Final Report
on the CIPM Key Comparison

CCAUV.V-K1.1

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ABSTRACT

This report of the CCAUV.V-K1.1 key comparison (KC) presents the final results of the second, follow-up CIPM comparison in the area of vibration, in this case defined as sinusoidal acceleration. The relation between the results of the participants in this follow-up comparison and the results of the first CIPM comparison in the field of vibration CCAUV.V-K1 is calculated via a procedure using one linking laboratory and is fully described. Using this linking, the results of the participants can be directly compared with the results of other comparisons like CCAUV.V-K1.
Supplementing the scope of the original CIPM comparison the frequency range of the reported KC was extended up to 10 kHz and the measurand phase was included for some of the participants.
The Technical Protocol that was used is included as Appendix A and the full uncertainty budgets are given in Appendix B.

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1 Introduction

This report presents the results of the second CIPM comparison in the area of „vibration“, what in this case means sinusoidal acceleration. It is the final report which is published in the KCDB of the BIPM.
The participants agreed to the results circulated confidentially in the draft A report. The calculus applied for this linking process is identical to that already used and described in the final report of the EUROMET.AUV.V-K1 comparison. Using this the results of the participants can be directly compared to the results of other comparisons, be it CCAUV.V-K1 itself or others, which are linked to it as well. This comparison can be considered as an amendment to CCAUV.V-K1, which is performed to link the participants from different RMOs to the Key Comparison Reference value of CCAUV.V-K1

The Technical Protocol (c.f. App. A:) specifies in detail the aim and the task of the comparison, the conditions of measurement, the transfer standards used, measurement instructions and other items. A brief survey is given in the following sections.

2 Participants

Four National Metrology Institutes (NMIs) from 3 RMO participated in the comparison CCAUV.V-K1.1 (c.f. table 1).

Table 1: List of participating institutes

Participant number	Participant (laboratory name)*	Acronym	Country	Country Code	Calibration period
1	Physikalisch-Technische Bundesanstalt	PTB	Germany	DE	05/2006
2	National Institute of Metrology of China	NIM	China	CN	11/2006
3	National Physics Laboratory of India	NPLI	India	IN	12/2006
4	National Institute of Metrology, Standardization and Industrial Quality	INMETRO	Brazil	BR	08/2007

3 Task and Purpose of the Comparison

This second CIPM-level comparison in the field of acceleration was carried out in order to provide the necessary information for the acceptance of CMC entries for the participants 2 to 4.

In order to provide the necessary means for a linking of the results to the CIPM comparison CCAUV.V-K1 [1]. PTB was requested to volunteer as Pilot- and Linking laboratory.

4 Conditions and Instructions of Measurement

The participating laboratories observed fully or to a large extent the conditions stated in the Technical Protocol, i.e.

- frequencies in Hz:
  40, 80, 160 (reference frequency), 800, 2000, 5000 and additional frequencies down to 10 Hz and up to 10 kHz provided that they are included in the third octave series.
- amplitudes:
  A range of 10 m/s² to 200 m/s² was allowed with 100 m/s² being the preferred value.
- ambient temperature and accelerometer temperature during the calibration:
  23 °C ± 2 K (actual values should be stated within tolerances of ± 0.3 K).
- relative humidity: max. 75%
- mounting torque of the accelerometer: (2 ± 0.1) N·m

The comparison was performed in compliance with the “Guidelines for CIPM key comparisons” [2].

5 Transfer Standards as Artefacts

For the purpose of the comparison the pilot laboratory selected two accelerometers which data were not included in any published international cooperation work. Due to the short preparatory stage of the comparison a designated long term stability monitoring of the artefacts was not possible.

- One transfer standard accelerometer (single-ended), type 8305 WH 2335, S/N 1610168 (manufacturer: Brüel & Kjær) named **SE**-transducer subsequently (owner PTB)
- One reference standard accelerometer (back-to-back) type 8305, S/N 748376 (manufacturer: Brüel & Kjær) named **B2B**-transducer subsequently (owner NIM)

The investigation of the long-term stability was continued throughout the circulation period. The results of the PTB stability measurements and other individual data of the transfer standards are given in Section 7.

6 Circulation of the Artefacts

The circulation Type of this comparison was a star type, i.e. between the measurements at each participant's laboratory the artefacts were checked for stability (c.f. section 7.2) and the state of the mounting surface. If the quality of the mounting surface was degraded the artefacts were re-lapped in order to provide optimum conditions for the following participant.

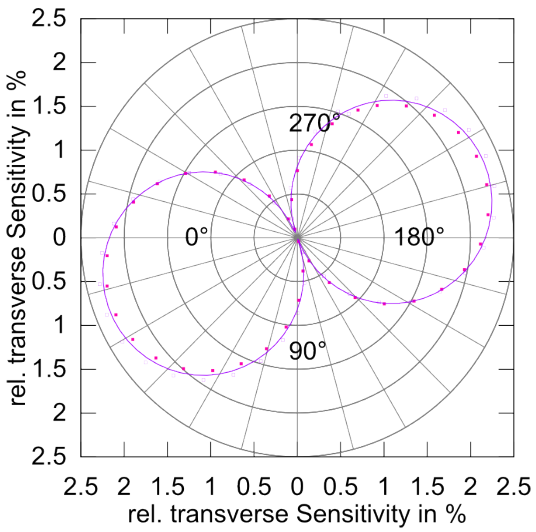
7 Results of the Measurements

7.1 Transverse Sensitivity

The sensitivity of the accelerometers towards a transverse excitation i.e. in a direction parallel to the mounting surface or orthogonal to their geometric axis was investigated in dedicated measurements.

For this investigation the artefacts were mounted to a mounting block on top off the slip table of PTB's 3-axis vibration exciter. The mounting block was equipped with two reference accelerometers pointing in x- and y-direction which were primary calibrated just before the measurements. Then the x- and y-exciters of the facility were driven synchronously with sinusoidal current of varying amplitude but zero phase difference. The amplitude was varied in a way that with successive runs the slip-table was performing sinusoidal rectilinear motions in different directions with a constant magnitude of acceleration amplitude of 60 m/s² at 40 Hz.

As usual the results are presented here in relative way as a fraction of the nominal sensitivity. The relative expanded uncertainty (k = 2) of this relative transverse sensitivity is estimated to be less than 10 %. Figures 1 and 2 give a graphical view of the results. The values of maximum transverse sensitivity are summarized in table 2.



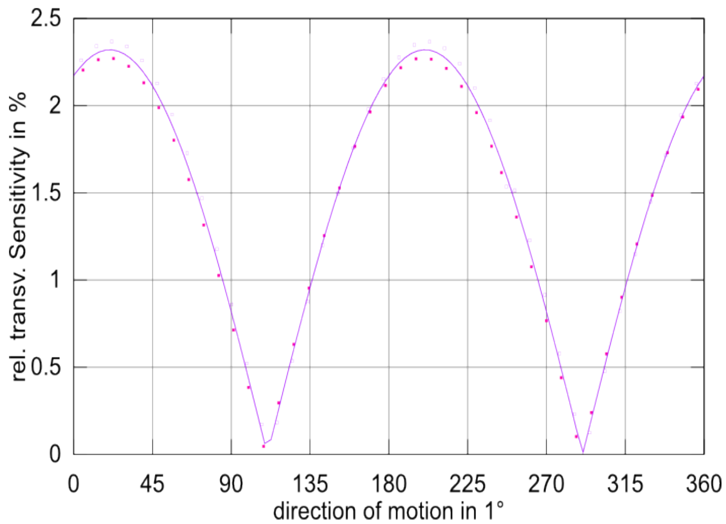


Fig. 1: **relative transverse sensitivity of the SE accelerometer in % of the nominal sensitivity, polar representation left, Cartesian representation right.**

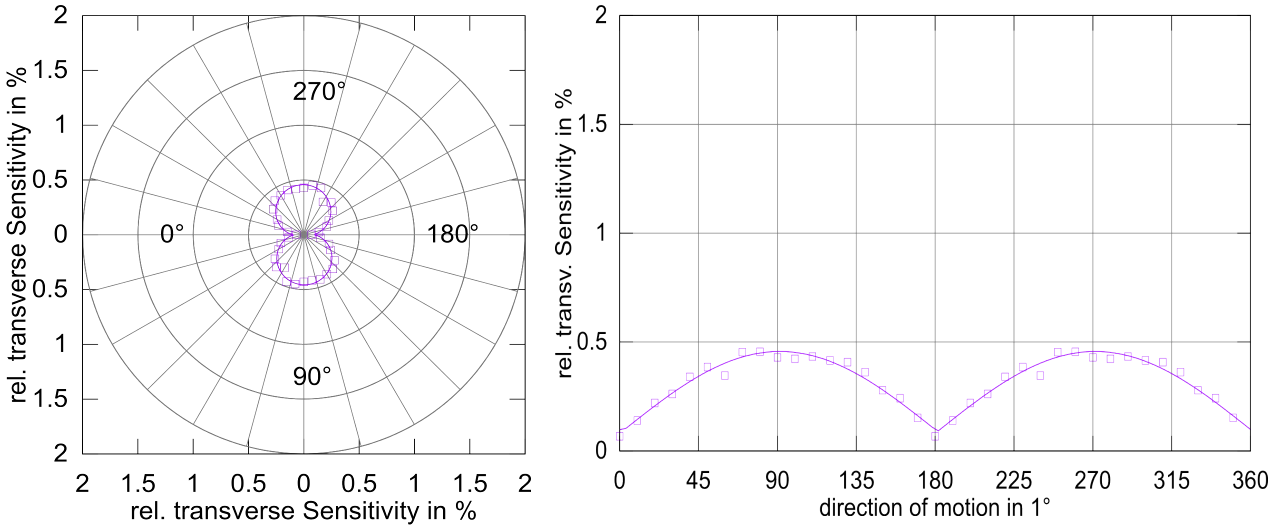


Fig. 2: relative transverse sensitivity of the B2B accelerometer in % of the nominal sensitivity, polar representation left, cartesian representation right.

Table 2: maximum transverse sensitivity of the artefacts a a percentage of the nominal sensitivity

Artefact	max. rel. transverse sensitivity in %
SE	< 2,5
B2B	< 0,5

7.2 Monitoring of stability

Starting with calibration data in autumn 2005 the artefacts were monitored during the period of the comparison by calibrations at those times when they were back at the pilot laboratory. As a representative of the overall change the measurements at reference frequency (160 Hz) are given in the following tables.

Table 3: Charge sensitivities of the SE accelerometer at 160 Hz during the monitoring measurements (rel. std. uncertainty (*k* = 1) *u* = 0,05 %)

Month rel. to 10/2005	S_{qa} in pC/(m/s²)	rel. exp. uncertainty in %
0	0,13069	0,1
2	0,13088	0,1
4	0,13079	0,1
5	0,13066	0,1
7	0,13064	0,1
8	0,13071	0,1
9	0,13065	0,1
11	0,13069	0,1
17	0,13040	0,1
18	0,13046	0,1
19	0,13046	0,1

Table 4: Charge sensitivities of the B2B accelerometer at 160 Hz during the monitoring measurements (rel. std. uncertainty (*k* = 1) *u* = 0,05 %)

Month rel. to 2/2005	S_{qa} in pC/(m/s²)	rel. exp. uncertainty in %
0	0,12606	0,1
14	0,12606	0,1
15	0,12600	0,1
32	0,12604	0,1

This monitoring measurements can in the simplest way be summarized by the following statistical properties. However, a graphical representation (c.f. fig. 3Fehler: Referenz nicht gefunden and 4) may suggest that the stability of the SE artefact was not as good as was originally hoped for, while the B2B artefact showed excellent long term stability.

Table 5: mean and standard deviation of the charge sensitivity of the artefacts calculated from the monitoring measurements.

Artefact	long term mean in pC/(m/s²)	rel. std. deviation in %
SE	0,13064	0,11
B2B	0,12604	0,02

7.3 Drift Analysis

From the monitoring data given in section 7.2 it appears that the SE transducers actual sensitivity might have drifted during the measurement period. In order to take this into account a linear least squares fit was applied to the monitoring data over time. The linear model is described by

$$S(t) = S_0 + D \cdot (t - t_0) \quad (1).$$

The model parameters S_0 and D as well as the respective co-variance matrix are fitted according to [3].

In order to check consistency the Chi-squared was calculated for the respective model and compared to the maximum X^2 of p = 0,05 and the respective degree of freedom ν.

Table 6: Model parameters for the linear drift of the linear drift of the artefacts.

Artefact	S_0 in pC/(m/s²)	$s(S_0)$ in pC/(m/s²)	D in (pC/(m/s²)) per month	s(D) in (pC/(m/s²)) per month	ν	χ^2	maximum χ^2	rel. std. dev. in %
SE	0,13082	3,5e-5	-1,94e-5	3,2e-6	9	12,4	16,92	0,056

For the SE the drift stated in table 6 converts to a relative value of approx. -0,18 % per year. For a direct comparison of the fitted linear drift to the model of constant sensitivity (c.f. table 5) the standard deviation of the measurements with respect to the values estimated by the model is calculated in the last column.

The monitoring data for both artefacts as well as the drift estimate for the SE are depicted in the figures 3 and 4 below.

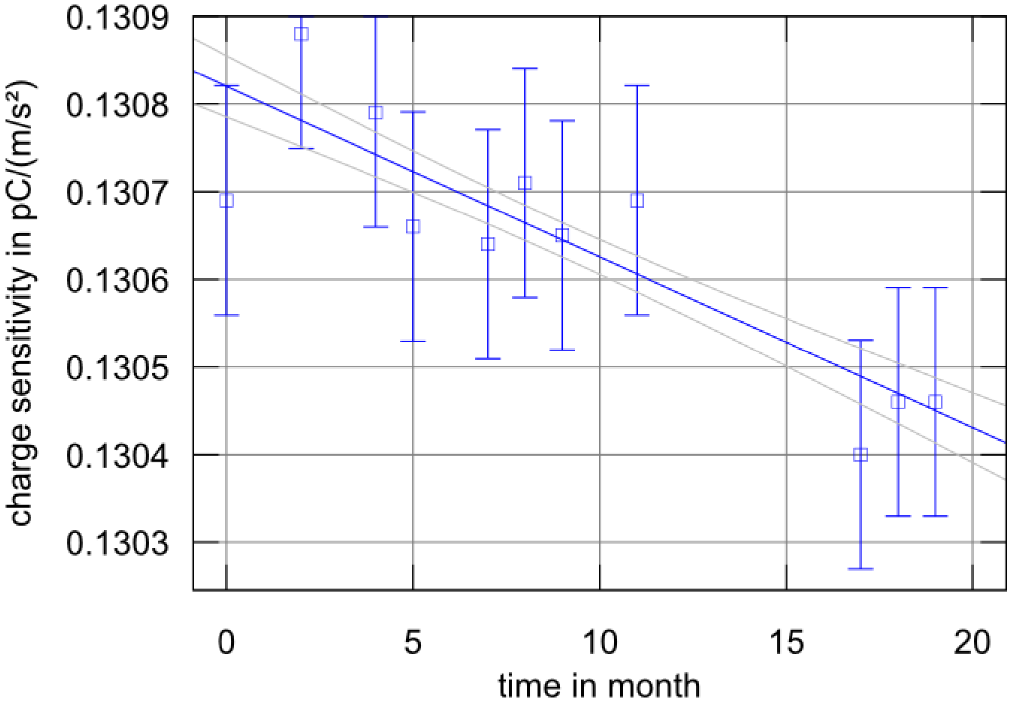


Fig. 3: Charge sensitivities in pC/(m/s²) of the SE accelerometer at 160 Hz over time in months during the monitoring measurements. Uncertainty bars for the exp. uncertainty (*k* = 2). And line (blue) of the fitted drift estimate with the confidence limits of the fit (grey).

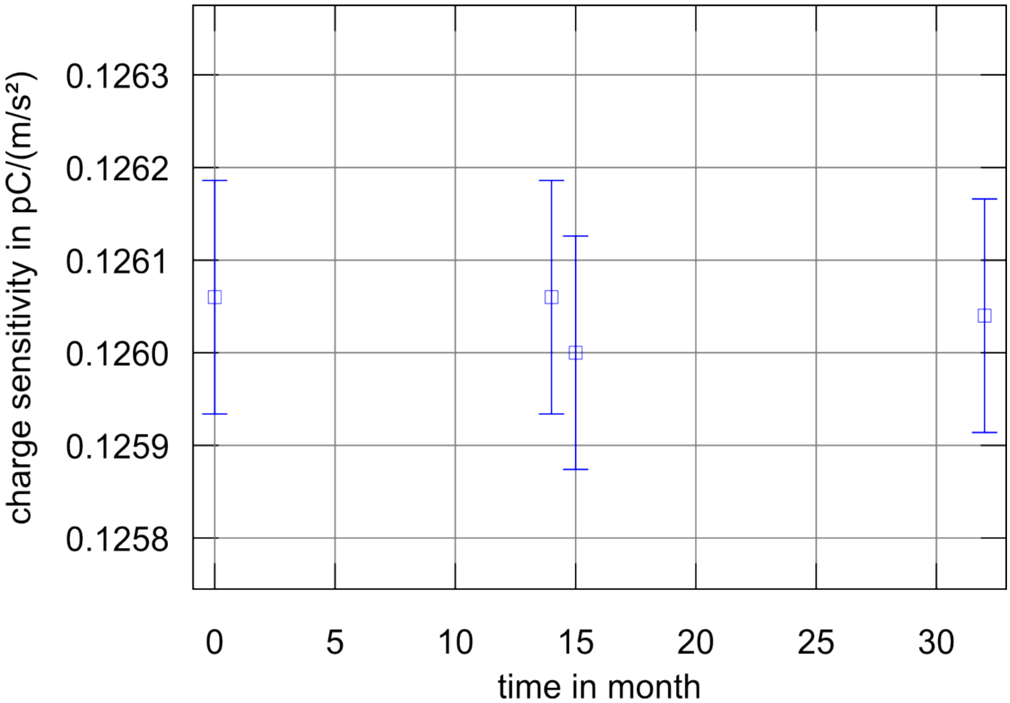


Fig. 4: Charge sensitivities in pC/(m/s²) of the B2B accelerometer at 160 Hz over time in months during the monitoring measurements. Uncertainty bars for the exp. uncertainty (*k* = 2).

It was agrred between the participants to use corrected (detrended) values for the calculation of the DOEs for the SE transducer, which means that according to relative time with respect to the comparison period the values reported from the participating laboratories are added to a certain drift value which increases the magnitude the later the participants measurements were in the schedule of the comparison (c. f. section 6). In addition the uncertainty stated by the participant would be increased by the uncertainty of this estimated drift value using a sum of squares. Only after this correction the DoE were determined. The correction for all frequencies was taken as a scaling factor (very close to unity) calculated from the drift at 160 Hz.

The uncertainty of the correction is calculated according to the laws of uncertainty propagation from the partial derivatives of the model equation (1).

$$U(S(t))=\sqrt{\left(\frac{\partial S}{\partial S_0}\right)^2 s^2(S_0)+\left(\frac{\partial S}{\partial D}\right)^2 s^2(D)+\left(\frac{\partial S}{\partial S_0}\frac{\partial S}{\partial D}\right) cov(S_0,D)} \qquad (2)$$

The components of the uncertainty calculation and its result in absolute and relative terms are summarized in table (7).

Table 7: summary of the terms ocurring in the uncertainty propagation of the drift model, which is proposed for correction.

partial derivatives	$\left(\frac{\partial S}{\partial S_0}\right)^2=1$	$\left(\frac{\partial S}{\partial D}\right)^2=(t-t_0)^2$	$\frac{\partial S}{\partial S_0}\frac{\partial S}{\partial D}=t-t_0$
variances	1,22e-9	1,0e-11	-9,1e-11
max. U(*S*)	4,64·10^{-5} pC/(m/s²)		rel. 0,03 %

Due to the second and third term of the quadratic sum in eq. (2) the uncertainty of the correction is depending on the time when the measurement has taken place in the course of the comparison.

In this report of the key comparison both results (with and without correction) will be presented for each laboratory.

7.4 Original Results of the Participants for the Magnitude of the complex Sensitivity

In the Following the results of the participating Institutes are given as reported first in a compact tabulated form and additionally in graphical representation for each artefact and frequency. The proposed correction is not applied so far.

7.4.1 The Single-Ended Accelerometer SN 1610168

Table 8: reported calibration results in pC/(m/s²) of the participants for the SE transducer with expanded relative uncertainty (*k* = 2) in %.

	PTB		NIM		NPLI		INMETRO	
frequency	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %
10	0,13058	0,10	0,13068	0,50	0,13070	1,00	0,13052	0,34
12,5	0,13055	0,10	0,13075	0,50	-	-	0,13053	0,34
16	0,13061	0,10	0,13076	0,50	-	-	0,13054	0,34
20	0,13060	0,10	0,13073	0,50	0,13070	0,70	0,13053	0,34
25	0,13064	0,10	0,13069	0,50	-	-	0,13053	0,24
31,5	0,13059	0,10	0,13074	0,50	-	-	0,13054	0,24
40	0,13061	0,10	0,13072	0,50	0,13070	0,70	0,13050	0,24
50	0,13062	0,10	0,13073	0,50	-	-	0,13047	0,24
63	0,13060	0,10	0,13071	0,50	-	-	0,13050	0,24
80	0,13061	0,10	0,13072	0,50	0,13080	0,70	0,13051	0,24
100	0,13062	0,10	0,13068	0,50	0,13080	0,70	0,13052	0,24
125	0,13062	0,10	0,13069	0,50	-	-	0,13051	0,24
160	0,13066	0,10	0,13073	0,20	0,13090	0,70	0,13048	0,24
200	0,13066	0,10	0,13075	0,50	0,13070	0,70	0,13051	0,24
250	0,13066	0,10	0,13079	0,50	-	-	0,13050	0,24
315	0,13095	0,10	0,13078	0,50	-	-	0,13052	0,24
400	0,13075	0,10	0,13077	0,50	-	-	0,13056	0,24
500	0,13072	0,10	0,13079	0,50	0,13060	0,70	0,13051	0,24
630	0,13072	0,10	0,13085	0,50	-	-	0,13058	0,24
800	0,13074	0,10	0,13080	0,50	0,13070	0,70	0,13060	0,24
1000	0,13079	0,10	0,13087	0,50	0,13070	0,70	0,13069	0,24
1250	0,13090	0,10	0,13097	0,50	-	-	0,13077	0,34
1600	0,13108	0,10	0,13109	0,50	-	-	0,13095	0,34
2000	0,13133	0,10	0,13126	0,50	0,13060	0,70	0,13116	0,34
2500	0,13161	0,10	0,13171	0,50	-	-	0,13149	0,50
3150	0,13215	0,10	0,13225	0,50	-	-	013200	0,50
4000	0,13309	0,10	0,13299	0,50	0,13060	1,00	0,13301	0,50
5000	0,13442	0,10	0,13428	0,50	0,13130	1,00	0,13432	1,00
6300	0,13670	0,30	0,13648	1,0	-	-	0,13620	1,50
8000	0,14064	0,30	0,14077	1,00	-	-	0,13950	1,50
10000	0,14676	0,30	0,14624	1,00	-	-	0,14639	1,50

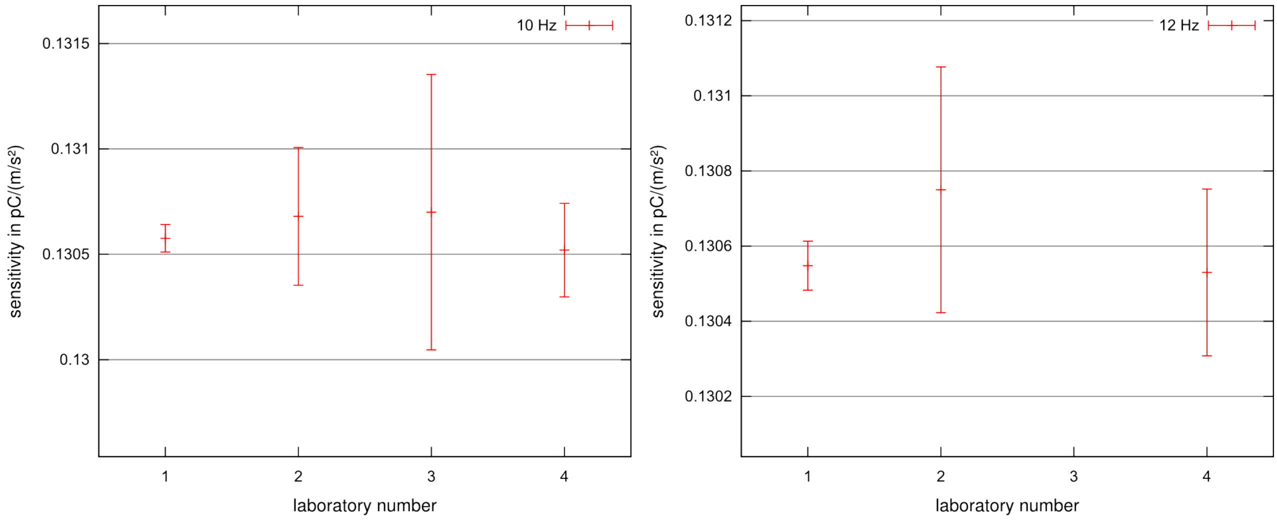


Fig. 5: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

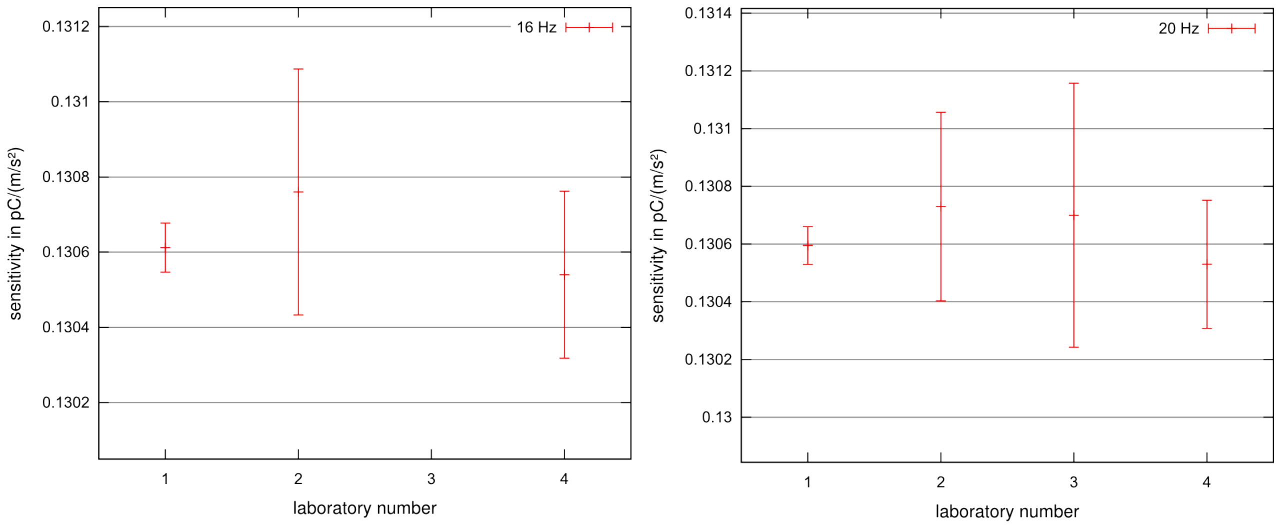


Fig. 6: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

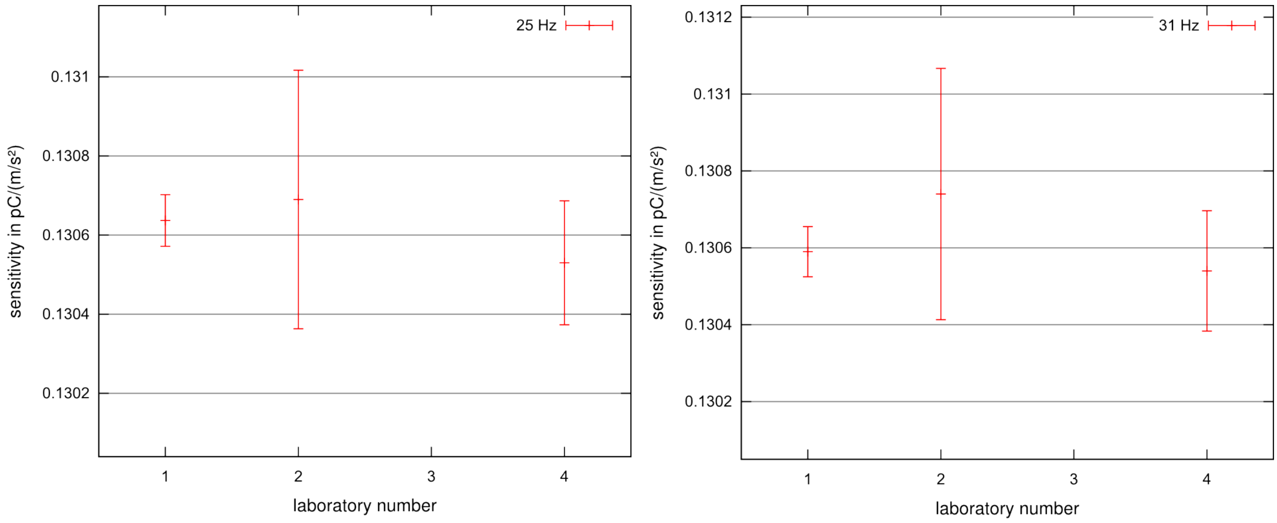


Fig. 7: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 25 Hz and 31,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

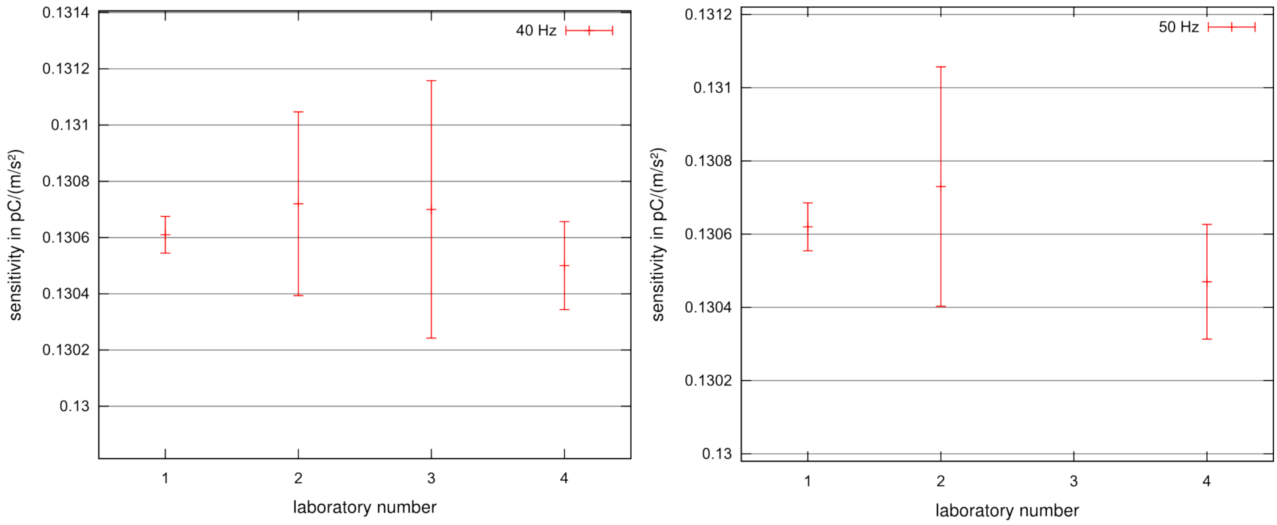


Fig. 8: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

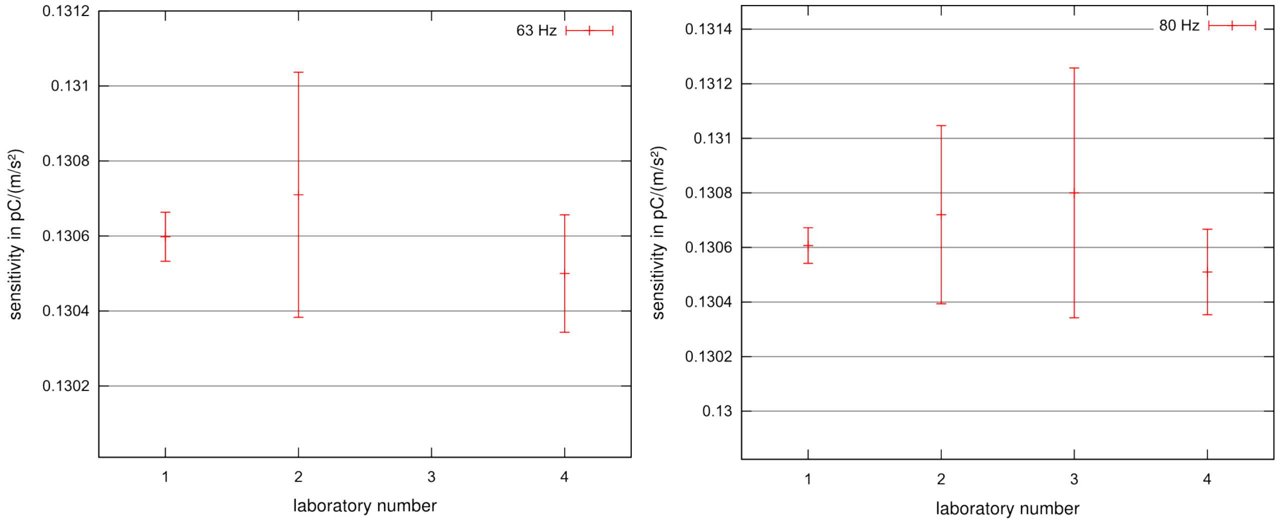


Fig. 9: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

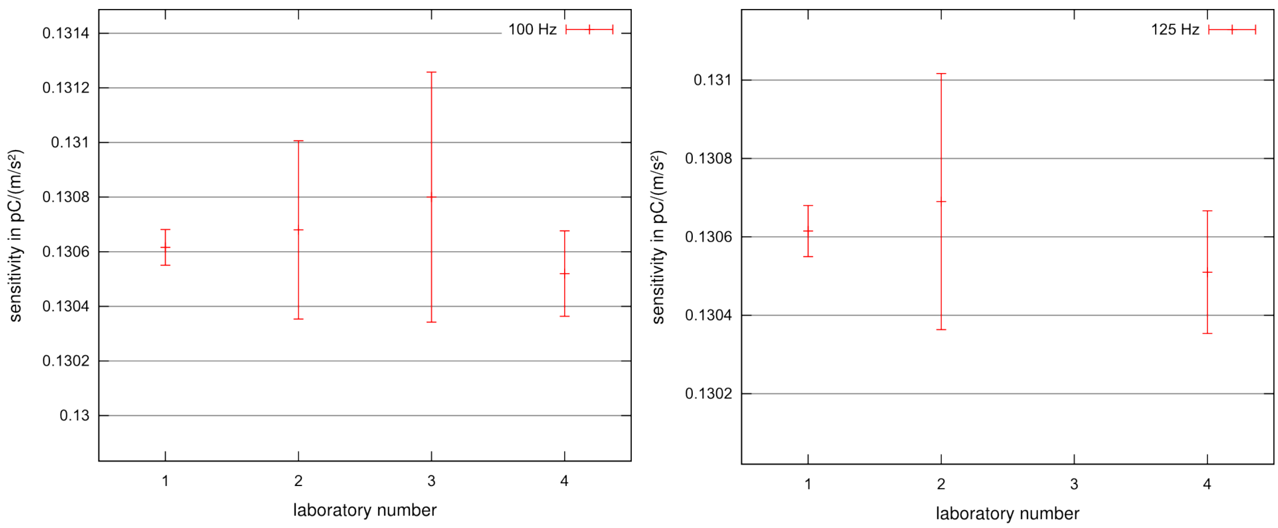


Fig. 10: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

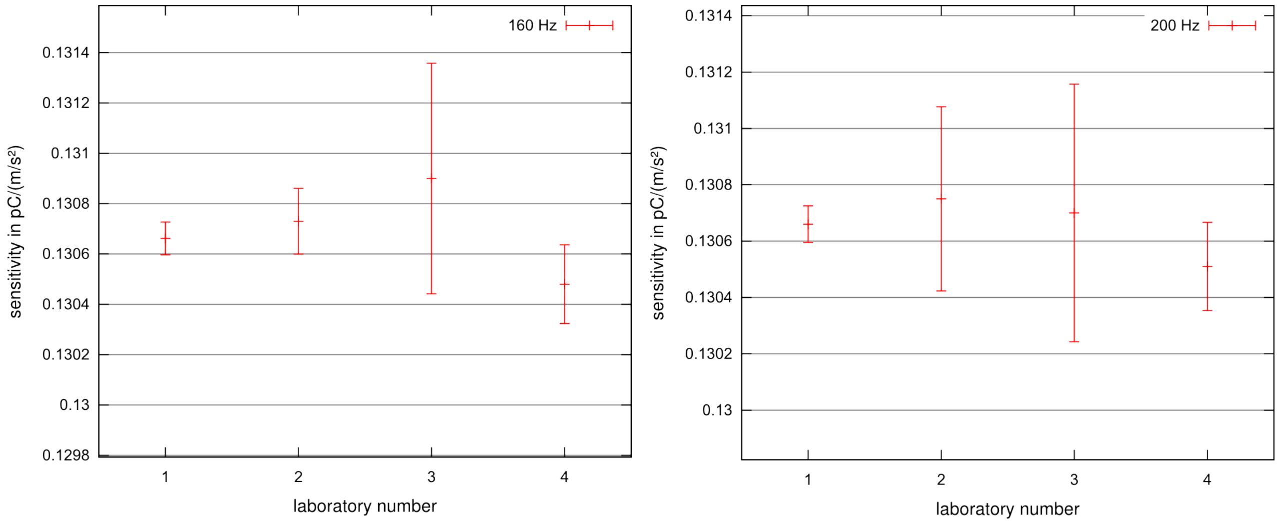


Fig. 11: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

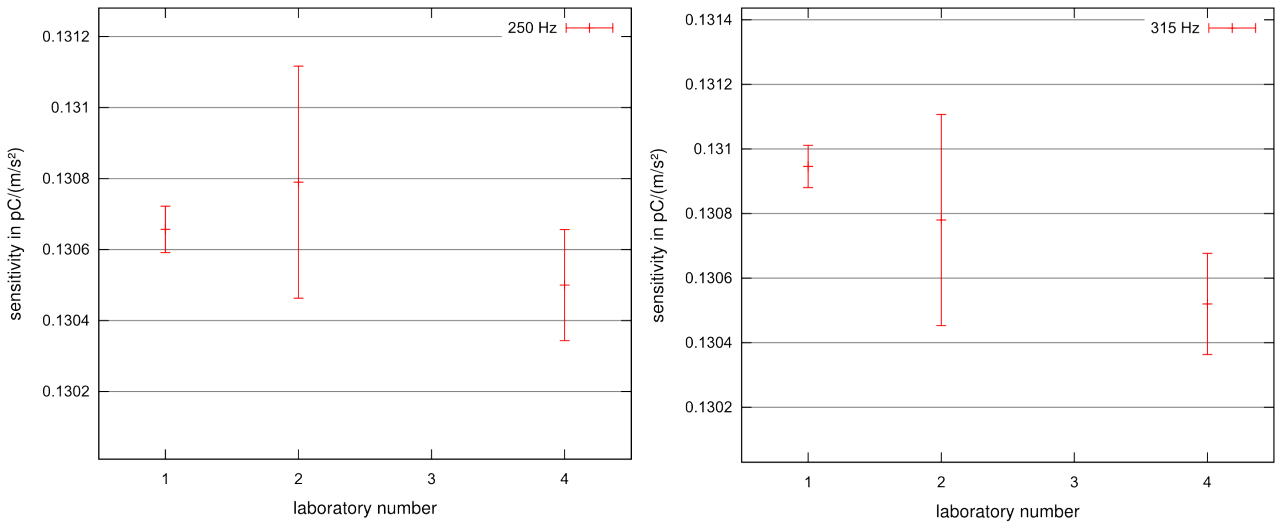


Fig. 12: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

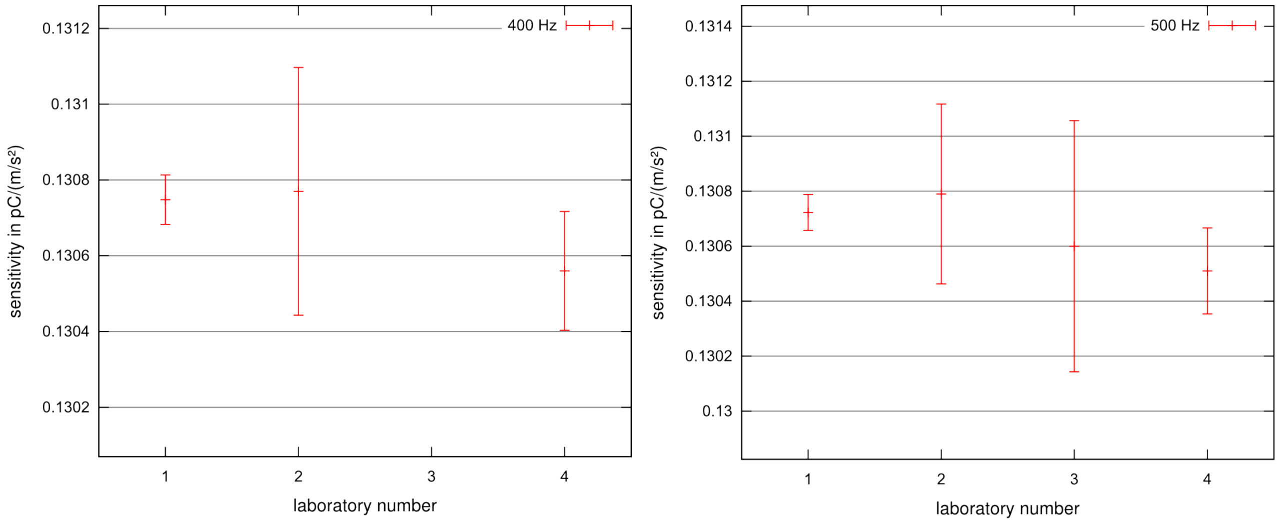


Fig. 13: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

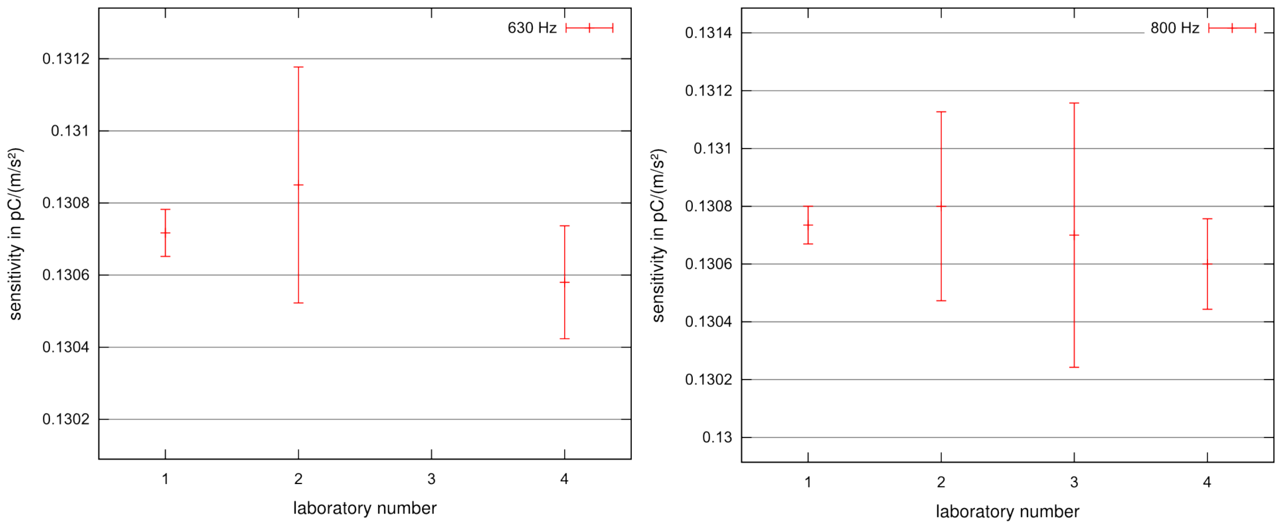


Fig. 14: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

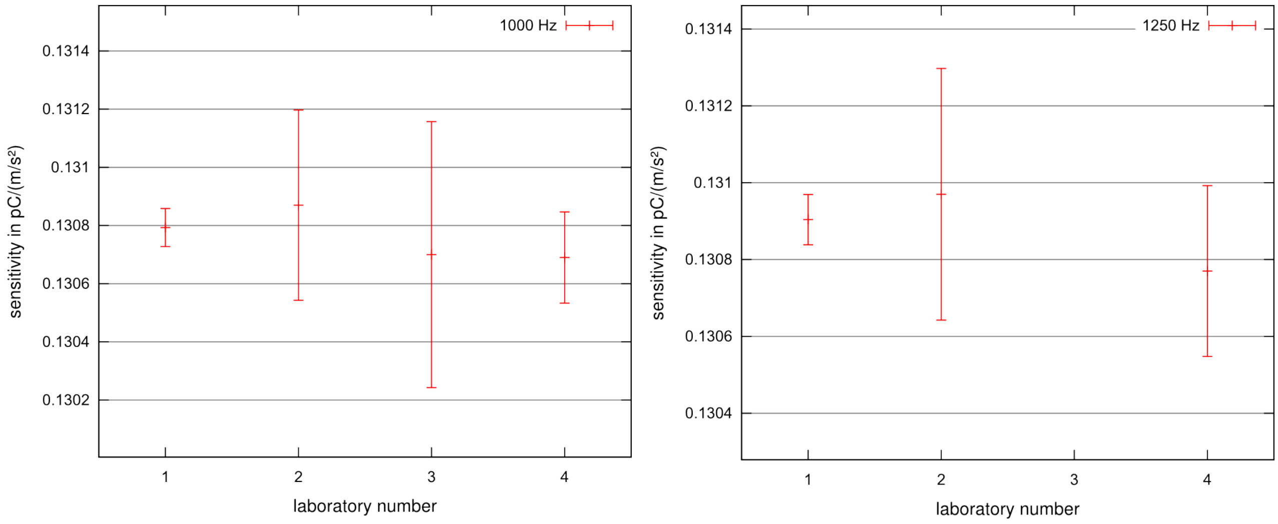


Fig. 15: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

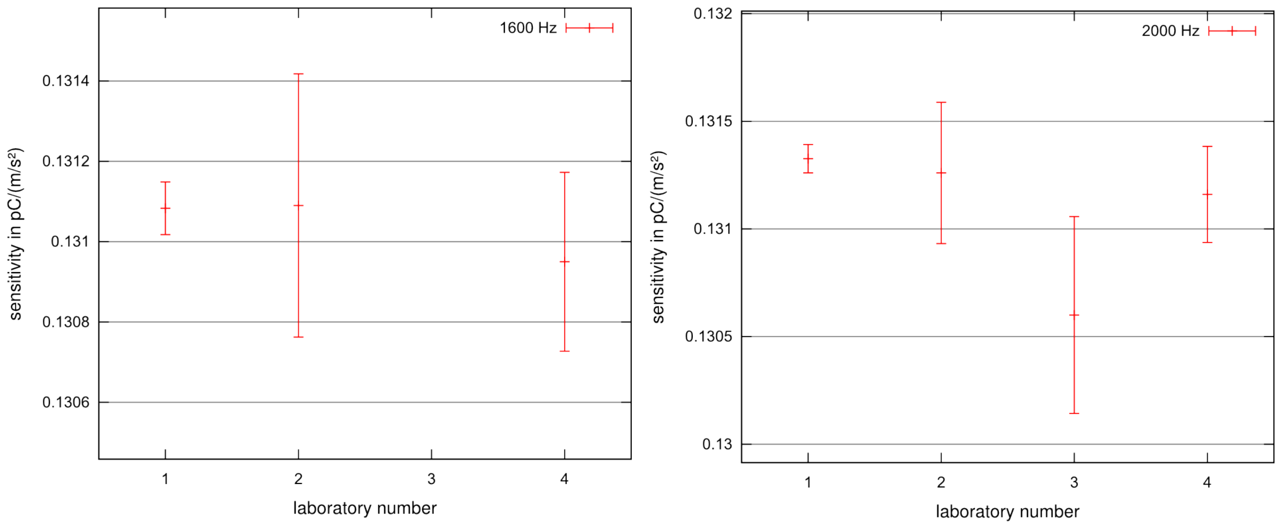


Fig. 16: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

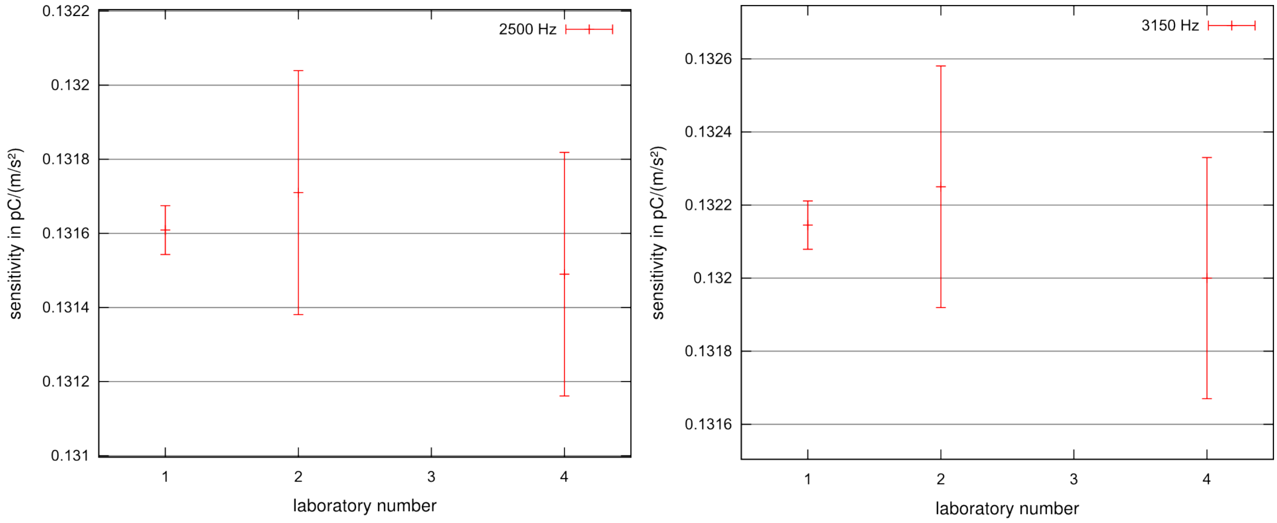


Fig. 17: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

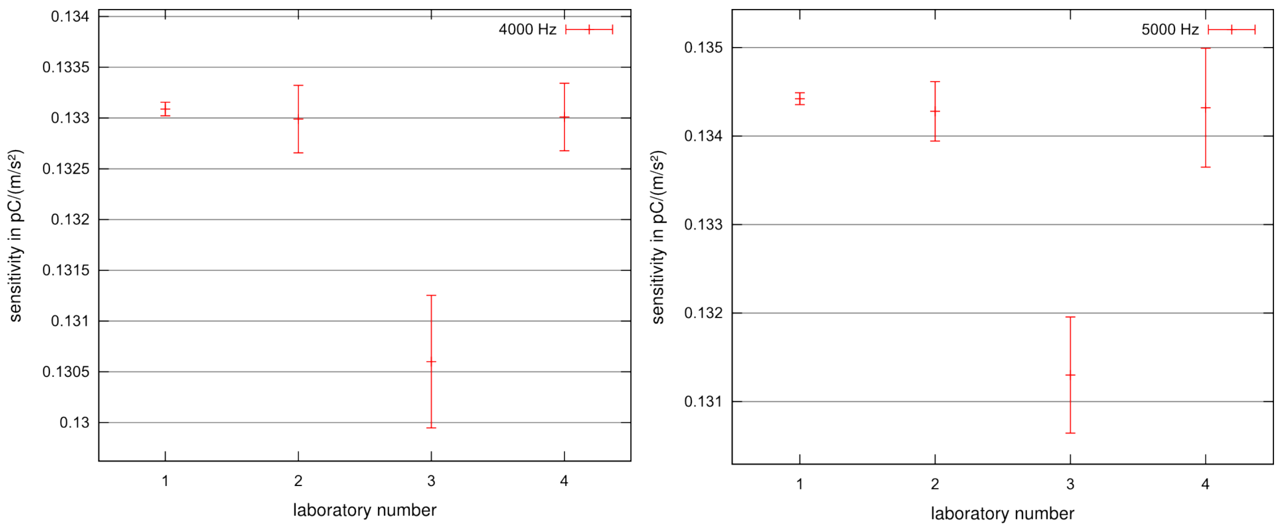


Fig. 18: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

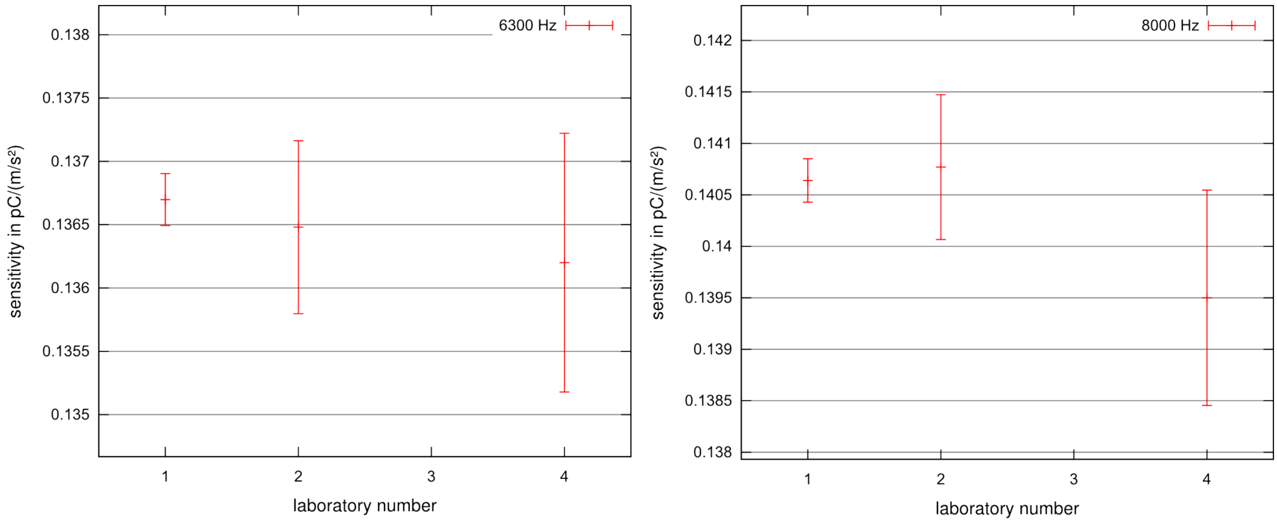


Fig. 19: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

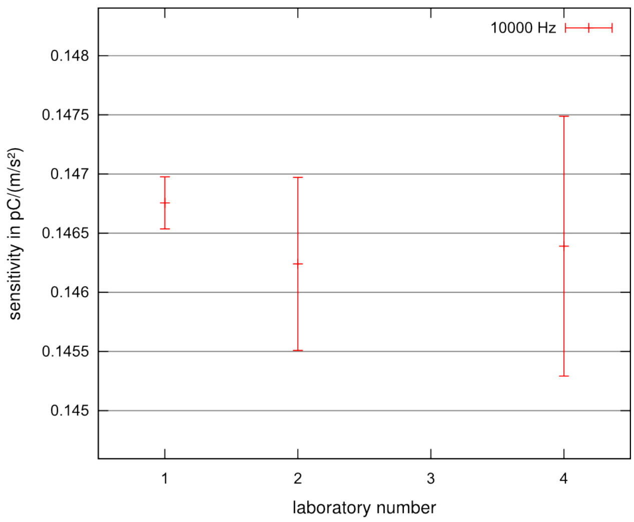


Fig. 20: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 10000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

7.4.2 The Single-Ended Accelerometer SN 1610168 after Drift Correction

In order to correct the data for the time dependent drift in sensitivity the model introduced in Eq. 2 was used. For that purpose the time dependant part of the equation was subtracted from the reported result x_i of the participant *i* with the formula

$$x_i^{\text{corr}} = x_i - D \cdot t_i \qquad (3)$$

where *D* is the slope of the fitted model, t_i denotes the time of the measurement (in month since beginning of the monitoring, c.f. table 1) and x_i^{corr} is the corrected result.

The standard uncertainty attributed to the corrected result is calculated with the sum of squares according to

$$U_i^{\text{corr}} = \sqrt{U_i^2 + U^2(S(t_i))} \qquad (4)$$

where $U(S(t_i))$ is calculated from Eq. (2). It should be noted, that due to the calculation with absolute values for the correction and it's uncertainty it happens in some cases, that the resulting relative uncertainty is somewhat smaller than that originally stated by the laboratory. However, the amount in such cases is negligible.

Table 9: calibration results in pC/(m/s²) of the participants for the SE transducer after correction of the drift with expanded relative uncertainty (*k* = 2) in %.

	PTB		NIM		NPLI		INMETRO	
frequency	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %
10	0,13071	0,1048	0,13093	0,5003	0,13097	0,9987	0,13095	0,3459
12,5	0,13068	0,1048	0,13100	0,5003	-	-	0,13096	0,3459
16	0,13075	0,1048	0,13101	0,5003	-	-	0,13097	0,3459
20	0,13073	0,1048	0,13098	0,5003	0,13097	0,6996	0,13096	0,3459
25	0,13077	0,1048	0,13094	0,5003	-	-	0,13096	0,2490
31,5	0,13073	0,1048	0,13099	0,5003	-	-	0,13097	0,2490
40	0,13075	0,1048	0,13097	0,5003	0,13097	0,6996	0,13093	0,2490
50	0,13076	0,1048	0,13098	0,5003	-	-	0,13090	0,2490
63	0,13073	0,1048	0,13096	0,5003	-	-	0,13093	0,2490
80	0,13074	0,1048	0,13097	0,5003	0,13107	0,6996	0,13094	0,2490
100	0,13075	0,1048	0,13093	0,5003	0,13107	0,6996	0,13095	0,2490
125	0,13075	0,1048	0,13094	0,5003	-	-	0,13094	0,2490
160	0,13080	0,1048	0,13098	0,2027	0,13117	0,6996	0,13091	0,2490
200	0,13080	0,1048	0,13100	0,5003	0,13097	0,6996	0,13094	0,2490
250	0,13079	0,1048	0,13104	0,5003	-	-	0,13093	0,2490
315	0,13108	0,1048	0,13103	0,5003	-	-	0,13095	0,2490
400	0,13088	0,1048	0,13102	0,5003	-	-	0,13099	0,2490
500	0,13086	0,1048	0,13104	0,5003	0,13087	0,6996	0,13094	0,2490
630	0,13085	0,1048	0,13110	0,5003	-	-	0,13101	0,2490
800	0,13087	0,1048	0,13105	0,5003	0,13097	0,6996	0,13103	0,2490
1000	0,13093	0,1048	0,13112	0,5003	0,13097	0,6996	0,13112	0,2490
1250	0,13104	0,1048	0,13122	0,5003	-	-	0,13120	0,3459
1600	0,13122	0,1048	0,13134	0,5003	-	-	0,13138	0,3458
2000	0,13146	0,1048	0,13151	0,5003	0,13087	0,6996	0,13159	0,3458
2500	0,13175	0,1048	0,13197	0,5003	-	-	0,13192	0,5031
3150	0,13228	0,1047	0,13251	0,5003	-	-	0,13243	0,5030
4000	0,13323	0,1047	0,13325	0,5003	0,13087	0,9987	0,13345	0,5030
5000	0,13456	0,1046	0,13454	0,5002	0,13157	0,9986	0,13476	0,9990
6300	0,13684	0,3012	0,13674	0,9986	-	-	0,13665	1,4966
8000	0,14079	0,3011	0,14104	0,9986	-	-	0,13996	1,4965
10000	0,14691	0,3010	0,14652	0,9986	-	-	0,14687	1,4964

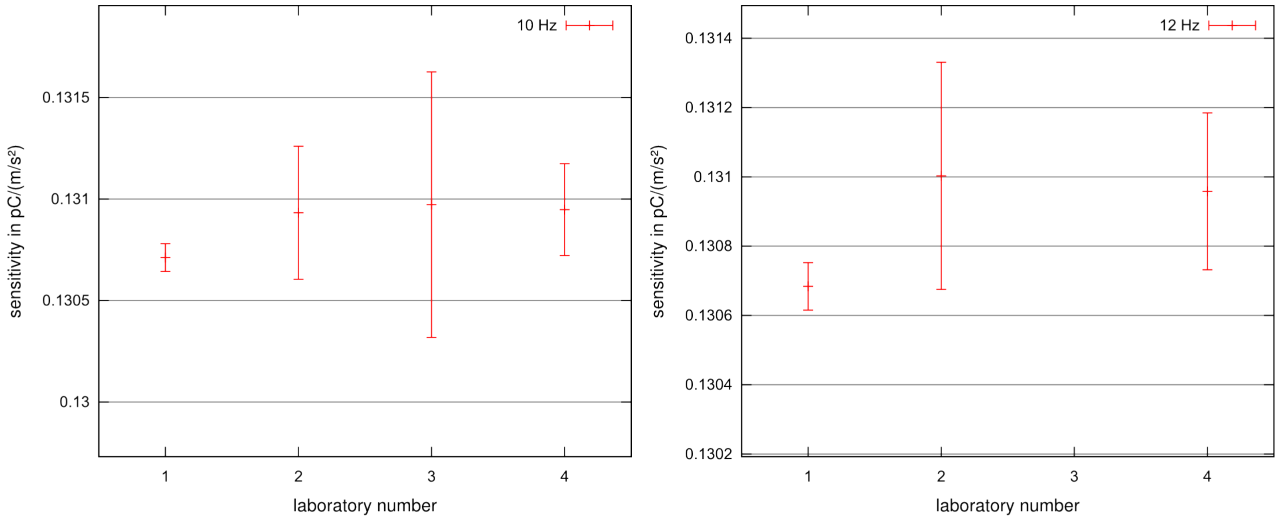


Fig. 21: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

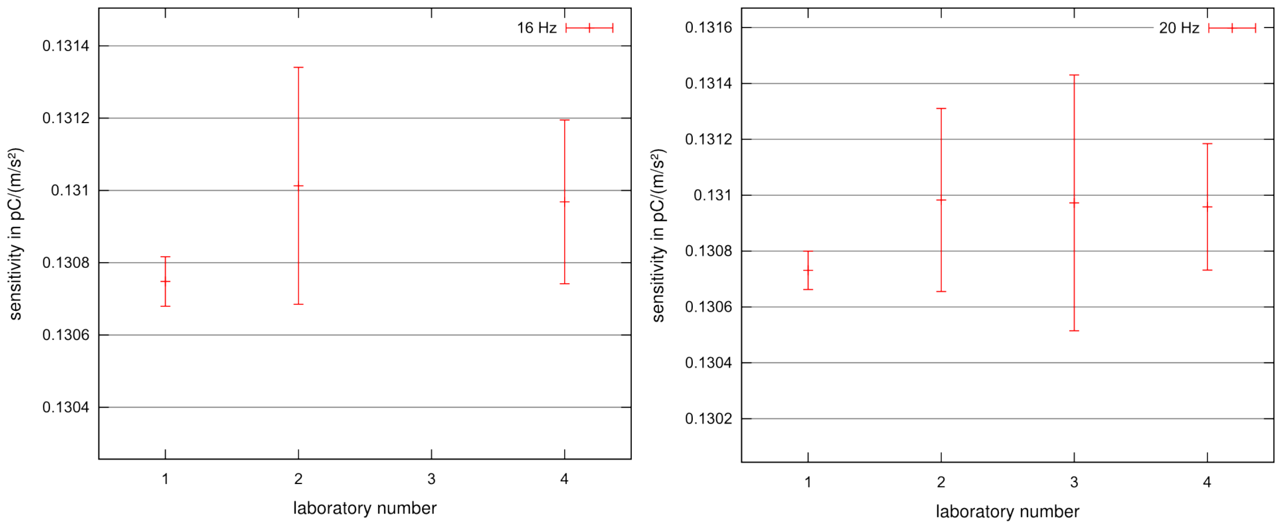


Fig. 22: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

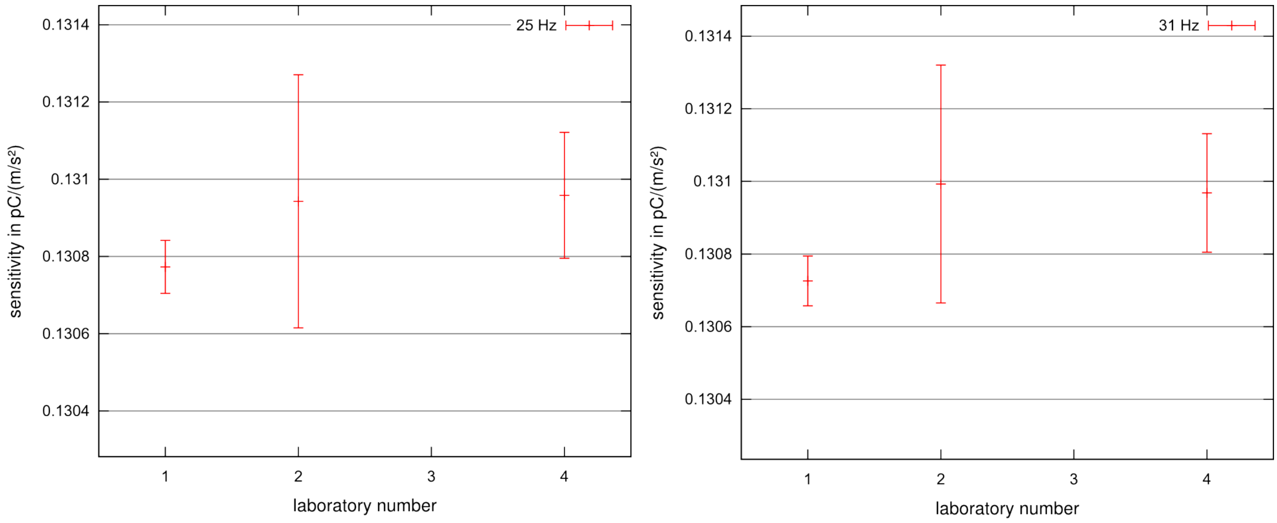


Fig. 23: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 25 Hz and 31 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

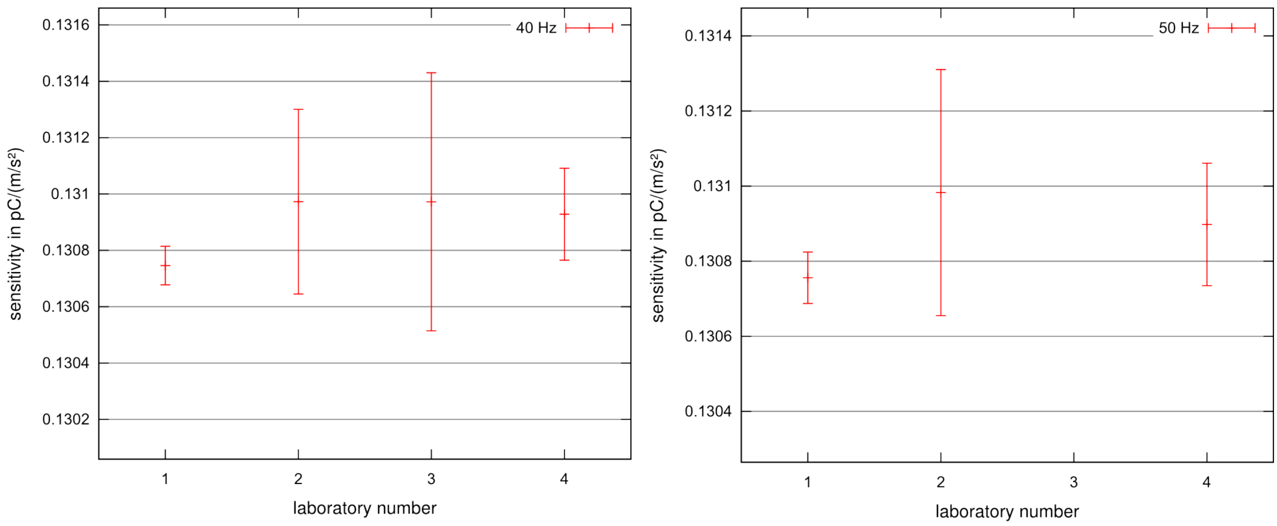


Fig. 24: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

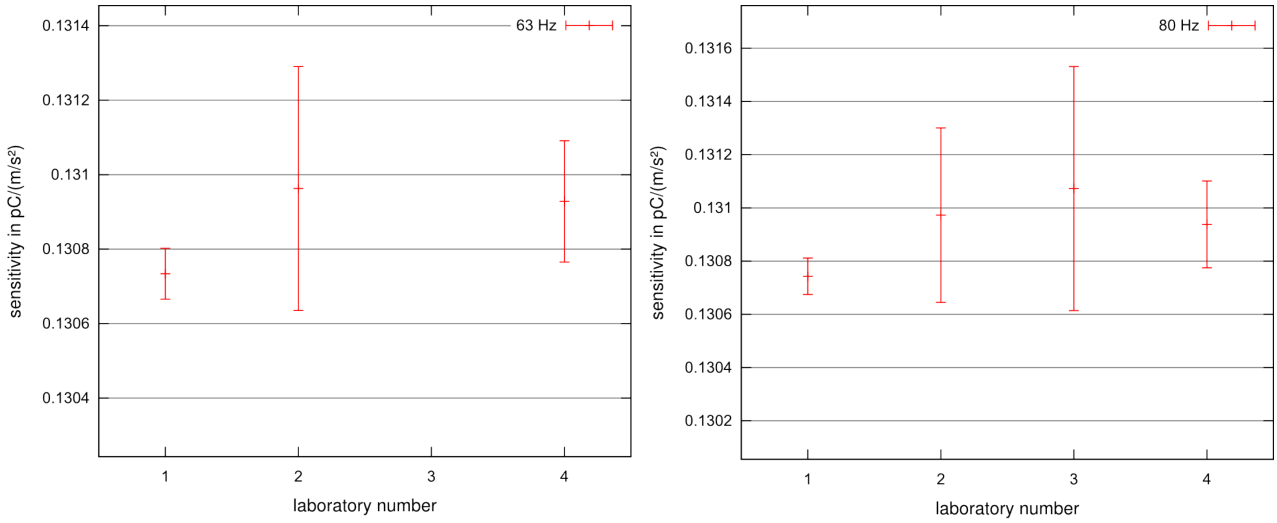


Fig. 25: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

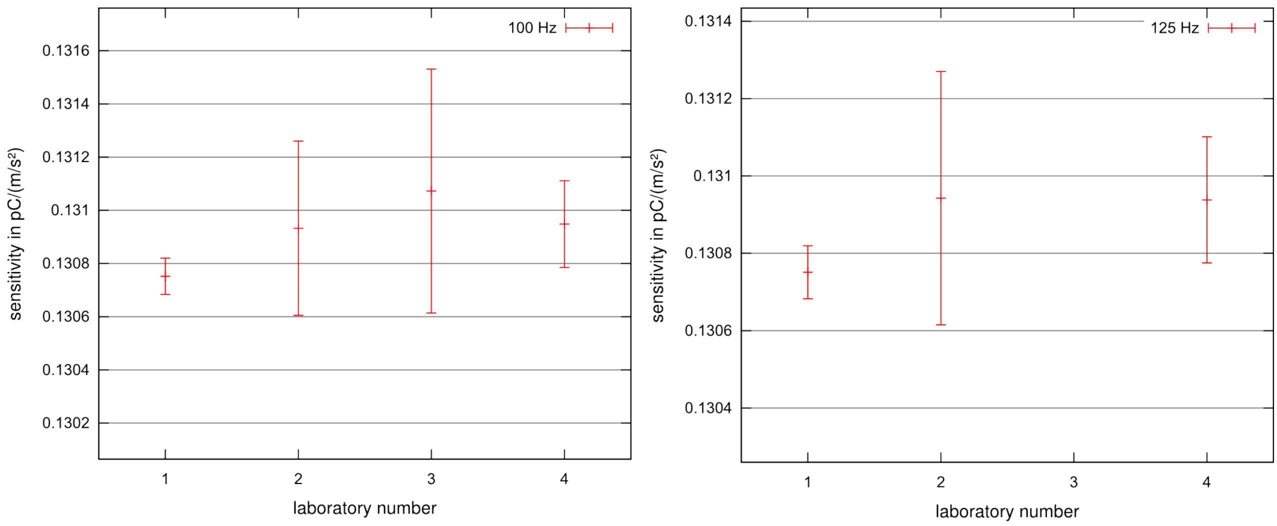


Fig. 26: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

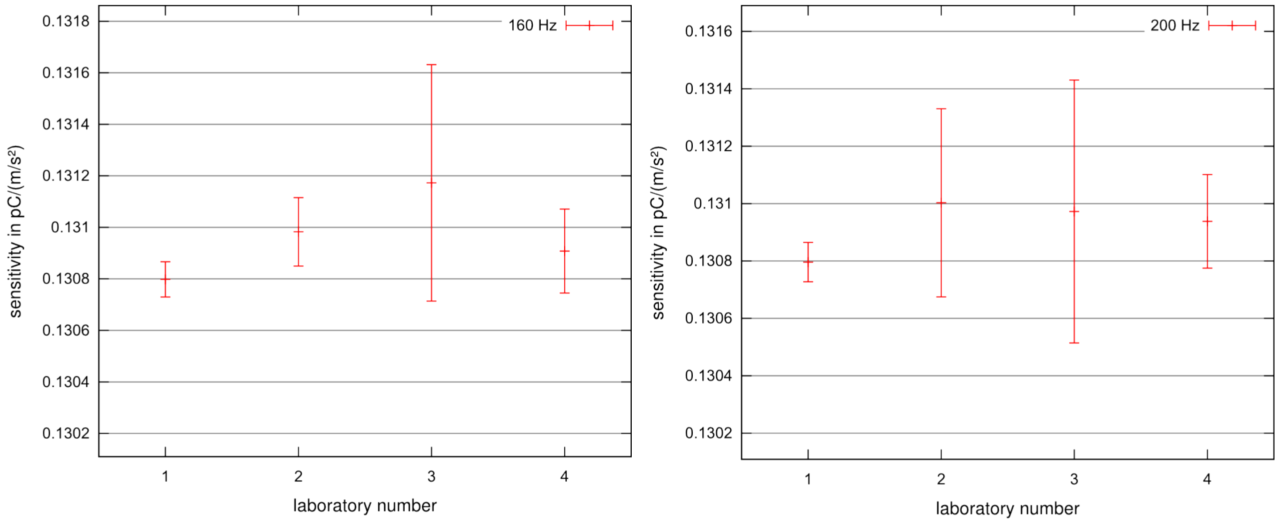


Fig. 27: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

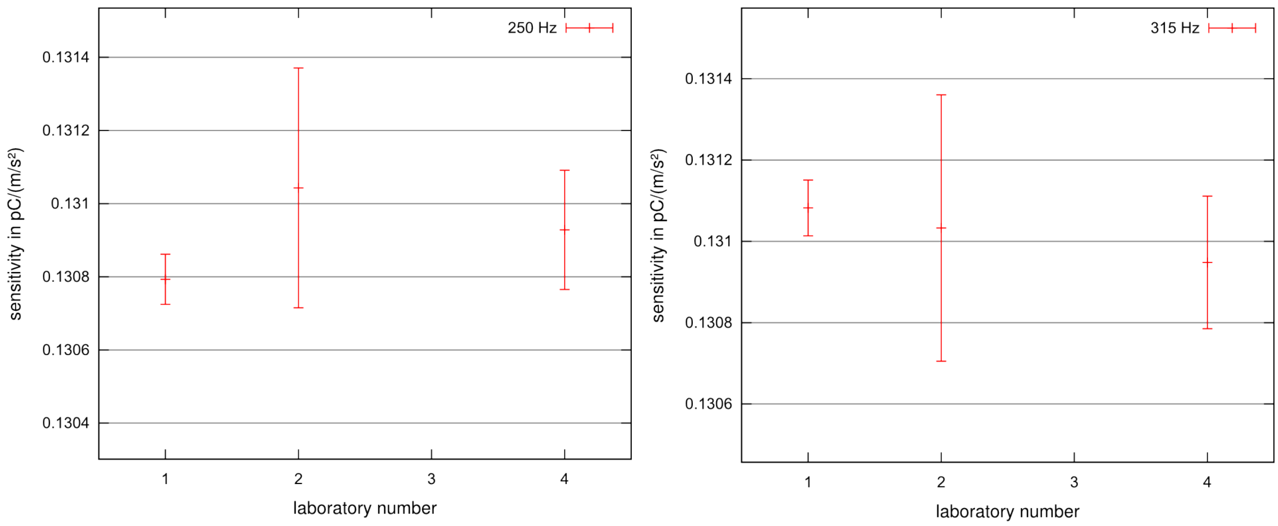


Fig. 28: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

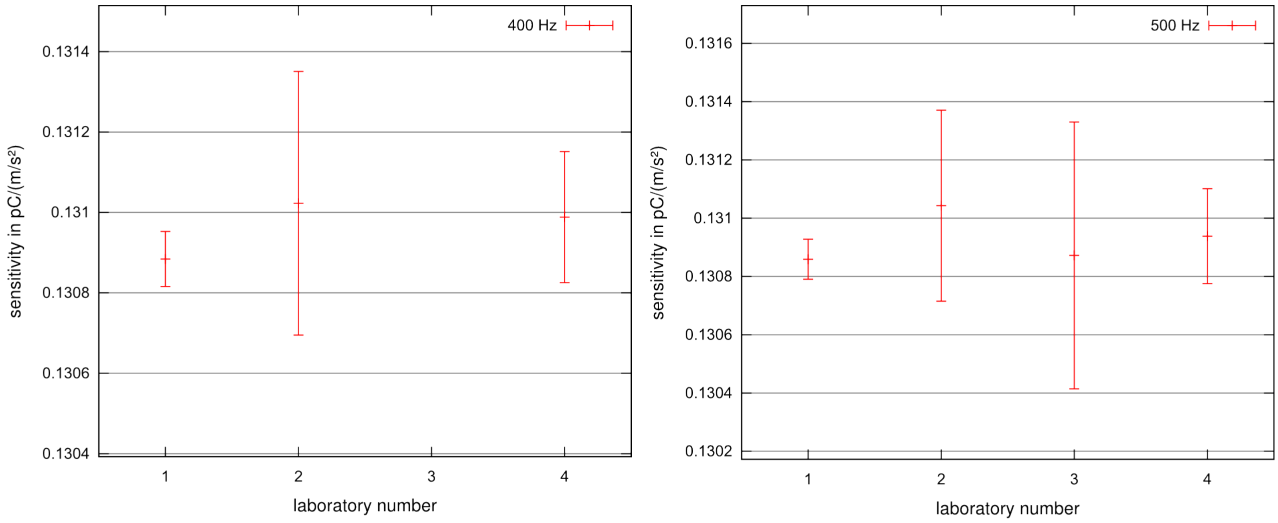


Fig. 29: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

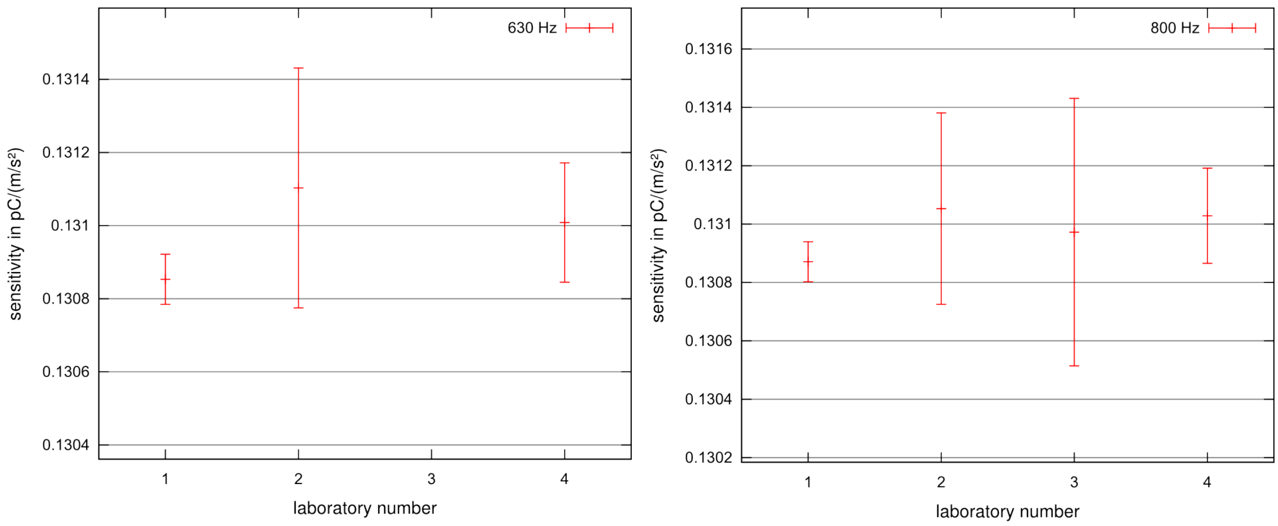


Fig. 30: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

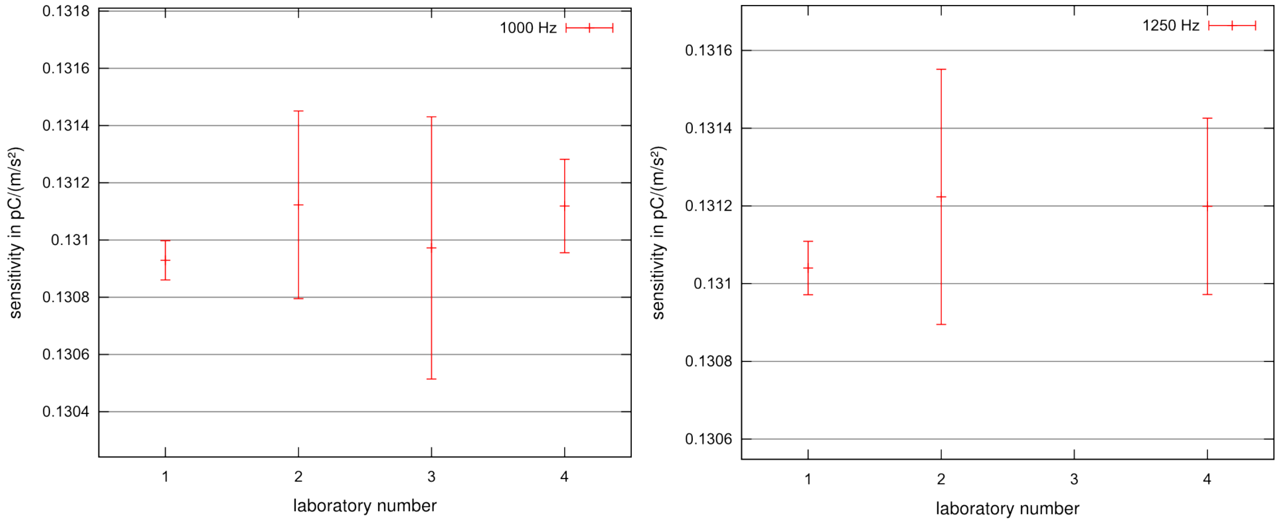


Fig. 31: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

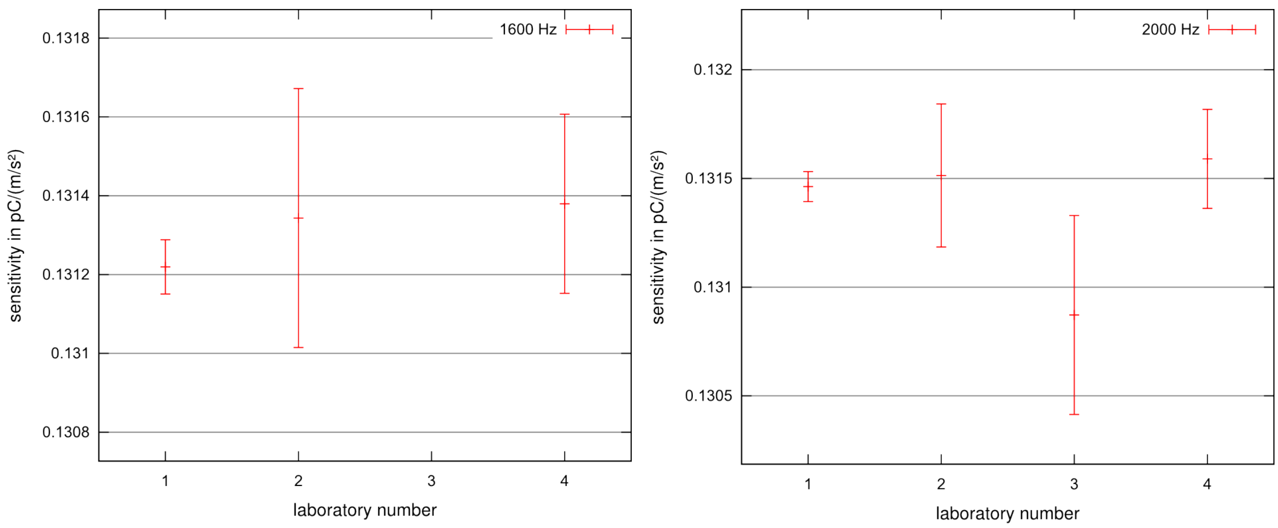


Fig. 32: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

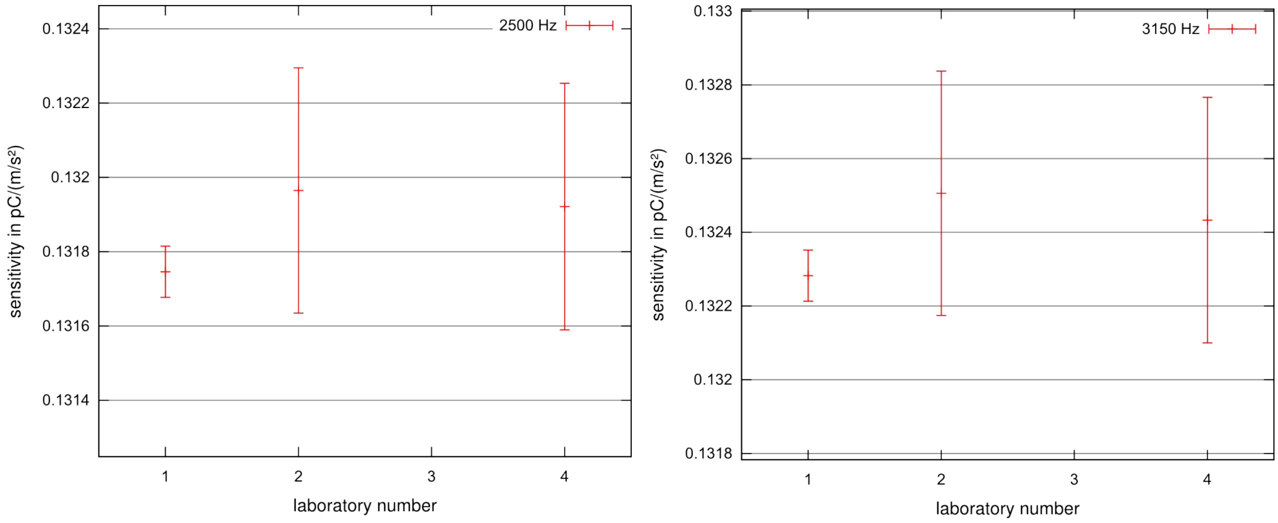


Fig. 33: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

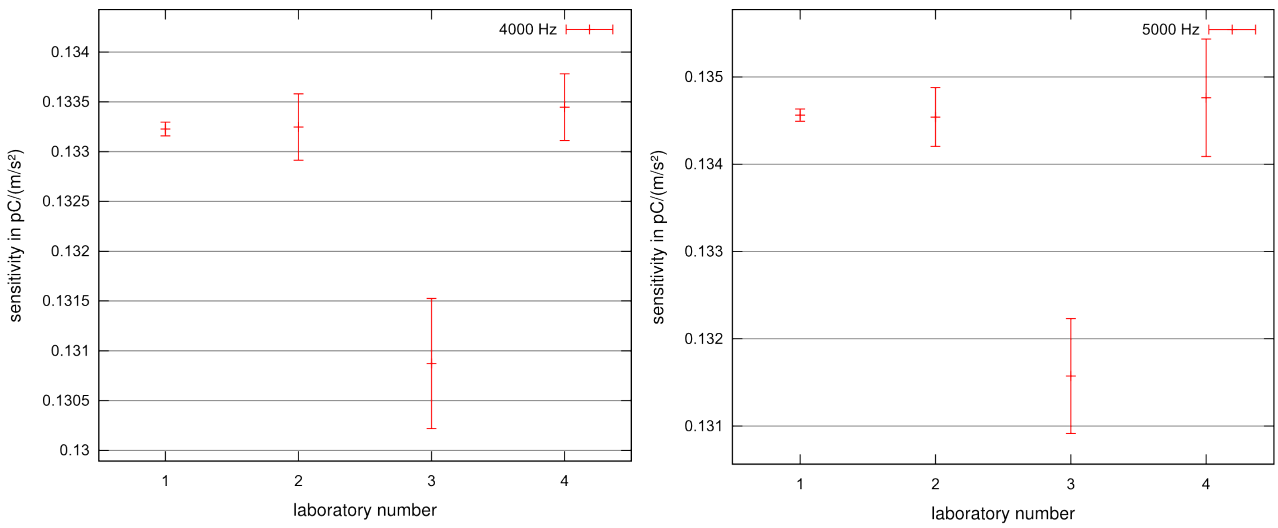


Fig. 34: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

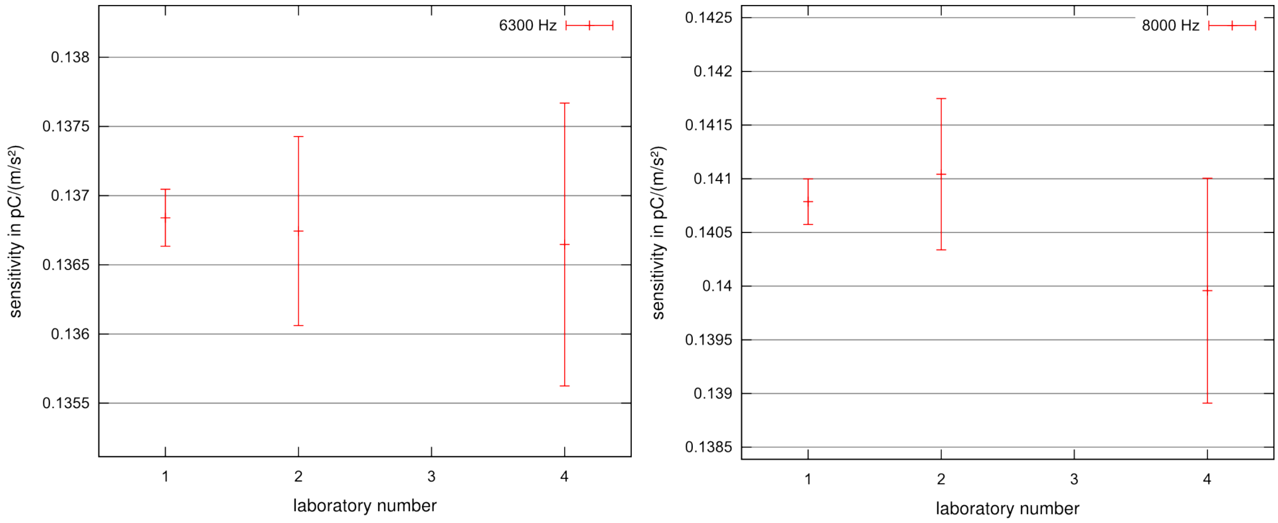


Fig. 35: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

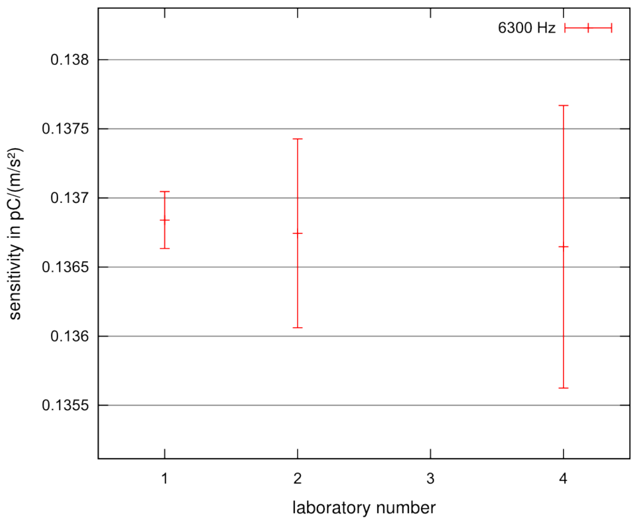


Fig. 36: Charge sensitivity of the SE transducer in pC/(m/s²) after correction of the drift for 10000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

7.4.3 Consistency of Results for the SE-Accelerometer

In order to check for consistency of the data a Chi-squared test was performed (c.f. [4]). This test revealed that for high frequencies the data were inconsistent if all participants results were included. This was already suggested by the outliers in fig. 18 , an indication of the cause for the inconsistency can be drawn by elimination of each laboratory in turn from the chi-squared test and re-checking with only the remaining participants. The results from this testing before drift correction are shown in Table 10. For those frequencies, where the data were consistent, columns 5 to 8 indicate which laboratory did report (+) results for the respective frequency and which did not (-). Table 11 shows the consistency after application of the drift correction.

Table 10: results of the consistency test for the reported results with the columns: frequency, X^2_{max} limit for *n*-1 degrees of freedom (*df*), X^2 calculated from the reported results, X^2 calculated from the reported results excluding the participant named in the header, X^2_{max} limit for *n*-2 degrees of freedom (*df*)

frequency in Hz	num. of particip. *n*	X^2_{max} (*df* = n-1)	calculated X^2	X^2 without PTB	X^2 without NIM	X^2 without NPLI	X^2 without INMETRO	X^2_{max} (*df* = n-2)
10	4	9,49	0,2	+	+	+	+	
12,5	3	7,81	0,38	+	+	-	+	
16	3	7,81	0,31	+	+	-	+	
20	4	9,49	0,31	+	+	+	+	
25	3	7,81	0,44	+	+	-	+	
31,5	3	7,81	0,31	+	+	-	+	
40	4	9,49	0,61	+	+	+	+	
50	3	7,81	0,94	+	+	-	+	
63	3	7,81	0,48	+	+	-	+	
80	4	9,49	0,67	+	+	+	+	
100	4	9,49	0,56	+	+	+	+	
125	3	7,81	0,46	+	+	-	+	
160	4	9,49	1,88	+	+	+	+	
200	4	9,49	0,91	+	+	+	+	
250	3	7,81	1,08	+	+	-	+	
315	3	7,81	6,39	+	+	-	+	
400	3	7,81	1,25	+	+	-	+	
500	4	9,49	1,71	+	+	+	+	
630	3	7,81	0,86	+	+	-	+	
800	4	9,49	0,7	+	+	+	+	
1000	4	9,49	0,48	+	+	+	+	
1250	3	7,81	0,39	+	+	-	+	
1600	3	7,81	0,33	+	+	-	+	
2000	4	9,49	2,91	+	+	+	+	
2500	3	7,81	0,23	+	+	-	+	
3150	3	7,81	0,29	+	+	-	+	
4000	4	9,49	14,45	11,96	14,4	0,13	14,43	5,99
5000	4	9,49	22,49	17,13	22,39	0,19	22,48	5,99
6300	3	7,81	0,30	+	+	-	+	
8000	3	7,81	1,2	+	+	-	+	
10000	3	7,81	0,54	+	+	-	+	

Table 11: results of the consistency test after Drift correction for the detrended results with the columns: frequency, X^2_{max} limit for *n*-1 degrees of freedom (*df*), X^2 calculated from the reported results, X^2 calculated from the reported results excluding the participant named in the header, X^2_{max} limit for *n*-2 degrees of freedom (*df*)

frequency in Hz	num. of particip. *n*	X^2_{max} (*df* = n-1)	calculated X^2	X^2 without PTB	X^2 without NIM	X^2 without NPLI	X^2 without INMETRO	X^2_{max} (*df* = n-2)
10	4	9,49	1,48	+	+	+	+	
12,5	3	7,81	2,13	+	+	-	+	
16	3	7,81	1,41	+	+	-	+	
20	4	9,49	1,62	+	+	+	+	
25	3	7,81	1,28	+	+	-	+	
31,5	3	7,81	2,35	+	+	-	+	
40	4	9,49	1,59	+	+	+	+	
50	3	7,81	1,02	+	+	-	+	
63	3	7,81	1,56	+	+	-	+	
80	4	9,49	1,98	+	+	+	+	
100	4	9,49	1,82	+	+	+	+	
125	3	7,81	1,36	+	+	-	+	
160	4	9,49	2,20	+	+	+	+	
200	4	9,49	1,06	+	+	+	+	
250	3	7,81	1,06	+	+	-	+	
315	3	7,81	0,58	+	+	-	+	
400	3	7,81	0,48	+	+	-	+	
500	4	9,49	0,47	+	+	+	+	
630	3	7,81	1,23	+	+	-	+	
800	4	9,49	1,04	+	+	+	+	
1000	4	9,49	1,39	+	+	+	+	
1250	3	7,81	0,71	+	+	-	+	
1600	3	7,81	0,56	+	+	-	+	
2000	4	9,49	2,00	+	+	+	+	
2500	3	7,81	0,66	+	+	-	+	
3150	3	7,81	0,61	+	+	-	+	
4000	4	9,49	13,37	12,85	13,36	0,41	12,86	5,99
5000	4	9,49	20,57	17,44	20,57	0,09	20,46	5,99
6300	3	7,81	0,05	+	+	-	+	
8000	3	7,81	0,76	+	+	-	+	
10000	3	7,81	0,26	+	+	-	+	

7.4.4 The Back-to-Back Accelerometer S/N 2161771

This section presents the results for the B2B accelerometer in the equivalent way as section 7.4.1.

Table 12: reported calibration results in pC/(m/s²) of the participants for the B2B transducer with expanded relative uncertainty (*k* = 2) in %.

	PTB		NIM		NPLI		INMETRO	
frequency	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %	S_{qa} in pC/ (m/s²)	rel. exp. unc. in %
10	0,12606	0,10	0,12589	0,50	0,12620	1,00	0,12604	0,34
12,5	0,12616	0,10	0,12592	0,50	-	-	0,12604	0,34
16	0,12602	0,10	0,12599	0,50	-	-	0,12603	0,34
20	0,12601	0,10	0,12594	0,50	0,12610	0,70	0,12601	0,34
25	0,12609	0,10	0,12598	0,50	-	-	0,12602	0,24
31,5	0,12605	0,10	0,12603	0,50	-	-	0,12603	0,24
40	0,12598	0,10	0,12601	0,50	0,12610	0,70	0,12598	0,24
50	0,12586	0,10	0,12562	0,50	-	-	0,12596	0,24
63	0,12598	0,10	0,12584	0,50	-	-	0,12599	0,24
80	0,12600	0,10	0,12594	0,50	0,12620	0,70	0,12600	0,24
100	0,12597	0,10	0,12599	0,50	0,12620	0,70	0,12601	0,24
125	0,12601	0,10	0,12600	0,50	-	-	0,12601	0,24
160	0,12606	0,10	0,12604	0,20	0,12630	0,70	0,12603	0,24
200	0,12617	0,10	0,12606	0,50	0,12610	0,70	0,12604	0,24
250	0,12601	0,10	0,12601	0,50	-	-	0,12603	0,24
315	0,12619	0,10	0,12609	0,50	-	-	0,12605	0,24
400	0,12610	0,10	0,12611	0,50	-	-	0,12609	0,24
500	0,12606	0,10	0,12613	0,50	0,12600	0,70	0,12612	0,24
630	0,12608	0,10	0,12624	0,50	-	-	0,12614	0,24
800	0,12614	0,10	0,12622	0,50	0,12600	0,70	0,12616	0,24
1000	0,12630	0,10	0,12625	0,50	0,12600	0,70	0,12624	0,24
1250	0,12646	0,10	0,12635	0,50	-	-	0,12630	0,34
1600	0,12660	0,10	0,12639	0,50	-	-	0,12645	0,34
2000	0,12680	0,10	0,12653	0,50	0,12560	0,70	0,12659	0,34
2500	0,12710	0,10	0,12681	0,50	-	-	0,12684	0,50
3150	0,12738	0,10	0,12722	0,50	-	-	0,12718	0,50
4000	0,12804	0,10	0,12769	0,50	0,12600	1,00	0,12784	0,50
5000	0,12884	0,10	0,12851	0,50	0,12380	1,00	0,12857	1,00
6300	0,13022	0,30	0,12975	1,00	-	-	0,13016	1,50
8000	0,13281	0,30	0,13279	1,00	-	-	0,13257	1,50
10000	0,13679	0,30	0,13697	1,00	-	-	0,13664	1,50

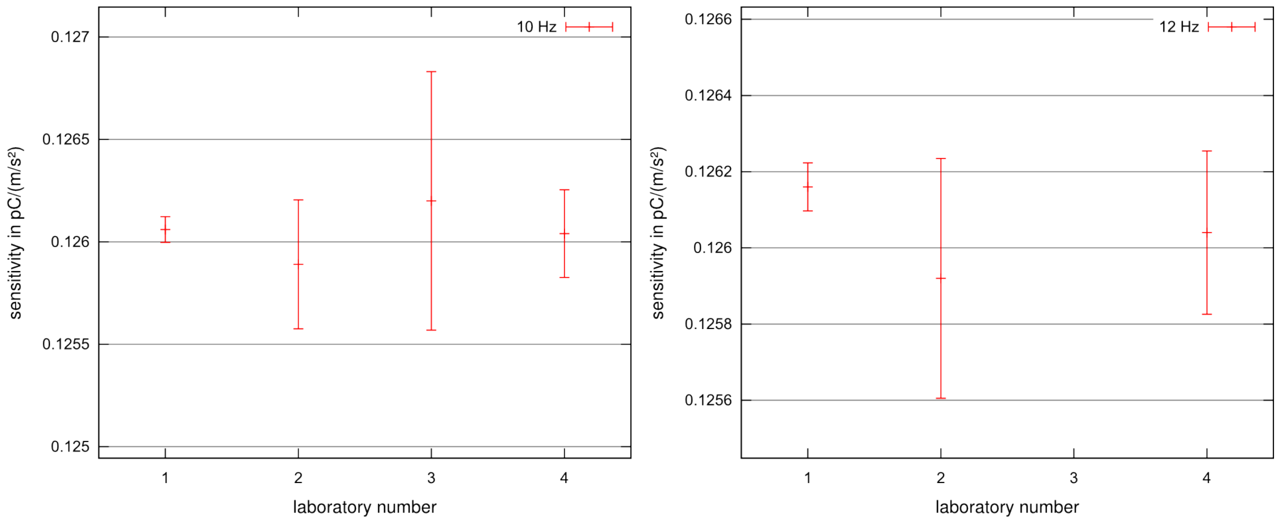


Fig. 37: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

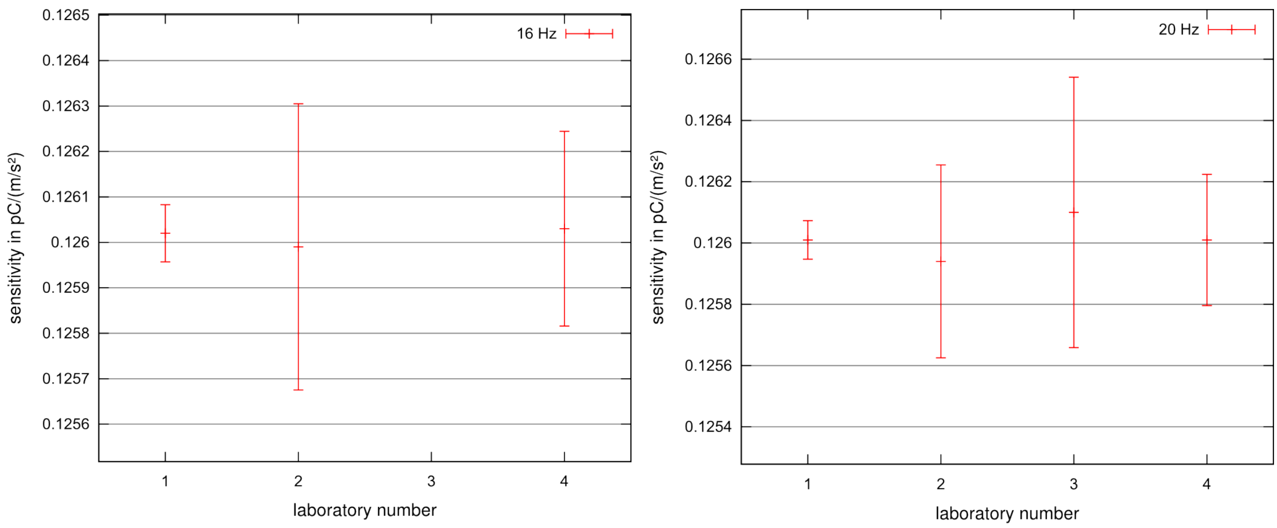


Fig. 38: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

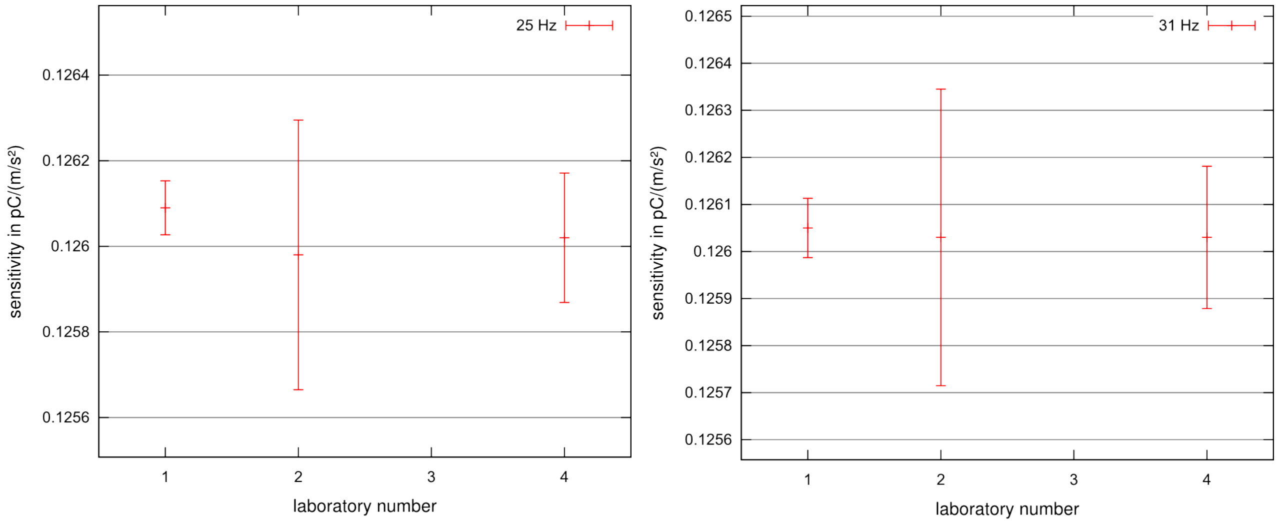


Fig. 39: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 25 Hz and 31,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

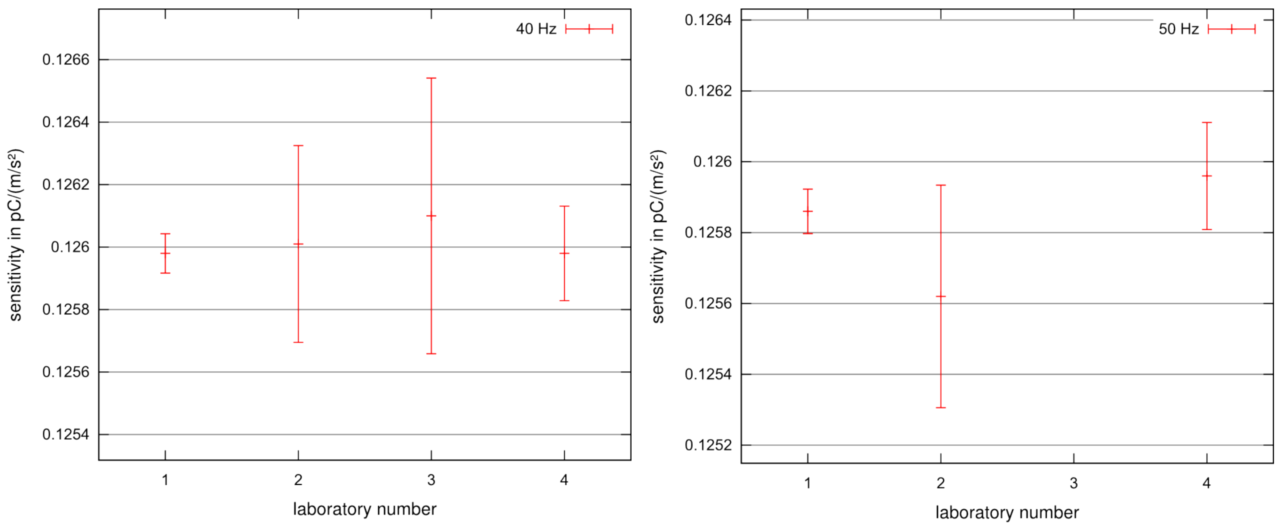


Fig. 40: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

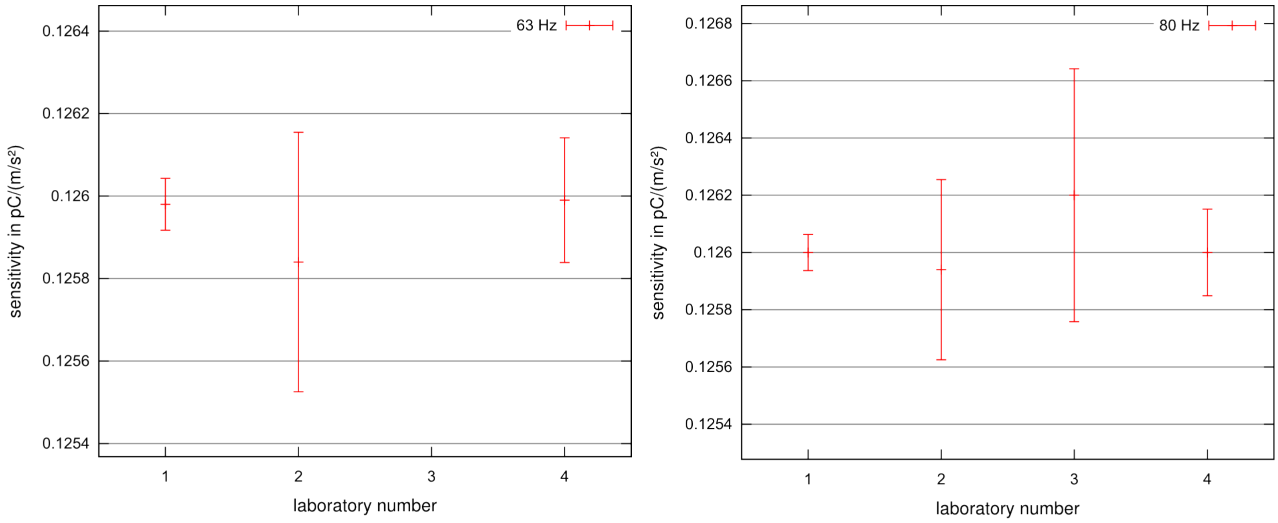


Fig. 41: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

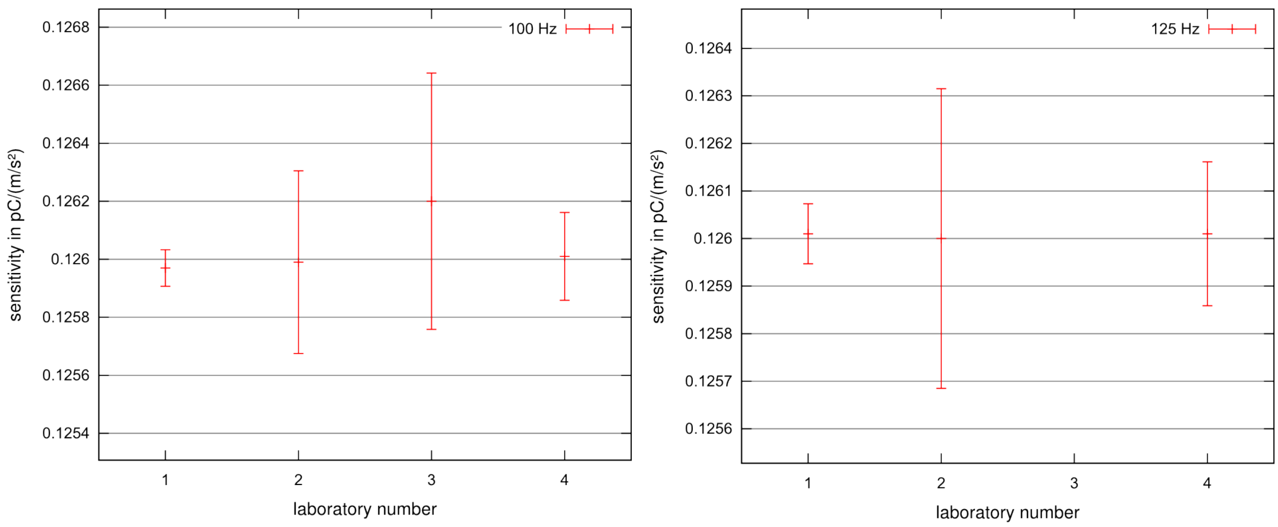


Fig. 42: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

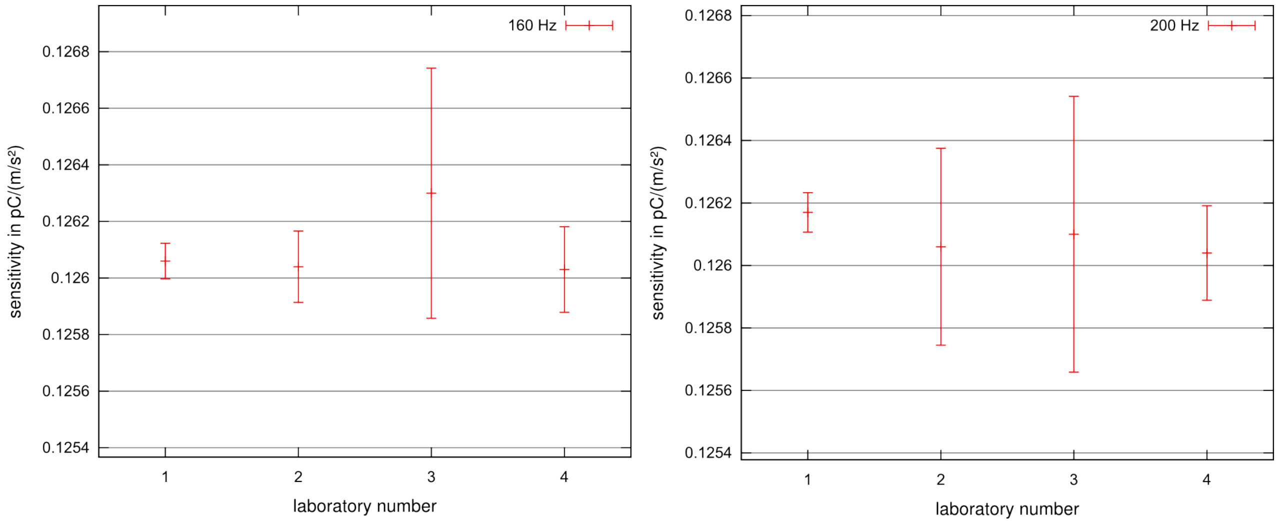


Fig. 43: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

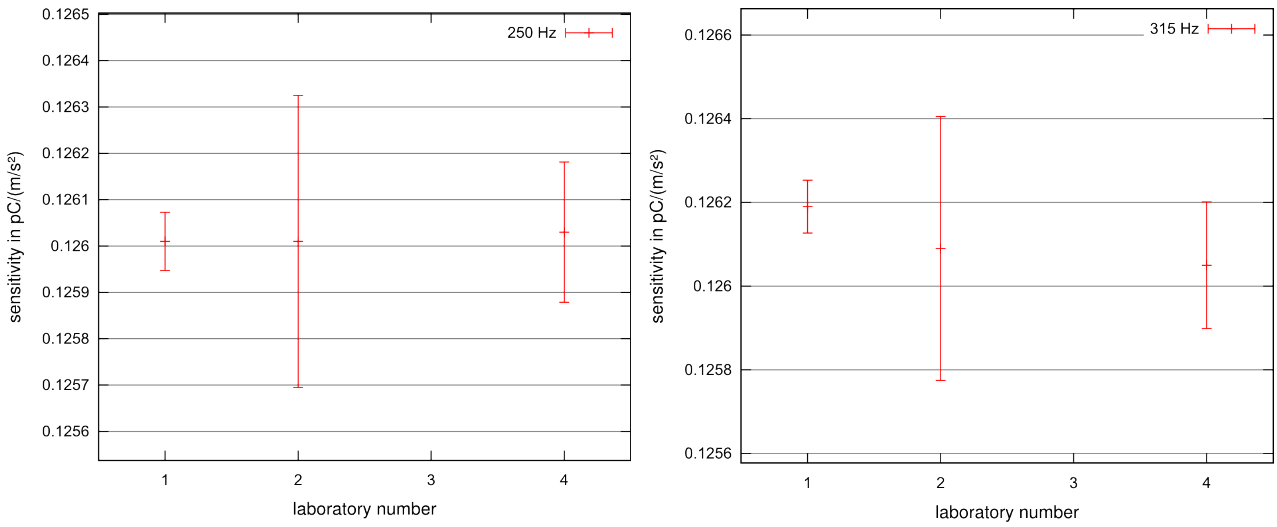


Fig. 44: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

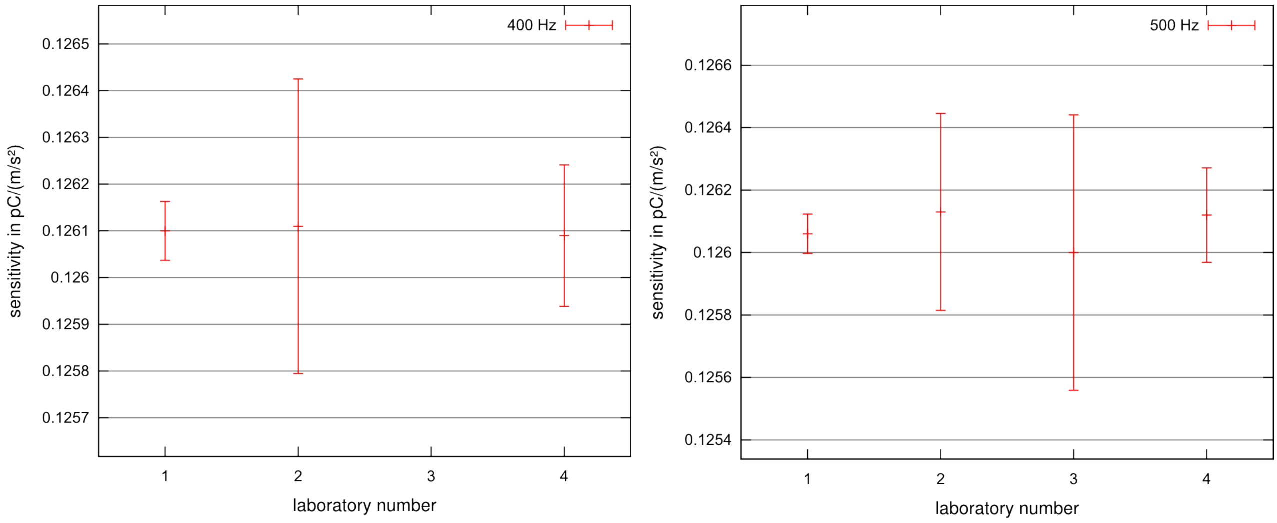


Fig. 45: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

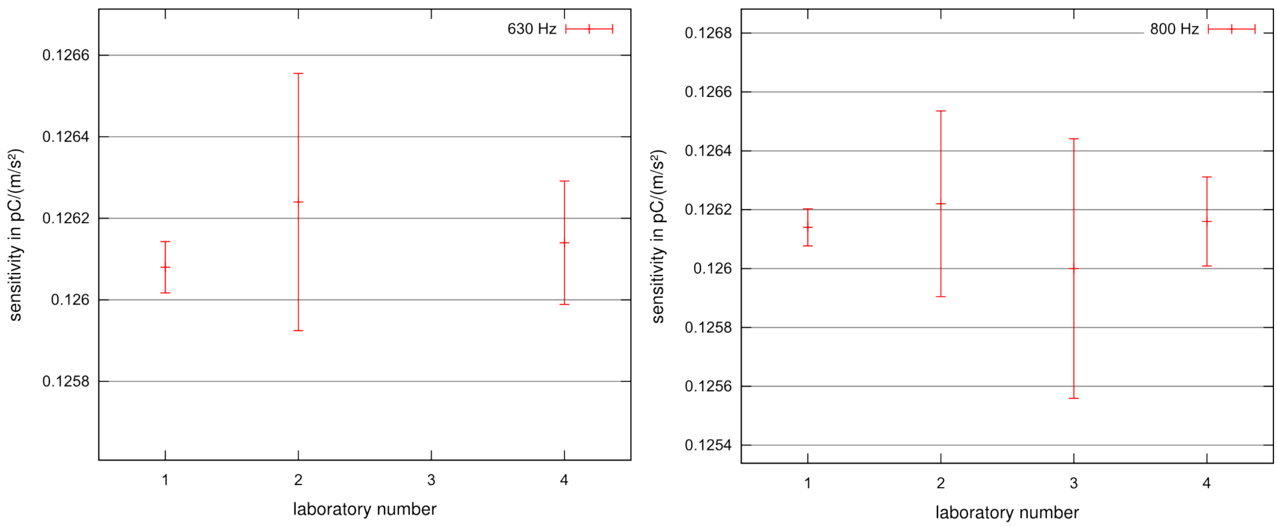


Fig. 46: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

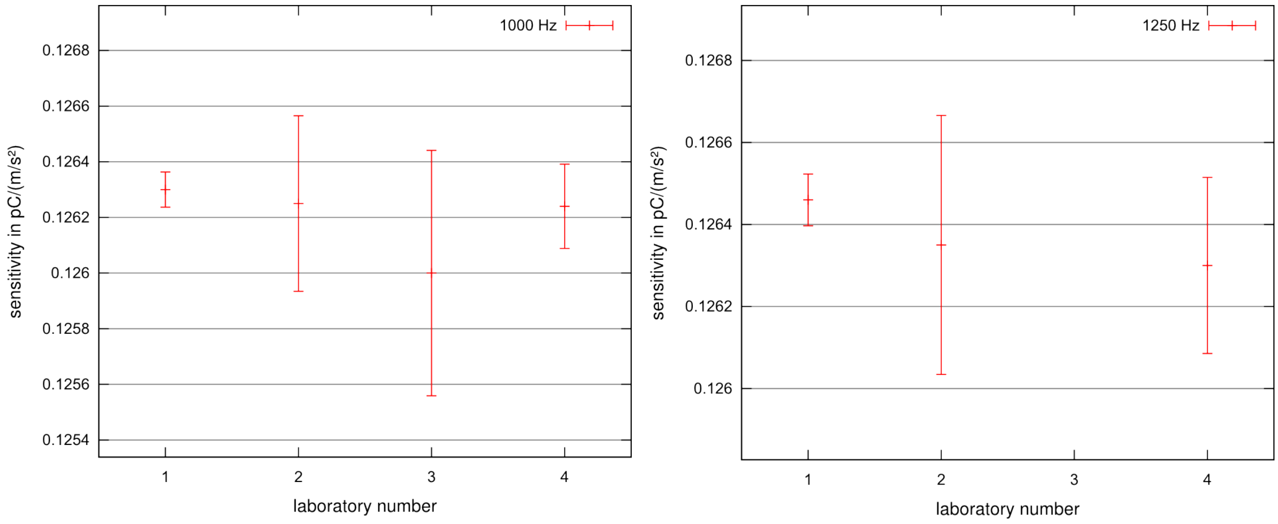


Fig. 47: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

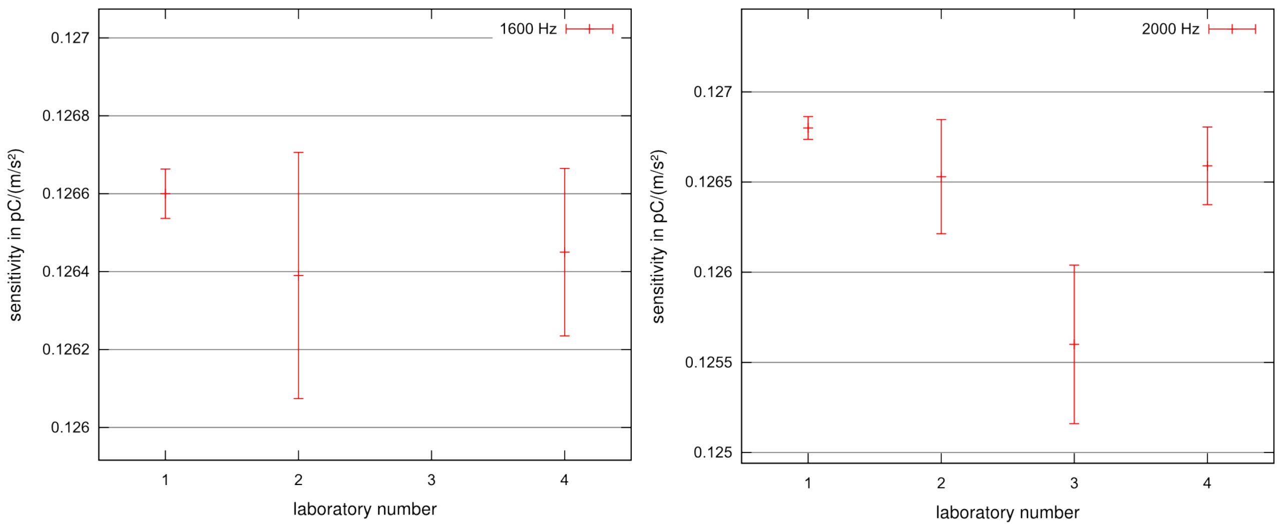


Fig. 48: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

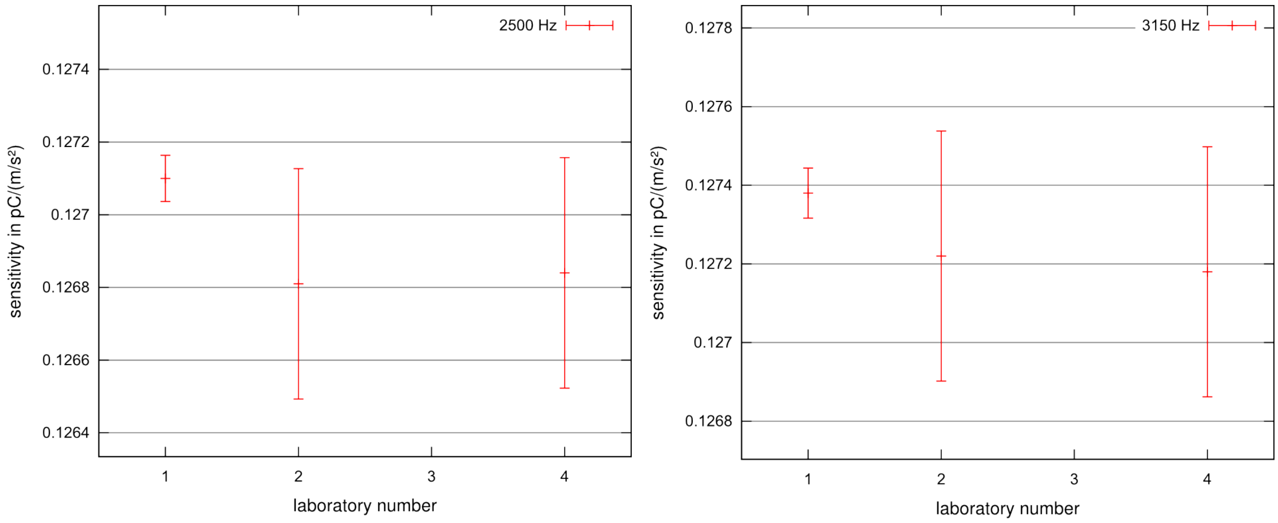


Fig. 49: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

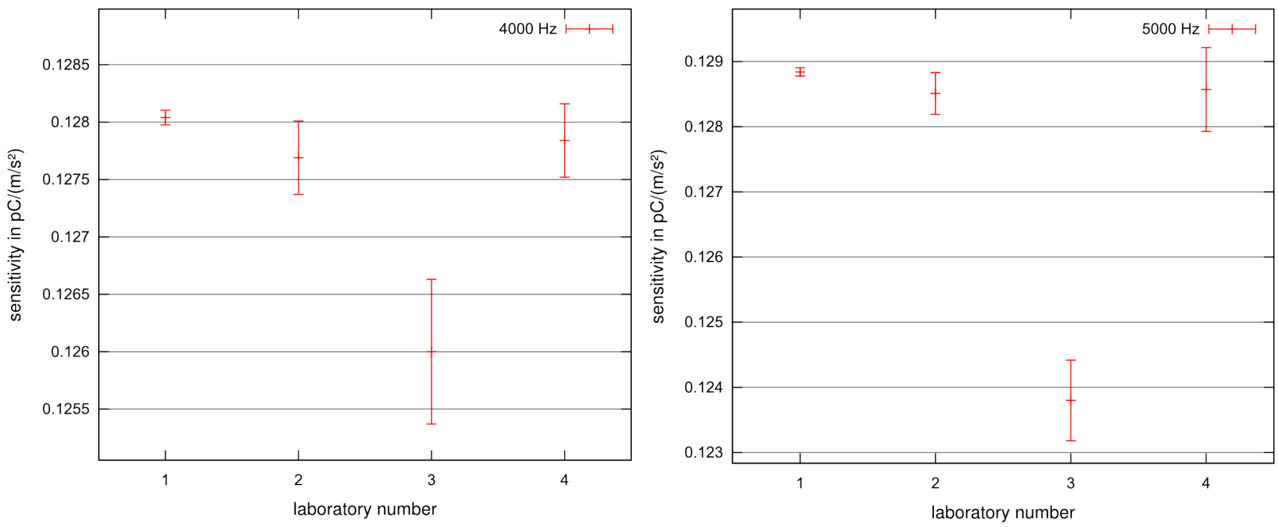


Fig. 50: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

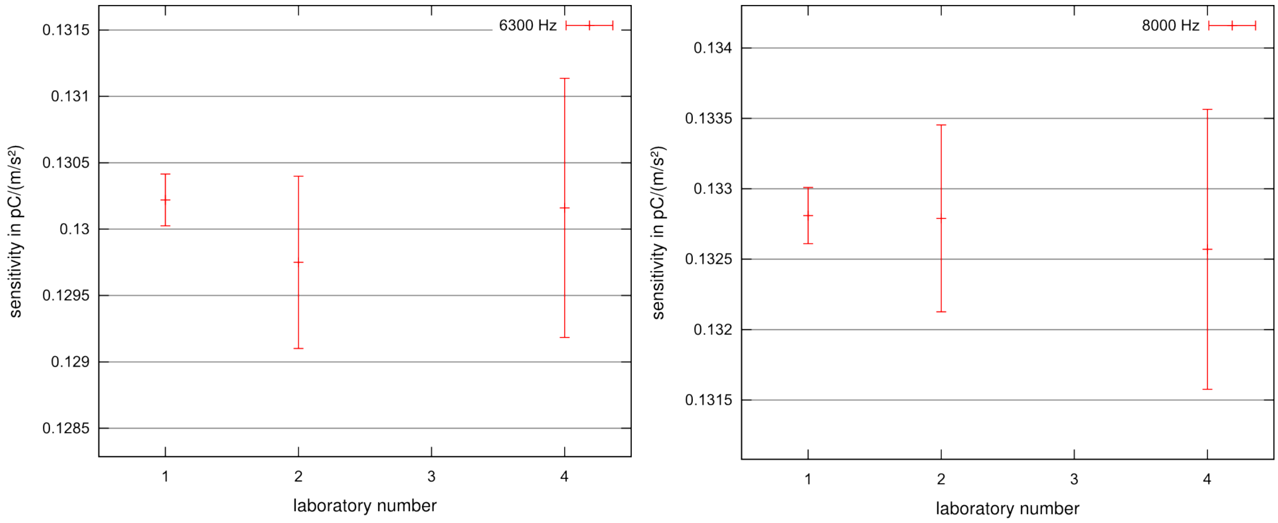


Fig. 51: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

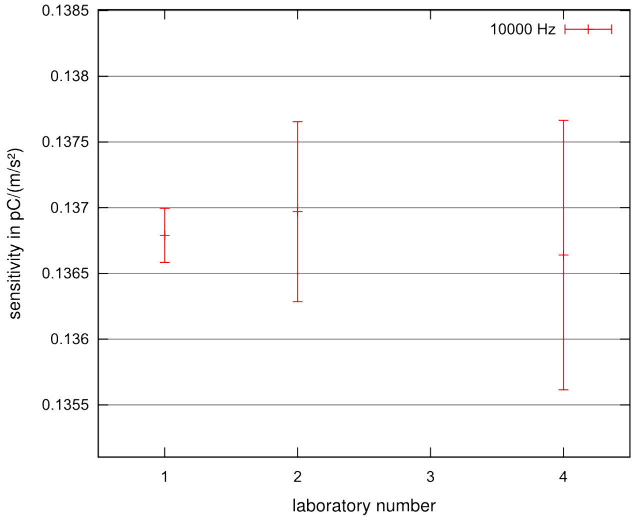


Fig. 52: Charge sensitivity of the B2B transducer in pC/(m/s²) reported by the participants for 10000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

7.4.5 Consistency of Results for the B2B-Accelerometer

In order to check for consistency of the data the same statistical test as described already in 7.4.3 was performed for the B2B accelerometer results. In case of inconsistency, again an indication of the cause can be drawn by elimination each laboratory in turn from the chi-squared test and checking for the three others. The results from this testing are shown in table 13.

Table 13: results of the consistency test after Drift correction for the reported results with the columns: frequency, X^2_{max} limit for *n*-1 degrees of freedom (*df*), X^2 calculated from the reported results, X^2 calculated from the reported results excluding the participant named in the header, X^2_{max} limit for *n*-2 degrees of freedom (*df*)

frequency in Hz	num. of particip. *n*	X^2_{max} (*df* = n-1)	calculated X^2	X^2 without PTB	X^2 without NIM	X^2 without NPLI	X^2 without INMETRO	X^2_{max} (*df* = n-2)
10	4	9,49	0,34	+	+	+	+	
12,5	3	7,81	0,81	+	+	-	+	
16	3	7,81	0,01	+	+	-	+	
20	4	9,49	0,09	+	+	+	+	
25	3	7,81	0,28	+	+	-	+	
31,5	3	7,81	0,02	+	+	-	+	
40	4	9,49	0,08	+	+	+	+	
50	3	7,81	1,01	+	+	-	+	
63	3	7,81	0,2	+	+	-	+	
80	4	9,49	0,24	+	+	+	+	
100	4	9,49	0,31	+	+	+	+	
125	3	7,81	0	+	+	-	+	
160	4	9,49	0,35	+	+	+	+	
200	4	9,49	0,72	+	+	+	+	
250	3	7,81	0,01	+	+	-	+	
315	3	7,81	0,79	+	+	-	+	
400	3	7,81	0,01	+	+	-	+	
500	4	9,49	0,2	+	+	+	+	
630	3	7,81	0,36	+	+	-	+	
800	4	9,49	0,18	+	+	+	+	
1000	4	9,49	0,57	+	+	+	+	
1250	3	7,81	0,6	+	+	-	+	
1600	3	7,81	0,83	+	+	-	+	
2000	4	9,49	8,5	+	+	+	+	
2500	3	7,81	1,4	+	+	-	+	
3150	3	7,81	0,6	+	+	-	+	
4000	4	9,49	11,66	7,06	10,68	1,48	11,4	5,99
5000	4	9,49	66,4	47,88	65,7	1,17	66,29	5,99
6300	3	7,81	0,5	+	+	-	+	
8000	3	7,81	0,06	+	+	-	+	
10000	3	7,81	0,09	+	+	-	+	

7.5 Results of the Participants for the Phase of the complex Sensitivity

7.5.1 Phase Measurement Results of the SE-Accelerometer

Three of the four participating laboratories were able to measure phase shift with their facilities. As an amendment, it was agreed that this results were supposed to be stated as well in the laboratories calibration report. They will be reported here as well and taken under consideration for the forthcoming analysis of degrees of equivalence DoE.

For acceleration signals $a(t)$ of the form

$$a(t)=\hat{a}\cdot\cos(\omega t+\varphi_a) \tag{5}$$

and the respective charge output signal $q(t)$ of the transducer of the form

$$q(t)=\hat{q}\cdot\cos(\omega t+\varphi_q) \tag{6}$$

the phase shift is defined according to ISO 16063-1 as

$$\Delta\varphi = \varphi_{qa} = \varphi_q-\varphi_a\cdot . \tag{7}$$

Table 14: reported calibration results in 1° of the participants for the phase shift φ_{qa} of the SE transducer with expanded uncertainty (k = 2) in 1°.

	PTB		NIM		NPLI		INMETRO	
frequency	φ_{qa} in 1°	exp. unc. in 1°	φ_{qa} in 1°	exp. unc. in 1°	φ_{qa} in 1°	exp. unc. in 1°	φ_{qa} in 1°	exp. unc. in 1°
10	-0,13	0,20	-0,05	0,50	-	-	-0,02	0,50
12,5	0,01	0,20	-0,06	0,50	-	-	-0,01	0,50
16	-0,07	0,20	-0,05	0,50	-	-	-0,01	0,50
20	0,09	0,20	-0,06	0,50	-	-	-0,01	0,50
25	0,00	0,20	-0,05	0,50	-	-	-0,01	0,50
31,5	-0,02	0,20	-0,05	0,50	-	-	-0,01	0,50
40	-0,12	0,20	-0,04	0,50	-	-	0,00	0,50
50	0,23	0,20	-0,07	0,50	-	-	0,00	0,50
63	-0,01	0,20	-0,07	0,50	-	-	0,00	0,50
80	-0,01	0,20	-0,06	0,50	-	-	0,01	0,50
100	-0,02	0,20	-0,05	0,50	-	-	0,01	0,50
125	-0,02	0,20	-0,05	0,50	-	-	0,01	0,50
160	-0,01	0,20	-0,05	0,20	-	-	-0,01	0,50
200	-0,04	0,20	-0,05	0,50	-	-	0,02	0,50
250	-0,01	0,20	0,04	0,50	-	-	0,03	0,50
315	-0,02	0,20	-0,06	0,50	-	-	0,04	0,50
400	-0,03	0,20	-0,07	0,50	-	-	0,00	0,50
500	-0,04	0,20	-0,08	0,50	-	-	0,05	0,50
630	-0,02	0,20	-0,1	0,50	-	-	0,05	0,50
800	-0,05	0,20	-0,13	0,50	-	-	0,04	0,50
1000	-0,04	0,20	-0,15	0,50	-	-	0,04	0,50
1250	-0,08	0,50	-0,18	0,75	-	-	0,05	1,00
1600	-0,11	0,50	-0,26	0,75	-	-	0,06	1,00
2000	-0,13	0,50	-0,29	0,75	-	-	0,05	1,00
2500	-0,3	0,50	-0,36	0,75	-	-	0,06	1,00
3150	-0,17	0,50	-0,43	0,75	-	-	0,09	1,00
4000	-0,33	0,50	-0,55	0,75	-	-	0,06	1,00
5000	-0,39	0,50	-0,69	0,75	-	-	0,03	1,00
6300	-0,38	0,50	-0,83	1,00	-	-	0,16	1,50
8000	-0,51	0,50	-1,00	1,00	-	-	0,01	1,50
10000	-1,03	0,50	-1,42	1,00	-	-	0,12	1,50

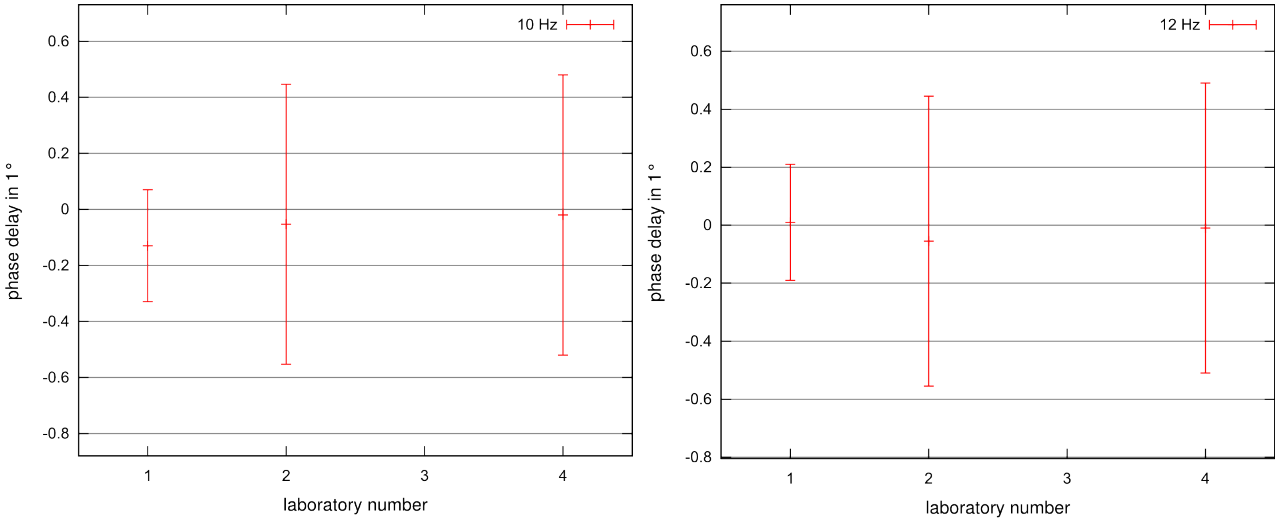


Fig. 53: Phase shift of the SE transducer in 1° reported by the participants for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

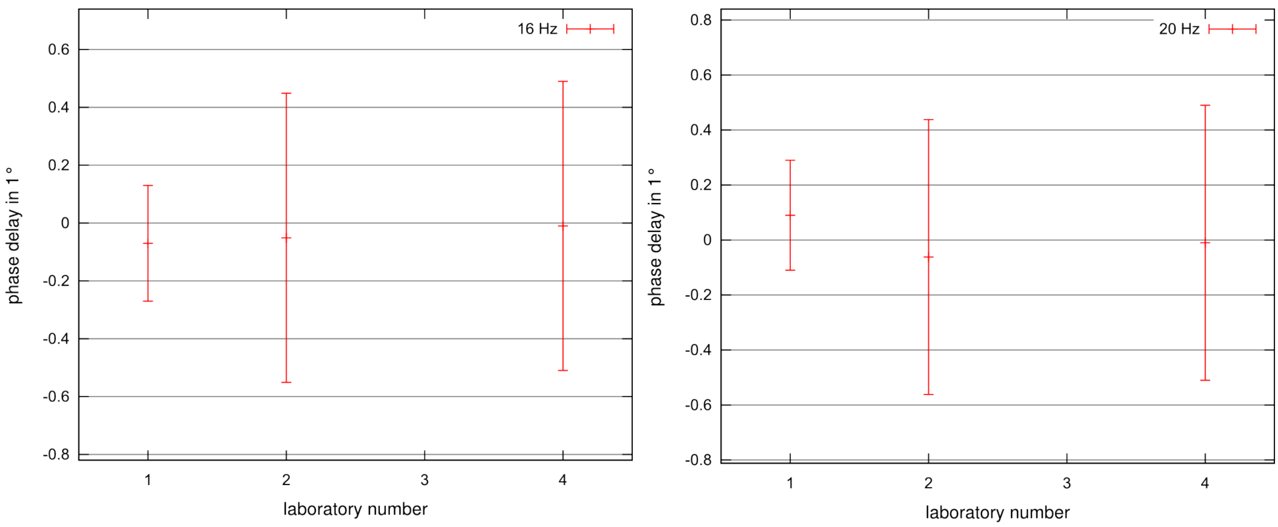


Fig. 54: Phase shift of the SE transducer in 1° reported by the participants for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

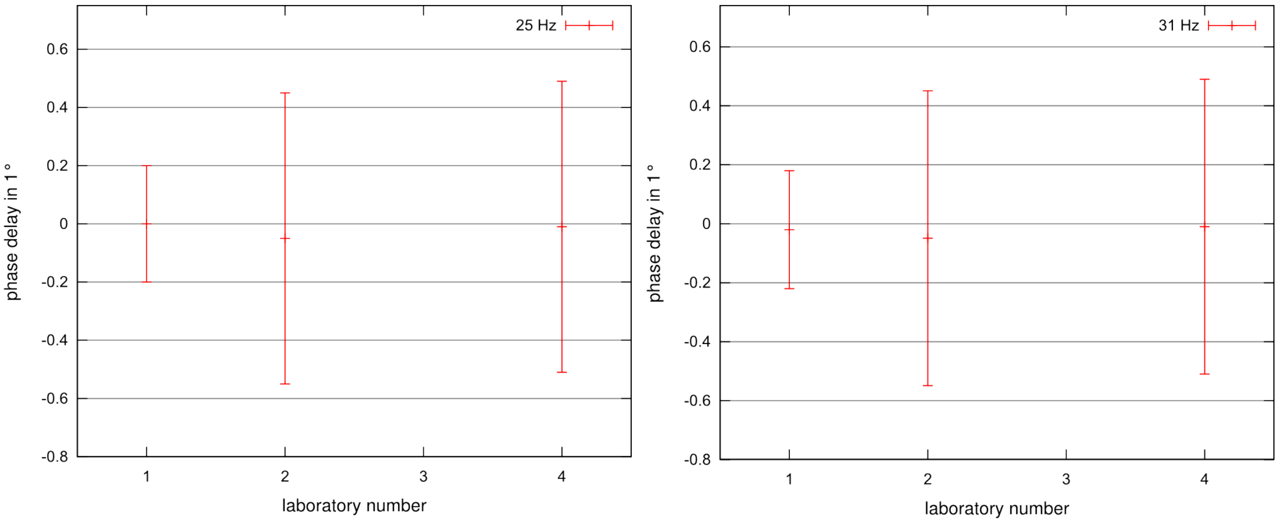


Fig. 55: Phase shift of the SE transducer in 1° reported by the participants for 25 Hz and 31,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

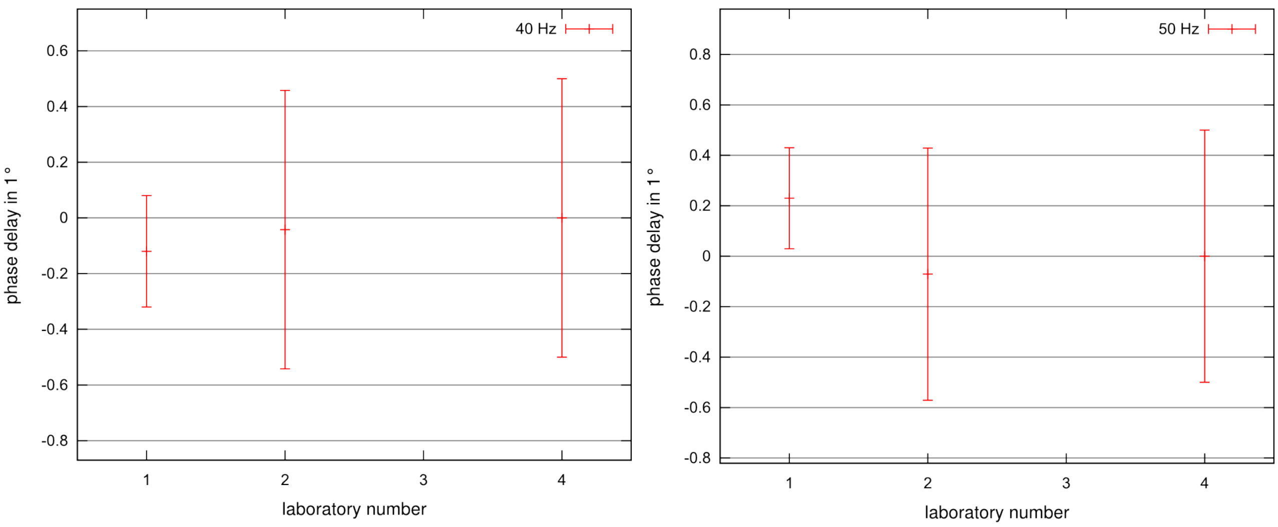


Fig. 56: Phase shift of the SE transducer in 1° reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

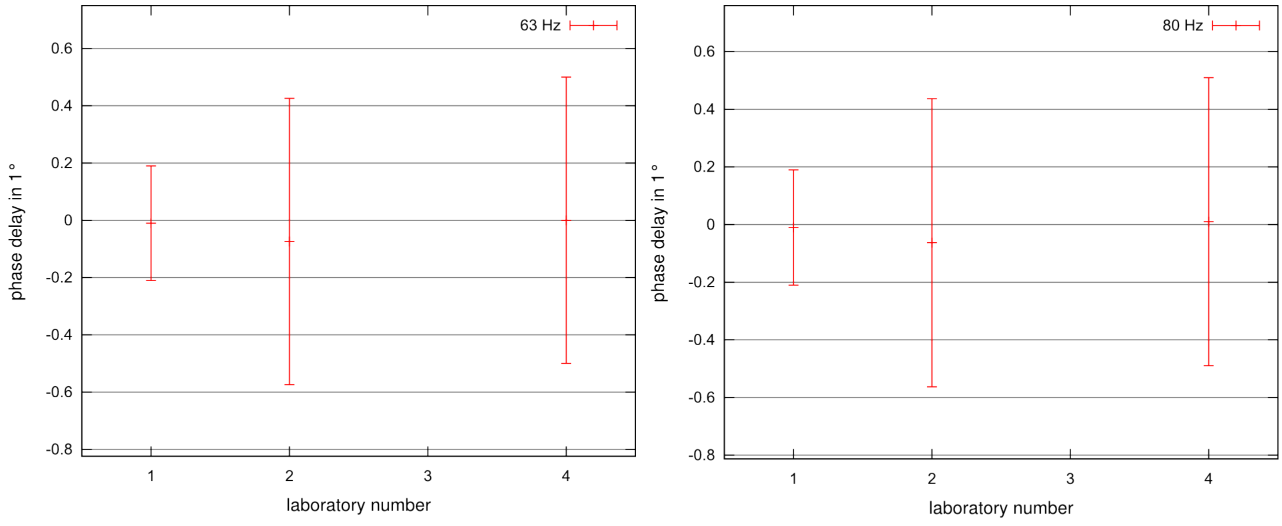


Fig. 57: Phase shift of the SE transducer in 1° reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

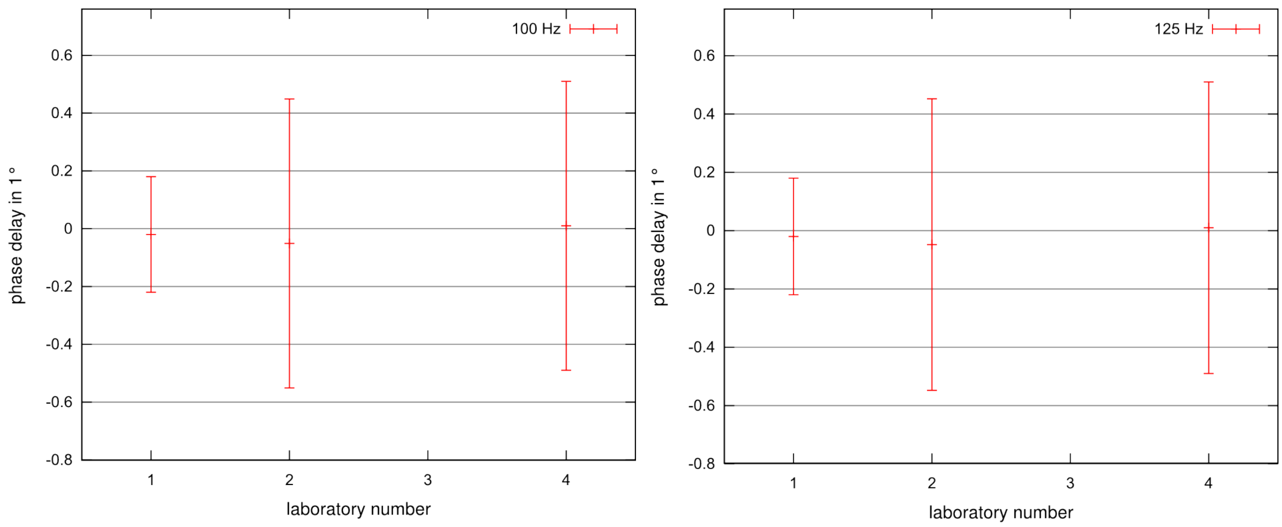


Fig. 58: Phase shift of the SE transducer in 1° reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

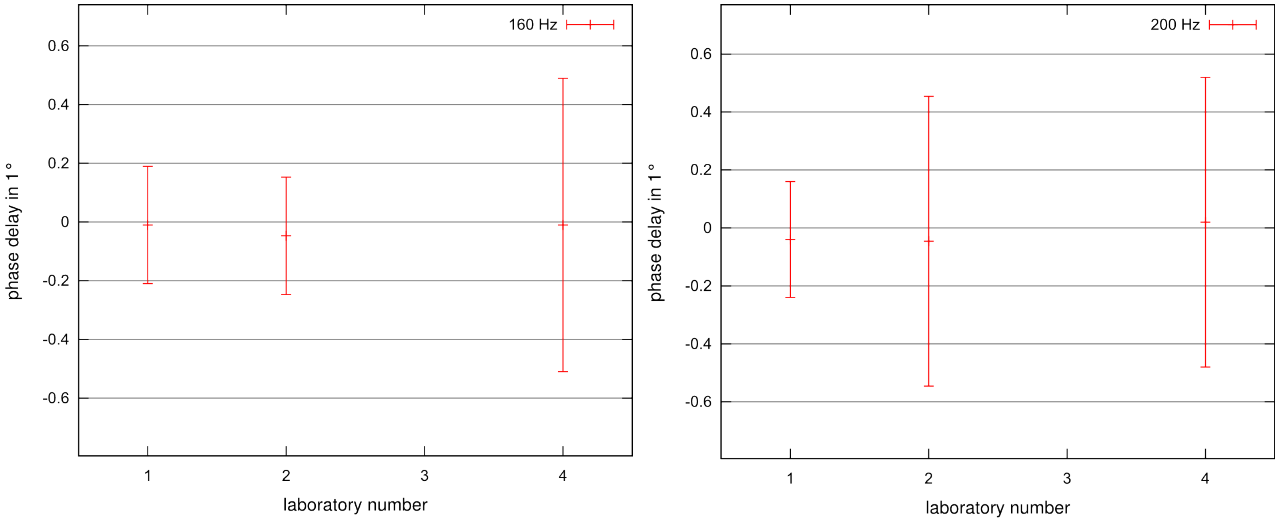


Fig. 59: Phase shift of the SE transducer in 1° reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

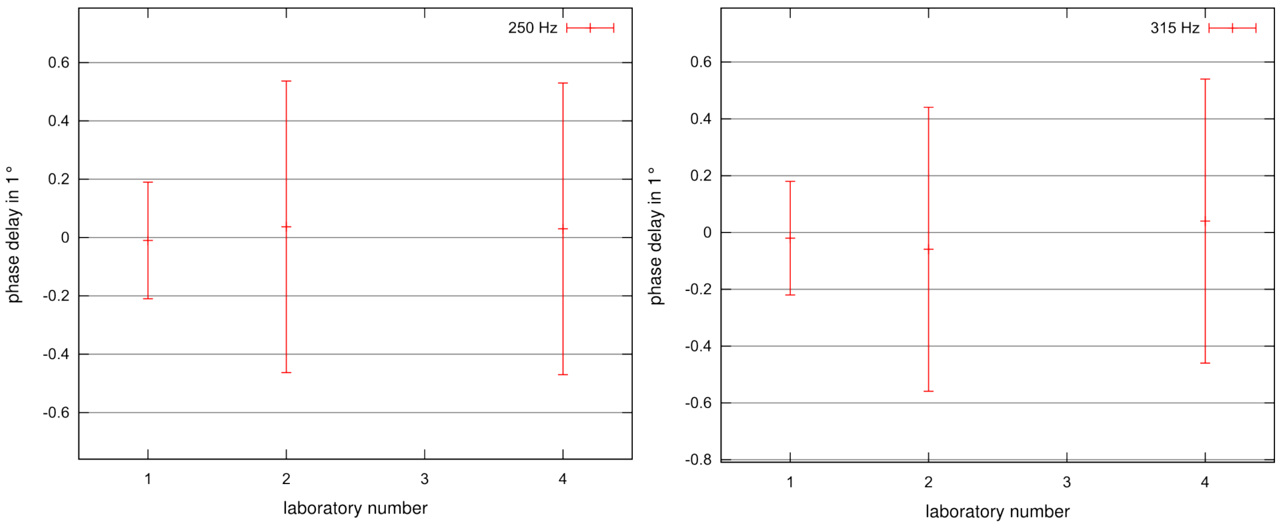


Fig. 60: Phase shift of the SE transducer in 1° reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

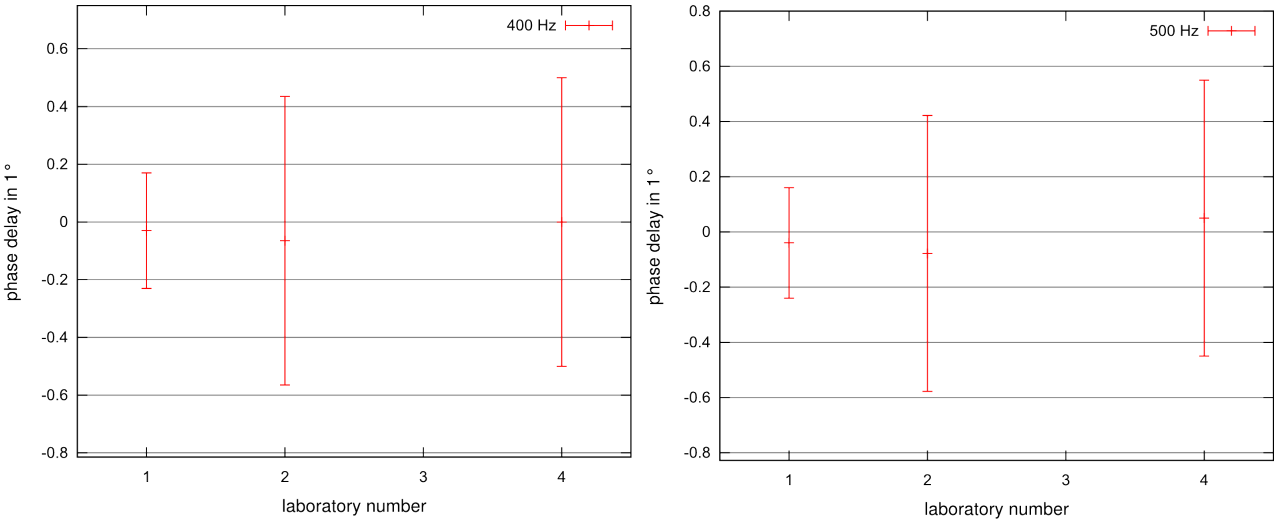


Fig. 61: Phase shift of the SE transducer in 1° reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

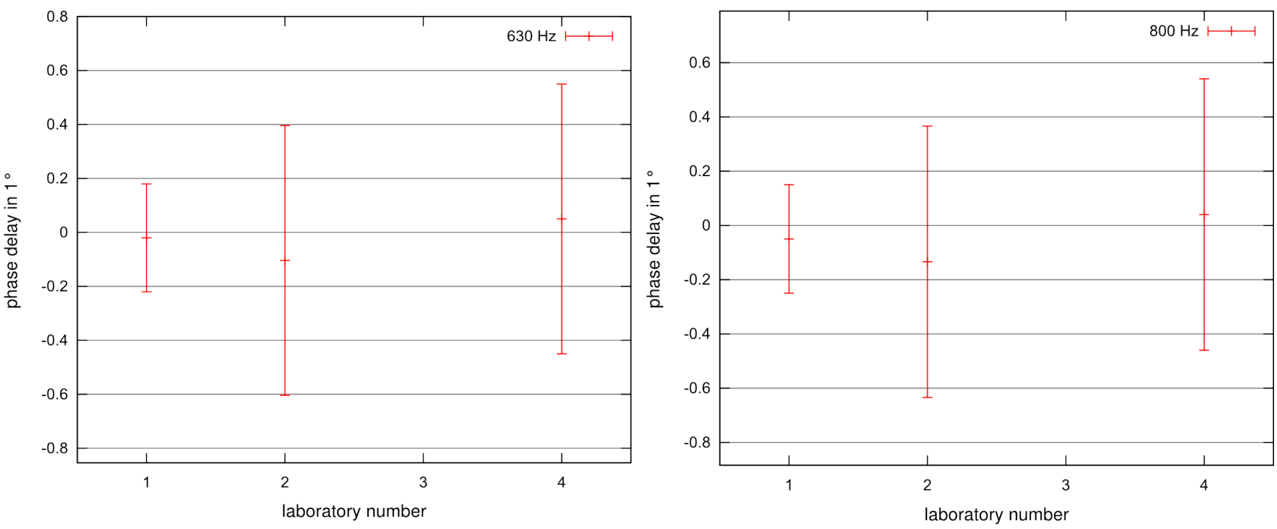


Fig. 62: Phase shift of the SE transducer in 1° reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

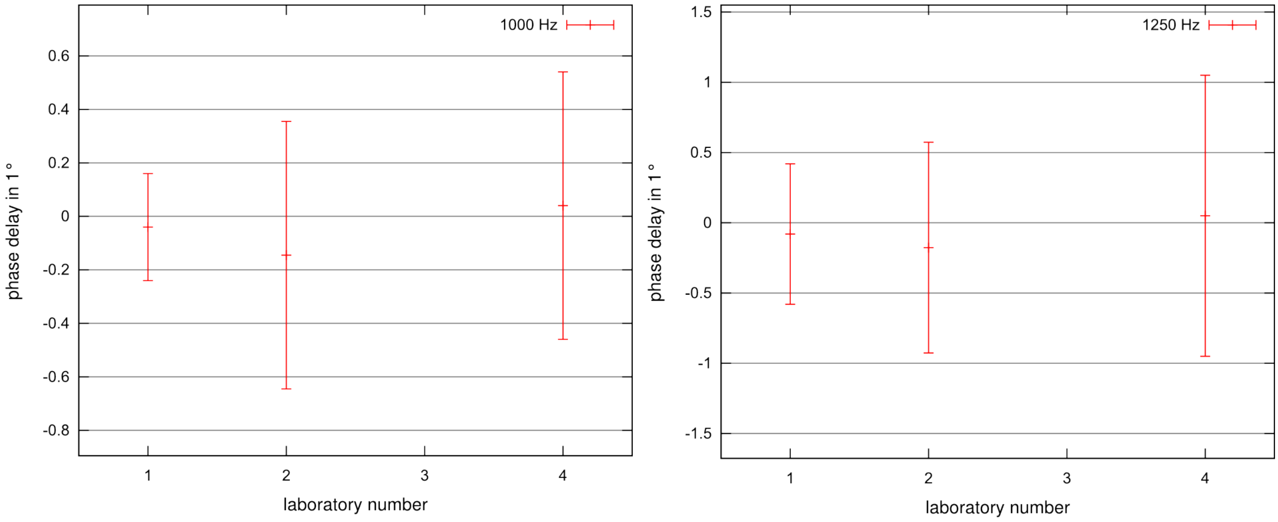


Fig. 63: Phase shift of the SE transducer in 1° reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

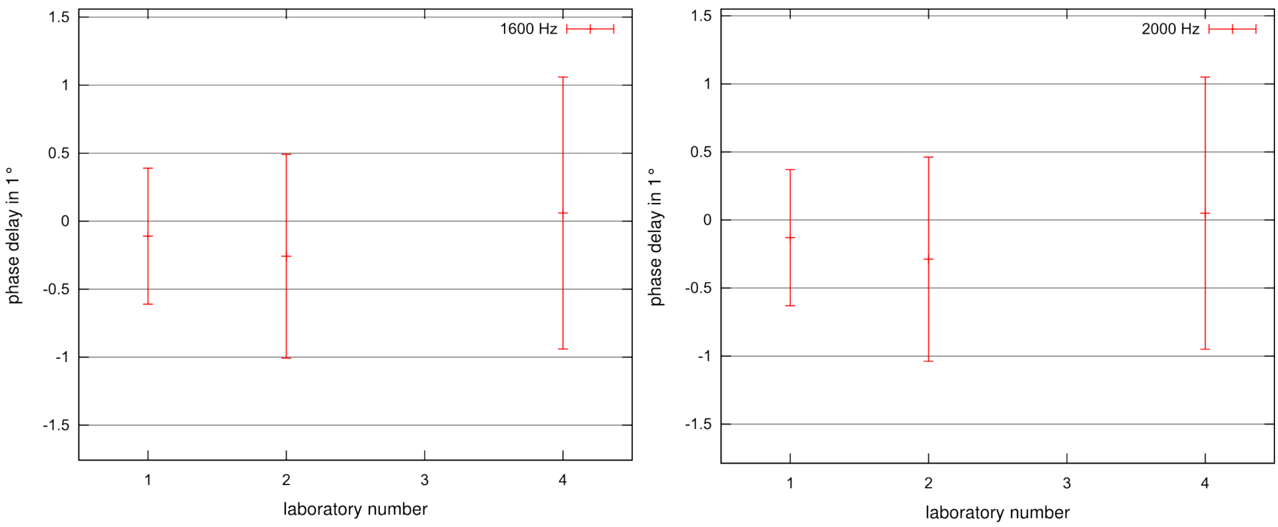


Fig. 64: Phase shift of the SE transducer in 1° reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

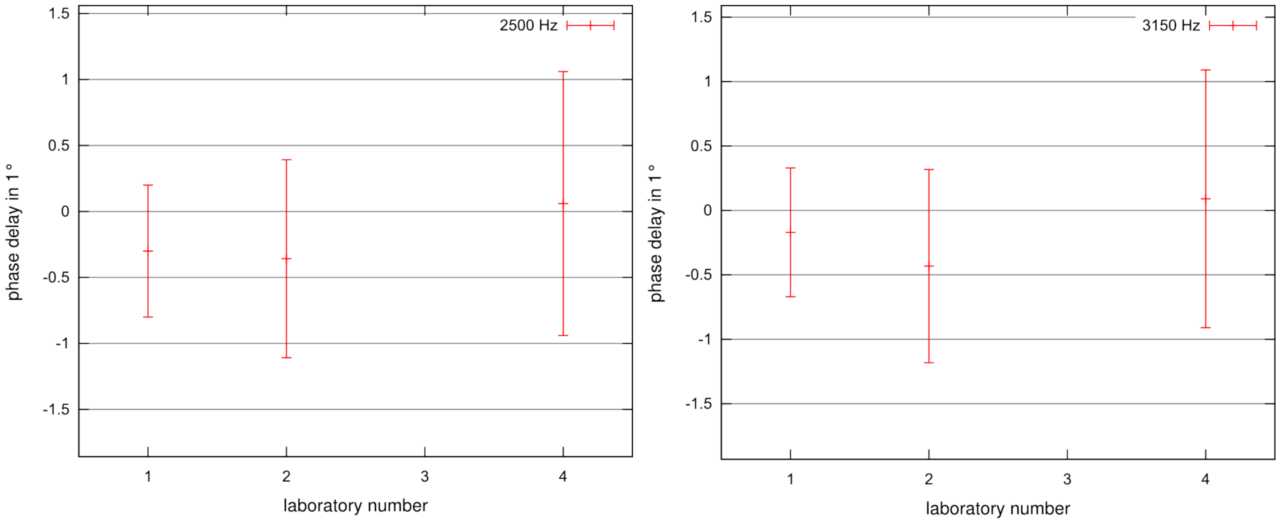


Fig. 65: Phase shift of the SE transducer in 1° reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

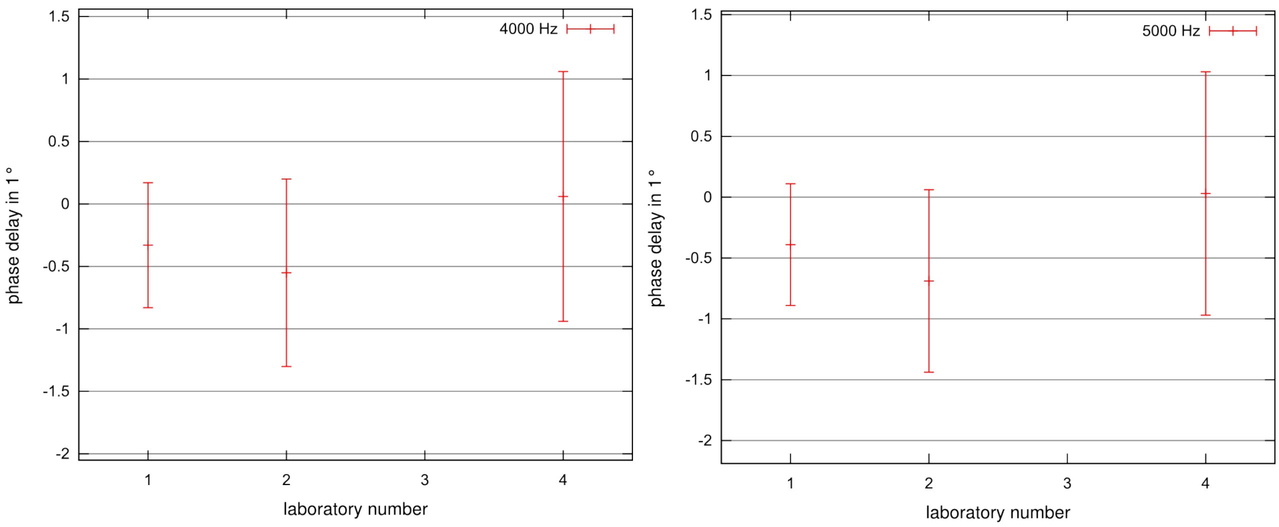
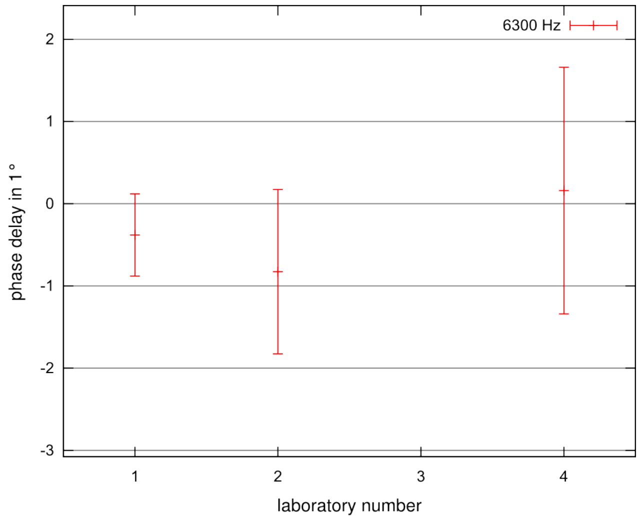


Fig. 66: Phase shift of the SE transducer in 1° reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).



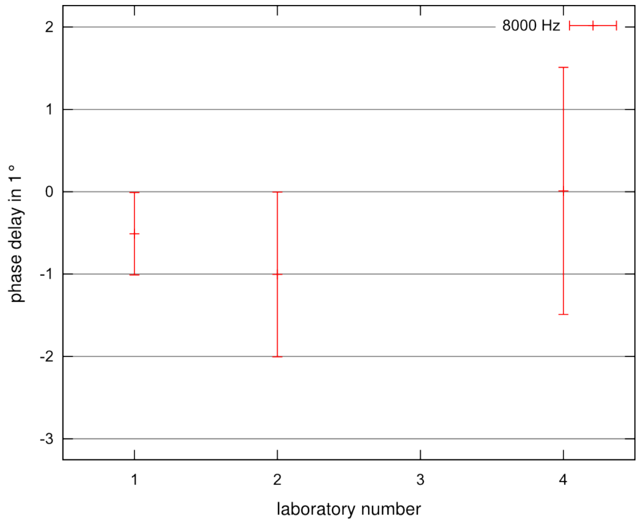


Fig. 67: Phase shift of the SE transducer in 1° reported by the participants for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

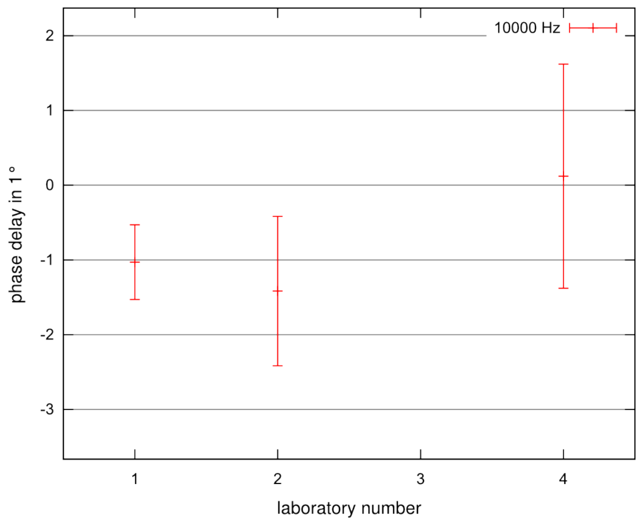


Fig. 68: Phase shift of the SE transducer in 1° reported by the participants for 10000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

7.5.2 Consistency of Phase shift Results for the SE-Accelerometer

In the same way as is was performed and reported above for the results of the magnitude of sensitivity the consistency check of all results was done for the phase shift measurements as well.

Table 15: results of the consistency test for the reported results of phase shift with the columns: frequency, X^2_{max} limit for *n*-1 degrees of freedom (*df*), X^2 calculated from the reported results, X^2 calculated from the reported results excluding the participant named in the header

frequency in Hz	num. of particip. *n*	X^2_{max} (*df* = n-1)	calculated X^2	X^2 without PTB	X^2 without NIM	X^2 without NPLI	X^2 without INMETRO
10	3	7,81	0,22	+	+	-	+
12,5	3	7,81	0,06	+	+	-	+
16	3	7,81	0,05	+	+	-	+
20	3	7,81	0,41	+	+	-	+
25	3	7,81	0,03	+	+	-	+
31,5	3	7,81	0,01	+	+	-	+
40	3	7,81	0,25	+	+	-	+
50	3	7,81	1,75	+	+	-	+
63	3	7,81	0,06	+	+	-	+
80	3	7,81	0,05	+	+	-	+
100	3	7,81	0,03	+	+	-	+
125	3	7,81	0,03	+	+	-	+
160	3	7,81	0,07	+	+	-	+
200	3	7,81	0,05	+	+	-	+
250	3	7,81	0,05	+	+	-	+
315	3	7,81	0,08	+	+	-	+
400	3	7,81	0,03	+	+	-	+
500	3	7,81	0,15	+	+	-	+
630	3	7,81	0,19	+	+	-	+
800	3	7,81	0,24	+	+	-	+
1000	3	7,81	0,28	+	+	-	+
1250	3	7,81	0,13	+	+	-	+
1600	3	7,81	0,27	+	+	-	+
2000	3	7,81	0,30	+	+	-	+
2500	3	7,81	0,50	+	+	-	+
3150	3	7,81	0,73	+	+	-	+
4000	3	7,81	0,96	+	+	-	+
5000	3	7,81	1,33	+	+	-	+
6300	3	7,81	1,29	+	+	-	+
8000	3	7,81	1,41	+	+	-	+
10000	3	7,81	2,94	+	+	-	+

7.5.3 Phase Measurement Results of the B2B-Accelerometer

Table 16: reported calibration results in 1° of the participants for the phase shift φ_{qa} of the B2B transducer with expanded uncertainty (k = 2) in 1°.

	PTB		NIM		NPLI		INMETRO	
frequency	φ_{qa} in 1°	exp. unc. in 1°	φ_{qa} in 1°	exp. unc. in 1°	φ_{qa} in 1°	exp. unc. in 1°	φ_{qa} in 1°	exp. unc. in 1°
10	-0,02	0,20	-0,03	0,50	-	-	-0,03	0,50
12,5	-0,03	0,20	-0,04	0,50	-	-	-0,02	0,50
16	-0,05	0,20	0,00	0,50	-	-	-0,02	0,50
20	-0,03	0,20	-0,03	0,50	-	-	0,00	0,50
25	-0,01	0,20	-0,01	0,50	-	-	0,00	0,50
31,5	-0,01	0,20	-0,01	0,50	-	-	0,00	0,50
40	-0,03	0,20	-0,02	0,50	-	-	0,01	0,50
50	-0,09	0,20	-0,05	0,50	-	-	0,01	0,50
63	-0,03	0,20	-0,04	0,50	-	-	0,01	0,50
80	-0,03	0,20	-0,03	0,50	-	-	0,02	0,50
100	-0,02	0,20	-0,02	0,50	-	-	0,03	0,50
125	-0,02	0,20	-0,02	0,50	-	-	0,03	0,50
160	-0,07	0,20	-0,01	0,20	-	-	0,03	0,50
200	-0,10	0,20	-0,01	0,50	-	-	0,04	0,50
250	0,06	0,20	0,06	0,50	-	-	0,06	0,50
315	0,08	0,20	-0,02	0,50	-	-	0,07	0,50
400	0,02	0,20	-0,03	0,50	-	-	0,02	0,50
500	0,01	0,20	-0,04	0,50	-	-	0,07	0,50
630	0,04	0,20	-0,05	0,50	-	-	0,08	0,50
800	-0,01	0,20	-0,09	0,50	-	-	0,08	0,50
1000	-0,02	0,20	-0,12	0,50	-	-	0,08	0,50
1250	-0,03	0,50	-0,16	0,75	-	-	0,09	1,00
1600	0,10	0,50	-0,19	0,75	-	-	0,10	1,00
2000	-0,06	0,50	-0,27	0,75	-	-	0,09	1,00
2500	-0,15	0,50	-0,35	0,75	-	-	0,10	1,00
3150	-0,10	0,50	-0,45	0,75	-	-	0,12	1,00
4000	-0,21	0,50	-0,58	0,75	-	-	0,14	1,00
5000	-0,13	0,50	-0,72	0,75	-	-	0,14	1,00
6300	-0,28	0,50	-0,86	1,00	-	-	0,18	1,50
8000	-0,40	0,50	-1,47	1,00	-	-	0,14	1,50
10000	-0,39	0,50	-1,59	1,00	-	-	0,38	1,50

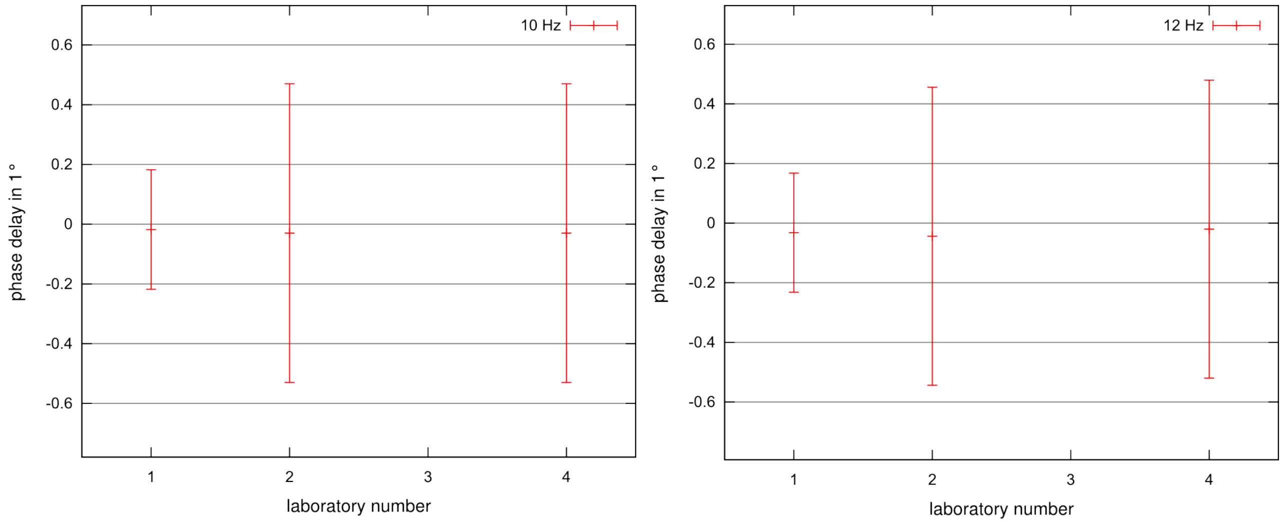


Fig. 69: Phase shift of the B2B transducer in 1° reported by the participants for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

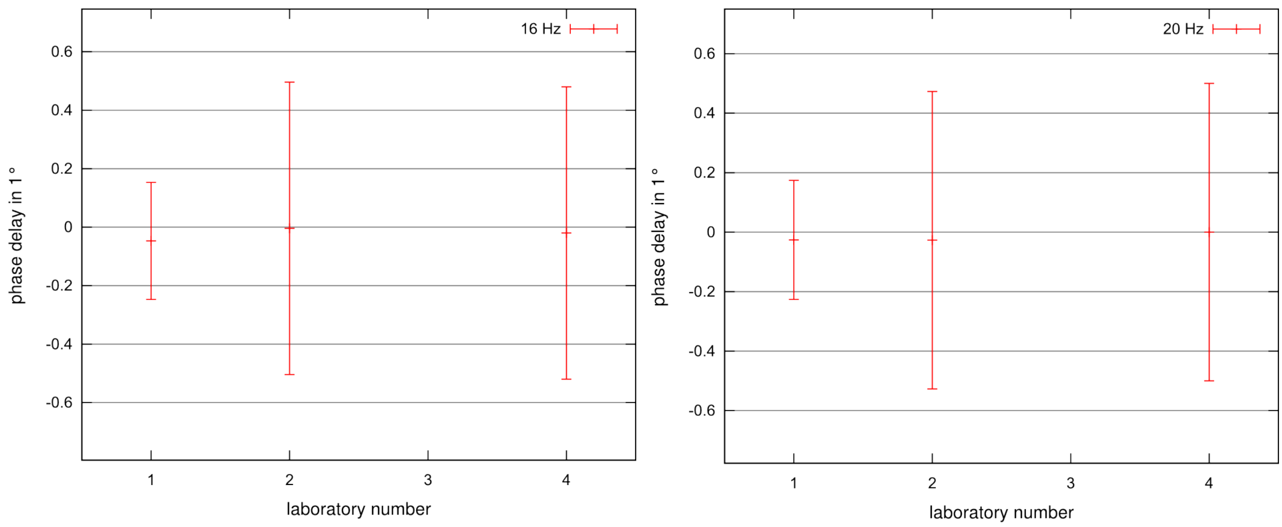


Fig. 70: Phase shift of the B2B transducer in 1° reported by the participants for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

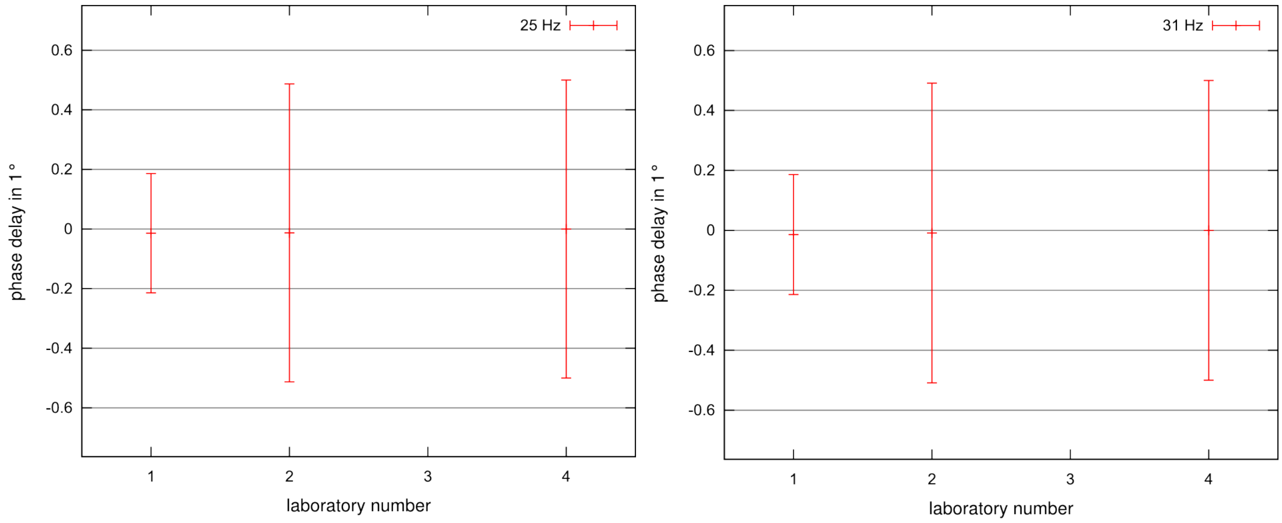


Fig. 71: Phase shift of the B2B transducer in 1° reported by the participants for 25 Hz and 31,5 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

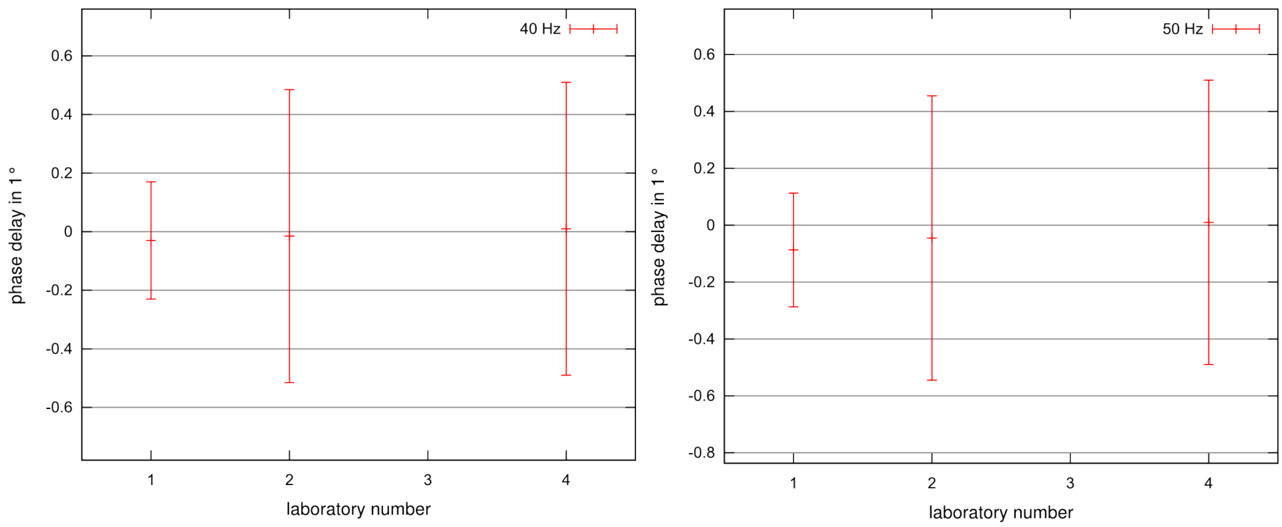


Fig. 72: Phase shift of the B2B transducer in 1° reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

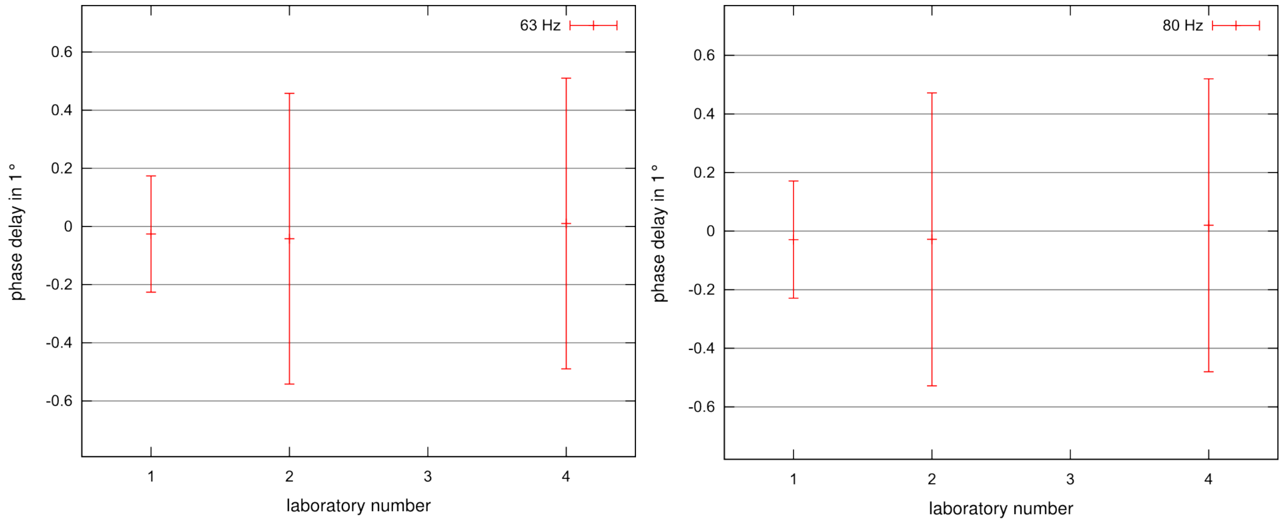


Fig. 73: Phase shift of the B2B transducer in 1° reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

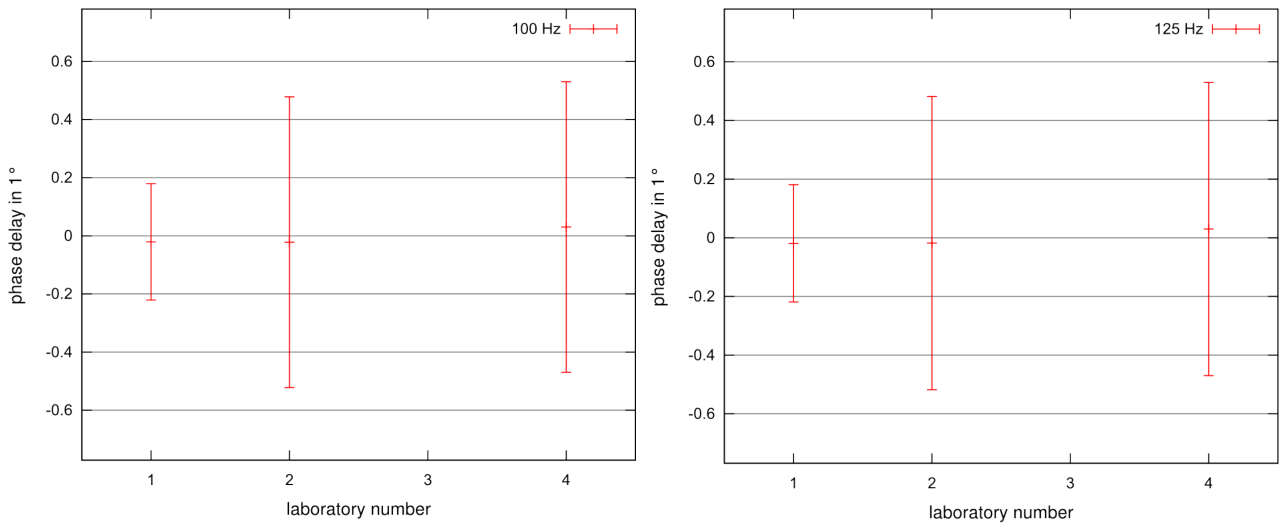


Fig. 74: Phase shift of the B2B transducer in 1° reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

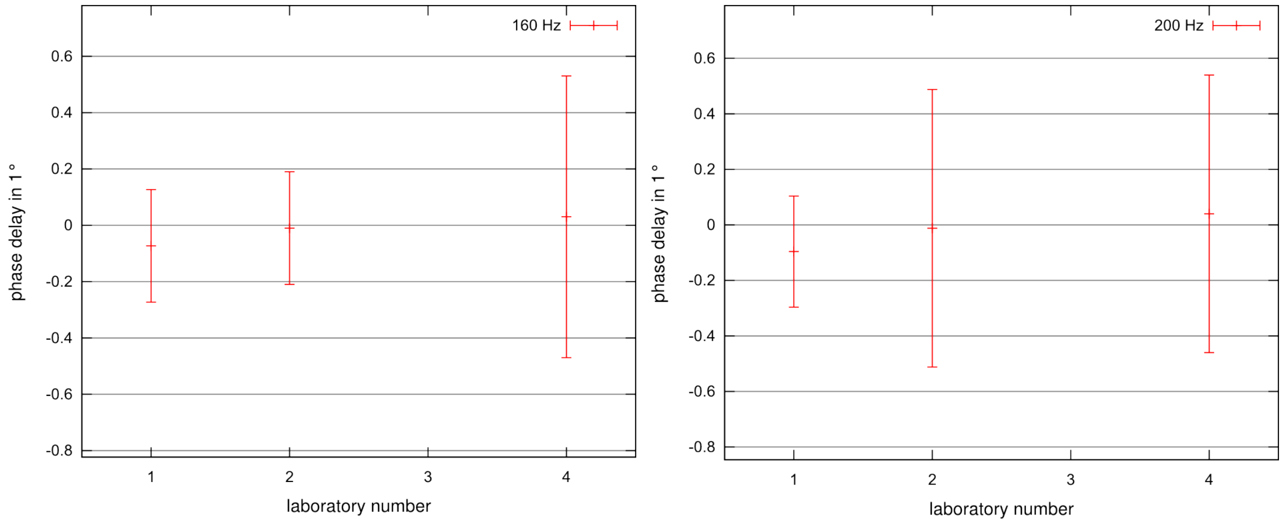


Fig. 75: Phase shift of the B2B transducer in 1° reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

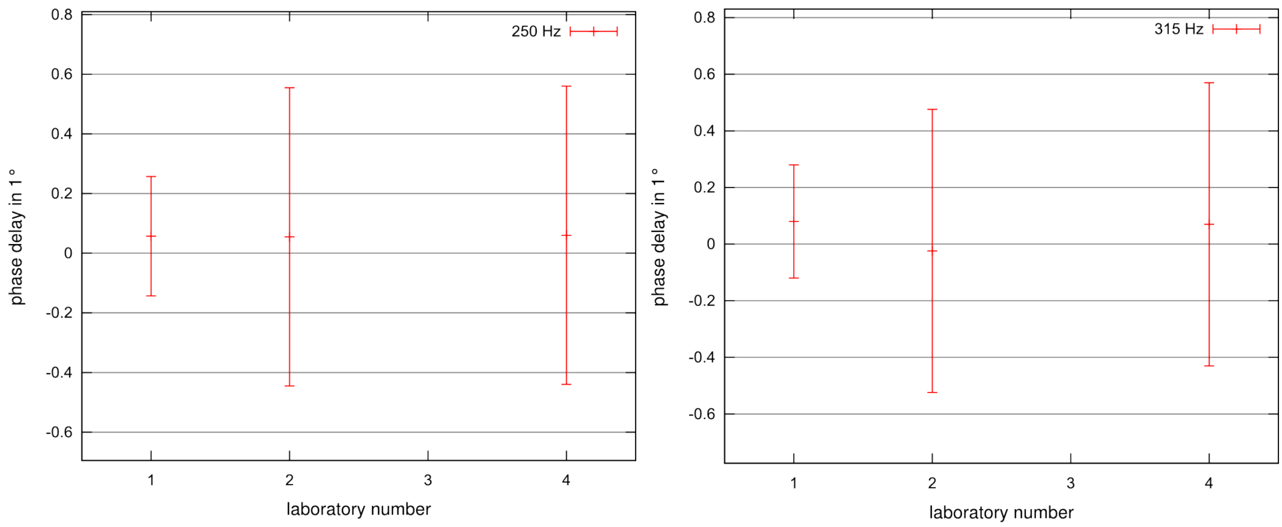


Fig. 76: Phase shift of the B2B transducer in 1° reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

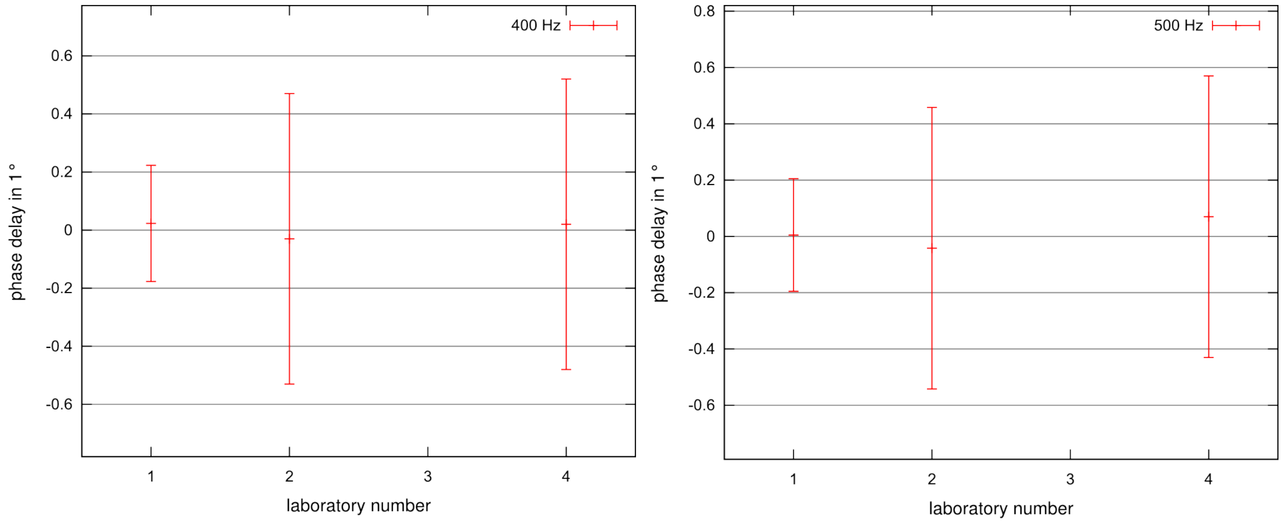


Fig. 77: Phase shift of the B2B transducer in 1° reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

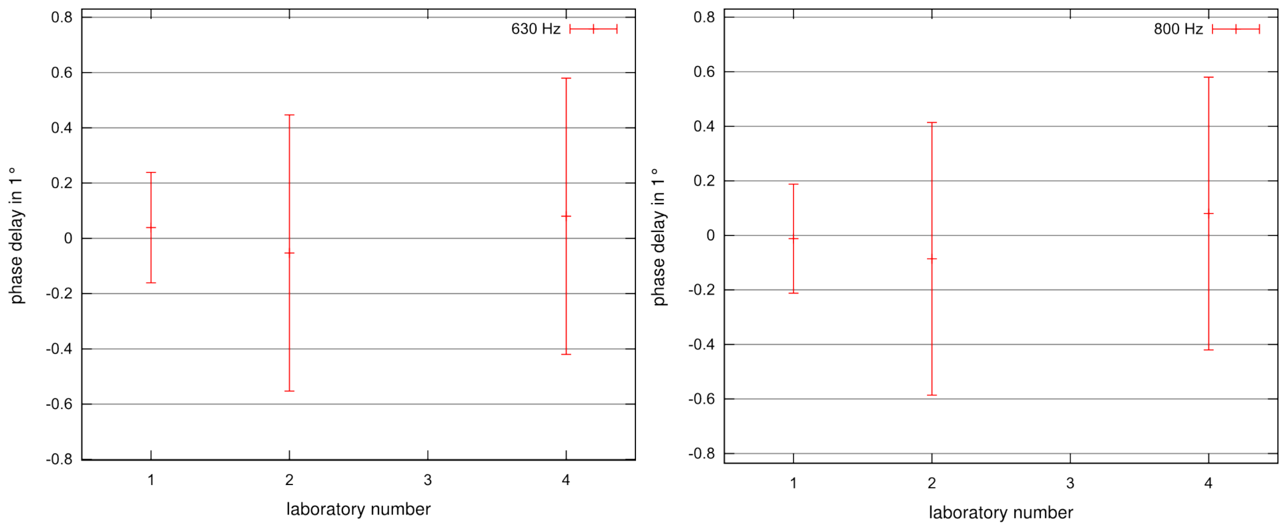


Fig. 78: Phase shift of the B2B transducer in 1° reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

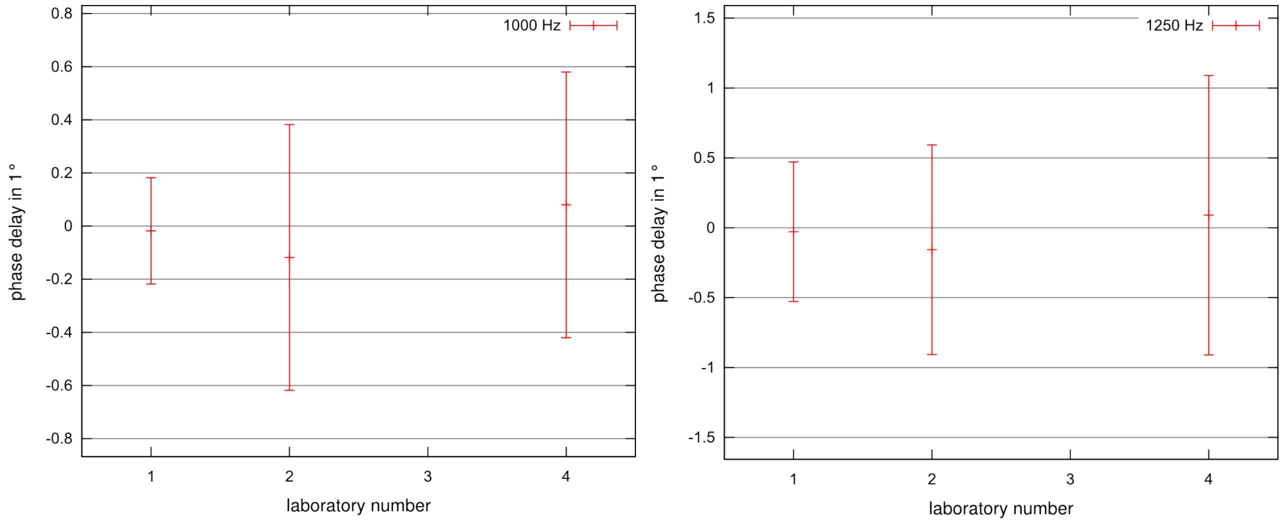


Fig. 79: Phase shift of the B2B transducer in 1° reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

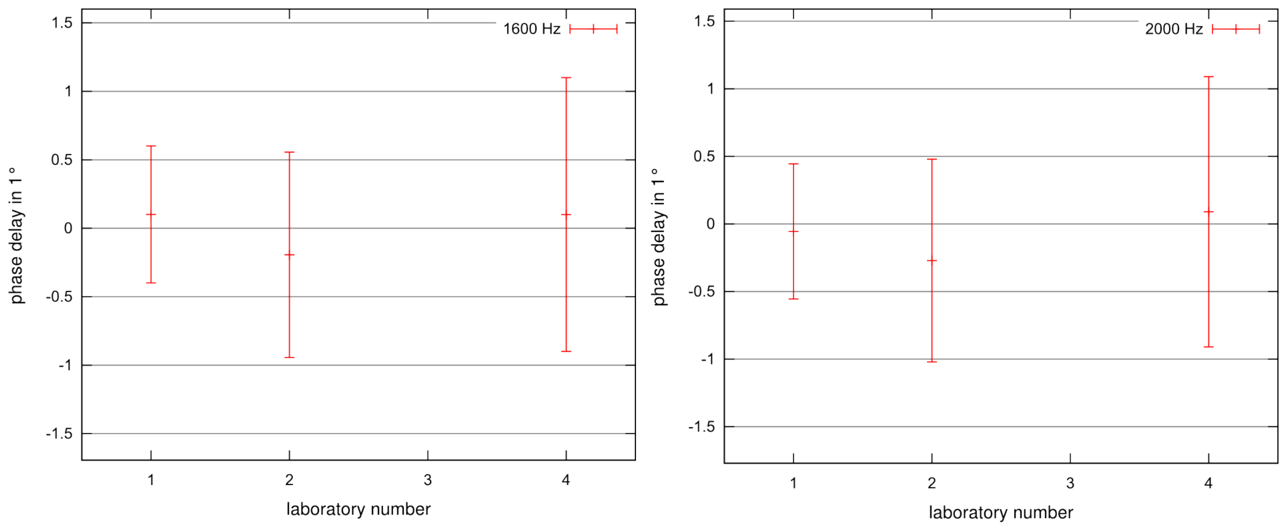


Fig. 80: Phase shift of the B2B transducer in 1° reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

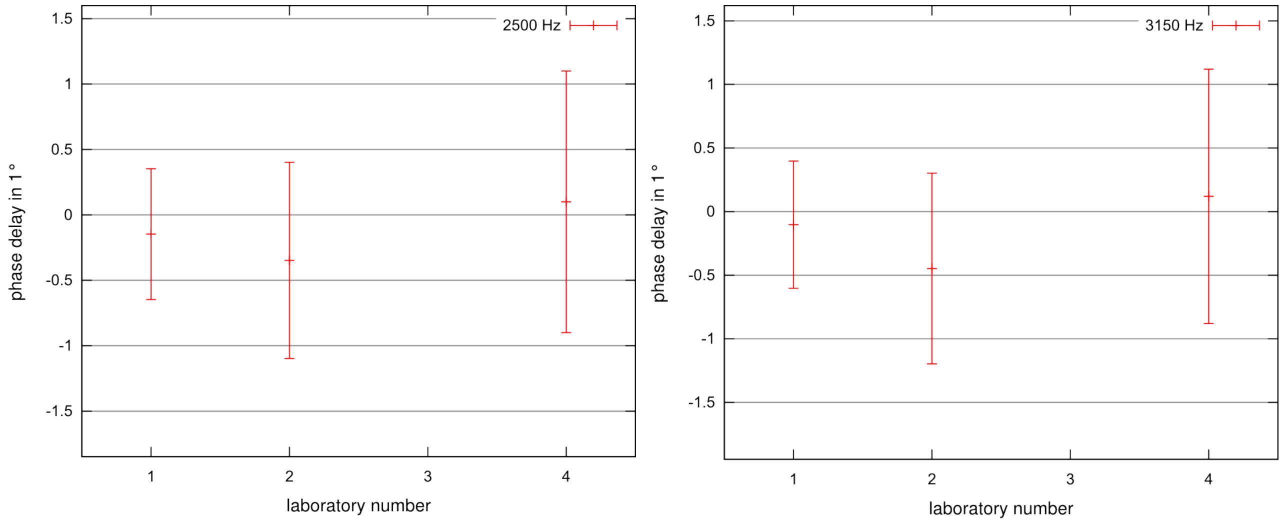


Fig. 81: Phase shift of the B2B transducer in 1° reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

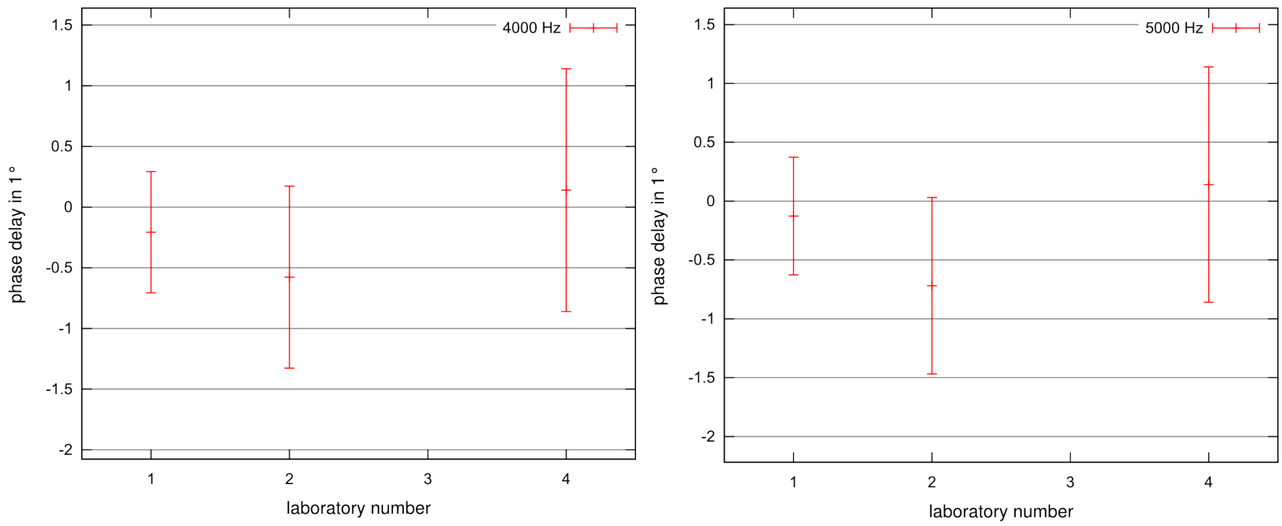


Fig. 82: Phase shift of the B2B transducer in 1° reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

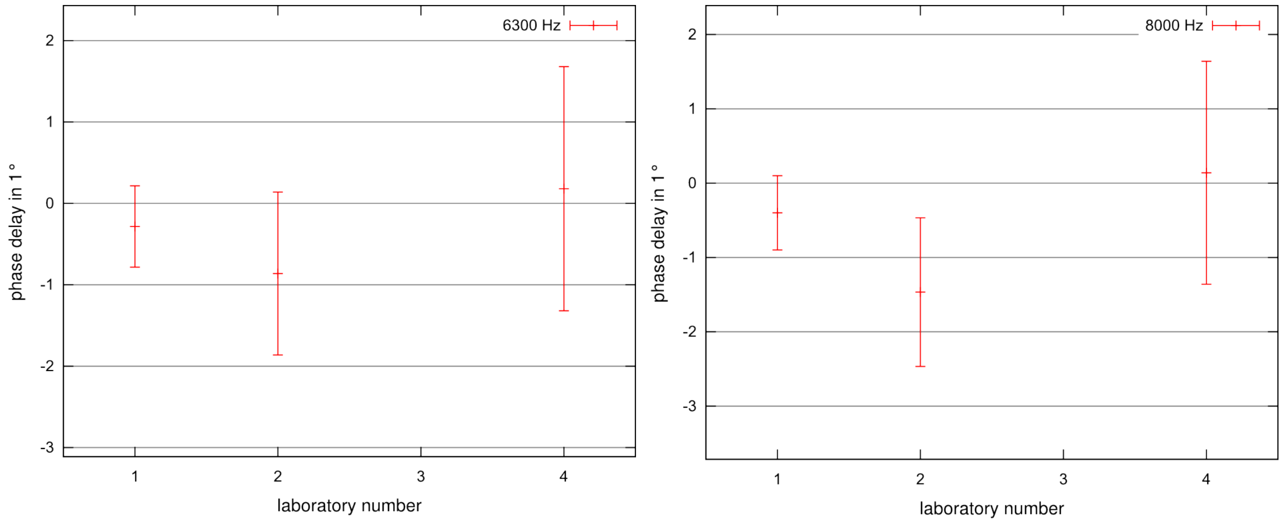


Fig. 83: Phase shift of the B2B transducer in 1° reported by the participants for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

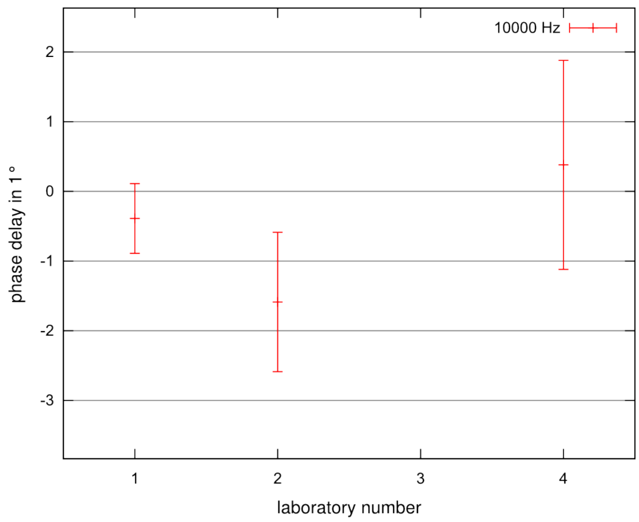


Fig. 84: Phase shift of the B2B transducer in 1° reported by the participants for 10000 Hz a excitation frequency with error bars representing the expanded uncertainty (*k* = 2).

7.5.4 Consistency of Results for the B2B-Accelerometer

Table 17: results of the consistency test for the reported results of phase shift with the columns: frequency, X^2_{max} limit for *n*-1 degrees of freedom (*df*), *X*² calculated from the reported results, *X*² calculated from the reported results excluding the participant named in the header, X^2_{max} limit for *n*-2 degrees of freedom (*df*)

frequency in Hz	num. of particip. *n*	X^2_{max} (*df* = n-1)	calculated X^2	X^2 without PTB	X^2 without NIM	X^2 without NPLI	X^2 without INMETRO	X^2_{max} (*df* = n-2)
10	3	7,81	0,003	+	+	-	+	
12,5	3	7,81	0,005	+	+	-	+	
16	3	7,81	0,03	+	+	-	+	
20	3	7,81	0,01	+	+	-	+	
25	3	7,81	0,003	+	+	-	+	
31,5	3	7,81	0,003	+	+	-	+	
40	3	7,81	0,02	+	+	-	+	
50	3	7,81	0,14	+	+	-	+	
63	3	7,81	0,02	+	+	-	+	
80	3	7,81	0,03	+	+	-	+	
100	3	7,81	0,04	+	+	-	+	
125	3	7,81	0,03	+	+	-	+	
160	3	7,81	0,27	+	+	-	+	
200	3	7,81	0,31	+	+	-	+	
250	3	7,81	0,0002	+	+	-	+	
315	3	7,81	0,15	+	+	-	+	
400	3	7,81	0,04	+	+	-	+	
500	3	7,81	0,1	+	+	-	+	
630	3	7,81	0,16	+	+	-	+	
800	3	7,81	0,22	+	+	-	+	
1000	3	7,81	0,31	+	+	-	+	
1250	3	7,81	0,17	+	+	-	+	
1600	3	7,81	0,46	+	+	-	+	
2000	3	7,81	0,38	+	+	-	+	
2500	3	7,81	0,52	+	+	-	+	
4000	3	7,81	1,4	+	+	-	+	
5000	3	7,81	2,41	+	+	-	+	
8000	3	7,81	4,57	+	+	-	+	
10000	3	7,81	6,25	+	+	-	+	

8 Results of the comparison

8.1 Degree of equivalence between the participants

In order to compare the individual reults of the participating laboratories of this comparison with one another the DoE of pairs of results with respect to a certain frequency were calculated. This DoE are each a pair of values of the difference D_{ij} between the respective participants *i* and *j* and the combined expanded uncertainty U_{ij} of this difference. These values are calculated for each frequency according to:

$$D_{ij}=x_i-x_j \quad (8)$$

$$U_{ij}=k\cdot\sqrt{u^2(x_i)+u^2(x_j)} \quad (9)$$

with a coverage factor of k = 2.

8.1.1 DoE for magnitude of sensitivity of the SE transducer

Table 18: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 for the SE transducer

		NIM		NPLI		INMETRO	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
10,0 Hz	PTB	-2,2	6,7	-2,6	13,2	-2,4	4,7
	NIM			-0,4	14,6	-0,2	8,0
	NPLI					0,2	13,8
12,5 Hz	PTB	-3,2	6,7			-2,7	4,7
	NIM					0,4	8,0
	NPLI						
16,0 Hz	PTB	-2,6	6,7			-2,2	4,7
	NIM					0,4	8,0
	NPLI						
20,0 Hz	PTB	-2,5	6,7	-2,4	9,3	-2,3	4,7
	NIM			0,1	11,3	0,2	8,0
	NPLI					0,1	10,2
25,0 Hz	PTB	-1,7	6,7			-1,9	3,5
	NIM					-0,2	7,3
	NPLI						
31,5 Hz	PTB	-2,7	6,7			-2,4	3,5
	NIM					0,2	7,3
	NPLI						

		NIM		NPLI		INMETRO	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
40,0 Hz	PTB	-2,3	6,7	-2,3	9,3	-1,8	3,5
	NIM			0,0	11,3	0,4	7,3
	NPLI					0,4	9,7
50,0 Hz	PTB	-2,3	6,7			-1,4	3,5
	NIM					0,8	7,3
	NPLI						
63,0 Hz	PTB	-2,3	6,7			-1,9	3,5
	NIM					0,3	7,3
	NPLI						
80,0 Hz	PTB	-2,3	6,7	-3,3	9,3	-2,0	3,5
	NIM			-1,0	11,3	0,3	7,3
	NPLI					1,3	9,7
100,0 Hz	PTB	-1,8	6,7	-3,2	9,3	-2,0	3,5
	NIM			-1,4	11,3	-0,2	7,3
	NPLI					1,2	9,7
125,0 Hz	PTB	-1,9	6,7			-1,9	3,5
	NIM					0,0	7,3
	NPLI						
160,0 Hz	PTB	-1,8	3,0	-3,7	9,3	-1,1	3,5
	NIM			-1,9	9,6	0,7	4,2
	NPLI					2,6	9,7
200,0 Hz	PTB	-2,1	6,7	-1,8	9,3	-1,4	3,5
	NIM			0,3	11,3	0,6	7,3
	NPLI					0,3	9,7
250,0 Hz	PTB	-2,5	6,7			-1,4	3,5
	NIM					1,1	7,3
	NPLI						
315,0 Hz	PTB	0,5	6,7			1,3	3,5
	NIM					0,8	7,3
	NPLI						
400,0 Hz	PTB	-1,4	6,7			-1,0	3,5
	NIM					0,3	7,3

		NIM		NPLI		INMETRO	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
	NPLI						
500,0 Hz	PTB	-1,8	6,7	-0,1	9,3	-0,8	3,5
	NIM			1,7	11,3	1,0	7,3
	NPLI					-0,7	9,7
630,0 Hz	PTB	-2,5	6,7			-1,6	3,5
	NIM					0,9	7,3
	NPLI						
800,0 Hz	PTB	-1,8	6,7	-1,0	9,3	-1,6	3,5
	NIM			0,8	11,3	0,2	7,3
	NPLI					-0,6	9,7
1000,0 Hz	PTB	-1,9	6,7	-0,4	9,3	-1,9	3,5
	NIM			1,5	11,3	0,0	7,3
	NPLI					-1,5	9,7
1250,0 Hz	PTB	-1,8	6,7			-1,6	4,7
	NIM					0,2	8,0
	NPLI						
1600,0 Hz	PTB	-1,2	6,7			-1,6	4,7
	NIM					-0,4	8,0
	NPLI						
2000,0 Hz	PTB	-0,5	6,7	5,9	9,3	-1,3	4,8
	NIM			6,4	11,3	-0,8	8,0
	NPLI					-7,2	10,2
2500,0 Hz	PTB	-2,2	6,7			-1,8	6,8
	NIM					0,4	9,4
	NPLI						
3150,0 Hz	PTB	-2,2	6,8			-1,5	6,8
	NIM					0,7	9,4
	NPLI						
4000,0 Hz	PTB	-0,2	6,8	23,6	13,1	-2,2	6,9
	NIM			23,7	14,7	-2,0	9,5
	NPLI					-25,7	14,7
5000,0 Hz	PTB	0,2	6,9	29,9	13,2	-2,0	13,5

		NIM		NPLI		INMETRO	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
	NIM			29,7	14,8	-2,2	15,1
	NPLI					-31,9	18,8
6300,0 Hz	PTB	1,0	14,3			1,9	20,9
	NIM					1,0	24,6
	NPLI						
8000,0 Hz	PTB	-2,6	14,7			8,3	21,4
	NIM					10,8	25,2
	NPLI						
10000,0 Hz	PTB	3,9	15,3			0,4	22,4
	NIM					-3,5	26,4
	NPLI						

		NIM		INMETRO	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}
		in 1°		in 1°	
10,0 Hz	PTB	-0,1	0,5	-0,1	0,5
	NIM			-0,0	0,7
12,5 Hz	PTB	0,1	0,5	0,0	0,5
	NIM			-0,0	0,7
16,0 Hz	PTB	-0,0	0,5	-0,1	0,5
	NIM			-0,0	0,7
20,0 Hz	PTB	0,2	0,5	0,1	0,5
	NIM			-0,1	0,7
25,0 Hz	PTB	0,1	0,5	0,0	0,5
	NIM			-0,0	0,7
31,5 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
40,0 Hz	PTB	-0,1	0,5	-0,1	0,5
	NIM			-0,0	0,7
50,0 Hz	PTB	0,3	0,5	0,2	0,5

		NIM		INMETRO	
	NIM			-0,1	0,7
63,0 Hz	PTB	0,1	0,5	-0,0	0,5
	NIM			-0,1	0,7
80,0 Hz	PTB	0,1	0,5	-0,0	0,5
	NIM			-0,1	0,7
100,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
125,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
160,0 Hz	PTB	0,0	0,3	0,0	0,5
	NIM			-0,0	0,5
200,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
250,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			0,0	0,7
315,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
400,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
500,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
630,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
800,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1000,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1250,0 Hz	PTB	0,1	0,9	-0,1	1,1
	NIM			-0,2	1,2
1600,0 Hz	PTB	0,1	0,9	-0,2	1,1
	NIM			-0,3	1,2
2000,0 Hz	PTB	0,2	0,9	-0,2	1,1
	NIM			-0,3	1,2
2500,0 Hz	PTB	0,1	0,9	-0,4	1,1

		NIM		INMETRO	
	NIM			-0,4	1,2
3150,0 Hz	PTB	0,3	0,9	-0,3	1,1
	NIM			-0,5	1,2
4000,0 Hz	PTB	0,2	0,9	-0,4	1,1
	NIM			-0,6	1,2
5000,0 Hz	PTB	0,3	0,9	-0,4	1,1
	NIM			-0,7	1,2
6300,0 Hz	PTB	0,4	1,1	-0,5	1,6
	NIM			-1,0	1,8
8000,0 Hz	PTB	0,5	1,1	-0,5	1,6
	NIM			-1,0	1,8
10000,0 Hz	PTB	0,4	1,1	-1,1	1,6
	NIM			-1,5	1,8

8.1.2 DoE for phase shift of sensitivity of the SE transducer

Table 19: DoE for phase shift of sensitivity between the participants of CCAUV.V-K1.1 for the SE transducer

		NIM		INMETRO	
		D_{ii}	U_{ii}	D_{ii}	U_{ii}
		in 1°		in 1°	
10,0 Hz	PTB	-0,1	0,5	-0,1	0,5
	NIM			-0,0	0,7
12,5 Hz	PTB	0,1	0,5	0,0	0,5
	NIM			-0,0	0,7
16,0 Hz	PTB	-0,0	0,5	-0,1	0,5
	NIM			-0,0	0,7
20,0 Hz	PTB	0,2	0,5	0,1	0,5
	NIM			-0,1	0,7
25,0 Hz	PTB	0,1	0,5	0,0	0,5
	NIM			-0,0	0,7
31,5 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
40,0 Hz	PTB	-0,1	0,5	-0,1	0,5
	NIM			-0,0	0,7
50,0 Hz	PTB	0,3	0,5	0,2	0,5

		NIM		INMETRO	
	NIM			-0,1	0,7
63,0 Hz	PTB	0,1	0,5	-0,0	0,5
	NIM			-0,1	0,7
80,0 Hz	PTB	0,1	0,5	-0,0	0,5
	NIM			-0,1	0,7
100,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
125,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
160,0 Hz	PTB	0,0	0,3	0,0	0,5
	NIM			-0,0	0,5
200,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
250,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			0,0	0,7
315,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
400,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
500,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
630,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
800,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1000,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1250,0 Hz	PTB	0,1	0,9	-0,1	1,1
	NIM			-0,2	1,2
1600,0 Hz	PTB	0,1	0,9	-0,2	1,1
	NIM			-0,3	1,2
2000,0 Hz	PTB	0,2	0,9	-0,2	1,1
	NIM			-0,3	1,2
2500,0 Hz	PTB	0,1	0,9	-0,4	1,1

		NIM		INMETRO	
	NIM			-0,4	1,2
3150,0 Hz	PTB	0,3	0,9	-0,3	1,1
	NIM			-0,5	1,2
4000,0 Hz	PTB	0,2	0,9	-0,4	1,1
	NIM			-0,6	1,2
5000,0 Hz	PTB	0,3	0,9	-0,4	1,1
	NIM			-0,7	1,2
6300,0 Hz	PTB	0,4	1,1	-0,5	1,6
	NIM			-1,0	1,8
8000,0 Hz	PTB	0,5	1,1	-0,5	1,6
	NIM			-1,0	1,8
10000,0 Hz	PTB	0,4	1,1	-1,1	1,6
	NIM			-1,5	1,8

8.1.3 DoE for magnitude of sensitivity the B2B transducer

Table 20: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 for the B2B transducer

		NIM		NPLI		INMETRO	
		D_{ii}	U_{ii}	D_{ii}	U_{ii}	D_{ii}	U_{ii}
		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
10,0 Hz	PTB	1,7	6,4	-1,4	12,7	0,2	4,5
	NIM			-3,1	14,1	-1,5	7,6
	NPLI					1,6	13,3
12,5 Hz	PTB	2,4	6,4			1,2	4,5
	NIM					-1,2	7,6
	NPLI						
16,0 Hz	PTB	0,3	6,4			-0,1	4,5
	NIM					-0,4	7,6
	NPLI						
20,0 Hz	PTB	0,7	6,4	-0,9	8,9	0,0	4,5
	NIM			-1,6	10,8	-0,7	7,6
	NPLI					0,9	9,8
25,0 Hz	PTB	1,1	6,4			0,7	3,3

		NIM		NPLI		INMETRO	
		D_{ii}	U_{ii}	D_{ii}	U_{ii}	D_{ii}	U_{ii}
		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
	NIM					-0,4	7,0
	NPLI						
31,5 Hz	PTB	0,2	6,4			0,2	3,3
	NIM					0,0	7,0
	NPLI						
40,0 Hz	PTB	-0,3	6,4	-1,2	8,9	0,0	3,3
	NIM			-0,9	10,8	0,3	7,0
	NPLI					1,2	9,3
50,0 Hz	PTB	2,4	6,4			-1,0	3,3
	NIM					-3,4	7,0
	NPLI						
63,0 Hz	PTB	1,4	6,4			-0,1	3,3
	NIM					-1,5	7,0
	NPLI						
80,0 Hz	PTB	0,6	6,4	-2,0	8,9	0,0	3,3
	NIM			-2,6	10,8	-0,6	7,0
	NPLI					2,0	9,3
100,0 Hz	PTB	-0,2	6,4	-2,3	8,9	-0,4	3,3
	NIM			-2,1	10,9	-0,2	7,0
	NPLI					1,9	9,3
125,0 Hz	PTB	0,1	6,4			0,0	3,3
	NIM					-0,1	7,0
	NPLI						
160,0 Hz	PTB	0,2	2,8	-2,4	8,9	0,3	3,3
	NIM			-2,6	9,2	0,1	3,9
	NPLI					2,7	9,3
200,0 Hz	PTB	1,1	6,4	0,7	8,9	1,3	3,3
	NIM			-0,4	10,8	0,2	7,0
	NPLI					0,6	9,3
250,0 Hz	PTB	0,0	6,4			-0,2	3,3
	NIM					-0,2	7,0
	NPLI						

		NIM		NPLI		INMETRO	
		D_{ii}	U_{ii}	D_{ii}	U_{ii}	D_{ii}	U_{ii}
		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
315,0 Hz	PTB	1,0	6,4			1,4	3,3
	NIM					0,4	7,0
	NPLI						
400,0 Hz	PTB	-0,1	6,4			0,1	3,3
	NIM					0,2	7,0
	NPLI						
500,0 Hz	PTB	-0,7	6,4	0,6	8,9	-0,6	3,3
	NIM			1,3	10,8	0,1	7,0
	NPLI					-1,2	9,3
630,0 Hz	PTB	-1,6	6,4			-0,6	3,3
	NIM					1,0	7,0
	NPLI						
800,0 Hz	PTB	-0,8	6,4	1,4	8,9	-0,2	3,3
	NIM			2,2	10,8	0,6	7,0
	NPLI					-1,6	9,3
1000,0 Hz	PTB	0,5	6,4	3,0	8,9	0,6	3,3
	NIM			2,5	10,8	0,1	7,0
	NPLI					-2,4	9,3
1250,0 Hz	PTB	1,1	6,4			1,6	4,5
	NIM					0,5	7,6
	NPLI						
1600,0 Hz	PTB	2,1	6,4			1,5	4,5
	NIM					-0,6	7,6
	NPLI						
2000,0 Hz	PTB	2,7	6,5	12,0	8,9	2,1	4,5
	NIM			9,3	10,8	-0,6	7,7
	NPLI					-9,9	9,8
2500,0 Hz	PTB	2,9	6,5			2,6	6,5
	NIM					-0,3	9,0
	NPLI						
3150,0 Hz	PTB	1,6	6,5			2,0	6,5
	NIM					0,4	9,0

		NIM		NPLI		INMETRO	
		D_{ii}	U_{ii}	D_{ii}	U_{ii}	D_{ii}	U_{ii}
		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
	NPLI						
4000,0 Hz	PTB	3,5	6,5	20,4	12,7	2,0	6,5
	NIM			16,9	14,1	-1,5	9,0
	NPLI					-18,4	14,1
5000,0 Hz	PTB	3,3	6,6	50,4	12,4	2,7	12,9
	NIM			47,1	13,9	-0,6	14,4
	NPLI					-47,7	17,8
6300,0 Hz	PTB	4,7	13,6			0,6	19,9
	NIM					-4,1	23,4
	NPLI						
8000,0 Hz	PTB	0,2	13,9			2,4	20,3
	NIM					2,2	23,9
	NPLI						
10000,0 Hz	PTB	-1,8	14,3			1,5	20,9
	NIM					3,3	24,7
	NPLI						

8.1.4 DoE for phase shift of sensitivity of the B2B transducer

Table 21: DoE for phase shift of sensitivity between the participants of CCAUV.V-K1.1 for the B2B transducer

		NIM		INMETRO	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}
		in 1°		in 1°	
10,0 Hz	PTB	0,0	0,5	0,0	0,5
	NIM			0,0	0,7
12,5 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
16,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			0,0	0,7
20,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
25,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
31,5 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
40,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
50,0 Hz	PTB	-0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
63,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
80,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
100,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
125,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
160,0 Hz	PTB	-0,1	0,3	-0,1	0,5
	NIM			-0,0	0,5
200,0 Hz	PTB	-0,1	0,5	-0,1	0,5
	NIM			-0,1	0,7
250,0 Hz	PTB	0,0	0,5	-0,0	0,5

		NIM		INMETRO	
		D_{ii}	U_{ii}	D_{ii}	U_{ii}
		in 1°		in 1°	
	NIM			-0,0	0,7
315,0 Hz	PTB	0,1	0,5	0,0	0,5
	NIM			-0,1	0,7
400,0 Hz	PTB	0,1	0,5	0,0	0,5
	NIM			-0,1	0,7
500,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
630,0 Hz	PTB	0,1	0,5	-0,0	0,5
	NIM			-0,1	0,7
800,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1000,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1250,0 Hz	PTB	0,1	0,9	-0,1	1,1
	NIM			-0,2	1,2
1600,0 Hz	PTB	0,3	0,9	0,0	1,1
	NIM			-0,3	1,2
2000,0 Hz	PTB	0,2	0,9	-0,1	1,1
	NIM			-0,4	1,2
2500,0 Hz	PTB	0,2	0,9	-0,2	1,1
	NIM			-0,4	1,2
3150,0 Hz	PTB	0,3	0,9	-0,2	1,1
	NIM			-0,6	1,2
4000,0 Hz	PTB	0,4	0,9	-0,3	1,1
	NIM			-0,7	1,2
5000,0 Hz	PTB	0,6	0,9	-0,3	1,1
	NIM			-0,9	1,2
6300,0 Hz	PTB	0,6	1,1	-0,5	1,6
	NIM			-1,0	1,8
8000,0 Hz	PTB	1,1	1,1	-0,5	1,6
	NIM			-1,6	1,8
10000,0 Hz	PTB	1,2	1,1	-0,8	1,6

		NIM		INMETRO	
		D_{ij}	U_{ij}	D_{ij}	U_{ij}
		in 1°		in 1°	
	NIM			-2,0	1,8

8.2 Degree of equivalence relative to the KCRV of CCAUV.V-K1

8.2.1 The Linking

In order to keep up the consistency of procedure and thus the comparability between the different KC in the field of vibration performed so far, the linking was calculated according to the same scheme, already applied for APMP.AUV.V-K1 and EUROMET.AUV.V-K1. The calculation procedure is described in [5] and [6] in more detail.
To put it simple, the linking transforms the results (x_i , $u(x_i)$) of the participants of CCAUV.V-K1.1 to scaled values z_i and their respective uncertainty $u(z_i)$, which are directly comparable to the results of CCAUV.V-K1 in absolute terms. The scaling is done with the so called linking factor *R*. This factor is calculated from the results of the linking laboratories in this subsequent KC and the KCRV on CIPM-level.

A specific characteristic for this subsequent comparison documented in this report is, that only one single linking laboratory, namely PTB, is responsible to calculate the estimate *r* of the linking factor *R* and it's corresponding uncertainty $u(r)$. Therefore the linking coefficient in this particular case is simply the ratio of the CIPM-KCRV and the results of the linking laboratory (PTB) in CCAUV.V-K1.1.

Since the linked results of the pilot are of no importance in the process (PTB already took part in CCAUV.V-K1 and EUROMET.AUV.V-K1), this section will concentrate on the linked results of the other three participants and their Degree of Equivalence (DoE) with the participants of CCAUV.V-K1 and with its reference value.

8.2.2 DoE relative to the KCRV of CCAUV.V-K1 for the SE transducer

In order to perform a comparison of the participants with the reference value of CCAUV.V-K1 the difference of the linked results z_i and its uncertainty is calculated. This gives the DoE relative to the KCRV. The following tables document this for the two transducers used in this comparison.

Table 22: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and the KCRV of CCAUV.V-K1 for the SE transducer

	NIM		NPLI		INMETRO	
	D_i	U_i	D_i	U_i	D_i	U_i
Frequency in Hz	in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
40,0	2,2	6,6	2,2	9,1	1,8	3,5
80,0	2,3	6,6	3,3	9,1	1,9	3,5
160,0	1,8	2,9	3,7	9,2	1,1	3,5
800,0	1,8	6,6	1,0	9,1	1,6	3,5
2000,0	0,5	6,6	-5,8	9,1	1,3	4,7

8.2.3 DoE to the KCRV of CCAUV.V-K1 for the B2B transducer

Table 23: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and the KCRV of CCAUV.V-K1 for the B2B transducer

	NIM		NPLI		INMETRO	
	D_i	U_i	D_i	U_i	D_i	U_i
Frequency in Hz	in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)		in 10^4 pC/(m/s²)	
40,0	0,3	6,5	1,2	9,0	0,0	3,3
80,0	-0,6	6,5	2,0	9,0	0,0	3,3
160,0	-0,2	2,8	2,4	9,0	-0,3	3,3
800,0	0,8	6,5	-1,4	9,0	0,2	3,3
2000,0	-2,7	6,5	-12,0	8,9	-2,1	4,5
5000,0	-3,3	6,6	-50,6	12,5	-2,7	13,0

8.3 Degree of equivalence relative to the participants of CCAUV.V-K1

8.3.1 DoE relative to the participants of CCAUV.V-K1 for the SE transducer

Table 24: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 40 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	-1,9	6,7	-1,9	9,2	-1,5	3,6
BNM-CESTA	-1,1	9,2	-1,1	11,1	-0,7	7,3
CSIRO-NML	-1,1	8,3	-1,1	10,5	-0,7	6,2
CMI	-4,6	8,8	-4,6	10,8	-4,2	6,8
CSIR-NML	3,9	11,2	3,9	12,8	4,3	9,7
CENAM	-2,8	9,2	-2,8	11,1	-2,4	7,3
NRC	-4,5	7,6	-4,5	9,9	-4,1	5,1
KRISS	-4,9	8,0	-4,9	10,2	-4,5	5,7
NMIJ	-6,8	8,5	-6,8	10,6	-6,4	6,4
VNIIM	-8,9	8,3	-8,9	10,4	-8,5	6,1
NIST	3,9	7,6	3,9	9,9	4,3	5,1
NMI-VSL	-1,6	13,5	-1,6	15,0	-1,2	12,3

Table 25: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 80 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	-2,0	6,7	-3,0	9,2	-1,6	3,6
BNM-CESTA	0,9	9,2	-0,1	11,2	1,3	7,3
CSIRO-NML	-3,1	7,6	-4,1	9,9	-2,7	5,1
CMI	-3,6	8,8	-4,6	10,9	-3,2	6,8
CSIR-NML	-0,1	11,2	-1,1	12,8	0,3	9,6
CENAM	-2,6	9,2	-3,6	11,1	-2,2	7,3
NRC	1,6	7,6	0,6	9,9	2,0	5,1
KRISS	-4,8	8,0	-5,8	10,2	-4,4	5,7
NMIJ	-4,3	9,0	-5,3	11,0	-3,9	7,0
VNIIM	-6,3	8,3	-7,3	10,4	-5,9	6,1
NIST	-2,1	7,6	-3,1	9,9	-1,7	5,1
NMI-VSL	-4,0	7,2	-5,0	9,6	-3,6	4,6

Table 26: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 160 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	-1,5	3,1	-3,4	9,2	-0,8	3,6
BNM-CESTA	1,3	7,0	-0,6	11,2	2,0	7,3
CSIRO-NML	-2,7	4,8	-4,6	9,9	-2,0	5,1
CMI	-1,7	6,6	-3,6	10,9	-1,0	6,8
CSIR-NML	-4,7	7,0	-6,6	11,1	-4,0	7,3
CENAM	-3,1	7,0	-5,0	11,1	-2,4	7,3
NRC	-0,3	4,8	-2,2	9,9	0,4	5,1
KRISS	-3,7	5,4	-5,6	10,2	-3,0	5,7
NMIJ	-3,9	6,3	-5,8	10,7	-3,2	6,6
VNIIM	-3,5	5,9	-5,4	10,5	-2,8	6,1
NIST	-0,7	4,8	-2,6	9,9	0,0	5,1
NMI-VSL	-2,2	5,2	-4,1	10,1	-1,5	5,5

Table 27: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 800 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	-2,1	6,7	-1,3	9,2	-1,9	3,6
BNM-CESTA	1,3	9,2	2,1	11,2	1,5	7,3
CSIRO-NML	-2,7	7,6	-1,9	9,9	-2,5	5,1
CMI	0,3	10,8	1,1	12,5	0,5	9,2
CSIR-NML	2,3	10,2	3,1	12,0	2,5	8,5
CENAM	-1,4	9,2	-0,6	11,2	-1,2	7,3
NRC	0,7	8,7	1,5	10,7	0,9	6,6
KRISS	-3,7	8,0	-2,9	10,2	-3,5	5,7
NMIJ	-4,7	10,9	-3,9	12,6	-4,5	9,4
VNIIM	-6,5	8,6	-5,7	10,7	-6,3	6,6
NIST	0,3	12,9	1,1	14,4	0,5	11,6
NMI-VSL	4,4	8,5	5,2	10,6	4,6	6,4

Table 28: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 2000 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	-0,5	6,7	5,8	9,2	-1,3	4,8
BNM-CESTA	-0,3	9,2	6,0	11,2	-1,1	8,0
CSIRO-NML	-1,3	7,6	5,0	9,9	-2,1	6,0
CMI	1,2	10,4	7,5	12,2	0,4	9,3
CSIR-NML	3,7	10,2	10,0	12,0	2,9	9,1
CENAM	0,2	12,3	6,5	13,8	-0,6	11,4
NRC	-3,6	10,8	2,7	12,5	-4,4	9,7
KRISS	-4,5	9,0	1,8	11,0	-5,3	7,7
NMIJ	10,8	9,3	17,1	11,2	10,0	8,0
VNIIM	-8,1	8,7	-1,8	10,7	-8,9	7,3
NIST	-2,3	11,0	4,0	12,7	-3,1	9,9
NMI-VSL	4,8	14,4	11,1	15,7	4,0	13,6

8.3.2 DoE to the participants of CCAUV.V-K1 of CCAUV.V-K1 for the B2B transducer

Table 29: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 40 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	0,3	6,5	-0,6	9,0	0,6	3,4
BNM-CESTA	0,8	9,0	-0,1	10,9	1,1	7,1
CSIRO-NML	0,8	8,1	-0,1	10,2	1,1	6,0
CMI	-1,3	8,6	-2,2	10,6	-1,0	6,6
CSIR-NML	8,8	13,1	7,9	14,5	9,1	11,9
CENAM	-2,1	9,0	-3,0	10,9	-1,8	7,1
NRC	-1,5	7,4	-2,4	9,7	-1,2	4,9
KRISS	-1,5	7,8	-2,4	10,0	-1,2	5,5
NMIJ	-3,3	8,3	-4,2	10,4	-3,0	6,2
VNIIM	-5,8	8,1	-6,7	10,2	-5,5	5,9
NIST	0,8	7,4	-0,1	9,7	1,1	4,9
NMI-VSL	-1,2	7,2	-2,1	9,5	-0,9	4,5

Table 30: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 80 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	1,0	6,5	-1,6	9,0	0,4	3,4
BNM-CESTA	2,8	9,0	0,2	10,9	2,2	7,1
CSIRO-NML	0,8	7,4	-1,8	9,7	0,2	4,9
CMI	0,8	8,5	-1,8	10,5	0,2	6,4
CSIR-NML	-4,2	10,9	-6,8	12,5	-4,8	9,4
CENAM	-0,5	9,0	-3,1	10,9	-1,1	7,1
NRC	4,5	7,4	1,9	9,7	3,9	4,9
KRISS	-0,5	7,8	-3,1	10,0	-1,1	5,5
NMIJ	0,4	8,8	-2,2	10,8	-0,2	6,8
VNIIM	-4,0	8,1	-6,6	10,2	-4,6	5,9
NIST	-0,2	7,4	-2,8	9,7	-0,8	4,9
NMI-VSL	-1,1	7,0	-3,7	9,3	-1,7	4,2

Table 31: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 160 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	0,3	2,9	-2,3	9,0	0,4	3,4
BNM-CESTA	0,9	6,9	-1,7	10,9	1,0	7,1
CSIRO-NML	-0,1	4,6	-2,7	9,7	0,0	4,9
CMI	-0,1	6,4	-2,7	10,6	0,0	6,6
CSIR-NML	-0,1	6,9	-2,7	10,9	0,0	7,1
CENAM	-0,1	6,9	-2,7	10,9	0,0	7,1
NRC	1,4	4,6	-1,2	9,7	1,5	4,9
KRISS	-1,2	5,3	-3,8	10,0	-1,1	5,5
NMIJ	-0,1	6,2	-2,7	10,5	0,0	6,4
VNIIM	2,1	5,7	-0,5	10,3	2,2	6,0
NIST	-1,1	4,6	-3,7	9,7	-1,0	4,9
NMI-VSL	-0,1	5,1	-2,7	9,9	0,0	5,3

Table 32: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 800 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	-1,2	6,5	1,0	9,0	-0,6	3,4
BNM-CESTA	1,9	9,0	4,1	10,9	2,5	7,1
CSIRO-NML	-1,1	7,4	1,1	9,7	-0,5	4,9
CMI	-1,1	9,4	1,1	11,2	-0,5	7,5
CSIR-NML	0,9	9,0	3,1	10,9	1,5	7,1
CENAM	-1,4	9,0	0,8	10,9	-0,8	7,1
NRC	0,6	8,5	2,8	10,5	1,2	6,4
KRISS	-1,6	7,8	0,6	10,0	-1,0	5,5
NMIJ	-2,0	9,2	0,2	11,1	-1,4	7,3
VNIIM	2,7	8,5	4,9	10,5	3,3	6,4
NIST	-4,1	12,6	-1,9	14,0	-3,5	11,3
NMI-VSL	4,0	9,0	6,2	10,9	4,6	7,1

Table 33: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 2000 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	3,0	6,5	12,3	8,9	2,4	4,6
BNM-CESTA	4,4	9,0	13,7	10,9	3,8	7,7
CSIRO-NML	2,4	7,4	11,7	9,6	1,8	5,8
CMI	2,0	8,8	11,3	10,7	1,4	7,5
CSIR-NML	2,4	9,9	11,7	11,7	1,8	8,8
CENAM	3,5	12,0	12,8	13,5	2,9	11,1
NRC	3,4	10,6	12,7	12,2	2,8	9,5
KRISS	1,6	8,0	10,9	10,1	1,0	6,5
NMIJ	1,6	8,7	10,9	10,6	1,0	7,3
VNIIM	20,4	8,5	29,7	10,5	19,8	7,2
NIST	-1,6	10,7	7,7	12,3	-2,2	9,7
NMI-VSL	0,6	8,3	9,9	10,3	0,0	6,9

Table 34: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 5000 Hz

	NIM		NPLI		INMETRO	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
CCAUV.V-K1	in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4		in pC/(m/s²) · 10^4	
PTB	3,1	7,0	50,4	12,7	2,5	13,2
BNM-CESTA						
CSIRO-NML	4,7	8,3	52,0	13,5	4,1	13,9
CMI	3,2	10,1	50,5	14,7	2,6	15,1
CSIR-NML	1,7	11,1	49,0	15,4	1,1	15,8
CENAM	2,8	12,2	50,1	16,2	2,2	16,6
NRC	2,7	15,4	50,0	18,7	2,1	19,0
KRISS	4,3	8,6	51,6	13,7	3,7	14,1
NMIJ	2,8	18,3	50,1	21,1	2,2	21,4
VNIIM	17,1	11,0	64,4	15,3	16,5	15,7
NIST	1,7	16,8	49,0	19,9	1,1	20,2
NMI-VSL	2,6	49,3	49,9	50,4	2,0	50,6

9 Conclusion

During the CCAUV.V-K1.1 comparison four laboratories of different countries measured the (complex) charge sensitivities of two artefacts, a single ended and a back-to-back accelerometer in a frequency range between 10 Hz and 10 kHz. Three of the laboratories included in their results the full frequency range with magnitude and phase shift, while one laboratory limited the results to the scope given by the previous CCAUV.V-K1 comparison [3], I.e. magnitude from 40 Hz to 5 kHz.

One laboratory (PTB) was acting as pilot and linking laboratory, as it had taken part in the CCAUV.V-K1, too. The other three participants were linked to the results of this former comparison via the pilot laboratory.

For the purpose of comparison over the wider scope the degrees of equivalence were calculated between the participants of CCAUV.V-K1.1 over the full frequency range for magnitude and phase shift. While the DoE with respect to CCAUV.V-K1 were only calculated where applicable.

A major complication during the reported comparison proved to be the instability of one of the two artefacts. This problem, however, could be solved based on the model of a linear drift combined with the appropriate correction and a supplementary uncertainty component related to this correction.

With only very few exceptions the results of the participants proved to be consistent with each other as well as with those of the participants of CCAUV.V-K1 within the limits of the reported measurement uncertainties.

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Appendix A: Technical Protocol

Technical Protocol of the Comparison in Vibration between NIM (China) NPL (India) INMETRO (Brazil) and PTB (Germany)

1 Task and purpose of the comparison

In the field of vibration and shock, this regional comparison is organized in order to compare measurements of sinusoidal linear accelerations in the frequency range from 40 Hz to 5 kHz. Moreover, the magnitude of the complex sensitivity calibration and measurement capabilities (CMCs) of the NMIs for accelerometer calibration are to be examined and compared and linked to the CIPM comparison CCAUV.V-K1.

It is the task of the comparison to measure the magnitude of the complex charge sensitivity of two accelerometer standards (back-to-back and single ended in design) at different frequencies with acceleration amplitudes as specified in section 2.

The charge sensitivity is calculated as the ratio of the amplitude of the accelerometer output charge to the amplitude of the acceleration at its reference surface. The reference surface is defined as the transfer surface of the accelerometer.

The magnitude of the complex charge sensitivity shall be given in pico coulomb per metre per second squared (pC/(m/s²)) for the different measurement conditions specified in section 2.

A calibrated charge amplifier is to be used to measure the output charge and phase shift of the accelerometer standards, applying appropriate electrical calibration methods. For the calibration of the accelerometer standards, 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. Supplementary measurement results of the participants might be considered in the report if appropriate.

2 Conditions of measurement

The measurements have to comply with the following conditions:

- mandatory vibration frequencies:
  40 Hz, 80 Hz, 160 Hz, 800 Hz, 2000 Hz, 5000 Hz
  (Optionally the lab can measure at other frequencies provided they are included in the third-oktave frequency series between 10 Hz and 10 kHz, results at additional frequencies between 10 Hz and 10 kHz will be reported).

- acceleration amplitudes:
  A range of 10 m/s^2 to 200 m/s^2 is admissible.
- ambient temperature and accelerometer temperature during the calibration:
  (23 ± 2)ºC (actual values to be stated within tolerances of ± 0.3ºC).
- relative humidity: max. 75 %
- mounting torque of the accelerometer: (2.0 ± 0.1) N·m

3 Transfer standard

As transfer standards, two types of piezoelectric accelerometers are to be used: standard accelerometer (back-to-back) type 8305 (Accelerometer A) and standard accelerometer (single-ended) type 8305 WH2335 (Accelerometer B) (manufacturer Brüel & Kjaer):

- Accelerometer A: Bruel & Kjaer model 8305
  serial number: 748737
  nominal charge sensitivity (magnitude): 0.13 pC/(m/s^2)

- Accelerometer B: Bruel & Kjaer model 8305 WH2335
  serial number: 1610168
  nominal charge sensitivity (magnitude): 0,13 pC/(m/s^2)

4 Circulation type and transportation

- The comparison has three participants.
- The transfer standard will be transported in a closed box, hand-carried by representatives of NIM or PTB.

5 Measurement instructions

The participating laboratories have to observe the following instructions:

- The charge amplifier used in the laboratory is to be calibrated using a standard capacitor and standard voltmeter, both traceable to national standards. The calibration of the charge amplifier has to be carried out shortly before the calibration, using values of the electric quantities similar to those expected in the accelerometer calibration.
- In order to suppress the effect of any non-rectilinear motion, the displacement has to be measured at least at four different points. These points should be equally spaced on the top surface of the back-to-back accelerometer.
- **Primary calibration of BB accelerometer (A) by laser interferometry:** The motion is to be sensed at the top surface (polished) without any dummy mass; no reflector (e.g. corner cube) must be attached to the top surface. The reflectivity of the polished

top surface will be 80 % or higher, and the flatness over the top surface in the order of 1 µm.

- **Primary calibration of SE accelerometer (B) by laser interferometry**:The reference surface for acceleration measurement is by definition the base or mounting surface of the accelerometer. If this surface is covered during the calibration, the motion is to be sensed on the moving part close to the accelerometer. Alternatively, the motion can be sensed at the mounting surface of the accelerometer via longitudinal holes in the moving part of the vibration exciter. ISO 16063-11 is to be observed.
- The mounting surface of the accelerometer and the moving part of the vibration exciter must be slightly lubricated before mounting.

Complete measurement series shall be carried out on different days under nominally the same conditions, except that the accelerometer is re-mounted and the cable refixed. The (mean) result of the all the measurement series is to be given as the final measurement result.

6 Communication of the results to the pilot laboratory

The participants will submit the calibration report to the PTB including descriptions of:

- the calibration equipment
- the calibration methods used
- the ambient conditions
- the mounting technique
- the calibration results
- the uncertainty of measurement (k = 2) for each measurement result

In each case, the uncertainties have to be evaluated in accordance with the Guide to the expression of uncertainty in measurement (GUM), which has been adapted to the calibration of vibration and shock transducers as stated in ISO 16063-1:1998, Annex A.

Appendix B: Uncertainty Budgets of the participants

PTB:

Measurement uncertainties applicable for the fringe counting method used in CCAUV.V-K1.1 from 10 Hz to 800 Hz for magnitude of complex sensitivity:

DUT	B&K 8305 or 8305-001	+ B&K 2650				
acceleration:	100 m/s²					
Voltage	typic. 1V				std. uncert. combined frequency ranges	
Disturbing Component	**comment**	**typical width**	**distribution**	**factor**	**10 Hz to 40 Hz**	**to 800Hz**
nominal Frequency	Generator accuracy	5,00E-05	rectangular	1,73	2,89E-05	2,89E-05
Accelerometer Voltage	DVM calibration (200mV to 900 mV)	5,00E-05	rectangular	1,73	2,89E-05	2,89E-05
Acceleration Ampl. by FC	optical misalignment, Heydeman correction, Wavelngth	1,00E-04	rectangular	1,73	5,77E-05	5,77E-05
harmonic distortion on Voltage measurement	estimated < 6e-5 max at 63 Hz		single point	2	3,00E-05	3,00E-05
Humm	50 Hz, ~0,7mV RMS	1,23E-05	single point	2,00	6,13E-06	3,83E-07
Noise	1,7mV RMS	0,00007225	single point	2	3,61E-05	2,26E-06
Transverse motion	1 % transv. Sensitivity @ 4% transv. Excitation		complex		1,14E-04	1,14E-04
Base Strain sensitivity	S = 0,005m/s² / µ€ € < 0,1 µm/m	depending on acc. Level	rectangular	1,73	2,89E-05	5,77E-06
Mounting torque	S = 6e-4/Nm; dM = 0,2 Nm	0,00012	rectangular	1,73	6,93E-05	6,93E-05
temperature sensitivity	S=2,5e-4 /K dT = 0,3 K	0,000075	rectangular	1,73	4,33E-05	4,33E-05
magnetic sensitivity	S=1/a *(m/s²)/T B < 0,03mT	depending on acc. Level	rectangular	1,73	1,73E-06	3,46E-07
airborne sound	S=0,008 m/s² at 154 dB max sound level 88 dB	8,00E-08	rectangular	1,73	4,62E-08	4,62E-08
quantization	suppressed by known phase-disturbance	1,00E-05	U-type	1,41	7,07E-06	7,07E-06
phase disturbance	Depending on ratio of stoch. Veloc. to stat. Veloc.	Stoch. Veloc. RMS 30µm/s	Steiner	1	1,78E-08	1,78E-08
trigger hysteresis	set hysteresis value 20 mV system. Dev. Corrected	est. remaining dev. < 1e-6		1	1,00E-06	1,00E-06
Low pass of photo detector voltage	f_c (-3db) 3 MHz	1,00E-07	rectangular	1,73	5,77E-08	5,77E-08
foto electric noise	RMS 2,5mV		Steiner	1	1,30E-05	2,00E-05
harmonical distortion	rectangular distrib. of relat. Phase. Only 1st harmonic essential, ampl. ratio 0,0012	1,33E-04	U-type	1,41	9,43E-05	9,43E-05
humm (50 Hz)	humm acc. 0,08m/s²	1,77E-05	rectangular	1,73	1,02E-05	1,60E-04
asynchronous measurement	voltage/acceleration/voltage	1,00E-04	rectangular	1,73	5,77E-05	5,77E-05
residual influences		1,00E-04	normal	1,41	7,07E-05	7,07E-05
exp. std. deviation		1,70E-04	normal	1,41	1,20E-04	1,20E-04
Charge Amplifier calibration		4,24E-04	normal	2	2,12E-04	2,12E-04
rel. std. uncertainty	**in %**				**0,0324**	**0,0358**
rel. comb. exp. Uncertainty (k=2)	**in %**				**0,0647**	**0,0716**
stated rel. comb. exp. Uncertainty	**in %**				**0,1000**	**0,1000**

Measurement uncertainties applicable for the sine approximation method method used in CCAUV.V-K1.1 from 1 kHz to 10 kHz for magnitude of complex sensitivity:

DUT	B&K 8305 or 8305-001	+ B&K 2650				
acceleration:	100 m/s²					
Voltage	typic. 1V					
Sample rate	10 MS/s	@ 12 Bit				
					std. uncert. combined frequency ranges	
Disturbing Component	**comment**	**95% value**	**distribution**	**factor**		
					500 Hz to 5 kHz	**to 10 kHz**
frequency of SAM	deviation of sample clock from generator clock	1,00E-04	rectangular	1,73	5,77E-05	5,77E-05
Accelerometer Voltage	sampling of HP3458A	5,00E-04	rectangular	1,73	2,89E-04	2,89E-04
Velocity amplitude	wave length, optical adjustment, deviation between the two beams	1,16E-05	normal	2,00	5,80E-06	5,80E-06
harmon. Distortion	mainly 1st harmonic		Steiner	1,00	7,84E-06	7,84E-06
Humm on Voltage	typical 1mV	5,00E-07	Steiner	1,00	5,00E-07	5,00E-07
Noise on Voltage	MC on influence to SAM duration 20ms, Un=1,0mV	6,60E-06	normal	1,00	3,30E-06	3,30E-06
Transverse Motion	S(transv) = 0,7% a(transv) < 4%		u-type	1,41	1,98E-04	1,98E-04
Base strain sensitivity	S = 0,005m/s² / µ€ € < 0,1 µm/m	5,00E-06	rectangular	1,73	2,89E-06	2,89E-06
mounting	S = 6e-4/Nm; dM = 0,2 Nm	1,20E-04	rectangular	1,73	6,93E-05	6,93E-05
Temperature	S=2,5e-4 /K dT = 0,3 K	7,50E-05	rectangular	1,73	4,33E-05	4,33E-05
Magnetic field	S=1/a *(m/s²)/T B < 0,03mT	3,00E-07	rectangular	1,73	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	1,73	4,62E-08	4,62E-08
Noise on Interferom.	noise level equiv. of 2 nm after demodulation, Monte Carlo		normal	1,00	1,10E-04	3,00E-04
a-synchronous Measurement	voltage/acceleration/voltage	1,00E-04	rectangular	1,73	5,77E-05	5,77E-05
charge ampl. calibration		4,24E-04	normal	2,00	2,12E-04	2,12E-04
resid. influences		1,00E-04	normal	1,41	7,07E-05	7,07E-05
exp. std. dev					2,30E-05	1,60E-04
rel. std. uncertainty	**in %**				**0,0446**	**0,0549**
rel. comb. exp. Uncertainty (k=2)	**in %**				**0,0891**	**0,1098**
stated rel. comb. exp. Uncertainty	**in %**				**0,1000**	**0,3000**

Measurement uncertainties applicable for the sine approximation method method used in CCAUV.V-K1.1 from 10 Hz to 10 Hz for phase of complex sensitivity:

DUT	B&K 8305 or 8305-001	+ B&K 2650				
acceleration:	100 m/s²					
Voltage	typic. 1V					
Sample rate	10 MS/s	@ 12 Bit				
					combined frequency ranges	
Disturbing Component	**comment**	**95% value**	**distribution**	**factor**	**10 Hz to 1 kHz**	**to 10 kHz**
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	1,00E-03
Noise on accelerometer Voltage output	Monte Carlo, SNR=500	< 2mV @ 1V	normal	1	4,00E-04	4,00E-04
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 100 ns	rectang.	1,73	2,08E-02	2,08E-01
Calibration Charge Amplifier B&K 2650	including Stability, reproducibility, methode (black box)	<0,02°	normal	2	2,00E-02	2,00E-02
Noise on heterodyne interferometer channel	noise level equiv. of 2 nm after demodulation, Monte Carlo	< 2nm	normal	1	1,43E-04	1,43E-02
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	5,00E-02	1,20E-01
std. uncertainty	**in 1°**				**0,059**	**0,242**
exp. Uncertainty (k=2)	**in 1°**				**0,118**	**0,484**
stated exp. Uncertainty	**in 1°**				**0,200**	**0,500**

INMETRO:

Uncertainty budget - Absolute Interferometric calibration of a back-to-back standard accelerometer (loading mass = 0 g)

ISO 16063-11:1999 - Table A.3 & A.5

CHARGE SENSITIVITY - MAGNITUDE

Relative expanded uncertainty or bounds of estimated error components (%)

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	frequency (Hz) 10	12,5	16	20	25	31,5	40	50	63	80	100	125	160	200	250	315
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	0,10	0,10	0,10	0,10	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity) - dev% from fit	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	0,00	0,00	0,01	0,02	0,01	0,01	0,04	0,07	0,04	0,03	0,02	0,02	0,01	0,00	0,01	0,01
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			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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	0,08	0,06	0,04	0,03	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00
13	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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)	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(A\ cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,10	0,10	0,10	0,10	0,09	0,08	0,07	0,06	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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/s^2)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,58	0,06	0,05	0,05	0,04	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,02	0,02	0,02	0,02
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)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	Relative uncertainty contribution $u_{rel,i}(y)$ (%) frequency (Hz) 10	12,5	16	20	25	31,5	40	50	63	80	100	125	160	200	250	315
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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	0,10	0,10	0,10	0,10	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,00	0,00	0,01	0,01	0,01	0,01	0,02	0,04	0,02	0,02	0,01	0,01	0,01	0,00	0,01	0,01
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			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,03	0,03	0,02	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	$u(\lambda\,cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(A\ cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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)	retangular	0,58	0,04	0,03	0,03	0,03	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	0,01
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)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=1)				0,14	0,13	0,13	0,13	0,10	0,09	0,09	0,10	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=2)				0,28	0,27	0,27	0,26	0,19	0,19	0,19	0,19	0,18	0,18	0,17	0,17	0,17	0,17	0,17	0,17

Uncertainty budget - Absolute Interferometric calibration of a back-to-back standard accelerometer (loading mass = 0

ISO 16063-11:1999 - Table A.3 & A.5

CHARGE SENSITIVITY - MAGNITUDE

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150	3500	3800	4000	4500	5000
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity) - dev% from fit	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,03	0,04	0,05	0,04	0,06	0,06	0,09	0,06	0,02	0,06	0,03	0,01	0,01	0,02	0,03	0,10	0,12
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		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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))	0,04	0,01	0,01	0,01	0,01	0,01	0,02	0,03	0,04	0,03	0,05	0,08	0,06	0,08	0,07	0,12	0,06
13	$u(\lambda \text{cal})$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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)	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(A \text{ cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Uncertainty budget - Absolute Interferometric calibration of a back-to-back standard accelerometer (loading mass = 0 g)
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Relative expanded uncertainty or bounds of estimated error components (%), frequency (Hz)

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	10	12,5	16	20	25	31,5	40	50	63	80	100	125	160	200	250	315
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	0,10	0,10	0,10	0,10	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity) - dev% from fit	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	0,00	0,00	0,01	0,02	0,01	0,01	0,04	0,07	0,04	0,03	0,02	0,02	0,01	0,00	0,01	0,01
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			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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	0,08	0,06	0,04	0,03	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00
13	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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)	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(A\ cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,10	0,10	0,10	0,10	0,09	0,08	0,07	0,06	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,58	0,06	0,05	0,05	0,04	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,02	0,02	0,02	0,02
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)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Uncertainty budget - Absolute Interferometric calibration of a back-to-back standard accelerometer (loading mass = 0

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i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	6500	7000	7500	8000	8500	9000	9500	10000	11000	12000	12500	13000	14000	15000	16000	17000	18000
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	0,05	0,05	0,05	0,05	0,05	0,05	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity) - dev% from fit	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,04	0,00	0,03	0,05	0,12	0,32	0,05	0,12	0,05	0,11	0,13	0,16	0,14	0,31	0,16	0,24	0,27
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		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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))	0,17	0,15	0,12	0,15	0,21	0,52	0,45	0,36	0,49	0,50	0,52	0,37	0,39	0,38	0,27	0,32	0,55
13	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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)	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(A\ cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	6500	7000	7500	8000	8500	9000	9500	10000	11000	12000	12500	13000	14000	15000	16000	17000	18000
1	$u(\hat{a}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
2	$u(\hat{a}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
3	$u(\hat{a}_D)$	effect of voltage disturbance on accelerometer output voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
4	$u(\hat{a}_T)$	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	retangular	0,02	0,00	0,02	0,03	0,07	0,18	0,03	0,07	0,03	0,06	0,08	0,09	0,08	0,18	0,09	0,14	0,16
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		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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))	0,07	0,06	0,05	0,06	0,09	0,21	0,18	0,15	0,20	0,20	0,21	0,15	0,16	0,16	0,11	0,13	0,23
13	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(A\ cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
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)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=1)			0,11	0,11	0,10	0,11	0,14	0,29	0,21	0,19	0,23	0,24	0,25	0,21	0,21	0,26	0,18	0,22	0,29
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=2)			0,23	0,21	0,20	0,22	0,28	0,59	0,41	0,38	0,46	0,47	0,49	0,41	0,42	0,52	0,36	0,44	0,59

Uncertainty budget - Absolute Interferometric calibration of a single-ended standard accelerometer
ISO 16063-11:1999 - Table A.3 & A.5

CHARGE SENSITIVITY - MAGNITUDE

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	Relative expanded uncertainty or bounds of estimated error components (%) frequency (Hz) 10	12,5	16	20	25	31,5	40	50	63	80	100	125	160	200	250	315
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	0,10	0,10	0,10	0,10	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,00	0,01	0,02	0,01	0,01	0,02	0,01	0,04	0,01	0,00	0,00	0,01	0,03	0,01	0,02	0,01
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			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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	0,02	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,02	0,01	0,02
13	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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)	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(A\ cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,10	0,10	0,10	0,10	0,09	0,08	0,07	0,06	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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/s^2)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,58	0,06	0,05	0,05	0,04	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,02	0,02	0,02	0,02
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)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

						Relative uncertainty contribution $u_{rel,i}(y)$ (%)															
						frequency (Hz)															
i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	10	12,5	16	20	25	31,5	40	50	63	80	100	125	160	200	250	315
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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	0,10	0,10	0,10	0,10	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,00	0,00	0,01	0,02	0,01	0,01	0,01
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			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,01	0,01	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,00	0,01	0,01	0,01
13	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(A\ cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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/s^2)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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)	retangular	0,58	0,04	0,03	0,03	0,03	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	0,01
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)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=1)				0,13	0,13	0,13	0,13	0,10	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=2)				0,27	0,27	0,27	0,26	0,19	0,19	0,18	0,18	0,17	0,17	0,17	0,17	0,18	0,17	0,17	0,17

Uncertainty budget - Absolute Interferometric calibration of a single-ended standard accelerometer

ISO 16063-11:1999 - Table A.3 & A.5

CHARGE SENSITIVITY - MAGNITUDE

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150	3500	3800	4000	4500	5000
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,02	0,03	0,01	0,01	0,02	0,02	0,04	0,03	0,01	0,02	0,01	0,00	0,02	0,03	0,08	0,08	0,09
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		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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))	0,03	0,11	0,01	0,02	0,02	0,03	0,02	0,04	0,07	0,07	0,09	0,10	0,11	0,10	0,17	0,21	0,20
13	$u(\lambda\,\text{cal})$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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)	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(A\ \text{cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150	3500	3800	4000	4500	5000
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,01	0,02	0,01	0,01	0,01	0,01	0,02	0,02	0,01	0,01	0,01	0,00	0,01	0,02	0,05	0,05	0,05
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		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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))	0,01	0,05	0,00	0,01	0,01	0,01	0,01	0,02	0,03	0,03	0,04	0,04	0,05	0,04	0,07	0,09	0,08
13	$u(\lambda\,\mathrm{cal})$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(A\ \mathrm{cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
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)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=1)			0,09	0,10	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,10	0,10	0,12	0,13	0,13
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=2)			0,17	0,20	0,17	0,17	0,17	0,17	0,18	0,18	0,18	0,18	0,19	0,19	0,20	0,19	0,24	0,26	0,26

Uncertainty budget - Absolute Interferometric calibration of a single-ended standard accelerometer
ISO 16063-11:1999 - Table A.3 & A.5

CHARGE SENSITIVITY - MAGNITUDE

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	6500	7000	7500	8000	8500	9000	9500	10000	11000	12000	12500	13000	14000	15000	16000	17000	18000
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	0,05	0,05	0,05	0,05	0,05	0,05	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
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	retangular	0,12	0,01	0,31	0,38	0,07	0,12	0,39	0,40	0,34	0,11	0,00	0,16	0,06	0,22	0,02	0,14	0,64
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		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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))	0,55	0,49	0,66	0,37	0,28	0,36	0,47	1,18	1,03	1,13	0,77	0,78	1,09	1,17	1,23	1,91	1,39
13	$u(\lambda \text{cal})$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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)	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(A \text{ cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
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)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	6500	7000	7500	8000	8500	9000	9500	10000	11000	12000	12500	13000	14000	15000	16000	17000	18000
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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)	0,05	0,05	0,05	0,05	0,05	0,05	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
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	retangular	0,07	0,01	0,18	0,22	0,04	0,07	0,23	0,23	0,20	0,06	0,00	0,09	0,03	0,13	0,01	0,08	0,37
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		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(\Phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(\Phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(\Phi_{M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(\Phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(\Phi_{M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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))	0,23	0,20	0,27	0,15	0,12	0,15	0,19	0,48	0,42	0,46	0,32	0,32	0,44	0,48	0,50	0,78	0,57
13	$u(\lambda \text{cal})$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(A \text{ cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	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/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
21	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
22	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
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)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=1)			0,25	0,22	0,33	0,28	0,15	0,18	0,31	0,54	0,48	0,48	0,33	0,35	0,46	0,51	0,51	0,79	0,69
	$u_{rel}(S_2)$	Estimated Uncertainty for acelerometer sensitivity (k=2)			0,50	0,43	0,67	0,56	0,30	0,36	0,62	1,08	0,95	0,96	0,67	0,70	0,91	1,01	1,03	1,59	1,37

Uncertainty budget - Absolute Interferometric calibration of a back-to-back standard accelerometer (loading mass = 0 g) — **ISO 16063-11:1999 - Table A.4 & A.6**

CHARGE SENSITIVITY - PHASE SHIFT

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) 10	12,5	16	20	25	31,5	40	50	63	80	100	125
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
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														
6	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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=5, std dev of the mean)	normal (sqrt(N))	0,45	0,03	0,01	0,01	0,04	0,01	0,01	0,00	0,00	0,00	0,00	0,01	0,01
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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,58	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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.	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{L,u,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	0,01
17	$u(e_{L,u,P})$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s^2)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u(e_{I,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	$u(e_{I,P})$	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	Uncertainty contribution $u_{rel,i}(y)$ (°) frequency (Hz) 10	12,5	16	20	25	31,5	40	50	63	80	100	125
1	$u(\hat{u}_V)$	accelerometer output phase measurement (ADC resolution)	results of different calibrations measured against hp3458A	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_D)$	voltage filtering effect on accelerometer output phase measurement	No filtering applied	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	$u(\hat{u}_T)$	effect of voltage disturbance on accelerometer output phase measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(s_Q)$	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	retangular	0,58	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
5	$u(s_H)$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90o nominal angle difference)	already included in i = 3			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(s_F)$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No filtering applied	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(s_{VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(s_{MD})$	effect of motion disturbance on diaplacementphase measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(s_{PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(s_{RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
11	$u(s_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,5	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
12	$u(S_{RE})$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	Estimated to be less than (for N=5, std dev of the mean at a single point measurement)	normal (sqrt(N))	0,45	0,01	0,01	0,00	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01
13	$u(G)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	$u(G)$	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)	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(\lambda cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
17	$u(e_{L,a,A})$	amplitude effect on gain of reference amplifier	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
18	$u(e_{L,a,P})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s^2)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
19	$u(e_{LA})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u(e_{LP})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
			Estimated to be less than (dT =+/- 1 oC		0,58												

Uncertainty budget - Absolute Interferometric calibration of a back-to-back standard accelerometer (loading mass = 0 g)

CHARGE SENSITIVITY - PHASE SHIFT

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	315	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,20
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														
6	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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=5, std dev of the mean)	normal (sqrt(N))	0,00	0,02	0,02	0,01	0,01	0,00	0,00	0,01	0,01	0,02	0,02	0,02	0,02
12	$u(\Delta\Phi_{A,cal})$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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.	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(\lambda \text{cal})$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{L,u,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
17	$u(e_{L,u,P})$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u(e_{I,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	$u(e_{I,P})$	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

Uncertainty budget - Absolute Interferometric calibration of a back-to-back standard accelerometer (loading mass = 0 g) | **ISO 16063-11:1999 - Table A.4 & A.6**

CHARGE SENSITIVITY - PHASE SHIFT

Expanded uncertainty or bounds of estimated error components (°)

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	frequency (Hz) 10	12,5	16	20	25	31,5	40	50	63	80	100	125
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
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														
6	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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=5, std dev of the mean)	normal (sqrt(N))	0,45	0,03	0,01	0,01	0,04	0,01	0,01	0,00	0,00	0,00	0,00	0,01	0,01
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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,58	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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.	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{L,a,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	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)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u(e_{I,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	$u(e_{I,P})$	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

Uncertainty budget - Absolute Interferometric calibration of a back-to-back standard accelerometer (loading mass = 0 g)

CHARGE SENSITIVITY - PHASE SHIFT

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	4500	5000	5500	6000	6300	6500	7000	7500	8000	8500	9000	9500	10000
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	0,05	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
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	retangular	0,20	0,20	0,20	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,50	0,50	0,50
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														
6	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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=5, std dev of the mean)	normal (sqrt(N))	0,07	0,08	0,21	0,12	0,15	0,15	0,13	0,15	0,20	0,28	0,41	0,18	0,18
12	$u(\Delta\Phi_{A,cal})$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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.	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	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)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{L,u,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
17	$u(e_{L,u,P})$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s²)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u(e_{I,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	$u(e_{I,P})$	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	4500	5000	5500	6000	6300	6500	7000	7500	8000	8500	9000	9500	10000
1	$u(\hat{u}_V)$	accelerometer output phase measurement (ADC resolution)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_D)$	voltage filtering effect on accelerometer output phase measurement	No filtering applied	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	$u(\hat{u}_T)$	effect of voltage disturbance on accelerometer output phase measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
4	$u(s_Q)$	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	retangular	0,12	0,12	0,12	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,29	0,29	0,29
5	$u(s_H)$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90o nominal angle difference)	already included in i = 3		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(s_F)$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No filtering applied	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(s_{VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(s_{MD})$	effect of motion disturbance on diaplacementphase measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(s_{PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(s_{RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
11	$u(s_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
12	$u(S_{RE})$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	Estimated to be less than (for N=5, std dev of the mean at a single point measurement)	normal (sqrt(N))	0,03	0,04	0,09	0,05	0,07	0,07	0,06	0,07	0,09	0,12	0,18	0,08	0,08
13	$u(G)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	$u(G)$	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)	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(\lambda \text{cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
17	$u(e_{1,a,A})$	amplitude effect on gain of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
18	$u(e_{1,a,P})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
19	$u(e_{1A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u(e_{1P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
		[illegible]	Estimated to be less than (dT =+/- 1 oC														

Uncertainty budget - Absolute Interferometric calibration of a single-ended standard accelerometer — **ISO 16063-11:1999 - Table A.4 & A.6**

CHARGE SENSITIVITY - PHASE SHIFT

Expanded uncertainty or bounds of estimated error components (°)

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	10	12,5	16	20	25	31,5	40	50	63	80	100	125
						frequency (Hz)											
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
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														
6	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01
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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,58	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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.	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	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	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{L,a,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	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/s^2)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u(e_{I,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	[illegible]	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	Factor x_i	Uncertainty contribution $u_{\text{rel},i}(y)$ (°) frequency (Hz) 10	12,5	16	20	25	31,5	40	50	63	80	100	125
1	$u(\hat{u}_V)$	accelerometer output phase measurement (ADC resolution)	results of different calibrations measured against hp3458A	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_D)$	voltage filtering effect on accelerometer output phase measurement	No filtering applied	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	$u(\hat{u}_T)$	effect of voltage disturbance on accelerometer output phase measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(s_Q)$	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	retangular	0,58	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
5	$u(s_H)$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90o nominal angle difference)	already included in i = 3			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(s_F)$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No filtering applied	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(s_{VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(s_{MD})$	effect of motion disturbance on diaplacementphase measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(s_{PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(s_{RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
11	$u(s_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,5	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	$u(G)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	$u(G)$	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)	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(\lambda \text{cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
17	$u(e_{1,a,A})$	amplitude effect on gain of reference amplifier	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
18	$u(e_{1,a,P})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s²)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
19	$u(e_{1A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u(e_{1P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
			Estimated to be less than (dT =+/- 1 oC		0,58												

Uncertainty budget - Absolute Interferometric calibration of a single-ended standard accelerometer

CHARGE SENSITIVITY - PHASE SHIFT

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	315	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,20
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														
6	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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))	0,01	0,01	0,02	0,00	0,00	0,01	0,01	0,02	0,02	0,03	0,03	0,05	0,07
12	$u(\Delta\Phi_{A,cal})$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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.	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(\lambda\text{cal})$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{L,a,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u(e_{I,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	$u(e_{I,P})$	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	315	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150
1	$u(\hat{u}_V)$	accelerometer output phase measurement (ADC resolution)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_D)$	voltage filtering effect on accelerometer output phase measurement	No filtering applied	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	$u(\hat{u}_T)$	effect of voltage disturbance on accelerometer output phase measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(s_Q)$	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	retangular	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,12
5	$u(s_H)$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90o nominal angle difference)	already included in i = 3		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(s_F)$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No filtering applied	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(s_{VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(s_{MD})$	effect of motion disturbance on diaplacementphase measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(s_{PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(s_{RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
11	$u(s_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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))	0,00	0,01	0,01	0,00	0,00	0,00	0,00	0,01	0,01	0,01	0,01	0,02	0,03
13	$u(G)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	$u(G)$	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)	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(\lambda cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
17	$u(e_{L,d,A})$	amplitude effect on gain of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
18	$u(e_{L,d,P})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
19	$u(e_{LA})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u(e_{LP})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
		[illegible]	Estimated to be less than (dT =+/- 1 oC														

Uncertainty budget - Absolute Interferometric calibration of a single-ended standard accelerometer

CHARGE SENSITIVITY - PHASE SHIFT

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	4500	5000	5500	6000	6300	6500	7000	7500	8000	8500	9000	9500	10000
1	$u(\Phi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
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)	0,05	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
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	retangular	0,20	0,20	0,20	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40
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														
6	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	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	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	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	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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))	0,06	0,14	0,30	0,38	0,09	0,10	0,11	0,28	0,21	0,09	0,16	0,30	0,36
12	$u(\Delta\Phi_{A,cal})$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	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.	retangular	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	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.	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	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)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{L,a,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	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/s^2)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u(e_{I,A})$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	$u(e_{I,P})$	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	description	Probability distribution model	4500	5000	5500	6000	6300	6500	7000	7500	8000	8500	9000	9500	10000
1	$u(\hat{u}_V)$	accelerometer output phase measurement (ADC resolution)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u(\hat{u}_D)$	voltage filtering effect on accelerometer output phase measurement	No filtering applied	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	$u(\hat{u}_T)$	effect of voltage disturbance on accelerometer output phase measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
4	$u(s_Q)$	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	retangular	0,12	0,12	0,12	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23
5	$u(s_H)$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90o nominal angle difference)	already included in i = 3		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	$u(s_F)$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No filtering applied	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
7	$u(s_{VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
8	$u(s_{MD})$	effect of motion disturbance on diaplacementphase measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
9	$u(s_{PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(s_{RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
11	$u(s_{FG})$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	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))	0,03	0,06	0,12	0,16	0,04	0,04	0,04	0,11	0,09	0,04	0,06	0,12	0,15
13	$u(G)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	$u(G)$	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)	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(\lambda\text{cal})$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
17	$u(e_{L,a,A})$	amplitude effect on gain of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
18	$u(e_{L,a,P})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s^2)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
19	$u(e_{I,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u(e_{I,P})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
			Estimated to be less than (dT =+/- 1 oC														

NIM:

Table of expanded measurement uncertainties of national standard measuring system (*k*=2), NIM, China

Frequency range Hz	National primary vibration measuring system	
	magnitude %	phase shift °
10 ... 1 k	0.5	0.5
> 1 k ... 5 k		0.75
> 5 k ... 10 k	1.0	1.5

Relative ***Total measurement uncertainty***and ***Expanded measurement uncertainty*** **(*k*=2)** are:

Frequency range Hz	Relative total measurement uncertainty	Expanded measurement uncertainty
10 ... 5 k	0.23 %	**0.46 %**
> 5 k ... 10 k	0.41 %	**0.82 %**

Absolute ***Total measurement uncertainty*** and ***Expanded measurement uncertainty*** **(*k*=2)** are:

Frequency range Hz	Absolute total measurement uncertainty	Expanded measurement uncertainty
10 ... 1 k	0.23 °	**0.46** °
> 1 k ... 5 k	0.35 °	**0.70** °
> 5 k ... 10 k	0.67 °	**1.34** °

- **Uncertainty budget for magnitude measurement results**

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	Uncertainty contribution $u_i(y)$
1	$u(\hat{u}_V)$	accelerometer output voltage measurement (waveform recorder; e.g. ADC-resolution)	3.0×10^{-4}
2	$u(\hat{u}_F)$	voltage filtering effect on accelerometer output amplitude measurement (frequency band limitation)	10 Hz ... <5 kHz: 5.0×10^{-4}; 5 k Hz ... 10 kHz: 2.0×10^{-3}
3	$u(\hat{u}_D)$	effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise)	10 Hz ... <5 kHz: 1.0×10^{-3}; 5 k Hz ... 10 kHz: 2.5×10^{-3}
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	10 Hz ... <5 kHz: 1.5×10^{-3}; 5 k Hz ... 10 kHz: 2.0×10^{-3}
5	$u(\hat{\varphi}_{M,Q})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	1.0×10^{-3}
6	$u(\hat{\varphi}_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	1.0×10^{-5}
7	$u(\hat{\varphi}_{M,VD})$	effect of voltage disturbance on phase amplitude measurement (e.g. random noise in the photoelectric measuring chains)	1.0×10^{-5}
8	$u(\hat{\varphi}_{M,MD})$	effect of motion disturbance on phase amplitude measurement (e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	10 Hz ... <5 kHz: 1.0×10^{-4}; 5 k Hz ... 10 kHz: 1.0×10^{-3}
9	$u(\hat{\varphi}_{M,PD})$	effect of phase disturbance on phase amplitude measurement (e.g. phase noise of the interferometer signals)	1.0×10^{-5}
10	$u(\hat{\varphi}_{M,RE})$	residual interferometric effects on phase amplitude measurement (interferometer function)	5.0×10^{-4}
11	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator)	1.0×10^{-5}
12	$u(S_{RE})$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	5.0×10^{-4}

Uncertainty budget for phase shift measurement results

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	Uncertainty contribution $u_i(y)$
1	$u(\varphi_{u,\mathrm{V}})$	accelerometer output phase measurement (waveform recorder; e.g. ADC-resolution)	0.10°
2	$u(\varphi_{u,\mathrm{F}})$	voltage filtering effect on accelerometer output phase measurement (frequency band limitation)	10 Hz ... <1 kHz: 0.10°; 1 kHz ... <5 kHz: 0.10°; 5 kHz ... 10kHz: 0.20°;
3	$u(\varphi_{u,\mathrm{D}})$	effect of voltage disturbance on accelerometer output phase measurement (e.g. hum and noise)	10 Hz ... <1 kHz: 0.10°; 1 kHz ... <5 kHz: 0.25°; 5 kHz ... 10kHz: 0.50°;
4	$u(\varphi_{u,\mathrm{T}})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	10 Hz ... <1 kHz: 0.05°; 1 kHz ... <5 kHz: 0.10°; 5 kHz ... 10kHz: 0.25°;
5	$u(\varphi_{s,\mathrm{Q}})$	effect of interferometer quadrature output signal disturbance on displacement phase measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	0.05°
6	$u(\varphi_{s,\mathrm{F}})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	0.05°
7	$u(\varphi_{s,\mathrm{VD}})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	0.01°
8	$u(\varphi_{s,\mathrm{MD}})$	effect of motion disturbance on displacement phase measurement (e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	10 Hz ... <1 kHz: 0.05°; 1 kHz ... <5 kHz: 0.10°; 5 kHz ... 10kHz: 0.25°;
9	$u(\varphi_{s,\mathrm{PD}})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	0.05°
10	$u(\varphi_{s,\mathrm{RE}})$	residual interferometric effects on displacement phase measurement (interferometer function)	0.05°
11	$u(\Delta\varphi_{\mathrm{RE}})$	residual effects on phase lag measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	0.01°

NPLI:

The Components of the Measurement uncertainty will be published seperately in a dedicated paper.