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EUROMET Projects 473 and 612: Comparison of the measurement of current transformers (CTs)

EUROMET.EM-S11 Final report

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Department for Innovation, Universities & Skills

EUROMET Projects 473 and 612:
Comparison of the measurement of current transformers (CTs)

Stuart Harmon and Lesley Henderson
Industry and Innovation Division

ABSTRACT

The Euromet comparison titled "Comparison of the measurement of current transformers" was carried out over two projects with NPL as pilot laboratory and thirteen other participating European National Measurement Institutes (NMI). Current transformer measurements made by the participating NMIs support a large number of measurements made in the electrical generation, supply and distribution industries in their own countries. They also support many transformer manufacturers who rely on national standards as a source of traceability.

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Authorised by Director, Industry and Innovation Division

TABLE OF CONTENTS

Introduction

The Euromet comparison titled “Comparison of the measurement of current transformers” was carried out over two projects with NPL as pilot laboratory. Project 473 started in April 1999, with ten other participating European National Measurement Institutes (NMI) and project 612 started in January 2001 with a further three European NMIs.

Current transformer measurements made by the participating NMIs support a large number of measurements made in the electrical generation, supply and distribution industries in their own countries. They also support many transformer manufacturers who rely on national standards as a source of traceability. The current (ratio) errors and phase displacement of each ratio of the uncompensated current transformer transfer standard were determined at a defined frequency, burden and power factor, using each participant’s standard measuring method and equipment.

Participants

Pilot laboratory:
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Project 473 participants and affiliation in order of transfer standard circulation:

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G Crotti, IEN, Istituto Elettrotecnico Nazionale "Galileo Farraris", Turin, Italy
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Project 612 Participants and affiliation in order of transfer standard circulation:

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Affiliation at time of publishing: LNE, Laboratoire national de métrologie et d'essais

H Çayci, UME, Ulusal Metroloji Enstitüsü, Gebze-Kocaeli, Turkey

Transfer standard

Manufacturer:	Smith Hobson Ltd, United Kingdom
Serial number:	J802857
Transformation ratios:	1000, 500, 200, 100, 50, 20, 10, 5, 1 / 5 A
Class and rating:	Class 0.01 at 5 VA, 50 Hz

Measurements

Each participating laboratory was asked to make measurements under their normal laboratory conditions using the following guidelines:

Transformation ratios:	All
Burden:	5 VA, cos $\beta = 1$
Test frequency;	50 or 60 Hz
Temperature:	20 or 23 ± 1 °C
Rated current:	120, 100, 50, 20, 10, 5 & 2% (1% optional)

Symbols and definitions

The symbols and definitions stated are in accordance with IEC 60044-1:2002 [1].

ε_X Current (ratio) error: The error which a transformer introduces into the measurement of a current and which arises from the fact that the actual transformation ratio is not equal to the rated transformation ratio. The current error expressed in ppm is given by the formula:

$$\varepsilon_X \text{ (ppm)} = 10^6 \times (K_n I_s - I_p) / I_p$$

K_n Rated transformation ratio.

I_p Actual primary current.

I_s Actual secondary current when I_p is flowing under the conditions of measurement.

Z_B Burden: The impedance of the secondary circuit in ohms and power factor. The burden is expressed as the apparent power in volt-amperes absorbed at a specified power factor and at the rated secondary current.

cos β Power factor for sinusoidal waveforms.

I/I_n Excitation current, expressed in percent of rated current.

δ_X Phase displacement: The difference in phase, expressed in µrad, between the primary and secondary current vectors, the direction of the vectors being so chosen that the angle is zero for a perfect transformer. The phase displacement is said to be positive when the secondary current vector leads the primary current vector.

ε_{ref} ε_X comparison reference values.

δ_{ref} δ_X comparison reference values.

χ_ε ε_X deviation from comparison reference values $\varepsilon_{ref.}$

χ_δ δ_X deviation from comparison reference values δ_{ref}.

U The expanded uncertainty of measurement supplied by each participant, stated as the standard uncertainty multiplied by a coverage factor *k*.

Measurement conditions and methods

From each participant's report, each laboratory's measuring conditions and method of calibration are summarised in the following table. Uncertainty values given in the table are those quoted in the participant's report.

Table 1: Measurement conditions

Laboratory	Date measured Note 1	Method Note 3	Temperature °C	Burden VA	Burden Cos β	Frequency Hz
NPL	Note 2	1	20 ± 1	5 ± 2%	1	50 & 60
SP	6/99	1	22 ± 1	5 ± 5%	-	50 ± 0.1
LBE	8/99	1	23 ± 1.5	5	1	50
PTB	9/99	1	23 ± 1	4.9	1	50 & 60
GUM	10/99	1	24	5 ± 3%	1	49.8 ± 0.1
OMH	11/99	1	23 ± 2	5 ± 1%	1	50
IEN	1/00	1	19-21	4.99 ± 0.03	1.00 ± 0.02	50
METAS	2/00	1	23 ± 1	5 ± 1%	1	50.5
BEV	4/00	1	18 ± 1	5 ± 1%	1	50
HUT	4/00	2	22 ± 1	5.2 ± 3%	1	55
MIKES	5/00	2	22.3 ± 1	≈ 6.25	-	49.4-53.8
CMI	2/01	1	23 ± 0.5	5 ± 0.5%	1	50
VMT/VMC	2/01	1	20.2 ± 0.1	5 ± 0.04	1	50
BNM-LCIE	4/01	1	20.0 ± 1	5	1	50
UME	12/01	1	23 ± 1	5	1	50

Note 1: The 'Date measured' is the month in which the last measurements were carried out.

Note 2: Measurements were made by NPL six times during both comparisons. Measurements were made at the start of project 473 in April 1999, two more sets were made during circulation in August 1999 and February 2000, and a final set at the end of the project in August 2000. Measurements were made at the start of project 612 in January 2001 and at the end of the project in May 2002.

Note 3: Two distinct 'Methods' were used by the participants to calculate the current error and phase displacement of each transfer standard ratio. Descriptions of each method are given in Appendix 2.

Method 1: Comparison against compensated current comparators and/or standard current transformers with errors measured on homemade or commercial test sets.

Method 2: Calibrated using Rogowski coil and/or current shunts with outputs measured using digital multimeters.

Traceability

Each participant supplied a statement of traceability to the SI. The following table shows if traceability is to their own national standards or if their traceability is to another national laboratory.

Table 2: Traceability

Laboratory	Traceable to own National Standards	Traceable to other National Standards
NPL	✓	
SP	✓	
LBE		PTB
PTB	✓	
GUM		PTB
OMH	✓	PTB
IEN	✓	
METAS	✓	
BEV		PTB
HUT	✓	
MIKES	✓	
CMI	✓	
VMT/VMC		PTB
BNM-LCIE	✓	
UME	✓	

Transfer standard behaviour

NPL measured the transfer standard six times during both projects, at the start and end of both projects and twice during circulation of project 473, so that any change of the transfer standard would be detected. The standard deviation of these measurements shows that there was no significant change throughout the period of the comparison.

Figure 1 shows the current error deviation from the reference value for the measurements made by NPL for ratio 50 / 5 at I/I_n = 100%, at a burden of 5 VA, unity power factor, at a frequency of 50 Hz and at an ambient temperature of 20 °C. Typically the standard deviation of the mean of all NPL's measurements can be shown to be less than 1 ppm.

Figure 1: Ratio 50 / 5, I/I_n = 100%, Transfer standard behaviour

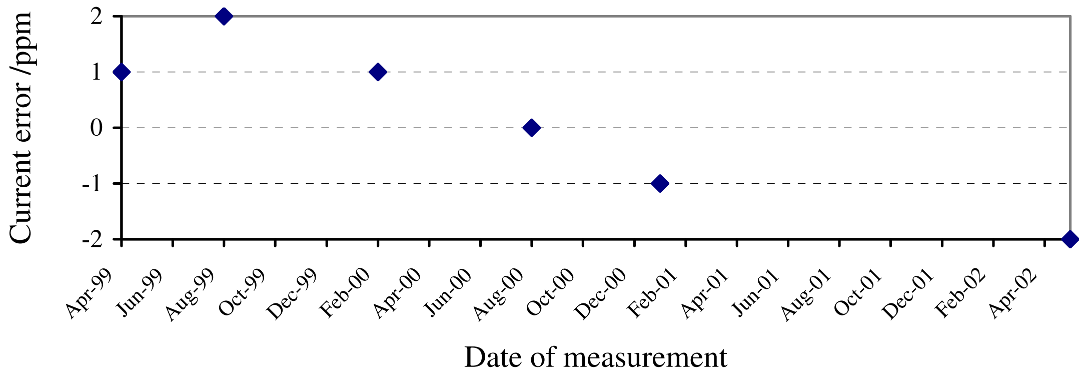
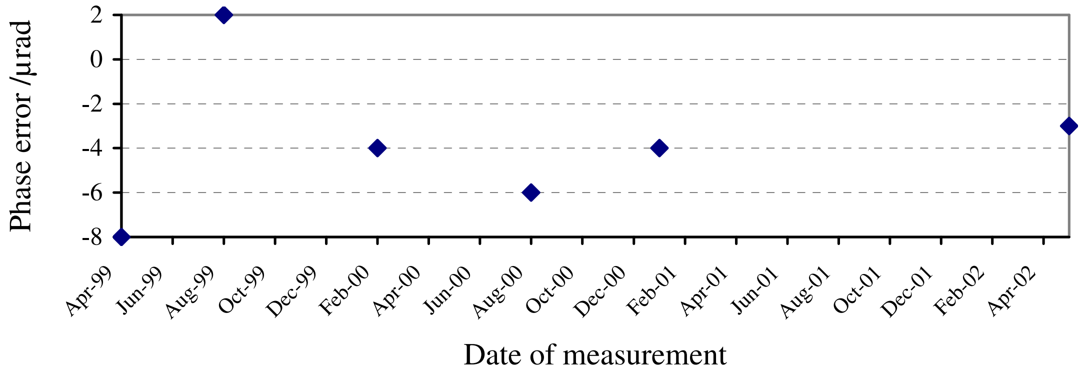


Figure 2 shows the phase displacement as a deviation from the reference value for the measurements made by NPL for ratio 50 / 5 at I/I_n = 100%, at a burden of 5 VA, unity power factor, at a frequency of 50 Hz and at an ambient temperature of 20 ˚C. Typically the standard deviation of the mean for NPL's phase displacement measurements can be shown to be less than 3 μrad.

Figure 2: Ratio 50 / 5, I/I_n = 100%, Transfer standard behaviour



Sample uncertainty budget

Table 3 shows a typical uncertainty budget used by NPL in the calculation of its uncertainty values. The uncertainty budget given shows the contributions associated with the measurements made on ratio 5 / 5 at I/I_n = 100%, at a burden of 5 VA, unity power factor, at a frequency of 50 Hz and at an ambient temperature of 20 ˚C. The uncertainty budgets supplied by each of the participants contained all or most of the principle contributions listed below and are given in Appendix 5.

Table 3: Sample uncertainty budget

Current error uncertainty, ratio 5 / 5, I/I_n = 120-2%							
Source of uncertainty	Value (±) ppm	Type	Prob.Dist.	Divisor	C_i	$u_i(y)$ (±) ppm	υ_i or υ_{eff}
Calibration of bridge and comparator	2	B	normal	2	1	1.000	∞
Error in the bridge	1	B	rectangular	1.7321	1	0.577	∞
Error due to frequency setting	1	B	rectangular	1.7321	1	0.577	∞
Resolution of test set	0.5	B	rectangular	1.7321	1	0.289	∞
Error due to burden setting	2.1	B	rectangular	1.7321	1	1.212	∞
Circuit configuration	2	B	normal	2	1	1.000	∞
Error due to current setting	1	B	rectangular	1.7321	1	0.577	∞
Repeatability	0.67	A	normal	1	1	0.650	5
Combined uncertainty						2.237	621
Expanded uncertainty			k=2			4.473	

The contributions for the 'Calibration of the bridge and comparator' and 'Error in the bridge' take into account any error of the test set and standard comparator used in calibration of the transfer standard.

The contribution for the error due to the burden setting takes into account the fact that the actual burden was either too high or too low. The change in ε_X and δ_X for a change in VA was calculated and then a contribution included in the budget.

The contribution for the error due to the setting of the test frequency takes into account any deviation from the stated measurement frequency.

The contribution for the error due to the current setting covers any inaccuracy in the setting of the applied current, I/I_n.

The value for repeatability is the standard deviation of the mean for each individual set of measurements.

The transfer standard was measured at 50 Hz and 60 Hz by NPL and PTB. The average change between the two frequencies measured by both laboratories is less than 5 ppm for current error and 5 µrad for phase displacement.

The influence of temperature on the measured values is not included in the uncertainty budget. The transfer device was measured by NPL at both 20 ºC and 23 ºC. The average difference between 20 ºC and 23 ºC for all ratios at all current levels is less than 2 ppm for current error and 5 µrad for phase displacement.

The degrees of freedom (υ_i) for all type B contributions are assumed to be infinite [2]. The effective degrees of freedom (υ_{eff}) for all type A contributions are estimated using the Welch-Satterwaite formula [2] based on the degrees of freedom of the individual uncertainty contributions u_i(y) to obtain a coverage factor k. The Welch-Satterwaite formula is:

$$v_{eff} = \frac{u^4(y)}{\sum_{i-1}^{N} \frac{u_i^4(y)}{v_i}}$$

For all measurements made by NPL, the reported expanded uncertainties are based on a standard uncertainty multiplied by a coverage factor of k = 2, which for a normal distribution provides a level of confidence of approximately 95%.

All participants included a similar statement, quoting a coverage factor of $k = 2$, except for IEN's phase displacement results which were quoted at $k = 2.2$ and METAS whose quoted coverage factor was $k \geq 2$.

Comparison reference value

The comparison reference values have been calculated using the weighted mean of each set of measurement results. The draft A report for project 473 used the median, described in NPL report CISE 42/99 [3], as the estimator of the reference value. This approach was used because it is less influenced by the presence of extreme values. After a participant from project 473 resubmitted results (with the consent of all participants) and with the inclusion of the results from project 612 there was no significant difference in the reference values obtained using either a weighted mean or the median. The difference in the comparison reference values calculated with and without the inclusion of results supplied from laboratories with traceability to other NMIs was generally within the reference value uncertainty. There were several exceptions however, with the most severe being the phase displacement reference value for ratio 1 / 5 at I/I_n = 120%, where the difference was 14 µrads. Therefore the comparison reference values have been calculated using only those laboratories whose results are not correlated to other National Measurement Institutes.

From [3], the comparison reference value ε_{ref}, calculated as the weighted mean of each set of measurements is given by:

$$\frac{\varepsilon_{ref}}{u_{ref}^2} = \sum_{j=1}^{N} \frac{\varepsilon_j}{u_j^2}$$

where ε_j is each participants individual result
u_j is each participants combined uncertainty for ε_j.

The standard deviation (standard uncertainty) u_{ref} of ε_{ref} is given by:

$$\frac{1}{u_{ref}^2} = \sum_{j=1}^{N} \frac{1}{u_j^2}$$

A 95% confidence level is given by:

$$\varepsilon_{ref} \pm k u_{ref}$$

where k is the coverage factor determined from the t_{95}-distribution table in [2].

For calculation of the phase displacement reference values substitute δ for ε.

Table 4 gives the comparison reference values, in ppm for current error and μrad for phase displacement, and associated uncertainties (at 95% confidence level) calculated from the above formulas. The results supplied from LBE, GUM, OMH, BEV and VMT/VMC were not used in the calculation of the comparison reference values as their results are correlated to another national institute. The results supplied by BNM-LCIE were not used in the calculation of the comparison reference values as they were received after the release of Draft A, see Appendix 3.

Table 4: Comparison reference values

I/I_n %	Ratio 1 / 5				Ratio 5 / 5				Ratio 10 / 5			
	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$
120	17	3	-85	4	13	2	-84	3	18	2	-81	4
100	15	3	-83	4	11	2	-86	3	17	2	-84	4
50	10	3	-90	4	6	2	-95	3	13	2	-93	4
20	6	3	-101	4	1	2	-104	3	9	2	-104	4
10	5	3	-107	4	-1	2	-110	3	7	2	-109	4
5	4	3	-111	4	-3	2	-114	3	6	2	-114	4
2	4	4	-116	6	-2	2	-117	4	5	3	-117	4
1	4	4	-117	6	-3	3	-120	4	5	3	-119	4

I/I_n %	Ratio 20 / 5				Ratio 50 / 5				Ratio 100 / 5			
	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$
120	7	2	-87	3	6	2	-86	3	3	2	-86	3
100	5	2	-90	3	4	2	-88	3	2	2	-89	3
50	0	2	-98	4	-2	2	-98	3	-3	2	-98	3
20	-5	2	-108	4	-9	2	-109	3	-9	2	-109	3
10	-8	2	-113	4	-13	2	-115	3	-12	2	-114	3
5	-9	2	-117	4	-15	2	-118	3	-13	2	-117	4
2	-10	3	-119	4	-15	3	-120	4	-13	3	-120	4
1	-11	3	-121	4	-16	3	-122	4	-14	3	-121	4

I/I_n %	Ratio 200 / 5				Ratio 500 / 5				Ratio 1000 / 5			
	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$	ε_{ref}	$U\varepsilon_{ref}$	δ_{ref}	$U\delta_{ref}$
120	19	2	-71	3	13	2	-76	4	22	3	-59	4
100	17	2	-74	3	11	2	-79	4	24	3	-62	4
50	9	2	-87	3	4	2	-91	4	25	2	-79	4
20	-1	2	-100	3	-3	2	-104	4	17	3	-96	4
10	-5	3	-108	3	-6	2	-111	4	11	3	-105	4
5	-10	3	-114	3	-10	2	-116	4	7	3	-112	5
2	-12	3	-117	4	-10	3	-119	4	2	5	-117	6
1	-13	3	-120	4	-11	3	-122	4	0	5	-122	6

Results

The results obtained from the comparison, are displayed in two ways. The first is a set of graphs showing the current error comparison results for all ratios at I/I_n = 100%. Selected graphs for lower current excitations and phase displacement are also shown. The graphs, Figures 3 to 17, show each participant's results as a deviation from the reference value and the uncertainty associated with each deviation. The uncertainty associated with each deviation from the reference value is calculated as the combination of each participant's individual expanded uncertainty and the expanded uncertainty of the reference value for that point. Also shown on each graph are the 95% confidence intervals for that set of results.

Following the graphs is a set of tables, Tables 5 to 22, displaying the results supplied by all participants, as deviations from the comparison reference values for both current error and phase displacement. The uncertainty associated with each deviation from the reference value is also given.

Figure 3: Ratio 1 / 5, I/I_n = 100%, current error comparison results

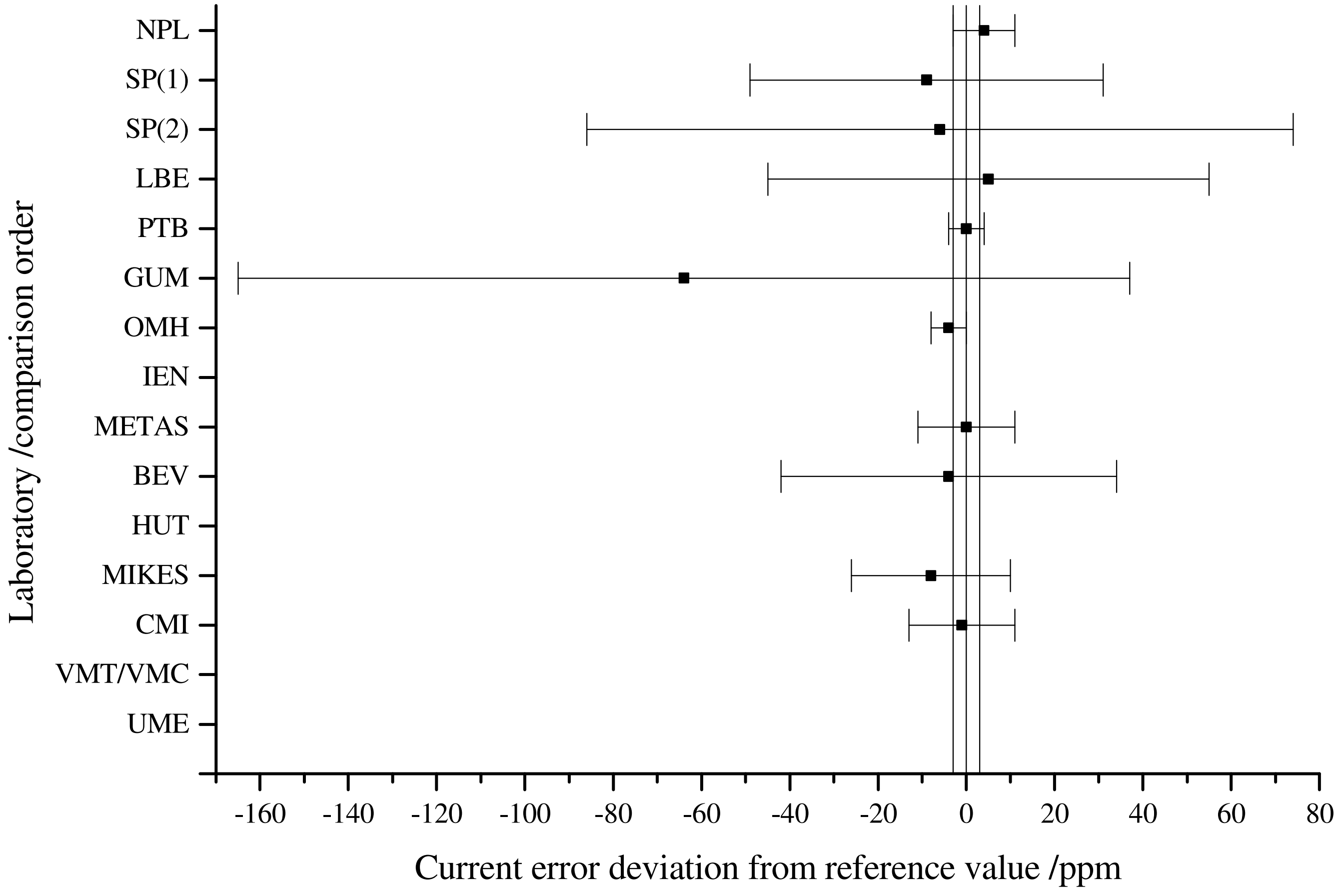


Figure 3 shows the current error comparison results for ratio 1 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 4: Ratio 5 / 5, I/I_n = 100%, current error comparison results

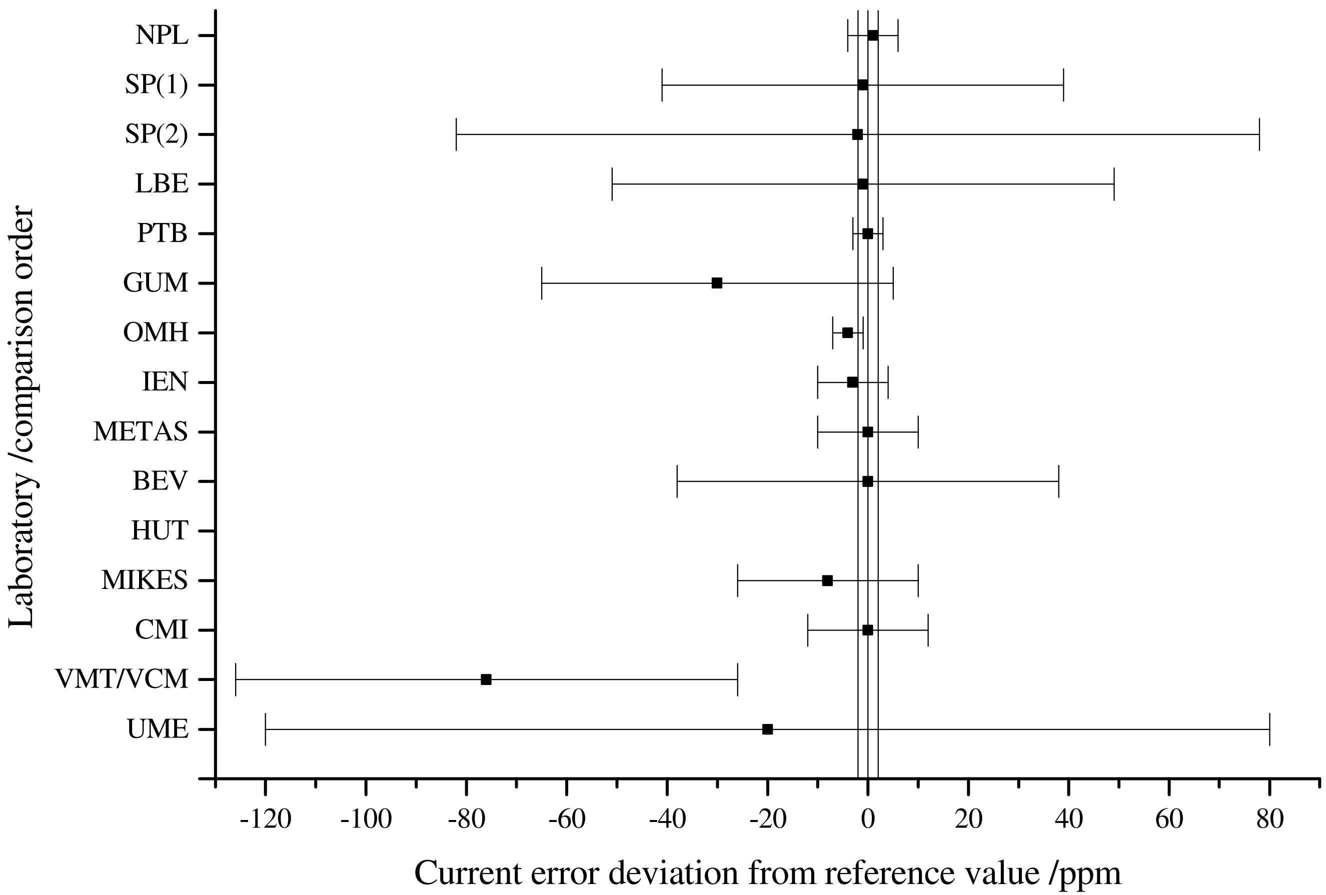


Figure 4 shows the current error comparison results for ratio 5 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 5: Ratio 5 / 5, I/I_n = 2%, current error comparison results

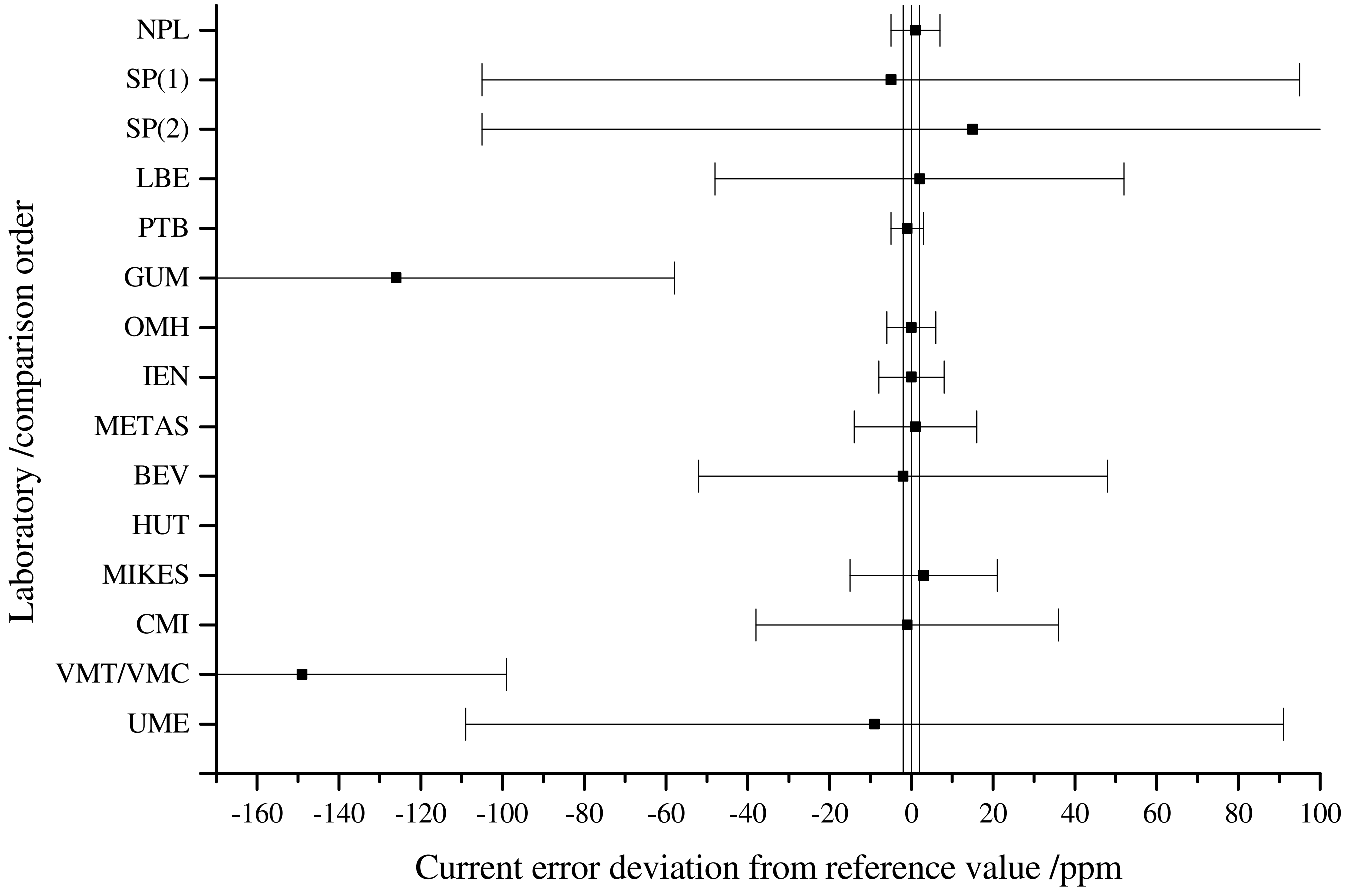


Figure 5 shows the current error comparison results for ratio 5 / 5, at I/I_n = 2%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 6: Ratio 5 / 5, I/I_n = 100%, phase displacement comparison results

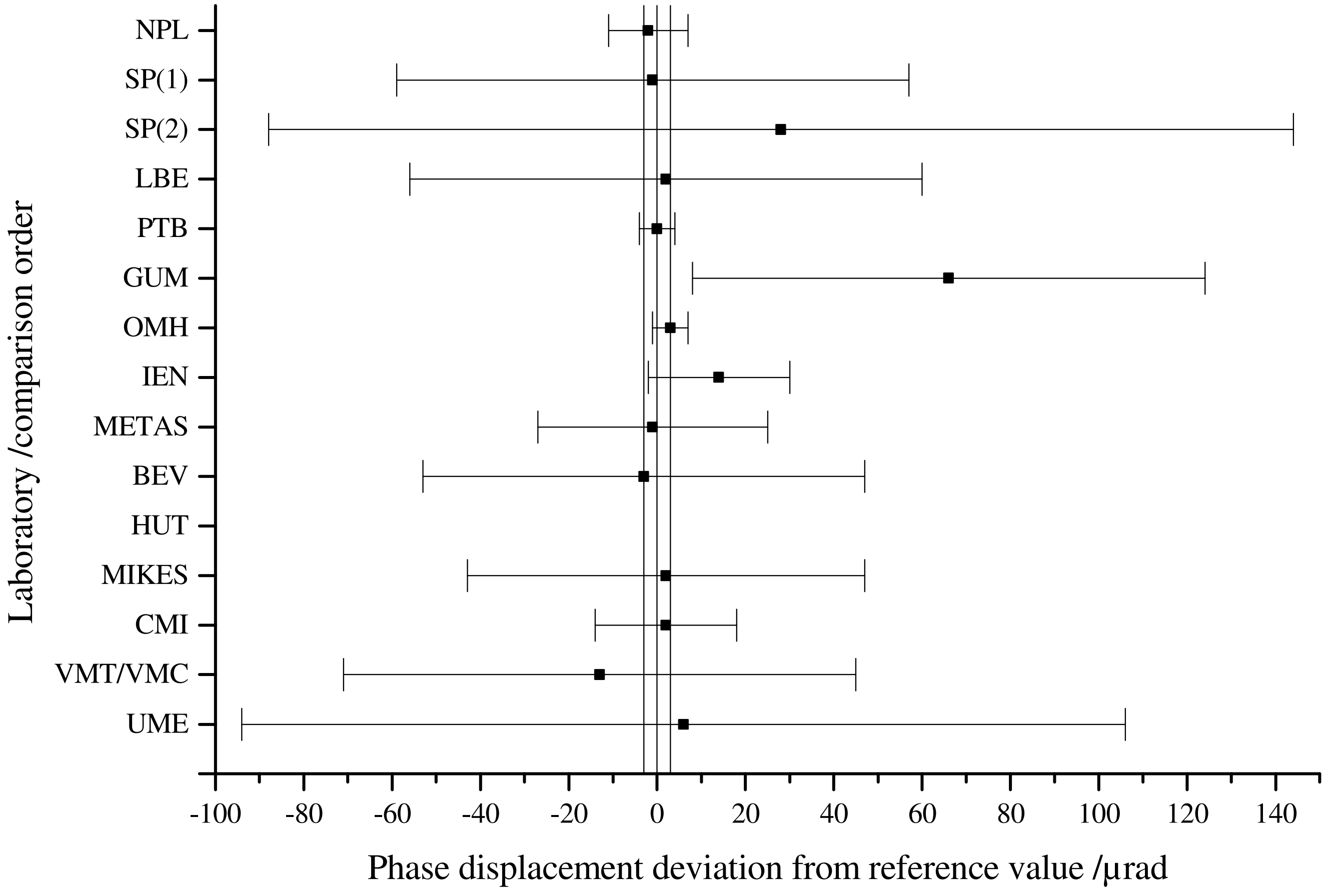


Figure 6 shows the phase displacement comparison results for ratio 5 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The δ_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 7: Ratio 5 / 5, I/I_n = 2%, phase displacement comparison results

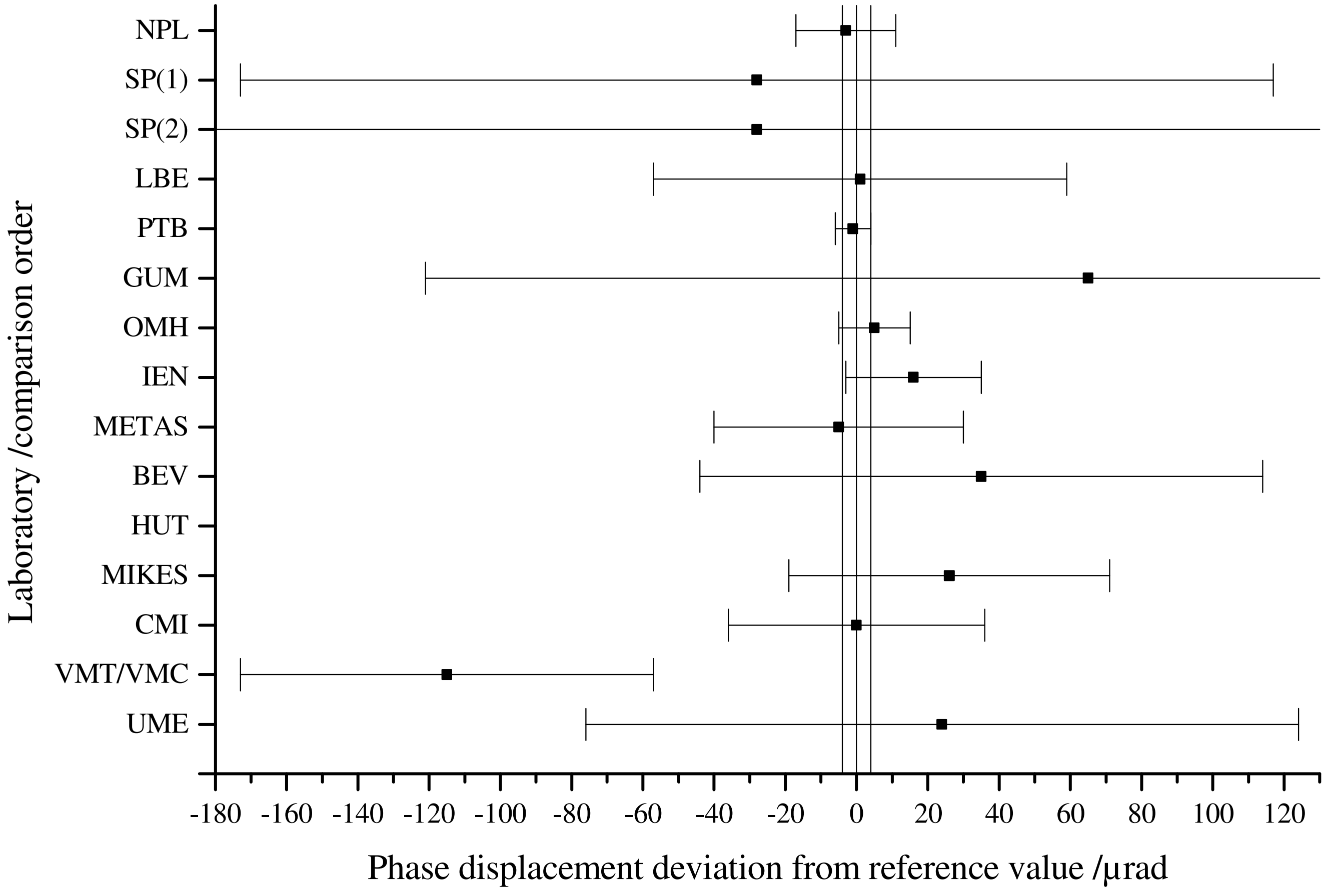


Figure 7 shows the phase displacement comparison results for ratio 5 / 5, at I/I_n = 2%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The δ_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 8: Ratio 10 / 5, I/I_n = 100%, current error comparison results

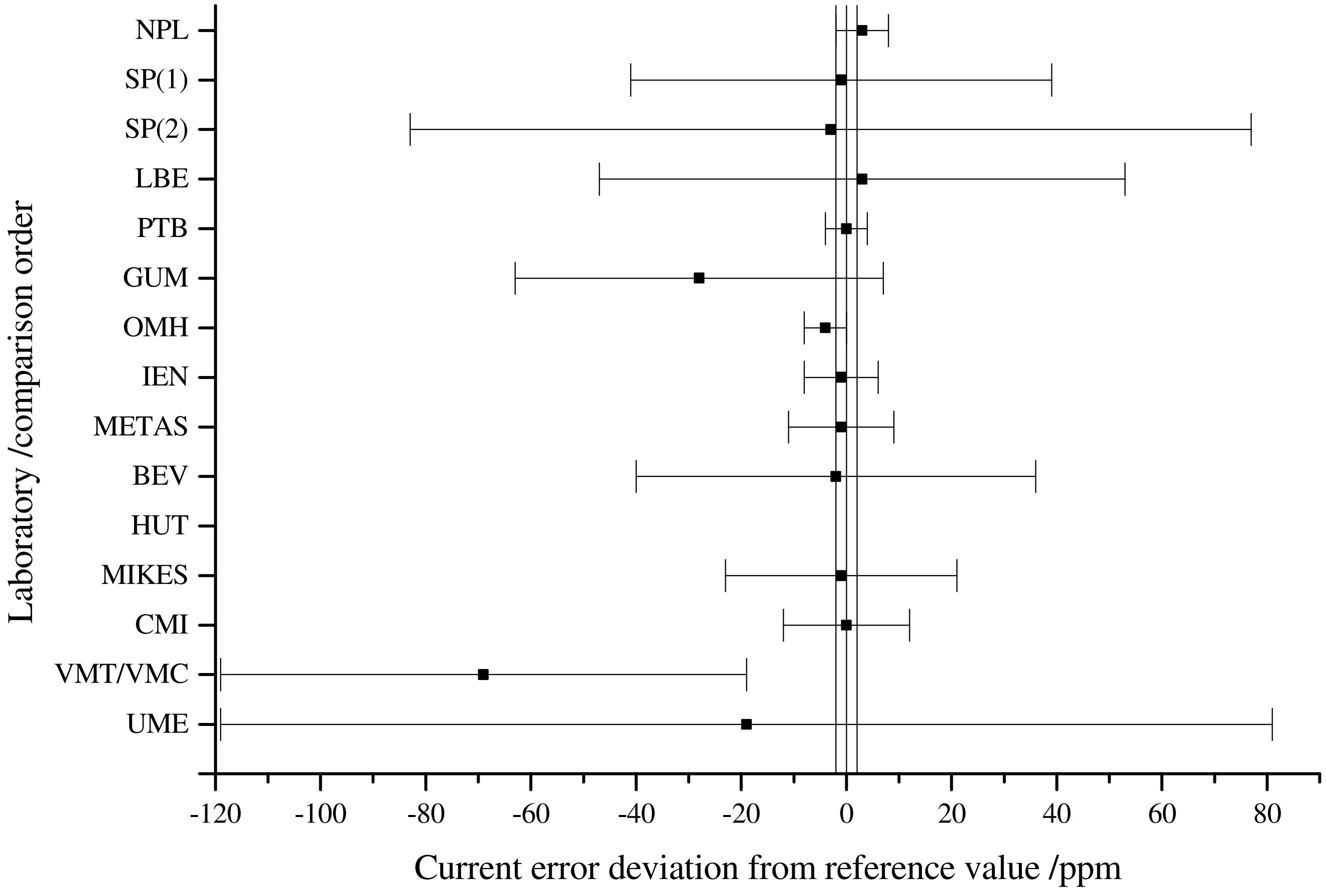


Figure 8 shows the current error comparison results for ratio 10 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 9: Ratio 20 / 5, I/I_n = 100%, current error comparison results

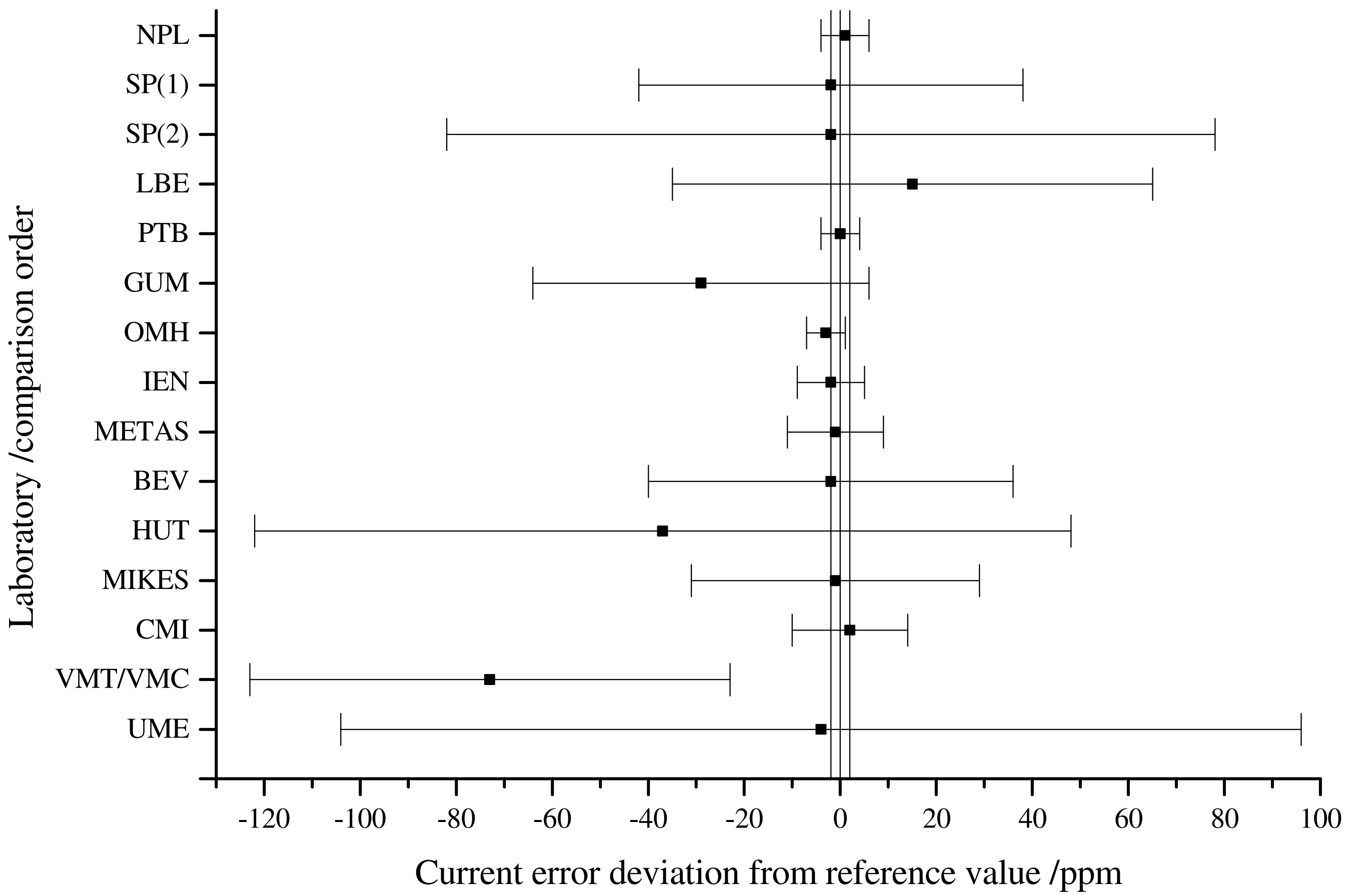


Figure 9 shows the current error comparison results for ratio 20 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 10: Ratio 50 / 5, I/I_n = 100%, current error comparison results

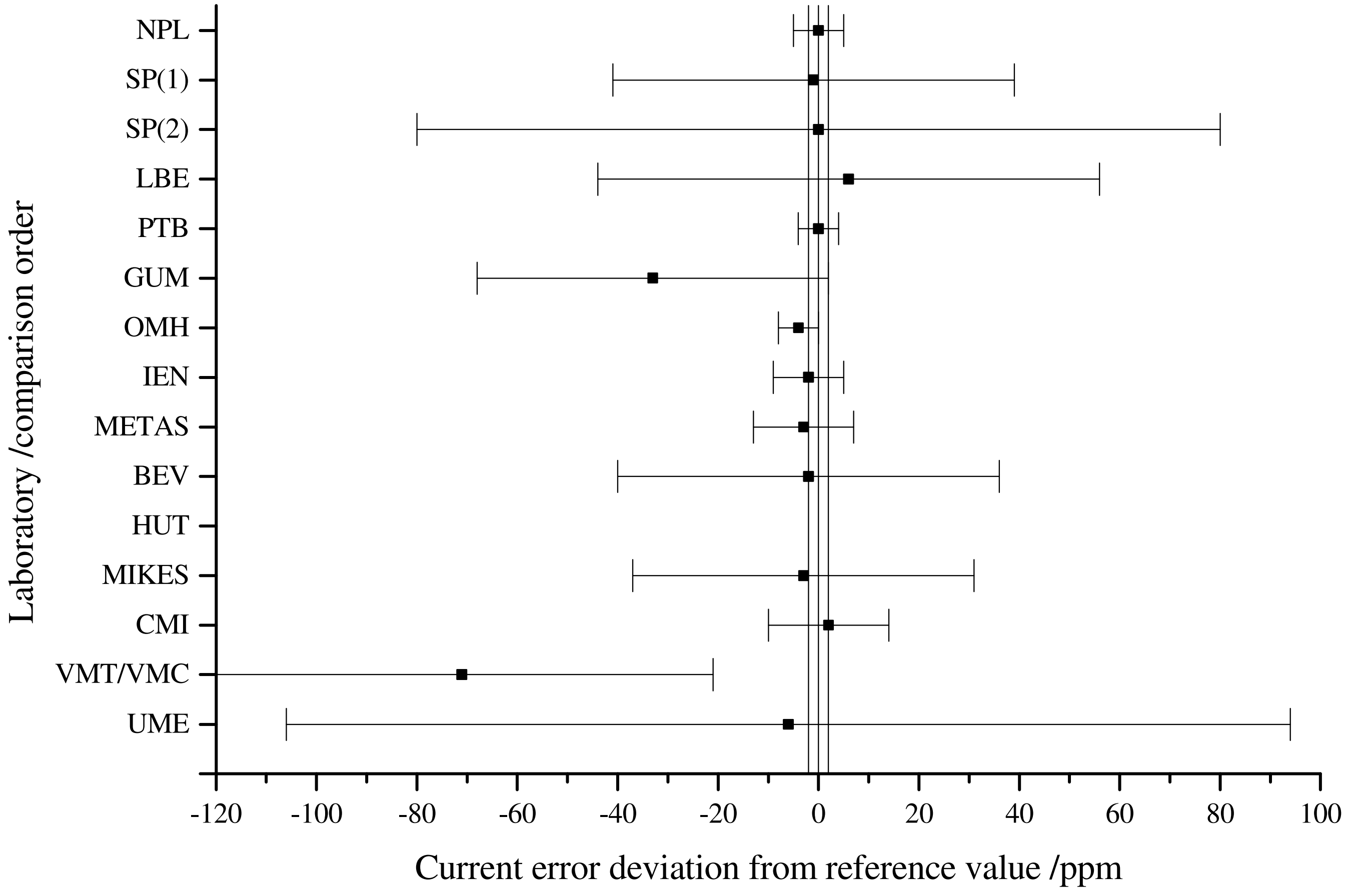


Figure 10 shows the current error comparison results for ratio 50 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 11: Ratio 100 / 5, I/I_n = 100%, current error comparison results

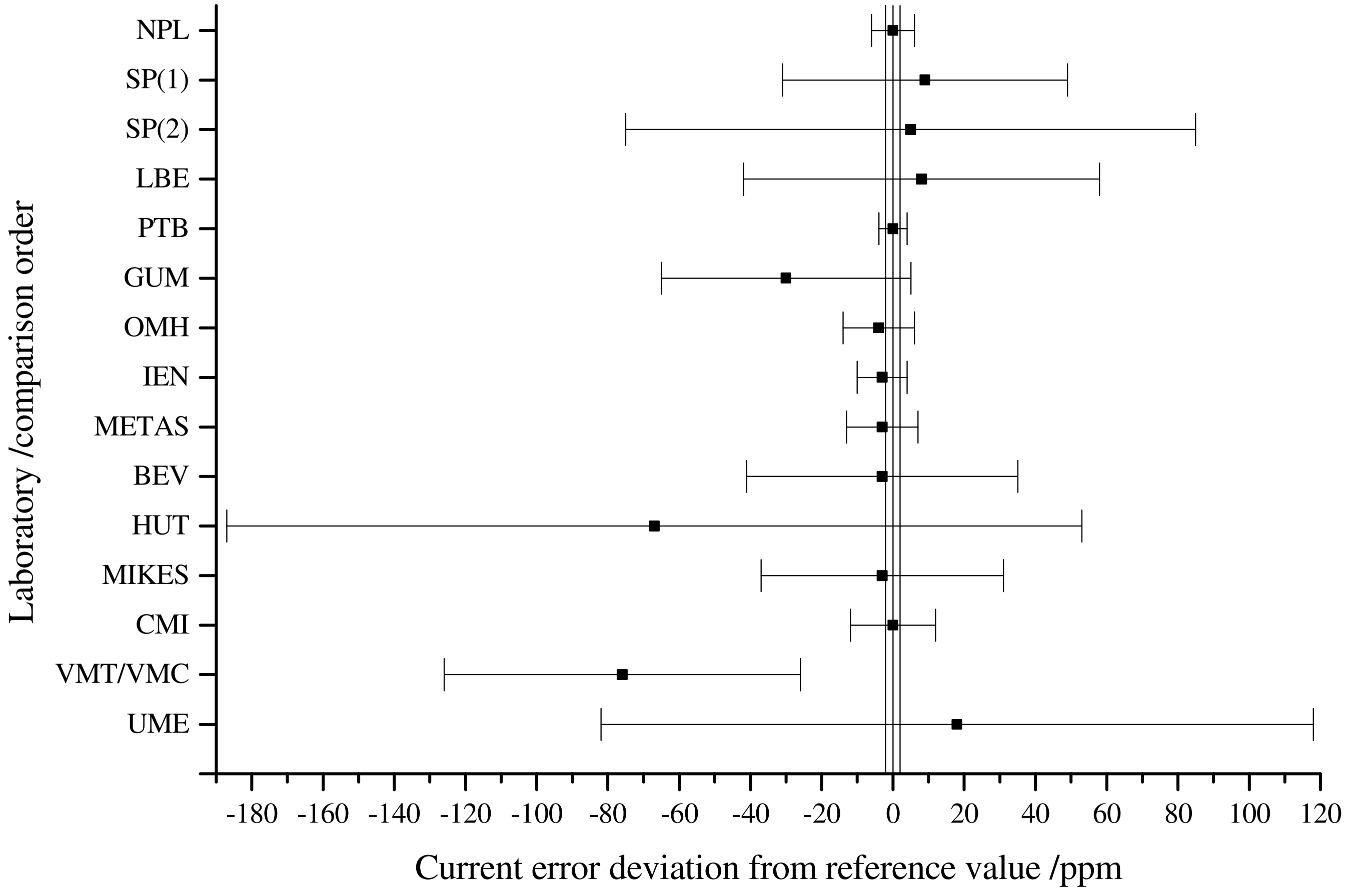


Figure 11 shows the current error comparison results for ratio 100 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 12: Ratio 200 / 5, I/I_n = 100%, current error comparison results

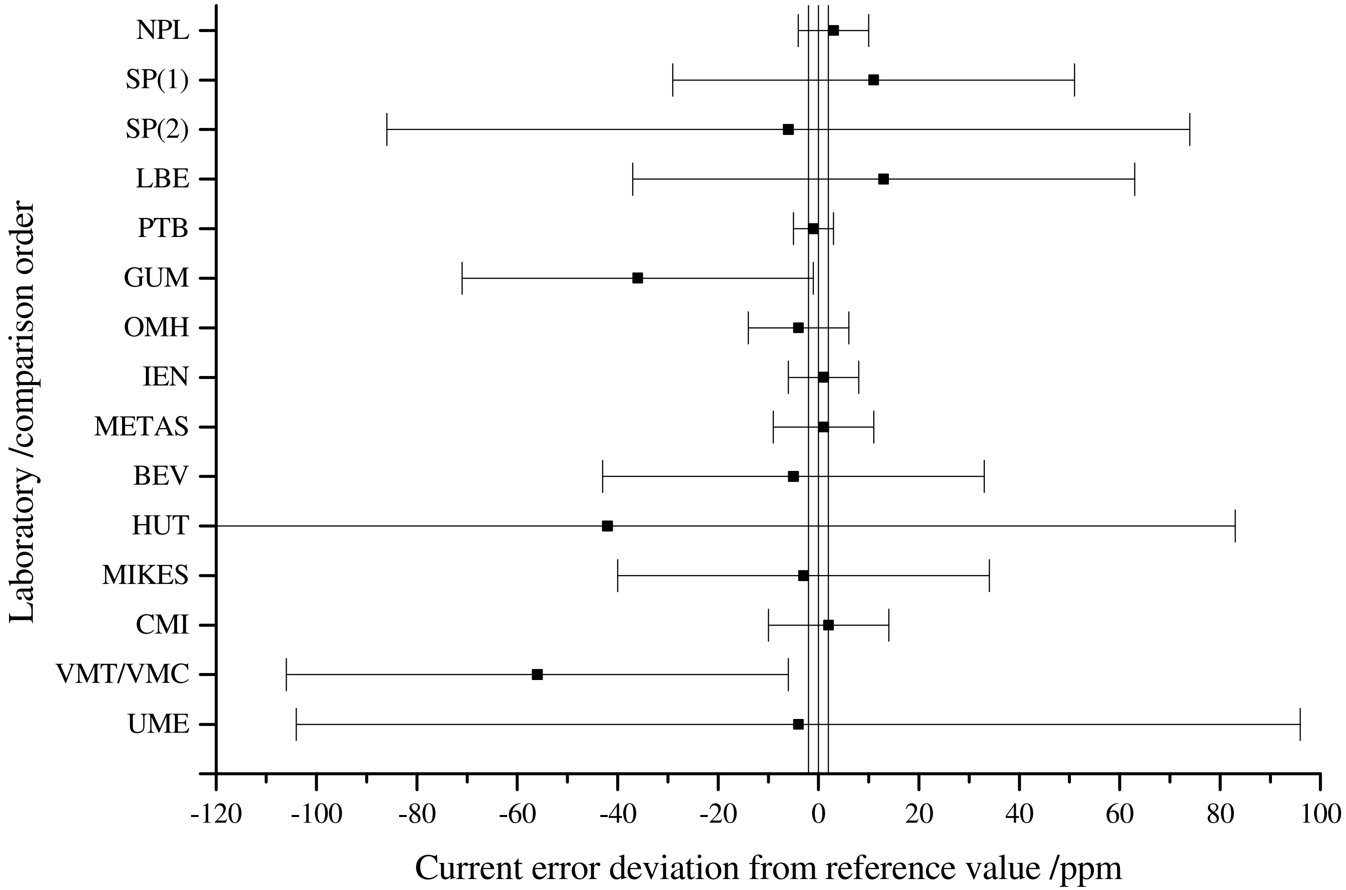


Figure 12 shows the current error comparison results for ratio 200 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 13: Ratio 500 / 5, I/I_n = 100%, current error comparison results

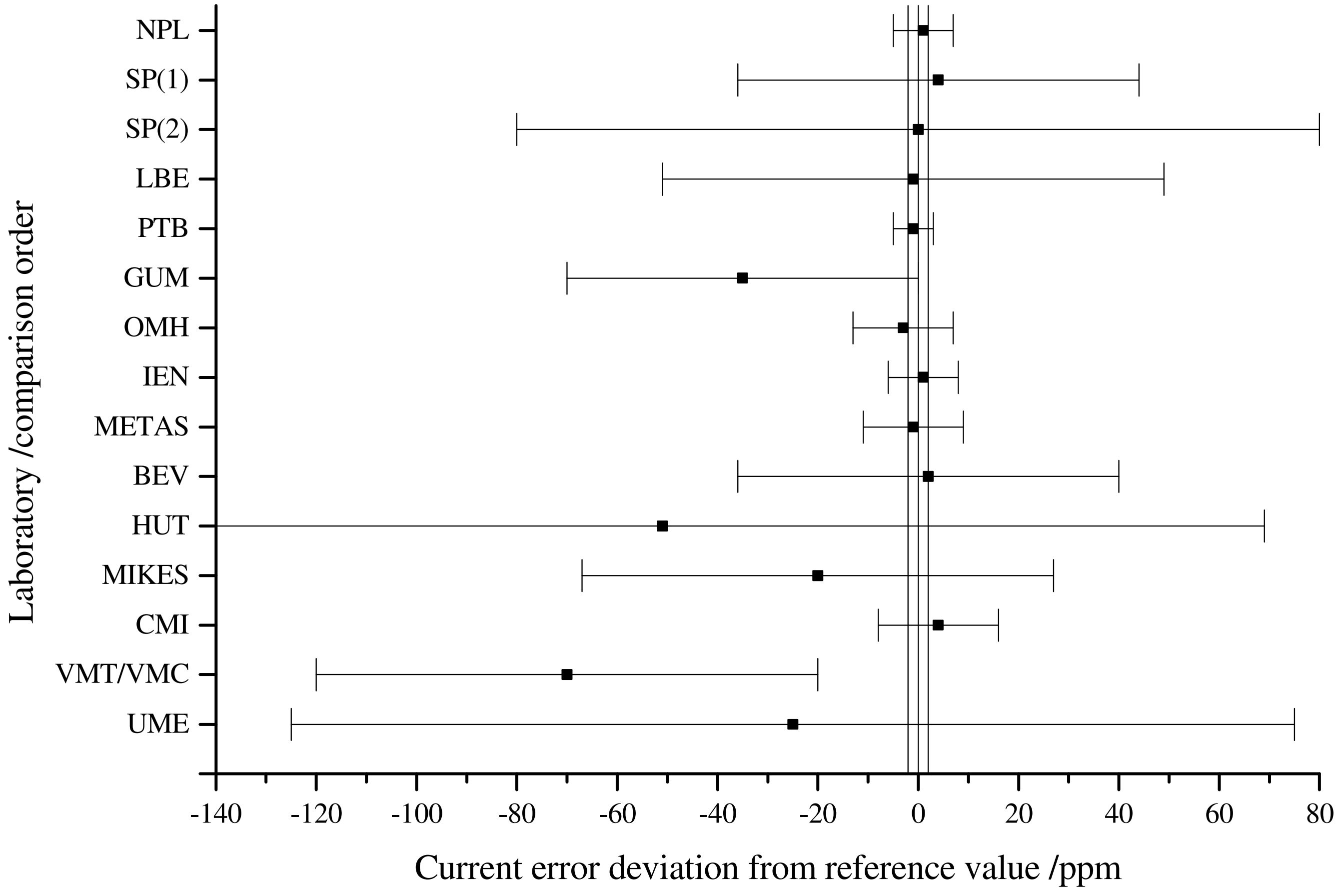


Figure 13 shows the current error comparison results for ratio 500 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 14: Ratio 500 / 5, I/I_n =2 %, current error comparison results

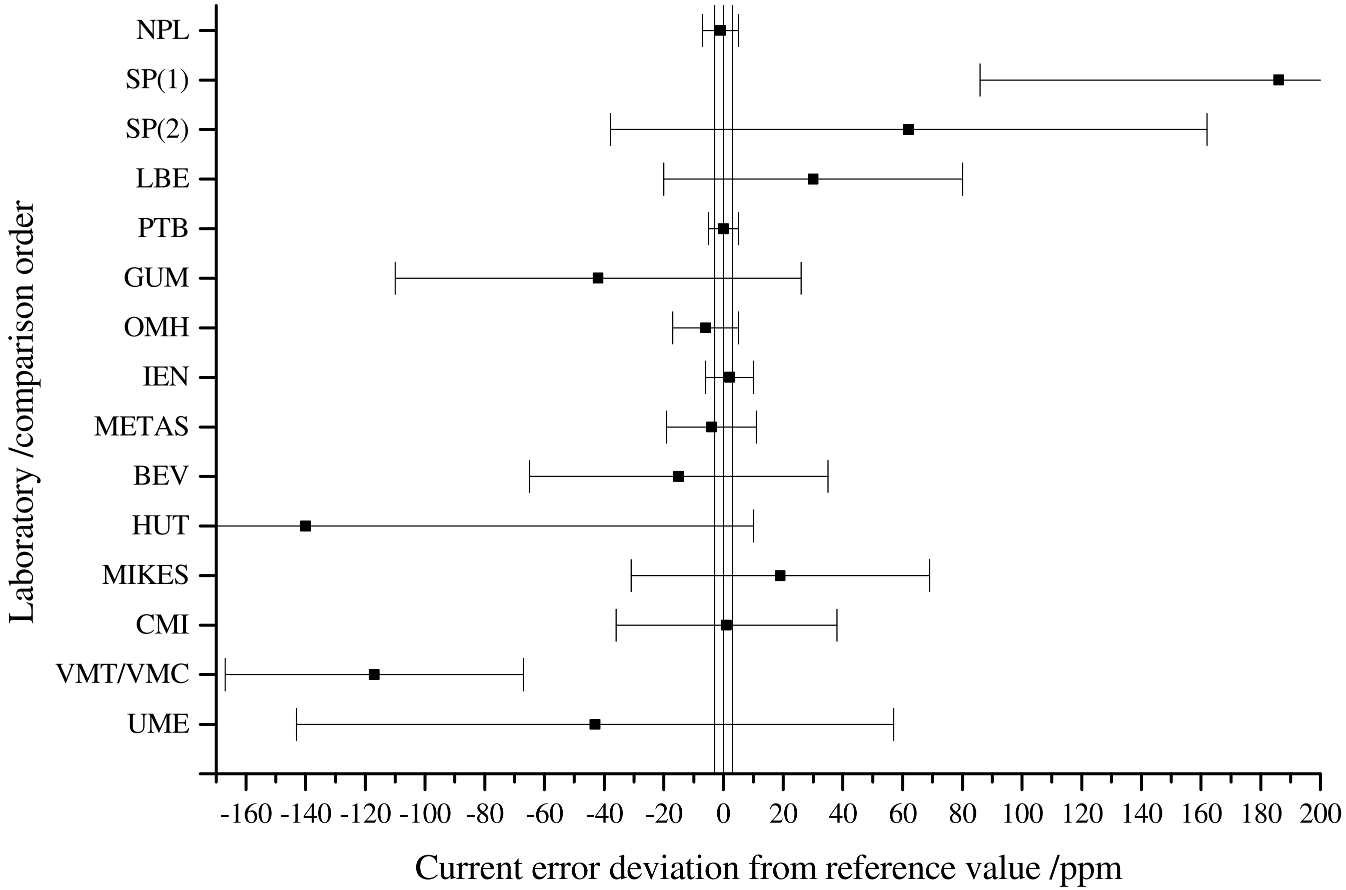


Figure 14 shows the current error comparison results for ratio 500 / 5, at I/I_n = 2%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 15: Ratio 500 / 5, I/I_n = 100%, phase displacement comparison results

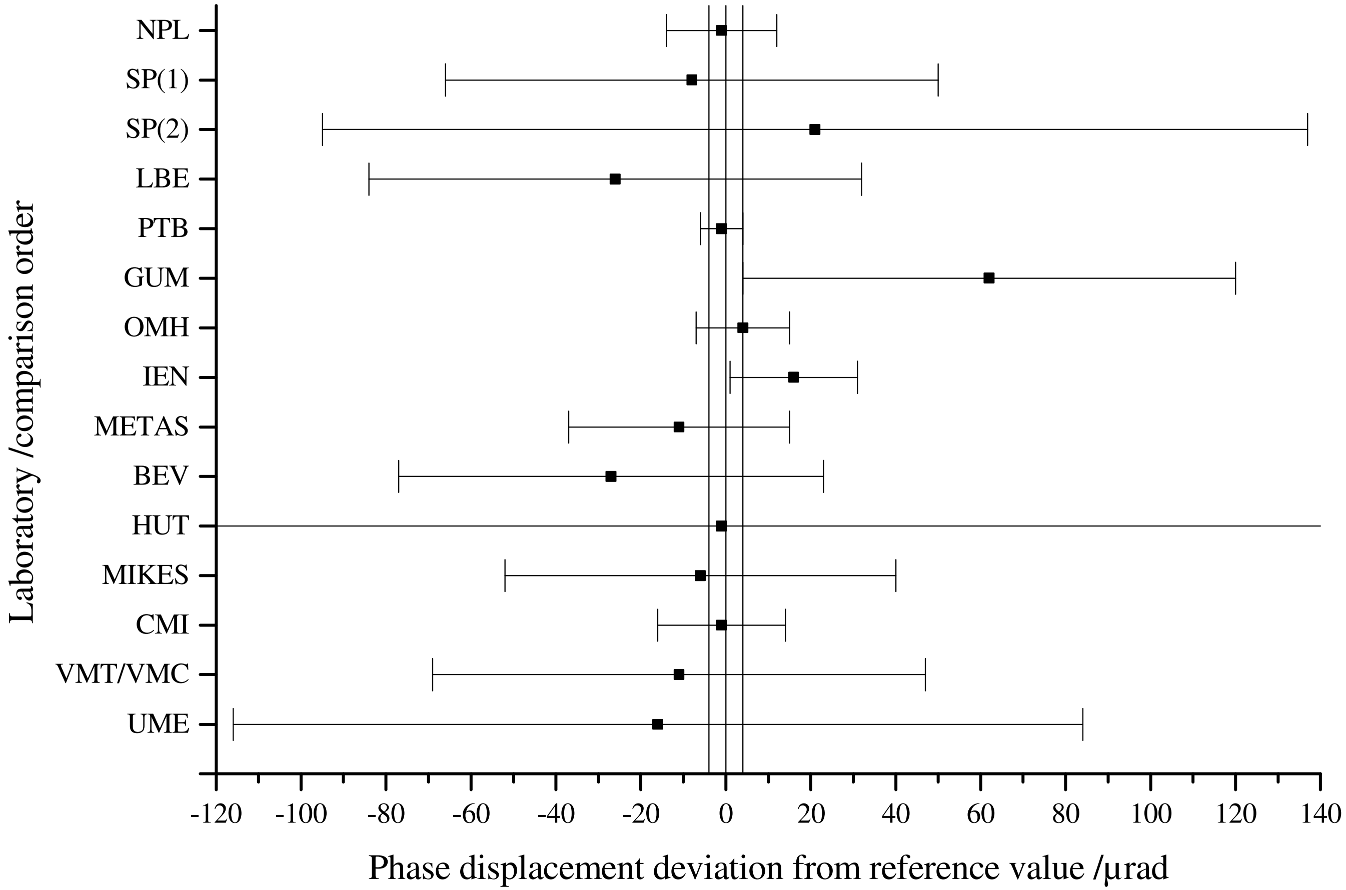


Figure 15 shows the phase displacement comparison results for ratio 500 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The δ_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 16: Ratio 500 / 5, I/I_n = 2%, phase displacement comparison results

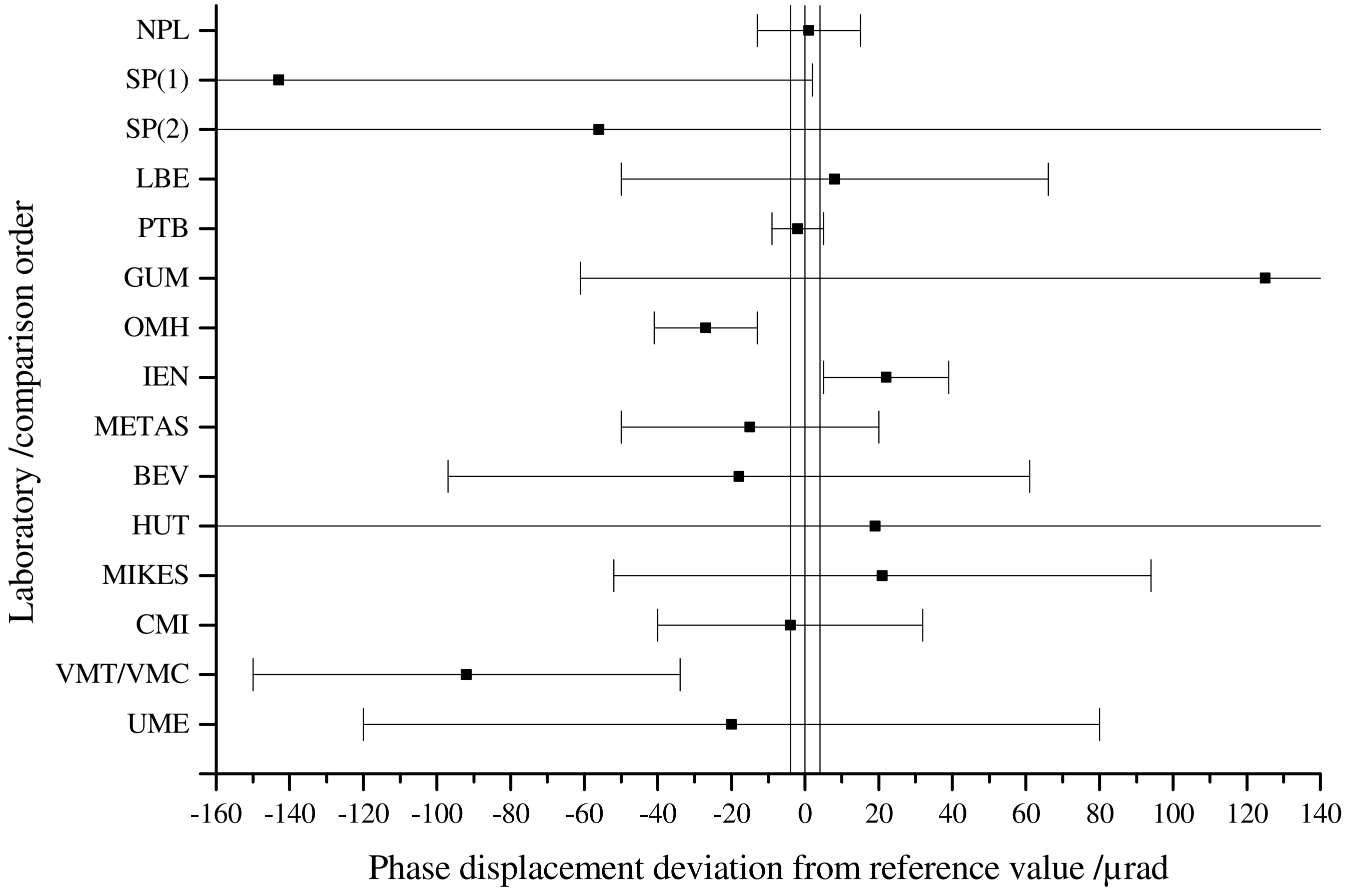


Figure 16 shows the phase displacement comparison results for ratio 500 / 5, at I/I_n = 2%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The δ_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Figure 17: Ratio 1000 / 5, I/I_n = 100%, current error comparison results

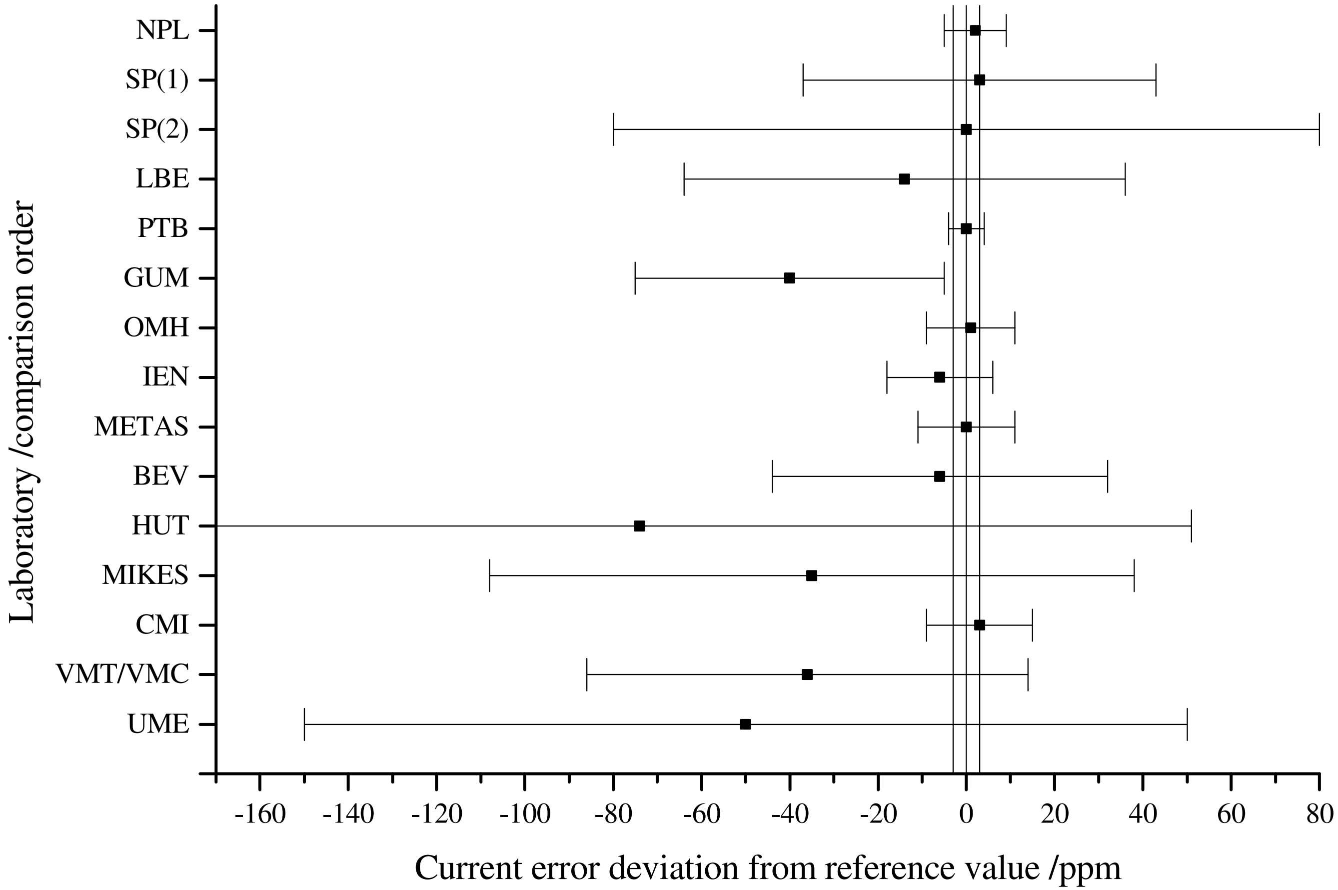


Figure 17 shows the current error comparison results for ratio 1000 / 5, at I/I_n = 100%, given as the deviation from the reference value. The error bars for each point show the uncertainty associated with each deviation. The ε_{ref} (central vertical line) and the 95% confidence intervals (outer vertical lines) are also shown.

Table 5: Current error deviations from reference values for ratio 1 / 5

I/I_n	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
%	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	4	7	-11	40	-7	80	13	50	-1	4	-67	101	-4	4	-	-
100	4	7	-9	40	-6	80	5	50	0	4	-64	101	-4	4	-	-
50	3	7	-9	40	-5	80	0	50	0	4	-62	101	-3	4	-	-
20	3	7	-13	40	-2	80	-6	50	0	4	-59	101	-2	6	-	-
10	2	7	-20	40	1	80	-15	50	-1	4	-49	101	-1	6	-	-
5	1	7	-22	100	6	80	-24	50	0	4	-47	101	0	6	-	-
2	0	7	-23	100	20	120	-14	50	0	6	-47	116	5	6	-	-
1	-3	11	-36	100	32	120	-14	50	1	7	-46	116	-	-	-	-

I/I_n	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
%	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	0	11	-4	38	-	-	-6	17	-1	12	-	-	-	-
100	0	11	-4	38	-	-	-8	18	-1	12	-	-	-	-
50	0	11	-6	38	-	-	-4	18	-1	12	-	-	-	-
20	1	11	0	38	-	-	0	18	-1	13	-	-	-	-
10	0	15	-5	38	-	-	3	18	-1	13	-	-	-	-
5	0	15	1	40	-	-	-	-	-1	16	-	-	-	-
2	1	15	-7	50	-	-	-	-	1	37	-	-	-	-
1	1	15	-14	68	-	-	-	-	3	59	-	-	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
$U\chi_\varepsilon$, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 6: Phase displacement deviations from reference values for ratio 1 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-14	16	-2	58	27	116	33	58	0	5	-28	105	24	5	-	-
100	-18	16	-4	58	25	116	28	58	1	5	-10	105	21	5	-	-
50	-21	16	3	58	3	116	20	58	1	5	0	105	21	5	-	-
20	-21	17	-15	58	-15	116	20	58	1	5	31	105	23	10	-	-
10	-22	17	-9	58	-68	116	11	58	1	6	26	105	23	10	-	-
5	-23	17	-34	145	-151	233	15	58	1	6	50	105	25	10	-	-
2	-23	20	-59	145	-437	233	14	58	2	8	52	198	33	11	-	-
1	-20	30	-87	145	-930	233	15	58	2	8	76	198	-	-	-	-

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	15	26	-14	50	-	-	5	45	3	16	-	-	-	-
100	10	26	-23	50	-	-	5	45	-1	16	-	-	-	-
50	11	26	10	50	-	-	11	45	-2	19	-	-	-	-
20	8	26	14	50	-	-	20	45	-1	22	-	-	-	-
10	8	35	0	50	-	-	24	45	-2	23	-	-	-	-
5	6	35	24	63	-	-	-	-	-3	25	-	-	-	-
2	8	35	37	79	-	-	-	-	-1	36	-	-	-	-
1	6	35	78	126	-	-	-	-	-4	61	-	-	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in µrad.
$U\chi_\delta$, is the expanded uncertainty for each deviation in µrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 7: Current error deviations from reference values for ratio 5 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε
120	1	5	-2	40	-3	80	-3	50	0	3	-30	35	-5	3	-3	7
100	1	5	-1	40	-2	80	-1	50	0	3	-30	35	-4	3	-3	7
50	1	5	-1	40	-2	80	4	50	0	3	-30	35	-4	3	-2	7
20	2	5	-2	40	1	80	-1	50	0	3	-33	35	-2	5	-1	7
10	2	5	-2	40	3	80	1	50	0	3	-42	35	-1	5	-1	7
5	2	5	-1	100	6	80	3	50	0	3	-61	35	-1	5	1	7
2	1	6	-5	100	15	120	2	50	-1	4	-126	68	0	6	0	8
1	0	6	-6	100	30	120	3	50	0	4	-234	68	-	-	-	-

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε	χ_ε	Uχ_ε
120	-1	10	-1	38	-	-	-10	18	-1	12	-71	50	-21	100
100	0	10	0	38	-	-	-8	18	0	12	-76	50	-20	100
50	0	10	0	38	-	-	-2	17	0	12	-87	50	-17	100
20	1	10	1	38	-	-	-1	18	0	13	-112	50	-14	100
10	1	15	1	38	-	-	1	18	0	13	-128	50	-11	100
5	2	15	1	40	-	-	4	18	0	16	-141	50	-9	100
2	1	15	-2	50	-	-	3	18	-1	37	-149	50	-9	100
1	2	15	-4	68	-	-	-	-	-1	59	-147	50	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
Uχ_ε, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 8: Phase displacement deviations from reference values for ratio 5 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-1	9	-3	58	26	116	3	58	0	4	64	58	3	4	13	16
100	-2	9	-1	58	28	116	2	58	0	4	66	58	3	4	14	16
50	-2	10	8	58	8	116	2	58	0	4	78	58	4	4	14	16
20	-2	12	-12	58	17	116	-1	58	-1	4	113	58	4	9	15	16
10	-2	12	-6	58	-6	116	2	58	-1	4	110	58	4	9	16	16
5	-2	12	-2	145	-2	233	1	58	-1	4	99	58	6	9	16	16
2	-3	14	-28	145	-28	233	1	58	-1	5	65	186	5	10	16	19
1	-1	16	-25	145	-84	233	-5	58	0	6	9	186	-	-	-	-

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-3	26	-3	50	-	-	-2	45	3	16	-39	58	6	100
100	-1	26	-3	50	-	-	2	45	2	16	-13	58	6	100
50	-7	26	-3	50	-	-	9	45	2	19	-28	58	10	100
20	-4	26	-1	50	-	-	16	45	1	22	-46	58	23	100
10	-9	35	4	50	-	-	20	45	1	23	-62	58	24	100
5	-2	35	13	63	-	-	24	45	0	25	-79	58	26	100
2	-5	35	35	79	-	-	26	45	0	36	-115	58	24	100
1	-2	35	83	126	-	-	-	-	0	61	-144	76	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in µrad.
$U\chi_\delta$, is the expanded uncertainty for each deviation in µrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 9: Current error deviations from reference values for ratio 10 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	3	5	-1	40	-3	80	2	50	0	4	-27	35	-4	4	-1	7
100	3	5	-1	40	-3	80	3	50	0	4	-28	35	-4	4	-1	7
50	2	5	-1	40	-3	80	-3	50	0	4	-28	35	-4	4	-1	7
20	2	5	-2	40	-4	80	1	50	-1	4	-28	35	-4	5	-1	7
10	2	6	-3	40	-4	80	3	50	-1	4	-32	35	-4	6	0	8
5	1	6	-4	100	-4	80	4	50	-1	4	-43	35	-5	6	-1	8
2	1	6	-6	100	-4	120	15	50	-1	5	-78	68	-3	6	1	8
1	0	6	-7	100	-12	120	25	50	-1	5	-138	68	-	-	1	8

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	0	10	-1	38	-	-	-2	24	0	12	-67	50	-19	100
100	-1	10	-2	38	-	-	-1	22	0	12	-69	50	-19	100
50	-2	10	2	38	-	-	4	18	0	12	-80	50	-16	100
20	-1	10	2	38	-	-	6	17	-1	13	-106	50	-14	100
10	-1	15	1	38	-	-	6	18	-1	13	-124	50	-11	100
5	-2	15	0	40	-	-	8	18	-1	16	-137	50	-11	100
2	-1	15	0	50	-	-	10	18	-2	37	-144	50	-10	100
1	0	15	4	68	-	-	-	-	-2	59	-135	50	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
$U\chi_\varepsilon$, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 10: Phase displacement deviations from reference values for ratio 10 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ
120	-6	12	-6	58	23	116	11	58	0	5	55	58	2	5	12	16
100	-5	12	-3	58	26	116	11	58	0	5	61	58	3	5	14	16
50	-5	12	6	58	6	116	12	58	0	5	70	58	4	5	14	16
20	-5	12	-12	58	17	116	11	58	0	5	104	58	5	10	16	16
10	-6	13	-7	58	22	116	10	58	-1	5	103	58	4	10	16	16
5	-4	13	-2	145	27	233	9	58	-1	5	94	58	5	10	17	16
2	-4	13	-28	145	30	233	1	58	-1	7	59	186	3	10	17	17
1	-3	13	-26	145	32	233	-12	58	-1	7	14	186	-	-	17	18

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ	χ_δ	Uχ_δ
120	0	26	-26	50	-	-	2	45	0	16	-37	58	18	100
100	0	26	-28	50	-	-	7	45	0	16	-9	58	19	100
50	0	26	-19	50	-	-	14	45	0	20	-24	58	28	100
20	2	26	-14	50	-	-	24	45	0	22	-42	58	37	100
10	1	35	-18	50	-	-	35	45	-1	23	-59	58	36	100
5	1	35	-17	63	-	-	38	45	0	26	-76	58	38	100
2	1	35	-9	79	-	-	42	45	-1	36	-115	58	43	100
1	3	35	17	126	-	-	-	-	-1	61	-166	58	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in µrad.
Uχ_δ, is the expanded uncertainty for each deviation in µrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 11: Current error deviations from reference values for ratio 20 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	1	5	-3	40	-3	80	13	50	0	4	-29	35	-4	4	-2	7
100	1	5	-2	40	-2	80	15	50	0	4	-29	35	-3	4	-2	7
50	1	5	-2	40	-4	80	10	50	0	4	-27	35	-2	4	-2	7
20	1	5	-4	40	-5	80	15	50	-1	4	-27	35	-1	5	-1	8
10	0	5	-3	40	-6	80	8	50	-1	4	-29	35	-2	5	-1	8
5	0	5	-5	100	-11	80	9	50	-1	4	-38	35	-2	5	-1	8
2	0	5	-6	100	-24	120	20	50	-1	5	-68	68	-5	6	0	8
1	-1	5	-7	100	-45	120	31	50	0	5	-122	68	-	-	1	9

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	-1	10	-1	38	-22	85	-2	34	2	12	-68	50	-5	100
100	-1	10	-2	38	-37	85	-1	30	2	12	-73	50	-4	100
50	-1	10	2	38	-35	85	4	22	2	13	-83	50	-5	100
20	-1	10	2	38	-40	85	10	17	3	14	-109	50	-5	100
10	0	15	1	38	-39	100	12	17	2	14	-124	50	-4	100
5	-1	15	0	40	-11	100	12	18	1	17	-137	50	-4	100
2	0	15	-3	50	-	-	12	18	1	37	-140	50	-2	100
1	0	15	-1	68	-	-	-	-	2	59	-130	50	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
$U\chi_\varepsilon$, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 12: Phase displacement deviations from reference values for ratio 20 / 5

I/I_n	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
%	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-6	11	0	58	29	116	11	58	0	5	64	58	3	5	11	16
100	-5	11	3	58	3	116	11	58	0	5	70	58	4	5	12	16
50	-6	11	11	58	11	116	11	58	0	5	75	58	4	5	12	16
20	-5	11	-8	58	21	116	12	58	0	5	111	58	6	10	14	16
10	-5	11	-3	58	26	116	11	58	0	5	107	58	7	10	14	16
5	-5	11	1	145	30	233	12	58	0	5	100	58	6	10	15	17
2	-5	11	-26	145	32	233	3	58	-1	7	64	186	7	10	14	18
1	-3	11	-24	145	63	233	-10	58	0	7	19	186	-	-	15	18

I/I_n	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
%	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	0	26	-24	50	57	240	0	46	-2	16	-27	58	11	100
100	3	26	-26	50	60	240	2	45	-2	16	-2	58	11	100
50	2	26	-17	50	58	240	9	45	-3	19	-18	58	12	100
20	3	26	-13	50	68	240	17	45	-3	22	-38	58	14	100
10	2	35	-17	50	33	240	22	45	-3	23	-55	58	14	100
5	4	35	-17	63	37	240	25	45	-3	26	-72	58	13	100
2	3	35	-10	79	-	-	27	45	-4	36	-108	58	10	100
1	5	35	12	126	-	-	-	-	-5	61	-126	70	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in µrad.
$U\chi_\delta$, is the expanded uncertainty for each deviation in µrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 13: Current error deviations from reference values for ratio 50 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	0	5	-1	40	-1	80	4	50	0	4	-33	35	-5	4	-2	7
100	0	5	-1	40	0	80	6	50	0	4	-33	35	-4	4	-2	7
50	0	5	-1	40	3	80	12	50	0	4	-30	35	-4	4	-2	8
20	0	5	-1	40	45	80	9	50	0	4	-27	35	-3	5	-1	8
10	1	5	-2	40	33	80	3	50	0	4	-27	35	-2	5	0	8
5	1	5	-1	100	65	600	5	50	0	4	-30	35	-1	5	0	8
2	0	5	-3	100	161	600	15	50	-1	5	-46	68	-4	6	-1	8
1	-1	5	-7	100	328	600	26	50	-1	5	-89	68	-	-	0	8

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	-3	10	-2	38	-	-	-6	34	2	12	-65	50	-7	100
100	-3	10	-2	38	-	-	-3	34	2	12	-71	50	-6	100
50	-3	10	1	38	-	-	3	34	1	13	-82	50	-7	100
20	-2	10	3	38	-	-	6	22	1	14	-107	50	-6	100
10	-2	15	0	38	-	-	9	18	2	14	-122	50	-5	100
5	-1	15	-1	40	-	-	11	19	2	17	-135	50	-4	100
2	-2	15	-9	50	-	-	9	19	0	37	-137	50	-15	100
1	0	15	-12	68	-	-	-	-	1	59	-131	50	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
$U\chi_\varepsilon$, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 14: Phase displacement deviations from reference values for ratio 50 / 5

	GB		SE				BE		DE		PL		HU		IT	
I/I_n	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
%	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-4	9	-1	58	-1	145	7	58	1	5	60	58	5	5	14	16
100	-4	9	1	58	1	145	9	58	0	5	68	58	5	5	15	16
50	-4	9	11	58	-18	145	11	58	0	5	75	58	6	5	16	16
20	-3	9	22	58	-66	145	13	58	0	5	112	58	8	10	18	16
10	-3	9	-1	58	-147	582	16	58	0	5	109	58	9	10	20	16
5	-3	9	2	145	-318	582	13	58	0	5	101	58	8	10	19	16
2	-3	9	4	145	-811	2036	4	58	-1	6	59	186	-2	10	18	17
1	-2	9	-23	145	-1711	2036	-6	58	-1	6	6	186	-	-	19	17

	CH		AT		FI				CZ		LT		TR	
I/I_n	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
%	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-1	26	-22	50	-	-	3	46	-3	16	-20	58	11	100
100	-2	26	-25	50	-	-	6	46	-4	16	4	58	7	100
50	-1	26	-16	50	-	-	16	46	-6	20	-13	58	14	100
20	1	26	-11	50	-	-	15	45	-6	23	-31	58	16	100
10	2	35	-15	50	-	-	20	45	-6	24	-48	58	16	100
5	2	35	-17	63	-	-	22	45	-8	26	-67	58	13	100
2	1	35	-12	79	-	-	24	45	-9	37	-102	58	-65	100
1	3	35	8	126	-	-	-	-	-9	61	-162	58	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in µrad.
$U\chi_\delta$, is the expanded uncertainty for each deviation in µrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 15: Current error deviations from reference values for ratio 100 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	0	6	9	40	4	80	7	50	1	4	-29	35	-4	10	-3	7
100	0	6	9	40	5	80	8	50	0	4	-30	35	-4	10	-3	7
50	0	6	10	40	10	80	13	50	0	4	-27	35	-4	10	-3	7
20	1	6	12	40	24	80	9	50	-1	4	-23	35	-3	11	-2	8
10	1	6	13	40	45	80	12	50	0	4	-21	35	-3	11	-1	8
5	1	6	13	100	88	600	3	50	-1	4	-22	35	-5	11	-1	8
2	0	6	13	100	205	600	13	50	-1	5	-29	68	-8	11	-1	8
1	0	6	14	100	433	600	14	50	0	5	-48	68	-	-	-1	9

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	-3	10	-2	38	-48	120	-5	34	1	12	-70	50	12	100
100	-3	10	-3	38	-67	120	-3	34	0	12	-76	50	18	100
50	-3	10	1	38	-97	120	3	34	0	13	-87	50	43	100
20	-1	10	1	38	-96	120	6	31	1	14	-111	50	93	100
10	0	15	-1	38	-88	120	11	24	0	13	-127	50	160	100
5	-1	15	-4	40	-77	120	15	22	0	16	-2	50	284	100
2	-1	15	-12	50	-82	120	15	21	-1	37	-138	50	298	100
1	2	15	-21	68	-	-	-	-	0	59	-119	50	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
$U\chi_\varepsilon$, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 16: Phase displacement deviations from reference values for ratio 100 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-5	10	28	58	-1	145	7	58	0	5	63	58	2	11	9	16
100	-3	10	31	58	2	145	8	58	0	5	66	58	3	11	11	16
50	-4	10	40	58	-18	145	8	58	0	5	75	58	4	11	11	16
20	-2	10	22	58	-95	145	10	58	0	5	112	58	6	13	14	16
10	-3	10	27	58	-177	582	9	58	0	5	111	58	7	13	14	16
5	-4	10	30	145	-378	582	9	58	0	5	105	58	6	13	14	17
2	-3	10	33	145	-927	2036	4	58	0	6	82	186	-6	14	15	17
1	-3	11	34	145	-1915	2036	-4	58	0	7	51	186	-	-	15	18

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-1	26	-25	50	26	240	-3	46	1	16	-31	58	-6	100
100	-1	26	-27	50	19	240	3	46	2	16	-7	58	-11	100
50	-1	26	-18	50	8	240	10	46	2	19	-22	58	-50	100
20	1	26	-13	50	9	240	20	46	3	22	-39	58	-128	100
10	1	35	-18	50	4	240	16	45	3	23	-55	58	-216	100
5	1	35	-21	63	-3	240	19	45	2	26	-73	58	-363	100
2	1	35	-16	79	-10	240	21	45	1	36	-105	58	-420	100
1	-1	35	4	126	-	-	-	-	-1	61	-154	58	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in μrad.
$U\chi_\delta$, is the expanded uncertainty for each deviation in μrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 17: Current error deviations from reference values for ratio 200 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	3	7	10	40	-5	80	11	50	-1	4	-36	35	-4	10	1	7
100	3	7	11	40	-6	80	13	50	-1	4	-36	35	-4	10	1	7
50	3	7	15	40	-7	80	21	50	-1	4	-34	35	-3	10	1	7
20	2	7	25	40	-4	80	21	50	-1	4	-31	35	-2	11	1	7
10	3	7	37	40	0	80	15	50	-1	4	-33	35	0	11	-1	8
5	4	7	65	100	9	80	20	50	-1	4	-38	35	-1	11	0	8
2	2	8	128	100	31	100	32	50	-1	5	-67	68	-3	11	0	8
1	1	8	196	100	71	100	43	50	0	5	-123	68	-	-	-1	9

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	1	10	-3	38	-19	125	-4	37	2	12	-50	50	-4	100
100	1	10	-5	38	-42	125	-3	37	2	12	-56	50	-4	100
50	0	10	-2	38	-59	125	1	34	2	12	-70	50	1	100
20	1	10	-3	38	-99	125	6	35	2	13	-100	50	15	100
10	1	15	-6	38	-95	125	12	33	0	13	-118	50	34	100
5	3	15	-8	40	-90	125	11	26	2	16	-127	50	45	100
2	1	15	-17	50	-	-	17	26	0	37	-125	50	90	100
1	3	15	-27	68	-	-	-	-	0	59	-99	50	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
$U\chi_\varepsilon$, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 18: Phase displacement deviations from reference values for ratio 200 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	0	10	13	58	13	116	10	58	-1	5	48	58	3	11	9	15
100	1	10	16	58	16	116	10	58	-1	5	51	58	4	11	9	15
50	-2	10	0	58	0	116	8	58	-1	5	64	58	6	11	11	16
20	-1	10	13	58	13	116	10	58	-1	5	103	58	6	13	13	16
10	0	10	-8	58	-8	116	9	58	-1	5	108	58	8	13	13	16
5	1	10	-61	145	-31	291	6	58	-1	5	108	58	0	13	15	16
2	0	11	-174	145	-87	291	1	58	-2	7	82	186	-7	14	15	18
1	4	14	-404	145	-200	291	-11	58	-1	7	59	186	-	-	17	18

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	1	26	-25	50	21	240	-16	46	4	15	-25	58	-2	100
100	-2	26	-28	50	24	240	-12	46	4	15	-1	58	-5	100
50	0	26	-18	50	27	240	0	46	3	19	-16	58	1	100
20	-2	26	-15	50	-20	240	11	46	3	22	-35	58	11	100
10	0	35	-19	50	8	240	11	47	4	23	-51	58	13	100
5	1	35	-21	63	4	240	8	53	4	25	-66	58	24	100
2	-2	35	-19	79	-	-	19	45	2	36	-98	58	6	100
1	-2	35	-2	126	-	-	-	-	6	61	-139	58	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in µrad.
$U\chi_\delta$, is the expanded uncertainty for each deviation in µrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 19: Current error deviations from reference values for ratio 500 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	2	6	2	40	0	80	-3	50	-1	4	-34	35	-3	10	2	7
100	1	6	4	40	0	80	-1	50	-1	4	-35	35	-3	10	1	7
50	1	6	10	40	0	80	16	50	-1	4	-33	35	-4	10	2	7
20	0	6	24	40	3	80	23	50	0	4	-29	35	-2	11	2	7
10	0	6	43	40	9	80	26	50	-1	4	-28	35	-2	11	1	7
5	1	6	81	100	23	80	30	50	0	4	-28	35	1	11	3	8
2	-1	6	186	100	62	100	30	50	0	5	-42	68	-6	11	2	8
1	-2	6	358	100	117	100	31	50	1	5	-66	68	-	-	3	8

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	-1	10	2	38	-43	120	-21	47	4	12	-64	50	-43	100
100	-1	10	2	38	-51	120	-20	47	4	12	-70	50	-25	100
50	-3	10	6	38	-54	120	-15	38	4	13	-82	50	-28	100
20	-3	10	5	38	-107	120	-11	35	3	13	-106	50	-10	100
10	-4	15	0	38	-114	120	-4	35	3	13	-122	50	-16	100
5	-3	15	-2	40	-130	150	-8	38	4	16	-126	50	-16	100
2	-4	15	-15	50	-140	150	19	50	1	37	-117	50	-43	100
1	-5	15	-27	68	-	-	-	-	1	59	-75	50	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
$U\chi_\varepsilon$, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 20: Phase displacement deviations from reference values for ratio 500 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-1	13	-11	58	18	116	-32	58	-1	5	56	58	2	11	16	15
100	-1	13	-8	58	21	116	-26	58	-1	5	62	58	4	11	16	15
50	1	13	4	58	4	116	15	58	-1	5	82	58	6	11	19	16
20	2	13	-12	58	17	116	17	58	-1	5	121	58	7	13	20	16
10	2	13	-34	58	-5	116	15	58	-1	5	128	58	8	13	22	16
5	1	14	-59	145	0	291	14	58	-1	5	128	58	4	14	22	16
2	1	14	-143	145	-56	291	8	58	-2	7	125	186	-27	14	22	17
1	-3	14	-285	145	-140	291	6	58	-1	7	116	186	-	-	25	17

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-8	26	-23	50	6	240	-9	46	-1	15	-34	58	-78	100
100	-11	26	-27	50	-1	240	-6	46	-1	15	-11	58	-16	100
50	-8	26	-19	50	11	240	3	46	-1	19	-25	58	22	100
20	-9	26	-15	50	24	240	15	46	-1	22	-42	58	15	100
10	-11	35	-20	50	21	240	24	46	-1	23	-55	58	10	100
5	-12	35	-22	63	16	240	23	49	-1	25	-67	58	-6	100
2	-15	35	-18	79	19	240	21	73	-4	36	-92	58	-20	100
1	-9	35	0	126	-	-	-	-	-5	61	-123	58	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in µrad.
$U\chi_\delta$, is the expanded uncertainty for each deviation in µrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 21: Current error deviations from reference values for ratio 1000 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	3	7	3	40	0	80	-12	50	0	4	-37	35	0	10	-8	15
100	2	7	3	40	0	80	-14	50	0	4	-40	35	1	10	-6	12
50	1	11	3	40	-1	80	-15	50	0	4	-33	35	-1	10	0	6
20	-1	11	19	40	5	80	-17	50	0	4	-29	35	-3	11	1	8
10	-2	13	44	40	13	80	-21	50	0	4	-33	35	-5	11	0	8
5	-4	13	89	100	28	80	-27	50	0	5	-49	35	-5	11	0	9
2	0	14	211	100	77	150	-12	50	0	8	-98	68	-5	12	0	9
1	1	14	402	100	152	150	-10	50	-1	8	-167	68	-	-	-1	9

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$	χ_ε	$U\chi_\varepsilon$
120	0	11	-6	38	-62	125	-33	84	3	12	-32	50	-74	100
100	0	11	-6	38	-74	125	-35	73	3	12	-36	50	-50	100
50	1	10	-7	38	-65	125	-30	48	5	13	-49	50	-33	100
20	0	11	-11	38	-122	125	-23	40	4	14	-81	50	-55	100
10	0	15	-15	38	-116	125	-16	37	4	14	-97	50	-21	100
5	-1	15	-20	40	-117	155	-12	38	3	17	-107	50	-29	100
2	0	15	-30	50	-137	155	-13	40	5	37	-98	50	-42	100
1	0	16	-40	68	-	-	-	-	7	59	-64	50	-	-

χ_ε, is the current error deviation from the reference value for each point supplied by each participant in ppm.
$U\chi_\varepsilon$, is the expanded uncertainty for each deviation in ppm.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Table 22: Phase displacement deviations from reference values for ratio 1000 / 5

I/I_n %	GB		SE				BE		DE		PL		HU		IT	
	NPL		SP (1)		SP (2)		LBE		PTB		GUM		OMH		IEN	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	0	10	30	58	1	116	4	58	0	6	47	58	-3	11	0	25
100	-4	10	33	58	4	116	1	58	0	6	50	58	-3	11	4	16
50	-3	10	21	58	21	116	-2	58	0	6	53	58	1	11	9	16
20	-4	10	9	58	9	116	-6	58	0	6	81	58	4	14	12	16
10	-4	10	18	58	-11	116	-8	58	0	6	82	58	6	14	14	16
5	-5	10	-4	145	-4	204	-13	58	0	8	77	58	6	14	15	16
2	-5	11	-58	145	-58	204	-20	58	-1	12	47	186	6	14	16	16
1	-5	12	-169	145	-140	204	-32	58	1	12	14	186	-	-	18	17

I/I_n %	CH		AT		FI				CZ		LT		TR	
	METAS		BEV		HUT		MIKES		CMI		VMT/VMC		UME	
	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$	χ_δ	$U\chi_\delta$
120	-2	26	-34	50	39	240	-20	46	2	16	62	58	-34	100
100	-5	26	-36	50	32	240	-17	46	2	16	-4	58	-11	100
50	-5	26	-24	50	39	240	-5	46	1	19	-18	58	27	100
20	-6	26	-20	50	36	240	9	46	0	22	-39	58	83	100
10	-6	35	-24	50	55	240	18	46	0	23	-52	58	22	100
5	-7	35	-25	63	-8	240	28	47	1	25	-65	58	20	100
2	-8	35	-21	79	-3	240	27	54	0	36	-87	58	-3	100
1	-3	35	-2	126	-	-	-	-	4	61	-110	58	-	-

χ_δ, is the phase displacement deviation from the reference value for each point supplied by each participant in µrad.
$U\chi_\delta$, is the expanded uncertainty for each deviation in µrad.
-, indicates that the point was not reported.
SP (1) refers to results given on pages 3 to 5 of their report and SP (2) refers to results given on pages 5 to 8 of their report.

Conclusion

There are several points to bear in mind whilst analysing the results of the comparison.

The ambient temperature at which the measurements were made varies from 18 to 24 ºC.

There is some variation in the burden at which the measurements were made, although most participants have included contributions in their uncertainty budgets for any deviation from the nominal value.

The quoted uncertainties given by each participant were quite varied over all the measured ratios. An extreme example is ratio 100 / 5 at I/I_n = 5% where the quoted uncertainties range from ± 4 ppm to ± 600 ppm for current error, and from ± 5 µrad to ± 2036 µrad for phase displacement.

In several cases participants have been making current transformer measurements with new measurement systems and techniques and, in one case for the first time, therefore a large amount of experience in the measurement and interpretation of results has been obtained from this comparison.

The results supplied by each participant generally show good agreement but with a few exceptions over the whole range of measured values. Deviations from the comparison reference value were mostly within the quoted uncertainties, but again with a few exceptions. It is helpful to analyse these outlying results in more detail and a summary of these is shown in Tables 23 and 24. Although the measurements were performed in this comparison early in the transition period of the Mutual Recognition Agreement (MRA), it is still useful to consider the results with reference to laboratories' declared Calibration and Measurement Capabilities (CMCs) and to propose actions where systematic effects are present.

The results in the comparison and in the CMC database are all quoted with an uncertainty confidence of 95%, so a 1 in 20 occurrence of an outlying result may be expected. There are 18 possible results (current error and phase displacement for 9 ratios), so participants having 1 or 2 lying outside the combined uncertainty of the result and the reference value may be expected on a statistical basis. It is likely that NPL, UME and OMH have results that may be considered on this basis, although one of OMH's outlying results is significantly larger than the relevant declared CMC.

There are clearly some laboratories, which have significant systematic effects in their results. These are GUM and BNM-LCIE, and their CMC declarations are clearly not supported. The situation for VMT/VMC was similar initially but was improved as they reassessed their analysis of uncertainty, although after they had seen the reference values. This is commented on elsewhere in this report.

Two remaining laboratories, SP and IEN, have some ratios with outlying results but possibly too many for a statistical reason. Where there appears to be some systematic effect the laboratory is encouraged to investigate. For IEN, the occurrence of discrepancies looks non-systematic but possibly the CMC declarations are too low. For

SP, there may be a systematic effect for the higher current ratios at low percentages of *I*/*I*n. And again, it is possible that their CMC declarations are too low.

The outlying differences given in Tables 23 and 24 are the difference between the deviations from the reference values, χ_ε and χ_δ, and the expanded uncertainty, $U\chi_\varepsilon$ and $U\chi_\delta$, for each deviation.

Table 23: Current error outlying results

Lab.	Extent of outlying results	Largest outlying difference	Expanded uncertainty	Declared CMC
UME	100 / 5, PR	198 ppm	100 ppm	none
OMH	5 / 5, PR 50 / 5, PR	2 ppm 1 ppm	3 ppm 4 ppm	5 ppm 10 ppm
SP	200, 500 and 1000 / 5, PR	302 ppm	100 ppm	30 ppm
GUM	5, 10, 20, 50, 200 and 1000 / 5, PR	166 ppm	68 ppm	30 ppm
BNM-LCIE	1, 5, 50 and 200 / 5, FR 10, 20, 100, 500 and 1000 / 5, PR	304 ppm 189 ppm	300 ppm 300 ppm	100 ppm 100 ppm
VMT/VMC	All results, prior to increase of uncertainties			none

Table 24: Phase displacement outlying results

Lab.	Extent of outlying results	Largest outlying difference	Expanded uncertainty	Declared CMC
NPL	1 / 5, PR	6 μrad	17 μrad	30 μrad
UME	100 / 5, PR	320 μrad	100 μrad	none
OMH	1 / 5, FR 500 / 5, PR	22 μrad 13 μrad	11 μrad 14 μrad	5 μrad 15 μrad
IEN	500 / 5, FR 10, 50 and 1000 / 5, PR	8 μrad 4 μrad	17 μrad 16 μrad	20 μrad 20 μrad
SP	1 / 5, PR 200, 500 and 1000 / 5, PR	697 μrad 259 μrad	233 μrad 145 μrad	60 μrad 30 μrad
GUM	5, 10, 20, 50, 100, 200, 500 and 1000 / 5, PR	70 μrad	58 μrad	61 μrad
BNM-LCIE	1 / 5, FR 5, 10, 20, 50, 100, 200, 500 and 1000 / 5, PR	263 μrad 260 μrad	120 μrad 120 μrad	100 μrad 100 μrad
VMT/VMC	All results, prior to increase of uncertainties			none

Legend

Lab.	Laboratory
PR	Partial ratio
FR	Full ratio

References

[1] IEC 60044-1:2002, Edition 1.2, Instrument Transformers - Part 1: Current Transformers

[2] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, Guide to the Expression of Uncertainty in Measurement, International Organisation for Standardization, Geneva, First Edition 1993.

[3] Cox MG, A discussion of approaches for determining a reference value in the analysis of key-comparison data, NPL Report CISE 42/99, 1999, 17p.

[4] Moore WJM and Miljanic PN, The Current Comparator, IEE Electrical Measurement series 4, Peter Peregrins Ltd, London, 1988, 120p.

APPENDIX 1: Types of standard used in comparison

Table 25 details the type of standard and/or instrument used by each participant in the measurement of the transfer standard.

Table 25: Types of standard used by participants

Lab.	Standard				Bridge		
	Rog/Shunt	Passive CCC	Electronic CCC	Standard transformer	Passive	Electronic	Homemade
NPL		✓			✓		
SP		✓			✓		
LBE			✓			✓	
PTB		✓				✓	✓
GUM			✓			✓	
OMH				✓		✓	
IEN		✓			✓		
METAS			✓			✓	
BEV				✓		✓	
HUT	✓						
MIKES	✓						
CMI			✓			✓	
VMT/VMC				✓		✓	
BNM-LCIE				✓			✓
UME			✓			✓	

Legend

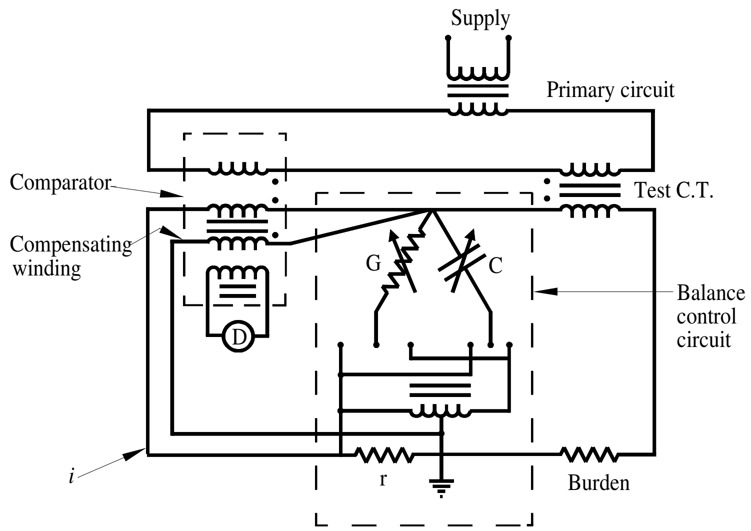
Lab.	Laboratory
CCC	Compensated current comparator
Rog/Shunt	Refers to measurements made using Rogowski coils and/or current shunts

APPENDIX 2: Measurement methods

Passive compensated current comparator method

Figure 18 shows the basic calibration circuit for the passive compensated current comparator designed by Kusters and Moore [4], with a test current transformer connected in series. The compensation winding, which has the same number of turns as the secondary winding, will have a current that is the difference between the comparator secondary winding current and the test transformer secondary current. If i is the nominal secondary current and α and β are respectively the errors of the comparator and the test transformer secondary currents, the compensation winding current is $(i + \alpha) - (i + \beta)$ which is equal to $(\alpha - \beta)$. In linking the detector core, the compensation winding ampere-turns due to α will subtract from those of $(i + \alpha)$ due to the secondary winding, giving a resultant due to i, which exactly cancels the primary ampere-turns. The detector core is therefore magnetized only by a current β, the error of the test current transformer. An equal and opposite current from the balance control circuit is injected into the compensation winding to give null deflection of the detector. The error β is then given by $i\mathrm{r}(\mathrm{G} + j\omega \mathrm{C})$.

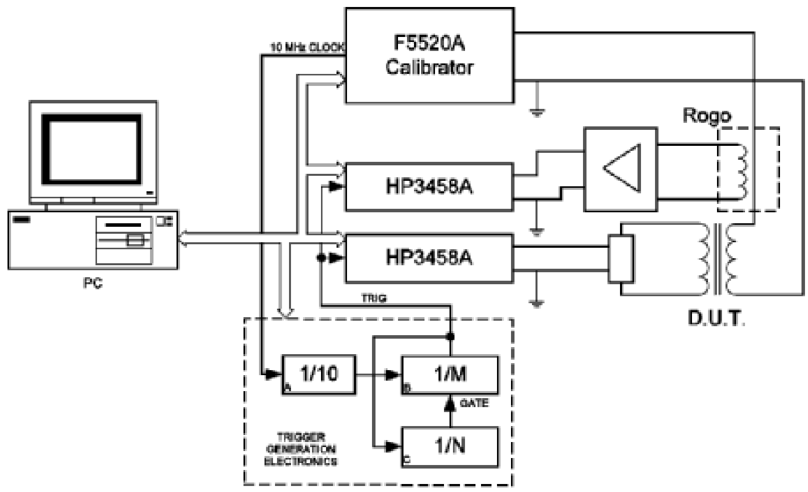
Figure 18: Basic calibration circuit



Rogowski and current shunt method

Figure 19 shows the Rogowski Coil/current shunt method, (diagram taken from MIKES report) where output voltages from calibrated current shunts/Rogowski coils and the DUT (device under test) are measured using calibrated digital multimeters and the DUTs, or in this case, the transfer standard's errors calculated from the ratio of those voltages.

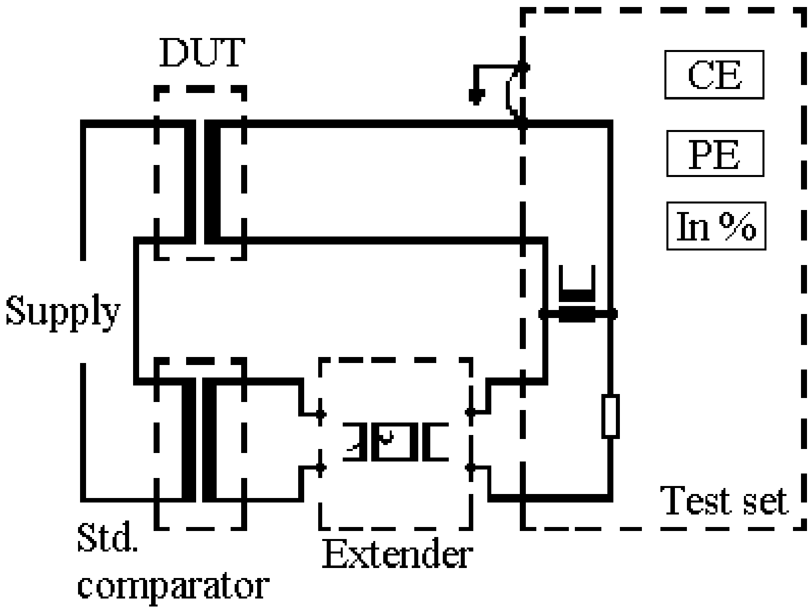
Figure 19: Rogowski/current shunt method



Electronically compensated comparator and test set

Figure 20 shows the calibration circuit for the electronically compensated comparator and test set. The transformer test set measures the transfer standard (marked DUT in circuit) errors by dividing the differential current into two components. These values are evaluated automatically as current error and phase displacement by the test set electronics.

Figure 20: Electronic measurement system



APPENDIX 3: BNM-LCIE Results

The following results were received from BNM-LCIE on 30 May 2002 after Draft A had been agreed by other participants. The results supplied by BNM-LCIE have not been used in the calculation of the comparison reference values given in Table 4.

The results in Table 26 are the deviations from the comparison reference values, in ppm for current error and μrad for phase displacement. The expanded uncertainty (k = 2) for each deviation is also shown in ppm and μrad.

Table 26: BNM-LCIE results as deviations from the comparison reference values

I/I_n	Ratio 1 / 5				Ratio 5 / 5				Ratio 10 / 5			
%	χ_ε	U	χ_δ	U	χ_ε	U	χ_δ	U	χ_ε	U	χ_δ	U
120	-127	25	105	25	-53	40	74	25	-38	40	71	25
100	-125	25	103	25	-61	40	66	25	-37	40	64	25
50	-130	25	90	25	-56	40	65	25	-33	40	63	25
20	-156	25	71	25	-51	40	64	25	-29	40	44	25
10	-185	25	77	25	-69	40	50	25	-57	40	29	25
5	-254	25	21	25	-107	40	34	25	-116	40	-16	25
2	-454	150	-134	50	-248	150	-33	50	-205	150	-83	50
1	-604	300	-383	120	-597	300	-180	120	-405	300	-181	120

I/I_n	Ratio 20 / 5				Ratio 50 / 5				Ratio 100 / 5			
%	χ_ε	U	χ_δ	U	χ_ε	U	χ_δ	U	χ_ε	U	χ_δ	U
120	-37	40	77	25	-66	40	86	25	-23	40	86	25
100	-55	40	70	25	-64	40	88	25	-22	40	89	25
50	-50	40	68	25	-58	40	68	25	-7	40	68	25
20	-55	40	48	25	-51	40	49	25	-21	40	49	25
10	-72	40	23	25	-67	40	25	25	-38	40	24	25
5	-91	40	-13	25	-95	40	-32	25	-67	40	-43	25
2	-190	150	-131	50	-185	150	-180	50	-137	150	-230	50
1	-489	300	-179	120	-384	300	-278	120	-386	300	-379	120

I/I_n	Ratio 200 / 5				Ratio 500 / 5				Ratio 1000 / 5			
%	χ_ε	U	χ_δ	U	χ_ε	U	χ_δ	U	χ_ε	U	χ_δ	U
120	-59	40	21	25	-13	40	66	25	-62	40	-1	25
100	-77	40	24	25	-31	40	79	25	-34	40	22	25
50	-69	40	27	25	-34	40	81	25	35	40	69	25
20	-59	40	10	25	-37	40	44	25	33	40	36	25
10	-55	40	-22	25	-54	40	21	25	9	40	15	25
5	-70	40	-66	25	-70	40	-44	25	-37	40	-48	25
2	-138	150	-233	50	-140	150	-231	50	-102	150	-233	50
1	-387	300	-380	120	-389	300	-378	120	-400	300	-378	120

APPENDIX 4: Amended uncertainty values from VMT/VMC

Following VMT/VMC investigating the measurement uncertainties regarding their standard transformer, they have supplied re-calculated uncertainty values. As these values were supplied after issuing of the comparison reference values they are included in this appendix for completeness.

For VMT/VMC values given in Figures 3 to 17 and Tables 5 to 22, for all current error measurements the expanded uncertainty should be ± 153 ppm (± 0.0153%), not ± 50 ppm as stated in the figures/tables. For all phase displacement measurements the expanded uncertainty should be ± 439 µrad (1.51 minutes), not ± 58 µrad as stated in the figures/tables.

APPENDIX 5: Sample uncertainty budgets

SP sample uncertainty budget

Quantity Testpoints 120-100-50-20-10 %	Estimate [PPM]	Analysis	Sensitivity coefficient	Standard Uncertainty [PPM]	Stated uncertainty Within +/-
Guildline 9900 200-10 % Exp. Uncert.	30	2	1	15,00	
Standard deviation in % *2,3 /ret(3)	1	1	1	1,09	
Dependence of burden +/- 5 %	4	1,73	1	2,31	
Exact point of measuring +/- 1 %	0,1	1,73	1	0,06	
Resolution in PPM	0,1	3,46	1	0,03	
Combined standard uncertainty				15,22	
Expanded uncertainty				30,43	40

BEV sample uncertainty budget

Current error uncertainty budget

quantity X_i	estimate x_i	standard uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(y)$
$F_{i,m}$	$35 \cdot 10^{-6}$	$3,9 \cdot 10^{-6}$	normal	1,0	$3,9 \cdot 10^{-6}$
$F_{i,N}$	$-20 \cdot 10^{-6}$	$17,3 \cdot 10^{-6}$	rectangular	1,0	$17,3 \cdot 10^{-6}$
$F_{i,B}$	0	$1,7 \cdot 10^{-6}$	rectangular	1,0	$1,7 \cdot 10^{-6}$
$F_{i,O}$	0	$5,8 \cdot 10^{-6}$	rectangular	1,0	$5,8 \cdot 10^{-6}$
F_i	$15 \cdot 10^{-6}$				$18,75 \cdot 10^{-6}$

Phase displacement uncertainty budget

quantity X_i	estimate x_i	standard uncertainty $u(x_i)$	probability distribution	sensitivity coefficient c_i	uncertainty contribution $u_i(y)$
$\delta_{i,m}$	$-128 \cdot 10^{-6}$ rad	$1,9 \cdot 10^{-6}$ rad	normal	1,0	$1,9 \cdot 10^{-6}$ rad
$\delta_{i,N}$	$29 \cdot 10^{-6}$ rad	$16,8 \cdot 10^{-6}$ rad	rectangular	1,0	$16,8 \cdot 10^{-6}$ rad
$\delta_{i,B}$	0	$3,5 \cdot 10^{-6}$ rad	rectangular	1,0	$3,5 \cdot 10^{-6}$ rad
$\delta_{i,O}$	0	$17,3 \cdot 10^{-6}$ rad	rectangular	1,0	$17,3 \cdot 10^{-6}$ rad
δ_i	$-99 \cdot 10^{-6}$				$24,45 \cdot 10^{-6}$ rad

where:
F_i and δ_i are the current ratio error and phase displacement respectively,
$F_{i,m}$ and $\delta_{i,m}$ are the mean value of 3 measurements,
$F_{i,N}$ and $\delta_{i,N}$ are the error of the standard transformers,
$F_{i,B}$ and $\delta_{i,B}$ are the standard uncertainty for the calibration of the measuring bridge,
$F_{i,O}$ and $\delta_{i,O}$ take into account other influences (e.g. influences of the current source).

PTB sample uncertainty budget

uncertainty budget
50 Hz; example: **500 A / 5 A**; I/I_n = **120 %**;

PTB Braunschweig, section 2.31, instrument transformers and high-voltage technique
EUROMET project 473; comparison of CT : (1 A to 1000 A) / 5 A; April 1999 - March 2000

CT$_N$: **IW 51**; 22.09.1999; lfd. Nr. 249 & 257; last update: 25.02.2000

current error ε_X

quantity X_i	estimated value x_i	limits	distribution	standard uncertainty $u(x_i)$	sensitivity coefficient c_i	uncertainty component $u_i(y)$	type
ε_{DA} (SEKAM; n = 10)	15.7 x 10-6	0.07 x 10-6	normal	0.02 x 10-6	1	0.02 x 10-6	A
ε_{DB} (SEKAM)	0	1.00 x 10-6	normal	0.50 x 10-6	1	0.50 x 10-6	B
ε_R (reproducibility)	0	1.80 x 10-6	rectangular	1.04 x 10-6	1	1.04 x 10-6	B
ε_{N1} (standard CT)	0.3 x 10-6	1.00 x 10-6	normal	0.50 x 10-6	1	0.50 x 10-6	B
ε_{N2} (influence of ε_{DA} and δ_{DA})	-1.9 x 10-6	1.00 x 10-6	rectangular	0.58 x 10-6	1	0.58 x 10-6	B
B (actual burden)	4.9 VA	0.10 %	normal	0.05 %	-17 x 10-6/VA	-0.04 x 10-6	B
ε_B (influence of burden)	-1.7 x 10-6	0.30 x 10-6	rectangular	0.17 x 10-6	1	0.17 x 10-6	B
ε_{MP} (influence of I/I_n)	0	0.11 x 10-6	rectangular	0.06 x 10-6	1	0.06 x 10-6	B
ε_F (influence of frequency)	0	0.03 x 10-6	rectangular	0.02 x 10-6	1	0.02 x 10-6	B
$\varepsilon_X = \varepsilon_{DA} + \varepsilon_{N1} + \varepsilon_{N2} + \varepsilon_B$	12.4 x 10-6					1.40 x 10-6	
measured value (*k* =2)	**12 x 10-6**	**± 3 x 10-6**					

phase displacement δ_X

quantity X_i	estimated value x_i	limits	distribution	standard uncertainty $u(x_i)$	sensitivity coefficient c_i	uncertainty component $u_i(y)$ in crad	type
δ_{DA} (SEKAM; n = 10)	-78.0 urad	0.08 urad	normal	0.03 urad	1	0.03 urad	A
δ_{DB} (SEKAM)	0	1.00 urad	normal	0.50 urad	1	0.50 urad	B
δ_R (reproducibility)	0	2.80 urad	rectangular	1.62 urad	1	1.62 urad	B
δ_{N1} (standard CT)	-0.5 urad	1.50 urad	normal	0.75 urad	1	0.75 urad	B
δ_{N2} (influence of ε_{DA} and δ_{DA})	-1.4 urad	1.00 urad	rectangular	0.58 urad	1	0.58 urad	B
B (actual burden)	4.9 VA	0.10 %	normal	0.05 %	26 urad/VA	0.06 urad	B
δ_B (influence of burden)	2.6 urad	1.10 urad	rectangular	0.64 urad	1	0.64 urad	B
δ_{MP} (influence of I/I_n)	0	0.22 urad	rectangular	0.13 urad	1	0.13 urad	B
δ_F (influence of frequency)	0	0.13 urad	rectangular	0.08 urad	1	0.08 urad	B
$\delta_X = \delta_{DA} + \delta_{N1} + \delta_{N2} + \delta_B$	-77.3 urad					2.05 urad	
measured value (*k* =2) :	**-77 urad**	**4 urad**	; measured value (*k* =2) :		-0.265´	± 0.014´	

METAS sample uncertainty budget

Components	***Type***	***Distribution***	***Standard uncertainties***			
			I/In = 1 %…10 %		I/In = 20 %…120 %	
	(AorB)	r:rectang.	***I error***	***Phase***	***I error***	***Phase***
		n:normal	(ppm)	(min)	(ppm)	(min)
Reference Current Transformer	B	r	6.0	0.040	4.0	0.030
Measurements						
Random noise (one measurement)	A	n	1.0	0.020	1.0	0.010
Non-linearity of the bridge	B	r	2.0	0.020	1.0	0.010
Frequency effects (±1 Hz)	B	r	0.3	0.004	0.3	0.004
Burden (±1 % of Pn)	B	r	0.7	0.005	0.7	0.005
Temperature (23 °C ±1 °C)	B	r	0.5	0.005	0.5	0.005
Reproducibility of the set-up	B	r	2.0	0.020	2.0	0.020
Combined standard uncertainty (effective degrees of freedom: 13, 12, 15 and 12 resp.)			6.8	0.054	4.8	0.040
Expanded uncertainty U, 95% Confidence level			14.8	0.119	10.2	0.089

GUM sample uncertainty budget

Ratio 5…1000/5 A/A. Uncertainty budget for ratio error x 10^{-6}

Uncertainty sources	Standard uncertainty for 120%…5% x I_n	Standard uncertainty for 2% and 1% x I_n	Probaility distribution	Sensitivity coefficient
Calibration of reference current transformer	15	15	normal	1.0
Error of current transformer bridge	10 / √3	50 / √3	rectangular	1.0
Calibration of current transformer bridge	5	5	normal	1.0
Error of burden box	3 / √3	3 / √3	rectangular	1.0
Error of indication of results	1 / √12	1 / √12	rectangular	1.0
Uncertainty type A	4.5	8.5	normal	1.0
Contribution to the standard uncertainty	17.5	34		

Ratio 5…1000/5 A/A. Uncertainty budget of phase displacement [min]

Uncertainty sources	Standard uncertainty for 120%…5% x I_n	Standard uncertainty for 2% and 1% x I_n	Probaility distribution	Sensitivity coefficient
Calibration of reference current transformer	0.05	0.05	normal	1.0
Error of current transformer bridge	0.10 / √3	0.50 / √3	rectangular	1.0
Calibration of current transformer bridge	0.05	0.05	normal	1.0
Error of burden box	0.03 / √3	0.03 / √3	rectangular	1.0
Error of indication of results	0.01 / √12	0.01 / √12	rectangular	1.0
Uncertainty type A	0.03	0.11	normal	1.0
Contribution to the standard uncertainty	0.1	0.32		

LBE sample uncertainty budget

1. Ratio uncertainties (%)

σ_1 : value (1σ) on the results of our Tettex CT comparator calibration at PTB * 0,001 5

σ_2 : calibration operation own 0,002 / $\sqrt{3}$

σ_3 : precision of the burden * 0,002 / $\sqrt{3}$

$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2} = 0{,}002\,2\ \%$

$2\sigma = 0{,}004\,4\ \%$ round up to 0,005 %

2. Phase uncertainties (minutes)

σ_1 : value (1σ) on the results of the PTB * calibration 0,05

σ_2 : calibration operation own 0,04 / $\sqrt{3}$

σ_3 : precision of the burden * 0,05 / $\sqrt{3}$

$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2} = 0{,}062\ '$

$2\sigma = 0{,}124\ '$ round up to 0,2 '

OMH sample uncertainty budget

Uncertainty estimation for the ratio error (u_h):

Source of uncertainty	Current level: 120%...50%			Current level: 20%...2%		
	type A |%|	type B |%|		type A |%|	type B |%|	
		I_n=50A	I_n>50A		I_n=50A	I_n>50A
Standard transformer	-	$2 \cdot 10^{-4}$	$10 \cdot 10^{-4}$	-	$2 \cdot 10^{-4}$	$10 \cdot 10^{-4}$
Measuring bridge	-	$2 \cdot 10^{-4}$		-	$2 \cdot 10^{-4}$	
Comparison	$0{,}6 \cdot 10^{-4}$	-		$4{,}4 \cdot 10^{-4}$	-	
Expanded uncertainty (coverage factor k=2)		$2{,}9 \cdot 10^{-4}$	$10{,}2 \cdot 10^{-4}$		$5{,}2 \cdot 10^{-4}$	$11{,}4 \cdot 10^{-4}$

IEN sample uncertainty budget

Rated ratio 5 A / 5 A uncertainty budget

Primary current [%I_n]	η_{CT} [ppm]	η_o u(η_o) [ppm]	distrib. type	η_R u(η_R) [ppm]	distrib. type	$\delta_{m,r}$ u(δ_m) [ppm]	distrib. type	u_c [ppm]	ν	k_p	$U(\eta_{CT})$ [ppm]
2	-2	2.9	rect.	1.9	rect.	1.4	rect.	3.8	>100	2.0	7.6
5	-2	2.9	"	1.9	"	1.4	"	3.7	>100	2.0	7.4
10	-1.5	2.9	"	1.8	"	1.4	"	3.7	>100	2.0	7.4
20	0.2	2.9	"	1.7	"	1.4	"	3.6	>100	2.0	7.2
50	4.1	2.9	"	1.6	"	1.4	"	3.6	>100	2.0	7.2
100	8.1	2.9	"	1.5	"	1.4	"	3.5	>100	2.0	7.0
120	9.6	2.9	"	1.5	"	1.4	"	3.5	>100	2.0	7.0

where:
η_{CT} is the measurement value of the CT ratio error,
η_o is the error of the compensated current comparator,
η_R is the bridge reading of the difference,
$\delta_{m,r}$ is a term related to the measurement repeatability.

HUT sample uncertainty budget

Model equation:

$CT_{ratio}=Ratio_{rog10m}*K_{rog}/K_{10m}*(1+\delta Ratio_{rog10m});$
$K_{10m}=(1+\delta stab_{10m})*(1+\delta warm_{10m})/R_{10m};$
$K_{1m}=K_{10m}*Ratio_{10c1c}*(1+\delta Ratio_{10c1c})*(1+\delta stab_{1m})*(1+\delta warm_{1m});$
$K_{rog}=K_{1m}*Ratio_{1crog}*(1+\delta Ratio_{1crog})*f_{rog}/f_{CTratio}*(1+\delta stab_{rog})*(1+\delta warm_{rog});$

Uncertainty budget:

Quantity	Value	Standard uncertainty	Degrees of freedom	Sensitivity coefficient	Uncertainty contribution	Index
$Ratio_{rog10m}$	39.7819960	$82.4\cdot10^{-6}$	9	5.03	$414\cdot10^{-6}$	0.1 %
$\delta Ratio_{rog10m}$	0.0	$20.0\cdot10^{-6}$	50	200	$4.00\cdot10^{-3}$	12.0 %
$f_{CTratio}$	55.00026209	$5.55\cdot10^{-6}$	9	-3.64	$-20.2\cdot10^{-6}$	0.0 %
f_{rog}	55.0002669	$16.8\cdot10^{-6}$	48	3.64	$61.3\cdot10^{-6}$	0.0 %
K_{10m}	96.82698	$2.17\cdot10^{-3}$				
R_{10m}	0.0103277					
$\delta stab_{10m}$	0.0	$10.0\cdot10^{-6}$	50	0.0	0.0	0.0 %
$\delta warm_{10m}$	0.0	$20.0\cdot10^{-6}$	50	0.0	0.0	0.0 %
K_{1m}	707.3214	0.0309				
$Ratio_{10c1c}$	7.3050036	$14.9\cdot10^{-6}$	78	27.4	$407\cdot10^{-6}$	0.1 %
$\delta Ratio_{10c1c}$	0.0	$30.0\cdot10^{-6}$	50	200	$6.00\cdot10^{-3}$	27.1 %
$\delta stab_{1m}$	0.0	$10.0\cdot10^{-6}$	50	200	$2.00\cdot10^{-3}$	3.0 %
$\delta warm_{1m}$	0.0	$20.0\cdot10^{-6}$	50	200	$4.00\cdot10^{-3}$	12.0 %
K_{rog}	486.8076	0.0284				
$Ratio_{1crog}$	0.68824095	$7.26\cdot10^{-6}$	48	291	$2.11\cdot10^{-3}$	3.3 %
$\delta Ratio_{1crog}$	0.0	$30.0\cdot10^{-6}$	50	200	$6.00\cdot10^{-3}$	27.1 %
$\delta stab_{rog}$	0.0	$20.0\cdot10^{-6}$	50	200	$4.00\cdot10^{-3}$	12.0 %
$\delta warm_{rog}$	0.0	$10.0\cdot10^{-6}$	50	200	$2.00\cdot10^{-3}$	3.0 %
CT_{ratio}	200.0081	0.0124	247			

Result:

Quantity: CT_{ratio}
Value: 200.008
Expanded uncertainty: ±0.025
Coverage factor: 2.0
Coverage probability: 95.45%

HUT sample uncertainty budget cont.

List of quantities:

Quantity	Unit	Definition
CT_{ratio}		calibration result, ratio of CT
$Ratio_{rog10m}$		voltage ratio, measured with Rogowski coil (high current) and shunt 0.01 ohm (low current)
$\delta Ratio_{rog10m}$		Uncertainty of voltage ratio measurement when measuring ratio of CT
$f_{CTratio}$		frequency when calibrating CT
f_{rog}		frequency of auxiliary calibration when calibrating Rogowski coil
K_{10m}		Scale factor for reference shunt
R_{10m}		Nominal value for 0.01 ohm shunt
$\delta stab_{10m}$		stability of 0.01 ohm reference shunt
$\delta warm_{10m}$		warming of 0.01 ohm reference shunt
K_{1m}		Scale factor for 0.001 ohm shunt
$Ratio_{10c1c}$		Auxiliary calibration, voltage ratio 0.001 ohm and 0.01 ohm shunts, measuring current 5.5 A
$\delta Ratio_{10c1c}$		Uncertainty of measurement when making auxiliary calibration, because of low voltage levels
$\delta stab_{1m}$		stability of 0.001 ohm shunt
$\delta warm_{1m}$		warming of 0.001 ohm shunt
K_{rog}		Measured scale factor for Rogowski coil
$Ratio_{1crog}$		Auxiliary calibration, ratio of 0.001 ohm shunt and Rogowski coil, measuring current 20 A
$\delta Ratio_{1crog}$		Uncertainty of measurement when making auxiliary calibration, because of low voltage levels
$\delta stab_{rog}$		stability of Rogowski coil
$\delta warm_{rog}$		warming of Rogowski coil

MIKES sample uncertainty budget

Amplitude Uncertainty contributions of 10 A: % A Shunt/Shunt measurement

Freq [Hz]	Current [%]	rm [10^6]	Alpha_200 [10^6]	T_200 [10^6]	T_0_200 [10^6]	Alpha_75 [10^6]	T_amb [10^6]	T_0_amb [10^6]	Rho [10^6]	rcal [10^6]	I-SET [10^6]	Unc. [10^6]
49.4	120	0.1	-0.5	-0.3	0.3	-0.3	3.9	-3.9	-1.0	-13.8	0.1	15
49.4	100	0.1	-0.1	-0.3	0.3	-0.3	3.9	-3.9	-0.8	-11.0	0.1	12
49.4	50	0.1	-0.1	-0.3	0.3	-0.3	3.9	-3.9	-0.6	-6.8	0.0	9
49.4	20	0.1	0.0	-0.3	0.3	-0.3	3.9	-3.9	-0.8	-5.9	0.0	8
49.4	10	0.2	-0.1	-0.3	0.3	-0.3	3.9	-3.9	-0.8	-5.8	0.0	8
49.4	5	0.3	0.0	-0.3	0.3	-0.3	3.9	-3.9	-0.6	-5.8	0.0	8
49.4	2	0.9	0.1	-0.3	0.3	-0.3	3.9	-3.9	-0.8	-5.8	0.0	8
53.8	120	0.1	0.8	-0.3	0.3	-0.3	3.9	-3.9	-1.0	-13.8	0.1	15
53.8	100	0.1	0.2	-0.3	0.3	-0.3	3.9	-3.9	-0.8	-11.0	0.1	12
53.8	50	0.0	0.1	-0.3	0.3	-0.3	3.9	-3.9	-0.6	-6.8	0.0	9
53.8	20	0.0	-0.2	-0.3	0.3	-0.3	3.9	-3.9	-0.8	-5.9	0.0	8
53.8	10	0.0	-0.1	-0.3	0.3	-0.3	3.9	-3.9	-0.8	-5.8	0.0	8
53.8	5	0.1	-0.1	-0.3	0.3	-0.3	3.9	-3.9	-0.6	-5.8	0.0	8
53.8	2	0.2	0.1	-0.3	0.3	-0.3	3.9	-3.9	-0.8	-5.8	0.0	8

where:
rm is the measured ratio of the voltages across the shunts,
Alpha_200 is the temperature coefficient of the 200 mΩ shunt in secondary circuit,
T_200 is the temperature of the 200 mΩ shunt during the actual transformer measurement,
T_0_200 is the temperature of the 200 mΩ shunt during the calibration,
Alpha _75 is the temperature coefficient of the 75 mΩ shunt in primary circuit,
T_amb is the ambient temperature during the actual transformer measurement,
T_0_amb is the ambient temperature during the calibration,
Rho represents the error introduced into the system by the resolution of the DMMs,
rcal is the calibrated ratio of the system,

CMI sample uncertainty budget

ratio: 1 A/5 A												
current	resultant value			type A uncertainty			type B uncertainty			combined uncertainty		
I_N [%]	ε_I [ppm]	δ_I [min]	δ_I [µrad]	$U_{A\varepsilon}$ [ppm]	$U_{A\delta}$ [min]	$U_{A\delta}$ [µrad]	$U_{B\varepsilon}$ [ppm]	$U_{B\delta}$ [min]	$U_{B\delta}$ [µrad]	U_ε [ppm]	U_δ [min]	U_δ [µrad]
120	**15.7**	**-0.281**	**-82**	0.3	0.006	1.6	5.9	0.026	7.6	**5.9**	**0.027**	**7.8**
100	**13.8**	**-0.288**	**-84**	0.3	0.005	1.6	5.9	0.026	7.6	**5.9**	**0.027**	**7.8**
50	**9.1**	**-0.317**	**-92**	0.3	0.006	1.7	6.2	0.033	9.5	**6.2**	**0.033**	**9.7**
20	**5.3**	**-0.352**	**-102**	0.4	0.006	1.8	6.7	0.037	10.8	**6.7**	**0.037**	**10.9**
10	**3.5**	**-0.375**	**-109**	0.3	0.006	1.8	6.7	0.039	11.3	**6.7**	**0.039**	**11.4**
5	**3.0**	**-0.392**	**-114**	0.3	0.006	1.9	8.2	0.043	12.6	**8.2**	**0.044**	**12.7**
2	**5.3**	**-0.403**	**-117**	2.5	0.009	2.6	18.3	0.061	17.9	**18.5**	**0.062**	**18.1**
1	**7.3**	**-0.417**	**-121**	2.0	0.005	1.4	29.4	0.104	30.3	**29.5**	**0.104**	**30.3**

where:
ε_I is the resultant ratio error (mean value)
δ_I is the resultant phase displacement (mean value)
$U_{A\varepsilon}$ and $U_{A\delta}$ is the standard type A uncertainty determined from n = 5 measurements,
$U_{B\varepsilon}$ and $U_{B\delta}$ is a combination of maximum errors associated with the standard comparator, the measuring bridge and adjustment of the current and burden.

UME sample uncertainty budget

The estimated errors of the following table are combined as if they were true, independent random errors. A uniform distribution is assumed for each of them. For a uniform distribution

$$s = \frac{d}{\sqrt{3}}$$

where *s* is the standard deviation, and *d* is the maximum value of the estimated error. The combined standard deviation is the square root of the sum of the squares of the individual standard deviations.

ESTIMATED POSSIBLE INSTABILITIES	Ratio Correction	Phase Angle
Core Magnetization	20 ppm	45 µrad
Uncertainty in Burden	15 ppm	35 µrad
Transformer Temperature	10 ppm	25 µrad
Current Value	15 ppm	35 µrad
Electromagnetic Interference	15 ppm	15 µrad
Combined Uncertainty	**19,8 ppm**	**42,1 µrad**

The reference current transformer was used with the test set having the systematic uncertainties of 10 ppm and 10 µrad as given in the following table.

SYSTEMATIC UNCERTAINTY OF UME EQUIPMENT	Ratio Correction	Phase Angle
Reference Current Transformer	10 ppm	10 µrad
Test Set	10 ppm	10 µrad
Total Systematic Uncertainty	**14,2 ppm**	**14,2 µrad**

In estimating the overall uncertainty, the random and systematic uncertainty components are combined using the guidelines of the “Guide to the Expression of Uncertainty in Measurement (GUM, ISO 1993)”. The two components are combined on a root-sum-squared basis at the two-sigma level.

U_r = **42,8 ppm**
U_p = **85,8 µrad**

The Overall Uncertainty	The rounded off figure of **100 ppm** (or **µrad**) is preferred to use for both error components.

VMT/VMC sample uncertainty budget

Current error f,%

Quantity Xi	Estimate xi	Standard uncertainty U,(Xi)	Probability distribution	Sensitivity coefficient ci	Uncertainty contribution Ui(y)
Ket sert	-0,004	5,00E-03	Normal	1	2,50E-03
TEBB77	0	5,57E-05	Normal	1	2,78E-05
Kmat vid	-0,01113	3,67E-05	Normal	1	1,83E-05
apval	1	1,00E-04	Triangular	1	4,08E-05
Kf	-0,01513			U(k)	2,50E-03
Kf = Ket sert + Kmat vid				U,k=2	5,00E-03

δ

Quantity Xi	Estimate xi	Standard uncertainty U,(Xi)	Probability distribution	Sensitivity coefficient ci	Uncertainty contribution Ui(y)
Ket sert	0,3	2,00E-01	Normal	1	1,00E-01
TEBB77	0	5,50E-03	Normal	1	2,75E-03
Kmat vid	-1,099	2,34E-03	Normal	1	1,17E-03
Tinklo dažnis	49,9997	4,30E-03	Square	1	2,48E-03
apval	1	1,00E-02	Triangular	1	4,08E-03
Kδ	-0,798993			U(δ)	1,00E-01
Kδ = Kmat vid × Ftinklo dažnis : 50 + Ket sert				U,k=2	2,00E-01

where:
Ket sert is the current error and phase displacement of the reference from its calibration certificate,
TEBB77 is the reading of the comparator,
Kmat vid is the observed difference in current error and phase displacement,
apval is resolution of the comparator,
Tinklo dažnis is the frequency of the mains supply,

BNM-LCIE sample uncertainty budget

RATIO

All ratios, except 1/5 A, I > 0,02.In

Quantity Xi	Estimate xi	Standard uncertainty *u(xi)*	Probability distribution /method of evaluation (A,B)	Sensitivity coefficient *ci*	Standard uncertainty contribution ci.*u(xi)*
Kd	1	1.10^{-6}.Kd	BR1	1	1.10^{-6}
S	0,1	1.10^{-5}.S	BR2	10	1.10^{-5}
r2	1000	1.10^{-5}.r2	BR3	5.10^{-4}	5.10^{-6}
R	0,2	1.10^{-5}.R	BR4	5	1.10^{-5}
r1	1000	1.10^{-5}.r1	BR5	5.10^{-4}	5.10^{-6}
Ke	Ke	1.10^{-5}.Ke	BR6	1/Ke	1.10^{-5}
Kd	1	6.10^{-6}.Kd	BL3	1	6.10^{-5}
Combined standard uncertainty (k=1)					2.10^{-5}
Expanded uncertainty (k=2)					40.10^{-6}

PHASE

All ratios, I > 0,02.In

Quantity Xi	Estimate xi	Standard uncertainty *u(xi)*	Probability distribution /method of evaluation (A,B)	Sensitivity Coefficient *Ci*	Standard uncertainty contribution ci.*u(xi)*
C1	5.10^{-9}	1.10^{-4}.C	BR1	$1,6.10^{5}$	8.10^{-8}
C2	5.10^{-9}	1.10^{-4}.C	BR1	$1,6.10^{5}$	2.10^{-8}
r	1000	1.10^{-5}.r	BR2	1.10^{-6}	1.10^{-8}
ω	100.π	1.10^{-3}.ω	BR3	3.10^{-6}	1.10^{-6}
C1	5.10^{-9}	0,06 nF	BL1	$1,6.10^{5}$	1.10^{-5}
combined standard uncertainty (k=1)					1.10^{-5}
Expanded uncertainty (k=2)					25.10^{-6}

where:
Kd (BR1) is the inductive divider in the bridge,
Kd (BL3) represents the sensitivity of the set-up; the zero of the detector is adjusted by means of the inductive divider,
S is the calibrated burden shunt,
R is the calibrated shunt connected to the secondary of the reference current transformer,
r1 and r2 represent calibration of resistors r1 and r2 in the bridge,
Ke is calibration of the reference transformer,
C1 (BR1) and C2 represent calibration of capacitors C1 and C2 in the bridge,
C1 (BL1) represents the sensitivity of the set-up; the zero of the detector is adjusted by means of capacitor C1,
r represents calibration of the resistor in the bridge,
ω is the measurement of the frequency.