FINAL REPORT ON THE EURAMET KEY COMPARISON EURAMET.AUV.V-K3

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1. Introduction

This report presents the result of the first EURAMET comparison in the area in ‘’low frequency vibration’’ what in this case means sinusoidal acceleration between DC and 200 Hz following [1] and [2].

The report defines a weighted mean (WM), for those cases, where applicable, and reports the respective Degrees of Equivalence.

The technical protocol (c.f. App A) specifies in detail the aim and the task of the comparison, the conditions of measurements, the transfer standard used, measurement instructions and other items. A brief overview is given in the following sections

2. Participants

NMIs of nine European countries took part in the comparison. They are listed in chronological order of measurement in table 2.

Table 2.1: List of participants and schedule of Euramet.AUV.V-K3

Participant number	Particpant Laboratory	Acronym	Country	Calibration period (week/year)
1	Laboratoire National de métrologie et d’Essais	LNE	France	12/12/2011 to 06/01/2012
2	Czech Metrology Institute	CMI	Czech Republic	10/02 to 28/02/2012
3	SP Technical Research Institute of Sweden	SP	Sweden	23/03 to 10/04/2012
4	Swiss federal office of metrology	METAS	Switzerland	30/04 to 20/05/2012
5	Istituto Nazionale di Ricerca Metrologica	INRIM	Italy	24/08 to 08/10/2012
6	Central Office of Measures	GUM	Poland	29/11 to 18/12/2012
7	Centro Español de Metrología	CEM	Spain	17/01 to 30/01/2013
8	Physikalisch-Technische Bundesanstalt	PTB	Germany	08/02 to 07/03/2013

9	Danish Primay Laboratory of Acoustics	DPLA	Denmark	23/03 to 23/05/2013
10	Centre for Metrology and Accreditation	MIKES	Finland	23/06 to 28/08/2013

3. Task and purpose of the comparison

In the field of vibration, this comparison was organised in order to compare measurements of sinusoidal linear accelerations in the frequency range DC to 200 Hz with a mandatory range from 1 Hz to 80 Hz.
Recent development and improvements done by several NMIs have extended the low frequency vibration limit of calibration capabilities down to 0,5 Hz and even lower. During the EURAMET TC-AUV meeting in 2010, it was agreed that a low frequency comparison is needed. Two other RMO comparison in low frequency range were under progress: APMP.AUV.V-S1 and AFRIMETS.AUV.V-S2.

During the circulating period from February 2011 to September 2013, 10 national metrology institutes (NMIs) from EURAMET calibrated one Q Flex accelerometer (servo type) as transfer standard by primary method. It was the task of the comparison to measure the magnitude and the phase of the complex sensitivity of the standard at different frequencies specified in the technical protocol (TP) and in a certain range of acceleration (cf. appendix A).

The voltage sensitivity is calculated as the ratio of the amplitude of the accelerometer standard output voltage to the amplitude of the acceleration at its reference surface. The magnitude of the amplitude voltage sensitivity is given in millivolts per meter per second square (mV/(m/s^2)) for the different measurement conditions specified in section 4 of the TP.

For the calibration of this accelerometer, all NMIs applied laser interferometry in compliance with the international standard ISO 16063-11:1999 in order to cover the entire frequency range chosen within a specified range of the acceleration amplitude with specified uncertainties.

The reported sensitivity and associated uncertainties of measurements were used for the calculation of the weighted mean (WM).

4. Transfer standard as artefacts

For the purpose of the comparison, the pilot laboratory monitored one of its own accelerometers for about 2 years. It is the accelerometer QA 700 SN 39477. The accelerometer is fixed on the WB 3519 conditioning module, which convert the output of the accelerometer in mA/(m/s^2) to a voltage sensitivity in mV/(m/s^2). This conditioning module must be supplied and a junction box WB 3479 is used for that purpose. It has to be connected to a +15 / 0 / -15V power supply unit (3 banana plugs) and from chassis/shield to ground or 0 V (1 banana plug) on the measurement instrument. The supply voltage shall be accurate within +/- 0.2 V.

To increase the sensitivity of the accelerometer and to reduce phenomena linked to ground troubles, some modifications were made in the conditioning module WB 3519. Hence, the nominal sensitivity of the accelerometer after modification was 500 mV(m/s²).

The investigation of the long term stability was continued throughout the circulation period. The results of the LNE stability measurements of the transfer standard are given section 6.

5. Circulation of the artefacts

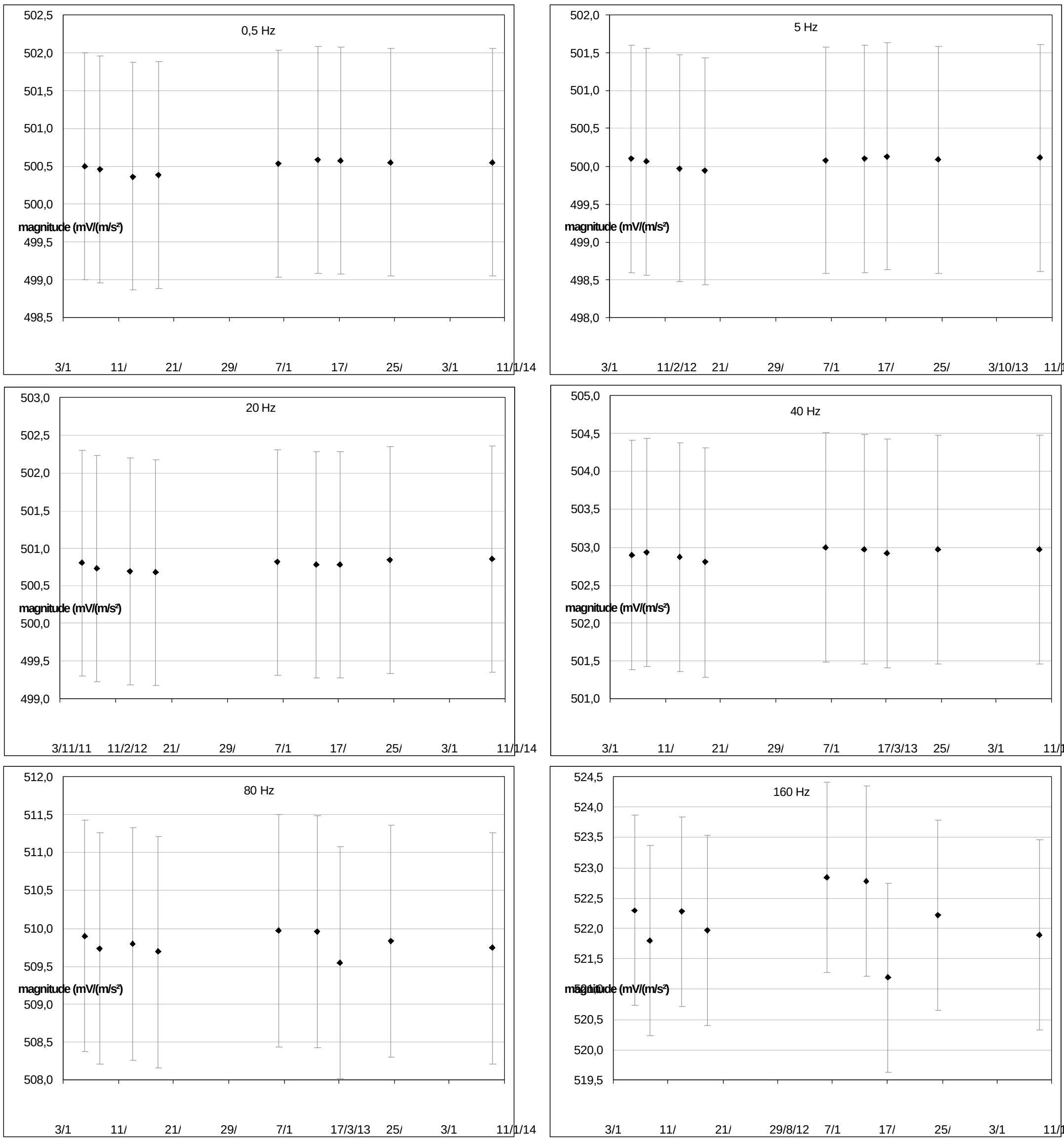
The transducer was circulated in a star type fashion with a measurement period of two weeks provided for each participant and two weeks for the pilot laboratory also. Between each measurement by a participant, a monitoring measurement of the accelerometer was performed except for two times where it was not possible. Two times, the monitoring was not possible due to troubles with the calibration system of the pilot laboratory. It was agreed by all the participants to continue the measurements without monitoring.

6. Results of the monitoring measurements

The artefact was monitored by the pilot laboratory during the whole comparison. Due to the star type typology, typically a monitoring measurement was performed between each of the participant's measurement. Due to troubles with the calibration system of the pilot lab, two monitorings were not performed.

As a representative of the overall change, the measurements at several example frequencies are presented in figure 6. They depict the stability of the artefact over time for the duration of the comparison.

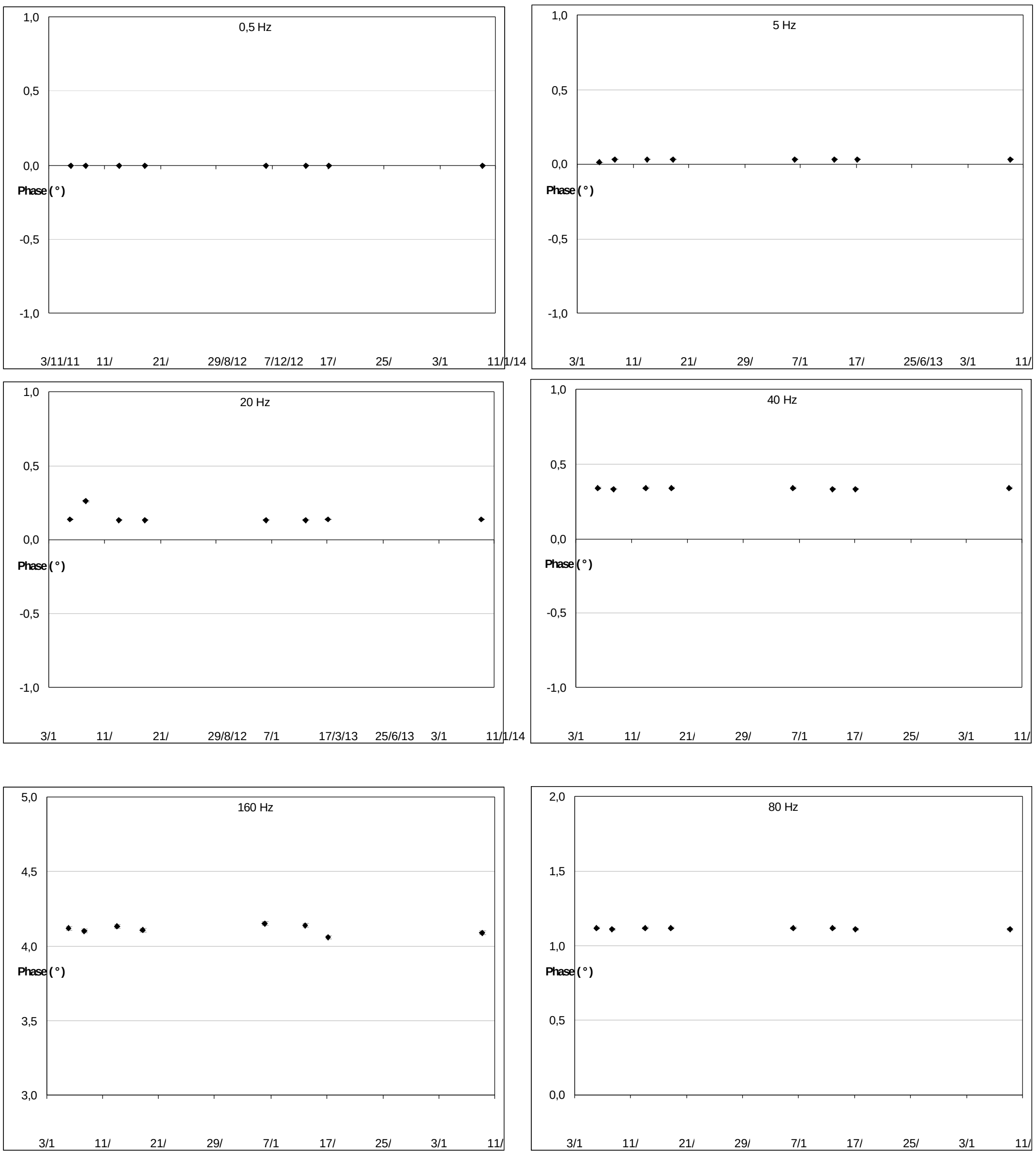
Figure 6.1 Monitoring of the amplitude sensitivity over the comparison period



The visual inspection of the graphed results allows to conclude that the device was sufficiently stable during the whole period of the comparison.

Concerning the phase of the complex sensitivity, the following graphs present the phase measured at some example frequencies. No uncertainties are presented as the pilot doesn't supply official results. The scale gives information about the deviation as it is absolute deviation to the mean in °. Compared to the uncertainties claimed by the participants, it can be concluded that the phase of the complex sensitivity of the sensor did not drift during the comparison.

Figure 6.2 Monitoring of the phase sensitivity over the comparison period



7. Results of the participants

The following sections report the results submitted by the participants of the comparison to the pilot laboratory using the mandatory report spreadsheet. The results presented are in mV/(m/s²) for the magnitude and in ° for the phase.

The axis of the excitation was the horizontal one for all the participants of this comparison.

7.1 Results for the magnitude of the complex sensitivity

table 7.1: Reported participant's results for the magnitude of the accelerometer with relative expanded uncertainties (*k*=2)

	LNE		CMI		SP		METAS		INRIM	
actual frequency	magnitude of voltage sensitivity	rel. exp. Unc.	magnitude of voltage sensitivity	rel. exp. Unc.	magnitude of voltage sensitivity	rel. exp. Unc.	magnitude of voltage sensitivity	rel. exp. Unc.	magnitude of voltage sensitivity	rel. exp. Unc.
in Hz	mV/(m/s²)	%	mV/(m/s²)	%	mV/(m/s²)	%	mV/(m/s²)	%	mV/(m/s²)	%
DC			500,2	0,2	500,1	0,2	500,06	0,01	500,0	0,4
0,1			509,0	1,7						
0,125			506,1	1,1						
0,16			504,5	0,8						
0,2			502,8	0,5			501,5	0,47		
0,25			501,8	0,4			499,8	0,38		
0,315			501,5	0,4	495,3	1,8	500,0	0,34		
0,4			501,3	0,4	497,0	1,1	500,3	0,32		
0,5	500,5	0,3	500,9	0,4	498,2	0,8	500,2	0,32	498,8	0,4
0,63	500,3	0,3	500,7	0,4	499,0	0,5	500,3	0,31		
0,8	500,0	0,3	500,6	0,4	499,4	0,4	500,2	0,31	498,3	0,4
1	500,1	0,3	500,6	0,4	499,6	0,3	500,3	0,30	497,9	0,4
1,25	500,1	0,3	500,8	0,4	499,7	0,3	500,3	0,30	498,4	0,4
1,60	500,1	0,3	500,8	0,4	499,8	0,3	500,4	0,30	498,9	0,4
2	500,2	0,3	500,6	0,4	499,9	0,3	500,2	0,30	499,2	0,4
2,50	500,0	0,3	500,7	0,4	500,1	0,3	500,3	0,29	499,2	0,4
3,15	500,1	0,3	500,6	0,4	500,0	0,3	500,3	0,29	499,2	0,4
4	500,1	0,3	500,6	0,4	500,1	0,3	500,3	0,29	499,0	0,4
5	500,1	0,3	500,6	0,4	500,1	0,3	500,4	0,24	499,1	0,4
6,3	500,1	0,3	500,7	0,4	500,2	0,3	500,5	0,24	499,1	0,4
8	500,2	0,3	500,9	0,4	500,2	0,3	500,5	0,24	499,2	0,4
10	500,2	0,3	500,8	0,4	500,3	0,3	500,6	0,37	499,2	0,4
12,5	500,3	0,3	500,9	0,4	500,5	0,3	500,6	0,37	499,3	0,4
16	500,5	0,3	501,1	0,4	500,6	0,3	500,8	0,37	499,7	0,4
20	500,8	0,3	501,5	0,4	500,9	0,3	501,0	0,37	500,1	0,4
25	501,2	0,3	502,1	0,4	501,3	0,3	501,4	0,36	500,4	0,4
31,5	501,9	0,3	502,9	0,4	502,0	0,3	502,1	0,36	501,2	0,4
40	502,9	0,3	503,6	0,4	502,8	0,3	503,2	0,36	502,3	0,4
50	504,4	0,3	504,8	0,4	502,9	0,3	504,9	0,36	504,1	0,4
63	506,7	0,3	507,2	0,4	505,8	0,4	507,0	0,70	506,3	0,4
80	509,9	0,3	509,7	0,4	509,7	0,4	510,2	0,70	508,7	0,4
100	513,7	0,3	513,8	0,4	513,8	0,4	514,1	0,70	513,7	0,4
125	518,0	0,3	518,1	0,4	519,0	0,4	518,6	0,70	517,9	0,4
160	522,3	0,3	522,7	0,4			522,7	0,70	522,0	0,4
200			519,0	0,4	522,1	1,1	525,3	0,70		

	GUM		CEM		PTB		DPLA		MIKES	
actual frequency	magnitude of voltage sensitivity	rel. exp. Unc.	magnitude of voltage sensitivity	rel. exp. Unc.	magnitude of voltage sensitivity	rel. exp. Unc.	magnitude of voltage sensitivity	rel. exp. Unc.	magnitude of voltage sensitivity	rel. exp. Unc.
in Hz	mV/(m/s²)	%	mV/(m/s²)	%	mV/(m/s²)	%	mV/(m/s²)	%	mV/(m/s²)	%
DC					500,00	0,2	500,21	0,05		
0,1					497,72	0,5	500,4	0,5		
0,125					498,79	0,5	500,3	0,5		
0,16					498,83	0,5	500,4	0,5		
0,2					499,45	0,3	499,9	0,4		
0,25					499,25	0,3	499,9	0,4		
0,315					499,69	0,3	499,9	0,4		
0,4			499,9	0,5	499,62	0,2	499,9	0,4		
0,5			499,9	0,5	499,72	0,2	500,0	0,4		
0,63			499,9	0,5	499,70	0,2	499,9	0,4		
0,8			499,9	0,5	499,78	0,2	499,9	0,4		
1	500,40	0,7	499,9	0,5	499,82	0,2	499,9	0,4	499,6	0,5
1,25	500,41	0,7	499,9	0,5	499,81	0,2	499,9	0,4	499,7	0,5
1,60	500,32	0,7	499,9	0,5	499,82	0,2	499,9	0,4	499,7	0,5
2	500,18	0,7	499,9	0,5	499,87	0,2	499,9	0,4	499,6	0,5
2,50	500,24	0,7	499,9	0,5	499,75	0,2	499,9	0,4	499,7	0,5
3,15	500,18	0,7	499,9	0,5	499,75	0,2	499,9	0,4	500,0	0,5
4	500,22	0,7	499,9	0,5	499,81	0,2	500,0	0,4	499,9	0,5
5	500,32	0,7	500,0	0,5	499,72	0,2	500,0	0,4	500,0	0,5
6,3	500,34	0,7	500,0	0,5	499,75	0,2	500,0	0,4	500,1	0,5
8	500,32	0,7	500,1	0,5	499,76	0,2	500,0	0,4	500,1	0,5
10	500,42	0,6	500,1	0,5	499,78	0,1	500,1	0,4	500,1	0,5
12,5	500,48	0,6	500,1	0,5	499,90	0,1	500,2	0,4	500,1	0,5
16	500,70	0,6	500,4	0,5	500,12	0,1	500,4	0,4	500,3	0,5
20	500,97	0,5	500,7	0,5	500,44	0,1	500,8	0,4	500,5	0,5
25	501,41	0,5	501,1	0,5	500,86	0,1	501,2	0,5	501,0	0,5
31,5	502,04	0,5	501,8	0,5	501,57	0,1	501,7	0,5	501,6	0,5
40	503,03	0,5	502,8	0,5	502,64	0,1	502,5	0,5	502,4	0,5
50	506,07	0,5	504,3	0,5	504,15	0,1	504,5	0,5	504,3	0,6
63	506,74	0,5	506,4	0,5	506,41	0,1	505,9	0,5	506,3	0,6
80	510,04	0,6	510,3	0,5	509,67	0,1	515,8	1,5	509,0	1,0
100	513,96	0,6			513,71	0,1				
125	518,45	0,6			517,84	0,1				
160	522,14	0,7			522,45	0,1				
200					525,05	0,1				

7.2 Results for the phase of the complex sensitivity

table 7.2: Reported participant's results for the phase shift of the accelerometer with absolute expanded uncertainties (*k*=2)

	LNE		CMI		SP		METAS		INRIM	
actual frequency	phase of voltage sensitivity	abs. exp. Unc.	phase of voltage sensitivity	abs. exp. Unc.	phase of voltage sensitivity	abs. exp. Unc.	phase of voltage sensitivity	abs. exp. Unc.	phase of voltage sensitivity	abs. exp. Unc.
in Hz	in °		in °		in °		in °		in °	
DC										
0,1			0,06	0,30						
0,125			-0,01	0,30						
0,16			-0,01	0,30						
0,2			0,02	0,30			-0,08	0,78		
0,25			0,01	0,30			0,09	0,78		
0,315			0,00	0,30	-0,02	0,30	0,07	0,78		
0,4			0,00	0,30	-0,02	0,30	0,03	0,78		
0,5			0,00	0,30	-0,01	0,30	0,03	0,78		
0,63			0,00	0,30	0,00	0,30	0,01	0,78		
0,8			0,01	0,30	-0,01	0,30	0,02	0,78		
1			-0,08	0,30	-0,01	0,30	0,01	0,46		
1,25			-0,12	0,30	-0,01	0,30	0,00	0,46		
1,6			-0,15	0,30	-0,01	0,30	0,00	0,46		
2,0			-0,20	0,30	-0,01	0,30	0,00	0,46		
2,50			-0,21	0,30	-0,01	0,30	-0,01	0,46		
3,15			-0,14	0,30	-0,02	0,30	-0,02	0,46		
4			-0,15	0,30	-0,02	0,30	-0,02	0,46		
5			-0,08	0,30	-0,03	0,30	-0,03	0,46		
6,3			-0,07	0,30	-0,04	0,30	-0,03	0,46		
8			-0,03	0,30	-0,05	0,30	-0,05	0,46		
10			-0,01	0,30	-0,06	0,30	-0,07	0,46		
12,5			0,03	0,30	-0,08	0,30	-0,10	0,40		
16			-0,06	0,30	-0,09	0,30	-0,11	0,40		
20			-0,10	0,30	-0,13	0,30	-0,14	0,40		
25,0			-0,14	0,30	-0,18	0,30	-0,17	0,41		
31,5			-0,19	0,30	-0,25	0,30	-0,24	0,41		
40			-0,34	0,30	-0,34	0,30	-0,33	0,41		
50			-0,44	0,50	-0,43	0,30	-0,47	0,41		
63			-0,68	0,50	-0,65	0,30	-0,71	0,72		
80			-1,08	0,50	-1,11	0,30	-1,08	0,72		
100			-1,67	0,50	-1,68	0,30	-1,73	0,72		
125			-2,57	0,50	-2,59	0,40	-2,66	0,72		
160			-4,04	0,50			-4,00	0,72		
200			-5,89	0,50			-5,89	0,72		

	GUM		CEM		PTB		DPLA		MIKES	
actual frequency	phase of voltage sensitivity	abs. exp. Unc.	phase of voltage sensitivity	abs. exp. Unc.	phase of voltage sensitivity	abs. exp. Unc.	phase of voltage sensitivity	abs. exp. Unc.	phase of voltage sensitivity	abs. exp. Unc.
in Hz	in °		in °		in °		in °		in °	
DC										
0,1					-0,05	0,20	-0,20	0,30		
0,125					-0,16	0,20	0,00	0,30		
0,16					-0,07	0,20	0,00	0,30		
0,2					-0,09	0,20	0,00	0,30		
0,25					-0,05	0,20	0,00	0,30		
0,315					-0,04	0,20	0,00	0,30		
0,4			-0,07	0,50	-0,06	0,20	0,00	0,30		
0,5			-0,06	0,50	-0,05	0,20	0,00	0,30		
0,63			-0,05	0,50	-0,04	0,20	0,00	0,30		
0,8			-0,04	0,50	-0,05	0,20	0,00	0,30		
1	-0,04	0,70	-0,04	0,50	-0,03	0,20	-0,01	0,30	-0,02	0,60
1,25	-0,03	0,70	-0,03	0,50	-0,05	0,20	-0,01	0,30	-0,03	0,60
1,6	-0,03	0,70	-0,03	0,50	-0,05	0,20	-0,01	0,30	0,00	0,60
2,0	-0,03	0,70	-0,03	0,50	-0,06	0,20	-0,01	0,30	-0,03	0,60
2,50	-0,03	0,70	-0,03	0,50	-0,04	0,20	-0,01	0,30	-0,05	0,60
3,15	-0,03	0,70	-0,03	0,50	-0,05	0,20	-0,02	0,30	-0,04	0,60
4	-0,03	0,70	-0,03	0,50	-0,07	0,20	-0,02	0,30	-0,05	0,60
5	-0,04	0,70	-0,04	0,50	-0,05	0,20	-0,03	0,30	-0,06	0,60
6,3	-0,04	0,70	-0,04	0,50	-0,07	0,20	-0,04	0,30	-0,06	0,60
8	-0,05	0,70	-0,05	0,50	-0,09	0,20	-0,05	0,30	-0,09	0,60
10	-0,06	0,70	-0,07	0,50	-0,09	0,20	-0,06	0,30	-0,10	0,60
12,5	-0,07	0,70	-0,10	0,50	-0,12	0,20	-0,08	0,30	-0,14	0,60
16	-0,09	0,70	-0,11	0,50	-0,15	0,20	-0,10	0,30	-0,18	0,60
20	-0,13	0,60	-0,13	0,50	-0,19	0,20	-0,14	0,30	-0,24	0,60
25,0	-0,17	0,60	-0,18	0,50	-0,24	0,20	-0,20	0,30	-0,29	0,60
31,5	-0,23	0,60	-0,24	0,50	-0,32	0,20	-0,23	0,50	-0,40	0,60
40	-0,32	0,60	-0,33	0,50	-0,43	0,20	-0,29	0,50	-0,52	0,60
50	-0,42	0,60	-0,47	0,50	-0,59	0,20	-0,44	0,50	-0,68	0,70
63	-0,72	0,70	-0,70	0,50	-0,85	0,20	-0,8	1,0	-1,11	0,70
80	-1,07	0,70	-0,91	0,50	-1,28	0,20	-0,8	1,0	-1,5	1,1
100	-1,70	0,70			-1,86	0,20				
125	-2,65	0,70			-2,87	0,20				
160	-4,09	0,80			-4,40	0,20				
200					-6,32	0,20				

8. Degrees of equivalence with respect to the weighted mean

The evaluation of the results was performed using a weighted mean of the form :

$$x_{WM}(f) = \sum \frac{x_i(f)}{u_i^2(f)} \cdot \left(\sum \frac{1}{u_i^2(f)} \right)^{-1} \qquad (1)$$

$$u_{WM}(f) = \left(\sum \frac{1}{u_i^2(f)} \right)^{-1/2} \qquad (2)$$

where the summation was performed over the largest consistent subset of the results of the participants according to (1). In the equations the following shortcuts were used:

$x_i(f)$ Result of participant i of the largest consistent subset at frequency f

$u_i(f)$ absolute standard uncertainty of participant i of the largest consistent subset at frequency f

$x_{\mathrm{WM}}(f)$ best estimate of the weighted mean (WM) sensitivity at frequency f

$u_{\mathrm{WM}}(f)$ estimated absolute standard uncertainty for the weighted mean (WM) at frequency f

Consistency check was performed for phase and magnitude of the complex sensitivity. The consistency test defined by Cox in [3,4] was applied in order to determine the participants that are members of the largest consistent subset (MoCS).

Tale 8.0 presents the results of the consistency test for both magnitude and phase results.
Cells in yellow are when $X^2obs > X^2(nu)$

Table 8.0 : results of the consistency test respectively for amplitude (left) and phase (right)

Frequency	number of participants	number of degrees of freedom	X²obs	X²(nu) with P<0,05
DC	6	5	1,56	11,07
0,1	3	2	7,38	5,991
0,125	3	2	5,77	5,991
0,16	3	2	5,71	5,991
0,2	4	3	6,37	7,815
0,25	4	3	4,26	7,815
0,315	5	4	3,46	9,488
0,4	6	5	3,56	11,07
0,5	8	7	3,81	14,067
0,63	7	6	1,81	12,592
0,8	8	7	3,36	14,067
1	10	9	5,06	16,919
1,25	10	9	3,67	16,919
1,6	10	9	2,35	16,919
2	10	9	1,35	16,919
2,5	10	9	1,70	16,919
3,15	10	9	1,38	16,919
4	10	9	1,76	16,919
5	10	9	2,09	16,919
6,3	10	9	2,33	16,919
8	10	9	2,33	16,919
10	10	9	2,76	16,919
12,5	10	9	2,55	16,919
16	10	9	2,12	16,919
20	10	9	2,01	16,919
25	10	9	2,49	16,919
31,5	10	9	2,42	16,919
40	10	9	1,54	16,919
50	10	9	6,28	16,919
63	10	9	1,46	16,919
80	10	9	3,96	16,919
100	7	6	0,08	12,592
125	7	6	1,46	12,592
160	6	5	0,32	11,07
200	4	3	32,85	7,815

Frequency	number of participants	number of degrees of freedom	X²obs	X²(nu) with P<0,05
DC				
0,1	3	2	1,49	5,991
0,125	3	2	1,13	5,991
0,16	3	2	0,21	5,991
0,2	4	3	0,46	7815
0,25	4	3	0,23	7,815
0,315	5	4	0,14	9,488
0,4	6	5	0,21	11,07
0,5	6	5	0,15	11,07
0,63	6	5	0,10	11,07
0,8	6	5	0,15	11,07
1	8	7	0,18	2,167
1,25	8	7	0,42	14,067
1,6	8	7	0,65	14,067
2	8	7	1,20	14,067
2,5	8	7	1,34	14,067
3,15	8	7	0,48	14,067
4	8	7	0,57	14,067
5	8	7	0,09	14,067
6,3	8	7	0,06	14,067
8	8	7	0,14	14,067
10	8	7	0,18	14,067
12,5	8	7	0,72	14,067
16	8	7	0,30	14,067
20	8	7	0,30	14,067
25	8	7	0,36	14,067
31,5	8	7	0,66	14,067
40	8	7	0,71	14,067
50	8	7	1,28	14,067
63	8	7	1,53	14,067
80	8	7	2,77	14,067
100	5	4	1,37	9,488
125	5	4	2,65	9,488
160	4	3	3,00	7,815
200	3	2	3,55	5,991

8.1 Results for the magnitude of the complex sensitivity

In the following section, the results of the participants are given in a tabulated form and in a graphical representation with reference to the WM (zero line) for each frequency.

Results which were excluded from the largest consistent subset (non MoCS) and which therefore did not contribute to the WM are also marked by a asterisk (*).
For the further evaluation of the comparison the degrees of equivalence with respect to the WM are proposed to be calculated according to:

$$d_{i,WM}(f) = x_i(f) - x_{WM}(f) \qquad (3)$$

$$u^2_{i,WM}(f) = \begin{cases} u_i^2(f) - u_{WM}^2(f) & \text{for MoCs} \\ u_i^2(f) + u_{WM}^2(f) & \text{for non MoCS} \end{cases} \qquad (4)$$

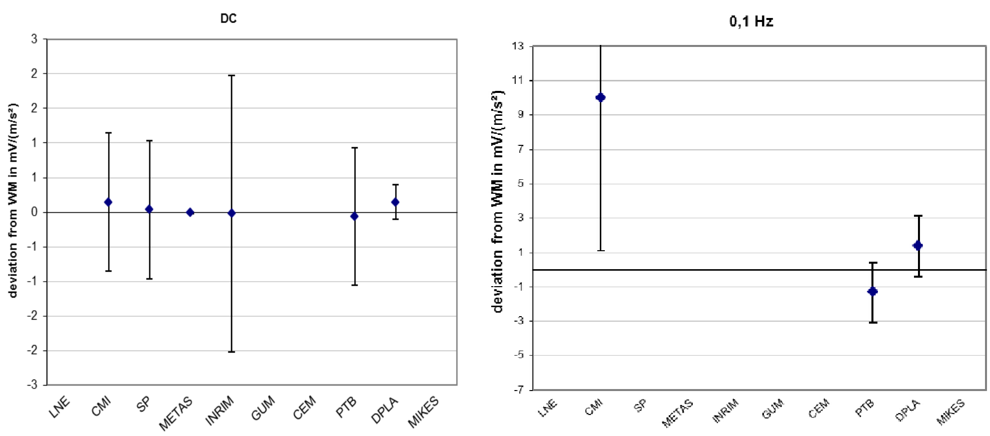
The formulas are applicable for both phase and magnitude results. In the subsequent table results with $d_{i,WM}(f) > 2.u_{i,WM}(f)$ are marked by a yellow background.

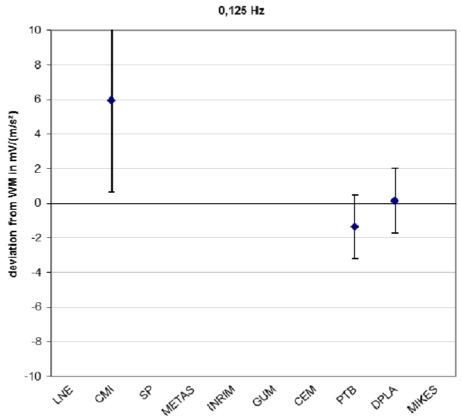
Table 8.1.1: Unilateral degrees of equivalence for the magnitude of sensitivity with absolute standard uncertainties

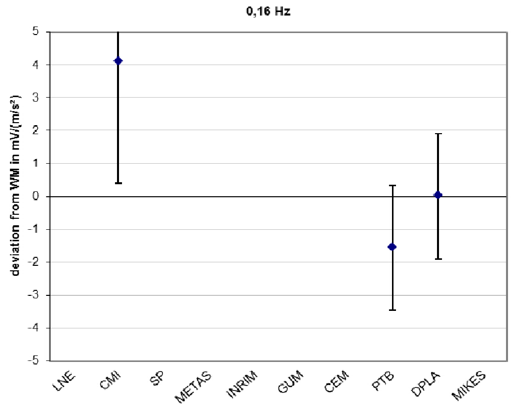
	WM		LNE		CMI		SP		METAS		INRIM	
actual frequency	X_{WM}	u_{WM}	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$
in Hz	mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)	
DC	500,06	0,02	/	/	0,15	0,50	0,04	0,50	-0,01	0,01	-0,02	1,00
0,1	499,05	0,88	/	/	9,95 (*)	4,42 (*)	/	/	/	/	/	/
0,125	500,14	0,84	/	/	5,96	2,65	/	/	/	/	/	/
0,16	500,40	0,81	/	/	4,10	1,85	/	/	/	/	/	/
0,2	500,43	0,49	/	/	2,37	1,16	/	/	1,07	1,07	/	/
0,25	500,03	0,45	/	/	1,77	0,90	/	/	-0,22	0,84	/	/
0,315	500,12	0,44	/	/	1,38	0,90	-4,82	4,44	-0,12	0,73	/	/
0,4	499,95	0,35	/	/	1,35	0,94	-2,95	2,71	0,30	0,73	/	/
0,5	499,93	0,30	0,57	0,69	0,97	0,96	-1,73	1,97	0,22	0,73	-1,13	0,95
0,63	499,97	0,31	0,33	0,69	0,73	0,95	-0,97	1,21	0,33	0,72	/	/
0,8	499,79	0,29	0,21	0,69	0,81	0,96	-0,39	0,96	0,36	0,72	-1,49	0,95
1	499,81	0,27	0,29	0,70	0,79	0,96	-0,21	0,70	0,46	0,70	-1,91	0,96
1,25	499,89	0,27	0,21	0,70	0,91	0,97	-0,19	0,70	0,43	0,70	-1,49	0,96
1,60	499,94	0,27	0,16	0,70	0,86	0,97	-0,14	0,70	0,41	0,70	-1,04	0,96
2	499,96	0,27	0,24	0,70	0,64	0,96	-0,06	0,70	0,26	0,70	-0,76	0,96
2,50	499,96	0,27	0,04	0,70	0,74	0,97	0,14	0,70	0,39	0,67	-0,76	0,96
3,15	499,95	0,27	0,15	0,70	0,65	0,97	0,05	0,70	0,30	0,67	-0,75	0,96
4	499,98	0,27	0,12	0,70	0,62	0,97	0,12	0,70	0,34	0,67	-0,98	0,96
5	500,02	0,26	0,08	0,70	0,58	0,97	0,08	0,70	0,42	0,54	-0,92	0,96
6,3	500,06	0,26	0,04	0,70	0,64	0,97	0,14	0,70	0,44	0,54	-0,96	0,96
8,0	500,09	0,26	0,11	0,70	0,81	0,97	0,11	0,70	0,37	0,54	-0,89	0,96
10	499,94	0,20	0,26	0,72	0,86	0,98	0,36	0,72	0,69	0,90	-0,74	0,98
12,5	500,05	0,20	0,25	0,72	0,85	0,98	0,45	0,72	0,53	0,90	-0,75	0,98
16	500,27	0,20	0,23	0,72	0,83	0,98	0,33	0,72	0,55	0,91	-0,57	0,98
20	500,58	0,20	0,22	0,72	0,92	0,98	0,32	0,72	0,41	0,91	-0,48	0,98
25	501,01	0,20	0,19	0,72	1,09	0,98	0,29	0,73	0,44	0,88	-0,61	0,98
31,5	501,71	0,20	0,19	0,73	1,19	0,99	0,29	0,73	0,36	0,88	-0,51	0,98
40	502,72	0,20	0,18	0,73	0,88	0,99	0,08	0,73	0,47	0,88	-0,42	0,98
50	504,20	0,20	0,21	0,73	0,60	0,99	-1,30	0,73	0,69	0,89	-0,10	0,99
63	506,44	0,21	0,26	0,73	0,76	0,99	-0,64	0,99	0,56	1,76	-0,14	0,99
80	509,69	0,22	0,21	0,73	0,01	1,00	0,01	1,00	0,51	1,77	-0,99	0,99
100	513,73	0,22	-0,03	0,74	0,07	1,00	0,07	1,00	0,37	1,79	-0,03	1,00
125	517,95	0,22	0,05	0,74	0,15	1,01	1,05	1,01	0,65	1,80	-0,05	1,01
160	522,43	0,23	-0,13	0,75	0,27	1,02	/	/	0,27	1,81	-0,43	1,02
200	525,03	0,26	/	/	-6,03	1,07	-2,93	2,86	0,27	1,82	/	/

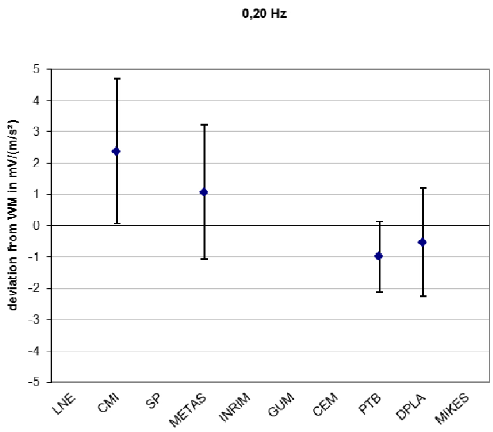
	WM		GUM		CEM		PTB		DPLA		MIKES	
actual frequency	X_{WM}	u_{WM}	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$
in Hz	mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)	
DC	500,06	0,02	/	/	/	/	-0,06	0,50	0,15	0,12	/	/
0,1	499,05	0,88	/	/	/	/	-1,33	0,88	1,35	0,89	/	/
0,125	500,14	0,84	/	/	/	/	-1,35	0,92	0,16	0,93	/	/
0,16	500,40	0,81	/	/	/	/	-1,57	0,95	0,00	0,95	/	/
0,2	500,43	0,49	/	/	/	/	-0,98	0,57	-0,53	0,87	/	/
0,25	500,03	0,45	/	/	/	/	-0,78	0,60	-0,13	0,89	/	/
0,315	500,12	0,44	/	/	/	/	-0,43	0,61	-0,22	0,90	/	/
0,4	499,95	0,35	/	/	-0,05	1,20	-0,33	0,36	-0,05	0,94	/	/
0,5	499,93	0,30	/	/	-0,03	1,21	-0,21	0,40	0,07	0,95	/	/
0,63	499,97	0,31	/	/	-0,07	1,21	-0,27	0,40	-0,07	0,95	/	/
0,8	499,79	0,29	/	/	0,11	1,22	-0,01	0,41	0,11	0,96	/	/
1	499,81	0,27	0,59	1,73	0,09	1,22	0,01	0,42	0,09	0,96	-0,21	1,22
1,25	499,89	0,27	0,52	1,73	0,01	1,22	-0,08	0,42	0,01	0,96	-0,19	1,22
1,60	499,94	0,27	0,38	1,73	-0,04	1,22	-0,12	0,42	-0,04	0,96	-0,24	1,22
2	499,96	0,27	0,22	1,73	-0,06	1,22	-0,09	0,42	-0,06	0,96	-0,36	1,22
2,50	499,96	0,27	0,28	1,73	-0,06	1,22	-0,21	0,42	-0,06	0,96	-0,26	1,22
3,15	499,95	0,27	0,23	1,73	-0,05	1,22	-0,20	0,42	-0,05	0,96	0,05	1,22
4	499,98	0,27	0,24	1,73	-0,08	1,22	-0,17	0,42	0,02	0,96	-0,08	1,22
5	500,02	0,26	0,30	1,73	-0,02	1,22	-0,30	0,43	-0,02	0,97	-0,02	1,22
6,3	500,06	0,26	0,28	1,73	-0,06	1,22	-0,31	0,43	-0,06	0,97	0,04	1,22
8,0	500,09	0,26	0,23	1,73	0,01	1,22	-0,33	0,43	-0,09	0,97	0,01	1,22
10	499,94	0,20	0,48	1,49	0,16	1,23	-0,16	0,15	0,16	0,98	0,16	1,23
12,5	500,05	0,20	0,43	1,49	0,05	1,23	-0,15	0,15	0,15	0,98	0,05	1,23
16	500,27	0,20	0,43	1,49	0,13	1,24	-0,15	0,15	0,13	0,98	0,03	1,23
20	500,58	0,20	0,39	1,24	0,12	1,24	-0,14	0,15	0,22	0,98	-0,08	1,24
25	501,01	0,20	0,40	1,24	0,09	1,24	-0,15	0,15	0,19	1,24	-0,01	1,24
31,5	501,71	0,20	0,33	1,24	0,09	1,24	-0,14	0,15	-0,01	1,24	-0,11	1,24
40	502,72	0,20	0,31	1,24	0,08	1,24	-0,08	0,15	-0,22	1,24	-0,32	1,24
50	504,20	0,20	1,87	1,25	0,10	1,24	-0,05	0,15	0,30	1,25	0,10	1,50
63	506,44	0,21	0,30	1,25	-0,04	1,25	-0,03	0,14	-0,54	1,25	-0,14	1,50
80	509,69	0,22	0,35	1,51	0,61	1,26	-0,02	0,14	6,11	3,86	-0,69	2,54
100	513,73	0,22	0,23	1,53	/	/	-0,02	0,13	/	/	/	/
125	517,95	0,22	0,50	1,54	/	/	-0,11	0,13	/	/	/	/
160	522,43	0,23	-0,29	1,81	/	/	0,02	0,12	/	/	/	/
200	525,03	0,26	/	/	/	/	0,019	0,044	/	/	/	/

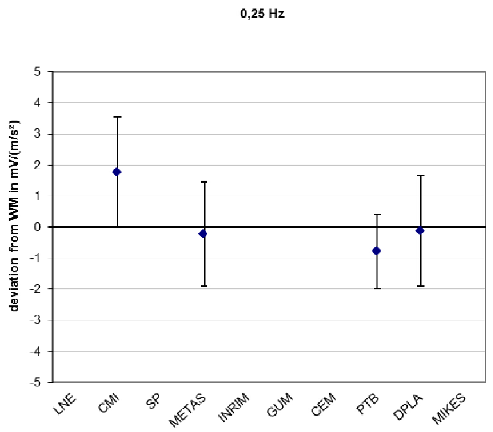
Figure 8.1.1 : Deviation of the magnitude from the WM for all frequencies of the comparison with expanded uncertainties $U_{i,w}$ (k=2)

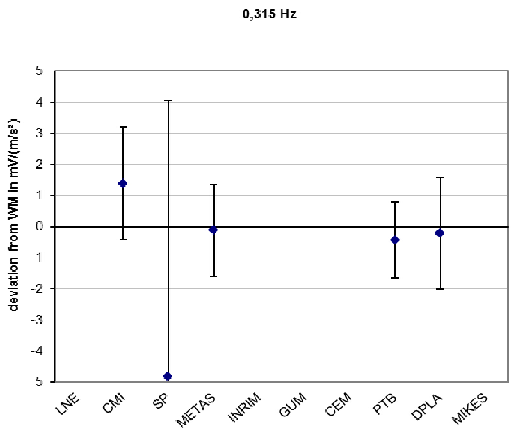


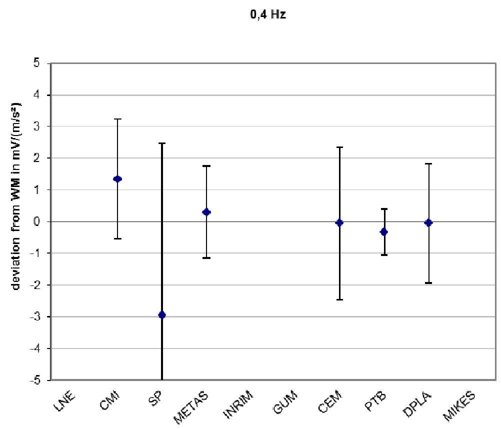

0,125 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

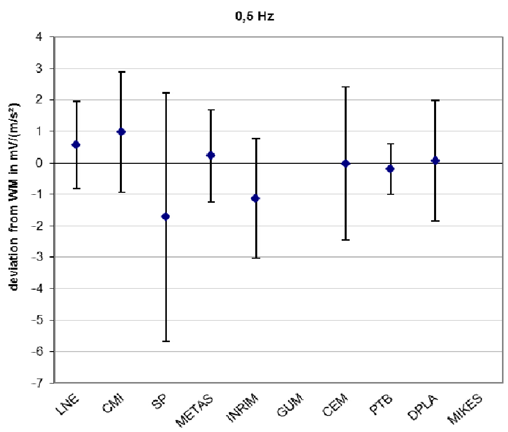

0,16 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

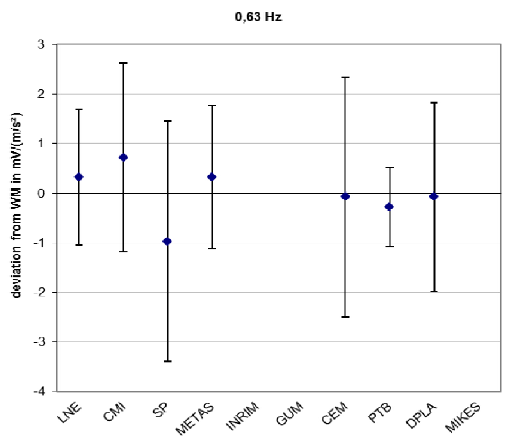

0,20 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

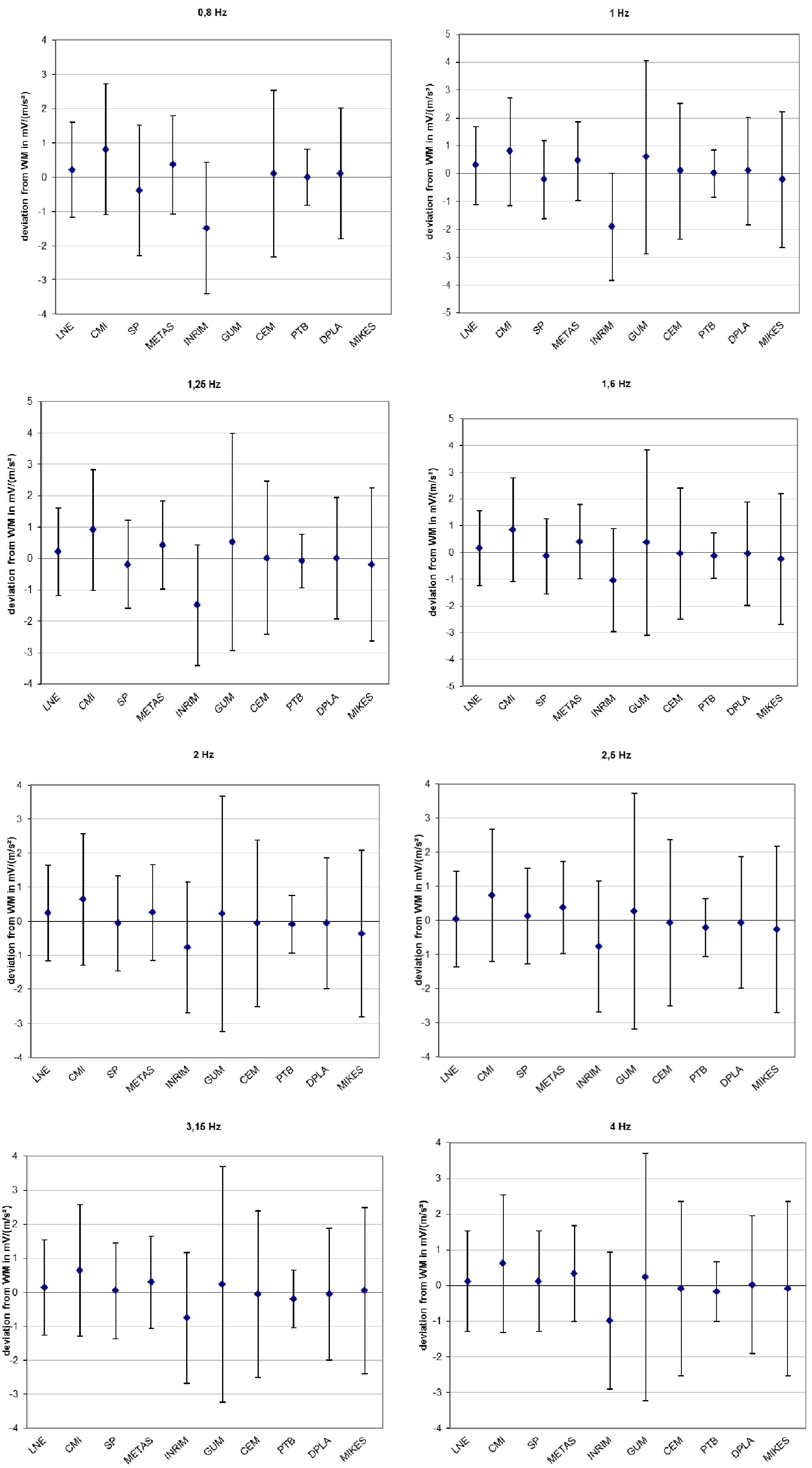

0,25 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

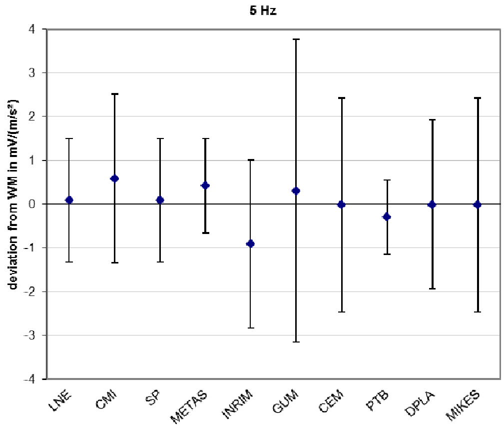

0,315 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

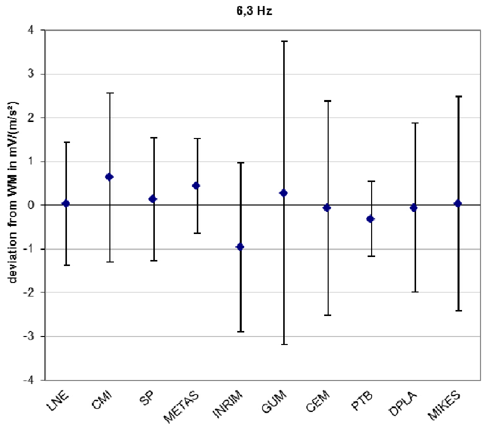

0,4 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

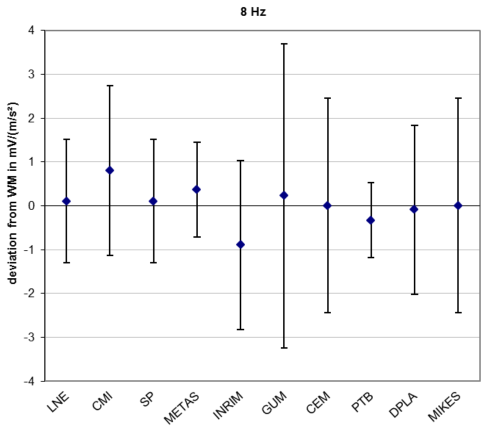

0,5 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

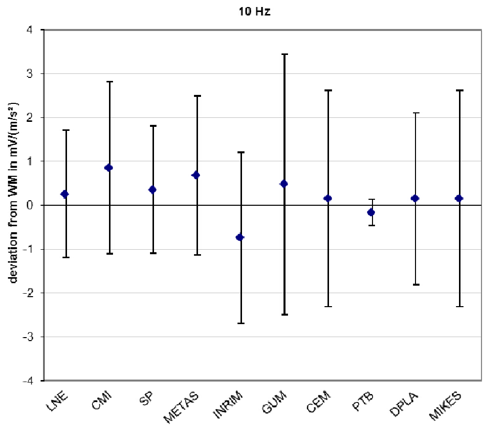

0,63 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

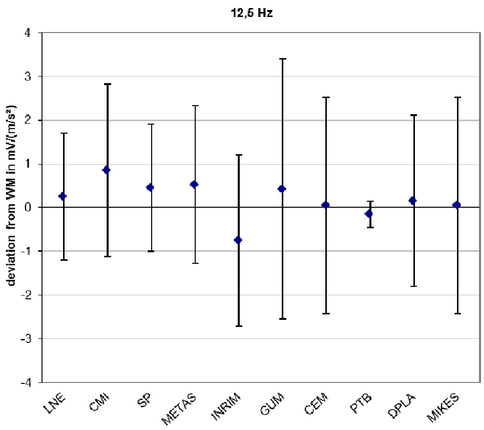

0,8 Hz
1 Hz
1,25 Hz
1,6 Hz
2 Hz
2,5 Hz
3,15 Hz
4 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

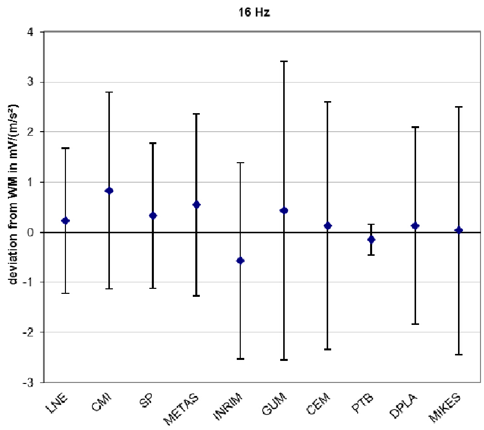

5 Hz
deviation from WM in mV/(m/s²)
4
3
2
1
0
-1
-2
-3
-4
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

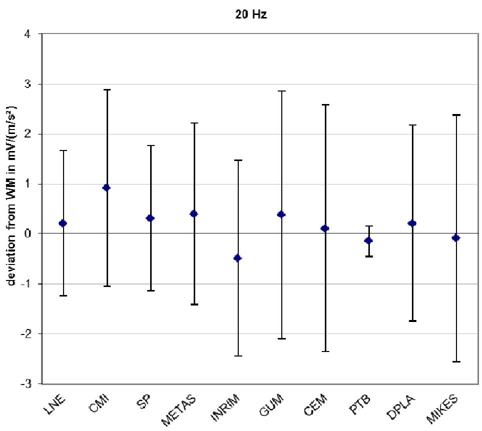

6,3 Hz
deviation from WM in mV/(m/s²)
4
3
2
1
0
-1
-2
-3
-4
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

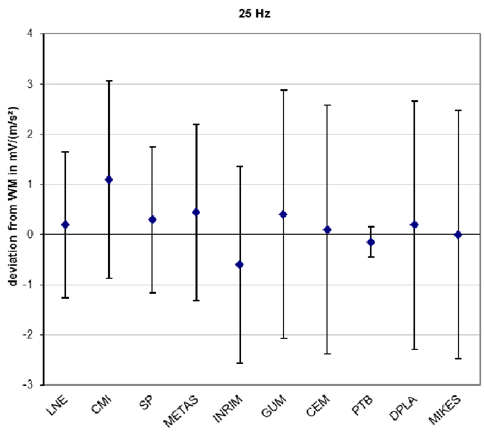

8 Hz
deviation from WM in mV/(m/s²)
4
3
2
1
0
-1
-2
-3
-4
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

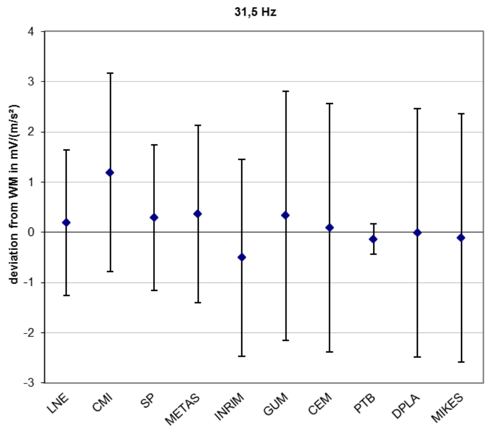

10 Hz
deviation from WM in mV/(m/s²)
4
3
2
1
0
-1
-2
-3
-4
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

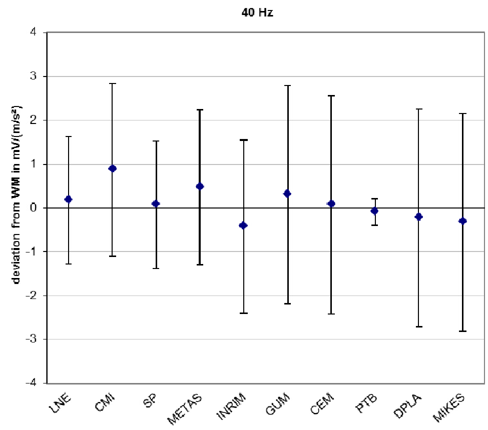

12,5 Hz
deviation from WM in mV/(m/s²)
4
3
2
1
0
-1
-2
-3
-4
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

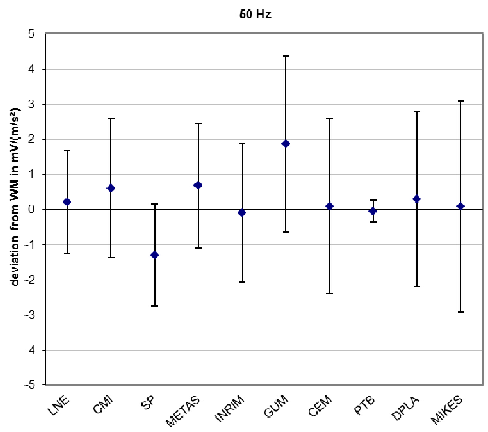

16 Hz
deviation from WM in mV/(m/s²)
4
3
2
1
0
-1
-2
-3
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

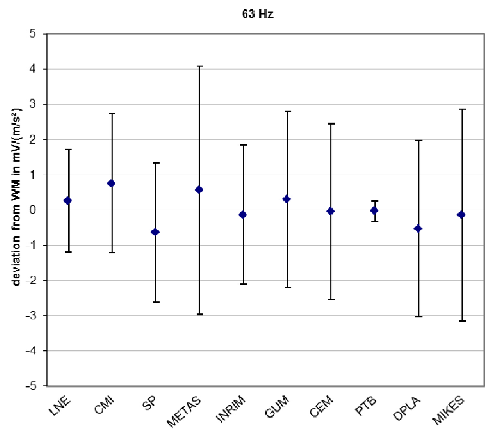

20 Hz
deviation from WM in mV/(m/s²)
4
3
2
1
0
-1
-2
-3
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

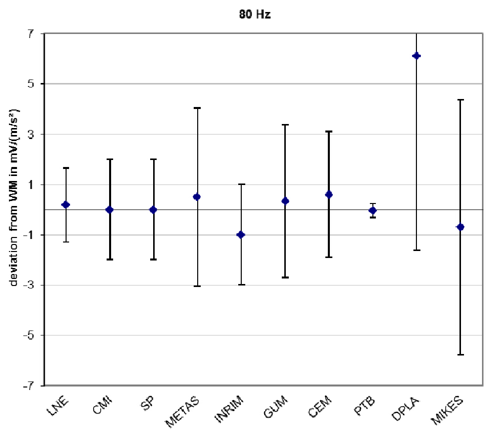

25 Hz
deviation from WM in mV/(m/s²)
4
3
2
1
0
-1
-2
-3
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

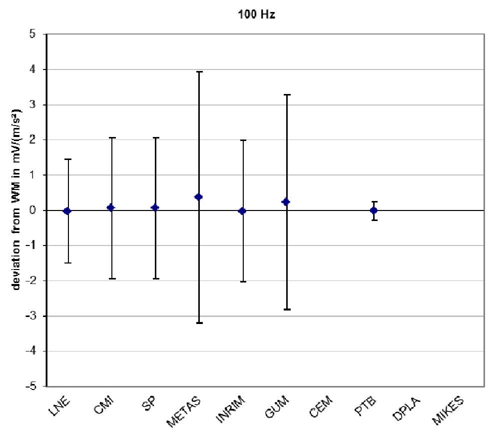

31,5 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

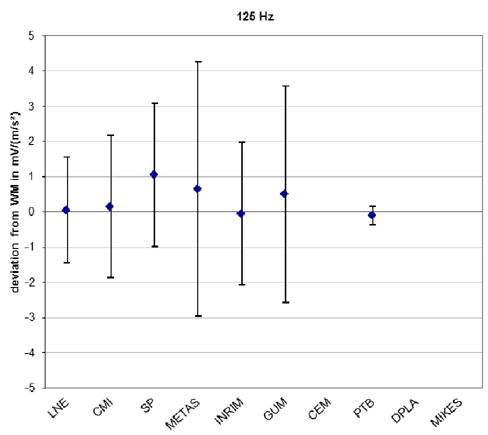

40 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

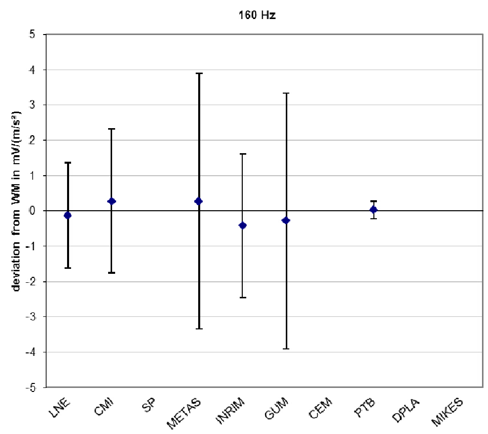

50 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

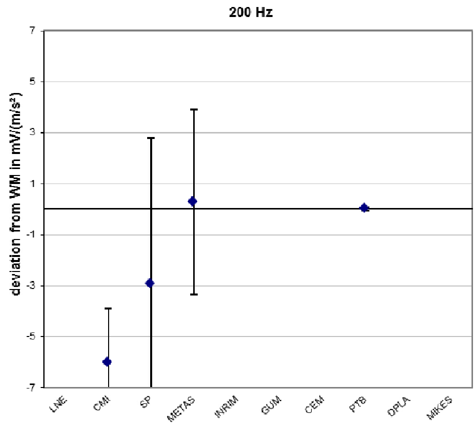

63 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES


80 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES


100 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES


125 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES


160 Hz
deviation from WM in mV/(m/s²)
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES


200 Hz
deviation from WM in mV/(m/s²)
7
5
3
1
-1
-3
-5
-7
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

8.2 Results for the phase of the complex sensitivity

In the following section, the results of the participants are given in a tabulated form and in a graphical representation with reference to the WM (zero line) for each frequency. All the laboratories are contributing to the WM as all participants are MoCS for the whole frequency domain.

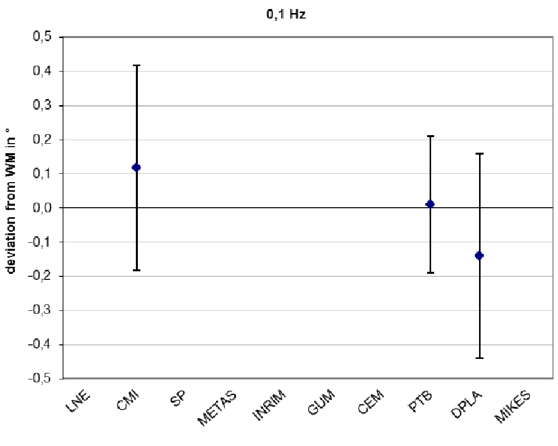
In the subsequently presented tables, all results meet the condition $d_{i,WM}(f)<2.u_{i,WM}(f)$.

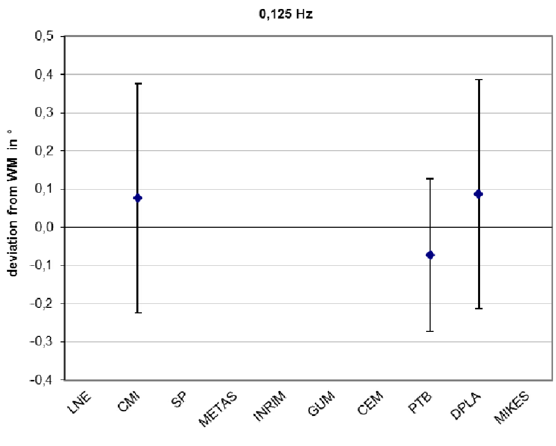
Table 8.2.1: Unilateral degrees of equivalence for the phase of sensitivity with absolute standard uncertainties

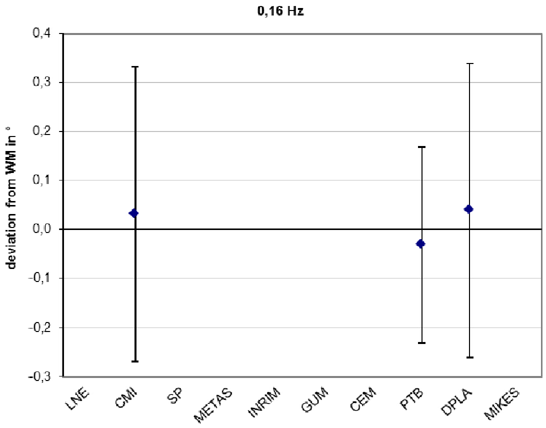
	WM		LNE		CMI		SP		METAS		INRIM	
actual frequency	x_{WM}	u_{WM}	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$
in Hz	in °		in °		in °		in °		in °		in °	
0,1	-0,06	0,07	/	/	0,12	0,13	/	/	/	/	/	/
0,125	-0,09	0,07	/	/	0,08	0,13	/	/	/	/	/	/
0,16	-0,04	0,07	/	/	0,03	0,13	/	/	/	/	/	/
0,2	-0,05	0,07	/	/	0,06	0,13	/	/	-0,04	0,38	/	/
0,25	-0,02	0,07	/	/	0,03	0,13	/	/	0,11	0,38	/	/
0,315	-0,02	0,06	/	/	0,02	0,14	0,00	0,14	0,09	0,38	/	/
0,4	-0,03	0,06	/	/	0,03	0,14	0,01	0,14	0,06	0,38	/	/
0,5	-0,02	0,06	/	/	0,03	0,14	0,01	0,14	0,05	0,38	/	/
0,63	-0,02	0,06	/	/	0,02	0,14	0,02	0,14	0,03	0,38	/	/
0,8	-0,02	0,06	/	/	0,03	0,14	0,01	0,14	0,05	0,38	/	/
1	-0,03	0,06	/	/	-0,05	0,14	0,02	0,14	0,03	0,22	/	/
1,25	-0,04	0,06	/	/	-0,08	0,14	0,03	0,14	0,04	0,22	/	/
1,6	-0,05	0,06	/	/	-0,10	0,14	0,04	0,14	0,04	0,22	/	/
2,0	-0,06	0,06	/	/	-0,14	0,14	0,05	0,14	0,06	0,22	/	/
2,50	-0,05	0,06	/	/	-0,16	0,14	0,04	0,14	0,05	0,22	/	/
3,15	-0,05	0,06	/	/	-0,09	0,14	0,03	0,14	0,03	0,22	/	/
4	-0,06	0,06	/	/	-0,09	0,14	0,04	0,14	0,04	0,22	/	/
5	-0,05	0,06	/	/	-0,04	0,14	0,02	0,14	0,02	0,22	/	/
6,3	-0,05	0,06	/	/	-0,01	0,14	0,01	0,14	0,02	0,22	/	/
8	-0,06	0,06	/	/	0,03	0,14	0,01	0,14	0,02	0,22	/	/
10	-0,07	0,06	/	/	0,05	0,14	0,01	0,14	0,00	0,22	/	/
12,5	-0,08	0,06	/	/	0,11	0,14	0,00	0,14	-0,01	0,19	/	/
16	-0,11	0,06	/	/	0,05	0,14	0,02	0,14	0,01	0,19	/	/
20	-0,15	0,06	/	/	0,05	0,14	0,02	0,14	0,01	0,19	/	/
25,0	-0,20	0,06	/	/	0,06	0,14	0,02	0,14	0,03	0,20	/	/
31,5	-0,27	0,06	/	/	0,08	0,14	0,02	0,14	0,03	0,20	/	/
40	-0,38	0,06	/	/	0,03	0,14	0,04	0,14	0,05	0,20	/	/
50	-0,51	0,07	/	/	0,08	0,24	0,08	0,14	0,04	0,19	/	/
63	-0,78	0,07	/	/	0,10	0,24	0,13	0,13	0,07	0,35	/	/
80	-1,17	0,07	/	/	0,10	0,24	0,06	0,13	0,09	0,35	/	/
100	-1,78	0,08	/	/	0,12	0,24	0,10	0,13	0,06	0,35	/	/
125	-2,77	0,08	/	/	0,20	0,24	0,18	0,18	0,12	0,35	/	/
160	-4,32	0,09	/	/	0,28	0,23	/	/	0,32	0,35	/	/
200	-6,24	0,09	/	/	0,35	0,23	/	/	0,35	0,35	/	/

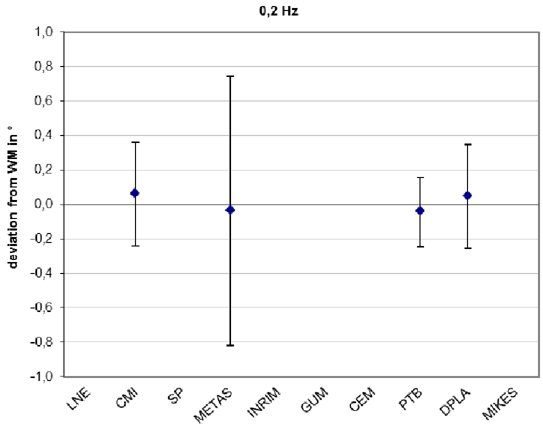
	WM		GUM		CEM		PTB		DPLA		MIKES	
actual frequency	x_{WM}	u_{WM}	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$	$d_{i,WM}$	$u_{i,WM}$
in Hz	in °		in °		in °		in °		in °		in °	
0,1	-0,06	0,07	/	/	/	/	0,01	0,07	-0,14	0,13	/	/
0,125	-0,09	0,07	/	/	/	/	-0,07	0,07	0,09	0,13	/	/
0,16	-0,04	0,07	/	/	/	/	-0,03	0,07	0,04	0,13	/	/
0,2	-0,05	0,07	/	/	/	/	-0,04	0,07	0,05	0,13	/	/
0,25	-0,02	0,07	/	/	/	/	-0,03	0,07	0,02	0,13	/	/
0,315	-0,02	0,06	/	/	/	/	-0,02	0,08	0,02	0,14	/	/
0,4	-0,03	0,06	/	/	-0,04	0,24	-0,03	0,08	0,03	0,14	/	/
0,5	-0,02	0,06	/	/	-0,04	0,24	-0,03	0,08	0,02	0,14	/	/
0,63	-0,02	0,06	/	/	-0,03	0,24	-0,02	0,08	0,02	0,14	/	/
0,8	-0,02	0,06	/	/	-0,02	0,24	-0,03	0,08	0,02	0,14	/	/
1	-0,03	0,06	-0,01	0,34	-0,01	0,24	0,00	0,08	0,02	0,14	0,01	0,29
1,25	-0,04	0,06	0,01	0,34	0,01	0,24	-0,01	0,08	0,03	0,14	0,01	0,29
1,6	-0,05	0,06	0,02	0,34	0,02	0,24	0,00	0,08	0,04	0,14	0,05	0,29
2,0	-0,06	0,06	0,03	0,34	0,03	0,24	0,00	0,08	0,05	0,14	0,03	0,29
2,50	-0,05	0,06	0,02	0,34	0,02	0,24	0,01	0,08	0,04	0,14	0,00	0,29
3,15	-0,05	0,06	0,02	0,34	0,02	0,24	0,00	0,08	0,03	0,14	0,01	0,29
4	-0,06	0,06	0,03	0,34	0,03	0,24	-0,01	0,08	0,04	0,14	0,01	0,29
5	-0,05	0,06	0,01	0,34	0,01	0,24	0,00	0,08	0,02	0,14	-0,01	0,29
6,3	-0,05	0,06	0,01	0,34	0,01	0,24	-0,02	0,08	0,01	0,14	-0,01	0,29
8	-0,06	0,06	0,01	0,34	0,01	0,24	-0,03	0,08	0,01	0,14	-0,03	0,29
10	-0,07	0,06	0,01	0,34	0,00	0,24	-0,02	0,08	0,01	0,14	-0,03	0,29
12,5	-0,08	0,06	0,01	0,35	-0,02	0,24	-0,04	0,08	0,00	0,14	-0,06	0,29
16	-0,11	0,06	0,02	0,35	0,00	0,24	-0,04	0,08	0,01	0,14	-0,07	0,29
20	-0,15	0,06	0,02	0,29	0,02	0,24	-0,04	0,08	0,01	0,14	-0,09	0,29
25,0	-0,20	0,06	0,03	0,29	0,02	0,24	-0,04	0,08	0,00	0,14	-0,09	0,29
31,5	-0,27	0,06	0,04	0,29	0,03	0,24	-0,05	0,08	0,04	0,24	-0,13	0,29
40	-0,38	0,06	0,06	0,29	0,05	0,24	-0,05	0,08	0,09	0,24	-0,14	0,29
50	-0,51	0,07	0,09	0,29	0,04	0,24	-0,08	0,08	0,07	0,24	-0,17	0,34
63	-0,78	0,07	0,06	0,34	0,08	0,24	-0,07	0,07	0,02	0,50	-0,33	0,34
80	-1,17	0,07	0,10	0,34	0,26	0,24	-0,11	0,07	0,34	0,49	-0,32	0,55
100	-1,78	0,08	0,08	0,34	/	/	-0,08	0,07	/	/	/	/
125	-2,77	0,08	0,12	0,34	/	/	-0,10	0,06	/	/	/	/
160	-4,32	0,09	0,23	0,39	/	/	-0,08	0,05	/	/	/	/
200	-6,24	0,09	/	/	/	/	-0,08	0,04	/	/	/	/

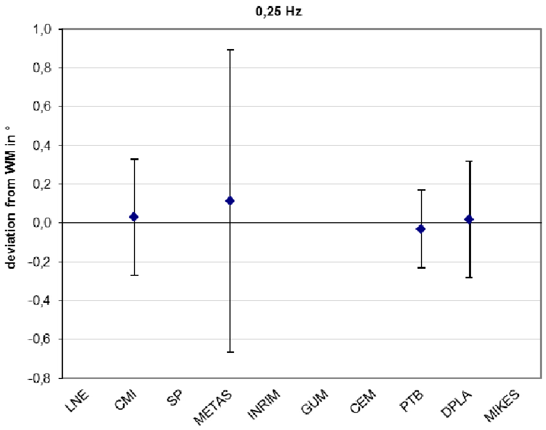
Figure 8.2.1 : Deviation of the phase from the WM for all frequencies of the comparison (excepted DC)

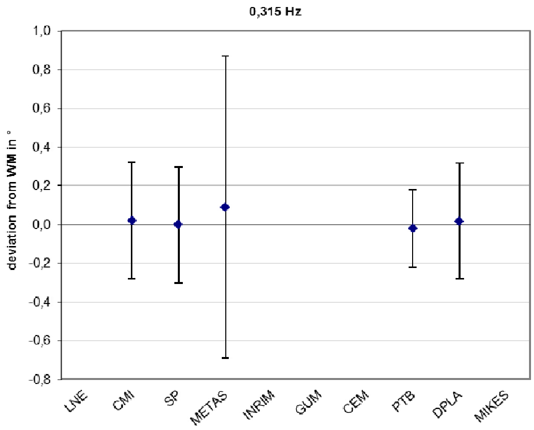


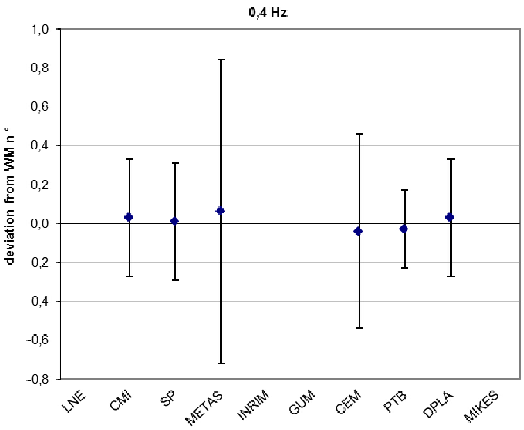


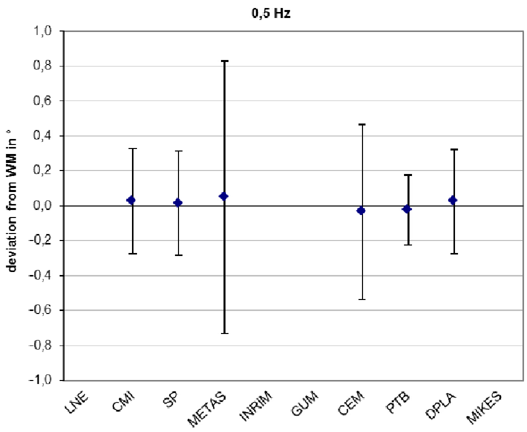

0,16 Hz
deviation from WM in °
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

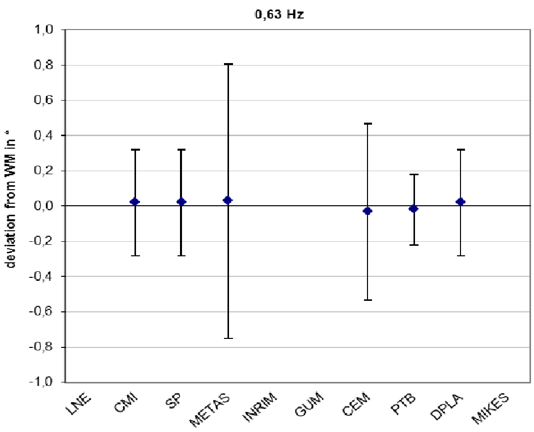

0,2 Hz
deviation from WM in °
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

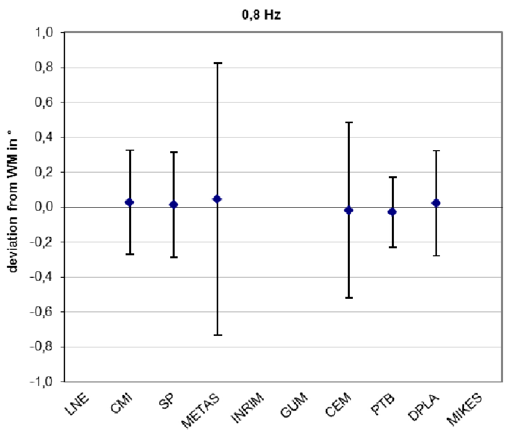

0,25 Hz
deviation from WM in °
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

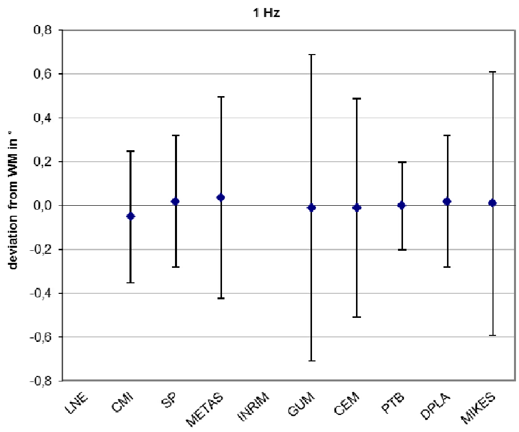

0,315 Hz
deviation from WM in °
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

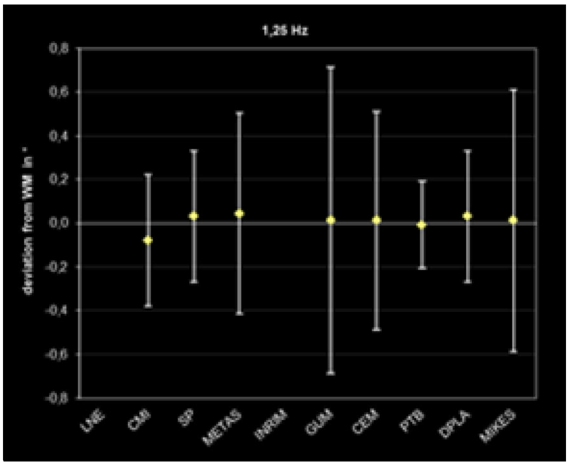

0,4 Hz
deviation from WM n °
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

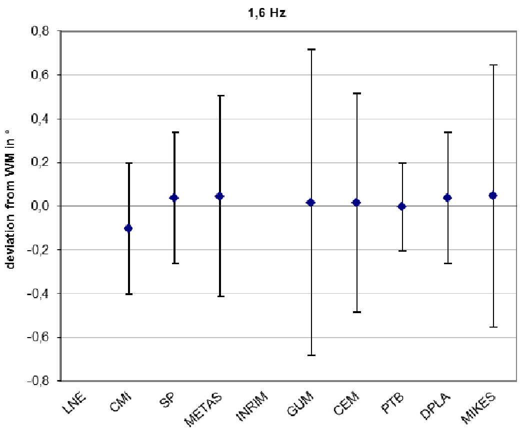

0,5 Hz
deviation from WM in °
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

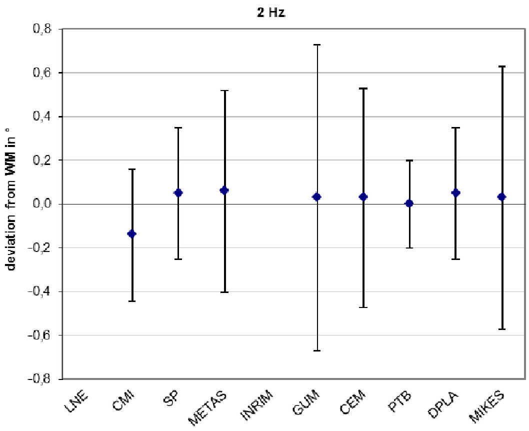

0,63 Hz
deviation from WM in °
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

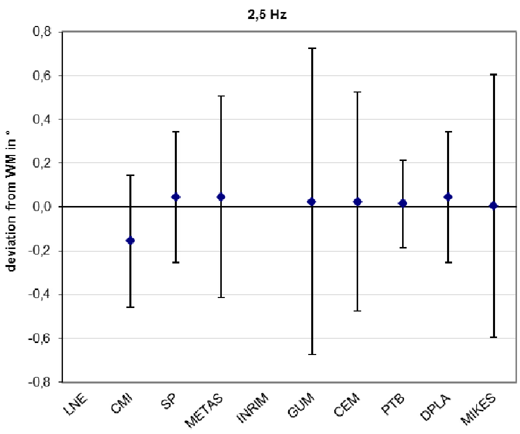

0,8 Hz
deviation from WM in °
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

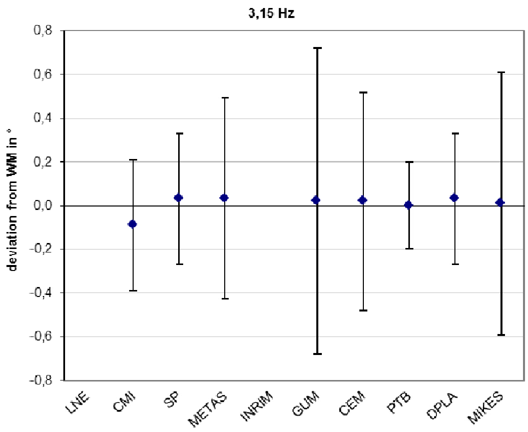

1 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

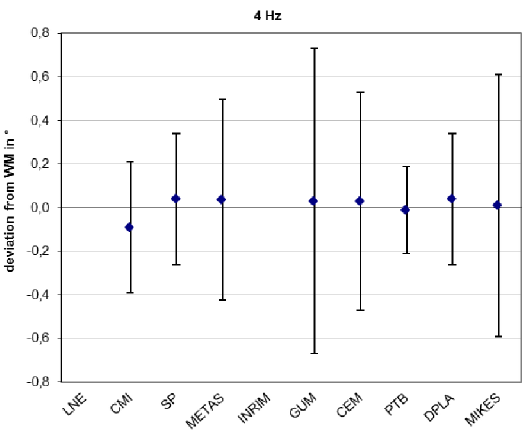

1,25 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

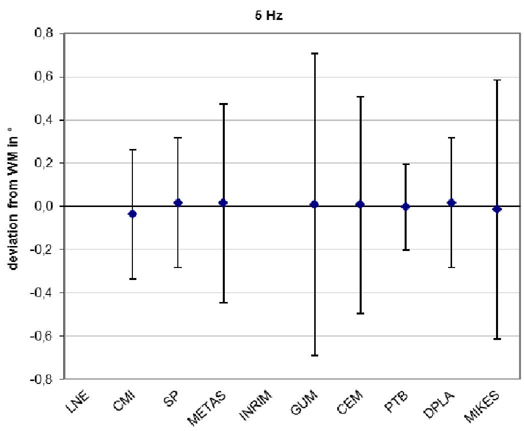

1,6 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

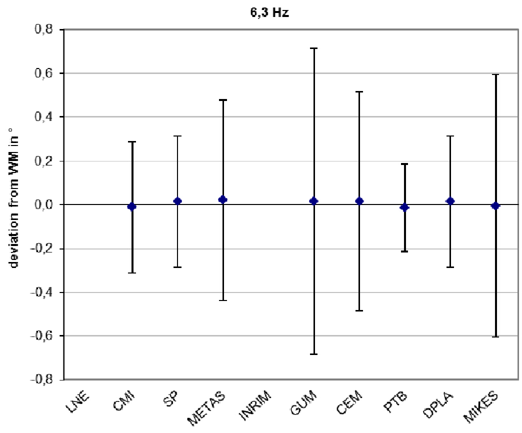

2 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

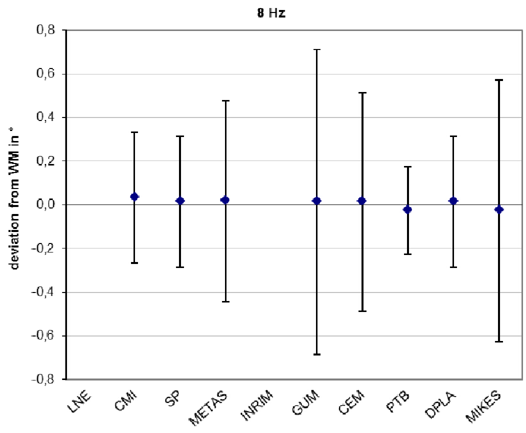

2,5 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

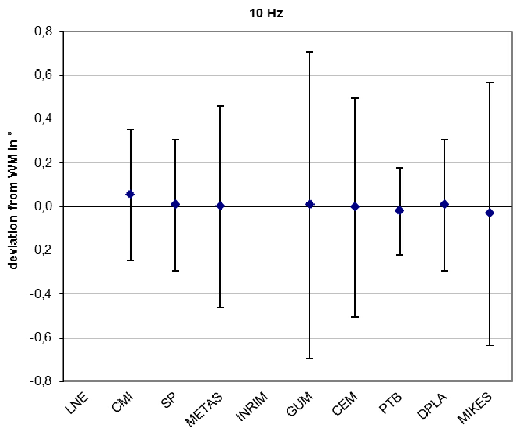

3,15 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

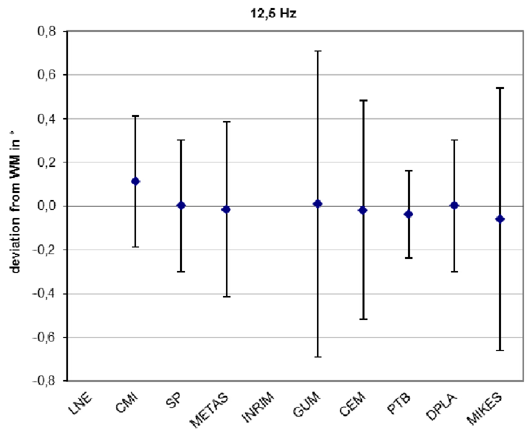

4 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

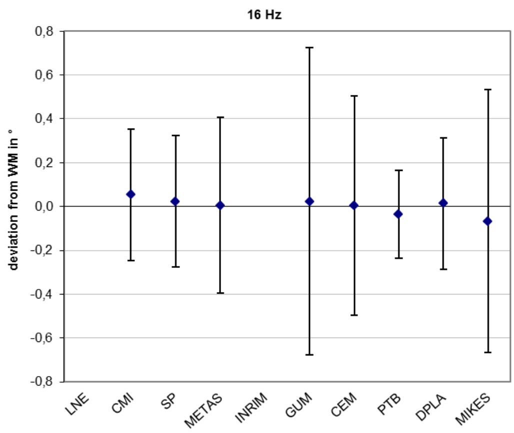

5 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

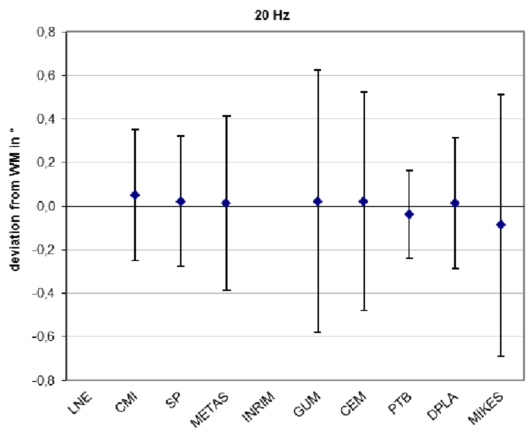

6,3 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

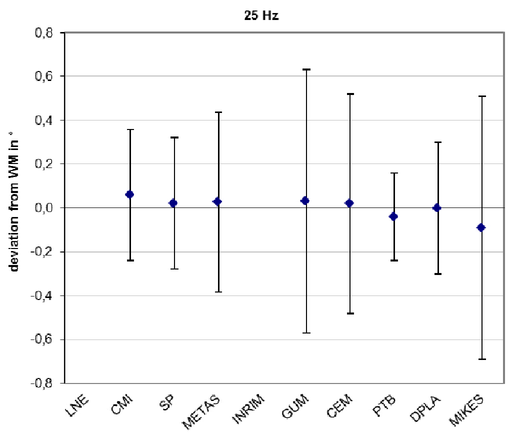

8 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

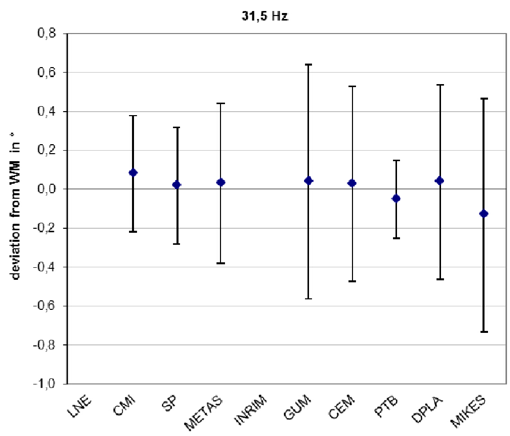

10 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

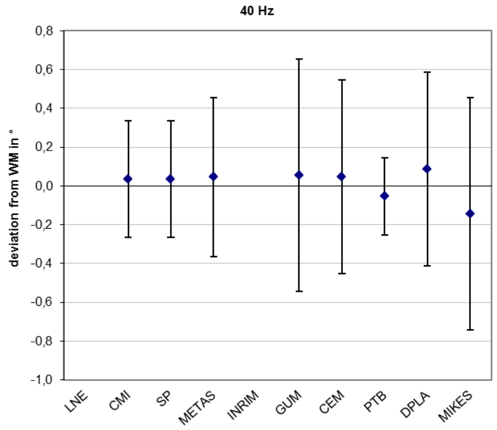

12,5 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

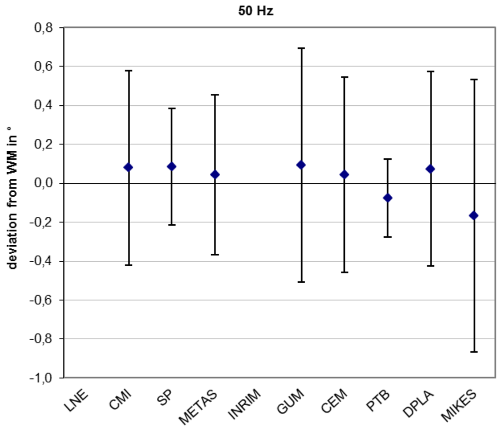

16 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

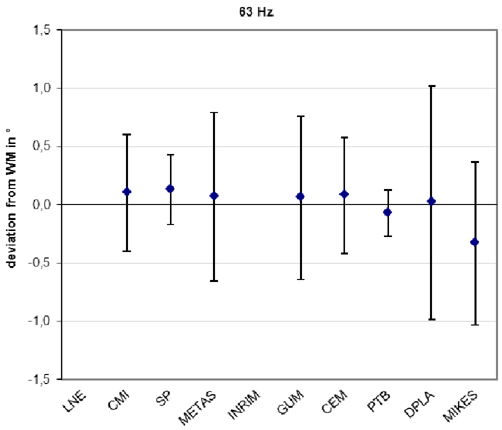

20 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

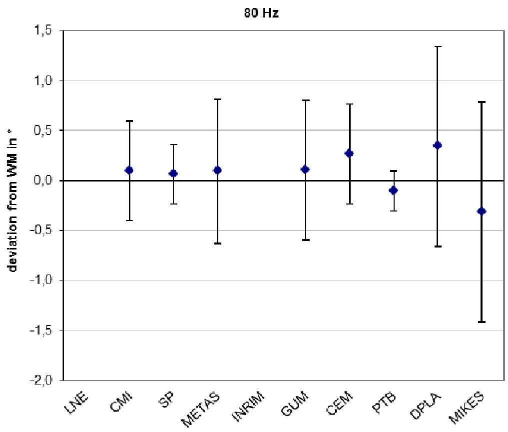

25 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

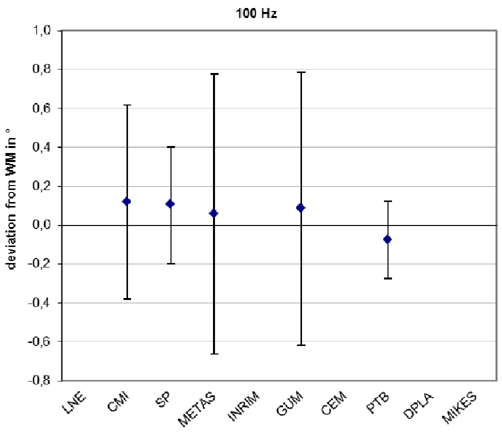

31,5 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
-1,0
LNE
CMI
SP
METAS
INRIM
GUM
CEM
PTB
DPLA
MIKES

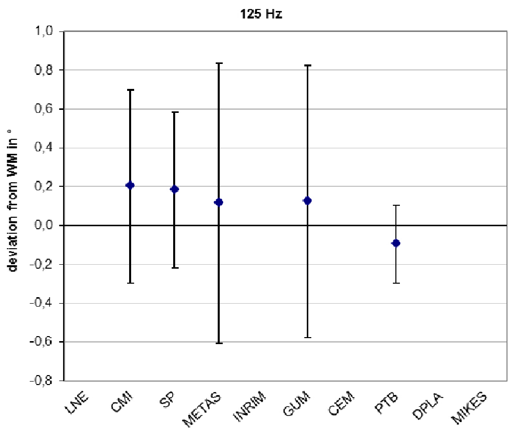

40 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
-1,0
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

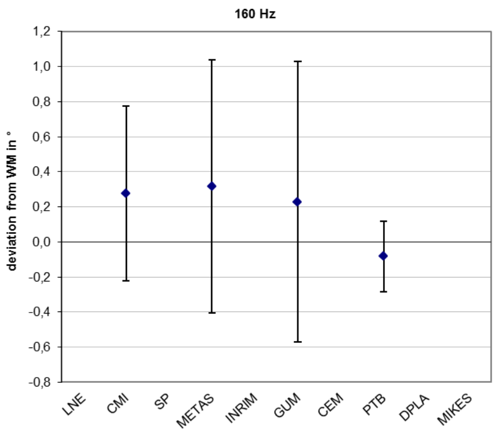

50 Hz
deviation from WM in °
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
-1,0
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

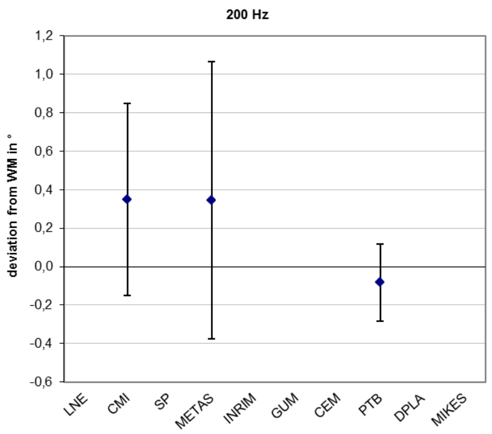

63 Hz
deviation from WM in °
1,5
1,0
0,5
0,0
-0,5
-1,0
-1,5
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES


80 Hz
deviation from WM in °
1,5
1,0
0,5
0,0
-0,5
-1,0
-1,5
-2,0
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES


100 Hz
deviation from WM in °
1,0
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES


125 Hz
deviation from WM in °
1,0
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES


160 Hz
deviation from WM in °
1,2
1,0
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES


200 Hz
deviation from WM in °
1,2
1,0
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
LNE CMI SP METAS INRIM GUM CEM PTB DPLA MIKES

9. Conclusion

LNE reported results of the regional key comparison EURAMET.AUV.V-K3 as the pilot laboratory. Results from the participants for this first comparison in low frequency domain in Europe are mostly consistent within their declared expanded uncertainties for magnitude results. For phase ones, all results were contributing to the weighted mean and all degrees of equivalence were lower than the expanded uncertainties. For magnitude results, difficulties appears, as one can expect, in very low and very high frequencies relatively to the considered domain. This comparison will be linked in the future to the low frequency CIPM key comparison CCAUV.V-K3 at the overlapping frequencies from 0,1 to 40 Hz.

10. Acknowledgment

The author gratefully acknowledges all the participating institutes as co-authors for their cooperation and fruitful discussion :

Milan Prasil – CMI, Håkan Andersson - SP, Christian Hof - METAS, Alessandro Schiavi - INRIM , Joanna Kolasa- GUM , Nieves Medina - CEM , Susanne Gazioch and Thomas Bruns - PTB, Torben R. Licht - DPLA , Jussi Hamalainen – MIKES.

The autor gratefully acknowledges the Key Comparison Working Group from CCAUV and especially its chairman Gustavo Ripper – INMETRO and its secretary Susanne PICARD - BIPM for their contribution on this report.

Bibliography

[1] ISO 16063-1 :1998 methods for the calibration of vibration and shock transducers – part 1 : Basic concepts

[2] ISO 16063-1 :1998 methods for the calibration of vibration and shock transducers – part 11 : Primary vibration calibration by laser interferometry

[3] M.G. Cox, The evaluation of key comparison data, Metrologia, 2002, volume 39, p 5989-595

[4] M.G. Cox, The evaluation of key comparison data: determining a largest consistent subset., Metrologia, 2007, 44, 187-200

Annex A - Technical protocol

Technical protocol of the Comparison in the field of vibration EURAMET.AUV.V-S1

Primary calibration of accelerometers at low frequencies

1. Participants

The following laboratories are participant in the proposed comparison:

- LNE / France
- PTB / Germany
- CMI / Czech Republic
- DPLA / Denmark
- METAS / Switzerland
- SP / Sweden
- GUM / Poland
- CEM / Spain
- MIKES / Finland
- INRIM / Italy

2. Aim and task of the comparison

According to the rules set up by the CIPM MRA, the consultative committees of the CIPM have the responsibility to establish “degrees of equivalence” (DoE) between the different measurement standards operated by the national NMIs. This is done by conducting key comparisons (KC) on different levels of the international metrological infrastructure.
The results of this comparison will, after approval for equivalence, form the new basis for DoE derived in subsequent RMO key comparisons, and therefore be the foundation for the registration of “calibration and measurement capabilities” (CMC) in the framework of the CIPM MRA.

The specific task of this comparison is the measurement of the magnitude and phase of the complex voltage sensitivity of one servo accelerometer at frequencies and amplitudes specified in clause 4 in low frequency domain as no comparison has ever been performed in this domain.
The voltage sensitivity shall be calculated as the ratio of the amplitude of the output of the accelerometer to the amplitude of the acceleration at its reference surface with primary means in accordance with ISO 16063-11 : 1999 “Methods for the calibration of vibration and shock transducers - Part 11: Primary vibration calibration by laser interferometry”.
The reported sensitivities and associated uncertainties are then supposed to be used for the calculation of the DoE between the participating NMI and the key comparison reference value.

3. Pilot Laboratory

The pilot laboratory for this comparison is LNE (France). The pilot will report its results to the CCAUV-Executive Secretary before the first measurement of the participants.

The delivery address for the set of artifacts and the written and signed reports is:

Laboratoire national de métrologie et d’essais (LNE)
Métrologie Accélérométrie Batiment L
29 avenue Roger Hennequin
78197 TRAPPES Cedex
France

The contact person is Claire BARTOLI :
Email : claire.bartoli@lne.fr
Phone : +33 1 30 69 13 76
Fax : +33 1 30 6912 34

4. Device under test and measurement conditions

For the calibration task of this comparison, the device is a servo accelerometer QA700 SN 39477 fixed on the WB 3519 conditioning module coupled to a supply junction box WB 3479. The accelerometer is fixed on a plate of size 65 mm * 42 mm. The distance between the holes are 25.2 mm (≈ 1 inch) and 50.4 mm (≈ 2 inches) which permits mounting on platforms with both 25 mm and 0.5 inch patterns. The supplied screws are M5 and 10-32 UNF types. The cable is fixed to the accelerometer and is a LEMO 7 pin connection on the other side. The junction box has an input in LEMO 7 pin and a BNC output. The junction box WB 3479 has to be connected to a +15 / 0 / -15V power supply unit (3 banana plugs) and from chassis/shield connection WB 3479 to ground or 0 (1 banana plug) on measurement instrument. The voltage shall be within +/- 0.2 V.

The nominal sensitivity of the accelerometer is 500 mV/(m/s²).

The mass of the accelerometer (QA700+WB3519) is 280g.

The reference surface will be a small mirror fixed on a face of the accelerometer (fixed with a 10-32 UNF screw). The size of the tool for applying the torque on the mirror is M11. The calibration has to be performed in the horizontal axis of the plate.

The following pictures present the standard accelerometer with its mirror and the junction box.

The schema of the WB3519 and of the junction box WB 3479 are given in annex A.

The frequency range of the measurement is **mandatory** from 1 to 80 Hz.
The participating laboratories could give results for the frequency range DC to 200 Hz.
The laboratories are supposed to measure at the exact frequencies corresponding to these nominal frequencies (all values are in Hz) :
0.1, 0.125, 0.16, 0.2, 0.25, 0.315, 0.4, 0.5, 0.63, 0.8, 1, 1.25, 1.6, 2, 2.5, 3.15, 4, 5, 6.3, 8, 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80, 100, 125, 160, 200.

The value of the exact frequencies can be calculated from fn=fr*10^(n/10) with fr the reference frequency 1 000 Hz; n will takes values between –40 and –7 (cf. ISO 266 standard).

Optionally, the laboratories can specify some frequencies of the list as experiments. The results at these frequencies will not be included in the report and will not be usable to claim CMCs.

The DC_{gn} response (± 90°) of the accelerometer could be included as experiments.

Specific conditions for the measurement of this comparison are :

- Acceleration amplitudes: preferably 0.05 m/s² to 30 m/s².
- Ambient temperature and accelerometer temperature during the calibration: (23 ± 3)°C.
- Relative humidity: max 75%.
- Mounting torque of the mirror on the accelerometer: 2 N.m.
- Screw coupling of the box on the table.

5. Circulation type and transportation

The transducer is circulated in a star type fashion with a measurement period of two weeks for each participant. Between two subsequent measurements, the transducer is measured by the pilot lab in order to monitor the long term stability.

The transducer will be transported in a specific box by an international transportation agency (eg UPS, TNT ,…). The participating laboratories will support the costs of the transportation to and from the pilot laboratory. The transportation has to include an insurance covering a value of 5 000 € in case of damage or lost during the transportation.

The schedule is planned as follows :
For information W6 is from 6 to 10 of February 2012. W1 /13 is from 1 to 4th of january 2013.

Participant	Transportation to participant	Measurement	Transportation to pilot	Monitoring measurement
CMI	W 6	W 7 - 8	W 9	W 10 - 11
SP	W 12	W 13 - 14	W 15	W 16 - 17
METAS	W 18	W 19 - 20	W 21- 25	W 26 - 27
INRIM	W 28	W 29 - 30	W 31	W 32 - 33
CEM	W 37	W 38 - 39	W 40	W 41 - 42
GUM	W 43	W 44 - 45	W 46	W 47 - 48
PTB	W 49	W 50 – 51	W 1 / 13	W 2 - 3 / 13
DPLA	W 4	W 5 - 6	W 7	W 8 - 9
MIKES	W 10	W 11 - 12	W 13	W 14 - 15

6. Measurement and analysis instructions

The participants have to observe the following rules :

- The motion should be measured with the laser directly on the supplied mirror.
- The participating laboratories should supply the power supply unit (+ and - 15 ± 0.2V).
- The motion will be measured on the center of the mirror taking care to avoid scratch on the surface of the mirror.
- The mounting surface of the mirror should be slightly lubricated before mounting.
- The calibration is to be carried out in accordance with the usual procedure of the participating laboratory.
- It is advised that the measurement results should be compiled from complete series carried out on different days under nominally the same conditions except that the transducer and the mirror are remounted. The standard deviation of the subsequent measurements should be included in the report.

7. Communication of the results to the pilot lab

Each participating laboratory will submit one printed and signed calibration report for the accelerometer to the pilot laboratory including the following:

- The magnitude (mandatory) and the phase (not mandatory) of the complex voltage sensitivity of the servo accelerometer for at least each mandatory point
- A description of the calibration system used for the comparison and the mounting techniques and configuration of the accelerometer on the exciter plate.
- A description of the calibration method used.
- The position of the shaker (vertical or horizontal)
- A documented record of the ambient conditions during measurements.
- The calibration results including the relative expanded measurement uncertainty and the applied coverage factor.
- A detailed uncertainty budget for the system covering all components of measurement uncertainty calculated according to GUM:1995 and ISO 16063-11 Annex A . Including among other information on the type of uncertainty (A or B), assumed distribution function and repeatability component.

In addition each laboratory will receive one electronic spreadsheet prepared by the pilot laboratory where the calibration results have to be filled in following the structure given in the file. The use of the electronic spreadsheet for reporting is **mandatory**. The consistency between the results in the electronic form and in the printed and signed calibration report is the responsibility of the participating laboratory. The data submitted in the electronic spreadsheet will be taken as the official results submitted for the comparison.
The results have to be submitted to the pilot laboratory within 6 weeks after the measurements.

8. Remark on the post processing

Presuming consistency of the results, the comparison reference value and the degrees of equivalence will be calculated according to the established methods as a weighted mean as agreed upon already for CCAUV.V-K1.
In case of damage or loss of the artefact, the comparison will be evaluated as far in the schedule as possible, and any further action concerning continuation will be decided in coordination with the participants.

References

[1] ISO 16063-11:1998 “Methods for the calibration of vibration and shock transducers – Part 1: Basic concepts”

[2] ISO 16063-11:1999 “Methods for the calibration of vibration and shock transducers – Part 11: Primary vibration calibration by laser interferometry”

[3] ISO/IEC 17025:2005 “General requirements for the competence of testing and calibration laboratories”

[4] ISO/IEC Guide 98-3:2008 “Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)”

[5] ISO/IEC Guide 98-3:2008/Suppl 1:2008 “Propagation of distributions using a Monte Carlo method”

ANNEX A : Technical Protocol

Product Data

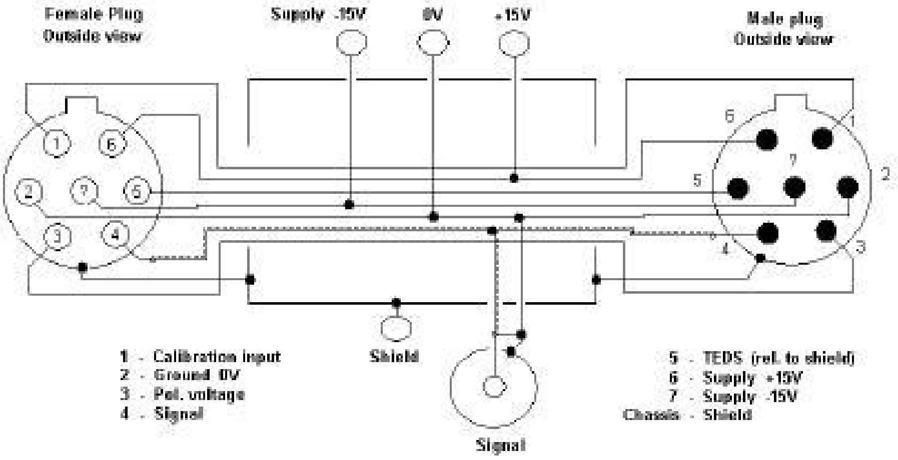
Customised Product

WB-3479 7 pin LEMO Junction Box

Description

The Type WB-3479 7 pin LEMO Junction Box is suitable to insert between a unit fitted with the 7-pin LEMO microphone connector and a PULSE or a NEXUS.
It is then possible to measure directly on the signal and the power supply pins in the LEMO plug or use an external ± 15 V Power supply for calibration of a preamplifier unit alone.

Diagram

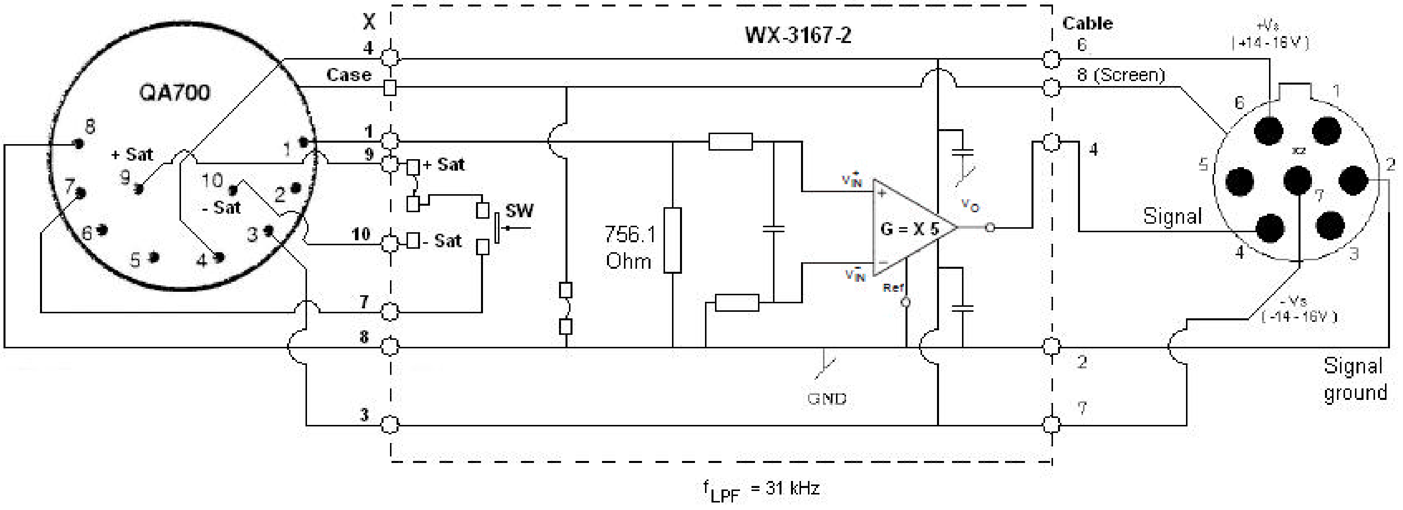


Brüel & Kjær

Customised Product Unit (CPU)
Tel.: +45 45 800500, Fax: +45 45 807621

28072003

SCHEMA of the QA 700 / WB 3519



PIN *FUNCTION* **QA700**

1 SIGNAL OUTPUT (SIG OUT)
2 CURRENT SELF-TEST
3 -V SUPPLY INPUT
4 +V SUPPLY INPUT
5 NOT ASSIGNED
6 TEMPERATURE SENSOR (NOT ASSIGNED, QA-T150)
7 VOLTAGE SELF-TEST
8 POWER/SIGNAL RETURN (GND)
9 -REGULATOR OUTPUT (-REG OUT)
10 +REGULATOR OUTPUT (+REG OUT)

Annex B : Measurement uncertainty Budget (MUB)

1 – LNE

Amplitude sensitivity

		Description	Unc contribution	0,5 to 1 Hz	1 to 10 Hz	10 to 40 Hz	40 to 160 Hz
		uncertainty on the output signal measurement of the accelerometer		%	%	%	%
1	$u(\hat{u}_V)$	Accelerometer output voltage measurement	*u* 1 (S)	0,078	0,069	0,069	0,068
2	$u(\hat{u}_F)$	Voltage filtering effect on output voltage measurement	*u* 2 (S)	0,006	0,006	0,006	0,006
3	$u(\hat{u}_D)$	Voltage disturbance on the output voltage measurement	*u* 3 (S)	0,006	0,006	0,006	0,006
4	$u(\hat{u}_T)$	Effect of transverse sensitivity of the accelerometer on the ouptput voltage measurement	*u* 4 (S)	0,013	0,013	0,020	0,047
		uncertainty on the displacement measurement through the interferometric phase					
5	$u(\hat{\varphi}_{M,Q})$	Interferometric quadrature signal disturbance on the output of the interferometer displacement phase (offset, deviation from 90° nominal angle difference, deviation of voltage amplitude,...)	*u5* (S)	0,058	0,058	0,058	0,058
6	$u(\hat{\varphi}_{M,F})$	Filtering effect on the displacement phase amplitude measurement (frequency band limitation)	*u6* (S)				
7	$u(\hat{\varphi}_{M,VD})$	Voltage disturbance on the phase displacement measurement (random noise of the photoélectric measuring chain)	*u7* (S)				
8	$u(\hat{\varphi}_{M,MD})$	Motion disturbance on the phase displacement amptitude (drift, relative movement between the accelerometer surface and the spot sent back to the interferometer)	*u8* (S)	0,047	0,003	0,001	0,002
9	$u(\hat{\varphi}_{M,PD})$	phase disturbance on amplitude of the displacement phase measurement	*u* 9 (S)				
10	$u(\hat{\varphi}_{M,RE})$	longitudinal and transverse relative movements	*u10* (S)	0,016	0,016	0,041	0,041
10a		laser wavelenght	*u* 10a (S)	0,001	0,001	0,001	0,001
11	$u(f_G)$	vibration frequency measurement	*u11* (S)	0,026	0,026	0,026	0,026
12	$u(S_{ER})$	temperature influence	*u* 12 (S)	0,017	0,017	0,017	0,017
13	$u(S_{ER})$	repetability	*u* 13 (S)		0,050	0,050	0,050
		standard uncertainty on the amplitude sensitivity		**0,151**	**0,113**	**0,118**	**0,125**
		estimated expanded uncertainty on the amplitude sensitivity (k=2)		**0,302**	**0,226**	**0,236**	**0,251**
		reported expanded uncertainty on the amplitude sensitivity (k=2)		**0,30%**			

2 –CMI

Amplitude sensitivity

i	Standard unceraintiy component u(x_i)	Source of uncertainty	Relative uncertainty contribution ui(S) [%]				
1	u($\hat{u}_V$)	accelerometer output voltage measurement (waveform recorder; ADC-resolution)	0,1	0,09	0,09	0,09	0,08
2	u($\hat{u}_F$)	voltage filtering effect on accelerometer output amplitude measurement (frequency band limitation)	0,01	0,01	0,01	0,01	0,008
3	u($\hat{u}_D$)	effect of voltage disturbance on accelerometer outout voltage measurement (hum and noise)	0,01	0,01	0,01	0,01	0,01
4	u($\hat{u}_T$)	effect of transverse, rocking and bending acceleration on accelerometer output voltage measurement	0,84	0,54	0,38	0,22	0,16
5	u($f_{M,Q}$)	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	0,05	0,05	0,05	0,05	0,05
6	u($f_{M,F}$)	interferometr signal filtering effect on phase amplitude measurement (frequency band limitation) - included in 5					
7	u($f_{M,VD}$)	effect of voltage disturbance on phase amplitude measurement (random noise noise in the photoelektric measuring chains) - included in 5					
8	u($f_{M,MD}$)	effect of motion disturbance on phase amplitude measurement (drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	0,03	0,03	0,03	0,03	0,03
9	u($f_{M,PD}$)	effect of phase disturbance on phase amplitude measurement (phase noise of the interferometer signals) - included in 5					
10	u($f_{M,RE}$)	residual interferometric effects on phase amplitude measurement (interferometric function) - included in 5					
11	u(f_{FG})	vibration frequency measurement (frequency generator and indicator)	0,003	0,003	0,003	0,003	0,003
12	u(S_{RE})	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	0,05	0,05	0,05	0,05	0,05
		Expanded relative uncertainty of measurement the magnitude of sensitivity (k=2) [%]	**1,70**	**1,11**	**0,80**	**0,50**	**0,40**
		Frequency [Hz]	**0,1**	**0,125**	**0,16**	**0,2**	**0,25 - 200**

Phase sensitivity

i	Standard uncerainty componen t u(x_i)	Source of uncertainty	Uncertainty contribution ui(S) [%]	
1	u($f_{u,V}$)	accelerometer output phase measurement (waweform recorder; ADC-resolution)	0,14	0,23
2	u($f_{u,F}$)	voltage filtering effect on accelerometer output phase measurement (frequency band limitation) - included in 1		
3	u($f_{u,D}$)	effect of voltage disturbance on accelerometer outout phase measurement (hum and noise)	0,01	0,03
4	u($f_{u,T}$)	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transver sensitivity)	0,04	0,09
5	u($f_{s,Q}$)	effect of interferometer quadrature output signal disturbance on displacement phase measurement (offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	0,01	0,01
6	u($f_{s,F}$)	interferometr signal filtering effect on displacement phase measurement (frequency band limitation) - included in 5		
7	u($f_{s,VD}$)	effect of voltage disturbance on displacement phase measurement (random noise noise in the photoelectric measuring chains) - included in 5		
8	u($f_{s,MD}$)	effect of motion distubance ondisplacement phase measurement (drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	0	0
9	u($f_{s,PD}$)	effect of phase disturbance on displacement phase measurement (phase noise of the interferometer signals) - included in 5		
10	u($f_{s,RE}$)	residual interferometric effects on displacement phase amplitude measurement (interferometric function)	0,01	0,01
11	u(?f_{RE})	residual effects onphase shift measurement (random effect in repeat measurements; experimental standard deviation of arithmetic mean)	0,03	0,03
		Expanded relative uncertainty of measurement the phase shift of sensitivity (k=2) [%]	0,30	0,50
		Frequency [Hz]	0,1 - 40	50 - 200

3- SP

Magnitude sensitivity

Freq.	Relative standard uncertainty component (%)												
(Hz)	1	2	3	4	5	6	7	8	9	10	11	12	Combined
0,315	0,01	0,01	0,01	0,87	0,06	0,01	0,01	0,02	0,11	0,05	0,01	0,06	0,88
0,4	0,01	0,01	0,01	0,54	0,06	0,01	0,01	0,02	0,06	0,05	0,01	0,06	0,55
0,5	0,01	0,01	0,01	0,35	0,06	0,01	0,01	0,02	0,06	0,05	0,01	0,06	0,36
0,63	0,01	0,01	0,01	0,22	0,06	0,01	0,01	0,02	0,05	0,05	0,01	0,04	0,24
0,8	0,01	0,01	0,01	0,14	0,06	0,01	0,01	0,02	0,04	0,05	0,01	0,04	0,17
1	0,01	0,01	0,01	0,09	0,06	0,01	0,01	0,02	0,03	0,05	0,01	0,04	0,13
1,25	0,01	0,01	0,01	0,06	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,11
1,6	0,01	0,01	0,01	0,04	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
2	0,01	0,01	0,01	0,03	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
2,5	0,01	0,01	0,01	0,03	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
3,15	0,01	0,01	0,01	0,03	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
4	0,01	0,01	0,01	0,03	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
5	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
6,3	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
8	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
10	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
12,5	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
16	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
20	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
25	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
31,5	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
40	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,10
50	0,01	0,01	0,01	0,07	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,11
63	0,01	0,01	0,01	0,18	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,20
80	0,01	0,01	0,01	0,18	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,04	0,20
100	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,06	0,10
125	0,01	0,01	0,01	0,02	0,06	0,01	0,01	0,02	0,02	0,05	0,01	0,06	0,10

Uncertainty source for magnitude sensitivity	Distribution
1 - Accelerometer voltage measurement	Rectangular
2 - Accelerometer output filtering	Rectangular
3 - Voltage disturbance on accelerometer signal	Rectangular
4 - Transverse, rocking and bending movements of accelerometer - A: Earth's gravity adding - B: Transverse acceleration	 Rectangular Special (1/ ‾)
5 - Disturbance of quadrature output signal	Rectangular
6 - Interferometer signal filtering	Rectangular
7 - Voltage disturbance on phase amplitude measurement	Rectangular
8 - Motion disturbance on phase amplitude measurement	Rectangular
9 - Phase disturbance on phase amplitude measurement	Rectangular
10 - Residual interferometric effects on phase amplitude measurement	Rectangular
11 - Vibration frequency	Rectangular
12 - Residual effects on sensitivity measurement - A: Other residual effects - B: Type A uncertainty	 Rectangular σ=1

Phase sensitivity

Freq.	Standard uncertainty component (°)											
(Hz)	1	2	3	4	5	6	7	8	9	10	11	-	Combined
0,315	0,02	0,01	0,02	0,01	0,06	0,01	0,02	0,03	0,01	0,06	0,01		0,09
0,4	0,02	0,01	0,02	0,01	0,06	0,01	0,02	0,03	0,01	0,06	0,01		0,09
0,5	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,03	0,01	0,06	0,01		0,09
0,63	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
0,8	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
1	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
1,25	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
1,6	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
2	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
2,5	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
3,15	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
4	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
5	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
6,3	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
8	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
10	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
12,5	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
16	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
20	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
25	0,01	0,01	0,01	0,01	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
31,5	0,01	0,01	0,01	0,02	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
40	0,01	0,01	0,01	0,02	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
50	0,01	0,01	0,01	0,03	0,06	0,01	0,02	0,02	0,01	0,06	0,01		0,09
63	0,01	0,01	0,01	0,06	0,06	0,01	0,02	0,02	0,01	0,06	0,02		0,11
80	0,01	0,01	0,01	0,06	0,06	0,01	0,02	0,02	0,01	0,06	0,02		0,11
100	0,01	0,01	0,01	0,06	0,06	0,01	0,02	0,02	0,01	0,06	0,02		0,11
125	0,01	0,01	0,01	0,09	0,09	0,01	0,02	0,02	0,01	0,06	0,02		0,14

Uncertainty source for phase sensitivity	Distribution
1 - Accelerometer phase measurement	Rectangular
2 - Accelerometer output filtering	Rectangular
3 - Voltage disturbance on accelerometer signal	Rectangular
4 - Transverse, rocking and bending movements of accelerometer	Rectangular
5 - Disturbance of quadrature output signal	Rectangular
6 - Interferometer signal filtering	Rectangular
7 - Voltage disturbance on displacement phase measurement	Rectangular
8 - Motion disturbance on displacement phase measurement	Rectangular
9 - Phase disturbance on displacement phase measurement	Rectangular
10 - Residual interferometric effects on displacement phase measurement	Rectangular
11 - Residual effects on displacement phase measurement (Type A uncertainty)	σ=1

4- METAS

Magnitude sensitivity

Individual contributions to the measurement uncertainty (magnitude)

Pos.	Contribution X	w (x_j)	0.2	0.4	0,63 - < 1	1 - <2.5	2.5 - < 5	5 - < 10	10 - <20	20 - <63	63 - 200
			Frequency / Hz								
1	Curvature of beam	$w(S_S)$	1.75E-03	4.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Voltage measurement	$w(U)$	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04
3	Frequency	$w(w)$	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
4	Amplifier gain	$w(G)$	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04
5	Amplifier frequency response	$w(K_F)$	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	5.00E-04	5.00E-04	5.00E-04	5.00E-04
6	Transverse motion	$w(K_T)$	7.00E-05	7.00E-05	7.00E-05	7.00E-05	7.00E-05	7.00E-05	7.00E-05	1.40E-04	3.00E-03
7	Harmonic excitation	$w(K_D)$	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Hum	$w(K_H)$	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
9	Noise	$w(K_N)$	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
10	Measuring position dependence	$w(K_{GL})$	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.50E-03	1.50E-03	1.50E-03
11	Mounting of transducer	$w(K_{MT})$	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-05	1.40E-04
12	Mounting of cable	$w(K_{MC})$	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	9.00E-04	7.00E-04	7.00E-04
13	Relative motion	$w(K_{REL})$	5.00E-04	5.00E-04	5.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-05	1.00E-05	1.00E-05
14	Temperature stability	$w(K_{TK})$	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05
15	Linearity	$w(K_L)$	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
16	Long term stability	$w(K_I)$	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
17	Residual contributions	$w(K_{RES})$	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
	Relative measurement uncertainty		2.34E-03	1.61E-03	1.55E-03	1.48E-03	1.47E-03	1.19E-03	1.86E-03	1.78E-03	3.49E-03
	Expanded uncertainty (k=2)		4.68E-03	3.23E-03	3.10E-03	2.96E-03	2.94E-03	2.38E-03	3.72E-03	3.56E-03	6.97E-03
	Expanded uncertainty (k=2)	%	**0.47**	**0.32**	**0.31**	**0.30**	**0.29**	**0.24**	**0.37**	**0.36**	**0.70**

METAS Measurement uncertainty (magnitude) for steady excitation at 1 g

Individual contributions to the measurement uncertainty (magnitude)

Pos.	Contribution X_j	$w(x_j)$	DC
1	DC voltage meas (hp3458A)	*w (U)*	6.90E-05
2	angular misalignement	*w (a)*	2.00E-05
3	local g	*w(g)*	1.00E-05
4	Residual contributions	*w (res)*	1.00E-05
	Relative measurement uncertainty		7.32E-05
	Expanded uncertainty (k=2)		1.46E-04
	Expanded uncertainty (k=2)	%	**0.01**

Phase sensitivity

Individual contributions to the measurement uncertainty (phase)

Pos.	Contributior Phi j	u (Phi_j)	Frequency / Hz 0.2	0.4	0.63 - < 1	1 - <10	10 - <20	20 - 63	>63 - 200
1	Curvature of beam	u (Phi_S)	1.00E-02	1.00E-02	1.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Voltage measurement	u (Phi_R)	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02
3	Frequency	u (Phi_w)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Amplifier gain	u (Phi_G)	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
5	Amplifier frequency response	u (Phi_F)	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
6	Transverse motion	u (Phi_T)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	3.00E-01
7	Harmonic excitation	u (Phi_D)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Hum	u (Phi_H)	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
9	Noise	u (Phi_N)	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
10	Measuring position dependence	u (Phi_{GL})	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-01	1.00E-01	1.00E-01
11	Mounting of transducer	u (Phi_{MT})	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02
12	Mounting of cable	u (Phi_{MC})	3.00E-01	3.00E-01	3.00E-01	1.40E-01	7.00E-02	5.00E-02	5.00E-02
13	Relative motion	u (Phi_{REL})	2.00E-01	2.00E-01	2.00E-01	1.00E-01	5.00E-02	5.00E-02	5.00E-02
14	Temperature stability	u (Phi_{TK})	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
15	Linearity	u (Phi_L)	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
16	Long term stability	u (Phi_I)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Residual contributions	u (Phi_{RES})	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
	absolute Messunsicherheit		3.91E-01	3.91E-01	3.91E-01	2.30E-01	2.01E-01	2.07E-01	3.60E-01
	erweiterte absolute Messunsicherheit		7.83E-01	7.83E-01	7.83E-01	4.59E-01	4.02E-01	4.14E-01	7.20E-01
	Erweiterte Messunsicherheit	°	**0.78**	**0.78**	**0.78**	**0.46**	**0.40**	**0.41**	**0.72**

5 – INRIM

Magnitude sensitivity

Uncertainty	description	Type	distibution	factor	degrees of freedom	Standard uncertainty (%)
u_{ri}	Repeatability	A	normal	1	9	0.05
u_{rp}	reproducibility	A	normal	1	2	0.1
u_{mt}	accelerations transverse	B	rectangular	$1/\sqrt{3}$	30	0.1
u_{d}	distorsion	A	normal	1	30	0.06
u_{sc}	Stability conditionator	B	rectangular	$1/\sqrt{3}$	30	0.06
u_{ac}	linearity conditionator	B	rectangular	$1/\sqrt{3}$	30	0.04
u_{at}	linearity transducer	B	rectangular	$1/\sqrt{3}$	30	0.04
u_{co}	Counting error	A	normal	1	30	0.03
u_{amp}	amplifier noise	A	normal	1	30	0.08

$$u_S = \sqrt{u_{ri}^2 + u_{rp}^2 + u_{mt}^2 + u_d^2 + u_{sc}^2 + u_{ac}^2 + u_{at}^2 + u_{co}^2 + u_{amp}^2}$$

$$u_S = 0.2\ \%$$

The total degrees of freedom are calculated using the Welch-Satterthwaite formula's:

$$\nu = \frac{u_S^4}{\sum_i^7 \frac{u_i^4}{\nu_i}}$$

and are

$$\nu_{eff} = 29$$

Using the t-student distribution, a coverage factor, k=2 has been evaluated.

So, the expanded uncertainty, calculated as $U_S = k \cdot u_S$ expressed as the standard uncertainty multiplied by the coverage factor $k = 2$, corresponds to a probability of coverage of about 95%.

$$U_{S\,(95\,\%)} = 0.4\ \%$$

6 - GUM

Magnitude sensititvity

i	Source of uncertainty	Distribution (type of uncertainty)	Uncertainty contribution				
			1 Hz to < 10 Hz	10 Hz to < 19,953 Hz	19,953 Hz to < 79,433 Hz	79,433 Hz to < 158,489Hz	158,489 Hz
1	Accelerometer output voltage measurement	normal (B)	0,00045	0,00045	0,00045	0,00045	0,00045
2	Vibration velocity	normal (B)	0,00010	0,00010	0,00010	0,00010	0,00010
3	Frequency of vibration signal	rectangular (B)	0,00001	0,00001	0,00001	0,00001	0,00001
4	Amplifier transfer coefficient (gain)	normal (B)	0,00040	0,00040	0,00040	0,00050	0,00050
5	Frequency response	normal (B)	0,00050	0,00050	0,00050	0,00050	0,00050
6	Transverse motion	rectangular (B)	0,00035	0,00035	0,00035	0,00125	0,00250
7	Harmonics	rectangular (B)	0,00001	0,00001	0,00001	0,00001	0,00001
8	Hum	normal (B)	0,00010	0,00010	0,00010	0,00020	0,00020
9	Noise	normal (B)	0,00001	0,00001	0,00001	0,00001	0,00001
10	Geometrical dependence on measurement location	rectangular (B)	0,00100	0,00150	0,00150	0,00150	0,00150
11	Transducer mounting	rectangular (B)	0,00150	0,00150	0,00150	0,00150	0,00150
12	Cable mounting	rectangular (B)	0,00300	0,00200	0,00100	0,00100	0,00100
13	Relative motion	rectangular (B)	0,00010	0,00001	0,00001	0,00001	0,00001
14	Temperature change	rectangular (B)	0,00002	0,00002	0,00002	0,00002	0,00002
15	Linearity	rectangular (B)	0,00001	0,00001	0,00001	0,00001	0,00001
16	Instability of vibration signal with time	rectangular (B)	0,00001	0,00001	0,00001	0,00001	0,00001
17	Residual interferometric effects on measurement	rectangular (B)	0,00050	0,00050	0,00050	0,00050	0,00050
18	Standard deviation of arithmetic mean	normal (A)	0,00005	0,00004	0,00014	0,00022	0,00040
Total relative measurement uncertainty			0,00364	0,00308	0,00255	0,00285	0,00359
Expanded measurement uncertainty (k = 2), rounded			0,7 %	0,6 %	0,5%	0,6 %	0,7 %

Phase sensitivity

i	Source of uncertainty	Distribution (type of uncertainty)	Uncertainty contribution in °			
			1 Hz to < 19,953 Hz	19,953 Hz to < 63,096 Hz	63,096 Hz to <158,489 Hz	158,489Hz
1	Accelerometer output voltage measurement	normal (B)	0,10	0,10	0,10	0,10
2	Vibration velocity	normal (B)	0,01	0,01	0,01	0,01
3	Frequency of vibration signal	rectangular (B)	0,01	0,01	0,01	0,01
4	Amplifier transfer coefficient (gain)	normal (B)	0,10	0,10	0,15	0,15
5	Frequency response	normal (B)	0,10	0,10	0,10	0,10
6	Transverse motion	rectangular (B)	0,10	0,10	0,20	0,25
7	Hum	normal (B)	0,01	0,01	0,02	0,02
8	Noise	normal (B)	0,01	0,01	0,01	0,01
9	Geometrical dependence on measurement location	rectangular (B)	0,01	0,10	0,10	0,10
10	Transducer mounting	rectangular (B)	0,10	0,10	0,10	0,10
11	Cable mounting	rectangular (B)	0,20	0,10	0,10	0,10
12	Relative motion	rectangular (B)	0,10	0,05	0,05	0,05
13	Temperature change	rectangular (B)	0,01	0,01	0,01	0,01
14	Linearity	rectangular (B)	0,01	0,01	0,01	0,01
15	Instability of vibration signal with time	rectangular (B)	0,01	0,01	0,01	0,01
16	Residual interferometric effects on measurement	rectangular (B)	0,10	0,10	0,10	0,10
17	Standard deviation of arithmetic mean	normal (A)	0,01	0,01	0,01	0,03
Total relative measurement uncertainty			0,33°	0,29°	0,35°	0,39°
Expanded measurement uncertainty (k = 2), rounded			0,70°	0,60°	0,70°	0,80°

7 - CEM

Magnitude

Description	Relative expanded uncertainty (%)	Probability distribution	Factor	Uncertainty type	Uncertainty contribution (%)
Laser	0,26	normal	2	B	0,13
Voltage	0,06	normal	2	B	0,03
Vibration signal frequency	0,002	rectangular	1,732	B	0,001
Gain coefficient (amplifiers)	0,04	normal	2	B	0,02
Frequency response	0,20	normal	2	B	0,10
Transverse motion	0,08	rectangular	1,732	B	0,05
Hum	0,02	rectangular	1,732	B	0,01
Noise	0,002	rectangular	1,732	B	0,001
Cable layout	0,20	rectangular	1,732	B	0,12
Relative Motion	0,10	rectangular	1,732	B	0,06
Temperature response	0,01	rectangular	1,732	B	0,006
Geometric location of the laser beam	0,20	rectangular	1,732	B	0,115
Repetibility	0,20	normal	1	A	0,00
Temperature influence on sensor	0,0003	rectangular	1,732	B	0,00
	Expanded uncertainty				0,5

Phase

Description	Relative expanded uncertainty (1º)	Probability distribution	Factor	Uncertainty type	Uncertainty contribution (1º)
Laser	0,10	normal	2	B	0,05
Voltage	0,007	normal	2	B	0,004
Gain coefficient (amplifiers)	0,20	normal	2	B	0,10
Frequency response	0,20	normal	2	B	0,10
Transverse motion	0,20	rectangular	1,732	B	0,12
Hum	0,02	rectangular	1,732	B	0,012
Noise	0,02	rectangular	1,732	B	0,012
Cable layout	0,1	rectangular	1,732	B	0,06
Temperature response	0,01	rectangular	1,732	B	0,006
Geometric location of the laser beam	0,1	rectangular	1,732	B	0,058
Repetibility	0,10	normal	1	A	0,10
	Expanded uncertainty				0,5

8 - PTB

Magnitude sensititivy

DUT	QFlex QA3000
acceleration:	-0,025 m/s² to 1 m/s²
Voltage	< 1V

Disturbing Component	comment	95% value	distribution	factor	combined frequency ranges: 0,1 Hz - <0,2 Hz	0,2 Hz - < 0,4 Hz	0,4 Hz - < 10 Hz	10 Hz – 200 Hz	DC
frequency of SAM	deviation of sample clock from generator clock		rectangular	1,732	5,77E-05	5,77E-05	5,77E-05	5,77E-05	
Accelerometer Voltage	sampling of HP3458A	5,00E-04	rectangular	1,732	2,89E-04	2,89E-04	2,89E-04	2,89E-04	2,89E-04
Velocity amplitude	wave length, optical adjustment,	1,16E-05	normal	2	5,80E-06	5,80E-06	5,80E-06	5,80E-06	
harmon. Distortion	mainly 1st harmonic		Steiner	1	7,84E-06	7,84E-06	7,84E-06	7,84E-06	
Humm on Voltage	typical 1mV	5,00E-07	Steiner	1	5,00E-07	5,00E-07	5,00E-07	5,00E-07	
Influence of Noise on Voltage	MC on influence to SAM duration 20ms, Un=1,0mV		normal	1	3,30E-06	3,30E-06	3,30E-06	3,30E-06	
Transverse Motion, Non-planarity	S(transv) = 0,7% a(transv) < 4%		u-type	1,414	1,30E-03	7,00E-04	2,50E-04	2,00E-04	
Base strain sensitivity	S = 0,005m/s² / µ€ € < 0,1 µm/m	0,000005	rectangular	1,732	2,89E-06	2,89E-06	2,89E-06	2,89E-06	
mounting	S = 6e-4/Nm; dM = 0,2 Nm	0,00012	rectangular	1,732	6,93E-05	6,93E-05	6,93E-05	6,93E-05	
Temperature	S=2,5e-4 /K dT = 0,3 K	0,000075	rectangular	1,732	4,33E-05	4,33E-05	4,33E-05	4,33E-05	
Magnetic field	S=1/a *(m/s²)/T B < 0,03mT	0,0000003	rectangular	1,732	1,73E-07	1,73E-07	1,73E-07	1,73E-07	
Airborne acoustics	S=0,008 m/s² at 154 dB max sound level 88 dB	8,00E-08	rectangular	1,732	4,62E-08	4,62E-08	4,62E-08	4,62E-08	
Noise on Interferom.	noise level equiv. of 2 nm after demodulation, Monte Carlo		normal	1	1,10E-04	1,10E-04	1,10E-04	1,10E-04	
a-synchronous Measurement	voltage/acceleration/voltage	1,00E-04	rectangular	1,732	5,77E-05	5,77E-05	5,77E-05	5,77E-05	
charge ampl. calibration					2,12E-04	2,12E-04	2,12E-04	2,12E-04	
resid. influences		1,00E-04	normal	1,414	7,07E-05	7,07E-05	7,07E-05	7,07E-05	
exp. std. dev					2,00E-03	1,20E-03	4,00E-04	1,50E-04	
angle deviation to normal	in degree	1,5	rectangular	1,732					5,94E-004
local gravity	from force lab 9,81252 m/s2	1,00E-005	normal	1					1,00E-005
rel. std. uncertainty	**in %**				**0,24**	**0,14**	**0,06**	**0,047**	**0,066**
rel. comb. exp. Uncertainty (k=2)	**in %**				**0,48**	**0,29**	**0,12**	**0,094**	**0,132**
stated rel. comb. exp. Uncertainty	**in %**				**0,50**	**0,30**	**0,20**	**0,100**	**0,200**

Phase sensitivity

DUT QFlex QA3000
acceleration: -0,025 m/s² to 1 m/s²
Voltage < 1V

Disturbing Component	comment	95% value	distribution	factor	combined frequency ranges 0,1 Hz - <0,4 Hz	combined frequency ranges 0,4 Hz – 200 Hz
Channel a-synchronisity	all frequencies	< 10 ns	normal	2	1,80E-03	1,80E-02
Humm (50 Hz)	Monte Carlo, multiples of 20ms are evaluated	equivalent displacement amp. 4 µm	normal	1	8,00E-03	8,00E-03
Noise on accelerometer Voltage output	Monte Carlo, SNR=500	< 2mV @ 1V	normal	1	8,00E-02	1,00E-02
Transverse/Rocking motion	1 % transv. Sensitivity @ 10% transv. Excitation	rel. Phase 0 … 2pi	U-type (by MC)	1	7,00E-04	7,00E-04
delay of Laser Vibrom. + Mixer + Filter	absolut correction 1,54µs applied	uncert. of correction 60 ns	rectang.	1,73	4,97E-06	2,49E-03
Noise on heterodyne interferometer channel	noise level equiv. of 2 nm after demodulation, Monte Carlo	< 2nm	normal	1	1,43E-04	1,43E-04
Motion disturbance	drift, relative motion evaluation as velocity and period by period	estimated < 0,02°	normal	2	1,00E-02	1,00E-02
exp. Std. deviation		typical < 0,02°	normal	2	8,00E-03	4,00E-03
std. uncertainty	**in 1°**				**0,081**	**0,025**
exp. Uncertainty (k=2)	**in 1°**				**0,168**	**0,049**
stated exp. Uncertainty	**in 1°**				**0,2**	**0,2**

9 – DPLA

Magnitude sensitivity

i	Budget of Uncertainties (Magnitude) 3629 Quadrature system with air-bearing shaker APS129	Uncertainty Contribution	Relative expanded uncertainty or bounds of estimated error components	Probability distribution model	Factor	Contribution u,i (y) 0.10 Hz to <0.2 Hz	0.2 Hz to 1 Hz	>1 Hz to 2 Hz	>2 Hz to 10 Hz	> 10 Hz to 20 Hz	> 20 Hz to 63 Hz	> 63 Hz to 200 Hz
	Notes:											
	Cal. Mode: Voltage											
	All values are 1 sigma values											
i	Description		[%]		xi	%	%	%	%	%	%	%
1		u1 (S)	0,044	Normal (k = 2)	0,5	0,063	0,042	0,023	0,024	0,025	0,033	0,022
2		u2 (S)	0,010	Rectangular	0,577	0,006	0,006	0,006	0,006	0,006	0,006	0,006
3		u3 (S)	0,010	Rectangular	0,577	0,006	0,006	0,006	0,006	0,006	0,006	0,006
4		u4 (S)	0,200	Special	0,23570	0,009	0,009	0,009	0,009	0,141	0,189	0,283
4a		u4a (S)	0,000	Normal (k = 2)	0,5	0,000	0,000	0,000	0,000	0,000	0,000	0,000
5		u5 (S)	0,050	Rectangular	0,577	0,029	0,029	0,029	0,029	0,029	0,029	0,029
6		u6 (S)	Included in 5									
7		u7 (S)	Included in 5									
8		u8 (S)	0,100	Rectangular	0,236	0,024	0,024	0,024	0,024	0,024	0,024	0,024
9		u9 (S)	Included in 5									
10		u10 (S)	Included in 5									
11		u11 (S)	0,0025	Rectangular	1,1547	0,003	0,003	0,003	0,003	0,003	0,003	0,003
12 a		u12a (S)	0,08944271	Rectangular	0,5773	0,05164	0,05164	0,05164	0,05164	0,05164	0,05164	0,5773
12 b		u12b (S)		Correlated	1	0,080	0,040	0,010	0,008	0,001	0,001	0,000
	Uncertainty for accelerometer sensitivity S2		Standard uncertainty (k = 1)			0,191	0,137	0,098	0,097	0,179	0,224	0,668
	Uncertainty for accelerometer sensitivity S2		95% conf.level uncertainty (k = 2)			0,382	0,274	0,196	0,193	0,358	0,448	1,335
	Uncertainty for accelerometer sensitivity S2		Reported uncertainty			0,5	0,4	0,4	0,4	0,4	0,5	1,5

Phase sensitivity

i	Quantity	Description	Unc.	Expanded	Probability	Factor	Contribution	u,i (y)				
	Numbering following 10 16063-11 table A	Budget of Uncertainties (Phase) 3629 Quadrature system with air-bearing shaker APS129										
		Notes:	Contribution	uncertainty or bounds	distribution							
		Cal. Mode: Voltage		of estimated error	model		> 0.1 Hz	> 0.3 Hz	> 5 Hz	> 10 Hz	> 25 Hz	> 50 Hz
		All values are 1 sigma values		components			to 0.3 Hz	to 5 Hz	to 10 Hz	to 25 Hz	to 50 Hz	to 80 Hz
i	Quantity	Description		[degrees]		xi	[degrees]	[degrees]	[degrees]	[degrees]	[degrees]	[degrees]
1	φ	Accelerometer output phase measurement (waveform recorder; e.g. ADCresolution)	u1 (S)	0,200	Rectangular	0,577	0,115	0,115	0,115	0,115	0,115	0,115
2	φ	Voltage filtering effect on accelerometer output phase measurement (frequency band limitation)	u2 (S)	Included in 1	Rectangular	0,577						
3	φ	Effect of voltage disturbance on accelerometer output voltage phase measurement (e.g. hum and noise)	u3 (S)	0,010	Rectangular	0,577	0,006	0,006	0,006	0,006	0,006	0,006
4	φ	Effect of transverse, rocking and bending acceleration on accelerometer output voltage phase measurement (transverse sensitivity)	u4 (S)	0,060	Special	0,23570	0,014	0,014	0,014	0,014	0,177	0,354
4a	φ	Calibration factor for Reference charge amplifier phase response	u4a (S)	0,000	Rectangular	0,577	0,000	0,000	0,000	0,000	0,000	0,000
5	φ	Effect of interferometer quadrature output signal disturbance on displacement phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	u5 (S)	0,010	Rectangular	0,577	0,006	0,006	0,006	0,006	0,006	0,006
6	φ	Interferometer signal filtering effect on displacement phase amplitude measurement (frequency band limitation)	u6 (S)	Included in 5								
7	φ	Effect of voltage disturbance on displacement phase amplitude measurement (e.g. random noise in the photoelectric measuring chains)	u7 (S)	Included in 5								
8	φ	Effect of motion disturbance on displacement phase amplitude measurement (e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	u8 (S)	0,057	Rectangular	0,577	0,033	0,033	0,033	0,033	0,033	0,033
9	φ	Effect of phase disturbance on displacement phase amplitude measurement (e.g. phase noise of the interferometer signals)	u9 (S)	Included in 5								
10	φ	Residual interferometric effects on displacement phase amplitude measurement (interferometer function)	u10 (S)	0,010	Rectangular	0,577	0,006	0,006	0,006	0,006	0,006	0,006
11	Δφ	Residual effects on phase shift measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	u12 (S)	0,050	Rectangular	0,577	0,058	0,058	0,029	0,029	0,029	0,029
	Δφ	Uncertainty for accelerometer sensitivity Δφ			Standard uncertainty (k = 1)		0,134	0,134	0,125	0,125	0,216	0,375
		Uncertainty for accelerometer sensitivity Δφ			95% conf.level uncertainty (k = 2)		0,269	0,269	0,249	0,249	0,432	0,749
		Uncertainty for accelerometer sensitivity Δφ			Reported uncertainty		0,3	0,3	0,3	0,3	0,5	1,0

10 – MIKES

Magnitude sensitivity

The relative expanded uncertainty of measurement of the sensitivity **magnitude $U_{rel}(S)$**

i	Standard uncertainty component u(xi)	Source of uncertainty	Relative expanded uncertainty or bounds of estimated error components (%)			Probability distribution model, method of evaluation (A or B)	Factor	Sensitivity coefficient	Relative uncertainty contribution $u_{rel,i}(y)$ (%)		
			0.8 Hz- 40 Hz	50 Hz- 63 Hz	80 Hz				0.8 Hz- 40 Hz	50 Hz- 63 Hz	80 Hz
1	$u(\hat{a}_V)$	accelerometer output voltage measurement (waveform recorder; e.g. ADC-resolution)	0.1	0.1	0.1	rectangular, B	1/√3	1	0.06	0.06	0.06
2	$u(\hat{a}_F)$	voltage filtering effect on accelerometer output amplitude measurement (frequency band limitation)	0.01	0.01	0.01	rectangular, B	1/√3	1	0.01	0.01	0.01
3	$u(\hat{a}_D)$	effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise)	0.01	0.01	0.01	rectangular, B	1/√3	1	0.01	0.01	0.01
4	$u(\hat{a}_T)$	effect of transverse, rocking and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	0.2	0.1	0.15	rectangular, B	1/√3	1	0.12	0.06	0.09
5	$u(\hat{\varphi}_{M,Q})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	0.15	0.15	0.2	rectangular, B	1/√3	1	0.09	0.09	0.12
6	$u(\hat{\varphi}_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	0.01	0.01	0.01	rectangular, B	1/√3	1	0.01	0.01	0.01
7	$u(\hat{\varphi}_{M,VD})$	effect of voltage disturbance on phase amplitude measurement (e.g. random noise in the photoelectric measuring chains)	0.05	0.05	0.05	rectangular, B	1/√3	1	0.03	0.03	0.03
8	$u(\hat{\varphi}_{M,MD})$	effect of motion disturbance on phase amplitude measurement (e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	0.1	0.1	0.2	rectangular, B	1/√3	1	0.06	0.06	0.12
9	$u(\hat{\varphi}_{M,PD})$	effect of phase disturbance on phase amplitude measurement (e.g. phase noise of the interferometer signals)	0.05	0.05	0.05	rectangular, B	1/√3	1	0.03	0.03	0.03
10	$u(\hat{\varphi}_{M,RE})$	residual interferometric effects on phase amplitude measurement (interferometer function)	0.1	0.1	0.15	rectangular, B	1/√3	1	0.06	0.06	0.09
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	0.01	0.01	0.01	rectangular, B	1/√3	2	0.01	0.01	0.01
12	$u(S_{RE})$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	0.15	0.25	0.41	normal (k=1), A	1	1	0.15	0.25	0.41
	Total relative uncertainty (%)								0.24	0.29	0.46
	Expanded measurement uncertainty at k = 2 (%)								0.47	0.58	0.93
	Expanded measurement uncertainty at k = 2 (%), rounded value								0.5	0.6	1.0

Phase sensitivity

The expanded uncertainty of measurement of the phase shift $U(\Delta\varphi)$

i	Standard uncertainty component u(xi)	Source of uncertainty	Expanded uncertainty or bounds of estimated error components (°)			Probability distribution model, method of evaluation (A or B)	Factor	Sensitivity coefficient	Uncertainty contribution $u_i(y)$ (°)		
			0.8 Hz- 40 Hz	50 Hz- 63 Hz	80 Hz				0.8 Hz- 40 Hz	50 Hz- 63 Hz	80 Hz
1	$u(\varphi_{u,V})$	accelerometer output phase measurement (waveform recorder; e.g. ADC-resolution)	0.10	0.10	0.10	rectangular, B	1/√3	1	0.06	0.06	0.06
2	$u(\varphi_{u,F})$	voltage filtering effect on accelerometer output phase measurement (frequency band limitation)	0.00	0.00	0.00	rectangular, B	1/√3	1	0.00	0.00	0.00
3	$u(\varphi_{u,D})$	effect of voltage disturbance on accelerometer output phase measurement (e.g. hum and noise)	0.01	0.01	0.01	rectangular, B	1/√3	1	0.01	0.01	0.01
4	$u(\varphi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	0.23	0.11	0.17	rectangular, B	1/√3	1	0.13	0.06	0.10
5	$u(\varphi_{s,Q})$	effect of interferometer quadrature output signal disturbance on displacement phase measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	0.17	0.17	0.23	rectangular, B	1/√3	1	0.10	0.10	0.13
6	$u(\varphi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	0.01	0.01	0.01	rectangular, B	1/√3	1	0.01	0.01	0.01
7	$u(\varphi_{s,VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	0.06	0.06	0.06	rectangular, B	1/√3	1	0.03	0.03	0.03
8	$u(\varphi_{s,MD})$	effect of motion disturbance on displacement phase measurement (e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	0.11	0.11	0.23	rectangular, B	1/√3	1	0.06	0.06	0.13
9	$u(\varphi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	0.06	0.06	0.06	rectangular, B	1/√3	1	0.03	0.03	0.03
10	$u(\varphi_{s,RE})$	residual interferometric effects on displacement phase measurement (interferometer function)	0.11	0.11	0.17	rectangular, B	1/√3	1	0.06	0.06	0.10
11	$u(\Delta\varphi_{RE})$	residual effects on phase shift measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	0.17	0.29	0.47	normal (k=1), A	1	1	0.17	0.29	0.47
	Total uncertainty (°)								0.26	0.33	0.53
	Expanded measurement uncertainty at k = 2 (°)								0.53	0.67	1.06
	Expanded measurement uncertainty at k = 2 (°), rounded value								0.6	0.7	1.1