SIM.EM-K6.1, SIM.EM-K9.1 COMPARISON REPORT

AC-DC VOLTAGE TRANSFER DIFFERENCE

Bilateral INMETRO-LNE

FINAL REPORT

Renata de BARROS e VASCONCELLOS, Andre POLETAEFF

SIM Bilateral INMETRO-LNE AC-DC Voltage Transfer Difference Comparison Report, Final Report

2012-2013

1 Introduction

The objective of this comparison is to compare the measurement capabilities of INMETRO and LNE in the field of AC-DC Voltage Transfer. INMETRO participated in the previous SIM comparison of AC/DC voltage transfer standards in 2004. In the last few years INMETRO has been improving the methodology of its AC-DC Voltage Transfer difference measurements, now using multijunction thermal converters. This comparison is aimed to validate the new INMETRO calibration method and to support new uncertainties that INMETRO will report to SIM for their inclusion in the CIPM MRA KCDB.

SIM.EM-K6.1 is an intercomparison of 1.5 V at 10 Hz, 1 kHz, 20 kHz, 50 kHz, 100 kHz, and 1 MHz.
SIM.EM-K9.1 is an intercomparison of 1000 V at 10 Hz, 1 kHz, 20 kHz, 50 kHz, and 100 kHz.

2 Definition of the Measurand

The ac-dc voltage transfer difference, δ, of a transfer standard is defined as:

$$\delta = (V_{ac} - V_{dc}) / V_{dc}. \qquad (1)$$

where:

- V_{ac} is the rms value of the ac input voltage.
- V_{dc} is the dc input voltage which when reversed produces the same mean output voltage of the transfer standard as V_{ac}.

3 Traveling Standards

The travelling standard for 1.5 V voltage measurements is a Planar Multijunction Thermal Converter, with a nominal heater resistance of 180 ohms, identified as 180-3 1.5 V, serial number 299 - 2001, manufactured by IPHT Jena (Figure 1).

It has the following nominal parameters:

Rated Input Voltage: 1.5 V
Heater Resistance: 224 Ω
Thermocouple Resistance: 10.5 kΩ
Output Voltage at Rated Voltage: 86 mV
The Thermal Converter has an N-Female-type input connector and a type UHF-Twin output connector.

Figure 1. PMJTC 180-3 1.5 V

The travelling standard for 1000 V voltage measurements are a Planar Multijunction Thermal Converter, of nominally 400 ohms, identified as 400-2 1000 V, serial number 294 - 2001, manufactured by IPHT Jena, and a Resistor, model 792 A-7002, serial number 1230030, manufactured by Fluke (Figure 2).

They have the following nominal parameters:

Thermal Converter, 400-2

Rated Input Voltage: 2.4 V
Heater Resistance: 490 Ω
Thermocouple Resistance: 12 kΩ
Output Voltage at Rated Voltage: 107 mV
The Thermal Converter has an N-Female-type input connector and a type UHF-Twin output connector.

Resistor, 1000 V

Nominal Resistance: 200 kΩ
Input Connector N-female
Output Connector N-male

Figure 2. PMJTC 400-2 with resistor 1000V

4 Method of computation of the Key Comparison Reference Values

LNE values are used to determine the Key Comparison Reference Values (KCRV).

$$X_{KCDB} = \text{LNE value}$$

The results from SIM.EM-K6.1 and SIM.EM-K9.1 intercomparisons are linked to the CCEM through the LNE differences from the CCEM-K6.a and CCEM-K9 intercomparisons reference values. There is no link for results at 10 Hz and 50 kHz for the SIM.EM-K6.1 comparison and at 10 Hz for the SIM.EM-K9.1 comparison.

5 Organization

The National Institute of Metrology, Quality and Technology (INMETRO) is the pilot laboratory. The circulation of traveling standards began at INMETRO, where they were calibrated using the new INMETRO AC-DC voltage difference calibration system, against a reference multijunction thermal converter. The standards were hand-carried to LNE, where they were also calibrated. The standards then returned to INMETRO, also by hand-carrier. Finally, the standards were recalibrated at INMETRO, and the results from both laboratories were compared.

5.1 Coordinator and members of the review committee

Renata de Barros e Vasconcellos: rbvasconcellos@inmetro.gov.br
Renato Afonso Jr.: rajunior@inmetro.gov.br
Andre Poletaeff: andre.poletaeff@lne.fr

5.2 Participants

INMETRO (Brazil)
LNE (France)

5.3 Time Schedule

The standards were measured at INMETRO from 14th September to 22nd November 2012 and from 5th December to 22nd January 2013.
The standards were measured at LNE from 26th to 30th November 2012.

6 Measurements points

Table I. AC-DC Voltage transfer difference measurement points

Test No.	Test Voltage	Test frequency
1	1.5 V	10 Hz
2	1.5 V	1 kHz
3	1.5 V	20 kHz
4	1.5 V	50 kHz
5	1.5 V	100 kHz
6	1.5 V	1 MHz
7	1000 V	10 Hz
8	1000 V	1 kHz
9	1000 V	20 kHz
16	1000 V	50 kHz
17	1000 V	100 kHz

7 Method of measurements

7.1 INMETRO method

Two separate calibrators (Fluke 5720A) deliver an ac and a dc voltage. An ac-dc switch made by METAS connects the parallel combination of the DUT and an INMETRO standard alternatively to the ac source or the dc source. Two nano-voltmeters (Keithley 182) measure the output voltage of the PMJTCs.
The ac, dc+, ac, dc-, ac sequence was used for each measurement. The delay time was 60 s. Before each voltage measurement the system was stabilized for 30 minutes then 12 sequential measurements were done with the voltage applied. The sources and the meters are GPIB (IEEE-488) controlled.

7.1.1 Statement of Traceability

The basic standard for ac-dc voltage transfer is a 1.5 V Planar Multijunction Thermal Converter (PMJTC) traceable to PTB. To build up the voltage scale from 1.5 V to 1000 V, different voltage standards have to be calibrated against each other, using the step-up procedure.

7.2 LNE method

The diagram of the set-up used at LNE is given in Figure 3.

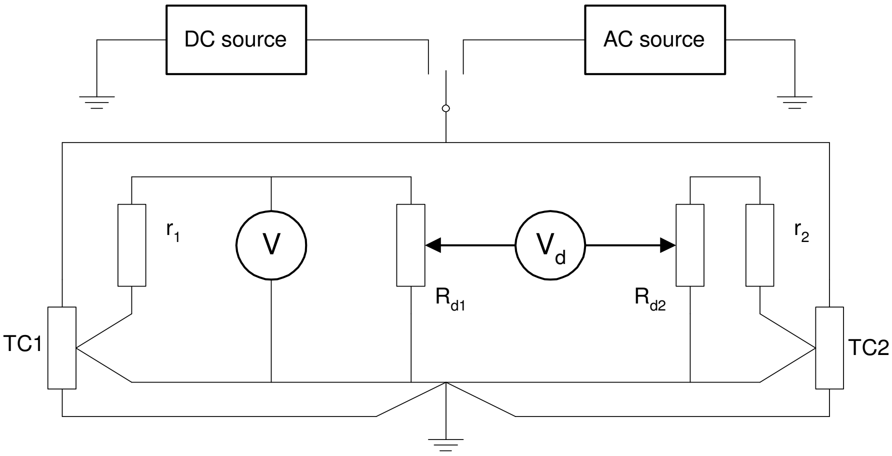

Figure 3 : Block diagram of the LNE set-up.

The reference converter (TC1) and the unit under test (TC2) are connected in parallel and their outputs are loaded by resistive dividers. Voltages delivered by an AC and a DC sources are successively applied through an AC-DC switch to the input of the converters. A nano-voltmeter noted V measures the output of the reference converter and an other nano-voltmeter noted V_d measures the “differential” voltage between the outputs of the dividers. The ratio of divider R_{d2} allows voltage V_d to remain close to zero even if the output voltage of TC2 is significantly higher than the output of TC1. The ratio of divider RD1 is determined to minimize the influence of possible slight variation of the input voltage of the converters on the differential voltage.
The sequence AC, DC+, DC-, AC, DC+, DC-, AC, DC+, DC-, AC is applied to the input of the converters. These successive voltages are applied at regular time intervals and voltages V and V_d are measured each time. The difference between the AC-DC transfer differences of both converters is computed from this set of data. A more detailed description of the system is given in [1].

8 Measurement results

The measurement results for SIM.EM-K6.1 are shown in subsection 8.1, and the results for SIM.EM-K9.1 are shown in subsection 8.2.

8.1 Measurement performed at 1.5 V

Results linked to the CCEM-K6.a comparison are reported in table II, those without any link to CCEM comparisons are given in table III. All results are summarized in a graphical form in Figures 4 to 9.

Table II. AC-DC difference of the traveling standard measured by INMETRO and LNE with a link to the CCEM-K6a comparison at 1.5 V

1.5 V	Measured ac-dc voltage difference (μV/V)								
Laboratory	Date	1 kHz		20 kHz		100 kHz		1 MHz	
		δ	U	δ	U	δ	U	δ	U
INMETRO	set-2012	0.1	2.2	0.9	2.2	1.0	5.1	-18.3	12.1
INMETRO	out-2012	0.0	2.2	0.6	2.2	0.7	5.1	-17.4	12.1
INMETRO	nov-2012	0.1	2.2	0.8	2.2	0.9	5.1	-15.6	12.1
INMETRO	nov-2012	0.1	2.2	0.5	2.2	0.9	5.1	-15.3	12.1
LNE (CCEM-K6a)	nov-2012	0.1	1.5	0.1	2.5	1.7	5	-6	42
INMETRO	dez-2012	-0.2	2.2	0.7	2.2	0.7	5.1	-16.5	12.1
INMETRO	jan-2013	0.0	2.2	0.7	2.2	0.9	5.1	-12.8	12.1

Table III. AC-DC difference of the traveling standard measured by INMETRO and LNE at 1.5 V

1.5 V	Measured ac-dc voltage difference (μV/V)				
Laboratory	Date	10 Hz		50 kHz	
		δ	U	δ	U
INMETRO	set-2012	3.7	3.4	1.3	2.2
INMETRO	out-2012	3.7	3.4	1.3	2.2
INMETRO	nov-2012	3.8	3.4	0.9	2.2
INMETRO	nov-2012	3.5	3.4	1.1	2.2
LNE	nov-2012	-0.3	5.4	1.2	3.8
INMETRO	dez-2012	3.7	3.4	1.1	2.2
INMETRO	jan-2013	3.6	3.4	1.0	2.2

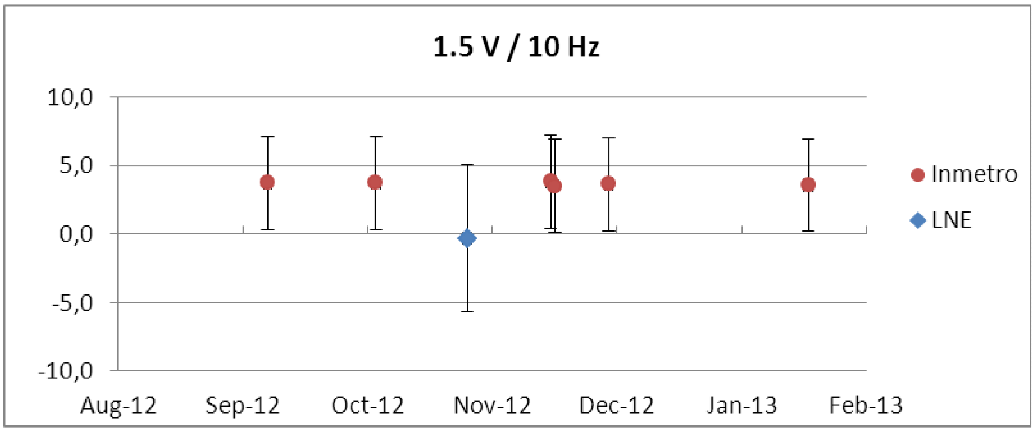

Figure 4. Results of measurement at 1.5 V 10 Hz

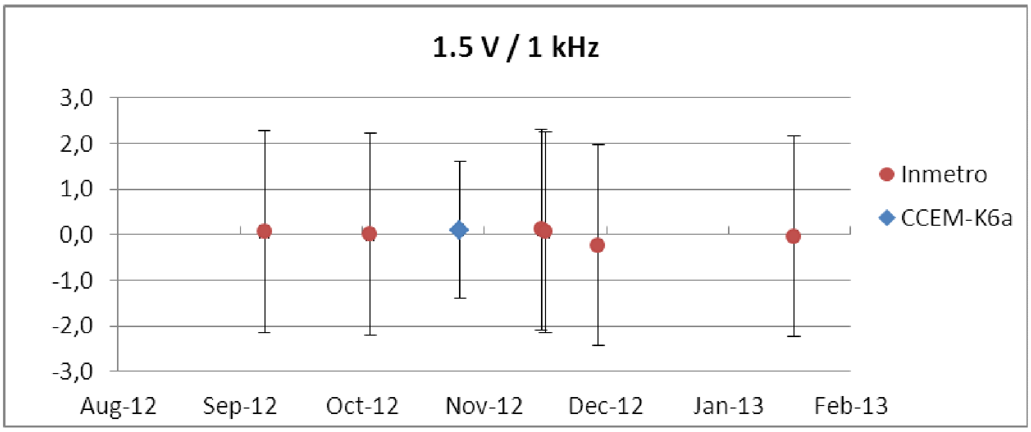

Figure 5. Results of measurement at 1.5 V 1 kHz

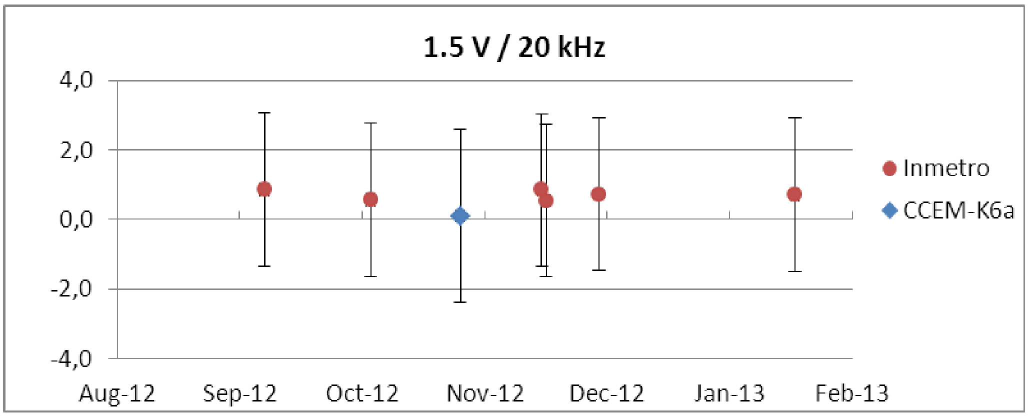

Figure 6. Results of measurement at 1.5 V 20 kHz

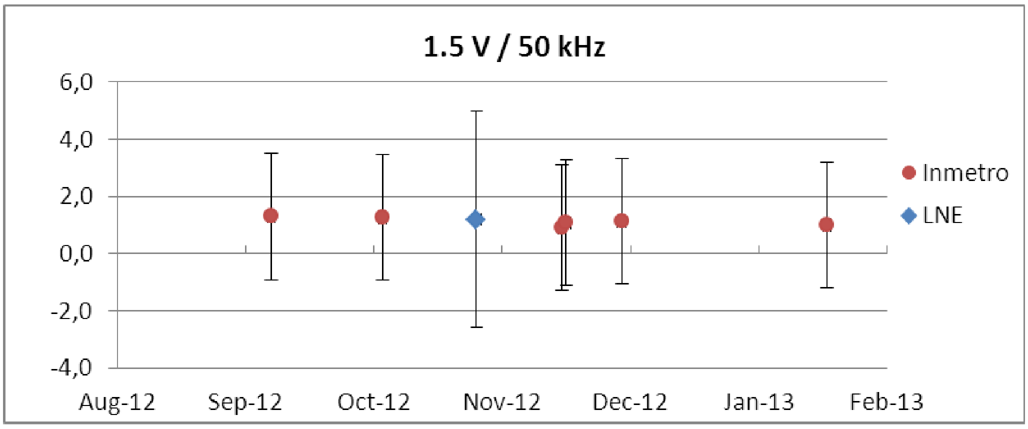

Figure 7. Results of measurement at 1.5 V 50 kHz

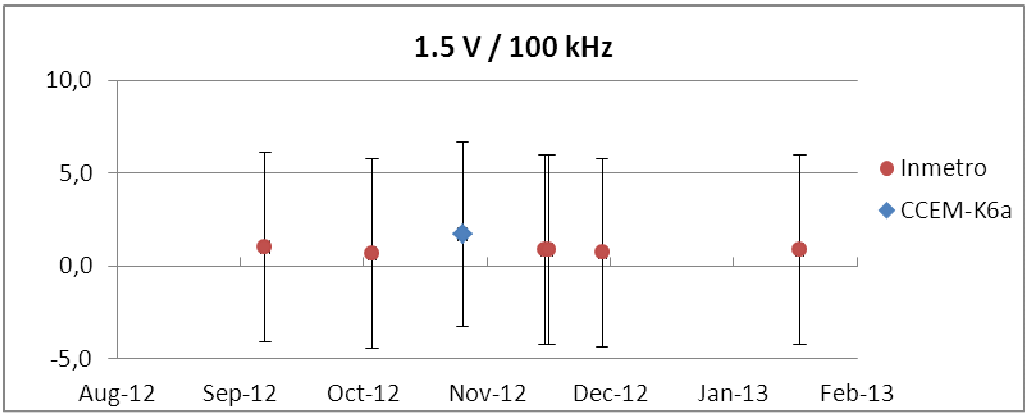

Figure 8. Results of measurement at 1.5 V 100 kHz

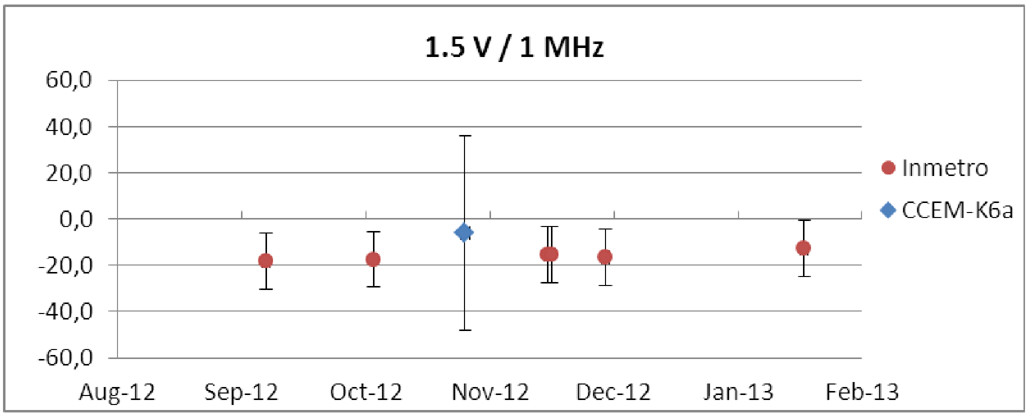

Figure. 9. Results of measurement at 1.5 V 1 MHz

8.2 Measurement performed at 1000 V

Results linked to the CCEM-K9 comparison are reported in table IV, those without any link to CCEM comparisons are given in table VI. All results are summarized under a graphical form in Figures 10 to 14.

Table IV. AC-DC difference of the traveling standard measured by INMETRO and LNE with a link to the CCEM-K9 comparison at 1000 V

1000 V	Measured ac-dc voltage difference (µV/V)								
Laboratory	Date	1 kHz		20 kHz		50 kHz		100 kHz	
		δ	U	δ	U	δ	U	δ	U
INMETRO	set-2012	1.1	12.4	-7.5	12.6	-45.8	15.6	-171.3	33.0
INMETRO	out-2012	0.6	12.4	-7.9	12.6	-47.6	15.6	-173.7	33.0
INMETRO	nov-2012	1.6	12.4	-8.8	12.6	-49.1	15.6	-177.1	33.0
LNE (CCEM-K9)	nov-2012	-2.6	16	-9.1	35	-50.2	69	-179.2	69
INMETRO	dez-2012	1.2	12.4	-9.3	12.6	-49.4	15.6	-177.0	33.0
INMETRO	dez-2012	0.5	12.4	-9.4	12.6	-49.1	15.6	-175.5	33.0

Table V. AC-DC difference of the traveling standard measured by INMETRO and LNE at 1000 V

1000 V	**Measured ac-dc voltage difference (μV/V)**		
Laboratory	**Date**	**10 Hz**	
		δ	**U**
INMETRO	set-2012	11.4	14.4
INMETRO	out-2012	11.3	14.4
LNE	nov-2012	-8.9	45
INMETRO	dez-2012	10.5	14.4
INMETRO	dez-2012	11.0	14.4

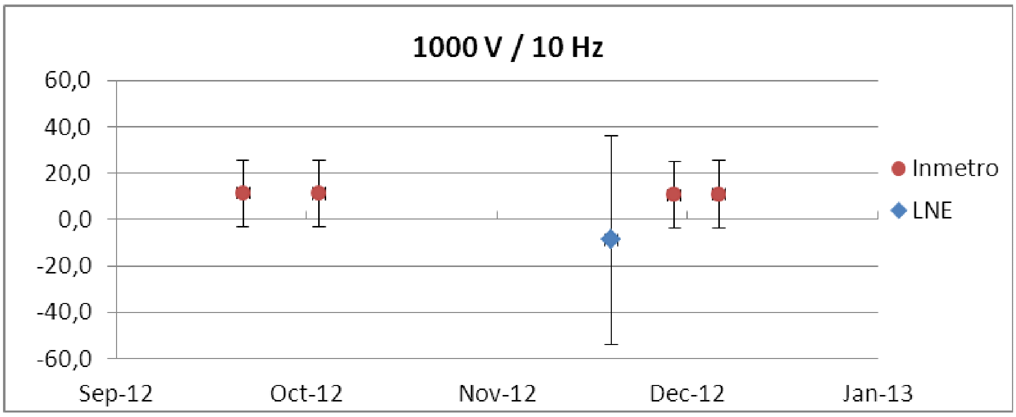

Figure 10. Results of measurement at 1000 V 10 Hz

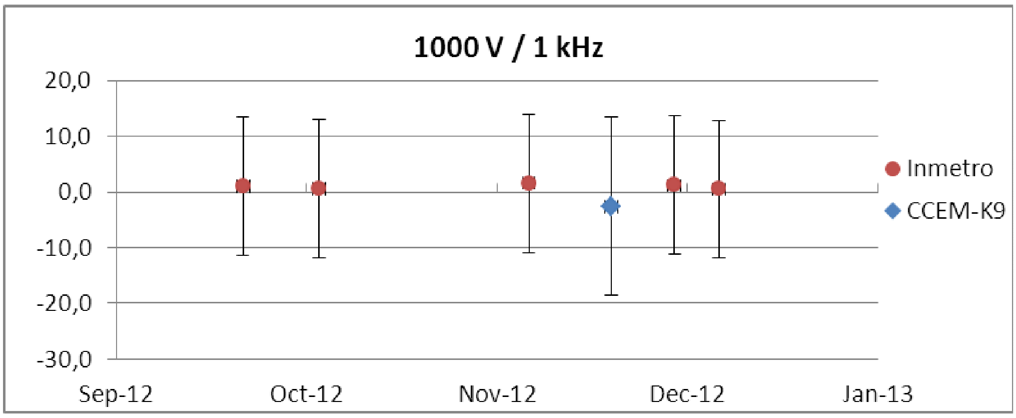

Figure 11. Results of measurement at 1000 V 1 kHz

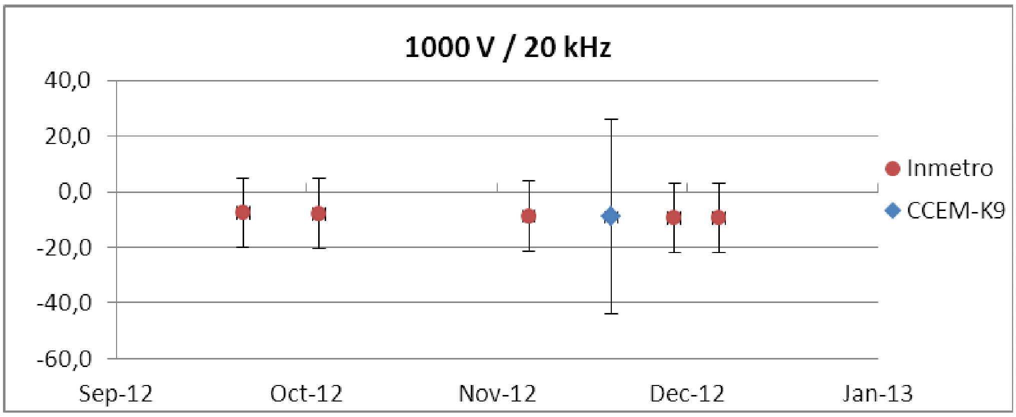

Figure 12. Results of measurement at 1000 V 20 kHz

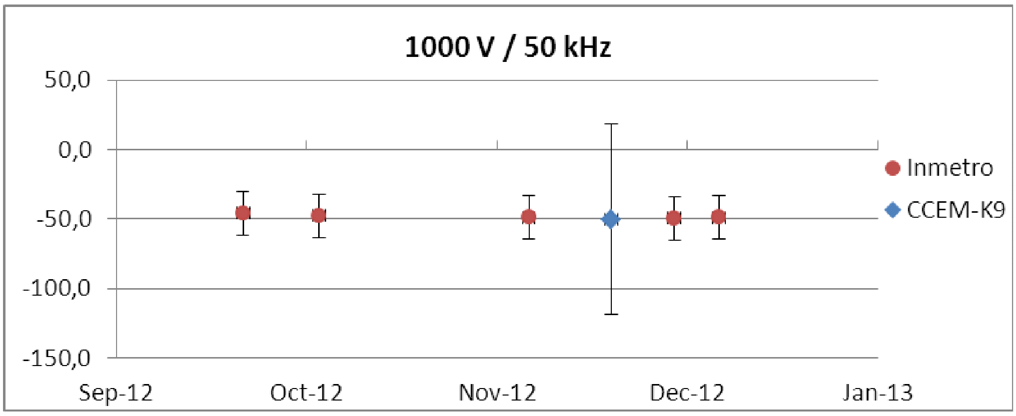

Figure 13. Results of measurement at 1000 V 50 kHz

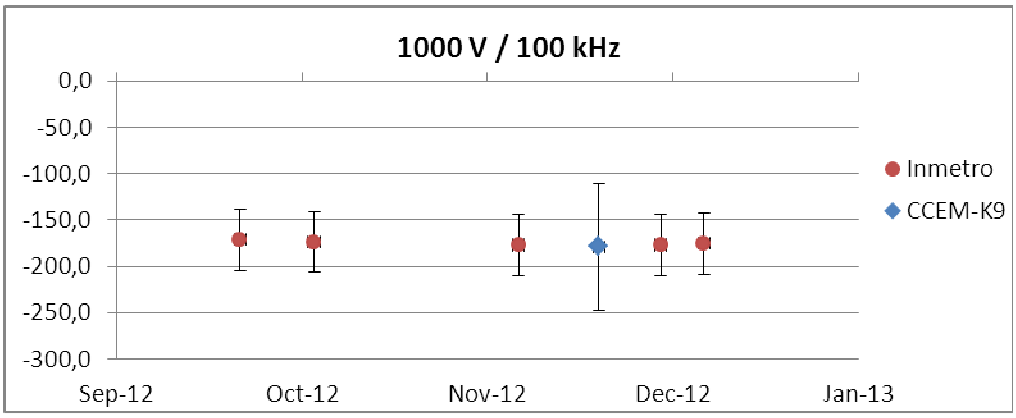

Figure 14. Results of measurement at 1000 V 100 kHz

9 Degrees of equivalence of INMETRO with the Key Comparison Reference Value (KCRV)

The KCRV value of SIM.EM-K6.1 or SIM.EM-K9.1 is the value of the traveling standard measured by LNE, on condition that the reference value of the LNE standard is linked to the CCEM-K6.a or CCEM-K9 comparison.

9.1 Linking the LNE standards to the CCEM comparisons

The degrees of equivalence $DE_{CCEM}[LNE]$ of LNE with KCRV of the CCEM comparisons are computed from :

$$DE_{CCEM}[LNE] = X_{CCEM}[LNE] - KCRV_{CCEM}$$

where $X_{CCEM}[LNE]$ represents the value of the CCEM comparison traveling standard measured by LNE which is given by :

$$X_{CCEM}[LNE] = REF[LNE] + Meas_{CCEM}[LNE]$$

where $REF[LNE]$ is the AC-DC transfer difference of the LNE standard obtained from the LNE calibration performed just before participating in the CCEM comparison and $Meas_{CCEM}[LNE]$ the difference measured by LNE between the traveling standard and the LNE standard. The LNE standard is considered linked to the CCEM comparison, if the value $REF_{CCEM}[LNE]$ that should have led to $DE_{CCEM}[LNE] = 0$ is assigned to its AC-DC transfer difference which leads to :

$$KCRV_{CCEM} = REF_{CCEM}[LNE] + Meas_{CCEM}[LNE]$$

and then to :

$$REF_{CCEM}[LNE] = KCRV_{CCEM} - Meas_{CCEM}[LNE]$$

The uncertainty associated with $REF_{CCEM}[LNE]$ is finally given by :

$$U(REF_{CCEM}[LNE]) = \left\{U^2(KCRV_{CCEM}) + U^2(Mes_{CCEM}[LNE]) + U^2(drift)\right\}^{1/2}$$

$U(drift)$ is an additional uncertainty component associated with an eventual drift of the LNE standard in the time interval between the CCEM and the SIM comparisons. This component has been considered as negligible for measurements at 1.5 V.
The detailed uncertainty budget for the LNE standards linked to the CCEM-K6.a and the CCEM-K9 comparisons is given in tables VI and VII.

Table VI. Uncertainty of the LNE standard linked to the CCEM-K6.a comparison (µV/V)

Frequency	**1 kHz**	**20 kHz**	**100 kHz**	**1 MHz**
$U(KCRV_{CCEM\text{-}K6.a})$ (k = 2.4)	0.4	0.5	1	6.7
$u(KCRV_{CCEM\text{-}K6.a})$ (k = 1)	0.2	0.3	0.5	3.4
$u(Meas_{CCEM\text{-}K6.a}[LNE])$ (Type A)	0.1	0.1	0.1	0.1
$u(Meas_{CCEM\text{-}K6.a}[LNE])$ (Type B)	0.1	0.1	0.1	0.1
$u(REF_{CCEM\text{-}K6.a}[LNE])$	0.2	0.3	0.5	3.4
$U(REF_{CCEM\text{-}K6.a}[LNE])$ (k = 2)	0.4	0.6	1	6.7

Table VII. Uncertainty of the LNE standard linked to the CCEM-K9 comparison (µV/V)

Frequency	1 kHz	20 kHz	50 kHz	100 kHz
$U(KCRV_{CCEM\text{-}K9})$ (k = 2)	3.1	3.7	5.0	10
$u(KCRV_{CCEM\text{-}K9})$ (k = 1)	1.6	1.9	2.5	5.0
$u(Meas_{CCEM\text{-}K9}[LNE])$ (Type A)	0.2	0.1	0.3	0.3
$u(Meas_{CCEM\text{-}K9}[LNE])$ (Type B)	0.8	0.8	0.8	0.8
$u(drift)$	1.5	2.5	3.0	3.0
$u(REF_{CCEM\text{-}K9}[LNE])$	2.3	3.2	4.0	5.9
$U(REF_{CCEM\text{-}K9}[LNE])$ (k = 2)	4.6	6.4	8.0	12

9.2 KCRV of the SIM.EM-K6.1 and SIM.EM-K9.1 comparisons

The KCRV of the SIM comparisons is defined as the value of the travelling standards measured by LNE, using LNE standards linked to the CCEM comparisons, then :

$$KCRV_{SIM} = REF_{CCEM}[LNE] + Meas_{SIM}[LNE]$$

where $Meas_{SIM}[LNE]$ is the difference measured by LNE between the SIM comparison travelling standard and the LNE standard.

The uncertainty on KCRV is then computed from :

$$u(KCRV_{SIM}) = \left\{u^2(REF_{CCEM}[LNE]) + u^2(Meas_{SIM}[LNE])\right\}^{1/2}$$

The detailed uncertainty budget for the KCRV of the SIM.EM-K6.1 and SIM.EM-K9.1 comparisons is presented in tables VIII and IX. Values assigned to the KCRV are reported in tables X and XI.

Table VIII. Uncertainty of the SIM.EM-K6.1 comparison KCRV (µV/V)

Frequency	1 kHz	20 kHz	100 kHz	1 MHz
$u(REF_{CCEM\text{-}K6.a}[LNE])$	0.2	0.3	0.5	3.4
$u(Meas_{SIM.EM\text{-}K6.1}[LNE])$ (Type A)	0.2	0.2	0.2	0.2
$u(Meas_{SIM.EM\text{-}K6.1}[LNE])$ (Type B)	0.2	0.2	0.6	0.9
$u(KCRV_{SIM.EM\text{-}K6.1})$	0.4	0.4	0.8	3.5
$U(KCRV_{SIM.EM\text{-}K6.1})$ (k = 2)	0.7	0.9	1.6	7.1

Table IX. Uncertainty of the SIM.EM-K9.1 comparison KCRV (µV/V)

Frequency	1 kHz	20 kHz	100 kHz	1 MHz
$u(REF_{CCEM\text{-}K9}[LNE])$	2.3	3.2	4.0	5.9
$u(Meas_{SIM.EM\text{-}K9.1}[LNE])$ (Type A)	0.3	0.2	0.4	0.3
$u(Meas_{SIM.EM\text{-}K9.1}[LNE])$ (Type B)	1.0	1.0	2.0	2.0
$u(KCRV_{SIM.EM\text{-}K9.1})$	2.6	3.4	4.5	6.2
$U(KCRV_{SIM.EM\text{-}K9.1})$ (k = 2)	5.2	6.8	9.0	13

9.3 Degrees of equivalence of INMETRO with KCRV

The degrees of equivalence $DE_{SIM}[INMETRO]$ of INMETRO with KCRV of the SIM comparisons are computed from :

$$DE_{SIM}[INMETRO] = X_{SIM}[INMETRO] - KCRV_{SIM}$$

where $X_{SIM}[INMETRO]$ represents the value of the SIM comparison traveling standard measured by INMETRO. As the KCRV of SIM comparisons is linked to the KCRV of CCEM comparisons, the degrees of equivalence with SIM KCRV are equivalent with the degrees of equivalence with CCEM KCRV.
The uncertainty associated with the degrees of equivalence is then derived from :

$$u(DE_{SIM}[INMETRO]) = \{u^2(X_{SIM}[INMETRO]) + u^2(KCRV_{SIM})\}^{1/2}$$

The degrees of equivalence of INMETRO are presented in tables X and XI. The value adopted for $X_{SIM}[INMETRO]$ is a root square sum of the INMETRO uncertainty and the measurement uncertainty reported by LNE for this comparison.

Table X. Degrees of equivalence of INMETRO for the SIM.EM-K6.1 comparison expressed in µV/V

Frequency	**1 kHz**		**20 kHz**		**100 kHz**		**1 MHz**	
Voltage : 1.5 V	**Value**	**Uncert. (*k* = 2)**	**Value**	**Uncert. (*k* = 2)**	**Value**	**Uncert. (*k* = 2)**	**Value**	**Uncert. (*k* = 2)**
$X_{SIM.EM-K6.1}[INMETRO]$	0.0	2.7	0.7	3.3	0.9	7.1	-16	43.7
$KCRV_{SIM.EM-K6.1}$	0.1	0.7	0.1	0.9	1.7	1.6	-6	7.1
$DE_{SIM.EM-K6.1}[INMETRO]$	-0.1	2.8	0.6	3.4	-0.8	7.3	-10	44.3

Table XI. Degrees of equivalence of INMETRO for the SIM.EM-K9.1 comparison expressed in µV/V

Frequency	**1 kHz**		**20 kHz**		**50 kHz**		**100 kHz**	
Voltage : 1000 V	**Value**	**Uncert. (*k* = 2)**	**Value**	**Uncert. (*k* = 2)**	**Value**	**Uncert. (*k* = 2)**	**Value**	**Uncert. (*k* = 2)**
$X_{SIM.EM-K9.1}[INMETRO]$	1.0	20.2	-8.6	37.2	-48.2	70.7	-175	76.5
$KCRV_{SIM.EM-K9.1}$	-2.6	5.2	-9.1	6.8	-50.2	9.0	-179	13
$DE_{SIM.EM-K9.1}[INMETRO]$	3.6	20.9	0.5	37.8	2.0	71.3	4	77.6

All data used to link the SIM.EM-K6.1 and SIM.EM-K9.1 comparisons to the respective CCEM-K6.a and CCEM-K9 comparisons can be found in references [2] and [3].

10 Conclusion

The degrees of equivalence of INMETRO with KCRV range between 0.1 µV/V and 10 µV/V in the frame of the SIM.EM-K6.1 comparison and between 0.5 µV/V and 4 µV/V in the frame of the SIM.EM-K9.1 comparison. In all cases, they are consistent with the associated uncertainties.
For results that are not linked to CCEM comparisons, the agreement between INMETRO and LNE is very good at 1.5 V/50 kHz (0.1 µV/V). At 10 Hz (at 1.5 V and at 1000 V) a larger difference is observed between the two laboratories, which remains nevertheless consistent with the given uncertainties.

REFERENCES

[1] Andre POLETAEFF, "Automated Comparator for Accurate AC-DC Difference Measurements at the BNM-LCIE", *IEEE Trans. Instrum. Meas.*, vol. 48, n°2, pp 412-414, April 1999.

[2] Manfred KLONZ, "CCEM-K6.a Final report", available on the web site of the BIPM.

[3] Andre POLETAEFF, "CCEM-K9 Final report", available on the web site of the BIPM.

Appendix I

List of participants

Organization	Country	Contact Person	E-mail	Shipping Address
INMETRO	Brazil	Renata de Barros e Vasconcellos, Renato Afonso Jr.	rbvasconcellos@inmetro.gov.br rajunior@inmetro.gov.br	INMETRO - Av. Nossa Senhora das Graças, 50 Duque de Caxias – RJ 25250-020, Brazil Phone: 55 21 2679 9093
LNE	France	Andre Poletaeff	andre.poletaeff@lne.fr	Laboratoire national de métrologie et d'essais - LNE 29, avenue Roger Hennequin - 78197 Trappes cedex Phone: 33 1 30 69 10 00

Appendix II

SUMMARY OF UNCERTAINTY BUDGET

Institute: Inmetro - National Institute of Metrology, Quality and Technology

Measurement Voltage: 1.5 V

Contribution of:	Standard Uncertainty (μV/V) at frequency						Type A or B	Distribution
	10 Hz	**1 kHz**	**20 kHz**	**50 kHz**	**100 kHz**	**1 MHz**		
$u(\delta_{Standard})$	1.7	1.0	1.0	1.0	2.5	5.4	B	Normal
$u(\delta_{CA})$	0.1	0.1	0.1	0.0	0.1	0.1	A	Normal
$u(\delta_{C})$	0.1	0.1	0.1	0.1	0.1	0.1	B	Rectangular
$u(\delta_{Diff.\ Setups})$	0.2	0.2	0.2	0.2	0.1	2.7	A	Rectangular
$u(\delta_{Connectors})$	0.1	0.1	0.1	0.1	0.2	0.1	B	Rectangular

Combined unc (k=1):	1.7	1.1	1.0	1.1	2.5	6.0
Expanded unc:	3.4	2.2	2.2	2.2	5.1	12.1

Model equation:

$$\delta_{ac\text{-}dc} = \delta_{Standard} + \delta_{CA} + \delta_{C} + \delta_{Diff.\ Setups} + \delta_{Connectors} \qquad (2)$$

With

$\delta_{Standard}$ Transfer difference of standard
δ_{CA} Contribution of the mean of repeated twelve measurements
δ_{C} Contribution of the measurement set-up
$\delta_{Diff.\ Setups}$ Contribution of different set-ups measurements performed in the comparison
$\delta_{Connectors}$ Contribution of connectors ac-dc difference

The sum of the variances of the different contributions results in the variance of the result:

$$u^2(\delta_{ac\text{-}dc}) = u^2(\delta_{Standard}) + u^2(\delta_{CA}) + u^2(\delta_{C}) + u^2(\delta_{Diff.\ Setups}) + u^2(\delta_{Connectors}) \qquad (3)$$

with

$u(\delta_{Standard})$ Standard calibration uncertainty
$u(\delta_{CA})$ Variance of the contribution of the mean of repeated twelve measurements
$u(\delta_{C})$ Variance of the contribution of the measurement set-up
$u(\delta_{Diff.\ Setups})$ Variation of the difference obtained from different set-ups
$u(\delta_{Connectors})$ Connectors ac-dc difference

Measurement Voltage: 1000 V

Contribution of:	**Standard Uncertainty (μV/V) at frequency**				
	10 Hz	**1 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
$u^2 (\delta_{Step\ 300V})$	5.8	5.0	5.1	6.5	12.4
$u (\delta_{CA})$	0.4	0.5	0.2	0.6	0.5
$u^2 (\delta_{C})$	0.1	0.3	0.9	1.6	2.1
$u^2(\delta_{Resistor})$	2.0	2.0	2.0	2.5	3.5
$u^2 (\delta_{LF})$	2.3	0.0	0.0	0.0	0.0
$u^2 (\delta_{Amplifier})$	3.0	3.0	3.0	3.0	10.0
$u^2 (\delta_{Connectors})$	0.3	0.3	0.3	0.3	0.3

Combined unc (k=1):	7.2	6.2	6.3	7.8	16.5
Expanded unc:	14.4	12.4	12.6	15.6	33.0

Model equation (step-up):

$$\delta_{step\,i} = \delta_{step\,i\text{-}1} + \delta_{CA} + \delta_{C} + \delta_{Resistor} + \delta_{LF} + \delta_{Amplifier} + \delta_{Connectors}$$

with

$\delta_{step\,i\text{-}1}$ Transfer difference of standard at the step i-1.
δ_{CA} Contribution of the mean of repeated twelve measurements.
δ_{C} Contribution of the measurement step-up.
$\delta_{Resistor}$ Contribution of the resistor.
δ_{LF} Transfer difference due to low frequency behavior of PMJTC.
$\delta_{Amplifier}$ Contribution of the high voltage amplifier.
$\delta_{Connectors}$ Contribution of connectors ac-dc difference.

The sum of the variances of the different contributions results in the variance of the result:

$$u^2 (\delta_{step\,i}) = u^2 (\delta_{Step\,i\text{-}1}) + u^2 (\delta_{CA}) + u^2(\delta_{C}) + u^2 (\delta_{Resistor}) + u^2 (\delta_{LF}) + u^2(\delta_{Amplifier}) + u^2(\delta_{Connectors})$$

with

$u^2 (\delta_{Step\,i\text{-}1})$ Variance of the transfer difference of the standard at the step i-1.
$u^2 (\delta_{CA})$ Variance of the mean of twelve measurements.
$u^2 (\delta_{C})$ Variance of the measured transfer difference in step-up.
$u^2(\delta_{Resistor})$ Variance of the transfer difference due to resistor.
$u^2 (\delta_{LF})$ Variance of the transfer difference due to low frequency behavior of the PMJTC.
$u^2 (\delta_{Amplifier})$ Variance of the transfer difference due to high voltage amplifier.
$u^2 (\delta_{Connectors})$ Connectors ac-dc difference.

SUMMARY OF UNCERTAINTY BUDGET

Institute: LNE - Laboratoire National de Métrologie et d'Essais

Measurement Voltage: 1.5 V

Contribution of:	Standard Uncertainty (μV/V) at frequency						Type A or B	Distribution
	10 Hz	1 kHz	20 kHz	50 kHz	100 kHz	1 MHz		
u(LNE standard)	2.5	-	-	1.6	-	-	B	Normal
Measurement (Type A)	0.2	-	-	0.8	-	-	A	Normal
Measurement (Type B)	1	-	-	0.6	-	-	B	Normal

Combined unc (k=1):	2.7	-	-	1.9	-	-
Expanded unc:	5.4	-	-	3.8	-	-

The uncertainty budget for frequencies 1 kHz, 20 kHz, 100 kHz and 1 MHz is detailed in tables VI and VIII.

Measurement Voltage: 1000 V

Contribution of:	Standard Uncertainty (μV/V) at frequency					Type A or B	Distribution
	10 Hz	1 kHz	20 kHz	50 kHz	100 kHz		
u(LNE standard)	22.4	-	-	-	-	B	Normal
Measurement (Type A)	0.3	-	-	-	-	A	Normal
Measurement (Type B)	2	-	-	-	-	B	Normal

Combined unc (k=1)	22.5	-	-	-	-
Expanded unc:	45	-	-	-	-

The uncertainty budget for frequencies 1 kHz, 20 kHz, 50 kHz and 100 kHz is detailed in tables VII and IX.