SIM Comparison of AC-DC Current Transfer Difference, SIM.EM-K12

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ABSTRACT — **A key comparison of the AC-DC current transfer difference has been carried out by the Inter-American Metrology System (SIM) Regional Metrology Organization (RMO). Its purpose was to establish an equivalence of AC-DC current transfer difference at 10 mA and 5 A between the national metrology institutes (NMIs), in support of the International Committee for Weights and Measures (CIPM) Mutual Recognition Agreement (MRA). The comparison artifact was a Planar Multijunction Thermal Converter (PMJTC) at 10 mA and a 5 A shunt at 5 A measurements. Six SIM NMIs participated in the comparison as well as NIS, National Institute of Standard of Egypt.**

Results linking the SIM.EM-K12 to CCEM-K12 show agreement of SIM NMIs to other RMOs.

Index Terms **— Measurement, measurement standards, measurement techniques, AC-DC, current transfer difference, measurement uncertainty, precision measurements, uncertainty.**

I. INTRODUCTION

In the Inter-American Metrology System (SIM) there are several National Metrology Institutes (NMIs). From them only three participated in the CCEM key Comparisons of the ac-dc current transfer difference CCEM-K12. In accordance with the CIPM-MRA objectives, the NMIs establish an equivalence between their national measurement standards by performing regional comparisons.

The SIM.EM-K12 comparison was proposed to assess the measurement capabilities of the remaining SIM NMIs, in the ac-dc current transfer difference. The test points were selected to facilitate link of the results of this comparison with the equivalent CCEM K12 Key Comparison, through the three NMIs participating in both. INTI, Argentina provided the travelling standard, and piloted and coordinated the comparison. It was agreed that the comparison reference values were to be based on the results provided by the participating laboratories with participation in the CCEM-K12 key comparison.

II. TRAVELING STANDARD, MEASUREMENT POINTS AND PARTICIPANTS

The travelling standard for current of 10 mA was a Planar Multijunction Thermal Converter (PMJTC), identified as "PMJTC-90-2". The travelling standard for current of 5 A comprises the same 10 mA/1V PNJTC as well as a 0.2 Ω coaxial shunt, identified as "SHUNT 5 A".

The ac-dc difference of each travelling standard was to be measured at its nominal current and the following frequencies: 10 Hz, 55 Hz, 1 kHz, 10 kHz, 20 kHz, 50 kHz and 100 kHz.

The traveling standards were measured at INTI at the beginning and the end of the comparison schedule. The traveling standards travelled regionally between participant laboratories, with two intermediate stops at INTI.

Table I shows the participants of the comparison

Table I. SIM.EM-K12 Participants

Country	NMI
Argentina	INTI
Uruguay	UTE
Canada	NRC
USA	NIST
Mexico	CENAM
Brazil	INMETRO
Egypt	NIS

III. METHOD OF COMPUTATION OF THE CRV

The comparison reference values (CRV) for each of the measured 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 reference value was determined as:

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

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

The expanded uncertainty of the reference value was calculated,

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

IV. REPORTED RESULTS

The reported results for each participant at 10 mA and 5 A are shown in Tables II and III.

Table II. Reported results at 10 mA

	Measured AC-DC difference δ_i and expanded uncertainty U_i in μA/A													
	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	δ_i	U_i	δ_i	U_i	δ_i	U_i	δ_i	U_i	δ_i	U_i	δ_i	U_i	δ_i	U_i
INTI	8,0	6,0	0,6	4,0	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	4,0	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	4,0	-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	-1,0	5,5	-2,7	6,4	----	----	----	----	----	----
INTI	9,8	6,0	-0,2	4,0	-0,2	3,0	-0,1	3,0	-0,3	3,0	1,5	10,0	4,1	20,0

Table III. Reported results at 5 A

	Measured AC-DC difference δ_i and expanded uncertainty U_i in μA/A													
	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	δ_i	U_i	δ_i	U_i	δ_i	U_i	δ_i	U_i	δ_i	U_i	δ_i	U_i	δ_i	U_i
INTI	-4,8	8,0	0,0	5,0	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	5,0	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	16,0
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	5,0	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	5,0	1,1	5,0	-1,8	7,0	2,1	10,0	10,0	13,0	32,2	22,0

Table IV. DoE of all NMIs with respect to the CRV at 10 mA

	Degree of equivalence DoE and expanded uncertainty U_i at 10 mA in μA/A													
	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i
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

Table V. DoE of all NMIs with respect to the CRV at 5 A

	Degree of equivalence DoE and expanded uncertainty U at 10 mA in μA/A													
	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	D_i	U_i	D_i	U_i	D_i	U_i	D_i	U_i	D_i	U_i	D_i	U_i	D_i	U_i
INTI	-0,2	4,5	0,4	2,1	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	-0,8	13,2	-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	-0,6	2,1	0,7	2,1	-1,0	3,7	1,0	6,4	1,5	8,2	14,3	15,4
UTE	----	----	1,4	23,6	0,3	23,6	14,1	29,4	----	----	----	----	----	----
INMETRO	4,2	7,1	-0,1	7,8	-1,5	3,8	0,3	3,5	1,3	2,2	1,9	2,2	0,6	3,0
CENAM	----	----	-1,6	41,8	-1,7	35,7	17,1	39,6	----	----	----	----	----	----
NIST	4,6	17,8	-1,6	17,4	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	1,0	2,1	1,0	2,1	0,0	3,7	0,4	6,4	-1,5	8,2	9,9	15,4
NIS	----	----	0,0	16,2	18,3	16,7	288,1	19,1	----	----	----	----	----	----
INTI	-1,1	4,5	0,1	2,1	-0,6	2,1	-1,7	3,7	1,4	6,4	2,0	8,2	13,8	15,4

V. LINKAGE WITH CCEM-K12

INTI, NRC and NIST participated in the CCEM-K12 comparison. The results of statistically linking the other SIM.EM.K-12 participants to the CCEM-K12 participants were calculated based on approach described in [1] by using the measurement results from the linking laboratories. Tables VI and VII list the degree of equivalence (DoE) of the four other NMIs with respect to the CCEM-K12 [2] key comparison reference value (KCRV) and the corresponding expanded uncertainties of the DoE´s. Units are in tables.

Table VI. DoE of all NMIs with respect to the KCRV at 10 mA

	Degree of equivalence DoE with the KCRV and expanded uncertainty U_i at 10 mA in μA/A													
	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i
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
NIS	-5,6	3,8	-1,1	2,9	-1,1	5,6	-3,1	6,7	----	----	----	----	----	----

Table VII. DoE of all NMIs with respect to the KCRV at 5 A

	Degree of equivalence DoE with the KCRV and expanded uncertainty U_i at 5 A in μA/													
	10 Hz		55 Hz		1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i	DoE	U_i
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	----	----	----	----	----	----
NIS	----	----	0,4	18,6	15,8	18,5	288,8	22,0	----	----	----	----	----	----

VI. CONCLUSION

The AC-DC transfer differences of the travelling standards have been measured at 10 mA and 5 A at frequencies 10 Hz, 55 Hz, 1 kHz, 10 kHz, 20 kHz, 50 kHz and 100 kHz. The comparison reference values were calculated as the weighted mean of the results of the NMIs with independent realizations of their 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 will perform a bilateral comparison in these points at a later date.

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