SIM Regional Comparison of AC-DC CURRENT TRANSFER DIFFERENCE SIM.EM-K12

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1. Introduction

In the Sistema Interamericano de Metrología (SIM) there are several National Metrology Institutes (NMIs) with ac-dc current transfer difference CMCs (Calibration and Measurement Capabilities). Only three of these NMIs participated in the CCEM Key Comparison of the ac-dc Current Transfer Standard, CCEM-K12.

The SIM.EM-K12 was conducted to assess the measurement capabilities in the ac-dc current transfer difference of the remaining SIM NMIs. The test points were selected to link the results of the SIM comparison with the CCEM Key Comparison, through the three NMIs participating in both.

INTI provided the travelling standard and piloted and coordinated the comparison. It was agreed between the participants that the SIM comparison reference values were to be based on the results provided by the laboratories with participation in both Key Comparisons.

2. Participants and comparison schedule

Table I. List of participants

NIST	National Institute of Standards and Technology, USA Contact. Thomas E. Lipe (thomas.lipe@nist.gov)
CENAM	Centro Nacional de Metrología (CENAM) Contact: Sara Campos (scampos@cenam.mx)
UTE	Administración Nacional de Usinas e Transmisiones Eléctricas, Uruguay Contact: Spaggiari, Alfredo (ASpaggiari@ute.com.uy)
NRC	National Research Council, Canada Contact: Peter Filipski (Piotr.Filipski@nrc-cnrc.gc.ca)
INMETRO	Instituto Nacional de Metrologia, Qualidade e Tecnologia, Brasil Contact: Renata Vasconcellos (rbvasconcellos@inmetro.gov.br)
INTI	Instituto Nacional de Tecnología Industrial, Argentina Contact: Lucas Di Lillo (ldili@inti.gob.ar)
ICE	Instituto Costarricense de Electricidad, Costa Rica. Contact: Sánchez Vargas Harold (HSanchez@ice.go.cr)
SIC	Superintendencia de Industria y Comercio, Colombia. Contact: Alexander Martinez (amartinez@correo.sic.gov.co)
NIS	National Institute for Standards, Egypt. Contact: Mamdouh Halawa (mamdouh_alawa@yahoo.com)

Comparison schedule

Laboratory	Date of measurements	
INTI	**---**	July 2nd, 2010
In transit	July 2nd, 2010	July 19th, 2010
UTE	July 19th, 2010	August 20th, 2010
In transit	August 20th, 2010	September 9th, 2010
NRC	September 9th, 2010	October 10th, 2010
In transit	October 10th, 2010	October 18th, 2010
INTI	October 18th, 2010	April 8th, 2011
In transit	April 8th, 2011	April 13th, 2011
NRC	April 13th, 2011	May 8th, 2011
In transit	May 8th, 2011	May 10th, 2011
NIST	May 10th, 2011	July 19th, 2011
In transit	July 19th, 2011	July 27th,2011
CENAM	July 27th, 2011	September 22nd, 2011
In transit	September 22nd, 2011	October 10th, 2011
ICE	October 10th, 2011	December 20th, 2011
In transit	December 20th, 2011	January 26th, 2012
INMETRO	January 26th, 2012	March 31st, 2012
In transit	March 31st, 2012	April 20th, 2012
INTI	April 20th, 2012	July 7th, 2012
In transit	July 7th, 2012	July 26th, 2012
NIS	July 26th, 2012	August 30th, 2012
In transit	August 30th, 2012	September 26th , 2012
INTI	September 26th, 2012	

3. Organisation of the comparison

Prior to the comparison, a pilot comparison was organised between the pilot laboratory, Instituto Nacional de Tecnología Industrial (INTI), and the National Research Council (NRC). As a result of this comparison, the long term stability of the travelling standards was confirmed and preliminary reference values were established.

The travelling standards were dispatched from INTI in July 2010. The pilot laboratory was kept informed by e-mail or fax of the arrival of the package and of the shipping of the package to the next participant. The next participant was also informed by e-mail or fax by the shipping NMI that the package is in transit.

Each participating laboratory was required to cover the costs of the measurement, transportation and customs clearance, as well as any damage that may have occurred within its country. The pilot laboratory covered the overall costs for the organisation of the comparison. The pilot laboratory had no insurance for any loss or damage of the travelling standards.

4. Unexpected incidents

When the standards were received by the NRC, the participant detected that the input connector of the shunt was damaged. After communication with the pilot laboratory, it was decided that the standards should come back to INTI to be repaired and measured again. This operation took seven months and after a new measurement the standards were sent again to NRC.

When the standard was received by ICE (Costa Rica) the NMI informed to the pilot laboratory that they did not have the equipment to make the measurements. ICE withdrew from the comparison. After three months the standard was shipped to INMETRO (Brazil). At the same time, SIC (Colombia) informed the pilot laboratory that due to internal problems, they could not make the measurements. The SIC also withdrew from the comparison.

In 2011, the National Institute for Standards Egypt (NIS) asked to participate in the comparison. The participants agreed to have a bilateral comparison between Egypt and INTI, at the end of the comparison. The results of NIS are included in this report.

A data logger for monitoring temperature, humidity and pressure during transportation was included in the same package as the travelling standards. Unfortunately, when the standards arrived at CENAM it was not possible to download the data or to restart the data logger. Due to this incident, it was not possible to monitor these parameters during transportation.

5. Travelling standards and measuring instructions

Travelling standards description

10 mA

The travelling standard for 10 mA was a Planar Multijunction Thermal Converter, identified as “PMJTC-90-2”, manufactured by INTI (Fig. 1). The following are their nominal parameters:

Rated Input Current:	10 mA
Heater Resistance:	111 Ω
Thermocouple Resistance:	12 kΩ
Output Voltage at Rated Current:	100 mV

The Thermal Converter has an N-Female-type input connector and a type 10SL-4S output connector.

Fig.1. Physical layout of the thermal converter PMJTC-90-2

5 A

The travelling standard for 5 A comprises a 0.2 Ω coaxial shunt, identified as “SHUNT 5 A**”** (Fig. 2) and a 1 V Planar Multijunction Thermal Converter, identified as “PMJTC-90-2” (Fig. 1). Both have been manufactured at INTI. The following are its nominal parameters:

Current Shunt, 5 A	
Nominal Resistance	0.2 Ω
Input Connector	UHF
Output Connector	N-female

Thermal Converter, PMJTC-90-2	
Rated Input Voltage	1 V
Input Resistance	111 Ω
Thermocouple Resistance	12 kΩ
Output Voltage at Rated Voltage	100 mV

Fig. 2. Physical layout of the 5 A shunt

6. Quantities to be measured and measurement conditions

Ac-dc current transfer difference was defined as

$$\delta = \frac{I_{ac} - I_{dc}}{I_{dc}}$$

Where

I_{ac} is a rms ac current, and I_{dc} is a dc current which, when reversed, produces the same mean output response as the rms ac current.
Differences were expressed in microamperes per ampere (μA/A) and a positive sign signifies that more ac than dc current was required for the same output response.

7. Measurement instructions

The following instructions were stated in the protocol:

- Upon receiving the package, check input and output resistances of the thermal converter. Check also that there is a high resistance (>100 MΩ) between the input heater and the output thermopile. In making these preliminary measurements, make sure **not to exceed** the nominal current of the thermal converter. In case of any failure, inform the pilot laboratory immediately.
- To protect the thermocouple, one terminal of the thermocouple must remain at the ground potential at all times during the measurements.
- Care should be taken not to apply the test current above nominal, which may destroy the travelling standards.
- Recommended ambient conditions are temperature (23 ± 1) °C and relative humidity (50 ± 5) %.
- At least 30 minutes should be allowed for stabilization after the first application of the test current.
- The measurement frequency should be within 1 % of its nominal value. The frequency and its uncertainty must be reported.
- Sufficient delay time should be used between successive applications of the alternating and direct currents.
- A data logger will travel together with the travelling standard. It will be continuously monitoring the temperature, the relative humidity and the atmospheric pressure. The data logger should be left in the transportation case and it should be kept in the measurement area.

The measurement points are indicated in Table II.

Table II. Measurement points in ac-dc current transfer difference comparison

Test #.	Test Current	Test frequency
1	10 mA	10 Hz
2	10 mA	55 Hz
3	10 mA	1 kHz
4	10 mA	10 kHz
5	10 mA	20 kHz
6	10 mA	50 kHz
7	10 mA	100 kHz
8	5 A	10 Hz
9	5 A	55 Hz
10	5 A	1 kHz
11	5 A	10 kHz
12	5 A	20 kHz
13	5 A	50 kHz
14	5 A	100 kHz

8. Methods of measurement

Table III and Table IV show the reference standard used by each participant as well as the measurement method and the source of traceability at 10 mA and 5 A. This information was included by each participant in the report sent to the pilot laboratory.

Table III. Reference standards and measurement methods at 10 mA

Laboratory	Reference standard	Measurement method	Source of traceability
NIST	MJTC	Direct Comparison	In-house
CENAM	PMJTC	Direct Comparison	PTB
UTE	TCC	Direct Comparison	PTB
NRC	MJTC CTVC	Direct Comparison	In-house
INMETRO	PMJTC	Direct Comparison	PTB
INTI	PMJTC	Direct Comparison	In-house /PTB
NIS	PMJTC	Direct Comparison	PTB

Table IV. Reference standards and measurement methods at 5 A

Laboratory	Reference standard	Measurement method	Source of traceability
NIST	SJTC + 5 A shunt	Build-up	In-house
CENAM	PMJTC + 5 A shunt	Direct Comparison	NRC
UTE	Reference TCC	Direct Comparison	PTB
NRC	SJTC + 5 A shunt	Build-up	In-house
INMETRO	PMJTC + 5 A shunt	Build-up	In-house
INTI	PMJTC + 5 A shunt	Build-up	In-house
NIS	PMJTC + Fluke A40 shunt	Direct Comparison	PTB

9. Measurement Results

Table V shows the AC-DC current difference δ_i and the expanded uncertainty (95%) $U_{\delta i}$ reported by each participant at 10 mA. Figures 3 to 8 show the data from the Table V in a graphic form.

Table V

Measured ac-dc difference and expanded uncertainty in µA/A														
δ_i	Reported AC-DC Difference													
$U_{\delta i}$	Expanded Uncertainty of the Reported AC-DC Difference													
Level	**10 mA**													
	10 Hz		**55 Hz**		**1 kHz**		**10 kHz**		**20 kHz**		**50 kHz**		**100 kHz**	
	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$
INTI	8,0	6,0	0,6	6,0	0,1	3,0	0,1	3,0	0,4	3,0	1,0	10,0	2,0	20,0
NRC	8,3	1,6	0,3	1,0	0,0	0,9	0,2	1,8	0,1	1,9	0,9	1,9	3,2	2,0
INTI	10,2	6,0	0,6	6,0	0,0	3,0	1,3	3,0	-0,7	3,0	3,3	10,0	0,3	20,0
UTE	----	----	-4,0	12,0	-4,0	12,0	-3,0	14,0	----	----	----	----	----	----
INMETRO	8,2	3,3	0,5	3,3	0,0	3,2	-0,1	3,3	-0,1	3,3	-0,2	3,2	0,8	3,2
CENAM	----	-----	0,6	22,0	0,4	22,0	0,5	22,0	1,1	22,0	3,8	22,0	1,7	24,0
NIST	9,0	9,0	0,0	6,0	-1,0	4,0	1,0	4,0	2,0	4,0	6,0	7,0	11,0	10,0
INTI	10,1	6,0	0,7	6,0	-0,2	3,0	1,2	3,0	1,7	3,0	1,5	10,0	0,8	20,0
NIS	2,8	3,1	-0,9	2,7	-1	5,5	-2,7	6,4	----	----	----	----	----	----
INTI	9,8	6,0	-0,2	6,0	-0,2	3,0	-0,1	3,0	-0,3	3,0	1,5	10,0	4,1	20,0

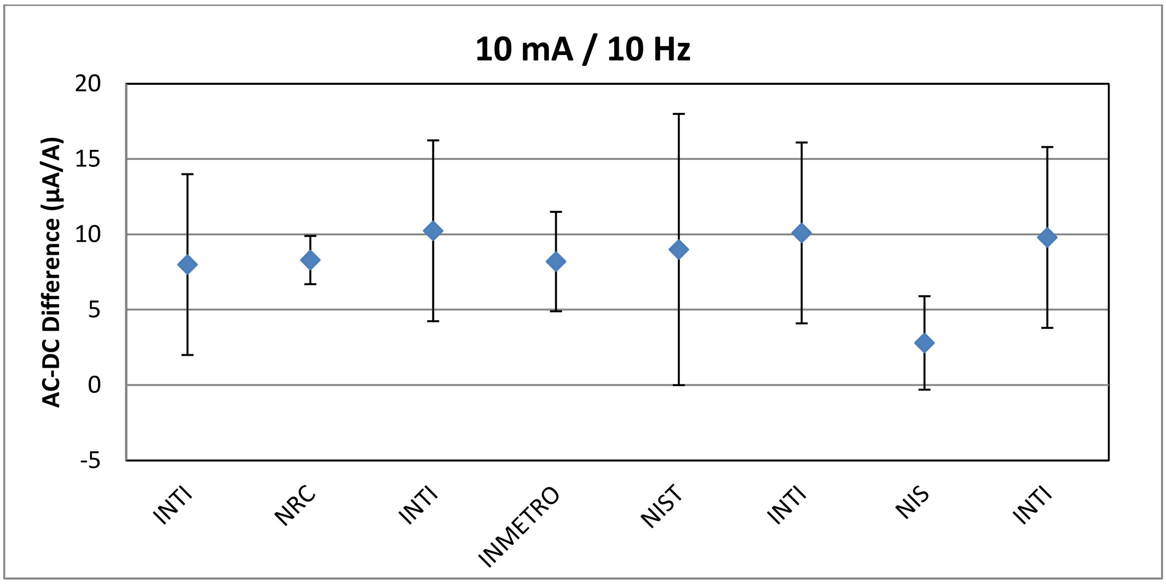

Fig. 3. Measured ac-dc difference and expanded uncertainty at 10 Hz.

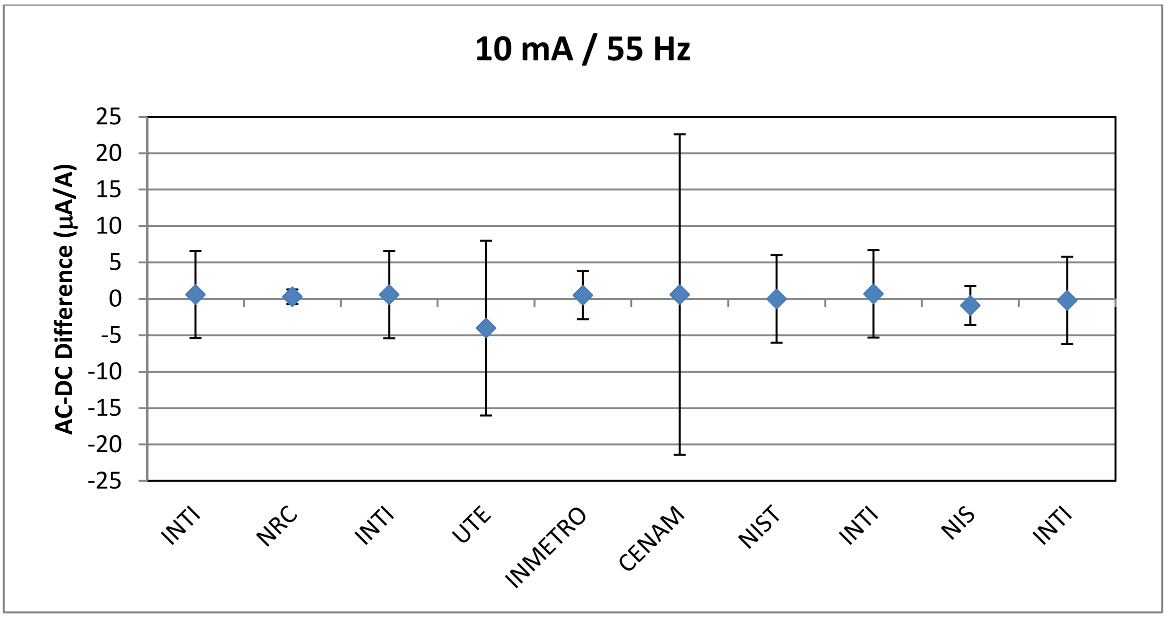

Fig. 4. Measured ac-dc difference and expanded uncertainty at 55 Hz.

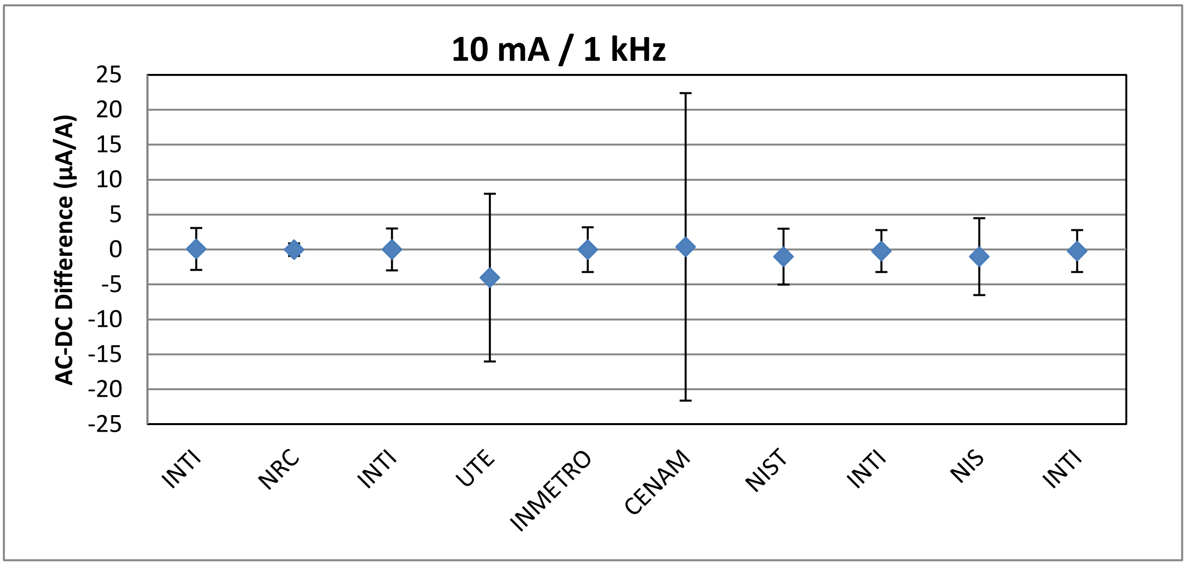

Fig. 5. Measured ac-dc difference and expanded uncertainty at 1 kHz.

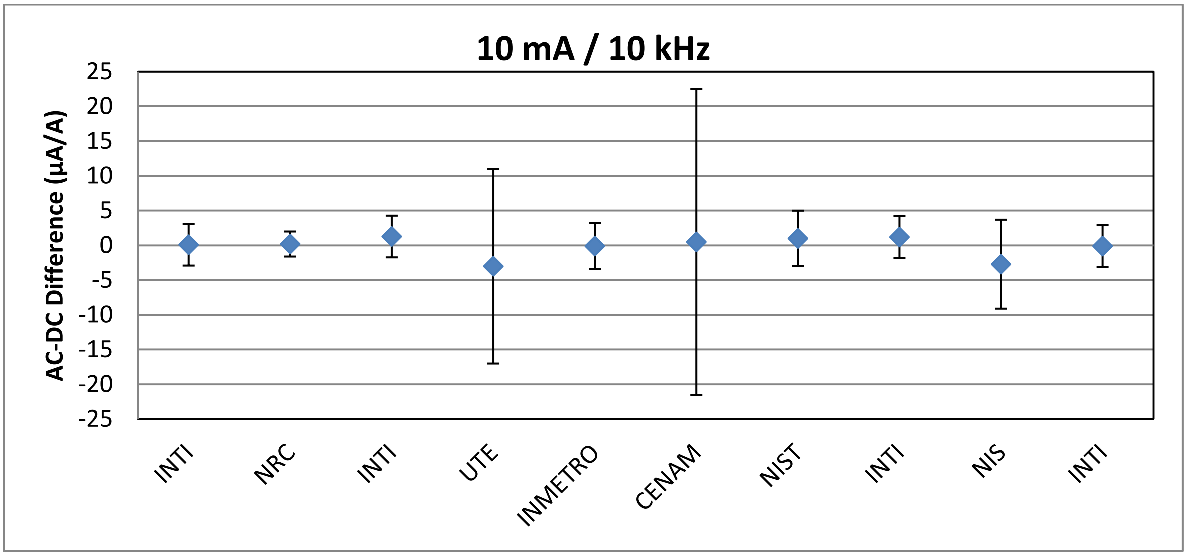

Fig. 6. Measured ac-dc difference and expanded uncertainty at 10 kHz.

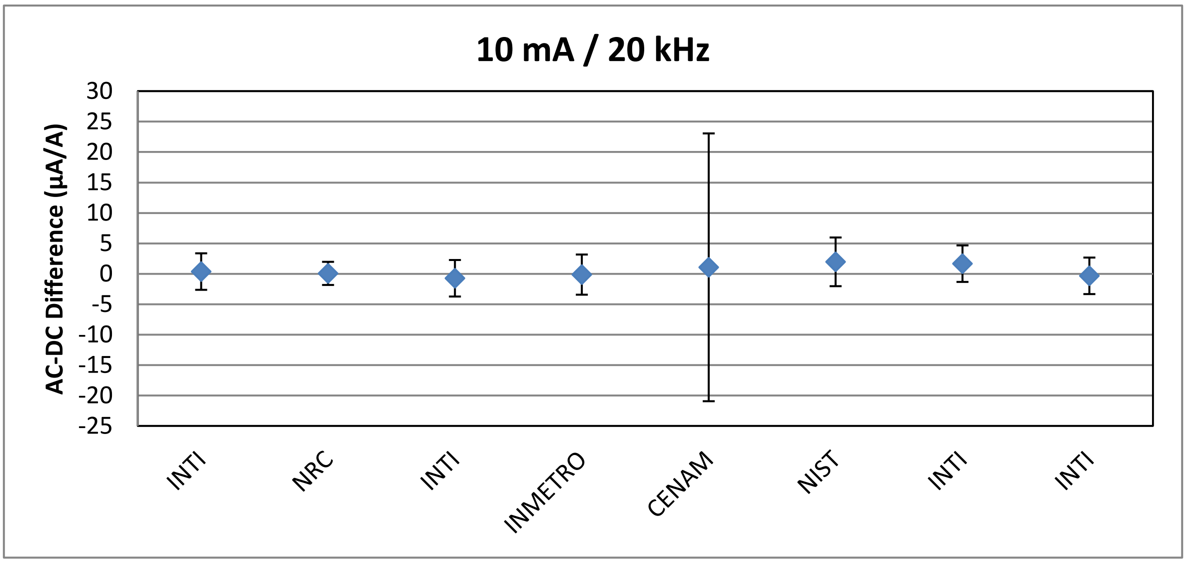

Fig. 7. Measured ac-dc difference and expanded uncertainty at 20 kHz.

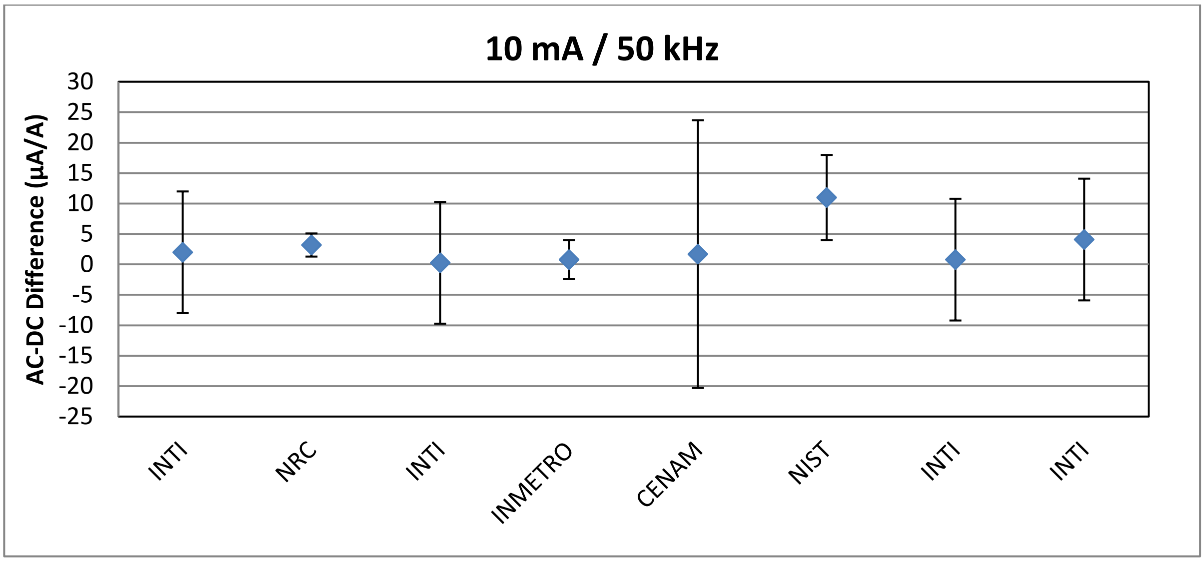

Fig. 8. Measured ac-dc difference and expanded uncertainty at 50 kHz.

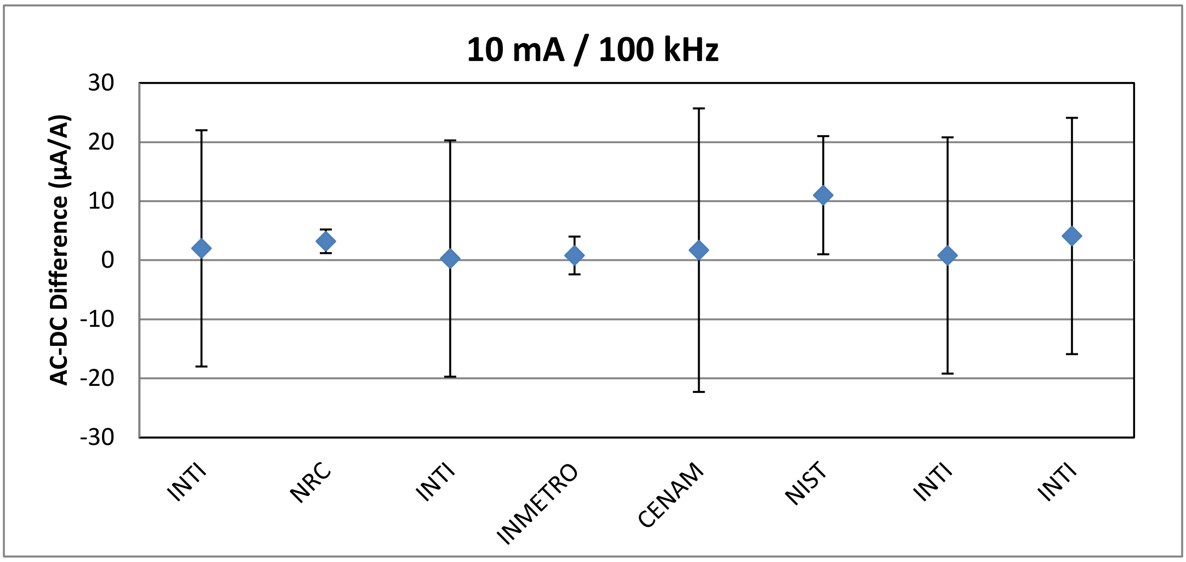

Fig. 9. Measured ac-dc difference and expanded uncertainty at 100 kHz.

Table VI shows the AC-DC current transfer difference δ_i and the expanded uncertainty (95%) $U_{\delta i}$ reported by each participant at 5 A.

Figures 10 to 16 show the data from Table VI in a graphic form.

Table VI

Measured ac-dc difference and expanded uncertainty in µA/A														
δ_i	**Reported AC-DC Difference**													
$U_{\delta i}$	**Expanded Uncertainty of the Reported AC-DC Difference**													
Level	**5 A**													
	10 Hz		**55 Hz**		**1 kHz**		**10 kHz**		**20 kHz**		**50 kHz**		**100 kHz**	
	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$	δ_i	$U_{\delta i}$
INTI	-4,8	8,0	0,0	7,0	2,0	5,0	-0,2	7,0	2,6	10,0	9,8	13,0	29,4	22,0
NRC	-4,9	14,7	-1,2	14,0	-0,9	14,0	1,6	14,7	-1,3	14,6	6,8	19,6	14,0	30,7
INTI	-5,2	8,0	-1,0	7,0	2,4	5,0	-1,1	7,0	1,7	10,0	9,5	13,0	32,7	22,0
UTE	---	---	1,0	24,0	2,0	24,0	14,0	30,0	----	----	----	----	----	----
INMETRO	-0,4	9,7	-0,5	9,0	0,2	5,9	0,2	6,9	2,0	8,0	9,9	10,3	19,0	16,6
CENAM	---	---	-2,0	42,0	0,0	36,0	17,0	40,0	----	----	----	---	----	----
NIST	0,0	19,0	-2,0	18,0	2,0	17,0	2,0	17,0	0,0	21,0	6,0	27,0	-4,0	33,0
INTI	-5,7	8,0	0,6	7,0	2,7	5,0	-0,1	7,0	1,1	10,0	6,5	13,0	28,4	22,0
NIS	---	---	-0,4	16,8	20,0	17,3	288,0	20,0	---	---	---	---	---	---
INTI	-5,7	8,0	-0,3	7,0	1,1	5,0	-1,8	7,0	2,1	10,0	10,0	13,0	32,2	22,0

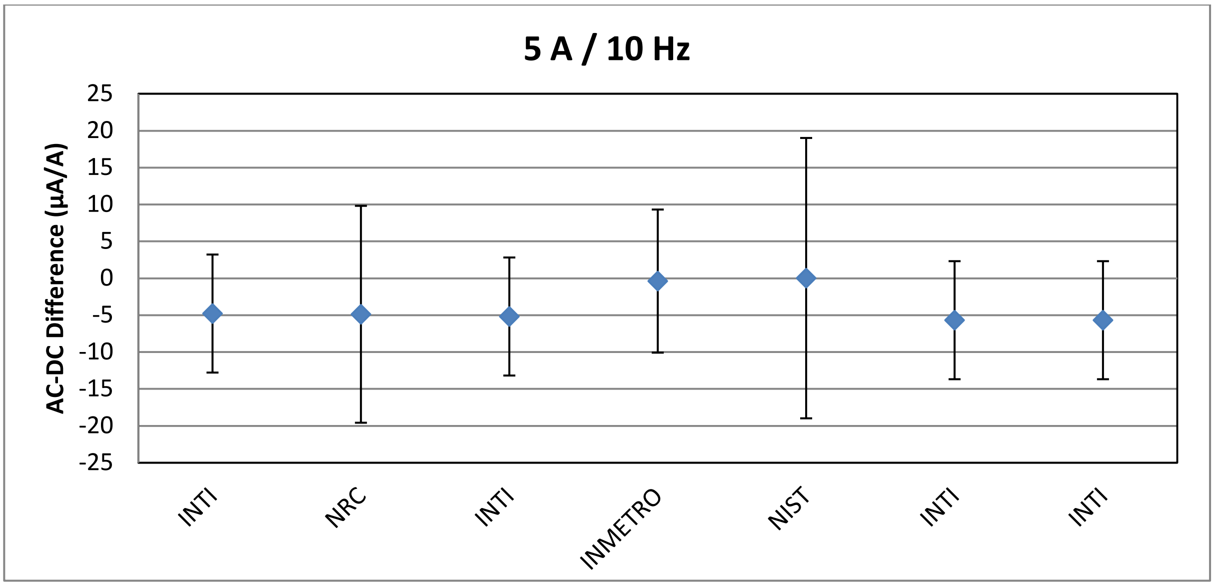

Fig. 10. Measured ac-dc difference and expanded uncertainty at 10 Hz.

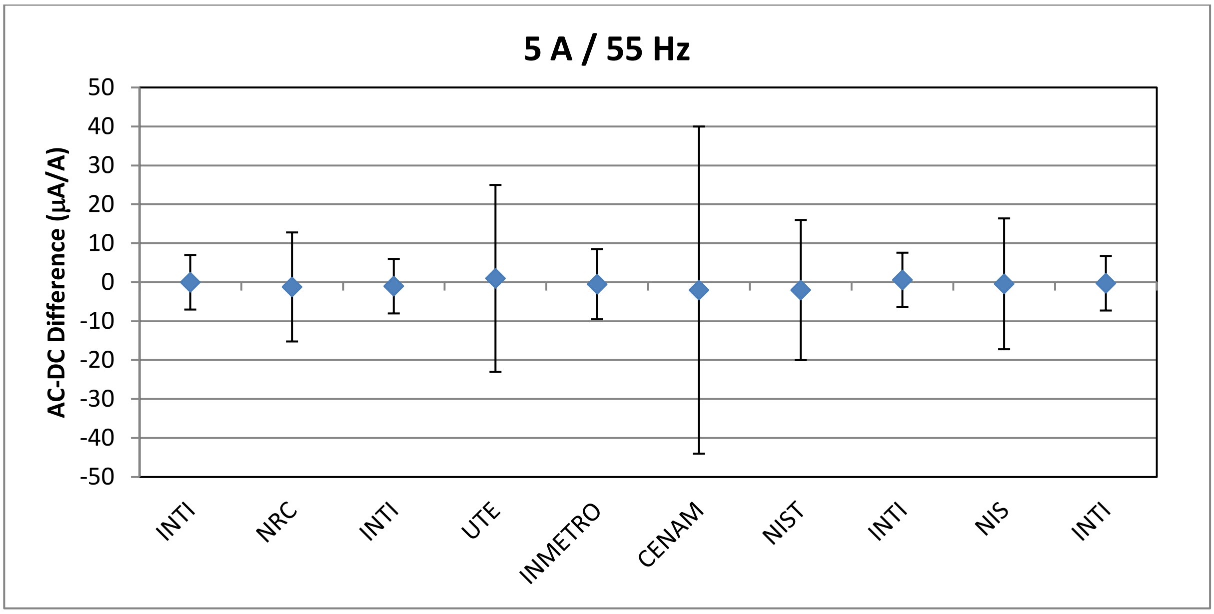

Fig. 11. Measured ac-dc difference and expanded uncertainty at 55 Hz.

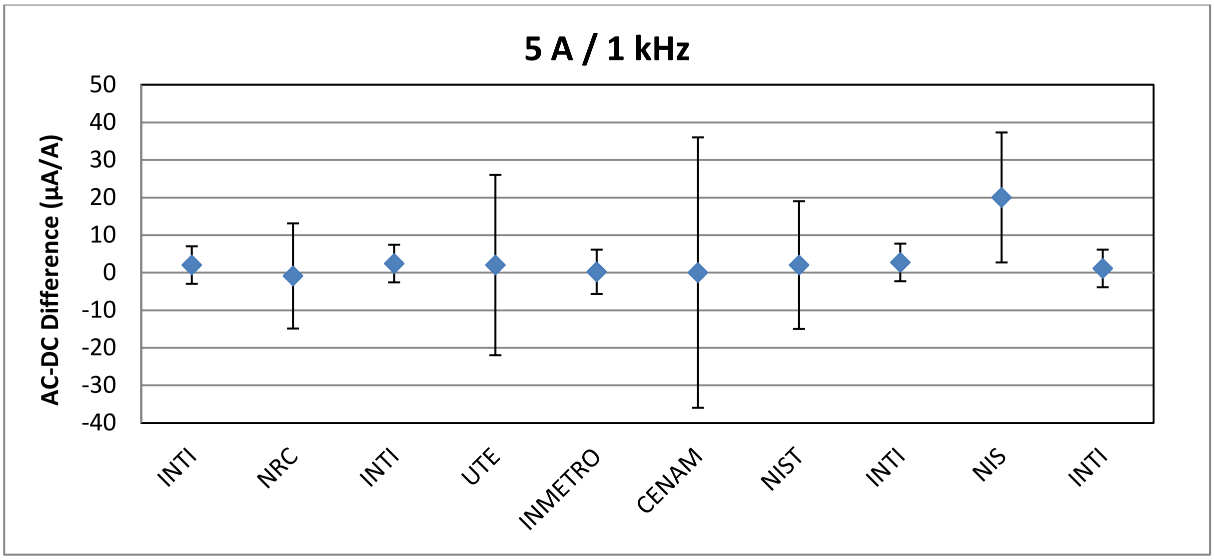

Fig. 12. Measured ac-dc difference and expanded uncertainty at 1 kHz.

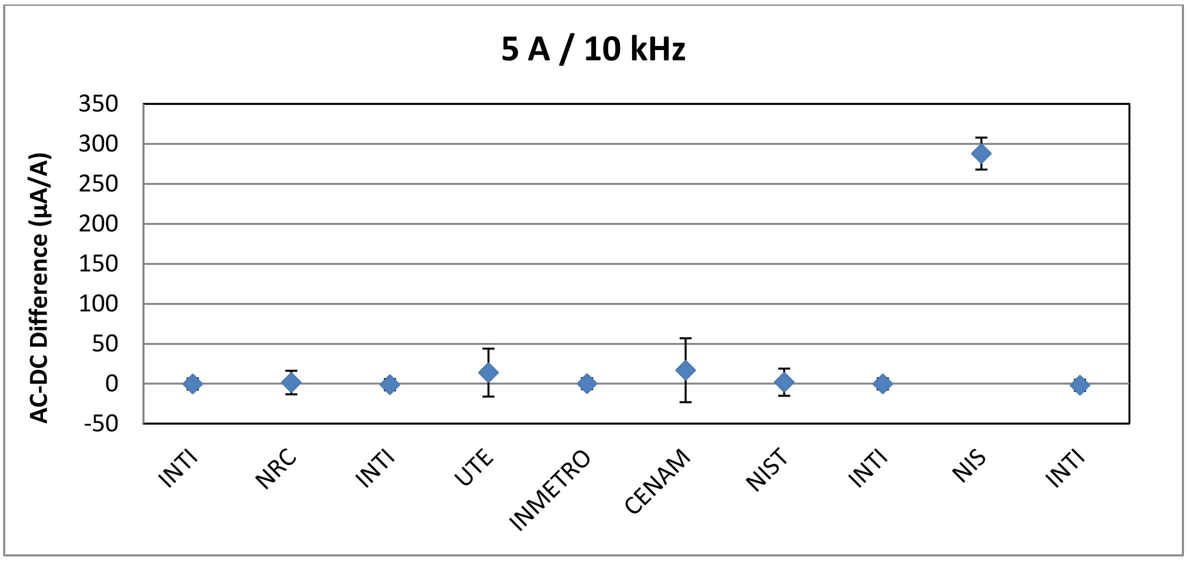

Fig. 13. Measured ac-dc difference and expanded uncertainty at 10 kHz.

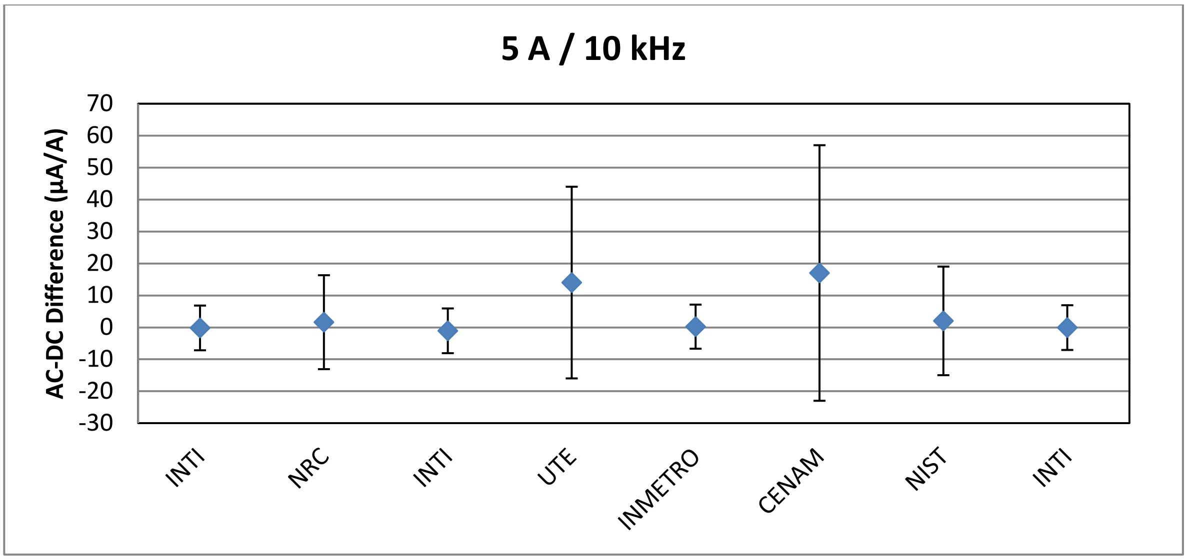

Fig. 13bis. Measured ac-dc difference and expanded uncertainty at 10 kHz excluding NIS values.

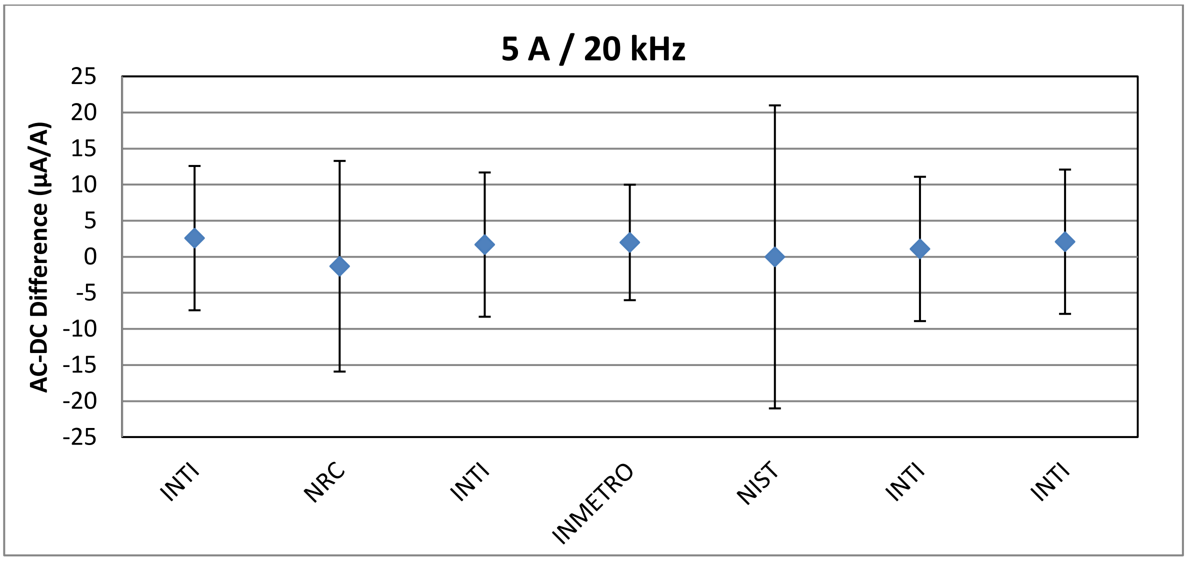

Fig. 14. Measured ac-dc difference and expanded uncertainty at 20 kHz.

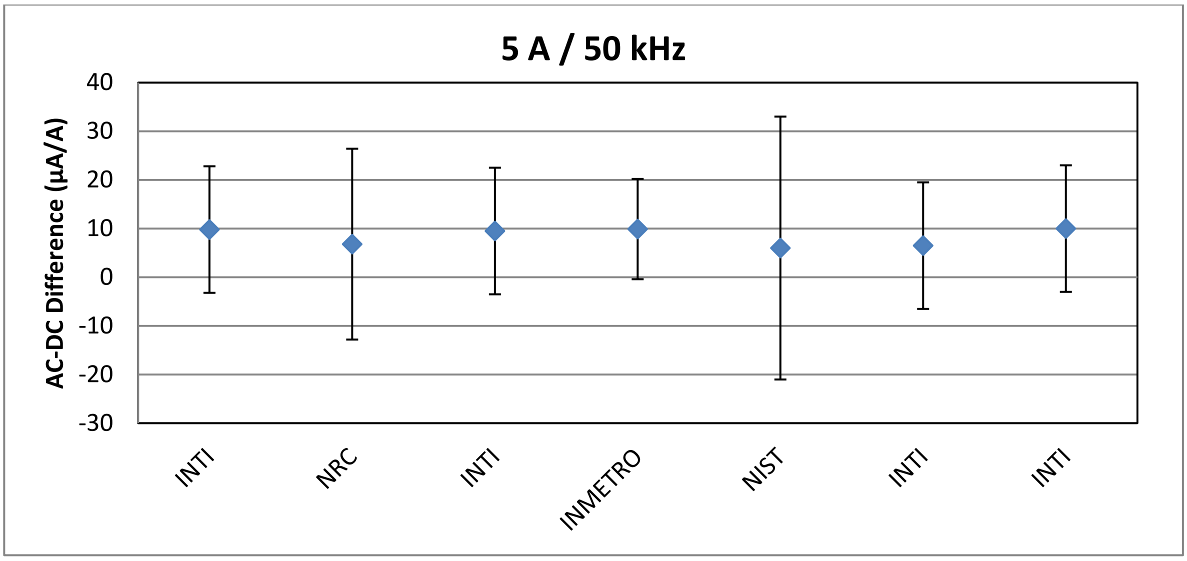

Fig. 15. Measured ac-dc difference and expanded uncertainty at 50 kHz.

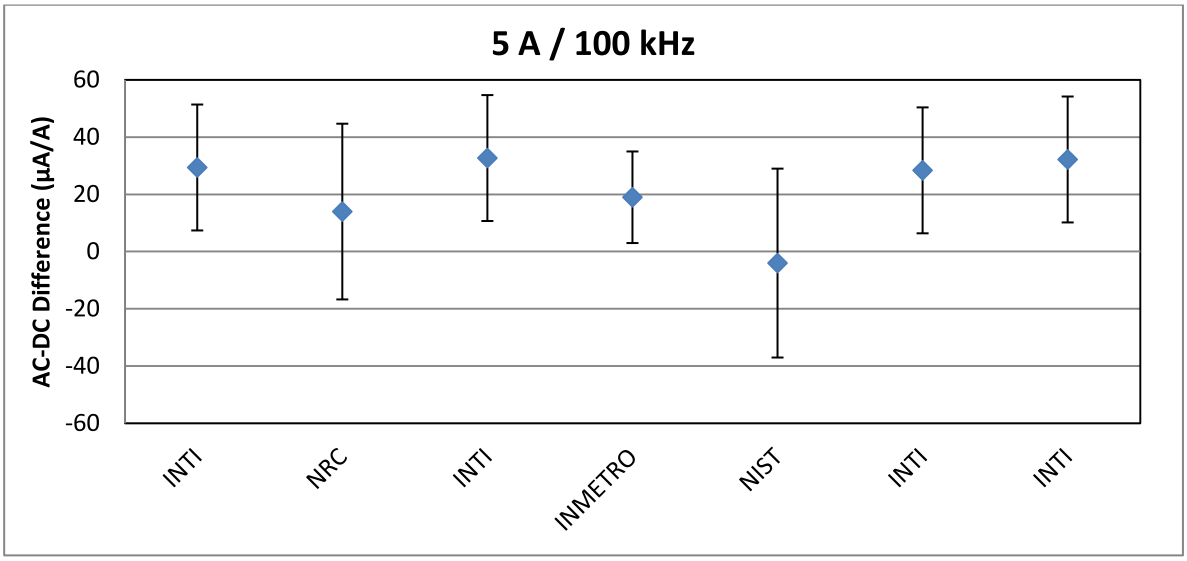

Fig. 16. Measured ac-dc difference and expanded uncertainty at 100 kHz.

10. Determination of the comparison reference value

The reference values for each of the measuring points was calculated as the weighted mean of the reported values from laboratories in SIM who have taken part in the CCEM-K12 Key Comparison and whose reported values had been taken in consideration to calculate the reference values in such comparison, (i.e. NRC, NIST and INTI).

The comparison reference value was determined as:

$$CRV = \frac{\sum_{i=1}^{3} \delta_i / U_{\delta_i}^2}{\sum_{i=1}^{3} 1 / U_{\delta_i}^2}$$

Where $U_{\delta i}$ is the expanded uncertainty associated with δ_i value, reported with a confidence level of 95 %.

The expanded uncertainty of the comparison reference value is:

$$U_{CRV} = \frac{1}{\sqrt{\sum_{i=1}^{3} 1 / U_{\delta i}^{2}}}$$

11. Degree of equivalence

The degree of equivalence D_{iE} between the i-th participant and the reference value CRV was evaluated as follows:

$$D_{iE} = \delta_i - CRV$$

For the laboratories without contribution to the reference value, the expanded uncertainty of D_{iE} (U_{iE}) was estimated as:

$$U_{iE} = k_{Di}\sqrt{u_{\delta_i}^2 + u_{CRV}^2}$$

For the laboratories with contribution to the reference value, the expanded uncertainty of D_{iE} (U_{iE}) was estimated as:

$$U_{iE} = k_{Di}\sqrt{u_{\delta_i}^2 - u_{CRV}^2}$$

Table VII shows the degrees of equivalence, D_{iE}, with the CRV and the corresponding expanded uncertainty U_{iE} at 10 mA.

TableVII

Degree of equivalence with the CRV and expanded uncertainty in µA/A														
D_{iE}	**Difference NMI-CRV**													
U_{iE}	**Expanded uncertainty of D_{iE} (coverage factor k=2)**													
Level	**10 mA**													
	10 Hz		**55 Hz**		**1 kHz**		**10 kHz**		**20 kHz**		**50 kHz**		**100 kHz**	
	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}
INTI	-0,4	5,8	0,3	3,9	0,1	2,9	-0,3	2,6	0,0	2,6	-0,3	9,8	-1,5	19,9
NRC	-0,1	0,5	0,0	0,3	0,0	0,3	-0,2	1,1	-0,3	1,2	-0,4	0,6	-0,3	0,4
INTI	1,8	5,8	0,3	3,9	0,1	2,9	0,9	2,6	-1,1	2,6	2,0	9,8	-3,2	19,9
UTE	----	----	-4,3	12,0	-4,0	12,0	-3,4	14,1	----	----	----	----	----	----
INMETRO	-0,2	3,6	0,2	3,4	0,0	3,3	-0,5	3,6	-0,5	3,6	-1,5	3,7	-2,7	3,7
CENAM	----	----	0,3	22,0	0,0	22,0	0,1	22,0	0,7	22,1	2,5	22,1	-1,8	24,1
NIST	0,6	8,9	-0,3	5,9	-1,0	3,9	0,6	3,7	1,6	3,7	4,7	6,8	7,5	9,8
INTI	1,7	5,8	0,4	3,9	-0,2	2,9	0,8	2,6	1,3	2,6	0,2	9,8	-2,7	19,9
NIS	-5,6	3,5	-1,2	2,9	-1,0	5,6	-3,1	6,6	----	----	----	----	----	----
INTI	1,4	5,8	-0,5	3,9	-0,2	2,9	-0,5	2,6	-0,7	2,6	0,2	9,8	0,6	19,9

Figures 17 to 23 show the data from the Table VII in a graphic form.

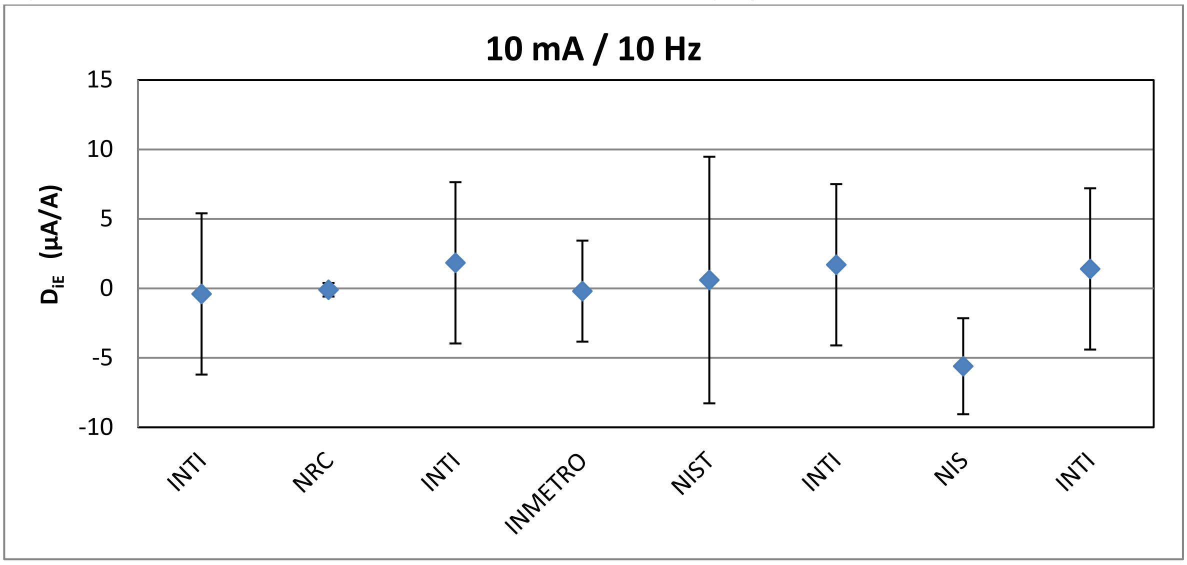

Fig. 17. Degree of equivalence with the CRV and expanded uncertainty at 10 Hz.

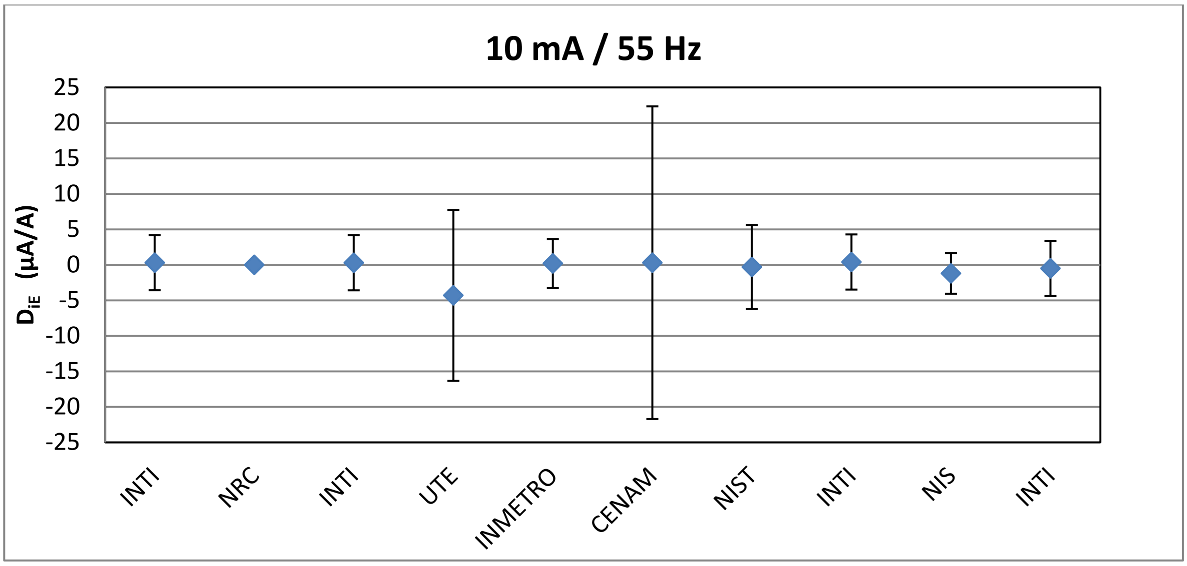

Fig. 18. Degree of equivalence with the CRV and expanded uncertainty at 55 Hz.

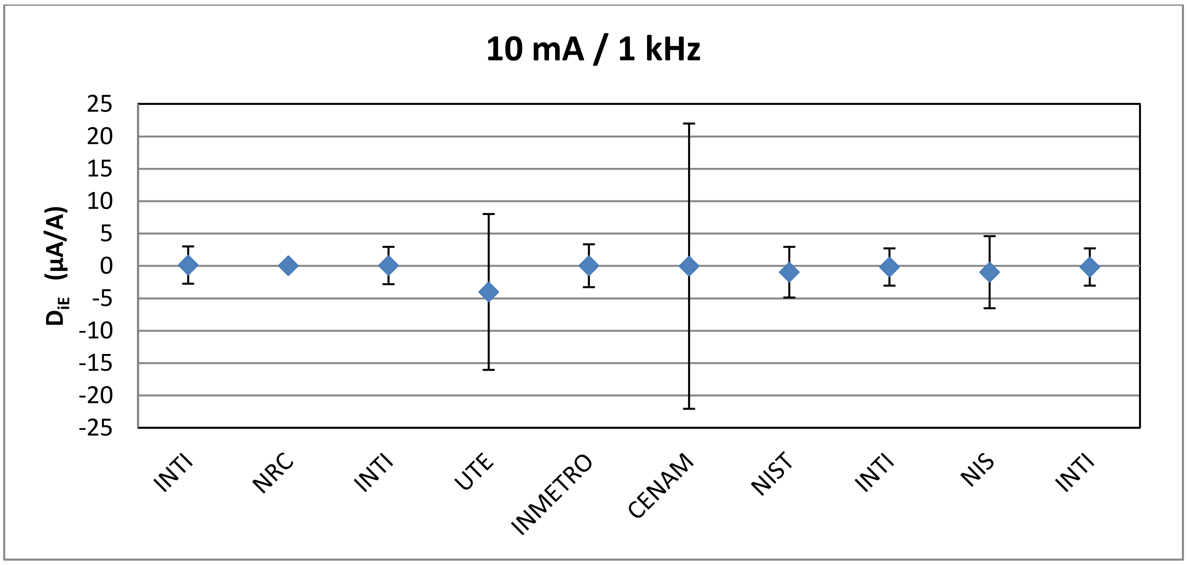

Fig. 19. Degree of equivalence with the CRV and expanded uncertainty at 1 kHz.

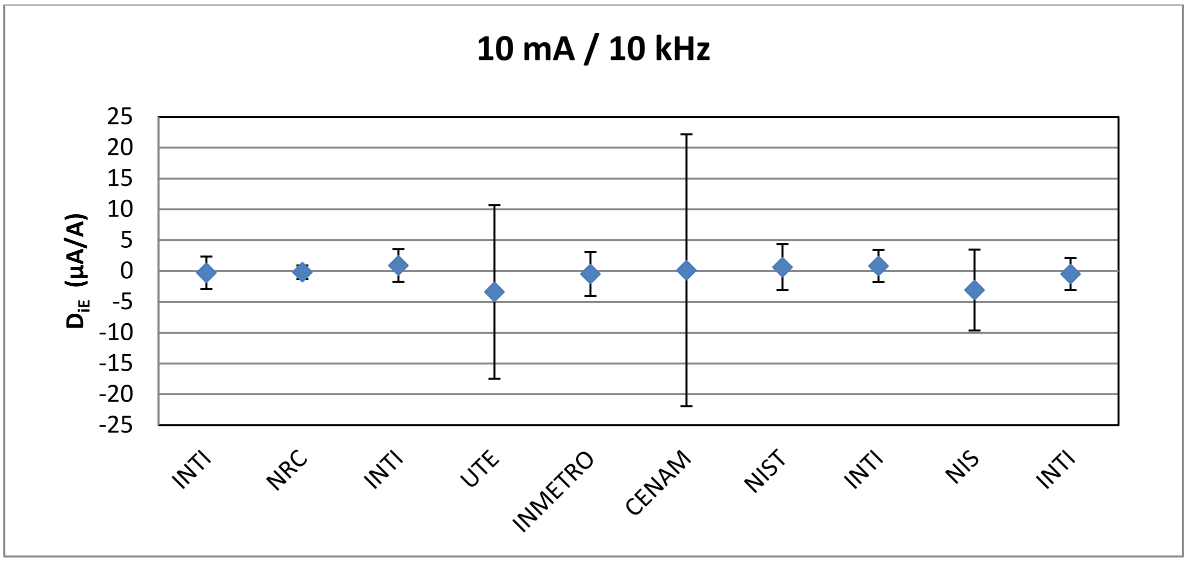

Fig. 20. Degree of equivalence with the CRV and expanded uncertainty at 10 kHz.

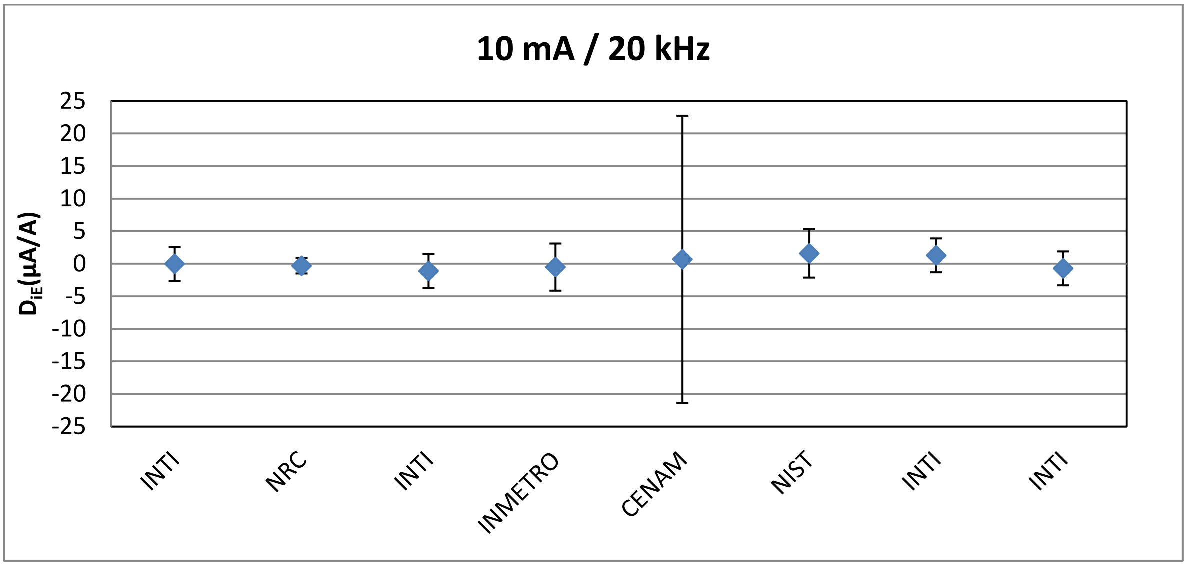

Fig. 21. Degree of equivalence with the CRV and expanded uncertainty at 20 kHz.

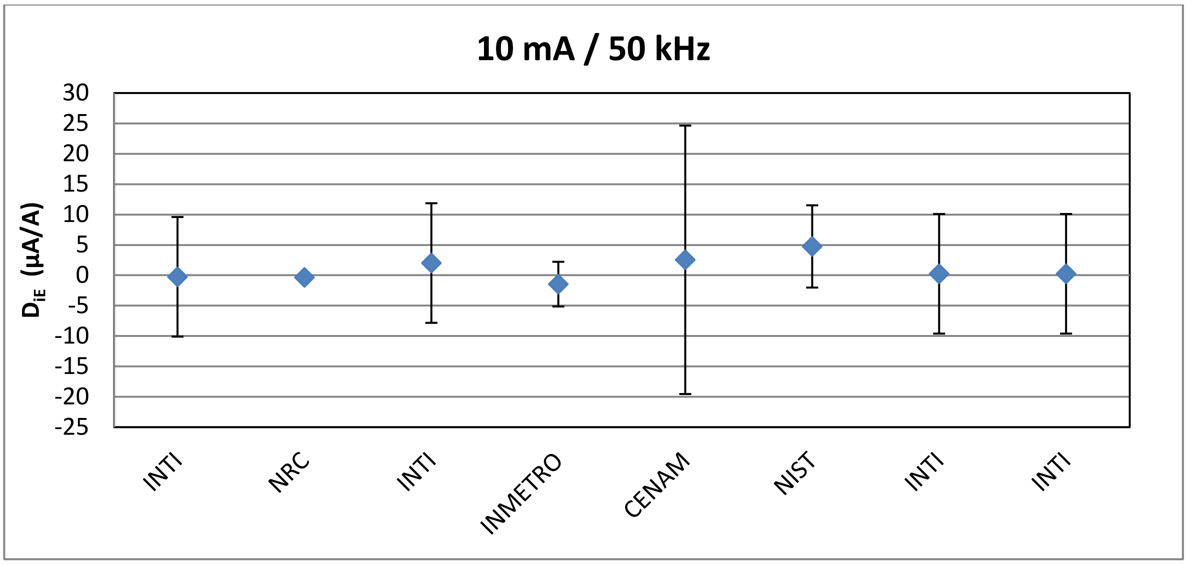

Fig. 22. Degree of equivalence with the CRV and expanded uncertainty at 50 kHz.

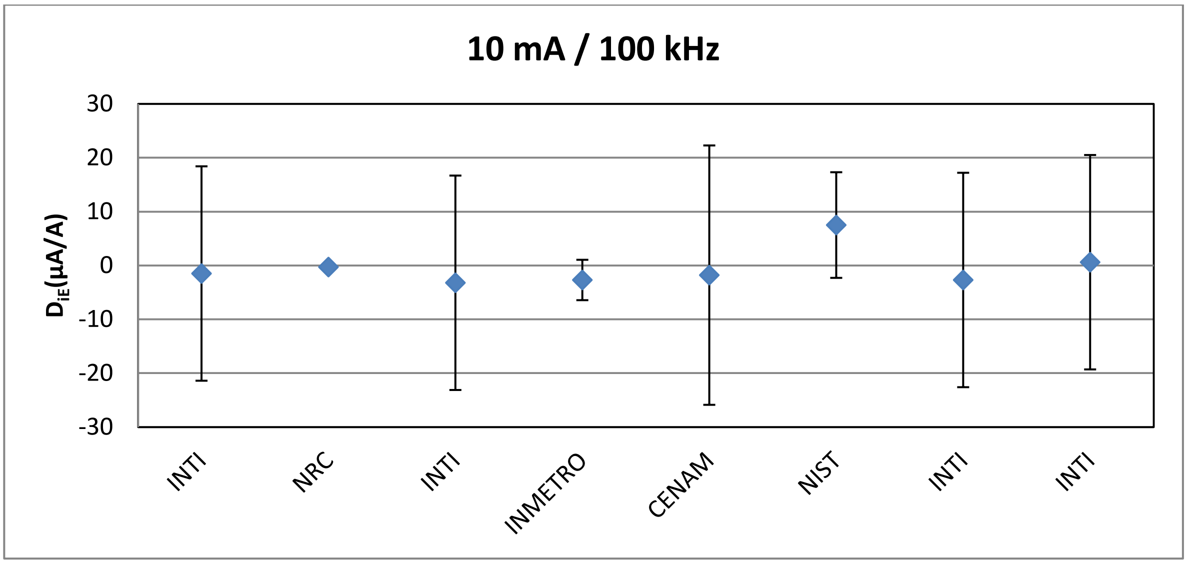

Fig. 23. Degree of equivalence with the CRV and expanded uncertainty at 100 kHz.

Table VIII shows, for each participant, the degree of equivalence D_{iE} with the CRV and the corresponding expanded uncertainty U_{DiE} at 5 A.

Table VIII

Degree of equivalence with the CRV and expanded uncertainty in µA/A														
D_{iE}	**Difference NMI-CRV**													
U_{iE}	**Expanded uncertainty of D_{iE} (coverage factor k=2)**													
Level	**5 A**													
	10 Hz		**55 Hz**		**1 kHz**		**10 kHz**		**20 kHz**		**50 kHz**		**100 kHz**	
	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}	D_{iE}	U_{iE}
INTI	-0,2	4,5	0,5	3,7	0,3	2,1	-0,2	3,7	1,8	6,4	1,9	8,2	10,9	15,4
NRC	-0,3	13,1	-0,7	12,7	-2,6	13,2	1,7	13,5	-2,0	12,4	-1,2	16,8	-4,4	26,4
INTI	-0,6	4,5	-0,5	3,7	0,7	2,1	-1,0	3,7	1,0	6,4	1,5	8,2	14,3	15,4
UTE	---	---	1,5	23,3	0,3	24,4	14,1	30,6	----	----	----	----	----	----
INMETRO	4,2	11,7	0,0	6,8	-1,5	7,4	0,3	9,1	1,3	11,1	1,9	14,4	0,6	22,4
CENAM	---	---	-1,5	41,6	-1,7	36,3	17,1	40,4	----	----	----	---	----	----
NIST	4,6	17,8	-1,5	17,0	0,3	16,4	2,1	15,9	-0,7	19,5	-2,0	25,1	-22,4	29,0
INTI	-1,1	4,5	1,1	3,7	1,0	2,1	0,0	3,7	0,4	6,4	-1,5	8,2	9,9	15,4
NIS	---	---	0,1	15,7	18,3	17,9	288,1	20,9	---	---	---	---	---	---
INTI	-1,1	4,5	0,3	3,7	-0,6	2,1	-1,7	3,7	1,4	6,4	2,0	8,2	13,8	15,4

Figures 24 to 30 show the data from the Table VIII in a graphic form.

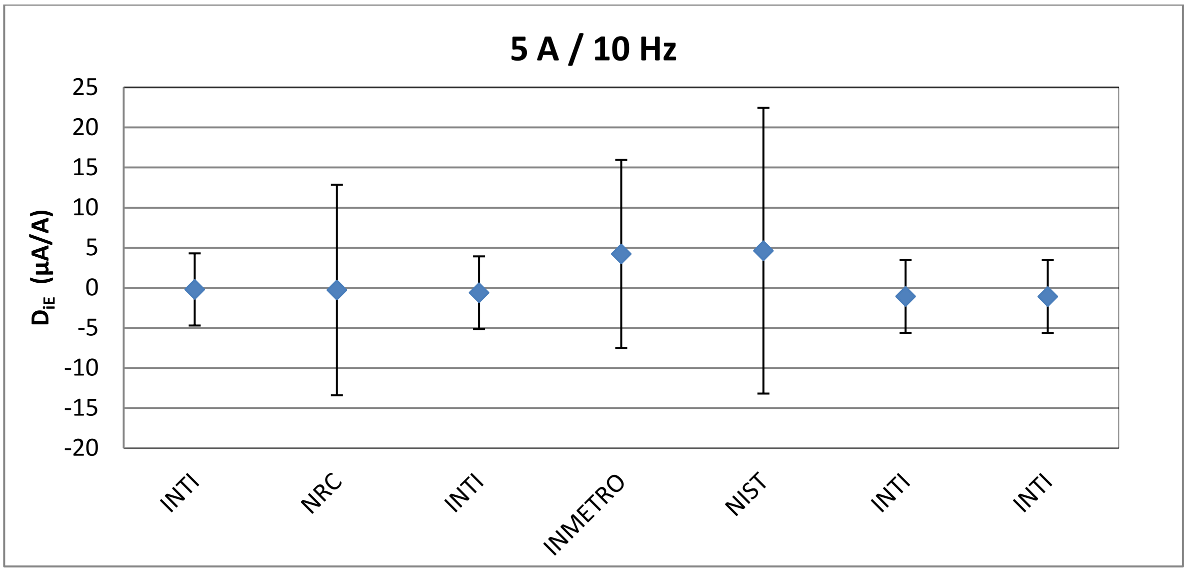

Fig. 24. Degree of equivalence with the CRV and expanded uncertainty at 10 Hz.

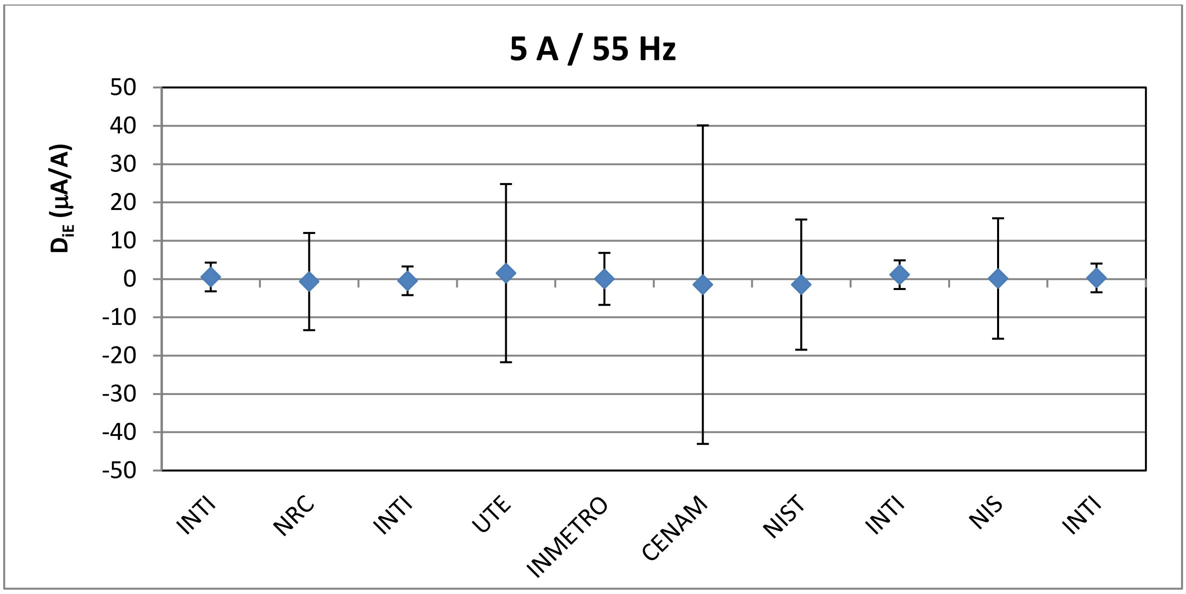

Fig. 25. Degree of equivalence with the CRV and expanded uncertainty at 55 Hz.

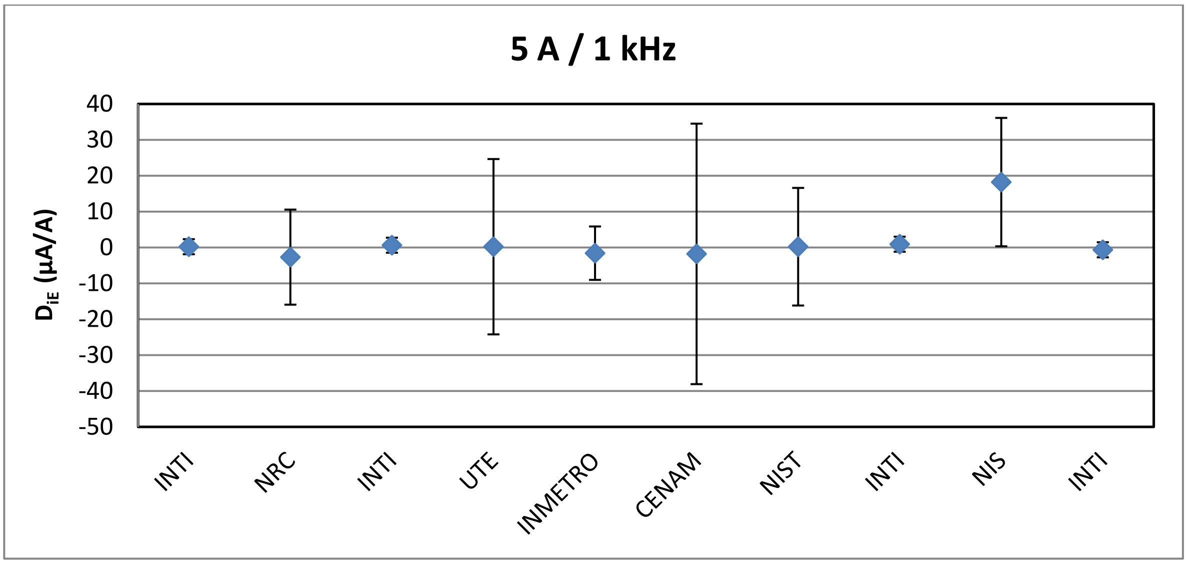

Fig. 26. Degree of equivalence with the CRV and expanded uncertainty at 1 kHz.

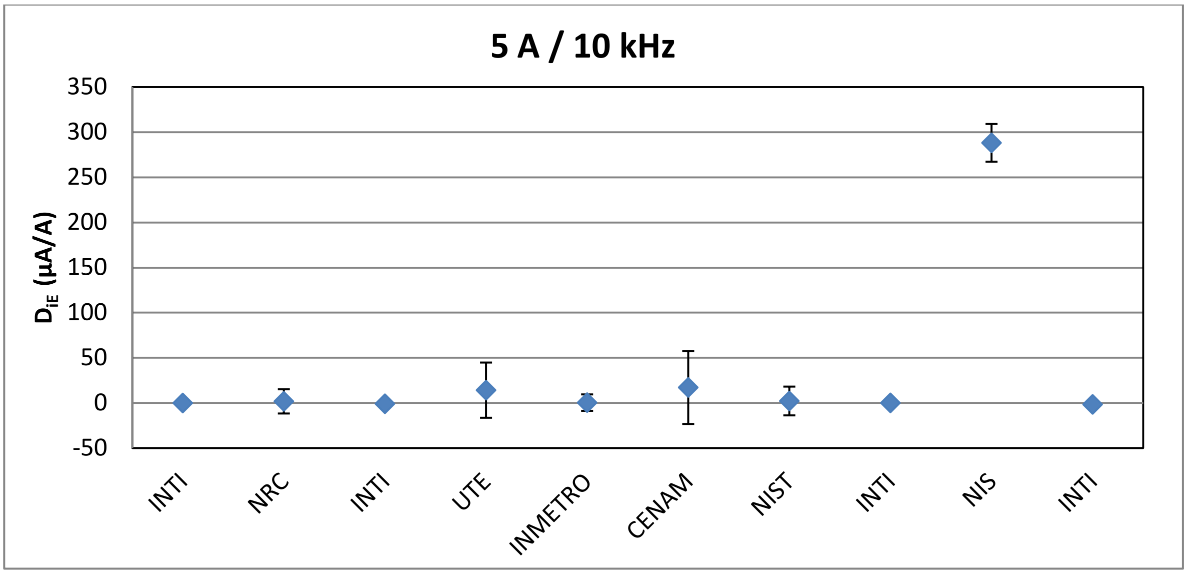

Fig. 27. Degree of equivalence with the CRV and expanded uncertainty at 10 kHz.

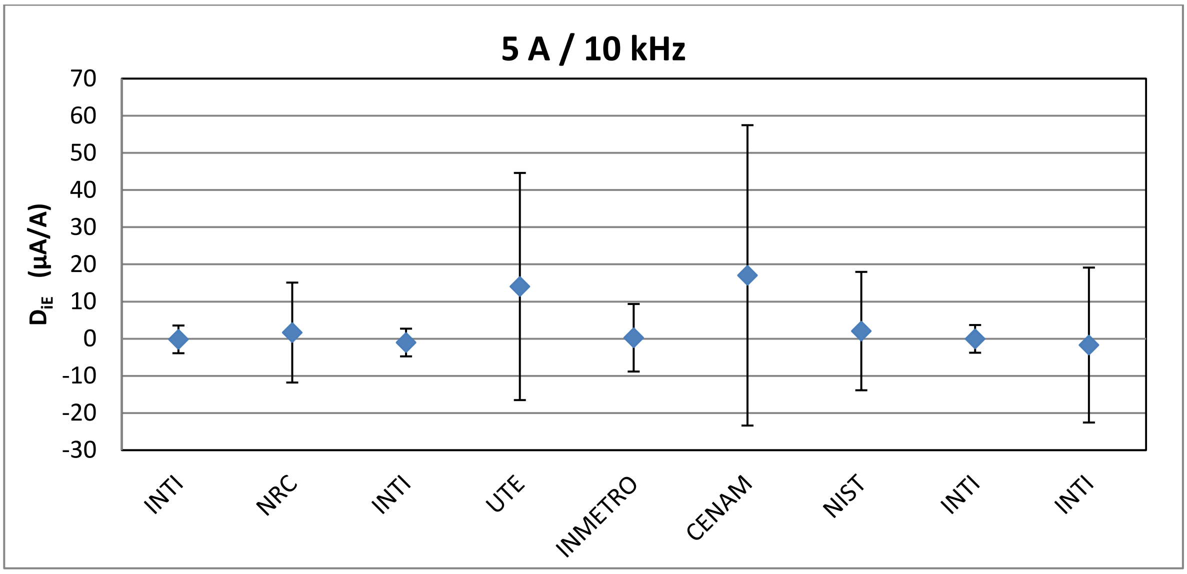

Fig. 27bis. Degree of equivalence with the CRV and expanded uncertainty at 10 kHz excluding NIS values.

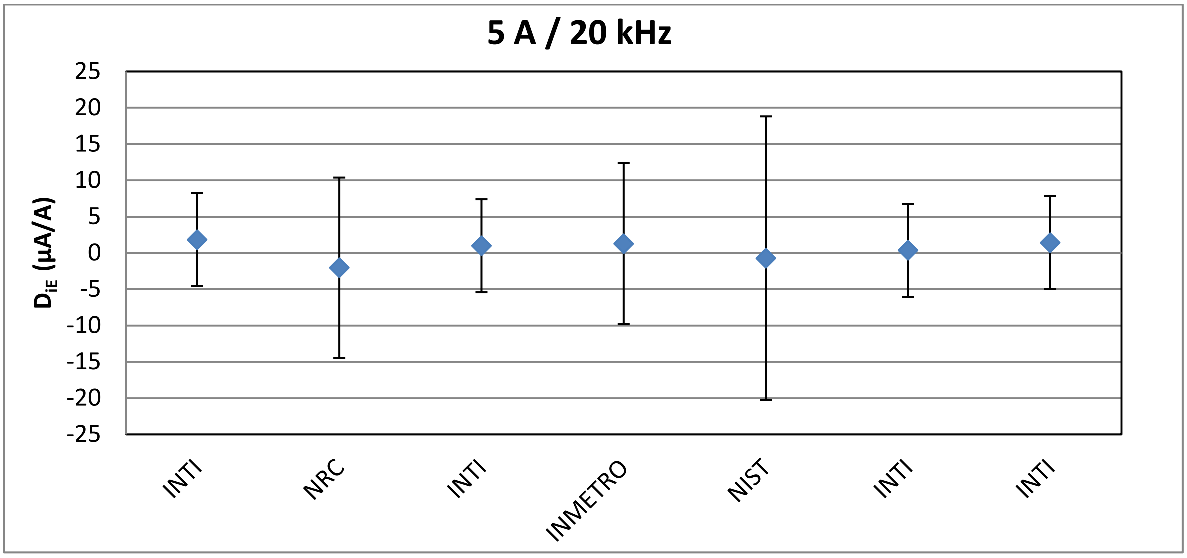

Fig. 28. Degree of equivalence with the CRV and expanded uncertainty at 20 kHz.

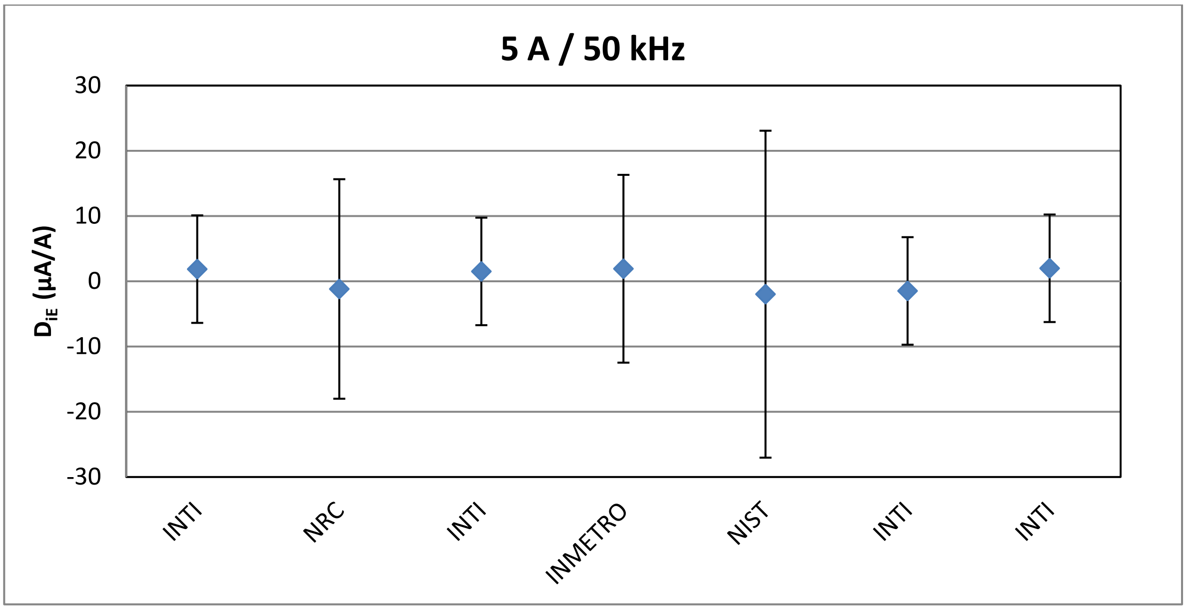

Fig. 29. Degree of equivalence with the CRV and expanded uncertainty at 50 kHz.

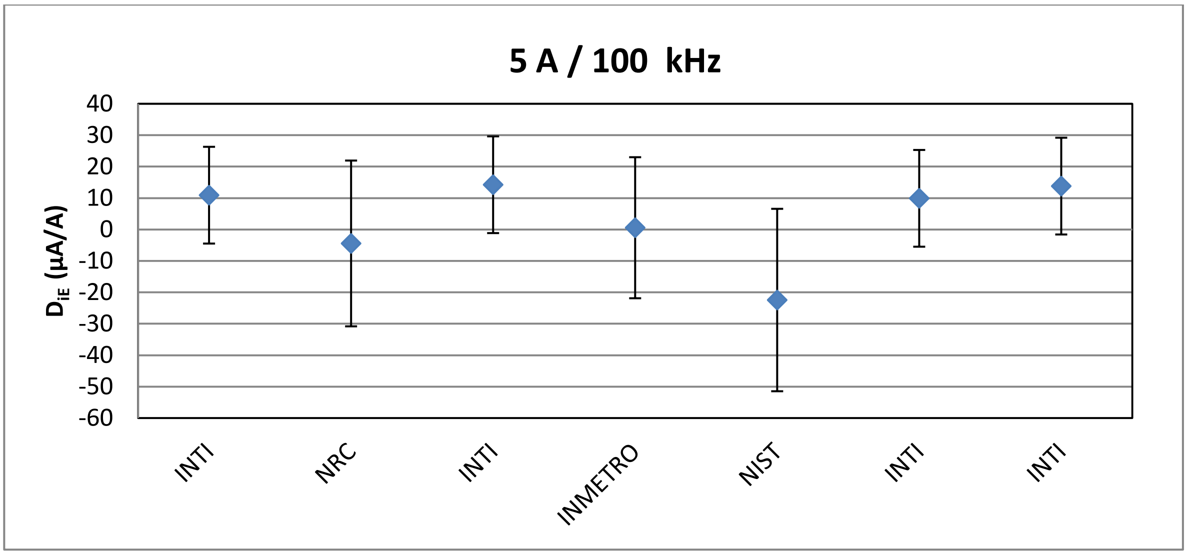

Fig. 30. Degree of equivalence with the CRV and expanded uncertainty at 100 kHz.

12. Linking to the Key comparison CCEM-K12

The results of the CCEM–K12 key comparison are available, [1]. Rather than evaluating the differences between pairs of laboratories, only the differences between the results of participants who took part in the SIM comparison but have not participated in the CCEM comparison and the CCEM key comparison reference value (KCRV) was calculated.

The degree of equivalence for the *i*-NMI had not participated in CCEM–K12, D_{iC}, is determined as:

$$D_{iC} = D_{iE} - \Delta$$

where

D_{iE} is the degree of equivalence with the CRV for *i*-NMI participating in SIM.EM-K12 only

Δ is the correction for the difference between the CRV and KCRV

The correction between the CRV and the KCRV as measured by the linking i-NMI, Δ_{iLink}, is used to estimate the correction, Δ, because:

$$\Delta_{iLink} = D_{iLinkC} - D_{iLinkE}$$

where

D_{iLinkC} is the degree of equivalence with the KCRV for linking *i*-MNI participating in CCEM–K12

D_{iLinkE} is the degree of equivalence with the CRV for linking *i*-NMI participating in SIM.EM-K12

The correction, Δ, is calculated as the weighted mean of the linking NMIs estimates:

$$\Delta = \frac{\sum_{iLink} \frac{\Delta_{iLink}}{u^2_{\Delta iLink}}}{\sum_{iLink} \frac{1}{u^2_{\Delta iLink}}}$$

where the standard uncertainty $u_{\Delta iLink}$ is given by:

$$u^2_{\Delta iLink} = u^2_{DiLinkC} + u^2_{DiLinkE}$$

The standard uncertainty of the estimated correction, u_Δ, is calculated as the uncertainty of the weighted mean:

$$u^2_\Delta = \frac{1}{\sum_{iLink} \frac{1}{u^2_{\Delta iLink}}}$$

The standard uncertainty of the degree of equivalence with KCRV for the *i*-NMI that participated in the CCEM–K12, u_{DiC} , was calculated as:

$$u_{DiC}^2 = u_{DiE}^2 + u_\Delta^2$$

Finally the expanded uncertainty U_{DiC} is equal to:

$$U_{DiC} = k_{DiC} u_{DiC}$$

Corrections for linking to CCEM-K12

Three NMIs, NIST, NRC, INTI, act as the linking laboratories.

Tables VIII and IX show, for the linking NMIs, the degree of equivalence with the KCRV and its expanded uncertainty, D_{iLinkC} and U_{iLinkC} , and the CRV, D_{iLinkE} and U_{iLinkE} , as well as the correction with expanded uncertainty between the CRV and KCRV, Δ_{iLink} and $U_{\Delta iLink}$, at 10 mA, in μA/A.

Table VIII

Level	10 mA							
	10 Hz		55 Hz		1 kHz		10 kHz	
	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}
INTI	-1,4	6,1	1,8	6,0	2,3	3,0	2,4	3,1
NIST	4,4	9,0	-0,2	6,0	-1,0	4,0	1,2	3,9
NRC	-0,1	1,4	-0,1	0,6	0,1	0,6	-0,6	1,2
	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}
INTI	1,1	5,8	0,1	3,9	0,0	2,9	0,0	2,6
NIST	0,6	8,9	-0,3	5,9	-0,9	3,9	0,6	3,7
NRC	-0,1	0,5	0,0	0,3	0,1	0,3	-0,2	1,1
	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$
INTI	-2,5	8,4	1,7	7,2	2,3	4,2	2,4	4,0
NIST	3,8	12,7	0,1	8,4	-0,1	5,6	0,6	5,4
NRC	0,0	1,5	-0,1	0,7	0,0	0,7	-0,4	1,6

Table IX

Level	10 mA					
	20 kHz		50 kHz		100 kHz	
	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}
INTI	2,3	5,0	1,5	10,0	0,8	20,0
NIST	1,2	3,9	3,3	7,0	6,8	10,0
NRC	-0,6	1,7	-0,8	1,4	-0,8	1,3
	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}
INTI	-0,1	2,6	0,5	9,8	-1,7	19,9
NIST	1,6	3,7	4,7	6,8	4,5	9,8
NRC	-0,3	1,2	-0,4	0,6	-0,3	0,4
	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$
INTI	2,4	5,6	1,0	14,0	2,5	28,2
NIST	-0,4	5,4	-1,4	9,8	2,3	14,0
NRC	-0,3	2,1	-0,4	1,5	-0,5	1,4

Tables X and XI show, for the linking NMIs, the degree of equivalence with the KCRV and its expanded uncertainty, D_{iLinkC} and U_{iLinkC}, and the CRV, D_{iLinkE} and U_{iLinkE}, as well as the correction with expanded uncertainty between the CRV and KCRV, Δ_{iLink} and $U_{\Delta iLink}$, at 5 A, in μA/A.

Table X

Level	5 A							
	10 Hz		55 Hz		1 kHz		10 kHz	
	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}
INTI	1,3	7,9	-0,9	6,9	2,9	4,8	-1,5	6,8
NIST	3,1	18,9	4,3	17,9	2,5	16,9	6,6	16,9
NRC	0,0	14,9	0,1	13,9	-1,1	13,9	-2,5	14,9
	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}
INTI	-0,8	4,5	0,2	2,1	0,4	2,1	-0,7	3,7
NIST	4,6	17,8	-1,6	17,4	0,3	16,4	2,1	15,9
NRC	-0,3	13,1	-0,8	13,2	-2,6	13,2	1,7	13,5
	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$
INTI	2,1	9,1	-1,1	7,2	2,6	5,2	-0,8	7,7
NIST	-1,5	26,0	5,9	25,0	2,2	23,5	4,5	23,2
NRC	0,3	19,8	0,9	19,2	1,5	19,2	-4,2	20,1

Table XI

Level	5 A					
	20 kHz		50 kHz		100 kHz	
	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}	D_{iLinkC}	U_{iLinkC}
INTI	0,9	7,6	3,4	12,4	0,1	21,3
NIST	0,6	20,8	1,5	26,7	-25,7	32,05
NRC	0,4	14,8	-1,1	19,6	-11,3	30,5
	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}	D_{iLinkE}	U_{iLinkE}
INTI	1,2	6,4	1,0	8,2	12,2	15,4
NIST	-0,7	19,5	-2,0	25,1	-22,4	29,0
NRC	-2,0	12,4	-1,2	16,8	-4,4	26,4
	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$	Δ_{iLink}	$U_{\Delta iLink}$
INTI	-0,3	9,9	2,4	14,9	-12,1	26,3
NIST	1,3	28,5	3,5	36,6	-3,3	43,6
NRC	2,4	19,3	0,1	25,8	-6,9	40,3

Table XII. The corrections Δ, between the CRV and the KCRV with standard uncertainties u_Δ in μA/A, at 10 mA.

10 mA							
	10 Hz	**55 Hz**	**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Δ	0,0	-0,1	0,1	0,0	0,0	-0,4	-0,5
$\mathbf{u}_\Delta$	1,5	0,7	0,7	1,5	1,8	1,5	1,4

Table XIII. The corrections Δ, between the CRV and the KCRV with standard uncertainties u_Δ in μA/A, at 5 A.

5 A							
	10 Hz	**55 Hz**	**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Δ	1,4	-0,4	2,5	-0,7	0,4	2,0	-9,1
$\mathbf{u}_\Delta$	7,9	6,5	4,9	6,9	8,4	12,2	19,7

Table XIV. Degree of equivalence D_{iC} with the KCRV with corresponding expanded uncertainty $U_{D_{iC}}$ in µA/A, at 10 mA

Degree of equivalence with the KCRV and expanded uncertainty in µA/A														
D_{iC}	**Difference NMI- KCRV**													
U_{iC}	**Expanded uncertainty of** D_{iC}													
Level	**10 mA**													
	10 Hz		**55 Hz**		**1 kHz**		**10 kHz**		**20 kHz**		**50 kHz**		**100 kHz**	
	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}
INTI	-1,4	6,1	1,8	6,0	2,3	3,0	2,4	3,1	2,3	5,0	1,5	10,0	0,8	20,0
NRC	-0,1	1,4	-0,1	0,6	0,1	0,6	-0,6	1,2	-0,6	1,7	-0,8	1,4	-0,8	1,3
INTI	-1,4	6,1	1,8	6,0	2,3	3,0	2,4	3,1	2,3	5,0	1,5	10,0	0,8	20,0
UTE	----	----	-4,2	12,1	-4,1	12,0	-3,4	14,2	----	----	----	----	----	----
INMETRO	-0,2	3,9	0,3	3,5	-0,1	3,4	-0,5	3,9	-0,5	4,0	-1,1	4,0	-2,2	4,0
CENAM	----	----	0,4	22,0	-0,1	22,0	0,1	22,1	0,7	22,1	2,9	22,1	-1,3	24,1
NIST	4,4	9,0	-0,2	6,0	-1,0	4,0	1,2	3,9	1,2	3,9	3,3	7,0	6,8	10,0
INTI	-1,4	6,1	1,8	6,0	2,3	3,0	2,4	3,1	2,3	5,0	1,5	10,0	0,8	20,0
NIS	-5,6	3,8	-1,1	2,9	-1,1	5,6	-3,1	6,7	----	----	----	----	----	----
INTI	-1,4	6,1	1,8	6,0	2,3	3,0	2,4	3,1	2,3	5,0	1,5	10,0	0,8	20,0

Table XV. Degree of equivalence D_{iC} with the KCRV with corresponding expanded uncertainty $U_{D_{iC}}$ in µA/A, at 5 A

Degree of equivalence with the KCRV and expanded uncertainty in µA/A														
D_{iC}	**Difference NMI- KCRV**													
U_{iC}	**Expanded uncertainty of** D_{iC}													
Level	**5 A**													
	10 Hz		**55 Hz**		**1 kHz**		**10 kHz**		**20 kHz**		**50 kHz**		**100 kHz**	
	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}	D_{iC}	U_{iC}
INTI	1,3	7,9	-0,9	6,9	5,9	4,8	-1,5	6,8	0,9	7,6	3,4	12,4	0,1	21,3
NRC	0,0	14,9	0,1	13,9	-1,1	13,9	-2,4	14,9	0,4	14,8	-1,1	19,6	-11,3	30,5
INTI	1,3	7,9	-0,9	6,9	5,9	4,8	-1,5	6,8	0,9	7,6	3,4	12,4	0,1	21,3
UTE	----	----	1,8	25,3	-2,2	24,9	14,8	31,3	----	----	----	----	----	----
INMETRO	2,8	14,1	0,3	12,0	-4,0	8,9	1,0	11,4	0,9	13,9	-0,1	18,9	9,7	29,9
CENAM	----	----	-1,2	42,7	-4,2	36,6	17,8	41,0	----	----	----	----	----	----
NIST	3,1	18,9	4,3	17,9	2,5	16,9	6,6	16,9	0,6	20,8	1,5	26,7	-25,7	32,5
INTI	1,3	7,9	-0,9	6,9	5,9	4,8	-1,5	6,8	0,9	7,6	3,4	12,4	0,1	21,3
NIS	----	----	0,4	18,6	15,8	18,5	288,8	22,0	----	----	----	----	----	----
INTI	1,3	7,9	-0,9	6,9	5,9	4,8	-1,5	6,8	0,9	7,6	3,4	12,4	0,1	21,3

Figures 31 to 37 show the degree of equivalence D_{iC} with the KCRV with corresponding expanded uncertainty $U_{D_{iC}}$ for each NMI and measurement point, at 10 mA.

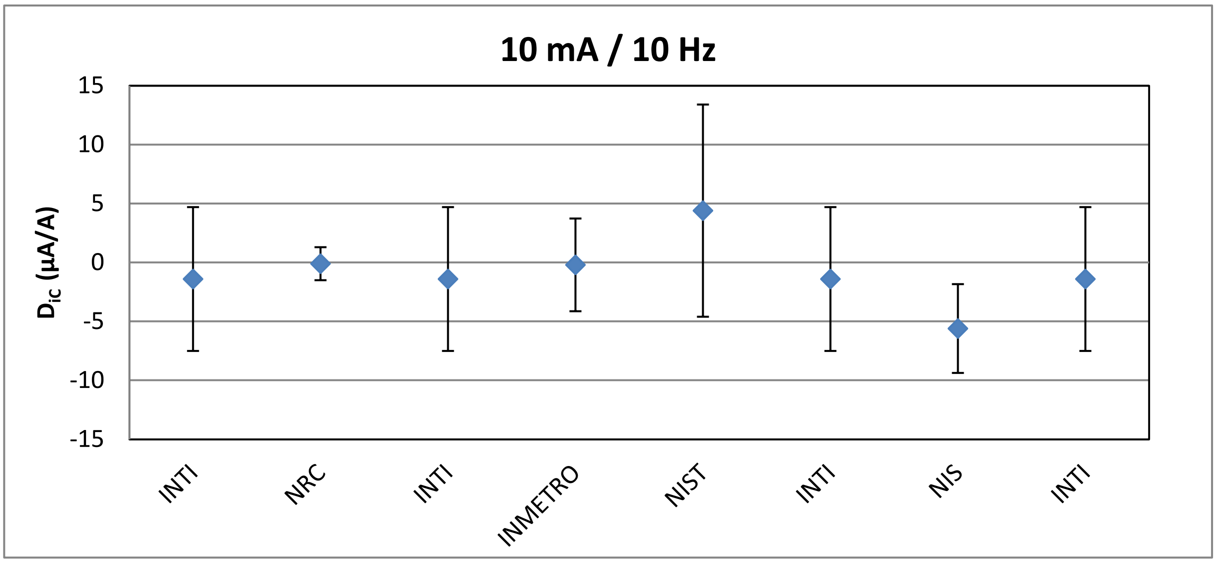

Fig. 31. Degree of equivalence with the KCRV and expanded uncertainty at 10 Hz.

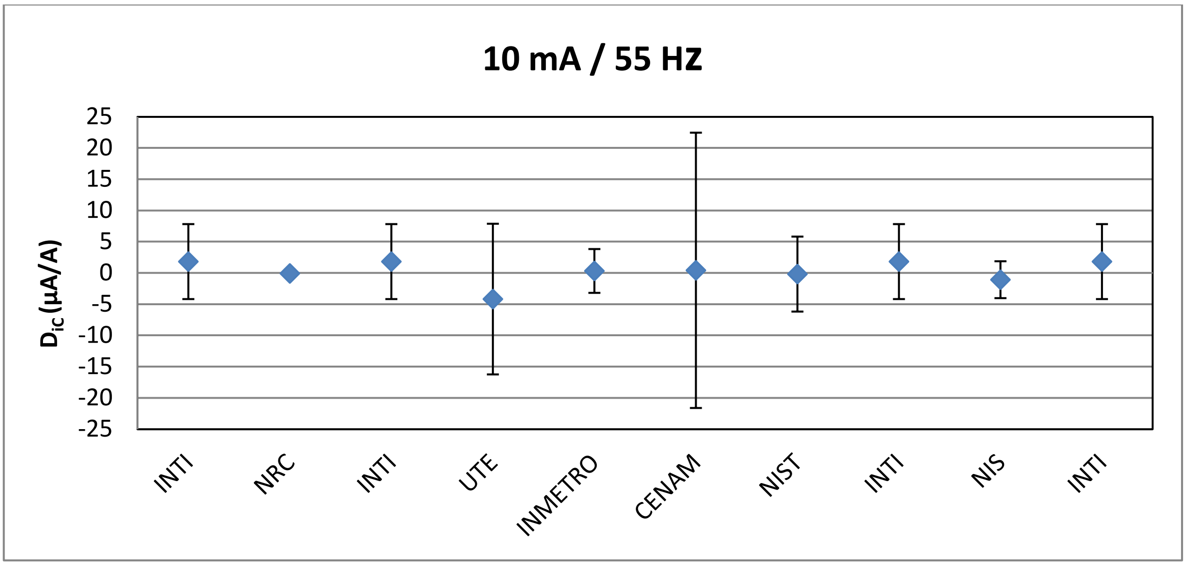

Fig. 32. Degree of equivalence with the KCRV and expanded uncertainty at 55 Hz.

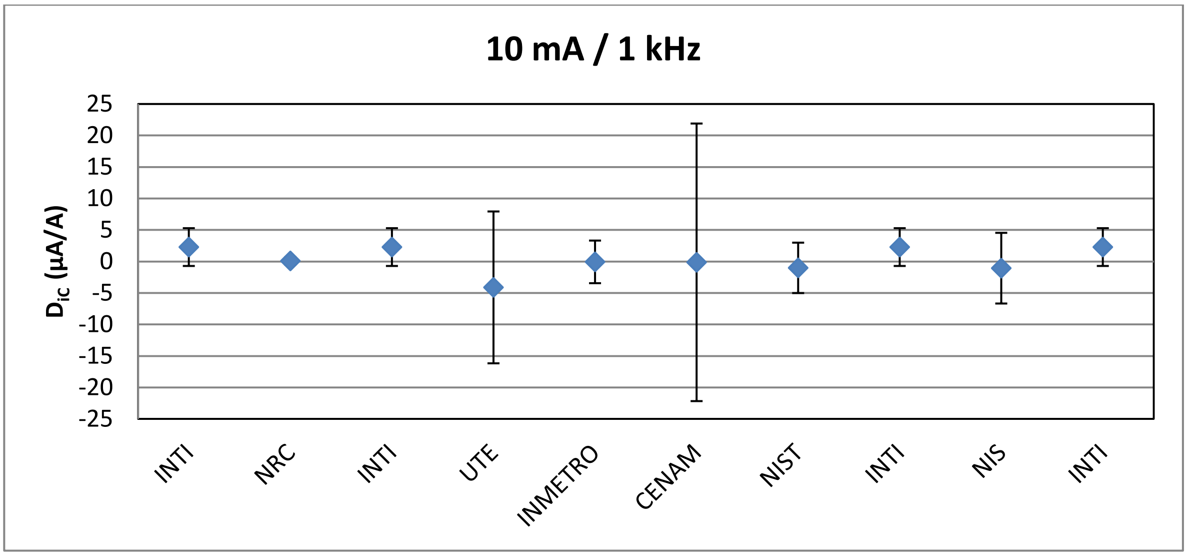

Fig. 33. Degree of equivalence with the KCRV and expanded uncertainty at 1 kHz.

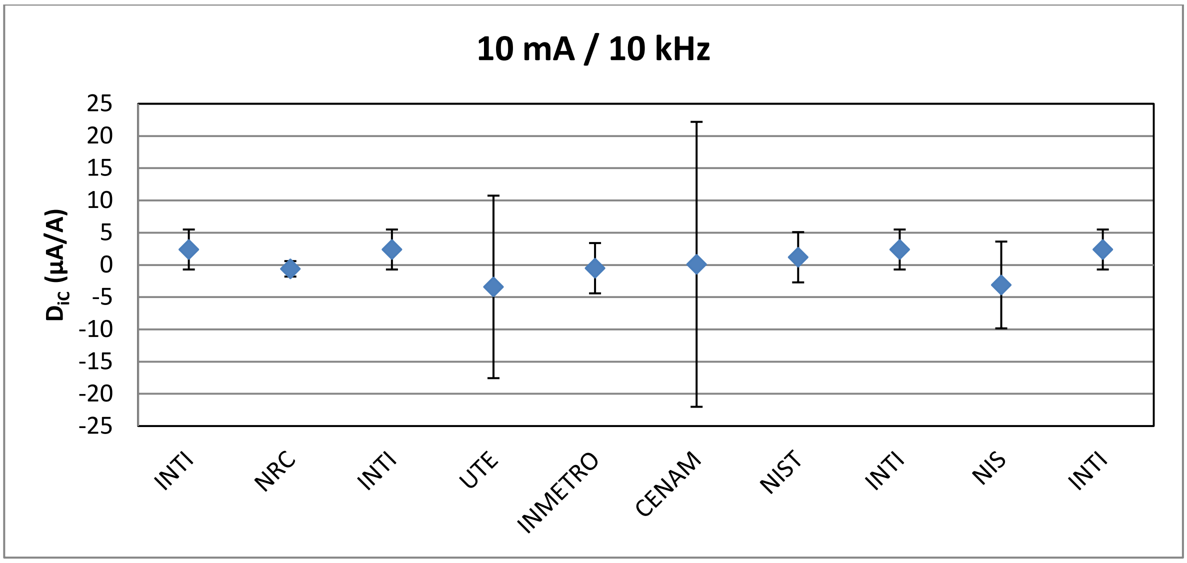

Fig. 34. Degree of equivalence with the KCRV and expanded uncertainty at 10 kHz.

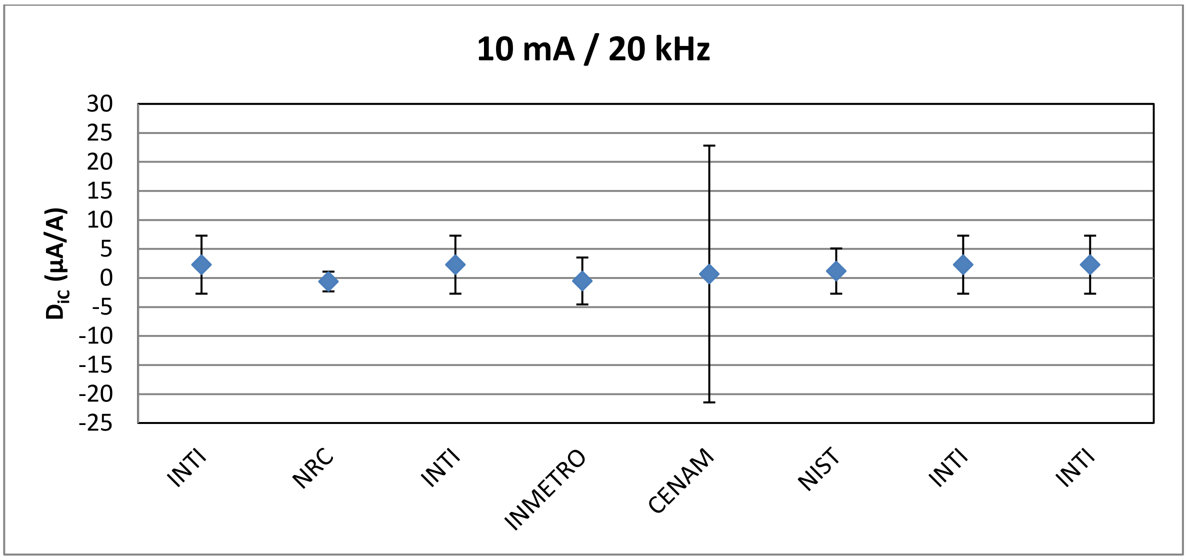

Fig. 35. Degree of equivalence with the KCRV and expanded uncertainty at 20 kHz.

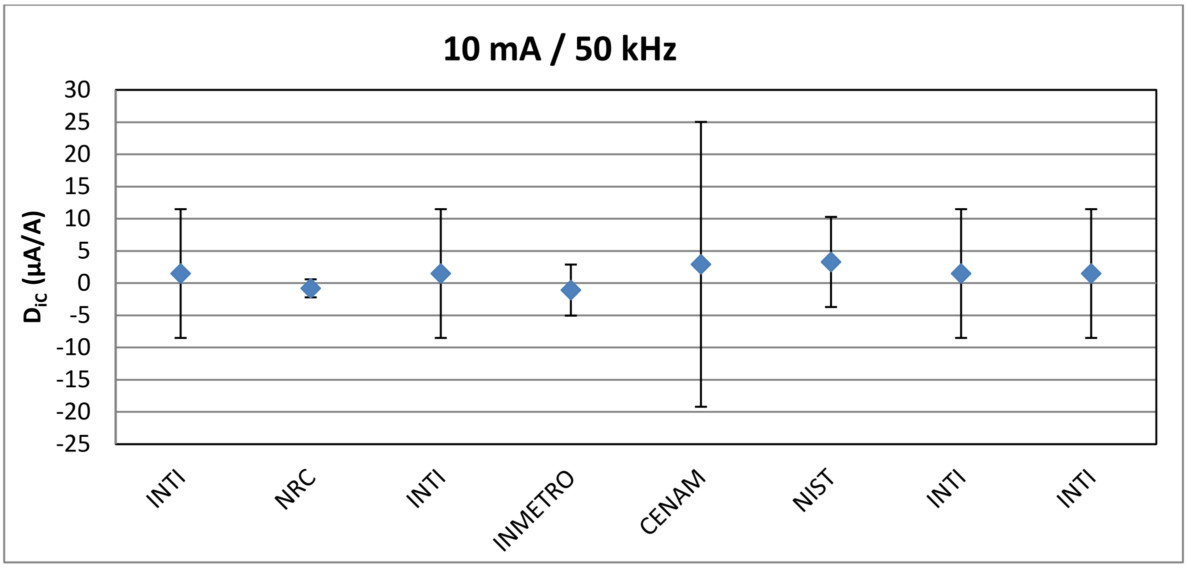

Fig. 36. Degree of equivalence with the KCRV and expanded uncertainty at 50 kHz.

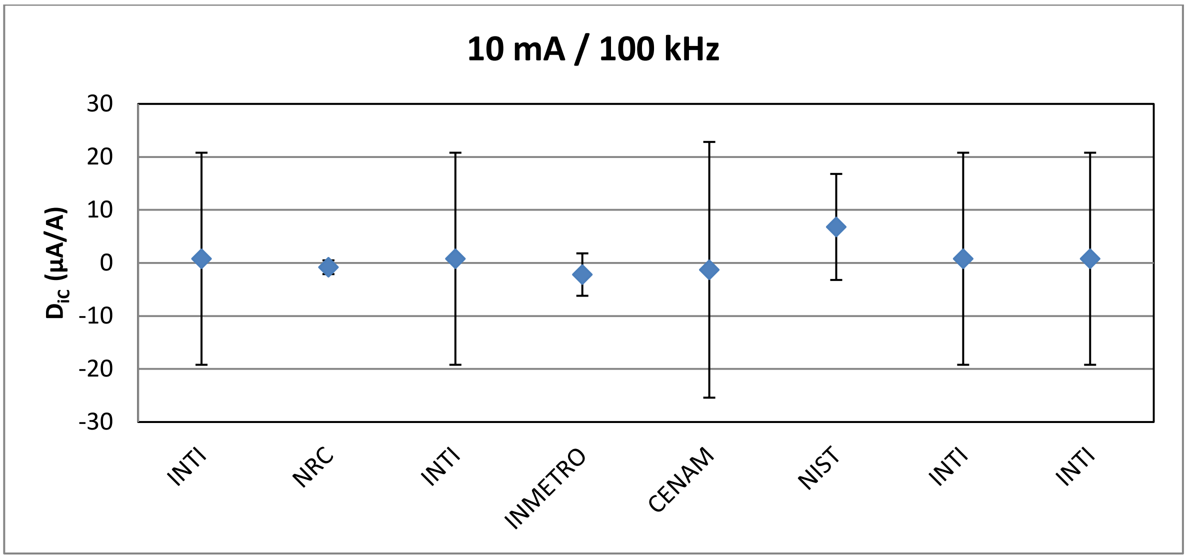

Fig. 37. Degree of equivalence with the KCRV and expanded uncertainty at 100 kHz.

Figures 38 to 44 show degree of equivalence D_{iC} with the KCRV with corresponding expanded uncertainty $U_{D_{iC}}$ for each NMI and measurement point, at 5 A.

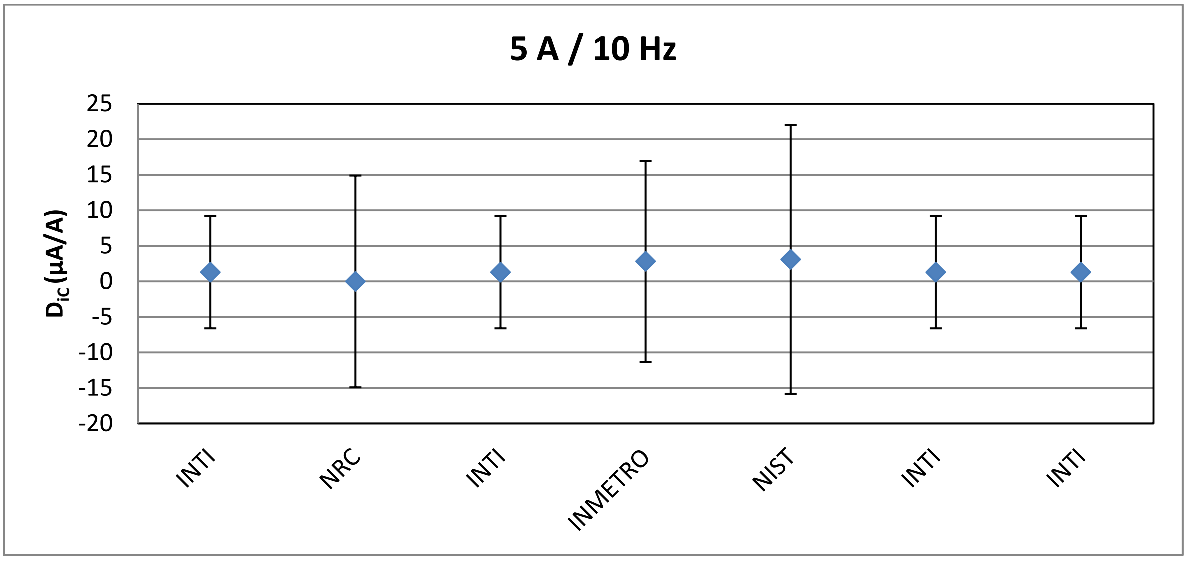

Fig. 38. Degree of equivalence with the KCRV and expanded uncertainty at 10 Hz.

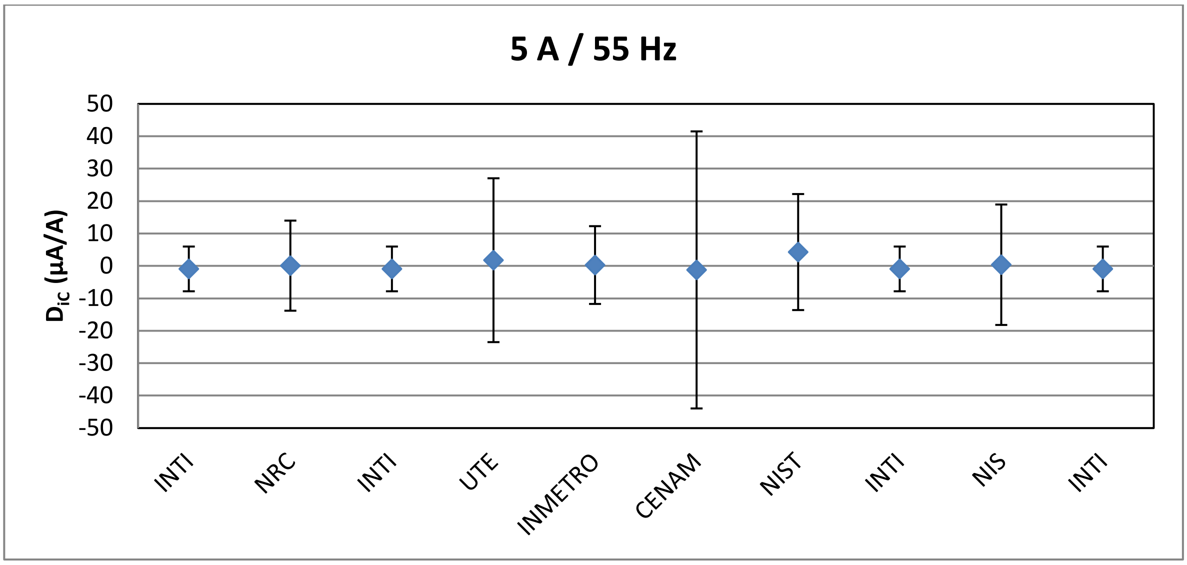

Fig. 39. Degree of equivalence with the KCRV and expanded uncertainty at 55 Hz.

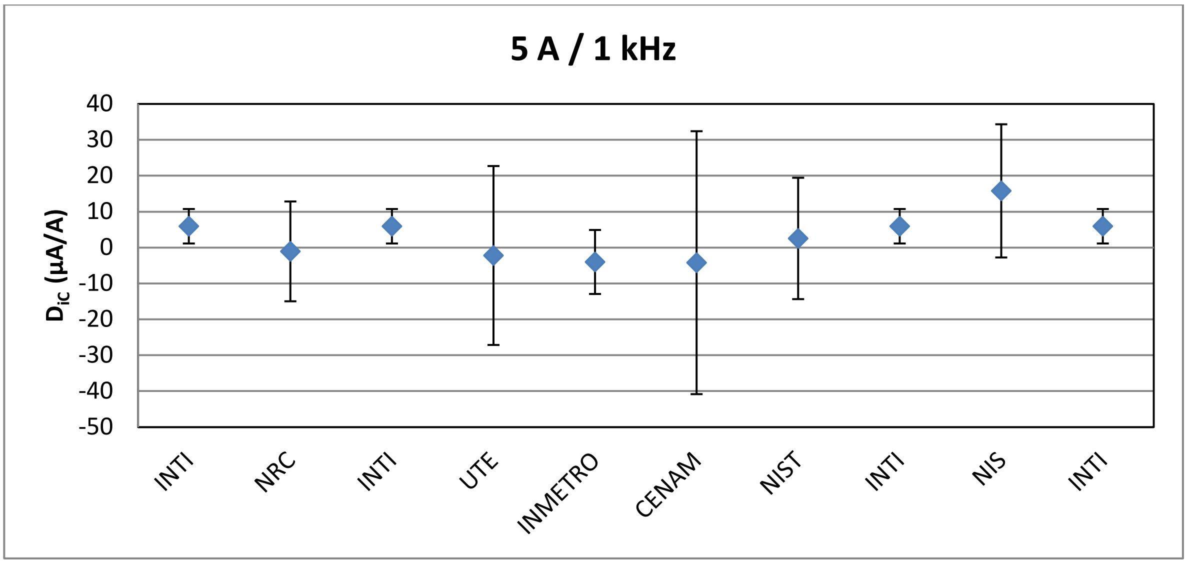

Fig. 40. Degree of equivalence with the KCRV and expanded uncertainty at 1 kHz.

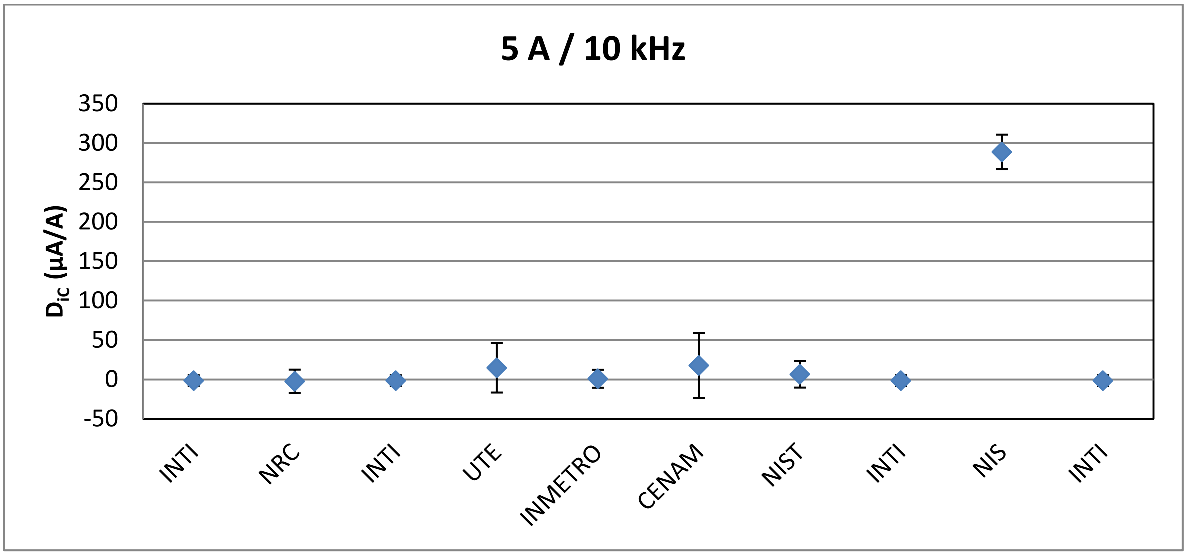

Fig. 41. Degree of equivalence with the KCRV and expanded uncertainty at 10 kHz.

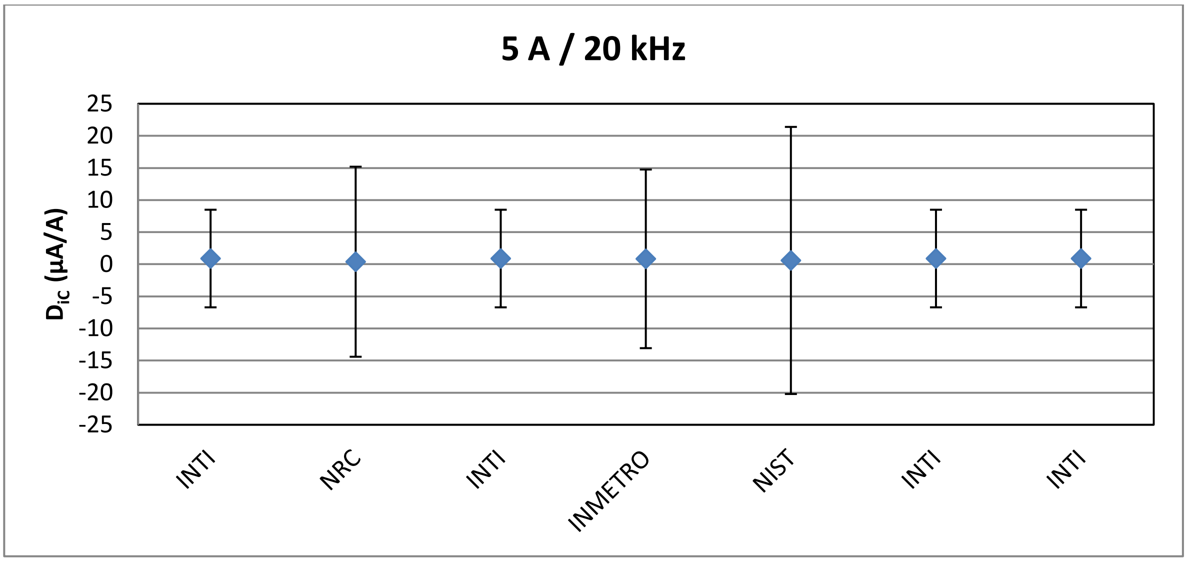

Fig. 42. Degree of equivalence with the KCRV and expanded uncertainty at 20 kHz.

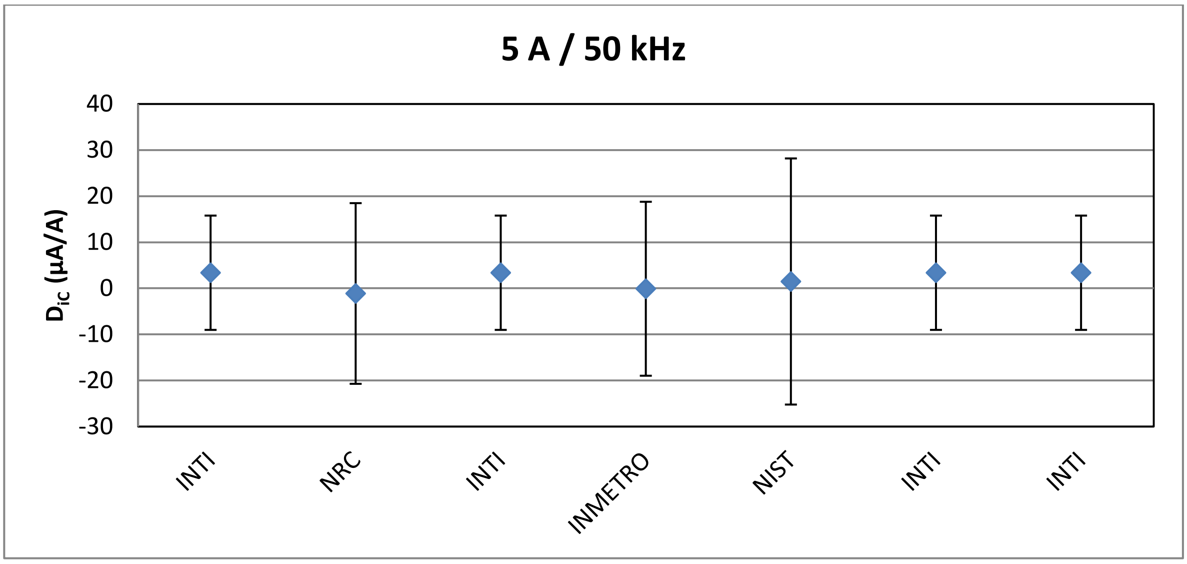

Fig. 43. Degree of equivalence with the KCRV and expanded uncertainty at 50 kHz.

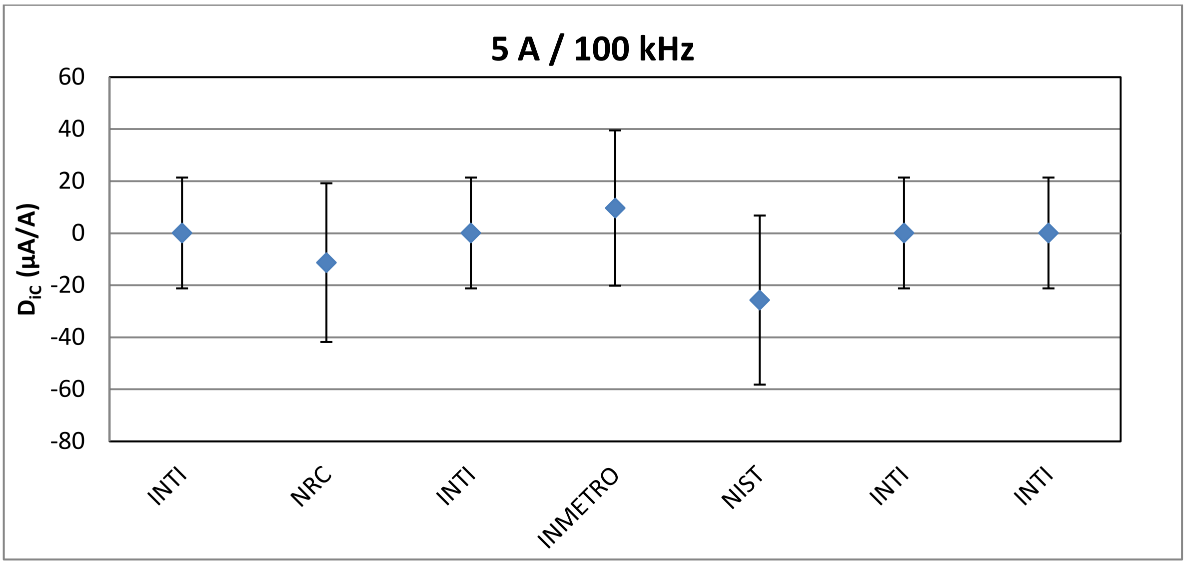

Fig. 44. Degree of equivalence with the KCRV and expanded uncertainty at 100 kHz.

13. Summary and conclusions

The circulation of the travelling standard in the regional key comparison SIM.EM-K12 of ac-dc current transfer difference began in July 2010 and ended in September 2012. Two participants withdrew from the comparison.

The ac-dc current transfer differences of the travelling standards have been measured at 10 mA and 5 A, at the frequencies 10 Hz, 55 Hz, 1 kHz, 10 kHz, 20 kHz, 50 kHz, 100 kHz. The key comparison reference values (CRV) were calculated as the weighted mean of the results of the NMIs with independent realizations of primary standards and low reported uncertainties. The degrees of equivalence with the CRV and the degree of equivalence with the KCRV of CCEM-K12 show very good agreement. In the case of NIS, the NMI is going to evaluate the results at 5 A / 1 kHz and 5 A /10 kHz and is going to ask for a bilateral comparison in these points.

14. References

[1] Key International Comparison of ac-dc Current Transfer Standards CCEM-K12. Final report. Dr. Ilya Budovsky. NMIA, Australia. September 2012
http://www.bipm.org/utils/common/pdf/final_reports/EM/K12/CCEM-K12.pdf

[2] Final report of key comparison EURAMET.EM-K11. ac-dc voltage transfer difference at low voltages. Karl-Erik Rydler and Valter Tarasso. SP Technical Research Institute of Sweden. January 2011.
http://iopscience.iop.org/0026-1394/48/1A/01011

APPENDIX I. UNCERTAINTY BUDGETS

CENAM, MEXICO

Measurement Current: 10 mA

Contribution of:	Standard Uncertainty (µA/A) at frequency							
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	Type A	Distribution
Standard deviation	-----	0.2	0.1	0.2	0.2	0.2	0.1	A	Normal
Nanovoltmeter stability	-----	1.7	1.7	1.7	1.7	1.7	1.7	A+B	Normal
Calibration of standards	-----	2.5	2.5	2.5	2.5	2.5	5.0	A+B	Normal
Stability of standards	-----	2.0	2.0	2.0	2.0	2.0	2.0	A+B	Normal
Repeatability	-----	0.3	0.2	0.2	0.7	0.6	1.1	A	Normal
Measurement system	-----	10	10	10	10	10	10	B	Rectangular
Combined uncertainty	-----	11	11	11	11	11	12		
Expanded uncertainty	-----	**22**	**22**	**22**	**22**	**22**	**24**		

ν eff	-----	100	100	100	104	104	131
coverage factor k	-----	2.0	2.0	2.0	2.0	2.0	2.0

Measurement Current: 5 A

Contribution of:	Standard Uncertainty (µA/A) at frequency							
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	Type A	Distribution
Standard deviation	-----	1	1	1	-----	-----	-----	A	Normal
Nanovoltmeter stability	-----	2	2	2	-----	-----	-----	A+B	Normal
Calibration of standards	-----	9	9	11	-----	-----	-----	A+B	Normal
Stability of standards	-----	5	5	5	-----	-----	-----	A+B	Normal
Repeatability	-----	8	1	7	-----	-----	-----	A	Normal
Measurement system	-----	15	15	15	-----	-----	-----	B	Rectangular
Combined uncertainty	-----	20	18	20	-----	-----	-----		
Expanded uncertainty	-----	**42**	**36**	**40**	-----	-----	-----		

ν eff	-----	**75**	**149**	**116**	-----	-----	-----
coverage factor k	-----	**2.1**	**2.0**	**2.0**	-----	-----	-----

NIS, EGYPT

i. Measurement Current: 10 mA

Contribution of:	Standard Uncertainty (µA/A) at frequency:				Type of Uncertainty	Distribution
	10 Hz	55 Hz	1 kHz	10 kHz		
Repeatability of 14 measurements in same conditions	0.54	0.42	2.4	2.9	A	Normal
Uncertainty of the reference standard	1	0.5	0.5	0.5	B	Normal
Uncertainty due to the frequency applied	1	1	1	1	B	Normal
Uncertainty due to the "Reproducibility"	0.34	0.65	0.88	0.83	A	Normal
Combined uncertainty (k=1)	1.55	1.35	2.75	3.2		
Expanded uncertainty (k=2)	3.1	2.7	5.5	6.4		

ii. Measurement Current: 5 A

Contribution of:	Standard Uncertainty (µA/A) at frequency:				Type of Uncertainty	Distribution
	10 Hz	55 Hz	1 kHz	10 kHz		
Repeatability of 14 measurements in same conditions	NA	3.3	3.4	3.7	A	Normal
Uncertainty of the reference standard	NA	7.5	7.5	7.5	B	Normal
Uncertainty due to the frequency applied	NA	1	1	1	B	Normal
Uncertainty due to the "Reproducibility"	NA	1.5	1.1	4	A	Normal
Combined uncertainty (k=1)	NA	8.4	8.35	9.3		
Expanded uncertainty (k=2)	NA	16.8	16.7	18.6		

NIST, USA

i. Measurement Current: 10 mA

Contribution of:	Standard Uncertainty / 10^{-6} at frequency							Type A or B	Distri-bution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Primary/Reference Standards (includes buildup from primary standards and frequency extension from 1 kHz)	0.58	0.42	0.42	0.42	0.89	1.64	1.80	B	Normal
Pooled Standard Deviation for primary intercomparisons and reference buildup	0.50	0.29	0.29	0.29	0.29	0.45	0.55	A	Normal
NIST Comparator System	2.20	1.11	0.68	0.68	0.68	1.06	1.31	B	Normal
Uncertainties for NIST standards									
Stability	2.50	1.70	0.75	0.75	0.75	1.70	2.00	B	Uniform
Bead	1.00	0.80	0.20	0.20	0.70	2.00	2.90	B	Uniform
Reproducibility	1.00	1.00	0.80	0.80	0.80	1.00	1.25	B	Uniform
Total contribution from NIST standards (k = 1)	3.70	2.45	1.40	1.40	1.74	3.45	4.38	B	Normal
Comparison of CCEM-K12 to NIST standards									
Pooled Standard Deviation for CCEM-K12 comparison	0.70	0.90	0.90	0.80	0.80	0.30	0.30	A	Normal
NIST Comparator System	2.20	1.11	0.68	0.68	0.68	1.06	1.31	B	Normal
Stability of CCEM-K12	0.60	0.70	0.67	0.49	0.67	0.49	1.34	B	Uniform
Combined unc (k=1)	4.40	2.92	1.92	1.82	2.14	3.65	4.77		
Expanded unc:	8.80	5.84	3.84	3.63	4.28	7.30	9.55		

ii. Measurement Current: 5 A

Contribution of:	Standard Uncertainty / 10^{-6} at frequency							Type A or B	Distri-bution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Primary/Reference Standards (includes buildup from primary standards – 8 steps)	7.70	7.70	7.70	7.70	9.20	12.00	15.20	B	Normal
Pooled Standard Deviation for primary intercomparisons and reference buildup	1.71	1.25	0.90	1.00	1.20	2.00	2.00	A	Normal
NIST Comparator System	2.30	2.00	2.00	2.00	2.30	2.30	2.30		Normal
Uncertainties for NIST standards									
Level Coefficient	2.20	2.00	2.00	2.00	2.00	2.00	2.90	B	Uniform
Stability	2.50	1.70	0.75	0.75	0.75	1.70	2.00	B	Uniform
Bead	0.50	0.50	0.50	0.50	1.50	3.00	4.00	B	Uniform
Proximity Effect	1.00	1.00	1.00	1.00	1.00	1.00	1.25	B	Uniform
Reproducibility	1.00	1.00	0.80	0.80	0.80	1.00	1.25	B	Uniform
Total contribution from NIST standards (k = 1)	8.99	8.60	8.40	8.41	9.99	13.10	16.50	B	Normal
Comparison of CCEM-K12 to NIST standards									
Pooled Standard Deviation for CCEM-K12 comparison	0.70	0.90	0.90	0.80	0.80	0.30	0.30	A	Normal
NIST Comparator System	2.30	2.00	2.00	2.00	2.30	2.30	2.30	B	Normal
Stability of CCEM-K12	0.60	0.70	0.67	0.49	0.67	0.49	1.34	B	Uniform
Combined unc (k=1)	9.32	8.90	8.71	8.69	10.30	13.31	16.71		
Expanded unc:	18.65	17.81	17.41	17.39	20.60	26.62	33.43		

INMETRO, BRASIL

i. Measurement Current: 10 mA

Contribution of:	Standard Uncertainty (μA/A) at frequency							Type A or B	Distribution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Reference standard	1,5	1,5	1,5	1,5	1,5	1,5	1,5	B	Normal
Standard deviation of 15 measurements	0,08	0,06	0,10	0,07	0,08	0,06	0,06	A	Normal
measurement set-up	0,06	0,06	0,06	0,06	0,06	0,06	0,06	B	Rectangular
Variation of the difference obtained from different set-ups	0,64	0,68	0,41	0,68	0,61	0,56	0,47	A	Rectangular
Connectors	0,12	0,06	0,06	0,06	0,06	0,06	0,17	B	Rectangular

Combined unc (k=1):	1,6	1,6	1,6	1,6	1,6	1,6	1,6
Expanded unc:	3,3	3,3	3,2	3,3	3,3	3,2	3,2

ii. Measurement Current: 5 A

Contribution of:	Standard Uncertainty (μA/A) at frequency							Type A or B	Distribution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Reference standard	4,6	4,3	2,8	3,2	3,7	4,9	7,9	B	Normal
Standard deviation of 15 measurements	0,19	0,22	0,16	0,22	0,24	0,17	0,24	A	Normal
Measurement set-up	0,12	0,12	0,12	0,12	0,12	0,12	0,12	B	Rectangular
Variation of the difference obtained from different set-ups	1,25	1,02	0,86	1,15	1,33	1,24	2,05	A	Rectangular
Connectors	0,12	0,06	0,06	0,06	0,06	0,12	0,58	B	Rectangular

Combined unc (k=1):	4,8	4,4	2,9	3,4	3,9	5,1	8,2
Expanded unc:	9,7	9,0	5,9	6,9	8,0	10,3	16,6

INTI, ARGENTINA

i. Measurement Current: 10 mA

Contribution of:	Standard Uncertainty (µA/A) at frequency							Type A or B	Distribution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Std of 12 measurements	0,5	0,3	0,2	0,3	0,2	0,2	0,2	A	n
AC-DC transfer difference of the standard	3,0	3,0	1,5	1,5	1,5	5,0	10,0	B	n
Stability of Keithley 182-1	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	B	r
Stability of Keithley 182-2	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	B	r
AC-DC transfer difference due to connectors	0,10	0,10	0,10	0,20	0,20	0,30	0,50	B	r
Combined unc (k=1)	**3,0**	**3,0**	**1,5**	**1,5**	**1,5**	**5,0**	**10**		
Expanded unc.	**6,0**	**6,0**	**3,0**	**3,0**	**3,0**	**10,0**	**20**		

ii. Measurement Current: 5 A

Contribution of:	Standard Uncertainty (µA/A) at frequency							Type A or B	Distribution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Std of 12 measurements	0,70	0,40	0,40	0,70	0,30	0,40	0,80	A	n
AC-DC transfer difference of the standard	4,00	2,50	2,50	3,50	5,00	6,50	11,00	B	n
Stability of Keithley 182-1	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	$6,1\cdot10^{-11}$	B	r
Stability of Keithley 182-2	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	$3,9\cdot10^{-11}$	B	r
AC-DC transfer difference due to connectors	0,10	0,10	0,10	0,20	0,20	0,30	0,50	B	r
Combined unc (k=1)	**4,00**	**2,50**	**2,50**	**3,50**	**5,00**	**6,50**	**11,00**		
Expanded unc.	**8,00**	**5,00**	**5,00**	**7,00**	**10,00**	**13,00**	**22,00**		

NRC, CANADA

i. Measurement Current: 10 mA

Contribution of:	Standard Uncertainty (µA/A) at frequency							Type A or B	Distri-bution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Reference Standard	0.7	0.2	0.2	0.9	0.9	0.9	1.0	A+B	normal
Comparison with std.	0.2	0.2	0.3	0.2	0.2	0.2	0.2	A	normal
Magnitude/n-meas	0.3	0.2	0.2	0.3	0.3	0.3	0.3	B	uniform
Combined unc. (k=1)	0.8	0.5	0.5	0.9	1.0	0.9	1.0		
Expanded unc:	1.6	1.0	0.9	1.8	1.9	1.9	2.0		

ii. Measurement Current: 5 A

Contribution of:	Standard Uncertainty (µA/A) at frequency							Type A or B	Distri-bution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Reference Std, shunt	6.6	6.9	6.9	6.9	6.8	9.4	13.6	A+B	normal
Reference Std., TVC V2S1f	0.8	0.5	0.5	1.0	1.0	1.0	1.4	A+B	normal
Comparison with std.	0.2	0.1	0.1	0.1	0.1	0.2	0.3	B	uniform
Magnitude/n-meas.	0.4	0.3	0.3	0.3	0.3	0.3	0.4	B	uniform
Potential position	0.2	0.1	0.1	0.1	0.1	0.0	0.1	B	uniform
Guarding unc.	0.4	0.4	0.4	0.5	0.3	0.3	0.6	B	uniform
Closure	3.2	1.2	1.1	2.3	2.4	2.5	6.8	B	uniform
Combined unc. (k=1)	7.4	7.0	7.0	7.3	7.3	9.8	15.3		
Expanded unc:	14.7	14.0	14.0	14.7	14.6	19.6	30.7		

UTE, URUGUAY

i. Measurement Current: 10 mA

Contribution of	Standard Uncertainty (μA/A) at frequency							Type A or B	Distribution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Reference standard	--------	5	5	5	--------	--------	--------	B	Normal
Measuring setup	--------	3	3	5	--------	--------	--------	B	Normal
Reproducibility	--------	1	2	1	--------	--------	--------	A	Normal

Combined uncertainty (k=1)	--------	6	6	7	--------	--------	--------
Expanded uncertainty	--------	12	12	14	--------	--------	--------

ii. Measurement Current: 5 A

Contribution of	Standard Uncertainty (μA/A) at frequency							Type A or B	Distribution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		
Reference standard	--------	11	12	14	--------	--------	--------	B	Normal
Measuring setup	--------	3	3	5	--------	--------	--------	B	Normal
Reproducibility	--------	2	2	5	--------	--------	--------	A	Normal

Combined uncertainty (k=1)	--------	12	12	15	--------	--------	--------
Expanded uncertainty	--------	24	24	30	--------	--------	--------

APPENDIX II. TECHNICAL PROTOCOL

SIM.EM-K12 COMPARISON PROTOCOL

AC-DC CURRENT TRANSFER DIFFERENCE
May 2010 – March 2011

INDEX

1. SCOPE

In order to strengthen the Interamerican Metrology System (SIM), interaction among its National Metrology Institutes (NMIs) must be promoted. At the same time according with the CIPM Mutual Recognition Agreement (MRA) objectives, NMIs must establish the degree of equivalence between their national measurement standards by performing regional comparisons, among other activities.

The objective of this comparison, registered as SIM.EM-K12, is to compare the measurement capabilities of NMIs in SIM in the field of ac-dc current transfer measurement. This action is aimed at determining the degree of equivalence of measuring capabilities in ac-dc current transfer difference. The proposed test points are selected to evaluate the measuring capabilities of the participants, both their measurement standards and their measuring procedures.

2. DEFINITION OF THE MEASURAND

The quantity to be measured is defined as follows:
Ac-dc current transfer difference is defined as

$$\delta = \frac{I_{ac} - I_{dc}}{I_{dc}} \qquad (1)$$

where
- I_{ac} is an rms ac current, and
- I_{dc} is a dc current which, when reversed, produces the same mean output response as the rms ac current.

Differences are expressed in microamperes per ampere (μA/A) and a positive sign means that more ac than dc current was required for the same output response.

3. TRAVELLING STANDARDS DESCRIPTION

- **10 mA**

The travelling standard for current of 10 mA is a Planar Multijunction Thermal Converter, identified as "PMJTC-90-2", manufactured by INTI (Fig. 2). It has the following nominal parameters:

Rated Input Current:	10 mA
Heater Resistance:	111 Ω
Thermocouple Resistance:	12 kΩ
Output Voltage at Rated Current:	100 mV

The Thermal Converter has an N-Female-type input connector and a type 10SL-4S output connector.

- **5 A**

The travelling standard for current of 5 A comprises a 0.2 Ω coaxial shunt, identified as "SHUNT 5 A" (Fig. 1) and a 1 V Planar Multijunction Thermal Converter, identified as "PMJTC-90-2" (Fig. 2). Both have been manufactured at INTI. Their main parameters are as follows:

Current Shunt, 5 A

Nominal Resistance	0.2 Ω
Input Connector	UHF
Output Connector	N-female

Thermal Converter, PMJTC-90-2

Rated Input Voltage:	1 V
Input Resistance:	111 Ω
Thermocouple Resistance:	12 kΩ
Output Voltage at Rated Voltage:	100 mV

Figure 1 Physical layout of the 5 A shunt.

Figure 2 Physical layout of the thermal converter PMJTC-90-2.

4. List of Participants

NIST National Institute of Standard and Technology, USA
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Contact: Lucas Di Lillo (ldili@inti.gov.ar)

NIS National Institute for Standards of Egypt
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5. TIMETABLE

As the comparison has to be finished within a reasonable period of time, **seven weeks** will be allowed for each participant. This time includes clearing customs, receiving, unpacking, preparation, making measurements, initial analysis of data, repeat if necessary, and shipping to the next laboratory.
The travel standard maximum time of measurement in each laboratory is 4 weeks. After this period of time, the standard should be send to the next participant.

The pilot laboratory is the Instituto Nacional de Tecnología Industrial (INTI). The travelling standard will be dispatched from INTI on May 23rd, 2010 and it should return to INTI in March 11th, 2011.
Table I shows the schedule for the SIM.EM-K12 Comparison. This can be adjusted due to dispatch time delay.

Table I: **Schedule for the SIM.EM-K12 Comparison of Ac-dc Current Transfer** (4 weeks for measurements and 3 weeks to dispatch forecast)

Laboratory	Reception of travelling standard	Dispatch of travelling standard
INTI		
UTE	23 May 2010	9 July 2010
CENAM	9 July 2010	27 August 2010
NIST	27 August 2010	15 October 2010
NRC	15 October 2010	3 December 2010
SIC	3 December 2010	21 January 2011
INMETRO	21 January 2011	18 March 2011
INTI	18 March 2011	April 14th 2012
NIS	April 14th 2012	March 16th 2012

6. PROCEDURE IN CASE OF UNEXPECTED DELAY

If unexpected circumstances avoid a laboratory to carry out its measurements within the established schedule, it should send the travelling standard without delay to the next laboratory, according to the timetable. In case any participating laboratory needs to keep the travelling standard for a few days more than those established in the schedule, it must contact the pilot laboratory at least two weeks before the end of its term in order to determinate if the travelling standard can stay longer or not, depending on the required days the participating laboratory applies for.

7. TRANSPORTATION AND CUSTOMS

- Transportation is at each laboratory's own responsibility and cost. Due to the time constraints please use a recognised courier service e.g. UPS or DHL for the transport of the travelling standard. Do not use a forwarding agent that does not guarantee an adequate delivery time, inclusive of the time for customs procedure

- On receipt of the case, unpack the devices carefully and check for any damage. The list of contents of the packing case should also be checked. Also check carefully that the carnet has been stamped on entry into your country.
- Before sending the case out, check the packing list and ensure everything is enclosed.
- A letter issued by INTI describing the travelling standard and the purpose of its travel will be attached with the instrument and should be used during its pass by customs in order that each participant can ask for temporal importation authorization. Please do not forget to include this document before passing the travelling standard to the next laboratory. At each transport the letter must be presented at customs on leaving the country and upon the arrival in the country of destination. (The letter is attached to this document, see Appendix I).

8. HANDLING THE TRAVELLING STANDARD

The travelling standard must be handled with care. Please, the receiving laboratory must inform the pilot laboratory upon the arrival of the travelling standard, by e-mail or by fax. Make sure that all the accompanying devices are complete upon reception (See Appendix V). Inform again the pilot laboratory and the next participant the details when sending the travelling standard.

Please at the arrival of the travelling standard to your laboratory test some points with the transfer standard, to verify if there is any damage caused during transportation, especially if you notice particular scratches on its container. In case of damage or evident malfunctioning of the travelling standard the pilot laboratory shall be informed immediately, see Appendix V.

Prepare the transport to the next participant so that the travelling standard can be sent immediately after the measurements are completed.

9. MEASUREMENTS POINTS

The measurements points are indicated in Table II.

Table II. Measurement points in ac-dc current transfer difference

Test #.	Test Current	Test frequency
1	10 mA	10 Hz
2	10 mA	55 Hz
3	10 mA	1 kHz
4	10 mA	10 kHz
5	10 mA	20 kHz
6	10 mA	50 kHz
7	10 mA	100 kHz
8	5 A	10 Hz
9	5 A	55 Hz
10	5 A	1 kHz
11	5 A	10 kHz
12	5 A	20 kHz
13	5 A	50 kHz
14	5 A	100 kHz

10. MEASUREMENT CONDITIONS

- Upon receiving the package, check input and output resistances of the two thermal converters. Check also that there is a high resistance (>100 MΩ) between the input and the output. In making these preliminary measurements, make sure **not to exceed** the nominal current of the thermal converters. In case of any failure, inform the pilot laboratory immediately.
- The connection of the output of the thermocouples to earth must remain at all times to protect the thermocouple.
- Care should be taken not to apply current above nominal, which may destroy the travelling standards.
- Recommended ambient conditions are temperature (23±1) °C and relative humidity (50±5) %.
- At least 30 minutes should be allowed for stabilisation after the first application of current.
- The measurement frequency should be within 1 % of its nominal value. The frequency and its uncertainty must be reported.
- Sufficient delay time should be used between successive applications of alternating and direct current.
- A datalogger will travel together with the travelling standard. It will be continuously monitoring temperature, relative humidity and atmospheric pressure. The datalogger should be left in the transportation case and it should be kept in the measurement area.

11. REPORTING RESULTS

In order to have a uniform format with the same information from all the participants, the participants should send their reports following the format described in Appendix II and Appendix III. Each participating laboratory should send its results to the pilot laboratory, within six weeks after the measurements are completed.

12. DETERMINATION OF THE REFERENCE VALUE

The reference values for each one of the measuring points will be calculated as the weighted mean of the reported values from laboratories in SIM who have taken part in the CCEM-K12 key comparison and whose reported values had been taken in consideration to calculate the reference values in such comparison. (i.e. NRC, NIST, INTI)

12.1 Reference value

The reference value is determined as:

$$\delta_{\text{reference value SIM.EMK12}} = \frac{\sum_{i=1}^{3} \delta_i / U_{\delta_i}^2}{\sum_{i=1}^{3} 1 / U_{\delta_i}^2} \quad (2)$$

where $U_{\delta i}$ is the expanded uncertainty associated with δ_i values, used to calculate the reference value, reported with a confidence level of 95 %.

Then the expanded uncertainty of the reference value will be,

$$(3) \quad U_{\text{reference value SIM.EMK12}} = \frac{1}{\sqrt{\sum_{i=1}^{3} 1 / U_{\delta i}^{2}}}$$

12.2 Degree of equivalence

The degree of equivalence (D_i) between the i-th participating laboratory with respect to the reference value, will be evaluated as the difference between the reported value from the i-th participating laboratory (δ_i) and the reference value,

$$D_i = \delta_i - \delta_{\text{reference value SIM.EMK12}} \quad (4)$$

For the participating laboratories that do not contribute to the reference value, the expanded uncertainty of the degree of equivalence will be evaluated as,

$$U_{D_i} = \sqrt{U_{\delta_i}^2 + U_{\delta_{\text{reference value}}}^2} \quad (5)$$

For the laboratories whose values contribute to the reference value, the expanded uncertainty of the degree of equivalence will be evaluated as,

$$U_{D_i} = \sqrt{U_{\delta_i}^2 - U_{\text{reference value SIM.EMK12}}^2} \quad (6)$$

12.3 Degree of equivalence between pairs

The degree of equivalence between the values of any pair of laboratories (D_{ij}), will be evaluated as the difference between their reported values,

$$D_{ij} = \delta_i - \delta_j \quad (7)$$

The expanded uncertainty of the degree of equivalence between pairs will be evaluated as,

$$U_{D_{ij}} = \sqrt{U_{\delta_i}^2 + U_{\delta_j}^2 - 2 * r(\delta_i, \delta_j) * U_{\delta_i} * U_{\delta_j}} \quad (8)$$

Correlation is expected when δ_i and δ_j have common traceability to a third national laboratory. Participating laboratories are required to ask the laboratory that performed the calibration of their standards to provide its uncertainty budget in order to be able to evaluate the correlation.

13. MEASUREMENT UNCERTAINTY

A detailed uncertainty analysis and an uncertainty budget in accordance with the ISO Guide to the Expression of Uncertainty in Measurement should be reported.

To have a more comparable uncertainty evaluation, a list of principal uncertainty contributions is given, but the uncertainty contributions will depend on the measuring methods used.

- reference standard(s);
- step-up procedure;
- measuring setup;
- level dependence, e.g. due to dc-effects;
- connectors;
- temperature;
- measurement frequency;
- reproducibility;

14. COMPARISON REPORT

Each participant is asked to submit a report within one month after completing the measurements. The report should contain at least the following:

- Detailed description of the measurement setup and the reference standard;
- Definition of the measurand;
- Detailed description of the measurement procedure;
- A statement of traceability, if the national standard is not considered to be a primary standard
- The measurement results;
- The ambient conditions of the measurement: the temperature and the humidity with limits of variation
- A complete uncertainty budget in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement, including degrees of freedom for every component and calculation of the coverage factor. Such an analysis is a prerequisite to be

considered in the calculation of the key comparison reference value. It is also an essential part of the final report which will appear in the BIPM Key Comparison Database.

The participants are also asked to report a summary of the measurement results, see Appendix I. Please also send the report and the summary by e-mail.

The pilot laboratory will inform a participating laboratory if there is a large deviation between the results of the laboratory and the preliminary reference values. No other information on the results will be communicated before the completion of the circulation.

15. ORGANISATION

The pilot laboratory for the comparison is the Instituto Nacional de Tecnología Industrial (INTI), Argentina.
Please inform the pilot laboratory of the arrival of the package by e-mail or fax. Please inform the pilot laboratory again of the details when sending the package to the next participant, and also inform the next participant by e-mail or fax. A relevant fax form is enclosed in Appendix IV. Prepare the transport to the next participant so that the travelling standard can be sent immediately after the measurements are completed.

Each participating laboratory covers the costs of the measurement, transportation and customs clearance as well as for any damage that may occur within its country. The pilot laboratory covers the overall costs for the organisation of the comparison.

16. COMPARISON COORDINATOR AND MEMBERS OF THE SUPPORT GROUP

Any questions related to the comparison should be directed the comparison coordinator:

Lic. Lucas Di Lillo
Instituto Nacional de Tecnología Industrial – INTI
Av. Gral. Paz 5445,
B1650WAB
San Martín, Buenos Aires
Argentina

phone: (+5411) 4724-6200 Ext. 6673
fax: (+5411) 4713-4140
email: ldili@inti.gob.ar

Members of the support group:

Name	Organization	Address	email
Sara Campos	Centro Nacional de Metrología (CENAM)	km 4.5 Carretera a los Cués. El Marqués. Querétaro C.P. 76246. MEXICO	scampos@cenam.mx
Gregory Kyriazis	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro)	Av. Nossa Senhora das Graças, 50 25250-020 Duque de Caxias – RJ - Brasil	gakyriazis@inmetro.gov.br

Appendix I
LETTER TO THE CUSTOMS

Buenos Aires, Argentina, XXXX

To whom it may concern,

These devices are intended for comparison of the National Measurement Standards of Argentina, México, United States of America, Uruguay, Colombia, Brazil and Canada. The devices are to be returned to Argentina on November 2010 at the completion of this program.

National Agencies Involved:

▪ MEXICO Centro Nacional de Metrología (CENAM) km 4,5 Carretera a los Cués. El Marqués Querétaro C.P. 76241. México Tel: +52 442 211-05-00 ext. 3424 Fax: +52 442 211-05-48 ***Contact: Sara Campos*** e-mail: scampos@cenam.mx	▪ ARGENTINA Instituto Nacional de Tecnología Industrial (INTI) Parque Tecnológico Miguelete, Av. Gral. Paz e/Albarellos y Av. De los Constituyentes CC 157(1650) San Martín, Buenos Aires, Argentina Tel.: +5411 4754-4141 Fax: +5411 4713-4140 Contact: Lucas Di Lillo e-mail: ldili@inti.gob.ar
▪ URUGUAY Administración Nacional de Usinas y Transmisiones Eléctricas (UTE) Paraguay 2385 CP 11800 Montevideo, Uruguay Tel. +598 2 924 2042 Fax. +598 2 924 2004 ***Contact: Daniel Slomovitz*** e-mail: Labute@ute.com.uy d.slomovitz@ieee.org	▪ COLOMBIA Laboratorio de Corriente Continua y Alterna División de Metrología, Superintendencia de Industria y Comercio AK 50 # 26-55, Interior 2, CAN. Bogotá,D.C., Colombia tel: (57 1) 5 880 222 (57 1) 5 737 070 ext 1 442 Alexander Martínez López e-mail: amartinez@correo.sic.gov.co
▪ USA National Institute of Standard and Technology 100 Bureau Drive, M/S 8171, Gaithersburg, MD 20899-8171, USA Phone: 301 975 4251 Fax: 301 926 3972 Contact. Thomas Lipe e-mail: thomas.lipe@nist.gov	▪ CANADA National Research Council Canada | M-36, 1200 Montreal Road, Ottawa, Ontario K1A 0R6 Government of Canada | Gouvernement du Canada Phone: 613-993-2313 Fax 613-952-1394 Contact: Dr. Peter Filipski e-mail:Peter.Filipski@nrc-cnrc.gc.ca
▪ Brazil Instituto Nacional de Metrologia, Normalização e Qualidade Industrial Av. Nossa Senhora das Graças, 50 Duque de Caxias – RJ 25250-020, Brazil Phone: xx55(21)26791627 Fax: xx(21)26791627 Contact. Regis P. Landim e-mail: rplandim@inmetro.gov.br ▪	▪ Egypt National Institute for Standards Tersa Street, Haram PO Box 136 Giza, Code 1221, Egypt Phone: +202-333889783 Contact: Mamdouh Halawa (mamdouh_halawa@yahoo.com

The interlaboratory comparison package contains the following items packed in a case with dimensions 50 cm x 25 cm x 35 cm. The weight of the package is approximately around 2 kg.

Qty	Description	Value (USD)
1	AC-DC transfer standards Planar multijunction Thermal Converter, identified as "PMJTC-90-2", manufactured by INTI	1000.00
1	Temperature, Humidity and Pressure Datalogger	700.00
1	5 ampere travelling standard comprises a 0.2 Ω coaxial shunt, identified "SHUNT 5 A"	1000.00
(Value only for customs effects) Total		2700.00

Lic. Lucas Di Lillo
Instituto Nacional de Tecnología Industrial
Colectora de Avenida General Paz 5445 entre Albarellos y Avenida de los Constituyentes
Casilla de correo 157
B1650KNA · San Martín
República Argentina
Email: ldili@inti.gob.ar

Appendix II
SUMMARY OF RESULTS

Appendix II. Summary of Results

SIM Key International Comparison of AC-DC Current Transfer Standards SIM.EM-K12

Please also send this information by e-mail.

Institute:

Date of measurements:

Remarks:

Measurement Results:

Current	Measured ac-dc current difference (μA/A) at frequency						
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
10 mA							
5 A							

Expanded Uncertainty:

Current	Expanded Uncertainty (μA/A) at frequency						
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
10 mA							
5 A							

Measurement Frequency:

Current	Nominal Frequency						
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
Meas. Frequency							
Expanded Uncertainty							

Environmental parameters:

	Min	Max	Remarks
Ambient temperature (ºC)			
Relative humidity (%)			

Appendix III
SUMMARY OF UNCERTAINTY BUDGET

Appendix III. Summary of Uncertainty Budget

SIM Key International Comparison of AC-DC Current Transfer Standards SIM.EM-K12

Please also send this information by e-mail.

Institute:

Date:

Remarks:

Measurement Current : 10 mA

Contribution of:	Standard Uncertainty (μA/A) at frequency							Type A or B	Distri-bution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		

Combined uncertainty (k=1):							
Expanded uncertainty:							

Measurement Current : 5 A

Contribution of:	Standard Uncertainty (μA/A) at frequency							Type A or B	Distri-bution
	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz		

Combined uncertainty (k=1):							
Expanded uncertainty:							

Appendix IV. Packing List

SIM Key International Comparison of AC-DC Current Transfer Standards SIM.EM-K12

Item	Approx. Value (U$S)	Dimensions (mm)	Weight (kg)
Planar Multijunction Thermal Converter, INTI, PMJTC-90-2	1000	50 cm x 25 cm x 30 cm	2
Current Shunt, INTI, SHUNT 5 A	1000		
Datalogger	700		
This Protocol			
Total Value	2700		

All items have been manufactured by INTI. They are to be transported in the custom carry case supplied. The maximum dimensions of the carry case are 50 cm x 25 cm x 35 cm. The weight of the package is approximately around 2 kg.

Appendix V

Forms for Notifying Receipt and Shipment of Artefact

Appendix V Forms for Notifying Receipt and Shipment of Artefact

SIM Key International Comparison of AC-DC Current Transfer Standards SIM.EM-K12

ARTEFACTS RECEIVED

To:...(sender and coordinator)....

The package was received at ....(name of laboratory).... on ...(date)..

The condition when it was received was *in good physical and working order

*damaged – (explain)

____
(name of participant)

ARTEFACTS SHIPPED

To: (recipient and coordinator)

The package was shipped through ....(shipper)..... on ...(date).. The shippers agent in the recipient country is ....(agent name and contact details).......................

Shipping Details:

Expected date of arrival at destination country:..............

Shipped: door-to-door / port –to – port

Air Way Bill No. (house): ....

If available: Master Air Way Bill No:
Flight details:

____
(Name of Participant)