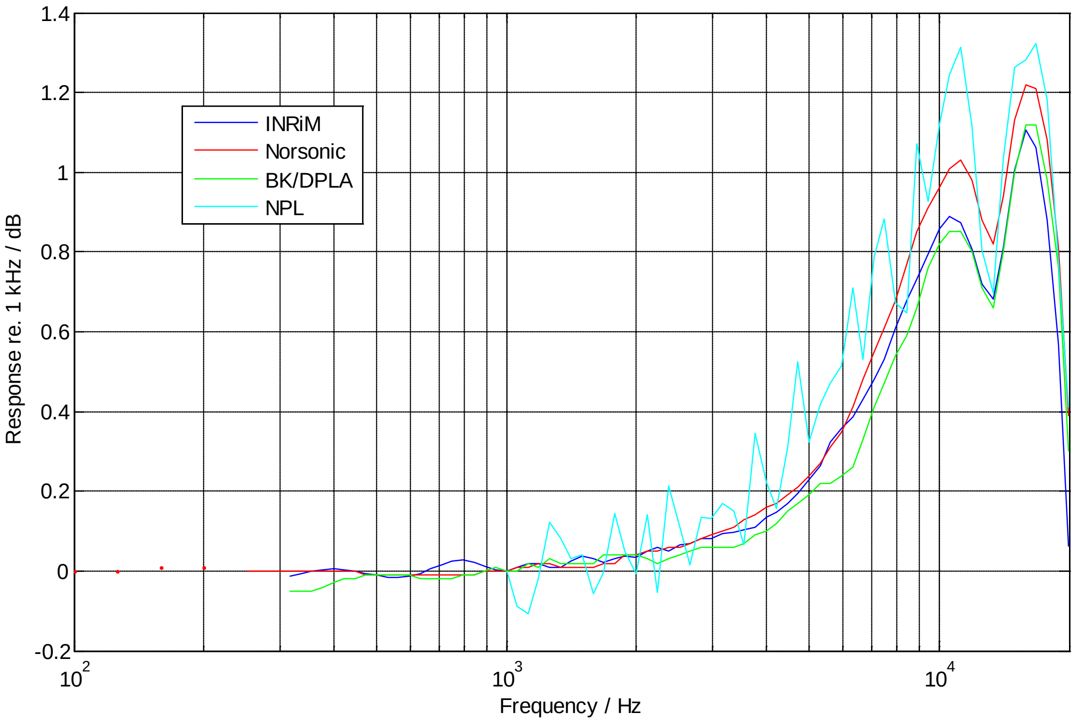

Figure 4.3.2. Microphone Free Field Response re. 1 kHz, ER laboratories.

The results among laboratories that use reflection elimination are more consistent, as results from the comparison of fig. 4.3.1 and 4.3.2.

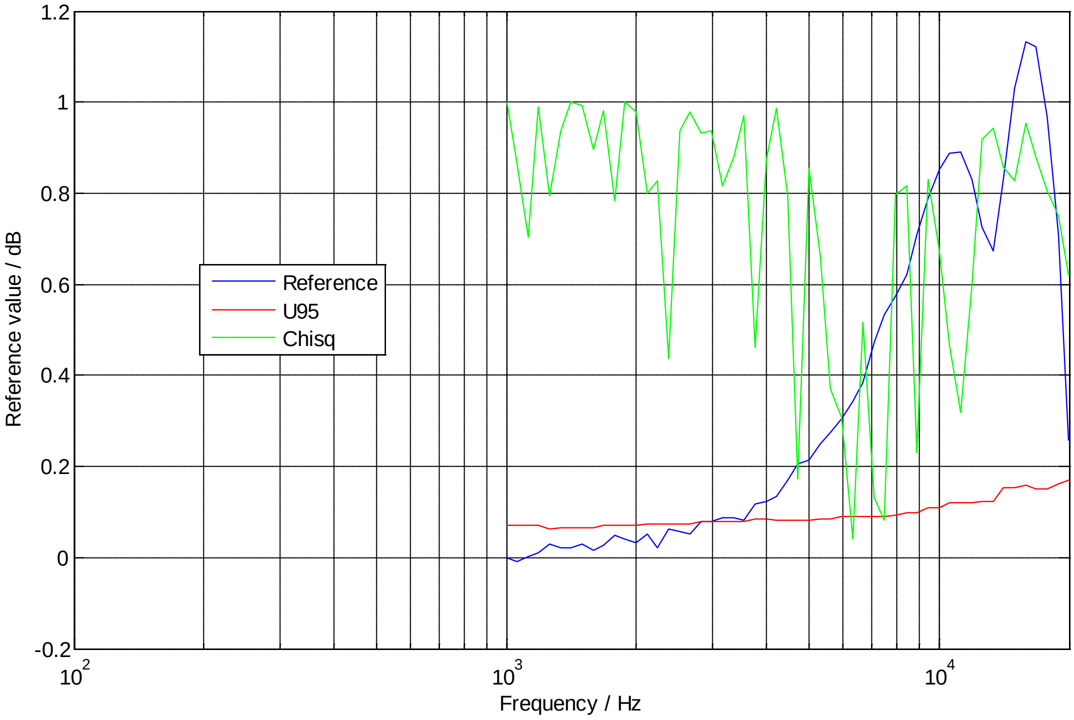

Figure 4.3.3. Reference values Laboratories that use techniques for reducing the effect of reflections. Reference value. χ^2 test scale is adimensional.

And finally, only laboratories that use time selective techniques (INRiM, Norsonic, DPLA) are compared. The consistency check is good.

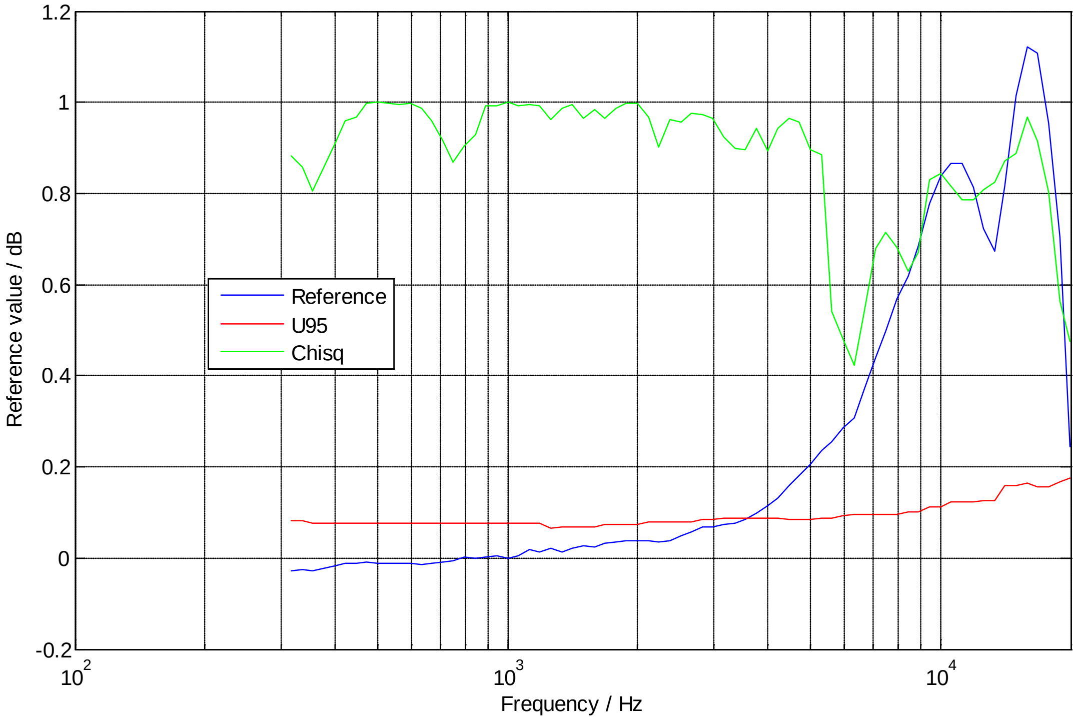

Figure 4.3.4. Reference values. Laboratories that use time selective techniques for reducing the effect of reflections. Reference value. χ^2 test scale is adimensional.

Traditional techniques seem reliable below 500 Hz-1 kHz, at higher frequencies it looks like that no anechoic room in this comparison is good enough, without enhancement techniques. Time series processing techniques in this case seem to get a smoother response than spatial average .

In any case below 1 kHz for a ½” microphone it is likely that the uncertainty may be higher than the difference between pressure and free field response.

4.4 Microphone Pressure and simulated Pressure responses

The protocol of project 1056 asked for optional measurement of pressure or simulated pressure (electrostatic actuator) response. Many laboratories performed one measurement, DPLA measured both pressure and actuator response. The pressure response was measured by means of multi frequency calibrator (MFC) by DPLA, IA, by simultaneous comparison by INRiM, Norsonic and NPL, Norsonic using a jig, INRiM a closed coupler (CC), NPL a CC up to 2 kHz and a jig above that frequency, all according to IEC standard 61094 part 5, Metas used an electrostatic actuator.

Only INRiM, Norsonic, Metas and DPLA measured at the required frequency spacing, and this fact makes comparison of results complicated. In any case different devices produce different pressure responses, as is clearly visible in fig. 4.4.1 that shows the deviations of each measurement from the average of all the pressure responses that were carried out at the required frequencies. The deviation in itself does not have a well defined significance, a smaller deviation does not imply that the measurement is good, the figure is presented just to put in evidence that a "pressure response" does not exist, it is always necessary to specify the method and device.

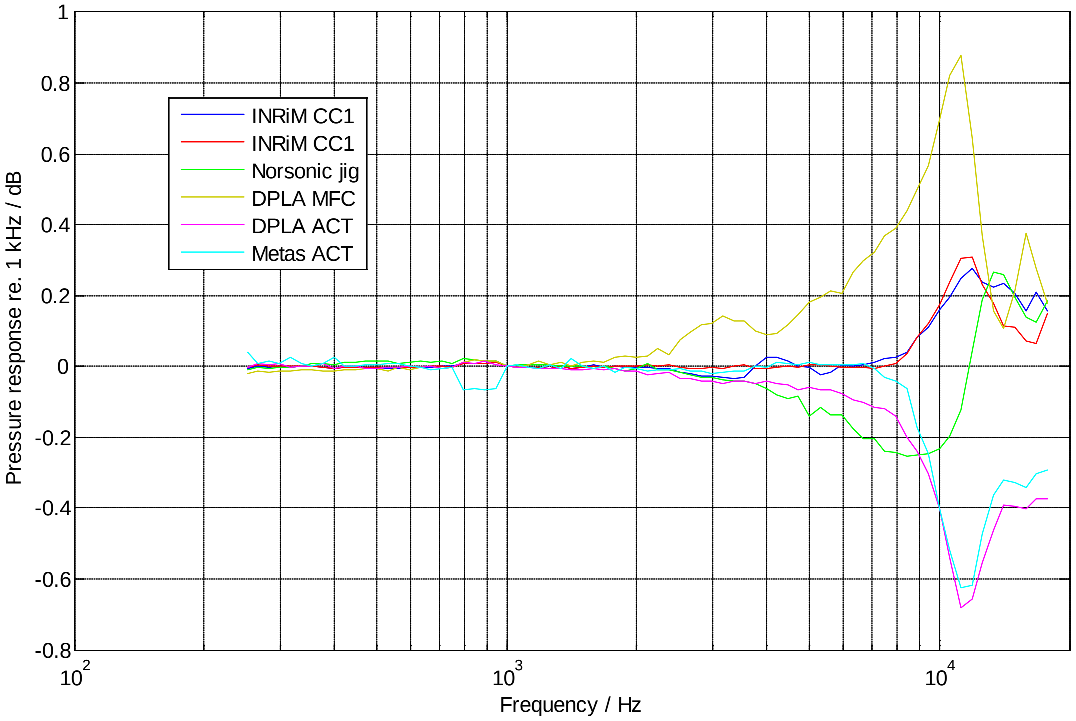

Fig. 4.4.1. Variation of pressure response, relative to 1 kHz. For ACT CC jig meanings, refer to text.

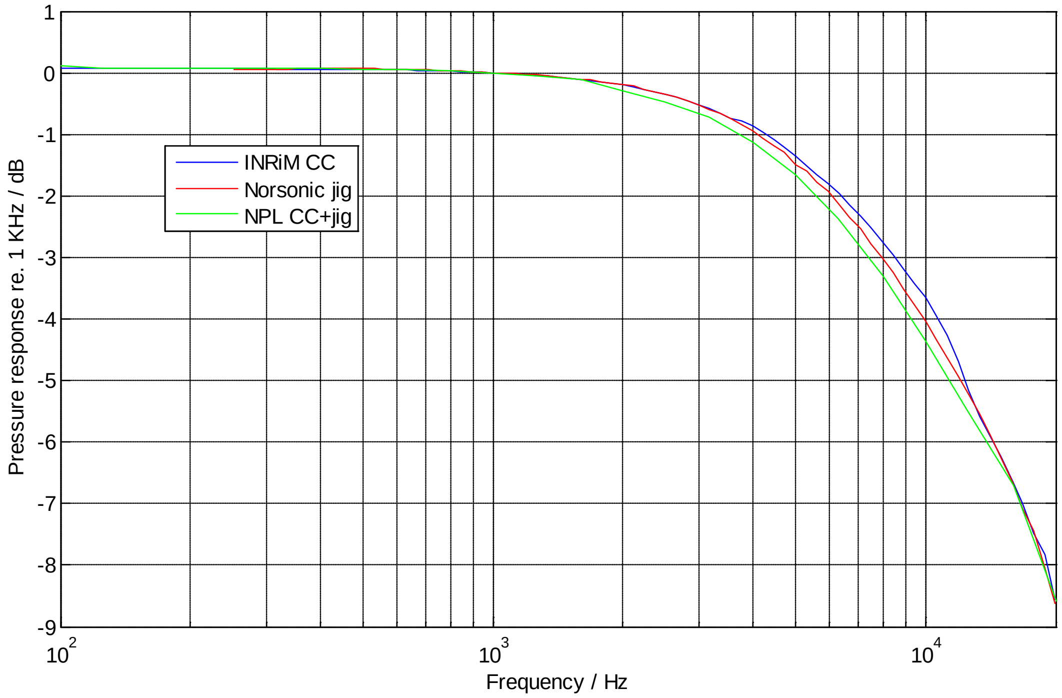

Figure 4.4.2. Pressure response relative to 1 kHz. Simultaneous comparison with CC and jig.

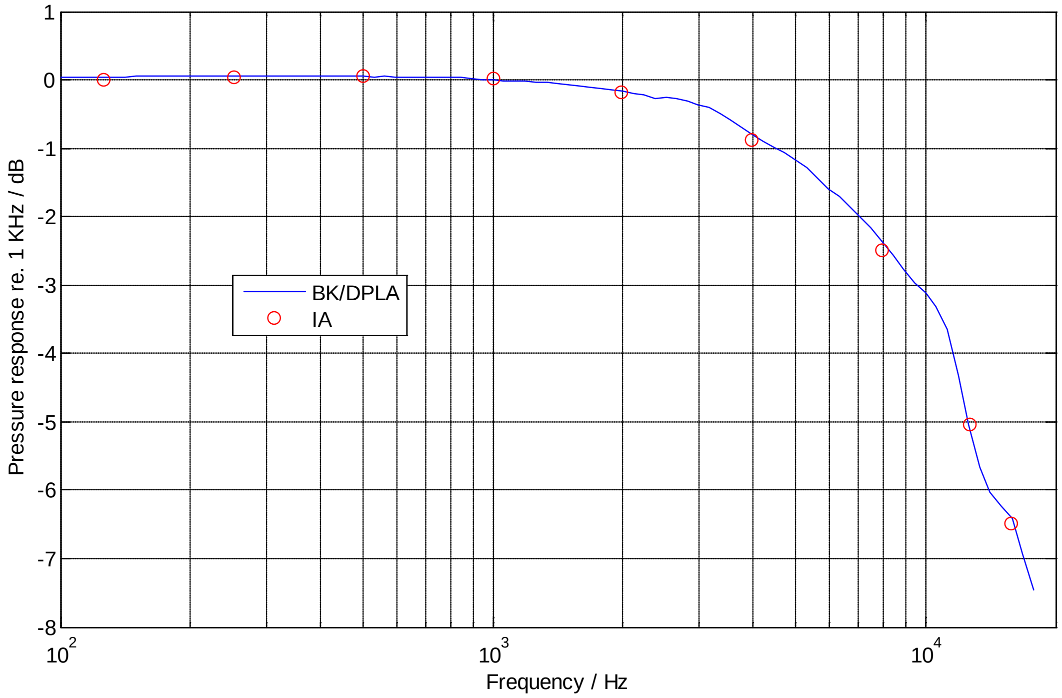

Figure 4.4.3. Pressure response relative to 1 kHz. Multi frequency calibrator.

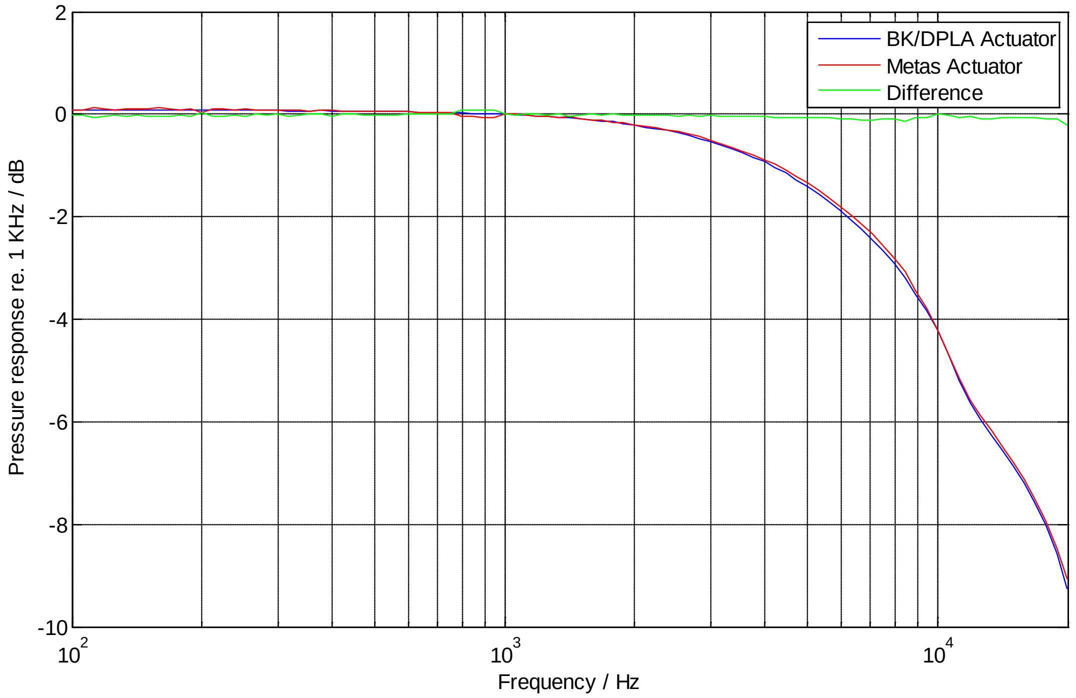

Figure 4.4.4. Pressure response relative to 1 kHz. Electrostatic actuator.

In figure 4.4.2 to 4.4.4 the pressure response measured are shown, grouped according to measurement method. The agreement of electrostatic actuator (fig. 4.4.4) and multi frequency calibrator (fig. 4.4.3), is very good.

The measurements using the jig were made with the test microphone grid removed, and this fact may explain the differences at high frequencies with the closed coupler measurement, as shown in fig. 4.4.2.

The number of measurements for each category is too low for any reasonable statistical analysis. It is however clear than when dealing with free field to pressure or actuator response corrections, it is necessary to specify what kind of pressure measurement and device are involved in the determination of the correction.

5. Stability of instrument under test

The pilot laboratory measured the SLM in November 2008, as scheduled in the timetable, and then after the end of measurements, in July 2009. The environmental parameters were different, in particular the temperature was 20-21 °C in the first measurement, 25,2 °C in the second, at the extremes of the range allowed in the IEC 62585 standard. In fig. 5.1 the results, at 1/12 octave frequencies, are reported. Differences at low frequency are probably due to windowing artefacts (a shorter window has been used in the last measurement, due to an earlier reflection in the modified mounting system).

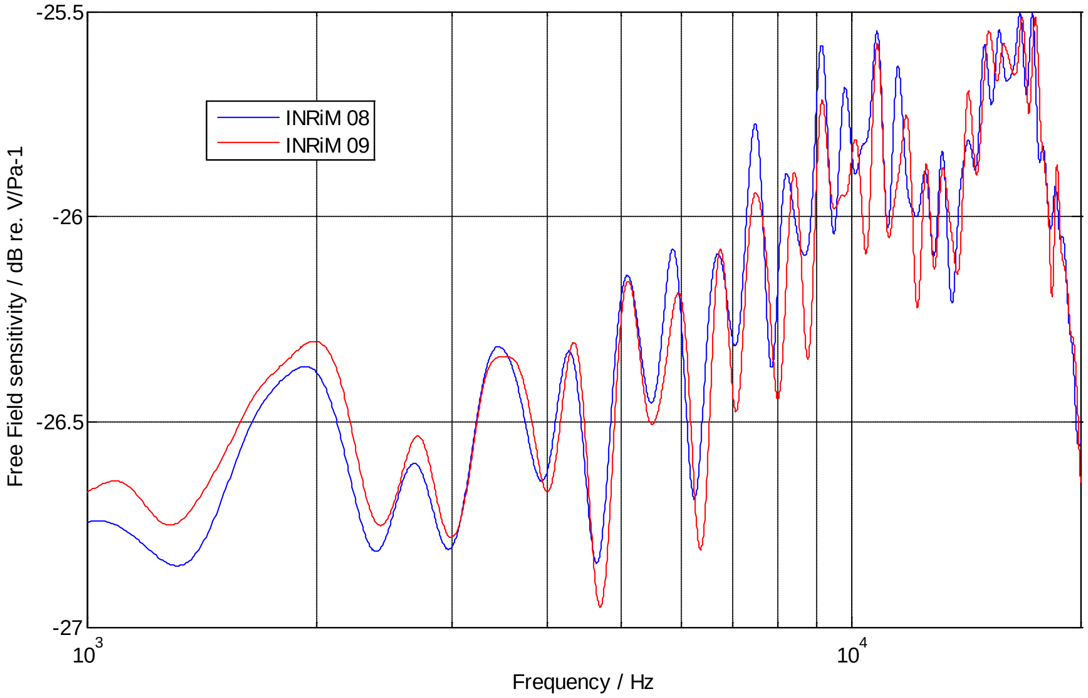

Figure 5.1 Free field response of SLM at INRiM, at the beginning and at the end of the circulation.

One of the participants (DPLA) corrected the frequency scale of the measurement according to the influence of temperature on the speed of sound. The laboratory performed measurements both at 20 °C and 23 °C and the correction was applied in order to avoid a smoothing of peaks and valleys in the response average.

The correction was applied to INRiM measurement, that were at the extreme of the temperature range allowed in IEC 62585 standard.

In fig. 5.2 the free field correction determined at INRiM is plotted both as measured and taking into account the different speed of sound, about 343,8 m/2 in the November 08 test at 20 °C and 347,4 m/s in the July 09 test at 25,2 °C.

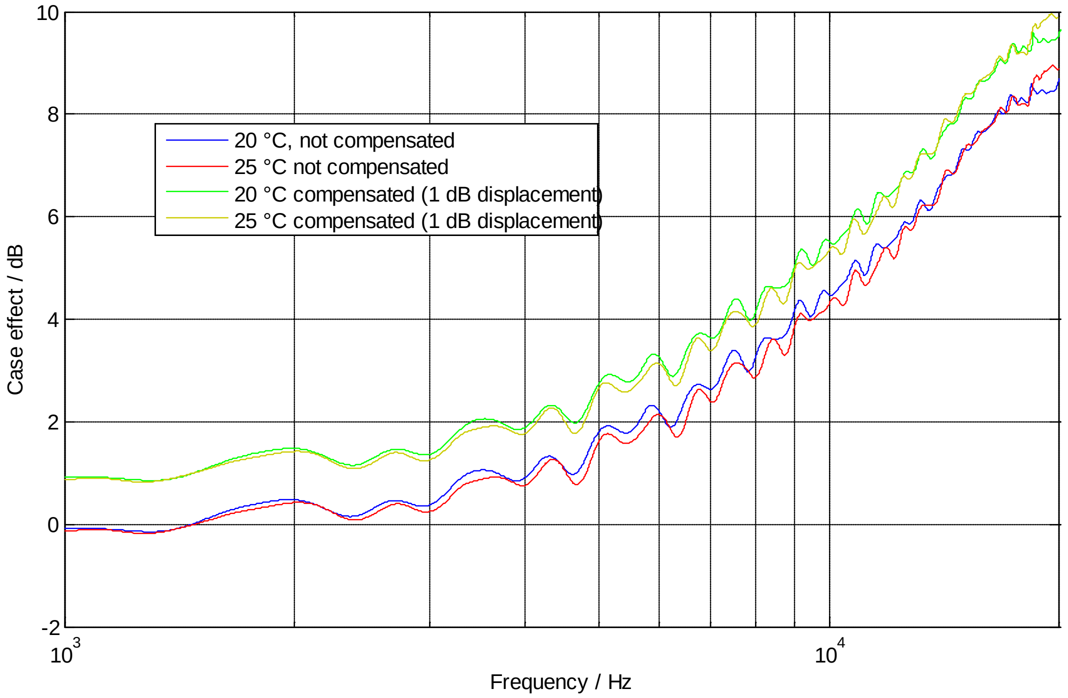

Figure 5.2. Free field correction with compensation for the speed of sound, both measurements referred to the speed of sound at 23 °C (reference temperature).

At frequencies between 1 and 5 kHz the effect is quite visible. At higher frequencies the large number of reflections complicates the pattern and the uncertainty is higher and the correction does not succeed in “aligning” the curves.

A check has been made on pressure response with comparison coupler. The environmental parameters changed in a way similar to Free Field response. In Table 5.1 the responses at the beginning and end of compassion are shown. The results are in both cases the ratio of the output voltages of the microphone of the SLM and of the reference microphone, and comprehend the gain of the measuring chain. The drift of the measurement chain is believed to be less than 0,05 dB.

The instrument may be considered stable within the limits typical of an instrument for the measurements of noise. The variation may be attributed to different environmental conditions. It appears that the difference in sensitivity to environmental conditions between the microphone under test and the LS2p reference microphone is not negligible and the uncertainty budget should consider this component in more detail. More investigation is needed but it is out of the scope of this project.

Please note that the values do not take into consideration the preamplifier gain in the reference channel, i.e. the values of the reference microphone are not open circuit values. Same preamplifier, reference microphone and measuring chain has been used in both tests.

Table 5.1. Pressure sensitivity at beginning and end of circulation

Frequency	Start	End	diff
	Nov-09	Jul-09	
Hz	dB	dB	dB
31,62	-26,61	-26,47	-0,15
39,81	-26,67	-26,46	-0,21
50,12	-26,60	-26,45	-0,15
63,10	-26,59	-26,46	-0,13
79,43	-26,59	-26,46	-0,13
100,00	-26,59	-26,46	-0,13
125,89	-26,59	-26,46	-0,13
158,49	-26,58	-26,46	-0,13
199,53	-26,59	-26,46	-0,13
251,19	-26,59	-26,46	-0,13
316,23	-26,60	-26,47	-0,13
398,11	-26,60	-26,47	-0,13
501,19	-26,61	-26,48	-0,13
630,96	-26,62	-26,49	-0,13
794,33	-26,63	-26,51	-0,13
1000,00	-26,66	-26,53	-0,13
1059,25	-26,67	-26,54	-0,13
1122,02	-26,68	-26,55	-0,13
1188,50	-26,69	-26,56	-0,13
1258,93	-26,70	-26,57	-0,13
1333,52	-26,71	-26,58	-0,13
1412,54	-26,73	-26,60	-0,13
1496,24	-26,74	-26,61	-0,13
1584,89	-26,76	-26,63	-0,13
1678,80	-26,78	-26,65	-0,13
1778,28	-26,80	-26,67	-0,13
1883,65	-26,83	-26,70	-0,13
1995,26	-26,86	-26,73	-0,13
2113,49	-26,89	-26,76	-0,13
2238,72	-26,93	-26,79	-0,14
2371,37	-26,97	-26,83	-0,14
2511,89	-27,01	-26,87	-0,14
2660,73	-27,06	-26,92	-0,14
2818,38	-27,11	-26,97	-0,14
2985,38	-27,17	-27,03	-0,15
3162,28	-27,24	-27,09	-0,15
3349,65	-27,32	-27,16	-0,16
3548,13	-27,40	-27,23	-0,16
3758,37	-27,45	-27,33	-0,12
3981,07	-27,52	-27,43	-0,10
4216,97	-27,62	-27,52	-0,10
4466,84	-27,74	-27,63	-0,11
4731,51	-27,87	-27,75	-0,12
5011,87	-28,01	-27,88	-0,13
5308,84	-28,17	-28,01	-0,15
5623,41	-28,31	-28,16	-0,15
5956,62	-28,45	-28,33	-0,12
6309,57	-28,62	-28,50	-0,12
6683,44	-28,80	-28,68	-0,12
7079,46	-28,98	-28,87	-0,11
7498,94	-29,18	-29,07	-0,10
7943,28	-29,39	-29,28	-0,11
8413,95	-29,62	-29,49	-0,12
8912,51	-29,84	-29,72	-0,12
9440,61	-30,08	-29,95	-0,14
10000,00	-30,32	-30,17	-0,14
10592,54	-30,59	-30,43	-0,17
11220,18	-30,93	-30,74	-0,19
11885,02	-31,35	-31,20	-0,16
12589,25	-31,83	-31,71	-0,12
13335,21	-32,25	-32,17	-0,08
14125,38	-32,56	-32,56	-0,01
14962,36	-32,91	-32,88	-0,03
15848,93	-33,29	-33,25	-0,04
16788,04	-33,65	-33,66	0,02
17782,79	-34,14	-34,02	-0,12
18836,49	-34,49	-34,78	0,29
19952,62	-35,21	-35,51	0,30

Except for noise problems around 50 Hz and poor repeatability at the two highest frequencies, it seems that around resonance the sensitivity change is very small, and that there is a sensitivity change that may be attributed at the (very) different environmental conditions. The pilot laboratory unfortunately did not make measurements of pressure sensitivity at or near reference conditions.

The manufacturer may help with his data, if available, on sensitivity to environmental parameters to check whether the change in sensitivity may be caused by environmental conditions variations. According to the results of this comparison, it may be possible that the sensitivity to temperature of the free field response is higher than the one of pressure response.

6. Conclusions.

The aim of the project was to assess the present situation in SLM Free Field measurements, and one of the requirement was to follow the standard measurement procedure in use at each laboratory.

The spirit of project was taken even too seriously by some of the participating laboratories, that submitted data in their own usual format and frequency values! This complicated somewhat the preparation of the report, and the analysis had to be separated according to different groups of laboratories, in order to make good use of all data submitted and of the work of each participant.

The additional information hopefully compensates the fact that the analysis is less rigorous.

One of the problem that seem to arise from a preliminary examination of the data, and from the comments expressed in the reports of some laboratory , is that the measurand is sometime elusive, and even if the repeatability is good over a short period of time, some outlier appears from time to time in the measurements. The complexity of the reflection/diffraction at high frequency, and its dependency on temperature, pressure, and speed of sound may explain these phenomena, or these effects may be caused by the occasional instability of the microphone.

This effects of course are amplified by the fact that measurements are made at fixed frequencies, either by sinusoidal signals, or by taking a spectrum line in measurements that use signal processing: this is a very taxing requirement for a response with narrow peaks and valleys that may shift in frequency with changes of environmental conditions. Therefore the uncertainties declared by laboratories are reasonable per se, but the reproducibility of the measurements at different places or in different conditions should include an additional component, or in other words, a method to evaluate repeatability should be defined clearly. The consistency check failed in many occasions, and it is suggested to repeat the comparison with the following modifications:

1. More stable and better characterised microphone (e.g. LS2p or even better a highly stable free field measurement microphone).
2. Use of a technique to reduce the effect of reflections even in anechoic rooms.
3. Standardised mounting for the SLM.
4. Standardised (or agreed) method for low frequency measurement for laboratories that use time selective techniques and are not able to perform measurement over the whole frequency range.
5. If possible, circulate a device for pressure response.
6. Last but not least, strict respect of the test frequencies!

This new project may be proposed as a formal comparison, and be used to support the CMC for SLM.

7. Bibliography

[1] M.G. Cox. The evaluation of key comparison data. *Metrologia, 2002, 39, 585-595*

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