APMP.EM-K12

APMP Key Comparison of ac-dc Current Transfer Standards

Final Report

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1 Introduction and Scope

The CCEM-K12 [1] comparison of ac-dc current transfer standards was conducted during 2005 to 2007 with three participants from the Asia-Pacific Metrology Programme (APMP), namely National Measurement Institute (NMIA, pilot), Australia, D.I. Mendeleyev Institute for Metrology (VNIIM), Russia, and National Metrology Centre (NMC, A*STAR), Singapore.

In order to link more National Metrology Institutes (NMI) within APMP to the key comparison CCEM-K12, the APMP Technical Committee for Electricity and Magnetism (TCEM) decided to conduct this corresponding Regional Metrology Organization (RMO) key comparison APMP.EM-K12, with NMC as the pilot laboratory. A support group was formed consisting of members from NMIA, Australia, Measurement Standards Laboratory (MSL), New Zealand, and National Metrology Institute (NMIJ), Japan.

The comparison scope is the same as CCEM-K12:

Current: 10 mA and 5 A
Frequency: 10 Hz, 55 Hz, 1 kHz and 10 kHz
(Optional: 20 kHz, 50 kHz and 100 kHz).

The comparison was conducted in two separate loops among APMP member and associate member NMIs. The measurements were carried out from February 2014 to December 2015.

2 Participants and Organization

2.1 Comparison Participants

Twelve laboratories participated in the comparison, as listed in Table 1.

Table 1: List of participants.

No	*Name and Contact*	*Acronym*
1	National Metrology Centre, A*STAR, Singapore Contact: Dr Jing Tao, jing_tao@nmc.a-star.edu.sg	NMC
2	National Measurement Institute, Australia Contact: Mr Thomas Hagen, thomas.hagen@measurement.gov.au	NMIA
3	Standards and Calibration Laboratory, Hong Kong, China Contact: Dr Steven Yang, steven.yang@itc.gov.hk	SCL
4	National Metrology Institute, Japan Contact: Dr Hiroyuki Fujiki, h-fujiki@aist.go.jp	NMIJ
5	Korea Research Inst of Standards and Science, Rep of Korea Contact: Dr Hyung-Kew Lee, hyungkew.lee@kriss.re.kr	KRISS
6	National Institute of Metrology, China Contact: Mr Zhang Jiangtao, Zhangjt@nim.ac.cn	NIM

No	Name and Contact	Acronym
7	Measurement Standards Laboratory, New Zealand Contact: Mr Murray Early, murray.early@callaghaninnovation.govt.nz	MSL
8	National Metrology institute of South Africa, South Africa Contact: Dr Eugene Golovins , egolovins@nmisa.org	NMISA
9	National Institute of Metrology, Thailand Contact: Mr Chalit Kumtawee, chalit@nimt.or.th	NIMT
10	National Metrology Institute of Malaysia, Malaysia Contact: Dr Muhammad Azwan bin Ibrahim, mdazwan@sirim.my	NMIM
11	VietNam Metrology Institute, Viet Nam Contact: Mr. Nguyen Anh Son, sonna@vmi.gov.vn	VMI
12	Center for Measurement Standards, Industrial Technology Research Institute, Chinese Taipei Contact person: Ms Hsiu-Ju Tsai, sarahtsai@itri.org.tw	CMS/ITRI

2.2 Comparison Schedule

The tests of the comparison were scheduled in two travelling cycles in 2014 and 2015 for one and half years. Six weeks were allocated for each laboratory. This includes four weeks for measurements in laboratories and two weeks for shipments: customs clearance, transportation, unpacking, packing and shipping to the next laboratory. The time slot for each laboratory was scheduled according to their preferences expressed in a survey before scheduling. Table 2 shows the original comparison schedule as well as the actual travelling dates recorded.

Table 2: Original schedule and actual date record in comparison.

Laboratory	Original Schedule		Actual Record	
	From	To	Date receiving	Date sending
NMC		**13 Feb 2014**		**12 Feb 2014**
NMIA	20 Feb 2014	3 Apr 2014	18 Feb 2014	25 Mar 2014
SCL	3 Apr 2014	15 May 2014	31 Mar 2014	29 Apr 2014
NMIJ	15 May 2014	26 Jun 2014	8 May 2014	10 Jun 2014
KRISS	26 Jun 2014	7 Aug 2014	20 Jun 2014	5 Aug 2014
NIM	7 Aug 2014	18 Sep 2014	12 Sep 2014	20 Oct 2014
NMC	**18 Sep 2014**	**30 Oct 2014**	**28 Oct 2014**	**31 Mar 2015**
MSL	30 Oct 2014	11 Dec 2014	9 Apr 2015	8 May 2015
NMISA	11 Dec 2014	22 Jan 2015	20 May 2015	16 Jun 2015
NIMT	22 Jan 2015	5 Mar 2015	3 Jul 2015	27 Jul 2015
NMIM	5 Mar 2015	16 Apr 2015	4 Aug 2015	18 Sep 2015
VMI	16 Apr 2015	28 May 2015	2 Oct 2015	28 Oct 2015
CMS/ITRI	28 May 2015	9 Jul 2015	3 Nov 2015	1 Dec 2015
NMC	**9 Jul 2015**		**4 Dec 2015**	

2.3 Comparison Organization

Prior to the comparison the long-term stabilities of the travelling standards were confirmed in NMC both for the thermal converter (10 mA) and its combination with the 5 A shunt (see §3).

The travelling standards were dispatched from NMC in February 2014 and returned in October 2014 the first loop, and again in March 2015 and December 2015 respectively the second loop. The pilot laboratory was kept informed by each participant by emails of the arrival of the package and again when sending the package to the next participant. The next participant was also informed by email when sending the package.

Each participating laboratory covered the duties and costs of the measurement, customs clearance, domestic transportation and door-to-door airfare to the next participant. The pilot laboratory arranged and covered costs of the insurance of the travelling package, two ATA carnets (one for each loop), and air shipments to the first laboratories of each loop: NMIA and MSL. A 10 mA thermal converter, as described in §3.1 was specially purchased and characterized, and a fixture fabricated for this comparison. Fluke Corporation kindly loaned a new 5A Fluke A40B dc and ac current shunt to extend the comparison value to 5 A. Its long-term stability was confirmed together with the thermal converter in NMC prior to the comparison. The participants were reminded to use recognized courier services to ensure the smooth run of the comparison.

Delays in comparison appeared in three cases.

Though ATA carnet was arranged beforehand, it was not realized, until the package reached the Chinese customs from KRISS, that China's carnet scope only includes exhibition items from overseas. This made the package remain at the customs for six weeks and NIM had to apply separately for the import and export of the package with deposit.

Further delay was resulted for customs clearance when the package came back to NMC at the end of first loop, because the pre-applied carnet had no record and stamps for entering and leaving China. It further affected the arrangement of second ATA carnet of the same package, and the second travelling loop was thus rescheduled with a delay of five months.

The third delay was in the shipment from NMISA to NIMT. The standard package remained at the Johannesburg airport and the Thai customs for more than one week respectively, though colleagues from both laboratories traced and reported the shipment daily.

Other shipments and laboratory measurements were in schedule. See Figure 1 and the last two columns of Table 2 for time records.

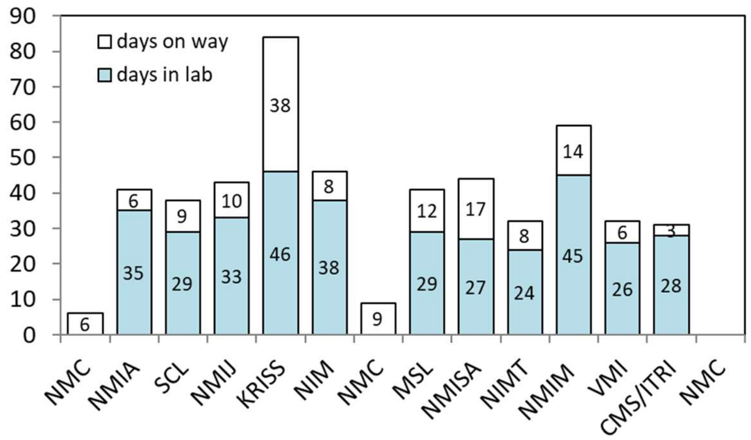


Figure 1: Numbers of days in participating laboratories and on way to next laboratories.

2.4 Withdrawals

MSL found inevitable effects of a renovation during their measurement and informed the pilot laboratory of their withdrawal with no result submission. VMI did not submit results either.

3 Travelling Standards and Measuring Instructions

3.1 Description of the travelling standards for 10 mA

The travelling standard for the current of 10 mA is a Planar Multi-Junction Thermal Converter (PMJTC), Serial number 32, manufactured by IPHT, Germany. It has the following nominal parameters:

Rated Input Current:	10 mA
Heater Resistance:	90 Ω
Thermocouple Resistance:	6.64 kΩ
Output Voltage at Rated Current:	90 mV.

The thermal converter has a type-N female input connector and a UHF Twin female output connector, see Figure 2 a).

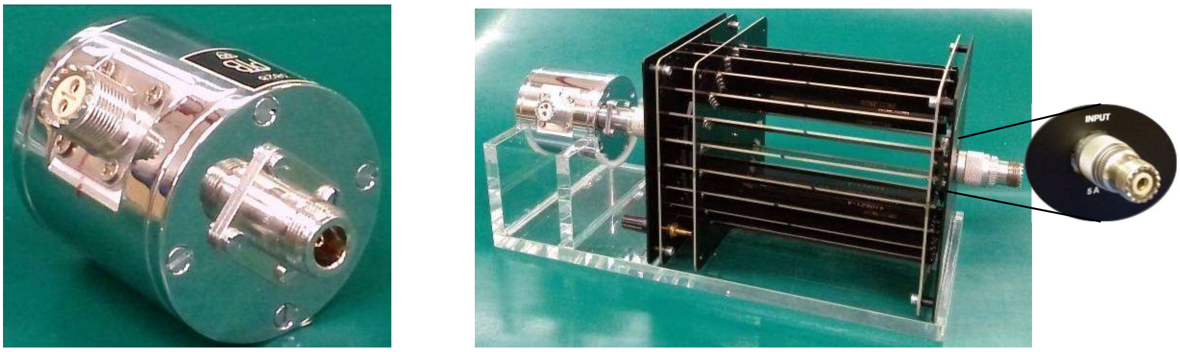
3.2 Description of the travelling standards for 5 A

The travelling standard for the current of 5 A comprises a Fluke A40B-5A precision current shunt, Serial number 163962344, and the above PMJTC for 10 mA. The current shunt has the following nominal parameters:

Nominal Resistance:	0.16 Ω

Nominal output voltage at 5A: 0.8 V
Power coefficient of resistance: < 0.5 μΩ/Ω/W.

It has type-N female connectors at both its input and output. For the current comparison, a type-N male-to-male adaptor is attached to the shunt's output for connecting with the PMJTC, and a UHF female-to-type-N male connector is attached to its input. A Perspex fixture is provided for easily assembling of the 5 A travelling standard. When assembled correctly the travelling standard can be positioned firmly on a flat surface, see Figure 2 b).



a) b)

Figure 2: Travelling standards: a) PMJTC for 10 mA (Type-N female for input and UHF twin female for output); b) Assembly of a current shunt and the PMJTC for 5 A (UHF female for input and UHF twin female for output).

3.3 Quantities to be measured and measurement conditions

Ac-dc current transfer difference is 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 are expressed in microamperes per ampere (μA/A). A positive sign signifies that more ac than dc current is required for the same output response, and vice versa.

In this comparison, the ac-dc differences of the respective travelling standards at 10 mA and at 5 A were measured at the following frequencies:

- Mandatory: 10 Hz, 55 Hz, 1 kHz, and 10 kHz
- Optional: 20 kHz, 50 kHz, and 100 kHz.

Recommended ambient conditions are 23 ± 1 °C in temperature and 50 ± 5 % in relative humidity.

3.4 Measurement instructions

The following detailed instructions were given to the participants in the comparison technical protocol (§10.3):

1. The PMJTC is with delicate circuits and care needs to be taken to avoid any mechanical shocks.
2. Upon receiving the package, check if there is any damage during transportation. Check input and output resistances of the PMJTC. Check that there is high resistance (>100 MΩ) between the input and output. Make sure not to exceed the nominal currents of the PMJTC (10 mA, for both input and output). In case of any failure, inform the pilot laboratory immediately.
3. The ac-dc transfer differences of the travelling standards are to be measured at the “Lo” position, i.e. with both its input and output earthed. The connection to earth must remain at all times to avoid excessive voltage between its heater and thermocouples which easily damages the insulation.
4. Test the travelling standard at a few points to verify if there is any failure. In case of any damage or failure, inform the pilot laboratory immediately.
5. Connect the PMJTC (see Figure 2 a)) to carry out 10 mA measurements. According to Figure 2 b), assemble it with the shunt for 5 A measurements.
6. Care should be taken not to apply current above nominal values, which may destroy the travelling standards.
7. At least 30 minutes should be allowed for stabilisation after the first application of current.
8. The measurement frequency should be within 1 % of its nominal value. The frequency and its uncertainty must be reported.
9. Sufficient delay time should be used between successive applications of alternating and direct currents.
10. Measurement result should be submitted to the pilot laboratory within one month after each participant’s measurements.

4 Methods of Measurements

The methods of measurements and the reference standards used in each participating laboratories are summarized in Table 3 and Table 4 respectively for 10 mA and 5 A.

Table 3: Reference standards and measurement methods at 10 mA.

Laboratory	*Reference standard*	*Measurement method*	*Source of traceability*
NMC	PMJTC	Direct comparison	PTB
NMIA	Micropotentialmeter TC	Direct comparison	In-house

Laboratory	*Reference standard*	*Measurement method*	*Source of traceability*
SCL	Fluke A55 TC	Direct comparison	NMIA
NMIJ	MJTC	Direct comparison	In-house
KRISS	PMJTC	Direct comparison	PTB
NIM	NIM MJTC, PMJTC	Direct comparison	In-house
NMISA	Fluke shunt + MJTC	Direct comparison	NPL
NIMT	Fluke shunt + 792A	Direct comparison	PTB
NMIM	NMIA Shunt + SJTC	Direct comparison	NMIA
CMS/ITRI	PMJTC	Direct comparison	PTB

Table 4: Reference standards and measurement methods at 5 A.

Laboratory	*Reference standard*	*Measurement method*	*Source of traceability*
NMC	Holt shunt + PMJTC	Build-up	In-house
NMIA	NMIA shunt + SJTC	Build-up	In-house
SCL	Fluke shunt + A55 TC	Direct comparison	NMIA
NMIJ	Fluke shunt + MJTC	Built-up	In-house
KRISS	Fluke shunt + PMJTC	Direct comparison	PTB
NIM	Fluke shunt + PMJTC	Build-up	In-house
NMISA	Fluke shunt + MJTC	Build-down	In-house
NIMT	Holt shunt + PMJTC	Direct comparison	PTB
NMIM	NMIA shunt + SJTC	Direct comparison	NMIA
CMS/ITRI	Fluke shunt + SJTC	Build-up	In-house

5 Repeated Measurements of the Pilot Laboratory

Tables 5 and 6 give the measured results together with the expanded uncertainties at a level of confidence of approximately 95 % of the travelling standards in the pilot laboratory for a period of 29 months, including prior to, during and after the comparison circulations. Figure 3 and Figure 4 further illustrate the results with charts.

According to the small deviations of these measurements, as shown in Tables 5 and 6, no correction due to long term drift of the travelling standards were taken to the results and conclusions in §6.

Table 5: ac-dc differences of the 10 mA travelling standard measured by NMC, in µA/A.

Date	*Frequency*						
	10Hz	*55Hz*	*1kHz*	*10kHz*	*20kHz*	*50kHz*	*100kHz*
Jul-13	4.0	0.0	- 0.3	0.9	0.8	2.3	3.3
Jan-14	4.1	0.1	- 0.3	0.9	1.0	2.0	2.5
Oct-14	4.1	0.0	0.0	0.9	0.6	2.3	2.4
Mar-15	4.3	0.2	- 0.3	1.0	0.9	2.4	2.7
Dec-15	4.2	0.0	- 0.1	0.9	0.9	2.0	2.7
Maximum deviation	0.2	0.2	0.2	0.1	0.4	0.4	0.8
Expanded Uncertainty	4.0	3.8	3.7	3.7	3.6	3.9	3.7

Table 6: ac-dc differences of the 5 A travelling standard measured by NMC, in µA/A.

Date	*Frequency*						
	10Hz	55Hz	1kHz	10kHz	20kHz	50kHz	100kHz
Jul-13	7	- 2	0	- 2	0	- 4	- 15
Jan-14	7	- 2	0	- 1	0	- 4	- 15
Oct-14	7	- 2	0	- 1	1	- 3	- 12
Mar-15	7	- 2	0	- 1	1	- 3	- 11
Dec-15	7	- 1	0	- 1	0	- 4	- 15
Maximum deviation	0	1	0	1	1	1	4
Expanded Uncertainty	13	13	13	13	13	13	23

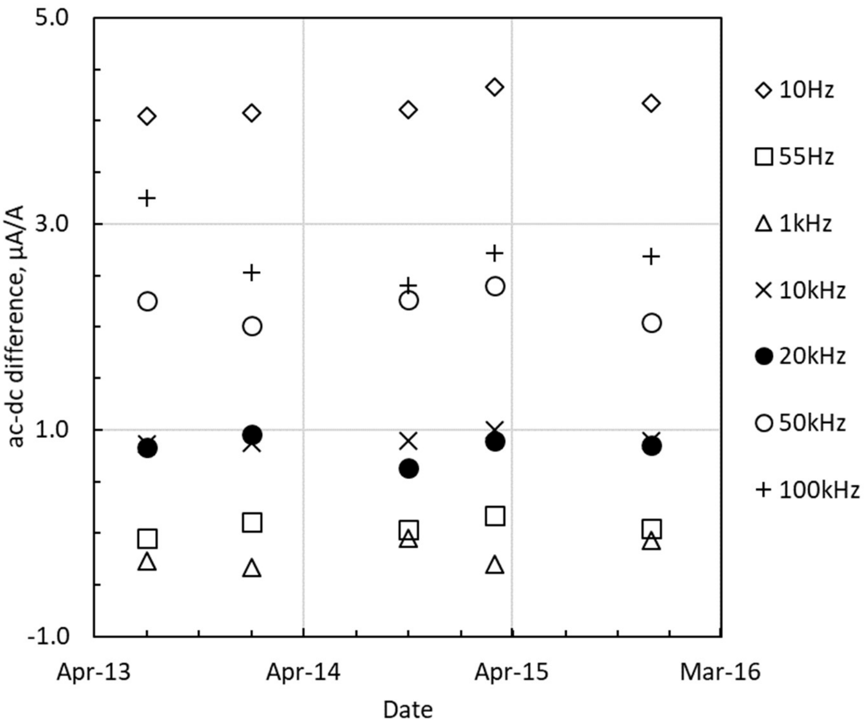


Figure 3: ac-dc differences of the 10 mA travelling standard measured in NMC.

6 Measurement Results

6.1 Reported Results

The results submitted by the participants are summarised in Table 7. The expanded uncertainties of measurement results at a level of confidence of approximately 95 % are given in Table 8. Shaded cells indicate that measurements were not carried out by the participants at those frequencies.

All the submitted results are compared graphically in §10.1.

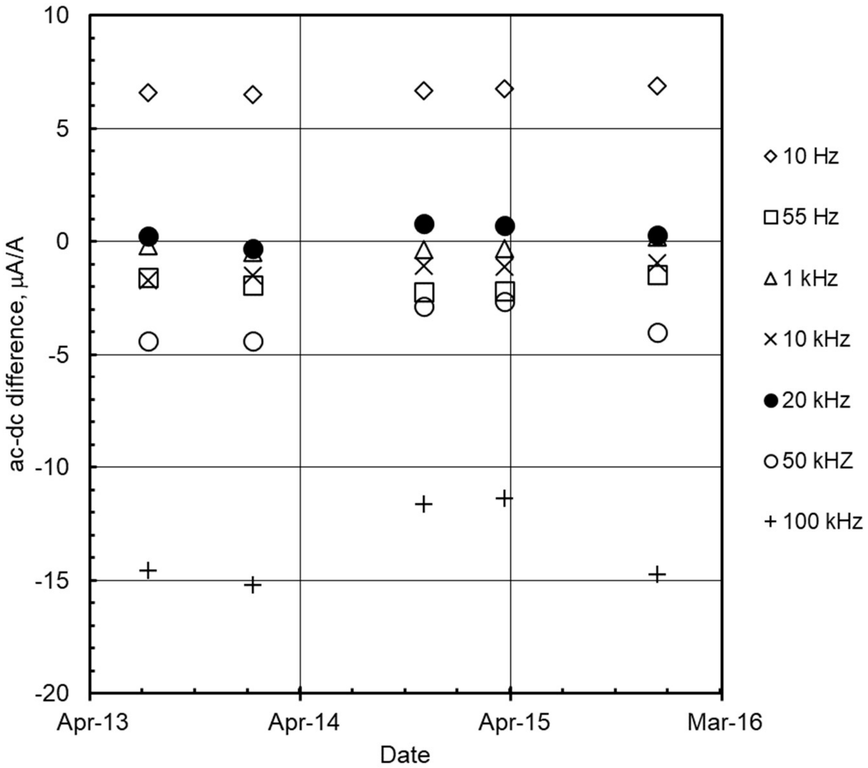


Figure 4: ac-dc differences of the 5 A travelling standard measured in NMC.

Table 7: Reported ac-dc differences, µA/A.

Laboratory	*Measurement Period*	10 mA							5 A						
		10Hz	55Hz	1kHz	10kHz	20kHz	50kHz	100kHz	10Hz	55Hz	1kHz	10kHz	20kHz	50kHz	100kHz
NMC	Jan ‘14	4.1	0.1	- 0.3	0.9	1.0	2.0	2.5	7	- 2	0	- 1	1	- 3	- 12
NMIA	Feb-Mar ‘14	5.9	0.4	- 0.1	0.1	0.4	1.2	2.9	3.4	0.9	-0.1	0	2.8	2.9	1.0
SCL	Apr ‘14	4	1	0	3				2	4	11	23			
NMIJ	May-Jun ‘14	3.0	0.3	0.0	0.3	0.5	1.2	2.3	1.7	- 0.8	- 0.6	- 0.6	- 1.6	- 3.2	- 9.3
KRISS	Jun-Aug ‘14	4.6	0	0.1	1				4.6	0.2	0.1	- 1.1			
NIM	Sep-Oct ‘14	3.1	0.0	0.0	0.4	1.8	4.3	9.0	3.3	4.6	- 0.3	- 6.0	- 9.5	-16.6	-33.1
NMC	Mar ‘15	4.1	0.0	0.0	0.9	0.6	2.3	2.4	7	- 2	0	- 1	1	- 3	- 11
NMISA	May-Jun ‘15	- 2.2	3.5	- 0.8	- 2.3	- 4.8	- 7.0	- 10.4	- 27.7	- 2.3	- 13.8	- 1.1	- 3.0	- 23.5	- 23.6
NIMT	Jul ‘15	4	0	0	1	3	4	0	3	1	0	5	10	7	-19
NMIM	Aug -Sep ‘15	5.5	- 0.6	- 0.3	0.0				2.3	- 1.9	- 2.0				
CMS/ITRI	Nov-Dec ‘15		- 4.9	- 2.3	- 3.1	- 2.6	2.0	7.8		0.4	0.3	- 2.3	- 4.3	- 15.5	- 44.9
NMC	Dec ‘15	4.2	0.0	- 0.1	0.9	0.9	2.0	2.7	7	- 2	0	- 1	0	- 4	- 15

Table 8: Reported expanded measurement uncertainties (95 %), µA/A.

Laboratory	10 mA							5A						
	10Hz	55Hz	1kHz	10kHz	20kHz	50kHz	100kHz	10Hz	55Hz	1kHz	10kHz	20kHz	50kHz	100kHz
NMC	4.0	3.8	3.7	3.7	3.6	3.9	3.7	13	13	13	13	13	13	23
NMIA	2.3	1.1	1.2	1.2	1.3	1.5	1.9	5.4	4.6	4.3	5	5.3	7	12
SCL	17	16	13	18				27	24	23	42			

Laboratory	10 mA							5A						
	10Hz	55Hz	1kHz	10kHz	20kHz	50kHz	100kHz	10Hz	55Hz	1kHz	10kHz	20kHz	50kHz	100kHz
NMIJ	5.4	2.2	1.4	2.2	2.6	3.4	5.6	14	6.2	5.6	6.4	7.6	12	18
KRISS	5	4	4	7				13	13	13	14			
NIM	5	4	4	4	5	6	8	15	14	14	15	18	25	30
NMISA	15	14	14	16	16	17	26	65	32	28	26	65	110	210
NIMT	8	8	8	8	8	8	13	22	22	22	22	22	34	46
NMIM	10	7.7	7.6	8.5				15	9.5	26				
CMS/ITRI		21	11	11	15	18	25		48	45	45	58	73	97

6.2 Determination of the Reference Values

The reference values of this comparison are based on the results of participants who took part in the CCEM-K12 comparison, or have independent realizations of primary standards for ac-dc current differences. Three laboratories satisfy the criteria: NMC, NMIA and NMIJ. Their results are treated as uncorrelated.

NMC, NMIA participated the CCEM-K12 comparison, and contributed to the reference values of CCEM-K12 (NMC only at 5 A). Both NMIA and NMIJ realize their respective primary standards independently.

The reference value δ_R at each frequency was obtained as the weighted mean of the reported results of the selected laboratories

$$\delta_R = u_R^2 \cdot \sum_{i=1}^{n} \delta_i \cdot \frac{1}{u_i^2} \tag{1}$$

where δ_i and u_i are the reported result and associated standard uncertainty of Laboratory *i*. $n = 3$ for both 10 mA and 5 A.

$$u_R = \sqrt{\frac{1}{\sum_{i=1}^{n} \frac{1}{u_i^2}}} \tag{2}$$

is the standard uncertainty of the reference value δ_R.

The determined reference values and their expanded uncertainties U_R (=2 u_R) are summarized in Table 9.

Table 9: Reference values and their associated uncertainties (~ 95 %), µA/A.

Current	*Frequency* / *Items*	10 Hz	55 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
10 mA	Reference value, δ_R	5.2	0.4	- 0.1	0.2	0.5	1.3	2.8
	Uncertainty, U_R	1.9	1.0	0.9	1.0	1.1	1.3	1.6
5 A	Reference values, δ_R	3.6	0.1	- 0.3	- 0.3	1.3	0.6	- 3.7
	Uncertainty, U_R	4.7	3.6	3.3	3.8	4.1	5.5	9.2

6.3 Degree of Equivalence with the Reference Values

The degree of equivalence D_i of laboratory i with the reference value δ_R is calculated by

$$D_i = \delta_i - \delta_R \tag{3}$$

for each frequency. For the laboratories whose results were used in calculating the reference value the correlation with the reference value was taken into account. The standard uncertainty u_{iD} of D_i is thus calculated by

$$u_{iD}^2 = u_i^2 - u_R^2 \tag{4}$$

For the rest of the participants

$$u_{iD}^2 = u_i^2 + u_R^2 \tag{5}$$

Coverage factor of $k = 2$ was used for determining the expanded uncertainties (at ~ 95%) U_{iD}. The calculated degrees of equivalence are given in Table 10 and Table 11, respectively for 10 mA and 5 A, together with their expanded uncertainties.

Table 10: Degree of equivalence D_i and expanded uncertainty (at ~ 95 %) U_{iD} at 10 mA, µA/A.

Laboratory	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}
NMC	- 1.1	3.5	- 0.3	3.7	- 0.3	3.6	0.7	3.6	0.5	3.4	0.7	3.7	- 0.3	3.3
NMIA	0.7	1.3	0.0	0.6	0.0	0.8	- 0.1	0.6	-0.1	0.7	- 0.1	0.8	0.1	1.0
SCL	- 1	17	1	16	0	13	3	18						
NMIJ	- 2.2	5.1	- 0.1	2.0	0.1	1.1	0.1	2.0	0.0	2.4	- 0.1	3.1	- 0.5	5.4
KRISS	- 0.6	5.3	- 0.4	4.1	0.2	4.1	0.8	7.1						
NIM	- 2.1	5.3	- 0.4	4.1	0.1	4.1	0.2	4.1	1.3	5.1	3.0	6.1	6.2	8.2
NMISA	- 7	15	3	14	- 1	14	- 3	16	- 5	16	- 8	17	- 13	26
NIMT	- 1.2	8.2	- 0.4	8.1	0.1	8.0	0.8	8.1	2.5	8.1	2.7	8.1	- 3	13
NMIM	0	10	- 1.0	7.8	- 0.2	7.7	- 0.2	8.6						
CMS/ITRI			- 5	21	- 2	11	- 3	11	- 3	15	1	18	5	25

Table 11: Degree of equivalence D_i and expanded uncertainty (at ~ 95 %) U_{iD} at 5 A, µA/A.

Laboratory	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}	D_i	U_{iD}
NMC	3	12	- 3	13	0	13	- 1	13	- 1	13	- 4	12	- 8	21
NMIA	- 0.2	2.7	0.8	2.9	0.2	2.8	0.3	3.3	1.5	3.3	2.3	4.4	4.7	7.8
SCL	- 2	28	4	25	11	23	23	42						
NMIJ	- 2	13	- 0.9	5.1	- 0.3	4.5	- 0.3	5.2	- 2.9	6.4	- 4	11	- 6	16
KRISS	1	14	0.1	14	1	14	- 1	15						
NIM	0	16	5	14	0	14	- 6	16	- 11	19	- 17	26	- 30	32
NMISA	- 31	65	- 2	32	- 14	28	- 1	26	- 4	66	- 20	110	- 20	200
NIMT	- 1	22	1	22	0	22	5	22	9	22	6	34	- 15	47
NMIM	- 1	16	- 2	10	- 2	26								
CMS/ITRI			0	48	1	45	- 2	45	- 6	58	- 16	73	- 41	97

6.4 Degree of Equivalence between Pairs of Laboratories

The degree of equivalence D_{ij} between results of laboratories i and j is calculated by

$$D_{ij} = \delta_i - \delta_j \tag{6}$$

with a standard uncertainty u_{ijD} of D_{ij} calculated by

$$u_{ijD}^2 = u_i^2 + u_j^2 \tag{7}$$

where δ_i and u_i are submitted results and standard uncertainty of laboratory i. Coverage factor of $k = 2$ was used for determining the expanded uncertainties (at ~ 95%) U_{ijD} (= 2 u_{ijD}) of the degree of equivalence D_{ij} between results of laboratories i and j. The calculated results are summarized in Appendix 10.2.

7 Link between APMP.EM-K12 and CCEM-K12

7.1 Linking Value of APMP.EM-K12 to CCEM-K12

Two laboratories, NMC and NMIA, participated in both CCEM-K12 [1] and the current comparison, APMP.EM-K12. Their performances, i.e. degrees of equivalence, in both comparisons are employed to link the two comparisons.

The linking value d_i of laboratory i between the two comparisons is defined as [2,3]

$$d_i = D_i - D_{i,CCEM} \tag{8}$$

provided that the performances of the two linking laboratories remain relatively constant over the period between the two comparisons. In (8), D_i is the degree of equivalence with a reference value in APMP.EM-K12 of laboratory i (as presented in Table 10 and Table 11), $D_{i,CCEM}$ that of the same laboratory concluded in CCEM-K12 (Tables 9 and 10) [1] (also copied here in Table 13 and Table 14 below). The standard uncertainty u_{id} of d_i is obtained by

$$u_{id}^2 = u_{iD}^2 + u_{iD,CCEM}^2 \qquad (9)$$

with u_{iD} and $u_{iD,CCEM}$ the standard uncertainties of D_i and $D_{i,CCEM}$ respectively. The linking value d of the current comparison to CCEM-K12 comparison is the weighted average of the linking values of the two laboratories

$$d = u_d^2 \cdot \sum_{i=1}^{2} d_i \cdot \frac{1}{u_{id}^2} \qquad (10)$$

where

$$u_d = \sqrt{\frac{1}{\sum_{i=1}^{2} \frac{1}{u_{id}^2}}} \qquad (11)$$

is the standard uncertainty of *d*. The calculated results are summarized in Table 12.

Table 12: Linking values *d* of APMP.EM-K12 to CCEM-K12 and expanded uncertainty U_d (at ~95 %), µA/A.

Current	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	d	U_d	*d*	U_d	*d*	U_d	*d*	U_d	*d*	U_d	*d*	U_d	*d*	U_d
10 mA	3.1	2.2	0.3	1.0	0.3	1.2	0.0	1.0	0.1	1.0	0.0	1.4	0.1	1.9
5 A	0.5	4.9	0.2	4.8	0.2	4.7	1.5	4.9	2.1	4.9	4.8	7.8	9	13

7.2 Degree of Equivalence with the Reference Value of CCEM-K12

With the linking values given in Table 12, the degrees of equivalence with reference values of CCEM-K12, $D_{i,CCEM}$, of laboratory i participating in APMP.EM-K12 only can be determined by

$$D_{i,CCEM} = D_i - d \qquad (12)$$

where D_i is the degree of equivalence of the lab with the reference value of APMP.EM-K12 presented in Table 10 and Table 11.

The standard uncertainty of $D_{iD,CCEM}$ is calculated by

$$u_{iD,CCEM}^2 = u_{iD}^2 + u_d^2 \qquad (13)$$

where u_{iD} and u_d are the standard uncertainties of D_i and d.

The calculated degrees of equivalence with the reference values of CCEM-K12 are summarized in Table 13 and Table 14 respectively for 10 mA and 5 A, and presented graphically in Figure 5 to Figure 18. The entries of the two linking laboratories, NMC and NMIA, are those from CCEM-K12 comparison [1].

Table 13: Degrees of equivalence with reference values of CCEM-K12 $D_{i,CCEM}$ and expanded uncertainty (at ~ 95 %) $U_{iD,CCEM}$, at 10 mA, µA/A.

Laboratory	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$
NMC*	- 0.6	7.1	- 1.2	7.0	- 1.0	7.0	- 0.8	7.0	- 0.8	7.0	0.3	7.0	1.8	12.0
NMIA*	- 2.6	1.8	- 0.3	0.8	- 0.3	0.9	- 0.1	0.8	- 0.2	0.7	- 0.1	1.2	0.0	1.6
SCL	- 4	17	0	16	0	13	3	18						
NMIJ	- 5.2	5.5	- 0.4	2.2	- 0.2	1.6	0.1	2.2	- 0.1	2.5	- 0.1	3.4	- 0.6	5.7
KRISS	- 3.6	5.8	- 0.7	4.2	- 0.1	4.3	0.8	7.1						
NIM	- 5.1	5.8	- 0.7	4.2	- 0.2	4.3	0.2	4.2	1.2	5.2	3.0	6.3	6.1	8.4
NMISA	- 10	15	3	14	- 1	14	- 3	16	- 5	16	- 8	17	- 13	26
NIMT	- 4.2	8.5	- 0.7	8.1	- 0.2	8.1	0.8	8.1	2.4	8.1	2.7	8.2	- 3	13
NMIM	- 3	10	- 1.3	7.8	- 0.5	7.7	- 0.2	8.6						
CMS/ITRI			- 6	20	- 3	11	- 3	11	- 3	14	1	18	5	24

*Concluded at CCEM-K12 comparison [1].

Table 14: Degrees of equivalence with reference values of CCEM-K12 $D_{i,CCEM}$ and expanded uncertainty (at ~ 95 %) $U_{iD,CCEM}$, at 5 A, µA/A.

Laboratory	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$	$D_{i,CCEM}$	$U_{iD,CCEM}$
NMC*	- 2	25	- 1	25	- 3	25	- 2	25	- 0	25	- 2	25	- 5	43
NMIA*	-0.6	4.2	0.5	3.9	0.1	3.9	-1.2	3.8	-0.7	3.7	-3.0	6.9	- 5	11
SCL	- 2	27	4	24	11	23	22	42						
NMIJ	- 2	14	- 1.1	5.1	- 0.5	6.5	- 1.8	7.2	- 5.0	8.0	- 9	13	- 14	20
KRISS	1	15	0	13	0	14	- 2	15						
NIM	- 1	16	4	14	0	15	- 7	16	- 13	19	- 22	26	- 38	33
NMISA	- 32	65	-3	32	- 14	28	- 2	26	- 6	65	- 30	110	- 30	200
NIMT	- 1	23	1	22	0	22	4	23	7	23	2	35	- 24	48
NMIM	- 2	17	- 2	11	- 2	27								
CMS/ITRI			0	48	0	45	-4	45	- 8	58	- 21	73	- 50	98

*Concluded at CCEM-K12 comparison [1].

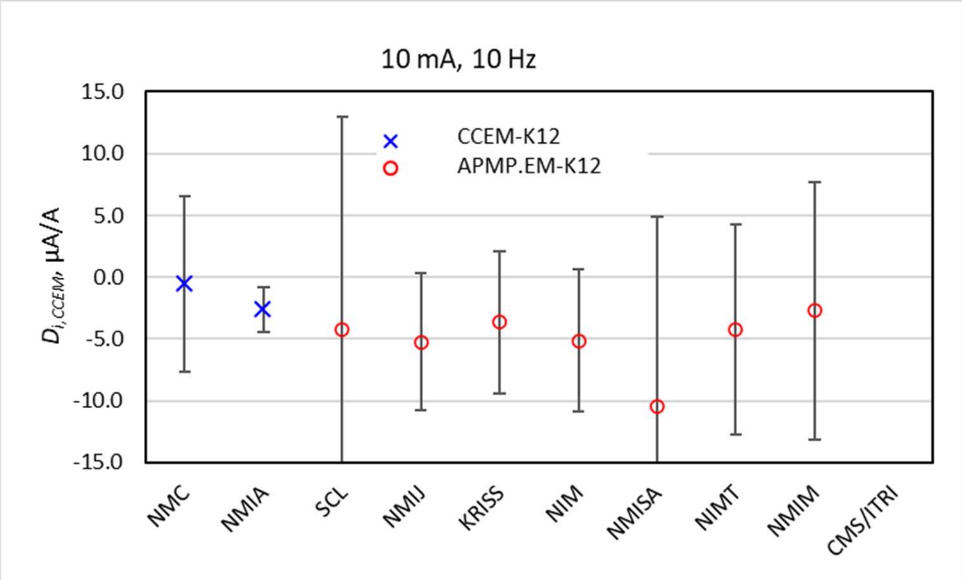


Figure 5: Degree of equivalence $D_{i,CCEM}$ with reference value (10 mA, 10 Hz) of CCEM-K12.

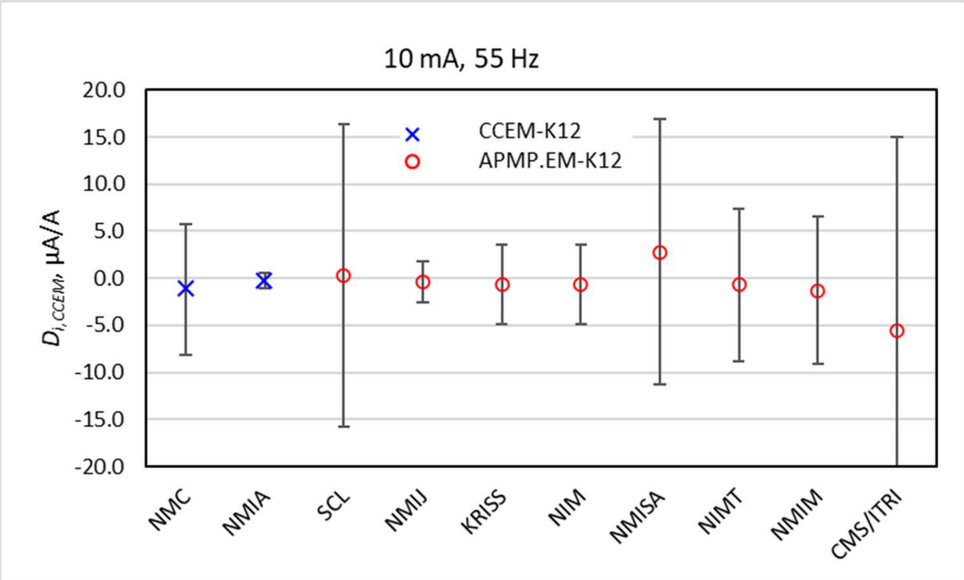


Figure 6: Degree of equivalence $D_{i,CCEM}$ with reference value (10 mA, 55 Hz) of CCEM-K12.

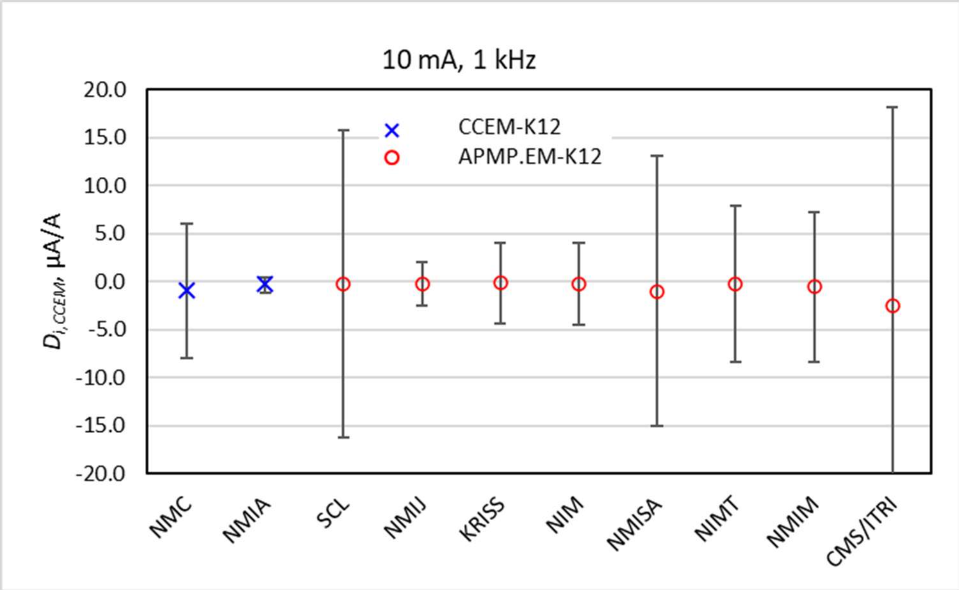


Figure 7: Degree of equivalence $D_{i,CCEM}$ with reference value (10 mA, 1 kHz) of CCEM-K12.

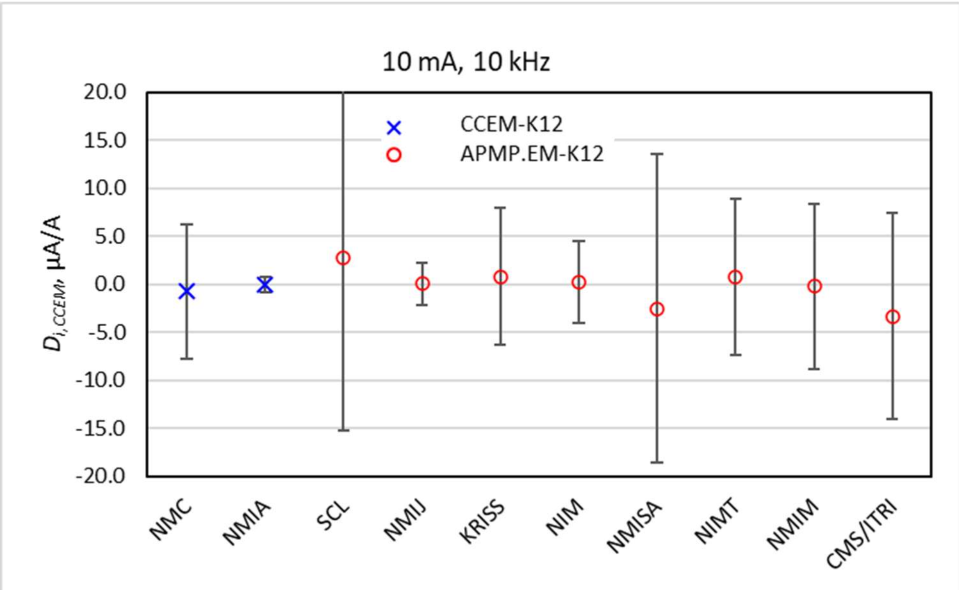


Figure 8: Degree of equivalence $D_{i,CCEM}$ with reference value (10 mA, 10 kHz) of CCEM-K12.

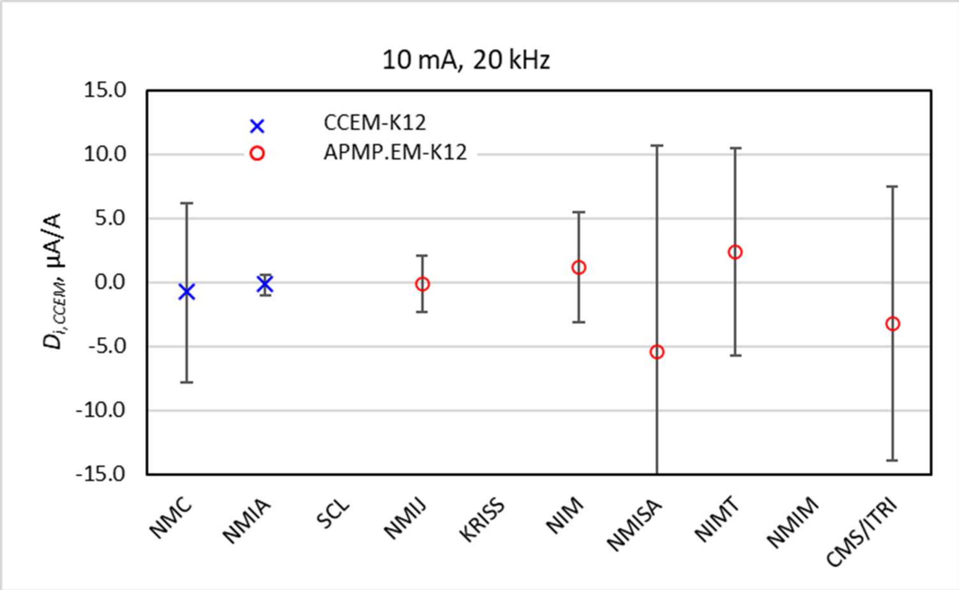


Figure 9: Degree of equivalence $D_{i,CCEM}$ with reference value (10 mA, 20 kHz) of CCEM-K12.

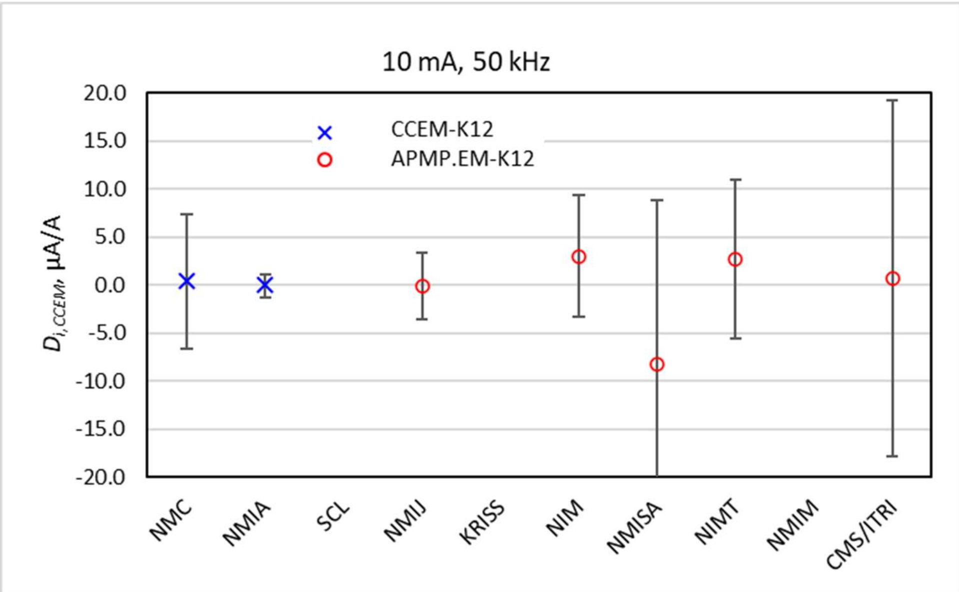


Figure 10: Degree of equivalence $D_{i,CCEM}$ with reference value (10 mA, 50 kHz) of CCEM-K12.

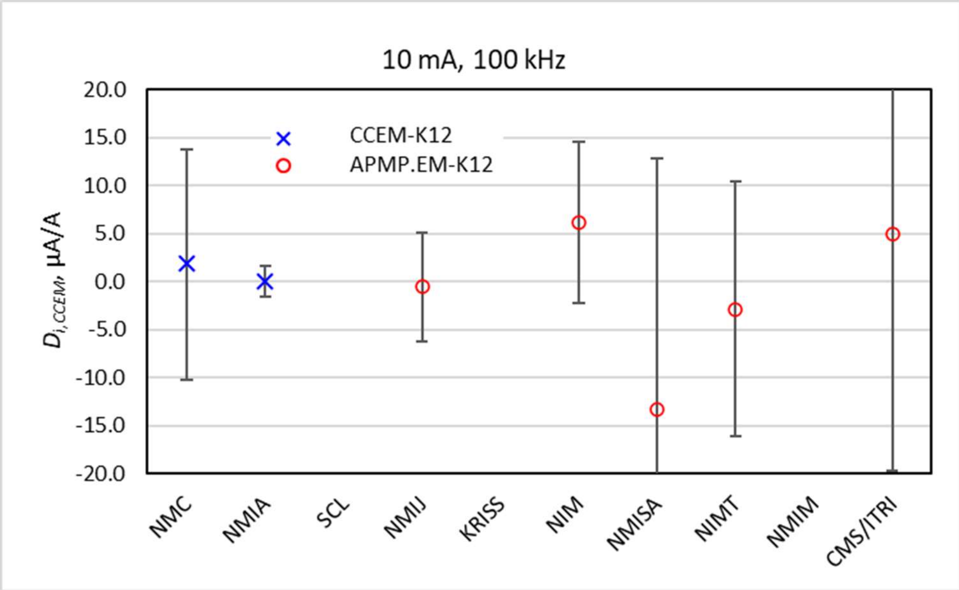


Figure 11: Degree of equivalence $D_{i,CCEM}$ with reference value (10 mA, 100 kHz) of CCEM-K12.

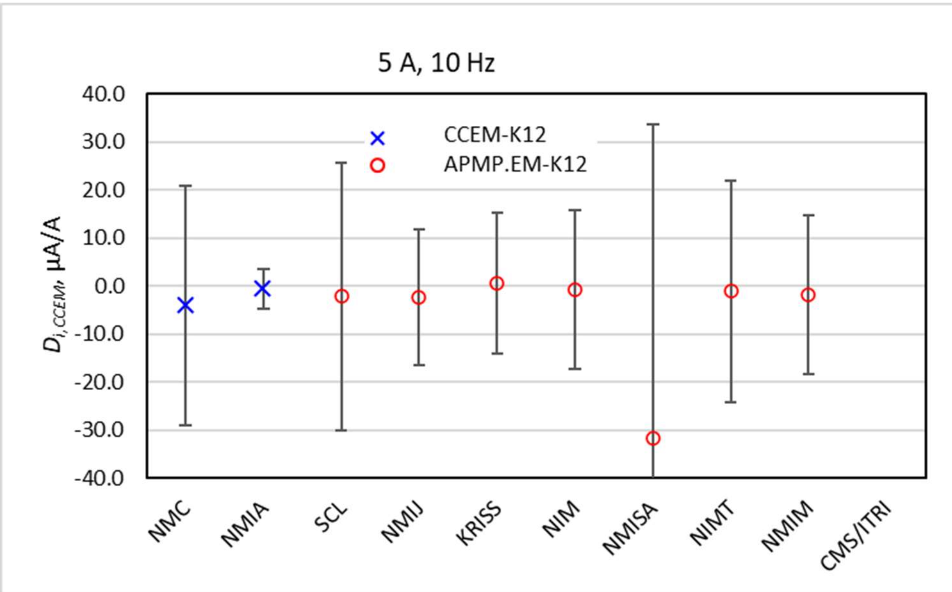


Figure 12: Degree of equivalence $D_{i,CCEM}$ with reference value (5 A, 10 Hz) of CCEM-K12.

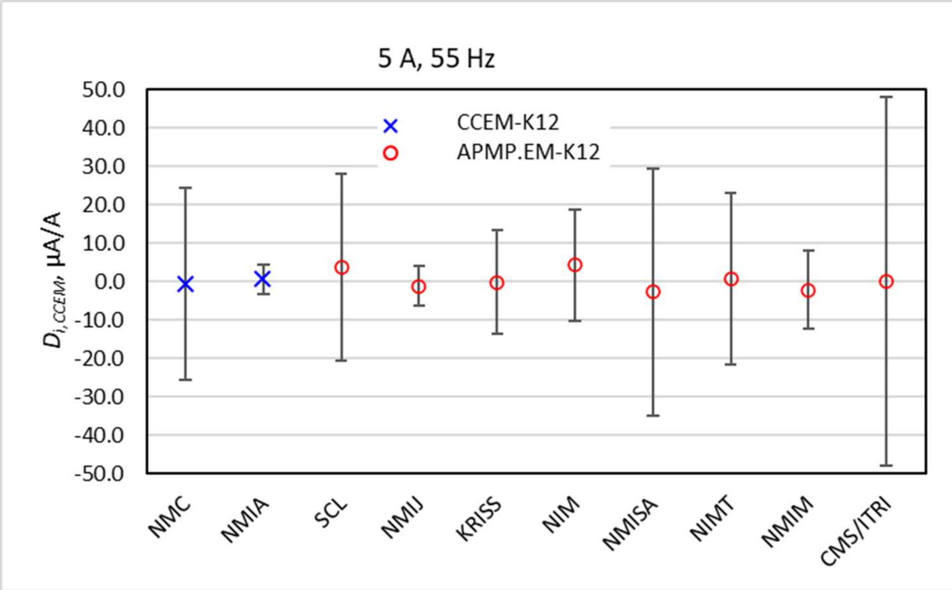


Figure 13: Degree of equivalence $D_{i,CCEM}$ with reference value (5 A, 55 Hz) of CCEM-K12.

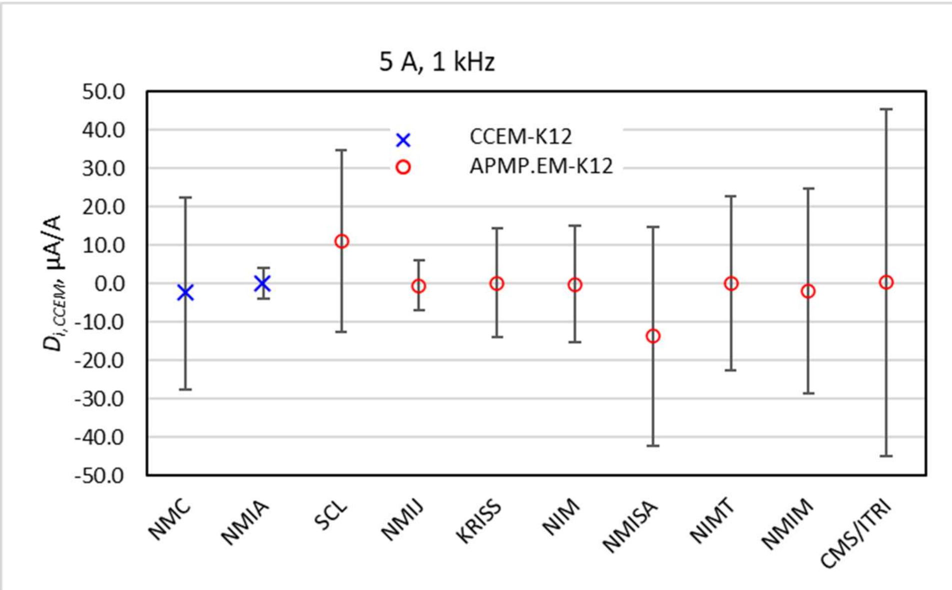


Figure 14: Degree of equivalence $D_{i,CCEM}$ with reference value (5 A, 1 kHz) of CCEM-K12.

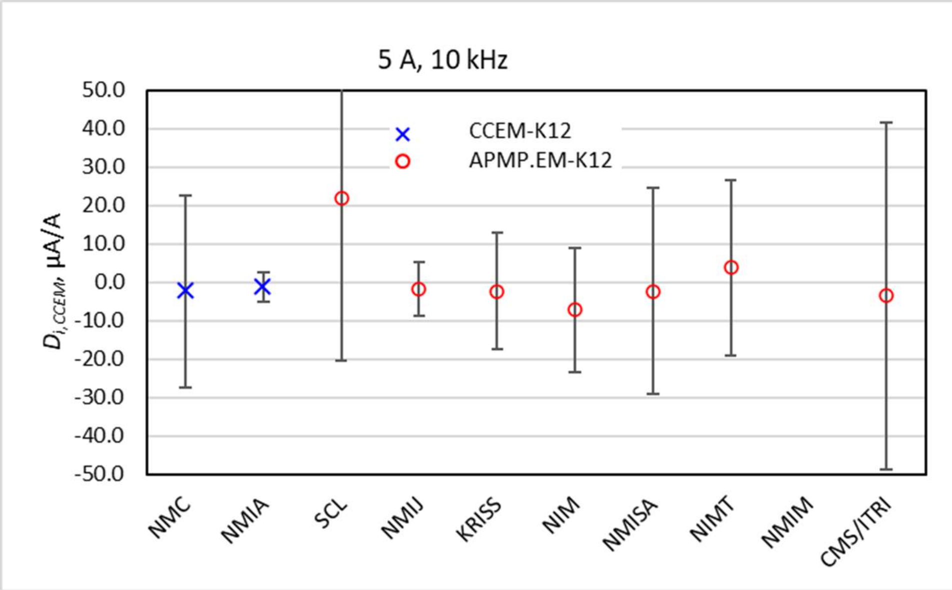


Figure 15: Degree of equivalence $D_{i,CCEM}$ with reference value (5 A, 10 kHz) of CCEM-K12.

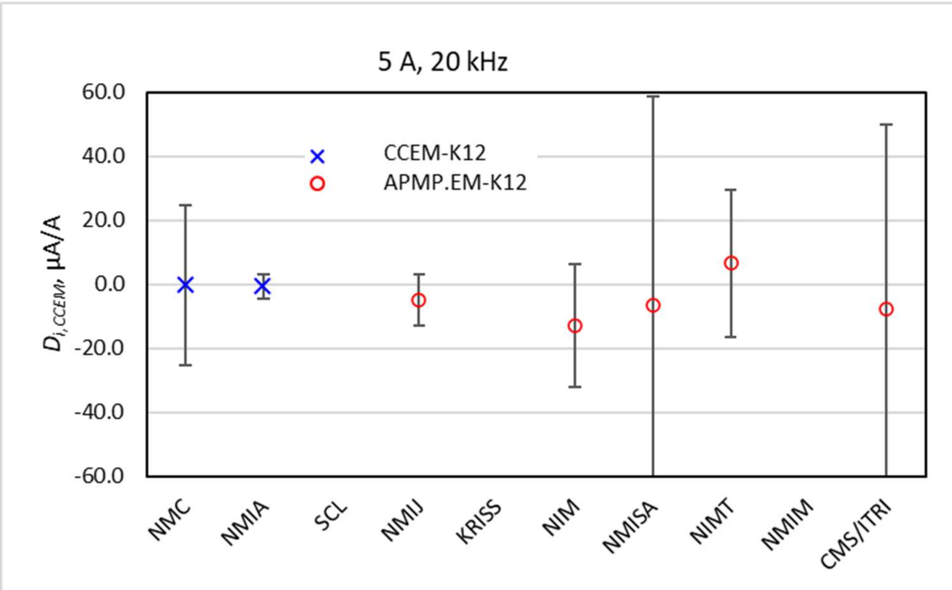


Figure 16: Degree of equivalence $D_{i,CCEM}$ with reference value (5 A, 20 kHz) of CCEM-K12.

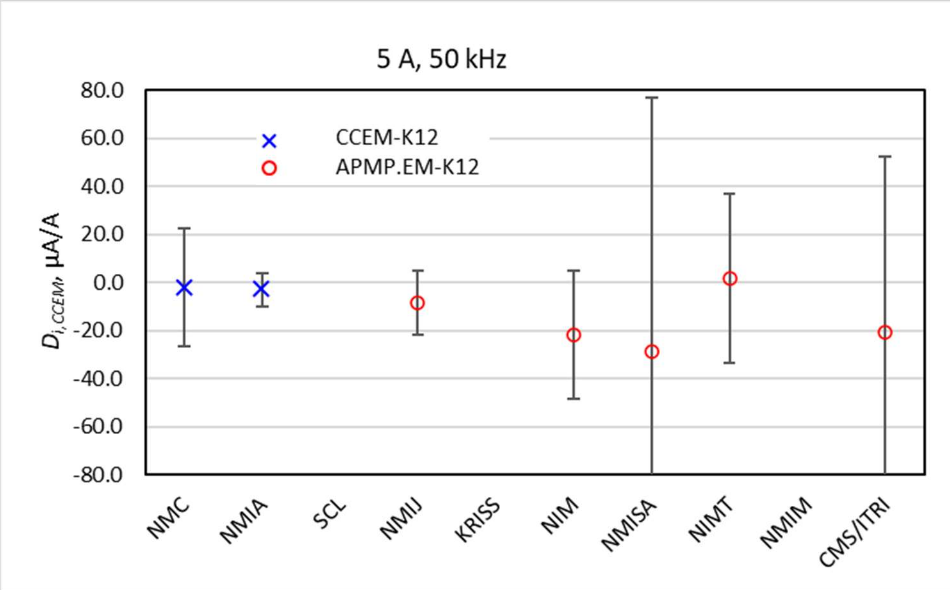


Figure 17: Degree of equivalence $D_{i,CCEM}$ with reference value (5 A, 50 kHz) of CCEM-K12.

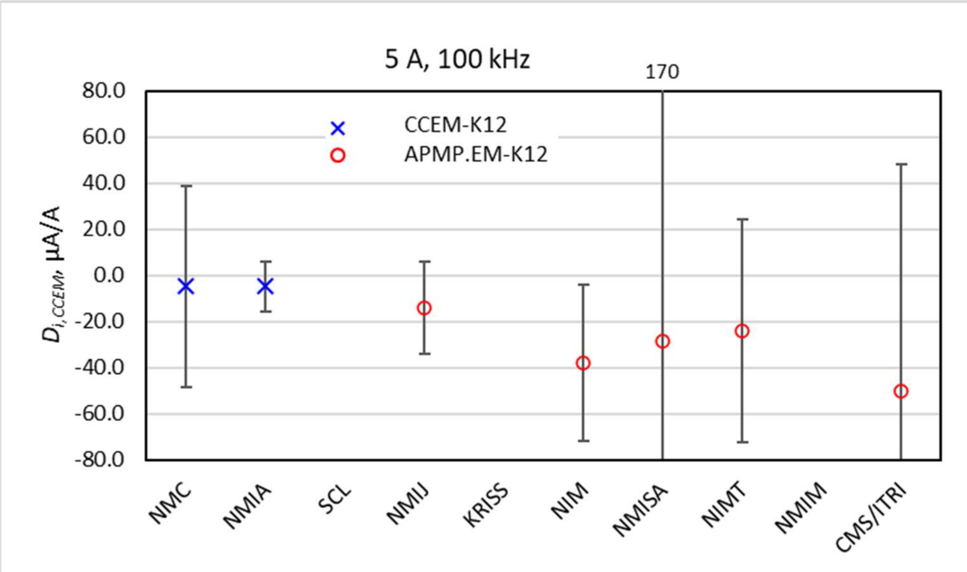


Figure 18: Degree of equivalence $D_{i,CCEM}$ with reference value (5 A, 100 kHz) of CCEM-K12.

8 Summary and Conclusions

In order to link more APMP NMIs to CCEM-K12 Key Comparison of ac-dc current transfer standards, a regional comparison, APMP.EM-K12 was carried out among 12 NMIs between Feb 2014 and Dec 2015. Two participants withdrew later from the comparison.

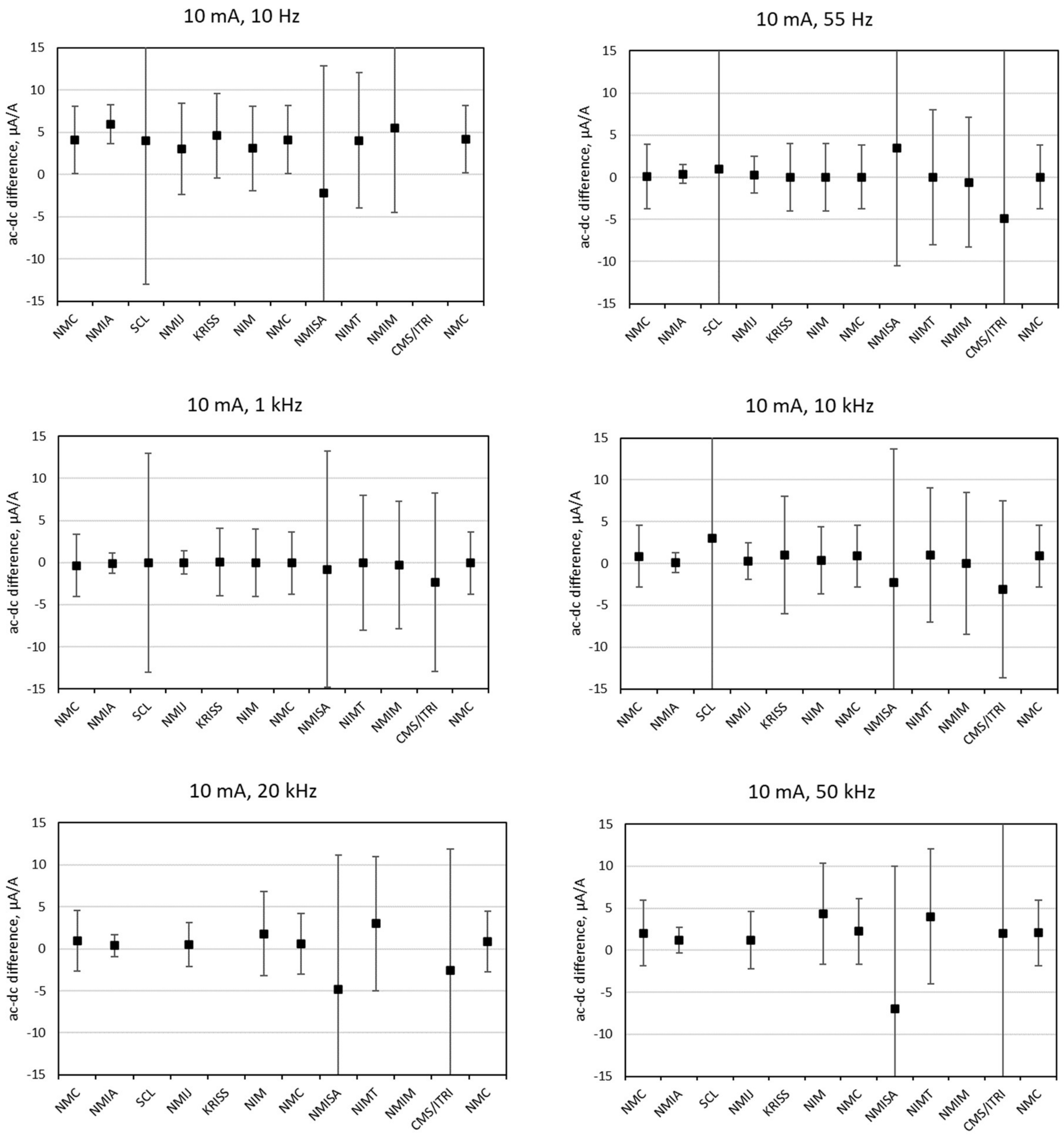
The ac-dc current transfer differences of the travelling standards were measured at the currents of 10 mA and 5 A, and at the frequencies of 10 Hz, 55 Hz, 1 kHz, 10 kHz, 20 kHz, 50 kHz and 100 kHz. The reference values of this comparison were calculated as the weighted mean of the results of the laboratories that participated in CCEM-K12 or with independent realizations of primary standards. The degrees of equivalence with the reference values of the current comparison and those with CCEM-K12 are concluded as given in §6.3 and §7.2. They generally show good agreements. The participants are to evaluate their respective performances and follow up with necessary changes or confirmations of their CMCs.

9 References

1. Budovsky, I., “Key international comparison of ac-dc current transfer standards CCEM-K12, final report”, Apr 2011.
2. Delahaye, F. and Witt, T.J., “Linking the results of key comparison CCEM-K4 with the 10 pF results of EUROMET.EM-K4,” Metrologia Technical Supplement, Vol. 39, 01005. 2002.
3. Budovsky, I., “Final report on APMP.EM-K6.a: APMP international comparison of ac–dc transfer standards at the lowest attainable level of uncertainty”, Metrologia, Vol. 47, Technical Supplement 1, Jan 2010.

10 Appendices

10.1 Graphical Comparisons of Submitted Results



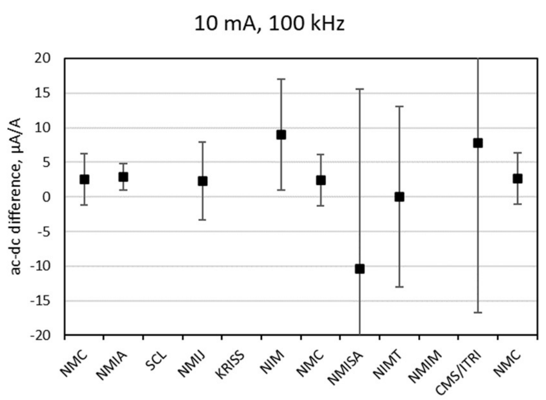
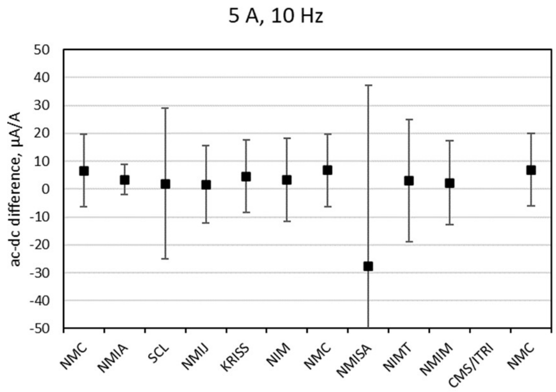
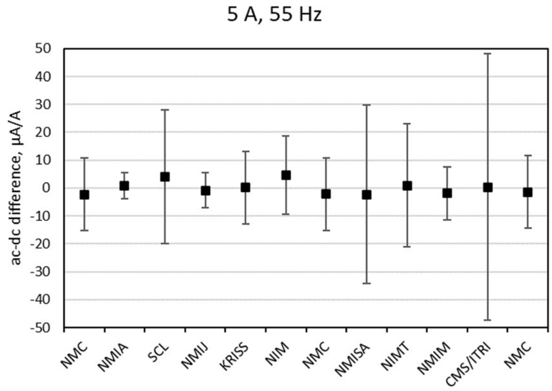
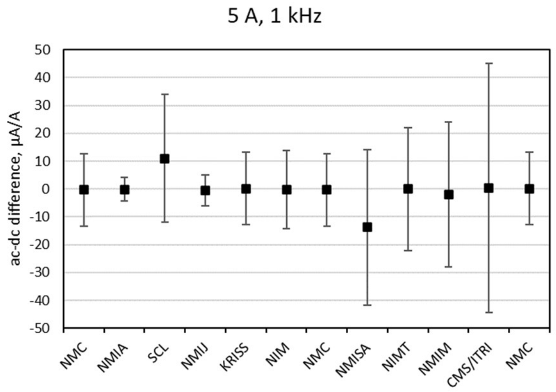
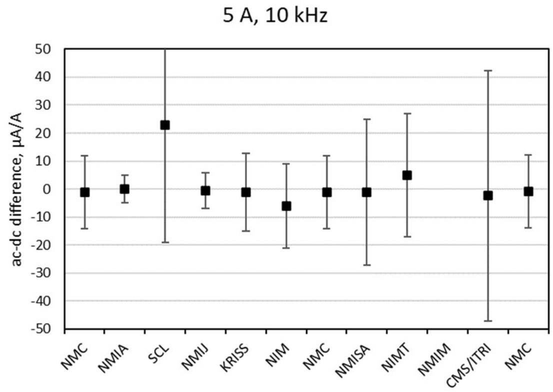


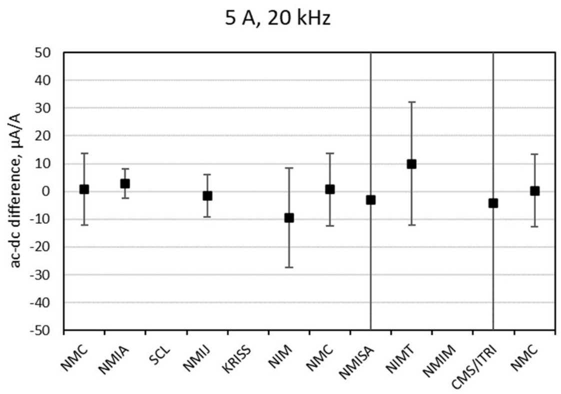
Figure 19: Measured ac-dc difference and expanded uncertainty (at ~ 95 %) at 10 mA (see Table 7 and Table 8 for data).

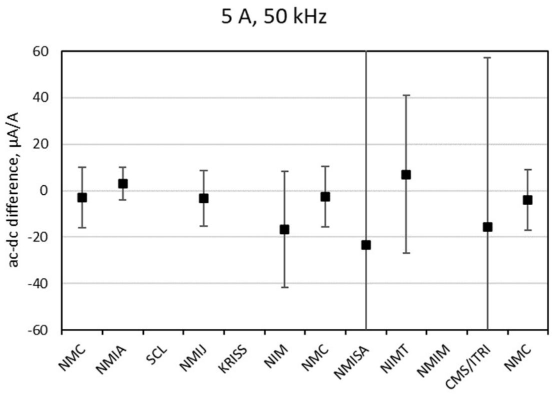












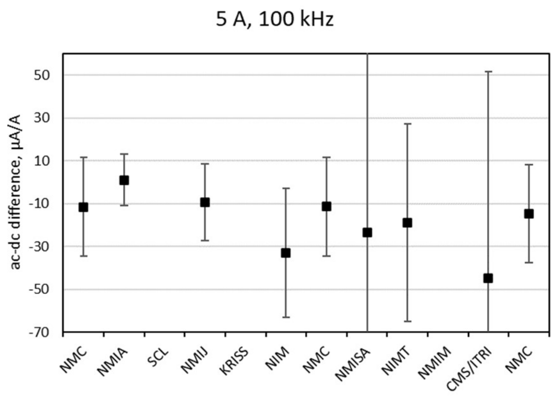


Figure 20: Measured ac-dc difference and expanded uncertainty (at ~ 95 %) at 5 A (see Table 7 and Table 8 for data).

10.2 Degree of Equivalence between Pairs of Laboratories

Refer to §6.4 for definitions and formula used.

10 mA, 10 Hz

j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
i	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			1.8	4.6	-0.1	17.5	-1.1	6.7	0.5	6.4	-1.0	6.4	-6.3	15.5	-0.1	8.9	1.4	10.8		
NMIA	-1.8	4.6			-1.9	17.2	-2.9	5.9	-1.3	5.5	-2.8	5.5	-8.1	15.2	-1.9	8.3	-0.4	10.3		
SCL	0.1	17.5	1.9	17.2			-1.0	17.8	0.6	17.7	-0.9	17.7	-6.2	22.7	0.0	18.8	1.5	19.7		
NMIJ	1.1	6.7	2.9	5.9	1.0	17.8			1.6	7.4	0.1	7.4	-5.2	15.9	1.0	9.7	2.5	11.4		
KRISS	-0.5	6.4	1.3	5.5	-0.6	17.7	-1.6	7.4			-1.5	7.1	-6.8	15.8	-0.6	9.4	0.9	11.2		
NIM	1.0	6.4	2.8	5.5	0.9	17.7	-0.1	7.4	1.5	7.1			-5.3	15.8	0.9	9.4	2.4	11.2		
NMISA	6.3	15.5	8.1	15.2	6.2	22.7	5.2	15.9	6.8	15.8	5.3	15.8			6.2	17.0	7.7	18.0		
NIMT	0.1	8.9	1.9	8.3	0.0	18.8	-1.0	9.7	0.6	9.4	-0.9	9.4	-6.2	17.0			1.5	12.8		
NMIM	-1.4	10.8	0.4	10.3	-1.5	19.7	-2.5	11.4	-0.9	11.2	-2.4	11.2	-7.7	18.0	-1.5	12.8				
CMS/ITRI																				

10 mA, 55 Hz

j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
i	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			0.3	4.0	0.9	16.4	0.2	4.4	-0.1	5.5	-0.1	5.5	3.4	14.5	-0.1	8.9	-0.7	8.6	-5.0	20.9
NMIA	-0.3	4.0			0.6	16.0	-0.1	2.5	-0.4	4.1	-0.4	4.1	3.1	14.0	-0.4	8.1	-1.0	7.8	-5.3	20.6
SCL	-0.9	16.4	-0.6	16.0			-0.7	16.2	-1.0	16.5	-1.0	16.5	2.5	21.3	-1.0	17.9	-1.6	17.8	-5.9	26.1
NMIJ	-0.2	4.4	0.1	2.5	0.7	16.2			-0.3	4.6	-0.3	4.6	3.2	14.2	-0.3	8.3	-0.9	8.0	-5.2	20.7
KRISS	0.1	5.5	0.4	4.1	1.0	16.5	0.3	4.6			0.0	5.7	3.5	14.6	0.0	8.9	-0.6	8.7	-4.9	21.0
NIM	0.1	5.5	0.4	4.1	1.0	16.5	0.3	4.6	0.0	5.7			3.5	14.6	0.0	8.9	-0.6	8.7	-4.9	21.0
NMISA	-3.4	14.5	-3.1	14.0	-2.5	21.3	-3.2	14.2	-3.5	14.6	-3.5	14.6			-3.5	16.1	-4.1	16.0	-8.4	24.9
NIMT	0.1	8.9	0.4	8.1	1.0	17.9	0.3	8.3	0.0	8.9	0.0	8.9	3.5	16.1			-0.6	11.1	-4.9	22.1
NMIM	0.7	8.6	1.0	7.8	1.6	17.8	0.9	8.0	0.6	8.7	0.6	8.7	4.1	16.0	0.6	11.1			-4.3	22.0
CMS/ITRI	5.0	20.9	5.3	20.6	5.9	26.1	5.2	20.7	4.9	21.0	4.9	21.0	8.4	24.9	4.9	22.1	4.3	22.0		

10 mA, 1 kHz

j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
i	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			0.2	3.9	0.3	13.5	0.3	4.0	0.4	5.4	0.3	5.4	-0.5	14.5	0.3	8.8	0.0	8.5	-2.0	11.2
NMIA	-0.2	3.9			0.1	13.1	0.1	1.8	0.2	4.2	0.1	4.2	-0.7	14.1	0.1	8.1	-0.2	7.7	-2.2	10.7
SCL	-0.3	13.5	-0.1	13.1			0.0	13.1	0.1	13.6	0.0	13.6	-0.8	19.1	0.0	15.3	-0.3	15.1	-2.3	16.8
NMIJ	-0.3	4.0	-0.1	1.8	0.0	13.1			0.1	4.2	0.0	4.2	-0.8	14.1	0.0	8.1	-0.3	7.7	-2.3	10.7
KRISS	-0.4	5.4	-0.2	4.2	-0.1	13.6	-0.1	4.2			-0.1	5.7	-0.9	14.6	-0.1	8.9	-0.4	8.6	-2.4	11.3
NIM	-0.3	5.4	-0.1	4.2	0.0	13.6	0.0	4.2	0.1	5.7			-0.8	14.6	0.0	8.9	-0.3	8.6	-2.3	11.3
NMISA	0.5	14.5	0.7	14.1	0.8	19.1	0.8	14.1	0.9	14.6	0.8	14.6			0.8	16.1	0.5	15.9	-1.5	17.6
NIMT	-0.3	8.8	-0.1	8.1	0.0	15.3	0.0	8.1	0.1	8.9	0.0	8.9	-0.8	16.1			-0.3	11.0	-2.3	13.3
NMIM	0.0	8.5	0.2	7.7	0.3	15.1	0.3	7.7	0.4	8.6	0.3	8.6	-0.5	15.9	0.3	11.0			-2.0	13.0
CMS/ITRI	2.0	11.2	2.2	10.7	2.3	16.8	2.3	10.7	2.4	11.3	2.3	11.3	1.5	17.6	2.3	13.3	2.0	13.0		

10 mA, 10 kHz

i \ j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			-0.8	3.9	2.1	18.4	-0.6	4.3	0.1	7.9	-0.5	5.4	-3.2	16.4	0.1	8.8	-0.9	9.3	-4.0	11.2
NMIA	0.8	3.9			2.9	18.0	0.2	2.5	0.9	7.1	0.3	4.2	-2.4	16.0	0.9	8.1	-0.1	8.6	-3.2	10.7
SCL	-2.1	18.4	-2.9	18.0			-2.7	18.1	-2.0	19.3	-2.6	18.4	-5.3	24.1	-2.0	19.7	-3.0	19.9	-6.1	20.9
NMIJ	0.6	4.3	-0.2	2.5	2.7	18.1			0.7	7.3	0.1	4.6	-2.6	16.2	0.7	8.3	-0.3	8.8	-3.4	10.8
KRISS	-0.1	7.9	-0.9	7.1	2.0	19.3	-0.7	7.3			-0.6	8.1	-3.3	17.5	0.0	10.6	-1.0	11.0	-4.1	12.7
NIM	0.5	5.4	-0.3	4.2	2.6	18.4	-0.1	4.6	0.6	8.1			-2.7	16.5	0.6	8.9	-0.4	9.4	-3.5	11.3
NMISA	3.2	16.4	2.4	16.0	5.3	24.1	2.6	16.2	3.3	17.5	2.7	16.5			3.3	17.9	2.3	18.1	-0.8	19.2
NIMT	-0.1	8.8	-0.9	8.1	2.0	19.7	-0.7	8.3	0.0	10.6	-0.6	8.9	-3.3	17.9			-1.0	11.7	-4.1	13.3
NMIM	0.9	9.3	0.1	8.6	3.0	19.9	0.3	8.8	1.0	11.0	0.4	9.4	-2.3	18.1	1.0	11.7			-3.1	13.6
CMS/ITRI	4.0	11.2	3.2	10.7	6.1	20.9	3.4	10.8	4.1	12.7	3.5	11.3	0.8	19.2	4.1	13.3	3.1	13.6		

10 mA, 20 kHz

i \ j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			-0.6	3.8			-0.5	4.4			0.8	6.2	-5.8	16.4	2.0	8.8			-3.6	14.9
NMIA	0.6	3.8					0.1	2.9			1.4	5.2	-5.2	16.1	2.6	8.1			-3.0	14.6
SCL																				
NMIJ	0.5	4.4	-0.1	2.9							1.3	5.6	-5.3	16.2	2.5	8.4			-3.1	14.7
KRISS																				
NIM	-0.8	6.2	-1.4	5.2			-1.3	5.6					-6.6	16.8	1.2	9.4			-4.4	15.3
NMISA	5.8	16.4	5.2	16.1			5.3	16.2			6.6	16.8			7.8	17.9			2.2	21.6
NIMT	-2.0	8.8	-2.6	8.1			-2.5	8.4			-1.2	9.4	-7.8	17.9					-5.6	16.6
NMIM																				
CMS/ITRI	3.6	14.9	3.0	14.6			3.1	14.7			4.4	15.3	-2.2	21.6	5.6	16.6				

10 mA, 50 kHz

i \ j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			-0.8	4.2			-0.8	5.2			2.3	7.2	-9.0	17.4	2.0	8.9			0.0	18.8
NMIA	0.8	4.2					0.0	3.7			3.1	6.2	-8.2	17.1	2.8	8.1			0.8	18.5
SCL																				
NMIJ	0.8	5.2	0.0	3.7							3.1	6.9	-8.2	17.3	2.8	8.7			0.8	18.7
KRISS																				
NIM	-2.3	7.2	-3.1	6.2			-3.1	6.9					-11.3	18.0	-0.3	10.0			-2.3	19.4
NMISA	9.0	17.4	8.2	17.1			8.2	17.3			11.3	18.0			11.0	18.8			9.0	25.1
NIMT	-2.0	8.9	-2.8	8.1			-2.8	8.7			0.3	10.0	-11.0	18.8					-2.0	20.1
NMIM																				
CMS/ITRI	0.0	18.8	-0.8	18.5			-0.8	18.7			2.3	19.4	-9.0	25.1	2.0	20.1				

10 mA, 100 kHz

i \ j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			0.4	4.2			-0.2	6.7			6.5	8.8	-12.9	26.3	-2.5	13.5			5.3	24.8
NMIA	-0.4	4.2					-0.6	5.9			6.1	8.2	-13.3	26.1	-2.9	13.1			4.9	24.6
SCL																				
NMIJ	0.2	6.7	0.6	5.9							6.7	9.8	-12.7	26.6	-2.3	14.2			5.5	25.1
KRISS																				
NIM	-6.5	8.8	-6.1	8.2			-6.7	9.8					-19.4	27.2	-9.0	15.3			-1.2	25.8
NMISA	12.9	26.3	13.3	26.1			12.7	26.6			19.4	27.2			10.4	29.1			18.2	35.7
NIMT	2.5	13.5	2.9	13.1			2.3	14.2			9.0	15.3	-10.4	29.1					7.8	27.7
NMIM																				
CMS/ITRI	-5.3	24.8	-4.9	24.6			-5.5	25.1			1.2	25.8	-18.2	35.7	-7.8	27.7				

5 A, 10 Hz																				
j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
i	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			-3.3	14.1	-4.7	30.0	-5.0	19.1	-2.1	18.4	-3.4	19.8	-34.4	66.3	-3.7	25.6	-4.4	19.8		
NMIA	3.3	14.1			-1.4	27.5	-1.7	15.0	1.2	14.1	-0.1	15.9	-31.1	65.2	-0.4	22.7	-1.1	15.9		
SCL	4.7	30.0	1.4	27.5			-0.3	30.4	2.6	30.0	1.3	30.9	-29.7	70.4	1.0	34.8	0.3	30.9		
NMIJ	5.0	19.1	1.7	15.0	0.3	30.4			2.9	19.1	1.6	20.5	-29.4	66.5	1.3	26.1	0.6	20.5		
KRISS	2.1	18.4	-1.2	14.1	-2.6	30.0	-2.9	19.1			-1.3	19.8	-32.3	66.3	-1.6	25.6	-2.3	19.8		
NIM	3.4	19.8	0.1	15.9	-1.3	30.9	-1.6	20.5	1.3	19.8			-31.0	66.7	-0.3	26.6	-1.0	21.2		
NMISA	34.4	66.3	31.1	65.2	29.7	70.4	29.4	66.5	32.3	66.3	31.0	66.7			30.7	68.6	30.0	66.7		
NIMT	3.7	25.6	0.4	22.7	-1.0	34.8	-1.3	26.1	1.6	25.6	0.3	26.6	-30.7	68.6			-0.7	26.6		
NMIM	4.4	19.8	1.1	15.9	-0.3	30.9	-0.6	20.5	2.3	19.8	1.0	21.2	-30.0	66.7	0.7	26.6				
CMS/ITRI																				

5 A, 55 Hz																				
j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
i	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			3.1	13.8	6.2	27.3	1.4	14.4	2.4	18.4	6.8	19.1	-0.1	34.5	3.2	25.6	0.3	16.1	2.6	49.4
NMIA	-3.1	13.8			3.1	24.4	-1.7	7.7	-0.7	13.8	3.7	14.7	-3.2	32.3	0.1	22.5	-2.8	10.6	-0.5	47.9
SCL	-6.2	27.3	-3.1	24.4			-4.8	24.8	-3.8	27.3	0.6	27.8	-6.3	40.0	-3.0	32.6	-5.9	25.8	-3.6	53.4
NMIJ	-1.4	14.4	1.7	7.7	4.8	24.8			1.0	14.4	5.4	15.3	-1.5	32.6	1.8	22.9	-1.1	11.3	1.2	48.1
KRISS	-2.4	18.4	0.7	13.8	3.8	27.3	-1.0	14.4			4.4	19.1	-2.5	34.5	0.8	25.6	-2.1	16.1	0.2	49.4
NIM	-6.8	19.1	-3.7	14.7	-0.6	27.8	-5.4	15.3	-4.4	19.1			-6.9	34.9	-3.6	26.1	-6.5	16.9	-4.2	49.7
NMISA	0.1	34.5	3.2	32.3	6.3	40.0	1.5	32.6	2.5	34.5	6.9	34.9			3.3	38.8	0.4	33.4	2.7	57.4
NIMT	-3.2	25.6	-0.1	22.5	3.0	32.6	-1.8	22.9	-0.8	25.6	3.6	26.1	-3.3	38.8			-2.9	24.0	-0.6	52.5
NMIM	-0.3	16.1	2.8	10.6	5.9	25.8	1.1	11.3	2.1	16.1	6.5	16.9	-0.4	33.4	2.9	24.0			2.3	48.6
CMS/ITRI	-2.6	49.4	0.5	47.9	3.6	53.4	-1.2	48.1	-0.2	49.4	4.2	49.7	-2.7	57.4	0.6	52.5	-2.3	48.6		

5 A, 1 kHz																				
j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
i	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			0.2	13.7	11.3	26.4	-0.3	14.2	0.4	18.4	0.0	19.1	-13.5	30.9	0.3	25.6	-1.7	29.1	0.6	46.6
NMIA	-0.2	13.7			11.1	23.4	-0.5	7.1	0.2	13.7	-0.2	14.6	-13.7	28.3	0.1	22.4	-1.9	26.4	0.4	45.0
SCL	-11.3	26.4	-11.1	23.4			-11.6	23.7	-10.9	26.4	-11.3	26.9	-24.8	36.2	-11.0	31.8	-13.0	34.7	-10.7	50.4
NMIJ	0.3	14.2	0.5	7.1	11.6	23.7			0.7	14.2	0.3	15.1	-13.2	28.6	0.6	22.7	-1.4	26.6	0.9	45.1
KRISS	-0.4	18.4	-0.2	13.7	10.9	26.4	-0.7	14.2			-0.4	19.1	-13.9	30.9	-0.1	25.6	-2.1	29.1	0.2	46.6
NIM	0.0	19.1	0.2	14.6	11.3	26.9	-0.3	15.1	0.4	19.1			-13.5	31.3	0.3	26.1	-1.7	29.5	0.6	46.9
NMISA	13.5	30.9	13.7	28.3	24.8	36.2	13.2	28.6	13.9	30.9	13.5	31.3			13.8	35.6	11.8	38.2	14.1	52.8
NIMT	-0.3	25.6	-0.1	22.4	11.0	31.8	-0.6	22.7	0.1	25.6	-0.3	26.1	-13.8	35.6			-2.0	34.1	0.3	49.9
NMIM	1.7	29.1	1.9	26.4	13.0	34.7	1.4	26.6	2.1	29.1	1.7	29.5	-11.8	38.2	2.0	34.1			2.3	51.8
CMS/ITRI	-0.6	46.6	-0.4	45.0	10.7	50.4	-0.9	45.1	-0.2	46.6	-0.6	46.9	-14.1	52.8	-0.3	49.9	-2.3	51.8		

5 A, 10 kHz																				
j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
i	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			1.1	13.9	24.1	44.0	0.5	14.5	0.0	19.1	-4.9	19.8	0.0	29.1	6.1	25.6			-1.2	46.6
NMIA	-1.1	13.9			23.0	42.3	-0.6	8.1	-1.1	14.9	-6.0	15.8	-1.1	26.5	5.0	22.6			-2.3	45.0
SCL	-24.1	44.0	-23.0	42.3			-23.6	42.5	-24.1	44.3	-29.0	44.6	-24.1	49.4	-18.0	47.4			-25.3	61.3
NMIJ	-0.5	14.5	0.6	8.1	23.6	42.5			-0.5	15.4	-5.4	16.3	-0.5	26.8	5.6	22.9			-1.7	45.2
KRISS	0.0	19.1	1.1	14.9	24.1	44.3	0.5	15.4			-4.9	20.5	0.0	29.5	6.1	26.1			-1.2	46.8
NIM	4.9	19.8	6.0	15.8	29.0	44.6	5.4	16.3	4.9	20.5			4.9	30.0	11.0	26.6			3.7	47.1
NMISA	0.0	29.1	1.1	26.5	24.1	49.4	0.5	26.8	0.0	29.5	-4.9	30.0			6.1	34.1			-1.2	51.7
NIMT	-6.1	25.6	-5.0	22.6	18.0	47.4	-5.6	22.9	-6.1	26.1	-11.0	26.6	-6.1	34.1					-7.3	49.8
NMIM																				
CMS/ITRI	1.2	46.6	2.3	45.0	25.3	61.3	1.7	45.2	1.2	46.8	-3.7	47.1	1.2	51.7	7.3	49.8				

5 A, 20 kHz

i \ j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			2.0	14.0			-2.4	15.1			-10.3	22.2	-3.8	66.3	9.2	25.6			-5.1	58.7
NMIA	-2.0	14.0					-4.4	9.3			-12.3	18.8	-5.8	65.2	7.2	22.6			-7.1	57.4
SCL																			-4.3	57.2
NMIJ	2.4	15.1	4.4	9.3							-7.9	19.5	-1.4	65.4	11.6	23.3			-2.7	57.7
KRISS																			-4.3	57.2
NIM	10.3	22.2	12.3	18.8			7.9	19.5					6.5	67.4	19.5	28.4			5.2	60.0
NMISA	3.8	66.3	5.8	65.2			1.4	65.4			-6.5	67.4			13.0	68.6			-1.3	86.6
NIMT	-9.2	25.6	-7.2	22.6			-11.6	23.3			-19.5	28.4	-13.0	68.6					-14.3	61.3
NMIM																			-4.3	57.2
CMS/ITRI	5.1	58.7	7.1	57.4			2.7	57.7			-5.2	60.0	1.3	86.6	14.3	61.3				

5 A, 50 kHz

i \ j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			5.8	14.8			-0.3	17.7			-13.7	28.2	-20.6	105.8	9.9	36.4			-12.6	73.8
NMIA	-5.8	14.8					-6.1	13.9			-19.5	26.0	-26.4	105.2	4.1	34.7			-18.4	72.9
SCL																				
NMIJ	0.3	17.7	6.1	13.9							-13.4	27.7	-20.3	105.7	10.2	36.1			-12.3	73.6
KRISS																				
NIM	13.7	28.2	19.5	26.0			13.4	27.7					-6.9	107.9	23.6	42.2			1.1	76.8
NMISA	20.6	105.8	26.4	105.2			20.3	105.7			6.9	107.9			30.5	110.4			8.0	127.7
NIMT	-9.9	36.4	-4.1	34.7			-10.2	36.1			-23.6	42.2	-30.5	110.4					-22.5	80.2
NMIM																				
CMS/ITRI	12.6	73.8	18.4	72.9			12.3	73.6			-1.1	76.8	-8.0	127.7	22.5	80.2				

5 A, 100 kHz

i \ j	NMC		NMIA		SCL		NMIJ		KRISS		NIM		NMISA		NIMT		NMIM		CMS/ITRI	
	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
NMC			12.6	25.9			2.3	29.2			-21.5	37.8	-12.0	205.3	-7.4	51.4			-33.3	99.3
NMIA	-12.6	25.9					-10.3	21.6			-34.1	32.3	-24.6	204.4	-20.0	47.5			-45.9	97.3
SCL																				
NMIJ	-2.3	29.2	10.3	21.6							-23.8	35.0	-14.3	204.8	-9.7	49.4			-35.6	98.3
KRISS																				
NIM	21.5	37.8	34.1	32.3			23.8	35.0					9.5	206.2	14.1	54.9			-11.8	101.2
NMISA	12.0	205.3	24.6	204.4			14.3	204.8			-9.5	206.2			4.6	209.1			-21.3	225.7
NIMT	7.4	51.4	20.0	47.5			9.7	49.4			-14.1	54.9	-4.6	209.1					-25.9	107.0
NMIM																				
CMS/ITRI	33.3	99.3	45.9	97.3			35.6	98.3			11.8	101.2	21.3	225.7	25.9	107.0				

10.3 Comparison Protocol

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

Technical Protocol

Pilot Laboratory: National Metrology Centre, A*STAR, Singapore

1 Introduction and Scope

The CCEM-K12 comparison of ac-dc current transfer standards was conducted during 2005 to 2007 with three APMP participants, NMIA (AU, pilot), VNIIM (RU) and NMC (SG). APMP TCEM decided to conduct a follow-up APMP comparison to link more APMP members to the CCEM key comparison, and agreed that NMC would be the pilot laboratory of this comparison. A support group was formed consisting of members from NMIA (AU), SML (NZ) and NMIJ (JP).

The comparison scope will be the same as CCEM-K12:

Current: 10 mA and 5 A
Frequency: 10 Hz, 55 Hz, 1 kHz and 10 kHz
(Optional: 20 kHz, 50 kHz and 100 kHz)

2 Definition of the Measurand

Ac-dc current transfer difference is 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 are expressed in microamperes per ampere (μA/A). A positive sign signifies that more ac than dc current is required for the same output response.

3 The Travelling Standards

- **10 mA**

The travelling standard for the current of 10 mA is a Planar MultiJunction Thermal Converter (PMJTC), Serial number 32/2009, manufactured by IPHT, Germany. It has the following nominal parameters:

Rated Input Current:	10 mA
Heater Resistance:	90 Ω
Thermocouple Resistance:	6.64 kΩ
Output Voltage at Rated Current:	90 mV

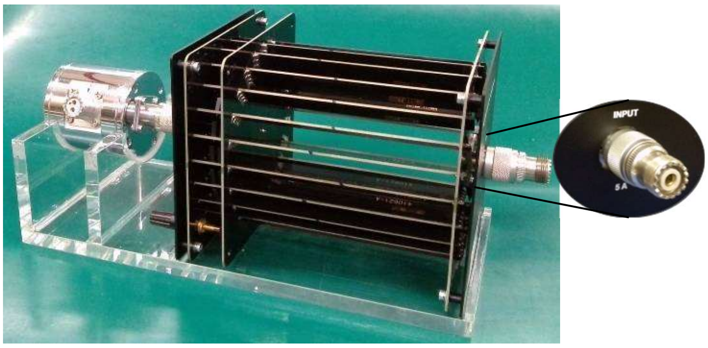
The thermal converter has a type-N female input connector and a UHF Twin female output connector, see Figure 1 a).

- **5 A**

The travelling standard for the current of 5 A comprises a Fluke A40B-5A precision current shunt, Serial number 163962344, and the above PMJTC for 10 mA. The current shunt has the following nominal parameters:

Nominal Resistance:	0.16 Ω
Nominal output voltage at 5A:	0.8 V
Power coefficient of resistance:	< 0.5 $\mu\Omega/\Omega/W$

It has type-N female connectors at both its input and output. For the current comparison, a type-N male-to-male adaptor is attached to the shunt's output for connecting with the PMJTC, and a UHF female-to-type-N male connector is attached to its input. A Perspex fixture is provided for easily assembling of the 5 A travelling standard. When assembled correctly the travelling standard can be positioned firmly on a flat surface, see Figure 1 b).



a) b)

Figure A1 Travelling standards: a) PMJTC for 10 mA (Type-N female for input and UHF twin female for output); b) Assembly of a current shunt and the PMJTC for 5 A (UHF female for input and UHF twin female for output).

4 Participating Laboratories and Organization

The following 12 laboratories will be participating the comparison.

NIMT National Institute of Metrology, Thailand
Contact: Mr Chalit Kumtawee, chalit@nimt.or.th
NIM National Institute of Metrology
Contact: Mr Zhang Jiangtao, Zhangjt@nim.ac.cn
NMIJ National Metrology Institute, Japan
Contact: Dr Hiroyuki Fujiki, h-fujiki@aist.go.jp
KRISS Korea Research Inst of Standards and Science, Rep of Korea
Contact: Hyung-Kew Lee, hyungkew.lee@kriss.re.kr
SCL Standards and Calibration Laboratory, Hong Kong, China
Contact: Dr Steven Yang, steven.yang@itc.gov.hk
NMIA National Measurement Institute, Australia
Contact: Thomas Hagen, thomas.hagen@measurement.gov.au
MSL Measurement Standards Laboratory, New Zealand
Contact: Mr Murray Early, murray.early@callaghaninnovation.govt.nz
NMISA National Metrology institute of South Africa, South Africa
Contact: Dr Eugene Golovins , egolovins@nmisa.org
NML-SIRIM National Metrology Laboratory, Malaysia
Contact: Dr. Mohd Nasir Zainal Abidin, drnasir@sirim.my
VMI VietNam Metrology Institute, Viet Nam
Contact: Mr. Nguyen Anh Son, sonna@vmi.gov.vn
CMS/ITRI Center for Measurement Standards / ITRI, Chinese Taipei
Contact: Hsiu-Ju Tsai, sarahtsai@itri.org.tw

NMC National Metrology Centre, A*STAR Singapore
Contact: Dr Jing Tao, jing_tao@nmc.a-star.edu.sg

The pilot laboratory is the NMC.

The support group consists of

- Dr Ilya Budovsky, NMIA
- Mr Murray Early, MSL, and
- Dr Hiroyuki Fujiki, NMIJ.

Each participating laboratory covers the costs of the measurement, transportations 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. The pilot laboratory has no insurance for any loss or damage of the travelling standard.

5 Time Schedule

As the comparison has to be finished within a reasonable period of time and the participant group is relatively big, six weeks will be allowed for each laboratory. This includes the time of customs clearance, transportation, unpacking, preparation and carrying out measurements, packing and shipping to the next laboratory.

The travelling standards will be dispatched from NMC on 20 January 2014, and will return after the completion of each of the two loops for evaluations. The schedule for this comparison is shown in Table . It may be adjusted prior and during the implementation due to unforeseen circumstances.

The longest measurement time in a laboratory is limited as four weeks. If a laboratory could not carry out its measurement within the agreed time period, it should contact the pilot laboratory and ship the travelling standards without delay to the next participant.

Table A1 Schedule for the APMP.EM-k12 Comparison of AC-DC current transfer standards

Date	*Laboratory*
20 Feb 2014	**NMC**
20 Feb 2014 − 3 Apr 2014	NMIA
3 Apr 2014 − 15 May 2014	SCL
15 May 2014 – 26 Jun 2014	NMIJ
26 Jun 2014 − 7 Aug 2014	KRISS
7 Aug 2014 − 18 Sep 2014	NIM
18 Sep 2014 – 30 Oct 2014	**NMC**
30 Oct 2014 – 11 Dec 2014	MSL
11 Dec 2014 − 22 Jan 2015	NMISA
22 Jan 2015 – 5 Mar 2015	NIMT
5 Mar 2015 − 16 Apr 2015	NML-SIRIM
16 Apr 2015 – 28 May 2015	VMI
28 May 2015 – 9 Jun 2015	CMS/ITRI
9 Jun 2015	**NMC**

6 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 standards. Do not use a forwarding agent that does not guarantee an adequate delivery time, inclusive of the time for customs procedure.
- The case of the transfer standards will be transported with an ATA Carnet and a accompanying letter, as shown in 0, for customs clearance. Please take special care to ensure that the carnet always stays with the package.
- On receipt of the case, unpack the devices carefully and check for any damage. The list of contents of the packing case (0) 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. Ensure that the carnet is packed outside the case for easy access by Customs and ensure that the carnet is stamped by Customs on exit from your

country. Prepare the transport to the next participant beforehand so that the travelling standard can be sent immediately after the measurements in your laboratory are completed.

- Please inform the pilot laboratory and the sender of the arrival of the package by e-mail or fax. Please inform the pilot laboratory and the next participant of the details when sending the package to the next participant by e-mail or fax. A relevant fax form is enclosed in 0.

7 Measurement Conditions

a). The PMJTC is with delicate circuits and care needs to be taken to avoid any mechanical shocks.

b). Upon receiving the package, check if there is any damage during transportation. Check input and output resistances of the PMJTC. Check that there is high resistance (>100 MΩ) between the input and output. Make sure **not to exceed** the nominal currents of the PMJTC (10mA, for both input and output). In case of any failure, inform the pilot laboratory immediately.

c). The ac-dc transfer differences of the travelling standards are to be measured at the “Lo” position, i.e. with both its input and output earthed. The connection to earth must remain at all times to avoid excessive voltage between its heater and thermocouples which easily damages the insulation.

d). Test the travelling standard at a few points to verify if there is any failure. In case of any damage or failure, inform the pilot laboratory immediately.

e). Connect the PMJTC (see Figure a)) to carry out 10 mA measurements. According to Figure b) to assemble it with the shunt for 5 A measurements.

f). Care should be taken not to apply current above nominal values, which may destroy the travelling standards.

g). Recommended ambient conditions are 23±1°C in temperature and 50±5% in relative humidity.

h). At least 30 minutes should be allowed for stabilisation after the first application of current.

i). The measurement frequency should be within 1 % of its nominal value. The frequency and its uncertainty must be reported.

j). Sufficient delay time should be used between successive applications of alternating and direct currents.

8 Measuring Scheme

The ac-dc difference at 10 mA (PMJTC) and 5 A (Shunt + PMJTC) should be measured at the following frequencies:

- Mandatory: 10 Hz, 55 Hz, 1 kHz, and 10 kHz
- Optional: 20 kHz, 50 kHz, and 100 kHz.

9 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 set-up,
- level dependence, e.g. due to dc-effects,
- connectors,
- temperature,
- measurement frequency, and
- reproducibility.

10 Report of the Comparison

Each participant is to submit a report within one month after completing 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*.

The participants are also asked to report separately a summary of the measurement results, see 0 and 0. Both the report and the summary are to be sent 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.

11 Comparison Coordinator

Any questions related to the comparison should be directed the Comparison Coordinator:

Dr T Jing
National Metrology Centre, 1 Science Park Drive, Singapore 118221
Phone: (+65) 6279 1911, Fax: (+65) 6279 1995
Email: jing_tao@nmc.a-star.edu.sg

* 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.

Attachment 1: Letter with ATA Carnet

To whom it may concern

These devices are intended for an international comparison of the national measurement standards of Singapore, Thailand, China, Japan, Rep of Korea, Hong Kong (China), Australia, New Zealand, South Africa, Malaysia and Viet Nam.

These devices are the properties of the NMC, Singapore, and are to be returned to NMC after the completion of this program.

The national agencies involved are:

Singapore National Metrology Centre (NMC) 1 Science Park Drive, Singapore 118221 Contact: Dr Jing Tao Tel +65.62791911, Fax: +65.62791995, E-mail: jing_tao@nmc.a-star.edu.sg
Australia National Measurement Institute Bradfield Rd, West Lindfield NSW 2070 Contact: Thomas Hagen Tel: +61(2)8467 3542, Fax: +61(2)8467 3783, Email: thomas.hagen@measurement.gov.au
Hong Kong, China Standards and Calibration Laboratory 36/F., Immigration Tower, 7 Gloucester Road, Wanchai Contact: Dr Steven Yang Tel: +852.2829 4855, Fax: +852.2824 1302, Email: steven.yang@itc.gov.hk
Japan National Metrology Institute AIST Tsukuba Central 3-1 1-1-1 Umezono, Tsukuba-shi Ibaraki 305-8563 Contact: Dr Hiroyuki Fujiki Tel +81(29)861 5543, Fax +81(29)861 3469, Email: h-fujiki@aist.go.jp
Rep of Korea Korea Research Inst of Standards and Science, 267 Gajeong-ro, Yuseong-gu, Daejeon, 305-040 Contact: Dr Hyung-Kew Lee Tel: +82 (42)8685165, Fax: +82(42)8685018, Email: hyungkew.lee@kriss.re.kr
China National Institute of Metrology (NIM) No.18, Bei San Huan Dong Lu, Beijing 100013 Contact: Dr Zhang Jiangtao Tel: +86.10 64524514, Fax: +86.10 64218629, E-mail: Zhangjt@nim.ac.cn
New Zealand Measurement Standards Laboratory 69 Gracefield Rd, Lower Hutt 5040 Contact: Dr Murray Early Tel: +64 (4) 9313192, Fax: +64 (4) 9313190, Email: murray.early@callaghaninnovation.govt.nz
South Africa National Metrology institute of South Africa Building 5, Meiring Naude Rd, Brummeria, Pretoria Contact: Dr Eugene Golovins Tel: +27.722572246, Fax: +27.867752271, Email: egolovins@nmisa.org
Thailand National Institute of Metrology (NIMT) 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120 Contact: Mr Chalit Kumtawee Tel: +66.25775100 -1234, Fax: +66.25773658, E-mail: chalit@nimt.or.th
Malaysia National Metrology Laboratory, SIRIM Pt 4803, Bandar Baru Salak Tinggi, 43900 Sepang Selangor Contact: Dr. Mohd Nasir Zainal Abidin Tel: +603.8778 1647, Fax: +603.8778 1661, Email: drnasir@sirim.my
Viet Nam Vietnam Metrology Institute No. 8 Hoang Quoc Viet Road, Cau Giay Dist., Ha Noi Contact: Mr. Nguyen Anh Son

Tel: +84(4) 38361134, Fax: +84(4) 37564260, E-mail: sonna@vmi.gov.vn
Chinese Taipei Center for Measurement Standards / Industrial Technology Research Institute Bldg 16, 321, Sec. 2, Kuang Fu Rd., Hsinchu, 30011, Taiwan Contact: Hsiu-Ju Tsai Tel: +886 3 5732104, Fax: +886 3 5732292, Email: sarahtsai@itri.org.tw

Attachment 2: Packing List

APMP.EM-K12 Comparison of AC-DC Current Transfer Standards

Item	*Value (US$)*	*Dimensions (mm)*
IPHT-PTB Planar Multi-Junction Thermal Converter	1,171.00	ϕ 60 × 60
(PMJTC), S/N 32/2009		
Fluke A40B-5A precision current shunt, S/N		
163962344	4,450.00	L170 × W130 × H130
Support for 5A assembly		
N-type male to UHF female adopter (Attached to	119.00	L280 × W130 × H70
shunt "in")	51.00	
N-type mal e to N-type male adopter (attached to shunt		
"out")	25.00	
Technical Protocol		
Total Value	**5,816.00**	

All items are to be transported in the custom carry case supplied.
The dimensions of the carry case are 530mm× 440mm× 220mm. The total weight of the package is around 8 kg.

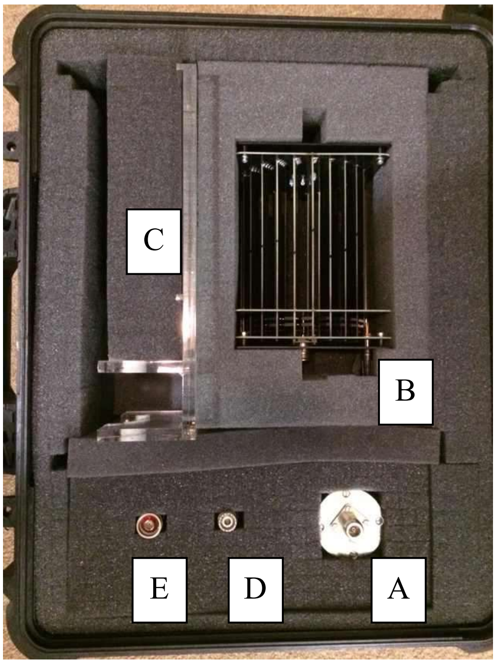


Figure A2 Parkage assembly

(See above table for item's letters.)

Attachment 3: Forms for Notifying Receipt and Shipment of Artefact

APMP.EM-K12 Comparison of AC-DC Current Transfer Standards

ARTEFACTS RECEIVED

To: (both 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: (both 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)

Attachment 4: Summary of Results

APMP.EM-K12 Comparison of AC-DC Current Transfer Standards

(Please send this information by e-mail to the pilot laboratory)

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							
5A							

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							
5A							

Frequency Measurement:

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 (%)			

Attachment 5: Summary of Uncertainty Budget

APMP.EM-K12 Comparison of AC-DC Current Transfer Standards

(Please send this information by e-mail to the pilot laboratory)

Institute:

Date:

Remarks:

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		

Combined uncertainty							
Expanded uncrtaitny							

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		

Combined uncertaitny							
Expanded uncertaitny							