## Final Report of APMP.AUV.V-K3.1: Key comparison in the field of Acceleration on the complex voltage sensitivity

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#### **1.** Introduction

This report presents the results of the APMP comparison in the area of 'vibration', which here refers to the calibration of the accelerometer standards set in compliance with method 1 or method 3 as recommended in the international standard ISO 16063-11:1999.

The participants have reached a consensus and considered the most appropriate method, then referred to CCAUV.V-K3 report [1], the weighted mean and the degrees of equivalence were evaluated for this particular comparison. The calculation of the key weighted mean was in accordance with the Guidelines for CIPM key comparisons [2].

The "linking" procedure was applied to establish the relationship between the results of the participants and those of the CIPM comparison in the field of vibration, which was CCAUV.V-K3. Only one pilot laboratory, NIM, acted as the linking laboratory. The linking factors were defined as the ratio and difference for magnitude and phase shift respectively through the NIM results in CCAUV.V-K3 and APMP.AUV.V-K3.1. Using the linking factors, this RMO results of six participants were directly compared with the results of CCAUV.V-K3.

The Technical Protocol presented in Annex A, shows the aim and the task, the conditions for the measurements, the transfer standard used, the measurement instructions and the time schedule of this comparison.

#### 2. Participants

Six national metrology institutes (NMIs) from Asia Pacific Metrology Programme (APMP), and Intra-Africa Metrology System (AFRIMETS) participated in the comparison. They are listed in the chronological order of measurement in Table 2.1.

#### **3.** Task and purpose of the comparison

According to the rules set up by the CIPM MRA, the consultative committees of the CIPM have the responsibility to establish degrees of equivalence between the different measurement standards operated by the NMIs. This was done by conducting key comparisons (KC) on different levels of the international metrological infrastructure. The previous key comparisons CCAUV.V-K1, CCAUV.V-K2, and CCAUV.V-K3, in the frequency range 40 Hz to 5 kHz, 10 Hz to 10 kHz and 0.1 Hz to 40 Hz were completed in the year 2001, 2014 and 2016, respectively.

Recently, the APMP NMIs had improved the calibration capabilities and extended their lowfrequency vibration limit down to 0.1 Hz. Thus, the decision was taken to launch the preparation of comparison during the meeting of APMP TCAUV in 2017. The task of the comparison was to compare measurements of linear vibration calibration within the frequency range 0.1 Hz to 40 Hz. The results of this APMP comparison will, after approval by CCAUV, serve as supporting evidence for "calibration and measurement capabilities" (CMCs) at low vibration frequency.

No.	Participant Laboratory	Acronym	Economy	Calibration period (Y/M/D)	Remark
1	Center for Measurement Standards - Industrial Technology Research Institute	CMS-ITRI	Chinese Taipei	2018/05/21 to 2018/05/27	Pilot institute
2	National Institute of Metrology, China	NIM	China	2018/06/05 to 2018/07/08	Coordinating institute
3	National Institute of Metrology (Thailand)	NIMT	Thailand	2018/07/16 to 2018/07/29	
4	Korea Research Institute of Standards and Science	KRISS	Republic of Korea	2018/08/06 to 2018/08/19	
5	National Metrology Institute of South Africa	NMISA	South Africa	2018/08/27 to 2018/09/09	
6	CSIR - National Physical Laboratory of India	CSIR-NPLI	India	2018/09/17 to 2018/09/28	

Table 2.1 List of participants and schedule of APMP AUV.V-K3.1

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

For the calibration of the accelerometer standard set, method 3 of the international standard ISO 16063-11:1999 had to be applied for the entire frequency range. Specifically, the magnitude of the complex voltage sensitivity had to be given in millivolts per meter per second squared  $(mV/(m/s^2))$  and phase shift in degrees (°) for the different measurement conditions specified in the Annex A. The reported complex voltage sensitivities and associated uncertainties were used for the calculation of the degrees of equivalence between the participating NMI and to the KCRV computed for CCAUV.V-K3.

#### 4. Transfer standard used as artifact

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

- One transfer standard accelerometer (single-ended), type SA704, S/N 1054 (manufacturer: NIM).
- One signal conditioner, type MSA-I, S/N 131211 (manufacturer: NIM).

The artifact set was monitored by the pilot laboratory at least once a month before and after the circulation. The monitoring results show the artifact was in controlled condition based on the collected data.

#### 5. Circulation of the artifact

The transducer set was circulated between the participating laboratories considering a measurement period of two weeks provided for each participating laboratory and one week for the pilot laboratory. Any careless drop could change its sensitivity or even damage it; therefore, the artifact set was hand-carried during transportation between participants with great caution.

#### 6. Results of the monitoring measurements

Starting with calibration data in July 2017, the accelerometer standard set was measured by the pilot laboratory before and after the circulation of the artifact. As a representative of the overall variation during the monitored period, the measurements at several sample frequencies are shown in Figure 6.1 and Figure 6.2

The stability of the artifact was monitored through a series of monitoring measurements. The measurement results are summarized by the statistical properties and are shown in Tables 6.1 and 6.2. This analysis indicates that the stability of the artifacts was acceptable considering the standard uncertainty claimed. It is worth noting that the option of gain 100 was selected on the conditioner for frequencies from 0.1 Hz to 0.4 Hz. To allow direct comparison with the magnitude of sensitivity results for the frequencies higher than 0.4 Hz, the normalization of 1/100 was used to describe the monitoring results.

Frequency	Long term mean	rel. std. dev.	rel. std. unc.
(Hz)	(mV/(m/s <sup>2</sup> ))	(%)	(%)
0.1	131.08	0.02	0.15
0.5	131.03	0.02	0.15
1	130.98	0.03	0.15
1.6	130.96	0.03	0.15
6.3	130.97	0.02	0.15
10.	130.97	0.02	0.15
16	130.98	0.02	0.15
40	131.68	0.02	0.15

 Table 6.1 Mean and its relative standard deviation of voltage sensitivity of the artifacts calculated from the monitoring measurements.

 Table 6.2 Mean and its standard deviation of phase shift of the artifacts calculated from the monitoring measurements

Frequency	Long term mean	abs. std. dev.	abs. std. unc.
(Hz)	(°)	(°)	(°)
0.1	-0.37	0.01	0.15
0.5	-0.02	0.01	0.15
1	-0.07	0.01	0.15
1.6	-0.09	0.01	0.15
6.3	-0.24	0.01	0.15
10	-0.41	0.02	0.15
16	-0.66	0.02	0.15
40	-1.90	0.02	0.15



Figure 6.1 Monitoring of the voltage sensitivity over the comparison period.



Figure 6.2 Monitoring of the phase shift over the comparison period

#### 7. Results of the participants

The following sections are presenting the results from the participants submitted to the pilot laboratory using the mandatory report spreadsheet. The results presented are in  $mV/(m/s^2)$  and degree (°) for the magnitude and phase shift, respectively. The vibration excitation was horizontal for CMS-ITRI, NIM, KRISS, NMISA and CSIR-NPLI, and vertical for NIM and NIMT. Whether the calibration was performed in vertical or horizontal direction at or below 0.4 Hz, the bias from earth gravitational acceleration was compensated to zero by adding offset with the signal conditioner in actual measurement by participants. Normalization of 1/100 was applied to compensate for the gain setting of 100 on the conditioner for frequencies from 0.1 Hz to 0.4 Hz. That means in this frequency range, the reported magnitude of sensitivity was divided by 100 for each participant.

#### 7.1 Results for the magnitude of the complex voltage sensitivity

Results for the horizontal and the vertical excitation and for frequency range from 0.1 Hz to 40 Hz are shown in Tables 7.1.1 and 7.1.2, respectively.

Horizontal	CMS-I	TRI	NIN	1	KRI	SS	NMI	SA	CSIR-I	NPLI
actual frequency	magnitude of voltage sensitivity	rel.exp. Unc.								
(Hz)	(mV/(m/s <sup>2</sup> ))	(%)								
0.1	131.07	0.3	131.19	0.3	132.40	1.3	131.27	0.8	131.24	1.0
0.125	131.01	0.3	131.19	0.3	131.91	1.0	131.28	0.8	131.21	1.0
0.16	131.02	0.3	131.19	0.3	131.67	0.8	131.35	0.8	131.19	1.0
0.2	130.99	0.3	131.19	0.3	131.51	0.5	131.29	0.8	131.22	1.0
0.25	130.97	0.3	131.18	0.3	131.42	0.5	131.26	0.5	131.18	1.0
0.315	130.95	0.3	131.17	0.3	131.32	0.3	131.25	0.5	131.16	1.0
0.4	130.96	0.3	131.16	0.2	131.22	0.3	131.21	0.5	131.14	1.0
0.5	131.01	0.3	131.02	0.2	131.08	0.4	130.98	0.5	131.14	0.7
0.63	131.00	0.3	131.08	0.2	131.07	0.4	130.99	0.5	131.15	0.7
0.8	130.97	0.3	131.01	0.2	131.11	0.4	130.99	0.5	131.15	0.7
1	130.94	0.3	131.00	0.2	131.13	0.4	130.98	0.3	131.06	0.7
1.25	130.93	0.3	130.99	0.2	131.13	0.4	131.00	0.3	131.14	0.7
1.6	130.94	0.3	130.98	0.2	131.09	0.3	131.01	0.3	131.14	0.7
2	130.94	0.3	130.99	0.2	130.98	0.3	131.01	0.3	131.09	0.7
2.5	130.94	0.3	131.00	0.2	130.97	0.3	131.01	0.3	131.14	0.7
3.15	130.93	0.3	131.02	0.2	130.98	0.3	131.01	0.3	131.15	0.7
4	130.95	0.3	130.99	0.2	130.95	0.3	131.01	0.3	131.10	0.7
5	130.94	0.3	130.99	0.2	130.96	0.3	131.03	0.3	131.10	0.7
6.3	130.96	0.3	131.00	0.2	131.01	0.3	131.01	0.3	131.17	0.7
8	130.97	0.3	131.01	0.2	131.02	0.3	130.98	0.3	131.10	0.7
10	130.97	0.3	131.02	0.2	131.03	0.3	130.98	0.3	131.10	0.7
12.5	131.00	0.3	131.04	0.2	131.05	0.3	130.98	0.3	131.19	0.7
16	131.04	0.3	131.07	0.2	131.13	0.3	130.99	0.3	131.20	0.7
20	131.06	0.3	131.12	0.2	131.17	0.3	130.96	0.3	131.23	0.8
25	131.11	0.3	131.20	0.2	131.23	0.3	130.95	0.3	131.25	0.8
31.5	131.27	0.3	131.35	0.2	131.36	0.3	131.03	0.3	131.42	0.9
40	131.68	0.3	131.70	0.2	131.53	0.3	131.23	0.3	131.59	0.9

Table 7.1.1 Reported participants' results for the magnitude of the accelerometer sensitivity with relative expanded uncertainties (k = 2) for horizontal excitation.

Vertical	NIN	Л	NIMT		
actual frequency	magnitude of voltage sensitivity	rel.exp. Unc.	magnitude of voltage sensitivity	rel.exp. Unc.	
(Hz)	$(mV/(m/s^2))$	(%)	$(mV/(m/s^2))$	(%)	
0.1	131.09	0.3	131.14	0.60	
0.125	131.10	0.3	131.19	0.60	
0.16	131.11	0.3	131.10	0.60	
0.2	131.15	0.3	131.16	0.60	
0.25	131.14	0.3	131.16	0.60	
0.315	131.15	0.3	131.14	0.60	
0.4	131.16	0.2	131.13	0.60	
0.5	131.15	0.2	130.95	0.60	
0.63	131.07	0.2	130.97	0.60	
0.8	131.03	0.2	130.94	0.60	
1	131.02	0.2	130.96	0.51	
1.25	131.01	0.2	130.96	0.51	
1.6	131.00	0.2	130.93	0.51	
2	131.00	0.2	130.93	0.48	
2.5	130.99	0.2	130.91	0.48	
3.15	130.98	0.2	130.95	0.48	
4	130.99	0.2	130.93	0.48	
5	130.98	0.2	130.93	0.45	
6.3	130.99	0.2	130.93	0.41	
8	130.99	0.2	131.00	0.41	
10	131.01	0.2	131.00	0.38	
12.5	131.03	0.2	131.01	0.38	
16	131.07	0.2	131.05	0.38	
20	131.10	0.2	131.10	0.38	
25	131.15	0.2	131.18	0.38	
31.5	131.28	0.2	131.32	0.38	
40	131.50	0.2	131.52	0.38	

Table 7.1.2 Reported participants' results for the magnitude of the accelerometer sensitivity with relative expanded uncertainties (k = 2) for vertical excitation

### 7.2 Results for the phase shift of the complex voltage sensitivity

Table 7.2.1 Reported participants' results for the phase shift of the accelerometer sensitivity with expanded uncertainties (k = 2) for horizontal excitation

Horizontal	CMS-I	TRI	NI	M	KR	ISS	NM	ISA	CSIR-N	IPLI
actual frequency	phase of voltage sensitivity	abs.exp. Unc.								
(Hz)	(*)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	(°)
0.1	-0.35	0.3	-0.34	0.2	-0.34	0.2	-0.36	0.2	-0.37	1.0
0.125	-0.42	0.3	-0.42	0.2	-0.42	0.2	-0.43	0.2	-0.44	1.0
0.16	-0.55	0.3	-0.54	0.2	-0.53	0.2	-0.54	0.2	-0.53	1.0
0.2	-0.68	0.3	-0.68	0.2	-0.67	0.2	-0.68	0.2	-0.64	1.0
0.25	-0.85	0.3	-0.85	0.2	-0.83	0.2	-0.85	0.2	-0.83	1.0
0.315	-1.07	0.3	-1.07	0.2	-1.04	0.2	-1.07	0.2	-1.10	1.0
0.4	-1.35	0.3	-1.36	0.2	-1.33	0.2	-1.35	0.2	-1.33	1.0
0.5	-0.02	0.3	-0.02	0.2	-0.01	0.2	-0.01	0.2	-0.32	0.7
0.63	-0.02	0.3	-0.02	0.2	-0.01	0.2	-0.01	0.2	-0.27	0.7
0.8	-0.03	0.3	-0.04	0.2	-0.01	0.2	-0.02	0.2	-0.24	0.7
1	-0.04	0.3	-0.05	0.2	-0.02	0.2	-0.02	0.2	-0.20	0.7
1.25	-0.05	0.3	-0.06	0.2	-0.03	0.2	-0.02	0.2	-0.18	0.7
1.6	-0.06	0.3	-0.07	0.2	-0.05	0.2	-0.03	0.2	-0.17	0.7
2	-0.07	0.3	-0.09	0.2	-0.06	0.2	-0.04	0.2	-0.19	0.7
2.5	-0.09	0.3	-0.12	0.2	-0.09	0.2	-0.04	0.2	-0.20	0.7
3.15	-0.12	0.3	-0.13	0.2	-0.12	0.2	-0.05	0.2	-0.22	0.7
4	-0.15	0.3	-0.18	0.2	-0.16	0.2	-0.07	0.2	-0.23	0.7
5	-0.22	0.3	-0.22	0.2	-0.21	0.2	-0.09	0.2	-0.27	0.7
6.3	-0.25	0.3	-0.28	0.2	-0.27	0.2	-0.14	0.2	-0.43	0.7
8	-0.33	0.3	-0.36	0.2	-0.34	0.2	-0.15	0.2	-0.40	0.7
10	-0.38	0.3	-0.45	0.2	-0.43	0.2	-0.17	0.2	-0.48	0.7
12.5	-0.53	0.3	-0.56	0.2	-0.54	0.2	-0.22	0.2	-0.58	0.7
16	-0.69	0.3	-0.72	0.2	-0.69	0.2	-0.28	0.2	-0.76	0.7
20	-0.85	0.3	-0.90	0.2	-0.88	0.2	-0.35	0.2	-1.03	0.8
25	-1.02	0.3	-1.14	0.2	-1.11	0.2	-0.42	0.2	-1.37	0.8
31.5	-1.35	0.3	-1.47	0.2	-1.42	0.2	-0.51	0.2	-1.84	0.9
40	-2.05	0.3	-2.07	0.2	-1.83	0.2	-0.70	0.2	-1.99	0.9

Vertical	Vertical NIM NIMT			
actual frequency	phase of voltage sensitivity	abs.exp. Unc.	phase of voltage sensitivity	abs.exp. Unc.
(HZ)	( )	( )	( )	( ' )
0.1	-0.30	0.2	-0.34	0.83
0.125	-0.41	0.2	-0.46	0.83
0.16	-0.54	0.2	-0.55	0.83
0.2	-0.67	0.2	-0.70	0.83
0.25	-0.84	0.2	-0.86	0.83
0.315	-1.07	0.2	-1.09	0.83
0.4	-1.35	0.2	-1.38	0.83
0.5	-0.01	0.2	-0.03	0.83
0.63	-0.02	0.2	-0.04	0.83
0.8	-0.02	0.2	-0.04	0.83
1	-0.04	0.2	-0.04	0.61
1.25	-0.06	0.2	-0.06	0.61
1.6	-0.07	0.2	-0.07	0.61
2	-0.09	0.2	-0.08	0.54
2.5	-0.11	0.2	-0.10	0.54
3.15	-0.14	0.2	-0.13	0.54
4	-0.18	0.2	-0.16	0.54
5	-0.23	0.2	-0.20	0.47
6.3	-0.29	0.2	-0.26	0.47
8	-0.37	0.2	-0.34	0.47
10	-0.46	0.2	-0.43	0.45
12.5	-0.58	0.2	-0.55	0.45
16	-0.74	0.2	-0.71	0.45
20	-0.93	0.2	-0.90	0.45
25	-1.16	0.2	-1.13	0.45
31.5	-1.43	0.2	-1.45	0.45
40	-1.89	0.2	-1.87	0.45

Table 7.2.2 Reported participants' results for the phase shift of the accelerometer sensitivity with expanded uncertainties (k = 2) for vertical excitation

#### 8. Degrees of equivalence with respect to the RMO weighted mean value

The evaluation of the results was performed using a weighted mean computed with the following equations [3]:

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

$$u_{\rm WM}(f) = \left(\sum_{i=1}^{n} \frac{1}{u_i^2(f)}\right)^{-1/2}$$
(2)

where

$x_i(f)$	result of participant <i>i</i> at frequency <i>f</i>
$u_i(f)$	absolute standard uncertainty of participant $i$ at frequency $f$
$x_{\rm WM}(f)$	best estimate of the weighted mean sensitivity at frequency $f u_{WM}(f)$
	estimated absolute standard uncertainty for the weighted mean
	at frequency f

Consistency checks were performed for magnitude and phase shift of the complex voltage sensitivity. The test defined by Cox [4, 5] was applied to determine the participants that were members of the **Largest Consistent Subset** (LCS). The weighted mean was finally determined through the participants in the members of the consistent subset. Tables 8, are the consistency test results for both magnitude and phase shift respectively. Cells are highlighted in yellow and with an asterisk (\*) when  $\chi^2_{obs} > \chi^2(v)$ . Cells in Table 8(a) highlighted in yellow and marked with an asterisk (\*) were considered as not within the LCS and were excluded from the calculation of the weighted mean. It should be noted that, NMISA's results from 16 Hz to 40 Hz did not contribute to the calculation of the weighted mean for phase shift. Tables 8(a) and 8(b) present the results of the consistency test applied to the horizontal and vertical excitation results reported by the LCS for magnitude (left) and phase shift (right), respectively.

# Table 8 Results of the consistency test applied to all the horizontal excitation results reported by the participants respectively for magnitude (left) and phase shift (right)

Frequency (Hz)	Number of Participants	Number of Degrees of Freedom	$\chi^2_{obs}$	$\chi^2(\upsilon) \label{eq:constraint}$ with p<0.05	Frequency (Hz)	Number of Participants	Number of Degrees of Freedom	$\chi^2_{obs}$	$\chi^2_{(\upsilon)}$ with p<0.05
0.1	5	4	2.31	9.49	0.1	5	4	0.02	9.49
0.125	5	4	1.93	9.49	0.125	5	4	0.01	9.49
0.16	5	4	1.56	9.49	0.16	5	4	0.02	9.49
0.2	5	4	1.94	9.49	0.2	5	4	0.01	9.49
0.25	5	4	1.62	9.49	0.25	5	4	0.03	9.49
0.315	5	4	1.82	9.49	0.315	5	4	0.06	9.49
0.4	5	4	1.03	9.49	0.4	5	4	0.04	9.49
0.5	5	4	0.13	9.49	0.5	5	4	0.76	9.49
0.63	5	4	0.20	9.49	0.63	5	4	0.54	9.49
0.8	5	4	0.26	9.49	0.8	5	4	0.43	9.49
1	5	4	0.35	9.49	1	5	4	0.28	9.49
1.25	5	4	0.45	9.49	1.25	5	4	0.23	9.49
1.6	5	4	0.40	9.49	1.6	5	4	0.21	9.49
2	5	4	0.12	9.49	2	5	4	0.27	9.49
2.5	5	4	0.20	9.49	2.5	5	4	0.42	9.49
3.15	5	4	0.26	9.49	3.15	5	4	0.50	9.49
4	5	4	0.15	9.49	4	5	4	0.79	9.49
5	5	4	0.19	9.49	5	5	4	1.21	9.49
6.3	5	4	0.19	9.49	6.3	5	4	1.64	9.49
8	5	4	0.10	9.49	8	5	4	2.93	9.49
10	5	4	0.11	9.49	10	5	4	4.90	9.49
12.5	5	4	0.21	9.49	12.5	5	4	7.83	9.49
16	5	4	0.35	9.49	16	5	4	13.16*	9.49
20	5	4	0.72	9.49	20	5	4	20.71*	9.49
25	5	4	1.34	9.49	25	5	4	35.28*	9.49
31.5	5	4	2.05	9.49	31.5	5	4	62.09*	9.49
40	5	4	4.07	9.49	40	5	4	117.00*	9.49

Note: Cells were highlighted in yellow and with an asterisk (\*) when  $\chi^2_{obs} > \chi^2(v)$ 

Table 8(a) Results of the consistency test applied to all the horizontal excitation results reported by the largest consistent subset respectively for magnitude (left)

Frequency (Hz)	Number of Participants	Number of Degrees of Freedom	$\chi^2_{obs}$	$\chi^2_{(\upsilon)}$ with p<0.05	Frequency (Hz)	Number of Participants	Number of Degrees of Freedom	$\chi^2_{obs}$	$\chi^2_{(\upsilon)}$ with p<0.05
0.1	5	4	2.31	9.49	0.1	5	4	0.02	9.49
0.125	5	4	1.93	9.49	0.125	5	4	0.01	9.49
0.16	5	4	1.56	9.49	0.16	5	4	0.02	9.49
0.2	5	4	1.94	9.49	0.2	5	4	0.01	9.49
0.25	5	4	1.62	9.49	0.25	5	4	0.03	9.49
0.315	5	4	1.82	9.49	0.315	5	4	0.06	9.49
0.4	5	4	1.03	9.49	0.4	5	4	0.04	9.49
0.5	5	4	0.13	9.49	0.5	5	4	0.76	9.49
0.63	5	4	0.20	9.49	0.63	5	4	0.54	9.49
0.8	5	4	0.26	9.49	0.8	5	4	0.43	9.49
1	5	4	0.35	9.49	1	5	4	0.28	9.49
1.25	5	4	0.45	9.49	1.25	5	4	0.23	9.49
1.6	5	4	0.40	9.49	1.6	5	4	0.21	9.49
2	5	4	0.12	9.49	2	5	4	0.27	9.49
2.5	5	4	0.20	9.49	2.5	5	4	0.42	9.49
3.15	5	4	0.26	9.49	3.15	5	4	0.50	9.49
4	5	4	0.15	9.49	4	5	4	0.79	9.49
5	5	4	0.19	9.49	5	5	4	1.21	9.49
6.3	5	4	0.19	9.49	6.3	5	4	1.64	9.49
8	5	4	0.10	9.49	8	5	4	2.93	9.49
10	5	4	0.11	9.49	10	5	4	4.90	9.49
12.5	5	4	0.21	9.49	12.5	5	4	7.83	9.49
16	5	4	0.35	9.49	16	4	3	0.08	7.81
20	5	4	0.72	9.49	20	4	3	0.21	7.81
25	5	4	1.34	9.49	25	4	3	0.82	7.81
31.5	5	4	2.05	9.49	31.5	4	3	1.25	7.81
40	5	4	4.07	9.49	40	4	3	3.17	7.81

#### and phase shift (right)

Frequency (Hz)	Number of Participants	Number of Degrees of Freedom	$\chi^2_{\rm obs}$	$\chi^2_{(\upsilon)}$ with p<0.05	Frequency (Hz)	Number of Participants	Number of Degrees of Freedom	$\chi^2_{obs}$	$\chi^2_{(\upsilon)}$ with p<0.05
0.1	2	1	0.02	3.84	0.1	2	1	0.01	3.84
0.125	2	1	0.04	3.84	0.125	2	1	0.01	3.84
0.16	2	1	0.00	3.84	0.16	2	1	0.00	3.84
0.2	2	1	0.00	3.84	0.2	2	1	0.00	3.84
0.25	2	1	0.00	3.84	0.25	2	1	0.00	3.84
0.315	2	1	0.00	3.84	0.315	2	1	0.00	3.84
0.4	2	1	0.00	3.84	0.4	2	1	0.00	3.84
0.5	2	1	0.22	3.84	0.5	2	1	0.00	3.84
0.63	2	1	0.05	3.84	0.63	2	1	0.00	3.84
0.8	2	1	0.05	3.84	0.8	2	1	0.00	3.84
1	2	1	0.03	3.84	1	2	1	0.00	3.84
1.25	2	1	0.01	3.84	1.25	2	1	0.00	3.84
1.6	2	1	0.04	3.84	1.6	2	1	0.00	3.84
2	2	1	0.04	3.84	2	2	1	0.00	3.84
2.5	2	1	0.06	3.84	2.5	2	1	0.00	3.84
3.15	2	1	0.01	3.84	3.15	2	1	0.00	3.84
4	2	1	0.03	3.84	4	2	1	0.00	3.84
5	2	1	0.03	3.84	5	2	1	0.01	3.84
6.3	2	1	0.03	3.84	6.3	2	1	0.01	3.84
8	2	1	0.00	3.84	8	2	1	0.01	3.84
10	2	1	0.00	3.84	10	2	1	0.01	3.84
12.5	2	1	0.00	3.84	12.5	2	1	0.01	3.84
16	2	1	0.00	3.84	16	2	1	0.02	3.84
20	2	1	0.00	3.84	20	2	1	0.01	3.84
25	2	1	0.01	3.84	25	2	1	0.01	3.84
31.5	2	1	0.01	3.84	31.5	2	1	0.00	3.84
40	2	1	0.01	3.84	40	2	1	0.00	3.84

Table 8(b) Results of the consistency test applied to all the vertical excitation results reported
by the participants respectively for magnitude (left) and phase shift (right)

#### 8.1 Results for the magnitude of the complex voltage sensitivity

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

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

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

These formulas were applied for both magnitude and phase shift results. Unilateral degrees of equivalence obtained from results which were excluded from the LCS and which therefore did not contribute to the calculation of the weighted mean.

Horizontal	Weighte	d Mean	CMS	-ITRI	N	Μ	KR	ISS	NM	ISA	CSIR	-NPLI
Frequency	X <sub>WM</sub>	U <sub>WM</sub>	d <sub>i,WM</sub>	U <sub>i,WM</sub>								
(Hz)	(mV/(	m/s <sup>2</sup> ))	(mV/(	$m/s^2$ ))	(mV/(	$m/s^2$ ))	(mV/(	$m/s^2$ ))	(mV/(	$m/s^2$ ))	(mV/(	$m/s^2$ ))
0.1	131.17	0.27	-0.10	0.31	0.02	0.31	1.23	1.8	0.10	1.1	0.07	1.3
0.125	131.15	0.27	-0.14	0.31	0.04	0.31	0.76	1.3	0.14	1.1	0.06	1.3
0.16	131.16	0.26	-0.14	0.31	0.03	0.31	0.51	1.1	0.19	1.1	0.04	1.3
0.2	131.16	0.25	-0.17	0.32	0.02	0.32	0.35	0.62	0.13	1.1	0.06	1.3
0.25	131.15	0.24	-0.18	0.33	0.03	0.33	0.27	0.62	0.11	0.62	0.03	1.3
0.315	131.16	0.22	-0.21	0.34	0.02	0.34	0.16	0.34	0.09	0.63	0.00	1.4
0.4	131.13	0.19	-0.17	0.36	0.03	0.21	0.09	0.36	0.07	0.64	0.01	1.4
0.5	131.03	0.20	-0.02	0.35	-0.01	0.20	0.05	0.51	-0.05	0.64	0.11	0.90
0.63	131.06	0.20	-0.06	0.35	0.03	0.20	0.01	0.51	-0.07	0.64	0.09	0.90
0.8	131.02	0.20	-0.05	0.35	-0.01	0.20	0.09	0.51	-0.03	0.64	0.13	0.90
1	131.00	0.19	-0.06	0.36	0.00	0.22	0.13	0.51	-0.02	0.36	0.06	0.91
1.25	131.00	0.19	-0.07	0.36	-0.01	0.22	0.13	0.51	-0.01	0.36	0.14	0.91
1.6	131.01	0.18	-0.07	0.36	-0.02	0.22	0.08	0.36	0.00	0.36	0.14	0.91
2	130.98	0.18	-0.04	0.36	0.00	0.22	0.00	0.36	0.02	0.36	0.11	0.91
2.5	130.99	0.18	-0.05	0.36	0.01	0.22	-0.02	0.36	0.02	0.36	0.16	0.91
3.15	131.00	0.18	-0.07	0.36	0.02	0.22	-0.02	0.36	0.01	0.36	0.15	0.91
4	130.98	0.18	-0.03	0.36	0.01	0.22	-0.03	0.36	0.03	0.36	0.11	0.91
5	130.99	0.18	-0.05	0.36	0.01	0.22	-0.03	0.36	0.04	0.36	0.11	0.91
6.3	131.00	0.18	-0.04	0.36	0.00	0.22	0.01	0.36	0.01	0.36	0.17	0.91
8	131.00	0.18	-0.03	0.36	0.01	0.22	0.02	0.36	-0.02	0.36	0.10	0.91
10	131.01	0.18	-0.04	0.36	0.01	0.22	0.02	0.36	-0.03	0.36	0.09	0.91
12.5	131.03	0.18	-0.03	0.36	0.01	0.22	0.02	0.36	-0.05	0.36	0.16	0.91
16	131.07	0.18	-0.03	0.36	0.00	0.22	0.06	0.36	-0.08	0.36	0.14	0.91
20	131.09	0.18	-0.03	0.36	0.03	0.22	0.08	0.36	-0.13	0.36	0.14	1.1
25	131.14	0.18	-0.03	0.36	0.06	0.22	0.09	0.36	-0.19	0.36	0.11	1.1
31.5	131.27	0.18	0.00	0.36	0.07	0.22	0.09	0.36	-0.25	0.36	0.15	1.2
40	131.57	0.18	0.11	0.36	0.13	0.22	-0.04	0.36	-0.34	0.36	0.02	1.2

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

Vertical	Weighted Mean		N	Μ	NIMT		
Frequency	X <sub>WM</sub>	U <sub>WM</sub>	d <sub>i,WM</sub>	U <sub>i,WM</sub>	d <sub>i,WM</sub>	U <sub>i,WM</sub>	
(Hz)	$(mV/(m/s^2))$		(mV/(	$m/s^2$ ))	$(mV/(m/s^2))$		
0.1	131.10	0.36	-0.01	0.18	0.04	0.72	
0.125	131.12	0.36	-0.02	0.18	0.07	0.72	
0.16	131.11	0.36	0.00	0.18	-0.01	0.72	
0.2	131.16	0.36	0.00	0.18	0.01	0.72	
0.25	131.14	0.36	0.00	0.18	0.02	0.72	
0.315	131.15	0.36	0.00	0.18	-0.01	0.72	
0.4	131.16	0.27	0.00	0.10	-0.03	0.76	
0.5	131.13	0.27	0.02	0.10	-0.18	0.76	
0.63	131.06	0.27	0.01	0.10	-0.09	0.76	
0.8	131.02	0.27	0.01	0.10	-0.09	0.76	
1	131.01	0.26	0.01	0.11	-0.05	0.63	
1.25	131.00	0.26	0.01	0.11	-0.04	0.63	
1.6	130.99	0.26	0.01	0.11	-0.06	0.63	
2	130.99	0.26	0.01	0.12	-0.06	0.59	
2.5	130.98	0.26	0.01	0.12	-0.07	0.59	
3.15	130.98	0.26	0.01	0.12	-0.03	0.59	
4	130.98	0.26	0.01	0.12	-0.05	0.59	
5	130.97	0.26	0.01	0.12	-0.05	0.55	
6.3	130.98	0.25	0.01	0.13	-0.04	0.48	
8	130.99	0.25	0.00	0.13	0.00	0.48	
10	131.01	0.25	0.00	0.14	-0.01	0.44	
12.5	131.03	0.25	0.00	0.14	-0.01	0.44	
16	131.06	0.25	0.00	0.14	-0.01	0.44	
20	131.10	0.25	0.00	0.14	0.01	0.46	
25	131.16	0.25	-0.01	0.14	0.02	0.46	
31.5	131.29	0.25	-0.01	0.14	0.03	0.46	
40	131.50	0.25	-0.01	0.14	0.02	0.46	

Table 8.1.2: Unilateral degrees of equivalence for the magnitude (vertical) of sensitivity with absolute expanded uncertainties (k = 2)



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





Figure 8.1.1 Deviation of the magnitude (horizontal) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2). (Cont.)





Figure 8.1.1 Deviation of the magnitude (horizontal) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2). (Cont.)



Figure 8.1.1 Deviation of the magnitude (horizontal) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2). (Cont.)

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Figure 8.1.2 Deviation of the magnitude (vertical) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2).

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Figure 8.1.2 Deviation of the magnitude (vertical) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2). (Cont.)

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Figure 8.1.2 Deviation of the magnitude (vertical) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2). (Cont.)



Figure 8.1.2 Deviation of the magnitude (vertical) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2). (Cont.)

### 8.2 Results for the phase shift of the complex voltage sensitivity

Horizontal	Weighte	ed Mean	CMS-ITRI		NIM		KRISS		NMISA		CSIR-NPLI	
Frequency	X <sub>WM</sub>	U <sub>WM</sub>	d <sub>i,WM</sub>	U <sub>i,WM</sub>								
(Hz)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	(°)
0.1	-0.35	0.11	0.00	0.29	0.006	0.17	0.01	0.17	-0.01	0.17	-0.02	1.0
0.125	-0.42	0.11	0.00	0.29	0.000	0.17	0.00	0.17	-0.01	0.17	-0.02	1.0
0.16	-0.54	0.11	-0.01	0.29	-0.004	0.17	0.01	0.17	0.00	0.17	0.01	1.0
0.2	-0.68	0.11	0.00	0.29	-0.002	0.17	0.01	0.17	0.00	0.17	0.04	1.0
0.25	-0.84	0.11	-0.01	0.29	-0.006	0.17	0.01	0.17	-0.01	0.17	0.01	1.0
0.315	-1.06	0.11	-0.01	0.29	-0.009	0.17	0.02	0.17	-0.01	0.17	-0.04	1.0
0.4	-1.35	0.11	0.00	0.29	-0.013	0.17	0.02	0.17	0.00	0.17	0.02	1.0
0.5	-0.02	0.11	0.00	0.29	-0.003	0.17	0.01	0.17	0.01	0.17	-0.30	0.7
0.63	-0.02	0.11	0.00	0.29	0.000	0.17	0.01	0.17	0.01	0.17	-0.25	0.7
0.8	-0.03	0.11	0.00	0.29	-0.012	0.17	0.02	0.17	0.01	0.17	-0.21	0.7
1	-0.03	0.11	-0.01	0.29	-0.012	0.17	0.01	0.17	0.01	0.17	-0.17	0.7
1.25	-0.04	0.11	-0.01	0.29	-0.015	0.17	0.01	0.17	0.02	0.17	-0.14	0.7
1.6	-0.05	0.11	-0.01	0.29	-0.017	0.17	0.00	0.17	0.03	0.17	-0.12	0.7
2	-0.07	0.11	0.00	0.29	-0.023	0.17	0.01	0.17	0.03	0.17	-0.12	0.7
2.5	-0.09	0.11	0.00	0.31	-0.032	0.17	0.00	0.17	0.05	0.17	-0.11	0.7
3.15	-0.11	0.11	-0.01	0.31	-0.025	0.17	-0.01	0.17	0.06	0.17	-0.11	0.7
4	-0.14	0.11	-0.01	0.31	-0.041	0.17	-0.02	0.17	0.07	0.17	-0.09	0.7
5	-0.18	0.11	-0.04	0.31	-0.041	0.17	-0.03	0.17	0.09	0.17	-0.09	0.7
6.3	-0.24	0.11	-0.01	0.31	-0.045	0.17	-0.03	0.17	0.10	0.17	-0.19	0.7
8	-0.29	0.11	-0.04	0.31	-0.068	0.17	-0.05	0.17	0.14	0.17	-0.11	0.7
10	-0.36	0.11	-0.02	0.31	-0.092	0.17	-0.07	0.17	0.18	0.17	-0.12	0.7
12.5	-0.45	0.11	-0.08	0.31	-0.108	0.17	-0.09	0.17	0.24	0.17	-0.13	0.7
16	-0.70	0.13	0.01	0.30	-0.016	0.16	0.01	0.16	0.43	0.24	-0.06	0.7
20	-0.89	0.13	0.04	0.30	-0.015	0.16	0.01	0.16	0.54	0.24	-0.14	0.8
25	-1.11	0.13	0.09	0.30	-0.025	0.16	0.00	0.16	0.70	0.24	-0.26	0.8
31.5	-1.44	0.13	0.09	0.30	-0.033	0.16	0.02	0.16	0.93	0.24	-0.40	0.9
40	-1.97	0.13	-0.08	0.30	-0.102	0.16	0.14	0.16	1.27	0.24	-0.02	0.9

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

Vertical	Weighte	ed Mean	N	M	NIMT		
Frequency	X <sub>WM</sub>	U <sub>WM</sub>	d <sub>i,WM</sub>	U <sub>i,WM</sub>	d <sub>i,WM</sub>	U <sub>i,WM</sub>	
(Hz)	(°)	(°)	(°)	(°)	(°)	(°)	
0.1	-0.30	0.20	0.00	0.05	-0.04	0.82	
0.125	-0.41	0.20	0.00	0.05	-0.04	0.82	
0.16	-0.54	0.20	0.00	0.05	-0.01	0.82	
0.2	-0.67	0.20	0.00	0.05	-0.03	0.82	
0.25	-0.84	0.20	0.00	0.05	-0.02	0.82	
0.315	-1.07	0.20	0.00	0.05	-0.02	0.82	
0.4	-1.35	0.20	0.00	0.05	-0.02	0.82	
0.5	-0.01	0.20	0.00	0.05	-0.02	0.82	
0.63	-0.02	0.20	0.00	0.05	-0.02	0.82	
0.8	-0.03	0.20	0.00	0.05	-0.01	0.82	
1	-0.04	0.20	0.00	0.07	0.00	0.60	
1.25	-0.06	0.20	0.00	0.07	0.00	0.60	
1.6	-0.07	0.20	0.00	0.07	0.00	0.60	
2	-0.09	0.19	0.00	0.07	0.01	0.51	
2.5	-0.11	0.19	0.00	0.07	0.01	0.51	
3.15	-0.14	0.19	0.00	0.07	0.01	0.51	
4	-0.18	0.19	0.00	0.07	0.02	0.51	
5	-0.22	0.19	0.00	0.08	0.02	0.45	
6.3	-0.28	0.19	0.00	0.08	0.02	0.45	
8	-0.36	0.19	0.00	0.08	0.02	0.45	
10	-0.46	0.19	0.00	0.08	0.02	0.43	
12.5	-0.57	0.19	0.00	0.08	0.03	0.43	
16	-0.74	0.19	-0.01	0.08	0.03	0.43	
20	-0.92	0.19	0.00	0.08	0.03	0.43	
25	-1.16	0.19	0.00	0.08	0.03	0.43	
31.5	-1.43	0.19	0.00	0.08	-0.01	0.43	
40	-1.89	0.19	0.00	0.08	0.01	0.43	

Table 8.2.2 Unilateral degrees of equivalence for the phase shift (vertical) of sensitivity with
absolute expanded uncertainties $(k = 2)$

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Figure 8.2.1 Deviation of the phase shift (horizontal) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2)





Figure 8.2.1 Deviation of the phase shift (horizontal) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2) (Cont.)





Figure 8.2.1 Deviation of the phase shift (horizontal) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2) (Cont.)



Figure 8.2.1 Deviation of the phase shift (horizontal) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2) (Cont.)

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Figure 8.2.2 Deviation of the phase shift (Vertical) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2)

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Figure 8.2.2 Deviation of the phase shift (Vertical) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2) (Cont.)

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Figure 8.2.2 Deviation of the phase shift (Vertical) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2) (Cont.)



Figure 8.2.2 Deviation of the phase shift (Vertical) from the weighted mean for all frequencies of the comparison with expanded uncertainties  $U_{i,WM}$  (k = 2) (Cont.)

#### 9. Linking procedure and degrees of equivalence with the KCRV

The linking procedure to the relevant CC comparison and calculation of the KCRV are described in this chapter. It was recommended to consider the influence of correlation of the results of the linking laboratory(ies) based on the procedure described in the previous publication by Clemens Elster et al [6]. The linking transforms the results  $(y_i, u(y_i))$  of the participants of this comparison to scaled values  $z_i$  and their respective uncertainties  $u(z_i)$ , which are directly comparable to the relevant CC comparison results of CCAUV.V-K3. The scaling was done with the so-called linking factor r. Then, r is defined by two complex voltage sensitivities ( $x_{\text{NIM}}$  and  $y_{\text{NIM}}$ ) in the CIPM and RMO comparisons of NIM (linking laboratory) as follows.

## 9.1 Degrees of equivalence for the magnitude of the complex voltage sensitivity

The linking factor for magnitude between CIPM and RMO comparisons was defined as following.

$$r_m = \frac{x_{NIM_m}}{y_{NIM_m}} \tag{5}$$

where the uncertainty associated was described as

$$u^{2}(r_{m}) = \left(\frac{\partial r_{m}}{\partial x_{NIM_{m}}}\right)^{2} u^{2}(x_{NIM_{m}}) + \left(\frac{\partial r_{m}}{\partial y_{NIM_{m}}}\right)^{2} u^{2}(y_{NIM_{m}}) + 2\left(\frac{\partial r_{m}}{\partial x_{NIM_{m}}}\right) \left(\frac{\partial r_{m}}{\partial y_{NIM_{m}}}\right) u(x_{NIM_{m}}) u(y_{NIM_{m}}) r(x_{NIM_{m}}, y_{NIM_{m}})$$
(6)

Considering the correlation coefficient of uncertainty in two comparisons  $r(x_{NIM_m}, y_{NIM_m})$  was equal to 1, equation (6) can be written as equation (7).

$$u^{2}(r_{m}) = \left(\frac{1}{y_{NIM_{m}}}\right)^{2} u^{2}(x_{NIM_{m}}) + \left(-\frac{x_{NIM_{m}}}{y_{NIM_{m}}^{2}}\right)^{2} u^{2}(y_{NIM_{m}}) -2\left(\frac{x_{NIM_{m}}}{y_{NIM_{m}}^{3}}\right) u(x_{NIM_{m}})u(y_{NIM_{m}})$$
(7)

Then APMP.AUV.V-K3.1 result can be transformed to the scaled value  $z_{i_m}$  of CCAUV.V-K3 employing  $r_m$  as follows

$$z_{i_m} = r_m y_{i_m} = \frac{x_{NIM_m}}{y_{NIM_m}} y_{i_m} \tag{8}$$

Thus, the degrees of equivalence are given as the differences between the scaled complex voltage sensitivities in the APMP.AUV.V-K3.1 and the KCRV of the CCAUV.V.K3.

$$d_{i,KCRV_{\rm m}} = z_{i_m} - x_{KCRV_{\rm m}} = \frac{x_{NIM_m}}{y_{NIM_m}} y_{i_m} - x_{KCRV_{\rm m}}$$
<sup>(9)</sup>

Here yim is independent of other variables, and the squared standard uncertainties associated
with these differences are described as follows

$$u^{2}(d_{i,KCRV_{m}}) = \left(\frac{y_{im}}{y_{NIM_{m}}}\right)^{2} u^{2}(x_{NIM_{m}}) + \left(-\frac{x_{NIM_{m}}y_{im}}{y^{2}_{NIM_{m}}}\right)^{2} u^{2}(y_{NIM_{m}}) + \left(\frac{x_{NIM_{m}}}{y_{NIM_{m}}}\right)^{2} u^{2}(y_{im}) + (-1)^{2} u^{2}(x_{KCRV_{m}}) + 2\left(\frac{y_{im}}{y_{NIM_{m}}}\right) \left(-\frac{x_{NIM_{m}}y_{im}}{y^{2}_{NIM_{m}}}\right) u(x_{NIM_{m}}, y_{NIM_{m}}) + 2\left(\frac{y_{im}}{y_{NIM_{m}}}\right) (-1) u(x_{NIM_{m}}, x_{KCRV_{m}}) + 2\left(-\frac{x_{NIM_{m}}y_{im}}{y^{2}_{NIM_{m}}}\right) (-1) u(y_{NIM_{m}}, x_{KCRV_{m}}) + 2\left(-\frac{x_{NIM_{m}}y_{im}}{y^{2}_{NIM_{m}}}\right) (-1) u(y_{NIM_{m}}, x_{KCRV_{m}})$$
(10)

# 9.2 Degrees of equivalence for the phase shift of the complex voltage sensitivity

The linking factor for phase shift between CIPM and RMO comparisons was defined as following.

$$r_p = x_{NIM_p} - y_{NIM_p} \tag{11}$$

where the uncertainty associated was described as

$$u^{2}(r_{p}) = \left(\frac{\partial r_{p}}{\partial x_{NIM_{p}}}\right)^{2} u^{2} \left(x_{NIM_{p}}\right) + \left(\frac{\partial r_{p}}{\partial y_{NIM_{p}}}\right)^{2} u^{2} \left(y_{NIM_{p}}\right) + 2\left(\frac{\partial r_{p}}{\partial x_{NIM_{p}}}\right) \left(\frac{\partial r_{p}}{\partial y_{NIM_{p}}}\right) u \left(x_{NIM_{p}}\right) u \left(y_{NIM_{p}}\right) r \left(x_{NIM_{p}}, y_{NIM_{p}}\right)$$
(12)

Considering the correlation coefficient of uncertainty in two comparisons  $r(x_{NIM}, y_{NIM})$  was equal to 1, equation (12) can be written as equation (13).

$$u^{2}(r_{p}) = (1)^{2}u^{2}(x_{NIM_{p}}) + (-1)^{2}u^{2}(y_{NIM_{p}}) - 2u(x_{NIM_{p}})u(y_{NIM_{p}})$$
(13)

APMP.AUV.V-K3.1 comparison participant result can be transformed to the scaled value  $z_{in}$  of CCAUV.V.K3 comparison employing *r* as follows

$$z_{i_p} = y_{i_p} + r_p = y_{i_p} + (x_{NIM_p} - y_{NIM_p})$$
(14)

Thus, the degrees of equivalence are given as the differences between the scaled complex voltage sensitivities in the APMP.AUV.V-K3.1 comparison and the KCRV of the CCAUV.V.K3 CIPM comparison.

$$d_{i,\text{KCRV}_{p}} = z_{i_{p}} - x_{KCRV_{p}} = y_{i_{p}} + (x_{NIM_{p}} - y_{NIM_{p}}) - x_{KCRV_{p}}$$
(15)

Here  $y_{ip}$  is independent of other variables, and the squared standard uncertainties associated with these differences are described as follows

$$u^{2}\left(d_{i,KCRV_{p}}\right) = u^{2}\left(y_{i_{p}}\right) + u^{2}\left(x_{NIM_{p}}\right) + (-1)^{2}u^{2}\left(y_{NIM_{p}}\right) + (-1)^{2}u^{2}\left(x_{KCRV_{p}}\right) + 2(-1)u\left(x_{NIM_{p}}, x_{KCRV_{p}}\right) + 2u\left(y_{NIM_{p}}, x_{KCRV_{p}}\right)$$

$$(16)$$

#### 9.3 Result

Both in equation (10) and (16), the same processes were performed as below. Because  $r(x_{NIM}, y_{NIM})$  is equal to 1, the item  $u(x_{NIM}, y_{NIM})$  is equal to  $u(x_{NIM})u(y_{NIM})$ .

The item  $r(x_{NIM}, x_{KCRV})$  was carried out as follows.

$$r(x_{NIM}, x_{KCRV}) = \frac{\frac{\partial x_{NIM} \partial x_{KCRV}}{\partial x_{NIM} \partial x_{NIM}} u^2(x_{NIM})}{u(x_{NIM})u(x_{KCRV})} = \frac{1 \cdot \frac{1/u^2(x_{NIM})}{1/u^2(x_{KCRV})} u^2(x_{NIM})}{u(x_{NIM})u(x_{KCRV})} = \frac{u(x_{KCRV})}{u(x_{NIM})}$$
(17)

The transformation of  $u(x_{NIM}, x_{KCRV}) = u(x_{NIM})u(x_{KCRV})r(x_{NIM}, x_{KCRV})$  was rewritten as follows.

$$u(x_{NIM}, x_{KCRV}) = u(x_{KCRV})u(x_{KCRV}) = u^2(x_{KCRV})$$
(18)

Also, the transformation of  $u(y_{NIM}, x_{KCRV}) = u(y_{NIM})u(x_{KCRV})r(y_{NIM}, x_{KCRV})$  can be given as equation (19) same as equation (17) because  $r(x_{NIM}, y_{NIM}) = 1$ .

$$r(y_{NIM}, x_{KCRV}) = \frac{\frac{1/u^2(x_{NIM})}{1/u^2(x_{KCRV})}u(x_{NIM}, y_{NIM})}{u(y_{NIM})u(x_{KCRV})} = \frac{u(x_{KCRV})}{u(y_{NIM})u^2(x_{NIM})}u(x_{NIM}, y_{NIM}) = r(x_{NIM}, y_{NIM})\frac{u(x_{KCRV})}{u(x_{NIM})} = r(x_{NIM}, x_{KCRV})r(x_{NIM}, y_{NIM}) = r(x_{NIM}, x_{KCRV})$$
(19)

Finally, the transformation can be rewritten as

$$u(y_{NIM}, x_{KCRV}) = u(x_{KCRV})u(x_{KCRV})u(y_{NIM})/u(x_{NIM})$$
  
=  $u^{2}(x_{KCRV})u(y_{NIM})/u(x_{NIM})$  (20)

The value of equation (18) at each frequency is shown in Table 9.3.1.

#### APMP.AUV.V-K3.1

Frequency	u(x <sub>KCRV</sub> )	u(x <sub>NIM</sub> )	r(x <sub>NIM</sub> , x <sub>KCRV</sub> )	Frequency	u(x <sub>KCRV</sub> )	u(x <sub>NIM</sub> )	r(x <sub>NIM</sub> , x <sub>KCRV</sub> )
(Hz)	$(mV/(m/s^2))$	$(mV/(m/s^2))$		(Hz)	(°)	(°)	
0.1	0.08	0.35	0.23	0.1	0.02	0.10	0.20
0.125	0.08	0.35	0.23	0.125	0.02	0.10	0.20
0.16	0.08	0.35	0.23	0.16	0.02	0.10	0.20
0.2	0.06	0.35	0.17	0.2	0.02	0.10	0.20
0.25	0.06	0.35	0.17	0.25	0.02	0.10	0.20
0.315	0.06	0.35	0.17	0.315	0.02	0.10	0.20
0.4	0.05	0.14	0.36	0.4	0.02	0.10	0.20
0.5	0.04	0.14	0.29	0.5	0.02	0.10	0.20
0.63	0.04	0.14	0.29	0.63	0.02	0.10	0.20
0.8	0.04	0.14	0.29	0.8	0.02	0.10	0.20
1	0.04	0.14	0.29	1	0.02	0.10	0.20
1.25	0.04	0.14	0.29	1.25	0.02	0.10	0.20
1.6	0.04	0.14	0.29	1.6	0.02	0.10	0.20
2	0.04	0.14	0.29	2	0.02	0.10	0.20
2.5	0.04	0.14	0.29	2.5	0.02	0.10	0.20
3.15	0.04	0.14	0.29	3.15	0.02	0.10	0.20
4	0.04	0.14	0.29	4	0.02	0.10	0.20
5	0.04	0.14	0.29	5	0.02	0.10	0.20
6.3	0.04	0.14	0.29	6.3	0.04	0.10	0.40
8	0.04	0.14	0.29	8	0.04	0.10	0.40
10	0.04	0.14	0.29	10	0.04	0.10	0.40
12.5	0.04	0.14	0.29	12.5	0.04	0.10	0.40
16	0.04	0.14	0.29	16	0.04	0.10	0.40
20	0.04	0.14	0.29	20	0.04	0.10	0.40
25	0.04	0.14	0.29	25	0.04	0.10	0.40
31.5	0.04	0.14	0.29	31.5	0.04	0.10	0.40
40	0.04	0.14	0.29	40	0.04	0.10	0.40

Table 9.3.1 Correlation coefficients of combined standard uncertainty between CCAUV.V-K3 and APMP.AUV.V-K3.1 international comparison for magnitude (left) and phase shift (right)

These degrees of equivalence of the Acceleration are each a pair of values of the difference  $d_{i,\text{KCRV}}$  between the respective corresponding participants *i* and KCRV with the expanded uncertainty  $U_{i,\text{KCRV}}$  of this difference. (See Tables 9.3.2, 9.3.3 and Figure 9.3.1, 9.3.2) These values were calculated with a coverage factor of k = 2 for each frequency according to:

$$d_{i,KCRV} = z_i - x_{KCRV} \tag{21}$$

$$U_{i,KCRV} = k \cdot \sqrt{u^2(d_{i,KCRV})}$$
<sup>(22)</sup>

Table 9.3.2 Degrees of equivalence to the KCRV of CCAUV.V-K3 for the magnitude of sensitivity with absolute expanded uncertainties (k = 2)

Horizontal	CMS	-ITRI	KR	ISS	NMISA		CSIR-NPLI		
Frequency	d <sub>i,KCRV</sub>	$U_{i, \text{KCRV}}$	$d_{i,KCRV}$	$U_{i, \text{KCRV}}$	$d_{i,KCRV}$ $U_{i,KCRV}$		$d_{i,KCRV}$	$U_{i, \text{KCRV}}$	
(Hz)	mV/(	$m/s^2$ )	mV/(	$m/s^2$ )	$mV/(m/s^2)$		mV/(	$m/s^2$ )	
0.1	-0.74	0.51	0.64	1.9	-0.53	1.2	-0.57	1.5	
0.125	-0.60	0.51	0.34	1.5	-0.31	1.2	-0.39	1.5	
0.16	-0.45	0.51	0.23	1.2	-0.10	1.2	-0.27	1.5	
0.2	-0.44	0.51	0.10	0.75	-0.12	1.2	-0.20	1.5	
0.25	-0.37	0.51	0.10	0.75	-0.06	0.75	-0.15	1.5	
0.315	-0.34	0.51	0.05	0.51	-0.03	0.75	-0.12	1.5	
0.4	-0.28	0.43	-0.01	0.43	-0.02	0.70	-0.09	1.4	
0.5	0.04	0.43	0.11	0.57	0.01	0.70	0.18	1.0	
0.63	0.00	0.43	0.07	0.57	-0.02	0.70	0.15	1.0	
0.8	0.00	0.43	0.14	0.57	0.02	0.70	0.18	1.0	
1	-0.01	0.43	0.19	0.57	0.03	0.43	0.12	1.0	
1.25	-0.03	0.43	0.18	0.57	0.04	0.43	0.19	1.0	
1.6	-0.02	0.43	0.13	0.43	0.05	0.43	0.19	1.0	
2	-0.07	0.43	-0.03	0.43	0.00	0.43	0.09	1.0	
2.5	-0.04	0.43	-0.01	0.43	0.03	0.43	0.17	1.0	
3.15	-0.06	0.43	-0.01	0.43	0.02	0.43	0.17	1.0	
4	-0.03	0.43	-0.03	0.43	0.04	0.43	0.12	1.0	
5	-0.08	0.43	-0.06	0.43	0.01	0.43	0.09	1.0	
6.3	-0.06	0.43	-0.01	0.43	-0.01	0.43	0.16	1.0	
8	-0.02	0.43	0.03	0.43	-0.01	0.43	0.12	1.0	
10	0.01	0.43	0.07	0.43	0.02	0.43	0.14	1.0	
12.5	0.03	0.43	0.08	0.43	0.01	0.43	0.23	1.0	
16	0.13	0.43	0.22	0.43	0.08	0.43	0.30	1.0	
20	-0.21	0.43	-0.10	0.43	-0.32	0.43	-0.04	1.2	
25	-0.19	0.43	-0.07	0.43	-0.36	0.43	-0.05	1.2	
31.5	-0.03	0.43	0.06	0.43	-0.29	0.43	0.13	1.3	
40	0.07	0.43	-0.09	0.43	-0.40	0.43	-0.02	1.3	

Horizontal	CMS	-ITRI	KR	ISS	NMISA		CSIR-NPLI		
Frequency	$d_{i,KCRV}$	$U_{i,KCRV}$	d <sub>i,KCRV</sub>	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	$d_{i,KCRV}$	$U_{i,KCRV}$	
(Hz)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	(°)	
0.1	-0.02	0.31	-0.01	0.21	-0.03	0.21	-0.04	1.01	
0.125	-0.01	0.31	-0.01	0.21	-0.02	0.21	-0.03	1.01	
0.16	-0.02	0.31	0.00	0.21	-0.01	0.21	0.00	1.01	
0.2	-0.01	0.31	0.00	0.21	-0.01	0.21	0.03	1.01	
0.25	0.00	0.31	0.02	0.21	0.00	0.21	0.02	1.01	
0.315	0.00	0.31	0.03	0.21	0.00	0.21	-0.03	1.01	
0.4	0.01	0.31	0.03	0.21	0.01	0.21	0.03	1.01	
0.5	0.02	0.31	0.03	0.21	0.03	0.21	-0.28	0.71	
0.63	-0.01	0.31	0.00	0.21	0.00	0.21	-0.26	0.71	
0.8	0.06	0.31	0.08	0.21	0.07	0.21	-0.15	0.71	
1	0.03	0.31	0.05	0.21	0.05	0.21	-0.13	0.71	
1.25	0.03	0.31	0.05	0.21	0.06	0.21	-0.10	0.71	
1.6	0.03	0.31	0.04	0.21	0.06	0.21	-0.08	0.71	
2	0.03	0.31	0.04	0.21	0.06	0.21	-0.09	0.71	
2.5	0.05	0.33	0.05	0.21	0.10	0.21	-0.06	0.71	
3.15	0.04	0.33	0.04	0.21	0.11	0.21	-0.06	0.71	
4	0.06	0.33	0.05	0.21	0.14	0.21	-0.02	0.71	
5	0.03	0.33	0.04	0.21	0.16	0.21	-0.02	0.71	
6.3	0.05	0.33	0.03	0.22	0.16	0.22	-0.13	0.71	
8	0.03	0.33	0.02	0.22	0.21	0.22	-0.04	0.71	
10	0.08	0.33	0.03	0.22	0.29	0.22	-0.02	0.71	
12.5	0.04	0.33	0.03	0.22	0.35	0.22	-0.01	0.71	
16	0.04	0.33	0.04	0.22	0.45	0.22	-0.03	0.71	
20	0.09	0.33	0.06	0.22	0.59	0.22	-0.09	0.81	
25	0.19	0.33	0.10	0.22	0.79	0.22	-0.16	0.81	
31.5	0.21	0.33	0.14	0.22	1.05	0.22	-0.28	0.91	
40	0.05	0.33	0.27	0.22	1.40	0.22	0.11	0.91	

Table 9.3.3 Degrees of equivalence to the KCRV of CCAUV.V-K3 for the phase shift of sensitivity with absolute expanded uncertainties (k = 2)



Figure 9.3.1 Deviation of the magnitude from the KCRV for all frequencies of the comparison with expanded uncertainties  $U_{i,\text{KCRV}}$  (k = 2)

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Figure 9.3.1 Deviation of the magnitude from the KCRV for all frequencies of the comparison with expanded uncertainties  $U_{i,\text{KCRV}}$  (k = 2) (Cont.)

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Figure 9.3.1 Deviation of the magnitude from the KCRV for all frequencies of the comparison with expanded uncertainties  $U_{i,\text{KCRV}}$  (k = 2) (Cont.)



Figure 9.3.1 Deviation of the magnitude from the KCRV for all frequencies of the comparison with expanded uncertainties  $U_{i,\text{KCRV}}$  (k = 2) (Cont.)



Figure 9.3.2 Deviation of the phase shift from the KCRV for all frequencies of the comparison with expanded uncertainties  $U_{i,\text{KCRV}}$  (k = 2)



Figure 9.3.2 Deviation of the phase shift from the KCRV for all frequencies of the comparison with expanded uncertainties  $U_{i,\text{KCRV}}$  (k = 2) (Cont.)



Figure 9.3.2 Deviation of the phase shift from the KCRV for all frequencies of the comparison with expanded uncertainties  $U_{i,\text{KCRV}}$  (k = 2) (Cont.)



Figure 9.3.2 Deviation of the phase shift from the KCRV for all frequencies of the comparison with expanded uncertainties  $U_{i,\text{KCRV}}$  (k = 2) (Cont.)

# **10.** Conclusion

The key comparison APMP AUV.V-K3.1 in vibration revealed the current calibration capabilities of the six participants from APMP and AFRIMETS. All of the participating laboratories provided their calibration results, which were mostly consistent with each other within their declared expanded uncertainties for magnitude and phase results. For the phase shift, only one participant failed to contribute to the weighted mean values calculated for five frequencies out of a total of twenty-seven comparison frequencies.

The RMO key comparison in vibration APMP.AUV.V-K3.1 had been successfully finished. All participating laboratories had their results linked to the KCRV of the relevant CIPM level key comparison, namely CCAUV.V-K3, via linking laboratory NIM. The degrees of equivalence of the participants to the KCRV can be used to support their calibration and measurement capabilities.

# 11. Acknowledgment

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# Annex A : Technical protocol

# Technical Protocol of the APMP Key Comparison APMP.AUV.V-K3.1

## Task and Purpose of the Comparison

Since recent improvements at the APMP NMIs have extended the low-frequency vibration limit of calibration capabilities down to 0.1 Hz, the decision was taken to make a preparation of comparison during the meeting of APMP TCAUV in 2017. The task of the comparison is to compare measurements of linear vibration calibration within the frequency range from 0.1 Hz to 40 Hz. The results of this APMP comparison will, after approval by CCAUV, serve as evidence at low vibration frequency for the registration of 'calibration and measurement capabilities' (CMC) for NMIs in the framework of the CIPM MRA.

It is the task of the comparison to measure the complex voltage sensitivity of one standard acceleration measuring chain or simply calling an accelerometer standard set (including a quartz-flexure servo-accelerometer of single-ended type and a signal conditioner) at different frequencies with acceleration amplitudes as specified in section 3. The voltage sensitivity is to be calculated as the ratio of the amplitude of the output voltage of the accelerometer standard set to the acceleration at its reference surface. The magnitude of the complex voltage sensitivity shall be given in millivolt per metres per second squared ( $mV/(m/s^2)$ ) and the phase shift in degrees.

For the calibration of the accelerometer standard set, laser interferometry in compliance with method 1 or method 3 of the international standard ISO 16063-11:1999 has to be applied, in order to cover the entire frequency range.

The reported complex voltage sensitivities and associated uncertainties will be used for the calculation of the degrees of equivalence between the participating NMI and to the weighted mean link to CCAUV.V-K3.

# **Pilot Laboratory**

Pilot laboratory for this regional key comparison is

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# **Device under Test and Measurement Conditions**

For the calibration task of this key comparison, one quartz-flexure accelerometer set will be circulated between participating laboratories. The set includes a 'single-ended' (SE) servo accelerometer, namely a SA 704 (SN: to be decided), with a signal conditioner, namely MSA-I (SN: to be decided) and a power supply for the conditioner.

The complex voltage sensitivity of the accelerometer set shall be calibrated according to those procedures and conditions implemented by the laboratory in conformance with ISO 16063-11. The complex voltage sensitivities reported shall be for the complete accelerometer set (or acceleration measuring chain), including all effects from the signal conditioner. The frequency range of the measurements is from 0.1 Hz to 40 Hz. Specifically, the laboratories are supposed to measure at the following frequencies (all values in Hz):

0.1, 0.125, 0.16, 0.2, 0.25, 0.315, 0.4, 0.5, 0.63, 0.8, 1, 1.25, 1.6, 2, 2.5, 3.15, 4, 5, 6.3, 8, 10, 12.5, 16, 20, 25, 31.5, 40.

Depending on the stroke limitation of the shaker used in the NMI, some frequencies can be considered optional as listed below.

0.1 to 0.4	0.5 to 20	25 to 40
optional	mandatory	optional

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

Specific conditions for the measurements of this KC are:

- Acceleration amplitudes: a range of  $0.05 \text{ m/s}^2$  to  $30 \text{ m/s}^2$  is recommended.
- Ambient temperature and accelerometer temperature during the calibration:
- $(23 \pm 2)$  °C (actual values to be stated within tolerances of  $\pm 0.3$  °C).
- Relative humidity: max. 75 %RH.
- The input line voltage of the power supply for the signal conditioner is 220 V.

# **Circulation Type, Schedule and Transportation**

The transducer set will be circulated between the participating laboratories considering a measurement period of two weeks provided for each participating laboratory and one week for the pilot laboratory.

At the beginning and the end of the circulation as well as between certain subsequent measurements of participating laboratories, the transducer set is measured by the pilot laboratory in order to check reference values and to monitor the stability of the transducer set.

Participant	Measurement	Transportation to next Participant
CMS-ITRI	2018/05/21 - 2018/05/27	2018/05/28 - 2018/06/04
NIM	2018/06/05 - 2018/07/08	2018/07/09 - 2018/07/15
NIMT	2018/07/16 - 2018/07/29	2018/07/30 - 2018/08/05
KRISS	2018/08/06 - 2018/08/19	2018/08/20 - 2018/08/26
NMISA	2018/08/27 - 2018/09/09	2018/09/10 - 2018/09/16
CSIR-NPLI	2018/09/17 - 2018/09/28	2018/09/29 - 2018/10/07
CMS-ITRI	2018/10/08 - 2018/10/12	

The schedule is planned as follows:

The cost of transportation to the next participating laboratory shall be covered by the participating laboratory. The transducer set has to be hand-carried with great caution. In case the transducer set gets damaged or lost during transportation, the participating laboratory responsible for the delivery should pay  $6,000 \notin$  to the pilot laboratory.

# **Measurement and Analysis Instructions**

The participating laboratories have to observe the following instructions:

- The motion of the quartz-flexure accelerometer shall be measured on the moving part of the horizontal vibration exciter, close to the accelerometer's mounting surface, since the mounting (reference) surface is usually not directly accessible.
- The mounting surface of the accelerometer and the moving part of the exciter must be slightly lubricated before mounting.
- The cable between accelerometer and signal conditioner should be taken from the set delivered to the laboratory.

- It is advised that the measurement results should be compiled from complete measurement series carried out at different days under nominally the same conditions, except that the accelerometer is remounted and the cable re-attached. The standard deviation of the subsequent measurements should be included in the report.
- Participants should not perform any experiments other than comparison measurements stipulated in this protocol with the artifact.

# **Communication of the Results to Pilot Laboratory**

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

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

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

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

The pilot laboratory will submit its set of results to the executive secretary of CCAUV in advance to start the circulation for measurements by the other participating laboratories.

# **Remarks on post processing**

Presuming consistency of the results, the degrees of equivalence will be calculated according to the established methods agreed upon already for CCAUV.V-K1. This regional key comparison is to be linked to the CIPM key comparison CCAUV.V-K3. The degrees of equivalence will be determined in reference to the key comparison reference value (KCRV) calculated for CCAUV.V-K3.

## References

- ISO 16063-1:1998 'Methods for the calibration of vibration and shock transducers Part 1: Basic concepts.
- [2] ISO 16063-11:1999 'Methods for the calibration of vibration and shock transducers Part 11: Primary vibration calibration by laser interferometry'.
- [3] ISO/IEC 17025:2017 'General requirements for the competence of testing and calibration laboratories'.
- [4] ISO/IEC Guide 98-3:2008 'Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement (GUM:1995).
- [5] ISO/IEC Guide 98-3:2008/Supplement 1:2008 'Propagation of distributions using a Monte Carlo method'.

#### APMP.AUV.V-K3.1

# Annex A:

#### I. Items List and Settings of Conditioning Amplifier

The set includes a 'single-ended' (SE) servo accelerometer, namely a SA 704 (SN: 1054), with a signal conditioner, namely MSA-I (SN:131211) and a power supply for the conditioner.

NO.	Item	Quantity
1	Servo accelerometer	1
2	Signal conditioner	1
3	Signal cable	1
4	Power cord	1
5	Technical protocol	1



MSA-I (SN:131211)



#### APMP.AUV.V-K3.1

#### Front side



#### Rear side



Power input 220V

Power on

#### Procedure of zero setting of conditioning amplifier:

- 1. Using the knob of 'Coarse' to adjust to zero first;
- 2. Using the knob of 'Fine' to adjust to zero precisely;
- 3. Setting the gain to 100 and repeat steps 1 and 2, to get more precise value of zero if necessary.
- 4. "Input selection" switch on the MSA-I conditioning amplifier should be on "Current input".

# Other settings:

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

# **II.** Reports Information

- 1. Calibration method.
- 2. Frequency range
- 3. Installation of equipment.
- 4. Environmental conditions, ambient temperature.
- 5. Uncertainty budget.

#### Example:

Laboratory	CMS	S-ITR	I						
1.	Sine	App	roximation Metho	d					
2.	Freq	uency	y range from 0.1 H	Iz to 4	40	) Hz			
3.	Hori	zonta	1 / APS 500						
4.	(23 ±	± 2) °	C / 55 % RH						
5.	i	Standard Uncertainty contribution u(xi)	ISO -SAM- Urel(S)	Uncertainty contribution ui(y)		i	Standard Uncertainty contribution	ISO -SAM - U( $\Delta \varphi$ )	Uncertainty contribution ui(y)
	1	$u(\tilde{u}_V)$	accelerometer output voltage measurement(waveform recorder; e.g. ADC-resolution)	u <sub>1</sub> (S)		1	u(φ <sub>u,V</sub> )	accelerometer output phase measurement(waveform	$u_i(\Delta \varphi)$
	2	u(û <sub>F</sub> )	voltage filtering effect on accelerometer output amplitude measurement(frequency band limitation)	u2(S)		2	u(φ <sub>n.F</sub> )	voltage filtering effect on accelerometer output phase	u;(Δφ)
	3	u(û <sub>D</sub> )	effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise)	uj(S)		3	u(φ <sub>u,D</sub> )	effect of voltage disturbance on accelerometer output phase measurement (e.g. hum and noise)	u3(Δφ)
	4	u(û <sub>T</sub> )	effect of transverse, rocking, and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	u4(S)	4	$u(\varphi_{u,T})$	effect of transverse, rocking, and bending acceleration on accelerometer output phase measurement (transverse	u <sub>i</sub> (Δφ)	
	5	u( φ <sub>M.Q</sub> )	effect of interferometer quadrature output signal disturbance on phase amplitude measurement(e.g. offsets, voltage amplitude deviation, deviation from 90 <sup>0</sup> nominal angle difference)	r quadrature output signal disturbance easurement(e.g. offsets, voltage leviation from 90 <sup>0</sup> nominal angle 5		5	u(\$\varphi_{s,Q}\$)	sensitivity) effect of interferometer quadrature output signal disturbance on displacement phase measurement(e.g. offsets, voltage amolitude deviation, deviation from 90 <sup>0</sup> nominal angle.	u <u>5</u> (Δφ)
	6	$u(\varphi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	$u_{\theta}(S)$				difference)	
	7	u(φ <sub>M,VD</sub> )	effect of voltage disturbance on phase amplitude measurement(e.g. random noise in the photoelectric	u;(S)		6	$\mathrm{u}(\varphi_{\mathrm{s},\mathrm{F}})$	interferometer signal filtering effect on displacement phase amplitude measurement (frequency band limitation)	u <sub>6</sub> (Δφ)
	8	u( φ <sub>MMD</sub> )	measuring chains) effect of motion disturbance on phase amplitude measurement(e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the	u <sub>8</sub> (S)		7	$\mathrm{u}(\varphi_{\mathrm{s,VD}})$	effect of voltage disturbance on displacement phase amplitude measurement(e.g. random noise in the photoelectric measuring chains)	u;(Δφ)
	9	u( $\varphi_{M,PD}$ )	interferometer) effect of phase disturbance on phase amplitude measurement(e.g. phase noise of the interferometer signals)	u <sub>l</sub> (S)		8	$u(\varphi_{s,MD})$	effect of motion disturbance on displacement phase amplitude measurement(e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	$u_8(\Delta \varphi)$
	10	$u(\varphi_{\rm M,RE})$	residual interferometric effects on phase amplitude measurement(interferometer function)	u <sub>10</sub> (S)		9	u(φ <sub>s.PD</sub> )	effect of phase disturbance on displacement phase amplitude measurement(e.g. phase noise of the interferometer signals)	u <sub>2</sub> (Δφ)
	11	u(f <sub>FG</sub> )	vibration frequency measurement (frequency generator and indicator)	u <sub>11</sub> (S)		10	$u(\phi_{s,RE})$	residual interferometric effects on displacement phase amplitude measurement(interferometer function)	u <sub>10</sub> (Δφ)
	12	u(S <sub>RE</sub> )	residual effects on sensitivity measurement(e.g. random effect in repeat measurements; experimental standard devitation of arithmetic mean)	u <sub>12</sub> (S)		11	$u(\Delta \varphi_{RE})$	residual effects on phase shift measurement(e.g. random effect in repeat measurements; experimental standard devitation of arithmetic mean)	$u_{\rm H}(\Delta  \varphi)$

Note: The report file should be provided as word file with the scanning of signing pages.

# Annex B : Measurement Uncertainty Budget (MUB)

# I. CMS-ITRI

# Magnitude sensitivity

	D. Voltage Sensitivity uncertainty budget - CMS-ITRI										
	Standard Uncertainty		Uncertainty	Estimated U	ncertainty(%)	Probability Divisor		Standard Uncerta Ui	ainty contribution (y)		
i	contribution u(xi)	ISO -SAM- Urel(S)	contribution ui(y)	0.1 Hz to 0.4 Hz	0.5 Hz to 40 Hz	Distribution	factor	0.1 Hz to 0.4 Hz	0.5 Hz to 40 Hz		
1	$u(\hat{u}_V)$	accelerometer output voltage measurement(Type A repeat stability)	u <sub>i</sub> (S)	0.23	0.18	normal	2	0.115	0.090		
2	u(û <sub>F</sub> )	voltage filtering effect on accelerometer output amplitude measurement(frequency band limitation)	u <sub>2</sub> (S)	0.08	0.03	Rectangular	1.732	0.046	0.017		
3	$u(\hat{u}_D)$	effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise)	u <sub>3</sub> (S)	0.02	0.02	Rectangular	1.732	0.012	0.012		
4	$u(\hat{u}_T)$	effect of transverse, rocking, and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	u <sub>4</sub> (S)	0.05	0.05	Rectangular	1.732	0.029	0.029		
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)	u <sub>5</sub> (S)	0.11	0.11	Rectangular	1.732	0.064	0.064		
6	$u(\phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	u <sub>6</sub> (S)	0.03	0.03	Rectangular	1.732	0.017	0.017		
7	$u(\phi_{M,VD})$	effect of voltage disturbance on phase amplitude measurement(e.g. random noise in the photoelectric measuring chains)	u7(S)	0.01	0.01	Rectangular	1.732	0.006	0.006		
8	u( $\phi_{M,MD}$ )	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)	u <sub>8</sub> (S)	0.01	0.01	Rectangular	1.732	0.006	0.006		
9	$u(\phi_{M,PD})$	effect of phase disturbance on phase amplitude measurement(e.g. phase noise of the interferometer signals)	u <sub>9</sub> (S)	0.01	0.01	Rectangular	1.732	0.006	0.006		
10	$u(\phi_{M,RE})$	residual interferometric effects on phase amplitude measurement(interferometer function)	u <sub>10</sub> (S)	0.02	0.02	Rectangular	1.732	0.012	0.012		
11	u(f <sub>FG</sub> )	vibration frequency measurement (frequency generator and indicator)	u <sub>11</sub> (S)	0.01	0.01	Rectangular	1.732	0.006	0.006		
12	u(S <sub>RE</sub> )	residual effects on sensitivity measurement(e.g. random effect in repeat measurements; experimental standard devitation of arithmetic mean)	u <sub>12</sub> (S)	0.05	0.05	Rectangular	1.732	0.029	0.029		
Combined Uncertainty of amplitude measurement (in %) 0.148 0.122									0.122		
	Expanded Uncertainty of amplitude measurement (in %) (Coverage factor k = 2)										

	E. Phasee Sensitivity uncertainty budget - CMS-ITRI										
	Standard Uncertainty		Uncertainty	Estimated U	ncertainty(°)	Probability	Divisor	Standard Uncerta Ui	ainty contribution (y)		
1	contribution u(xi)	ISO -SAM - U(Δφ)	ui(y)	0.1 Hz to 0.4 Hz	0.5 Hz to 40 Hz	Distribution	factor	0.1 Hz to 0.4 Hz	0.5 Hz to 40 Hz		
1	$u(\phi_{u,V})$	accelerometer output phase measurement(Type A repeat stability)	$u_i(\Delta\phi)$	0.19	0.13	normal	2	0.095	0.065		
2	$u\!\left(\phi_{u,F}\right)$	voltage filtering effect on accelerometer output phase measurement(frequency band limitation)	$u_2(\Delta\phi)$	0.02	0.02	Rectangular	1.732	0.012	0.012		
3	$u(\phi_{u,D})$	effect of voltage disturbance on accelerometer output phase measurement (e.g. hum and noise)	u <sub>3</sub> (Δφ)	0.02	0.02	Rectangular	1.732	0.012	0.012		
4	$u(\phi_{u,T})$	effect of transverse, rocking, and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	$u_4(\Delta\phi)$	0.1	0.1	Rectangular	1.732	0.058	0.058		
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° nominal angle difference)	u <sub>5</sub> (Δφ)	0.1	0.1	Rectangular	1.732	0.058	0.058		
6	$u(\phi_{s,F})$	interferometer signal filtering effect on displacement phase amplitude measurement (frequency band limitation)	u <sub>6</sub> (Δφ)	0.03	0.03	Rectangular	1.732	0.017	0.017		
7	$u(\phi_{s,\text{VD}})$	effect of voltage disturbance on displacement phase amplitude measurement(e.g. random noise in the photoelectric measuring chains)	u <sub>7</sub> (Δφ)	0.05	0.05	Rectangular	1.732	0.029	0.029		
8	$u(\phi_{s,MD})$	effect of motion disturbance on displacement phase amplitude measurement(e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	u <sub>8</sub> (Δφ)	0.05	0.05	Rectangular	1.732	0.029	0.029		
9	$u(\phi_{s,PD})$	effect of phase disturbance on displacement phase amplitude measurement(e.g. phase noise of the interferometer signals)	u9(Δφ)	0.05	0.05	Rectangular	1.732	0.029	0.029		
10	$u(\phi_{s,RE})$	residual interferometric effects on displacement phase amplitude measurement(interferometer function)	u <sub>10</sub> (Δφ)	0.05	0.05	Rectangular	1.732	0.029	0.029		
11	$u(\Delta \phi_{RE})$	residual effects on phase shift measurement(e.g. random effect in repeat measurements; experimental standard devitation of arithmetic mean)	$u_{11}(\Delta\phi)$	0.06	0.06	Rectangular	1.732	0.035	0.035		
	Combined Uncertainty of amplitude measurement (in °)								0.126		
	Expanded Uncertainty of amplitude measurement (in $^\circ$ ) (Coverage factor k = 2)										

# II. NIM

# Magnitude sensitivity

		D. Ve	oltage Sensi	tivity uncertaint	y budget - NIM				
	Standard Uncertainty		Uncertainty	Estimated U	ncertainty(%)	Probability	Divisor	Standard Uncertain	ty contribution Ui(y)
i	contribution u(xi)	ISO -SAM- Urel(S)	contribution ui(y)	0.1 Hz to < 0.4 Hz	0.4 Hz to 40 Hz	Distribution	factor	0.1 Hz to < 0.4 Hz	0.4 Hz to 40 Hz
1	$u(\hat{u}_V)$	accelerometer output voltage measurement(waveform recorder; e.g. ADC- resolution)	u <sub>l</sub> (S)	0.006	0.006	Rectangular	1.732	0.003	0.003
2	u(û <sub>F</sub> )	voltage filtering effect on accelerometer output amplitude measurement(frequency band limitation)	u <sub>2</sub> (S)	0.01	0.01	Rectangular	1.732	0.006	0.006
3	$u(\hat{u}_D)$	effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise)	u <sub>3</sub> (S)	0.02	0.02	Rectangular	1.732	0.012	0.012
4	u(û <sub>T</sub> )	effect of transverse, rocking, and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	u <sub>4</sub> (S)	0.02	0.02	Rectangular	1.732	0.012	0.012
5	$u(\phi_{M,Q})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement(e.g. offsets, voltage amplitude deviation, deviation from $90^{9}$ nominal angle difference)	u <sub>5</sub> (S)	0.1	0.1	Rectangular	1.732	0.058	0.058
6	$u(\phi_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	u <sub>6</sub> (S)	0.01	0.01	Rectangular	1.732	0.006	0.006
7	$u\!\left(\phi_{M,VD}\right)$	effect of voltage disturbance on phase amplitude measurement(e.g. random noise in the photoelectric measuring chains)	u7(S)	0.05	0.05	Rectangular	1.732	0.029	0.029
8	$u\!\left(\phi_{M,MD}\right)$	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)	u <sub>8</sub> (S)	0.05	0.05	Rectangular	1.732	0.029	0.029
9	$u\!\left(\phi_{M,PD}\right)$	effect of phase disturbance on phase amplitude measurement(e.g. phase noise of the interferometer signals)	u <sub>9</sub> (S)	0.05	0.05	Rectangular	1.732	0.029	0.029
10	$u\!\left(\phi_{M,RE}\right)$	residual interferometric effects on phase amplitude measurement(interferometer function)	u <sub>10</sub> (S)	0.05	0.05	Rectangular	1.732	0.029	0.029
11	$u(f_{FG})$	1.732	0.000	0.000					
12	u(S <sub>RE</sub> )	residual effects on sensitivity measurement(e.g. random effect in repeat measurements; experimental standard devitation of arithmetic mean)	u <sub>12</sub> (S)	0.05	0.05	Rectangular	1.732	0.029	0.029
13	u(Sv)	Vibration set acceleration sensitivity amplitude and phase shift stability	u <sub>13</sub> (S)	0.2	0.1	normal	3	0.067	0.033
14	u(Su)	effect of other effects on accelerometer output voltage measurements	u <sub>14</sub> (S)	0.05	0.05	Rectangular	1.732	0.029	0.029
		Combined Uncertainty	of amplitude me	asurement (%)				0.115	0.099
		Expanded Uncertainty of	amplitude measu	rement (%)(k=2)				0.30	0.20

		E. Ph	asee Sensit	ivity uncertainty	v budget - NIM				
	Standard Uncertainty		Uncertainty	Estimated U	nce rtainty(°)	Probability	Divisor	Standard Uncertain	ty contribution Ui(y)
1	contribution u(xi)	ISO -SAM - U(Δφ)	contribution ui(y)	0.1 Hz to < 0.4 Hz	0.4 Hz to 40 Hz	Distribution	factor	0.1 Hz to < 0.4 Hz	0.4 Hz to 40 Hz
1	$u(\phi_{u,V})$	accelerometer output phase measurement(waveform recorder; e.g. ADC- resolution)	$u_{l}(\Delta\phi)$	0.015	0.01	Rectangular	1.732	0.009	0.006
2	$u(\phi_{u,F})$	voltage filtering effect on accelerometer output phase measurement(frequency band limitation)	u <sub>2</sub> (Δφ)	0.01	0.01	Rectangular	1.732	0.006	0.006
3	$u(\phi_{u,D})$	effect of voltage disturbance on accelerometer output phase measurement (e.g. hum and noise)	u <sub>3</sub> (Δφ)	0.02	0.02	Rectangular	1.732	0.012	0.012
4	$u(\phi_{u,T})$	effect of transverse, rocking, and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	$u_4\!(\Delta\phi)$	0.04	0.04	Rectangular	1.732	0.023	0.023
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 <sup>0</sup> nominal angle difference)	u <sub>5</sub> (Δφ)	0.1	0.1	Rectangular	1.732	0.058	0.058
6	$u(\phi_{s,F})$	interferometer signal filtering effect on displacement phase amplitude measurement (frequency band limitation)	$u_6\!(\Delta\phi)$	0.01	0.01	Rectangular	1.732	0.006	0.006
7	u(φ <sub>s,VD</sub> )	effect of voltage disturbance on displacement phase amplitude measurement(e.g. random noise in the photoelectric measuring chains)	u <sub>7</sub> (Δφ)	0.05	0.05	Rectangular	1.732	0.029	0.029
8	$u(\phi_{s,MD})$	effect of motion disturbance on displacement phase amplitude measurement(e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	$u_{g}(\Delta\phi)$	0.05	0.05	Rectangular	1.732	0.029	0.029
9	u(φ <sub>s,PD</sub> )	effect of phase disturbance on displacement phase amplitude measurement(e.g. phase noise of the interferometer signals)	u <sub>9</sub> (Δφ)	0.05	0.05	Rectangular	1.732	0.029	0.029
10	u( $\phi_{s,RE}$ )	1.732	0.029	0.029					
11	u(Δφ <sub>RE</sub> )	residual effects on phase shift measurement(e.g. random effect in repeat measurements; experimental standard devitation of arithmetic mean)	u <sub>11</sub> (Δφ)	0.002	0.002	Rectangular	1.732	0.001	0.001
12	u(φv)	Vibration set acceleration sensitivity amplitude and phase shift stability	u <sub>12</sub> (Δφ)	0.2	0.1	normal	3	0.067	0.033
13	u(φu)	effect of other effects on accelerometer output voltage measurements	u <sub>13</sub> (Δφ)	0.05	0.05	Rectangular	1.732	0.029	0.029
		Combined Uncertainty	of amplitude me	easurement (°)				0.113	0.097
		Expanded Uncertainty of a	amplitude measu	urement ( °)( <i>k</i> =2)				0.30	0.20

# III. NIMT

# Magnitude sensitivity

· · ·	Standard Uncertainty contribution u(Xi) u(û <sub>t</sub> )	ISO -SAM- Urel(S) Vibration velocity (Uncertainty of tracing back)	Uncertainty contribution ui(y) u <sub>1</sub> (S)	Probability Distribution Normal		Divisor 2	Divisor 1.1 to 0.8 H z	Divisor 1.1 to 0.8 H 20.8 to 1.6 H	Divisor 0.1 to 0.8 H 40.8 to 1.6 H 1.6 to 4 H z	Divisor 0.1 to 0.8 H 40.8 to 1.6 H 1.6 to 4 H z > 4 to 5 H z 2 0.10 0.10 0.10 0.10 0.10	Divisor     1.1 to 0.8 Hz0.8 to 1.6 H     1.6 to 4 Hz     4 to 5 Hz     >5 to 8 Hz       2     0.10     0.10     0.10     0.10     0.10
2	μ(û <sub>X</sub> )	Voltage Ux	u <sub>2</sub> (S)	Normal	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
3	$u(\hat{u}_w)$	Angular frequency of v signal	u3(S)	Square	1.732		0.001	0.001 0.001	0.001 0.001 0.001	0.001 0.001 0.001 0.001	0.001 0.001 0.001 0.001
4	$u(\hat{u}_{Gr})$	Amplifier gain	$u_4(S)$	Normal	2		0.02	0.02 0.02	0.02 0.02 0.02	0.02 0.02 0.02 0.02	0.02 0.02 0.02 0.02
5	$u(\hat{u}_{K\!f})$	Frequency response	u5(S)	Normal	2		0.1	0.1 0.1	0.1 0.1 0.1	0.1 0.1 0.1 0.1	0.1 0.1 0.1 0.05
9	$u(\hat{u}_{Kq})$	Transverse motion	$u_{\delta}(S)$	Square	1.732		0.007	0.007 0.007	0.007 0.007 0.007	0.007 0.007 0.007 0.007	0.007 0.007 0.007 0.007
7	$u(\hat{u}_{Ko})$	Harmonics	$u_7(S)$	Square	1.732		0.001	0.001 0.00	0.001 0.00 0.001	0.001 0.00 0.001 0.001	0.001 0.00 0.001 0.001 0.001
8	u(û <sub>Kbr</sub> )	Hum	u <sub>8</sub> (S)	Normal	2		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
9	$\mathfrak{u}(\hat{\mathfrak{u}}_{\mathrm{Kr}})$	Noise	u <sub>9</sub> (S)	Normal	2		0.001	0.001 0.001	0.001 0.001 0.001	0.001 0.001 0.001 0.001	0.001 0.001 0.001 0.001 0.001
10	$u(\hat{u}_{Kgmo})$	Effect of geometric location	u <sub>10</sub> (S)	Square	1.732		0.001	0.001 0.001	0.001 0.001 0.001	0.001 0.001 0.001 0.001	0.001 0.001 0.001 0.001
11	$u(\hat{u}_{Kmk})$	Sensor attachment	u <sub>11</sub> (S)	Square	1.732		0	0 0	0 0 0	0 0 0 0	0 0 0 0
12	$\mathfrak{u}(\hat{\mathfrak{u}}_{\mathrm{Krel}})$	Cable routing and fixing	u <sub>12</sub> (S)	Square	1.732		0.25	0.25 0.2	0.25 0.2 0.18	0.25 0.2 0.18 0.16	0.25 0.2 0.18 0.16 0.16
13	$u(\hat{u}_{Ktk})$	Relative motion	u <sub>13</sub> (S)	Square	1.732		0.05	0.05 0.02	0.05 0.02 0.01	0.05 0.02 0.01 0.01	0.05 0.02 0.01 0.01 0.01
14	$u(\hat{u}_{Kl})$	Temperature change	u <sub>14</sub> (S)	Square	1.732	-	0.0015	0.0015 0.0015	0.0015 0.0015 0.0015	0.0015 0.0015 0.0015 0.0015	0.0015 0.0015 0.0015 0.0015
15	$\mathfrak{u}(\hat{\mathfrak{u}}_{\mathrm{Ki}})$	Linearity	u <sub>15</sub> (S)	Square	1.732		0.001	0.001 0.001	0.001 0.001 0.001	0.001 0.001 0.001 0.001	0.001 0.001 0.001 0.001 0.001
16	$\mathfrak{u}(\hat{\mathfrak{u}}_{\mathrm{Kres}})$	Temporal instability of v signal	u <sub>16</sub> (S)	Square	1.732		0.001	0.001 0.001	0.001 0.001 0.001	0.001 0.001 0.001 0.001	0.001 0.001 0.001 0.001 0.001
17	$u(\hat{u}_{Kgmo})$	Residual effects	$u_{17}(S)$	Square	1.732		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
18	$u(\hat{u}_{rep})$	Repeatability	u <sub>18</sub> (S)	Normal	1	(	0.0094	0.0094 0.0071	0.0094 0.0071 0.0044	0.0094 0.0071 0.0044 0.0051	0.0094 0.0071 0.0044 0.0051 0.0081
		Combined Uncertainty					0.298	0.298 0.254	0.298 0.254 0.238	0.298 0.254 0.238 0.223	0.298 0.254 0.238 0.223 0.205
		Expanded Uncertainty					0.60	0.60 0.51	0.60 0.51 0.48	0.60 0.51 0.48 0.45	0.60 0.51 0.48 0.45 0.41

		18	17	16	15	14	13	12	=	10	9	8	7	6	5	4	3	2	1	<b></b> -
		$\mathfrak{u}(\Delta \varphi \operatorname{Kre}_{s})$	$u(\Delta \varphi \operatorname{Kre}_s)$	$u(\Delta \varphi_{\rm KI})$	$u(\Delta \varphi_{\rm KL})$	$u(\Delta \varphi_{Kik})$	$u(\Delta \varphi_{Krel})$	$u(\Delta \varphi_{Kmk})$	$u(\Delta \varphi_{Kna})$	$\mathfrak{u}(\varphi_{\mathrm{Kbd}})$	$u(\varphi_{Kr})$	$u(\varphi_{Khr})$	$u(\varphi_{Ko})$	$u(\varphi_{Kq})$	$u(\varphi_{K})$	$\mathfrak{u}(\varphi_{\mathfrak{u},\mathrm{G}})$	u(φ <sub>w</sub> )	$\mathfrak{u}(\varphi_{\mathfrak{u},\mathbf{x}})$	$\mathfrak{u}(\varphi_{\mathfrak{u},\mathrm{V}})$	Standard Uncertainty contribution u(xi)
Expanded Uncertainty	Combined Uncertainty	Repeatability	Residual effects	Temporal instability of v signal	Linearity	Temperature chage	Relative motion	Cable routing and fixing	Sensor attanchment	Effect of geometric location	Noise	Hum	Harmonics	Transverse motion	Feqneucy response	Amplifier gain	Angular frequency of v signal	Voltage Ux	Vibration velocity (Uncertatinty of tracing back)	ISO - SAM - U( $\Delta \varphi$ )
		$u_{18}(\Delta \varphi)$	$\mathfrak{u}_{\mathrm{I7}}(\Delta \varphi)$	$u_{16}(\Delta \varphi)$	$u_{15}(\Delta \varphi)$	$u_{14}(\Delta \varphi)$	$u_{13}(\Delta \varphi)$	$u_{12}(\Delta \varphi)$	$\mathfrak{u}_{11}(\Delta \varphi)$	$u_{10}(\Delta \varphi)$	$\mathfrak{u}_9(\Delta \varphi)$	$\mathfrak{u}_8(\Delta \varphi)$	$\mathfrak{u}_{7}(\Delta \varphi)$	$\mathfrak{u}_{6}(\Delta \varphi)$	$\mathfrak{u}_{\mathfrak{S}}(\Delta \varphi)$	$u_4(\Delta \varphi)$	$u_3(\Delta \varphi)$	$u_2(\Delta \varphi)$	$u_{\rm I}(\Delta \varphi)$	Uncertainty contribution ui(y)
		Normal	Square	Square	Square	Square	Square	Square	Square	Square	Normal	Normal	Square	Square	Normal	Normal	Square	Normal	Normal	Probability Distribution
		1	1.732	1.732	1.732	1.732	1.732	1.732	1.732	1.732	2	2	1.732	1.732	2	2	1.732	2	2	Divisor
0.83	0.416	0.0025	0.100	0.010	0.010	0.010	0.200	0.300	0.000	0.010	0.010	0.010	0.000	0.000	0.100	0.100	0.000	0.100	0.050	0.1 to 0.8 Hz
0.61	0.305	0.0016	0.100	0.010	0.010	0.010	0.100	0.200	0.000	0.010	0.010	0.010	0.000	0.000	0.100	0.100	0.000	0.100	0.050	≫0.8 to 1.6 Hz
0.54	0.270	0.0008	0.100	0.010	0.010	0.010	0.100	0.140	0.000	0.010	0.010	0.010	0.000	0.000	0.100	0.100	0.000	0.100	0.050	>1.6 to 4 Hz
0.47	0.236	0.0004	0.100	0.010	0.010	0.010	0.050	0.100	0.000	0.010	0.010	0.010	0.000	0.000	0.100	0.100	0.000	0.100	0.050	10 8 Hz
0.45	0.225	0.0008	0.100	0.010	0.010	0.010	0.050	0.070	0.000	0.010	0.010	0.010	0.000	0.000	0.100	0.100	0.000	0.100	0.050	>8 to 40 Hz

# IV. KRISS

# Magnitude sensitivity

Uncertainty component ccelerometer output voltage neasurement ffect of laser wavelength ffect of transverse, rocking, and ending acceleration on accelerometer ending acceleration on accelerometer utput voltage measurement (transverse	D. Comment DAQ resolution and calibration recommendation value hum on accelerometer output voltage measurement transverse acceleration on accelerometer output voltage measurement	Voltage S Symbol u1 u2 u3 u4	Type B B B B	ty uncertain Distribution rectangular rectangular rectangular	rty budge Factor 0.577 1 0.577	t - KRISS 0.1 Hz 4.5E-02 1.5E-04 8.4E-06 7.1E-06	0.125 Hz 4.5E-02 1.5E-04 8.4E-06 7.1E-06	Unce 0.16 Hz 4.5E-02 1.5E-04 8.4E-06 7.1E-06	rtainty contr       0.2 Hz to       0.25 Hz       4.5E-02       1.5E-04       8.4E-06       7.1E-06	<b>ibution</b> 0.315 Hz to 0.4 Hz 4.5E-02 1.5E-04 8.4E-06 7.1E-06	<0.4 Hz to 1.25 Hz 1.9E-01 1.5E-04 5.1E-04 7.1E-06	< 1.25 Hz to 40 Hz 1.2E-01 1.5E-04 4.6E-05 7.1E-06
voltage disturbance	hum on accelerometer output voltage neasurement	5. 6	5 W	rectangular	0.577	8.4E-06	8.4E-06	8.4E-06	8.4E-06	8.4E-06	5.1E-04	4.6E-05
effect of transverse, rocking, and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	transverse acceleration on accelerometer output voltage measurement	u4	θ	U-type	1.41	7.1E-06	7.1E-06	7.1E-06	7.1E-06	7.1E-06	7.1E-06	7.1E-06
effect of cosine error	interferometer misalignment	uS	в	rectangular	0.577	7.2E-04	7.2E-04	7.2E-04	7.2E-04	7.2E-04	7.2E-04	7.2E-04
harmonics on accelerometer output voltage measurment	total distortion on accelerometer output voltage measurment	uó	A	rectangular	0.577	5.8E-06	5.8E-06	5.8E-06	5.8E-06	5.8E-06	8.0E-07	6.8E-07
effect of voltage disturbance on phase amplitude measurement	random noise in the photoelectric measuring chains on phase amplitude measurement	u7	в	rectangular	0.577	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02
effect of motion disturbance on phase amplitude measurement	relative motion between the accelerometer reference surface and the spot sensed by the interferometer on phase amplitude measurement	u8	в	normal	-	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02
vibration frequency measurement	deviation of sample clock from generator clock	u9	в	rectangular	0.577	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03	5.8E-03
residual effects on sensitivity measurement	repeat measurements; experimental standard devitation of arithmetic mean	u10	А	normal	1	5.0E-01	4.5E-01	3.0E-01	2.0E-01	2.2E-02	2.3E-02	2.2E-02
R	elative combined standard uncertainty				in %	5.0E-01	4.5E-01	3.1E-01	2.1E-01	0.061	0.196	0.123
	Relative expanded uncertainty (k=2)				in %	1.0E+00	9.1E-01	6.1E-01	4.2E-01	0.122	0.392	0.246
	Stated relative expanded uncertainty				in %	1.3	1	0.8	0.5	0.3	0.4	0.3

	E. Phasee Sensitivity uncertainty	y budget	- KRIS	<b>2</b> 2		
						Uncertainty contribution
Uncertainty coponent	Comment		Туре	Distribution	Factor	0.1 Hz to 40 Hz
accelerometer output phase measuremen	ADC-resolution	ul	в	rectangular	0.577	3.6E-05
voltage disturbance on accelerometer output phase measurement	hum and noise	u2	в	rectangular	0.577	4.7E-02
transverse, rocking, and bending acceleration on accelerometer output phase measurement	transverse acceleration on accelerometer output phase measurement	u3	в	U-type	1	7.0E-04
voltage disturbance on displacement phase amplitude measurement	random noise in the photoelectric measuring chains	u4	в	rectangular	0.577	5.0E-06
motion disturbance on displacement phase amplitude measurement	drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer	uS	В	rectangular	0.577	1.2E-02
phase disturbance on displacement phase amplitude measurement	phase noise of the interferometer signals	ub	в	rectangular	0.577	2.9E-04
delay of laser interferometer	delay of laser interferometer	u7	В	rectangular	0.577	4.2E-06
residual effects on phase shift measurement	random effect in repeat measurements; experimental standard devitation of arithmetic mean	u8	А	normal	1	1.7E-02
	combined standard uncertainty				in °	0.051
	expanded uncertainty (k=2)				in °	0.103
	stated expanded uncertainty				in °	0.2

# V. NMISA

#### Magnitude sensitivity

	Uncertain			Best Measu	About UBM	-	0_ Stand	0_ Stand	Ú <sub>RES</sub> Resid	<i>μ</i> <sub>T</sub> Effect <i>μ</i> <sub>RES</sub> Resid	<ul> <li>μ<sub>D</sub> Effect</li> <li>μ<sub>RES</sub> Resid</li> <li>μ<sub>RES</sub> Stand</li> </ul>	<ul> <li>μ<sub>D</sub> Effect</li> <li>μ<sub>PES</sub> Resid</li> <li>μ<sub>AES</sub> Stand</li> </ul>	0 <sub>0</sub> Effect 0 <sub>T</sub> Effect 0 <sub>RES</sub> Resid	Δ <sub>D</sub> Effect Δ <sub>T</sub> Effect Δ <sub>RES</sub> Resid	G C4 Charg	S <sub>F</sub> Filteri G <sub>CA</sub> Charg d <sub>D</sub> Effect d <sub>RES</sub> Resid	<ul> <li> <sup>0</sup>V Accel S<sub>F</sub> Filteria G<sub>CA</sub> Chang G<sub>D</sub> Effect <sup>0</sup>D Effect d<sub>T</sub> Effect d<sub>RS</sub> Resid A_ASIAN A</li></ul>	λ <sub>U</sub> Uncert           ů <sub>V</sub> Accelé           S <sub>F</sub> Filterin           G <sub>CL</sub> Charg           ů <sub>D</sub> Effect           ů <sub>T</sub> Effect           ů <sub>RS</sub> Resid           ů <sub>RS</sub> Resid	fre     Vibrat       Åu     Uncer $\hat{u}_{V}$ Accelo $\hat{u}_{V}$ Accelo $\hat{u}_{V}$ Creating $G_{ct}$ Change $\hat{u}_{T}$ Effect $\hat{u}_{T}$ Effect $\hat{u}_{RES}$ Resid $\hat{u}_{-L}$ Stand	φ net     Resid       fno     Vibrait       λ <sub>U</sub> Uncer       û <sub>V</sub> Accelé       S <sub>F</sub> Filterit       G <sub>CA</sub> Charg       d <sub>D</sub> Effect       û <sub>T</sub> Effect       û <sub>RES</sub> Resid	φ no     Effect       φ net     Resid       fro     Vfbrak       λ <sub>U</sub> Uncert       ĝ <sub>Y</sub> Accelo       ĝ <sub>Y</sub> Accelo       ĝ <sub>Y</sub> Resid       ĝ <sub>Y</sub> Charg       ĝ <sub>Y</sub> Effect	Pac     Effect       Pac     Resid       fre     Vibrati       dy     Accelo       dy     Accelo       gr     Filteri       Gcu     Charg       dy     Effect       dy     Effect       dy     Resid       dy     Accelo       dy     Resid       dy     Resid	φ ιο     Effect       φ ιο     Effect       φ ne     Resid       f no     V/brai       δ <sub>V</sub> Uncer       δ <sub>V</sub> Accel       G ci     Charg       G ci     Charg       d <sub>V</sub> Resid       d <sub>RSS</sub> Resid	φ <sub>0</sub> Intente       φ <sub>NO</sub> Effect       φ <sub>NO</sub> Effect       φ <sub>NO</sub> Effect       φ <sub>NO</sub> Effect       φ <sub>NO</sub> Resid       J <sub>V</sub> Uncer       J <sub>V</sub> Accelo       J <sub>V</sub> Accelo       J <sub>V</sub> Charg       G <sub>CA</sub> Charg       J <sub>NES</sub> Effect       J <sub>NES</sub> Resid	μ       φο     Intente       φο     Effect       φο     Chars       βο     Effect       φο     Chars       φο     Effect       φο     φο       φο     φο       φο     φο       φο     φο       φο     φο       φο       φο       φο    <	μ       φο     Inflanfa       φο     Effloct       φnc     Effloct       φnc     Effloct       φnc     Effloct       φnc     Kassistic       βnc     Effloct       φnc     Vibrait       βnc     Vibrait       βnc     Vibrait       βnc     Filteri       βnc     Charg       βnc     Effloct       βnc     Effloct       βnc     Effloct       βnc     Effloct       βnc     Effloct       βnc     Sand       βnc     Sand	Symbol           u           \$\varphi_0\$	ymbol           μ           φ <sub>10</sub> Intenfa           φ <sub>10</sub> Effect           φ <sub>11</sub> Charg           φ <sub>11</sub> Effect           φ <sub>11</sub> Effect           φ <sub>11</sub> Effect           φ <sub>12</sub> Effec	Symbol           u           φ <sub>0</sub> Intenfe           φ <sub>0</sub> Effect           φ <sub>10</sub> Chasg           φ <sub>10</sub> Effect           φ <sub>10</sub>	Vescription:           u           y	Pescription:           u           ymbol           po           Effect           Qr           Gcu           Qr           Charg           Qr           Effect           Qr           Qr           Zthering           Qr           Zthering           Qr           Zthering           Qr           Zthering           Qr           Zthering	U     U       Symbol     Intenfe       V     Intenfe       V     Intenfe       V     Effect       V     Effect       V     Intenfe       V     Effect       V     Intenfe       V     Effect       V     Intenfe       V     Effect       V     Intenfe       Sr     Filteri       GcA     Charg       Grad     Charg       Jacab     Effect
	nty of Measurement (Including UUT C		contribution)	urement Capability (Excluding UUT			dard deviation on accelerometer output voltage measurement	dard deviation on accelerometer output voltage measurement	dual effects on accelerometer output voltage measurement dard deviation on accelerometer output voltage measurement	1 of transverse motion on accelerometer output voltage measure dual effects on accelerometer output voltage measurement dard deviation on accelerometer output voltage measurement	1 of voltage disturbance on accelerometer output voltage measure 1 of transverse motion on accelerometer output voltage measure buai effects on accelerometer output voltage measurement dard deviation on accelerometer output voltage measurement	Unit Under Test / C     Voltage disturbance on accelerometer output voltage measure t of transverse motion on accelerometer output voltage measure dual effects on accelerometer output voltage measurement dard deviation on accelerometer output voltage measurement	▼ Unit Under Test / C 1 of voltage disturbance on accelerometer output voltage measure 1 of transverse motion on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement	▼ Unit Under Test / C 1 of voltage disturbance on accelerometer output voltage measure 1 of transverse motion on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement	ge amplifier gain accuracy	ge amplifier gain accuracy ▼ Unit Under Test / C 1 of voltage disturbance on accelerometer output voltage measure 1 of transverse motion on accelerometer output voltage measure 1 of transverse motion on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement	lerometer output voltage measurement (ADC resolution/accuracy ing effect on sensitivity measurement ge amplifier gain accuracy v Unit Under Test / C t of voltage disturbance on accelerometer output voltage measure t of transverse motion on accelerometer output voltage measure t of transverse motion on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement	trtainty on laser wavelength measurement kerometer output voltage measurement (ADC resolution/accuracy ing effect on sensitivity measurement ge amplifier gain accuracy ▼ Unit Under Test / C T of transverse motion on accelerometer output voltage measurement t of transverse motion on accelerometer output voltage measurement t of transverse motion on accelerometer output voltage measurement dard deviation on accelerometer output voltage measurement	lion frequency measurement accuracy stainty on laser wavelength measurement (ADC resolution/accuracy ing effect on sensitivity measurement ge amplifier gain accuracy to voltage disturbance on accelerometer output voltage measure t of voltage disturbance on accelerometer output voltage measurement t of transverse motion on accelerometer output voltage measurement data effects on accelerometer output voltage measurement data deviation on accelerometer output voltage measurement	dual interferometric effects on phase amplifude measurement tion frequency measurement accuracy rfainly on laser wavelength measurement derometer output voltage measurement (ADC resolution/accuracy ge amplifier gain accuracy T Unit Under Test / C Unit Under Test / C Unit Under Test / C to voltage disturbance on accelerometer output voltage measurement 1 of voltage disturbance on accelerometer output voltage measurement 1 of voltage moderometer output voltage measurement dual effects on accelerometer output voltage measurement	1 of phase disturbance on phase amplitude measurement dual interferometric effects on phase amplitude measurement intrainity on laser wavelength measurement (ADC resolution/accuracy elerometer output voltage measurement (ADC resolution/accuracy ge amplifier gain accuracy V Unit Under Test / C to voltage disturbance on accelerometer output voltage measurement 1 of transverse motion on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement	1 of motion disturbance on phase amplitude measurement 1 of phase disturbance on phase amplitude measurement dual interferometric effects on phase amplitude measurement lifon frequency measurement (ADC resolution/accuracy ritainy on laser wavelength measurement derometer output voltage measurement econneter output voltage measurement dual effect on sensitivity measurement 1 of voltage disturbance on accelerometer output voltage measurement 1 of voltage disturbance on accelerometer output voltage measurement 1 of voltage disturbance on accelerometer output voltage measurement 1 of transverse motion on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement	1 of voltage disturbance on phase amplitude measurement 1 of phase disturbance on phase amplitude measurement trainity on laser wavelength measurement tion frequency measurement (ADC resolution/accuracy isrometer output voltage measurement (ADC resolution/accuracy isrometer output voltage measurement to frequency y Unit Under Test / C 1 of voltage disturbance on accelerometer output voltage measurement 1 of voltage measurement	ferometer output signal disturbance on phase amplitude measurement 1 of motion disturbance on phase amplitude measurement 1 of phase disturbance on phase amplitude measurement 1 of nequency measurement accuracy trainity on laser wavelength measurement (ADC resolution/accurac) isrometer output voltage measurement (ADC resolution/accurac) isrometer output voltage measurement isrometer output voltage measurement isrometer output voltage measurement to f voltage disturbance on accelerometer output voltage measurement 1 of voltage disturbance on accelerometer output voltage measurement to f transverse motion on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement	Standards and Reference Equipm to voltage disturbance on phase amplitude measurement of motion disturbance on phase amplitude measurement to phase disturbance on phase amplitude measurement dual interferometric effects on phase amplitude measurement dual interferometric effects on phase amplitude measurement dual interferometric output voltage measurement for frequency measurement (ADC resolutioniaccurac) ing effect on sensitivity measurement ing effect on sensitivity measurement amplifier gain accuracy Turbulage disturbance on accelerometer output voltage measurement tof voltage disturbance on accelerometer output voltage measurement tof voltage disturbance on accelerometer output voltage measurement dual effects on accelerometer output voltage measurement		Source of Uncertain     Standards and Reference Equipm     Standards and Reference Equipm     for voltage disturbance on phase amplitude measurement     for motion disturbance on phase amplitude measurement     for frequency measurement accuracy     for frequency measurement (ADC resolution/accurac)     for voltage measurement     for oftage measurement     for oftage disturbance on accelerometer output voltage measurement     for voltage disturbance	Mathematical Model:     Input Quantity     (Source of Uncertail     (To voltage disturbance on phase amplitude measurement     1 of voltage disturbance on phase amplitude measurement     1 of voltage disturbance on phase amplitude measurement     tor frequency measurement (ADC resolutioniaccurac)     ing effect on sensitivity measurement     icon frequency measurement     icon sensitivity measurement	Mathematical Model:     Input Quantity     Source of Uncertair     Standards and Reference Equipm     Standards and Reference Equipm     Standards and Reference Equipm     Standards and Reference Equipm     of voltage disturbance on phase amplitude measurement     of phase disturbance on phase amplitude measurement     of requency measurement     of phase disturbance on phase amplitude measurement     of requency measurement     of requency measurement     of requency measurement     for frequency measurement     for frequency     reality on laser wavelength measurement     for oftage field on sensitivity measurement     for ordinge disturbance on accelerometer output voltage measurement     tof voltage disturbance on accelerometer output voltage measurement     tof transverse motion on accelerometer output voltage measurement     daal effects on accelerometer output voltage measurement     daal effects on accelerometer output voltage measurement	Sensitivity calibration (modulus) as per l' Mathematical Model: Input Quantity (Source of Uncertain Source of Uncertain Source of Uncertain (Source	Sensitivity calibration (modulus) as per li Mathematical Model: Input Quantity (Source of Uncertair Standards and Reference Equipm V Standards and Reference Equipm (Source of Uncertair (Source of Uncertair (Sourc	Sensitivity calibration (modulus) as per l Mathematical Model: Input Quantity (Source of Uncertain Source of Uncertain Source of Uncertain (Source o
(Normal)	Expanded Uncertainty	Expanded Uncertainty		Combined Uncertainty	TOTAL CC	stage measurement			ge measurement	odput vollage measurement ge measurement	output voltage measurement Judput voltage measurement ge measurement	Unit Under Test / Calibration (Uncorrelated) routput voltage measurement xutput voltage measurement ge measurement	Unit Under Test / Calibration (Uncorrelated) roufpd voltage measurement subput voltage measurement ge measurement	Unit Under Test / Calibration (Uncorrelated) output voltage measurement output voltage measurement ge measurement	Unit Under Test / Calibration (Uncorrelated) output voltage measurement ge measurement	Unit Under Test / Calibration (Uncorrelated) output voltage measurement per measurement	DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) routput voltage measurement utput voltage measurement ge measurement	DC resolution/accuracy) DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated)	DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) Unit Voltage measurement Judput voltage measurement ge measurement	Itude measurement DC resolution/accuracy) DC resolution/accuracy) output voltage measurement page measurement	le measurement fude measurement DC resolution/accuracy) DC resolution/accuracy) cutput voltage measurement vulput voltage measurement ge measurement	le measurement Inde measurement DC resolution/accuracy) DC resolution/accuracy) Curit Under Test / Calibration (Uncorrelated) output voltage measurement output voltage measurement ge measurement	de measurement le measurement litude measurement DC resolution/accuracy) DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) routput voltage measurement output voltage measurement ge measurement	ase amplitude de measurement le measurement ltude measurement Ltude measurement DC resolution/accuracy) DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated)	<b>J Reference Equipment (Uncorrelated) ▼</b> ase amplitude de measurement de measurement fitude measurement funder Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated)	I Reference Equipment (Uncorrelated) ▼ ase amplitude de measurement le measurement litude measurement litude measurement DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated)	Input Quantity Iselerence Equipment (Uncorrelated) V ase amplitude de measurement de measurement funde measurement funde measurement DC resolution/accuracy) DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated)	Input Guantity (Source of Uncertainty) (Source of Uncertainty) sea amplitude de measurement de measurement itude measurement DC resolution/accuracy) DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated)	anatical Model: Input Quantity (Source of Uncertainty) I Reference Equipment (Uncorrelated) ▼ ase amplitude ase amplitude measurement fe measurement finde measurement DC resolution/accuracy) DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated)	on (modulus) as per ISO 16063-11 method 3 Input Quantity (Source of Uncertainty) I Reference Equipment (Uncorrelated) ▼ ase amplifude de measurement fe measurement Inde measurement Inde measurement DC resolution/accuracy) DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) routput voltage measurement output voltage measurement ge measurement	samatical Model: Input Quantity (Source of Uncertainty) (Source of Uncertainty) J Reference Equipment (Uncorrelated) ▼ ase amplitude measurement de measurement funde measurement Itude measurement DC resolution/accuracy) DC resolution/accuracy) Unit Under Test / Calibration (Uncorrelated) Unit Under Test / Calibration (Uncorrelated)	Source of Uncertainty) Source of Uncertainty) Source of Uncertainty) Selerence Equipment (Uncorrelated)  Selerence Equipment (Uncorrelated)  Selerence Equipment (Uncorrelated) Selerence Equipment Selerence
TOTAL COMBINED UNCERTAIN certainty Confidence Level T	TOTAL COMBINED UNCERTAIN Perfainity Confidence Level 0 k=2 20 k=5%	TOTAL COMBINED UNCERTAIN Certainity Confidence Level T	TOTAL COMBINED UNCERTAIN	TOTAL COMBINED UNCERTAIN								Jncorrelated) T	Jncorrelated) Y	Incorrelated) V	Incorrelated) V	Incorrelated) V	Incorrelated) Y	Incorrelated) Y	Incorrelated) Y	Incorrelated) V	Incorrelated) V	Incorrelated) V	Incorrelated) T	Incorrelated) Y	Plated)	elated) <b>V</b>	elated) V	elated) Y	Incorrelated) V	Incorrelated) V	Interfood 3	Incorrelated) T
0,300 <b>RTAINTY</b> 0,14	0,300 <b>RTAINTY</b> 0,14 0,28	0,300 <b>RTAINTY</b> 0,14 0,28	0,300 RTAINTY 0,14	0,300 RTAINTY	0,300			0,025	0,025		0,035	0,035	0,035	0,035	0,035	0,046	0,087	0,000 0,0087 0,00	0,006 0,007 0,008	0,012 0,006 0,000 0,006 0,000 0	0,006 0,006 0,006 0,000 0,008 0,008 0,008 0,008 0,008 0,008 0,008 0,008 0,008 0,008 0,008 0,006	0,012 0,006 0,006 0,006 0,007 0,007 0,007 0,007 0,007	0,000 0,012 0,012 0,006 0,007 0,006 0,000 0,000 0,000 0,000	0,006 0,000 0,002 0,005 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,007 0,006 0,007 0,007 0,007 0,007 0,007 0,007 0,007 0,007 0,007 0,007 0,007 0,007 0,007 0,007 0,000 0,007 0,000 0,007 0,000 0,007 0,000 0,007 0,000 0,007 0,000 0,007 0,000000	0,006 0,000 0,000 0,012 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,000000	0,1 H2 9,2 H2 9,006 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,012 0,010000000000	0,1Hz 9,2Hz 9,000 0,000000	0,1H2 > 0,2H2 > 0,006 0,000 0,007 0,007 0,006 0,000 0,006 0,000 0,006 0,000 0,006 0,000 0,006 0,000 0,006 0,000 0,006 0,000 0,006 0,000 0,006 0,000000	Secial           0,1Hz         y           0,2Hz         y           0,000         0,000           0,0012         0,000           0,006         0,006	Make &           0,1 Hz         Serial           0,2 Hz         9           0,006         0,000           0,0012         0,0012           0,006         0,000           0,006         0,006<	Model:         Model:         Model:         Model:         Model:         Model:         Model:         Model:         Strink         Strink         Strink         Model:         Mode:         Mode:         Mode: <td>Image: Name of a function of a func</td>	Image: Name of a function of a func
0,200	0,200 ( 0,117 ( 0,23	0,200 0,117 0	0,200	0,200	0,200			0,025	0,015	0,020	200	0.025	0.005		0,100	0,046	0,005	0,000	0,006 0,006 0,035 0,046 0,100 0,046 0,100 0,046 0,100 0,005	0,012 0,006 0,000 0,035 0,046 0,100	0,006 0,012 0,006 0,000 0,000 0,035 0,046 0,046	0,006 0,006 0,012 0,006 0,000 0,000 0,000 0,046 0,005	0,000 0,006 0,006 0,006 0,007 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000	0,006 0,000 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006 0,006	0,000         0,000 <td< td=""><td><ul> <li>&gt;0,2 Hz</li> <li>&lt;1 Hz</li> <li>10</li> <li>0,006</li> <li></li></ul></td><td>&gt;0.2Hz &lt;1Hz % % % % 10006 0,006</td><td>&gt;0,2Hz         to           %         0,02Hz         to           %         1         to           %         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006</td><td>×0,2 Hz         to           &lt;1 Hz</td>         to           0,006         0,006           0,006         0,006           0,006         0,006           0,006         0,006           0,006         0,006           0,006         0,006           0,006         0,006           0,006         0,006           0,006         0,006</td<>	<ul> <li>&gt;0,2 Hz</li> <li>&lt;1 Hz</li> <li>10</li> <li>0,006</li> <li></li></ul>	>0.2Hz <1Hz % % % % 10006 0,006	>0,2Hz         to           %         0,02Hz         to           %         1         to           %         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006           0,006         0,006         0,006	×0,2 Hz         to           <1 Hz	>0,2 Hz         10           <1 Hz	* 0,2 Hz * 0,2 Hz * 1 Hz 0,006 0,	Ny         Ny           wrowt, aaund by BB%.            >0,2 Hz            >0,006            0,006            0,006            0,006            0,006            0,006            0,006            0,006            0,006            0,006            0,006            0,006            0,006            0,006           0,006            0,006            0,006            0,046            0,046
0,100 0,	0,100 0, 0,20 0, 0,20 0,	0,100 0, 0,20 0,	0,100 0,	0,100 0;	0,100 0,	in czn'n	0,0 CZ010	~	0,025 0,0	0,015 0,0					0,050 0,:	0,058 0,0	0,058 0,0 0,050 0;	0,000 0,/ 0,058 0,/ 0,050 0, 0,050 0,	0,029 0, 0,000 0, 0,058 0, 0,059 0, 0,050 0,	0,006 0, 0,029 0, 0,058 0, 0,058 0, 0,056 0, 0,056 0,	0,006 0, 0,006 0, 0,029 0, 0,058 0, 0,058 0, 0,056 0,	0,009 0; 0,006 0, 0,006 0, 0,029 0, 0,058 0, 0,058 0, 0,056 0;	0,000 0, 0,006 0, 0,006 0, 0,006 0, 0,008 0, 0,008 0, 0,008 0, 0,008 0, 0,009 0, 0,009 0, 0,009 0, 0,009 0, 0,000 0,000 0, 0,000 0,000 0, 0,000 0,000 0, 0,000 0,000 0,000 0, 0,0000 0,000 0,000 0,000 0,000 0,000 0,000 0,000 0,000	0.006 0, 0.000 0, 0.006 0, 0.006 0, 0.006 0, 0.000 0, 0.008 0, 0.008 0, 0.009 0, 0.0000 0, 0.00000 0, 0.00000 0, 0.0000 0, 0.0000 0, 0.00000 0, 0.0000000000	0.000         0.000         0.000           0.000         0.000         0.000           0.000         0.000         0.000           0.000         0.000         0.000           0.000         0.000         0.000	1HE         >1           101HHZ         >1           0006         00           0006         00           0006         00           0006         00           0006         00           0006         00           0006         00           0006         00           000723         00           00088         00           00098         00           00090         00	Standard Unc <b>% % % % % % % % % %</b>	Standard Urt           1Hz         >1           1Hz         >1           0.0006         01           0.0006         01           0.0006         01           0.0006         01           0.0006         01           0.0006         01           0.0006         01           0.0006         01           0.0007         01           0.0008         01           0.0058         01           0.0050         01	Standard Un           HHz         >1           NHZ         >1           NHZ         >1           NHZ         >1           NO006         00           0,0006         00           0,0006         00           0,0006         00           0,0006         00           0,0007         00           0,0008         00           0,0009         00	Standard         Intel         >1           11Hz         >1         Intel         >1           1006         01         0006         01           0006         01         0000         00           0006         01         0000         00           0006         01         0000         00           0006         01         0000         00           0006         01         00         00           0006         01         00         00           00058         01         00         00           00050         00         00         00           00050         00         00         00           00059         00         00         00	Standard Under Standa	Standard         Inc.         Fig.           Bitle         Bitle         Bitle           Bitle         Bitle         Bitle           Bitle         Standard         Unc           Standard         Standard         Unc           Standard         Standard         Standard           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           0006         00         00           00060         00         00           00060         00         00
0,035 0,025 0,025 0,150 0,200 0	0,035 0,025 0,150 0,200 0,184 0,325 0,37 0,65	0,035 0,025 0,150 0,200 0,184 0,325 0,37 0,65	0,035 0,025 0,150 0,200 0,150 0,200 0	0,035 0,025 0,150 0,200	0,035 0,025 0,150 0,200	0,035 0,025	0,035 0,025		0,025 0,040	0,030 0,025				-	0,100 0,100	0,058 0,115 0,100 0,100	0,035 0,035 0,058 0,115 0,100 0,100	0,000 0,000 0,035 0,035 0,058 0,115 0,100 0,100	0,040 0,087 0,000 0,000 0,035 0,035 0,058 0,115 0,100 0,100	0,066 0,058 0,040 0,087 0,000 0,000 0,035 0,035 0,035 0,115 0,058 0,115 0,100 0,100	0,029 0,058 0,006 0,058 0,040 0,087 0,000 0,000 0,005 0,035 0,058 0,115 0,100 0,100	0,115 0,231 0,028 0,068 0,046 0,068 0,040 0,067 0,000 0,000 0,035 0,035 0,058 0,115 0,100 0,100	0,000 0,001 0,115 0,231 0,029 0,058 0,006 0,058 0,040 0,008 0,040 0,008 0,035 0,035 0,035 0,115 0,058 0,115 0,100 0,100	0.058 0.115 0.000 0.001 0.115 0.231 0.029 0.058 0.006 0.058 0.006 0.008 0.005 0.035 0.035 0.035 0.035 0.115 0.058 0.115	%         %           0.058         0.115           0.000         0.001           0.115         0.231           0.006         0.068           0.006         0.068           0.000         0.000           0.003         0.003           0.035         0.035           0.036         0.115           0.103         0.100	>1 MH2         5 KH2           <5 MH2         10 7 MH1           0.068         0.115           0.002         0.001           0.115         0.231           0.006         0.058           0.006         0.058           0.000         0.008           0.000         0.008           0.000         0.008           0.005         0.035           0.058         0.115           0.058         0.116           0.100         0.100	Uncertainty Contril           St NH2:         St NH2:           C 51 NH2:         To 7 NH1           %         %           0,068         0,115           0,002         0,008           0,006         0,087           0,000         0,087           0,000         0,088           0,003         0,035           0,038         0,115           0,100         0,100	Vincertainty Contril           I MHZ         SkHz           S ShHz         No 7 MH           %         %           0,008         0,115           0,008         0,231           0,006         0,068           0,006         0,068           0,000         0,003           0,005         0,035           0,035         0,115           0,100         0,100	Uncertainty Contril StHz: 5.1412: 5.1412: S.1412: 5.1412: S.1412: 0.7.141 0.008: 0.115 0.008: 0.015 0.008: 0.008 0.000 0.009 0.000 0.009 0.005 0.00	Enderso Enderso State: Stat	Strukt         Skitz           Course, Luse, Course         Course           Course         Skitz           Skitz         Skitz	State         State <th< td=""></th<>
025 0,050 200 0,350 325 0,468	025 0,050 200 0,350 325 0,468 65 0,94	200 0,050 200 0,350 325 0,468 65 0,94	025 0,050 200 0,350 325 0,468	200 0,350	025 0,050	025 0,050	025 0,050		040 0,050	025 0,025					100 0,100	115 0,115 100 0,100	035 0,035 115 0,115 100 0,100	000 0,000 035 0,035 115 0,115 100 0,100	0,115 0000 0,000 035 0,035 1115 0,115 100 0,100	058 0,029 087 0,115 000 0,000 035 0,035 115 0,115 100 0,100	0658 0,058 0,029 067 0,115 0000 0,000 0000 0,000 1115 0,115 1115 0,115	231         0,404           058         0,029           058         0,029           058         0,029           0687         0,115           0000         0,000           0035         0,033           115         0,115           100         0,100	0001         0.001           221         0.404           058         0.029           058         0.029           068         0.029           087         0.115           033         0.033           115         0.115           115         0.110           100         0.100	1115         0.115           0001         0.001           231         0.404           058         0.058           058         0.029           058         0.029           058         0.023           066         0.000           035         0.035           115         0.115           115         0.115           116         0.110	%         %           1115         0.115           0001         0.001           2231         0.404           2231         0.404           2058         0.029           0058         0.029           0067         0.115           0000         0.000           0000         0.0035           115         0.115           100         0.103	HHZ         > 7 HHZ           KHZ         to 12 HHZ           1115         0,115           0001         0,001           2211         0,404           231         0,404           231         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           058         0,029           057         0,115           0100         0,100           115         0,115           115         0,110	Antibution UF(y)           Ithic         > 7 Mit           Ithic         > 7 Mit           Ithic         > 7 Mit           Ithic         > 7 Mit           Ithic         0.115           0.001         0.001           231         0.404           231         0.404           0038         0.023           058         0.023           058         0.003           000         0.000           000         0.003           115         0.115           010         0.103           115         0.115	Attribution UF(y)           Attribution UF(y)           Introductor           Introductor           Vitit           Introductor           Vitit           Introductor           Vitit           Introductor           Vitit           Introductor           Vitit           Introductor           Introl	King         King           1115         0,7145           1115         0,7145           1115         0,7145           1115         0,001           1231         0,404           1231         0,404           100         0,000           0035         0,003           115         0,115           100         0,003           115         0,115           115         0,115           115         0,115           115         0,115           115         0,115           115         0,115           115         0,115           115         0,115	Range:           HHz         > 7 KHz           KHZ         > 7 KHz           KHZ         0.115           0.001         0.001           221         0.404           231         0.404           231         0.404           231         0.029           058         0.029           058         0.023           053         0.033           115         0.115           0100         0.000           115         0.115           0100         0.003           115         0.115           115         0.115	Kange:           Range:           Ra	Kange:           Range:           Range:           Kit           > 7 INH2           KH           115           0,011           0,013           0,023           0,035           0,035           0,035           0,035           115           0,115           0,029           0,035           0,035           115           0,115
0 0,050 0,450	0 0,050 0,450 4 1,11	00 0,050 00 0,450 00,450 4 1,11	0 0,050 0,450	0 0,050 0,450	0 0,050 0,450	0,050	0,050	-	0.125	0,100					0 0,100	5 0,115 10 0,100	5 0,035 5 0,115 10 0,100	00 0,000 15 0,035 15 0,115 10 0,100	5 0,144 10 0,000 15 0,035 15 0,115 10 0,100	99 0,058 15 0,144 10 0,000 15 0,035 15 0,115 16 0,100	88         0,115           19         0,058           5         0,144           10         0,000           15         0,035           15         0,115           15         0,115           15         0,100	M         0,462           28         0,115           19         0,058           15         0,144           10         0,000           15         0,115           15         0,035           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115	11         0,001           14         0,462           38         0,115           39         0,068           15         0,144           00         0,005           15         0,115           15         0,035           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115	15         0,173           11         0,001           14         0,462           15         0,115           19         0,068           15         0,144           15         0,035           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115	%           15         0,173           11         0,001           14         0,462           15         0,115           19         0,068           15         0,144           15         0,005           15         0,005           15         0,015           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,116           15         0,116           15         0,116           15         0,116           15         0,116	Hz         >12.KHz           VHZ         10.15.KHz           %         %           15         0,173           10         0,001           11         0,462           2         0,058           38         0,115           15         0,144           15         0,035           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115           15         0,115	A         >12 kHz           KHZ         10 15 kHz           S         0,173           I         0,4001           I         0,4621           I         0,165           I         0,003           I         0,003           I         0,003           I         0,003           I         0,003           I         0,0115           I         0,035           I         0,0115           I         0,0115           I         0,0115           I         0,0115           I         0,0115           I         0,0135           I         0,0135	S=0//a           //         //a           //         >12.84/z           //         10.15.84/z           //         %           //         0.015.84/z           //         %           //         0.001           //         0.462           //         0.008           //         0.003           //         0.003           //         0.003           //         0.0115           //         0.0035           //         0.0115           //         0.0115           //         0.0115           //         0.0115           //         0.0115           //         0.0115           //         0.0115           //         0.0115           //         0.0115           //         0.0115           //         0.0115	S=Ú/á           V <td>ye:         S=0//81           /)         //1           /)         //1           //1         //1           //1         0.001           //1         0.001           //1         0.001           //2         0.115           //2         0.058           //2         0.058           //2         0.005           //2</td> <td>NICE         S=0/á           //         //           //</td> <td>No.00-70/7000/00           S=0//a1           S=0//a1           N           I          I          I         I         I           I         I         I         I           I         I         I         I         I           I         I         I         I         I         I         I           I</td>	ye:         S=0//81           /)         //1           /)         //1           //1         //1           //1         0.001           //1         0.001           //1         0.001           //2         0.115           //2         0.058           //2         0.058           //2         0.005           //2	NICE         S=0/á           //         //           //	No.00-70/7000/00           S=0//a1           S=0//a1           N           I          I          I         I         I           I         I         I         I           I         I         I         I         I           I         I         I         I         I         I         I           I
0,125	0,125 0,050 0,500 0,598 0,698	0,125 0,050 0,500 0,698 1,40	0,125	0,125	0,125	0,125	0,125 0,050	0,125		0,150					0,100	0,231	0,035 0,231 0,100	0,000 0,035 0,231 0,100	0,173 0,000 0,035 0,231 0,100	0,115 0,173 0,000 0,035 0,231 0,201	0,289 0,115 0,000 0,035 0,231 0,100	0,482 0,289 0,115 0,173 0,000 0,000 0,035 0,0231 0,100	0,002 0,462 0,289 0,115 0,115 0,000 0,000 0,035 0,035 0,231	0,289 0,002 0,462 0,289 0,115 0,115 0,117 0,000 0,005 0,005 0,010	%           0,289           0,002           0,462           0,289           0,115           0,1173           0,000           0,003           0,003           0,003           0,010	Iz         >15 MHz           %         0,289           0,002         0,002           0,0462         0,462           0,115         0,1173           0,000         0,000           0,003         0,003           0,003         0,003           0,033         0,0100	R         >15         R           tr         tr         0.205         NH4r         R           0,0002         0,0002         0,462         0,0002         0,462         0,115         0,0003         0	R         R         R           VIA         >15 MHz         R           VIA         %         0.002           0.0002         0.462         0.462           0.115         0.115         0.115           0.0001         0.0035         0.031           0.0101         0.0101         0.0101	R         R           visure         visure           visure         0.289           0.0002         0.462           0.115         0.115           0.0035         0.0331	0,1 Hz to 2	0,1 Hz to 2 0,1 Hz to 2 0,1 Hz to 2 0,2 Hz 10,2 0 Hz 10,2 Hz 10,	0,1 Hz to 2
V <sub>eff</sub> 100	100 III	X         100           I         100	<b>V</b>	100	100	100	100	100	***	100 ii					100 ii	100	100 ii	100 ii 100 ii 100 ii	100 ii 100 ii 100 ii	100 H	100 iii 100 iii 100 iii 100 iii	100 100 100 100 100 100 100 100 100 100	100 iii iii iii iii iii iii iii iii iii	100 100 100 100 100 100 100 100 100 100	100 100 100 100 100 100 100 100 100 100	100 100 100 100 100 100 100 100 100 100	Reliability         Det Fr           100         1           100         1           100         1           100         1           100         1           100         1           100         1           100         1           100         1           100         1           100         1           100         1           100         1           100         1           100         1	Reliability         Det Fr           %         Det           100         iii	d         Del           Reliability         Del           100         ii           100         iii	d Reliability 100 100 100 100 100 100 100 100 100 10	d         Det Fellability         Det Fr           100         iii         iii	A         Det           Reliability         Det           100         ii
7 ES	7 ES 2,00	7 ES	7 ES	7 ES	7 65			infinite Tri	infinite Tru	infinite Un					infinite Co	infinite e=	infinite Ma infinite e=	infinite Un infinite Ma infinite e=	infinite ISI infinite Un infinite Ma infinite e=	infinite No infinite ISI infinite Un infinite e= infinite cc	infinite Co infinite No infinite ISV infinite Un infinite Mi infinite Co	infinite Rad infinite Co infinite No infinite No infinite Un infinite G	infinite visa infinite Rei infinite Visa infinite Visa infinite Visa infinite Visa infinite e= infinite e=	infinite (Marchae) infinite (Marchae) infinite (Marchae) infinite (Marchae) infinite (Marchae) infinite (Marchae) infinite (Marchae) infinite (Marchae)	v v infinite ost infinite ost infinite ost infinite vo infinite IS infinite IS infinite IS	infinite v infinite v	Infinite Inf	Infinite	Pegrees of infinite i	infinite vi infinite vi infini	Pagress of Freedom infinite on the infinite on	e No
Checked and Approved By:	Checked and Approved By:	Checked and Approved By:	Checked and Approved By:			SDM for sensitivity calulation using 4 points		nbo-electric effect	ranseverse error for a transverse sensitivity of 1%	17HD = 1/4(d/100) <sup>2</sup> ; Maximum allowed by ISO 16063					onditiong amplifier uncertainty	درور المرابع onditiong amplifier uncertainty	anufacturer's specification worse case on 1 V range =t01 <sub>mp</sub> 3² /onditiong amplifier uncertainty	Incertainty quoted on certificate fanufacturer's specification worse case on 1 V range ={t/fr <sub>ep</sub> y <sup>2</sup> -onditiong amplifier uncertainty	SO 1606S-11 requirement: s 0,05 % of reading Incertainty quoted on certificate lanufacturer's specification worse case on 1 V range ={(th <sub>reb</sub> ) <sup>2</sup> conditiong amplifier uncertainty	ti aware of any so 15063-11 requirement: s 0,05 % of reading Incertainly quoted on certificate lanufacturer's specification worse case on 1 V range =(th <sub>np</sub> ) <sup>2</sup> onditiong amplifier uncertainty	omected for using Heydemann correction procedure of aware of any 50 16063-11 requirement: s10.05 % of reading Incertainty quoted on certificate lanufacturer's specification worse case on 1 V range =(01 <sub>40</sub> ) <sup>2</sup> onditiong amplifier uncertainty	Internation between service spot, eather and accelerometer: corrected for using Haydemann correction procedure for aware of any 1016083-11 requirement: \$ 0,05 % of reading noertainly quoted on certificate fanufacturer's specification worse case on 1 V range =(th <sub>tb</sub> ) <sup>2</sup> -onditiong amplifier uncertainty	testi noromater riske in wardet by the testion motion between sensing sock either and acceleratories isster motion between sensing sock either and acceleratories corrected for using Heydemann correction procedure to aware of any to 16083-11 requirement: \$ 0,05 % of reading incertainty quoted on certificate famufacturer's specification worse case on 1 V range =(M <sub>R0</sub> ) <sup>2</sup> /onditiong amplifier uncertainty	rande white weak and a devices ~ 50° result with high mark condition ~ 50° taken mounder description right. Wrate care + 10/W1000 laiden motio between sent and a conferentiat. Corrected for using Heydemann correction procedure to taken of any 50 16063-11 requirement: \$ 0,05 % of reading incertainty quoted on certificate famulacturer's specification worse case on 1 V range =(1/fm) <sup>2</sup> conditiong amplifier uncertainty	s debt, volge anslade beviation, <- 90' menual with high and provide the VA. Balan mounder of sensing services organ know organ know and the most beware service organ know organ know corrected for using Haydemann correction procedure to aware of any SO 16063-11 requirement: \$ 0,05 % of reading Incertainty quoted on certificate famulacturer's specification worse case on 1 V range ={(fm,b) <sup>2</sup> conditiong amplifier uncertainty	Remarks a diverse values and the developed of the develop	Remarks a detx, valups anytikde deviders, o- 60' strain anounder of service providers table modion between service go down cycle. Vroes use in 1924/0000 table modion between service go downeed interaction advantant for using Haydemann correction procedure for aware of any SO 15063-111 requirement: 5 0,05 % of reading Incertainty quoted on certificate for undertuner's specification worse case on 1 V range =(ff <sub>rep</sub> ) <sup>2</sup> -e(ff <sub>rep</sub> ) <sup>2</sup>	Remarks states voltage anytikate devalues, <> 80' mended with hypomet provides taken monote of devalues are voltage of the taken of taken of the taken of the taken of taken of the taken of taken o	Ian Veldman Remarks s offers, virbuge writikule dividiers, ~> 50' removed with high-format procedure tester motion before restring good without p is the tester motion before restring good without and accollementer roter care calculateder for using Haydemann correction procedure for aware of any 50 16063-111 requirement: \$0,05 % of reading Incertainty quoted on certificate Incertainty quoted on certificate Incertainty quoted on certificate Incertainty guoted on certificate (ffr <sub>eb</sub> ) <sup>2</sup> =(ffr <sub>eb</sub> ) <sup>2</sup>	Metrologist Ian Veldman Ian Veldman semarks semarks settin volume methode feeldings of the second se	Metrologist     Ian Veldman     Ian Veldman     Safets, stage weaker building ~ 50' mende we highward ponder model weaker grade to the stage	AVIVS-0001  Metrologist  Ian Veldman  and veldman  semarks  Remarks  remover sensor solar order or 100/1000 remover solar order or 100/1000 remover solar order

#### APMP.AUV.V-K3.1

		Unc		Best	About UBM	Û RES	ÛRES	ů,	ů <sub>o</sub>		Ф <sub>сл</sub>	φ <sub>u,F</sub>	φ <sub>a,V</sub>	Δ	<b>₽</b> s,RE	<b>φ</b> <sub>s</sub> ,ρ <sub>0</sub>	Øs.up	<b>₽</b> s,vD	φ <sub>a</sub> Q	u		Symbol			Description:			
	contribution)	ertainty of Measurement (Including UUT	contribution)	Measurement Capability (Excluding UUT		Standard deviation on accelerometer phase shift measureme	Residual effects on accelerometer output voltage measurem	Effect of transverse motion on accelerometer output phase m	Effect of voltage disturbance on accelerometer output phase	▼ Unit Under Test / Calib	Charge amplifier phase accuracy	Filtering effect on accelerometer output phase measurement	Accelerometer output phase measurement (ADC resolution/a	Environmental effects on phase shift measurement	Residual interferometric effects on displacement phase meas	Effect of phase disturbance on displacement phase measure	Effect of motion disturbance on displacement phase measure	Effect of voltage disturbance on displacement phase measur	Interferometer output signal disturbance on displacement pha	▼ Standards and Reference		Input Q (Source of U	Mathematical Mod		Complex Sensitivity Calibration (Pha			
	Expanded Uncertainty	Combined Uncertainty (Normal)	Expanded Uncertainty	Combined Uncertainty (Normal)	TOTAL COMBI	ont	ent	neasurement	measurement	ration (Uncorrelated) ▼			accuracy)		surement	ment	ement	ement	ase measurement	Equipment (Uncorrelated)		uantity Incertainty)	lel:	and and has included in the second	se) as per ISO 16063-11 method	Reference: Guide to the E		
1 21/22	k = 2	▼Confidence Level▼	95,45 %	▼Confidence Level▼	INED UNCERTAINTY																				ω	opression of Uncertainty in Meas		T MATENY /III
	0,2	0,10	0,2	0,09		0,050	0,005	0,012	0,012		0,035	0,029	0,025	0,017	0,012	0,040	0,029	0,029	0,035	C	0,1 Hz to 100 Hz			Serial number:	Make & model:	urement, issued by B	, and	BM
	0,3	0,13	0,20	0,10		0,090	0,010	0,017	0,023		0,040	0,029	0,025	0,017	0,012	0,040	0,029	0,040	0,046	(")	> 100 Hz to 1 kHz	Standard				IPM, IEC, IFCC, ISC		
	0,5	0,24	0,4	0,22		0,100	0,025	0,029	0,069		0,050	0,087	0,100	0,029	0,046	0,115	0,058	0,058	0,075	(")	> 1 kHz < 5 kHz	Uncertainty		_	Brüel End	D, IUPAC, IUPAP,		
	0,8	0,39	0,7	0,36		0,150	0,025	0,058	0,144		0,127	0,231	0,150	0,058	0,058	0,087	0,069	0,069	0,115	(")	5 kHz to 12 kHz	Contributio	S <sub>phase</sub> = L	23	& Kjær evco	OML - ISO 1995		
	1,2	0,60	1,1	0,54		0,250	0,025	0,058	0,231		0,127	0,289	0,200	0,115	0,173	0,144	0,115	0,144	0,231	(")	> 12 kHz to 15 kHz	n Ui(y)	JUT Phase		Rance:	5 (ISBN 92-67-10		
	1,6	0,80	1,15	0,58		0,550	0,058	0,058	0,289		0,127	0,289	0,175	0,087	0,173	0,173	0,231	0,202	0,202	(")	> 15 kHz to 20 kHz		- Ref <sub>Phase</sub>			188-9)		
	k =	Veff	k =	Veff		100	100	100	100		100	100	100	100	100	100	100	100	100	%		Reliability	- Ref <sub>Delay</sub>	011110000	n 1 Hz to 20		Proce	Certif
	2,00	infinite	2,00	infinite		infinite	infinite	infinite	infinite		infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite	~	infinite	Degrees of Freedom	- AtoD <sub>Ph</sub>		kH7		dure No	cate No
				Checked and Approved By:		ESDM for sensitivity calulation using 5 cycles minimum	Tribo-electric effect	Transeverse error for a transverse sensitivity of 1%	U <sub>THD</sub> = ½(d/100)2; Maximum allowed by ISO 16063		Certified value	e=(t/fHp)2	SAM phase calculation accuracy	ISO 16063-11 requirement: < 0,05 % of reading	Not aware of any	Corrected for using Heydemann correction procedure	Relative motion between sensing spot, exiter and accelerometer. Worse case calculated for 16mm double ended accelerometer.	Additive uncorrelated noise is reduced by 1/√n. Where n=number of samples pes vibration cycle. Worse case =10%/1000	e.g. offsets, vollage amplitude deviations, <> 90° Corrected with Heydemant procedure		Remarks		se - DSP <sub>Delay</sub>	lan Veldman	Metrologist		AV/VS-0001	AV/VS-3709

# VI. CSIR-NPLI

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# Magnitude sensitivity

		D. Voltage Sensitivity uncer	rtainty budg	et - CSIR-N	PLI		
i	Standard Uncertainty contribution u(xi)	ISO -SAM- Ure(S)	Uncertainty contribution ui(y)	0.1 Hz ≤ f < 0.5 Hz	0.5 Hz ≤ f < 20 Hz	20 Hz ≤ f < 31.5 Hz	$31.5 \mathrm{Hz} \leq f \\ < 40 \mathrm{Hz}$
1	u(û <sub>v</sub> )	accel erometer output voltage measurement(waveform recorder; e.g. ADC-resolution)	u(S)	0.139	0.115	0.115	0.115
2	u(û;)	voltage filtering effect on accelerometer output amplitude measurement(frequency band limitation)	ų(S)	0.115	0.115	0.115	0.115
3	<b>u</b> (û <sub>0</sub> )	effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise)	u <sub>i</sub> (S)	0.115	0.115	0.115	0.115
4	<b>u</b> (û <sub>i</sub> )	effect of transverse, rocking, and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	ų(S)	0.115	0.06	0.06	0.09
5	<b>υ(φ</b> <sub>M.Q</sub> )	effect of interferometer quadrature output signal disturbance on phase amplitude measurement(e.g offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	ų(S)	0.115	0.06	0.09	0.09
6	<b>u</b> (φ <sub>M.F</sub> )	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	u(S)	0.115	0.06	0.06	0.09
7	<b>u</b> ( $\phi_{M,VD}$ )	effect of voltage disturbance on phase amplitude measurement(e.g. random noise in the photoelectric measuring chains)	u(S)	0.115	0.06	0.09	0.115
8	<b>u</b> (φ <sub>M,MD</sub> )	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)	<b>u</b> (S)	0.1731	0.11	0.11	0.115
9	$\mathbf{u}(\mathbf{\phi}_{MPD})$	effect of phase disturbance on phase amplitude measurement(e.g. phase noise of the interferometer signals)	u(S)	0.115	0.11	0.11	0.115
10	$\mathbf{u}(\mathbf{\phi}_{MRE})$	residual interferometric effects on phase amplitude measurement(interferometer function)	u <sub>10</sub> (S)	0.115	0.115	0.115	0.115
11	$\mathbf{u}(\mathbf{f}_{FG})$	vibration frequency measurement (frequency generator and indicator)	u <sub>1</sub> (S)	0.001	0.001	0.001	0.001
12	u(S <sub>RE</sub> )	residual effects on sensitivitymeasurement(e.g. random effect in repeat measurements; experimental standard devitation of arithmetic mean)	u <sub>2</sub> (S)	0.289	0.173	0.242	0.289
		Combined Uncertainty (in %)		0.50	0.35	0.40	0.45
		E xpanded Uncertainty (k=2) in %		1.00	0.70	0.80	0.90

		E. Phasee Sensitivity uncer	tainty budge	et - CSIR-NI	PLI		
i	Standard Uncertainty contribution u(xi)	ISO -SAM - U(Δφ)	Uncertainty contribution ui(y)	0.1 Hz ≤ f < 0.5 Hz	0.5 Hz ≤ f < 20 Hz	20 Hz ≤ f < 31.5 Hz	31.5 Hz ≤ f < 40 Hz
1	$u(\phi_{u,v})$	accelerometer output phase measurement(waveform recorder; e.g. ADC-resolution)	$u_l(\Delta \phi)$	0.173	0.144	0.144	0.144
2	u(φ <sub>uF</sub> )	voltage filtering effect on accelerom eter output phase measurem ent(frequency band limitation)	u <u>γ</u> (Δφ)	0.173	0.11	0.133	0.133
3	u(q <sub>u,D</sub> )	effect of voltage disturbance on accelerometer output phase measurement (e.g. hum and noise)	u <sub>3</sub> (Δφ)	0.173	0.11	0.115	0.115
4	$u(\phi_{u,T})$	effect of transverse, rocking, and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	<b>u</b> <sub>4</sub> (Δφ)	0.173	0.11	0.115	0.115
5	u(φ <sub>s,Q</sub> )	effect of interferometer quadrature output signal disturbance on displacement phase measurement(e.g. offsets, voltage amplitude deviation, deviation from 90 <sup>0</sup> nominal angle difference)	ц(Δφ)	0.029	0.029	0.029	0.029
6	$u\!\left(\phi_{g,\overline{p}}\right)$	interferometer signal filtering effect on displacement phase amplitude measurement (frequency band limitation)	υ <sub>σ</sub> (Δφ)	0.029	0.029	0.029	0.029
7	$u(\phi_{s,VD})$	effect of voltage disturbance on displacement phase amplitude measurement(e.g. random noise in the photoelectric measuring chains)	u <sub>7</sub> (Δφ)	0.029	0.029	0.029	0.029
8	$\textbf{u}(\phi_{s,MD})$	effect of motion disturbance on displacement phase amplitude measurement(e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	$u_{g}(\Delta \phi)$	0.029	0.029	0.029	0.029
9	$u(\phi_{s,PD})$	effect of phase disturbance on displacement phase amplitude measurement(e.g. phase noise of the interferometer signals)	$u_{g}(\Delta \phi)$	0.115	0.11	0.115	0.115
10	$u(\phi_{s,RE})$	residual interferometric effects on displacement phase amplitude measurement(interferometer function)	$u_{10}(\Delta \phi)$	0.173	0.144	0.144	0.173
11	$u\!\left(\!\Delta\phi_{R\!E}\!\right)$	residual effects on phase shift measurement(e.g. random effect in repeat measurements; experimental standard devitation of arithmetic mean)	$u_{11}^{}(\Delta\phi)$	0.289	0.173	0.242	0.289
		Combined Uncertainty (in °)		0.50	0.35	0.40	0.45
		Expanded Uncertainty (k=2) in °		1.00	0.70	0.80	0.90