Final Report of CCAUV.V-K3: Key comparison in the field of Acceleration on the complex charge sensitivity

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1. Introduction

This report presents the results of the first CCAUV comparison in the area of low-frequency ‘vibration’, which in this case means sinusoidal acceleration.

The participants have reached consensus and considered the weighted mean as the most appropriate method for this particular comparison to compute the key comparison reference values (KCRVs) and the degrees of equivalence (DoEs). Detailed analysis and application of the method for use of the weighted mean in comparisons in the field of vibration, is documented in the CCAUV.V-K1 report [1]. The calculation of the KCRVs is also in accordance with the Guidelines for CIPM key comparisons [2].

The Technical Protocol, published in 2015 [3], specifies in detail the aim, the task of the comparison, the conditions for the measurements, the transfer standard used, measurement instructions, time schedule and other items. A brief survey of the Technical Protocol is given in the following sections.

2. Participants

Fourteen metrology institutes (NMIs) from five Regional Metrology Organizations (RMOs) participated in the comparison. They are listed in chronological order of measurement in Table 2.1.

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

No.	Participant Laboratory	Acronym	Country	RMO	Calibration period (week/year)
1	National Institute of Metrology, China	NIM	China	APMP	35/2014 to 09/2016
2	Laboratoire National de Métrologie et d’Essais	LNE	France	EURAMET	37/2014 to 39/2014
3	Physikalisch-Technische Bundesanstalt	PTB	Germany	EURAMET	40/2014 to 42/2014
4	Brüel & Kjaer Sound & Vibration Measurement Ltd - Danish Primary Laboratory for Acoustics Section	BKSV-DPLA	Denmark	EURAMET	43/2014 to 45/2014
5	Central Office of Measures	GUM	Poland	EURAMET	46/2014 to 48/2014
6	Swiss Federal Office of Metrology	METAS	Switzerland	EURAMET	49/2014 to 03/2015

7	National Metrology Institute of South Africa	NMISA	South Africa	AFRIMETS	12/2015 to 14/2015
8	Instituto Nacional de Metrologia, Qualidade e Tecnologia	INMETRO	Brazil	SIM	15/2015 to 17/2015
9	Centro Nacional de Metrologia	CENAM	Mexico	SIM	18/2015 to 20/2015
10	National Measurement Institute of Australia	NMIA	Australia	APMP	21/2015 to 23/2015
11	National Metrology Institute of Japan	NMIJ	Japan	APMP	24/2015 to 26/2015
12	Korea Research Institute of Standards and Science	KRISS	Republic of Korea	APMP	27/2015 to 29/2015
13	D.I. Mendeleyev Institute for Metrology	VNIIM	Russia Federation	COOMET	30/2015 to 32/2015
14	National Metrology Centre, Agency for Science, Technology and Research	NMC A*STAR	Singapore	APMP	33/2015 to 35/2015

3. Task and purpose of the comparison

According to the rules set up by the CIPM MRA [4], the consultative committees of the CIPM have the responsibility to establish Degrees of Equivalence (DoEs) between the different measurement standards operated by the NMIs. This is done by conducting key comparisons (KC) on different levels of the international metrological infrastructure. The previous top level KCs in the field of vibration metrology, CCAUV.V-K1 was completed in the year 2001 in the frequency range 40 Hz to 5 kHz, and CCAUV.V-K2 was completed in the year 2014 in the frequency range 10 Hz to 10 kHz.

However, recent developments in technology and improvements at the NMIs have extended the low-frequency vibration limit of calibration capabilities down to 0.4 Hz and even down to 0.1 Hz or lower frequencies. Therefore during the 8th meeting of CCAUV in 2012, the decision was taken to make preparations for a further comparison targeted at the low frequency range.

In the field of vibration, this key comparison was organized in order to compare measurements of sinusoidal linear accelerations in the frequency range from 0.1 Hz to 40 Hz. Moreover, the complex sensitivity calibration and measurement capabilities (CMCs) of the participating laboratories for accelerometer calibration were to be examined and compared. It was the task of the comparison to measure the complex sensitivity of one accelerometer standard set (a quartz-flexure servo accelerometer of single-ended type and a signal conditioner) at different frequencies with acceleration amplitudes as specified in Section 3. The results of this key comparison will, after approval of equivalence, serve as the foundation to stablish the Key Comparison Reference Values (KCRV) at low vibration frequency to determine the DoEs derived from three existing regional low frequency key comparisons. These DoEs will provide a supporting evidence for the registration of 'calibration and measurement capabilities' (CMC) in the framework of the CIPM MRA [4].

The results of this comparison are expected to provide direct support to CMCs related to the primary calibration of complex voltage sensitivity of both acceleration measuring chains and accelerometers at low frequencies. This support can be extended to a wider scope of measurements, including primary calibration of complex charge sensitivity and current sensitivity of accelerometers.

For the calibration of the accelerometer standard set, laser interferometry in compliance with method 3 of the international standard ISO 16063-11:1999 had to be applied in order to cover the entire frequency range. Specifically, the magnitude of the complex voltage sensitivity had to be given in millivolts per metre per second squared (mV/(m/s^2)) and phase shift in degrees (°) for the different measurement conditions specified in Section 4.

The reported complex sensitivities and associated uncertainties are then supposed to be used for the calculation of the DoEs between the participating NMI and the KCRVs.

4. Transfer standard as artefacts

For the purpose of the comparison the pilot laboratory selected one accelerometer of which monitoring data for six months were available and not included in any published international cooperation work.

- One transfer standard accelerometer (single-ended), type SA704, S/N 1040 (manufacturer: NIM).
- One signal conditioner, type MSA-I, S/N 02011001 (manufacturer: NIM).

The investigation of the long-term stability was continued throughout the circulation period. The results of the NIM stability measurements and other individual data of the transfer standards are given in Section 6.

5. Circulation of the artefacts

The accelerometer standard set was circulated in two loops with a measurement period of two weeks provided for each participating laboratory and one week for the monitoring measurements carried out by the pilot laboratory. At the beginning and the end of the circulation as well as between certain subsequent measurements of participating laboratories, the accelerometer standard set was measured by the pilot laboratory in order to monitor the stability of the accelerometer standard set.

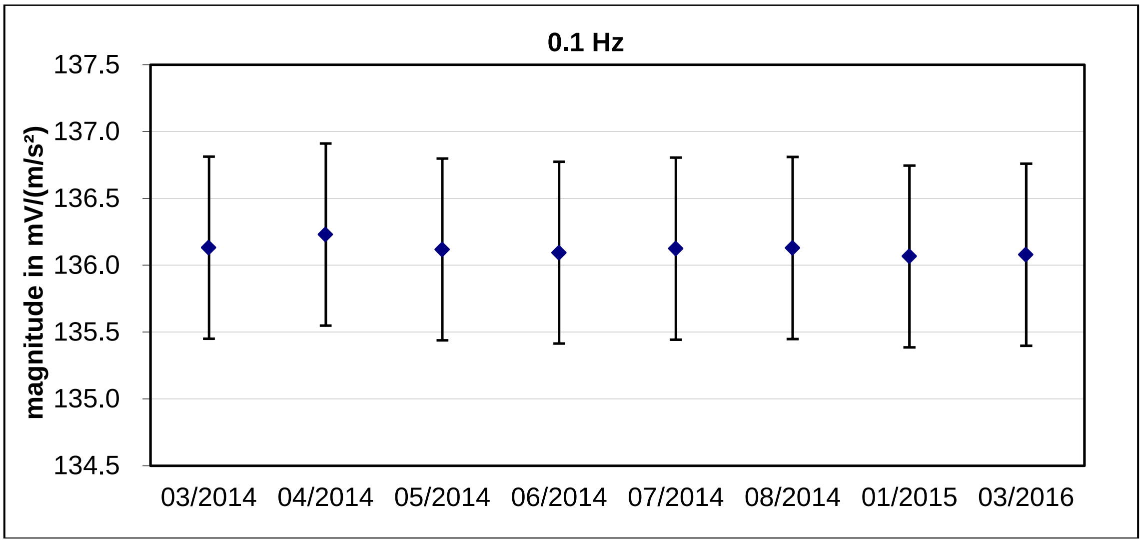
The acceleration input range of the SA-704 is 600 m/s^2 and the highest environment shock is 1000 m/s^2. Therefore, any violent drop could change its sensitivity or even damage it. The accelerometer standard set had to be hand-carried during transportation between participants with great caution.

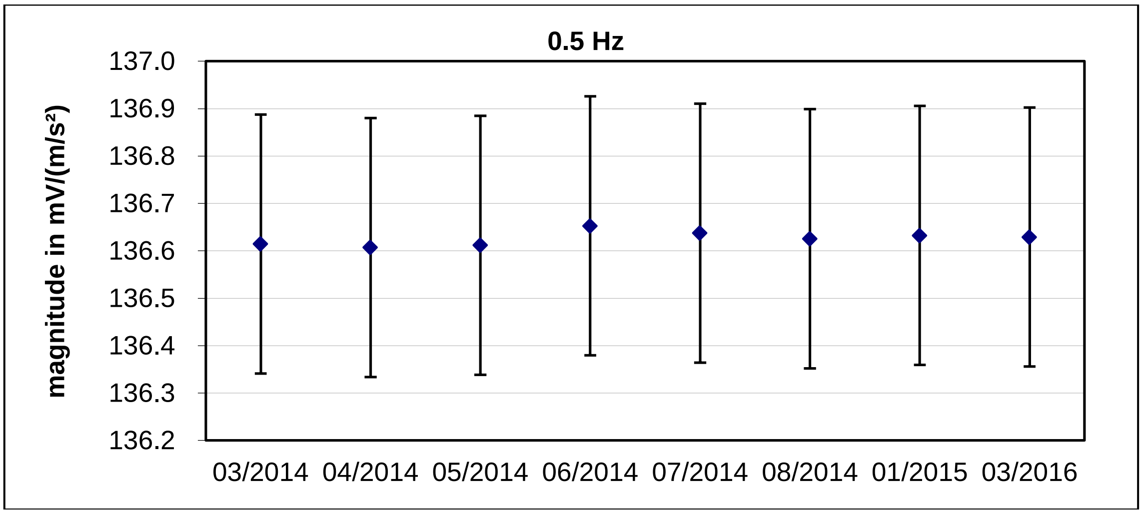
6. Results of the monitoring measurements

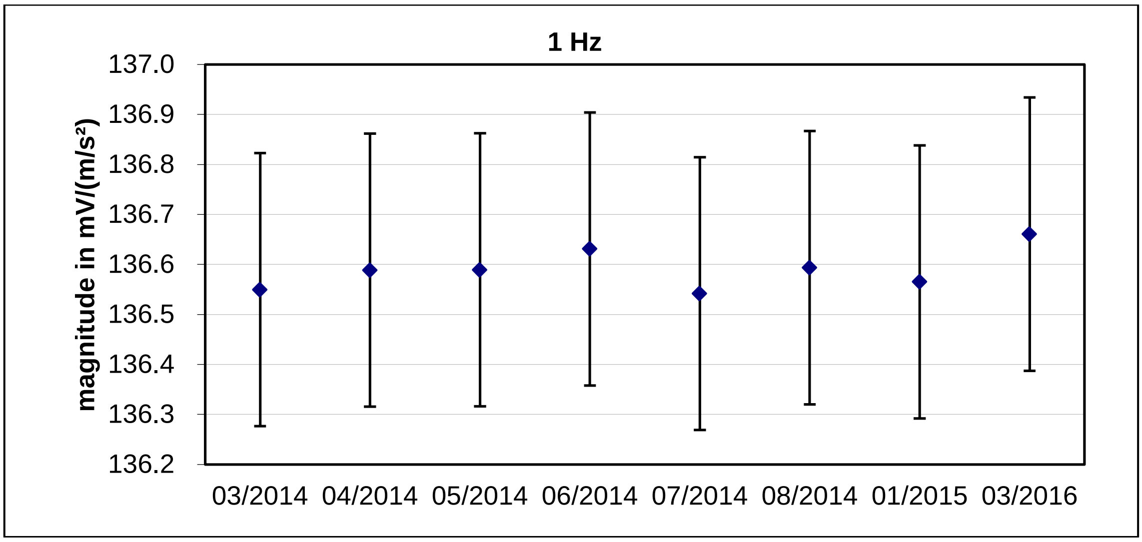
Starting with calibration data in February 2014, the artefacts were monitored during the preparation period and the intervals of the comparison when it was back at the pilot laboratory. As a representative of the overall change, the measurements at several sample frequencies are presented in Figure 6.1 and Figure 6.2. These figures depict the stability of the artefact over time for the duration of the comparison.

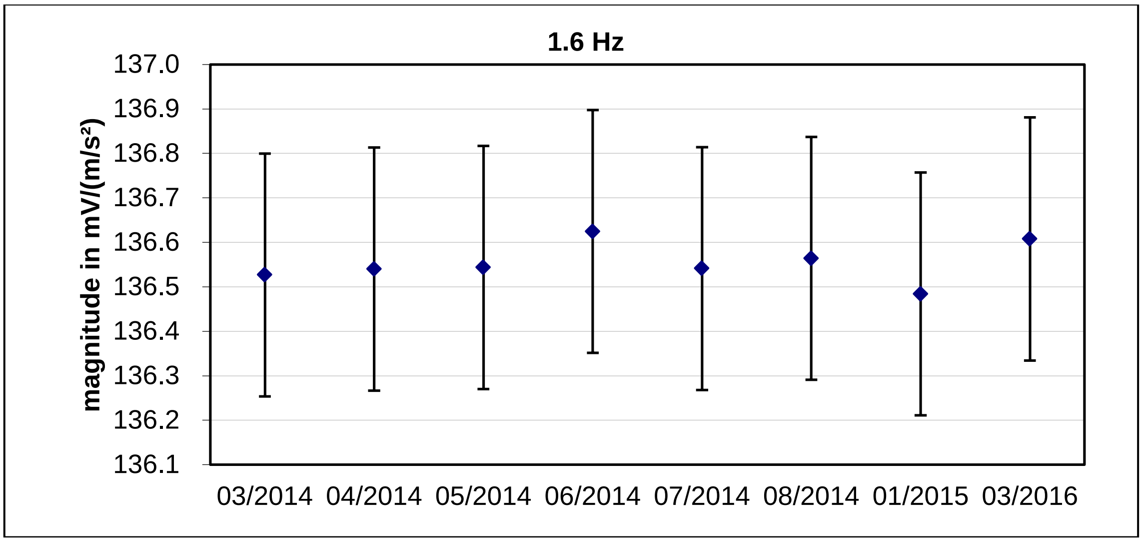
It is worth noting that normalization was applied to the values between 0.1 Hz and 0.4 Hz. At these frequencies, the 20 dB gain option was selected on the conditioner, which gave a nominal voltage sensitivity of approximately 1300 mV/(m/s^2). The pilot laboratory applied a -20 dB correction to all the results in the frequency range to allow direct comparison with the results reported for the frequencies higher than 0.4 Hz, for which a 0 dB gain was used.

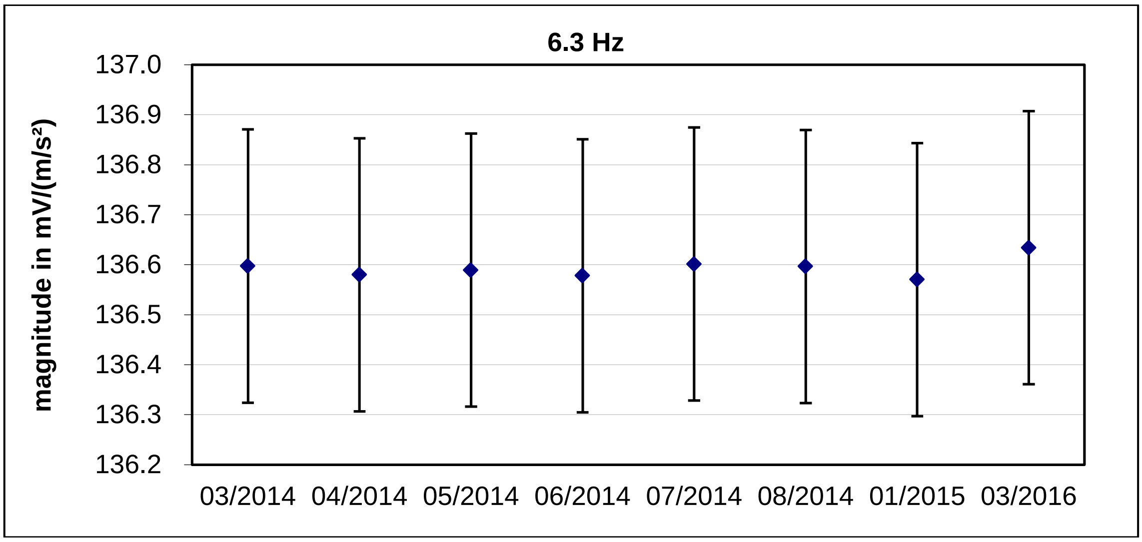
Figure 6.1 Monitoring of the amplitude sensitivity over the comparison period

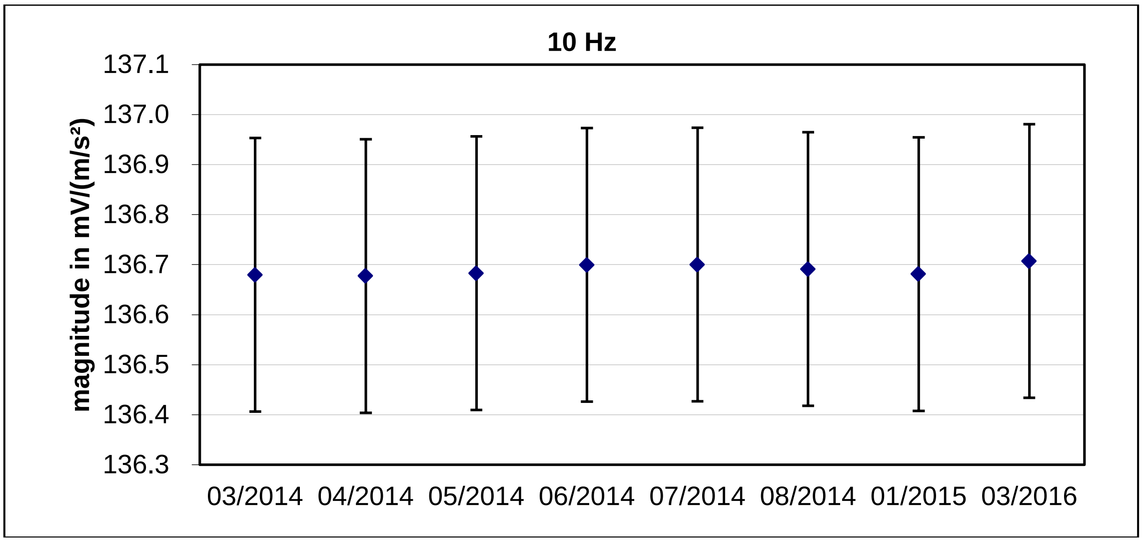


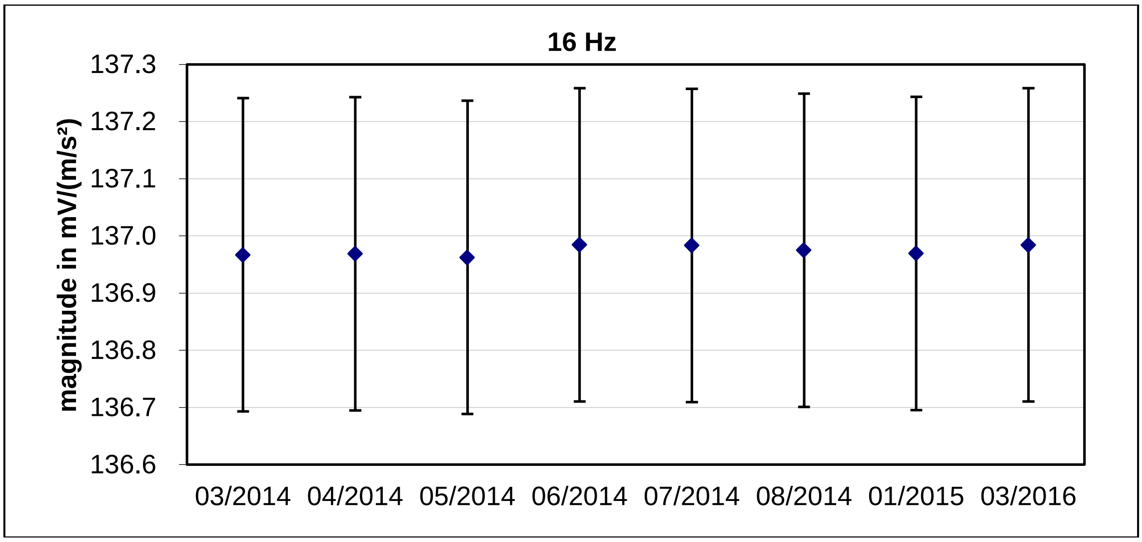



1 Hz
magnitude in mV/(m/s²)
137.0
136.9
136.8
136.7
136.6
136.5
136.4
136.3
136.2
03/2014
04/2014
05/2014
06/2014
07/2014
08/2014
01/2015
03/2016


1.6 Hz
magnitude in mV/(m/s²)
137.0
136.9
136.8
136.7
136.6
136.5
136.4
136.3
136.2
136.1
03/2014
04/2014
05/2014
06/2014
07/2014
08/2014
01/2015
03/2016


6.3 Hz
magnitude in mV/(m/s²)
137.0
136.9
136.8
136.7
136.6
136.5
136.4
136.3
136.2
03/2014
04/2014
05/2014
06/2014
07/2014
08/2014
01/2015
03/2016


10 Hz
magnitude in mV/(m/s²)
137.1
137.0
136.9
136.8
136.7
136.6
136.5
136.4
136.3
03/2014 04/2014 05/2014 06/2014 07/2014 08/2014 01/2015 03/2016


16 Hz
magnitude in mV/(m/s²)
137.3
137.2
137.1
137.0
136.9
136.8
136.7
136.6
03/2014 04/2014 05/2014 06/2014 07/2014 08/2014 01/2015 03/2016

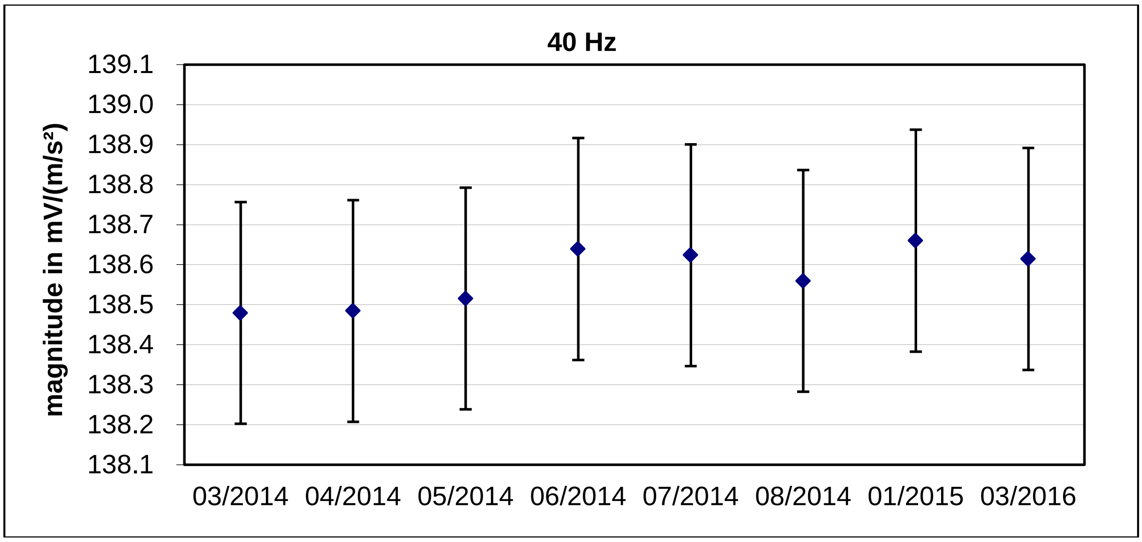
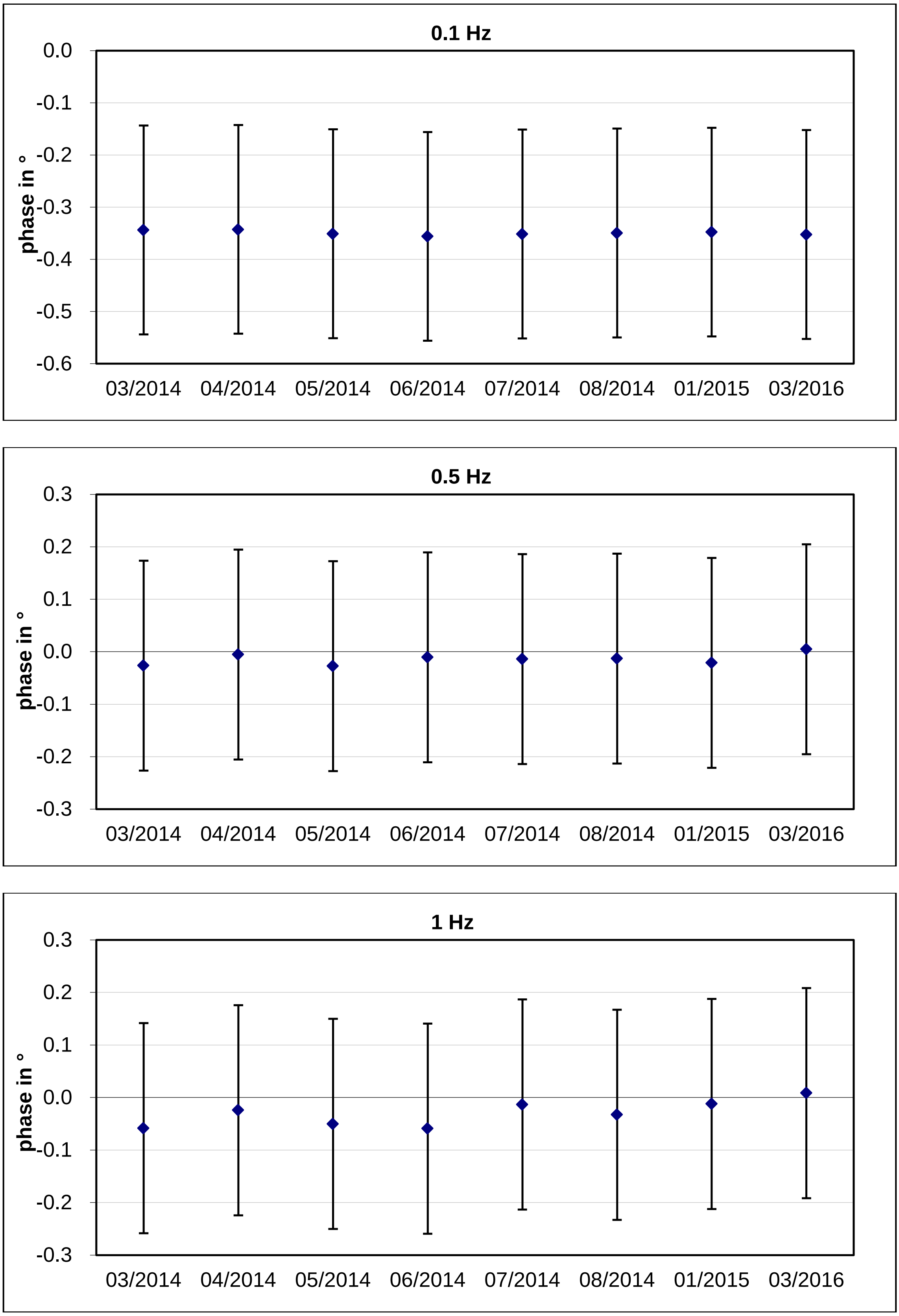
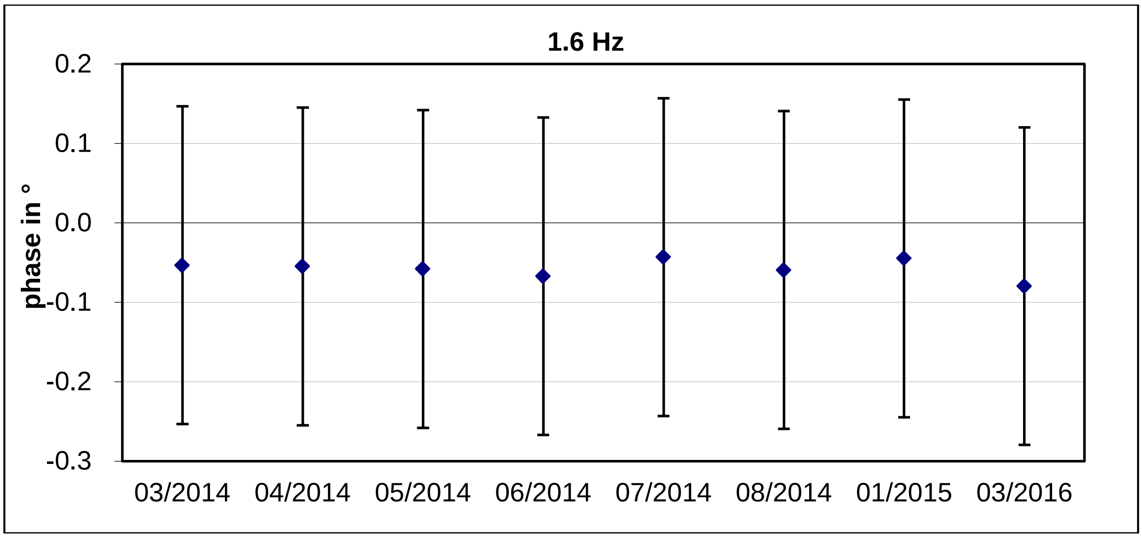
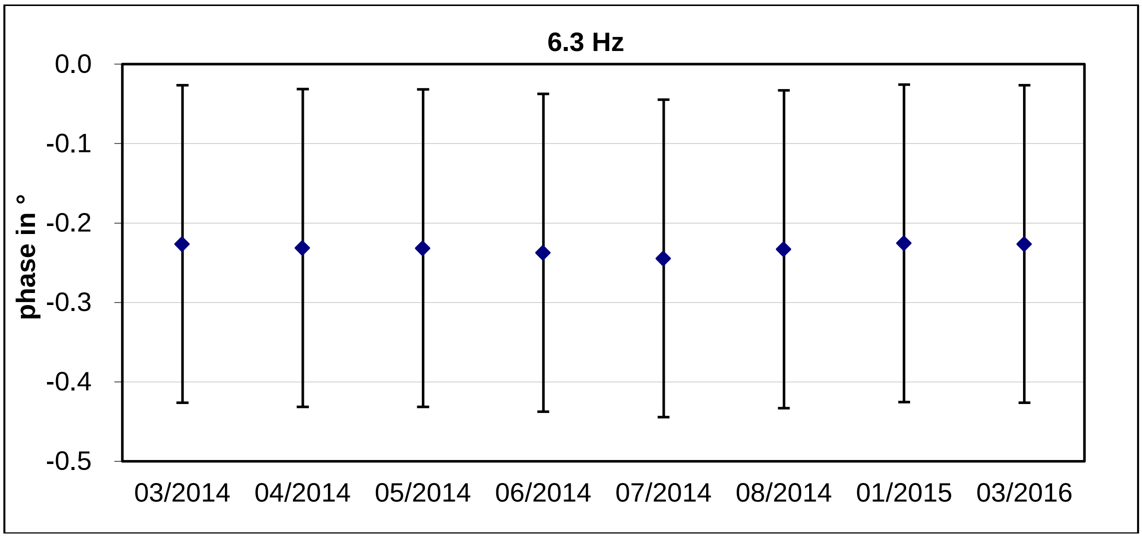
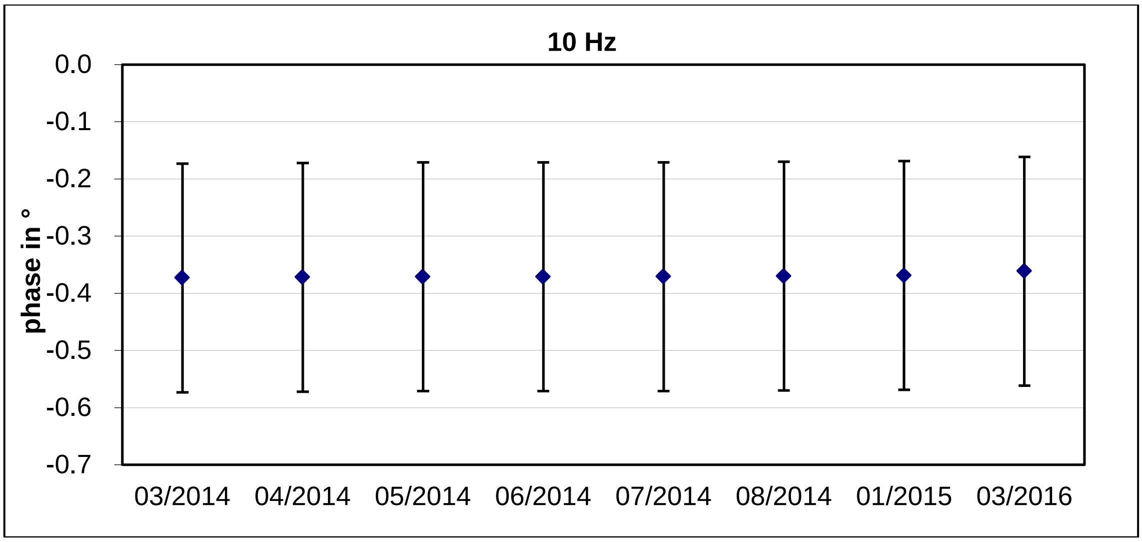

40 Hz
magnitude in mV/(m/s²)
139.1
139.0
138.9
138.8
138.7
138.6
138.5
138.4
138.3
138.2
138.1
03/2014 04/2014 05/2014 06/2014 07/2014 08/2014 01/2015 03/2016

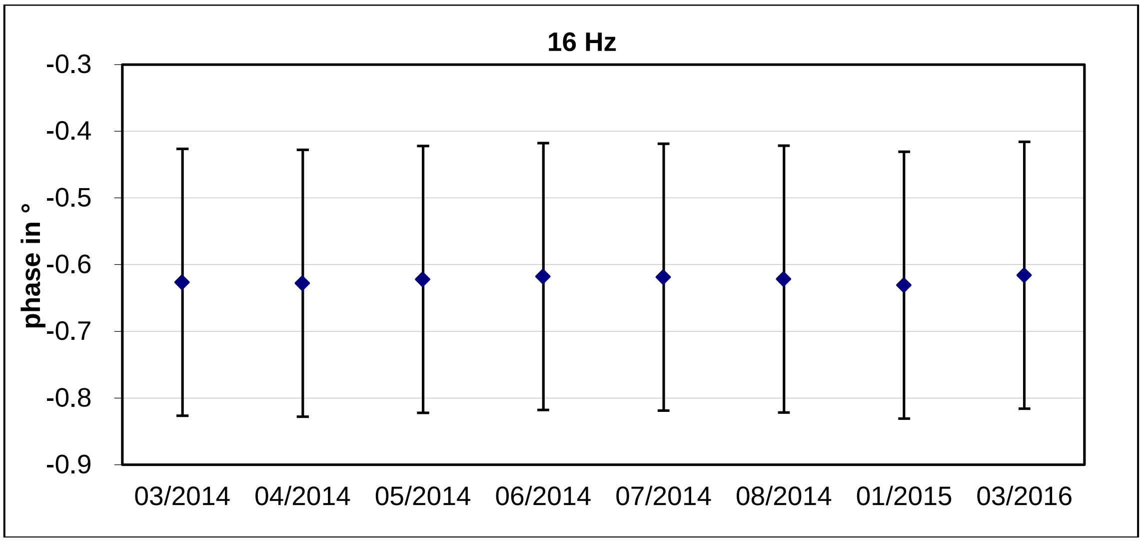
Figure 6.2 Monitoring of the phase sensitivity over the comparison period

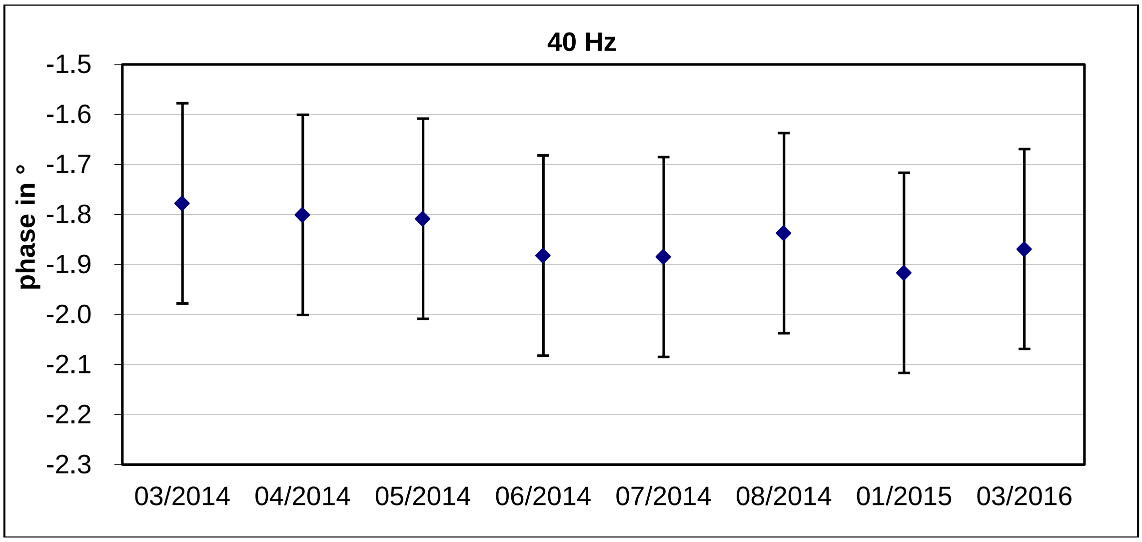



1.6 Hz
phase in °
0.2
0.1
0.0
-0.1
-0.2
-0.3
03/2014
04/2014
05/2014
06/2014
07/2014
08/2014
01/2015
03/2016


6.3 Hz
phase in °
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
03/2014
04/2014
05/2014
06/2014
07/2014
08/2014
01/2015
03/2016


10 Hz
phase in °
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
03/2014
04/2014
05/2014
06/2014
07/2014
08/2014
01/2015
03/2016





A visual inspection of the above results indicates that the artefact was sufficiently stable during the whole period of the comparison.

7. Results of the participants

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

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

Note that VNIIM did not submit its results

7.1 Results for the magnitude of the complex sensitivity

It should be noted that the results for frequencies below 0.5 Hz in table 7.1 are the reported values by the participants after correction for the gain was applied by the pilot laboratory to all magnitude values reported.

Table 7.1.1: Reported participants' results for the magnitude of the accelerometer set with relative expanded uncertainties (k = 2)

	NIM		LNE		PTB		BKSV-DPLA		GUM	
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)	%
0.1	136.13	0.5			136.55	0.5	137.09	0.5		
0.125	136.30	0.5			136.59	0.5	136.84	0.5		
0.16	136.42	0.5			136.56	0.5	136.75	0.5		
0.2	136.49	0.5			136.57	0.3	136.72	0.4	138.03	0.9
0.25	136.53	0.5			136.55	0.3	136.66	0.4	137.56	0.9
0.315	136.55	0.5			136.54	0.3	136.65	0.4	137.24	0.9
0.4	136.57	0.2	136.84	0.3	136.53	0.2	136.63	0.4	137.04	0.5
0.5	136.63	0.2	136.68	0.3	136.45	0.2	136.55	0.4	136.85	0.5
0.63	136.64	0.2	136.68	0.3	136.46	0.2	136.57	0.4	136.80	0.5
0.8	136.59	0.2	136.59	0.3	136.47	0.2	136.56	0.4	136.72	0.5
1	136.59	0.2	136.56	0.3	136.48	0.2	136.52	0.4	136.70	0.4
1.25	136.57	0.2	136.59	0.3	136.48	0.2	136.54	0.4	136.68	0.4
1.60	136.56	0.2	136.59	0.3	136.48	0.2	136.54	0.4	136.67	0.4
2	136.52	0.2	136.58	0.3	136.49	0.2	136.53	0.4	136.67	0.4
2.50	136.57	0.2	136.58	0.3	136.47	0.2	136.53	0.4	136.67	0.4
3.15	136.58	0.2	136.58	0.3	136.47	0.2	136.55	0.4	136.66	0.4
4	136.58	0.2	136.60	0.3	136.48	0.2	136.55	0.4	136.67	0.4
5	136.56	0.2	136.60	0.3	136.47	0.2	136.57	0.4	136.70	0.3
6.3	136.60	0.2	136.62	0.3	136.49	0.2	136.58	0.4	136.72	0.3
8	136.63	0.2	136.64	0.3	136.53	0.2	136.62	0.4	136.76	0.3
10	136.69	0.2	136.69	0.3	136.56	0.1	136.67	0.4	136.83	0.3
12.5	136.78	0.2	136.76	0.3	136.64	0.1	136.75	0.4	136.85	0.3
16	136.98	0.2	136.90	0.3	136.80	0.1	136.89	0.4	137.00	0.3
20	136.91	0.2	137.10	0.3	137.04	0.1	137.10	0.4	137.20	0.3
25	137.26	0.2	137.37	0.3	137.37	0.1	137.32	0.5	137.49	0.3
31.5	137.82	0.2	137.83	0.3	137.88	0.1	137.80	0.5	137.93	0.3
40	138.56	0.2	138.49	0.3	138.63	0.1	138.93	0.5	138.59	0.3

	METAS		NMISA		INMETRO		CENAM		NMIA	
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)	%
0.1			140.96	0.6			136.97	0.7	137.03	0.2
0.125			139.24	0.6			136.94	0.7	136.88	0.2
0.16			138.33	0.6			136.86	0.7	136.80	0.2
0.2	136.52	0.31	137.71	0.6	136.84	0.25	136.81	0.5	136.76	0.2
0.25	136.58	0.31	137.31	0.6	136.75	0.25	136.70	0.5	136.72	0.2
0.315	136.64	0.31	137.03	0.6	136.69	0.25	136.63	0.5	136.70	0.2
0.4	136.66	0.31	136.86	0.6	136.63	0.25	136.63	0.5	136.67	0.2
0.5	136.61	0.31	136.58	0.3	136.55	0.25	136.37	0.3	136.57	0.2
0.63	136.63	0.31	136.52	0.3	136.56	0.25	136.30	0.3	136.56	0.2
0.8	136.62	0.31	136.49	0.3	136.52	0.25	136.29	0.3	136.56	0.2
1	136.63	0.30	136.50	0.3	136.51	0.25	136.35	0.3	136.55	0.2
1.25	136.62	0.30	136.51	0.3	136.50	0.25	136.39	0.3	136.56	0.2
1.60	136.62	0.30	136.50	0.3	136.49	0.25	136.38	0.3	136.56	0.2
2	136.64	0.29	136.51	0.3	136.49	0.25	136.42	0.3	136.56	0.2
2.50	136.63	0.29	136.50	0.3	136.50	0.25	136.43	0.3	136.56	0.2
3.15	136.64	0.29	136.49	0.3	136.51	0.25	136.45	0.3	136.56	0.2
4	136.66	0.29	136.54	0.3	136.50	0.25	136.48	0.3	136.57	0.2
5	136.66	0.24	136.52	0.3	136.50	0.25	136.48	0.3	136.58	0.2
6.3	136.66	0.24	136.54	0.3	136.55	0.25	136.52	0.3	136.60	0.2
8	136.71	0.24	136.59	0.3	136.52	0.25	136.55	0.3	136.64	0.2
10	136.77	0.37	136.65	0.3	136.56	0.25	136.61	0.3	136.69	0.2
12.5	136.79	0.37	136.75	0.3	136.65	0.25	136.64	0.3	136.76	0.2
16	136.94	0.37	136.87	0.3	136.70	0.25	136.87	0.3	136.90	0.2
20	137.12	0.36	137.13	0.3	136.97	0.25	137.03	0.3	137.09	0.2
25	137.39	0.36	137.43	0.3	137.29	0.25	137.28	0.3	137.38	0.2
31.5	137.87	0.36	137.86	0.3	137.69	0.25	137.71	0.3	137.83	0.2
40	138.49	0.36	138.59	0.3	138.31	0.25	138.36	0.3	138.49	0.2

	NMIJ		KRISS		VNIIM		A*STAR	
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.
in Hz	mV/(m/s²)	%	mV/(m/s²)	%	mV/(m/s²)	%	mV/(m/s²)	%
0.1	136.65	0.15	138.66	0.20			136.30	0.56
0.125	136.65	0.15	137.86	0.15			136.55	0.52
0.16	136.65	0.15	137.32	0.10			136.71	0.51
0.2	136.65	0.15	137.07	0.10			136.77	0.40
0.25	136.64	0.15	136.86	0.10			136.75	0.40
0.315	136.64	0.15	136.75	0.10			136.73	0.40
0.4	136.63	0.15	136.66	0.10			136.69	0.27
0.5	136.54	0.15	136.61	0.10			136.63	0.27
0.63	136.54	0.15	136.57	0.10			136.67	0.27
0.8	136.54	0.15	136.56	0.10			136.61	0.27
1	136.54	0.15	136.55	0.10			136.58	0.29
1.25	136.54	0.15	136.55	0.10			136.60	0.29
1.60	136.54	0.15	136.54	0.10			136.59	0.29
2	136.54	0.15	136.55	0.10			136.60	0.29
2.50	136.55	0.15	136.55	0.10			136.61	0.30
3.15	136.55	0.15	136.57	0.10			136.62	0.30
4	136.56	0.15	136.59	0.10			136.64	0.30
5	136.58	0.15	136.63	0.10			136.68	0.31
6.3	136.59	0.15	136.68	0.10			136.70	0.31
8	136.62	0.15	136.58	0.10			136.73	0.31
10	136.67	0.15	136.60	0.10			136.76	0.33
12.5	136.75	0.15	136.70	0.10			136.84	0.32
16	136.89	0.15	136.70	0.10			136.96	0.35
20	137.09	0.15	136.71	0.10			137.15	0.33
25	137.38	0.15	136.98	0.10			137.43	0.31
31.5	137.77	0.2	137.59	0.10			137.88	0.31
40	138.47	0.2	138.25	0.10			138.59	0.29

7.2 Results for the phase of the complex sensitivity

Table 7.2.1: Reported participants' results for the phase shift of the accelerometer set with absolute expanded uncertainties (k = 2)

	NIM		LNE		PTB		BKSV-DPLA		GUM	
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 °	
0.1	-0.35	0.20			-0.40	0.20	-0.38	0.30		
0.125	-0.43	0.20			-0.50	0.20	-0.46	0.30		
0.16	-0.55	0.20			-0.64	0.20	-0.55	0.30		
0.2	-0.68	0.20			-0.79	0.20	-0.68	0.30	-0.77	0.90
0.25	-0.85	0.20			-0.93	0.20	-0.85	0.30	-0.94	0.90
0.315	-1.07	0.20			-1.17	0.20	-1.09	0.30	-1.15	0.90
0.4	-1.36	0.20	-0.02	0.50	-1.48	0.20	-1.36	0.30	-1.42	0.50
0.5	-0.01	0.20	-0.02	0.50	-0.08	0.20	-0.02	0.30	-0.08	0.50
0.63	-0.04	0.20	-0.02	0.50	-0.08	0.20	-0.02	0.30	-0.07	0.50
0.8	0.01	0.20	-0.03	0.50	-0.09	0.20	-0.03	0.30	-0.07	0.50
1	-0.03	0.20			-0.08	0.20	-0.04	0.30	-0.07	0.50
1.25	-0.05	0.20			-0.10	0.20	-0.05	0.30	-0.07	0.50
1.60	-0.06	0.20			-0.12	0.20	-0.06	0.30	-0.08	0.50
2	-0.08	0.20	-0.09	0.50	-0.15	0.20	-0.07	0.30	-0.09	0.50
2.50	-0.10	0.20	-0.11	0.50	-0.14	0.20	-0.09	0.30	-0.10	0.50
3.15	-0.12	0.20	-0.14	0.50	-0.17	0.20	-0.12	0.30	-0.12	0.50
4	-0.16	0.20	-0.15	0.50	-0.22	0.20	-0.14	0.30	-0.15	0.50
5	-0.16	0.20	-0.19	0.50	-0.22	0.20	-0.18	0.30	-0.18	0.50
6.3	-0.23	0.20	-0.25	0.50	-0.28	0.20	-0.23	0.30	-0.23	0.50
8	-0.31	0.20	-0.30	0.50	-0.37	0.20	-0.29	0.30	-0.29	0.50
10	-0.37	0.20	-0.37	0.50	-0.43	0.20	-0.37	0.30	-0.37	0.50
12.5	-0.47	0.20	-0.47	0.50	-0.54	0.20	-0.47	0.30	-0.47	0.50
16	-0.62	0.20	-0.61	0.50	-0.71	0.20	-0.61	0.30	-0.60	0.50
20	-0.76	0.20	-0.78	0.50	-0.89	0.20	-0.80	0.30	-0.77	0.50
25	-0.96	0.20	-1.00	0.50	-1.15	0.20	-1.01	0.30	-1.00	0.50
31.5	-1.28	0.20	-1.34	0.50	-1.51	0.20	-1.38	0.50	-1.32	0.50
40	-1.84	0.20	-1.82	0.50	-2.06	0.20	-1.76	0.50	-1.81	0.50

	METAS		NMISA		INMETRO		CENAM		NMIA	
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 °	
0.1			-0.38	0.40			-0.28	0.20	-0.37	0.30
0.125			-0.44	0.40			-0.25	0.20	-0.43	0.30
0.16			-0.55	0.40			-0.35	0.20	-0.54	0.30
0.2	-0.58	0.78	-0.68	0.40	-0.68	0.25	-0.42	0.20	-0.68	0.30
0.25	-0.76	0.78	-0.85	0.40	-0.84	0.25	-0.68	0.50	-0.85	0.30
0.315	-1.00	0.78	-1.07	0.40	-1.06	0.25	-0.83	0.50	-1.07	0.30
0.4	-1.30	0.78	-1.34	0.40	-1.35	0.25	-1.06	0.50	-1.35	0.30
0.5	0.02	0.78	-0.02	0.40	-0.02	0.25	-0.34	0.50	-0.02	0.30
0.63	0.01	0.78	-0.02	0.40	-0.02	0.25	-0.42	0.50	-0.02	0.30
0.8	0.00	0.78	-0.03	0.40	-0.03	0.25	-0.56	0.50	-0.03	0.30
1	-0.02	0.46	-0.04	0.40	-0.04	0.25	-0.68	0.50	-0.03	0.30
1.25	-0.03	0.46	-0.04	0.40	-0.04	0.25	-0.93	0.50	-0.04	0.30
1.60	-0.04	0.46	-0.06	0.40	-0.06	0.25	-1.17	0.50	-0.05	0.30
2	-0.06	0.46	-0.07	0.40	-0.07	0.25	-1.35	0.50	-0.06	0.30
2.50	-0.08	0.46	-0.09	0.40	-0.09	0.25	-1.59	0.50	-0.08	0.30
3.15	-0.10	0.46	-0.11	0.40	-0.11	0.25	-2.13	0.50	-0.10	0.30
4	-0.14	0.46	-0.14	0.40	-0.14	0.25	-2.70	0.50	-0.13	0.30
5	-0.18	0.46	-0.18	0.40	-0.18	0.25	-3.37	0.50	-0.16	0.30
6.3	-0.23	0.46	-0.23	0.40	-0.23	0.25	-4.36	0.50	-0.20	0.30
8	-0.29	0.46	-0.29	0.40	-0.30	0.25	-5.37	0.50	-0.28	0.30
10	-0.36	0.40	-0.37	0.80	-0.38	0.25	-6.71	0.50	-0.34	0.30
12.5	-0.47	0.40	-0.47	0.40	-0.48	0.25	-8.37	0.50	-0.42	0.30
16	-0.60	0.40	-0.60	0.50	-0.62	0.25	-10.72	0.50	-0.55	0.30
20	-0.76	0.41	-0.79	0.50	-0.84	0.25	-13.41	0.50	-0.69	0.30
25	-0.99	0.41	-1.04	0.50	-1.06	0.25	-16.69	0.50	-0.90	0.30
31.5	-1.30	0.41	-1.37	0.50	-1.38	0.25	-20.92	0.50	-1.22	0.30
40	-1.78	0.41	-1.90	0.50	-1.91	0.25	-26.55	0.50	-1.68	0.30

	NMIJ		KRISS		VNIIM		A*STAR	
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.
in Hz	in °		in °		in °		in °	
0.1	-0.34	0.05	-0.01	0.20			-0.24	0.87
0.125	-0.42	0.05	-0.01	0.10			-0.31	0.86
0.16	-0.54	0.05	-0.02	0.10			-0.57	0.86
0.2	-0.68	0.05	-0.02	0.10			-0.69	0.51
0.25	-0.85	0.05	-0.03	0.10			-0.84	0.51
0.315	-1.07	0.05	-0.04	0.10			-1.08	0.51
0.4	-1.35	0.05	-0.05	0.10			-1.35	0.31
0.5	-0.02	0.05	-0.05	0.10			-0.01	0.31
0.63	-0.02	0.05	-0.07	0.10			-0.01	0.31
0.8	-0.03	0.05	-0.09	0.10			-0.03	0.31
1	-0.04	0.05	-0.10	0.10			-0.03	0.35
1.25	-0.05	0.05	-0.13	0.10			-0.04	0.35
1.60	-0.06	0.05	-0.17	0.10			-0.05	0.35
2	-0.07	0.05	-0.20	0.10			-0.07	0.35
2.50	-0.09	0.05	-0.25	0.10			-0.10	0.35
3.15	-0.12	0.05	-0.31	0.10			-0.14	0.35
4	-0.15	0.05	-0.39	0.10			-0.17	0.35
5	-0.19	0.05	-0.48	0.10			-0.23	0.35
6.3	-0.25	0.10	-0.60	0.10			-0.28	0.35
8	-0.30	0.10	-0.76	0.10			-0.34	0.35
10	-0.38	0.10	-0.95	0.10			-0.41	0.35
12.5	-0.48	0.10	-1.18	0.10			-0.50	0.35
16	-0.62	0.10	-1.55	0.10			-0.75	0.35
20	-0.80	0.10	-1.92	0.10			-0.84	0.35
25	-1.02	0.10	-2.44	0.10			-1.07	0.35
31.5	-1.38	0.10	-3.10	0.10			-1.37	0.35
40	-1.85	0.10	-4.10	0.10			-1.86	0.35

8. Degrees of equivalence with respect to the weighted mean

The evaluation of the results was performed using a weighted mean computed with the following equations:

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

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

where the WM was calculated using the results of the participants according to [1]. In the equations above the following symbols were used:

$x_i(f)$	result of participant i at frequency f
$u_i(f)$	absolute standard uncertainty of participant i 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 checks were performed for phase and magnitude of the complex sensitivity. The test defined by Cox in [5, 6] was applied in order to determine the participants that are members of the largest consistent subset (LCS).

The key comparison reference values (KCRV) were finally determined by recalculating the WM using the participants that are members of the largest consistent subset (MoCS):

$x_{\mathrm{KCRV}}(f)$	best estimate of the KCRV at frequency f
$u_{\mathrm{KCRV}}(f)$	estimated absolute standard uncertainty of the KCRV at frequency f

Table 8.1 presents the results of the consistency test for both magnitude and phase results. Cells are highlighted in yellow when $X^2obs > X^2(nu)$.

Table 8.1 a: Results of the consistency test applied to all the results reported by the participants respectively for magnitude (left) and phase (right)

Frenquency in Hz	number of participants	number of degrees of freedom	X^2obs	X^2(nu) with P<0,05
0.1	8	7	107.81	14.07
0.125	8	7	39.68	14.07
0.16	8	7	16.87	14.07
0.2	11	10	13.22	18.31
0.25	11	10	5.66	18.31
0.315	11	10	2.37	18.31
0.4	12	11	3.65	19.68
0.5	13	12	3.44	21.03
0.63	13	12	3.89	21.03
0.8	13	12	2.69	21.03
1	13	12	1.88	21.03
1.25	13	12	1.46	21.03
1.60	13	12	1.47	21.03
2	13	12	1.26	21.03
2.50	13	12	1.31	21.03
3.15	13	12	1.35	21.03
4	13	12	1.40	21.03
5	13	12	2.52	21.03
6.3	13	12	2.83	21.03
8	13	12	2.24	21.03
10	13	12	3.66	21.03
12.5	13	12	2.89	21.03
16	13	12	7.50	21.03
20	13	12	21.37	21.03
25	13	12	24.59	21.03
31.5	13	12	11.32	21.03
40	13	12	19.83	21.03

F renquency in Hz	number of participants	number of degrees of freedom	X^2obs	X^2(nu) with P<0,05
0.1	8	7	0.92	14.07
0.125	8	7	3.67	14.07
0.16	8	7	4.61	14.07
0.2	11	10	7.97	18.31
0.25	11	10	1.19	18.31
0.315	11	10	1.99	18.31
0.4	12	11	31.39	19.68
0.5	13	12	2.24	21.03
0.63	13	12	3.53	21.03
0.8	13	12	5.99	21.03
1	12	11	7.65	19.68
1.25	12	11	14.24	19.68
1.60	12	11	23.12	19.68
2	13	12	30.96	21.03
2.50	13	12	42.94	21.03
3.15	13	12	74.32	21.03
4	13	12	119.37	21.03
5	13	12	184.72	21.03
6.3	13	12	287.62	21.03
8	13	12	438.37	21.03
10	13	12	684.74	21.03
12.5	13	12	1062.92	21.03
16	13	12	1749.25	21.03
20	13	12	2714.00	21.03
25	13	12	4206.20	21.03
31.5	13	12	6505.07	21.03
40	13	12	10327.75	21.03

Table 8.1 b: Results of the consistency test applied to all the results reported by the largest consistent subset respectively for magnitude (left) and phase (right)

Frenquency in Hz	number of participants	number of degrees of freedom	X^2obs	X^2(nu) with P<0,05
0.1	7	6	11.37	12.59
0.125	7	6	4.03	12.59
0.16	7	6	1.73	12.59
0.2	11	10	13.22	18.31
0.25	11	10	5.66	19.68
0.315	11	10	2.37	19.68
0.4	12	11	3.65	21.03
0.5	13	12	3.44	21.03
0.63	13	12	3.89	21.03
0.8	13	12	2.69	21.03
1	13	12	1.88	21.03
1.25	13	12	1.46	21.03
1.60	13	12	1.47	21.03
2	13	12	1.26	21.03
2.50	13	12	1.31	21.03
3.15	13	12	1.35	21.03
4	13	12	1.40	21.03
5	13	12	2.52	21.03
6.3	13	12	2.83	21.03
8	13	12	2.24	21.03
10	13	12	3.66	21.03
12.5	13	12	2.89	21.03
16	13	12	7.50	21.03
20	12	11	2.56	19.68
25	12	11	1.57	19.68
31.5	13	12	11.32	21.03
40	13	12	19.83	21.03

Frenquency in Hz	number of participants	number of degrees of freedom	X^2obs	X^2(nu) with P<0,05
0.1	8	7	0.92	14.07
0.125	8	7	3.67	14.07
0.16	8	7	4.61	14.07
0.2	11	10	7.97	18.31
0.25	11	10	1.19	18.31
0.315	11	10	1.99	18.31
0.4	12	11	3.10	19.68
0.5	13	12	2.24	21.03
0.63	13	12	3.53	21.03
0.8	13	12	5.99	21.03
1	12	11	7.65	19.68
1.25	12	11	14.24	19.68
1.60	11	10	4.23	18.31
2	13	12	5.92	21.03
2.50	13	12	8.52	21.03
3.15	13	12	12.16	21.03
4	13	12	19.34	21.03
5	11	10	0.29	18.31
6.3	11	10	0.32	18.31
8	11	10	0.52	18.31
10	11	10	0.37	18.31
12.5	11	10	0.55	18.31
16	11	10	1.53	18.31
20	11	10	1.72	18.31
25	11	10	2.90	18.31
31.5	11	10	3.99	18.31
40	11	10	6.00	18.31

The results presented in tables 7.1.1 and 7.2.1 marked with an asterisk (*) were considered as not within the LCS and were excluded from the calculation of the KCRV. It should be noted that KRISS's results from 0.1 Hz to 0.4 Hz did not contribute to the calculation of the KCRV because they did not use the same gain settings as all the other participants at those frequencies.

Table 8.1b presents the results of the consistency test applied to the results reported by the LCS respectively for magnitude (left) and phase (right).

For the further evaluation of the comparison, the unilateral degrees of equivalence with respect to the KCRV were calculated according to:

$$d_{i,KCRV}\,(f) = x_i\,(f) - x_{KCRV}\,(f) \tag{3}$$

$$u_{i,KCRV}^2\left(f\right) = \begin{cases} u_i^2\left(f\right) - u_{KCRV}^2\left(f\right) & \text{for results within the LCS} \\ u_i^2\left(f\right) + u_{KCRV}^2\left(f\right) & \text{for results not within the LCS} \end{cases} \tag{4}$$

These formulas were applied for both phase and magnitude results. In the subsequent tables 8.1.1 and 8.2.1, $U_i = 2\,u_i$ and the results are marked using a light brown background when $d_{i,KCRV}(f) > 2 \cdot u_{i,KCRV}(f)$.

Unilateral DoEs obtained from results which were excluded from the largest consistent subset and which therefore did not contribute to the calculation of the KCRV are marked with an asterisk (*) in tables 8.1.1 and 8.2.1.

DoEs were not calculated for KRISS from 0.1 Hz to 0.4 Hz because they did not follow the specified signal conditioner settings stated for this frequency range. Therefore, these DoEs are not included in the Tables and graphs presented in sections 8.1 and 8.2.

8.1 Results for the magnitude of the complex sensitivity

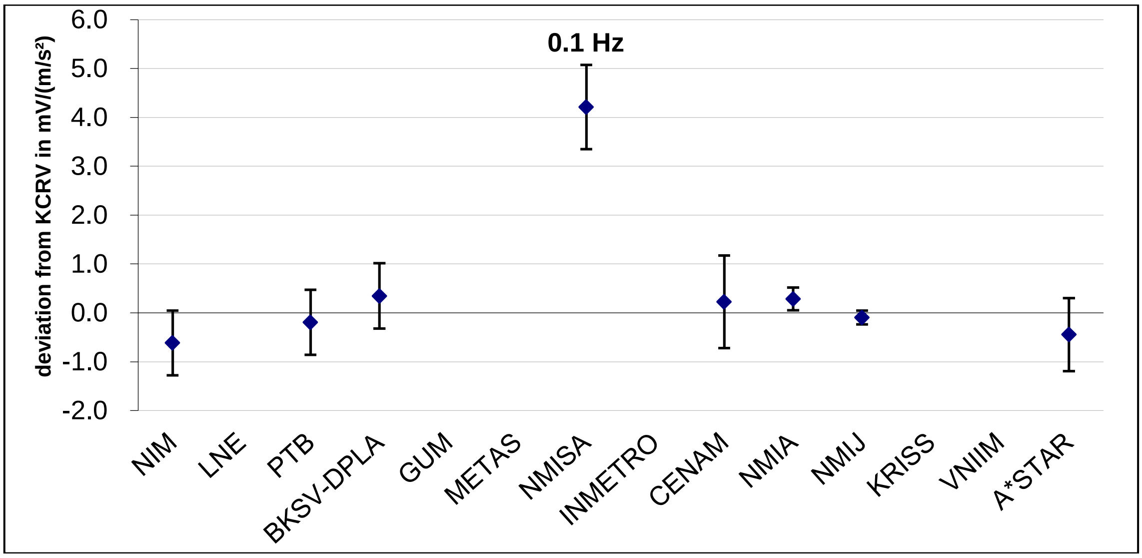
Table 8.1.1: Unilateral degrees of equivalence for the magnitude of sensitivity with absolute expanded uncertainties (k = 2)

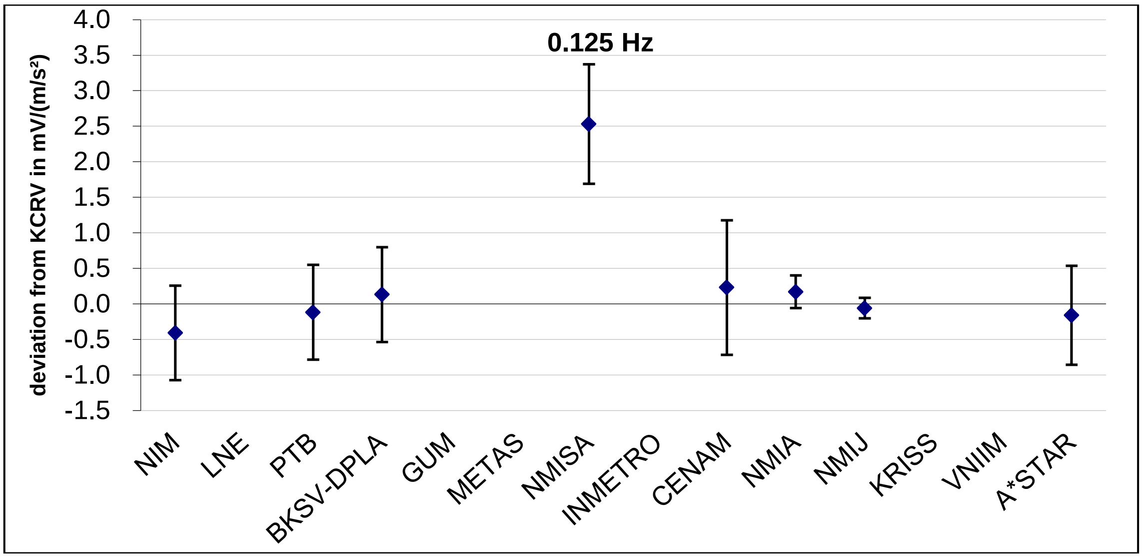
	KCRV		NIM		LNE		PTB		BKSV-DPLA		GUM	
actual frequency	X_{KCRV}	U_{KCRV}	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$
in Hz	mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)	
0.1	136.75	0.15	-0.62	0.66			-0.20	0.67	0.34	0.67		
0.125	136.71	0.15	-0.41	0.67			-0.12	0.67	0.13	0.67		
0.16	136.69	0.15	-0.27	0.67			-0.13	0.67	0.06	0.67		
0.2	136.72	0.12	-0.23	0.67			-0.15	0.39	0.00	0.53	1.31	1.24
0.25	136.68	0.12	-0.15	0.68			-0.13	0.40	-0.02	0.54	0.88	1.23
0.315	136.66	0.12	-0.11	0.68			-0.12	0.40	-0.01	0.54	0.58	1.23
0.4	136.64	0.10	-0.07	0.26	0.20	0.40	-0.11	0.26	-0.01	0.54	0.40	0.68
0.5	136.58	0.08	0.05	0.26	0.10	0.40	-0.13	0.26	-0.03	0.54	0.27	0.68
0.63	136.56	0.08	0.08	0.26	0.12	0.40	-0.10	0.26	0.01	0.54	0.24	0.68
0.8	136.55	0.08	0.04	0.26	0.04	0.40	-0.08	0.26	0.01	0.54	0.17	0.68
1	136.54	0.08	0.05	0.26	0.02	0.40	-0.06	0.26	-0.02	0.54	0.16	0.54
1.25	136.54	0.08	0.03	0.26	0.05	0.40	-0.06	0.26	0.00	0.54	0.14	0.54
1.60	136.54	0.08	0.02	0.26	0.05	0.40	-0.06	0.26	0.00	0.54	0.13	0.54
2	136.54	0.08	-0.02	0.26	0.04	0.40	-0.05	0.26	-0.01	0.54	0.13	0.54
2.50	136.55	0.08	0.02	0.26	0.03	0.40	-0.08	0.26	-0.02	0.54	0.12	0.54
3.15	136.55	0.08	0.03	0.26	0.03	0.40	-0.08	0.26	0.00	0.54	0.11	0.54
4	136.57	0.08	0.01	0.26	0.03	0.40	-0.09	0.26	-0.02	0.54	0.10	0.54
5	136.59	0.08	-0.03	0.26	0.01	0.40	-0.12	0.26	-0.02	0.54	0.11	0.40
6.3	136.62	0.08	-0.02	0.26	0.00	0.40	-0.13	0.26	-0.04	0.54	0.10	0.40
8	136.61	0.08	0.02	0.26	0.03	0.40	-0.08	0.26	0.01	0.54	0.15	0.40
10	136.63	0.07	0.06	0.26	0.06	0.40	-0.07	0.12	0.04	0.54	0.20	0.40
12.5	136.71	0.07	0.07	0.26	0.05	0.40	-0.07	0.12	0.04	0.54	0.14	0.40
16	136.82	0.07	0.16	0.26	0.08	0.40	-0.02	0.12	0.07	0.54	0.18	0.40
20	137.06	0.08	-0.15	0.26	0.04	0.41	-0.02	0.12	0.04	0.54	0.14	0.41
25	137.36	0.08	-0.10	0.26	0.01	0.40	0.01	0.11	-0.04	0.68	0.13	0.40
31.5	137.77	0.07	0.05	0.27	0.06	0.41	0.11	0.12	0.03	0.69	0.16	0.41
40	138.47	0.07	0.09	0.27	0.02	0.41	0.16	0.12	0.46	0.69	0.12	0.41

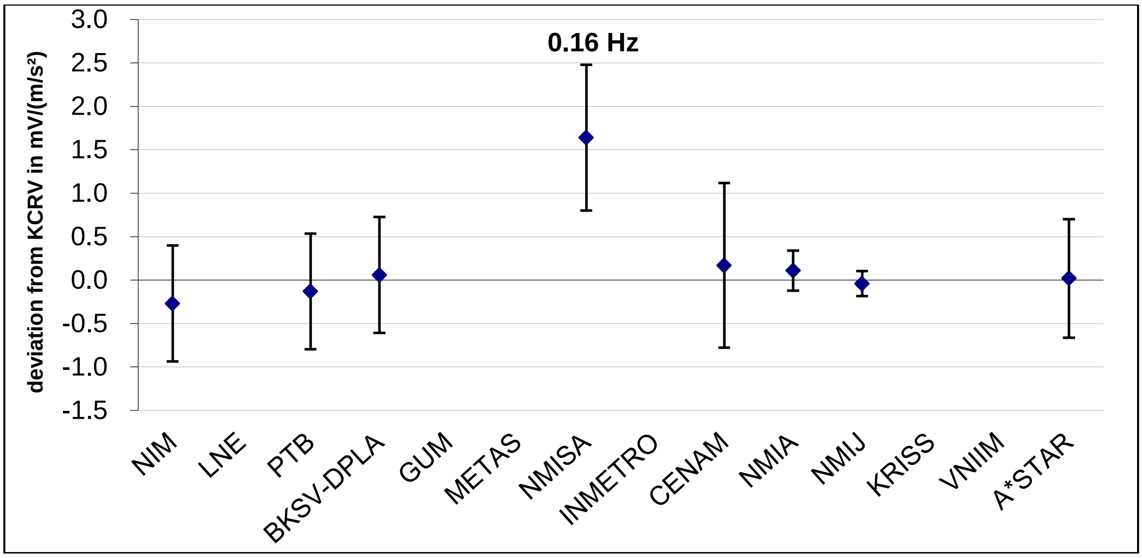
	KCRV		METAS		NMISA		INMETRO		CENAM		NMIA	
actual frequency	X_{KCRV}	U_{KCRV}	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$
in Hz	mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)	
0.1	136.75	0.15			4.21(*)	0.86(*)			0.22	0.95	0.28	0.23
0.125	136.71	0.15			2.53(*)	0.84(*)			0.23	0.95	0.17	0.23
0.16	136.69	0.15			1.64(*)	0.84(*)			0.17	0.95	0.11	0.23
0.2	136.72	0.12	-0.20	0.41	0.99	0.82	0.12	0.32	0.09	0.67	0.04	0.25
0.25	136.68	0.12	-0.10	0.41	0.63	0.82	0.07	0.33	0.02	0.68	0.04	0.26
0.315	136.66	0.12	-0.02	0.41	0.37	0.82	0.03	0.33	-0.03	0.68	0.04	0.26
0.4	136.64	0.10	0.02	0.42	0.22	0.82	-0.01	0.33	-0.01	0.68	0.03	0.26
0.5	136.58	0.08	0.03	0.42	0.00	0.40	-0.03	0.33	-0.21	0.40	-0.01	0.26
0.63	136.56	0.08	0.07	0.42	-0.04	0.40	0.00	0.33	-0.26	0.40	0.00	0.26
0.8	136.55	0.08	0.07	0.42	-0.06	0.40	-0.03	0.33	-0.26	0.40	0.01	0.26
1	136.54	0.08	0.09	0.40	-0.04	0.40	-0.03	0.33	-0.19	0.40	0.01	0.26
1.25	136.54	0.08	0.08	0.40	-0.03	0.40	-0.04	0.33	-0.15	0.40	0.02	0.26
1.60	136.54	0.08	0.08	0.40	-0.04	0.40	-0.05	0.33	-0.16	0.40	0.02	0.26
2	136.54	0.08	0.10	0.39	-0.03	0.40	-0.05	0.33	-0.12	0.40	0.02	0.26
2.50	136.55	0.08	0.08	0.39	-0.05	0.40	-0.05	0.33	-0.12	0.40	0.01	0.26
3.15	136.55	0.08	0.09	0.39	-0.06	0.40	-0.04	0.33	-0.10	0.40	0.01	0.26
4	136.57	0.08	0.09	0.39	-0.03	0.40	-0.07	0.33	-0.09	0.40	0.00	0.26
5	136.59	0.08	0.07	0.32	-0.07	0.40	-0.09	0.33	-0.11	0.40	-0.01	0.26
6.3	136.62	0.08	0.04	0.32	-0.08	0.40	-0.07	0.33	-0.10	0.40	-0.02	0.26
8	136.61	0.08	0.10	0.32	-0.02	0.40	-0.09	0.33	-0.06	0.40	0.03	0.26
10	136.63	0.07	0.14	0.50	0.02	0.40	-0.07	0.33	-0.02	0.40	0.06	0.26
12.5	136.71	0.07	0.08	0.50	0.04	0.40	-0.06	0.33	-0.07	0.40	0.05	0.26
16	136.82	0.07	0.12	0.50	0.05	0.40	-0.12	0.33	0.05	0.40	0.08	0.26
20	137.06	0.08	0.06	0.49	0.07	0.41	-0.09	0.34	-0.03	0.41	0.03	0.26
25	137.36	0.08	0.03	0.49	0.07	0.40	-0.07	0.33	-0.08	0.40	0.02	0.26
31.5	137.77	0.07	0.10	0.49	0.09	0.41	-0.08	0.34	-0.06	0.41	0.06	0.27
40	138.47	0.07	0.02	0.49	0.12	0.41	-0.16	0.34	-0.11	0.41	0.02	0.27

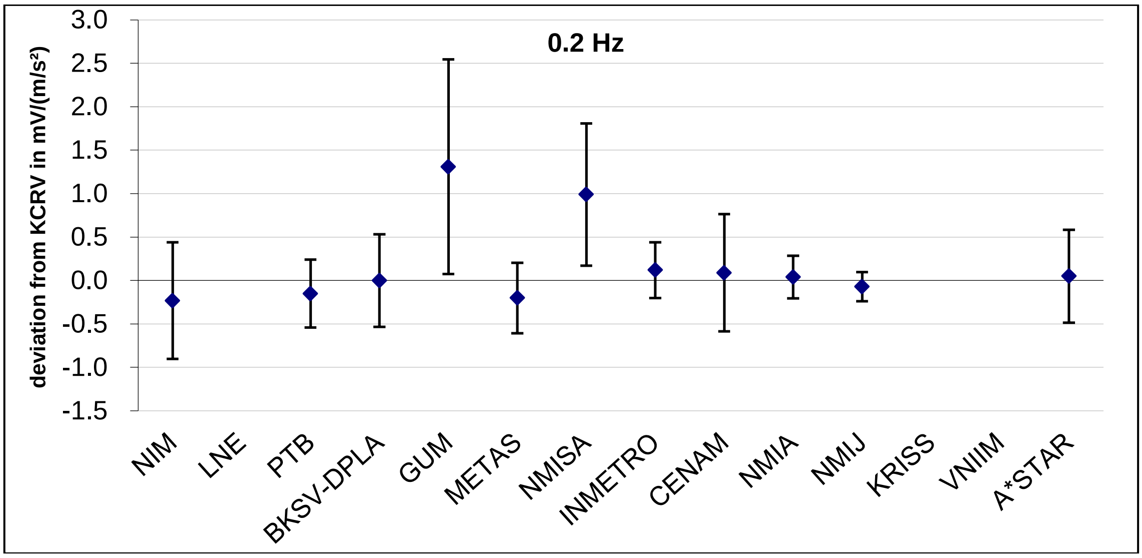
	KCRV		NMIJ		KRISS		VNIIM		A*STAR	
actual frequency	X_{KCRV}	U_{KCRV}	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$
in Hz	mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)		mV/(m/s²)	
0.1	136.75	0.15	-0.10	0.14					-0.45	0.75
0.125	136.71	0.15	-0.06	0.14					-0.16	0.69
0.16	136.69	0.15	-0.04	0.14					0.02	0.68
0.2	136.72	0.12	-0.07	0.17					0.05	0.53
0.25	136.68	0.12	-0.04	0.18					0.07	0.54
0.315	136.66	0.12	-0.02	0.18					0.07	0.54
0.4	136.64	0.10	-0.01	0.19					0.05	0.36
0.5	136.58	0.08	-0.04	0.19	0.03	0.11			0.05	0.36
0.63	136.56	0.08	-0.02	0.19	0.01	0.11			0.11	0.36
0.8	136.55	0.08	-0.01	0.19	0.01	0.11			0.06	0.36
1	136.54	0.08	0.00	0.19	0.01	0.11			0.04	0.39
1.25	136.54	0.08	0.00	0.19	0.01	0.11			0.06	0.39
1.60	136.54	0.08	0.00	0.19	0.00	0.11			0.05	0.39
2	136.54	0.08	0.00	0.19	0.01	0.11			0.06	0.39
2.50	136.55	0.08	0.00	0.19	0.00	0.11			0.06	0.40
3.15	136.55	0.08	0.00	0.19	0.02	0.11			0.07	0.40
4	136.57	0.08	-0.01	0.19	0.02	0.11			0.07	0.40
5	136.59	0.08	-0.01	0.19	0.04	0.11			0.09	0.42
6.3	136.62	0.08	-0.03	0.19	0.06	0.11			0.08	0.42
8	136.61	0.08	0.01	0.19	-0.03	0.11			0.12	0.42
10	136.63	0.07	0.04	0.19	-0.03	0.12			0.13	0.45
12.5	136.71	0.07	0.04	0.19	-0.01	0.12			0.13	0.43
16	136.82	0.07	0.07	0.19	-0.12	0.12			0.14	0.47
20	137.06	0.08	0.03	0.19	-0.35(*)	0.12(*)			0.09	0.45
25	137.36	0.08	0.02	0.19	-0.38(*)	0.16(*)			0.07	0.42
31.5	137.77	0.07	0.00	0.27	-0.18	0.12			0.11	0.42
40	138.47	0.07	0.00	0.27	-0.22	0.12			0.12	0.40

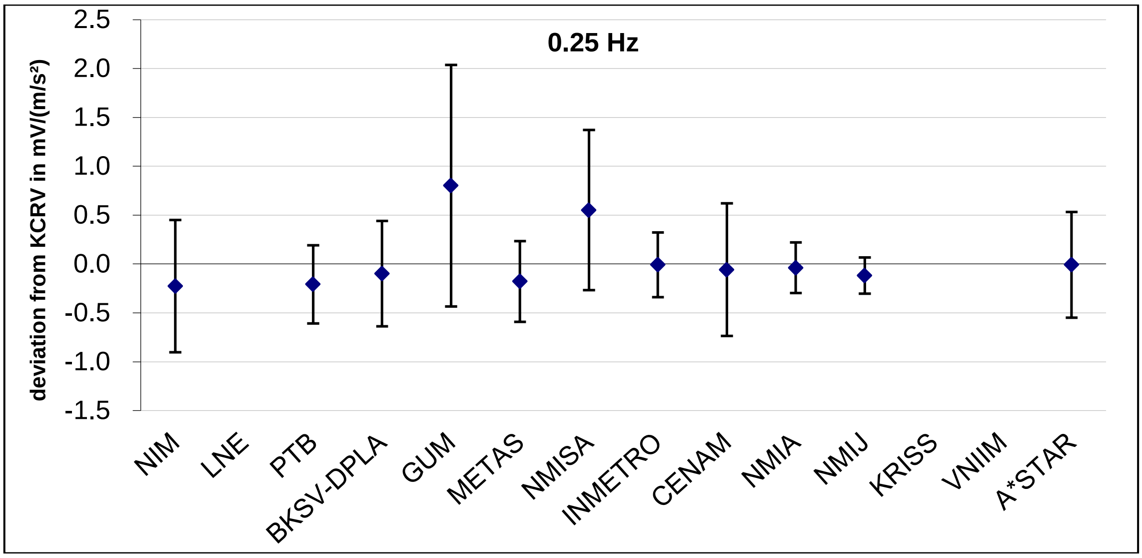
Figure 8.1.1 : Deviation of the magnitude from the KCRV for all frequencies of the comparison with expanded uncertainties $U_{i,\mathrm{KCRV}}$ (k = 2)

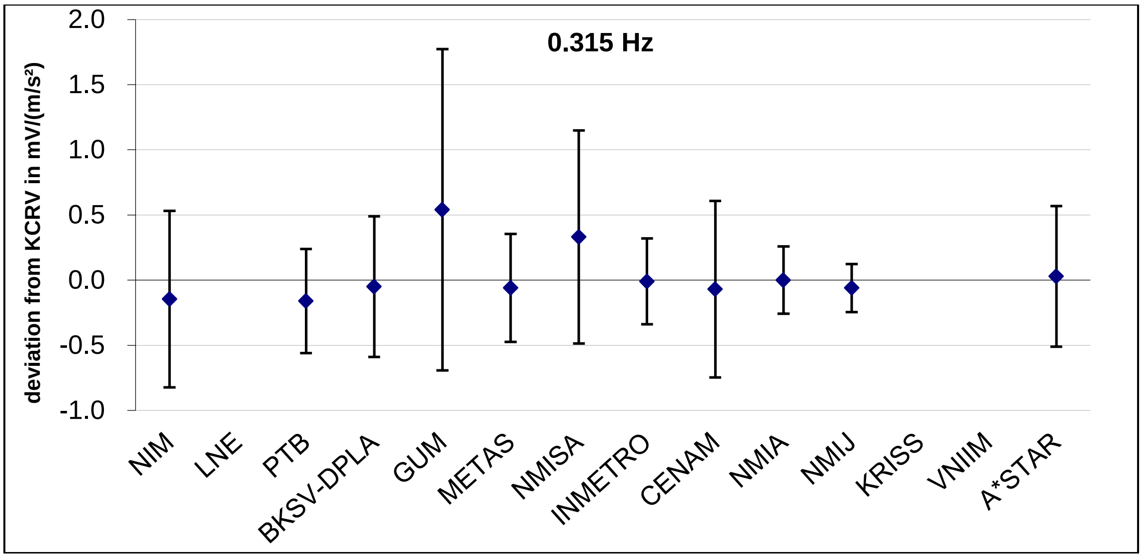


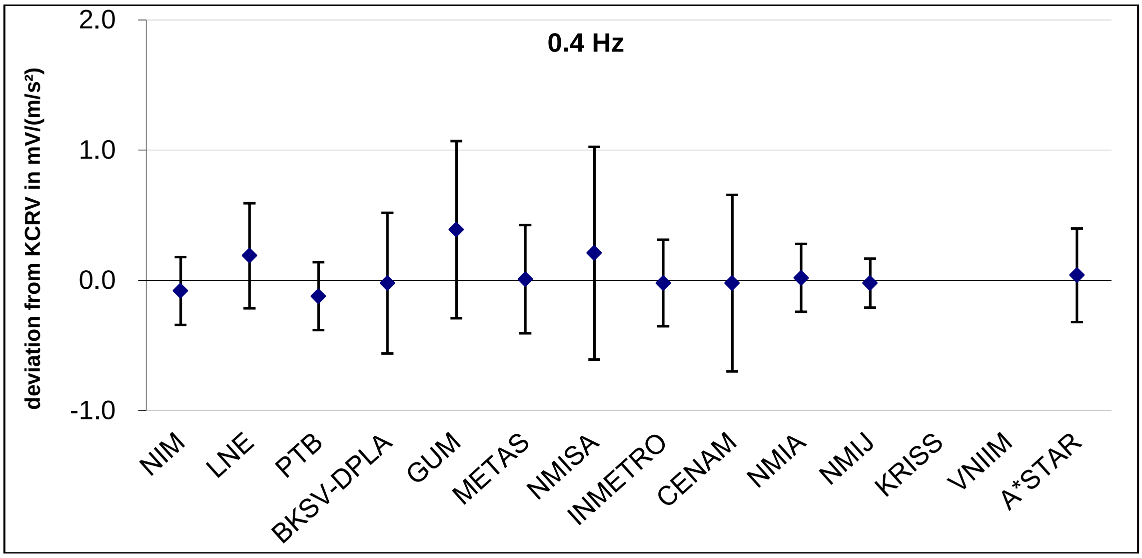

0.125 Hz
deviation from KCRV in mV/(m/s²)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

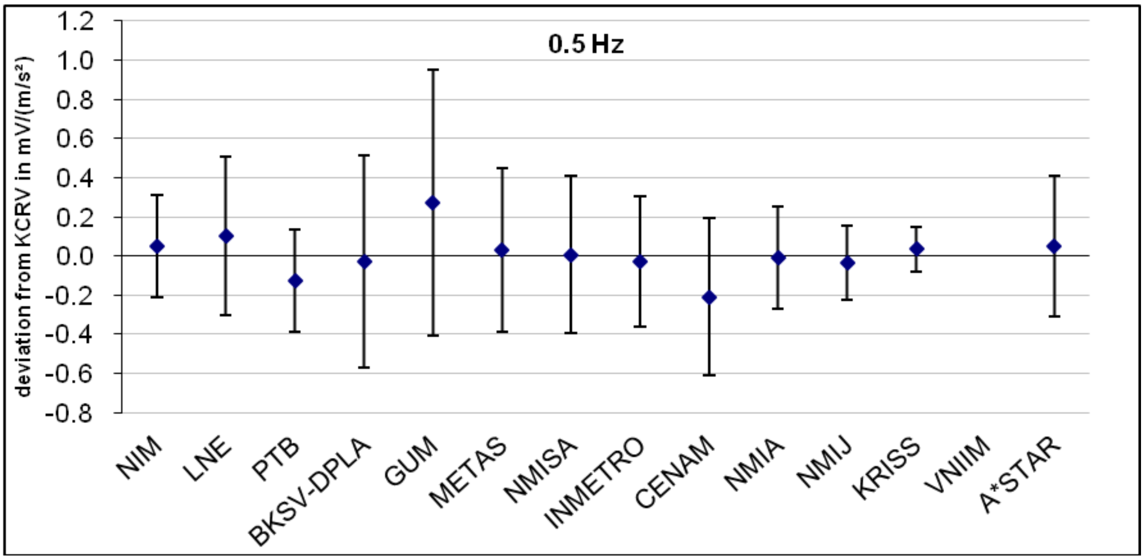

0.16 Hz
deviation from KCRV in mV/(m/s²)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

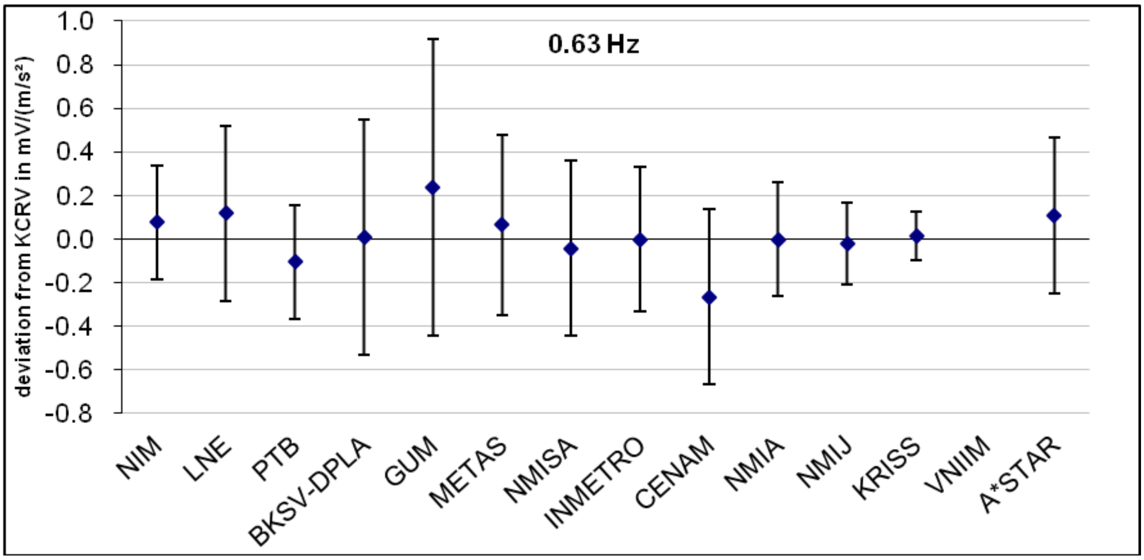

0.2 Hz
deviation from KCRV in mV/(m/s²)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

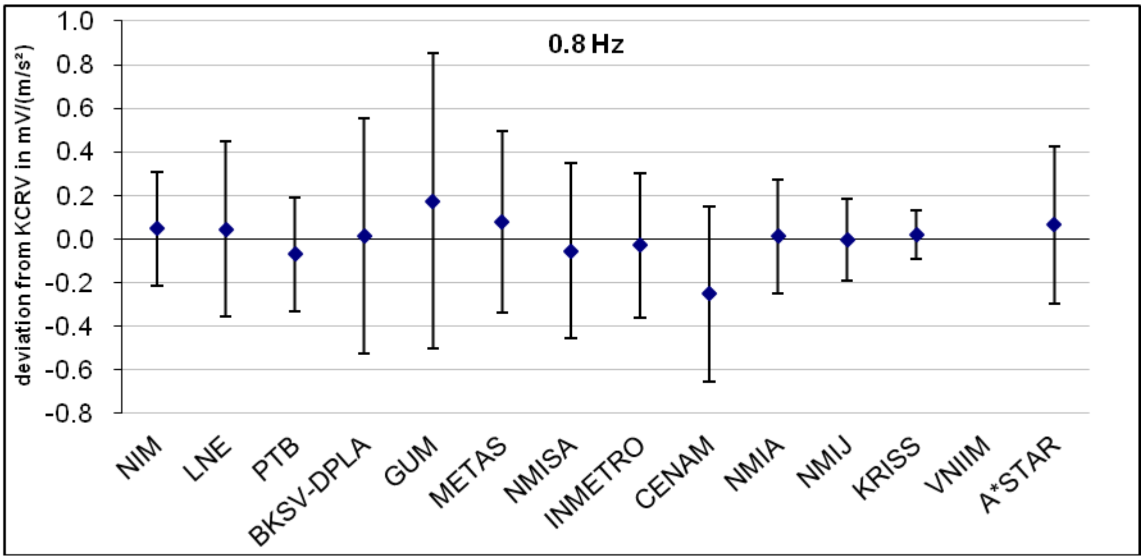

0.25 Hz
deviation from KCRV in mV/(m/s²)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

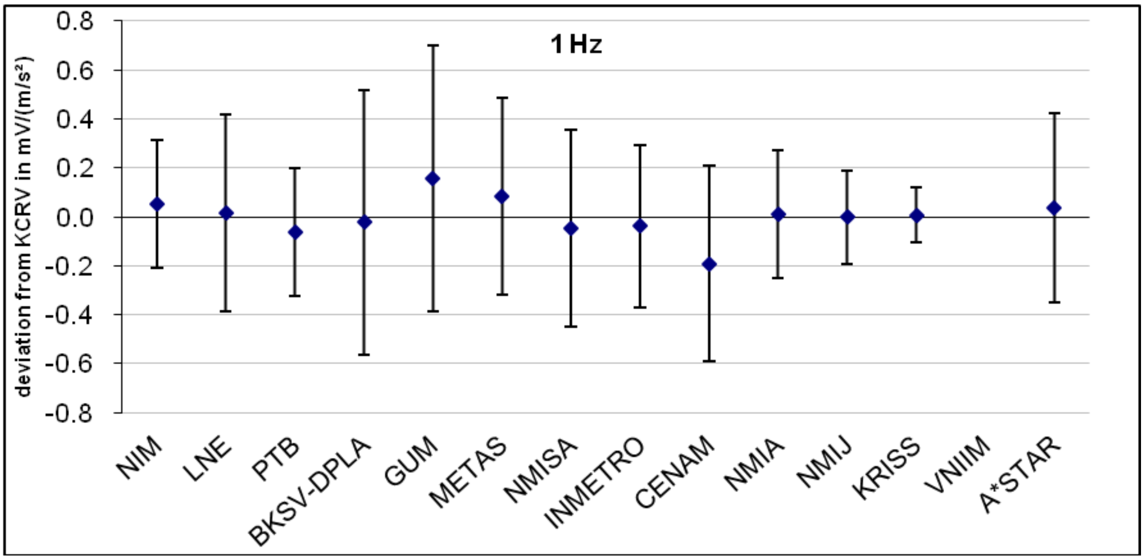

0.315 Hz
deviation from KCRV in mV/(m/s²)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

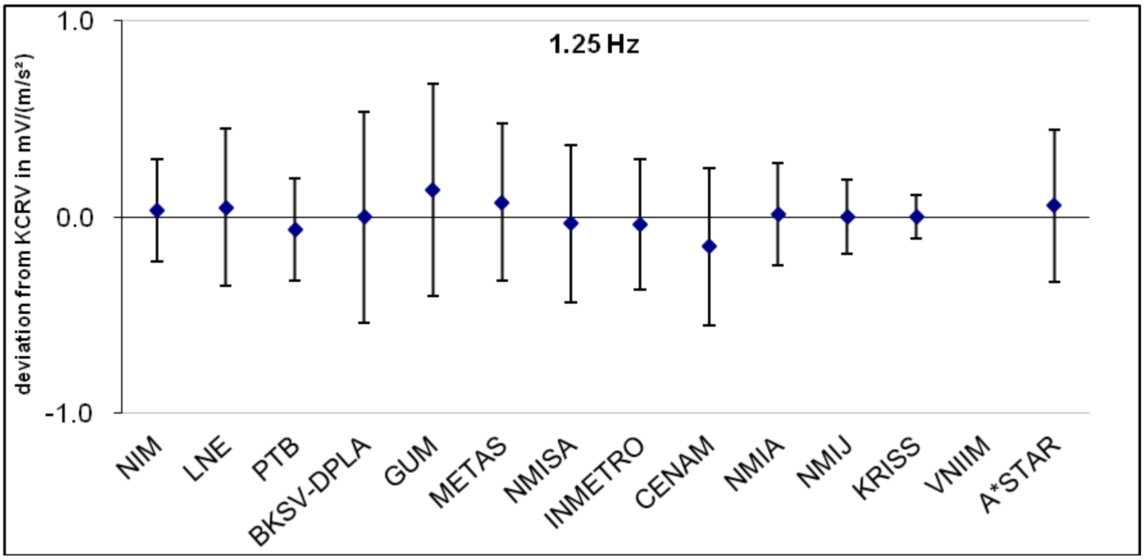

0.4 Hz
deviation from KCRV in mV/(m/s²)
2.0
1.0
0.0
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

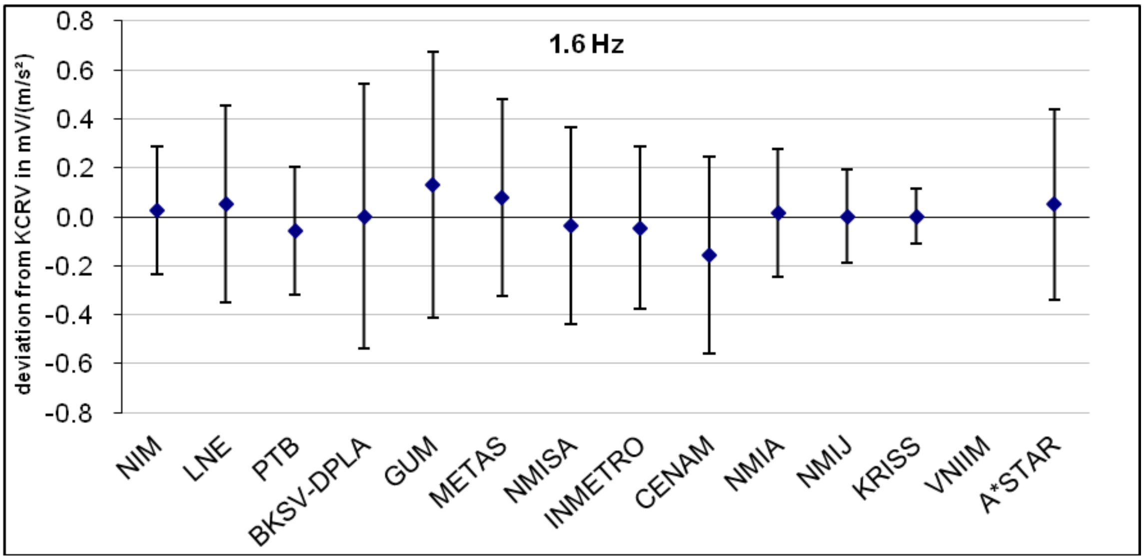

0.5 Hz
deviation from KCRV in mV/(m/s²)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

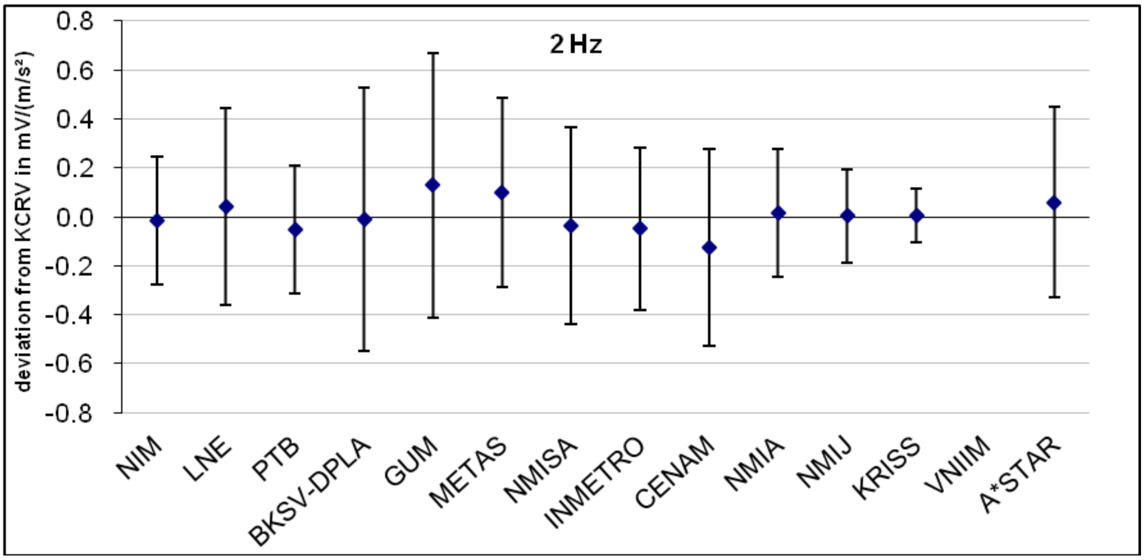

0.63 Hz
deviation from KCRV in mV/(m/s²)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

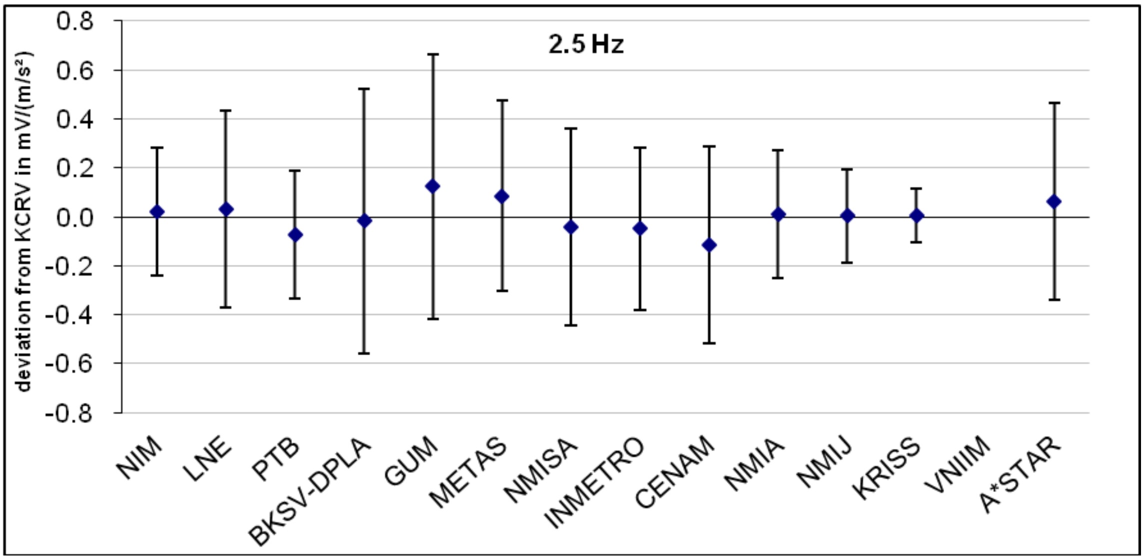

0.8 Hz
deviation from KCRV in mV/(m/s²)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

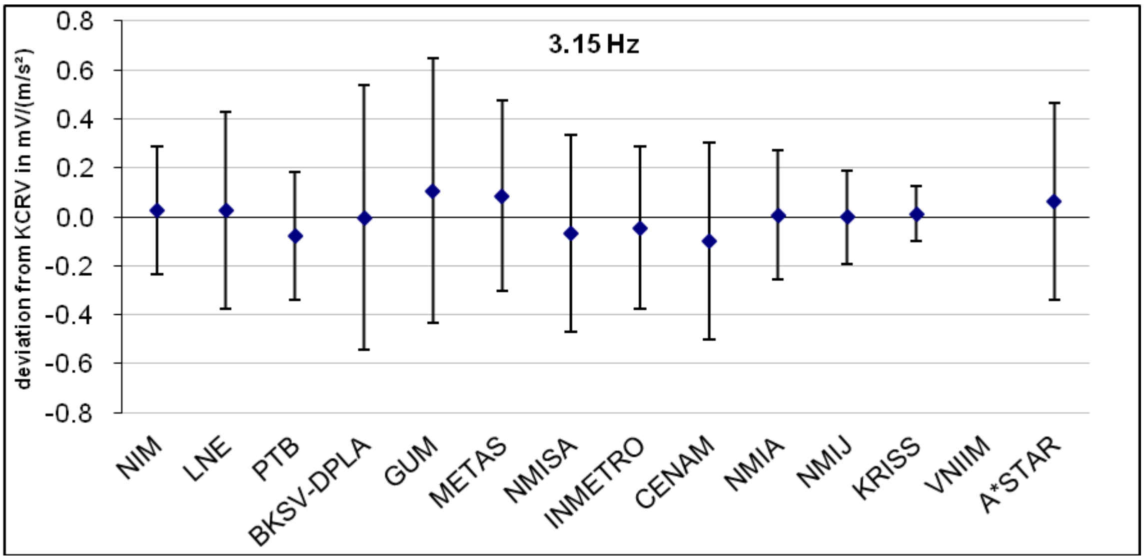

1 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

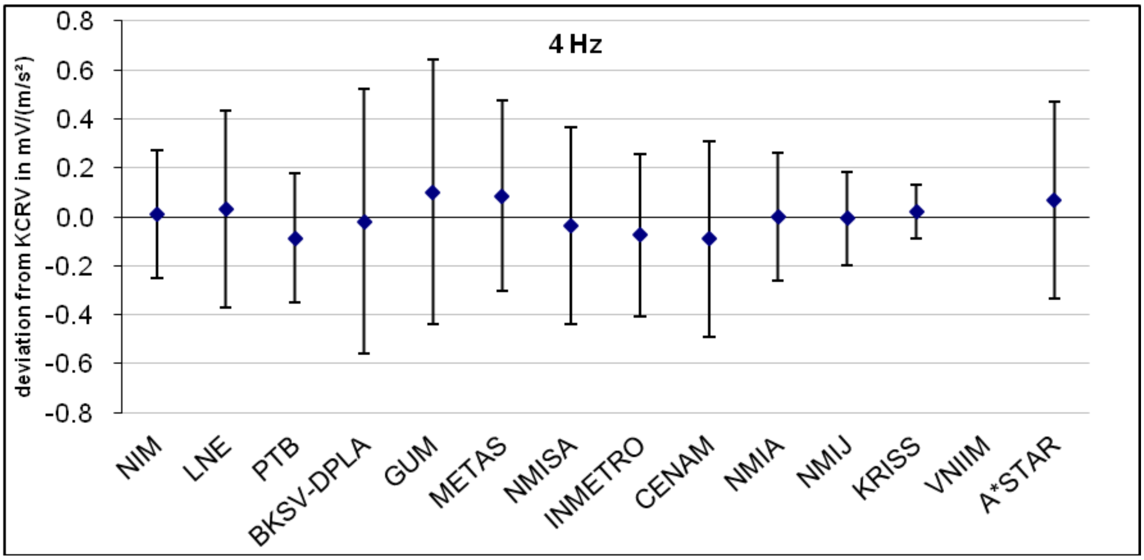

1.25 Hz
deviation from KCRV in mV/(m/s²)
1.0
0.0
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

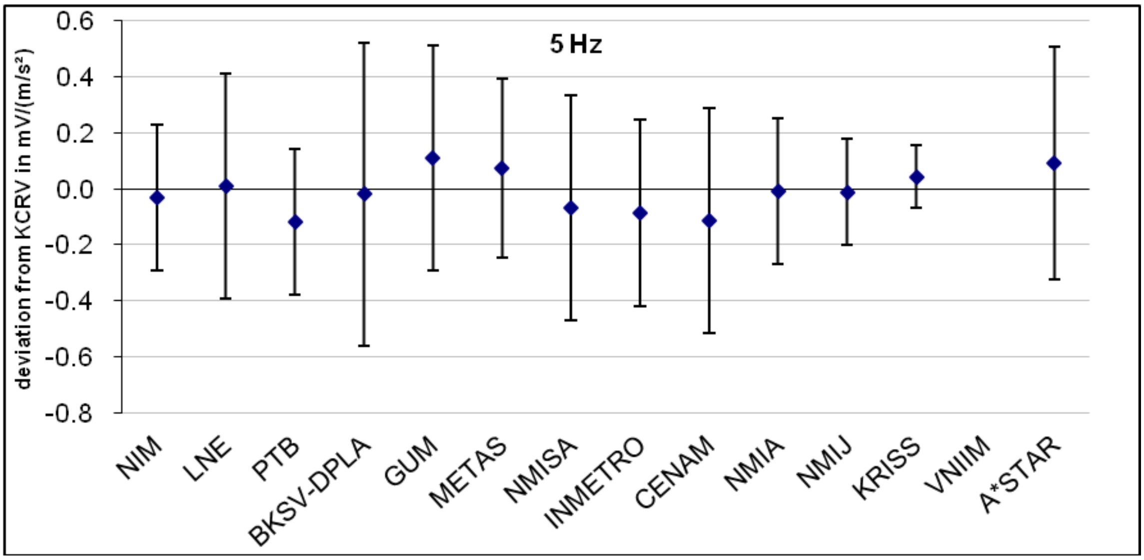

1.6 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

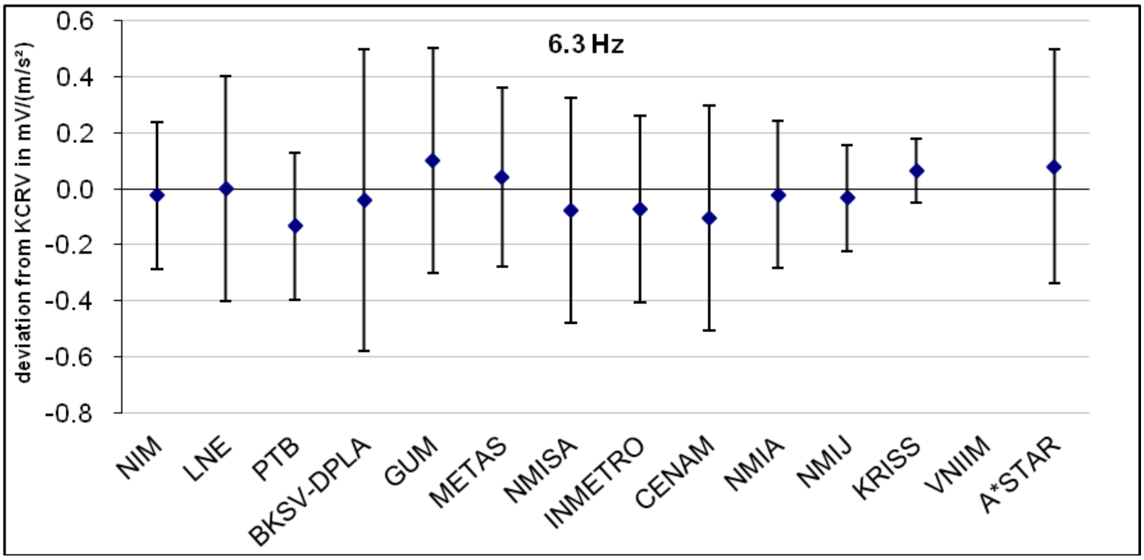

2 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

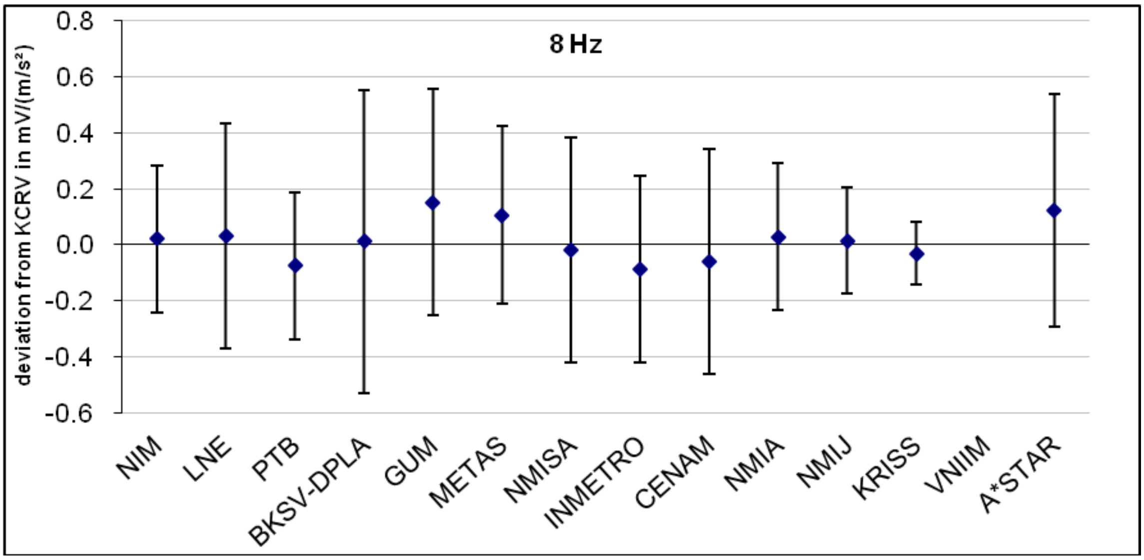

2.5 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

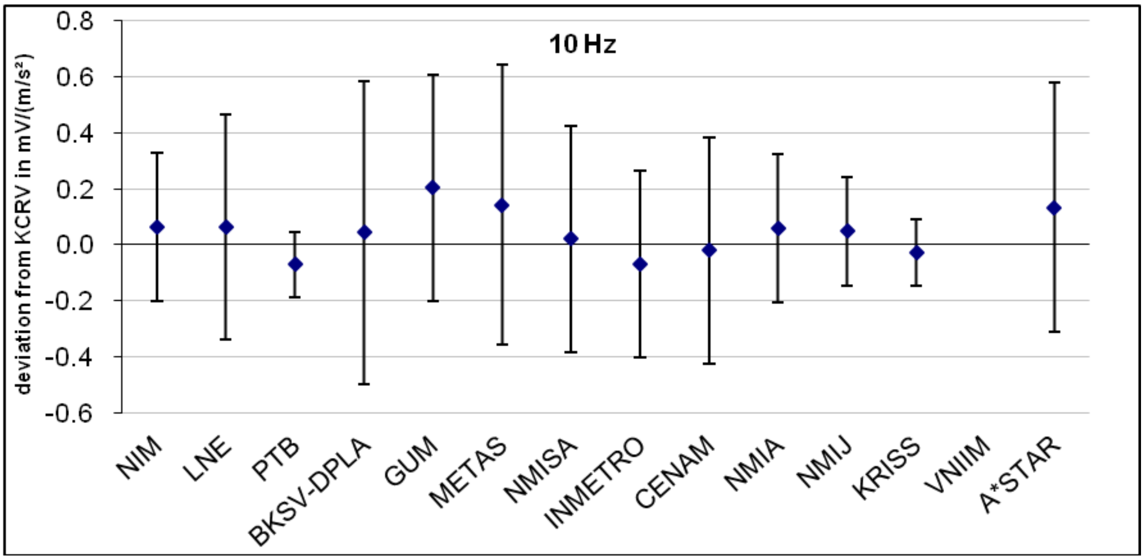

3.15 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

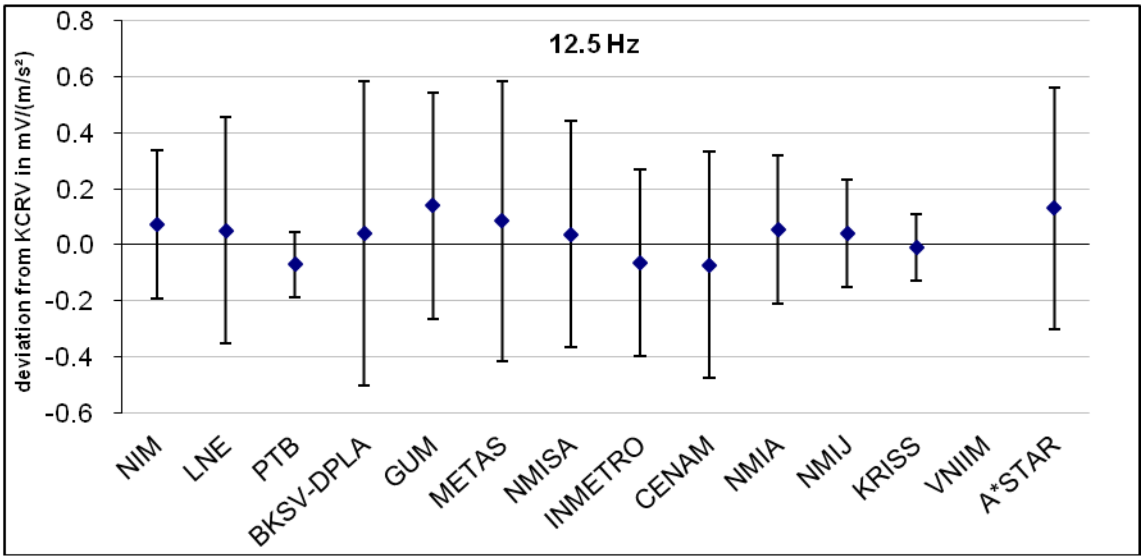

4 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

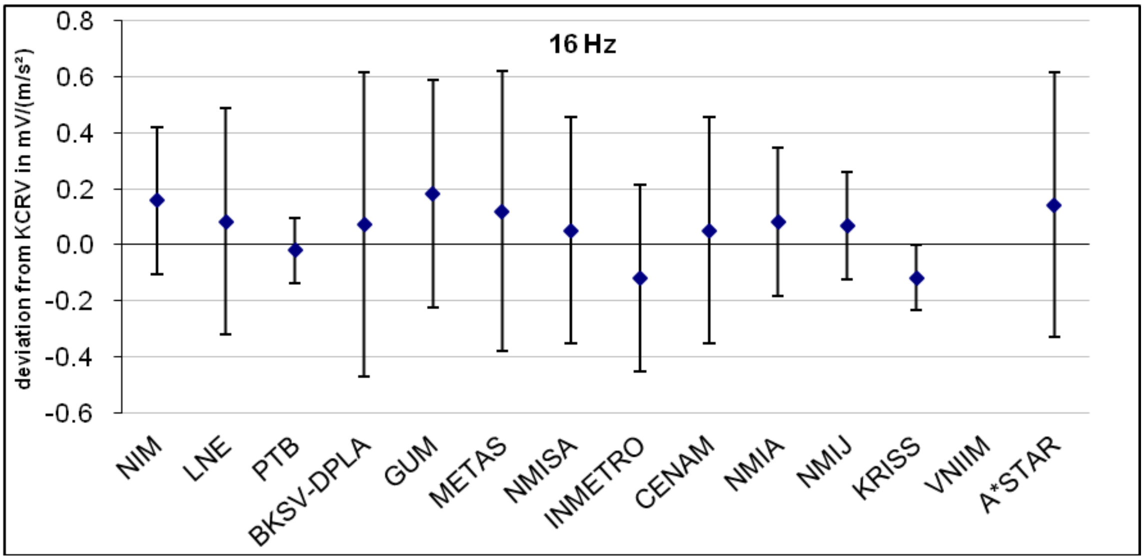

5 Hz
deviation from KCRV in mV/(m/s²)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

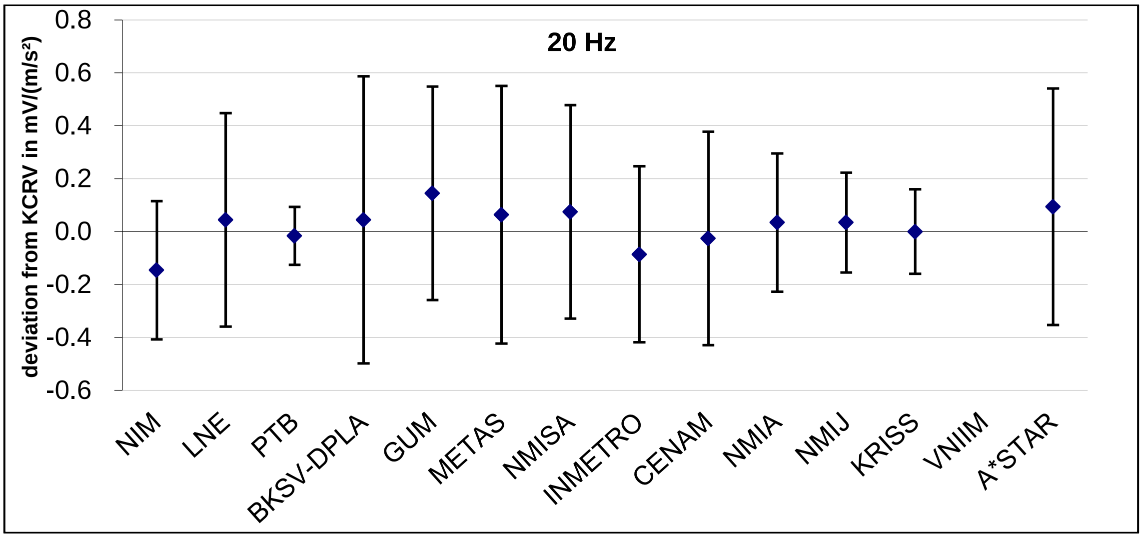

6.3 Hz
deviation from KCRV in mV/(m/s²)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

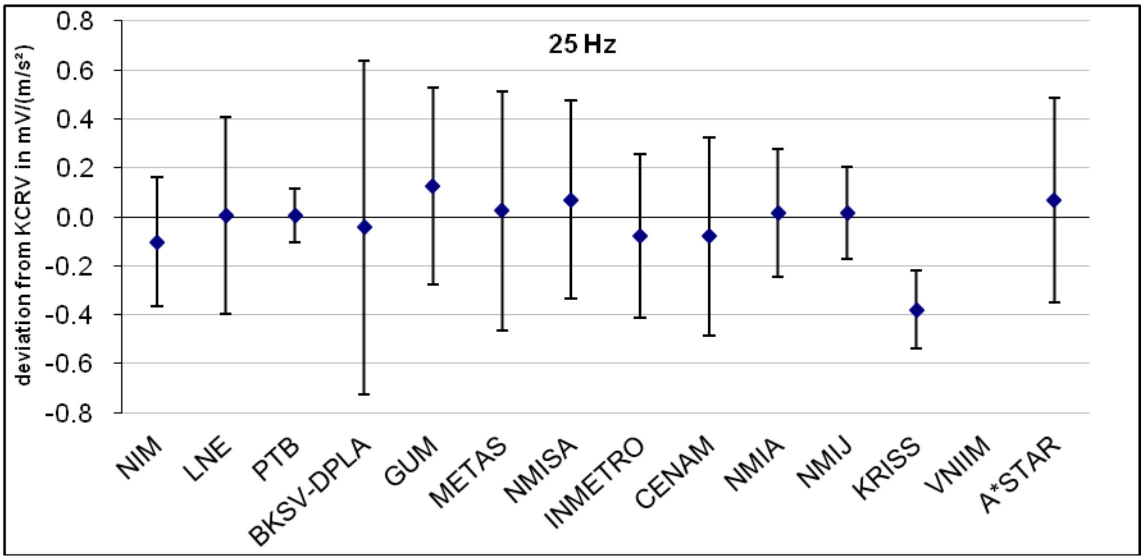

8 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

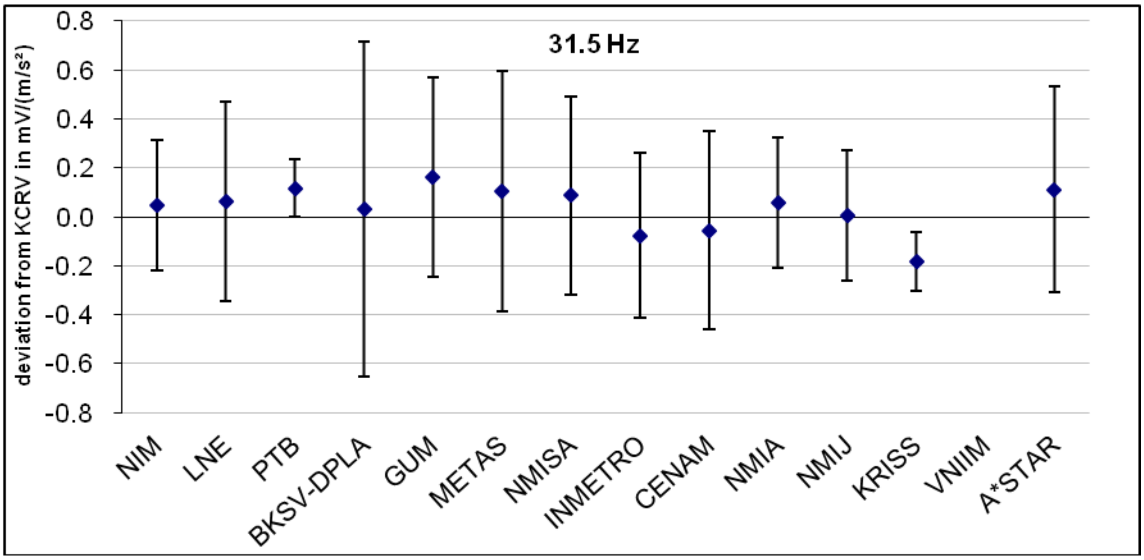

10 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

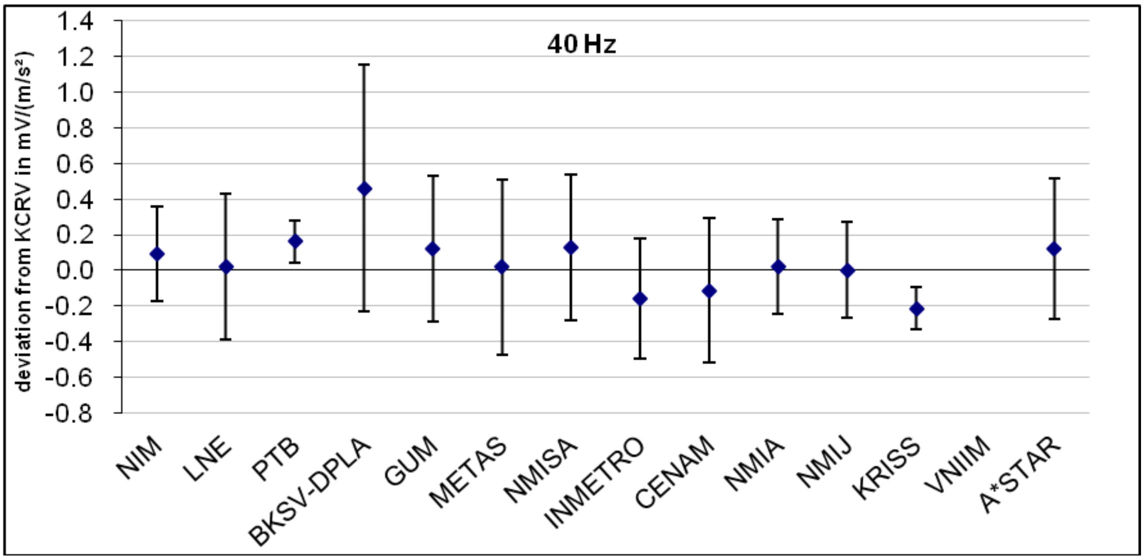

12.5 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


16 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


20 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


25 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


31.5 Hz
deviation from KCRV in mV/(m/s²)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


40 Hz
deviation from KCRV in mV/(m/s²)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

8.2 Results for the phase of the complex sensitivity

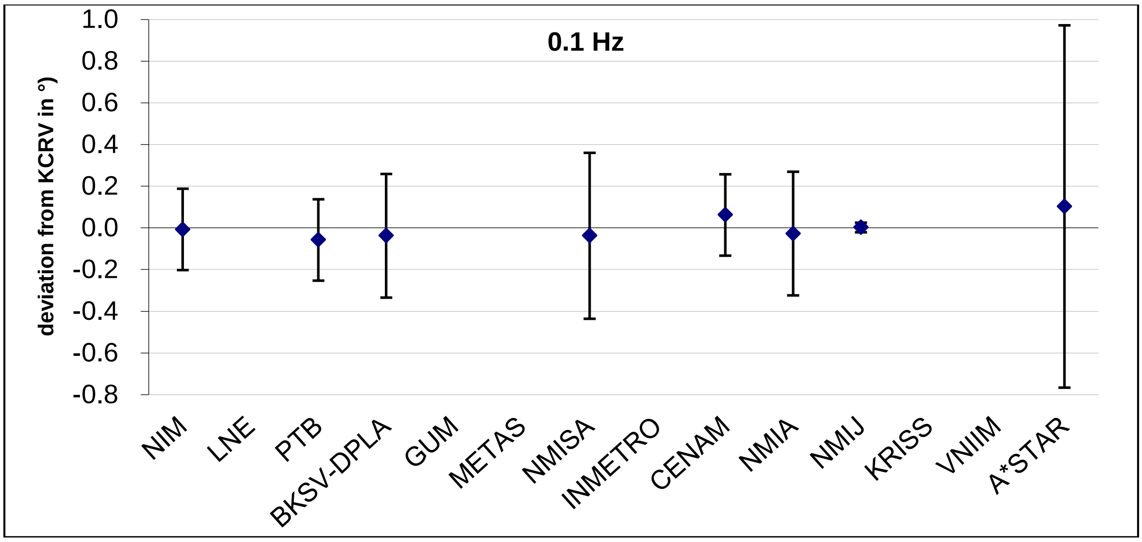
Table 8.2.1: Unilateral degrees of equivalence for the phase of sensitivity with absolute expanded uncertainties ($k = 2$)

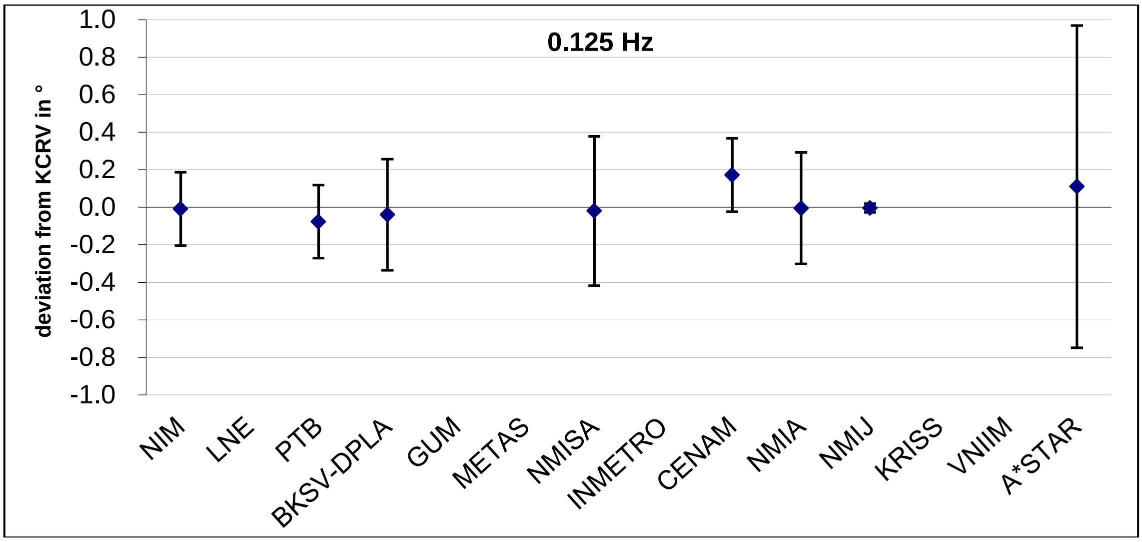
	KCRV		NIM		LNE		PTB		BKSV-DPLA		GUM	
actual frequency	X_{KCRV}	U_{KCRV}	$d_{I,KCRV}$	$U_{I,KCRV}$	$d_{I,KCRV}$	$U_{I,KCRV}$	$d_{I,KCRV}$	$U_{I,KCRV}$	$d_{I,KCRV}$	$U_{I,KCRV}$	$d_{I,KCRV}$	$U_{I,KCRV}$
in Hz	in °		in °		in °		in °		in °		in °	
0.1	-0.34	0.04	-0.01	0.19			-0.06	0.19	-0.04	0.30		
0.125	-0.42	0.04	-0.01	0.19			-0.08	0.19	-0.04	0.30		
0.16	-0.54	0.04	-0.01	0.19			-0.10	0.19	-0.01	0.30		
0.2	-0.67	0.04	-0.01	0.20			-0.12	0.20	-0.01	0.30	-0.10	0.90
0.25	-0.85	0.04	0.00	0.19			-0.08	0.19	0.00	0.30	-0.09	0.90
0.315	-1.07	0.04	0.00	0.19			-0.10	0.19	-0.02	0.30	-0.08	0.90
0.4	-1.36	0.04	0.00	0.20	1.34(*)	0.50(*)	-0.12	0.20	0.00	0.30	-0.06	0.50
0.5	-0.03	0.04	0.02	0.20	0.01	0.50	-0.05	0.20	0.01	0.30	-0.05	0.50
0.63	-0.03	0.04	-0.01	0.20	0.01	0.50	-0.05	0.20	0.01	0.30	-0.04	0.50
0.8	-0.04	0.04	0.05	0.20	0.01	0.50	-0.05	0.20	0.01	0.30	-0.03	0.50
1	-0.05	0.04	0.02	0.20			-0.03	0.20	0.01	0.30	-0.02	0.50
1.25	-0.07	0.04	0.02	0.20			-0.03	0.20	0.02	0.30	0.00	0.50
1.60	-0.08	0.04	0.02	0.20			-0.04	0.20	0.02	0.30	0.00	0.50
2	-0.09	0.04	0.01	0.20	0.00	0.50	-0.06	0.20	0.02	0.30	0.00	0.50
2.50	-0.12	0.04	0.02	0.20	0.01	0.50	-0.02	0.20	0.03	0.30	0.02	0.50
3.15	-0.15	0.04	0.03	0.20	0.01	0.50	-0.02	0.20	0.03	0.30	0.03	0.50
4	-0.19	0.04	0.03	0.20	0.04	0.50	-0.03	0.20	0.05	0.30	0.04	0.50
5	-0.19	0.04	0.03	0.20	0.00	0.50	-0.03	0.20	0.01	0.30	0.01	0.50
6.3	-0.25	0.07	0.02	0.19	0.00	0.50	-0.03	0.19	0.02	0.29	0.02	0.50
8	-0.31	0.07	0.00	0.19	0.01	0.50	-0.06	0.19	0.02	0.29	0.02	0.50
10	-0.38	0.07	0.01	0.19	0.01	0.50	-0.05	0.19	0.01	0.29	0.01	0.50
12.5	-0.48	0.07	0.01	0.19	0.01	0.50	-0.06	0.19	0.01	0.29	0.01	0.50
16	-0.63	0.07	0.01	0.19	0.02	0.50	-0.08	0.19	0.02	0.29	0.03	0.50
20	-0.80	0.07	0.04	0.19	0.02	0.50	-0.09	0.19	0.00	0.29	0.03	0.50
25	-1.03	0.07	0.07	0.19	0.03	0.50	-0.12	0.19	0.02	0.29	0.03	0.50
31.5	-1.37	0.07	0.09	0.19	0.03	0.50	-0.14	0.19	-0.01	0.50	0.05	0.50
40	-1.87	0.07	0.03	0.39	0.05	0.49	-0.19	0.19	0.11	0.49	0.06	0.49

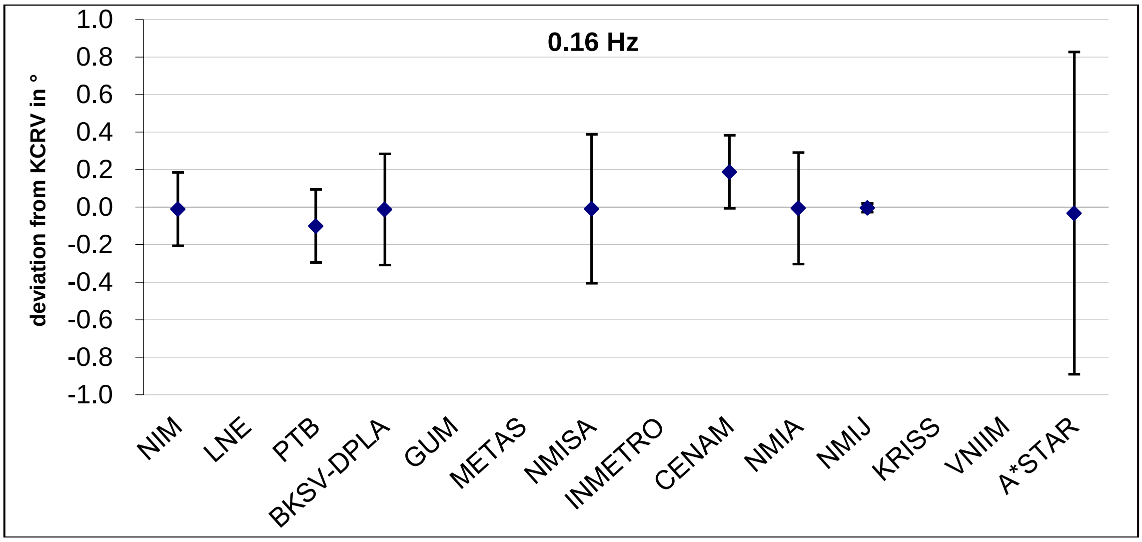
	KCRV		METAS		NMISA		INMETRO		CENAM		NMIA	
actual frequency	X_{KCRV}	U_{KCRV}	$d_{I,KCRV}$	$U_{I,KCRV}$	$d_{I,KCRV}$	$U_{I,KCRV}$	$d_{I,KCRV}$	$U_{I,KCRV}$	$d_{I,KCRV}$	$U_{I,KCRV}$	$d_{I,KCRV}$	$U_{I,KCRV}$
in Hz	in °		in °		in °		in °		in °		in °	
0.1	-0.34	0.04			-0.04	0.40			0.06	0.19	-0.03	0.30
0.125	-0.42	0.04			-0.02	0.40			0.17	0.19	-0.01	0.30
0.16	-0.54	0.04			-0.01	0.40			0.19	0.19	0.00	0.30
0.2	-0.67	0.04	0.09	0.78	-0.01	0.40	-0.01	0.25	0.25	0.20	-0.01	0.30
0.25	-0.85	0.04	0.09	0.78	0.00	0.40	0.01	0.25	0.17	0.50	0.00	0.30
0.315	-1.07	0.04	0.07	0.78	0.00	0.40	0.01	0.25	0.24	0.50	0.00	0.30
0.4	-1.36	0.04	0.06	0.78	0.02	0.40	0.01	0.25	0.30	0.50	0.01	0.30
0.5	-0.03	0.04	0.05	0.78	0.01	0.40	0.01	0.25	-0.31	0.50	0.01	0.30
0.63	-0.03	0.04	0.04	0.78	0.01	0.40	0.01	0.25	-0.39	0.50	0.01	0.30
0.8	-0.04	0.04	0.04	0.78	0.01	0.40	0.01	0.25	-0.52	0.50	0.01	0.30
1	-0.05	0.04	0.03	0.46	0.01	0.40	0.01	0.25	-0.63	0.50	0.02	0.30
1.25	-0.07	0.04	0.04	0.46	0.03	0.40	0.03	0.25	-0.86	0.50	0.03	0.30
1.60	-0.08	0.04	0.04	0.46	0.02	0.40	0.02	0.25	-1.09(*)	0.50(*)	0.03	0.30
2	-0.09	0.04	0.03	0.46	0.02	0.40	0.02	0.25	-1.25(*)	0.50(*)	0.03	0.30
2.50	-0.12	0.04	0.04	0.46	0.03	0.40	0.03	0.25	-1.47(*)	0.50(*)	0.04	0.30
3.15	-0.15	0.04	0.05	0.46	0.04	0.40	0.04	0.25	-1.98(*)	0.50(*)	0.05	0.30
4	-0.19	0.04	0.05	0.46	0.05	0.40	0.05	0.25	-2.51(*)	0.50(*)	0.06	0.30
5	-0.19	0.04	0.01	0.46	0.01	0.40	0.01	0.25	-3.18(*)	0.50(*)	0.03	0.30
6.3	-0.25	0.07	0.02	0.45	0.02	0.39	0.02	0.24	-4.11(*)	0.50(*)	0.05	0.29
8	-0.31	0.07	0.02	0.45	0.02	0.39	0.01	0.24	-5.06(*)	0.50(*)	0.03	0.29
10	-0.38	0.07	0.02	0.39	0.01	0.80	0.00	0.24	-6.33(*)	0.50(*)	0.04	0.29
12.5	-0.48	0.07	0.01	0.39	0.01	0.39	0.00	0.24	-7.89(*)	0.50(*)	0.06	0.29
16	-0.63	0.07	0.03	0.39	0.03	0.50	0.01	0.24	-10.09(*)	0.50(*)	0.08	0.29
20	-0.80	0.07	0.04	0.40	0.01	0.50	-0.04	0.24	-12.61(*)	0.50(*)	0.11	0.29
25	-1.03	0.07	0.04	0.40	-0.01	0.50	-0.03	0.24	-15.66(*)	0.50(*)	0.13	0.29
31.5	-1.37	0.07	0.07	0.40	0.00	0.50	-0.01	0.24	-19.55(*)	0.50(*)	0.15	0.29
40	-1.87	0.07	0.09	0.40	-0.03	0.49	-0.04	0.24	-24.68(*)	0.50(*)	0.19	0.29

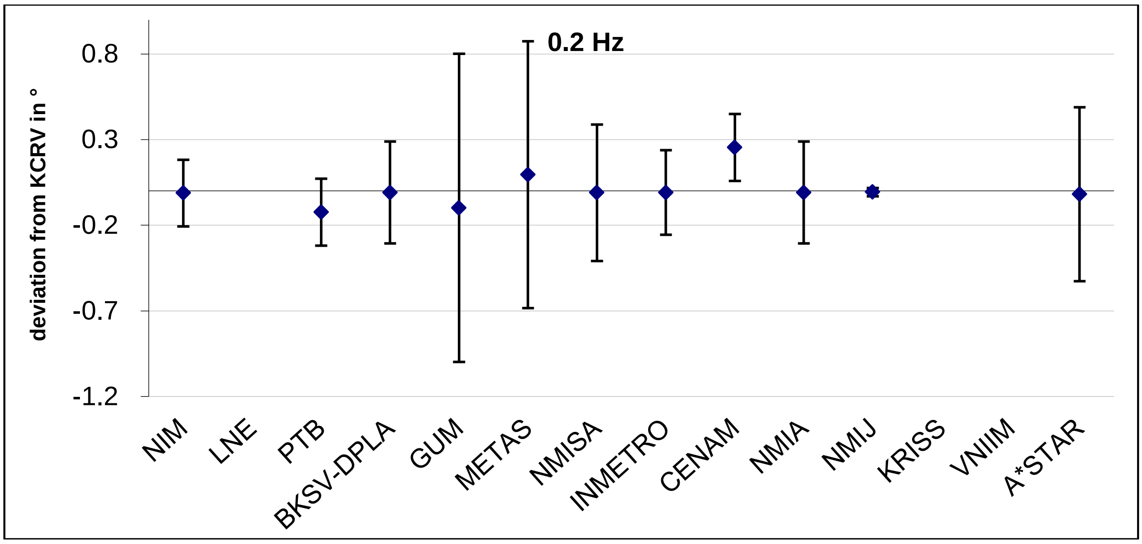
actual frequency	KCRV		NMIJ		KRISS		VNIIM		A*STAR	
	X_{KCRV}	U_{KCRV}	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$
in Hz	in °		in °		in °		in °		in °	
0.1	-0.34	0.04	0.00	0.02					0.10	0.87
0.125	-0.42	0.04	0.00	0.02					0.11	0.86
0.16	-0.54	0.04	0.00	0.02					-0.03	0.86
0.2	-0.67	0.04	-0.01	0.02					-0.02	0.51
0.25	-0.85	0.04	0.00	0.02					0.01	0.51
0.315	-1.07	0.04	0.00	0.02					-0.01	0.51
0.4	-1.36	0.04	0.01	0.02					0.01	0.31
0.5	-0.03	0.04	0.01	0.03	-0.02	0.09			0.02	0.31
0.63	-0.03	0.04	0.01	0.03	-0.04	0.09			0.02	0.31
0.8	-0.04	0.04	0.01	0.03	-0.05	0.09			0.01	0.31
1	-0.05	0.04	0.01	0.03	-0.05	0.09			0.02	0.35
1.25	-0.07	0.04	0.02	0.03	-0.06	0.09			0.03	0.35
1.60	-0.08	0.04	0.02	0.03	-0.09	0.09			0.03	0.35
2	-0.09	0.04	0.02	0.03	-0.11	0.09			0.02	0.35
2.50	-0.12	0.04	0.03	0.03	-0.13	0.09			0.02	0.35
3.15	-0.15	0.04	0.03	0.03	-0.16	0.09			0.01	0.35
4	-0.19	0.04	0.04	0.03	-0.20	0.09			0.02	0.35
5	-0.19	0.04	0.00	0.02	-0.29(*)	0.09(*)			-0.04	0.35
6.3	-0.25	0.07	0.00	0.07	-0.35(*)	0.12(*)			-0.03	0.34
8	-0.31	0.07	0.01	0.07	-0.45(*)	0.12(*)			-0.03	0.34
10	-0.38	0.07	0.00	0.07	-0.57(*)	0.12(*)			-0.03	0.34
12.5	-0.48	0.07	0.00	0.07	-0.70(*)	0.12(*)			-0.02	0.34
16	-0.63	0.07	0.01	0.07	-0.92(*)	0.12(*)			-0.12	0.34
20	-0.80	0.07	0.00	0.07	-1.12(*)	0.12(*)			-0.04	0.34
25	-1.03	0.07	0.01	0.07	-1.41(*)	0.12(*)			-0.04	0.34
31.5	-1.37	0.07	-0.01	0.07	-1.73(*)	0.12(*)			0.00	0.34
40	-1.87	0.07	0.02	0.07	-2.23(*)	0.12(*)			0.01	0.34

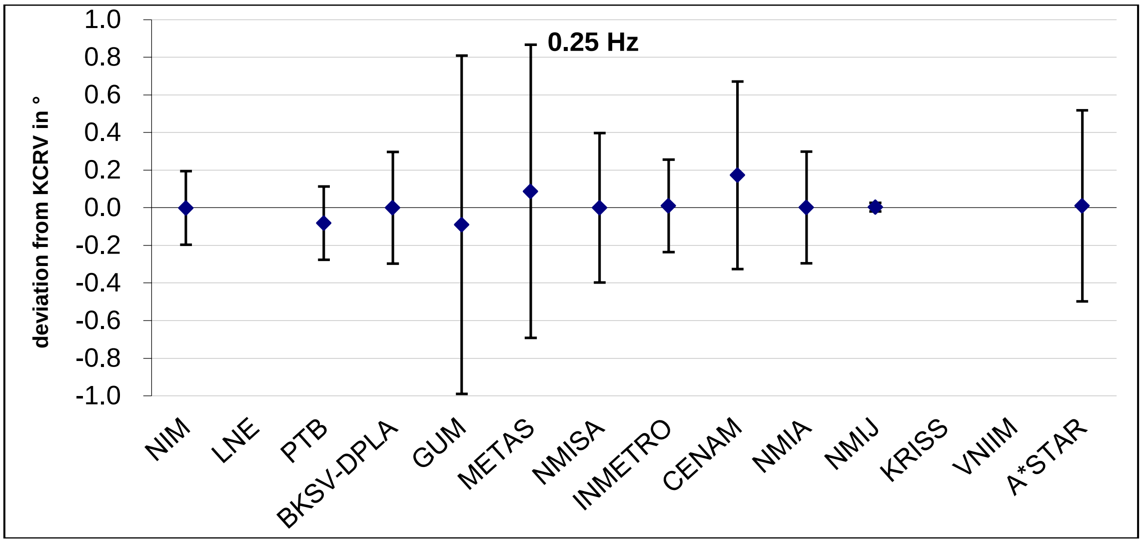
Figure 8.2.1: Deviation of the phase from the KCRV for all frequencies of the comparison with expanded uncertainties $U_{i,KCRV}$ ($k = 2$)

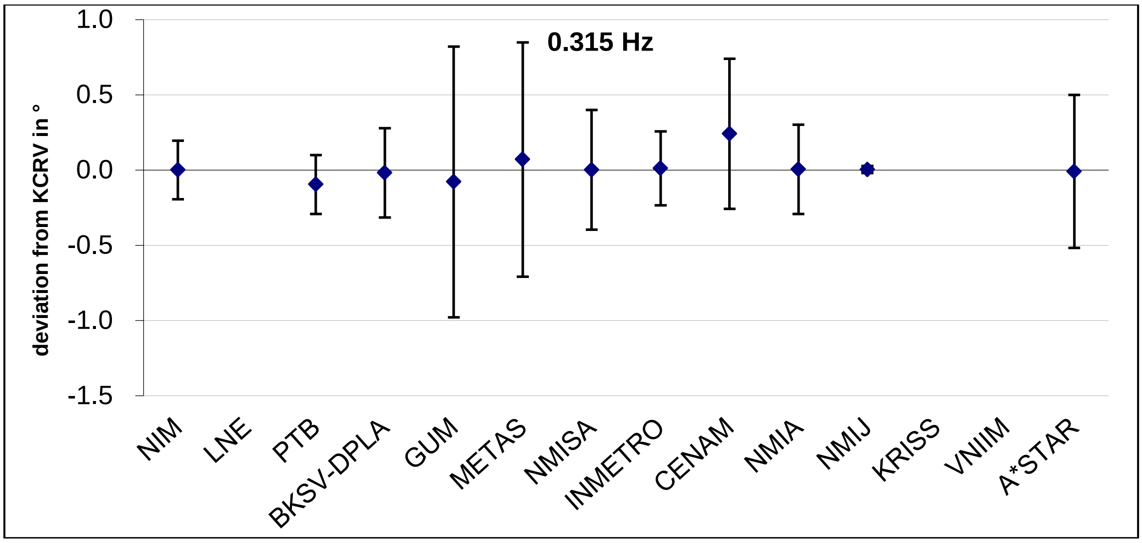


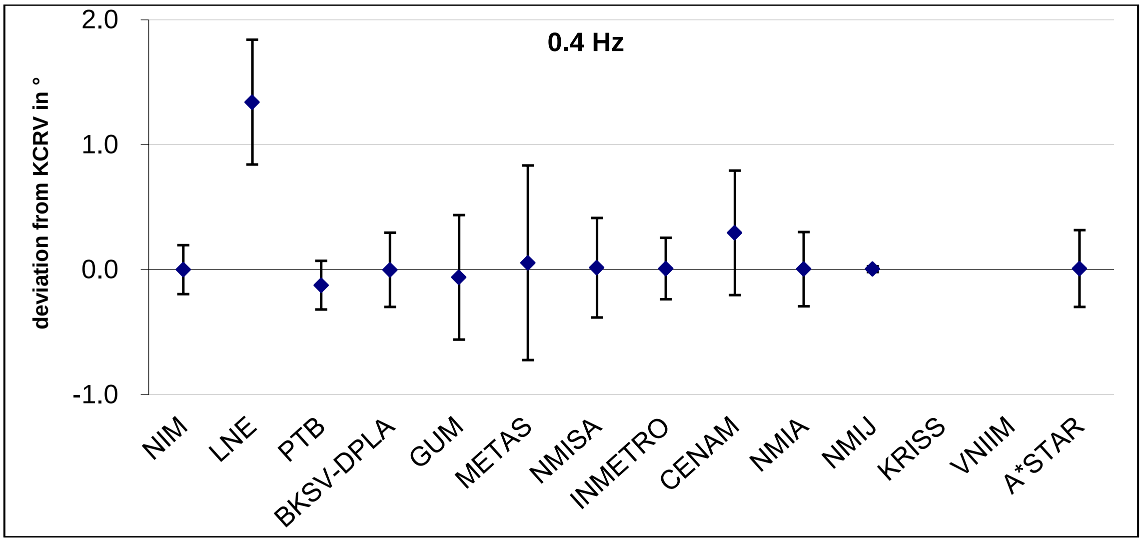

0.125 Hz
deviation from KCRV in °
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

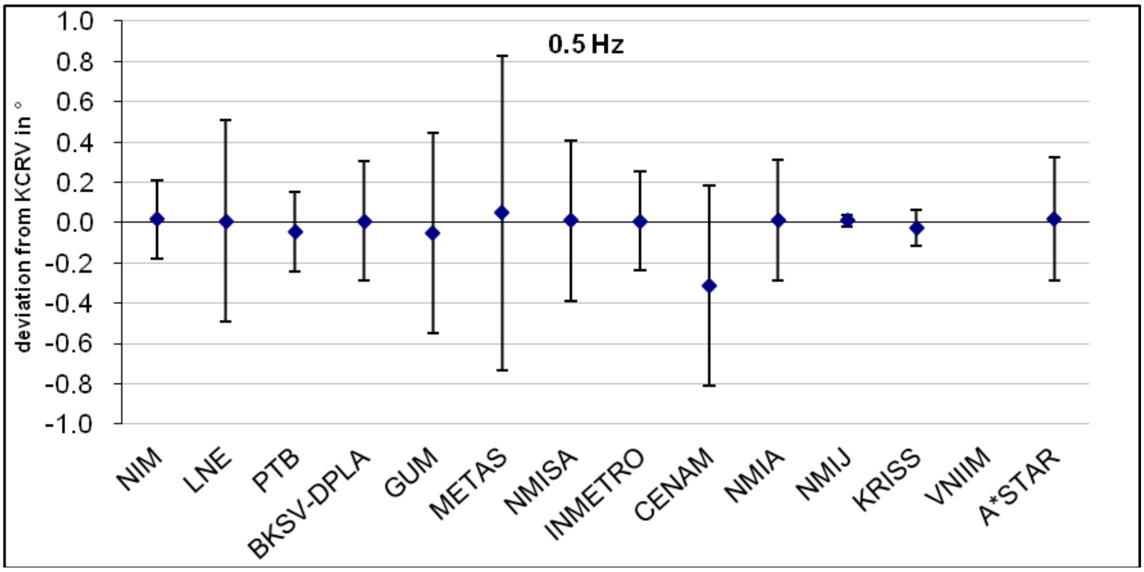

0.16 Hz
deviation from KCRV in °
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

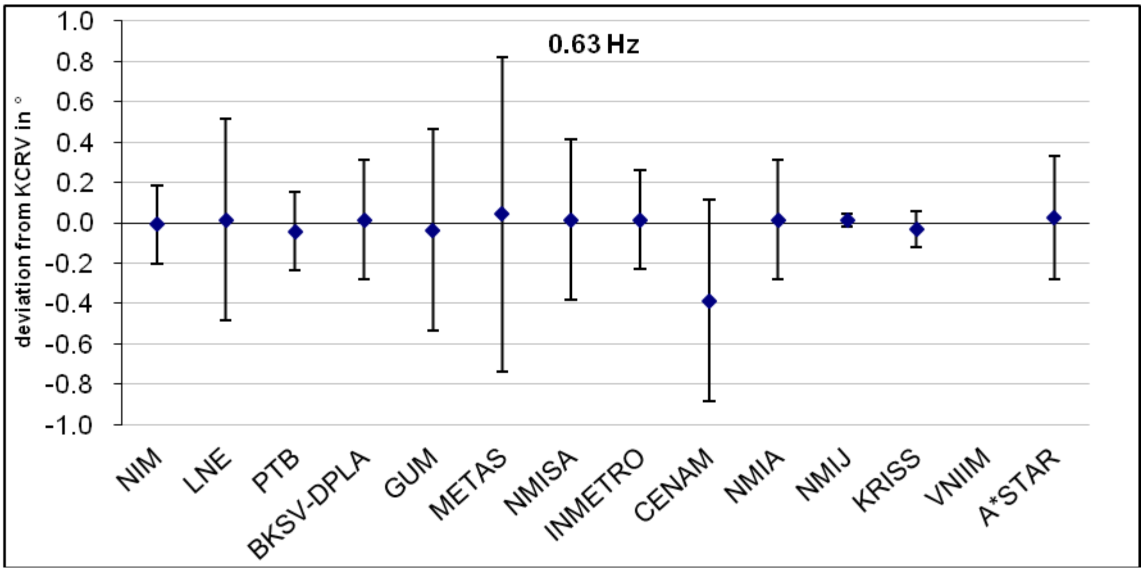

0.2 Hz
deviation from KCRV in °
0.8
0.3
-0.2
-0.7
-1.2
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

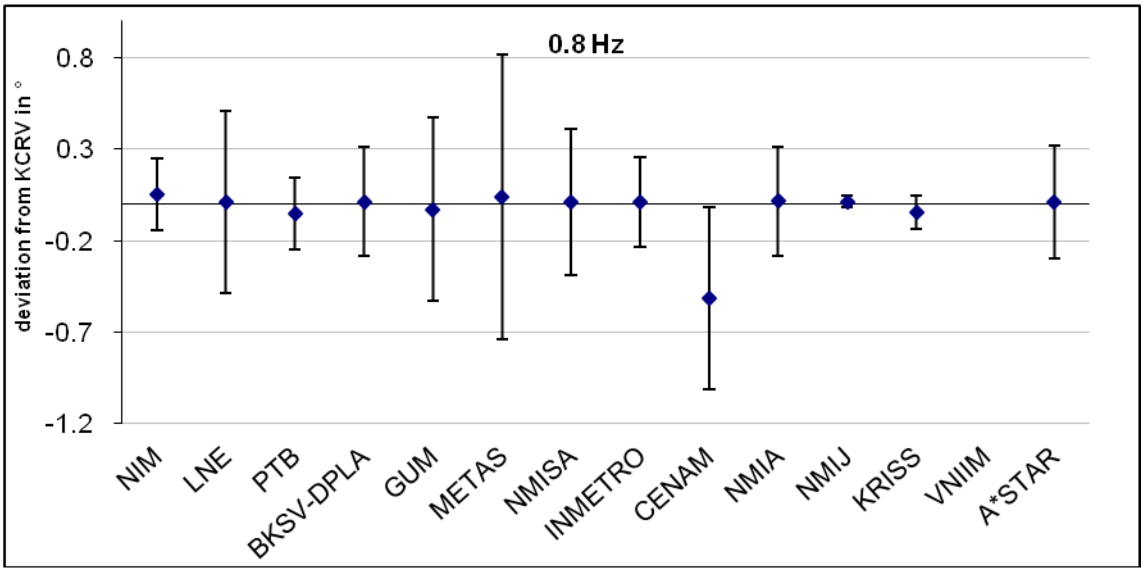

0.25 Hz
deviation from KCRV in °
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

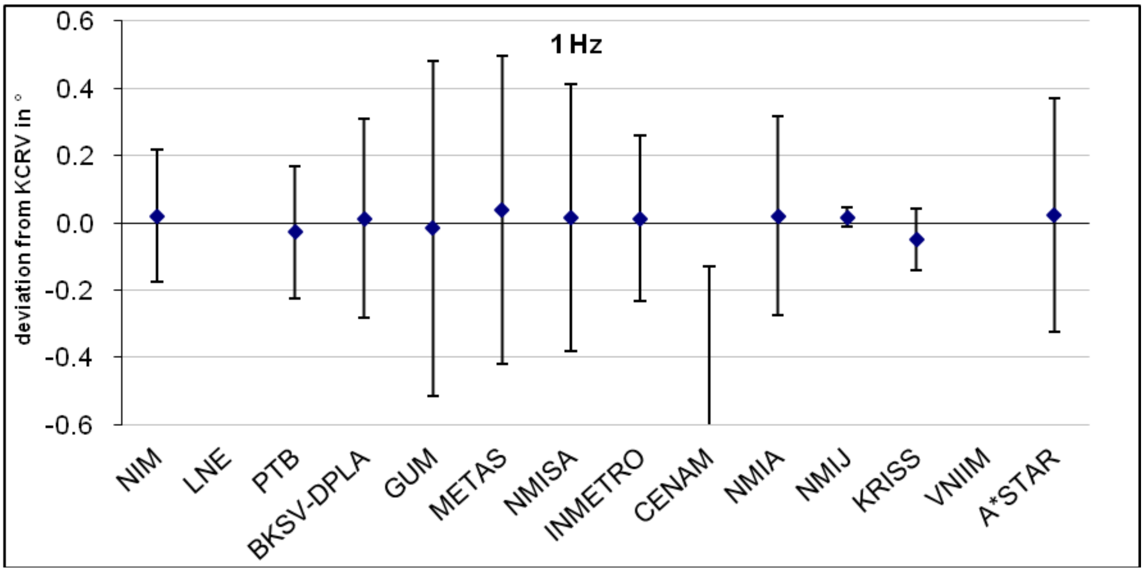

0.315 Hz
deviation from KCRV in °
1.0
0.5
0.0
-0.5
-1.0
-1.5
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

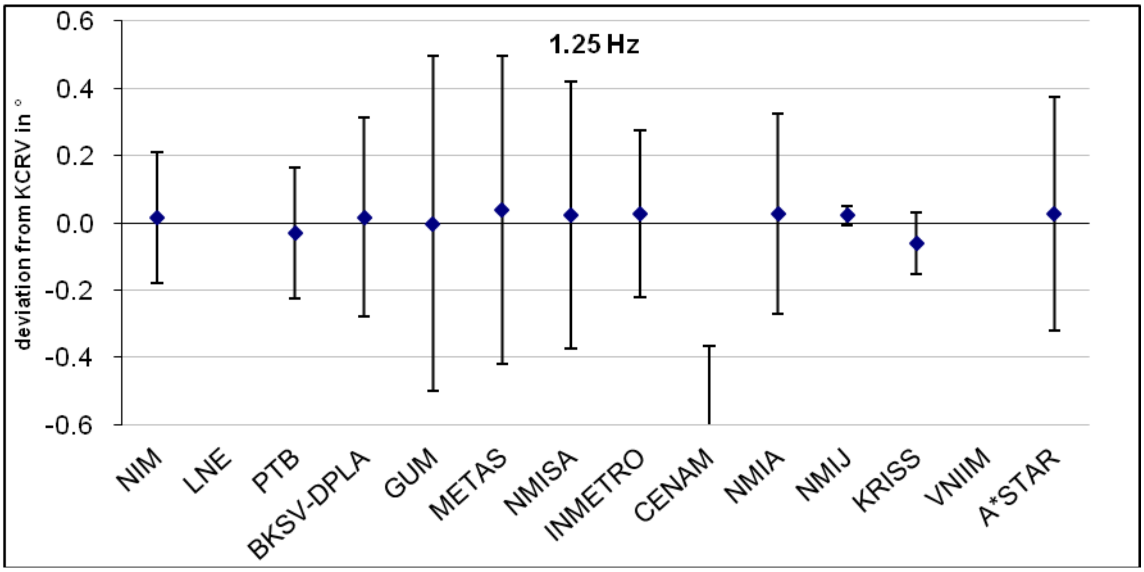

0.4 Hz
deviation from KCRV in °
2.0
1.0
0.0
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

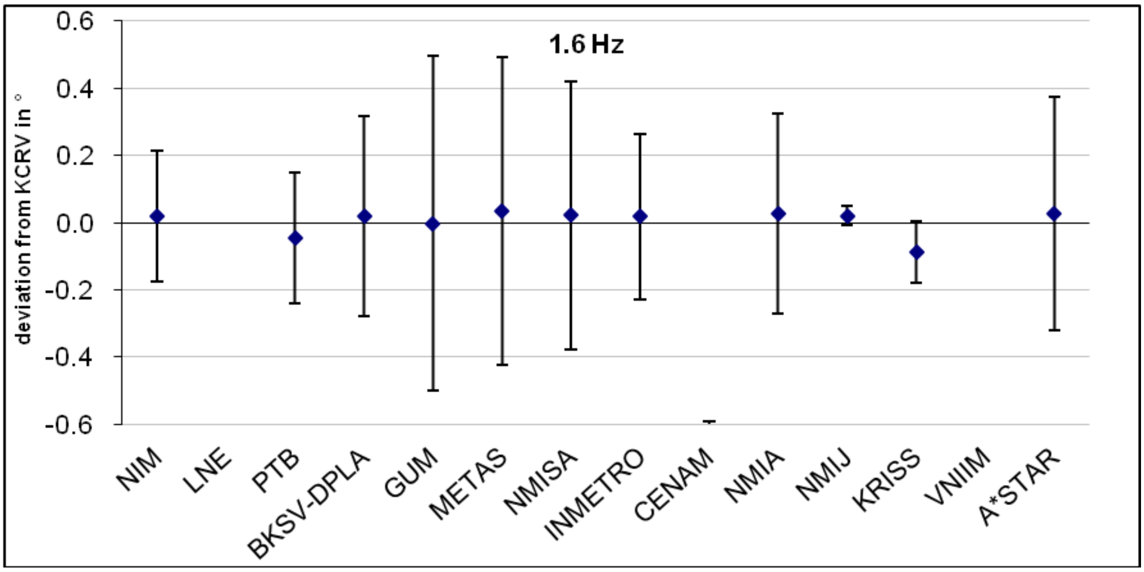

0.5 Hz
deviation from KCRV in °
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

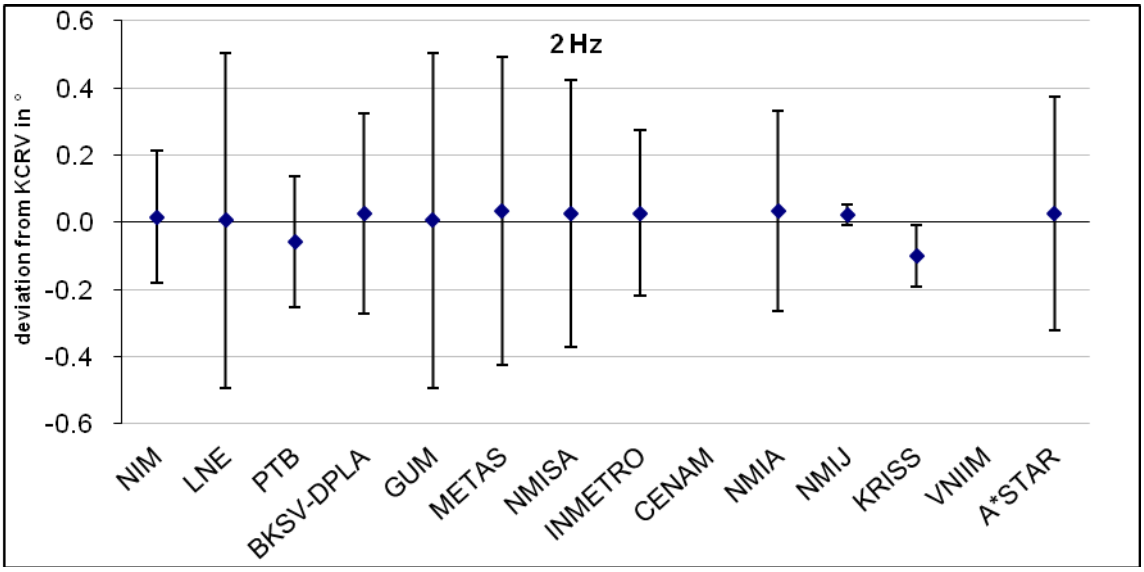

0.63 Hz
deviation from KCRV in °
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

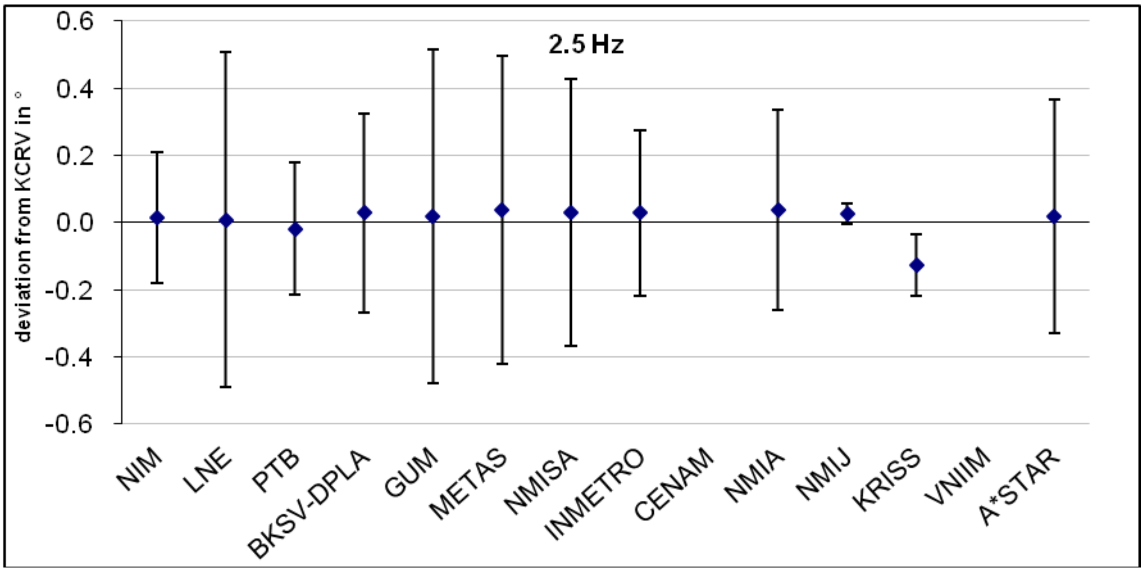

0.8 Hz
deviation from KCRV in °
0.8
0.3
-0.2
-0.7
-1.2
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

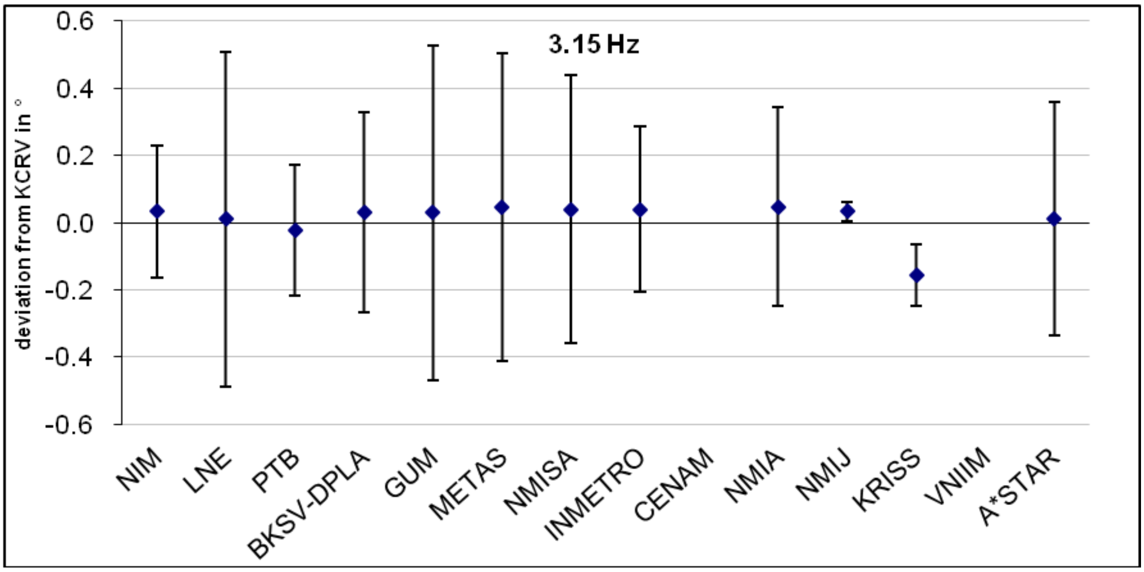

1 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

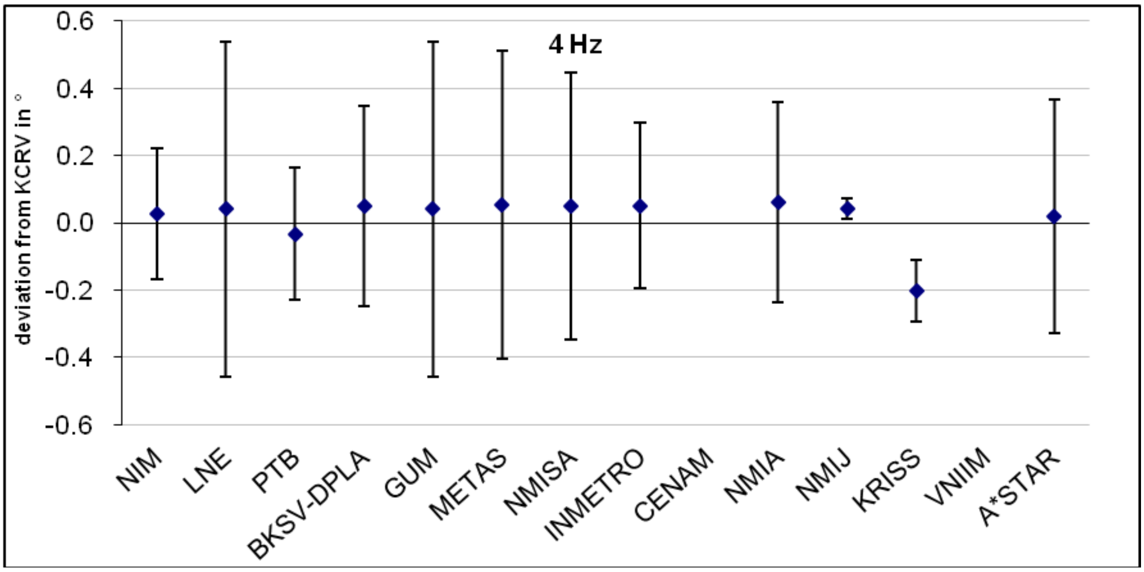

1.25 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

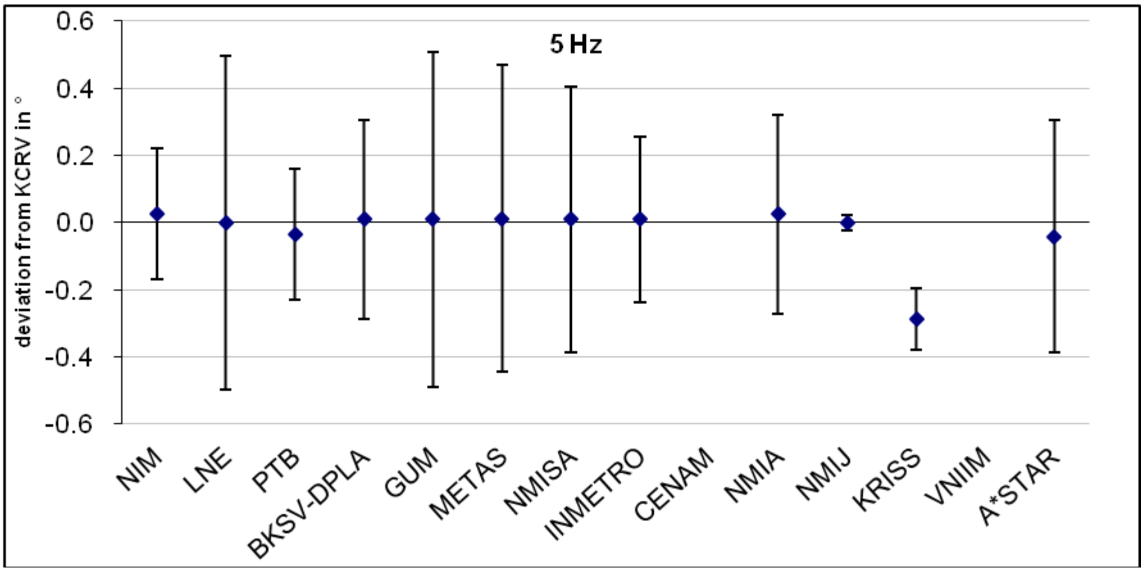

1.6 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


2 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


2.5 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


3.15 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


4 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


5 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
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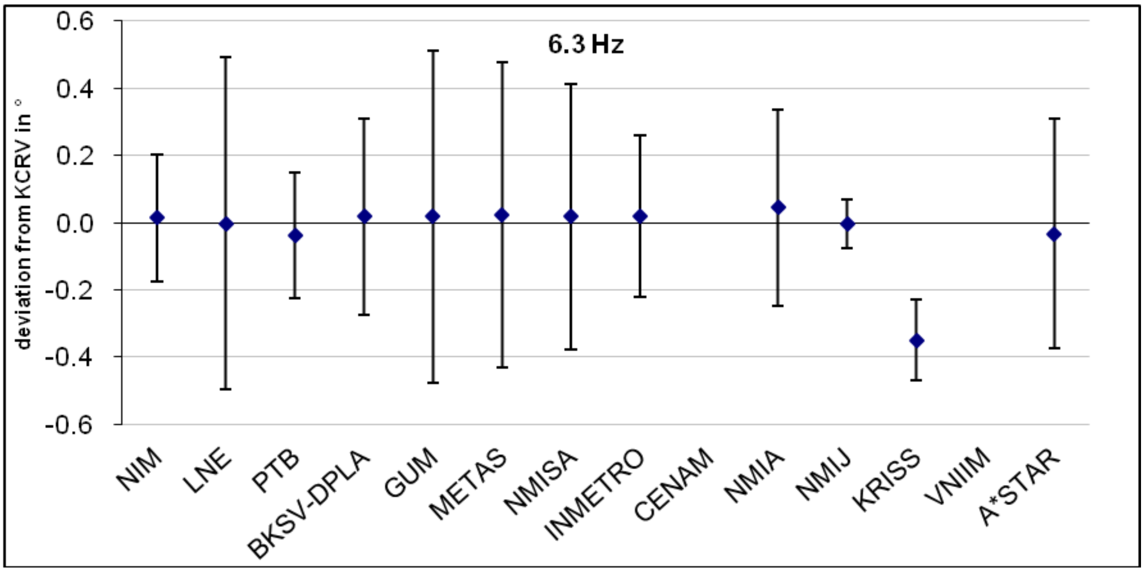
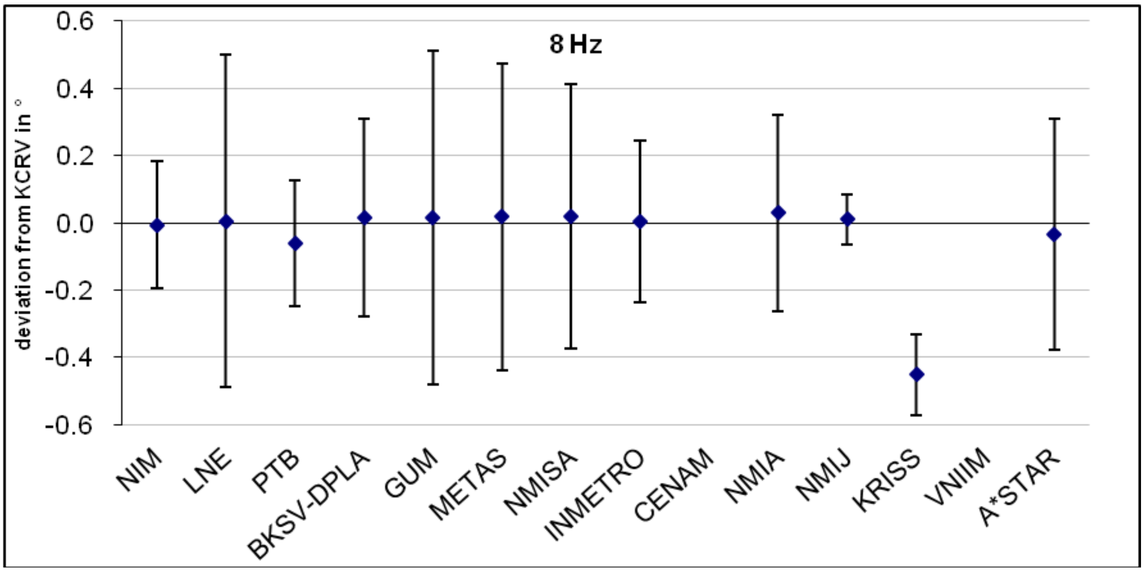
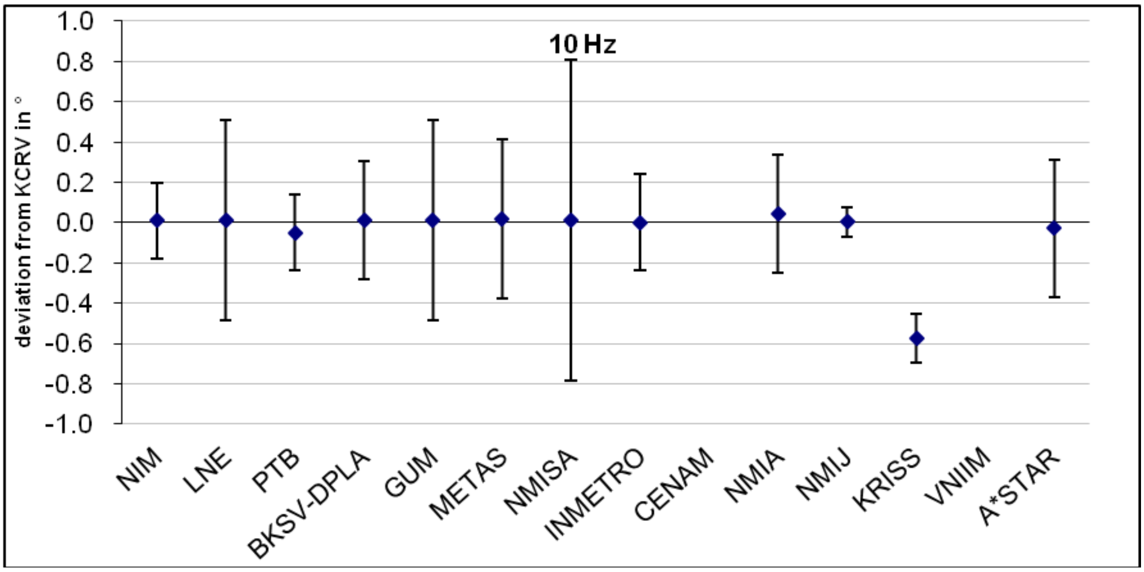
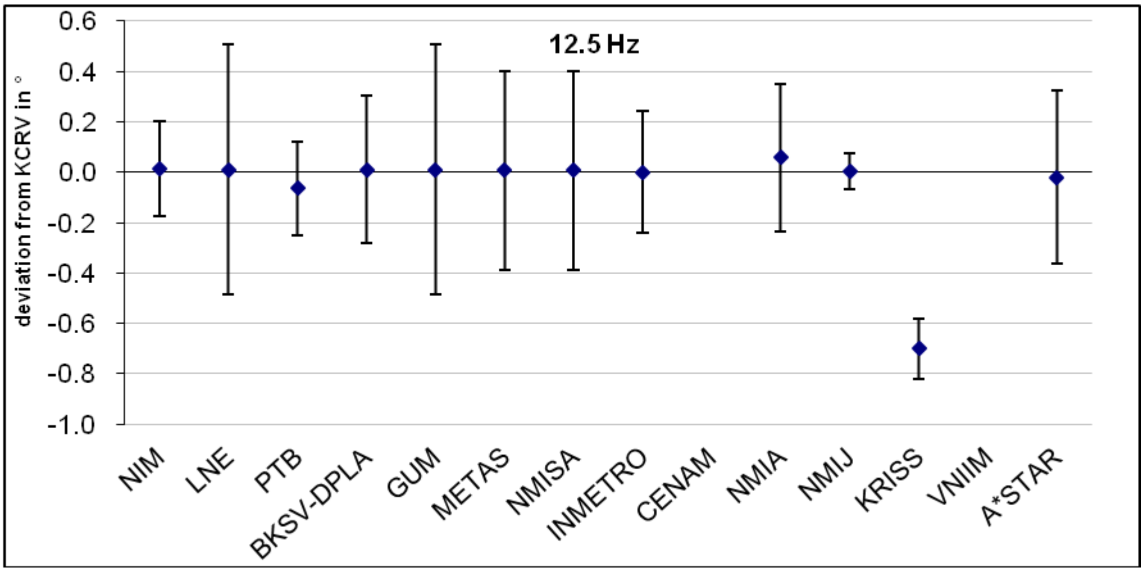
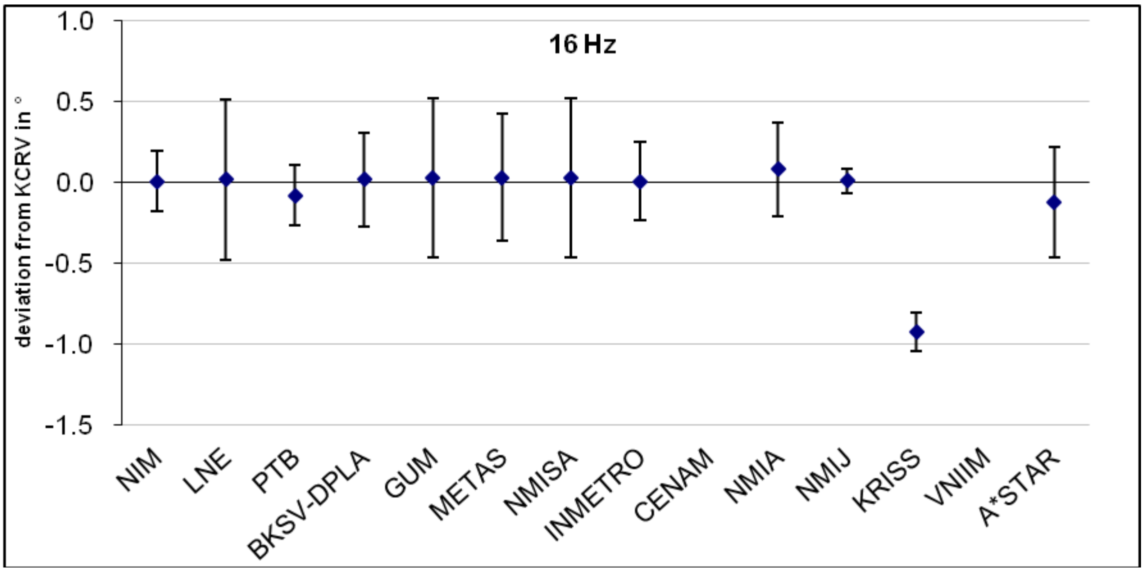
KRISS
VNIIM
A*STAR

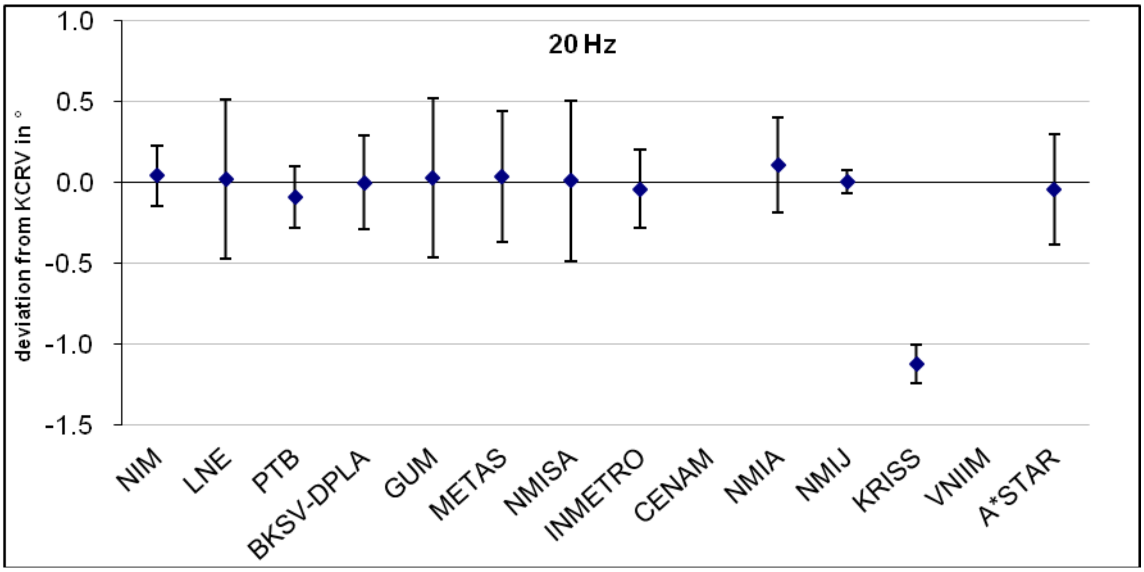

6.3 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

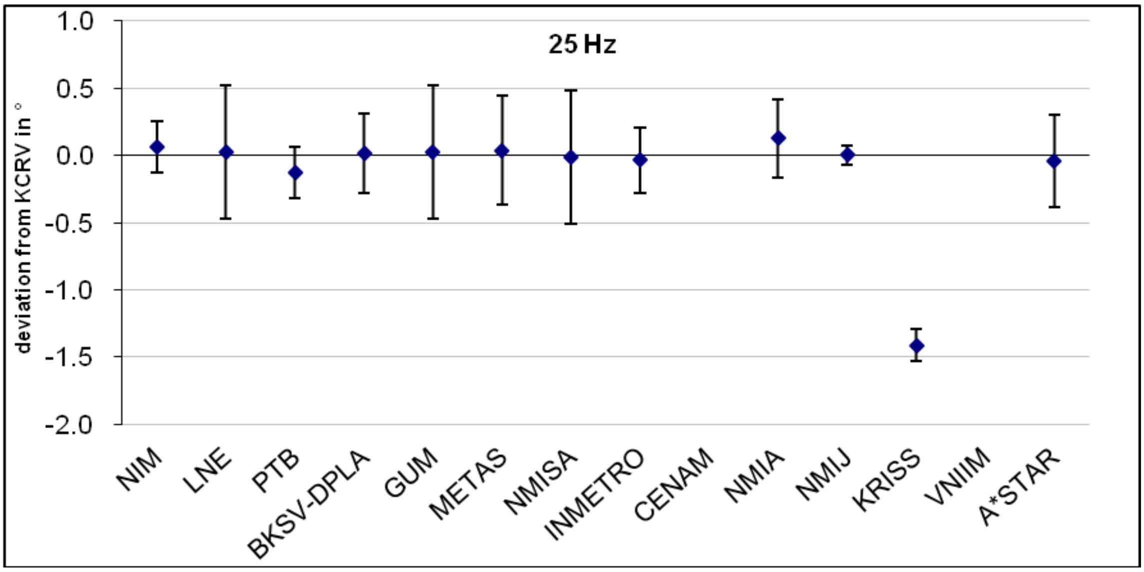

8 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


10 Hz
deviation from KCRV in °
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


12.5 Hz
deviation from KCRV in °
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


16 Hz
deviation from KCRV in °
1.0
0.5
0.0
-0.5
-1.0
-1.5
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


20 Hz
deviation from KCRV in °
1.0
0.5
0.0
-0.5
-1.0
-1.5
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


25 Hz
deviation from KCRV in °
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
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INMETRO
CENAM
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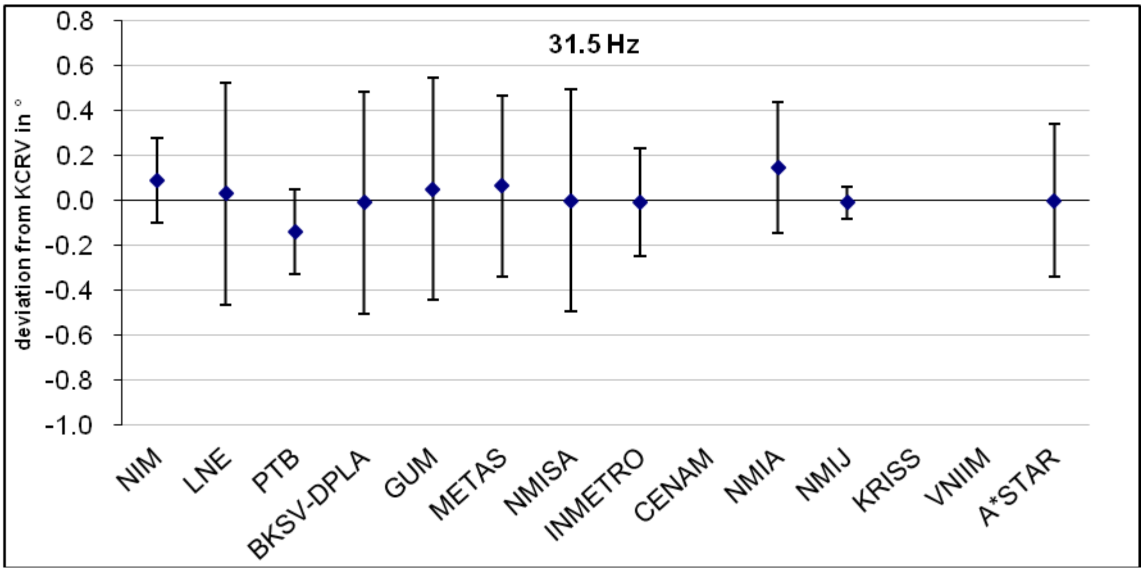
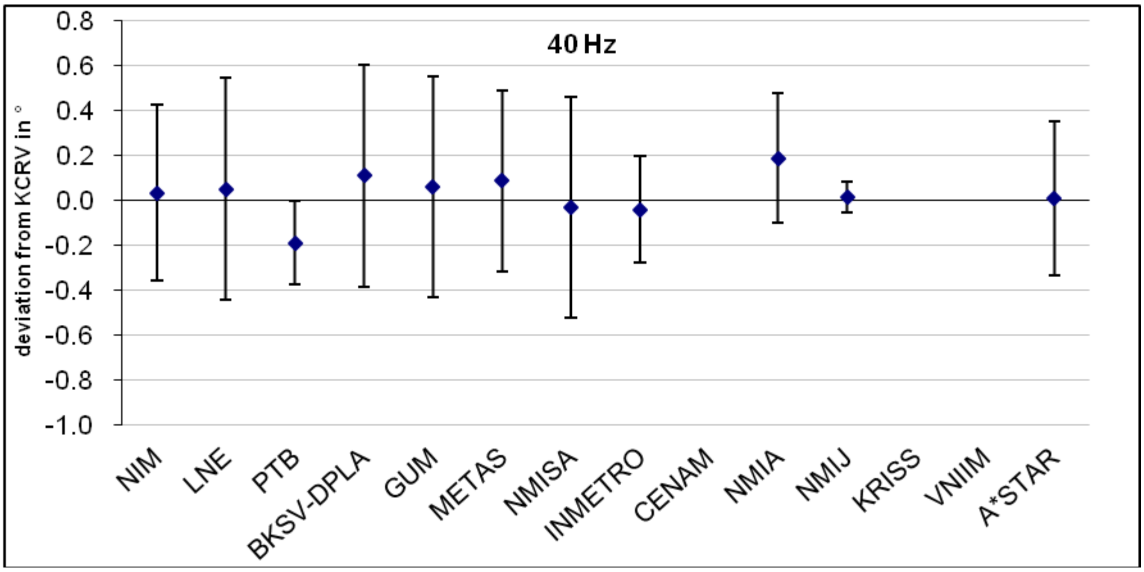
KRISS
VNIIM
A*STAR


31.5 Hz
deviation from KCRV in °
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR


40 Hz
deviation from KCRV in °
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
NIM
LNE
PTB
BKSV-DPLA
GUM
METAS
NMISA
INMETRO
CENAM
NMIA
NMIJ
KRISS
VNIIM
A*STAR

9. Conclusion

The first low-frequency CIPM key comparison CCAUV.V-K3 in vibration revealed the current calibration capabilities of the 14 participants of five RMOs.
All but one of the participating laboratories provided their calibration results, which were mostly consistent within their declared expanded uncertainties for magnitude results. Only two participants failed to contribute to the KCRV values calculated for five frequencies out of a total of twenty-seven comparison frequencies.
For phase shift, the situation was notably worse. Three participants could not contribute to the calculation of the KCRV values in a total of sixteen frequencies. Better understanding of their calibration devices and more reasonable evaluation of their calibration uncertainties will provide more accurate and reliable measurement results in the future.

10. Acknowledgment

The authors gratefully acknowledge all the participating institutes for their cooperation and support.

Bibliography

[1] von Martens, H.-J. et al., Final report on key comparison CCAUV.V-K1, 2003, Metrologia, 40, Tech. Suppl. 09001.

[2] Guidelines for CIPM key comparisons (Appendix F to the “Mutual recognition of national measurements standards and of measurement certificates issued by national metrology institutes” (MRA)). March 1, 1999.

[3] Technical Protocol of the CCAUV Key comparison CCAUV.V-K3 (Second version). NIM, Qiao Sun, 2015.

[4] Guide to the implementation of the CIPM MRA CIPM-MRA-G-01 VERSION 1.2. June, 2013.

[5] M.G. Cox, The evaluation of key comparison data, Metrologia, 2002, volume 39, p 589-595.

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

Annex A - Technical protocol (Second version)

Technical Protocol of CIPM Key Comparison CCAUV.V-K3

1 Task and Purpose 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 previous top level KC in the field of Vibration metrology, CCAUV.V-K1 was completed in the year 2001 in the frequency range from 40 Hz to 5 kHz. The ongoing CCAUV.V-K2 is aimed at frequency range from 10 Hz to 10 kHz.

However, recent developments in technology and improvements at the NMIs have extended the low frequency vibration limit of calibration capabilities down to 0.4 Hz and even to 0.1 Hz and lower. Therefore during the meeting of CCAUV in 2012, the decision was taken to make preparations for a further comparison targeted at a low frequency range.

In the field of vibration, this key comparison is organized in order to compare measurements of sinusoidal linear accelerations in the frequency range from 0.1 Hz to 40 Hz. Moreover, the complex sensitivity calibration and measurement capabilities (CMCs) of the participating laboratories for accelerometer calibration are to be examined and compared. It is the task of the comparison to measure the complex sensitivity of one accelerometer standard set (including a quartz-flexure servo accelerometer of single-ended type and a signal conditioner) at different frequencies with acceleration amplitudes as specified in section 3. The results of this key comparison will, after approval of equivalence, serve as the foundation at low vibration frequency for DoE derived from three existing regional low frequency supplementary comparisons and the registration of ‘calibration and measurement capabilities’ (CMC) in the framework of the CIPM MRA.

For the calibration of the accelerometer standard set, laser interferometry in compliance with method 3 of the international standard ISO 16063-11:1999 has to be applied, in order to cover the entire frequency range. Specifically, the magnitude of the complex voltage sensitivity shall be given in milli volt per meter per second squared (mV/(m/s²)) and phase shift in degree for the different measurement conditions specified in section 4.

The reported complex 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.

2 Pilot Laboratory

Pilot laboratory for this CIPM Key comparison is

Vibration and Gravity Laboratory
Mechanics and Acoustics Metrology Division
National Institute of Metrology, P.R. China
BeiSanHuanDongLu 18, ChaoYang District, 100013 Beijing, P.R. China

This is the delivery address for the set of artefact and the written and signed reports.

Contact Persons are

SUN Qiao	YANG Lifeng
Tel.: +86 10 64524623	Tel.: +86 10 64524606
e-mail: sunq@nim.ac.cn	e-mail: yanglf@nim.ac.cn
Fax: +86 10 64218628	

Co-Pilot laboratories for this key comparison are
Laboratoire national de metrologie et d'essais
and
National Metrology Institute of South Africa

Contact Persons are

Claire Bartoli	Ian Veldman
e-mail: claire.bartoli@lne.fr	e-mail: csveldman@nmisa.org
Tel.: +33 1 30 69 13 76	Tel.: +27 12 841 4008
Fax: +33 1 30 69 12 34	Fax: +27 86 509 0831

3 Device under Test and Measurement Conditions

For the calibration task of this comparison, one quartz-flexure accelerometer set will be circulated between the participating laboratories. The accelerometer set is one 'single ended' (SE) type, namely SA 704 (SN: *to be confirmed*), with a signal conditioner, namely MSA-I (SN: 02011001).

The accelerometer set is to be calibrated of its complex voltage sensitivity according to those procedures and conditions implemented by the laboratory in conformance with ISO 16063-11 which provides magnitude and phase shift information of the artefact. The complex sensitivities reported shall be for the accelerometer set, including all effects from the signal conditioner.

The frequency range of the measurements was agreed to be from 0.1 Hz to 40 Hz. Specifically, the laboratories are supposed to measure at the following frequencies (all values 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.

The mandatory frequency range is from 0.4 Hz to 40 Hz. The measurement conditions should be kept according to the laboratory's standard conditions for calibration of customers' accelerometers for claiming their best measurement capability or CMC where applicable. This presumes that these conditions comply with those defined by the applicable ISO documentary standards [1,2,3], simultaneously.

Specific conditions for the measurements of this comparison are:

- acceleration amplitudes: a range of 0.05 m/s^2 to 30 m/s^2 is recommended.
- ambient temperature and accelerometer temperature during the calibration: (23 ± 2) ºC (actual values to be stated within tolerances of ± 0.3 ºC).
- relative humidity: max. 75 % RH

4 Circulation Type, Schedule and Transportation

The transducer set is circulated in two loops with a measurement period of two weeks provided for each participating laboratory and one week for the pilot. At the beginning and the end of the circulation as well as between certain subsequent measurements of participating laboratories, the transducer set is measured at the pilot laboratory in order to fix reference values and to monitor the stability of the transducer set.

The schedule is planned as follows:

Participant	Measurement (calendar week)	Transportation to next Participant (calendar week)
NIM	35/2014*	36/2014
LNE	37-38/2014	39/2014
PTB	40-41/2014	42/2014
BKSV-DPLA	43-44/2014	45/2014
GUM	46-47/2014	48/2014
METAS	49-50/2014	3/2015
NIM	4/2015	5/2015
-	6-7/2015	11/2015
NMISA	12-13/2015	14/2015
INMETRO	15-16/2015	17/2015
CENAM	18-19/2015	20/2015
NMIA	21-22/2015	23/2015
NMIJ	24-25/2015	26/2015
KRISS	27-28/2015	29/2015
VNIIM	30-31/2015	32/2015
A*STAR	33-34/2015	35/2015
NIM	36/2015	

* 35/2014 refers to the period from Aug 25th to Aug 31st 2014

The cost of transportation to the next participating laboratory shall be covered by the participating laboratory. The transducer set has to be sent hand-carried with great caution. In case the transducer set gets damaged or lost during transportation, the participating laboratory for delivery should pay 4 000,- € to pilot laboratory for the set.

5 Measurement and Analysis Instructions

The participating laboratories have to observe the following instructions:

- The motion of the quartz-flexure accelerometer should be measured on the moving part of horizontal vibration exciter, close to the accelerometer's mounting surface, since the mounting (reference) surface is usually not directly accessible.
- The mounting surface of the accelerometer and the moving part of the exciter must be slightly lubricated before mounting.
- The cable between accelerometer and signal conditioner should be taken from the set delivered to the laboratory.
- It is advised that the measurement results should be compiled from complete measurement series carried out at different days under nominally the same conditions, except that the accelerometer is remounted and the cable re-attached. The standard deviation of the subsequent measurements should be included in the report.

6 Communication of the Results to Pilot Laboratory

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

- a description of the calibration systems used for the comparison and the mounting techniques for the accelerometer
- a description of the calibration methods used
- documented record of the ambient conditions during measurements
- the calibration results, including the relative expanded measurement uncertainty, and the applied coverage factor for each value
- a detailed uncertainty budget for the system covering all components of measurement uncertainty (calculated according to GUM [4,5]). Including, among others, information on the type of uncertainty (A or B), assumed distribution function and repeatability component.

In addition, the use of the electronic spreadsheets for reporting is mandatory. The format of spreadsheet will be provided by the pilot in due course. The consistency between the results in electronic form and the printed and signed calibration report is the responsibility of the participating laboratory. The data submitted in the electronic spreadsheet shall be deemed the official results submitted for the comparison.

The results have to be submitted to the pilot laboratory within four weeks after the measurements have been completed.

The pilot laboratory will submit its set of results to the executive secretary of CCAUV in advance to the first measurement of the participating laboratory.

7 Remarks on post processing

Presuming consistency of the results, the key comparison reference value and the degrees of equivalence will be calculated according to the established methods agreed upon already for CCAUV.V-K1.

References

[1] ISO 16063-1:1998 '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'

Annex1：Items list and Settings of conditioning amplifier

I. Item list: 1. Accelerometer; 2. Charge amplifier; 3. Cable; 4. Power cord;
4. Power adapter; 5. Fixture; 6. ATA Carnet; 7.Technical protocol.

II. Procedure of zero setting of conditioning amplifier:

1. Using the knob of 'Zero Coarse' to adjust to the zero first;
2. Using the knob of 'Zero Fine' to adjust to the zero precisely;
3. Setting the gain to 100 and repeat steps 1 and 2, to get more precise value of zero if necessary.

III. Other settings:.

Frequency	Filter Setup	Gain	Frequency	Filter Setup	Gain
Hz	Hz		Hz	Hz	
0.100	20	100	2.500	off	1
0.125	20	100	3.150	off	1
0.160	20	100	4.000	off	1
0.200	20	100	5.000	off	1
0.250	20	100	6.300	off	1
0.315	20	100	8.000	off	1
0.400	20	100	10.000	off	1
0.500	off	1	12.500	off	1
0.630	off	1	16.000	off	1
0.800	off	1	20.000	off	1
1.000	off	1	25.000	off	1
1.250	off	1	31.500	off	1
1.600	off	1	40.000	off	1
2.000	off	1	-	-	-

"Input selection" switch on the MSA-I conditioning amplifier should be on "Current input".

Annex B : Measurement uncertainty Budget (MUB)

1 – NIM

Magnitude sensitivity

UNCERTAINTY BUDGET MATRIX (UBM)

Certificate No	#REF!
Procedure No	AUVV-0001

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description	Sensitivity calibration (modulus) as per ISO 16063-11 method 3	Make & model:	China SA-704	Range:	0.1 Hz to < 0.4 Hz
		Serial number:	1040	Metrologist	YANG Lifeng

Mathematical Model: $S=\hat{u}/\hat{a}=\hat{u}/(2\pi f)^2 d$

Symbol u	Input Quantity (Source of Uncertainty)	Estimated Uncertainty $x(i)$	Unit	Probability Distribution (N, R, T, U)	k	Divisor factor	Standard Uncertainty $u(xi)$	Sensitivity Coefficient ci	Unit	Standard Uncertainty Contribution $Ui(y)$ %	Reliability %	Degrees of Freedom v	Remarks
	▼ Standards and Reference Equipment (Uncorrelated) ▼												
φ_G	Interferometer output signal disturbance on phase amplitude	0.01	%	Rectangular √3	2.00	1.73	5.77E-03	1	%	0.006	100	infinite	e.g. offsets, voltage amplitude deviations, ≠ 90° Corrected with Heydemann procedure
φ_{VD}	Effect of voltage disturbance on phase amplitude measurement	0.02	%	Rectangular √3	2.00	1.73	1.15E-02	0.01	%	0.000	100	infinite	Additive uncorrelated noise is reduced by 1/√n. Where n=number of samples per vibration cycle. Worse case [illegible]
φ_{MD}	Effect of motion disturbance on phase amplitude measurement	0.01	%	Rectangular √3	2.00	1.73	5.77E-03	1	%	0.006	100	infinite	Relative motion between sensing spot, exiter and accelerometer.
φ_{PD}	Effect of phase disturbance on phase amplitude measurement	0.02	%	Rectangular √3	2.00	1.73	1.15E-02	1	%	0.012	100	infinite	Corrected for using Heydemann correction procedure
φ_{RE}	Residual interferometric effects on phase amplitude measurement	0.02	%	Rectangular √3	2.00	1.73	1.15E-02	1	%	0.012	100	infinite	Not aware of any
f_{FG}	Vibration frequency measurement accuracy	0.0002	%	Rectangular √3	2.00	1.73	1.15E-04	1	%	0.000	100	infinite	ISO 16063-11 requirement: ≤ 0,05 % of reading
λ_U	Uncertainty on laser wavelength measurement	2.50E-11	nm	Normal k = 2	2.00	2.00	1.25E-11	100	%	0.000	100	infinite	Uncertainty quoted on certificate
δ_V	Accelerometer output voltage measurement (ADC resolution/accuracy)	0.15	%	Rectangular √3	2.00	1.73	8.66E-02	1	%	0.087	100	infinite	Manufacturer's specification worse case on 1 V range
S_F	Filtering effect on sensitivity measurement	0.15	%	Rectangular √3	2.00	1.73	8.66E-02	1	%	0.087	100	infinite	$e=(f/f_{HP})^2$
G_{CA}	Charge amplifier gain accuracy	0.00	%	Normal k = 2	2.00	2.00	0.00E+00	1	%	0.000	100	infinite	Conditioning amplifier uncertainty
	Resolution of Standard / Equipment (if applicable)										100		
	▼ Unit Under Test / Calibration (Uncorrelated) ▼												
δ_D	Effect of voltage disturbance on accelerometer output voltage measurement	0.002	%	Triangular √6		1.73	1.155E-03	1	%	0.001	100	infinite	$U_{THD}=½(d/100)^2$; Maximum allowed by ISO 16063
δ_T	Effect of transverse motion on accelerometer output voltage measurement	0.18	%	Triangular √6		1.73	1.039E-01	1	%	0.104	100	infinite	Transverse error for a transverse sensitivity of 1%
δ_{RES}	Residual effects on accelerometer output voltage measurement	0.3	%	Rectangular √12		3.00	1.000E-01	1	%	0.100	100	infinite	Tribo-electric effect
δ_σ	Standard deviation on accelerometer output voltage measurement	0.36	%	Rectangular √12		3.00	1.200E-01	1	%	0.120	100	infinite	ESDM for sensitivity calulation using 5 cycles minimum
	Resolution of UUT / Equipment (if applicable)										100		
	Data - Type "B" Evaluation Range of the results (Rectangular)										100		
	#REF!			Normal k = 1								4	No of Readings 5
About UBM	TOTAL COMBINED UNCERTAINTY									%			

NOTE ! ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼		0.124	V_{eff}	infinite	Checked and Approved By
	Expanded Uncertainty	95,45 %	K = 2	0.248	k =	2.00	SUN Qiao
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼		0.225	V_{eff}	infinite	
	Expanded Uncertainty	95,45 %	K = 2	0.5	k =	2.00	

UNCERTAINTY BUDGET MATRIX (UBM)										Certificate No		#REF!	
										Procedure No		AUVVV-0001	
Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)													
Description	Sensitivity calibration (modulus) as per ISO 16063-11 method 3	Make & model:		China SA-704				Range:		0.4 Hz to 40 Hz			Metrologist
		Serial number:		1040									YANG Lifeng
Mathematical Model:							$S=\hat{u}/\hat{a}=\hat{u}/(2\pi f)^2 d$						
Symbol	Input Quantity (Source of Uncertainty)	Estimated Uncertainty		Probability Distribution	k	Divisor factor	Standard Uncertainty	Sensitivity Coefficient		Standard Uncertainty Contribution Ui(y)	Reliability	Degrees of Freedom	Remarks
u	▼ Standards and Reference Equipment (Uncorrelated) ▼	(Xi)	Unit	(N, R, T, U)	▼	▼	U(Xi)	Ci	Unit	%	%	v	
φ_{CI}	Interferometer output signal disturbance on phase amplitude	0.01	%	Rectangular √3	2.00	1.73	5.77E-03	1	%	0.006	100	infinite	e.g. offsets, voltage amplitude deviations, +- 90° Corrected with Heydemann procedure
φ_{VD}	Effect of voltage disturbance on phase amplitude measurement	0.01	%	Rectangular √3	2.00	1.73	5.77E-03	0.01	%	0.000	100	infinite	Additive uncorrelated noise is reduced by 1/√n. Where n=numbers of samples per vibration cycle. Worse case
φ_{MD}	Effect of motion disturbance on phase amplitude measurement	0.01	%	Rectangular √3	2.00	1.73	5.77E-03	1	%	0.006	100	infinite	Relative motion between sensing spot, exiter and accelerometer.
φ_{PD}	Effect of phase disturbance on phase amplitude measurement	0.01	%	Rectangular √3	2.00	1.73	5.77E-03	1	%	0.006	100	infinite	Corrected for using Heydemann correction procedure
φ_{RE}	Residual interferometric effects on phase amplitude measurement	0.02	%	Rectangular √3	2.00	1.73	1.15E-02	1	%	0.012	100	infinite	Not aware of any
f_{FG}	Vibration frequency measurement accuracy	0.0002	%	Rectangular √3	2.00	1.73	1.15E-04	1	%	0.000	100	infinite	ISO 16063-11 requirement: ≤ 0,05 % of reading
λ_U	Uncertainty on laser wavelength measurement	2.50E-11	nm	Normal k = 2	2.00	2.00	1.25E-11	100	%	0.000	100	infinite	Uncertainty quoted on certificate
δ_V	Accelerometer output voltage measurement (ADC resolution/accuracy)	0.1	%	Rectangular √3	2.00	1.73	5.77E-02	1	%	0.058	100	infinite	Manufacturers specification worse case on 1 V range
S_F	Filtering effect on sensitivity measurement	0	%	Rectangular √3	2.00	1.73	0.00E+00	1	%	0.000	100	infinite	$e=(f/f_{FG})^2$
G_{CA}	Charge amplifier gain accuracy	0.00	%	Normal k = 2	2.00	2.00	0.00E+00	1	%	0.000	100	infinite	Conditiong amplifier uncertainty
	Resolution of Standard / Equipment (if applicable)										100		
▼ Unit Under Test / Calibration (Uncorrelated) ▼					NOTE! ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED								
δ_D	Effect of voltage disturbance on accelerometer output voltage measurement	0.001	%	Triangular √6		1.73	5.774E-04	1	%	0.001	100	infinite	$U_{HD}=½(d/100)^2$; Maximum allowed by ISO 16063
δ_T	Effect of transverse motion on accelerometer output voltage measurement	0.06	%	Triangular √6		1.73	3.464E-02	1	%	0.035	100	infinite	Transeverse error for a transverse sensitivity of 1%
δ_{RES}	Residual effects on accelerometer output voltage measurement	0.1	%	Rectangular √12		3.00	3.333E-02	1	%	0.033	100	infinite	Tribo-electric effect
δ_σ	Standard deviation on accelerometer output voltage measurement	0.16	%	Rectangular √12		3.00	5.333E-02	1	%	0.053	100	infinite	ESDM for sensitivity calulation using 5 cycles minimum
	Resolution of UUT / Equipment (if applicable)										100		
	Data - Type "B" Evaluation Range of the results (Rectangular)										100		
	#REF!			Normal k = 1								4	No of Readings 5
About UBM	TOTAL COMBINED UNCERTAINTY									%			
Best Measurement Capability (Excluding UUT contribution)			Combined Uncertainty (Normal)				▼ Level of Confidence ▼			0.060	V_{eff}	infinite	Checked and Approved By:
			Expanded Uncertainty				95,45 %	K = 2		0.120	k =	2.00	
Uncertainty of Measurement (Including UUT contribution)			Combined Uncertainty (Normal)				▼ Level of Confidence ▼			0.093	V_{eff}	infinite	SUN Qiao
			Expanded Uncertainty				95,45 %	K = 2		0.2	k =	2.00	

Phase sensitivity

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	AVVS-2663
	Procedure No	AVVS-0001

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description	Phase shift calibration as per ISO 16063-11 method 3	Make & model:	China SA-704	Range:	0.1Hz to 40 Hz	Metrologist
		Serial number:	1040			YANG Lifeng

Mathematical Model: $S_{Phase}=UUT_{Phase}-Ref_{Phase}-Ref_{Delay}-AtoD_{Phase}-DSP_{Delay}$

Symbol	Input Quantity (Source of Uncertainty)	Estimated Uncertainty		Probability Distribution	k	Divisor factor	Standard Uncertainty	Sensitivity Coefficient		Standard Uncertainty Contribution Ui(y)	Reliability	Degrees of Freedom	Remarks
u	▼ Standards and Reference Equipment (Uncorrelated) ▼	x(I)	Unit	(N, R, T, U)	▼	▼	U(XI)	CI	Unit	(°)	%	ν	
$\varphi_{x,IO}$	Interferometer output signal disturbance on displacement phase measurement	0.05	Degree	Rectangular √3	2.00	1.73	2.89E-02	1	Degree	0.029	100	infinite	e.g. offsets, voltage amplitude deviations, ≠ 90° Corrected with Heydemann procedure
$\varphi_{x,VD}$	Effect of voltage disturbance on displacement phase measurement	0.05	Degree	Rectangular √3	2.00	1.73	2.89E-02	1	Degree	0.029	100	infinite	Additive uncorrelated noise is reduced by 1/√n. Where n=number of samples per vibration cycle. Worse case =10%/1000
$\varphi_{x,MD}$	Effect of motion disturbance on displacement phase measurement	0.02	Degree	Rectangular √3	2.00	1.73	1.15E-02	1	Degree	0.012	100	infinite	Relative motion between sensing spot, exiter and accelerometer. Worse case calculated for 16mm double ended accelerometer.
$\varphi_{x,PD}$	Effect of phase disturbance on displacement phase measurement	0.01	Degree	Rectangular √3	2.00	1.73	5.77E-03	1	Degree	0.006	100	infinite	Corrected for using Heydemann correction procedure
$\varphi_{x,RE}$	Residual interferometric effects on displacement phase measurement	0.03	Degree	Rectangular √3	2.00	1.73	1.73E-02	1	Degree	0.017	100	infinite	Not aware of any
$\Delta\varphi_{E}$	Environmental effects on phase shift measurement	0.05	Degree	Rectangular √3	2.00	1.73	2.89E-02	1	Degree	0.029	100	infinite	ISO 16063-11 requirement: ≤ 0,05 % of reading
$\varphi_{u,V}$	Accelerometer output phase measurement (ADC resolution/accuracy)	0.05	Degree	Normal k = 2	2.00	2.00	2.50E-02	1	Degree	0.025	100	infinite	SAM phase calculation accuracy
$\varphi_{u,F}$	Filtering effect on accelerometer output phase measurement	0.1	Degree	Rectangular √3	2.00	1.73	5.77E-02	1	Degree	0.058	100	infinite	$e=(f/f_{-g})^2$
φ_{CA}	Charge amplifier phase accuracy	0.10	Degree	Normal k = 2	2.00	2.00	5.00E-02	1	Degree	0.050	100	infinite	
	Resolution of Standard / Equipment (if applicable)										100		
	▼ Unit Under Test / Calibration (Uncorrelated) ▼				NOTE !		ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED						
$\varphi_{u,D}$	Effect of voltage disturbance on accelerometer output phase measurement	0.1	Degree	k = ?		2.45	4.082E-02	1	Degree	0.041	100	infinite	U_{HD} = ½(d/100)²; Maximum allowed by ISO 16063
$\varphi_{u,T}$	Effect of transverse motion on accelerometer output phase measurement	0.06	Degree	k = ?		2.45	2.449E-02	1	Degree	0.024	100	infinite	Transeverse error for a transverse sensitivity of 1%
φ_{ESDM}	Standard deviation on accelerometer phase shift measurement	0.05	Degree	Rectangular √12		3.00	1.667E-02	1	Degree	0.017	100	infinite	ESDM for sensitivity calulation using 5 cycles minimum
				Normal k = 2									
	Resolution of UUT / Equipment (if applicable)										100		
	Data - Type "B" Evaluation Range of the results (Rectangular)										100		
	Data - Type "A" Evaluation Exp Std Deviation "s"			Normal k = 1								4	No of Readings 5
About UBM	TOTAL COMBINED UNCERTAINTY									(°)			
	Best Measurement Capability (Excluding UUT contribution)			Combined Uncertainty (Normal)			▼ Level of Confidence ▼			0.097	V_{eff}	infinite	Checked and Approved By:
				Expanded Uncertainty			95,45 %	K = 2		0.194	k =	2.00	
	Uncertainty of Measurement (Including UUT contribution)			Combined Uncertainty (Normal)			▼ Level of Confidence ▼			0.109	V_{eff}	infinite	SUN Qiao
				Expanded Uncertainty			95,45 %	K = 2		0.2	k =	2.00	

2 –LNE

Magnitude sensitivity

		Description	type	Contribution Incertitude	0,4 to 40 Hz
I					%
uncertainty on the measurement of the output of the accelerometer signal					
1	$u(\hat{u}V)$	Output voltage measurement	B	*u1 (S)*	0,054
1a	$u(sA)$	Conditionner gain	B	*u1a (SA)*	0,104
2	$u(\hat{u}F)$	Voltage filtering effects on the amplitude output	B	*u2 (S)*	0,006
3	$u(\hat{u}D)$	Voltage perturbation on the measure of the ouput voltage	B	*u3 (S)*	0,006
4	$u(\hat{u}T)$	Effect of transverse acceleration on the output voltage	B	*u4 (S)*	0,033
5	$u(STE)$	Effect of temperature sensitivity of the accelerometer on the output voltage	B	*u12 (S)*	0,030
uncertainty on the measurement of the phase amplitude amplitude					
6	$u(\hat{\varphi}M,Q)$	Effects of the interferometric quadrature output signal disturbance on the phase amplitude measurement	B	*u5 (S)*	0,029
7	$u(\hat{\varphi}M,F)$	Effect of the interferometric signal filtering on the phase amplitude measurement (limitation of the frequency band)		*u6 (S)*	Included in l6
8	$u(\hat{\varphi}M,VD\hat{\varphi}$	Effect of voltage disturbance on the phase amplitude measurement		*u7 (S)*	Included in l6
9	$u(\hat{\varphi}M,MD)$	Effect of motion of the vibration disturbance on the phase amplitude measurement	B	*u8 (S)*	0,017
10	$u(\hat{\varphi}M,PD)$	Residual interferometrics effects on the phase amplitude measurement		*u9 (S)*	Included in l6
11	$u(\hat{\varphi}M,RE)$	Longitudinal and transverse motion of the insulated table of the laser	B	*u10 (S)*	0,041
11b	$u(\hat{\varphi}M,LD)$	Wavelenght of the laser effect	B	*u10b (S)*	0,001
12	$u(fFG)$	Vibration frequency measurement	B	*u11 (S)*	0,002
13		Repeatability	A	*u13(S)*	0,020
		Relative standard uncertainty on accelerometer magnitude sensitivity (k=1)			**0,15**
		Relative expanded uncertainty on accelerometer magnitude sensitivity (k=2)			**0,30%**

Phase sensitivity

		Description	type	Contribution Incertitude	0,4 Hz to 40 Hz
I					degrees
uncertainty on the measurement of the output of the accelerometer signal					
1	$u(\hat{\varphi}_{u,V})$	Output phase measurement	B	$u1\,(\Delta\varphi)$	0,10
1a	$u(sA)$	Conditionner gain	B	$u1a\,(\Delta\varphi)$	0,10
2	$u(\hat{\varphi}_{u,F})$	Voltage filtering effects on the output phase	B	$u2\,(\Delta\varphi)$	0,10
3	$u(\hat{\varphi}_{u,D})$	Voltage perturbation on the measure of the ouput phase	B	$u3\,(\Delta\varphi)$	0,10
4	$u(\hat{\varphi}_{u,T})$	Effect of transverse acceleration on the output phase	B	$u4\,(\Delta\varphi)$	0,10
uncertainty on the measurement of the phase amplitude amplitude					
5	$u(\hat{\varphi}_{s},Q)$	Effects of the interferometric quadrature output signal disturbance on the phase amplitude measurement	B	$u5\,(\Delta\varphi)$	0,10
6	$u(\hat{\varphi}_{s},F)$	Effect of the interferometric signal filtering on the phase amplitude measurement (limitation of the frequency band)		$u6\,(\Delta\varphi)$	Included in I6
7	$u(\hat{\varphi}_{S,VD})$	Effect of voltage disturbance on the phase amplitude measurement		$u7\,(\Delta\varphi)$	Included in I6
8	$u(\hat{\varphi}_{S,MD})$	Effect of motion of the vibration disturbance on the phase amplitude measurement	B	$u8\,(\Delta\varphi)$	0,10
9	$u(\hat{\varphi}_{S,FD})$	Residual interferometrics effects on the phase amplitude measurement		$u9\,(\Delta\varphi)$	Included in I6
10	$u(\hat{\varphi}_{S,RE})$	Longitudinal and transverse motion of the insulated table of the laser	B	$u10\,(\Delta\varphi)$	0,10
11b	$u(\hat{\varphi}_{S,LD})$	Wavelenght of the laser effect	B	$u10b\,(\Delta\varphi)$	0,00
11	$u(fFG)$	Vibration frequency measurement	B	$u11\,(\Delta\varphi)$	0,10
12	$u(R)$	Repetability on the 3 measurements	A	$u12(\Delta\varphi$	0,10

Absolute standard uncertainty on accelerometer phase shift (k=1)	0,4
Absolute expanded uncertainty on accelerometer phase shift (k=2)	**0,5°**

3- PTB

Magnitude sensitivity

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

					combined frequency ranges	
Disturbing Component	**comment**	**95% value**	**distribution**	**factor**	**0,1 Hz - <0,4 Hz**	**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**

4- BKSV-DPLA

Magnitude sensitivity

	Numbering following	**Budget of Uncertainties (Magnitude)** **3629 Quadrature system with air-bearing shaker APS129** Notes:	Uncertainty Contribution	Relative expanded uncertainty or bounds	Probability distribution	Factor	Contribution u_i (y)					
	ISO 16063-11	Cal. Mode: Voltage		of estimated error	model		0.10 Hz	0.2 Hz	>1 Hz	>2 Hz	> 10 Hz	> 20 Hz
	Table A.3	All values are 1 sigma values		components			to <0.2 Hz	to 1 Hz	to 2 Hz	to 10 Hz	to 20 Hz	to 40 Hz
i	Quantity	Description		[%]		xi	%	%	%	%	%	%
1	$u(\hat{u}_V)$	Output voltage Measurement	u1 (S)	0.044	Normal (k = 2)	0.5	0.063	0.042	0.023	0.024	0.025	0.033
2	$u(\hat{u}_F)$	Voltage filtering effect on accelerometer output amplitude measurement (frequency band limitation)	u2 (S)	0.010	Rectangular	0.577	0.006	0.006	0.006	0.006	0.006	0.006
3	$u(\hat{u}_D)$	Effect of voltage disturbance on accelerometer output voltage 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	$u(\hat{u}_T)$	Effect of transverse, rocking and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	u4 (S)	0.200	Special	0.235702	0.009	0.009	0.009	0.009	0.141	0.189
4a	$u(S_Q)$	Calibration factor for Reference charge amplifier	u4a (S)	0.000	Normal (k = 2)	0.5	0.000	0.000	0.000	0.000	0.000	0.000
5	$u(\hat{\varphi}_{M,Q})$	measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	u5 (S)	0.050	Rectangular	0.577	0.029	0.029	0.029	0.029	0.029	0.029
6	$u(\hat{\varphi}_{M,F})$	Interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	u6 (S)	Included in 5								
7	$u(\hat{\varphi}_{M,VD})$	Effect of voltage disturbance on phase amplitude measurement (e.g. random noise in the photoelectric measuring chains)	u7 (S)	Included in 5								
8	$u(\hat{\varphi}_{M,MD})$	motion between the accelerometer reference surface and the spot sensed by the interferometer)	u8 (S)	0.100	Rectangular	0.236	0.024	0.024	0.024	0.024	0.024	0.024
9	$u(\hat{\varphi}_{M,PD})$	Effect of phase disturbance on phase amplitude measurement (e.g. phase noise of the interferometer signals)	u9 (S)	Included in 5								
10	$u(\hat{\varphi}_{M,RE})$	Residual interferometric effects on phase amplitude measurement (interferometer function)	u10 (S)	Included in 5								
11	$u(f_{FG})$	Vibration frequency measurement (frequency generator and indicator)	u11 (S)	0.0025	Rectangular	1.1547	0.003	0.003	0.003	0.003	0.003	0.003
12 a	$u(S_{RE})$	Residual effects on sensitivity measurement (e.g. random effect in repeat measurements: experimental standard deviation of arithmetic mean)	u12a (S)	0.089442719	Rectangular	0.57735	0.052	0.052	0.052	0.052	0.052	0.052
12 b	$u(S_{RE2})$	Effect on voltage -Influence from curve on APS air bearing bar caused by gravity	u12b (S)		Correlated	1	0.080	0.040	0.010	0.008	0.001	0.001
	$u_{rel}(S_2)$	**Uncertainty for accelerometer sensitivity S2**		**Standard uncertainty**		**(k = 1)**	**0.191**	**0.137**	**0.098**	**0.097**	**0.179**	**0.224**
		Uncertainty for accelerometer sensitivity S2		**95% conf. level uncertainty**		**(k = 2)**	**0.382**	**0.274**	**0.196**	**0.193**	**0.358**	**0.448**
		Uncertainty for accelerometer sensitivity S2			**Reported uncertainty**		**0.5**	**0.4**	**0.4**	**0.4**	**0.4**	**0.5**

Phase sensitivity

i	Numbering following ISO 16063-11 Table A.4	3629 Quadrature system with air-bearing shaker APS129 — Notes: Cal. Mode: Voltage; All values are 1 sigma values	Unc. Contribution	Expanded uncertainty or bounds of estimated components	Probability distribution model	Factor	Contribution u_i (y) > 0.1 Hz to 0.3 Hz	> 0.3 Hz to 5 Hz	> 5 Hz to 10 Hz	> 10 Hz to 25 Hz	> 25 Hz to 40 Hz
i	Quantity	Description		[degrees]		xi	[degrees]	[degrees]	[degrees]	[degrees]	[degrees]
1	$u(\varphi_{u,V})$	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
2	$u(\varphi_{u,F})$	Voltage filtering effect on accelerometer output phase measurement (frequency band limitation)	u2 (S)	Included in 1	Rectangular	0.577					
3	$u(\varphi_{u,D})$	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
4	$u(\varphi_{u,T})$	Effect of transverse, rocking and bending acceleration on accelerometer output voltage phase measurement (transverse sensitivity)	u4 (S)	0.060	Special	0.23570226	0.014	0.014	0.014	0.014	0.177
4a	$u(\varphi_{u,D})$	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
5	$u(\varphi_{s,Q})$	Effect of interferometer quadrature output signal disturbance on displacement phase amplitude	u5 (S)	0.010	Rectangular	0.577	0.006	0.006	0.006	0.006	0.006
6	$u(\varphi_{s,F})$	Interferometer signal filtering effect on displacement phase amplitude measurement (frequency band limitation)	u6 (S)	Included in 5							
7	$u(\varphi_{s,VD})$	amplitude measurement (e.g. random noise in the photoelectric measuring chains)	u7 (S)	Included in 5							
8	$u(\varphi_{s,MD})$	amplitude measurement (e.g. drift; relative motion between the accelerometer reference surface and the	u8 (S)	0.057	Rectangular	0.577	0.033	0.033	0.033	0.033	0.033
9	$u(\varphi_{s,PD})$	amplitude measurement (e.g. phase noise of the interferometer signals)	u9 (S)	Included in 5							
10	$u(\varphi_{s,RE})$	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
11	$u(\Delta\varphi_{RE})$	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
	$u(\Delta\varphi)$	sensitivity $\Delta\varphi$		Standard uncertainty		(k = 1)	0.134	0.134	0.125	0.125	0.216
		Uncertainty for accelerometer sensitivity $\Delta\varphi$		95% conf. level uncertainty		(k = 2)	0.269	0.269	0.249	0.249	0.432
		Uncertainty for accelerometer sensitivity $\Delta\varphi$		Reported uncertainty			0.3	0.3	0.3	0.3	0.5

5- GUM

Magnitude sensitivity

i	Source of uncertainty	Probability distribution	Uncertainty type	Divisor	Uncertainty contribution at frequencies			
					0,2 Hz ÷ 0,315 Hz	> 0,315 Hz ÷ 0,8 Hz	> 0,8 Hz ÷ 4 Hz	> 4 Hz ÷ 40 Hz
1	Accelerometer output voltage measurement	normal	B	2	0,03	0,03	0,03	0,03
2	Frequency of vibration signal	rectangular	B	1,732	0,001	0,001	0,001	0,001
3	Reference vibration velocity	normal	B	2	0,001	0,001	0,001	0,001
4	Magnitude of amplifier gain (G) in selected measuring channel	normal	B	2	0,02	0,02	0,02	0,02
5	Frequency response of G	normal	B	2	0,1	0,1	0,1	0,05
6	Transverse motion	rectangular	B	1,732	0	0	0,03	0,03
7	Harmonics	rectangular	B	1,732	0,01	0,01	0,01	0,01
8	Mains hum	rectangular	B	1,732	0,01	0,01	0,01	0,01
9	Noise	normal	B	1,732	0,001	0,001	0,001	0,001
10	Base strain	rectangular	B	1,732	0,001	0,001	0,001	0,001
11	Geometrical location of measurement	normal	B	1,732	0,005	0,005	0,005	0,005
12	Sensor mounting	rectangular	B	1,732	0,001	0,001	0,001	0,001
13	Cable layout	rectangular	B	1,732	0,025	0,015	0,01	0,01
14	Relative motion	rectangular	B	1,732	0,06	0,04	0,02	0,02
15	Temperature fluctuation	rectangular	B	1,732	0,0015	0,0015	0,0015	0,0015
16	Linearity deviations	rectangular	B	1,732	0,001	0,001	0,001	0,001
17	Instability of vibration signal	rectangular	B	1,732	0,001	0,001	0,001	0,001
18	Influence of magnetic fields	rectangular	B	1,732	0,1	0,1	0,05	0,05
19	Residual effects	rectangular	B	1,732	0,4	0,2	0,1	0,1
20	Standard deviation of arithmetic mean (rounded up)	normal	A	1	0,01	0,01	0,01	0,01
Total relative measurement uncertainty					0,4311	0,2519	0,1598	0,1343
Expanded measurement uncertainty (k = 2), rounded					0,9 %	0,5 %	0,4 %	0,3 %

Phase sensitivity

i	Source of uncertainty	Probability distribution	Uncertainty type	Divisor	Uncertainty contribution at frequencies		
					0,2 Hz ÷ 0,315 Hz	> 0,315 Hz ÷ 0,8 Hz	> 0,8 Hz ÷ 40 Hz
1	Accelerometer output voltage measurement	normal	B	2	0,05	0,05	0,05
2	Frequency of vibration signal	rectangular	B	1,732	0	0	0
3	Reference vibration velocity	normal	B	2	0,01	0,01	0,01
4	Magnitude of amplifier gain (G) in selected measuring channel	normal	B	2	0,01	0,01	0,01
5	Frequency response of G	normal	B	2	0,05	0,05	0,05
6	Transverse motion	rectangular	B	1,732	0	0	0,1
7	Harmonics	rectangular	B	1,732	0,01	0,01	0,01
8	Mains hum	rectangular	B	1,732	0,01	0,01	0,01
9	Noise	normal	B	1,732	0,01	0,01	0,01
10	Base strain	rectangular	B	1,732	0,01	0,01	0,01
11	Geometrical location of measurement	normal	B	1,732	0,001	0,001	0,001
12	Sensor mounting	rectangular	B	1,732	0,001	0,001	0,001
13	Cable layout	rectangular	B	1,732	0,02	0,01	0,01
14	Relative motion	rectangular	B	1,732	0,05	0,02	0,01
15	Temperature fluctuation	rectangular	B	1,732	0,01	0,01	0,01
16	Linearity deviations	rectangular	B	1,732	0,01	0,01	0,01
17	Instability of vibration signal	rectangular	B	1,732	0	0	0
18	Influence of magnetic fields	rectangular	B	1,732	0,1	0,1	0,05
19	Residual effects	rectangular	B	1,732	0,4	0,2	0,2
20	Standard deviation of arithmetic mean (rounded up)	normal	A	1	0,001	0,001	0,001
Total measurement uncertainty					0,4227 °	0,2373 °	0,2419 °
Expanded measurement uncertainty ($k = 2$), rounded					0,90 °	0,50 °	0,50 °

6- METAS

Magnitude sensitivity

Individual contributions to the measurement uncertainty (magnitude)										
Pos.	Contribution Xj	Distr.	Type	w (x_j)	Frequency / Hz					
					0,2 - < 1	1 - <2	2 - < 5	5 - < 10	10 - <20	20 - 63
1	Curvature of beam	Norm	B	w (S_S)	2.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Voltage measurement	Norm	B	w (U)	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04
3	Frequency	Rect	B	$w(w)$	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
4	Amplifier gain	Norm	B	w (G)	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04	2.00E-04
5	Amplifier frequency response	Norm	B	w (K_F)	1.00E-03	1.00E-03	1.00E-03	5.00E-04	5.00E-04	5.00E-04
6	Transverse motion	Rect	B	w (K_T)	7.00E-05	7.00E-05	7.00E-05	7.00E-05	7.00E-05	1.40E-04
7	Harmonic excitation	Rect	B	w (K_D)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Hum	Rect	B	w (K_H)	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
9	Noise	Norm	B	w (K_N)	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
10	Measuring position dependence	Rect	B	w (K_{GL})	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.50E-03	1.50E-03
11	Mounting of transducer	Rect	B	w (K_{MT})	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-05
12	Mounting of cable	Rect	B	w (K_{MC})	1.00E-03	1.00E-03	1.00E-03	1.00E-03	9.00E-04	7.00E-04
13	Relative motion	Rect	B	w (K_{REL})	5.00E-04	2.00E-04	1.00E-04	1.00E-04	1.00E-05	1.00E-05
14	Temperature stability	Rect	B	w (K_{TK})	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05	1.50E-05
15	Linearity	Rect	B	w (K_L)	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
16	Long term stability	Rect	B	w (K_I)	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
17	Residual contributions	Rect	B	w (K_{RES})	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
	Relative measurement uncertainty				1.57E-03	1.48E-03	1.47E-03	1.19E-03	1.86E-03	1.78E-03
	Expanded uncertainty (k=2)				3.14E-03	2.96E-03	2.94E-03	2.38E-03	3.72E-03	3.56E-03
	Expanded uncertainty (k=2)			%	0.31	0.30	0.29	0.24	0.37	0.36

Phase sensitivity

Pos.	Bestimmungs- / Einflussgröße	Distr.	Type	MU-Term	Frequency / Hz			
	Phi j			u (*Phi* $_j$)	0,2 - < 1	1 - <10	10 - <20	20 - 63
1	Curvature of beam	Norm	B	*u* (*Phi*$_S$)	1.00E-02	0.00E+00	0.00E+00	0.00E+00
2	Voltage measurement	Norm	B	*u* (*Phi*$_R$)	5.00E-02	5.00E-02	5.00E-02	5.00E-02
3	Frequency	Rect	B	*u* (*Phi*$_W$)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Amplifier gain	Norm	B	*u* (*Phi*$_G$)	1.00E-01	1.00E-01	1.00E-01	1.00E-01
5	Amplifier frequency response	Norm	B	*u* (*Phi*$_F$)	1.00E-01	1.00E-01	1.00E-01	1.00E-01
6	Transverse motion	Rect	B	*u* (*Phi*$_T$)	0.00E+00	0.00E+00	0.00E+00	7.00E-02
7	Harmonic excitation	Rect	B	*u* (*Phi*$_D$)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Hum	Rect	B	*u* (*Phi*$_H$)	1.00E-02	1.00E-02	1.00E-02	1.00E-02
9	Noise	Norm	B	*u* (*Phi*$_N$)	1.00E-02	1.00E-02	1.00E-02	1.00E-02
10	Measuring position dependence	Rect	B	*u* (*Phi*$_{GL}$)	1.00E-02	1.00E-02	1.00E-01	1.00E-01
11	Mounting of transducer	Rect	B	*u* (*Phi*$_{MT}$)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Mounting of cable	Rect	B	*u* (*Phi*$_{MC}$)	3.00E-01	1.40E-01	7.00E-02	5.00E-02
13	Relative motion	Rect	B	*u* (*Phi*$_{REL}$)	2.00E-01	1.00E-01	5.00E-02	5.00E-02
14	Temperature stability	Rect	B	*u* (*Phi*$_{TK}$)	1.00E-02	1.00E-02	1.00E-02	1.00E-02
15	Linearity	Rect	B	*u* (*Phi*$_L$)	1.00E-02	1.00E-02	1.00E-02	1.00E-02
16	Long term stability	Rect	B	*u* (*Phi*$_I$)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Residual contributions	Rect	B	*u* (*Phi*$_{RES}$)	1.00E-02	1.00E-02	1.00E-02	1.00E-02
	absolute measurement uncertainty				3.91E-01	2.30E-01	2.01E-01	2.07E-01
	Expanded uncertainty (k=2)				7.83E-01	4.59E-01	4.02E-01	4.14E-01
	Expanded uncertainty (k=2)			°	**0.78**	**0.46**	**0.40**	**0.41**

7- NMISA

Magnitude sensitivity

UNCERTAINTY BUDGET MATRIX (UBM)

Certificate No	AV\VS-3217	Procedure No	AV\VS-0001
Description:	Sensitivity calibration (modulus) as per ISO 16063-11 method 3	Make & model: / Serial number:	
Range:	0,1 Hz to < 0,4 Hz	Metrologist	Ian Veldman
Mathematical Model:	$S = \hat{u}/\hat{a} = \hat{u}/(2\pi f)^2 d$		

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Symbol	Input Quantity (Source of Uncertainty)	Estimated Uncertainty		Probability Distribution	k	Divisor factor	Standard Uncertainty	Sensitivity Coefficient		Standard Uncertainty Contribution $U_i(y)$	Reliability	Degrees of Freedom	Remarks
μ	▼ Standards and Reference Equipment (Uncorrelated) ▼	(X_i)	Unit	(N, R, T, U)	▼	▼	$U(X_i)$	C_i	Unit	%	%	ν	
φ_{Q}	Interferometer output signal disturbance on phase amplitude	0,01	%	Rectangular √3	2,00	1,73	5,77E-03	1	%	0,006	100	infinite	e.g. offsets, voltage amplitude deviations, <= 90° Corrected with Heydemann procedure
φ_{VD}	Effect of voltage disturbance on phase amplitude measurement	0,01	%	Rectangular √3	2,00	1,73	5,77E-03	0,01	%	0,000	100	infinite	Additive uncorrelated noise is reduced by 1/n. Where n=number of samples per vibration cycle. Worse case
φ_{MD}	Effect of motion disturbance on phase amplitude measurement	0,2	%	Rectangular √3	2,00	1,73	1,15E-01	1	%	0,115	100	infinite	relative motion between mounting fixture and accelerometer.
φ_{PD}	Effect of phase disturbance on phase amplitude measurement	0,01	%	Rectangular √3	2,00	1,73	5,77E-03	1	%	0,006	100	infinite	Corrected for using Heydemann correction procedure
φ_{RE}	Residual interferometric effects on phase amplitude measurement	0,01	%	Rectangular √3	2,00	1,73	5,77E-03	1	%	0,006	100	infinite	Not aware of any
f_{FG}	Vibration frequency measurement accuracy	0,05	%	Rectangular √3	2,00	1,73	2,89E-02	1	%	0,029	100	infinite	ISO 16063-11 requirement: ≤ 0,05 % of reading
λ_L	Uncertainty on laser wavelength measurement	2,50E-11	nm	Normal k = 2	2,00	2,00	1,25E-11	100	%	0,000	100	infinite	Uncertainty quoted on certificate
u_V	Accelerometer output voltage measurement (ADC resolution/accuracy)	0,15	%	Rectangular √3	2,00	1,73	8,66E-02	1	%	0,087	100	infinite	Manufacturer's specification worse case on 1 V range
S_F	Filtering effect on sensitivity measurement	0,11	%	Rectangular √3	2,00	1,73	6,35E-02	1	%	0,064	100	infinite	$a=(f/f_{sg})^2$
G_{CA}	Conditioning amplifier gain accuracy	0,00	%	Normal k = 2	2,00	2,00	0,00E+00	1	%	0,000	100	infinite	N/A Calibrated as a unit
	Resolution of Standard / Equipment (if applicable)										100		
	▼ Unit Under Test / Calibration (Uncorrelated) ▼						NOTE! ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED						
$\hat{u}_D$	Effect of voltage disturbance on accelerometer output voltage measurement	0,005	%	Triangular √6		1,73	2,887E-03	1	%	0,003	100	infinite	$U_{(rel)} = \frac{1}{2}(d/100)^2$; Maximum allowed by ISO 16063
$\hat{u}_T$	Effect of transverse motion on accelerometer output voltage measurement	0,1	%	Triangular √6		1,73	5,774E-02	1	%	0,058	100	infinite	Transverse error for a transverse sensitivity of 1%
$\hat{u}_{RE}$	Residual effects on accelerometer output voltage measurement	0,1	%	Normal k = 3		2,00	5,000E-02	1	%	0,050	100	infinite	Tribo-electric effect
$\hat{u}_s$	Standard deviation on accelerometer output voltage measurement	0,2	%	Normal k = 2,576		1,00	2,000E-01	1	%	0,200	100	infinite	ESDM for sensitivity calulation using 5 cycles minimum
$\hat{u}_{SNR}$	Signal to noise ratio	0,3	%			1,73	1,732E-01	1	%	0,173	100	infinite	Effect of signal to noise ration on SAM. The sensitivity coefficient is taken as 1 as the uncertainty is recorded
	Resolution of UUT / Equipment (if applicable)										100		
	Data - Type "B" Evaluation Range of the results (Rectangular)										100		
	Data - Type "A" Evaluation Exp Std Dev of the Mean (ESDM)			Normal k = 1								5	No of Readings 6
About UBM	TOTAL COMBINED UNCERTAINTY									%			

Best Measurement Capability (<u>Excluding</u> UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	0,161	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	0,322	k =	2,00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	0,319	V_{eff}	infinite	
	Expanded Uncertainty	95,45 % K = 2	0,6	k =	2,00	

UNCERTAINTY BUDGET MATRIX (UBM)											Certificate No		AV\VS-3217
											Procedure No		AV\VS-0001
Description:	Sensitivity calibration (modulus) as per ISO 16063-11 method 3	Make & model: / Serial number:						Range:	0,4 Hz to 50 Hz				Metrologist: Ian Veldman
	Mathematical Model:	$S=\hat{u}/\hat{a}=\hat{u}/(2\pi f)^2 d$											
Symbol	Input Quantity (Source of Uncertainty)	Estimated Uncertainty		Probability Distribution	k	Divisor factor	Standard Uncertainty	Sensitivity Coefficient		Standard Uncertainty Contribution $U_i(y)$	Reliability	Degrees of Freedom	Remarks
α	▼ Standards and Reference Equipment (Uncorrelated) ▼	(X)	Unit	(N, R, T, U)	▼	▼	u(X)	Ci	Unit	%	%	ν	
[illegible]	Interferometer output signal disturbance on phase amplitude	0,01	%	Rectangular √3	2,00	1,73	5,77E-03	1	%	0,006	100	infinite	e.g. offsets, voltage amplitude deviations, <> 90° Corrected with Heydemann procedure
[illegible]	Effect of voltage disturbance on phase amplitude measurement	0,01	%	Rectangular √3	2,00	1,73	5,77E-03	0,01	%	0,000	100	infinite	Additive uncorrelated noise is reduced by [illegible]
[illegible]	Effect of motion disturbance on phase amplitude measurement	0,1	%	Rectangular √3	2,00	1,73	5,77E-02	1	%	0,058	100	infinite	[illegible] accelerometer
[illegible]	Effect of phase disturbance on phase amplitude measurement	0,01	%	Rectangular √3	2,00	1,73	5,77E-03	1	%	0,006	100	infinite	Corrected for using Heydemann correction procedure
[illegible]	Residual interferometric effects on phase amplitude measurement	0,01	%	Rectangular √3	2,00	1,73	5,77E-03	1	%	0,006	100	infinite	Not aware of any
[illegible]	Vibration frequency measurement accuracy	0,05	%	Rectangular √3	2,00	1,73	2,89E-02	1	%	0,029	100	infinite	ISO 16063-11 requirement ≤ 0,05 % of reading
[illegible]	Uncertainty on laser wavelength measurement	2,50E-11	nm	Normal k = 2	2,00	2,00	1,25E-11	100	%	0,000	100	infinite	Uncertainty quoted on certificate
[illegible]	Accelerometer output voltage measurement (ADC resolution/accuracy)	0,15	%	Rectangular √3	2,00	1,73	8,66E-02	1	%	0,087	100	infinite	Manufacturer's specification worse case on 1 V range
[illegible]	Filtering effect on sensitivity measurement	0,11	%	Rectangular √3	2,00	1,73	6,35E-02	1	%	0,064	100	infinite	$a=(f/f_g)^7$
[illegible]	Conditioning amplifier gain accuracy	0,00	%	Normal k = 2	2,00	2,00	0,00E+00	1	%	0,000	100	infinite	N/A Calibrated as a unit
	Resolution of Standard / Equipment (If applicable)										100		
	▼ Unit Under Test / Calibration (Uncorrelated) ▼				NOTE! ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED								
[illegible]	Effect of voltage disturbance on accelerometer output voltage measurement	0,005	%	Triangular √6		1,73	2,887E-03	1	%	0,003	100	infinite	U_{THD} = ½(d/100)²; Maximum allowed by ISO 16063
[illegible]	Effect of transverse motion on accelerometer output voltage measurement	0,1	%	Triangular √6		1,73	5,774E-02	1	%	0,058	100	infinite	Transverse error for a transverse sensitivity of 1%
[illegible]	Residual effects on accelerometer output voltage measurement	0,1	%	Normal k = 3		2,00	5,000E-02	1	%	0,050	100	infinite	Tribo-electric effect
[illegible]	Standard deviation on accelerometer output voltage measurement	0,1	%	Normal k = 3		2,00	5,000E-02	1	%	0,050	100	infinite	ESDM for sensitivity calculation using 5 cycles minimum
	Resolution of UUT / Equipment (If applicable)										100		
	Data - Type "B" Evaluation Range of the results (Rectangular)										100		
	#REF!			Normal k = 1								9	No of Readings 10
[illegible]	TOTAL COMBINED UNCERTAINTY									%			
	Best Measurement Capability (Excluding UUT contribution)			Combined Uncertainty (Normal)			▼ Level of Confidence ▼			0,126	V_{eff}	infinite	Checked and Approved By:
				Expanded Uncertainty			95,45 %	K = 2		0,252	k =	2,00	
	Uncertainty of Measurement (Including UUT contribution)			Combined Uncertainty (Normal)			▼ Level of Confidence ▼			0,155	V_{eff}	infinite	
				Expanded Uncertainty			95,45 %	K = 2		0,3	k =	2,00	

Phase sensitivity

UNCERTAINTY BUDGET MATRIX (UBM)

Procedure No	AV\VS-0001		
Description:	Phase shift calibration as per ISO 16063-11 method 3	Make & model: / Serial number:	
Range:	0,1 Hz to < 0,4 Hz	Metrologist	Ian Veldman
Mathematical Model:	$S_{Phase}=UUT_{Phase}-Ref_{Phase}-Ref_{Delay}-AtoD_{Phase}-DSP_{Delay}$		

Symbol	Input Quantity (Source of Uncertainty)	Estimated Uncertainty		Probability Distribution	k	Divisor factor	Standard Uncertainty	Sensitivity Coefficient		Standard Uncertainty Contribution $U_i(y)$	Reliability	Degrees of Freedom	Remarks
u	▼ Standards and Reference Equipment (Uncorrelated) ▼	(xi)	Unit	(N, R, T, U)	▼	▼	U(xi)	Ci	Unit	(°)	%	ν	
$\varphi_{x,D}$	Interferometer output signal disturbance on displacement phase measurement	0,1	Degree	Rectangular √3	2,00	1,73	5,77E-02	1	Degree	0,058	100	infinite	[illegible] Corrected with Heydemann procedure
$\varphi_{x,VD}$	Effect of voltage disturbance on displacement phase measurement	0,05	Degree	Rectangular √3	2,00	1,73	2,89E-02	1	Degree	0,029	100	infinite	[illegible]
$\varphi_{x,MD}$	Effect of motion disturbance on displacement phase measurement	0,05	Degree	Rectangular √3	2,00	1,73	2,89E-02	1	Degree	0,029	100	infinite	Relative motion between sensing spot, exiter and accelerometer. Worse case calculated for 16mm double ended accelerometer.
$\varphi_{x,PD}$	Effect of phase disturbance on displacement phase measurement	0,1	Degree	Rectangular √3	2,00	1,73	5,77E-02	1	Degree	0,058	100	infinite	Corrected for using Heydemann correction procedure
$\varphi_{x,RE}$	Residual interferometric effects on displacement phase measurement	0,02	Degree	Rectangular √3	2,00	1,73	1,15E-02	1	Degree	0,012	100	infinite	Not aware of any
$\Sigma\varphi_{E}$	Environmental effects on phase shift measurement	0,03	Degree	Rectangular √3	2,00	1,73	1,73E-02	1	Degree	0,017	100	infinite	ISO 16063-11 requirement: ≤ 0,05 % of reading
$\varphi_{u,V}$	Accelerometer output phase measurement (ADC resolution/accuracy)	0,2	Degree	Normal k = 2	2,00	2,00	1,00E-01	1	Degree	0,100	100	infinite	SAM phase calculation accuracy
$\varphi_{u,F}$	Filtering effect on accelerometer output phase measurement	0	Degree	Rectangular √3	2,00	1,73	0,00E+00	1	Degree	0,000	100	infinite	$=(f/f_{c})^{2}$
$\varphi_{C,A}$	Charge amplifier phase accuracy	0,00	Degree	Normal k = 2	2,00	2,00	0,00E+00	1	Degree	0,000	100	infinite	
	Resolution of Standard / Equipment (If applicable)										100		
	▼ Unit Under Test / Calibration (Uncorrelated) ▼							NOTE! ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					
$\varphi_{x,D}$	Effect of voltage disturbance on accelerometer output phase measurement	0,1	Degree	Triangular √6		1,73	5,774E-02	1	Degree	0,058	100	infinite	U_{THD} = ½(d/100)²; Maximum allowed by ISO 16063
$\varphi_{x,T}$	Effect of transverse motion on accelerometer output phase measurement	0,05	Degree	Triangular √6		1,73	2,887E-02	1	Degree	0,029	100	infinite	Transeverse error for a transverse sensitivity of 1%
φ_{ESDM}	Standard deviation on accelerometer phase shift measurement	0,05	Degree	Normal k = 3		2,00	2,500E-02	1	Degree	0,025	100	infinite	ESDM for sensitivity caluation using 5 cycles minimum
				Normal k = 2									
	Resolution of UUT / Equipment (If applicable)										100		
	Data - Type "B" Evaluation Range of the results (Rectangular)										100		
	Data - Type "A" Evaluation Exp Std Deviation "s"			Normal k = 1								4	No of Readings 5
About UBM	TOTAL COMBINED UNCERTAINTY									(°)			

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	0,137	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	0,274	k =	2,00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	0,153	V_{eff}	infinite	
	Expanded Uncertainty	95,45 % K = 2	0,3	k =	2,00	

UNCERTAINTY BUDGET MATRIX (UBM)

Certificate No	AV\VS-3271
Procedure No	AV\VS-0001

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Phase shift calibration as per ISO 16063-11 method 3	Make & model: / Serial number:		Range:	0,4 Hz to 50 Hz	Metrologist: Ian Veldman

Mathematical Model: $S_{Phase} = UUT_{Phase} - Ref_{Phase} - Ref_{Delay} - AtoD_{Phase} - DSP_{Delay}$

Symbol	Input Quantity (Source of Uncertainty)	Estimated Uncertainty		Probability Distribution	*k*	Divisor factor	Standard Uncertainty	Sensitivity Coefficient		Standard Uncertainty Contribution $U_i(y)$	Reliability	Degrees of Freedom	Remarks
u	▼ Standards and Reference Equipment (Uncorrelated) ▼	(X_i)	Unit	(N, R, T, U)	▼	▼	$U(X_i)$	C_i	Unit	(°)	%	ν	
[illegible]	Interferometer output signal disturbance on displacement phase measurement	0,1	Degree	Rectangular √3	2,00	1,73	5,77E-02	1	Degree	0,058	100	infinite	e.g. effects, voltage amplitude deviations [illegible] Corrected with Heydemann procedure
[illegible]	Effect of voltage disturbance on displacement phase measurement	0,05	Degree	Rectangular √3	2,00	1,73	2,89E-02	1	Degree	0,029	100	infinite	Additive uncorrelated noise is reduced by [illegible] [illegible]
[illegible]	Effect of motion disturbance on displacement phase measurement	0,05	Degree	Rectangular √3	2,00	1,73	2,89E-02	1	Degree	0,029	100	infinite	Relative motion between sensing spot, exciter and accelerometer. Worst case calculated for [illegible] double ended accelerometer
[illegible]	Effect of phase disturbance on displacement phase measurement	0,05	Degree	Rectangular √3	2,00	1,73	2,89E-02	1	Degree	0,029	100	infinite	Corrected for using Heydemann correction procedure
[illegible]	Residual interferometric effects on displacement phase measurement	0,02	Degree	Rectangular √3	2,00	1,73	1,15E-02	1	Degree	0,012	100	infinite	Not aware of any
[illegible]	Environmental effects on phase shift measurement	0,03	Degree	Rectangular √3	2,00	1,73	1,73E-02	1	Degree	0,017	100	infinite	ISO 16063-11 requirement: ≤ 0,05 % of reading
[illegible]	Accelerometer output phase measurement (ADC resolution/accuracy)	0,1	Degree	Normal k = 2	2,00	2,00	5,00E-02	1	Degree	0,050	100	infinite	SAM phase calculation accuracy
[illegible]	Filtering effect on accelerometer output phase measurement	0	Degree	Rectangular √3	2,00	1,73	0,00E+00	1	Degree	0,000	100	infinite	No filters applied
[illegible]	Charge amplifier phase accuracy	0,00	Degree	Normal k = 2	2,00	2,00	0,00E+00	1	Degree	0,000	100	infinite	Calibrated
	Resolution of Standard / Equipment (If applicable)										100		
	▼ Unit Under Test / Calibration (Uncorrelated) ▼						NOTE!	ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					
[illegible]	Effect of voltage disturbance on accelerometer output phase measurement	0,1	Degree	Triangular √6		1,73	5,774E-02	1	Degree	0,058	100	infinite	U_{THD} = ½(d/100)²; Maximum allowed by ISO 16063
[illegible]	Effect of transverse motion on accelerometer output phase measurement	0,05	Degree	Triangular √6		1,73	2,887E-02	1	Degree	0,029	100	infinite	Transverse error for a transverse sensitivity of 1%
[illegible]	Standard deviation on accelerometer phase shift measurement	0,05	Degree	Normal k = 3		2,00	2,500E-02	1	Degree	0,025	100	infinite	ESDM for sensitivity calulation using 5 cycles minimum
				Normal k = 2									
	Resolution of UUT / Equipment (If applicable)										100		
	Data - Type "B" Evaluation. Range of the results (Rectangular)										100		
	Data - Type "A" Evaluation Exp Std Deviation "s"			Normal k = 1								4	No of Readings: 5
About UBM	TOTAL COMBINED UNCERTAINTY									(°)			

Best Measurement Capability (<u>Excluding</u> UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼		0,094	V_{eff}	infinite
	Expanded Uncertainty	95,45 %	K = 2	0,187	*k* =	2,00
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼		0,116	V_{eff}	infinite
	Expanded Uncertainty	95,45 %	K = 2	0,2	*k* =	2,00

Checked and Approved By:

8- INMETRO

Magnitude sensitivity

Uncertainty budget - Absolute Interferometric calibration of an acceleration measuring set
ISO 16063-11:1999 - Table A.3 & A.5

s/M% 0,060
(s/M%)/√N 0,024

VOLTAGE SENSITIVITY - MAGNITUDE

ACCELERATION MEASURING SET = SERVO-ACCELEROMETER + SIGNAL CONDITIONER

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor χ_i	Relative expanded uncertainty or bounds of estimated error components (%) frequency (Hz) 0,2 to 40
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	calibrations of DAQ	rectangular	0,58	0,05
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	rectangular	0,58	0,02
3	$u(\hat{u}_D)$	effect of voltage disturbance on accelerometer output voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	1	0,05
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	rectangular	0,58	0,03
5	$u(\Phi_{M,Q})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in i = 3	rectangular	0,58	0,02
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	rectangular	0,58	0,02
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	rectangular	0,58	0,03
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	rectangular	0,58	0,05
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	rectangular	0,58	0,05
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,05
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,5	0,0001
12	$u(S_{RE})$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,06
13	$u(\lambda\,\mathrm{cal})$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,0002
14	$u(\lambda_E)$	environmental effects on laser wavelength . Estimated to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %)	Estimated to be less than (Temp range from 21 to 25 degrees)	rectangular	0,58	0,0007
15	$u(A\ \mathrm{cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05
16	$u(e_{T,A})$	reference amplifiers tracking (deviations in gain for different amplification settings)	Not applicable. Amplifier used at a fixed gain setting			0,00
17	$u(e_{L,f,A})$	deviation from constant amplitude-frequency characteristic of reference amplifier	Not applicable. Amplifier calibrated at all frequencies			0,00
18	$u(e_{L,f,P})$	deviation from constant amplitude-frequency characteristic of reference accelerometer	Not applicable. Results reported with the input acceleration			0,00
19	$u(e_{L,a,A})$	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude range up to 100 m/s²)	rectangular	0,58	0,02
20	$u(e_{L,a,P})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s²)	rectangular	0,58	0,02
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	rectangular	0,58	0,03
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	rectangular	0,58	0,02
23	$u(e_{E,A})$	environmental effects on gain of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	rectangular	0,58	0,06
24	$u(e_{E,P})$	environmental effects on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0,02%/°C)	rectangular	0,58	0,02
25	$u(S_{SF})$	safety factor (reproducibility)	Estimated to be less than	rectangular	0,58	0,10

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor χ_i	frequency (Hz) 0,2 to 40
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	calibrations of DAQ	rectangular	0,58	0,03
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	rectangular	0,58	0,01
3	$u(\hat{u}_D)$	effect of voltage disturbance on accelerometer output voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	1	0,05
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	rectangular	0,58	0,02
5	$u(\Phi_{M,Q})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in i = 3	rectangular	0,58	0,01
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	rectangular	0,58	0,01
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	rectangular	0,58	0,02
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	rectangular	0,58	0,03
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	rectangular	0,58	0,03
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,02
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,5	0,00
12	$u(S_{RE})$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,02
13	$u(\lambda\ \mathrm{cal})$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,0001
14	$u(\lambda_E)$	environmental effects on laser wavelength . Estimated to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %)	Estimated to be less than (Temp range from 21 to 25 degrees)	rectangular	0,58	0,0004
15	$u(A\ \mathrm{cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,03
16	$u(e_{T,A})$	reference amplifiers tracking (deviations in gain for different amplification settings)	Not applicable. Amplifier used at a fixed gain setting			0,00
17	$u(e_{L,f,A})$	deviation from constant amplitude-frequency characteristic of reference amplifier	Not applicable. Amplifier calibrated at all frequencies			0,00
18	$u(e_{L,f,P})$	deviation from constant amplitude-frequency characteristic of reference accelerometer	Not applicable. Results reported with the input acceleration			0,00
19	$u(e_{L,a,A})$	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude range up to 100 m/s²)	rectangular	0,58	0,01
20	$u(e_{L,a,P})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s²)	rectangular	0,58	0,01
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	rectangular	0,58	0,02
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	rectangular	0,58	0,01
23	$u(e_{E,A})$	environmental effects on gain of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	rectangular	0,58	0,03
24	$u(e_{E,P})$	environmental effects on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	rectangular	0,58	0,01
25	$u(S_{SF})$	safety factor (reproducibility)	Estimated to be less than	rectangular	0,58	0,06

$u_c(S_2)/S_2$ %	Estimated relative combined standard uncertainty (%) for accelerometer sensitivity (k=1)	0,11
$U(S_2)/S_2$ %	Estimated relative expanded uncertainty (%) for accelerometer sensitivity (k=2)	0,23

	frequency (Hz) 0,2 to 40
Reported relative expanded Uncertainty for accelerometer sensitivity magnitude (k=2)	0,25

Phase sensitivity

Uncertainty budget - Absolute Interferometric calibration of an acceleration measuring set

s	0,005
s/√N	0,002

VOLTAGE SENSITIVITY - PHASE SHIFT

ACCELERATION MEASURING SET = SERVO-ACCELEROMETER + SIGNAL CONDITIONER

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	Expanded uncertainty or bounds of estimated error components (°) frequency (Hz) 0,2 to 40 Hz
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	calibrations of DAQ	normal (k=1)	1	0,05
2	$u(\Phi_{u,F})$	voltage filtering effect on accelerometer output phase measurement	No analog filtering applied. Special digital filter has negligible effect.	rectangular	0,58	0,02
3	$u(\Phi_{u,D})$	effect of voltage disturbance on output phase measurement (e.g hum and noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	1	0,05
4	$u(\Phi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	rectangular	0,58	0,05
5	$u(\Phi_{S,Q})$	effect of interferometer quadrature output signal disturbance on displacement phase measurement (e.g. offsets, voltage amplitude deviation, deviation from 90 degrees nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in i = 3	rectangular	0,58	0,02
6	$u(\Phi_{S,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	rectangular	0,58	0,02
7	$u(\Phi_{S,VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	rectangular	0,58	0,03
8	$u(\Phi_{S,MD})$	effect of motion disturbance on displacement phase measurement (e.g. drift; relative motion between accelerometer reference surface and the spot sensed by the interferometer)	Estimated to be less than	rectangular	0,58	0,05
9	$u(\Phi_{S,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	Estimated to be less than	rectangular	0,58	0,05
10	$u(\Phi_{S,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,05
11	$u(\Delta\Phi_{RE})$	residual effects on phase shift measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,002
12	$u(\Delta\Phi_{A,cal})$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05
13	$u(e_{T,A})$	reference amplifier tracking (deviations in phase for different amplification settings)	Not applicable. A single calibrated setting is used.	rectangular	0,58	0,0002
14	$u(e_{T,f,A})$	deviations from linear phase-frequency characteristic of reference amplifier	Not applicable. A single calibrated setting is used.	rectangular	0,58	0,0007
15	$u(\lambda\ cal)$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,5	0,05
16	$u(e_{1,a,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	rectangular	0,58	0,02
17	$u(e_{1,a,P})$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s²)	rectangular	0,58	0,02
18	$u(e_{1,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	rectangular	0,58	0,03
19	$u(e_{1,P})$	instability of reference accelerometer phase shift	Estimated to be less than	rectangular	0,58	0,02
20	$u(e_{E,A})$	environmental effects on phase shift of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	rectangular	0,58	0,06
21	$u(e_{E,P})$	environmental effects on phase shift of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	rectangular	0,58	0,02
22	$u(\Delta\Phi_{SF})$	safety factor (reproducibility)	Estimated to be less than	rectangular	0,58	0,10

VOLTAGE SENSITIVITY - PHASE SHIFT

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor χ_i	Uncertainty contribution $u_{rel,i}(y)$ (°) frequency (Hz) 0,2 to 40 Hz
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	calibrations of DAQ	normal (k=1)	1	0,05
2	$u(\Phi_{u,F})$	voltage filtering effect on accelerometer output phase measurement	No analog filtering applied. Special digital filter has negligible effect.	rectangular	0,58	0,01
3	$u(\Phi_{u,D})$	effect of voltage disturbance on output phase measurement (e.g hum and noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	1	0,05
4	$u(\Phi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	rectangular	0,58	0,03
5	$u(\Phi_{s,Q})$	effect of interferometer quadrature output signal disturbance on displacement phase measurement (e.g. offsets, voltage amplitude deviation, deviation from 90 degrees nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in i = 3	rectangular	0,58	0,01
6	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	rectangular	0,58	0,01
7	$u(\Phi_{s,VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	rectangular	0,58	0,02
8	$u(\Phi_{s,MD})$	effect of motion disturbance on displacement phase measurement (e.g. drift; relative motion between accelerometer reference surface and the spot sensed by the interferometer)	Estimated to be less than	rectangular	0,58	0,03
9	$u(\Phi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	Estimated to be less than	rectangular	0,58	0,03
10	$u(\Phi_{s,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,02
11	$u(\Delta\Phi_{RE})$	residual effects on phase shift measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,00
12	$u(\Delta\Phi_{A,cal})$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,03
13	$u(e_{T,A})$	reference amplifier tracking (deviations in phase for different amplification settings)	Not applicable. A single calibrated setting is used.	rectangular	0,58	0,00
14	$u(e_{T,f,A})$	deviations from linear phase-frequency characteristic of reference amplifier	Not applicable. A single calibrated setting is used.	rectangular	0,58	0,00
15	$u(\lambda\ \mathrm{cal})$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,5	0,03
16	$u(e_{L,e,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	rectangular	0,58	0,01
17	$u(e_{L,a,P})$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s²)	rectangular	0,58	0,01
18	$u(e_{I,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	rectangular	0,58	0,02
19	$u(e_{I,P})$	instability of reference accelerometer phase shift	Estimated to be less than	rectangular	0,58	0,01
20	$u(e_{E,A})$	environmental effects on phase shift of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	rectangular	0,58	0,04
21	$u(e_{E,P})$	environmental effects on phase shift of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	rectangular	0,58	0,01
22	$u(\Delta\Phi_{SF})$	safety factor (reproducibility)	Estimated to be less than	rectangular	0,58	0,06

$u_c(\Delta\Phi)$	Estimated combined standard uncertainty (°) for accelerometer phase shift (k=1)	0,12
$U(\Delta\Phi)$	Estimated expanded uncertainty (°) for accelerometer phase shift (k=2)	0,25

	frequency (Hz) 0,2 to 40
Reported expanded uncertainty (°) for accelerometer phase shift (k=2)	0,25

9- CENAM

Magnitude sensitivity

Magnitude Sensitivity (0.1 Hz to <0.2 Hz)

No.	Description	Distribution	Percent (%)
1	Accelerometer output voltage measurement	normal	1.60E-03
2	harmonic distortion (e.g. 1st and 3rd harmonics)	rectangular	1.33E-03
3	Residual interferometric effects on displacement measurement (e.g. temporal coherence of laser, lack of linear response of photodiodes)	normal	9.41E-04
4	Deviations from straight motion (e.g. due to air bearing, rocking motion, transverse motion)	normal	9.96E-04
5	filtering effect on displacement measurement (frequency band limitation)	rectangular	9.96E-04
6	effect of laser wavelenght drift (e.g. length of coherence)	rectangular	9.41E-04
7	amplifier gain calibration (e.g. offset, mains supply, stability of gain amplification)	rectangular	9.41E-04
8	vibration frequency measurement (e.g. frequency generator and counter)	normal	1.11E-03
9	Effect of displacement quantization on displacement measurement	rectangular	1.16E-03
10	Residual effects on sensitivity measurement	rectangular	9.96E-04
	Relative standard uncertainty (k=1)		0.35%
	Relative expanded uncertainty (k=2)		0.7%

Magnitude Sensitivity (0.2 Hz to <0.5 Hz)

No.	Description	Distribution	Percent (%)
1	Accelerometer output voltage measurement	normal	1.15E-03
2	harmonic distortion (e.g. 1st and 3rd harmonics)	rectangular	9.49E-04
3	Residual interferometric effects on displacement measurement (e.g. temporal coherence of laser, lack of linear response of photodiodes)	normal	6.72E-04
4	Deviations from straight motion (e.g. due to air bearing, rocking motion, transverse motion)	normal	7.12E-04
5	filtering effect on displacement measurement (frequency band limitation)	rectangular	7.12E-04
6	effect of laser wavelenght drift (e.g. length of coherence)	rectangular	6.72E-04
7	amplifier gain calibration (e.g. offset, mains supply, stability of gain amplification)	rectangular	6.72E-04
8	vibration frequency measurement (e.g. frequency generator and counter)	normal	7.91E-04
9	Effect of displacement quantization on displacement measurement	rectangular	8.30E-04
10	Residual effects on sensitivity measurement	rectangular	7.12E-04
	Relative standard uncertainty (k=1)		0.25%
	Relative expanded uncertainty (k=2)		0.5%

Magnitude Sensitivity (0.5 Hz to 40 Hz)

No.	Description	Distribution	Percent (%)
1	Accelerometer output voltage measurement	normal	6.88E-04
2	harmonic distortion (e.g. 1st and 3rd harmonics)	rectangular	5.69E-04
3	Residual interferometric effects on displacement measurement (e.g. temporal coherence of laser, lack of linear response of photodiodes)	normal	4.03E-04
4	Deviations from straight motion (e.g. due to air bearing, rocking motion, transverse motion)	normal	4.27E-04
5	filtering effect on displacement measurement (frequency band limitation)	rectangular	4.27E-04
6	effect of laser wavelenght drift (e.g. length of coherence)	rectangular	4.03E-04
7	amplifier gain calibration (e.g. offset, mains supply, stability of gain amplification)	rectangular	4.03E-04
8	vibration frequency measurement (e.g. frequency generator and counter)	normal	4.74E-04
9	Effect of displacement quantization on displacement measurement	rectangular	4.98E-04
10	Residual effects on sensitivity measurement	rectangular	4.27E-04
	Relative standard uncertainty (k=1)		0.15%
	Relative expanded uncertainty (k=2)		0.3%

Phase sensitivity

Phase Sensitivity (0.1 Hz to <0.25 Hz)

No.	Description	Distribution	Degrees (°)
1	Accelerometer output voltage measurement	normal	4.43E-02
2	harmonic distortion (e.g. 1st and 3rd harmonics)	rectangular	3.64E-02
3	Residual interferometric effects on displacement measurement (e.g. temporal coherence of laser, lack of linear response of photodiodes)	normal	2.72E-02
4	Deviations from straight motion (e.g. due to air bearing, rocking motion, transverse motion)	normal	2.85E-02
5	filtering effect on displacement measurement (frequency band limitation)	rectangular	2.85E-02
6	effect of laser wavelenght drift (e.g. length of coherence)	rectangular	2.69E-02
7	amplifier gain calibration (e.g. offset, mains supply, stability of gain amplification)	rectangular	2.69E-02
8	vibration frequency measurement (e.g. frequency generator and counter)	normal	3.16E-02
9	Effect of displacement quantization on displacement measurement	rectangular	3.32E-02
10	Residual effects on sensitivity measurement	rectangular	2.85E-02
	Relative standard uncertainty (k=1)		0.1°
	Relative expanded uncertainty (k=2)		0.2°

Phase Sensitivity (0.25 Hz to 40 Hz)

No.	Description	Distribution	Degrees (°)
1	Accelerometer output voltage measurement	normal	1.11E-01
2	harmonic distortion (e.g. 1st and 3rd harmonics)	rectangular	9.09E-02
3	Residual interferometric effects on displacement measurement (e.g. temporal coherence of laser, lack of linear response of photodiodes)	normal	6.80E-02
4	Deviations from straight motion (e.g. due to air bearing, rocking motion, transverse motion)	normal	7.12E-02
5	filtering effect on displacement measurement (frequency band limitation)	rectangular	7.12E-02
6	effect of laser wavelenght drift (e.g. length of coherence)	rectangular	6.72E-02
7	amplifier gain calibration (e.g. offset, mains supply, stability of gain amplification)	rectangular	6.72E-02
8	vibration frequency measurement (e.g. frequency generator and counter)	normal	7.91E-02
9	Effect of displacement quantization on displacement measurement	rectangular	8.30E-02
10	Residual effects on sensitivity measurement	rectangular	7.12E-02
	Relative standard uncertainty (k=1)		0.25°
	Relative expanded uncertainty (k=2)		0.5°

10- NMIA

Magnitude sensitivity

Source of Uncertainty	Symbol	U or semi-range (maximum)	Probability distribution model	k factor	Sensitivity coefficient	Relative contribution, u_i	dof
		%				%	
Accelerometer output voltage measurement (voltmeter)	u_1	0.086	normal	2.00	1	0.0432	30
Voltage filtering effect on accelerometer output amplitude measurement	u_2	0.000	rectangular	1.73	1	0.0000	10
Effect of voltage disturbance on accelerometer output voltage measurement	u_3	0.010	rectangular	1.73	1	0.0059	10
Effect of transverse, rocking and bending acceleration on accelerometer output voltage measurement	u_4	0.050	rectangular	1.73	1	0.0291	30
Effect of interferometer quadrature output signal disturbance on phase amplitude measurements	u_5	0.030	normal	2.00	1	0.0150	10
Interferometer signal filtering effect on phase amplitude measurement	u_6	0.000	rectangular	1.73	1	0.0000	30
Effect of voltage disturbance on phase amplitude measurement	u_7	0.010	rectangular	1.73	1	0.0058	30
Effect of motion disturbance on phase amplitude measurements (e.g. total distortion, relative motion between accelerometer reference surface and spot sensed by interferometer)	u_8	0.030	rectangular	1.73	1	0.0170	10
Effect of phase disturbance on phase amplitude measurement (e.g. phase noise of interferometer signal)	u_9	0.000	rectangular	1.73	1	0.0000	30
Interferometer effects on phase amplitude measurements	u_{10}	0.004	rectangular	1.73	1	0.0022	30
Vibration frequency measurement (frequency generator & indicator counter)	u_{11}	0.001	rectangular	1.73	1	0.0006	30
Residual effects on sensitivity measurements e.g. random effect in repeat measurements, ESDM.	u_{12}	0.1	normal	2.00	1	0.0500	26
Effect of shaker modes	u_{13}	0.000	rectangular	1.73	1	0.0000	10
Rounding error	u_{14}	0.005	rectangular	1.73	1	0.0029	100
Combined uncertainty squared, u_c^2						0.0058	
Combined uncertainty, u_c						0.0762	
Effective degrees of freedom						86	
Coverage or k factor						1.99	
Expanded uncertainty, U_e						0.152	
Stated expanded uncertainty (%) (round up of U_e)						**0.2**	

Phase sensitivity

Source of Uncertainty	Symbol	U or semi-range (maximum)	Probability distribution model	k factor	Sensitivity coefficient	Relative contribution	dof
		deg.				deg.	
Digitiser voltage resolution	$u_{1.1}$	0.05400	rectangular	1.73	1	0.031	30
Digitiser Phase Resolution	$u_{1.2}$	0.14400	rectangular	1.73	1	0.083	30
Digitiser pre-trigger resolution	$u_{1.3}$	0.00144	rectangular	1.73	1	0.001	30
Uncertainty associated with pre-digitisation phase delay (homodyne interferometer)	$u_{1.4}$	0.00043	rectangular	1.73	1	0.000	30
Voltage filtering effect on accelerometer output phase measurement	u_2	0.00000	rectangular	1.73	1	0.000	10
Effect of voltage disturbance on accelerometer output phase measurement	u_3	0.03440	normal	2.00	1	0.017	10
Effect of transverse, rocking, and bending acceleration on accelerometer output phase measurement	u_4	0.02950	rectangular	1.73	1	0.017	30
Effect of interferometer quadrature output signal disturbance on displacement phase measurement	$u_{5.1}$	0.01660	rectangular	1.73	1	0.010	10
FFT Tone detect residual uncertainty	$u_{5.2}$	0.00570	rectangular	1.73	1	0.003	10
Interferometer signal filtering effect on displacement phase measurement	u_6	0.00000	rectangular	1.73	1	0.000	30
Effect on voltage disturbance on displacement phase measurement	u_7	0.00570	rectangular	1.73	1	0.003	30
Effect of motion disturbance on displacement phase measurement	u_8	0.00017	rectangular	1.73	1	0.000	10
Effect of phase disturbance on displacement phase measurements	u_9	0.00001	rectangular	1.73	1	0.000	30
Residual interferometric effects on displacement phase measurement	u_{10}	0.00220	rectangular	1.73	1	0.001	30
Residual effects on phase shift measurements -Typical expected TYPE A repeat uncertainty	u_{11}	0.10000	normal	2.00	1	0.050	5
Rounding error	u_{12}	0.05000	rectangular	1.73	1	0.029	30
uncertainty squared, u_c^2 (deg.^{2})						0.0119	
uncertainty, u_c (deg.)						0.109	
Effective degrees of freedom						48.8	
Coverage or k factor						2.01	
Expanded uncertainty (deg.), U_c						0.22	
Stated expanded uncertainty (deg.) (round up of U_c)						**0.3**	

11- NMIJ

Magnitude sensitivity

Uncertainty component		Comment		Type	0.1 Hz - 25 Hz	> 25 Hz in %	Distribution	Factor	0.1 Hz - 25 Hz	> 25 Hz in %
Interferometer	Laser Wavelength	CIPM recommendation value	u1	B	1.5E-04	1.5E-04	Normal	1.00	1.5E-04	1.5E-04
	Relative Motion of Interferometer	Measured with monitoring accelerometer attached to the interferometer	u2	B	3.3E-02	5.5E-02	Normal	1.00	3.3E-02	5.5E-02
	Cosine Error	Maximum 0.1°	u3	B	8.7E-05	8.7E-05	Rectangular	0.58	5.0E-05	5.0E-05
Accelerometer	Digitizer correction coefficient	Estimated from 10 calibration results	u4	A	4.9E-04	4.9E-04	Normal	1.00	4.9E-04	4.9E-04
	Calibration of voltage standard	From calibration certificate	u5	B	6.1E-03	6.1E-03	Normal	1.00	6.1E-03	6.1E-03
	Transverse, rocking motion	1 % transverse sensitivity	u6	B	7.1E-04	5.6E-03	Normal	1.00	7.1E-04	5.6E-03
Other effects	Temperature fluctuation	0.02%/°C tempreture coefficient, ± 0.5°C	u7	B	1.0E-02	1.0E-02	Normal	1.00	1.0E-02	1.0E-02
	Nonlinearity	Effect on sensitivity: 0.01 %	u8	B	1.0E-02	1.0E-02	Normal	1.00	1.0E-02	1.0E-02
	Correction of gravity effect	Influence from curve on air bearing bar caused by gravity	u9	B	8.6E-07	4.4E-08	Rectangular	0.58	5.0E-07	2.5E-08
	Quantization error, fitting error, effect of digital filtering, noise, and distortion	Estimated by Monte Carlo simulation	u10	B	1.6E-03	1.0E-02	Normal	1.00	1.6E-03	1.0E-02
	Reproducability	Estimated from 10 measurements	u11	A	1.9E-03	2.0E-03	Normal	1.00	1.9E-03	2.0E-03
Relative standard uncertainty [%] (k = 1)									0.036	0.058
Relative expanded uncertainty [%] (k = 2)									0.073	0.117
Stated relative expanded uncertainty [%]									0.15	0.2

Phase sensitivity

Uncertainty Component		Comment		Type	0.1 Hz - 5 Hz in 1°	> 5 Hz in 1°	Distribution	Factor	0.1 Hz - 5 Hz in 1°	> 5 Hz in 1°
Interferometer	Delay of Laser Interferometer	Maximum 0.1 micro seconds	u1	B	3.8E-05	6.6E-04	Rectangular	0.58	2.18E-05	3.81E-04
	Relative Motion of Interferometer	Measured with monitoring accelerometer attached to the interferometer	u2	B	2.4E-04	3.2E-02	Normal	1.00	2.37E-04	3.15E-02
Accelerometer	Transverse motion	1 % transverse sensitivity	u3	B	1.7E-04	1.8E-03	Normal	1.00	1.66E-04	1.85E-03
Other effects	Channel asynchronousity	Maximum 0.5 micro seconds	u4	B	1.9E-04	3.3E-03	Rectangular	0.58	1.09E-04	1.91E-03
	Quantization error, fitting error, effect of digital filtering, noise, and distortion	Estimated by Monte Carlo Simulation	u5	B	2.6E-03	5.2E-03	Normal	1.00	2.60E-03	5.22E-03
	Reproducability	Estimated from 10 measurements	u6	A	7.6E-03	4.2E-03	Normal	1.00	7.64E-03	4.23E-03
Relative standard uncertainty [°] (k = 1)									0.008	0.032
Relative expanded uncertainty [°] (k = 2)									0.016	0.065
Stated relative expanded uncertainty [°]									0.05	0.1

12- KRISS

Magnitude sensitivity

Uncertainty components	Description	Relative standard uncertainty: u_r	Probability distribution	Sensitivity coefficient: c	Contributed amount: $c \cdot u_r$	Degree of freedom
$u_r(f)$	**Relative uncertainty of frequency readings**	**0.75E-12**	**Uniform**	**2**	**1.5E-12**	**∞**
$u_{r,S}(R_M, I_M)$	**Relative std. uncertainty of the magnitude of the complex sensitivity**	**6.74E-06**	**Normal**	**1**	**6.74E-06**	**360**
$u_r(s)$	**Relative std. uncertainty of the magnitude of the linear displacement**	**2.22E-07**	**-**	**1**	**2.22E-07**	
$u_{r,QE}$	Relative std. uncertainty of RLE quantization error	2.04E-07	Uniform	1	2.04E-07	-
$u_{r,SDE}$	Relative std. uncertainty of RLE sub-division error	7.15E-08	Normal	1	7.15E-08	-
u_{WLS}	RLE wavelength stability	5.0E-08	-	1	5.0E-08	-
$u_{r,ENL}$	Relative std. uncertainty of RLE electric noise level	1.01E-08	Uniform	1	1.01E-08	∞
$u_r(V)$	**Relative std. uncertainty of the magnitude of the voltage output**	**7.54E-05**	-	**1**	**7.54E-05**	
$u_{r,VS}$	Relative std. uncertainty of voltage calibration source	5.0E-05	Normal	1	5.0E-05	∞
$u_{r,GE}$	Relative std. uncertainty of ADC gain error	5.65E-05	Normal	1	5.65E-05	-
$u_{r,QEV}$	Relative std. uncertainty of ADC quantization error	4.67E-13	Uniform	1	4.67E-13	∞
$u_{r,EN}$	Relative std. uncertainty of ADC electric noise level	1.53E-06	Normal	1	1.53E-06	-
$u_r(S_{RE})$	Relative std. uncertainty of the magnitude repeatability of complex sensitivity	**1.0E-04**	**Normal**	**1**	**1.0E-04**	
$u_{r,c}(S_a)$	**Combined uncertainty**	**1.254E-4**	**-**	**1**	**1.254E-4**	
$U_r(S_a)$	**Expanded uncertainty: Calculated (k = 2, L.C. = 95 %)**	**2.51E-04**	**-**	**1**	**2.51E-04**	
	Expanded uncertainty: Stated (k = 2, L.C. = 95 %)	**-**	**-**	**-**	**1.00E-3**	

Phase sensitivity

Uncertainty components	Description	Standard uncertainty: u	Probability distribution	Sensitivity coefficient: c	Contributed amount: c·u	Degree of freedom
$u_{\Delta\varphi}(R_M,I_M)$	**Standard uncertainty of the phase shift of the complex sensitivity**	**5.07E-04°**	**Normal**	**1**	**5.07E-04°**	**360**
$u_{\Delta\varphi}(s)$	**Standard uncertainty of the phase shift of the linear displacement**	**3.60E-04°**	**Normal**	**1**	**3.60E-04°**	
$c_{AU}\times u_r(s)$	Effect of relative std. uncertainty of the magnitude of linear displacement measurement	2.22E-07	Normal	$180/\pi$	1.27E-05°	
$u_{\Delta\varphi,RLE}$	Data age of RLE unit	6.25E-07 s	Uniform	$360f$	3.60E-04°	∞
$u_{\Delta\varphi,PC}$	Time delay of position counter	1.00E-08 s	Uniform	$360f$	5.76E-06°	∞
$u_{\Delta\varphi}(V)$	**Relative uncertainty of the phase shift of the voltage output**	**4.32E-03°**	**Normal**	**1**	**4.32E-03°**	
$c_{AU}\times u_r(V)$	Effect of relative std. uncertainty of the magnitude of voltage output measurement	7.54E-05	-	$180/\pi$	4.32E-03°	
$u_{\Delta\varphi,AD}$	Std uncertainty of phase shift of calibrated AD converter	0			0	
$u_{\Delta\varphi,CL}$	Time delay caused by the length difference of two cables of the RLE output and the transducer output	2.0E-09 s	Normal	$360f$	1.15E-06°	-
$u_{\Delta\varphi}(S_{RE})$	**Relative std. uncertainty of the phase repeatability of complex sensitivity**	**5.0E-03°**	**Normal**	**1**	**5.0E-03°**	
$u_{\Delta\varphi,c}(S_a)$	**Combined uncertainty**	**6.64E-03°**	-	**1**	**6.64E-03°**	
$U_{\Delta\varphi}(S_a)$	**Expanded uncertainty: Calculated (k = 2, L.C. = 95 %)**	**1.33E-2°**	-	**1**	**1.33E-2°**	
	Expanded uncertainty: Stated (k = 2, L.C. = 95 %)	-	-	-	**0.10°**	

14- ASTAR

Magnitude sensitivity

Magnitude: / Uncertainty components	Probability distribution model	0.1 Hz	0.125 Hz	0.16 Hz	0.2 Hz - 0.315 Hz	0.4 Hz - 0.8 Hz	1 Hz - 2 Hz	2.5 Hz - 4 Hz	5 Hz - 8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz - 31.5 Hz	40 Hz
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
Output voltage measurement															
Voltage measurement	Normal	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02
Harmonics	Rectangular	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
Hum	Rectangular	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
Noise	Normal	1.00E-01	1.00E-01	1.00E-01	5.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
Transverse motion	Rectangular	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02	3.00E-02
Acceleration determination															
Reference laser	Normal	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03	1.41E-03
Relative motion between laser and shaker	Rectangular	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	4.00E-02	4.00E-02	5.44E-02	4.00E-02	8.83E-02	6.43E-02	4.00E-02	4.00E-02
Geometrical location of laser spot	Normal	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03	5.00E-03
Angular frequency	Rectangular	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Reference amplifier															
Amplifier gain	Normal	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02	2.00E-02
Frequency response	Normal	1.00E-01	1.00E-01	1.00E-01	1.00E-01	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02
Residual effect															
Base strain	Rectangular	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Sensor mounting	Rectangular	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Cable layout	Rectangular	3.60E-02	3.60E-02	3.60E-02	2.10E-02	1.30E-02	8.00E-03	8.00E-03	8.00E-03	8.00E-03	8.00E-03	8.00E-03	8.00E-03	8.00E-03	8.00E-03
Non-linearity	Rectangular	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Effect of sagging guide bars	Rectangular	1.40E-01	1.40E-01	1.40E-01	7.50E-02	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	0.00E+00
Exciter magnetic field	Rectangular	1.00E-01	1.00E-01	1.00E-01	1.00E-01	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02
Temperature variation	Rectangular	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03
Other environmental effects	Rectangular	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.08E-01	1.11E-01	1.16E-01	1.25E-01	1.27E-01	1.27E-01	1.25E-01	1.22E-01	1.24E-01	1.11E-01
Report resolution	Rectangular	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03	2.12E-03
	Type B Total	2.50E-01	2.50E-01	2.50E-01	2.00E-01	1.36E-01	1.47E-01	1.51E-01	1.57E-01	1.63E-01	1.59E-01	1.76E-01	1.63E-01	1.56E-01	1.47E-01
	Type A														
Number of measurement		10	10	10	10	10	10	10	10	10	10	10	10	10	10
Standard uncertainty		1.29E-01	7.71E-02	3.90E-02	2.56E-02	7.08E-03	1.33E-03	4.75E-03	6.40E-03	1.68E-02	9.01E-03	2.62E-03	5.24E-03	6.99E-03	1.23E-03
Combined uncertainty		0.28	0.26	0.25	0.20	0.14	0.15	0.15	0.16	0.16	0.16	0.18	0.16	0.16	0.15
Effective degree of freedom		2.27E+02	1.32E+03	1.77E+04	3.88E+04	1.36E+06	1.50E+09	1.02E+07	3.66E+06	9.16E+04	9.82E+05	2.04E+08	9.39E+06	2.52E+06	2.06E+09
Coverage factor		2.01	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Expended uncertainty [%]		0.56	0.52	0.51	0.40	0.27	0.29	0.30	0.31	0.33	0.32	0.35	0.33	0.31	0.29

Phase sensitivity

Phase: / Uncertainty components	Probability distribution model	0.1 Hz °	0.125 Hz °	0.16 Hz °	0.2 Hz - 0.315 Hz °	0.4 Hz - 0.8 Hz °	1 Hz - 2 Hz °	2.5 Hz - 4 Hz °	5 Hz - 8 Hz °	10 Hz °	12.5 Hz °	16 Hz °	20 Hz °	25 Hz - 31.5 Hz °	40 Hz °
Output voltage measurement															
Voltage measurement	Normal	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Harmonics	Rectangular	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Hum	Rectangular	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Noise	Normal	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Transverse motion	Rectangular	0.000	0.000	0.000	0.000	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Acceleration determination															
Reference laser	Normal	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Relative motion between laser and shaker	Rectangular	0.000	0.000	0.000	0.000	0.000	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Geometrical location of laser spot	Normal	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Angular frequency	Rectangular	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Reference amplifier															
Amplifier gain	Normal	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Frequency response	Normal	0.200	0.200	0.200	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Residual effect															
Base strain	Rectangular	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Sensor mounting	Rectangular	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cable layout	Rectangular	0.300	0.300	0.300	0.200	0.050	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Non-linearity	Rectangular	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Effect of sagging guide bars	Rectangular	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Exciter magnetic field	Rectangular	0.100	0.100	0.100	0.100	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Temperature variation	Rectangular	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Other environmental effects	Rectangular	0.200	0.200	0.200	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Report resolution	Rectangular	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
	Type B Total	0.428	0.428	0.428	0.257	0.153	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176	0.176
	Type A														
	Number of measurement	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Standard uncertainty	0.075	0.046	0.017	0.018	0.002	0.001	0.001	0.002	0.014	0.004	0.001	0.002	0.002	0.001
	Combined uncertainty	0.43	0.43	0.43	0.26	0.15	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Effective degree of freedom	1.11E+04	7.94E+04	3.84E+06	4.63E+05	2.28E+08	4.01E+10	1.79E+10	2.97E+08	2.73E+05	5.60E+07	2.86E+10	2.72E+08	7.61E+08	1.06E+10
	Coverage factor	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Expended uncertainty [°]	0.87	0.86	0.86	0.51	0.31	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35