EURAMET 1187

ANNEX 3

UNCERTAINTY BUDGETS

CONTENT

BEV

Example for 4 kA/5 A , I/I_N = 120% at 5 VA, resistive

Uncertainty budget for ε_I:

Quantity	**Standard uncertainty (ppm)**	**Probability distribution**	**Uncertainty contribution (ppm)**
Statistical spread of 3 measurands	1,3	normal	1,3
Standard current transformer BEV	30	normal k=2	15,0
Bridge, calibration	5	rectangular	2,9
Burden	15	rectangular	8,7
Other influences	10	rectangular	5,8
U(ε_I) for k=1			**18,5**

Uncertainty budget for δ_I:

Quantity	**Standard uncertainty (min)**	**Probability distribution**	**Uncertainty contribution (min)**
Statistical spread of 3 measurands	0,02	normal	0,02
Standard current transformer BEV	0,10	normal k=2	0,05
Bridge, calibration	0,03	rectangular	0,02
Burden	0,06	rectangular	0,03
Other influences	0,03	rectangular	0,02
U(δ_I) for k=1			**0,07**

BIM

Example for 6 kA/5 A , I/I_N = 50% at 15 VA, resistive

Uncertainty budget for ε_I:

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	Repeatability	Normal	-0,00694	0,0000123	9	1	1,23E-05	0,0080508
2	Reference standard	Rectangular	0	0,0005774	infinity	1	0,0005774	0,3778954
3	Error in the bridge	Rectangular	0	0,0012863	infinity	1	0,0012863	0,8419510
4	Drift of the reference standard	Rectangular	0	0,0005774	infinity	1	0,0005774	0,3778954
5	Resolution of test set	Rectangular	0	0,0000289	infinity	1	2,89E-05	0,0189160
6	Error due to burden setting	Rectangular	0	0,0000577	infinity	1	5,77E-05	0,0377666
7	Error due to current setting	Rectangular	0	0,0000722	infinity	1	7,22E-05	0,0472574
8	Circuit and temperature influence	Rectangular	0	0,0000577	infinity	1	5,77E-05	0,0377666
y		**Normal**	**-0,00694**	**0,0015278**	**infinity**			

Conf. level = 95,45%	***k* = 2,0000**
Result = -0,0069	***U* = 0,0031**

Model: $Y = X_1+X_2+X_3+X_4+X_5+X_6+X_7+X_8$

Uncertainty budget for δ_I:

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	Repeatability	Normal	0,45396	0,001014	9	1	0,001014	0,0171235
2	Reference standard	Rectangular	0	0,0288675	infinity	1	0,0288675	0,4874885
3	Error in the bridge	Rectangular	0	0,0426177	infinity	1	0,0426177	0,7196891
4	Drift of the reference standard	Rectangular	0	0,0288675	infinity	1	0,0288675	0,4874885
5	Resolution of test set	Rectangular	0	0,00289	infinity	1	0,00289	0,0488037
6	Error due to burden setting	Rectangular	0	0,00204	infinity	1	0,00204	0,0344497
7	Error due to current setting	Rectangular	0	0,002448	infinity	1	0,002448	0,0413396
8	Circuit and temperature influence	Rectangular	0	0,00204	infinity	1	0,00204	0,0344497
y		**Normal**	0,45396	0,0592168	**infinity**			

Conf. level = 95,45%	***k* = 2,0000**
Result = 0,45	***U* = 0,12**

Model: $Y = X_1+X_2+X_3+X_4+X_5+X_6+X_7+X_8$

CMI

Uncertainty budget for ε_I:

Quantity	Limits of error (ppm)	Distribution	Type	Uncertainty contribution (ppm)
Standard current comparator Tettex 4764	10	rectangular	B	5.8
System for error evaluation Tettex 2767	10	rectangular	B	5.8
Burden adjustment	2	rectangular	B	1.2
Primary current adjustment	2	rectangular	B	1.2
Measuring circuit arrangement	2	normal	B	1.2
Primary current swapping (k x l)	2	rectangular	B	1.2
Statistical spread of 5 measurements	3	normal	A	3.0
Standard combined $u(\varepsilon_I)$ for k=1				**9.0**

Uncertainty budget for δ_I:

Quantity	Limits of error (μrad)	Distribution	Type	Uncertainty contribution (μrad)
Standard current comparator Tettex 4764	15	rectangular	B	8.7
System for error evaluation Tettex 2767	18	rectangular	B	10.4
Burden adjustment	2	rectangular	B	1.2
Primary current adjustment	2	rectangular	B	1.2
Measuring circuit arrangement	3	normal	B	1.7
Primary current swapping (k x l)	15	rectangular	B	8.7
Statistical spread of 5 measurements	25	normal	A	25.0
Standard combined $u(\delta_I)$ for k=1				**29.8**

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Uncertainty budget for ratio error

Model of measurement for ratio error ε_I is given by the next formula:

$$\varepsilon_I = \Delta\varepsilon_I + \Delta\varepsilon_{I\_INST} + \Delta\varepsilon_{I\_INST\_CAL} + \Delta\varepsilon_{I\_INST\_RES} + \Delta\varepsilon_{I\_EST} + \Delta\varepsilon_{I\_EST\_CAL} + \\ + \Delta\varepsilon_{I\_B} + \Delta\varepsilon_{I\_B\_CAL} + \Delta\varepsilon_{Iref} + \Delta\varepsilon_{I\_AT} + \Delta\varepsilon_{I\_AT\_CAL} \quad (1)$$

where

ε_I is ratio error of the tested travelling standard current transformer, in microamper per amper [μA/A],

$\Delta\varepsilon_I$ is the calculated average value of N readings of ratio error indicated on the display of transformer test set (INST-2A), in microamper per amper [μA/A],

$\Delta\varepsilon_{I\text{-}INST}$ is correction of ratio error due to the manufacturer specifications of transformer test set (INST-2A), in microamper per amper [μA/A],

$\Delta\varepsilon_{I\text{-}INST\text{-}CAL}$ is correction of ratio error due to the uncertainty of transformer test set (INST-2A) calibration, in microamper per amper [μA/A],

$\Delta\varepsilon_{I\text{-}INST\text{-}RES}$ is correction of ratio error due to resolution of transformer test set (INST-2A), in microamper per amper, [μA/A],

$\Delta\varepsilon_{I\text{-}EST}$ is correction of ratio error due to the manufacturer specifications of reference current transformer EST, in microamper per amper, [μA/A],

$\Delta\varepsilon_{I\text{-}EST\text{-}CAL}$ is correction of ratio error due to the uncertainty of calibration for the reference current transformer EST, in microamper per amper, [μA/A],

$k_B\Delta\varepsilon_{I\text{-}B}$ is correction of ratio error due to error of burden, in microamper per amper [μA/A],

$\Delta\varepsilon_{I\text{-}B\text{-}CAL}$ is correction of ratio error due to the uncertainty of burden calibration, in microamper per amper [μA/A],

$k_{Iref}\,\Delta\varepsilon_{Iref}$ is correction of ratio error due to the deviation of the current from rated value, in microamper per amper [μA/A],

$\Delta\varepsilon_{I\text{-}AT}$ is correction of ratio error due to the error of adapter transformer AT (on ranges 6 kA, 8 kA and 10 kA) as given by the manufacturer, in microamper per amper [μA/A],

$\Delta\varepsilon_{I\text{-}AT\text{-}CAL}$ is correction of ratio error due to the uncertainty of calibration of adapter transformer, in microamper per amper [μA/A].

For calculations of ratio error ε_I we have done corrections due to error of adapter transformer $\Delta\varepsilon_{I\text{-}AT}$. Other corrections we did not do but those components are evaluated as uncertainties of measured ratio error of the tested traveling standard current transformer.

Sources of uncertainty in the ratio error determination

1) **Repeatability - Calculated average value of N readings of ratio error for traveling standard current transformer indicated on the display of transformer test set (INST-2A)**, $u_{A1}(\varepsilon_I)$

type A uncertainty, normal distribution, degrees of freedom (N-1)

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- the average value of measured ratio error and its associated experimental standard deviation is calculated,
- the type A uncertainty is calculated dividing standard deviation of ratio error measurement by square root of number of measurements.

2) uncertainty due to manufacturer specifications of transformer test set (INST-2A), $u_{B1} = u(\Delta\varepsilon_{I\text{-}INST})$
uncertainty type B, rectangular distribution, degrees of freedom infinity
-the value of manufacturer specification for ratio error of transformer test set (INST-2A) ± (0.2 % of readings + 0.1 % of range) we divide by $\sqrt{3}$.

3) uncertainty of measurement as given in calibration certificate for transformer test set (INST-2A), $u_{B2} = u(\Delta\varepsilon_{I\text{-}INST\text{-}CAL})$,
type B uncertainty, normal distribution, degrees of freedom 50
- the value of expanded uncertainty of measurement for reference standard transformer is taken from calibration certificate given by PTB, divided by 2.

4) uncertainty of ratio error of transformer test set (INST-2A) due to limited resolution, $u_{B3} = u(\Delta\varepsilon_{I\text{-}INST\text{-}RES})$,
uncertainty type B, rectangular distribution, degrees of freedom infinity
- the value of resolution 0,0001% for ratio error of transformer test set (INST-2A) we divide by $2\sqrt{3}$ and get result 0,00003%.

5) uncertainty of the reference current transformer EST for the measurement of ratio error as given by the manufacturer, $u_{B4} = u(\Delta\varepsilon_{I\text{-}EST})$
type B uncertainty, rectangular distribution, degrees of freedom infinity
- the value of manufacturer specification for ratio error of reference standard transformer we divide by $\sqrt{3}$.

6) uncertainty of measurement as given in calibration certificate for the reference current transformer EST, $u_{B5} = u(\Delta\varepsilon_{I\text{-}EST\text{-}CAL})$
type B uncertainty, normal distribution, degrees of freedom 50
- the value of expanded uncertainty of measurement for reference standard transformer is taken from calibration certificate given by PTB and divided by 2.

7) uncertainty due to error of burden, $u_{B6} = \mathrm{u}(k_B\Delta\varepsilon_{I\text{-}B})$
type B uncertainty rectangular distribution, degrees of freedom infinity
-the value of burden 5 VA (or 15 VA where applicable) is multiplied by 1 % and by k_B and divided by $\sqrt{3}$, to determine the influence of burden on the ratio error.

8) uncertainty of measurement as given in calibration certificate for the burden, $u_{B7} = u(\Delta\varepsilon_{I\text{-}B\text{-}CAL})$
type B uncertainty, normal distribution, degrees of freedom 50
- the value of expanded uncertainty for burden calibration is taken from calibration certificate given by DMDM and divided by 2.

9) uncertainty due to the deviation of the current from rated value, $u_{B8} = u(k_{Iref}\ \Delta\varepsilon_{Iref})$
type B uncertainty, rectangular distribution, degrees of freedom infinity
- the estimated deviation of the adjusted current 0.1% from the rated value is multiplied by k_{Iref} and divided by $\sqrt{3}$ to determine the influence of applied current on the ratio error.

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10) uncertainty of adapter standard transformer AT for the measurement of ratio error as given by the manufacturer, $u_{B9} = u(\Delta\varepsilon_{I\text{-}AT})$
uncertainty type B, rectangular distribution, degrees of freedom infinity
-because we corrected results by the value of adapter standard transformer ratio error, u_{B9} component of uncertainty is zero.
Adapter standard transformer we used for the measurement of ratio error for ranges 6 kA, 8 kA and 10 kA.

11) uncertainty of measurement as given in calibration certificate for the adapter current transformer, $u_{B10} = u(\Delta\varepsilon_{I\text{-}AT\text{-}CAL})$
type B uncertainty, normal distribution, degrees of freedom 50
- the value of expanded uncertainty of measurement for adapter standard transformer is taken from calibration certificate given by DMDM and divided by 2.

The combined standard uncertainty for the ratio error $u_C(\varepsilon_I)$
is calculated according to:

$$u_C(\varepsilon_I) = \begin{bmatrix} c_{A1}^2 \cdot u_{A1}^2(\Delta\varepsilon_I) + c_1^2 \cdot u^2(\Delta\varepsilon_{I-INST}) + c_2^2 \cdot u^2(\Delta\varepsilon_{I-INST-CAL}) + c_3^2 \cdot u^2(\Delta\varepsilon_{I-INST-RES}) + \\ + c_4^2 \cdot u^2(\Delta\varepsilon_{I-EST}) + c_5^2 \cdot u^2(\Delta\varepsilon_{I-EST-CAL}) + c_6^2 \cdot u^2(\Delta\varepsilon_{I-B}) + c_7^2 \cdot u^2(\Delta\varepsilon_{I-B-CAL}) + \\ c_8^2 \cdot u^2(\Delta\varepsilon_{Iref}) + c_9^2 \cdot u^2(\Delta\varepsilon_{I-AT}) + c_{10}^2 \cdot u^2(\Delta\varepsilon_{I-AT-CAL}) \end{bmatrix}^{1/2} \quad (2)$$

where c_{A1}, c_1 to c_{10} are sensitivity coefficients.

$$c_{A1} = c_1 = c_2 = c_3 = c_4 = c_5 = c_7 = c_9 = c_{10} = 1 \quad (3)$$

$$c_6 = k_B = \frac{\partial u_C(\varepsilon_I)}{\partial(\Delta\varepsilon_{I-B})} \cong \frac{[\varepsilon_I(I_{ref}, S_i) - \varepsilon_I(I_{ref}, S_i \cdot 1/100)]}{(S_i \cdot 1/100)} \quad (4)$$

where:

S_i	is the set value of burden of the tested transformer,
$\varepsilon_I(I_{ref}, S_i)$	is the ratio error of the tested transformer for I_{ref} and S_i,
$\varepsilon_I(I_{ref}, S_i \cdot 1/100)$	is the ratio error of the tested transformer for I_{ref} and burden $S_i \cdot 1/100$.

The sensitivity coefficient c_8 must be determined for each measurement point, ie. for the reference currents I_{ref} equal to: 0,01 I_n; 0,02 I_n; 0,05 I_n; 0,2 I_n; 1,0 I_n and 1,2 I_n for the same burden S_i.

$$c_8 = k_{Iref} = \frac{\partial u_c(\varepsilon_I)}{\partial(\Delta\varepsilon_{Iref})} = \frac{\varepsilon_I(I_{ref-1}, S_i) - \varepsilon_I(I_{ref-2}, S_i)}{(I_{ref-1} - I_{ref-2})} \quad (5)$$

where:

$\varepsilon_I(I_{ref-1}, S_i) - \varepsilon_I(I_{ref-2}, S_i)$	is a difference of values of ratio errors in two adjacent measurement points,

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S_i	is set value of burden of tested transformer,
$\varepsilon_I\ (I_{ref\text{-}1}, S_i)$	is ratio error of the tested transformer for measurement point $I_{ref\text{-}1}$ for S_i burden,
$\varepsilon_I\ (I_{ref\text{-}2}, S_i)$	is ratio error of the tested transformer for measurement point $I_{ref\text{-}2}$ for S_i burden.
$(I_{ref-1} - I_{ref-2})$	is difference of reference currents in two adjacent measurement points $I_{ref\text{-}1}$ and $I_{ref\text{-}2}$.

The examples of uncertainty budget for ratio error are given in tables 3 and 4.

Table 3: The uncertainty budget for the ratio error for
measurement point: 4000 A/ 5 A, burden 5 VA, I/In = 100 %

Quantity	Value [μA/A]	Standard uncertainty	Sensitivity koefficient c_i	$c_i \cdot u\ (x_i)$ [μA/A]
$\Delta\varepsilon_I$	**-83**	0.9 μA/A	1	0.9
$\Delta\varepsilon_{I\text{-}INST}$	**0**	1.25 μA/A	1	1.25
$\Delta\varepsilon_{I\text{-}INST\text{-}CAL}$	**0**	10 μA/A	1	10
$\Delta\varepsilon_{I\text{-}INST\text{-}RES}$	**0**	0.289 μA/A	1	0.289
$\Delta\varepsilon_{I\text{-}EST}$	**0**	5,774 μA/A	1	5,774
$\Delta\varepsilon_{I\text{-}EST\text{-}CAL}$	**0**	15.0 μA/A	1	15.0
$\Delta\varepsilon_{I\text{-}B}$	**0**	0.0289 VA	10 ppm/VA	0.289
$\Delta\varepsilon_{I\text{-}B\text{-}CAL}$	**0**	0.000018 VA	10 ppm/VA	0.00018
$\Delta\varepsilon_{Iref}$	**0**	0.058 %	0 ppm / %	0
$\Delta\varepsilon_{I\text{-}AT}$	**0**	0 μA/A	1	0
$\Delta\varepsilon_{I\text{-}AT\text{-}CAL}$	**0**	0 μA/A	1	0
ε_I	**-83**	Combined standard uncertainty $u_C\ (\varepsilon_I)$		**19.0**

Result of measurement:

Measured ratio error is	ε_I = - 83 μA/A.
Combined standard uncertainty is	$u_C\ (\varepsilon_I)$= 19.0 μA/A.
Expanded uncertainty is	$U\ (\varepsilon_I)$= 2 · 19.0 μA/A = 38.0 μA/A.

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Table 4: The uncertainty budget for the ratio error for
measurement point: 6000 A/ 5 A, burden 15 VA, I/In = 50 %

Quantity	Value [μA/A]	Standard uncertainty	Sensitivity koefficient c_i	$c_i \cdot u(x_i)$ [μA/A]
$\Delta\varepsilon_I$	**7**	13.0 μA/A	1	13.0
$\Delta\varepsilon_{I\text{-INST}}$	**0**	1.16 μA/A	1	1.16
$\Delta\varepsilon_{I\text{-INST-CAL}}$	**0**	10 μA/A	1	10
$\Delta\varepsilon_{I\text{-INST-RES}}$	**0**	0.289 μA/A	1	0.289
$\Delta\varepsilon_{I\text{-EST}}$	**0**	5.774 μA/A	1	5.774
$\Delta\varepsilon_{I\text{-EST-CAL}}$	**0**	15.0 μA/A	1	15.0
$\Delta\varepsilon_{I\text{-B}}$	**0**	0.0866 VA	10 ppm/VA	0.866
$\Delta\varepsilon_{I\text{-B-CAL}}$	**0**	0.000053 VA	10 ppm/VA	0.00053
$\Delta\varepsilon_{Iref}$	**0**	0.058 %	0 ppm/ %	0
$\Delta\varepsilon_{I\text{-AT}}$	**- 31**	0 μA/A	1	0
$\Delta\varepsilon_{I\text{-AT-CAL}}$	**0**	20.0 μA/A	1	20.0
ε_I	**-25**	Combined standard uncertainty $u_C(\varepsilon_I)$		**30.5**

Result of measurement:

Measured ratio error is	ε_I = - 25 μA/A.
Combined standard uncertainty is	$u_C(\varepsilon_I)$= 30.5 μA/A.
Expanded uncertainty is	$U(\varepsilon_I)$= 2 · 30.5 μA/A = 61.0 μA/A.

Uncertainty budget for phase displacement

Model of measurement for phase displacement δ_I is given by the next formula:

$$\delta_I = \Delta\delta_I + \Delta\delta_{I\_INST} + \Delta\delta_{I\_INST\_CAL} + \Delta\delta_{I\_INST\_RES} + \Delta\delta_{I\_EST} + \Delta\delta_{I\_EST\_CAL} + \\ + k_{phB}\Delta\delta_{I\_B} + k_{phIref}\Delta\delta_{Iref} + \Delta\delta_{I\_AT} \quad (6)$$

where

δ_I is phase displacement of the tested current transformer, in minutes [′],

$\Delta\delta_I$ is the calculated average value of N readings of phase displacement indicated on the display of transformer test set (INST-2A), in minutes [′],

$\Delta\delta_{I\text{-INST}}$ is correction of phase displacement due to manufacturer specifications of transformer test set (INST-2A), in minutes [′],

$\Delta\delta_{I\text{-INST-CAL}}$ is correction of phase displacement due to the uncertainty of transformer test set (INST-2A) calibration of phase displacement, in minutes [′],

$\Delta\delta_{I\text{-INST-RES}}$ is correction of phase displacement due to resolution of of transformer test set (INST-2A), in minutes [′],

$\Delta\delta_{I\text{-EST}}$ is correction of phase displacement due to the manufacturer specification for the reference current transformer EST, in minutes [′],

$\Delta\delta_{I\text{-EST-CAL}}$ is correction of phase displacement due to the uncertainty of calibration for the reference current transformer EST, in minutes [′],

$k_{phB}\Delta\delta_{I\text{-B}}$ is correction of phase displacement due to phase error of burden, in minutes [′],

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$k_{phIref}\,\Delta\delta_{Iref}$ is correction of phase displacement due to the deviation of the current from rated value, in minutes [′],

$\Delta\delta_{I\text{-AT}}$ is correction of phase displacement due to phase displacement of used adapter transformer, in minutes [′].

For calculations of phase displacement δ_I we have done corrections due to phase displacement of adapter transformer $\Delta\delta_{I\text{-AT}}$. Other corrienctions we did not do but those components are evaluated as uncertainties of measured phase displacement of the tested travelling standard current transformer.

Sources of uncertainty in the phase displacement determination

1) Repetability - Calculated average value of *N* readings of phase displacement indicated on the display of transformer test set (INST-2A), $u_{A2}(\delta_I)$

type A uncertainty, normal distribution, degrees of freedom (N-1)

- the average value of measured phase displacement and its associated experimental standard deviation is calculated,
- the type A uncertainty is calculated dividing standard deviation of phase displacement measurement by square root of number of measurements.

2) uncertainty due to manufacturer specifications for transformer test set (INST-2A) for the measurement of phase displacement, $u_{B11} = u(\Delta\delta_{I\text{-INST}})$

uncertainty type B, rectangular distribution, degrees of freedom infinity

-the value of manufacturer specification for phase displacement of transformer test set ± (0.2 % of readings + 0.1 % of range) we divide by $\sqrt{3}$.

3) uncertainty due to the uncertainty of transformer test set (INST-2A) calibration of phase displacement, $u_{B12} = u(\Delta\delta_{I\text{-INST-CAL}})$,

type B uncertainty, normal distribution, degrees of freedom 50

- the value of expanded uncertainty of measurement for reference standard transformer is taken from calibration certificate and divided by 2.

4) uncertainty due to limited resolution of phase displacement of transformer test set (INST-2A), $u_{B13} = u(\Delta\delta_{I\text{-INST-RES}})$,

uncertainty type B, rectangular distribution, degrees of freedom infinity

- the value of resolution 0,0001′ for phase displacement of device INST-2A we divide by $2\sqrt{3}$.

5) uncertainty of the reference current transformer for the measurement of phase displacement as given by the manufacturer, $u_{B14} = u(\Delta\delta_{I\text{-EST}})$

type B uncertainty, rectangular distribution, degrees of freedom infinity

- the value of manufacturer specification for phase displacement measurement of reference standard transformer we divide by $\sqrt{3}$.

6) uncertainty of measurement as given in calibration certificate for the reference current transformer, $u_{B15} = u(\Delta\delta_{I\text{-EST-CAL}})$

type B uncertainty, normal distribution, degrees of freedom 50

- the value of expanded uncertainty of measurement for reference standard transformer is taken from calibration certificate and divided by 2.

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7) uncertainty due to error of burden, $u_{B16} = u(k_{phB}\Delta\delta_{I\text{-}B})$
type B uncertainty rectangular distribution, degrees of freedom infinity
- the value of burden 5 VA (or 15 VA where applicable) is multiplied by 1 % and by k_{phB} and divided by $\sqrt{3}$ to determine the influence of burden on the phase displacement.

8) uncertainty due to the deviation of the current from rated value,
$u_{B17} = u(k_{phIref}\,\Delta\delta_{Iref})$
type B uncertainty, rectangular distribution, degrees of freedom infinity
- the estimated deviation of the adjusted current (± 0.1% *I*ref) from the rated value we divided by $\sqrt{3}$ and multipied by k_{phIref} to determine the influence of applied current on the phase displacement.

9) uncertainty due to the deviation of the measurement becouse adapter standard transformer AT, $u_{B18} = u(\Delta\delta_{I\text{-}AT})$
type B uncertainty, normal distribution, degrees of freedom 50
-because we have corrected results by the value for phase displacement of adapter standard transformer this component of uncertainty u_{B18} is zero.
Adapter standard transformer we used for the measurement of phase displacement for ranges 6 kA, 8 kA and 10 kA.

The combined standard uncertainty for the phase displacement $u_C(\delta_I)$ is calculated according to:

$$u_C(\delta_I) = \begin{bmatrix} c_{A2}^2 \cdot u_{A2}^2(\Delta\delta_I) + c_{11}^2 \cdot u^2(\Delta\delta_{I-INST}) + c_{12}^2 \cdot u^2(\Delta\delta_{I-INST-CAL}) + \\ c_{13}^2 \cdot u^2(\Delta\delta_{I-INST-RES}) + c_{14}^2 \cdot u^2(\Delta\delta_{I-EST}) + c_{15}^2 \cdot u^2(\Delta\delta_{I-EST-CAL}) + \\ c_{16}^2 \cdot u^2(k_{phB} \cdot \Delta\delta_{I-B}) + c_{17}^2 \cdot u^2(k_{phIref} \cdot \Delta\delta_{Iref}) + c_{18}^2 \cdot u^2(\Delta\delta_{I-AT}) \end{bmatrix}^{1/2} \quad (7)$$

where c_{A2}, c_{11} to c_{18} are sensitivity coefficients.

$$c_{A2} = c_{11} = c_{12} = c_{13} = c_{14} = c_{15} = c_{18} = 1 \quad (8)$$

$$c_{16} = k_{phB} = \frac{\partial u_C(\delta_I)}{\partial(\Delta\delta_{I-B})} \cong \frac{[\delta_I(I_{ref}, S_i) - \delta_I(I_{ref}, S_i \cdot 1/100)]}{(S_n \cdot 1/100)} \quad (9)$$

where:

S_i	is the set value of burden of the tested transformer,
$\delta_I(I_{ref}, S_i)$	is the phase displacement of the tested transformer for I_{ref} and S_i,
$\delta_I(I_{ref}, S_i \cdot 1/100)$	is the phase displacement of the tested transformer for I_{ref} and burden $S_i \cdot 1/100$.

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The sensitivity coefficient c_{15} must be determined for each measurement point, ie. for the reference currents I_{ref} equal to: 0,01 I_n; 0,02 I_n; 0,05 I_n; 0,2 I_n; 1,0 I_n and 1,2 I_n for the same burden S_i.

$$c_{17} = k_{phIref} = \frac{\partial u_c(\delta_I)}{\partial(\Delta\delta_{Iref})} = \frac{\delta_I(I_{ref-1}, S_i) - \delta_I(I_{ref-2}, S_i)}{(I_{ref-1} - I_{ref-2})} \tag{10}$$

where:

$\delta_I(I_{ref-1}, S_i) - \delta_I(I_{ref-2}, S_i)$	is a difference of values of phase displacement in two adjacent measurement points,
S_i	is set value of burden of tested transformer,
$\delta_I(I_{ref-1}, S_n)$	is phase displacement of the tested transformer for measurement point I_{ref-1} for S_i burden,
$\delta_I(I_{ref-2}, S_n)$	is phase displacement of the tested transformer for measurement point I_{ref-2} for S_i burden.
$(I_{ref-1} - I_{ref-2})$	is difference of reference currents in two adjacent measurement points I_{ref-1} and I_{ref-2} .

The examples of uncertainty budgets for phase displacement are given in tables 5 and 6.

Table 5: The uncertainty budget for the phase displacement for measurement point: 4000 A/ 5 A, burden 5 VA, I/In = 100 %

Quantity	Value [']	Standard uncertainty	Sensitivity koefficient c_i	$c_i \cdot u(x_i)$ [']
$\Delta\delta_I$	**0.7859'**	0.0233′	1	0.0233
$\Delta\delta_{I\text{-INST}}$	**0**	0.0067′	1	0.0067
$\Delta\delta_{I\text{-INST-CAL}}$	**0**	0.0500′	1	0.0500
$\Delta\delta_{I\text{-INST-RES}}$	**0**	0.00003′	1	0.00003
$\Delta\delta_{I\text{-EST}}$	**0**	0.0289′	1	0.0289
$\Delta\delta_{I\text{-EST-CAL}}$	**0**	0.0515′	1	0.0515
$\Delta\delta_{I\text{-B}}$	**0**	0.0289 VA	0.0920 ′/VA	0.0027
$\Delta\delta_{Iref}$	**0**	0.0577 %	0 ′/%	0
$\Delta\delta_{I\text{-AT}}$	**0**	0′	1	0
δ_I	**0.7859'**	Combined standard uncertainty $u_C(\delta_I)$		**0.0811'**

Result of measurement:

Measured phase displacement is	δ_I = 0.7859'.
Combined standard uncertainty is	$u_C(\delta_I)$ = 0.0811'.
Expanded uncertainty is	$U(\delta_I) = 2 \cdot 0.0811' = 0.1622'$.

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DMDM

Table 6: The uncertainty budget for the phase displacement for
measurement point: 6000 A/ 5 A, burden 15 VA, *I*/*I*n = 50 %

Quantity	Value [']	Standard uncertainty [']	Sensitivity koefficient c_i	$c_i \cdot u(x_i)$ [']
$\Delta\delta_I$	**0.4181'**	0.0641′	1	0.0641′
$\Delta\delta_{I\text{-INST}}$	**0**	0.0066′	1	0.0066′
$\Delta\delta_{I\text{-INST-CAL}}$	**0**	0.0500′	1	0.0500′
$\Delta\delta_{I\text{-INST-RES}}$	**0**	0.00003′	1	0.00003′
$\Delta\delta_{I\text{-EST}}$	**0**	0.0289′	1	0.0289′
$\Delta\delta_{I\text{-EST-CAL}}$	**0**	0.0515′	1	0.0515′
$\Delta\delta_{I\text{-B}}$	**0**	0.0866 VA	0.0920 ′/VA	0.0080
$\Delta\delta_{Iref}$	**0**	0.0577 %	0 ′/%	0
$\Delta\delta_{I\text{-AT}}$	**0.2645**	0′	1	0.5774′
δ_I	**0.6826'**	Combined standard uncertainty $u_C(\delta_I)$		**0.1010'**

Result of measurement:

Measured phase displacement is $\delta_I = 0.6826'$.

Combined standard uncertainty is $u_C(\delta_I) = 0.1010'$.

Expanded uncertainty is $U(\delta_I) = 2 \cdot 0.1010' = 0.2020'$.

GUM

Uncertainty budget for ε_I:

Burden (VA)	Ratio (kA/A)	Measured current I_M (% I_R)	Result value of ratio error ε_I (ppm)	Standard uncertainty type A of ε_I $u_{A\varepsilon}$ (ppm)	Standard uncertainty type B of ε_I $u_{B\varepsilon}$ (ppm)	Combined uncertainty of ε_I u_ε (ppm)
5 resistive	**4/5**	120	-87	1	19,3	19,4
		100	-85	1	19,3	19,4
		50	-74	1	19,3	19,4
		20	-59	1	19,3	19,4
		10	-48	1	19,3	19,4
		5	-32	1	19,3	19,4
		2	+5	1	28,4	28,4
		1	-	-	-	-
	10/5	120	-	-	-	-
		100	-18	1	19,3	19,4
		50	-14	1	19,3	19,4
		20	-2	1	19,3	19,4
		10	+1	1	19,3	19,4
		5	+8	1	19,3	19,4
		2	+27	1	28,4	28,4
		1	-	-	-	-

Uncertainty budget for δ_I:

Burden (VA)	Ratio (kA/A)	Measured current I_M (% I_R)	Result value of phase displacement δ_I (')	Standard uncertainty type A of δ_I $u_{A\delta}$ (')	Standard uncertainty type B of δ_I $u_{A\delta}$ (')	Combined uncertainty of δ_I $u_{A\delta}$ (')
5 resistive	**4/5**	120	+0,61	0,03	0,132	0,14
		100	+0,59	0,02	0,132	0,14
		50	+0,71	0,01	0,132	0,14
		20	+0,84	0,01	0,132	0,14
		10	+0,88	0,01	0,132	0,14
		5	+0,89	0,01	0,132	0,14
		2	+0,74	0,02	0,250	0,26
		1	-	-	-	-
	10/5	120	-	-	-	-
		100	+0,37	0,01	0,132	0,14
		50	+0,37	0,01	0,132	0,14
		20	+0,40	0,01	0,132	0,14
		10	+0,41	0,01	0,132	0,14
		5	+0,41	0,01	0,132	0,14
		2	+0,32	0,01	0,250	0,26
		1	-	-	-	-

INRIM

Uncertainty budget for ε_I ($I_p = 100\% I_n$):

Quantity/influence factor X_i	**Estimate** x_i **(ppm)**	**Standard unc. u(x_i) (ppm)**	**Probability distribution**	**Type**	**Sensitivity coefficient** c_i	**Uncertainty contribution** u_i **(ppm)**
Reference CT ratio error ε_{CTN}	0	13 (*)	Normal	B	1	13 (*)
ratio error ε_{IT} of IT test set	0	5	Normal	B	1	5
Mean value of IT test set opposite polarity indications and noise	ε_R	1.7	Normal	A	1	1.2
Burden $d\varepsilon_B$	0	1.4	Rectangular	B	1	1.7
Residual core magnetisation $d\varepsilon_M$	0	1.7	Rectangular	B	1	1.7
Current value $d\varepsilon_C$	0	1.6	Rectangular	B	1	1.2
Current adjusting time $d\varepsilon_T$	0	2.9	Rectangular	B	1	2.9
Measuring circuit arrangement $d\varepsilon_{MC}$	0	1.2	Rectangular	B	1	1.2
ε_I	ε_R					15
			Expanded Uncertainty ($k = 2$)			30

(*) For the 10000 A/5 A transformation ratio u(ε_{CTN}) = 16 ppm and u(ε_I)=18 ppm

Uncertainty budget for δ_I ($I_p = 100\% I_n$):

Quantity/influence factor X_i	**Estimate** x_i **(µrad)**	**Standard unc.** $u(x_i)$ **(µrad)**	**Probability distribution**	**Type**	**Sensitivity coefficient** c_i	**Uncertainty contribution** u_i**(µrad)**
Phase δ_{CTN} of the reference CT	0	22 (*)	Normal	B	1	22
Phase error δ_{IT} pf the CT test set	0	5	Normal	B	1	5
Mean value of IT test set opposite polarity indications and noise δ_R	δ_R	10	Normal	A	1	1.7
Burden influence $d\delta_B$	0	2.9	Rectangular	B	1	2.9
Residual core magnetisation $d\delta_M$	0	2.9	Rectangular	B	1	2.9
Current value $d\delta_C$	0	2.9	Rectangular	B	1	1.2
Current adjusting time $d\delta_T$	0	26	Rectangular	B	1	26
Measuring circuit arrangement $d\delta_{MC}$	0	2.3	Rectangular	B	1	2.3
δ_I	δ_R					36
			Expanded Uncertainty ($k = 2$)			72

(*) For the 10000 A/5 A transformation ratio u(δ_{CTN}) = 28 ppm and u(δ_I) = 40 ppm

LCOE

Uncertainty budget

for ratio error ε_I and phase displacement δ_I

$u_A =$ Uncertainty due to the repeatability of the measurements

$u_B =$ Type B uncertainty due to many factors:

- Current comparator certificate uncertainty.
- Current comparator drift with time.
- Bridge certificate uncertainty.
- Bridge specifications and drift.
- Any other uncertainty contribution due to the measurement method.
- Lack of resolution of the measurements.

$u_C =$ $u_C = \sqrt{u_A^2 + u_B^2}$

$U =$ $U = k \cdot u_C = 2 \cdot u_C$ (95% probability and coverage factor k=2)

LNE

Example for 4 kA/5 A , I/I_N = 120% at 5 VA, resistive

Measurand: ratio error ε_I

Quantity X_i $\varepsilon_I = -124 \cdot 10^{-6}$	**Standard uncertainty** $u(x_i)$	**Probability distribution /method of evaluation (A, B)**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(y)$
Setup calibration				
Reference standard CT	$10.0 \cdot 10^{-6}$	Normal (B)	1	$10.0 \cdot 10^{-6}$
Reproducibility	$8.0 \cdot 10^{-6}$	Type (A)	1	$8.0 \cdot 10^{-6}$
Tettex test set				
Accuracy	$11.0 \cdot 10^{-6}$	Normal (B)	1	$11.0 \cdot 10^{-6}$
Resolution	$0.3 \cdot 10^{-6}$	Rectangular (B)	1	$0.3 \cdot 10^{-6}$
Assembly				
Influence of primary circuit arrangement	$4.0 \cdot 10^{-6}$	Rectangular (B)	1	$4.0 \cdot 10^{-6}$
Burden				
Influence of burden	$0.3 \cdot 10^{-6}$	Rectangular (B)	1	$0.3 \cdot 10^{-6}$
Linearity	0	Rectangular (B)	1	0
Transformers proximity	0	Rectangular (B)	1	0
Repeatability	$3.0 \cdot 10^{-6}$	Rectangular (B)	1	$3.0 \cdot 10^{-6}$
Combined standard uncertainty (k = 1)				$17.6 \cdot 10^{-6}$
Expanded uncertainty (k = 2)				**$35.2 \cdot 10^{-6}$**

Measurand: phase displacement δ_I

Quantity X_i $\delta_I = 155.0 \cdot 10^{-6}$ rad	**Standard uncertainty** $u(x_i)$	**Probability distribution /method of evaluation (A, B)**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(y)$ **(rad)**
Setup calibration				
Reference standard CT	$10.0 \cdot 10^{-6}$	Normal (B)	1	$10.0 \cdot 10^{-6}$
Reproducibility	$9.0 \cdot 10^{-6}$	Type (A)	1	$9.0 \cdot 10^{-6}$
Tettex test set				
Accuracy	$11.0 \cdot 10^{-6}$	Normal (B)	1	$11.0 \cdot 10^{-6}$
Resolution	$0.3 \cdot 10^{-6}$	Rectangular (B)	1	$0.3 \cdot 10^{-6}$
Assembly				
Influence of primary circuit arrangement	$4.6 \cdot 10^{-6}$	Rectangular (B)	1	$4.6 \cdot 10^{-6}$
Burden				
Influence of burden	$0.7 \cdot 10^{-6}$	Rectangular (B)	1	$0.7 \cdot 10^{-6}$
Linearity	0	Rectangular (B)	1	0
Transformers proximity	0	Rectangular (B)	1	0
Repeatability	$0.0 \cdot 10^{-6}$	Rectangular (B)	1	$0.0 \cdot 10^{-6}$
Combined standard uncertainty (k = 1)				$18 \cdot 10^{-6}$
Expanded uncertainty (k = 2)				**$36 \cdot 10^{-6}$**

METAS

Influence	Type	Distribution	Uncertainty of ratio error (in ppm)		
			for $I_M/I_R \leq 5$ %	for 5 % < $I_M/I_R \leq 10$ %	for $I_M/I_R > 10$ %
Reference					
Standard current transformer	B	rectangular	10	5	5
Transformer testing system	B	rectangular	7	6	4
Measurements					
Statistic distribution	A	normal	3	3	2
Frequency	B	rectangular	5	3	2
Temperature	B	rectangular	1	2	3
Repeatability	B	rectangular	3	2	1
Burden	B	rectangular	5	3	3
Primary conductor alignment	A	normal	10	7	7
2-turn-setup	A	normal	5	3	3
Standard uncertainty type A for 1-turn-setup			10	8	7
Standard uncertainty type A for 2-turn-setup			12	8	8
Standard uncertainty type B for 1-turn-setup			14	9	8
Standard uncertainty type B for 2-turn-setup			14	9	8
Combined standard uncertainty for 1-turn-setup			18	12	11
Combined standard uncertainty for 2-turn-setup			19	12	11
Expanded uncertainty for 1-turn-setup			36	24	22
Expanded uncertainty for 2-turn-setup			37	25	22

Influence	Type	Distribution	Uncertainty of phase displacement (in ')		
			for $I_M/I_R \leq 5$ %	for 5 % < $I_M/I_R \leq 10$ %	for $I_M/I_R > 10$ %
Reference					
Standard current transformer	B	rectangular	0.05	0.05	0.03
Transformer testing system	B	rectangular	0.10	0.07	0.05
Measurements					
Statistic distribution	A	normal	0.03	0.01	0.01
Frequency	B	rectangular	0.05	0.03	0.02
Temperature	B	rectangular	0.01	0.02	0.02
Repeatability	B	rectangular	0.02	0.02	0.02
Burden	B	rectangular	0.01	0.01	0.01
Primary conductor alignment	A	normal	0.05	0.03	0.02
2-turn-setup	A	normal	0.01	0.01	0.01
Standard uncertainty type A for 1-turn-setup			0.06	0.03	0.02
Standard uncertainty type A for 2-turn-setup			0.06	0.03	0.02
Standard uncertainty type B for 1-turn-setup			0.12	0.10	0.07
Standard uncertainty type B for 2-turn-setup			0.12	0.10	0.07
Combined standard uncertainty for 1-turn-setup			0.14	0.10	0.07
Combined standard uncertainty for 2-turn-setup			0.14	0.10	0.07
Expanded uncertainty for 1-turn-setup			0.28	0.20	0.14
Expanded uncertainty for 2-turn-setup			0.28	0.20	0.15

The reported uncertainty of measurement is stated as the combined standard uncertainty multiplied by a coverage factor $k = 2$. The measured value (y) and the associated expanded uncertainty (U) represent the interval ($y \pm U$) which contains the value of the measured quantity with a probability of approximately 95 %. The uncertainty was estimated following the guidelines of the ISO (GUM:1995).

The measurement uncertainty contains contributions originating from the measurement standard, from the calibration method, from the environmental conditions and from the object being calibrated. The long-term characteristic of the object being calibrated is not included.

NPL

Current ratio error uncertainty: 120 to 5 % rated current							
Source of uncertainty	Value (±%)	Type	Prob.Dist.	Divisor	C_i	u_i (±%)	V_i or V_{eff}
Uncertainty in Calibration of G9908	0.001 0	B	normal	2	1	0.000 5	∞
Calibration of G9908	0.001 0	B	normal	2	1	0.000 5	∞
Error in the bridge	0.002 0	B	rectangular	1.732 1	1	0.001 2	∞
Error due to frequency setting	0.000 3	B	rectangular	1.732 1	1	0.000 1	∞
Resolution of test set	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Error due to burden setting	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Circuit configuation	0.001 0	B	normal	2	1	0.000 5	∞
Error due to current setting	0.000 3	B	rectangular	1.732 1	1	0.000 1	∞
Repeatability	0.000 4	A	normal	1	1	0.000 4	5
Combined uncertainty						0.001 5	1223
Expanded uncertainty		$k = 2$				0.003 0	

Current ratio error uncertainty: 2 % rated current							
Source of uncertainty	Value (±%)	Type	Prob.Dist.	Divisor	C_i	u_i (±%)	V_i or V_{eff}
Uncertainty in Calibration of G9908	0.003 1	B	normal	2	1	0.001 6	∞
Calibration of G9908	0.003 1	B	normal	2	1	0.001 6	∞
Error in the bridge	0.002 0	B	rectangular	1.732 1	1	0.001 2	∞
Error due to frequency setting	0.000 3	B	rectangular	1.732 1	1	0.000 1	∞
Resolution of test set	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Error due to burden setting	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Circuit configuation	0.001 0	B	normal	2	1	0.000 5	∞
Error due to current setting	0.000 3	B	rectangular	1.732 1	1	0.000 1	∞
Repeatability	0.000 3	A	normal	1	1	0.000 3	5
Combined uncertainty						0.002 6	26090
Expanded uncertainty		$k = 2$				0.005 2	

Current ratio error uncertainty: 1 % rated current							
Source of uncertainty	Value (±%)	Type	Prob.Dist.	Divisor	C_i	u_i (±%)	V_i or V_{eff}
Uncertainty in Calibration of G9908	0.004 5	B	normal	2	1	0.002 3	∞
Calibration of G9908	0.004 5	B	normal	2	1	0.002 3	∞
Error in the bridge	0.002 0	B	rectangular	1.732 1	1	0.001 2	∞
Error due to frequency setting	0.000 3	B	rectangular	1.732 1	1	0.000 1	∞
Resolution of test set	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Error due to burden setting	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Circuit configuation	0.001 0	B	normal	2	1	0.000 5	∞
Error due to current setting	0.000 3	B	rectangular	1.732 1	1	0.000 1	∞
Repeatability	0.000 3	A	normal	1	1	0.000 3	5
Combined uncertainty						0.003 5	89997
Expanded uncertainty		$k = 2$				0.007 0	

NPL

Phase displacement uncertainty: 120 to 5 % rated current							
Source of uncertainty	Value (±crad)	Type	Prob.Dist.	Divisor	C_i	u_i (±crad)	V_i or V_{eff}
Uncertainty in Calibration of G9908	0.001 0	B	normal	2	1	0.000 5	∞
Calibration of G9908	0.001 0	B	normal	2	1	0.000 5	∞
Error in the bridge	0.002 0	B	rectangular	1.732 1	1	0.001 1	∞
Error due to frequency setting	0.000 3	B	rectangular	1.732 1	1	0.000 1	∞
Resolution of test set	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Error due to burden setting	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Circuit configuation	0.001 0	B	normal	2	1	0.000 5	∞
Error due to current setting	0.000 3	B	rectangular	1.732 1	1	0.000 1	∞
Repeatability	0.000 5	A	normal	1	1	0.000 5	5
Combined uncertainty						0.001 5	560
Expanded uncertainty			$k = 2$			0.003 0	

Phase displacement uncertainty: 2 % rated current							
Source of uncertainty	Value (±crad)	Type	Prob.Dist.	Divisor	C_i	u_i (±crad)	V_i or V_{eff}
Uncertainty in Calibration of G9908	0.002 0	B	normal	2	1	0.001 0	∞
Calibration of G9908	0.002 0	B	normal	2	1	0.001 0	∞
Error in the bridge	0.002 0	B	rectangular	1.732 1	1	0.001 2	∞
Error due to frequency setting	0.000 3	B	rectangular	1.732 1	1	0.000 2	∞
Resolution of test set	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Error due to burden setting	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Circuit configuation	0.001 0	B	normal	2	1	0.000 5	∞
Error due to current setting	0.000 3	B	rectangular	1.732 1	1	0.000 2	∞
Repeatability	0.000 5	A	normal	1	1	0.000 5	5
Combined uncertainty						0.002 0	1738
Expanded uncertainty			$k = 2$			0.004 0	

Phase displacement uncertainty: 1% rated current							
Source of uncertainty	Value (±crad)	Type	Prob.Dist.	Divisor	C_i	u_i (±crad)	V_i or V_{eff}
Uncertainty in Calibration of G9908	0.002 0	B	normal	2	1	0.001 0	∞
Calibration of G9908	0.002 0	B	normal	2	1	0.001 0	∞
Error in the bridge	0.002 0	B	rectangular	1.732 1	1	0.001 2	∞
Error due to frequency setting	0.000 3	B	rectangular	1.732 1	1	0.000 2	∞
Resolution of test set	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Error due to burden setting	0.000 1	B	rectangular	1.732 1	1	0.000 1	∞
Circuit configuation	0.001 0	B	normal	2	1	0.000 5	∞
Error due to current setting	0.000 3	B	rectangular	1.732 1	1	0.000 2	∞
Repeatability	0.000 5	A	normal	1	1	0.000 5	5
Combined uncertainty						0.002 0	1738
Expanded uncertainty			$k = 2$			0.004 0	

The reported expanded uncertainties in Tables 5 to 10 are based upon a standard uncertainty multiplied by a coverage factor of $k = 2$, providing a coverage probability of approximately 95%. The quoted uncertainties apply only to the measured values and do not carry any implication as to the long-term stability of the current transformer.

PTB

MEASUREMENT UNCERTAINTY

The uncertainty budgets of PTB results $\varepsilon_{\mathrm{PTB}}$ and δ_{PTB} contain ten different contributions; Type-A uncertainty of the measurement and uncertainty of the bridge (1), uncertainty of the standard CT (2), burden variation (3), frequency variation (4), day to day reproducibility (5), swapping the primary and secondary connections of the CT (6), short-term stability due to self-heating at 50 % and or 100 % test point (7), due to eccentricity of the primary conductor (8), and due to an angular eccentricity (9) of the primary conductor.

An effect of the distance of the return conductor (10) is not taken into account, as the arrangement of the position of the CT is according to the requirements.

The expanded uncertainties (k = 2) of the PTB results are calculated according to

$$U(\varepsilon_{\mathrm{PTB}}) = 2 \cdot \sqrt{\sum_i u_{\mathrm{i}}^2(\varepsilon_{\mathrm{PTB}})}$$
$$U(\delta_{\mathrm{PTB}}) = 2 \cdot \sqrt{\sum_i u_{\mathrm{i}}^2(\delta_{\mathrm{PTB}})}$$

(1)

where u_{i} represents the standard uncertainty of the contribution with index i.

Index i (standard uncertainty contributions of the):

1) test set SEKAM II

2) standard transformer IW17 (4kA… 10kA) / 5A

3) due to a ± 3 % variation of the burden

4) due to a frequency variation of ± 2 % (or ± 1 Hz)

5) due to reproducibility of the measurement (day to day)

6) due to swapping the secondary terminals (grounding of either k or l terminal → capacitive effect in the secondary winding)

7) due to short term stability at 50 % and / or 100 % test point (self-heating)

8) due to a eccentricity of ± 1 cm (window type CT)

9) due to a angular eccentricity of ± 4° (window type CT)

10) due to the distance of the return conductor (window type CT)

PTB

Uncertainty budget of the current ratio error and the phase displacement for the ratios (4 kA – 5 kA)/5 A

uncertainty budget (traveling CT) 50 Hz; (4kA - 5kA) / 5A; $I_p / I_{p,r}$ = 1%... 120%		PTB Braunschweig working group 2.35 "Instrument transformer"		
current ratio error ε_x				
quantity x_i	**limits in µA / A**	**type**	**distribution**	**standard uncertainty $u(x_i)$**
$s(\varepsilon_X)$ (SEKAM II; n = 20)	0,5	A	normal	0,06
ε_{Bridge} (SEKAM II)	0,5	B	normal	0,25
ε_N (standard CT - IW17)	3	B	normal	1,50
ε_B (influence of burden)	2	B	normal	1,00
ε_F (influence of frequency)	0	B	normal	0,00
ε_{repro} (reproducibility; day to day)	4	B	rectangular	2,31
ε_{ground} (swapping ground; k ↔ l)	2	B	rectangular	1,15
ε_{drift} (at 50% and/or 100%)	2	B	rectangular	1,15
$\varepsilon_{Circuit,1}$ (eccentricity ± 1cm)	2	B	rectangular	1,15
$\varepsilon_{Circuit,2}$ (angular eccentricity ± 4°)	2	B	rectangular	1,15
$\varepsilon_{Circuit,3}$ (return conductor)	0	B	rectangular	0,00
			standard uncertainty $u(\varepsilon_x)$ =	**3,74 µA / A**
			round off - expanded measurement uncertainty (k = 2) $U_{PTB}(\varepsilon_x)$ =	**8,0 µA / A**
phase displacement δ_x				
quantity x_i	**limits in µrad**	**type**	**distribution**	**standard uncertainty $u(x_i)$**
$s(\delta_X)$ (SEKAM II; n = 20)	1	A	normal	0,11
δ_{Bridge} (SEKAM II)	0,5	B	normal	0,25
δ_N (standard CT - IW17)	4	B	normal	2,00
δ_B (influence of burden)	5	B	normal	2,50
δ_F (influence of frequency)	0	B	normal	0,00
δ_{repro} (reproducibility; day to day)	15	B	rectangular	8,66
δ_{ground} (swapping ground; k ↔ l)	2	B	rectangular	1,15
δ_{drift} (at 50% and/or 100%)	5	B	rectangular	2,89
$\delta_{Circuit,1}$ (eccentricity ± 1cm)	2	B	rectangular	1,15
$\delta_{Circuit,2}$ (angular eccentricity ± 4°)	2	B	rectangular	1,15
$\delta_{Circuit,3}$ (return conductor)	0	B	rectangular	0,00
			standard uncertainty $u(\delta_x)$ =	**9,88 µA / A**
			round off - expanded measurement uncertainty (k = 2) $U_{PTB}(\delta_x)$ =	**20,0 µA / A**

PTB

Uncertainty budget of the current ratio error and the phase displacement for the ratios (6 kA – 10 kA)/5 A

uncertainty budget (traveling CT) 50 Hz; (6kA - 10kA) / 5A; I_p / $I_{p,r}$ = 1%... 120%		PTB Braunschweig working group 2.35 "Instrument transformer"		
current ratio error ε_x				
quantity x_i	**limits in µA / A**	**type**	**distribution**	**standard uncertainty $u(x_i)$**
$s(\varepsilon_X)$ (SEKAM II; n = 20)	0,5	A	normal	0,06
ε_{Bridge} (SEKAM II)	0,5	B	normal	0,25
ε_N (standard CT - IW17)	3	B	normal	1,50
ε_B (influence of burden)	1	B	normal	0,50
ε_F (influence of frequency)	0	B	normal	0,00
ε_{repro} (reproducibility; day to day)	3	B	rectangular	1,73
ε_{ground} (swapping ground; k ↔ l)	2	B	rectangular	1,15
ε_{drift} (at 50% and/or 100%)	2	B	rectangular	1,15
$\varepsilon_{Circuit,1}$ (eccentricity ± 1cm)	2	B	rectangular	1,15
$\varepsilon_{Circuit,2}$ (angular eccentricity ± 4°)	2	B	rectangular	1,15
$\varepsilon_{Circuit,3}$ (return conductor)	0	B	rectangular	0,00
			standard uncertainty $u(\varepsilon_x)$ =	**3,30 µA / A**
			round off - expanded measurement uncertainty (k = 2) $U_{PTB}(\varepsilon_x)$ =	**7,0 µA / A**
phase displacement δ_x				
quantity x_i	**limits in µrad**	**type**	**distribution**	**standard uncertainty $u(x_i)$**
$s(\delta_X)$ (SEKAM II; n = 20)	1	A	normal	0,11
δ_{Bridge} (SEKAM II)	0,5	B	normal	0,25
δ_N (standard CT - IW17)	4	B	normal	2,00
δ_B (influence of burden)	2	B	normal	1,00
δ_F (influence of frequency)	0	B	normal	0,00
δ_{repro} (reproducibility; day to day)	10	B	rectangular	5,77
δ_{ground} (swapping ground; k ↔ l)	2	B	rectangular	1,15
δ_{drift} (at 50% and/or 100%)	4	B	rectangular	2,31
$\delta_{Circuit,1}$ (eccentricity ± 1cm)	3	B	rectangular	1,73
$\delta_{Circuit,2}$ (angular eccentricity ± 4°)	2	B	rectangular	1,15
$\delta_{Circuit,3}$ (return conductor)	0	B	rectangular	0,00
			standard uncertainty $u(\delta_x)$ =	**7,03 µA / A**
			round off - expanded measurement uncertainty (k = 2) $U_{PTB}(\delta_x)$ =	**15,0 µA / A**

RISE (SP)

Test point 20 - 120 %

Uncertainty contribution, Ratio error	**Estimate**	**Evaluation**	**Sensitivity**	**Uncertainty**	
1200/5A and higher	**[ppm]**		**coeff.**	**[ppm]**	
Standard uncertainty for bridge	20	1	1	20	
Contribution due to error in value of applied burden	1	1	1	1	
Contribution due to error in applied test point value	1	1.732	1	1	
Centering of conductor	1	1.732	1	1	
Resolution of bridge readout	1	3.46	1	0	
Combined standard uncertainty				**20**	ppm

Phase displacement	**[µrad]**			**[µrad]**	
Standard uncertainty for bridge	20	1	1	20	
Contribution due to error in value of applied burden	1	1	1	1	
Contribution due to error in applied test point value	1	1.732	1	1	
Centering of conductor	1	1.732	1	1	
Resolution of bridge readout	1	3.46	1	0	
Combined standard uncertainty				**20**	µrad
				0.069	**min**

Test point 10 %

Estimate	**Evaluation**	**Sensitivity**	**Uncertainty**	
[ppm]		**coeff.**	**[ppm]**	
23	1	1	23	
1	1	1	1	
1	1.732	1	1	
1	1.732	1	1	
1	3.46	1	0	
Combined standard uncertainty			**23**	ppm

[µrad]			**[µrad]**	
23	1	1	23	
1	1	1	1	
1	1.732	1	1	
1	1.732	1	1	
1	3.46	1	0	
Combined standard uncertainty			**23**	µrad
			0.077	**min**

RISE (SP)

Test point 5 %

Estimate	Evaluation	Sensitivity	Uncertainty	
[ppm]		coeff.	[ppm]	
30	1	1	30	
1	1	1	1	
1	1.732	1	1	
1	1.732	1	1	
1	3.46	1	0	
Combined standard uncertainty			**30**	ppm

[µrad]			[µrad]	
30	1	1	30	
1	1	1	1	
3	1.732	1	2	
1	1.732	1	1	
1	3.46	1	0	
Combined standard uncertainty			**30**	µrad
			0.103	**min**

Test point 2 %

Estimate	Evaluation	Sensitivity	Uncertainty	
[ppm]		coeff.	[ppm]	
50	1	1	50	
1	1	1	1	
1	1.732	1	1	
1	1.732	1	1	
1	3.46	1	0	
Combined standard uncertainty			**50**	ppm

[µrad]			[µrad]	
50	1	1	50	
1	1	1	1	
5	1.732	1	3	
1	1.732	1	1	
1	3.46	1	0	
Combined standard uncertainty			**50**	µrad
			0.172	**min**

RISE (SP)

Estimate	Evaluation	Sensitivity	Uncertainty	
[ppm]		coeff.	[ppm]	
100	1	1	100	
1	1	1	1	
1	1.732	1	1	
1	1.732	1	1	
1	3.46	1	0	
Combined standard uncertainty			**100**	ppm

[µrad]			[µrad]	
100	1	1	100	
1	1	1	1	
10	1.732	1	6	
1	1.732	1	1	
1	3.46	1	0	
Combined standard uncertainty			**100**	µrad
			0.344	**min**

UME

Uncertainty budget for ratio error ε_I and phase displacement δ_I

The following sample uncertainty budget given below shows the contributions associated with the measurements made on ratio 4 kA/5 A at I/I_N = 100%, at a burden of 5 VA, unity power factor, at a frequency of 50 Hz and an ambient temperature of 23 ˚C.

Quantity	Estimate	Standard Uncertainty (ppm)	Type	Probability Distribution	Sensitivity Coefficient	Uncertainty Contribution (ppm)
Calibration of bridge and comparator		5,8	B	normal	1	5,8
Error in the bridge		6,1	B	rectangular	1	6,1
Error due to burden setting		1,2	B	rectangular	1	1,2
Circuit configuration		5,8	B	normal	1	5,8
Repeatability		0,9	A	normal	1	0,9
Combined uncertainty						10.3
Expanded uncertainty (U) (k = 2)						**20.7**

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 the error included in the budget.

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

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%. The standard uncertainty of measurement has been determined in accordance with GUM and EA-4/02.

VSL

Uncertainty budget for ratio error ε_I and phase displacement δ_I

The magnitude ratio error has been defined in the protocol as

$$\varepsilon_I = \frac{r_{nom} \cdot I_s}{I_p} - 1 .$$

The measurement software used in our experiments gives us the ratio between the voltage signals representing the secondary currents of the transformer under test (I_s) and the reference transformer (I_s^{ref}),

$$r_{meas} = \frac{I_s}{I_s^{ref}}$$

Combining these two equations and adding uncertainty components we find the mathematical model for the magnitude ratio error:

$$\varepsilon_I = r_{meas} \cdot \left(1 + \varepsilon_{ref} + \varepsilon_{repr} + \varepsilon_{conf}\right) - 1 ,$$

where the components are explained in the list below:

ε_I	Magnitude ratio error of the transformer under test as defined in the protocol
r_{meas}	Measured ratio (I_s / I_s^{ref}) between the secondary currents of the transformer under test (I_s) and the reference transformer (I_s^{ref})
ε_{ref}	Magnitude ratio error of the reference transformer
ε_{repr}	Uncertainty due to reproducibility of the measurements, including orientation
ε_{conf}	Uncertainty due to double-loop configuration and positioning of the return conductors

An example uncertainty budget for the magnitude ratio error at 120 % of 4 kA with 15 VA burden is given in the table below:

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
r_{meas}	0.9998676 A/A	1.0 µA/A	normal	1	1.0 µA/A
ε_I^{ref}	3.0 µA/A	2.5 µA/A	normal	1	2.5 µA/A
δ_{repr}	0 µA/A	3.2 µA/A	rectangular	1	3.2 µA/A
δ_{conf}	0 µA/A	1.2 µA/A	rectangular	1	1.2 µA/A
ε_I	-135.4 µA/A	4.3 µA/A			

This leads to magnitude ratio error of (-135 ± 9) µA/A (k = 2).

An example uncertainty budget for the magnitude ratio error at 1 % of 10 kA with 5 VA burden is given in the table below:

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
r_{meas}	1.0000091 A/A	2.0 µA/A	normal	1	2.0 µA/A
ε_I^{ref}	3.0 µA/A	2.5 µA/A	normal	1	2.5 µA/A
δ_{repr}	0 µA/A	2.6 µA/A	rectangular	1	2.6 µA/A
δ_{conf}	0 µA/A	1.2 µA/A	rectangular	1	1.2 µA/A
ε_I	+6.1 µA/A	3.9 µA/A			

This leads to a magnitude ratio error of (6 ± 8) µA/A (k = 2).

VSL

:

The phase displacement has been defined in the protocol as the phase difference between the secondary current I_S and the primary current I_P. Our measurement software gives us the phase difference between the two secondary currents. Therefore, the mathematical model for the phase displacement is as follows:

$$\delta_I = \delta_{meas} - \delta_{ref} + \delta_{repr} + \delta_{conf} \ ,$$

where the components are explained in the list below:

δ_I Phase displacement of the transformer under test as defined in the protocol

δ_{meas} Measured phase between the secondary currents of the transformer under test (I_s) and the reference transformer (I_s^{ref})

δ_{ref} Phase displacement of the reference transformer

δ_{repr} Uncertainty due to reproducibility of the measurements, including orientation

δ_{conf} Uncertainty due to double-loop configuration and positioning of the return conductors

An example uncertainty budget for the phase displacement at 120 % of 4 kA with 15 VA burden is given in the table below:

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
δ_{meas}	-178.5 µrad	2.0 µrad	normal	1	2.0 µrad
δ_{ref}	-8.6 µrad	2.5 µrad	normal	1	2.5 µrad
δ_{repr}	0 µrad	6.6 µrad	rectangular	1	6.6 µrad
δ_{conf}	0 µrad	11.5 µrad	rectangular	1	11.5 µrad
δ_I	-187.1 rad	13.7 µrad			

This leads to a phase displacement of (-187 ± 27) µrad (k = 2).

An example uncertainty budget for the phase displacement at 1 % of 10 kA with 5 VA burden is given in the table below:

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
δ_{meas}	-136.1 µrad	2.0 µrad	normal	1	2.0 µrad
δ_{ref}	-8.6 µrad	2.5 µrad	normal	1	2.5 µrad
δ_{repr}	0 µrad	3.1 µrad	rectangular	1	3.1 µrad
δ_{conf}	0 µrad	8.7 µrad	rectangular	1	8.7 µrad
δ_I	-144.7 rad	9.5 µrad			

This leads to a phase displacement of (-145 ± 19) µrad (k = 2).

VTT MIKES

Calculation of ratio error ε_I uncertainty, current 5 000 A (ratio 10 000 A/5 A), burden 15 VA resistive

Model Equation:

$$CT_{ratio}=Ratio_{RogR2}*K_{rog}/K_{R2}*(1+\delta Ratio_{CTcal})*(1+\delta Lin_{Rog})*(1+\delta DVMrange)*(1+\delta position);$$

$$K_{rog}=K_R*(1+\delta stab_{rog})/Ratio_{RogCAL}*(1+\delta Ratio_{RogCAL});$$

List of Quantities:

Quantity	Unit	Definition
CT_{ratio}		Calibration result, ratio of CT
K_{rog}		Measured scale factor for Rogowski coil
$\delta stab_{rog}$		Stability of Rogowski coil
K_R		Constant (0.1 ohm)
K_{R2}		Current shunt (0.5 ohm) calibrated against 0.1 ohm shunt
δLin_{Rog}		Linearity of the Rogowski coil
$Ratio_{RogCAL}$		Auxiliary calibration, ratio of 0.1 ohm shunt and Rogowski coil, measuring current 7 A, during 19-27.2.2014
$Ratio_{RogR2}$		Voltage ratio, measured with Rogowski coil (high current) and shunt 0.2 ohm (low current)
$\delta Ratio_{RogCAL}$		Uncertainty of measurement when making auxiliary calibration, because of low voltage levels
δDVMrange		Uncertainty due to DVM ranges
δposition		Effect of non-centralized conductor (±2 cm)
$\delta Ratio_{CTcal}$		Uncertainty of voltage ratio measurement when measuring ratio of CT

$\delta stab_{rog}$:
Type B rectangular distribution
Value: 0
Halfwidth of Limits: $8\cdot 10^{-6}$

Estimated stability of Rogowski coil.

K_R:
Type B rectangular distribution
Value: 10
Halfwidth of Limits: $4\cdot 10^{-6}$

K_{R2}:
Type B rectangular distribution
Value: 2.00019224
Halfwidth of Limits: $4\cdot 10^{-6}$

δLin_{Rog}:
Type B rectangular distribution
Value: 0
Halfwidth of Limits: $14\cdot 10^{-6}$

$Ratio_{RogCAL}$:
Type A
Method of observation: Direct
Number of observation: 17

VTT MIKES

No.	Observation
1	0.012303223
2	0.012303235
3	0.012303211
4	0.012303227
5	0.012303194
6	0.012303224
7	0.012303168
8	0.012303188
9	0.012303164
10	0.012303146
11	0.012303196
12	0.012303212
13	0.012303215
14	0.012303203
15	0.012303196
16	0.012303227
17	0.012303196

Arithmetic Mean: 0.01230320147
Standard Deviation: $25\cdot 10^{-9}$
Standard Uncertainty: $5.98\cdot 10^{-9}$
Degrees of Freedom: 16

Ratio_{RogR2}:
Type A
Method of observation: Direct
Number of observation: 3

No.	Observation
1	4.921898436
2	4.921910164
3	4.921895235

Arithmetic Mean: 4.92190128
Standard Deviation: $7.9\cdot 10^{-6}$
Standard Uncertainty: $4.54\cdot 10^{-6}$
Degrees of Freedom: 2

$\delta\text{Ratio}_{RogCAL}$:
Type B rectangular distribution
Value: 0
Halfwidth of Limits: $10\cdot 10^{-6}$

δDVMrange:
Type B rectangular distribution
Value: 0
Halfwidth of Limits: $6\cdot 10^{-6}$

δposition:
Type B rectangular distribution
Value: 0
Halfwidth of Limits: $2.5\cdot 10^{-6}$

$\delta\text{Ratio}_{CTcal}$:
Type B normal distribution

Value: 0
Expanded Uncertainty: $5\cdot 10^{-6}$
Coverage Factor: 2

VTT MIKES

Uncertainty Budgets:

CT_{ratio}: Calibration result, ratio of CT

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$\delta stab_{rog}$	0.0	$4.62 \cdot 10^{-6}$	rectangular	2000	$9.2 \cdot 10^{-3}$	14.9 %
K_R	10.00000000	$2.31 \cdot 10^{-6}$	rectangular	200	$460 \cdot 10^{-6}$	0.0 %
K_{R2}	2.00019224	$2.31 \cdot 10^{-6}$	rectangular	-1000	$-2.3 \cdot 10^{-3}$	0.9 %
δLin_{Rog}	0.0	$8.08 \cdot 10^{-6}$	rectangular	2000	0.016	45.8 %
$Ratio_{RogCAL}$	0.01230320147	$5.98 \cdot 10^{-9}$	normal	$-160 \cdot 10^{3}$	$-970 \cdot 10^{-6}$	0.2 %
$Ratio_{RogR2}$	4.92190128	$4.54 \cdot 10^{-6}$	normal	410	$1.8 \cdot 10^{-3}$	0.6 %
$\delta Ratio_{RogCAL}$	0.0	$5.77 \cdot 10^{-6}$	rectangular	2000	0.012	23.3 %
δDVMrange	0.0	$3.46 \cdot 10^{-6}$	rectangular	2000	$6.9 \cdot 10^{-3}$	8.4 %
δposition	0.0	$1.44 \cdot 10^{-6}$	rectangular	2000	$2.9 \cdot 10^{-3}$	1.5 %
$\delta Ratio_{CTcal}$	0.0	$2.50 \cdot 10^{-6}$	normal	2000	$5.0 \cdot 10^{-3}$	4.4 %
CT_{ratio}	2000.0600	0.0239				

Measurements have been made with Rogowski coil (primary current) and 0.5 ohm shunt (secondary current).

K_{rog}: Measured scale factor for Rogowski coil

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$\delta stab_{rog}$	0.0	$4.62 \cdot 10^{-6}$	rectangular	810	$3.8 \cdot 10^{-3}$	38.8 %
K_R	10.00000000	$2.31 \cdot 10^{-6}$	rectangular	81	$190 \cdot 10^{-6}$	0.0 %
$Ratio_{RogCAL}$	0.01230320147	$5.98 \cdot 10^{-9}$	normal	-66000	$-390 \cdot 10^{-6}$	0.4 %
$\delta Ratio_{RogCAL}$	0.0	$5.77 \cdot 10^{-6}$	rectangular	810	$4.7 \cdot 10^{-3}$	60.7 %
K_{rog}	812.79657	$6.03 \cdot 10^{-3}$				

Output voltage of Rogowski coil is multiplied with factor to define current. Factor is dependent on frequency.

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
CT_{ratio}	2000.060	$24 \cdot 10^{-6}$ (relative)	2.00	95% (normal)
K_{rog}	812.797	0.012	2.00	manual

VTT MIKES

Calculation of phase displacement δ_I uncertainty, current 5 000 A (ratio 10 000 A/5 A), burden 15 VA, resistive

Model Equation:

$$CT_{phase} = 60*(Phase_{RogR2} - Phase_{Rog} - \delta Phase_{Rog} - Phase_{DVM} - \delta position)$$

List of Quantities:

Quantity	Unit	Definition
$Phase_{RogR2}$	deg	Calibration result, measured phase of CT
$Phase_{Rog}$	deg	
$\delta Phase_{Rog}$	deg	Stability of Phase
CT_{phase}	min	Result
$Phase_{DVM}$	deg	Phase corrections of DVMs
δposition		Effect of non-centralized conductor (±2 cm)

$Phase_{RogR2}$:
Type A
Method of observation: Direct
Number of observation: 3

No.	Observation
1	-89.97833085 deg
2	-89.97827411 deg
3	-89.97822595 deg

Arithmetic Mean: -89.9782770 deg
Standard Deviation: $53 \cdot 10^{-6}$ deg
Standard Uncertainty: $30.3 \cdot 10^{-6}$ deg
Degrees of Freedom: 2

$Phase_{Rog}$:
Type A
Method of observation: Direct
Number of observation: 9

No.	Observation
1	-89.98518721 deg
2	-89.9854912 deg
3	-89.98436895 deg
4	-89.98567421 deg
5	-89.98376528 deg
6	-89.98567421 deg
7	-89.98546509 deg
8	-89.98526315 deg
9	-89.98387189 deg

Arithmetic Mean: -89.984973 deg
Standard Deviation: $760 \cdot 10^{-6}$ deg
Standard Uncertainty: $254 \cdot 10^{-6}$ deg
Degrees of Freedom: 8

VTT MIKES

$\delta Phase_{Rog}$:

Type B rectangular distribution
Value: 0 deg
Halfwidth of Limits: 0.002 deg

$Phase_{DVM}$:
Type B rectangular distribution
Value: -0.0006 deg
Halfwidth of Limits: 0.0015 deg

δposition:
Type B rectangular distribution
Value: 0
Halfwidth of Limits: 0.0005

Uncertainty Budgets:

CT_{phase}: Result

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
$Phase_{RogR2}$	-89.9782770 deg	$30.3 \cdot 10^{-6}$ deg	normal	60	$1.8 \cdot 10^{-3}$ min	0.0 %
$Phase_{Rog}$	-89.984973 deg	$254 \cdot 10^{-6}$ deg	normal	-60	-0.015 min	2.9 %
$\delta Phase_{Rog}$	0.0 deg	$1.15 \cdot 10^{-3}$ deg	rectangular	-60	-0.069 min	59.7 %
$Phase_{DVM}$	$-600 \cdot 10^{-6}$ deg	$866 \cdot 10^{-6}$ deg	rectangular	-60	-0.052 min	33.6 %
δposition	0.0	$289 \cdot 10^{-6}$	rectangular	-60	-0.017 min	3.7 %
CT_{phase}	0.4378 min	0.0896 min				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
CT_{phase}	0.44 min	0.18 min	2.00	95% (normal)