CCEM-K9 COMPARISON OF AC-DC HIGH VOLTAGE STANDARDS

Key comparison final report

Andre POLETAEFF

LNE

29, avenue Roger Hennequin
78197 TRAPPES
FRANCE

Report on the CCEM-K9 comparison of AC-DC high voltage transfer standards.

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Andre POLETAEFF

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Abstract : From February 2000 to March 2003 the international CCEM-K9 key comparison of AC-DC high voltage transfer standards was completed. AC-DC transfer standards were compared at 200 V, 500 V and 1000 V. At 1 kHz, the agreement between the results submitted by the participants and the key comparison reference value is in the order of 5 µV/V at all test voltages. At the frequency of 100 kHz, the agreement is in the order of 10 µV/V and 15 µV/V at 500 V and 1000 V respectively.

1) Introduction :

AC-DC thermal transfer techniques provide at present time the most accurate link between AC RMS voltages and DC voltages. These techniques use thermal converters usually operating in the 1 V to 3 V range, which are associated with series range resistors for measurements at higher voltages. In order to reach a low level of uncertainty, their AC-DC transfer difference has to be determined in a step-up procedure.

At voltage levels of a few volts, most of National Metrology Institutes (NMIs) use multijunction thermal converters (MJTC) as primary standards in the low frequency domain. The frequency response of such converters, is very flat and close to their DC response from 10 Hz to 100 kHz, and can be accurately calculated in this frequency range [1]. A recent international comparison (CCEM-K6.a) [2] at voltages of 1.5 V and 3 V, using PTB MJTCs as travelling standards, showed an agreement between the participating NMIs better than 0.6 parts in 10^6 at 1 kHz and 1.4 parts in 10^6 at 100 kHz.

At higher voltages, the frequency response of AC-DC transfer standards is derived from the primary standards by a step-up procedure which consists in calibrating, one after the other, each unknown standard against the neighbouring already calibrated standard. The assumption is made that the AC-DC transfer difference of each standard remains constant between the reduced voltage at which it is calibrated and the full rated voltage at which it is then used, as the reference converter, in the next step of the step-up procedure. This assumption is generally valid for voltages up to 100 V or 200 V, but at higher voltages, a voltage level dependence of the AC-DC transfer difference is observed. Dielectric losses [3] and variations of the resistance of the range resistor with temperature changes [3] seem to be mainly responsible for this dependence. Specific difficulties occur then in the determination of the AC-DC differences of the AC-DC standards at these voltages, and particularly at frequencies above 20 kHz.

A previous comparison of such devices (CCE 92-4) showed large discrepancies between the results reported by the participants and no meaningful reference values for the travelling standards at these frequencies could be computed from the reported results. In May 1999, at the meeting of AC-DC transfer experts in Silkeborg, Denmark, it was decided to cancel this comparison. A new comparison, conforming to the BIPM guildline for key comparison and designated CCEM-K9, with new travelling standards, piloted by BNM-LNE, was restarted in February 2000. The support group was composed of METAS, SP and NRC. A regional key comparison, with the same travelling standards, designated EUROMET 557, started in parallel. At the same time, works performed in number of NMIs greatly improved performances of high voltage AC-DC transfer measurements [4-8].

2) Scope of the comparison

The purpose of the present comparison was to check the agreement between the NMIs in the field of AC-DC transfer measurements at 200 V, 500 V and 1000 V. The test frequencies were 1 kHz, 10 kHz, 20 kHz, 50 kHz and 100 kHz.

The quantity to be measured was the AC-DC transfer difference δ of the travelling high voltage thermal converters, defined as

$$\delta = \frac{V_{AC} - V_{DC}}{V_{DC}}$$

where:

- V_{AC} is the RMS value of the AC voltage applied at the input of the converter;
- V_{DC}, the direct voltage, which when reversed, produces the same mean output voltage of the converter as V_{AC}.

3) Organisation of the comparison and description of the travelling standards

The comparison was organised in two parallel loops. The CCEM and EUROMET loops were not separated.

In the first loop, the circulating standard (NIST-PTB/1000V) consisted of a PTB-IPHT 400 Ω planar multijunction thermal converter, provided by PTB, associated with a 1000 V range resistor (s/n 030) for FLUKE 792 A transfer standard provided by NIST. This standard had to be measured at all requested voltages and frequencies.

In the second loop, two standards were circulating. One of them (METAS/1000V) was a 1000 V standard (ref. RS1000/E + US6) developed and provided by METAS, consisting of a 1000 V range resistor associated with a single junction thermal converter, to be measured at 500 V and 1000 V. The second standard (NIST-PTB/500V) was a PTB-IPHT 400 Ω planar multijunction thermal converter, provided by PTB, associated with a 500 V range resistor (s/n 034) for FLUKE 792 A transfer standard, provided by NIST, to be measured at 200 V and 500 V (optional).

The link between the different standards was established by BNM-LNE, PTB and METAS, which participated in both loops. These laboratories also monitored the long term stability of the standards by repeated calibrations during the comparison

During the comparison the NIST-PTB/1000V standard was destroyed twice. Each time, the 400 Ω planar MJTC was replaced by PTB. Therefore, 5 standards were used in the comparison.

For one group of participants they were :

- NIST-PTB/1000V[1] from February 2000 to December 2000, and called S1 later in the report ;
- NIST-PTB/1000V[2] from January 2001 to October 2001, also called S2 ;
- NIST-PTB/1000V[3] from December 2001 to June 2002, also called S3.

For the other group they were :

- METAS/1000V, which was measured at 1000 V and 500 V, and called S4 later in the report ;
- NIST-PTB/500V, measured at 500 V (optional) and 200 V, also called S5.

Standard S3 was used only by the NMIs participating in the EUROMET part of the comparison. However, the link between different CCEM-K9 standards has been established by a global method, taking into account not only the official results of the pilot laboratory (BNM-LNE) and the support laboratories (PTB and METAS), but also their complementary, stability monitoring measurements of all travelling standards. For this reason the values of S3 are given also below.

4) Participating NMIs

The NMI’s are listed in the chronological order in which they participated for each travelling standard.

	LABORATORY	COUNTRY	Responsible person	Calibration date	Comparison
Travelling standard : NIST-PTB/1000V[1] (S1)					
1	BNM-LNE	France	Andre POLETAEFF	February 2000	CCEM-K9 EUR-557
2	DANIAmet-AREPA	Denmark	Torsten LIPPERT	July 2000	CCEM-K9 EUR-557
3	NPL	United Kingdom	G. JONES - P. WRIGHT	August 2000	CCEM-K9 EUR-557
4	SP	Sweden	Karl Erik RYDLER	September 2000	CCEM-K9 EUR-557
5	IEN	Italy	Umberto POGLIANO	October 2000	CCEM-K9 EUR-557
6	CEM	Spain	Miguel NEIRA	November 2000	CCEM-K9 EUR-557
Travelling standard : NIST-PTB/1000V[2] (S2)					
7	PTB	Germany	Manfred KLONZ	January 2001	CCEM-K9 EUR-557
8	VSL	The Netherlands	Cees Van MULLEM	May 2001	CCEM-K9 EUR-557
Travelling standards : METAS/1000V (S4) and NIST-PTB/500V (S5)					
9	INTI	Argentina	Hector LAIZ	July 2000	CCEM-K9
10	NMIA	Australia	Ilya BUDOVSKY	November 2000	CCEM-K9
11	NRC	Canada	Peter FILIPSKI	March 2001	CCEM-K9
12	VNIIM	Russia	G. P. TELITCHENKO	May 2001	CCEM-K9
13	METAS	Switzerland	Marc FLUELI	August 2001	CCEM-K9 EUR-557
14	NIST	United States	J. R. KINARD - T. E. LIPE	January 2002	CCEM-K9
15	NIM	China	J. ZHANG	May 2002	CCEM-K9

Table 1 : List of participating NMIs. Laboratories which performed complementary, stability monitoring measurements, are noted in blue.

The full names of the participating organisations are :
BNM-LNE : Bureau National de Métrologie – Laboratoire National d’Essais
DANIAmet-AREPA :
NPL : National Physical Laboratory
SP : Sveriges Provningsanstalt
IEN : Instituto Elettrotecnico Nazionale
CEM : Centro Espanol de Metrologia
PTB : Physikalisch-Technische Bundesanstalt
NMi-VSL : Netherlands Meetinstituut – Van Swiden Laboratorium
INTI : Instituto Nacional de Tecnologia Industrial
NMIA : National Measurement Institute of Australia
NRC : National Research Council Canada
VNIIM : D. I. Mendeleyev Institute for Metrology
METAS : Swiss Federal Office for Metrology and Accreditation
NIST : National Institute of Standards and Technology
NIM : National Institute of Metrology

5) Laboratory procedures and standards

The measuring procedures and standards used in the different NMIs have been described in more or less detail in their reports. Some of them have been published elsewhere.

Almost all participants use an automatic or semi-automatic system to compare the travelling standards against their reference standards. In general the AC-DC measurement consists of an input sequence DC+, AC, DC-, AC, etc… Each time, either the output voltages of both thermal converters are directly measured (dual-channel method), or one of them only and the difference between them (“differential” method).

The number of measurements differ from one institute to another.

6) Uncertainty statements

The participants were asked to provide detailed uncertainty budgets in accordance with the guide to the expression of uncertainty in measurements, first edition published in 1993 by BIPM/IEC/IFCC/ISO/IUPAP/OIML, based on the recommendation INC-1 (1980). In this report all the uncertainties are presented with a probability of 95 %.

Uncertainty budgets provided by the participants are given in appendix 2.

7) Determination of the key comparison reference value (KCRV)

Although several travelling standards have been used, only one value should be given as the reference value for the comparison. The AC-DC transfer difference of the travelling standard S2 (see the list of the travelling standards in section 3) has been arbitrarily chosen as the reference value. The procedure described in the WGKC/2002-27 document published by the CCEM has been adopted for the calculation of this value.

In order to take into account, in the calculation of the reference value, results reported by the participants who did not measure standard S2, we proceeded as follows:

1. In a first step, deviations of all travelling standards from S2 were calculated from results reported by laboratories which measured at least two of them (BNM-LNE, PTB and METAS).
2. Values given by each participant in the comparison were then adjusted by subtracting the deviation of the standard the participant measured from the standard S2.
3. The reference value d_{ref} and the associated uncertainty u_{ref} were calculated from this set of adjusted values using :

$$d_{ref} = \frac{\sum_i d_{adj,i} / (u_{adj,i})^2}{\sum_i 1/(u_{adj,i})^2} \quad \text{and} \quad u_{ref} = \sqrt{\frac{1}{\sum_i 1/(u_{adj,i})^2}}$$

where :

- $d_{adj,i}$ is the adjusted value for laboratory “L$_i$” ;
- $u_{adj,i}$ is the standard uncertainty of the adjusted value for laboratory “L$_i$” and is given by $u_{adj,i} = \sqrt{u_{rep,i}^2 + u_{dev,i}^2}$, $u_{rep,i}$ being the standard uncertainty reported by laboratory “L$_i$”, and $u_{dev,i}$ the standard uncertainty of the deviation of the standard measured by “L$_i$” from the standard S2.

Remark : Deviation of the standard S5 from the standard S2 was calculated in the first step. But as participants who measured S5 at 500 V also measured S4 at this voltage, only results reported for S4 have been taken into account in the calculation of the reference value at 500 V and in the calculation of the degree of equivalence between pairs of laboratories. In this way, the weight of the contribution of each participant to the KCRV remains the same. Nevertheless, results reported for S5 at 500 V are presented in this report for completeness.

Calculation of the deviations of the different standards from S2

The value $d_{rep}(S_i,L_j)_k$ of the AC-DC transfer difference of the travelling standard “S_i” reported by laboratory “L_j” (BNM-LNE, PTB or METAS), k being the number of the actual measurement, can be written :

$$d_{rep}(S_i,L_j)_k = d(S_i) + \delta(L_j) + \varepsilon_k \quad \text{where :}$$

- $d(S_i)$ is the AC-DC difference of the travelling standard “S_i” ;
- $\delta(L_j)$ is the systematic error of laboratory “L_j” assumed to be the same for all measurements performed by this laboratory at a given test point ;
- $\varepsilon_{i,j(i)}$ is the random measurement error of $d_{rep}(S_i,L_j)_k$.

Each reported value leads then to such an equation, creating a system of k_0 equations, where k_0 is the total number of measurements taken into account for this calculation. In order to get only one solution for this system, the supplementary condition $\sum_j \delta(L_j) = K$ has been added. Values computed for the $d(S_i)$’s depend on the arbitrary value assigned to K, but not the differences between them. The value of K has then been fixed to zero for the calculation of preliminary values of the AC-DC differences of the travelling standards.

This set of equations can be written in the matrix form :

$$[MeasRESULTS] = [X].[Y] + [\varepsilon]$$

where [*MeasRESULTS*] is the one column matrix of reported values for a given test point, [*Y*] the one column matrix of the preliminary “calculated values” of $d(S_i)$ and $d(L_j)$ (to be determined), and [*X*] the matrix of the system,

with the solution :

$$[estY] = ({}^T[X].[X])^{-1}.{}^T[X].[MeasRESULTS]$$

where [*estY*] is an estimate of [*Y*].

Deviations *d*(S1) – *d*(S2), *d*(S3) – *d*(S2), *d*(S4) – *d*(S2) and *d*(S5) – *d*(S2) have been deduced from preliminary values computed for *d*(S1), *d*(S2), *d*(S3), *d*(S4) and *d*(S5).

Calculation of the uncertainty of the deviations of the different standards from the standard S2.

The variance *Var*[*estY*] of [*estY*] is determined by :

$$Var[estY] = s^2.({}^T[X].[X])^{-1}$$

From the reported values (matrix [*MeasRESULTS*]) and the computed preliminary values (matrix [est*Y*]), a one column error matrix [ε] has been derived :

$$[\varepsilon] = [MeasRESULTS] - [X].[estY]$$

If its elements are noted ε_l, *s* is given by :

$$s^2 = \frac{\sum_l \varepsilon_l^2}{n-p}$$

where :

- *n* is the number of equations ;

- p, the number of parameters to determine.

The standard uncertainty of the determined parameters (matrix [$estY$]) is given in the main diagonal of matrix $Var[estY]$. If $u_{pr}(S_i)$ represents the standard uncertainty of the preliminary computed value of $d(S_i)$, the standard uncertainties u_{dev} of the deviations of the different travelling standards from S2 are given by :

- $u_{dev}(S1) = \sqrt{u_{pr}^2(S1) + u_{pr}^2(S2)}$ for S1 ;
- $u_{dev}(S3) = \sqrt{u_{pr}^2(S3) + u_{pr}^2(S2)}$ for S3
- $u_{dev}(S4) = \sqrt{u_{pr}^2(S4) + u_{pr}^2(S2)}$ for S4
- $u_{dev}(S5) = \sqrt{u_{pr}^2(S5) + u_{pr}^2(S2)}$ for S5

8) Presentation of the results

In this report, all results are given in µV/V and the uncertainties are presented with a probability of 95 %.

Reported values

Tables 2a to 2d show the values (column "d") and the expanded uncertainties (column "U") as reported by the participants. Additional, stability-monitoring, measurements performed by the pilot laboratory and the support laboratories are presented on a dark background.

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			d	*U*	**d**	*U*	**d**	*U*	**d**	*U*	**d**	*U*
Travelling standard : NIST-PTB/1000V[1] (S1)												
	BNM-LNE	France	**5.3**	*16*	**-1.9**	*35*	**-9.1**	*35*	**-33.6**	*69*	**-79**	*69*
	PTB	Germany	**-0.4**	*8*	**-3.8**	*8*	**-7.4**	*8*	**-23.4**	*10*	**-62.1**	*30*
	DANIAmet-AREPA	Denmark	**4**	*21*	**1**	*21*	**-1**	*26*	**-20**	*41*	**-58**	*81*
	NPL	United Kingdom	**-1**	*13*	**-6**	*13*	**-12**	*23*	**-29**	*32*	**-69**	*62*
	SP	Sweden	**2**	*9*	**0**	*10*	**-4**	*11*	**-17**	*15*	**-48**	*23*
	IEN	Italy	**-1.4**	*14.8*	**-5.8**	*15.2*	**-12.9**	*25*	**-32.8**	*37.2*	**-71.9**	*79.4*
	CEM	Spain	**-7**	*36*	**-3**	*40*	**-8**	*44*	**-38**	*64*	**-68**	*98*
	PTB	Germany	**-0.4**	*8*	**-3.9**	*8*	**-7.6**	*8*	**-23.1**	*10*	**-61.3**	*30*
Travelling standard : NIST-PTB/1000V[2] (S2)												
	PTB	Germany	**-0.5**	*8*	**-3.8**	*8*	**-7.2**	*8*	**-21.9**	*10*	**-56.6**	*30*
	BNM-LNE	France	**7.4**	*16*	**0.4**	*35*	**-6.3**	*35*	**-30.4**	*69*	**-72.4**	*69*
	METAS	Switzerland	**-1.6**	*6*	**-4.1**	*7*	**-7.6**	*7*	**-21.7**	*10*	**-51**	*28*
	VSL	The Netherlands	**3**	*20*	**-3.1**	*20*	**-10.1**	*25*	**-25.2**	*35*	**-61.4**	*50*
	BNM-LNE	France	**7.4**	*16*	**-0.3**	*35*	**-7.4**	*35*	**-31**	*69*	**-72.8**	*69*
Travelling standard : NIST-PTB/1000V[3] (S3)												
	PTB	Germany	**0.3**	*8*	**1.5**	*8*	**12.2**	*8*	**87.5**	*10*	**329.5**	*30*
	METAS	Switzerland	**-1.3**	*6*	**1**	*7*	**11.4**	*7*	**88.7**	*10*	**351**	*28*
Travelling standard : METAS/1000V (S4)												
	BNM-LNE	France	**5.7**	*16*	**3.9**	*35*	**7.9**	*35*	**48.6**	*69*	**216.2**	*69*
	METAS	Switzerland	**-0.6**	*6*	**2**	*7*	**9.7**	*7*	**59.8**	*10*	**241**	*28*
	INTI	Argentina	**-4**	*14*	**1**	*16*	**6**	*20*	**57**	*24*	**235**	*40*
	NMIA	Australia	**1.5**	*11*	**6**	*14*	**14**	*16*	**66**	*28*	**250**	*41*
	NRC	Canada	**1**	*10*	**7**	*10*	**17**	*10*	**69**	*12*	**237**	*24*
	VNIIM	Russia	**-0.1**	*20.2*	**2.6**	*20.6*	**6.1**	*32.4*	**38.8**	*51.6*	**260.4**	*101*
	METAS	Switzerland	**-1**	*6*	**1.6**	*7*	**9.4**	*7*	**59.8**	*10*	**241**	*28*
	NIST	United States	**7.9**	*17*	**7.2**	*17*	**16.7**	*16.2*	**57.8**	*21.4*	**231.6**	*29.2*
	NIM	China	**-0.3**	*24.2*	**3.9**	*24.4*	**12.4**	*29.2*	**58.3**	*45.4*	**218.1**	*59.6*
	METAS	Switzerland	**-0.6**	*6*	**2**	*7*	**9.4**	*7*	**59.7**	*10*	**241**	*28*
	BNM-LNE	France	**8**	*16*	**6.2**	*35*	**8.4**	*36*	**51**	*69*	**217.4**	*69*

Table 2a : Reported values ("d") and expanded uncertainties ("U") at 1000 V (in µV/V)

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			d	U	d	U	d	U	d	U	d	U
Travelling standard : NIST-PTB/1000V[1] (S1)												
	BNM-LNE	France	**1.8**	*13*	**-3.2**	*21*	**-6.8**	*21*	**-25.7**	*36*	**-67.7**	*36*
	PTB	Germany	**-0.6**	*8*	**-3**	*8*	**-7.4**	*8*	**-24.6**	*10*	**-67.9**	*22*
	DANIAmet-AREPA	Denmark	**3**	*21*	**0**	*21*	**-4**	*21*	**-22**	*21*	**-60**	*41*
	NPL	United Kingdom	**-1**	*13*	**-8**	*13*	**-13**	*17*	**-31**	*24*	**-75**	*46*
	SP	Sweden	**2**	*8*	**0**	*9*	**-5**	*10*	**-18**	*14*	**-55**	*21*
	IEN	Italy	**-0.6**	*9.4*	**-5.7**	*9.4*	**-13.1**	*14*	**-35.2**	*20.2*	**-80.4**	*47.6*
	CEM	Spain	**-2**	*30*	**-4**	*30*	**-5**	*30*	**-29**	*38*	**-62**	*50*
	PTB	Germany	**-0.5**	*8*	**-3**	*8*	**-7.5**	*8*	**-24.8**	*10*	**-67.4**	*22*
Travelling standard : NIST-PTB/1000V[2] (S2)												
	PTB	Germany	**-0.5**	*8*	**-2.8**	*8*	**-7**	*8*	**-22.5**	*10*	**-60.5**	*22*
	BNM-LNE	France	**3.8**	*13*	**-1.3**	*21*	**-4.9**	*21*	**-22.8**	*36*	**-62.1**	*36*
	METAS	Switzerland	**2.2**	*6*	**-4.4**	*6*	**-7.9**	*6*	**-23.1**	*9*	**-58**	*26*
	VSL	The Netherlands	**2.6**	*15*	**-4.3**	*15*	**-9.2**	*20*	**-25.7**	*25*	**-63.8**	*40*
	BNM-LNE	France	**3.3**	*13*	**-1.6**	*21*	**-5.5**	*21*	**-23.6**	*36*	**-62.6**	*36*
Travelling standard : NIST-PTB/1000V[3] (S3)												
	PTB	Germany	**0.1**	*8*	**2.4**	*8*	**12.4**	*8*	**88**	*10*	**332.1**	*22*
	METAS	Switzerland	**-1.3**	*6*	**0.9**	*6*	**11.2**	*6*	**87.6**	*9*	**343**	*26*
Travelling standard : METAS/1000V (S4)												
	BNM-LNE	France	**1.7**	*14*	**1.7**	*21*	**9.1**	*21*	**55.9**	*37*	**230.3**	*37*
	METAS	Switzerland	**-0.8**	*6*	**1.5**	*6*	**9.3**	*6*	**59.2**	*9*	**238**	*26*
	INTI	Argentina	**-3**	*12*	**-1**	*14*	**7**	*16*	**56**	*18*	**231**	*30*
	NMIA	Australia	**2.6**	*9*	**6**	*9*	**14**	*10*	**67**	*15*	**248**	*23*
	NRC	Canada	**1**	*8.8*	**6**	*8.6*	**16**	*10*	**68**	*10.6*	**235**	*24*
	VNIIM	Russia	**0.7**	*16.6*	**2.9**	*17*	**4.5**	*24.6*	**39.9**	*40.6*	**213.8**	*60.4*
	METAS	Switzerland	**-1.2**	*6*	**1.6**	*6*	**9.2**	*6*	**59.6**	*9*	**238**	*26*
	NIST	United States	**4.3**	*11*	**6.2**	*10.6*	**14.1**	*11.2*	**55.9**	*14*	**227**	*17.8*
	NIM	China	**-1.5**	*19.6*	**1.5**	*19.6*	**9.8**	*21.2*	**56**	*29.2*	**212.5**	*39.6*
	METAS	Switzerland	**-1.2**	*6*	**1.6**	*6*	**8.9**	*6*	**58.9**	*9*	**238**	*26*
	BNM-LNE	France	**3.4**	*14*	**3.5**	*21*	**10.6**	*21*	**56.8**	*37*	**229.7**	*37*

Table 2b : Reported values (“d”) and expanded uncertainties (“U”) at 500 V (in µV/V)

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			d	U	d	U	d	U	d	U	d	U
Travelling standard : NIST-PTB/500V (S5)												
	BNM-LNE	France	**0.6**	*13*	**-1.1**	*21*	**-0.8**	*21*	**3.8**	*36*	**31.9**	*36*
	METAS	Switzerland	**-1.7**	*6*	**-1.2**	*6*	**-0.3**	*6*	**6.8**	*9*	**38**	*26*
	INTI	Argentina	**-2**	*12*	**-3**	*14*	**-1**	*16*	**7**	*18*	**38**	*30*
	NMIA	Australia	**0.9**	*9*	**2**	*9*	**4**	*10*	**15**	*15*	**52**	*23*
	NRC	Canada	**1**	*10*	**3**	*10*	**6**	*10*	**17**	*16*	**43**	*28*
	VNIIM	Russia	**2.5**	*16.4*	**1.9**	*16.8*	**4**	*24.6*	**14.4**	*40.8*	**36.3**	*60.3*
	METAS	Switzerland	**-1.3**	*6*	**-1.1**	*6*	**-0.3**	*6*	**6.9**	*9*	**38**	*26*
	NIST	United States	**3.5**	*9.2*	**3.3**	*9.6*	**3.9**	*9.8*	**3.3**	*13*	**28.4**	*16.8*
	NIM	China	**-1.3**	*19.2*	**-2**	*19.2*	**-0.3**	*20.8*	**7.1**	*29*	**34.9**	*39.4*
	METAS	Switzerland	**-1.7**	*6*	**-1.3**	*6*	**-0.4**	*6*	**6.3**	*9*	**36**	*26*
	BNM-LNE	France	**3.9**	*13*	**1.3**	*21*	**2.1**	*21*	**5.8**	*37*	**31.9**	*37*

Table 2c : Reported values (“d”) and expanded uncertainties (“U”) at 500 V (optional) (in µV/V)

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			d	*U*	**d**	*U*	**d**	*U*	**d**	*U*	**d**	*U*
Travelling standard : NIST-PTB/1000V[1] (S1)												
	BNM-LNE	France	-1.6	12	-7.2	13	-9.1	13	-31.1	16	-76.5	16
	PTB	Germany	-0.5	8	-2.7	8	-8.3	8	-24.5	10	-67.9	22
	DANIAmet-AREPA	Denmark	2	11	-1	11	-6	11	-26	11	-72	26
	NPL	United Kingdom	5	12	-9	12	-11	14	-26	16	-67	20
	SP	Sweden	2	7	1	8	-3	9	-21	13	-55	19
	IEN	Italy	0.7	8.6	-5	8.8	-12.4	12.8	-34.7	18.2	-77.3	42.4
	CEM	Spain	2	22	2	22	-2	22	-22	24	-60	28.8
	PTB	Germany	0	8	-3.3	8	-7.5	8	-24.2	10	-66.9	22
Travelling standard : NIST-PTB/1000V[2] (S2)												
	PTB	Germany	-0.5	8	-3.3	8	-7.3	8	-22.7	10	-61.9	22
	BNM-LNE	France	2.9	12	-3.4	13	-6.3	13	-25.7	16	-70	16
	METAS	Switzerland	-2	6	-4.5	6	-8.2	6	-23.5	9	-61	24
	VSL	The Netherlands										
	BNM-LNE	France	0.8	12	-4.8	13	-8.7	13	-26.5	16	-71.6	16
Travelling standard : NIST-PTB/1000V[3] (S3)												
	PTB	Germany	-0.1	8	2.6	8	12.5	8	87.3	10	333.6	22
	METAS	Switzerland	-1.5	6	1.1	6	11.2	6	88.2	9	345	26
Travelling standard : NIST-PTB/500V (S5)												
	BNM-LNE	France	1.5	11	-1.2	12	0	12	3.8	16	29.6	16
	METAS	Switzerland	-1.2	6	-1.1	6	-0.3	6	6.9	9	38	24
	INTI	Argentina	-3	10	-2	10	-1	12	6	16	37	24
	NMIA	Australia	-0.1	7	1	7	1	8	10	11	45	18
	NRC	Canada	0	10	0	10	3	10	13	14	42	22.6
	VNIIM	Russia	2.5	12.6	1.9	12.4	4	20.2	15.6	30.2	37.3	40.4
	METAS	Switzerland	-1.4	6	-1.2	6	-0.2	6	6.9	9	38	24
	NIST	United States	5.5	5.6	4.2	5.8	4.8	6	9.4	7.8	39.8	10.8
	NIM	China	0.2	11	-2.4	11	-1.5	11	5.3	12.2	32.4	13.2
	METAS	Switzerland	-1.6	6	-1.3	6	-0.5	6	6.6	9	37	24
	BNM-LNE	France	1.4	11	-1.3	12	-0.4	12	2.1	16	25.8	16

Table 2d : Reported values (“d”) and expanded uncertainties (“U”) at 200 V (in µV/V)

Long term stability of the travelling standards

There are discrepancies between results reported by PTB and METAS for standard S3 at 100 kHz for all voltage levels. However, for standard S2, values reported by these two laboratories are in good agreement. Drift of standard S3 is the most credible explanation for these discrepancies, as such a behaviour has already been noticed for some devices of the same type during the first months of their use.

In order to take it into account, values reported for standard S3 have been corrected, assuming a linear drift between December 2001 (date of calibration by PTB) and June 2002 (date of calibration by METAS). The total drift δ_{drift} during this period was estimated using :

$$\delta_{drift} = d(S3/METAS) + d(S2/PTB) - d(S2/METAS) - d(S3/PTB)$$

where :

- *d(S3/METAS)* is the value reported by METAS for S3 ;
- *d(S2/PTB)*, the value reported by PTB for S2 ;
- *d(S2/METAS)*, the value reported by METAS for S2 ;
- *d(S3/PTB)*, the value reported by PTB for S3.

For all other standards, complementary measurements performed by BNM-LNE, PTB and METAS show a good long term stability.

Determination of deviations of standards S1, S3, S4 and S5 from standard S2

Tables 3a to 3c show all values reported by BNM-LNE, PTB and METAS, used to calculate deviations of standards S1, S3, S4 and S5 from S2. Values reported by PTB for S3 at 100 kHz are drift-corrected to the date of calibration by METAS.

		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
NIST-PTB/1000V[1] (S1)	BNM-LNE	5.3	-1.9	-9.1	-33.6	-79
	PTB	-0.4	-3.8	-7.4	-23.4	-62.1
	PTB	-0.4	-3.9	-7.6	-23.1	-61.3
NIST-PTB/1000V[2] (S2)	PTB	-0.5	-3.8	-7.2	-21.9	-56.6
	BNM-LNE	7.4	0.4	-6.3	-30.4	-72.4
	METAS	-1.6	-4.1	-7.6	-21.7	-51
NIST-PTB/1000V[3] (S3)	PTB	0.3	1.5	12.2	87.5	**345.4**
	METAS	-1.3	1	11.4	88.7	351
METAS/1000V (S4)	BNM-LNE	5.7	3.9	7.9	48.6	216.2
	METAS	-0.6	2	9.7	59.8	241
	METAS	-1	1.6	9.4	59.8	241
	METAS	-0.6	2	9.4	59.7	241
	BNM-LNE	8	6.2	8.4	51	217.4
Supplementary condition		0	0	0	0	0

Table 3a : Values used to calculate deviations of standards S1, S3 and S4 from standard S2 at 1000 V (in µV/V)

		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
NIST-PTB/1000V[1] (S1)	BNM-LNE	1.8	-3.2	-6.8	-25.7	-67.7
	PTB	-0.6	-3	-7.4	-24.6	-67.9
	PTB	-0.5	-3	-7.5	-24.8	-67.4
NIST-PTB/1000V[2] (S2)	PTB	-0.5	-2.8	-7	-22.5	-60.5
	BNM-LNE	3.8	-1.3	-4.9	-22.8	-62.1
	METAS	2.2	-4.4	-7.9	-23.1	-58
NIST-PTB/1000V[3] (S3)	PTB	0.1	2.4	12.4	88	**340.5**
	METAS	-1.3	0.9	11.2	87.6	343
METAS/1000V (S4)	BNM-LNE	1.7	1.7	9.1	55.9	230.3
	METAS	-0.8	1.5	9.3	59.2	238
	METAS	-1.2	1.6	9.2	59.6	238
	METAS	-1.2	1.6	8.9	58.9	238
	BNM-LNE	3.4	3.5	10.6	56.8	229.7
NIST-PTB/500V (S5)	BNM-LNE	0.6	-1.1	-0.8	3.8	31.9
	METAS	-1.7	-1.2	-0.3	6.8	38
	METAS	-1.3	-1.1	-0.3	6.9	38
	METAS	-1.7	-1.3	-0.4	6.3	36
	BNM-LNE	3.9	1.3	2.1	5.8	31.9
Supplementary condition		0	0	0	0	0

Table 3b : Values used to calculate deviations of standards S1, S3, S4 and S5 from standard S2 at 500 V (in µV/V)

		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
NIST-PTB/1000V[1] (S1)	BNM-LNE	-1.6	-7.2	-9.1	-31.1	-76.5
	PTB	-0.5	-2.7	-8.3	-24.5	-67.9
	PTB	0	-3.3	-7.5	-24.2	-66.9
NIST-PTB/1000V[2] (S2)	PTB	-0.5	-3.3	-7.3	-22.7	-61.9
	BNM-LNE	2.9	-3.4	-6.3	-25.7	-70
	METAS	-2	-4.5	-8.2	-23.5	-61
NIST-PTB/1000V[3] (S3)	PTB	-0.1	2.6	12.5	87.3	**344.1**
	METAS	-1.5	1.1	11.2	88.2	345
NIST-PTB/500V (S5)	BNM-LNE	1.5	-1.2	0	3.8	29.6
	METAS	-1.2	-1.1	-0.3	6.9	38
	METAS	-1.4	-1.2	-0.2	6.9	38
	METAS	-1.6	-1.3	-0.5	6.6	37
	BNM-LNE	1.4	-1.3	-0.4	2.1	25.8
Supplementary condition		0	0	0	0	0

Table 3c : Values used to calculate deviations of standards S1, S3 and S5 from standard S2 at 200 V (in µV/V)

Each column corresponding to a measurement frequency represents the one column matrix [*MeasRESULTS*] for this frequency (see section 7). The bottom (additional) element (equal to 0) represents the supplementary condition for $K = 0$.

The preliminary values of AC-DC difference of the standards S1, S2, S3, S4, (S5) are given by the 4 (5) bottom elements of the one column matrix $({}^{T}[X].[X])^{-1}.{}^{T}[X].[MeasRESULTS]$. They are shown in table 3d.

Standard	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
Values at 1000 V					
S1	1.03	-3.39	-8.16	-26.55	-65.43
S2	1.77	-2.50	-7.03	-24.67	-60.00
S3	1.89	2.29	11.53	84.88	341.44
S4	2.25	3.10	9.12	56.29	230.84
Values at 500 V					
S1	0.20	-3.50	-7.42	-24.92	-66.31
S2	1.83	-2.83	-6.60	-22.80	-60.20
S3	0.51	1.92	12.13	87.26	340.45
S4	0.18	2.32	9.52	58.09	233.84
S5	-0.24	-0.34	0.16	5.93	34.20
Values at 200 V					
S1	-1.41	-5.09	-8.66	-26.84	-70.12
S2	0.13	-3.73	-7.27	-23.97	-64.30
S3	-0.18	1.44	11.86	86.30	341.46
S5	0.25	-0.52	0.04	5.77	34.02

Table 3d : Preliminary values (calculated with the condition $K = 0$, see paragraph 7) of the AC-DC transfer difference of travelling standards (in µV/V).

Deviations of the different travelling standards from the standard S2 are computed from values given in table 3d. They are presented in table 3e.

	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
	dSi - dS2	*U*	**dSi - dS2**	*U*	**dSi - dS2**	*U*	**dSi - dS2**	*U*	**dSi - dS2**	*U*
Deviation at 1000 V										
S1	**-0.7**	*1.6*	**-0.9**	*1.6*	**-1.1**	*1.6*	**-1.9**	*1.6*	**-5.4**	*1.6*
S3	**0.1**	*1.8*	**4.8**	*1.8*	**18.6**	*1.6*	**109.5**	*1.8*	**401.4**	*1.8*
S4	**0.5**	*1.6*	**5.6**	*1.6*	**16.2**	*1.4*	**81.0**	*1.6*	**290.8**	*1.4*
Deviation at 500 V										
S1	**-1.6**	*2.2*	**-0.7**	*1.6*	**-0.8**	*1.8*	**-2.1**	*1.6*	**-6.1**	*2.2*
S3	**-1.3**	*2.4*	**4.8**	*1.6*	**18.7**	*1.8*	**110.1**	*1.8*	**400.7**	*2.4*
S4	**-1.6**	*2.0*	**5.1**	*1.4*	**16.1**	*1.6*	**80.9**	*1.6*	**294.0**	*2.0*
S5	**-2.1**	*2.0*	**2.5**	*1.4*	**6.8**	*1.6*	**28.7**	*1.6*	**94.4**	*2.0*
Deviation at 200 V										
S1	**-1.5**	*2.2*	**-1.4**	*1.8*	**-1.4**	*1.2*	**-2.9**	*2.2*	**-5.8**	*2.4*
S3	**-0.3**	*2.2*	**5.2**	*1.8*	**19.1**	*1.4*	**110.3**	*2.2*	**405.8**	*2.4*
S5	**0.1**	*2.0*	**3.2**	*1.6*	**7.3**	*1.2*	**29.7**	*2.0*	**98.3**	*2.2*

Table 3e : Deviation of the different travelling standards from standard S2 and associated expanded uncertainties (µV/V)

Adjusted values

Adjusted values have been obtained by subtracting from the reported values (Tables 2a to 2d), the deviation of the measured standard from standard S2 (Table 3e). The standard uncertainty u_{adj} of the adjusted value has been computed using $u_{adj} = \sqrt{u_{rep}^2 + u_{dev}^2}$, u_{rep} being the reported standard uncertainty and u_{dev}, the standard uncertainty of the deviation of the measured standard. Tables 4a to 4d show the adjusted values (column "d") with the associated expanded uncertainty (column "U").

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			d	*U*	**d**	*U*	**d**	*U*	**d**	*U*	**d**	*U*
Travelling standard : NIST-PTB/1000V[1] (S1)												
1	BNM-LNE	France	**6.0**	*16.1*	**-1.0**	*35.0*	**-8.0**	*35.0*	**-31.7**	*69.0*	**-73.6**	*69.0*
2	DANIAmet-AREPA	Denmark	**4.7**	*21.1*	**1.9**	*21.1*	**0.1**	*26.0*	**-18.1**	*41.0*	**-52.6**	*81.0*
3	NPL	United Kingdom	**-0.3**	*13.1*	**-5.1**	*13.1*	**-10.9**	*23.1*	**-27.1**	*32.0*	**-63.6**	*62.0*
4	SP	Sweden	**2.7**	*9.1*	**0.9**	*10.1*	**-2.9**	*11.1*	**-15.1**	*15.1*	**-42.6**	*23.1*
5	IEN	Italy	**-0.7**	*14.9*	**-4.9**	*15.3*	**-11.8**	*25.1*	**-30.9**	*37.2*	**-66.5**	*79.4*
6	CEM	Spain	**-6.3**	*36.0*	**-2.1**	*40.0*	**-6.9**	*44.0*	**-36.1**	*64.0*	**-62.6**	*98.0*
Travelling standard : NIST-PTB/1000V[2] (S2)												
7	PTB	Germany	**-0.5**	*8.0*	**-3.8**	*8.0*	**-7.2**	*8.0*	**-21.9**	*10.0*	**-56.6**	*30.0*
8	VSL	The Netherlands	**3.0**	*20.0*	**-3.1**	*20.0*	**-10.1**	*25.0*	**-25.2**	*35.0*	**-61.4**	*50.0*
Travelling standard : METAS/1000V (S4)												
9	INTI	Argentina	**-4.5**	*14.1*	**-4.6**	*16.1*	**-10.2**	*20.0*	**-24.0**	*24.1*	**-55.8**	*40.0*
10	NMIA	Australia	**1.0**	*11.1*	**0.4**	*14.1*	**-2.2**	*16.1*	**-15.0**	*28.0*	**-40.8**	*41.0*
11	NRC	Canada	**0.5**	*10.1*	**1.4**	*10.1*	**0.8**	*10.1*	**-12.0**	*12.1*	**-53.8**	*24.0*
12	VNIIM	Russia	**-0.6**	*20.3*	**-3.0**	*20.7*	**-10.1**	*32.4*	**-42.2**	*51.6*	**-30.4**	*101.0*
13	METAS	Switzerland	**-1.5**	*6.2*	**-4.0**	*7.2*	**-6.8**	*7.1*	**-21.2**	*10.1*	**-49.8**	*28.0*
14	NIST	United States	**7.4**	*17.1*	**1.6**	*17.1*	**0.5**	*16.3*	**-23.2**	*21.5*	**-59.2**	*29.2*
15	NIM	China	**-0.8**	*24.3*	**-1.7**	*24.5*	**-3.8**	*29.2*	**-22.7**	*45.4*	**-72.7**	*59.6*

Table 4a : Adjusted values ("d") and associated expanded uncertainties ("U") at 1000 V
(in µV/V)

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			d	U	d	U	d	U	d	U	d	U
Travelling standard : NIST-PTB/1000V[1] (S1)												
1	BNM-LNE	France	3.4	13.2	-2.5	21.1	-6.0	21.1	-23.6	36.0	-61.6	36.1
2	DANIAmet-AREPA	Denmark	4.6	21.1	0.7	21.1	-3.2	21.1	-19.9	21.1	-53.9	41.1
3	NPL	United Kingdom	0.6	13.2	-7.3	13.1	-12.2	17.1	-28.9	24.1	-68.9	46.1
4	SP	Sweden	3.6	8.3	0.7	9.1	-4.2	10.2	-15.9	14.1	-48.9	21.1
5	IEN	Italy	1.0	9.7	-5.0	9.5	-12.3	14.1	-33.1	20.3	-74.3	47.7
6	CEM	Spain	-0.4	30.1	-3.3	30.0	-4.2	30.1	-26.9	38.0	-55.9	50.0
Travelling standard : NIST-PTB/1000V[2] (S2)												
7	PTB	Germany	-0.5	8.0	-2.8	8.0	-7.0	8.0	-22.5	10.0	-60.5	22.0
8	VSL	The Netherlands	2.6	15.0	-4.3	15.0	-9.2	20.0	-25.7	25.0	-63.8	40.0
Travelling standard : METAS/1000V (S4)												
9	INTI	Argentina	-1.4	12.2	-6.1	14.1	-9.1	16.1	-24.9	18.1	-63.0	30.1
10	NMIA	Australia	4.2	9.2	0.9	9.1	-2.1	10.1	-13.9	15.1	-46.0	23.1
11	NRC	Canada	2.6	9.0	0.9	8.7	-0.1	10.1	-12.9	10.7	-59.0	24.1
12	VNIIM	Russia	2.3	16.7	-2.2	17.1	-11.6	24.7	-41.0	40.6	-80.2	60.4
13	METAS	Switzerland	0.4	6.3	-3.5	6.2	-6.9	6.2	-21.3	9.1	-56.0	26.1
14	NIST	United States	5.9	11.2	1.1	10.7	-2.0	11.3	-25.0	14.1	-67.0	17.9
15	NIM	China	0.1	19.7	-3.6	19.6	-6.3	21.3	-24.9	29.2	-81.5	39.7

Table 4b : Adjusted values (“d”) and associated expanded uncertainties (“U”) at 500 V (Values in µV/V)

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			d	U	d	U	d	U	d	U	d	U
Travelling standard : NIST-PTB/500V (S5)												
9	INTI	Argentina	0.1	12.2	-5.5	14.1	-7.8	16.1	-21.7	18.1	-56.4	30.1
10	NMIA	Australia	3.0	9.2	-0.5	9.1	-2.8	10.1	-13.7	15.1	-42.4	23.1
11	NRC	Canada	3.1	10.2	0.5	10.1	-0.8	10.1	-11.7	16.1	-51.4	28.1
12	VNIIM	Russia	4.6	16.5	-0.6	16.9	-2.8	24.7	-14.3	40.8	-58.1	60.3
13	METAS	Switzerland	0.8	6.3	-3.6	6.2	-7.1	6.2	-21.8	9.1	-56.4	26.1
14	NIST	United States	5.6	9.4	0.8	9.7	-2.9	9.9	-25.4	13.1	-66.0	16.9
15	NIM	China	0.8	19.3	-4.5	19.3	-7.1	20.9	-21.6	29.0	-59.5	39.5

Table 4c : Adjusted values (“d”) and associated expanded uncertainties (“U”) at 500 V (optional) (Values in µV/V)

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			d	U	d	U	d	U	d	U	d	U
Travelling standard : NIST-PTB/1000V[1] (S1)												
1	BNM-LNE	France	-0.1	12.2	-5.8	13.1	-7.7	13.1	-28.2	16.2	-70.7	16.2
2	DANIAmet-AREPA	Denmark	3.5	11.2	0.4	11.1	-4.6	11.1	-23.1	11.2	-66.2	26.1
3	NPL	United Kingdom	6.5	12.2	-7.6	12.1	-9.6	14.1	-23.1	16.2	-61.2	20.1
4	SP	Sweden	3.5	7.3	2.4	8.2	-1.6	9.1	-18.1	13.2	-49.2	19.2
5	IEN	Italy	2.2	8.9	-3.6	9.0	-11.0	12.9	-31.8	18.3	-71.5	42.5
6	CEM	Spain	3.5	22.1	3.4	22.1	-0.6	22.0	-19.1	24.1	-54.2	28.9
Travelling standard : NIST-PTB/1000V[2] (S2)												
7	PTB	Germany	-0.5	8.0	-3.3	8.0	-7.3	8.0	-22.7	10.0	-61.9	22.0
8	VSL	The Netherlands										
Travelling standard : NIST-PTB/500V (S5)												
9	INTI	Argentina	-3.1	10.2	-5.2	10.1	-8.3	12.1	-23.7	16.1	-61.3	24.1
10	NMIA	Australia	-0.2	7.3	-2.2	7.2	-6.3	8.1	-19.7	11.2	-53.3	18.1
11	NRC	Canada	-0.1	10.2	-3.2	10.1	-4.3	10.1	-16.7	14.1	-56.3	22.7
12	VNIIM	Russia	2.4	12.8	-1.3	12.5	-3.3	20.2	-14.1	30.3	-61.0	40.5
13	METAS	Switzerland	-1.5	6.3	-4.4	6.2	-7.5	6.1	-22.8	9.2	-60.3	24.1
14	NIST	United States	5.4	5.9	1.0	6.0	-2.5	6.1	-20.3	8.1	-58.5	11.0
15	NIM	China	0.1	11.2	-5.6	11.1	-8.8	11.1	-24.4	12.4	-65.9	13.4

Table 4d : Adjusted values (“d”) and associated expanded uncertainties (“U”) at 200 V (Values in µV/V)

Reference value

The key comparison reference value d_{ref} at a given test point of the comparison and the associated uncertainty u_{ref} have been computed from the adjusted values using :

$$d_{ref} = \frac{\sum_i d_{adj,i} / (u_{adj,i})^2}{\sum_i 1/(u_{adj,i})^2} \quad \text{and} \quad u_{ref} = \sqrt{\frac{1}{\sum_i 1/(u_{adj,i})^2}}$$

where :

- $d_{adj,i}$ is the adjusted value for laboratory “L_i” ;
- $u_{adj,i}$ is the standard uncertainty of the adjusted value for laboratory “L_i”

All adjusted values have been taken into account in this calculation except the value of DANIAmet-AREPA, which is traceable to PTB at these levels. Correlation which may exist between some participants at voltage levels of 1 V – 3 V has not been considered because of the large number of measurements in the step-up procedure, which makes the realisations at voltages above 100 V mainly independent. The reference values for the different voltage levels and measurement frequencies with associated expanded uncertainties are given in tables 5a to 5c.

1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
d	*U*	**d**	*U*	**d**	*U*	**d**	*U*	**d**	*U*
0.2	*3.1*	**-2.3**	*3.4*	**-5.2**	*3.7*	**-19.9**	*5.0*	**-53.1**	*10.0*

Table 5a : Reference value (“d”) and associated expanded uncertainty (“U”) at 1000 V (Values in µV/V)

1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
d	*U*	**d**	*U*	**d**	*U*	**d**	*U*	**d**	*U*
1.8	*2.8*	**-2.2**	*2.8*	**-5.8**	*3.2*	**-20.9**	*4.2*	**-59.9**	*7.6*

Table 5b : Reference value (“d”) and associated expanded uncertainty (“U”) at 500 V (Values in µV/V)

1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
d	*U*	**d**	*U*	**d**	*U*	**d**	*U*	**d**	*U*
1.4	*2.4*	**-2.5**	*2.5*	**-5.9**	*2.6*	**-21.9**	*3.5*	**-60.4**	*5.3*

Table 5c : Reference value (“d”) and associated expanded uncertainty (“U”) at 200 V (Values in µV/V)

Final results

Final results (degree of equivalence between each laboratory and the reference value) are expressed as the deviation of the adjusted values (see tables 4a to 4d) from the reference value. The final uncertainty u_{fin} (uncertainty of the degree of equivalence with the reference value) was computed from $u_{fin} = \sqrt{u_{adj}^2 - u_{ref}^2}$, u_{adj} being the uncertainty of the adjusted value and u_{ref} the uncertainty of the reference value. This relation, has been established in appendix C of the guidelines for the evaluation of key comparison data (WGKC/2002-27 document published by he CCEM) for laboratories whose independent results contributed to the key comparison reference value. For a laboratory whose result did not contribute to the KCRV but which is traceable to an other laboratory that contributes to the KCRV as it is the case for

DANIAmet-AREPA traceable to PTB, if it can be assumed that the reported uncertainty by DANIAmet-AREPA is mainly due to the uncertainty of the calibration at PTB, it is reasonable to express the results of these two laboratories as $d_{DANIAmet} = d'_{DANIAmet} + d_{PTB}$, where $d'_{DANIAmet}$ and d_{PTB} are mutually independent. Then :

$$\mathrm{var}\left(d_{DANIAmet} - d_{ref}\right) = \mathrm{var}(d_{DANIAmet}) + \mathrm{var}(d_{ref}) - 2\,\mathrm{cov}(d_{DANIAmet}, d_{ref}) \quad \text{and}$$

$$\mathrm{cov}(d_{DANIAmet}, d_{ref}) = \mathrm{cov}(d_{DANIAmet}, \sum_{j=1}^{n} g_j . d_j) = \mathrm{cov}(d'_{DANIAmet} + d_{PTB}, \sum_{j=1}^{n} g_j . d_j)$$

$$= \mathrm{cov}(d'_{DANIAmet}, \sum_{j=1}^{n} g_j . d_j) + \mathrm{cov}(d_{PTB}, \sum_{j=1}^{n} g_j . d_j) = 0 + \mathrm{cov}(d_{PTB}, g_{PTB} . d_{PTB} + \sum_{\substack{j=1 \\ j \neq PTB}}^{n} g_j . d_j)$$

$$= \mathrm{cov}(d_{PTB}, g_{PTB} . d_{PTB}) + \mathrm{cov}(d_{PTB}, \sum_{\substack{j=1 \\ j \neq PTB}}^{n} g_j . d_j) = g_{PTB} . \mathrm{cov}(d_{PTB}, d_{PTB}) + 0 = g_{PTB} . \mathrm{var}(d_{PTB}) = \mathrm{var}(d_{ref})$$

g_j (resp. g_{PTB}) being the normalized weight of laboratory j (resp. PTB) ($g_j = \dfrac{1/\mathrm{var}(d_j)}{1/\mathrm{var}(d_{ref})}$).

This finally gives :

$$\mathrm{var}(d_{DANIAmet} - d_{ref}) = \mathrm{var}(d_{DANIAmet}) - \mathrm{var}(d_{ref}) \quad \text{and then} \quad u_{fin-DANIAmet} = \sqrt{u^2_{adj-DANIAmet} - u^2_{ref}}$$

Tables 6a to 6d present the final results (column “d”) with the associated uncertainties (column “U”). Graphs 1 to 20 show the same results in a graphical form.

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			D	*U*	**D**	*U*	**D**	*U*	**D**	*U*	**D**	*U*
Travelling standard : NIST-PTB/1000V[1] (S1)												
1	BNM-LNE	France	**5.8**	*15.8*	**1.3**	*34.8*	**-2.8**	*34.8*	**-11.8**	*68.8*	**-20.5**	*68.3*
2	DANIAmet-AREPA	Denmark	**4.5**	*20.9*	**4.2**	*20.8*	**5.3**	*25.7*	**1.8**	*40.7*	**0.5**	*80.4*
3	NPL	United Kingdom	**-0.5**	*12.7*	**-2.8**	*12.7*	**-5.7**	*22.8*	**-7.2**	*31.6*	**-10.5**	*61.2*
4	SP	Sweden	**2.5**	*8.6*	**3.2**	*9.5*	**2.3**	*10.5*	**4.8**	*14.2*	**10.5**	*20.8*
5	IEN	Italy	**-0.9**	*14.6*	**-2.6**	*14.9*	**-6.6**	*24.8*	**-11.0**	*36.9*	**-13.4**	*78.8*
6	CEM	Spain	**-6.5**	*35.9*	**0.2**	*39.9*	**-1.7**	*43.8*	**-16.2**	*63.8*	**-9.5**	*97.5*
Travelling standard : NIST-PTB/1000V[2] (S2)												
7	PTB	Germany	**-0.7**	*7.4*	**-1.5**	*7.2*	**-2.0**	*7.1*	**-2.0**	*8.7*	**-3.5**	*28.3*
8	VSL	The Netherlands	**2.8**	*19.8*	**-0.8**	*19.7*	**-4.9**	*24.7*	**-5.3**	*34.6*	**-8.3**	*49.0*
Travelling standard : METAS/1000V (S4)												
9	INTI	Argentina	**-4.7**	*13.8*	**-2.3**	*15.7*	**-5.0**	*19.7*	**-4.1**	*23.6*	**-2.7**	*38.7*
10	NMIA	Australia	**0.8**	*10.7*	**2.7**	*13.7*	**3.0**	*15.7*	**4.9**	*27.5*	**12.3**	*39.8*
11	NRC	Canada	**0.3**	*9.6*	**3.7**	*9.5*	**6.0**	*9.4*	**7.9**	*11.0*	**-0.7**	*21.8*
12	VNIIM	Russia	**-0.8**	*20.1*	**-0.7**	*20.4*	**-4.9**	*32.2*	**-22.3**	*51.4*	**22.7**	*100.5*
13	METAS	Switzerland	**-1.7**	*5.4*	**-1.7**	*6.3*	**-1.6**	*6.1*	**-1.3**	*8.8*	**3.3**	*26.2*
14	NIST	United States	**7.2**	*16.8*	**3.9**	*16.8*	**5.7**	*15.9*	**-3.3**	*20.9*	**-6.1**	*27.4*
15	NIM	China	**-1.0**	*24.1*	**0.6**	*24.3*	**1.4**	*29.0*	**-2.8**	*45.1*	**-19.6**	*58.8*

Table 6a : Degree of equivalence with KCRV (“D”) and expanded uncertainties (“U”) at 1000 V (in µV/V)

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			D	*U*	**D**	*U*	**D**	*U*	**D**	*U*	**D**	*U*
Travelling standard : NIST-PTB/1000V[1] (S1)												
1	BNM-LNE	France	**1.6**	*12.9*	**-0.3**	*20.9*	**-0.2**	*20.9*	**-2.7**	*35.8*	**-1.7**	*35.3*
2	DANIAmet-AREPA	Denmark	**2.8**	*20.9*	**2.9**	*20.9*	**2.6**	*20.9*	**1.0**	*20.7*	**6.0**	*40.4*
3	NPL	United Kingdom	**-1.2**	*12.9*	**-5.1**	*12.8*	**-6.4**	*16.8*	**-8.0**	*23.7*	**-9.0**	*45.5*
4	SP	Sweden	**1.8**	*7.8*	**2.9**	*8.7*	**1.6**	*9.7*	**5.0**	*13.5*	**11.0**	*19.7*
5	IEN	Italy	**-0.8**	*9.3*	**-2.8**	*9.1*	**-6.5**	*13.7*	**-12.2**	*19.9*	**-14.4**	*47.1*
6	CEM	Spain	**-2.2**	*30.0*	**-1.1**	*29.9*	**1.6**	*29.9*	**-6.0**	*37.8*	**4.0**	*49.4*
Travelling standard : NIST-PTB/1000V[2] (S2)												
7	PTB	Germany	**-2.3**	*7.5*	**-0.6**	*7.5*	**-1.2**	*7.3*	**-1.6**	*9.1*	**-0.6**	*20.6*
8	VSL	The Netherlands	**0.8**	*14.7*	**-2.1**	*14.7*	**-3.4**	*19.7*	**-4.8**	*24.6*	**-3.9**	*39.3*
Travelling standard : METAS/1000V (S4)												
9	INTI	Argentina	**-3.2**	*11.9*	**-3.9**	*13.8*	**-3.3**	*15.8*	**-4.0**	*17.6*	**-3.1**	*29.1*
10	NMIA	Australia	**2.4**	*8.8*	**3.1**	*8.7*	**3.7**	*9.6*	**7.0**	*14.5*	**13.9**	*21.8*
11	NRC	Canada	**0.8**	*8.6*	**3.1**	*8.2*	**5.7**	*9.6*	**8.0**	*9.8*	**0.9**	*22.9*
12	VNIIM	Russia	**0.5**	*16.5*	**0.0**	*16.9*	**-5.8**	*24.5*	**-20.1**	*40.4*	**-20.3**	*59.9*
13	METAS	Switzerland	**-1.4**	*5.6*	**-1.3**	*5.5*	**-1.1**	*5.3*	**-0.4**	*8.1*	**3.9**	*25.0*
14	NIST	United States	**4.1**	*10.8*	**3.3**	*10.3*	**3.8**	*10.8*	**-4.1**	*13.5*	**-7.1**	*16.2*
15	NIM	China	**-1.7**	*19.5*	**-1.4**	*19.4*	**-0.5**	*21.1*	**-4.0**	*28.9*	**-21.6**	*39.0*

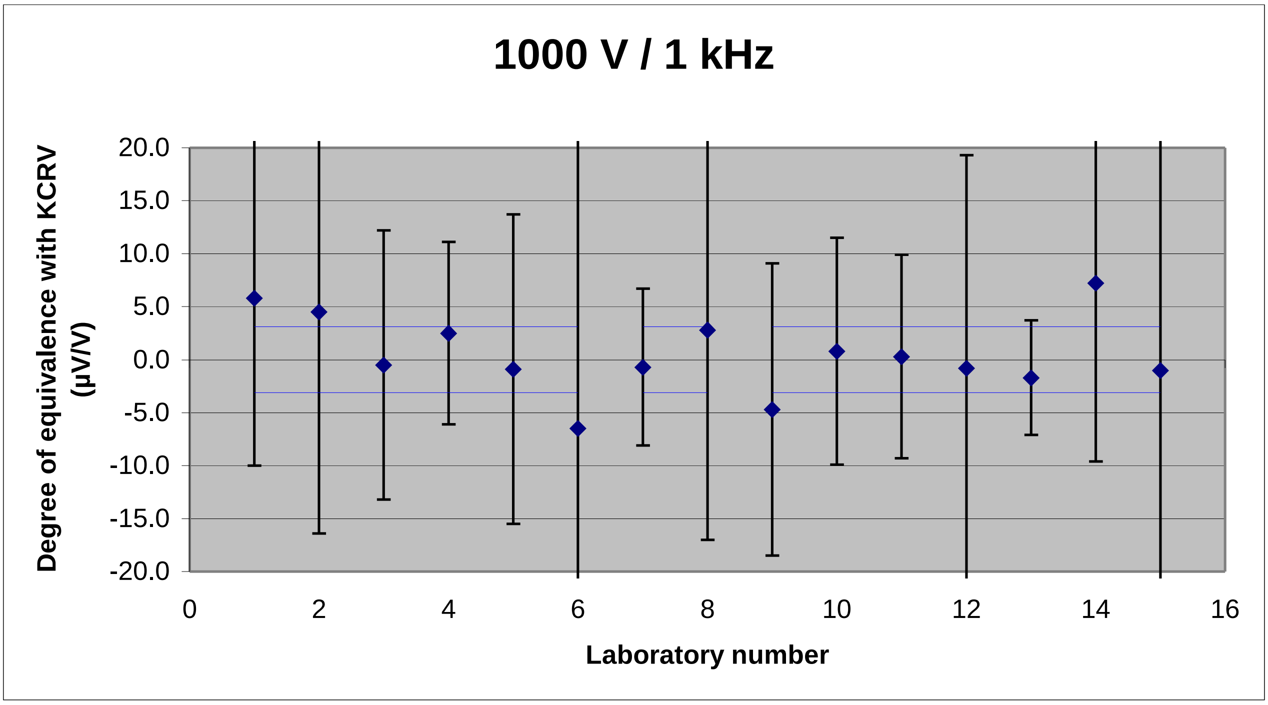
Table 6b : Degree of equivalence with KCRV (“D”) and expanded uncertainties (“U”) at 500 V (in µV/V)

	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			D	*U*	**D**	*U*	**D**	*U*	**D**	*U*	**D**	*U*
Travelling standard : NIST-PTB/500V (S5)												
9	INTI	Argentina	**-1.7**	*11.9*	**-3.3**	*13.8*	**-2.0**	*15.8*	**-0.8**	*17.6*	**3.5**	*29.1*
10	NMIA	Australia	**1.2**	*8.8*	**1.7**	*8.7*	**3.0**	*9.6*	**7.2**	*14.5*	**17.5**	*21.8*
11	NRC	Canada	**1.3**	*9.8*	**2.7**	*9.7*	**5.0**	*9.6*	**9.2**	*15.5*	**8.5**	*27.1*
12	VNIIM	Russia	**2.8**	*16.3*	**1.6**	*16.7*	**3.0**	*24.5*	**6.6**	*40.6*	**1.8**	*59.8*
13	METAS	Switzerland	**-1.0**	*5.6*	**-1.4**	*5.5*	**-1.3**	*5.3*	**-0.9**	*8.1*	**3.5**	*25.0*
14	NIST	United States	**3.8**	*9.0*	**3.0**	*9.3*	**2.9**	*9.4*	**-4.5**	*12.4*	**-6.1**	*15.1*
15	NIM	China	**-1.0**	*19.1*	**-2.3**	*19.1*	**-1.3**	*20.7*	**-0.7**	*28.7*	**0.4**	*38.8*

Table 6c : Degree of equivalence with KCRV (“D”) and expanded uncertainties (“U”) at 500 V (optional) (in µV/V)

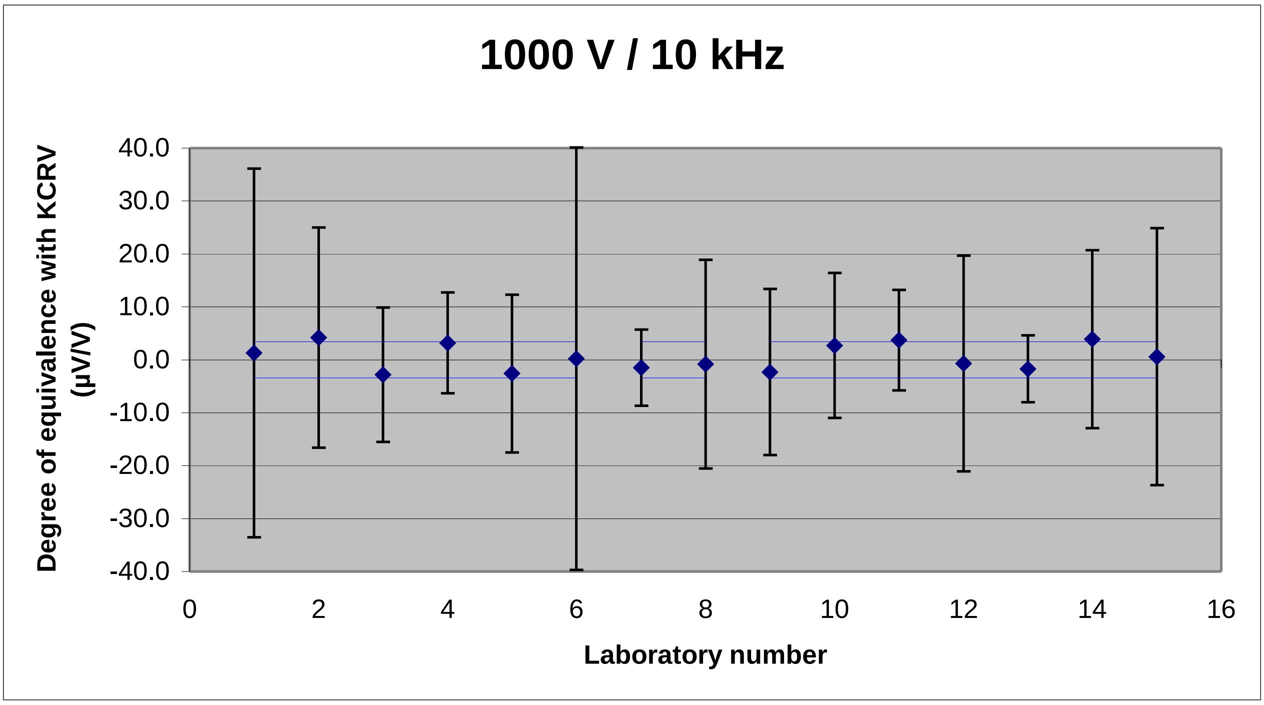
	LABORATORY	COUNTRY	1 kHz		10 kHz		20 kHz		50 kHz		100 kHz	
			D	*U*	**D**	*U*	**D**	*U*	**D**	*U*	**D**	*U*
Travelling standard : NIST-PTB/1000V[1] (S1)												
1	BNM-LNE	France	**-1.5**	*12.0*	**-3.3**	*12.9*	**-1.8**	*12.8*	**-6.3**	*15.8*	**-10.3**	*15.3*
2	DANIAmet-AREPA	Denmark	**2.1**	*10.9*	**2.9**	*10.8*	**1.3**	*10.8*	**-1.2**	*10.6*	**-5.8**	*25.6*
3	NPL	United Kingdom	**5.1**	*12.0*	**-5.1**	*11.8*	**-3.7**	*13.9*	**-1.2**	*15.8*	**-0.8**	*19.4*
4	SP	Sweden	**2.1**	*6.9*	**4.9**	*7.8*	**4.3**	*8.7*	**3.8**	*12.7*	**11.2**	*18.5*
5	IEN	Italy	**0.8**	*8.6*	**-1.1**	*8.6*	**-5.1**	*12.6*	**-9.9**	*18.0*	**-11.1**	*42.2*
6	CEM	Spain	**2.1**	*22.0*	**5.9**	*22.0*	**5.3**	*21.8*	**2.8**	*23.8*	**6.2**	*28.4*
Travelling standard : NIST-PTB/1000V[2] (S2)												
7	PTB	Germany	**-1.9**	*7.6*	**-0.8**	*7.6*	**-1.4**	*7.6*	**-0.8**	*9.4*	**-1.5**	*21.4*
8	VSL	The Netherlands										
Travelling standard : NIST-PTB/500V (S5)												
9	INTI	Argentina	**-4.5**	*9.9*	**-2.7**	*9.8*	**-2.4**	*11.8*	**-1.8**	*15.7*	**-0.9**	*23.5*
10	NMIA	Australia	**-1.6**	*6.9*	**0.3**	*6.8*	**-0.4**	*7.7*	**2.2**	*10.6*	**7.1**	*17.3*
11	NRC	Canada	**-1.5**	*9.9*	**-0.7**	*9.8*	**1.6**	*9.8*	**5.2**	*13.7*	**4.1**	*22.1*
12	VNIIM	Russia	**1.0**	*12.6*	**1.2**	*12.2*	**2.6**	*20.0*	**7.8**	*30.1*	**-0.6**	*40.2*
13	METAS	Switzerland	**-2.9**	*5.8*	**-1.9**	*5.7*	**-1.6**	*5.5*	**-0.9**	*8.5*	**0.1**	*23.5*
14	NIST	United States	**4.0**	*5.4*	**3.5**	*5.5*	**3.4**	*5.5*	**1.6**	*7.3*	**1.9**	*9.6*
15	NIM	China	**-1.3**	*10.9*	**-3.1**	*10.8*	**-2.9**	*10.8*	**-2.5**	*11.9*	**-5.5**	*12.3*

Table 6d : Degree of equivalence with KCRV (“D”) and expanded uncertainties (“U”) at 200 V (in µV/V)



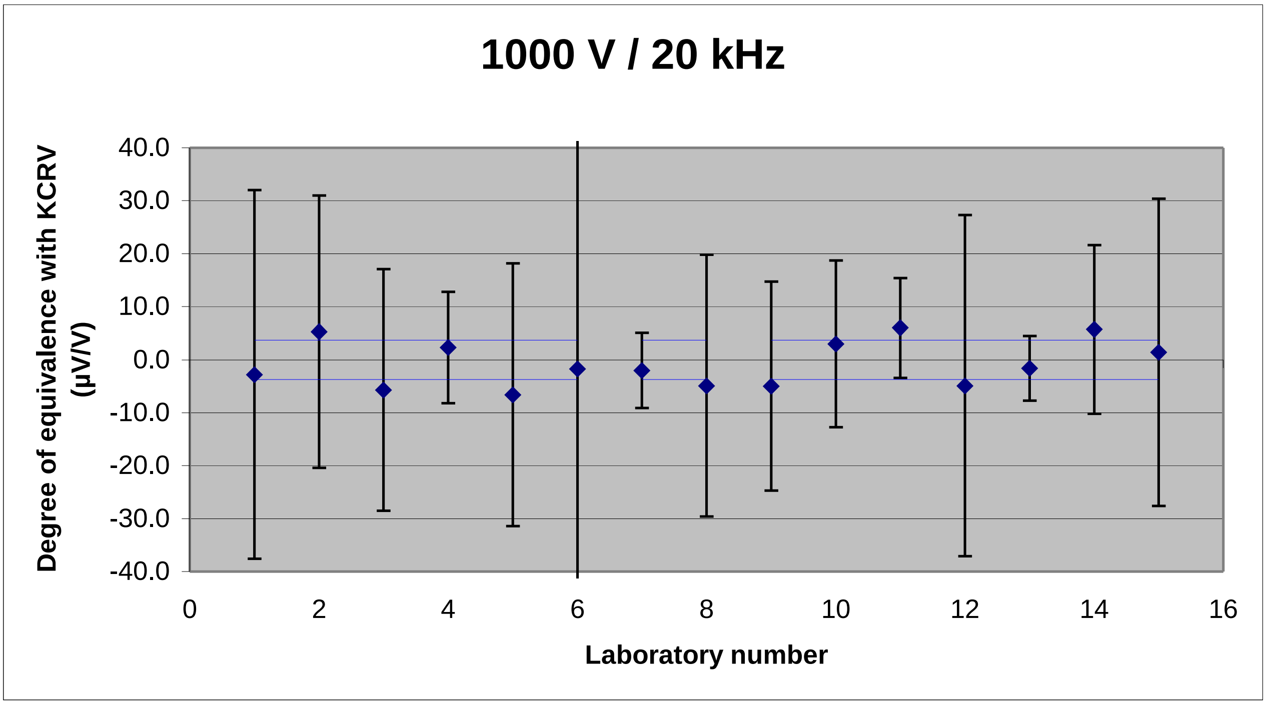
Graph 1 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 1000 V / 1 kHz

At 1000 V / 1 kHz, all reported expanded uncertainties overlap the reference value. Results of 5 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for most of the participants (12/15).



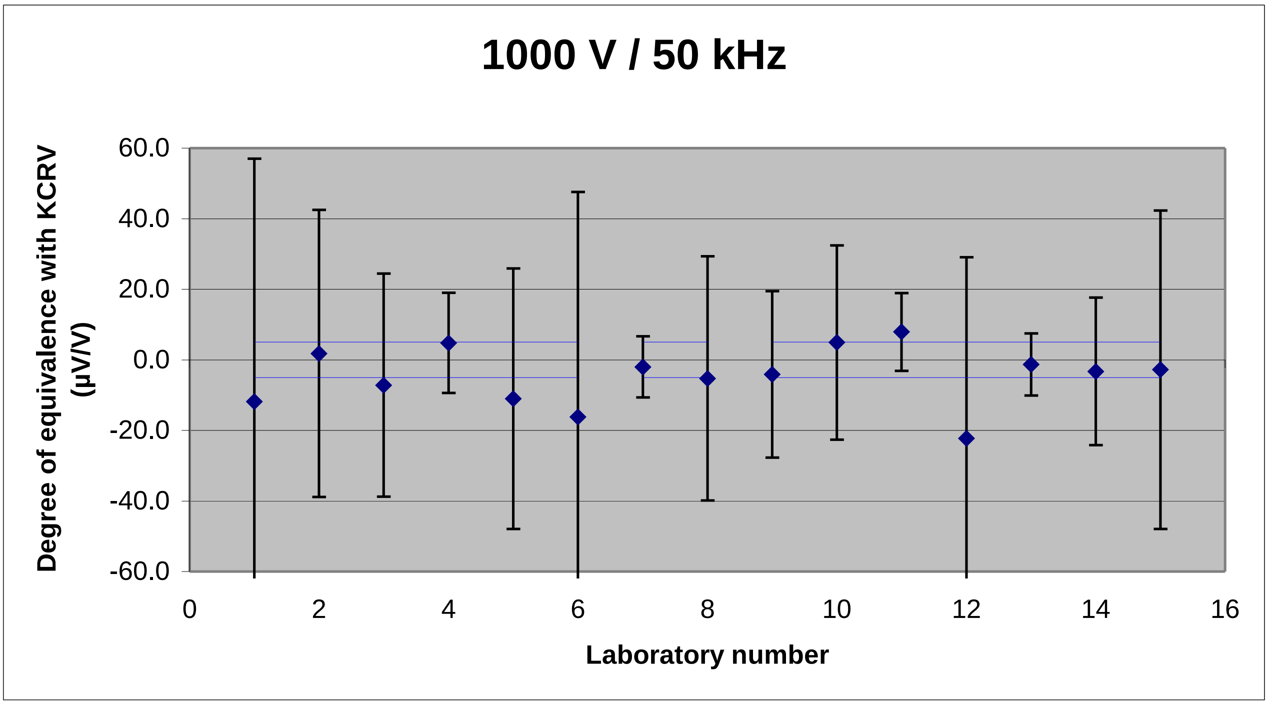
Graph 2 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 1000 V / 10 kHz

At 1000 V / 10 kHz, all given expanded uncertainties overlap the reference value. Results of 3 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for all the participants.



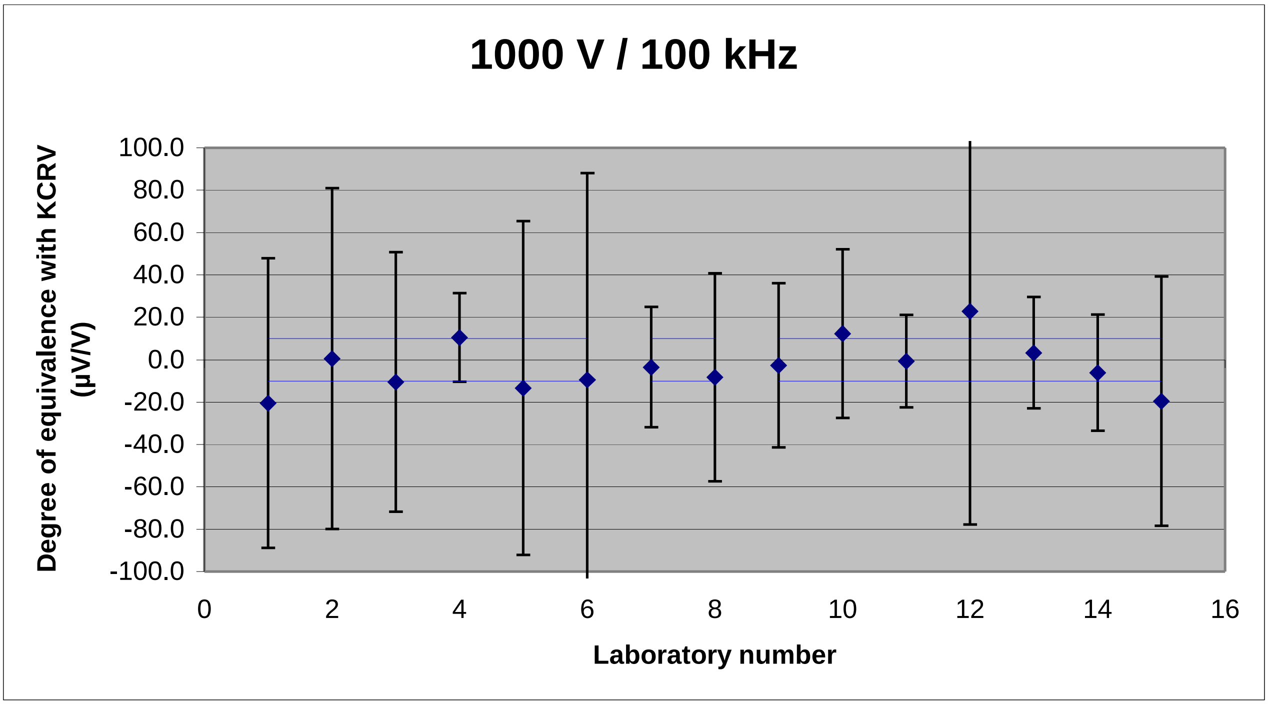
Graph 3 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 1000 V / 20 kHz

At 1000 V / 20 kHz, all given expanded uncertainties overlap the reference value. Results of 8 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for most of the participants (9/15).



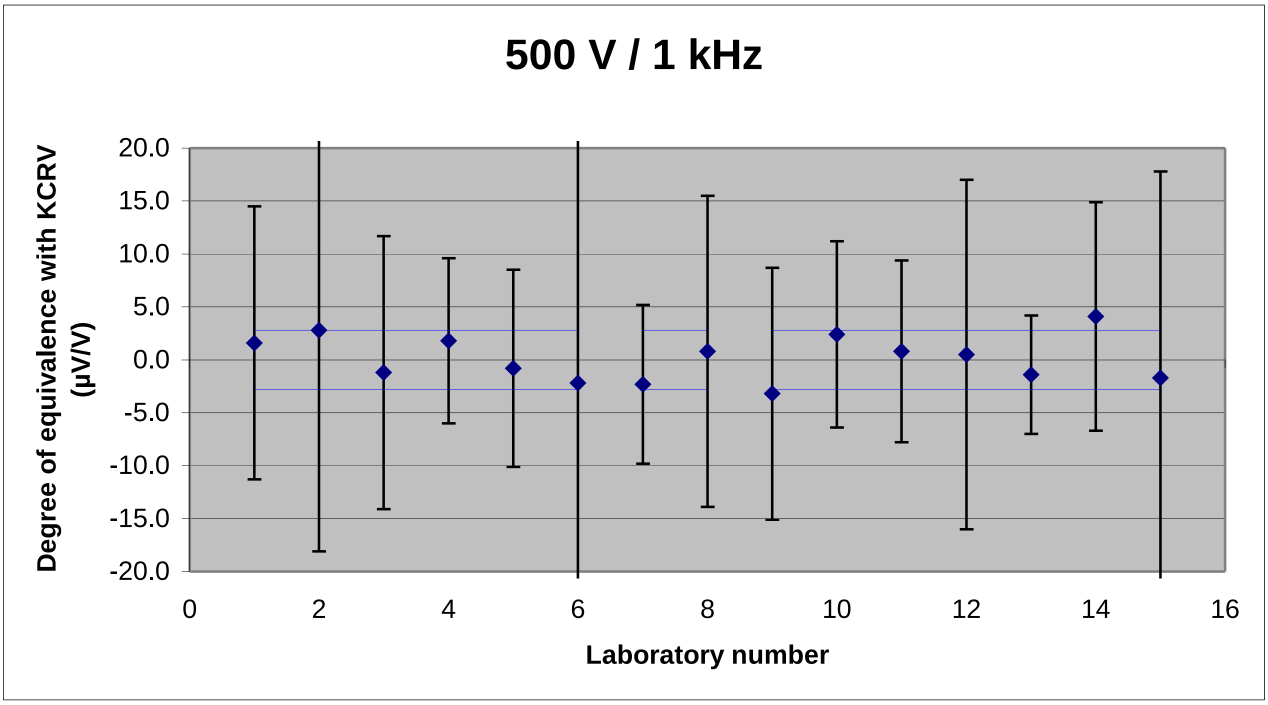
Graph 4 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 1000 V / 50 kHz

At 1000 V / 50 kHz, all given expanded uncertainties overlap the reference value. Results of 7 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 8 µV/V for most of the participants (11/15).



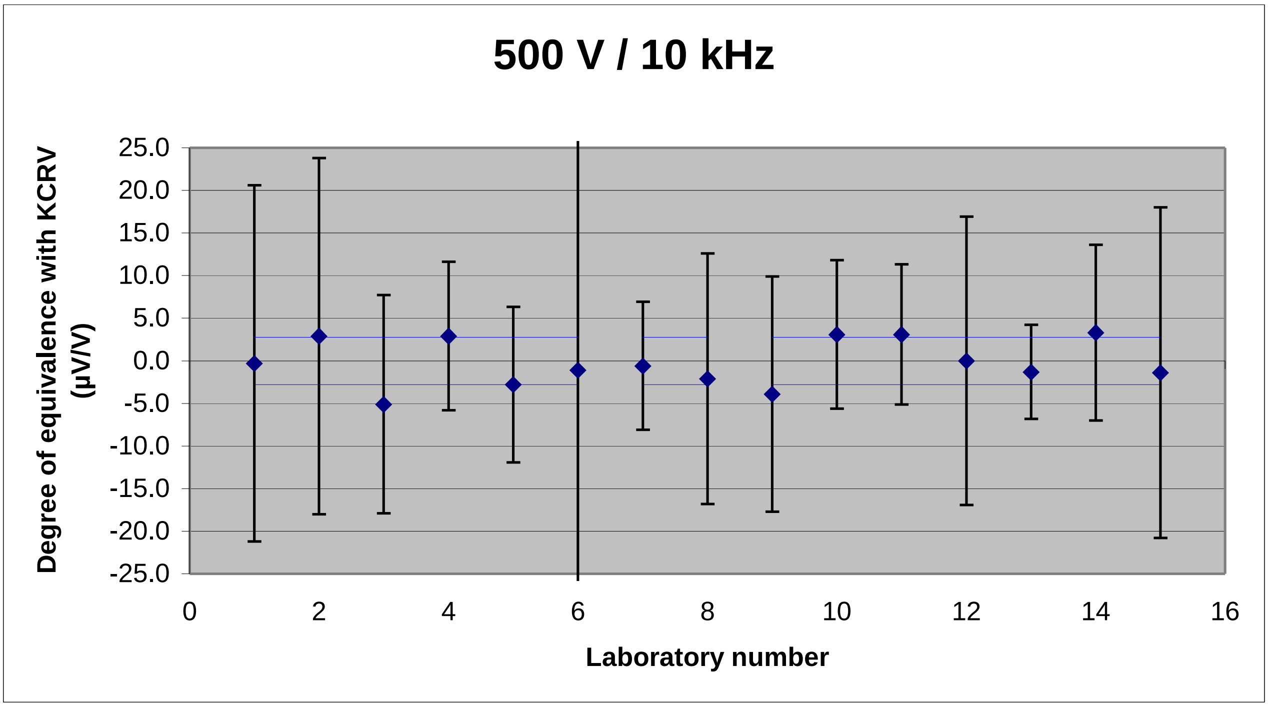
Graph 5 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 1000 V / 100 kHz

At 1000 V / 100 kHz, all given expanded uncertainties overlap the reference value. Results of 7 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 15 µV/V for most of the participants (12/15).



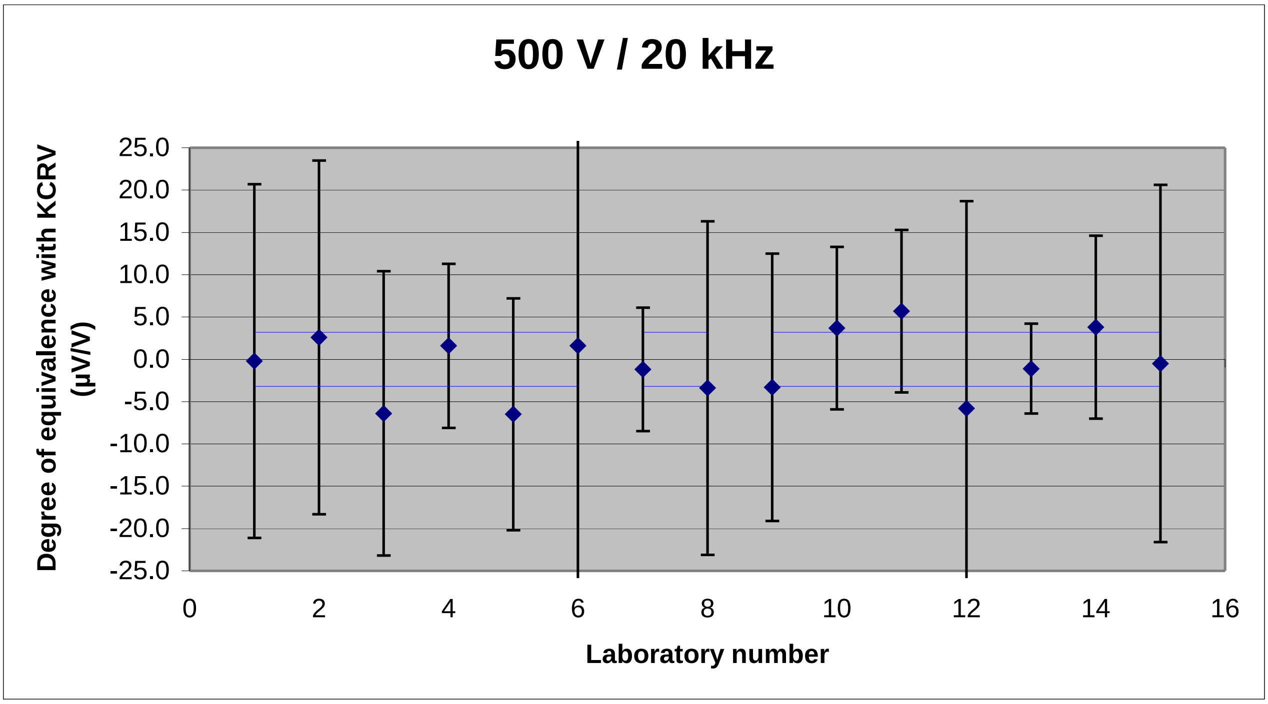
Graph 6 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 1 kHz

At 500 V / 1 kHz, all given expanded uncertainties overlap the reference value. Results of 2 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for all the participants.



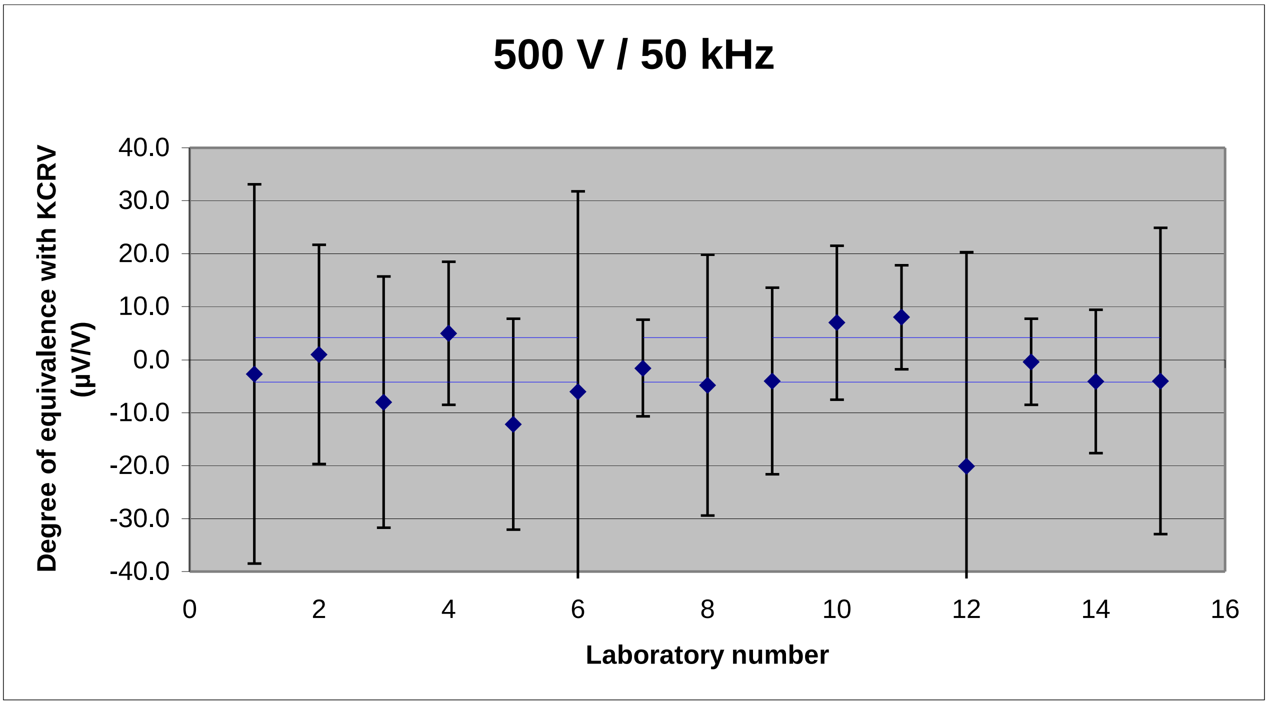
Graph 7 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 10 kHz

At 500 V / 10 kHz, all given expanded uncertainties overlap the reference value. Results of 7 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for most of the participants (14/15).



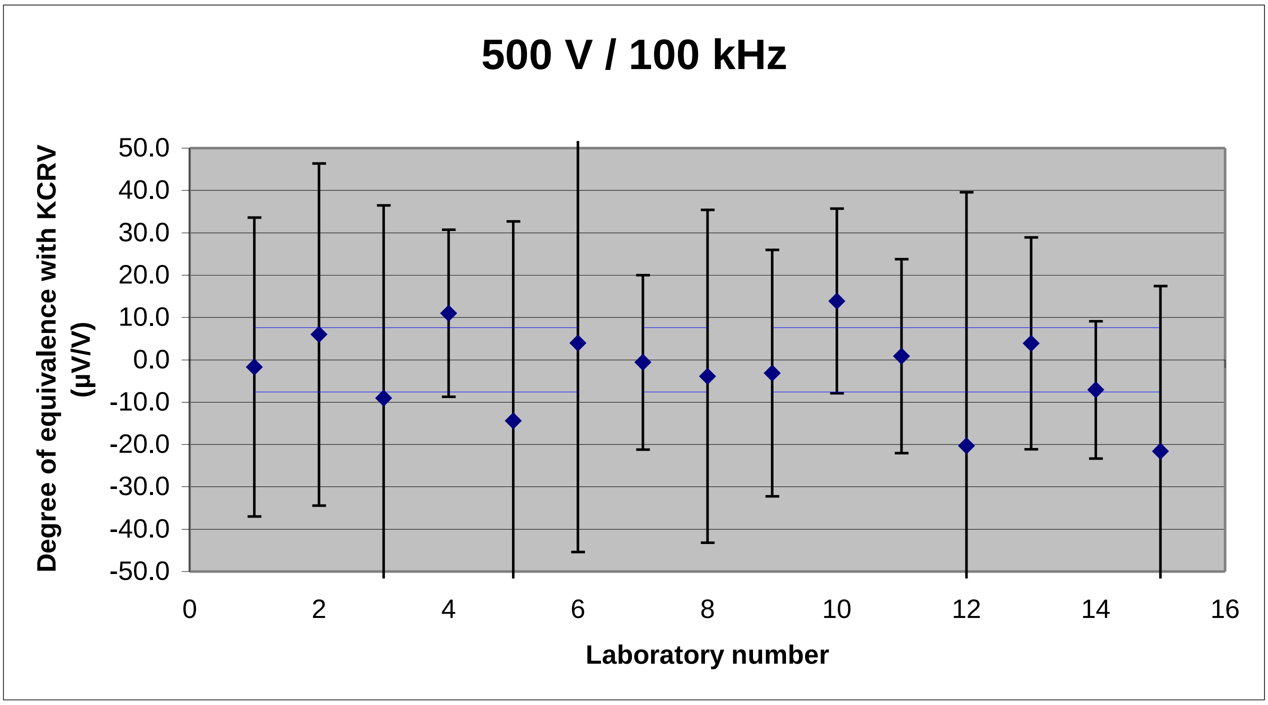
Graph 8 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 20 kHz

At 500 V / 20 kHz, all given expanded uncertainties overlap the reference value. Results of 8 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for most of the participants (11/15).



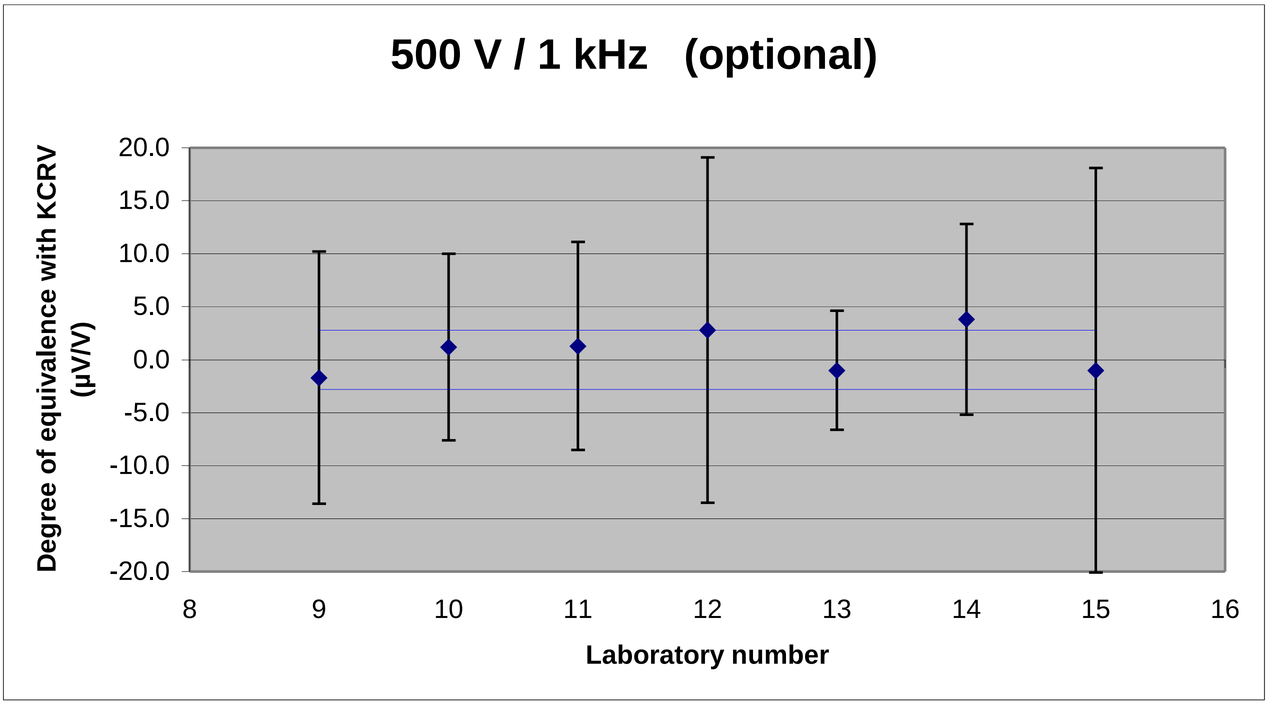
Graph 9 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 50 kHz

At 500 V / 50 kHz, all given expanded uncertainties overlap the reference value. Results of 8 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 10 µV/V for most of the participants (13/15).



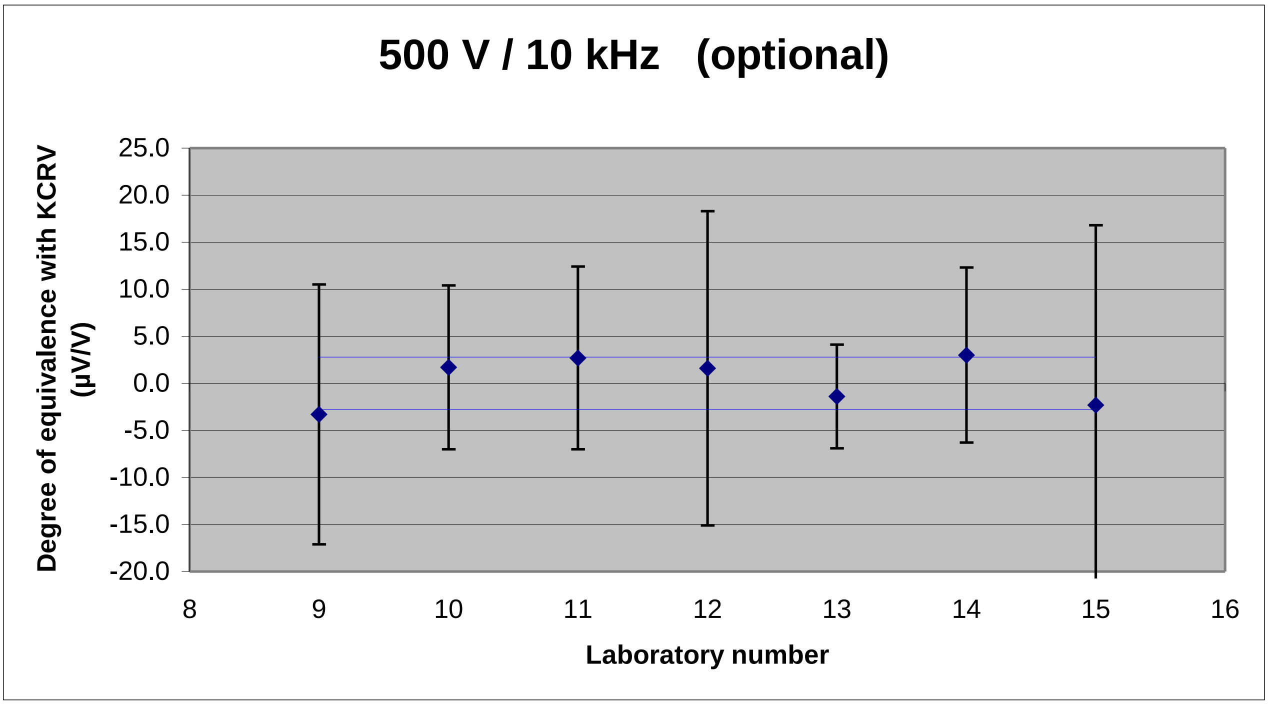
Graph 10 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 100 kHz

At 500 V / 100 kHz, all given expanded uncertainties overlap the reference value. Results of 6 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 10 µV/V for most of the participants (10/15).



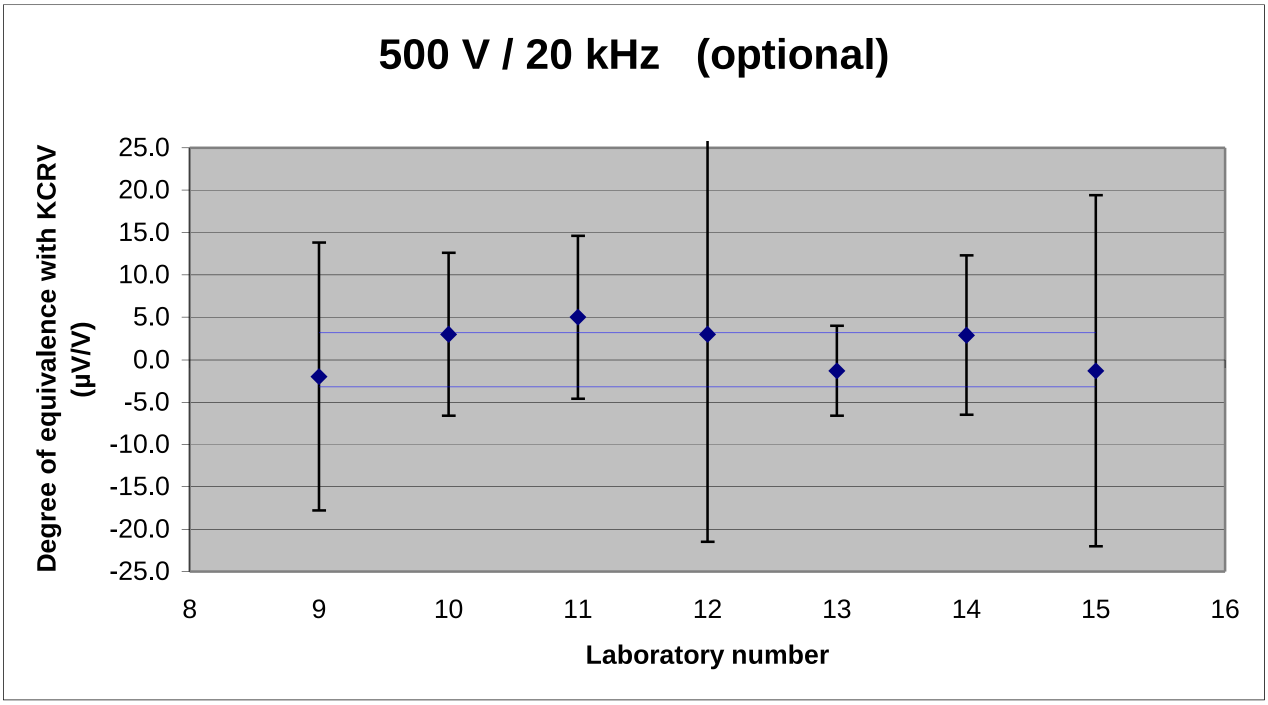
Graph 11 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 1 kHz (optional)

Optional measurements at 500 V / 1 kHz show an agreement better than 4 µV/V of all the participants with the reference value. All given expanded uncertainty overlap the reference value.



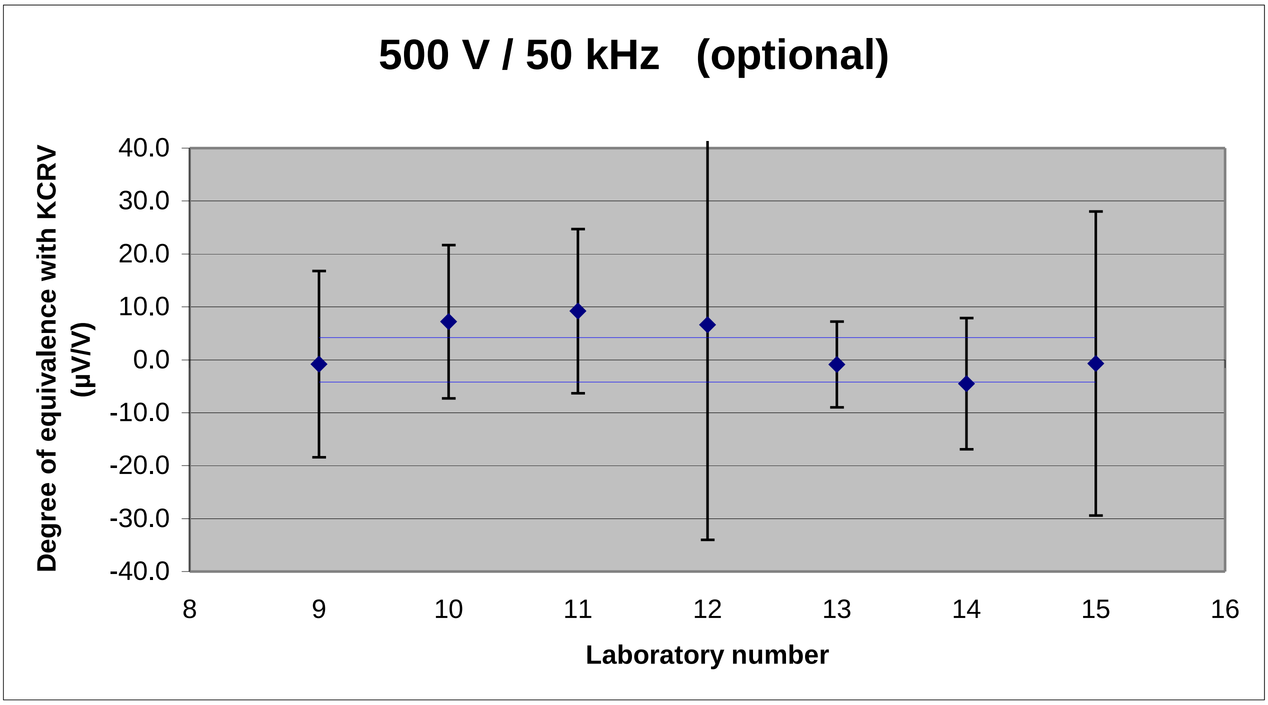
Graph 12 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 10 kHz (optional)

Optional measurements at 500 V / 10 kHz show an agreement better than 4 µV/V of all the participants with the reference value. All given expanded uncertainty overlap the reference value.



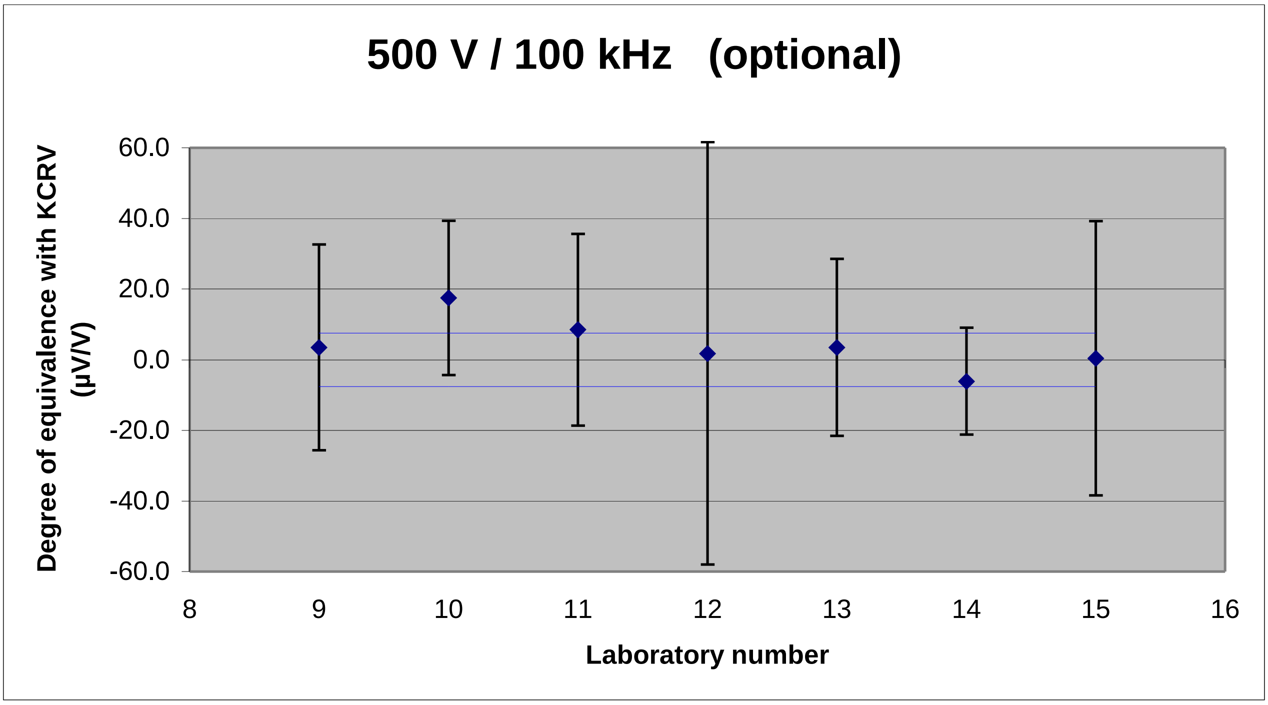
Graph 13 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 20 kHz (optional)

Optional measurements at 500 V / 20 kHz show an agreement better than 5 µV/V most of the participants (6/7) with the reference value. All given expanded uncertainty overlap the reference value.



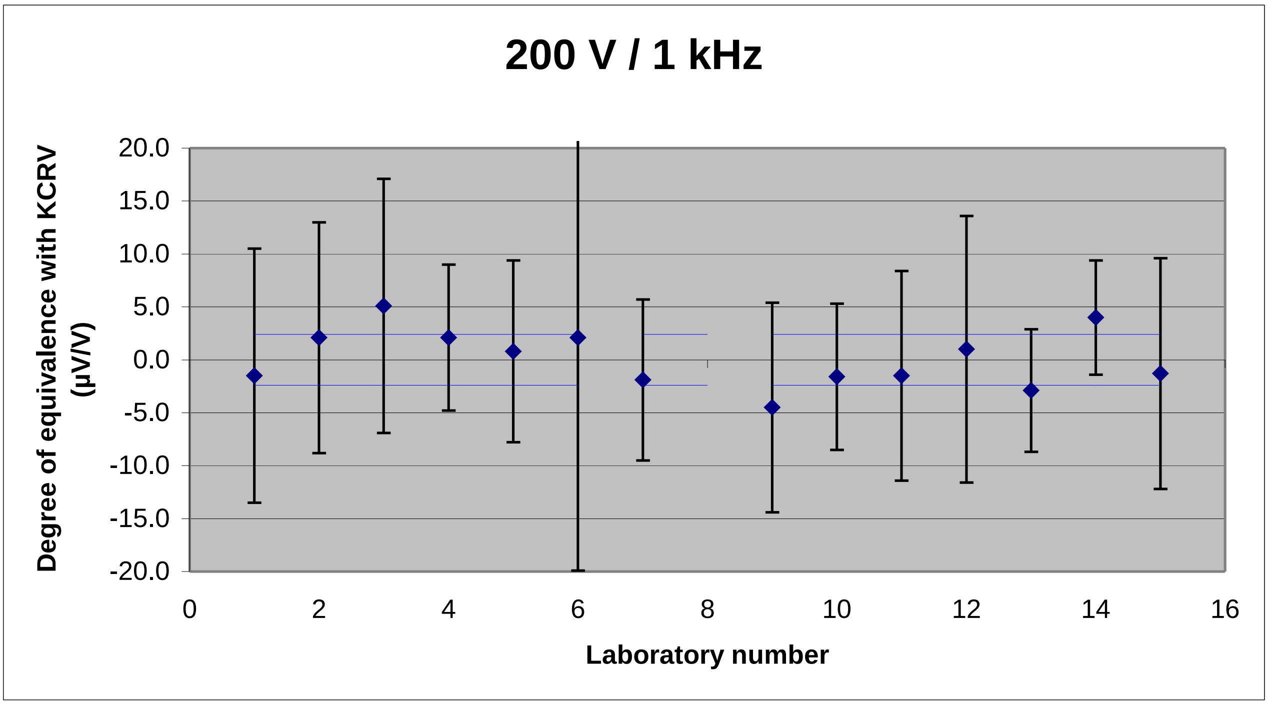
Graph 14 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 50 kHz (optional)

Optional measurements at 500 V / 50 kHz show an agreement better than 10 µV/V of all the participants with the reference value. All given expanded uncertainty overlap the reference value.



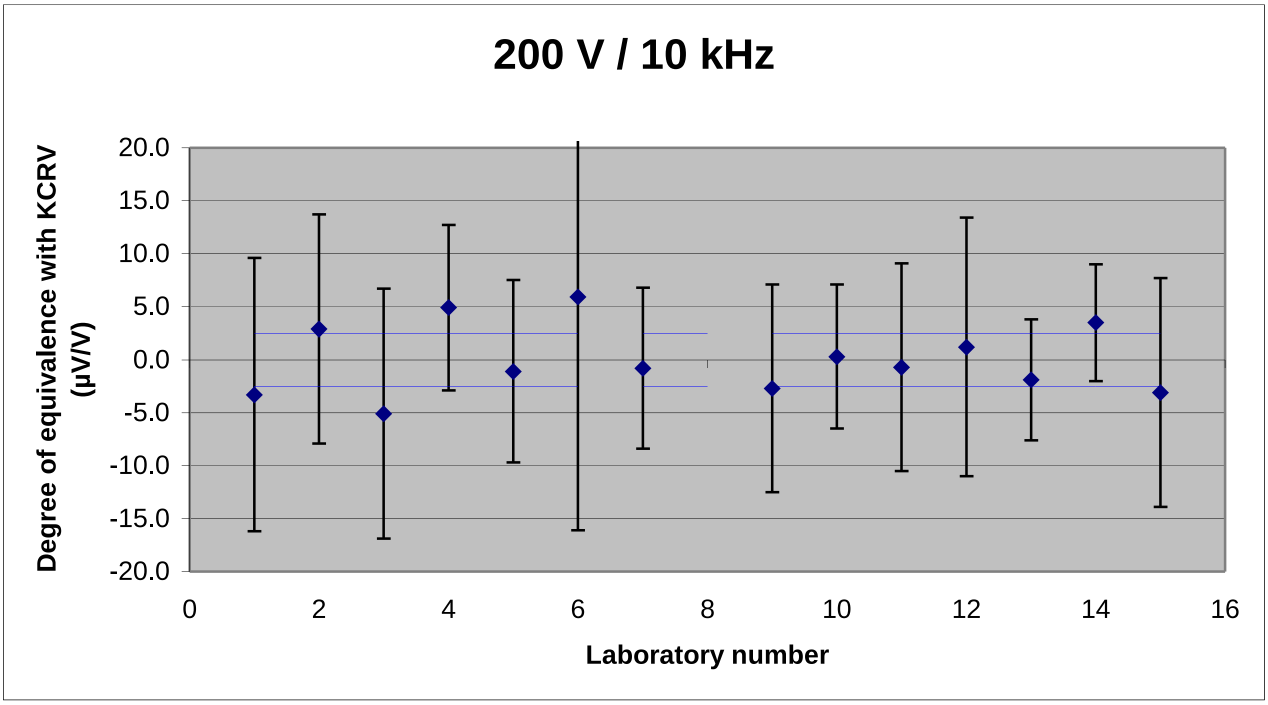
Graph 15 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 500 V / 100 kHz (optional)

Optional measurements at 500 V / 100 kHz show an agreement better than 10 µV/V of most of the participants (6/7) with the reference value. All given expanded uncertainty overlap the reference value.



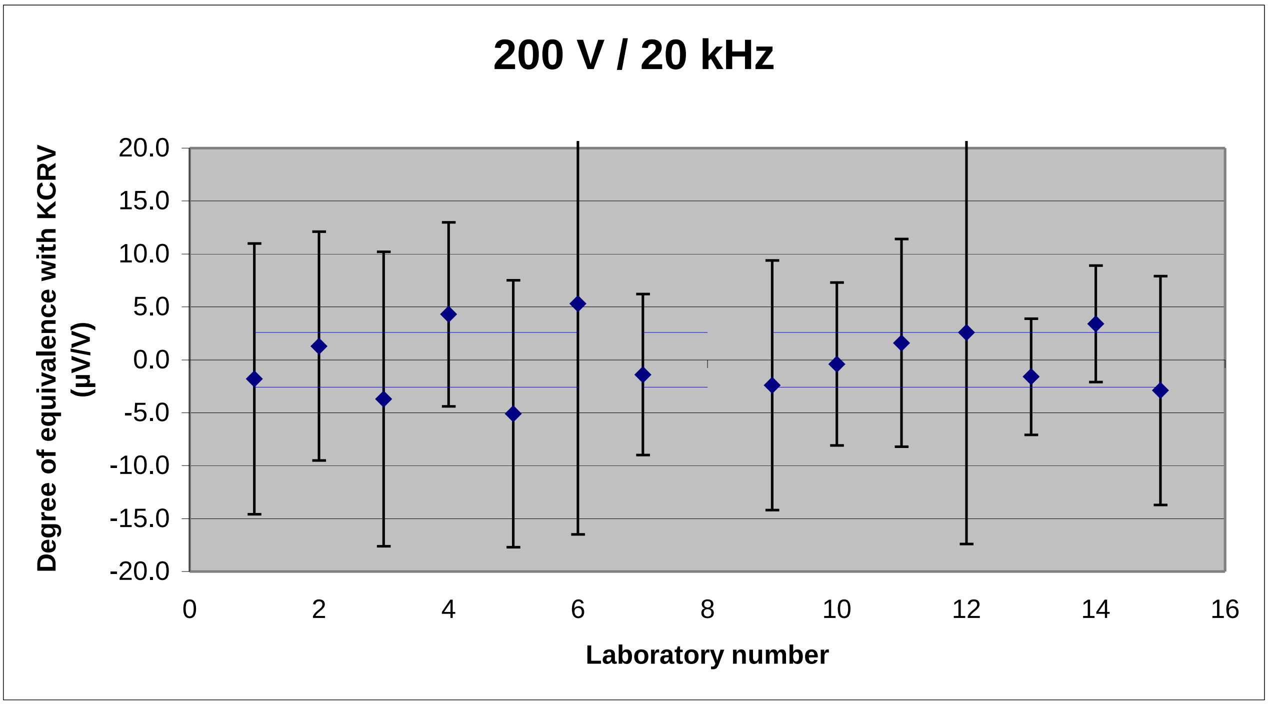
Graph 16 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 200 V / 1 kHz

At 200 V / 1 kHz, all given expanded uncertainties overlap the reference value. Results of 4 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for most of the participants (13/14).



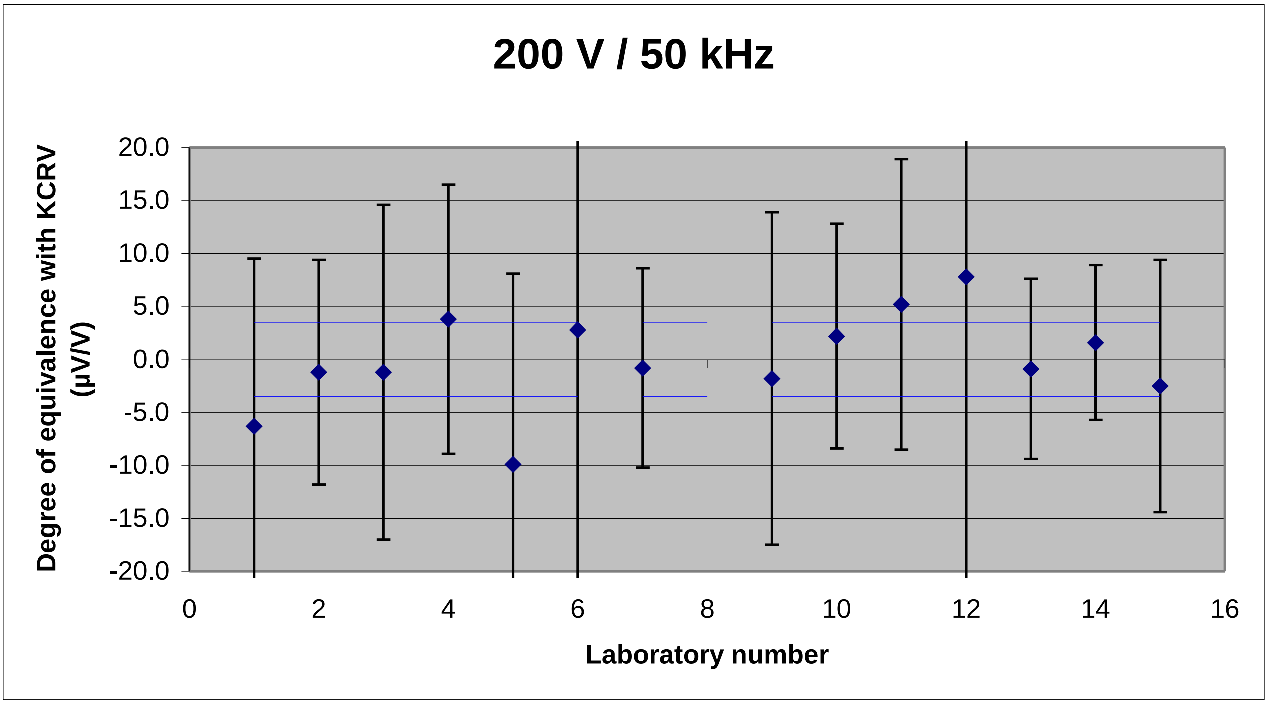
Graph 17 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 200 V / 10 kHz

At 200 V / 10 kHz, all given expanded uncertainties overlap the reference value. Results of 8 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for most of the participants (12/14).



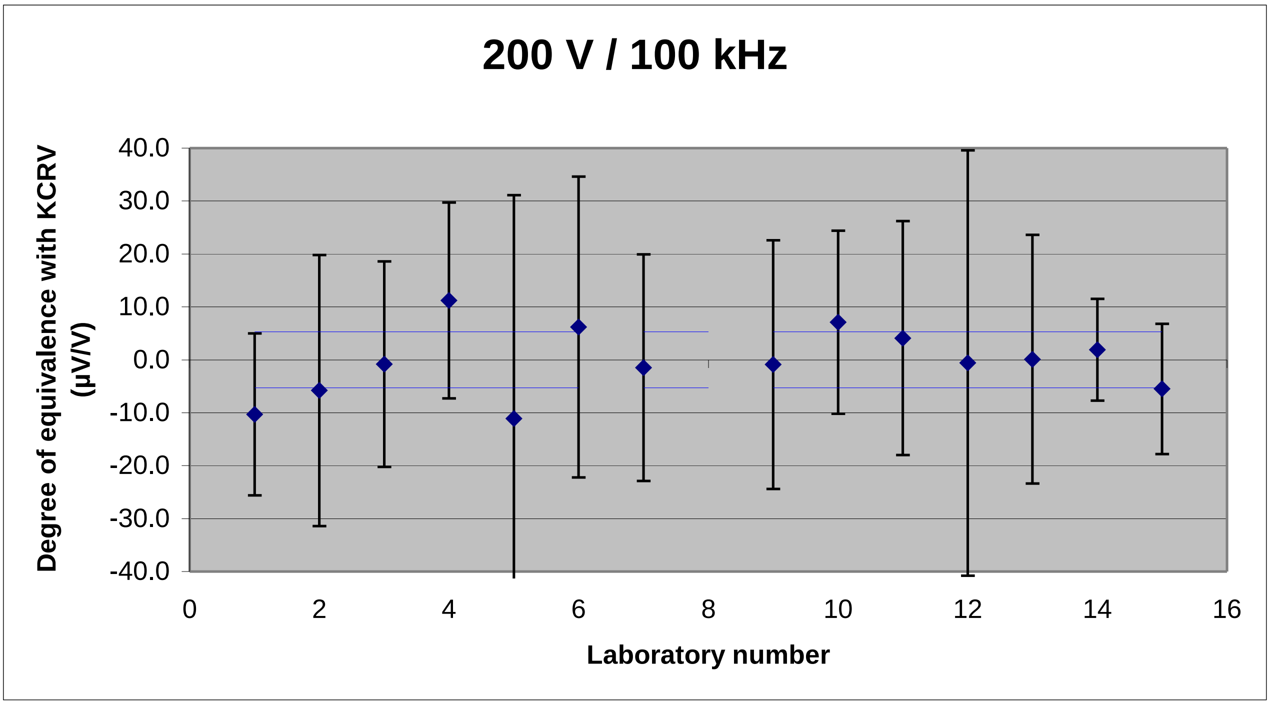
Graph 18 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 200 V / 20 kHz

At 200 V / 20 kHz, all given expanded uncertainties overlap the reference value. Results of 6 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for most of the participants (12/14).



Graph 19 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 200 V / 50 kHz

At 200 V / 50 kHz, all given expanded uncertainties overlap the reference value. Results of 5 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 5 µV/V for most of the participants (10/14).



Graph 20 : Degree of equivalence with KCRV and corresponding expanded uncertainty at 200 V / 100 kHz

At 200 V / 100 kHz, all given expanded uncertainties overlap the reference value. Results of 7 participants deviate from the KCRV by more than the reference uncertainty. The agreement with the reference value is better than 10 µV/V for most of the participants (11/14).

Consistency of the results

A chi-squared test has been applied to carry out an overall consistency check of the results obtained. For each measurement point (voltage // frequency), the observed chi-squared value χ_{obs}^2 has been computed from $\chi_{obs}^2 = \sum_{i=1}^{i=N} \frac{(x_i - x_{ref})^2}{u_{std}^2(x_i)}$ where

- x_i is the adjusted value for laboratory "*i*";
- x_{ref}, the reference value;
- $u_{std}(x_i)$, the standard uncertainty of the adjusted value;
- *N*, the number of laboratories taken into account in the test (all laboratories except DANIAmet-AREPA which is dependent from PTB).

The degree of freedom ν has been taken equal to $\nu = N - 1$.

The consistency check is considered as failing if $\Pr\{\chi^2(\nu) > \chi_{obs}^2\} < 5\%$, where "Pr" denotes "probability of".

Computed values are presented in Table 7.

Frequency	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
1000 V					
chi-obs^2	2.5725	2.0556	3.7206	4.4476	2.8568
ν	13	13	13	13	13
Probability	**99.91%**	**99.97%**	**99.38%**	**98.54%**	**99.84%**
500 V					
chi-obs^2	2.0165	3.3219	4.5059	7.4529	5.5305
ν	13	13	13	13	13
Probability	**99.98%**	**99.65%**	**98.45%**	**87.73%**	**96.16%**
200 V					
chi-obs^2	5.2062	5.1752	4.3486	3.5790	5.0057
ν	12	12	12	12	12
Probability	**95.07%**	**95.19%**	**97.63%**	**98.99%**	**95.78%**

Table 7 : Results of the chi-squared test

The chi-squared test confirms the consistency of the results of this comparison for all measurement points.

9) Conclusion

In December 2002, key comparison CCEM-K9 of AC-DC voltage transfer standards at voltage levels of 200 V, 500 V and 1000 V was completed. Travelling standards were supplied by PTB, NIST and METAS. The NIST-PTB standards were based on PTB planar MJTCs associated with high voltage range resistors for FLUKE 792 A. One standard, based on a single junction thermal converter, was developed and supplied by METAS.

The results show agreement with the reference value of all the participating NMIs within their given expanded uncertainties. This agreement is in the order of 5 µV/V at 1 kHz for all voltages and in the order of 15 µV/V at 1000 V / 100 kHz. Works performed in recent years at a number of NMIs in the high voltage AC-DC transfer area certainly greatly contributed to these good results.

Tables of the degree of equivalence of all participants are given in appendix 1.

10) Acknowledgment

The effort made by all colleagues participating in this comparison to show their best measurement capabilities and to adhere to the time schedule is gratefully acknowledged. NIST, PTB and METAS are also acknowledged for having supplied the travelling standards. Particular acknowledgment is addressed to Manfred KLONZ, Marc FLUELI, Karl Erik RYDLER and Peter FILIPSKI for the help they provided to the pilot laboratory in the organization of this comparison and the analysis of the results.

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APPENDIX 1

Degree of equivalence between pairs of laboratories

In the MRA, the estimation of the degree of equivalence will be used to express the relationship between each pair of participating laboratories.

The degree of equivalence between any pair of mutually independent laboratories *i* and *j* is given by:

$$D_{i,j} = d_i - d_j \quad \text{and} \quad U(D_{i,j}) = \sqrt{U^2(d_i) + U^2(d_j)}$$

where :

- d_i and d_j are the adjusted values for laboratories *i* and *j*;
- $U(d_i)$ and $U(d_j)$ the expanded uncertainties of these values.

In case of two mutually dependent laboratories (DANIAmet-AREPA and PTB) it is given by :

$$D_{i,j} = d_i - d_j \quad \text{and} \quad U(D_{i,j}) = \sqrt{\left| U^2(d_i) - U^2(d_j) \right|}$$

Tables 1a to 3t give the degrees of equivalence between all the pairs of participating laboratories.

Voltage : 1000 V			BNM-LNE		DANIAmet-AREPA		NPL		SP	
Frequency : 1 kHz			$d_{\mathrm{adj}\,j}$	$u(d_{adj\,j})$	$d_{\mathrm{adj}\,j}$	$u(d_{adj\,j})$	$d_{\mathrm{adj}\,j}$	$u(d_{adj\,j})$	$d_{\mathrm{adj}\,j}$	$u(d_{adj\,j})$
(1/4)			6.0	16.1	4.7	21.1	-0.3	13.1	2.7	9.1
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{\mathrm{adj}\,i}$	$u(d_{adj\,i})$								
BNM-LNE	6.0	16.1			1.3	26.6	6.3	20.8	3.3	18.5
DANIAmet-AREPA	4.7	21.1	-1.3	26.6			5.0	24.9	2.0	23.0
NPL	-0.3	13.1	-6.3	20.8	-5.0	24.9			-3.0	16.0
SP	2.7	9.1	-3.3	18.5	-2.0	23.0	3.0	16.0		
IEN	-0.7	14.9	-6.7	22.0	-5.4	25.9	-0.4	19.9	-3.4	17.5
CEM	-6.3	36.0	-12.3	39.5	-11.0	41.8	-6.0	38.4	-9.0	37.2
PTB	-0.5	8.0	-6.5	18.0	-5.2	19.6	-0.2	15.4	-3.2	12.2
VSL	3.0	20.0	-3.0	25.7	-1.7	29.1	3.3	24.0	0.3	22.0
INTI	-4.5	14.1	-10.5	21.5	-9.2	25.4	-4.2	19.3	-7.2	16.8
NMIA	1.0	11.1	-5.0	19.6	-3.7	23.9	1.3	17.2	-1.7	14.4
NRC	0.5	10.1	-5.5	19.1	-4.2	23.4	0.8	16.6	-2.2	13.6
VNIIM	-0.6	20.3	-6.6	26.0	-5.3	29.3	-0.3	24.2	-3.3	22.3
METAS	-1.5	6.2	-7.5	17.3	-6.2	22.0	-1.2	14.5	-4.2	11.1
NIST	7.4	17.1	1.4	23.5	2.7	27.2	7.7	21.6	4.7	19.4
NIM	-0.8	24.3	-6.8	29.2	-5.5	32.2	-0.5	27.7	-3.5	26.0

Table 1a : Degree of equivalence at 1000 V / 1 kHz (1/4)

Voltage : 1000 V			IEN		CEM		PTB		VSL	
Frequency : 1 kHz			$d_{\mathrm{adj}\,j}$	$u(d_{adj\,j})$	$d_{\mathrm{adj}\,j}$	$u(d_{adj\,j})$	$d_{\mathrm{adj}\,j}$	$u(d_{adj\,j})$	$d_{\mathrm{adj}\,j}$	$u(d_{adj\,j})$
(2/4)			-0.7	14.9	-6.3	36.0	-0.5	8.0	3.0	20.0
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{\mathrm{adj}\,i}$	$u(d_{adj\,i})$								
BNM-LNE	6.0	16.1	6.7	22.0	12.3	39.5	6.5	18.0	3.0	25.7
DANIAmet-AREPA	4.7	21.1	5.4	25.9	11.0	41.8	5.2	19.6	1.7	29.1
NPL	-0.3	13.1	0.4	19.9	6.0	38.4	0.2	15.4	-3.3	24.0
SP	2.7	9.1	3.4	17.5	9.0	37.2	3.2	12.2	-0.3	22.0
IEN	-0.7	14.9			5.6	39.0	-0.2	17.0	-3.7	25.0
CEM	-6.3	36.0	-5.6	39.0			-5.8	36.9	-9.3	41.2
PTB	-0.5	8.0	0.2	17.0	5.8	36.9			-3.5	21.6
VSL	3.0	20.0	3.7	25.0	9.3	41.2	3.5	21.6		
INTI	-4.5	14.1	-3.8	20.6	1.8	38.7	-4.0	16.3	-7.5	24.5
NMIA	1.0	11.1	1.7	18.6	7.3	37.7	1.5	13.7	-2.0	22.9
NRC	0.5	10.1	1.2	18.1	6.8	37.4	1.0	12.9	-2.5	22.5
VNIIM	-0.6	20.3	0.1	25.2	5.7	41.4	-0.1	21.9	-3.6	28.5
METAS	-1.5	6.2	-0.8	16.2	4.8	36.6	-1.0	10.2	-4.5	21.0
NIST	7.4	17.1	8.1	22.7	13.7	39.9	7.9	18.9	4.4	26.4
NIM	-0.8	24.3	-0.1	28.6	5.5	43.5	-0.3	25.6	-3.8	31.5

Table 1b : Degree of equivalence at 1000 V / 1 kHz (2/4)

Voltage : 1000 V **Frequency : 1 kHz** (3/4)			**INTI**		**NMIA**		**NRC**		**VNIIM**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-4.5	*14.1*	1.0	*11.1*	0.5	*10.1*	-0.6	*20.3*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	6.0	*16.1*	**10.5**	***21.5***	**5.0**	***19.6***	**5.5**	***19.1***	**6.6**	***26.0***
DANIAmet-AREPA	4.7	*21.1*	**9.2**	***25.4***	**3.7**	***23.9***	**4.2**	***23.4***	**5.3**	***29.3***
NPL	-0.3	*13.1*	**4.2**	***19.3***	**-1.3**	***17.2***	**-0.8**	***16.6***	**0.3**	***24.2***
SP	2.7	*9.1*	**7.2**	***16.8***	**1.7**	***14.4***	**2.2**	***13.6***	**3.3**	***22.3***
IEN	-0.7	*14.9*	**3.8**	***20.6***	**-1.7**	***18.6***	**-1.2**	***18.1***	**-0.1**	***25.2***
CEM	-6.3	*36.0*	**-1.8**	***38.7***	**-7.3**	***37.7***	**-6.8**	***37.4***	**-5.7**	***41.4***
PTB	-0.5	*8.0*	**4.0**	***16.3***	**-1.5**	***13.7***	**-1.0**	***12.9***	**0.1**	***21.9***
VSL	3.0	*20.0*	**7.5**	***24.5***	**2.0**	***22.9***	**2.5**	***22.5***	**3.6**	***28.5***
INTI	-4.5	*14.1*			**-5.5**	***18.0***	**-5.0**	***17.4***	**-3.9**	***24.8***
NMIA	1.0	*11.1*	**5.5**	***18.0***			**0.5**	***15.1***	**1.6**	***23.2***
NRC	0.5	*10.1*	**5.0**	***17.4***	**-0.5**	***15.1***			**1.1**	***22.7***
VNIIM	-0.6	*20.3*	**3.9**	***24.8***	**-1.6**	***23.2***	**-1.1**	***22.7***		
METAS	-1.5	*6.2*	**3.0**	***15.5***	**-2.5**	***12.8***	**-2.0**	***11.9***	**-0.9**	***21.3***
NIST	7.4	*17.1*	**11.9**	***22.2***	**6.4**	***20.4***	**6.9**	***19.9***	**8.0**	***26.6***
NIM	-0.8	*24.3*	**3.7**	***28.1***	**-1.8**	***26.8***	**-1.3**	***26.4***	**-0.2**	***31.7***

Table 1c : Degree of equivalence at 1000 V / 1 kHz (3/4)

Voltage : 1000 V **Frequency : 1 kHz** (4/4)			**METAS**		**NIST**		**NIM**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-1.5	*6.2*	7.4	*17.1*	-0.8	*24.3*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$						
BNM-LNE	6.0	*16.1*	**7.5**	***17.3***	**-1.4**	***23.5***	**6.8**	***29.2***
DANIAmet-AREPA	4.7	*21.1*	**6.2**	***22.0***	**-2.7**	***27.2***	**5.5**	***32.2***
NPL	-0.3	*13.1*	**1.2**	***14.5***	**-7.7**	***21.6***	**0.5**	***27.7***
SP	2.7	*9.1*	**4.2**	***11.1***	**-4.7**	***19.4***	**3.5**	***26.0***
IEN	-0.7	*14.9*	**0.8**	***16.2***	**-8.1**	***22.7***	**0.1**	***28.6***
CEM	-6.3	*36.0*	**-4.8**	***36.6***	**-13.7**	***39.9***	**-5.5**	***43.5***
PTB	-0.5	*8.0*	**1.0**	***10.2***	**-7.9**	***18.9***	**0.3**	***25.6***
VSL	3.0	*20.0*	**4.5**	***21.0***	**-4.4**	***26.4***	**3.8**	***31.5***
INTI	-4.5	*14.1*	**-3.0**	***15.5***	**-11.9**	***22.2***	**-3.7**	***28.1***
NMIA	1.0	*11.1*	**2.5**	***12.8***	**-6.4**	***20.4***	**1.8**	***26.8***
NRC	0.5	*10.1*	**2.0**	***11.9***	**-6.9**	***19.9***	**1.3**	***26.4***
VNIIM	-0.6	*20.3*	**0.9**	***21.3***	**-8.0**	***26.6***	**0.2**	***31.7***
METAS	-1.5	*6.2*			**-8.9**	***18.2***	**-0.7**	***25.1***
NIST	7.4	*17.1*	**8.9**	***18.2***			**8.2**	***29.8***
NIM	-0.8	*24.3*	**0.7**	***25.1***	**-8.2**	***29.8***		

Table 1d : Degree of equivalence at 1000 V / 1 kHz (4/4)

Voltage : 1000 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 10 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(1/4)			-1.0	*35.0*	1.9	*21.1*	-5.1	*13.1*	0.9	*10.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$								
BNM-LNE	-1.0	*35.0*			**-2.9**	***40.9***	**4.1**	***37.4***	**-1.9**	***36.5***
DANIAmet-AREPA	1.9	*21.1*	**2.9**	***40.9***			**7.0**	***24.9***	**1.0**	***23.4***
NPL	-5.1	*13.1*	**-4.1**	***37.4***	**-7.0**	***24.9***			**-6.0**	***16.6***
SP	0.9	*10.1*	**1.9**	***36.5***	**-1.0**	***23.4***	**6.0**	***16.6***		
IEN	-4.9	*15.3*	**-3.9**	***38.2***	**-6.8**	***26.1***	**0.2**	***20.2***	**-5.8**	***18.4***
CEM	-2.1	*40.0*	**-1.1**	***53.2***	**-4.0**	***45.3***	**3.0**	***42.1***	**-3.0**	***41.3***
PTB	-3.8	*8.0*	**-2.8**	***36.0***	**-5.7**	***19.6***	**1.3**	***15.4***	**-4.7**	***12.9***
VSL	-3.1	*20.0*	**-2.1**	***40.4***	**-5.0**	***29.1***	**2.0**	***24.0***	**-4.0**	***22.5***
INTI	-4.6	*16.1*	**-3.6**	***38.6***	**-6.5**	***26.6***	**0.5**	***20.8***	**-5.5**	***19.1***
NMIA	0.4	*14.1*	**1.4**	***37.8***	**-1.5**	***25.4***	**5.5**	***19.3***	**-0.5**	***17.4***
NRC	1.4	*10.1*	**2.4**	***36.5***	**-0.5**	***23.4***	**6.5**	***16.6***	**0.5**	***14.3***
VNIIM	-3.0	*20.7*	**-2.0**	***40.7***	**-4.9**	***29.6***	**2.1**	***24.5***	**-3.9**	***23.1***
METAS	-4.0	*7.2*	**-3.0**	***35.8***	**-5.9**	***22.3***	**1.1**	***15.0***	**-4.9**	***12.5***
NIST	1.6	*17.1*	**2.6**	***39.0***	**-0.3**	***27.2***	**6.7**	***21.6***	**0.7**	***19.9***
NIM	-1.7	*24.5*	**-0.7**	***42.8***	**-3.6**	***32.4***	**3.4**	***27.8***	**-2.6**	***26.6***

Table 1e : Degree of equivalence at 1000 V / 10 kHz (1/4)

Voltage : 1000 V			**IEN**		**CEM**		**PTB**		**VSL**	
Frequency : 10 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(2/4)			-4.9	*15.3*	-2.1	*40.0*	-3.8	*8.0*	-3.1	*20.0*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$								
BNM-LNE	-1.0	*35.0*	**3.9**	***38.2***	**1.1**	***53.2***	**2.8**	***36.0***	**2.1**	***40.4***
DANIAmet-AREPA	1.9	*21.1*	**6.8**	***26.1***	**4.0**	***45.3***	**5.7**	***19.6***	**5.0**	***29.1***
NPL	-5.1	*13.1*	**-0.2**	***20.2***	**-3.0**	***42.1***	**-1.3**	***15.4***	**-2.0**	***24.0***
SP	0.9	*10.1*	**5.8**	***18.4***	**3.0**	***41.3***	**4.7**	***12.9***	**4.0**	***22.5***
IEN	-4.9	*15.3*			**-2.8**	***42.9***	**-1.1**	***17.3***	**-1.8**	***25.2***
CEM	-2.1	*40.0*	**2.8**	***42.9***			**1.7**	***40.8***	**1.0**	***44.8***
PTB	-3.8	*8.0*	**1.1**	***17.3***	**-1.7**	***40.8***			**-0.7**	***21.6***
VSL	-3.1	*20.0*	**1.8**	***25.2***	**-1.0**	***44.8***	**0.7**	***21.6***		
INTI	-4.6	*16.1*	**0.3**	***22.3***	**-2.5**	***43.2***	**-0.8**	***18.0***	**-1.5**	***25.7***
NMIA	0.4	*14.1*	**5.3**	***20.9***	**2.5**	***42.5***	**4.2**	***16.3***	**3.5**	***24.5***
NRC	1.4	*10.1*	**6.3**	***18.4***	**3.5**	***41.3***	**5.2**	***12.9***	**4.5**	***22.5***
VNIIM	-3.0	*20.7*	**1.9**	***25.8***	**-0.9**	***45.1***	**0.8**	***22.2***	**0.1**	***28.8***
METAS	-4.0	*7.2*	**0.9**	***17.0***	**-1.9**	***40.7***	**-0.2**	***10.8***	**-0.9**	***21.3***
NIST	1.6	*17.1*	**6.5**	***23.0***	**3.7**	***43.6***	**5.4**	***18.9***	**4.7**	***26.4***
NIM	-1.7	*24.5*	**3.2**	***28.9***	**0.4**	***47.0***	**2.1**	***25.8***	**1.4**	***31.7***

Table 1f : Degree of equivalence at 1000 V / 10 kHz (2/4)

Voltage : 1000 V			INTI		NMIA		NRC		VNIIM	
Frequency : 10 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(3/4)			-4.6	16.1	0.4	14.1	1.4	10.1	-3.0	20.7
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$								
BNM-LNE	-1.0	35.0	3.6	38.6	-1.4	37.8	-2.4	36.5	2.0	40.7
DANIAmet-AREPA	1.9	21.1	6.5	26.6	1.5	25.4	0.5	23.4	4.9	29.6
NPL	-5.1	13.1	-0.5	20.8	-5.5	19.3	-6.5	16.6	-2.1	24.5
SP	0.9	10.1	5.5	19.1	0.5	17.4	-0.5	14.3	3.9	23.1
IEN	-4.9	15.3	-0.3	22.3	-5.3	20.9	-6.3	18.4	-1.9	25.8
CEM	-2.1	40.0	2.5	43.2	-2.5	42.5	-3.5	41.3	0.9	45.1
PTB	-3.8	8.0	0.8	18.0	-4.2	16.3	-5.2	12.9	-0.8	22.2
VSL	-3.1	20.0	1.5	25.7	-3.5	24.5	-4.5	22.5	-0.1	28.8
INTI	-4.6	16.1			-5.0	21.5	-6.0	19.1	-1.6	26.3
NMIA	0.4	14.1	5.0	21.5			-1.0	17.4	3.4	25.1
NRC	1.4	10.1	6.0	19.1	1.0	17.4			4.4	23.1
VNIIM	-3.0	20.7	1.6	26.3	-3.4	25.1	-4.4	23.1		
METAS	-4.0	7.2	0.6	17.7	-4.4	15.9	-5.4	12.5	-1.0	22.0
NIST	1.6	17.1	6.2	23.5	1.2	22.2	0.2	19.9	4.6	26.9
NIM	-1.7	24.5	2.9	29.4	-2.1	28.3	-3.1	26.6	1.3	32.1

Table 1g : Degree of equivalence at 1000 V / 10 kHz (3/4)

Voltage : 1000 V			METAS		NIST		NIM	
Frequency : 10 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(4/4)			-4.0	7.2	1.6	17.1	-1.7	24.5
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$						
BNM-LNE	-1.0	35.0	3.0	35.8	-2.6	39.0	0.7	42.8
DANIAmet-AREPA	1.9	21.1	5.9	22.3	0.3	27.2	3.6	32.4
NPL	-5.1	13.1	-1.1	15.0	-6.7	21.6	-3.4	27.8
SP	0.9	10.1	4.9	12.5	-0.7	19.9	2.6	26.6
IEN	-4.9	15.3	-0.9	17.0	-6.5	23.0	-3.2	28.9
CEM	-2.1	40.0	1.9	40.7	-3.7	43.6	-0.4	47.0
PTB	-3.8	8.0	0.2	10.8	-5.4	18.9	-2.1	25.8
VSL	-3.1	20.0	0.9	21.3	-4.7	26.4	-1.4	31.7
INTI	-4.6	16.1	-0.6	17.7	-6.2	23.5	-2.9	29.4
NMIA	0.4	14.1	4.4	15.9	-1.2	22.2	2.1	28.3
NRC	1.4	10.1	5.4	12.5	-0.2	19.9	3.1	26.6
VNIIM	-3.0	20.7	1.0	22.0	-4.6	26.9	-1.3	32.1
METAS	-4.0	7.2			-5.6	18.6	-2.3	25.6
NIST	1.6	17.1	5.6	18.6			3.3	29.9
NIM	-1.7	24.5	2.3	25.6	-3.3	29.9		

Table 1h : Degree of equivalence at 1000 V / 10 kHz (4/4)

Voltage : 1000 V			BNM-LNE		DANIAmet-AREPA		NPL		SP	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-8.0	35.0	0.1	26.0	-10.9	23.1	-2.9	11.1
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-8.0	35.0			-8.1	43.7	2.9	42.0	-5.1	36.8
DANIAmet-AREPA	0.1	26.0	8.1	43.7			11.0	34.8	3.0	28.3
NPL	-10.9	23.1	-2.9	42.0	-11.0	34.8			-8.0	25.7
SP	-2.9	11.1	5.1	36.8	-3.0	28.3	8.0	25.7		
IEN	-11.8	25.1	-3.8	43.1	-11.9	36.2	-0.9	34.2	-8.9	27.5
CEM	-6.9	44.0	1.1	56.3	-7.0	51.2	4.0	49.7	-4.0	45.4
PTB	-7.2	8.0	0.8	36.0	-7.3	24.8	3.7	24.5	-4.3	13.7
VSL	-10.1	25.0	-2.1	43.1	-10.2	36.1	0.8	34.1	-7.2	27.4
INTI	-10.2	20.0	-2.2	40.4	-10.3	32.9	0.7	30.6	-7.3	22.9
NMIA	-2.2	16.1	5.8	38.6	-2.3	30.6	8.7	28.2	0.7	19.6
NRC	0.8	10.1	8.8	36.5	0.7	27.9	11.7	25.3	3.7	15.1
VNIIM	-10.1	32.4	-2.1	47.7	-10.2	41.6	0.8	39.8	-7.2	34.3
METAS	-6.8	7.1	1.2	35.8	-6.9	27.0	4.1	24.2	-3.9	13.2
NIST	0.5	16.3	8.5	38.7	0.4	30.7	11.4	28.3	3.4	19.8
NIM	-3.8	29.2	4.2	45.6	-3.9	39.1	7.1	37.3	-0.9	31.3

Table 1i : Degree of equivalence at 1000 V / 20 kHz (1/4)

Voltage : 1000 V			IEN		CEM		PTB		VSL	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			-11.8	25.1	-6.9	44.0	-7.2	8.0	-10.1	25.0
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-8.0	35.0	3.8	43.1	-1.1	56.3	-0.8	36.0	2.1	43.1
DANIAmet-AREPA	0.1	26.0	11.9	36.2	7.0	51.2	7.3	24.8	10.2	36.1
NPL	-10.9	23.1	0.9	34.2	-4.0	49.7	-3.7	24.5	-0.8	34.1
SP	-2.9	11.1	8.9	27.5	4.0	45.4	4.3	13.7	7.2	27.4
IEN	-11.8	25.1			-4.9	50.7	-4.6	26.4	-1.7	35.5
CEM	-6.9	44.0	4.9	50.7			0.3	44.8	3.2	50.7
PTB	-7.2	8.0	4.6	26.4	-0.3	44.8			2.9	26.3
VSL	-10.1	25.0	1.7	35.5	-3.2	50.7	-2.9	26.3		
INTI	-10.2	20.0	1.6	32.1	-3.3	48.4	-3.0	21.6	-0.1	32.1
NMIA	-2.2	16.1	9.6	29.9	4.7	46.9	5.0	18.0	7.9	29.8
NRC	0.8	10.1	12.6	27.1	7.7	45.2	8.0	12.9	10.9	27.0
VNIIM	-10.1	32.4	1.7	41.0	-3.2	54.7	-2.9	33.4	0.0	41.0
METAS	-6.8	7.1	5.0	26.1	0.1	44.6	0.4	10.7	3.3	26.0
NIST	0.5	16.3	12.3	30.0	7.4	47.0	7.7	18.2	10.6	29.9
NIM	-3.8	29.2	8.0	38.6	3.1	52.9	3.4	30.3	6.3	38.5

Table 1j : Degree of equivalence at 1000 V / 20 kHz (2/4)

Voltage : 1000 V			**INTI**		**NMIA**		**NRC**		**VNIIM**	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(3/4)			-10.2	*20.0*	-2.2	*16.1*	0.8	*10.1*	-10.1	*32.4*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-8.0	*35.0*	**2.2**	***40.4***	**-5.8**	***38.6***	**-8.8**	***36.5***	**2.1**	***47.7***
DANIAmet-AREPA	0.1	*26.0*	**10.3**	***32.9***	**2.3**	***30.6***	**-0.7**	***27.9***	**10.2**	***41.6***
NPL	-10.9	*23.1*	**-0.7**	***30.6***	**-8.7**	***28.2***	**-11.7**	***25.3***	**-0.8**	***39.8***
SP	-2.9	*11.1*	**7.3**	***22.9***	**-0.7**	***19.6***	**-3.7**	***15.1***	**7.2**	***34.3***
IEN	-11.8	*25.1*	**-1.6**	***32.1***	**-9.6**	***29.9***	**-12.6**	***27.1***	**-1.7**	***41.0***
CEM	-6.9	*44.0*	**3.3**	***48.4***	**-4.7**	***46.9***	**-7.7**	***45.2***	**3.2**	***54.7***
PTB	-7.2	*8.0*	**3.0**	***21.6***	**-5.0**	***18.0***	**-8.0**	***12.9***	**2.9**	***33.4***
VSL	-10.1	*25.0*	**0.1**	***32.1***	**-7.9**	***29.8***	**-10.9**	***27.0***	**0.0**	***41.0***
INTI	-10.2	*20.0*			**-8.0**	***25.7***	**-11.0**	***22.5***	**-0.1**	***38.1***
NMIA	-2.2	*16.1*	**8.0**	***25.7***			**-3.0**	***19.1***	**7.9**	***36.2***
NRC	0.8	*10.1*	**11.0**	***22.5***	**3.0**	***19.1***			**10.9**	***34.0***
VNIIM	-10.1	*32.4*	**0.1**	***38.1***	**-7.9**	***36.2***	**-10.9**	***34.0***		
METAS	-6.8	*7.1*	**3.4**	***21.3***	**-4.6**	***17.6***	**-7.6**	***12.4***	**3.3**	***33.2***
NIST	0.5	*16.3*	**10.7**	***25.9***	**2.7**	***23.0***	**-0.3**	***19.2***	**10.6**	***36.3***
NIM	-3.8	*29.2*	**6.4**	***35.4***	**-1.6**	***33.4***	**-4.6**	***30.9***	**6.3**	***43.7***

Table 1k : Degree of equivalence at 1000 V / 20 kHz (3/4)

Voltage : 1000 V			**METAS**		**NIST**		**NIM**	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(4/4)			-6.8	*7.1*	0.5	*16.3*	-3.8	*29.2*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$						
BNM-LNE	-8.0	*35.0*	**-1.2**	***35.8***	**-8.5**	***38.7***	**-4.2**	***45.6***
DANIAmet-AREPA	0.1	*26.0*	**6.9**	***27.0***	**-0.4**	***30.7***	**3.9**	***39.1***
NPL	-10.9	*23.1*	**-4.1**	***24.2***	**-11.4**	***28.3***	**-7.1**	***37.3***
SP	-2.9	*11.1*	**3.9**	***13.2***	**-3.4**	***19.8***	**0.9**	***31.3***
IEN	-11.8	*25.1*	**-5.0**	***26.1***	**-12.3**	***30.0***	**-8.0**	***38.6***
CEM	-6.9	*44.0*	**-0.1**	***44.6***	**-7.4**	***47.0***	**-3.1**	***52.9***
PTB	-7.2	*8.0*	**-0.4**	***10.7***	**-7.7**	***18.2***	**-3.4**	***30.3***
VSL	-10.1	*25.0*	**-3.3**	***26.0***	**-10.6**	***29.9***	**-6.3**	***38.5***
INTI	-10.2	*20.0*	**-3.4**	***21.3***	**-10.7**	***25.9***	**-6.4**	***35.4***
NMIA	-2.2	*16.1*	**4.6**	***17.6***	**-2.7**	***23.0***	**1.6**	***33.4***
NRC	0.8	*10.1*	**7.6**	***12.4***	**0.3**	***19.2***	**4.6**	***30.9***
VNIIM	-10.1	*32.4*	**-3.3**	***33.2***	**-10.6**	***36.3***	**-6.3**	***43.7***
METAS	-6.8	*7.1*			**-7.3**	***17.8***	**-3.0**	***30.1***
NIST	0.5	*16.3*	**7.3**	***17.8***			**4.3**	***33.5***
NIM	-3.8	*29.2*	**3.0**	***30.1***	**-4.3**	***33.5***		

Table 1l : Degree of equivalence at 1000 V / 20 kHz (4/4)

Voltage : 1000 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 50 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-31.7	69.0	-18.1	41.0	-27.1	32.0	-15.1	15.1
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-31.7	69.0			-13.6	80.3	-4.6	76.1	-16.6	70.7
DANIAmet-AREPA	-18.1	41.0	13.6	80.3			9.0	52.1	-3.0	43.7
NPL	-27.1	32.0	4.6	76.1	-9.0	52.1			-12.0	35.4
SP	-15.1	15.1	16.6	70.7	3.0	43.7	12.0	35.4		
IEN	-30.9	37.2	0.8	78.4	-12.8	55.4	-3.8	49.1	-15.8	40.2
CEM	-36.1	64.0	-4.4	94.2	-18.0	76.1	-9.0	71.6	-21.0	65.8
PTB	-21.9	10.0	9.8	69.8	-3.8	39.8	5.2	33.6	-6.8	18.2
VSL	-25.2	35.0	6.5	77.4	-7.1	54.0	1.9	47.5	-10.1	38.2
INTI	-24.0	24.1	7.7	73.1	-5.9	47.6	3.1	40.1	-8.9	28.5
NMIA	-15.0	28.0	16.7	74.5	3.1	49.7	12.1	42.6	0.1	31.9
NRC	-12.0	12.1	19.7	70.1	6.1	42.8	15.1	34.3	3.1	19.4
VNIIM	-42.2	51.6	-10.5	86.2	-24.1	66.0	-15.1	60.8	-27.1	53.8
METAS	-21.2	10.1	10.5	69.8	-3.1	42.3	5.9	33.6	-6.1	18.2
NIST	-23.2	21.5	8.5	72.3	-5.1	46.3	3.9	38.6	-8.1	26.3
NIM	-22.7	45.4	9.0	82.6	-4.6	61.2	4.4	55.6	-7.6	47.9

Table 1m : Degree of equivalence at 1000 V / 50 kHz (1/4)

Voltage : 1000 V			**IEN**		**CEM**		**PTB**		**VSL**	
Frequency : 50 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			-30.9	37.2	-36.1	64.0	-21.9	10.0	-25.2	35.0
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-31.7	69.0	-0.8	78.4	4.4	94.2	-9.8	69.8	-6.5	77.4
DANIAmet-AREPA	-18.1	41.0	12.8	55.4	18.0	76.1	3.8	39.8	7.1	54.0
NPL	-27.1	32.0	3.8	49.1	9.0	71.6	-5.2	33.6	-1.9	47.5
SP	-15.1	15.1	15.8	40.2	21.0	65.8	6.8	18.2	10.1	38.2
IEN	-30.9	37.2			5.2	74.1	-9.0	38.6	-5.7	51.1
CEM	-36.1	64.0	-5.2	74.1			-14.2	64.8	-10.9	73.0
PTB	-21.9	10.0	9.0	38.6	14.2	64.8			3.3	36.5
VSL	-25.2	35.0	5.7	51.1	10.9	73.0	-3.3	36.5		
INTI	-24.0	24.1	6.9	44.4	12.1	68.4	-2.1	26.1	1.2	42.5
NMIA	-15.0	28.0	15.9	46.6	21.1	69.9	6.9	29.8	10.2	44.9
NRC	-12.0	12.1	18.9	39.2	24.1	65.2	9.9	15.7	13.2	37.1
VNIIM	-42.2	51.6	-11.3	63.7	-6.1	82.3	-20.3	52.6	-17.0	62.4
METAS	-21.2	10.1	9.7	38.6	14.9	64.8	0.7	14.3	4.0	36.5
NIST	-23.2	21.5	7.7	43.0	12.9	67.6	-1.3	23.8	2.0	41.1
NIM	-22.7	45.4	8.2	58.7	13.4	78.5	-0.8	46.5	2.5	57.4

Table 1n : Degree of equivalence at 1000 V / 50 kHz (2/4)

Voltage : 1000 V			**INTI**		**NMIA**		**NRC**		**VNIIM**	
Frequency : 50 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(3/4)			-24.0	*24.1*	-15.0	*28.0*	-12.0	*12.1*	-42.2	*51.6*
			$D_{i,j}$	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**
	$d_{adj\ i}$	$u(d_{adj\ i})$								
BNM-LNE	-31.7	*69.0*	**-7.7**	***73.1***	**-16.7**	***74.5***	**-19.7**	***70.1***	**10.5**	***86.2***
DANIAmet-AREPA	-18.1	*41.0*	**5.9**	***47.6***	**-3.1**	***49.7***	**-6.1**	***42.8***	**24.1**	***66.0***
NPL	-27.1	*32.0*	**-3.1**	***40.1***	**-12.1**	***42.6***	**-15.1**	***34.3***	**15.1**	***60.8***
SP	-15.1	*15.1*	**8.9**	***28.5***	**-0.1**	***31.9***	**-3.1**	***19.4***	**27.1**	***53.8***
IEN	-30.9	*37.2*	**-6.9**	***44.4***	**-15.9**	***46.6***	**-18.9**	***39.2***	**11.3**	***63.7***
CEM	-36.1	*64.0*	**-12.1**	***68.4***	**-21.1**	***69.9***	**-24.1**	***65.2***	**6.1**	***82.3***
PTB	-21.9	*10.0*	**2.1**	***26.1***	**-6.9**	***29.8***	**-9.9**	***15.7***	**20.3**	***52.6***
VSL	-25.2	*35.0*	**-1.2**	***42.5***	**-10.2**	***44.9***	**-13.2**	***37.1***	**17.0**	***62.4***
INTI	-24.0	*24.1*			**-9.0**	***37.0***	**-12.0**	***27.0***	**18.2**	***57.0***
NMIA	-15.0	*28.0*	**9.0**	***37.0***			**-3.0**	***30.6***	**27.2**	***58.8***
NRC	-12.0	*12.1*	**12.0**	***27.0***	**3.0**	***30.6***			**30.2**	***53.0***
VNIIM	-42.2	*51.6*	**-18.2**	***57.0***	**-27.2**	***58.8***	**-30.2**	***53.0***		
METAS	-21.2	*10.1*	**2.8**	***26.2***	**-6.2**	***29.8***	**-9.2**	***15.8***	**21.0**	***52.6***
NIST	-23.2	*21.5*	**0.8**	***32.3***	**-8.2**	***35.4***	**-11.2**	***24.7***	**19.0**	***55.9***
NIM	-22.7	*45.4*	**1.3**	***51.5***	**-7.7**	***53.4***	**-10.7**	***47.0***	**19.5**	***68.8***

Table 1o : Degree of equivalence at 1000 V / 50 kHz (3/4)

Voltage : 1000 V			**METAS**		**NIST**		**NIM**	
Frequency : 50 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(4/4)			-21.2	*10.1*	-23.2	*21.5*	-22.7	*45.4*
			$D_{i,j}$	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**
	$d_{adj\ i}$	$u(d_{adj\ i})$						
BNM-LNE	-31.7	*69.0*	**-10.5**	***69.8***	**-8.5**	***72.3***	**-9.0**	***82.6***
DANIAmet-AREPA	-18.1	*41.0*	**3.1**	***42.3***	**5.1**	***46.3***	**4.6**	***61.2***
NPL	-27.1	*32.0*	**-5.9**	***33.6***	**-3.9**	***38.6***	**-4.4**	***55.6***
SP	-15.1	*15.1*	**6.1**	***18.2***	**8.1**	***26.3***	**7.6**	***47.9***
IEN	-30.9	*37.2*	**-9.7**	***38.6***	**-7.7**	***43.0***	**-8.2**	***58.7***
CEM	-36.1	*64.0*	**-14.9**	***64.8***	**-12.9**	***67.6***	**-13.4**	***78.5***
PTB	-21.9	*10.0*	**-0.7**	***14.3***	**1.3**	***23.8***	**0.8**	***46.5***
VSL	-25.2	*35.0*	**-4.0**	***36.5***	**-2.0**	***41.1***	**-2.5**	***57.4***
INTI	-24.0	*24.1*	**-2.8**	***26.2***	**-0.8**	***32.3***	**-1.3**	***51.5***
NMIA	-15.0	*28.0*	**6.2**	***29.8***	**8.2**	***35.4***	**7.7**	***53.4***
NRC	-12.0	*12.1*	**9.2**	***15.8***	**11.2**	***24.7***	**10.7**	***47.0***
VNIIM	-42.2	*51.6*	**-21.0**	***52.6***	**-19.0**	***55.9***	**-19.5**	***68.8***
METAS	-21.2	*10.1*			**2.0**	***23.8***	**1.5**	***46.6***
NIST	-23.2	*21.5*	**-2.0**	***23.8***			**-0.5**	***50.3***
NIM	-22.7	*45.4*	**-1.5**	***46.6***	**0.5**	***50.3***		

Table 1p : Degree of equivalence at 1000 V / 50 kHz (4/4)

Voltage : 1000 V			BNM-LNE		DANIAmet-AREPA		NPL		SP	
Frequency : 100 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-73.6	*69.0*	-52.6	*81.0*	-63.6	*62.0*	-42.6	*23.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-73.6	*69.0*			**-21.0**	***106.5***	**-10.0**	***92.8***	**-31.0**	***72.8***
DANIAmet-AREPA	-52.6	*81.0*	**21.0**	***106.5***			**11.0**	***102.1***	**-10.0**	***84.3***
NPL	-63.6	*62.0*	**10.0**	***92.8***	**-11.0**	***102.1***			**-21.0**	***66.2***
SP	-42.6	*23.1*	**31.0**	***72.8***	**10.0**	***84.3***	**21.0**	***66.2***		
IEN	-66.5	*79.4*	**7.1**	***105.2***	**-13.9**	***113.5***	**-2.9**	***100.8***	**-23.9**	***82.7***
CEM	-62.6	*98.0*	**11.0**	***119.9***	**-10.0**	***127.2***	**1.0**	***116.0***	**-20.0**	***100.7***
PTB	-56.6	*30.0*	**17.0**	***75.3***	**-4.0**	***75.3***	**7.0**	***68.9***	**-14.0**	***37.9***
VSL	-61.4	*50.0*	**12.2**	***85.3***	**-8.8**	***95.2***	**2.2**	***79.7***	**-18.8**	***55.1***
INTI	-55.8	*40.0*	**17.8**	***79.8***	**-3.2**	***90.4***	**7.8**	***73.8***	**-13.2**	***46.2***
NMIA	-40.8	*41.0*	**32.8**	***80.3***	**11.8**	***90.8***	**22.8**	***74.4***	**1.8**	***47.1***
NRC	-53.8	*24.0*	**19.8**	***73.1***	**-1.2**	***84.5***	**9.8**	***66.5***	**-11.2**	***33.4***
VNIIM	-30.4	*101.0*	**43.2**	***122.4***	**22.2**	***129.5***	**33.2**	***118.6***	**12.2**	***103.7***
METAS	-49.8	*28.0*	**23.8**	***74.5***	**2.8**	***85.8***	**13.8**	***68.1***	**-7.2**	***36.3***
NIST	-59.2	*29.2*	**14.4**	***75.0***	**-6.6**	***86.2***	**4.4**	***68.6***	**-16.6**	***37.3***
NIM	-72.7	*59.6*	**0.9**	***91.2***	**-20.1**	***100.6***	**-9.1**	***86.1***	**-30.1**	***64.0***

Table 1q : Degree of equivalence at 1000 V / 100 kHz (1/4)

Voltage : 1000 V			IEN		CEM		PTB		VSL	
Frequency : 100 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			-66.5	*79.4*	-62.6	*98.0*	-56.6	*30.0*	-61.4	*50.0*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-73.6	*69.0*	**-7.1**	***105.2***	**-11.0**	***119.9***	**-17.0**	***75.3***	**-12.2**	***85.3***
DANIAmet-AREPA	-52.6	*81.0*	**13.9**	***113.5***	**10.0**	***127.2***	**4.0**	***75.3***	**8.8**	***95.2***
NPL	-63.6	*62.0*	**2.9**	***100.8***	**-1.0**	***116.0***	**-7.0**	***68.9***	**-2.2**	***79.7***
SP	-42.6	*23.1*	**23.9**	***82.7***	**20.0**	***100.7***	**14.0**	***37.9***	**18.8**	***55.1***
IEN	-66.5	*79.4*			**-3.9**	***126.2***	**-9.9**	***84.9***	**-5.1**	***93.9***
CEM	-62.6	*98.0*	**3.9**	***126.2***			**-6.0**	***102.5***	**-1.2**	***110.1***
PTB	-56.6	*30.0*	**9.9**	***84.9***	**6.0**	***102.5***			**4.8**	***58.4***
VSL	-61.4	*50.0*	**5.1**	***93.9***	**1.2**	***110.1***	**-4.8**	***58.4***		
INTI	-55.8	*40.0*	**10.7**	***89.0***	**6.8**	***105.9***	**0.8**	***50.0***	**5.6**	***64.1***
NMIA	-40.8	*41.0*	**25.7**	***89.4***	**21.8**	***106.3***	**15.8**	***50.9***	**20.6**	***64.7***
NRC	-53.8	*24.0*	**12.7**	***83.0***	**8.8**	***100.9***	**2.8**	***38.5***	**7.6**	***55.5***
VNIIM	-30.4	*101.0*	**36.1**	***128.5***	**32.2**	***140.8***	**26.2**	***105.4***	**31.0**	***112.7***
METAS	-49.8	*28.0*	**16.7**	***84.2***	**12.8**	***102.0***	**6.8**	***41.1***	**11.6**	***57.4***
NIST	-59.2	*29.2*	**7.3**	***84.6***	**3.4**	***102.3***	**-2.6**	***41.9***	**2.2**	***58.0***
NIM	-72.7	*59.6*	**-6.2**	***99.3***	**-10.1**	***114.8***	**-16.1**	***66.8***	**-11.3**	***77.8***

Table 1r : Degree of equivalence at 1000 V / 100 kHz (2/4)

Voltage : 1000 V			**INTI**		**NMIA**		**NRC**		**VNIIM**	
Frequency : 100 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(3/4)			-55.8	*40.0*	-40.8	*41.0*	-53.8	*24.0*	-30.4	*101.0*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-73.6	*69.0*	**-17.8**	***79.8***	**-32.8**	***80.3***	**-19.8**	***73.1***	**-43.2**	***122.4***
DANIAmet-AREPA	-52.6	*81.0*	**3.2**	***90.4***	**-11.8**	***90.8***	**1.2**	***84.5***	**-22.2**	***129.5***
NPL	-63.6	*62.0*	**-7.8**	***73.8***	**-22.8**	***74.4***	**-9.8**	***66.5***	**-33.2**	***118.6***
SP	-42.6	*23.1*	**13.2**	***46.2***	**-1.8**	***47.1***	**11.2**	***33.4***	**-12.2**	***103.7***
IEN	-66.5	*79.4*	**-10.7**	***89.0***	**-25.7**	***89.4***	**-12.7**	***83.0***	**-36.1**	***128.5***
CEM	-62.6	*98.0*	**-6.8**	***105.9***	**-21.8**	***106.3***	**-8.8**	***100.9***	**-32.2**	***140.8***
PTB	-56.6	*30.0*	**-0.8**	***50.0***	**-15.8**	***50.9***	**-2.8**	***38.5***	**-26.2**	***105.4***
VSL	-61.4	*50.0*	**-5.6**	***64.1***	**-20.6**	***64.7***	**-7.6**	***55.5***	**-31.0**	***112.7***
INTI	-55.8	*40.0*			**-15.0**	***57.3***	**-2.0**	***46.7***	**-25.4**	***108.7***
NMIA	-40.8	*41.0*	**15.0**	***57.3***			**13.0**	***47.6***	**-10.4**	***109.1***
NRC	-53.8	*24.0*	**2.0**	***46.7***	**-13.0**	***47.6***			**-23.4**	***103.9***
VNIIM	-30.4	*101.0*	**25.4**	***108.7***	**10.4**	***109.1***	**23.4**	***103.9***		
METAS	-49.8	*28.0*	**6.0**	***48.9***	**-9.0**	***49.7***	**4.0**	***36.9***	**-19.4**	***104.9***
NIST	-59.2	*29.2*	**-3.4**	***49.6***	**-18.4**	***50.4***	**-5.4**	***37.8***	**-28.8**	***105.2***
NIM	-72.7	*59.6*	**-16.9**	***71.8***	**-31.9**	***72.4***	**-18.9**	***64.3***	**-42.3**	***117.3***

Table 1s : Degree of equivalence at 1000 V / 100 kHz (3/4)

Voltage : 1000 V			**METAS**		**NIST**		**NIM**	
Frequency : 100 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(4/4)			-49.8	*28.0*	-59.2	*29.2*	-72.7	*59.6*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$						
BNM-LNE	-73.6	*69.0*	**-23.8**	***74.5***	**-14.4**	***75.0***	**-0.9**	***91.2***
DANIAmet-AREPA	-52.6	*81.0*	**-2.8**	***85.8***	**6.6**	***86.2***	**20.1**	***100.6***
NPL	-63.6	*62.0*	**-13.8**	***68.1***	**-4.4**	***68.6***	**9.1**	***86.1***
SP	-42.6	*23.1*	**7.2**	***36.3***	**16.6**	***37.3***	**30.1**	***64.0***
IEN	-66.5	*79.4*	**-16.7**	***84.2***	**-7.3**	***84.6***	**6.2**	***99.3***
CEM	-62.6	*98.0*	**-12.8**	***102.0***	**-3.4**	***102.3***	**10.1**	***114.8***
PTB	-56.6	*30.0*	**-6.8**	***41.1***	**2.6**	***41.9***	**16.1**	***66.8***
VSL	-61.4	*50.0*	**-11.6**	***57.4***	**-2.2**	***58.0***	**11.3**	***77.8***
INTI	-55.8	*40.0*	**-6.0**	***48.9***	**3.4**	***49.6***	**16.9**	***71.8***
NMIA	-40.8	*41.0*	**9.0**	***49.7***	**18.4**	***50.4***	**31.9**	***72.4***
NRC	-53.8	*24.0*	**-4.0**	***36.9***	**5.4**	***37.8***	**18.9**	***64.3***
VNIIM	-30.4	*101.0*	**19.4**	***104.9***	**28.8**	***105.2***	**42.3**	***117.3***
METAS	-49.8	*28.0*			**9.4**	***40.5***	**22.9**	***65.9***
NIST	-59.2	*29.2*	**-9.4**	***40.5***			**13.5**	***66.4***
NIM	-72.7	*59.6*	**-22.9**	***65.9***	**-13.5**	***66.4***		

Table 1t : Degree of equivalence at 1000 V / 100 kHz (4/4)

Voltage : 500 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 1 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			3.4	13.2	4.6	21.1	0.6	13.2	3.6	8.3
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	3.4	13.2			-1.2	24.9	2.8	18.7	-0.2	15.6
DANIAmet-AREPA	4.6	21.1	1.2	24.9			4.0	24.9	1.0	22.7
NPL	0.6	13.2	-2.8	18.7	-4.0	24.9			-3.0	15.6
SP	3.6	8.3	0.2	15.6	-1.0	22.7	3.0	15.6		
IEN	1.0	9.7	-2.4	16.4	-3.6	23.3	0.4	16.4	-2.6	12.8
CEM	-0.4	30.1	-3.8	32.9	-5.0	36.8	-1.0	32.9	-4.0	31.3
PTB	-0.5	8.0	-3.9	15.5	-5.1	19.6	-1.1	15.5	-4.1	11.6
VSL	2.6	15.0	-0.8	20.0	-2.0	25.9	2.0	20.0	-1.0	17.2
INTI	-1.4	12.2	-4.8	18.0	-6.0	24.4	-2.0	18.0	-5.0	14.8
NMIA	4.2	9.2	0.8	16.1	-0.4	23.1	3.6	16.1	0.6	12.4
NRC	2.6	9.0	-0.8	16.0	-2.0	23.0	2.0	16.0	-1.0	12.3
VNIIM	2.3	16.7	-1.1	21.3	-2.3	27.0	1.7	21.3	-1.3	18.7
METAS	0.4	6.3	-3.0	14.7	-4.2	22.1	-0.2	14.7	-3.2	10.5
NIST	5.9	11.2	2.5	17.4	1.3	23.9	5.3	17.4	2.3	14.0
NIM	0.1	19.7	-3.3	23.8	-4.5	28.9	-0.5	23.8	-3.5	21.4

Table 2a : Degree of equivalence at 500 V / 1 kHz (1/4)

Voltage : 500 V			**IEN**		**CEM**		**PTB**		**VSL**	
Frequency : 1 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			1.0	9.7	-0.4	30.1	-0.5	8.0	2.6	15.0
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	3.4	13.2	2.4	16.4	3.8	32.9	3.9	15.5	0.8	20.0
DANIAmet-AREPA	4.6	21.1	3.6	23.3	5.0	36.8	5.1	19.6	2.0	25.9
NPL	0.6	13.2	-0.4	16.4	1.0	32.9	1.1	15.5	-2.0	20.0
SP	3.6	8.3	2.6	12.8	4.0	31.3	4.1	11.6	1.0	17.2
IEN	1.0	9.7			1.4	31.7	1.5	12.6	-1.6	17.9
CEM	-0.4	30.1	-1.4	31.7			0.1	31.2	-3.0	33.7
PTB	-0.5	8.0	-1.5	12.6	-0.1	31.2			-3.1	17.0
VSL	2.6	15.0	1.6	17.9	3.0	33.7	3.1	17.0		
INTI	-1.4	12.2	-2.4	15.6	-1.0	32.5	-0.9	14.6	-4.0	19.4
NMIA	4.2	9.2	3.2	13.4	4.6	31.5	4.7	12.2	1.6	17.6
NRC	2.6	9.0	1.6	13.3	3.0	31.5	3.1	12.1	0.0	17.5
VNIIM	2.3	16.7	1.3	19.4	2.7	34.5	2.8	18.6	-0.3	22.5
METAS	0.4	6.3	-0.6	11.6	0.8	30.8	0.9	10.2	-2.2	16.3
NIST	5.9	11.2	4.9	14.9	6.3	32.2	6.4	13.8	3.3	18.8
NIM	0.1	19.7	-0.9	22.0	0.5	36.0	0.6	21.3	-2.5	24.8

Table 2b : Degree of equivalence at 500 V / 1 kHz (2/4)

Voltage : 500 V			**INTI**		**NMIA**		**NRC**		**VNIIM**	
Frequency : 1 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(3/4)			-1.4	*12.2*	4.2	*9.2*	2.6	*9.0*	2.3	*16.7*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	3.4	*13.2*	**4.8**	***18.0***	**-0.8**	***16.1***	**0.8**	***16.0***	**1.1**	***21.3***
DANIAmet-AREPA	4.6	*21.1*	**6.0**	***24.4***	**0.4**	***23.1***	**2.0**	***23.0***	**2.3**	***27.0***
NPL	0.6	*13.2*	**2.0**	***18.0***	**-3.6**	***16.1***	**-2.0**	***16.0***	**-1.7**	***21.3***
SP	3.6	*8.3*	**5.0**	***14.8***	**-0.6**	***12.4***	**1.0**	***12.3***	**1.3**	***18.7***
IEN	1.0	*9.7*	**2.4**	***15.6***	**-3.2**	***13.4***	**-1.6**	***13.3***	**-1.3**	***19.4***
CEM	-0.4	*30.1*	**1.0**	***32.5***	**-4.6**	***31.5***	**-3.0**	***31.5***	**-2.7**	***34.5***
PTB	-0.5	*8.0*	**0.9**	***14.6***	**-4.7**	***12.2***	**-3.1**	***12.1***	**-2.8**	***18.6***
VSL	2.6	*15.0*	**4.0**	***19.4***	**-1.6**	***17.6***	**0.0**	***17.5***	**0.3**	***22.5***
INTI	-1.4	*12.2*			**-5.6**	***15.3***	**-4.0**	***15.2***	**-3.7**	***20.7***
NMIA	4.2	*9.2*	**5.6**	***15.3***			**1.6**	***12.9***	**1.9**	***19.1***
NRC	2.6	*9.0*	**4.0**	***15.2***	**-1.6**	***12.9***			**0.3**	***19.0***
VNIIM	2.3	*16.7*	**3.7**	***20.7***	**-1.9**	***19.1***	**-0.3**	***19.0***		
METAS	0.4	*6.3*	**1.8**	***13.8***	**-3.8**	***11.2***	**-2.2**	***11.0***	**-1.9**	***17.9***
NIST	5.9	*11.2*	**7.3**	***16.6***	**1.7**	***14.5***	**3.3**	***14.4***	**3.6**	***20.2***
NIM	0.1	*19.7*	**1.5**	***23.2***	**-4.1**	***21.8***	**-2.5**	***21.7***	**-2.2**	***25.9***

Table 2c : Degree of equivalence at 500 V / 1 kHz (3/4)

Voltage : 500 V			**METAS**		**NIST**		**NIM**	
Frequency : 1 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(4/4)			0.4	*6.3*	5.9	*11.2*	0.1	*19.7*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$						
BNM-LNE	3.4	*13.2*	**3.0**	***14.7***	**-2.5**	***17.4***	**3.3**	***23.8***
DANIAmet-AREPA	4.6	*21.1*	**4.2**	***22.1***	**-1.3**	***23.9***	**4.5**	***28.9***
NPL	0.6	*13.2*	**0.2**	***14.7***	**-5.3**	***17.4***	**0.5**	***23.8***
SP	3.6	*8.3*	**3.2**	***10.5***	**-2.3**	***14.0***	**3.5**	***21.4***
IEN	1.0	*9.7*	**0.6**	***11.6***	**-4.9**	***14.9***	**0.9**	***22.0***
CEM	-0.4	*30.1*	**-0.8**	***30.8***	**-6.3**	***32.2***	**-0.5**	***36.0***
PTB	-0.5	*8.0*	**-0.9**	***10.2***	**-6.4**	***13.8***	**-0.6**	***21.3***
VSL	2.6	*15.0*	**2.2**	***16.3***	**-3.3**	***18.8***	**2.5**	***24.8***
INTI	-1.4	*12.2*	**-1.8**	***13.8***	**-7.3**	***16.6***	**-1.5**	***23.2***
NMIA	4.2	*9.2*	**3.8**	***11.2***	**-1.7**	***14.5***	**4.1**	***21.8***
NRC	2.6	*9.0*	**2.2**	***11.0***	**-3.3**	***14.4***	**2.5**	***21.7***
VNIIM	2.3	*16.7*	**1.9**	***17.9***	**-3.6**	***20.2***	**2.2**	***25.9***
METAS	0.4	*6.3*			**-5.5**	***12.9***	**0.3**	***20.7***
NIST	5.9	*11.2*	**5.5**	***12.9***			**5.8**	***22.7***
NIM	0.1	*19.7*	**-0.3**	***20.7***	**-5.8**	***22.7***		

Table 2d : Degree of equivalence at 500 V / 1 kHz (4/4)

Voltage : 500 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 10 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-2.5	*21.1*	0.7	*21.1*	-7.3	*13.1*	0.7	*9.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-2.5	21.1			**-3.2**	***29.9***	**4.8**	***24.9***	**-3.2**	***23.0***
DANIAmet-AREPA	0.7	*21.1*	**3.2**	***29.9***			**8.0**	***24.9***	**0.0**	***23.0***
NPL	-7.3	*13.1*	**-4.8**	***24.9***	**-8.0**	***24.9***			**-8.0**	***16.0***
SP	0.7	*9.1*	**3.2**	***23.0***	**0.0**	***23.0***	**8.0**	***16.0***		
IEN	-5.0	*9.5*	**-2.5**	***23.2***	**-5.7**	***23.2***	**2.3**	***16.2***	**-5.7**	***13.2***
CEM	-3.3	*30.0*	**-0.8**	***36.7***	**-4.0**	***36.7***	**4.0**	***32.8***	**-4.0**	***31.4***
PTB	-2.8	*8.0*	**-0.3**	***22.6***	**-3.5**	***19.6***	**4.5**	***15.4***	**-3.5**	***12.2***
VSL	-4.3	*15.0*	**-1.8**	***25.9***	**-5.0**	***25.9***	**3.0**	***20.0***	**-5.0**	***17.6***
INTI	-6.1	*14.1*	**-3.6**	***25.4***	**-6.8**	***25.4***	**1.2**	***19.3***	**-6.8**	***16.8***
NMIA	0.9	*9.1*	**3.4**	***23.0***	**0.2**	***23.0***	**8.2**	***16.0***	**0.2**	***12.9***
NRC	0.9	*8.7*	**3.4**	***22.9***	**0.2**	***22.9***	**8.2**	***15.8***	**0.2**	***12.6***
VNIIM	-2.2	*17.1*	**0.3**	***27.2***	**-2.9**	***27.2***	**5.1**	***21.6***	**-2.9**	***19.4***
METAS	-3.5	*6.2*	**-1.0**	***22.0***	**-4.2**	***22.0***	**3.8**	***14.5***	**-4.2**	***11.1***
NIST	1.1	*10.7*	**3.6**	***23.7***	**0.4**	***23.7***	**8.4**	***17.0***	**0.4**	***14.1***
NIM	-3.6	*19.6*	**-1.1**	***28.8***	**-4.3**	***28.8***	**3.7**	***23.6***	**-4.3**	***21.7***

Table 2e : Degree of equivalence at 500 V / 10 kHz (1/4)

Voltage : 500 V			**IEN**		**CEM**		**PTB**		**VSL**	
Frequency : 10 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			-5.0	*9.5*	-3.3	*30.0*	-2.8	*8.0*	-4.3	*15.0*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-2.5	*21.1*	**2.5**	***23.2***	**0.8**	***36.7***	**0.3**	***22.6***	**1.8**	***25.9***
DANIAmet-AREPA	0.7	*21.1*	**5.7**	***23.2***	**4.0**	***36.7***	**3.5**	***19.6***	**5.0**	***25.9***
NPL	-7.3	*13.1*	**-2.3**	***16.2***	**-4.0**	***32.8***	**-4.5**	***15.4***	**-3.0**	***20.0***
SP	0.7	*9.1*	**5.7**	***13.2***	**4.0**	***31.4***	**3.5**	***12.2***	**5.0**	***17.6***
IEN	-5.0	*9.5*			**-1.7**	***31.5***	**-2.2**	***12.5***	**-0.7**	***17.8***
CEM	-3.3	*30.0*	**1.7**	***31.5***			**-0.5**	***31.1***	**1.0**	***33.6***
PTB	-2.8	*8.0*	**2.2**	***12.5***	**0.5**	***31.1***			**1.5**	***17.0***
VSL	-4.3	*15.0*	**0.7**	***17.8***	**-1.0**	***33.6***	**-1.5**	***17.0***		
INTI	-6.1	*14.1*	**-1.1**	***17.1***	**-2.8**	***33.2***	**-3.3**	***16.3***	**-1.8**	***20.6***
NMIA	0.9	*9.1*	**5.9**	***13.2***	**4.2**	***31.4***	**3.7**	***12.2***	**5.2**	***17.6***
NRC	0.9	*8.7*	**5.9**	***12.9***	**4.2**	***31.3***	**3.7**	***11.9***	**5.2**	***17.4***
VNIIM	-2.2	*17.1*	**2.8**	***19.6***	**1.1**	***34.6***	**0.6**	***18.9***	**2.1**	***22.8***
METAS	-3.5	*6.2*	**1.5**	***11.4***	**-0.2**	***30.7***	**-0.7**	***10.2***	**0.8**	***16.3***
NIST	1.1	*10.7*	**6.1**	***14.4***	**4.4**	***31.9***	**3.9**	***13.4***	**5.4**	***18.5***
NIM	-3.6	*19.6*	**1.4**	***21.8***	**-0.3**	***35.9***	**-0.8**	***21.2***	**0.7**	***24.7***

Table 2f : Degree of equivalence at 500 V / 10 kHz (2/4)

Voltage : 500 V			**INTI**		**NMIA**		**NRC**		**VNIIM**	
Frequency : 10 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(3/4)			-6.1	14.1	0.9	9.1	0.9	8.7	-2.2	17.1
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-2.5	21.1	3.6	25.4	-3.4	23.0	-3.4	22.9	-0.3	27.2
DANIAmet-AREPA	0.7	21.1	6.8	25.4	-0.2	23.0	-0.2	22.9	2.9	27.2
NPL	-7.3	13.1	-1.2	19.3	-8.2	16.0	-8.2	15.8	-5.1	21.6
SP	0.7	9.1	6.8	16.8	-0.2	12.9	-0.2	12.6	2.9	19.4
IEN	-5.0	9.5	1.1	17.1	-5.9	13.2	-5.9	12.9	-2.8	19.6
CEM	-3.3	30.0	2.8	33.2	-4.2	31.4	-4.2	31.3	-1.1	34.6
PTB	-2.8	8.0	3.3	16.3	-3.7	12.2	-3.7	11.9	-0.6	18.9
VSL	-4.3	15.0	1.8	20.6	-5.2	17.6	-5.2	17.4	-2.1	22.8
INTI	-6.1	14.1			-7.0	16.8	-7.0	16.6	-3.9	22.2
NMIA	0.9	9.1	7.0	16.8			0.0	12.6	3.1	19.4
NRC	0.9	8.7	7.0	16.6	0.0	12.6			3.1	19.2
VNIIM	-2.2	17.1	3.9	22.2	-3.1	19.4	-3.1	19.2		
METAS	-3.5	6.2	2.6	15.5	-4.4	11.1	-4.4	10.7	-1.3	18.2
NIST	1.1	10.7	7.2	17.8	0.2	14.1	0.2	13.8	3.3	20.2
NIM	-3.6	19.6	2.5	24.2	-4.5	21.7	-4.5	21.5	-1.4	26.1

Table 2g : Degree of equivalence at 500 V / 10 kHz (3/4)

Voltage : 500 V			**METAS**		**NIST**		**NIM**	
Frequency : 10 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(4/4)			-3.5	6.2	1.1	10.7	-3.6	19.6
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$						
BNM-LNE	-2.5	21.1	1.0	22.0	-3.6	23.7	1.1	28.8
DANIAmet-AREPA	0.7	21.1	4.2	22.0	-0.4	23.7	4.3	28.8
NPL	-7.3	13.1	-3.8	14.5	-8.4	17.0	-3.7	23.6
SP	0.7	9.1	4.2	11.1	-0.4	14.1	4.3	21.7
IEN	-5.0	9.5	-1.5	11.4	-6.1	14.4	-1.4	21.8
CEM	-3.3	30.0	0.2	30.7	-4.4	31.9	0.3	35.9
PTB	-2.8	8.0	0.7	10.2	-3.9	13.4	0.8	21.2
VSL	-4.3	15.0	-0.8	16.3	-5.4	18.5	-0.7	24.7
INTI	-6.1	14.1	-2.6	15.5	-7.2	17.8	-2.5	24.2
NMIA	0.9	9.1	4.4	11.1	-0.2	14.1	4.5	21.7
NRC	0.9	8.7	4.4	10.7	-0.2	13.8	4.5	21.5
VNIIM	-2.2	17.1	1.3	18.2	-3.3	20.2	1.4	26.1
METAS	-3.5	6.2			-4.6	12.4	0.1	20.6
NIST	1.1	10.7	4.6	12.4			4.7	22.4
NIM	-3.6	19.6	-0.1	20.6	-4.7	22.4		

Table 2h : Degree of equivalence at 500 V / 10 kHz (4/4)

Voltage : 500 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-6.0	21.1	-3.2	21.1	-12.2	17.1	-4.2	10.2
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-6.0	21.1			-2.8	29.9	6.2	27.2	-1.8	23.5
DANIAmet-AREPA	-3.2	21.1	2.8	29.9			9.0	27.2	1.0	23.5
NPL	-12.2	17.1	-6.2	27.2	-9.0	27.2			-8.0	20.0
SP	-4.2	10.2	1.8	23.5	-1.0	23.5	8.0	20.0		
IEN	-12.3	14.1	-6.3	25.4	-9.1	25.4	-0.1	22.2	-8.1	17.5
CEM	-4.2	30.1	1.8	36.8	-1.0	36.8	8.0	34.7	0.0	31.8
PTB	-7.0	8.0	-1.0	22.6	-3.8	19.6	5.2	18.9	-2.8	13.0
VSL	-9.2	20.0	-3.2	29.1	-6.0	29.1	3.0	26.4	-5.0	22.5
INTI	-9.1	16.1	-3.1	26.6	-5.9	26.6	3.1	23.5	-4.9	19.1
NMIA	-2.1	10.1	3.9	23.4	1.1	23.4	10.1	19.9	2.1	14.4
NRC	-0.1	10.1	5.9	23.4	3.1	23.4	12.1	19.9	4.1	14.4
VNIIM	-11.6	24.7	-5.6	32.5	-8.4	32.5	0.6	30.1	-7.4	26.8
METAS	-6.9	6.2	-0.9	22.0	-3.7	22.0	5.3	18.2	-2.7	12.0
NIST	-2.0	11.3	4.0	24.0	1.2	24.0	10.2	20.5	2.2	15.3
NIM	-6.3	21.3	-0.3	30.0	-3.1	30.0	5.9	27.4	-2.1	23.7

Table 2i : Degree of equivalence at 500 V / 20 kHz (1/4)

Voltage : 500 V			**IEN**		**CEM**		**PTB**		**VSL**	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			-12.3	14.1	-4.2	30.1	-7.0	8.0	-9.2	20.0
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-6.0	21.1	6.3	25.4	-1.8	36.8	1.0	22.6	3.2	29.1
DANIAmet-AREPA	-3.2	21.1	9.1	25.4	1.0	36.8	3.8	19.6	6.0	29.1
NPL	-12.2	17.1	0.1	22.2	-8.0	34.7	-5.2	18.9	-3.0	26.4
SP	-4.2	10.2	8.1	17.5	0.0	31.8	2.8	13.0	5.0	22.5
IEN	-12.3	14.1			-8.1	33.3	-5.3	16.3	-3.1	24.5
CEM	-4.2	30.1	8.1	33.3			2.8	31.2	5.0	36.2
PTB	-7.0	8.0	5.3	16.3	-2.8	31.2			2.2	21.6
VSL	-9.2	20.0	3.1	24.5	-5.0	36.2	-2.2	21.6		
INTI	-9.1	16.1	3.2	21.5	-4.9	34.2	-2.1	18.0	0.1	25.7
NMIA	-2.1	10.1	10.2	17.4	2.1	31.8	4.9	12.9	7.1	22.5
NRC	-0.1	10.1	12.2	17.4	4.1	31.8	6.9	12.9	9.1	22.5
VNIIM	-11.6	24.7	0.7	28.5	-7.4	39.0	-4.6	26.0	-2.4	31.8
METAS	-6.9	6.2	5.4	15.5	-2.7	30.8	0.1	10.2	2.3	21.0
NIST	-2.0	11.3	10.3	18.1	2.2	32.2	5.0	13.9	7.2	23.0
NIM	-6.3	21.3	6.0	25.6	-2.1	36.9	0.7	22.8	2.9	29.3

Table 2j : Degree of equivalence at 500 V / 20 kHz (2/4)

Voltage : 500 V			**INTI**		**NMIA**		**NRC**		**VNIIM**	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(3/4)			-9.1	*16.1*	-2.1	*10.1*	-0.1	*10.1*	-11.6	*24.7*
			$D_{i,j}$	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-6.0	*21.1*	**3.1**	***26.6***	**-3.9**	***23.4***	**-5.9**	***23.4***	**5.6**	***32.5***
DANIAmet-AREPA	-3.2	*21.1*	**5.9**	***26.6***	**-1.1**	***23.4***	**-3.1**	***23.4***	**8.4**	***32.5***
NPL	-12.2	*17.1*	**-3.1**	***23.5***	**-10.1**	***19.9***	**-12.1**	***19.9***	**-0.6**	***30.1***
SP	-4.2	*10.2*	**4.9**	***19.1***	**-2.1**	***14.4***	**-4.1**	***14.4***	**7.4**	***26.8***
IEN	-12.3	*14.1*	**-3.2**	***21.5***	**-10.2**	***17.4***	**-12.2**	***17.4***	**-0.7**	***28.5***
CEM	-4.2	*30.1*	**4.9**	***34.2***	**-2.1**	***31.8***	**-4.1**	***31.8***	**7.4**	***39.0***
PTB	-7.0	*8.0*	**2.1**	***18.0***	**-4.9**	***12.9***	**-6.9**	***12.9***	**4.6**	***26.0***
VSL	-9.2	*20.0*	**-0.1**	***25.7***	**-7.1**	***22.5***	**-9.1**	***22.5***	**2.4**	***31.8***
INTI	-9.1	*16.1*			**-7.0**	***19.1***	**-9.0**	***19.1***	**2.5**	***29.5***
NMIA	-2.1	*10.1*	**7.0**	***19.1***			**-2.0**	***14.3***	**9.5**	***26.7***
NRC	-0.1	*10.1*	**9.0**	***19.1***	**2.0**	***14.3***			**11.5**	***26.7***
VNIIM	-11.6	*24.7*	**-2.5**	***29.5***	**-9.5**	***26.7***	**-11.5**	***26.7***		
METAS	-6.9	*6.2*	**2.2**	***17.3***	**-4.8**	***11.9***	**-6.8**	***11.9***	**4.7**	***25.5***
NIST	-2.0	*11.3*	**7.1**	***19.7***	**0.1**	***15.2***	**-1.9**	***15.2***	**9.6**	***27.2***
NIM	-6.3	*21.3*	**2.8**	***26.8***	**-4.2**	***23.6***	**-6.2**	***23.6***	**5.3**	***32.7***

Table 2k : Degree of equivalence at 500 V / 20 kHz (3/4)

Voltage : 500 V			**METAS**		**NIST**		**NIM**	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(4/4)			-6.9	*6.2*	-2.0	*11.3*	-6.3	*21.3*
			$D_{i,j}$	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**
	$d_{adj\,i}$	$u(d_{adj\,i})$						
BNM-LNE	-6.0	*21.1*	**0.9**	***22.0***	**-4.0**	***24.0***	**0.3**	***30.0***
DANIAmet-AREPA	-3.2	*21.1*	**3.7**	***22.0***	**-1.2**	***24.0***	**3.1**	***30.0***
NPL	-12.2	*17.1*	**-5.3**	***18.2***	**-10.2**	***20.5***	**-5.9**	***27.4***
SP	-4.2	*10.2*	**2.7**	***12.0***	**-2.2**	***15.3***	**2.1**	***23.7***
IEN	-12.3	*14.1*	**-5.4**	***15.5***	**-10.3**	***18.1***	**-6.0**	***25.6***
CEM	-4.2	*30.1*	**2.7**	***30.8***	**-2.2**	***32.2***	**2.1**	***36.9***
PTB	-7.0	*8.0*	**-0.1**	***10.2***	**-5.0**	***13.9***	**-0.7**	***22.8***
VSL	-9.2	*20.0*	**-2.3**	***21.0***	**-7.2**	***23.0***	**-2.9**	***29.3***
INTI	-9.1	*16.1*	**-2.2**	***17.3***	**-7.1**	***19.7***	**-2.8**	***26.8***
NMIA	-2.1	*10.1*	**4.8**	***11.9***	**-0.1**	***15.2***	**4.2**	***23.6***
NRC	-0.1	*10.1*	**6.8**	***11.9***	**1.9**	***15.2***	**6.2**	***23.6***
VNIIM	-11.6	*24.7*	**-4.7**	***25.5***	**-9.6**	***27.2***	**-5.3**	***32.7***
METAS	-6.9	*6.2*			**-4.9**	***12.9***	**-0.6**	***22.2***
NIST	-2.0	*11.3*	**4.9**	***12.9***			**4.3**	***24.2***
NIM	-6.3	*21.3*	**0.6**	***22.2***	**-4.3**	***24.2***		

Table 2l : Degree of equivalence at 500 V / 20 kHz (4/4)

Voltage : 500 V **Frequency : 50 kHz** (1/4)			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-23.6	*36.0*	-19.9	*21.1*	-28.9	*24.1*	-15.9	*14.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-23.6	*36.0*			**-3.7**	***41.8***	**5.3**	***43.4***	**-7.7**	***38.7***
DANIAmet-AREPA	-19.9	*21.1*	**3.7**	***41.8***			**9.0**	***32.1***	**-4.0**	***25.4***
NPL	-28.9	*24.1*	**-5.3**	***43.4***	**-9.0**	***32.1***			**-13.0**	***28.0***
SP	-15.9	*14.1*	**7.7**	***38.7***	**4.0**	***25.4***	**13.0**	***28.0***		
IEN	-33.1	*20.3*	**-9.5**	***41.4***	**-13.2**	***29.3***	**-4.2**	***31.6***	**-17.2**	***24.8***
CEM	-26.9	*38.0*	**-3.3**	***52.4***	**-7.0**	***43.5***	**2.0**	***45.0***	**-11.0**	***40.6***
PTB	-22.5	*10.0*	**1.1**	***37.4***	**-2.6**	***18.6***	**6.4**	***26.1***	**-6.6**	***17.3***
VSL	-25.7	*25.0*	**-2.1**	***43.9***	**-5.8**	***32.8***	**3.2**	***34.8***	**-9.8**	***28.8***
INTI	-24.9	*18.1*	**-1.3**	***40.3***	**-5.0**	***27.8***	**4.0**	***30.2***	**-9.0**	***23.0***
NMIA	-13.9	*15.1*	**9.7**	***39.1***	**6.0**	***26.0***	**15.0**	***28.5***	**2.0**	***20.7***
NRC	-12.9	*10.7*	**10.7**	***37.6***	**7.0**	***23.7***	**16.0**	***26.4***	**3.0**	***17.8***
VNIIM	-41.0	*40.6*	**-17.4**	***54.3***	**-21.1**	***45.8***	**-12.1**	***47.3***	**-25.1**	***43.0***
METAS	-21.3	*9.1*	**2.3**	***37.2***	**-1.4**	***23.0***	**7.6**	***25.8***	**-5.4**	***16.8***
NIST	-25.0	*14.1*	**-1.4**	***38.7***	**-5.1**	***25.4***	**3.9**	***28.0***	**-9.1**	***20.0***
NIM	-24.9	*29.2*	**-1.3**	***46.4***	**-5.0**	***36.1***	**4.0**	***37.9***	**-9.0**	***32.5***

Table 2m : Degree of equivalence at 500 V / 50 kHz (1/4)

Voltage : 500 V **Frequency : 50 kHz** (2/4)			**IEN**		**CEM**		**PTB**		**VSL**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-33.1	*20.3*	-26.9	*38.0*	-22.5	*10.0*	-25.7	*25.0*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-23.6	*36.0*	**9.5**	***41.4***	**3.3**	***52.4***	**-1.1**	***37.4***	**2.1**	***43.9***
DANIAmet-AREPA	-19.9	*21.1*	**13.2**	***29.3***	**7.0**	***43.5***	**2.6**	***18.6***	**5.8**	***32.8***
NPL	-28.9	*24.1*	**4.2**	***31.6***	**-2.0**	***45.0***	**-6.4**	***26.1***	**-3.2**	***34.8***
SP	-15.9	*14.1*	**17.2**	***24.8***	**11.0**	***40.6***	**6.6**	***17.3***	**9.8**	***28.8***
IEN	-33.1	*20.3*			**-6.2**	***43.1***	**-10.6**	***22.7***	**-7.4**	***32.3***
CEM	-26.9	*38.0*	**6.2**	***43.1***			**-4.4**	***39.3***	**-1.2**	***45.5***
PTB	-22.5	*10.0*	**10.6**	***22.7***	**4.4**	***39.3***			**3.2**	***27.0***
VSL	-25.7	*25.0*	**7.4**	***32.3***	**1.2**	***45.5***	**-3.2**	***27.0***		
INTI	-24.9	*18.1*	**8.2**	***27.2***	**2.0**	***42.1***	**-2.4**	***20.7***	**0.8**	***30.9***
NMIA	-13.9	*15.1*	**19.2**	***25.4***	**13.0**	***40.9***	**8.6**	***18.2***	**11.8**	***29.3***
NRC	-12.9	*10.7*	**20.2**	***23.0***	**14.0**	***39.5***	**9.6**	***14.7***	**12.8**	***27.2***
VNIIM	-41.0	*40.6*	**-7.9**	***45.4***	**-14.1**	***55.7***	**-18.5**	***41.9***	**-15.3**	***47.7***
METAS	-21.3	*9.1*	**11.8**	***22.3***	**5.6**	***39.1***	**1.2**	***13.6***	**4.4**	***26.7***
NIST	-25.0	*14.1*	**8.1**	***24.8***	**1.9**	***40.6***	**-2.5**	***17.3***	**0.7**	***28.8***
NIM	-24.9	*29.2*	**8.2**	***35.6***	**2.0**	***48.0***	**-2.4**	***30.9***	**0.8**	***38.5***

Table 2n : Degree of equivalence at 500 V / 50 kHz (2/4)

Voltage : 500 V			**INTI**		**NMIA**		**NRC**		**VNIIM**	
Frequency : 50 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(3/4)			-24.9	18.1	-13.9	15.1	-12.9	10.7	-41.0	40.6
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-23.6	36.0	1.3	40.3	-9.7	39.1	-10.7	37.6	17.4	54.3
DANIAmet-AREPA	-19.9	21.1	5.0	27.8	-6.0	26.0	-7.0	23.7	21.1	45.8
NPL	-28.9	24.1	-4.0	30.2	-15.0	28.5	-16.0	26.4	12.1	47.3
SP	-15.9	14.1	9.0	23.0	-2.0	20.7	-3.0	17.8	25.1	43.0
IEN	-33.1	20.3	-8.2	27.2	-19.2	25.4	-20.2	23.0	7.9	45.4
CEM	-26.9	38.0	-2.0	42.1	-13.0	40.9	-14.0	39.5	14.1	55.7
PTB	-22.5	10.0	2.4	20.7	-8.6	18.2	-9.6	14.7	18.5	41.9
VSL	-25.7	25.0	-0.8	30.9	-11.8	29.3	-12.8	27.2	15.3	47.7
INTI	-24.9	18.1			-11.0	23.6	-12.0	21.1	16.1	44.5
NMIA	-13.9	15.1	11.0	23.6			-1.0	18.6	27.1	43.4
NRC	-12.9	10.7	12.0	21.1	1.0	18.6			28.1	42.0
VNIIM	-41.0	40.6	-16.1	44.5	-27.1	43.4	-28.1	42.0		
METAS	-21.3	9.1	3.6	20.3	-7.4	17.7	-8.4	14.1	19.7	41.7
NIST	-25.0	14.1	-0.1	23.0	-11.1	20.7	-12.1	17.8	16.0	43.0
NIM	-24.9	29.2	0.0	34.4	-11.0	32.9	-12.0	31.1	16.1	50.1

Table 2o : Degree of equivalence at 500 V / 50 kHz (3/4)

Voltage : 500 V			**METAS**		**NIST**		**NIM**	
Frequency : 50 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(4/4)			-21.3	9.1	-25.0	14.1	-24.9	29.2
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$						
BNM-LNE	-23.6	36.0	-2.3	37.2	1.4	38.7	1.3	46.4
DANIAmet-AREPA	-19.9	21.1	1.4	23.0	5.1	25.4	5.0	36.1
NPL	-28.9	24.1	-7.6	25.8	-3.9	28.0	-4.0	37.9
SP	-15.9	14.1	5.4	16.8	9.1	20.0	9.0	32.5
IEN	-33.1	20.3	-11.8	22.3	-8.1	24.8	-8.2	35.6
CEM	-26.9	38.0	-5.6	39.1	-1.9	40.6	-2.0	48.0
PTB	-22.5	10.0	-1.2	13.6	2.5	17.3	2.4	30.9
VSL	-25.7	25.0	-4.4	26.7	-0.7	28.8	-0.8	38.5
INTI	-24.9	18.1	-3.6	20.3	0.1	23.0	0.0	34.4
NMIA	-13.9	15.1	7.4	17.7	11.1	20.7	11.0	32.9
NRC	-12.9	10.7	8.4	14.1	12.1	17.8	12.0	31.1
VNIIM	-41.0	40.6	-19.7	41.7	-16.0	43.0	-16.1	50.1
METAS	-21.3	9.1			3.7	16.8	3.6	30.6
NIST	-25.0	14.1	-3.7	16.8			-0.1	32.5
NIM	-24.9	29.2	-3.6	30.6	0.1	32.5		

Table 2p : Degree of equivalence at 500 V / 50 kHz (4/4)

Voltage : 500 V			BNM-LNE		DANIAmet-AREPA		NPL		SP	
Frequency : 100 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-61.6	36.1	-53.9	41.1	-68.9	46.1	-48.9	21.1
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-61.6	36.1			-7.7	54.8	7.3	58.6	-12.7	41.9
DANIAmet-AREPA	-53.9	41.1	7.7	54.8			15.0	61.8	-5.0	46.2
NPL	-68.9	46.1	-7.3	58.6	-15.0	61.8			-20.0	50.7
SP	-48.9	21.1	12.7	41.9	5.0	46.2	20.0	50.7		
IEN	-74.3	47.7	-12.7	59.9	-20.4	63.0	-5.4	66.4	-25.4	52.2
CEM	-55.9	50.0	5.7	61.7	-2.0	64.8	13.0	68.1	-7.0	54.3
PTB	-60.5	22.0	1.1	42.3	-6.6	34.8	8.4	51.1	-11.6	30.5
VSL	-63.8	40.0	-2.2	53.9	-9.9	57.4	5.1	61.1	-14.9	45.3
INTI	-63.0	30.1	-1.4	47.1	-9.1	51.0	5.9	55.1	-14.1	36.8
NMIA	-46.0	23.1	15.6	42.9	7.9	47.2	22.9	51.6	2.9	31.3
NRC	-59.0	24.1	2.6	43.5	-5.1	47.7	9.9	52.1	-10.1	32.1
VNIIM	-80.2	60.4	-18.6	70.4	-26.3	73.1	-11.3	76.0	-31.3	64.0
METAS	-56.0	26.1	5.6	44.6	-2.1	48.7	12.9	53.0	-7.1	33.6
NIST	-67.0	17.9	-5.4	40.3	-13.1	44.9	1.9	49.5	-18.1	27.7
NIM	-81.5	39.7	-19.9	53.7	-27.6	57.2	-12.6	60.9	-32.6	45.0

Table 2q : Degree of equivalence at 500 V / 100 kHz (1/4)

Voltage : 500 V			IEN		CEM		PTB		VSL	
Frequency : 100 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			-74.3	47.7	-55.9	50.0	-60.5	22.0	-63.8	40.0
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-61.6	36.1	12.7	59.9	-5.7	61.7	-1.1	42.3	2.2	53.9
DANIAmet-AREPA	-53.9	41.1	20.4	63.0	2.0	64.8	6.6	34.8	9.9	57.4
NPL	-68.9	46.1	5.4	66.4	-13.0	68.1	-8.4	51.1	-5.1	61.1
SP	-48.9	21.1	25.4	52.2	7.0	54.3	11.6	30.5	14.9	45.3
IEN	-74.3	47.7			-18.4	69.2	-13.8	52.6	-10.5	62.3
CEM	-55.9	50.0	18.4	69.2			4.6	54.7	7.9	64.1
PTB	-60.5	22.0	13.8	52.6	-4.6	54.7			3.3	45.7
VSL	-63.8	40.0	10.5	62.3	-7.9	64.1	-3.3	45.7		
INTI	-63.0	30.1	11.3	56.5	-7.1	58.4	-2.5	37.3	0.8	50.1
NMIA	-46.0	23.1	28.3	53.0	9.9	55.1	14.5	31.9	17.8	46.2
NRC	-59.0	24.1	15.3	53.5	-3.1	55.6	1.5	32.7	4.8	46.7
VNIIM	-80.2	60.4	-5.9	77.0	-24.3	78.5	-19.7	64.3	-16.4	72.5
METAS	-56.0	26.1	18.3	54.4	-0.1	56.5	4.5	34.2	7.8	47.8
NIST	-67.0	17.9	7.3	51.0	-11.1	53.2	-6.5	28.4	-3.2	43.9
NIM	-81.5	39.7	-7.2	62.1	-25.6	63.9	-21.0	45.4	-17.7	56.4

Table 2r : Degree of equivalence at 500 V / 100 kHz (2/4)

Voltage : 500 V			**INTI**		**NMIA**		**NRC**		**VNIIM**	
Frequency : 100 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(3/4)			-63.0	*30.1*	-46.0	*23.1*	-59.0	*24.1*	-80.2	*60.4*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$								
BNM-LNE	-61.6	*36.1*	**1.4**	***47.1***	**-15.6**	***42.9***	**-2.6**	***43.5***	**18.6**	***70.4***
DANIAmet-AREPA	-53.9	*41.1*	**9.1**	***51.0***	**-7.9**	***47.2***	**5.1**	***47.7***	**26.3**	***73.1***
NPL	-68.9	*46.1*	**-5.9**	***55.1***	**-22.9**	***51.6***	**-9.9**	***52.1***	**11.3**	***76.0***
SP	-48.9	*21.1*	**14.1**	***36.8***	**-2.9**	***31.3***	**10.1**	***32.1***	**31.3**	***64.0***
IEN	-74.3	*47.7*	**-11.3**	***56.5***	**-28.3**	***53.0***	**-15.3**	***53.5***	**5.9**	***77.0***
CEM	-55.9	*50.0*	**7.1**	***58.4***	**-9.9**	***55.1***	**3.1**	***55.6***	**24.3**	***78.5***
PTB	-60.5	*22.0*	**2.5**	***37.3***	**-14.5**	***31.9***	**-1.5**	***32.7***	**19.7**	***64.3***
VSL	-63.8	*40.0*	**-0.8**	***50.1***	**-17.8**	***46.2***	**-4.8**	***46.7***	**16.4**	***72.5***
INTI	-63.0	*30.1*			**-17.0**	***38.0***	**-4.0**	***38.6***	**17.2**	***67.5***
NMIA	-46.0	*23.1*	**17.0**	***38.0***			**13.0**	***33.4***	**34.2**	***64.7***
NRC	-59.0	*24.1*	**4.0**	***38.6***	**-13.0**	***33.4***			**21.2**	***65.1***
VNIIM	-80.2	*60.4*	**-17.2**	***67.5***	**-34.2**	***64.7***	**-21.2**	***65.1***		
METAS	-56.0	*26.1*	**7.0**	***39.9***	**-10.0**	***34.9***	**3.0**	***35.6***	**24.2**	***65.8***
NIST	-67.0	*17.9*	**-4.0**	***35.1***	**-21.0**	***29.3***	**-8.0**	***30.1***	**13.2**	***63.0***
NIM	-81.5	*39.7*	**-18.5**	***49.9***	**-35.5**	***46.0***	**-22.5**	***46.5***	**-1.3**	***72.3***

Table 2s : Degree of equivalence at 500 V / 100 kHz (3/4)

Voltage : 500 V			**METAS**		**NIST**		**NIM**	
Frequency : 100 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(4/4)			-56.0	*26.1*	-67.0	*17.9*	-81.5	*39.7*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$						
BNM-LNE	-61.6	*36.1*	**-5.6**	***44.6***	**5.4**	***40.3***	**19.9**	***53.7***
DANIAmet-AREPA	-53.9	*41.1*	**2.1**	***48.7***	**13.1**	***44.9***	**27.6**	***57.2***
NPL	-68.9	*46.1*	**-12.9**	***53.0***	**-1.9**	***49.5***	**12.6**	***60.9***
SP	-48.9	*21.1*	**7.1**	***33.6***	**18.1**	***27.7***	**32.6**	***45.0***
IEN	-74.3	*47.7*	**-18.3**	***54.4***	**-7.3**	***51.0***	**7.2**	***62.1***
CEM	-55.9	*50.0*	**0.1**	***56.5***	**11.1**	***53.2***	**25.6**	***63.9***
PTB	-60.5	*22.0*	**-4.5**	***34.2***	**6.5**	***28.4***	**21.0**	***45.4***
VSL	-63.8	*40.0*	**-7.8**	***47.8***	**3.2**	***43.9***	**17.7**	***56.4***
INTI	-63.0	*30.1*	**-7.0**	***39.9***	**4.0**	***35.1***	**18.5**	***49.9***
NMIA	-46.0	*23.1*	**10.0**	***34.9***	**21.0**	***29.3***	**35.5**	***46.0***
NRC	-59.0	*24.1*	**-3.0**	***35.6***	**8.0**	***30.1***	**22.5**	***46.5***
VNIIM	-80.2	*60.4*	**-24.2**	***65.8***	**-13.2**	***63.0***	**1.3**	***72.3***
METAS	-56.0	*26.1*			**11.0**	***31.7***	**25.5**	***47.6***
NIST	-67.0	*17.9*	**-11.0**	***31.7***			**14.5**	***43.6***
NIM	-81.5	*39.7*	**-25.5**	***47.6***	**-14.5**	***43.6***		

Table 2t : Degree of equivalence at 500 V / 100 kHz (4/4)

Voltage : 200 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 1 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-0.1	*12.2*	3.5	*11.2*	6.5	*12.2*	3.5	*7.3*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-0.1	*12.2*			**-3.6**	***16.6***	**-6.6**	***17.3***	**-3.6**	***14.3***
DANIAmet-AREPA	3.5	*11.2*	**3.6**	***16.6***			**-3.0**	***16.6***	**0.0**	***13.4***
NPL	6.5	*12.2*	**6.6**	***17.3***	**3.0**	***16.6***			**3.0**	***14.3***
SP	3.5	*7.3*	**3.6**	***14.3***	**0.0**	***13.4***	**-3.0**	***14.3***		
IEN	2.2	*8.9*	**2.3**	***15.2***	**-1.3**	***14.4***	**-4.3**	***15.2***	**-1.3**	***11.6***
CEM	3.5	*22.1*	**3.6**	***25.3***	**0.0**	***24.8***	**-3.0**	***25.3***	**0.0**	***23.3***
PTB	-0.5	*8.0*	**-0.4**	***14.6***	**-4.0**	***7.9***	**-7.0**	***14.6***	**-4.0**	***10.9***
INTI	-3.1	*10.2*	**-3.0**	***16.0***	**-6.6**	***15.2***	**-9.6**	***16.0***	**-6.6**	***12.6***
NMIA	-0.2	*7.3*	**-0.1**	***14.3***	**-3.7**	***13.4***	**-6.7**	***14.3***	**-3.7**	***10.4***
NRC	-0.1	*10.2*	**0.0**	***16.0***	**-3.6**	***15.2***	**-6.6**	***16.0***	**-3.6**	***12.6***
VNIIM	2.4	*12.8*	**2.5**	***17.7***	**-1.1**	***17.1***	**-4.1**	***17.7***	**-1.1**	***14.8***
METAS	-1.5	*6.3*	**-1.4**	***13.8***	**-5.0**	***12.9***	**-8.0**	***13.8***	**-5.0**	***9.7***
NIST	5.4	*5.9*	**5.5**	***13.6***	**1.9**	***12.7***	**-1.1**	***13.6***	**1.9**	***9.4***
NIM	0.1	*11.2*	**0.2**	***16.6***	**-3.4**	***15.9***	**-6.4**	***16.6***	**-3.4**	***13.4***

Table 3a : Degree of equivalence at 200 V / 1 kHz (1/4)

Voltage : 200 V			**IEN**		**CEM**		**PTB**		**INTI**	
Frequency : 1 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			2.2	*8.9*	3.5	*22.1*	-0.5	*8.0*	-3.1	*10.2*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-0.1	*12.2*	**-2.3**	***15.2***	**-3.6**	***25.3***	**0.4**	***14.6***	**3.0**	***16.0***
DANIAmet-AREPA	3.5	*11.2*	**1.3**	***14.4***	**0.0**	***24.8***	**4.0**	***7.9***	**6.6**	***15.2***
NPL	6.5	*12.2*	**4.3**	***15.2***	**3.0**	***25.3***	**7.0**	***14.6***	**9.6**	***16.0***
SP	3.5	*7.3*	**1.3**	***11.6***	**0.0**	***23.3***	**4.0**	***10.9***	**6.6**	***12.6***
IEN	2.2	*8.9*			**-1.3**	***23.9***	**2.7**	***12.0***	**5.3**	***13.6***
CEM	3.5	*22.1*	**1.3**	***23.9***			**4.0**	***23.6***	**6.6**	***24.4***
PTB	-0.5	*8.0*	**-2.7**	***12.0***	**-4.0**	***23.6***			**2.6**	***13.0***
INTI	-3.1	*10.2*	**-5.3**	***13.6***	**-6.6**	***24.4***	**-2.6**	***13.0***		
NMIA	-0.2	*7.3*	**-2.4**	***11.6***	**-3.7**	***23.3***	**0.3**	***10.9***		
NRC	-0.1	*10.2*	**-2.3**	***13.6***	**-3.6**	***24.4***	**0.4**	***13.0***	**3.0**	***14.5***
VNIIM	2.4	*12.8*	**0.2**	***15.6***	**-1.1**	***25.6***	**2.9**	***15.1***	**5.5**	***16.4***
METAS	-1.5	*6.3*	**-3.7**	***11.0***	**-5.0**	***23.0***	**-1.0**	***10.2***	**1.6**	***12.0***
NIST	5.4	*5.9*	**3.2**	***10.7***	**1.9**	***22.9***	**5.9**	***10.0***	**8.5**	***11.8***
NIM	0.1	*11.2*	**-2.1**	***14.4***	**-3.4**	***24.8***	**0.6**	***13.8***	**3.2**	***15.2***

Table 3b : Degree of equivalence at 200 V / 1 kHz (2/4)

Voltage : 200 V			**NMIA**		**NRC**		**VNIIM**		**METAS**	
Frequency : 1 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(3/4)			-0.2	*7.3*	-0.1	*10.2*	2.4	*12.8*	-1.5	*6.3*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-0.1	*12.2*	**0.1**	***14.3***	**0.0**	***16.0***	**-2.5**	***17.7***	**1.4**	***13.8***
DANIAmet-AREPA	3.5	*11.2*	**3.7**	***13.4***	**3.6**	***15.2***	**1.1**	***17.1***	**5.0**	***12.9***
NPL	6.5	*12.2*	**6.7**	***14.3***	**6.6**	***16.0***	**4.1**	***17.7***	**8.0**	***13.8***
SP	3.5	*7.3*	**3.7**	***10.4***	**3.6**	***12.6***	**1.1**	***14.8***	**5.0**	***9.7***
IEN	2.2	*8.9*	**2.4**	***11.6***	**2.3**	***13.6***	**-0.2**	***15.6***	**3.7**	***11.0***
CEM	3.5	*22.1*	**3.7**	***23.3***	**3.6**	***24.4***	**1.1**	***25.6***	**5.0**	***23.0***
PTB	-0.5	*8.0*	**-0.3**	***10.9***	**-0.4**	***13.0***	**-2.9**	***15.1***	**1.0**	***10.2***
INTI	-3.1	*10.2*	**-2.9**	***12.6***	**-3.0**	***14.5***	**-5.5**	***16.4***	**-1.6**	***12.0***
NMIA	-0.2	*7.3*			**-0.1**	***12.6***	**-2.6**	***14.8***	**1.3**	***9.7***
NRC	-0.1	*10.2*	**0.1**	***12.6***			**-2.5**	***16.4***	**1.4**	***12.0***
VNIIM	2.4	*12.8*	**2.6**	***14.8***	**2.5**	***16.4***			**3.9**	***14.3***
METAS	-1.5	*6.3*	**-1.3**	***9.7***	**-1.4**	***12.0***	**-3.9**	***14.3***		
NIST	5.4	*5.9*	**5.6**	***9.4***	**5.5**	***11.8***	**3.0**	***14.1***	**6.9**	***8.7***
NIM	0.1	*11.2*	**0.3**	***13.4***	**0.2**	***15.2***	**-2.3**	***17.1***	**1.6**	***12.9***

Table 3c : Degree of equivalence at 200 V / 1 kHz (3/4)

Voltage : 200 V			**NIST**		**NIM**	
Frequency : 1 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(4/4)			5.4	*5.9*	0.1	*11.2*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$				
BNM-LNE	-0.1	*12.2*	**-5.5**	***13.6***	**-0.2**	***16.6***
DANIAmet-AREPA	3.5	*11.2*	**-1.9**	***12.7***	**3.4**	***15.9***
NPL	6.5	*12.2*	**1.1**	***13.6***	**6.4**	***16.6***
SP	3.5	*7.3*	**-1.9**	***9.4***	**3.4**	***13.4***
IEN	2.2	*8.9*	**-3.2**	***10.7***	**2.1**	***14.4***
CEM	3.5	*22.1*	**-1.9**	***22.9***	**3.4**	***24.8***
PTB	-0.5	*8.0*	**-5.9**	***10.0***	**-0.6**	***13.8***
INTI	-3.1	*10.2*	**-8.5**	***11.8***	**-3.2**	***15.2***
NMIA	-0.2	*7.3*	**-5.6**	***9.4***	**-0.3**	***13.4***
NRC	-0.1	*10.2*	**-5.5**	***11.8***	**-0.2**	***15.2***
VNIIM	2.4	*12.8*	**-3.0**	***14.1***	**2.3**	***17.1***
METAS	-1.5	*6.3*	**-6.9**	***8.7***	**-1.6**	***12.9***
NIST	5.4	*5.9*			**5.3**	***12.7***
NIM	0.1	*11.2*	**-5.3**	***12.7***		

Table 3d : Degree of equivalence at 200 V / 1 kHz (4/4)

Voltage : 200 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 10 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(1/4)			-5.8	*13.1*	0.4	*11.1*	-7.6	*12.1*	2.4	*8.2*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$								
BNM-LNE	-5.8	*13.1*			**-6.2**	***17.2***	**1.8**	***17.9***	**-8.2**	***15.5***
DANIAmet-AREPA	0.4	*11.1*	**6.2**	***17.2***			**8.0**	***16.5***	**-2.0**	***13.9***
NPL	-7.6	*12.1*	**-1.8**	***17.9***	**-8.0**	***16.5***			**-10.0**	***14.7***
SP	2.4	*8.2*	**8.2**	***15.5***	**2.0**	***13.9***	**10.0**	***14.7***		
IEN	-3.6	*9.0*	**2.2**	***15.9***	**-4.0**	***14.3***	**4.0**	***15.1***	**-6.0**	***12.2***
CEM	3.4	*22.1*	**9.2**	***25.7***	**3.0**	***24.8***	**11.0**	***25.2***	**1.0**	***23.6***
PTB	-3.3	*8.0*	**2.5**	***15.4***	**-3.7**	***7.7***	**4.3**	***14.6***	**-5.7**	***11.5***
INTI	-5.2	*10.1*	**0.6**	***16.6***	**-5.6**	***15.1***	**2.4**	***15.8***	**-7.6**	***13.1***
NMIA	-2.2	*7.2*	**3.6**	***15.0***	**-2.6**	***13.3***	**5.4**	***14.1***	**-4.6**	***11.0***
NRC	-3.2	*10.1*	**2.6**	***16.6***	**-3.6**	***15.1***	**4.4**	***15.8***	**-5.6**	***13.1***
VNIIM	-1.3	*12.5*	**4.5**	***18.2***	**-1.7**	***16.8***	**6.3**	***17.4***	**-3.7**	***15.0***
METAS	-4.4	*6.2*	**1.4**	***14.5***	**-4.8**	***12.8***	**3.2**	***13.6***	**-6.8**	***10.3***
NIST	1.0	*6.0*	**6.8**	***14.5***	**0.6**	***12.7***	**8.6**	***13.6***	**-1.4**	***10.2***
NIM	-5.6	*11.1*	**0.2**	***17.2***	**-6.0**	***15.7***	**2.0**	***16.5***	**-8.0**	***13.9***

Table 3e : Degree of equivalence at 200 V / 10 kHz (1/4)

Voltage : 200 V			**IEN**		**CEM**		**PTB**		**INTI**	
Frequency : 10 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(2/4)			-3.6	*9.0*	3.4	*22.1*	-3.3	*8.0*	-5.2	*10.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$								
BNM-LNE	-5.8	*13.1*	**-2.2**	***15.9***	**-9.2**	***25.7***	**-2.5**	***15.4***	**-0.6**	***16.6***
DANIAmet-AREPA	0.4	*11.1*	**4.0**	***14.3***	**-3.0**	***24.8***	**3.7**	***7.7***	**5.6**	***15.1***
NPL	-7.6	*12.1*	**-4.0**	***15.1***	**-11.0**	***25.2***	**-4.3**	***14.6***	**-2.4**	***15.8***
SP	2.4	*8.2*	**6.0**	***12.2***	**-1.0**	***23.6***	**5.7**	***11.5***	**7.6**	***13.1***
IEN	-3.6	*9.0*			**-7.0**	***23.9***	**-0.3**	***12.1***	**1.6**	***13.6***
CEM	3.4	*22.1*	**7.0**	***23.9***			**6.7**	***23.6***	**8.6**	***24.3***
PTB	-3.3	*8.0*	**0.3**	***12.1***	**-6.7**	***23.6***			**1.9**	***12.9***
INTI	-5.2	*10.1*	**-1.6**	***13.6***	**-8.6**	***24.3***	**-1.9**	***12.9***		
NMIA	-2.2	*7.2*	**1.4**	***11.6***	**-5.6**	***23.3***	**1.1**	***10.8***	**3.0**	***12.5***
NRC	-3.2	*10.1*	**0.4**	***13.6***	**-6.6**	***24.3***	**0.1**	***12.9***	**2.0**	***14.3***
VNIIM	-1.3	*12.5*	**2.3**	***15.5***	**-4.7**	***25.4***	**2.0**	***14.9***	**3.9**	***16.1***
METAS	-4.4	*6.2*	**-0.8**	***11.0***	**-7.8**	***23.0***	**-1.1**	***10.2***	**0.8**	***11.9***
NIST	1.0	*6.0*	**4.6**	***10.9***	**-2.4**	***22.9***	**4.3**	***10.0***	**6.2**	***11.8***
NIM	-5.6	*11.1*	**-2.0**	***14.3***	**-9.0**	***24.8***	**-2.3**	***13.7***	**-0.4**	***15.1***

Table 3f : Degree of equivalence at 200 V / 10 kHz (2/4)

Voltage : 200 V **Frequency : 10 kHz** (3/4)			**NMIA**		**NRC**		**VNIIM**		**METAS**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-2.2	*7.2*	-3.2	*10.1*	-1.3	*12.5*	-4.4	*6.2*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-5.8	*13.1*	**-3.6**	***15.0***	**-2.6**	***16.6***	**-4.5**	***18.2***	**-1.4**	***14.5***
DANIAmet-AREPA	0.4	*11.1*	**2.6**	***13.3***	**3.6**	***15.1***	**1.7**	***16.8***	**4.8**	***12.8***
NPL	-7.6	*12.1*	**-5.4**	***14.1***	**-4.4**	***15.8***	**-6.3**	***17.4***	**-3.2**	***13.6***
SP	2.4	*8.2*	**4.6**	***11.0***	**5.6**	***13.1***	**3.7**	***15.0***	**6.8**	***10.3***
IEN	-3.6	*9.0*	**-1.4**	***11.6***	**-0.4**	***13.6***	**-2.3**	***15.5***	**0.8**	***11.0***
CEM	3.4	*22.1*	**5.6**	***23.3***	**6.6**	***24.3***	**4.7**	***25.4***	**7.8**	***23.0***
PTB	-3.3	*8.0*	**-1.1**	***10.8***	**-0.1**	***12.9***	**-2.0**	***14.9***	**1.1**	***10.2***
INTI	-5.2	*10.1*	**-3.0**	***12.5***	**-2.0**	***14.3***	**-3.9**	***16.1***	**-0.8**	***11.9***
NMIA	-2.2	*7.2*			**1.0**	***12.5***	**-0.9**	***14.5***	**2.2**	***9.6***
NRC	-3.2	*10.1*	**-1.0**	***12.5***			**-1.9**	***16.1***	**1.2**	***11.9***
VNIIM	-1.3	*12.5*	**0.9**	***14.5***	**1.9**	***16.1***			**3.1**	***14.0***
METAS	-4.4	*6.2*	**-2.2**	***9.6***	**-1.2**	***11.9***	**-3.1**	***14.0***		
NIST	1.0	*6.0*	**3.2**	***9.4***	**4.2**	***11.8***	**2.3**	***13.9***	**5.4**	***8.7***
NIM	-5.6	*11.1*	**-3.4**	***13.3***	**-2.4**	***15.1***	**-4.3**	***16.8***	**-1.2**	***12.8***

Table 3g : Degree of equivalence at 200 V / 10 kHz (3/4)

Voltage : 200 V **Frequency : 10 kHz** (4/4)			**NIST**		**NIM**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			1.0	*6.0*	-5.6	*11.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$				
BNM-LNE	-5.8	*13.1*	**-6.8**	***14.5***	**-0.2**	***17.2***
DANIAmet-AREPA	0.4	*11.1*	**-0.6**	***12.7***	**6.0**	***15.7***
NPL	-7.6	*12.1*	**-8.6**	***13.6***	**-2.0**	***16.5***
SP	2.4	*8.2*	**1.4**	***10.2***	**8.0**	***13.9***
IEN	-3.6	*9.0*	**-4.6**	***10.9***	**2.0**	***14.3***
CEM	3.4	*22.1*	**2.4**	***22.9***	**9.0**	***24.8***
PTB	-3.3	*8.0*	**-4.3**	***10.0***	**2.3**	***13.7***
INTI	-5.2	*10.1*	**-6.2**	***11.8***	**0.4**	***15.1***
NMIA	-2.2	*7.2*	**-3.2**	***9.4***	**3.4**	***13.3***
NRC	-3.2	*10.1*	**-4.2**	***11.8***	**2.4**	***15.1***
VNIIM	-1.3	*12.5*	**-2.3**	***13.9***	**4.3**	***16.8***
METAS	-4.4	*6.2*	**-5.4**	***8.7***	**1.2**	***12.8***
NIST	1.0	*6.0*			**6.6**	***12.7***
NIM	-5.6	*11.1*	**-6.6**	***12.7***		

Table 3h : Degree of equivalence at 200 V / 10 kHz (4/4)

Voltage : 200 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-7.7	*13.1*	-4.6	*11.1*	-9.6	*14.1*	-1.6	*9.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-7.7	*13.1*			**-3.1**	***17.2***	**1.9**	***19.3***	**-6.1**	***16.0***
DANIAmet-AREPA	-4.6	*11.1*	**3.1**	***17.2***			**5.0**	***18.0***	**-3.0**	***14.4***
NPL	-9.6	*14.1*	**-1.9**	***19.3***	**-5.0**	***18.0***			**-8.0**	***16.8***
SP	-1.6	*9.1*	**6.1**	***16.0***	**3.0**	***14.4***	**8.0**	***16.8***		
IEN	-11.0	*12.9*	**-3.3**	***18.4***	**-6.4**	***17.1***	**-1.4**	***19.2***	**-9.4**	***15.8***
CEM	-0.6	*22.0*	**7.1**	***25.7***	**4.0**	***24.7***	**9.0**	***26.2***	**1.0**	***23.9***
PTB	-7.3	*8.0*	**0.4**	***15.4***	**-2.7**	***7.7***	**2.3**	***16.3***	**-5.7**	***12.2***
INTI	-8.3	*12.1*	**-0.6**	***17.9***	**-3.7**	***16.5***	**1.3**	***18.6***	**-6.7**	***15.2***
NMIA	-6.3	*8.1*	**1.4**	***15.5***	**-1.7**	***13.8***	**3.3**	***16.3***	**-4.7**	***12.2***
NRC	-4.3	*10.1*	**3.4**	***16.6***	**0.3**	***15.1***	**5.3**	***17.4***	**-2.7**	***13.6***
VNIIM	-3.3	*20.2*	**4.4**	***24.1***	**1.3**	***23.1***	**6.3**	***24.7***	**-1.7**	***22.2***
METAS	-7.5	*6.1*	**0.2**	***14.5***	**-2.9**	***12.7***	**2.1**	***15.4***	**-5.9**	***11.0***
NIST	-2.5	*6.1*	**5.2**	***14.5***	**2.1**	***12.7***	**7.1**	***15.4***	**-0.9**	***11.0***
NIM	-8.8	*11.1*	**-1.1**	***17.2***	**-4.2**	***15.7***	**0.8**	***18.0***	**-7.2**	***14.4***

Table 3i : Degree of equivalence at 200 V / 20 kHz (1/4)

Voltage : 200 V			**IEN**		**CEM**		**PTB**		**INTI**	
Frequency : 20 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			-11.0	*12.9*	-0.6	*22.0*	-7.3	*8.0*	-8.3	*12.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-7.7	*13.1*	**3.3**	***18.4***	**-7.1**	***25.7***	**-0.4**	***15.4***	**0.6**	***17.9***
DANIAmet-AREPA	-4.6	*11.1*	**6.4**	***17.1***	**-4.0**	***24.7***	**2.7**	***7.7***	**3.7**	***16.5***
NPL	-9.6	*14.1*	**1.4**	***19.2***	**-9.0**	***26.2***	**-2.3**	***16.3***	**-1.3**	***18.6***
SP	-1.6	*9.1*	**9.4**	***15.8***	**-1.0**	***23.9***	**5.7**	***12.2***	**6.7**	***15.2***
IEN	-11.0	*12.9*			**-10.4**	***25.6***	**-3.7**	***15.2***	**-2.7**	***17.7***
CEM	-0.6	*22.0*	**10.4**	***25.6***			**6.7**	***23.5***	**7.7**	***25.2***
PTB	-7.3	*8.0*	**3.7**	***15.2***	**-6.7**	***23.5***			**1.0**	***14.6***
INTI	-8.3	*12.1*	**2.7**	***17.7***	**-7.7**	***25.2***	**-1.0**	***14.6***		
NMIA	-6.3	*8.1*	**4.7**	***15.3***	**-5.7**	***23.5***	**1.0**	***11.4***	**2.0**	***14.6***
NRC	-4.3	*10.1*	**6.7**	***16.4***	**-3.7**	***24.3***	**3.0**	***12.9***	**4.0**	***15.8***
VNIIM	-3.3	*20.2*	**7.7**	***24.0***	**-2.7**	***29.9***	**4.0**	***21.8***	**5.0**	***23.6***
METAS	-7.5	*6.1*	**3.5**	***14.3***	**-6.9**	***22.9***	**-0.2**	***10.1***	**0.8**	***13.6***
NIST	-2.5	*6.1*	**8.5**	***14.3***	**-1.9**	***22.9***	**4.8**	***10.1***	**5.8**	***13.6***
NIM	-8.8	*11.1*	**2.2**	***17.1***	**-8.2**	***24.7***	**-1.5**	***13.7***	**-0.5**	***16.5***

Table 3j : Degree of equivalence at 200 V / 20 kHz (2/4)

Voltage : 200 V **Frequency : 20 kHz** (3/4)			**NMIA**		**NRC**		**VNIIM**		**METAS**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-6.3	*8.1*	-4.3	*10.1*	-3.3	*20.2*	-7.5	*6.1*
			$\mathbf{D_{i,j}}$	$U_{i,j}$	$\mathbf{D_{i,j}}$	$U_{i,j}$	$\mathbf{D_{i,j}}$	$U_{i,j}$	$\mathbf{D_{i,j}}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-7.7	*13.1*	**-1.4**	***15.5***	**-3.4**	***16.6***	**-4.4**	***24.1***	**-0.2**	***14.5***
DANIAmet-AREPA	-4.6	*11.1*	**1.7**	***13.8***	**-0.3**	***15.1***	**-1.3**	***23.1***	**2.9**	***12.7***
NPL	-9.6	*14.1*	**-3.3**	***16.3***	**-5.3**	***17.4***	**-6.3**	***24.7***	**-2.1**	***15.4***
SP	-1.6	*9.1*	**4.7**	***12.2***	**2.7**	***13.6***	**1.7**	***22.2***	**5.9**	***11.0***
IEN	-11.0	*12.9*	**-4.7**	***15.3***	**-6.7**	***16.4***	**-7.7**	***24.0***	**-3.5**	***14.3***
CEM	-0.6	*22.0*	**5.7**	***23.5***	**3.7**	***24.3***	**2.7**	***29.9***	**6.9**	***22.9***
PTB	-7.3	*8.0*	**-1.0**	***11.4***	**-3.0**	***12.9***	**-4.0**	***21.8***	**0.2**	***10.1***
INTI	-8.3	*12.1*	**-2.0**	***14.6***	**-4.0**	***15.8***	**-5.0**	***23.6***	**-0.8**	***13.6***
NMIA	-6.3	*8.1*			**-2.0**	***13.0***	**-3.0**	***21.8***	**1.2**	***10.2***
NRC	-4.3	*10.1*	**2.0**	***13.0***			**-1.0**	***22.6***	**3.2**	***11.8***
VNIIM	-3.3	*20.2*	**3.0**	***21.8***	**1.0**	***22.6***			**4.2**	***21.2***
METAS	-7.5	*6.1*	**-1.2**	***10.2***	**-3.2**	***11.8***	**-4.2**	***21.2***		
NIST	-2.5	*6.1*	**3.8**	***10.2***	**1.8**	***11.8***	**0.8**	***21.2***	**5.0**	***8.7***
NIM	-8.8	*11.1*	**-2.5**	***13.8***	**-4.5**	***15.1***	**-5.5**	***23.1***	**-1.3**	***12.7***

Table 3k : Degree of equivalence at 200 V / 20 kHz (3/4)

Voltage : 200 V **Frequency : 20 kHz** (4/4)			**NIST**		**NIM**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-2.5	*6.1*	-8.8	*11.1*
			$\mathbf{D_{i,j}}$	$U_{i,j}$	$\mathbf{D_{i,j}}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$				
BNM-LNE	-7.7	*13.1*	**-5.2**	***14.5***	**1.1**	***17.2***
DANIAmet-AREPA	-4.6	*11.1*	**-2.1**	***12.7***	**4.2**	***15.7***
NPL	-9.6	*14.1*	**-7.1**	***15.4***	**-0.8**	***18.0***
SP	-1.6	*9.1*	**0.9**	***11.0***	**7.2**	***14.4***
IEN	-11.0	*12.9*	**-8.5**	***14.3***	**-2.2**	***17.1***
CEM	-0.6	*22.0*	**1.9**	***22.9***	**8.2**	***24.7***
PTB	-7.3	*8.0*	**-4.8**	***10.1***	**1.5**	***13.7***
INTI	-8.3	*12.1*	**-5.8**	***13.6***	**0.5**	***16.5***
NMIA	-6.3	*8.1*	**-3.8**	***10.2***	**2.5**	***13.8***
NRC	-4.3	*10.1*	**-1.8**	***11.8***	**4.5**	***15.1***
VNIIM	-3.3	*20.2*	**-0.8**	***21.2***	**5.5**	***23.1***
METAS	-7.5	*6.1*	**-5.0**	***8.7***	**1.3**	***12.7***
NIST	-2.5	*6.1*			**6.3**	***12.7***
NIM	-8.8	*11.1*	**-6.3**	***12.7***		

Table 3l : Degree of equivalence at 200 V / 20 kHz (4/4)

Voltage : 200 V **Frequency : 50 kHz** (1/4)			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-28.2	*16.2*	-23.1	*11.2*	-23.1	*16.2*	-18.1	*13.2*
			$D_{i,j}$	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-28.2	*16.2*			**-5.1**	***19.7***	**-5.1**	***23.0***	**-10.1**	***20.9***
DANIAmet-AREPA	-23.1	*11.2*	**5.1**	***19.7***			**0.0**	***19.7***	**-5.0**	***17.4***
NPL	-23.1	*16.2*	**5.1**	***23.0***	**0.0**	***19.7***			**-5.0**	***20.9***
SP	-18.1	*13.2*	**10.1**	***20.9***	**5.0**	***17.4***	**5.0**	***20.9***		
IEN	-31.8	*18.3*	**-3.6**	***24.5***	**-8.7**	***21.5***	**-8.7**	***24.5***	**-13.7**	***22.6***
CEM	-19.1	*24.1*	**9.1**	***29.1***	**4.0**	***26.6***	**4.0**	***29.1***	**-1.0**	***27.5***
PTB	-22.7	*10.0*	**5.5**	***19.1***	**0.4**	***5.1***	**0.4**	***19.1***	**-4.6**	***16.6***
INTI	-23.7	*16.1*	**4.5**	***22.9***	**-0.6**	***19.7***	**-0.6**	***22.9***	**-5.6**	***20.9***
NMIA	-19.7	*11.2*	**8.5**	***19.7***	**3.4**	***15.9***	**3.4**	***19.7***	**-1.6**	***17.4***
NRC	-16.7	*14.1*	**11.5**	***21.5***	**6.4**	***18.1***	**6.4**	***21.5***	**1.4**	***19.4***
VNIIM	-14.1	*30.3*	**14.1**	***34.4***	**9.0**	***32.4***	**9.0**	***34.4***	**4.0**	***33.1***
METAS	-22.8	*9.2*	**5.4**	***18.7***	**0.3**	***14.5***	**0.3**	***18.7***	**-4.7**	***16.1***
NIST	-20.3	*8.1*	**7.9**	***18.2***	**2.8**	***13.9***	**2.8**	***18.2***	**-2.2**	***15.5***
NIM	-24.4	*12.4*	**3.8**	***20.5***	**-1.3**	***16.8***	**-1.3**	***20.5***	**-6.3**	***18.2***

Table 3m : Degree of equivalence at 200 V / 50 kHz (1/4)

Voltage : 200 V **Frequency : 50 kHz** (2/4)			**IEN**		**CEM**		**PTB**		**INTI**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-31.8	*18.3*	-19.1	*24.1*	-22.7	*10.0*	-23.7	*16.1*
			$D_{i,j}$	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-28.2	*16.2*	**3.6**	***24.5***	**-9.1**	***29.1***	**-5.5**	***19.1***	**-4.5**	***22.9***
DANIAmet-AREPA	-23.1	*11.2*	**8.7**	***21.5***	**-4.0**	***26.6***	**-0.4**	***5.1***	**0.6**	***19.7***
NPL	-23.1	*16.2*	**8.7**	***24.5***	**-4.0**	***29.1***	**-0.4**	***19.1***	**0.6**	***22.9***
SP	-18.1	*13.2*	**13.7**	***22.6***	**1.0**	***27.5***	**4.6**	***16.6***	**5.6**	***20.9***
IEN	-31.8	*18.3*			**-12.7**	***30.3***	**-9.1**	***20.9***	**-8.1**	***24.4***
CEM	-19.1	*24.1*	**12.7**	***30.3***			**3.6**	***26.1***	**4.6**	***29.0***
PTB	-22.7	*10.0*	**9.1**	***20.9***	**-3.6**	***26.1***			**1.0**	***19.0***
INTI	-23.7	*16.1*	**8.1**	***24.4***	**-4.6**	***29.0***	**-1.0**	***19.0***		
NMIA	-19.7	*11.2*	**12.1**	***21.5***	**-0.6**	***26.6***	**3.0**	***15.1***	**4.0**	***19.7***
NRC	-16.7	*14.1*	**15.1**	***23.2***	**2.4**	***28.0***	**6.0**	***17.3***	**7.0**	***21.5***
VNIIM	-14.1	*30.3*	**17.7**	***35.4***	**5.0**	***38.8***	**8.6**	***32.0***	**9.6**	***34.4***
METAS	-22.8	*9.2*	**9.0**	***20.5***	**-3.7**	***25.8***	**-0.1**	***13.6***	**0.9**	***18.6***
NIST	-20.3	*8.1*	**11.5**	***20.1***	**-1.2**	***25.5***	**2.4**	***12.9***	**3.4**	***18.1***
NIM	-24.4	*12.4*	**7.4**	***22.2***	**-5.3**	***27.2***	**-1.7**	***16.0***	**-0.7**	***20.4***

Table 3n : Degree of equivalence at 200 V / 50 kHz (2/4)

Voltage : 200 V **Frequency : 50 kHz** (3/4)			**NMIA**		**NRC**		**VNIIM**		**METAS**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-19.7	11.2	-16.7	14.1	-14.1	30.3	-22.8	9.2
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-28.2	16.2	-8.5	19.7	-11.5	21.5	-14.1	34.4	-5.4	18.7
DANIAmet-AREPA	-23.1	11.2	-3.4	15.9	-6.4	18.1	-9.0	32.4	-0.3	14.5
NPL	-23.1	16.2	-3.4	19.7	-6.4	21.5	-9.0	34.4	-0.3	18.7
SP	-18.1	13.2	1.6	17.4	-1.4	19.4	-4.0	33.1	4.7	16.1
IEN	-31.8	18.3	-12.1	21.5	-15.1	23.2	-17.7	35.4	-9.0	20.5
CEM	-19.1	24.1	0.6	26.6	-2.4	28.0	-5.0	38.8	3.7	25.8
PTB	-22.7	10.0	-3.0	15.1	-6.0	17.3	-8.6	32.0	0.1	13.6
INTI	-23.7	16.1	-4.0	19.7	-7.0	21.5	-9.6	34.4	-0.9	18.6
NMIA	-19.7	11.2			-3.0	18.1	-5.6	32.4	3.1	14.5
NRC	-16.7	14.1	3.0	18.1			-2.6	33.5	6.1	16.9
VNIIM	-14.1	30.3	5.6	32.4	2.6	33.5			8.7	31.7
METAS	-22.8	9.2	-3.1	14.5	-6.1	16.9	-8.7	31.7		
NIST	-20.3	8.1	-0.6	13.9	-3.6	16.3	-6.2	31.4	2.5	12.3
NIM	-24.4	12.4	-4.7	16.8	-7.7	18.8	-10.3	32.8	-1.6	15.5

Table 3o : Degree of equivalence at 200 V / 50 kHz (3/4)

Voltage : 200 V **Frequency : 50 kHz** (4/4)			**NIST**		**NIM**	
			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
			-20.3	8.1	-24.4	12.4
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\,i}$	$u(d_{adj\,i})$				
BNM-LNE	-28.2	16.2	-7.9	18.2	-3.8	20.5
DANIAmet-AREPA	-23.1	11.2	-2.8	13.9	1.3	16.8
NPL	-23.1	16.2	-2.8	18.2	1.3	20.5
SP	-18.1	13.2	2.2	15.5	6.3	18.2
IEN	-31.8	18.3	-11.5	20.1	-7.4	22.2
CEM	-19.1	24.1	1.2	25.5	5.3	27.2
PTB	-22.7	10.0	-2.4	12.9	1.7	16.0
INTI	-23.7	16.1	-3.4	18.1	0.7	20.4
NMIA	-19.7	11.2	0.6	13.9	4.7	16.8
NRC	-16.7	14.1	3.6	16.3	7.7	18.8
VNIIM	-14.1	30.3	6.2	31.4	10.3	32.8
METAS	-22.8	9.2	-2.5	12.3	1.6	15.5
NIST	-20.3	8.1			4.1	14.9
NIM	-24.4	12.4	-4.1	14.9		

Table 3p : Degree of equivalence at 200 V / 50 kHz (4/4)

Voltage : 200 V			**BNM-LNE**		**DANIAmet-AREPA**		**NPL**		**SP**	
Frequency : 100 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(1/4)			-70.7	*16.2*	-66.2	*26.1*	-61.2	*20.1*	-49.2	*19.2*
			$D_{i,j}$	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-70.7	*16.2*			**-4.5**	***30.8***	**-9.5**	***25.9***	**-21.5**	***25.2***
DANIAmet-AREPA	-66.2	*26.1*	**4.5**	***30.8***			**-5.0**	***33.0***	**-17.0**	***32.5***
NPL	-61.2	*20.1*	**9.5**	***25.9***	**5.0**	***33.0***			**-12.0**	***27.8***
SP	-49.2	*19.2*	**21.5**	***25.2***	**17.0**	***32.5***	**12.0**	***27.8***		
IEN	-71.5	*42.5*	**-0.8**	***45.5***	**-5.3**	***49.9***	**-10.3**	***47.1***	**-22.3**	***46.7***
CEM	-54.2	*28.9*	**16.5**	***33.2***	**12.0**	***39.0***	**7.0**	***35.3***	**-5.0**	***34.7***
PTB	-61.9	*22.0*	**8.8**	***27.4***	**4.3**	***14.1***	**-0.7**	***29.8***	**-12.7**	***29.2***
INTI	-61.3	*24.1*	**9.4**	***29.1***	**4.9**	***35.6***	**-0.1**	***31.4***	**-12.1**	***30.9***
NMIA	-53.3	*18.1*	**17.4**	***24.3***	**12.9**	***31.8***	**7.9**	***27.1***	**-4.1**	***26.4***
NRC	-56.3	*22.7*	**14.4**	***27.9***	**9.9**	***34.6***	**4.9**	***30.4***	**-7.1**	***29.8***
VNIIM	-61.0	*40.5*	**9.7**	***43.7***	**5.2**	***48.2***	**0.2**	***45.3***	**-11.8**	***44.9***
METAS	-60.3	*24.1*	**10.4**	***29.1***	**5.9**	***35.6***	**0.9**	***31.4***	**-11.1**	***30.9***
NIST	-58.5	*11.0*	**12.2**	***19.6***	**7.7**	***28.4***	**2.7**	***23.0***	**-9.3**	***22.2***
NIM	-65.9	*13.4*	**4.8**	***21.1***	**0.3**	***29.4***	**-4.7**	***24.2***	**-16.7**	***23.5***

Table 3q : Degree of equivalence at 200 V / 100 kHz (1/4)

Voltage : 200 V			**IEN**		**CEM**		**PTB**		**INTI**	
Frequency : 100 kHz			$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$	$d_{adj\,j}$	$u(d_{adj\,j})$
(2/4)			-71.5	*42.5*	-54.2	*28.9*	-61.9	*22.0*	-61.3	*24.1*
			$D_{i,j}$	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**	**$D_{i,j}$**	**$U_{i,j}$**
	$d_{adj\,i}$	$u(d_{adj\,i})$								
BNM-LNE	-70.7	*16.2*	**0.8**	***45.5***	**-16.5**	***33.2***	**-8.8**	***27.4***	**-9.4**	***29.1***
DANIAmet-AREPA	-66.2	*26.1*	**5.3**	***49.9***	**-12.0**	***39.0***	**-4.3**	***14.1***	**-4.9**	***35.6***
NPL	-61.2	*20.1*	**10.3**	***47.1***	**-7.0**	***35.3***	**0.7**	***29.8***	**0.1**	***31.4***
SP	-49.2	*19.2*	**22.3**	***46.7***	**5.0**	***34.7***	**12.7**	***29.2***	**12.1**	***30.9***
IEN	-71.5	*42.5*			**-17.3**	***51.4***	**-9.6**	***47.9***	**-10.2**	***48.9***
CEM	-54.2	*28.9*	**17.3**	***51.4***			**7.7**	***36.4***	**7.1**	***37.7***
PTB	-61.9	*22.0*	**9.6**	***47.9***	**-7.7**	***36.4***			**-0.6**	***32.7***
INTI	-61.3	*24.1*	**10.2**	***48.9***	**-7.1**	***37.7***	**0.6**	***32.7***		
NMIA	-53.3	*18.1*	**18.2**	***46.2***	**0.9**	***34.2***	**8.6**	***28.5***	**8.0**	***30.2***
NRC	-56.3	*22.7*	**15.2**	***48.2***	**-2.1**	***36.8***	**5.6**	***31.7***	**5.0**	***33.2***
VNIIM	-61.0	*40.5*	**10.5**	***58.8***	**-6.8**	***49.8***	**0.9**	***46.1***	**0.3**	***47.2***
METAS	-60.3	*24.1*	**11.2**	***48.9***	**-6.1**	***37.7***	**1.6**	***32.7***	**1.0**	***34.1***
NIST	-58.5	*11.0*	**13.0**	***44.0***	**-4.3**	***31.0***	**3.4**	***24.6***	**2.8**	***26.5***
NIM	-65.9	*13.4*	**5.6**	***44.6***	**-11.7**	***31.9***	**-4.0**	***25.8***	**-4.6**	***27.6***

Table 3r : Degree of equivalence at 200 V / 100 kHz (2/4)

Voltage : 200 V			**NMIA**		**NRC**		**VNIIM**		**METAS**	
Frequency : 100 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(3/4)			-53.3	*18.1*	-56.3	*22.7*	-61.0	*40.5*	-60.3	*24.1*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$								
BNM-LNE	-70.7	*16.2*	**-17.4**	***24.3***	**-14.4**	***27.9***	**-9.7**	***43.7***	**-10.4**	***29.1***
DANIAmet-AREPA	-66.2	*26.1*	**-12.9**	***31.8***	**-9.9**	***34.6***	**-5.2**	***48.2***	**-5.9**	***35.6***
NPL	-61.2	*20.1*	**-7.9**	***27.1***	**-4.9**	***30.4***	**-0.2**	***45.3***	**-0.9**	***31.4***
SP	-49.2	*19.2*	**4.1**	***26.4***	**7.1**	***29.8***	**11.8**	***44.9***	**11.1**	***30.9***
IEN	-71.5	*42.5*	**-18.2**	***46.2***	**-15.2**	***48.2***	**-10.5**	***58.8***	**-11.2**	***48.9***
CEM	-54.2	*28.9*	**-0.9**	***34.2***	**2.1**	***36.8***	**6.8**	***49.8***	**6.1**	***37.7***
PTB	-61.9	*22.0*	**-8.6**	***28.5***	**-5.6**	***31.7***	**-0.9**	***46.1***	**-1.6**	***32.7***
INTI	-61.3	*24.1*	**-8.0**	***30.2***	**-5.0**	***33.2***	**-0.3**	***47.2***	**-1.0**	***34.1***
NMIA	-53.3	*18.1*			**3.0**	***29.1***	**7.7**	***44.4***	**7.0**	***30.2***
NRC	-56.3	*22.7*	**-3.0**	***29.1***			**4.7**	***46.5***	**4.0**	***33.2***
VNIIM	-61.0	*40.5*	**-7.7**	***44.4***	**-4.7**	***46.5***			**-0.7**	***47.2***
METAS	-60.3	*24.1*	**-7.0**	***30.2***	**-4.0**	***33.2***	**0.7**	***47.2***		
NIST	-58.5	*11.0*	**-5.2**	***21.2***	**-2.2**	***25.3***	**2.5**	***42.0***	**1.8**	***26.5***
NIM	-65.9	*13.4*	**-12.6**	***22.6***	**-9.6**	***26.4***	**-4.9**	***42.7***	**-5.6**	***27.6***

Table 3s : Degree of equivalence at 200 V / 100 kHz (3/4)

Voltage : 200 V			**NIST**		**NIM**	
Frequency : 100 kHz			$d_{adj\ j}$	$u(d_{adj\ j})$	$d_{adj\ j}$	$u(d_{adj\ j})$
(4/4)			-58.5	*11.0*	-65.9	*13.4*
			$D_{i,j}$	$U_{i,j}$	$D_{i,j}$	$U_{i,j}$
	$d_{adj\ i}$	$u(d_{adj\ i})$				
BNM-LNE	-70.7	*16.2*	**-12.2**	***19.6***	**-4.8**	***21.1***
DANIAmet-AREPA	-66.2	*26.1*	**-7.7**	***28.4***	**-0.3**	***29.4***
NPL	-61.2	*20.1*	**-2.7**	***23.0***	**4.7**	***24.2***
SP	-49.2	*19.2*	**9.3**	***22.2***	**16.7**	***23.5***
IEN	-71.5	*42.5*	**-13.0**	***44.0***	**-5.6**	***44.6***
CEM	-54.2	*28.9*	**4.3**	***31.0***	**11.7**	***31.9***
PTB	-61.9	*22.0*	**-3.4**	***24.6***	**4.0**	***25.8***
INTI	-61.3	*24.1*	**-2.8**	***26.5***	**4.6**	***27.6***
NMIA	-53.3	*18.1*	**5.2**	***21.2***	**12.6**	***22.6***
NRC	-56.3	*22.7*	**2.2**	***25.3***	**9.6**	***26.4***
VNIIM	-61.0	*40.5*	**-2.5**	***42.0***	**4.9**	***42.7***
METAS	-60.3	*24.1*	**-1.8**	***26.5***	**5.6**	***27.6***
NIST	-58.5	*11.0*			**7.4**	***17.4***
NIM	-65.9	*13.4*	**-7.4**	***17.4***		

Table 3t : Degree of equivalence at 200 V / 100 kHz (4/4)

APPENDIX 2

Uncertainty budgets

UNCERTAINTY BUDGET FOR BNM-LNE (FRANCE)

STEP UP PROCEDURE			1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
PRIMARY STANDARD	**Voltage (V) :**	**3**					
(PTB 3D-MJTC)	**Standard uncertainty**		**1**	**1**	**1**	**2**	**2**
Step n° 1	Voltage (V) :	**5**					
Measurement uncertainty :		Type A	0.2	0.2	0.2	0.2	0.5
		Type B	1.5	1.5	1.5	1.5	1.5
Uncertainty arising from voltage dependence :			0	0	0	0	0
Resulting standard uncertainty			**1.9**	**1.9**	**1.9**	**2.6**	**2.6**
Step n° 2	Voltage (V) :	**10**					
Measurement uncertainty :		Type A	0.4	0.2	0.2	0.4	0.2
		Type B	1.8	1.8	1.8	1.8	1.8
Uncertainty arising from voltage dependence :			0	0	0	0	0
Resulting standard uncertainty			**2.7**	**2.7**	**2.7**	**3.2**	**3.2**
Step n° 3	Voltage (V) :	**20**					
Measurement uncertainty :		Type A	0.4	0.3	0.2	0.3	0.9
		Type B	2	2	2	2	2
Uncertainty arising from voltage dependence :			0	0	0	0	0
Resulting standard uncertainty			**3.4**	**3.4**	**3.4**	**3.8**	**3.9**
Step n° 4	Voltage (V) :	**30**					
Measurement uncertainty :		Type A	0.2	0.1	0.4	0.2	0.3
		Type B	1.1	1.1	1.1	1.1	1
Uncertainty arising from voltage dependence :			0	0	0	0	0
Resulting standard uncertainty			**3.6**	**3.6**	**3.6**	**4**	**4.1**
Step n° 5	Voltage (V) :	**50**					
Measurement uncertainty :		Type A	0.2	0.5	1	0.3	0.4
		Type B	1.3	1.3	1.3	1.3	1.3
Uncertainty arising from voltage dependence :			0	0	0	0	0
Resulting standard uncertainty			**3.9**	**3.9**	**4**	**4.3**	**4.4**
Step n° 6	Voltage (V) :	**100**					
Measurement uncertainty :		Type A	0.3	0.5	0.6	0.6	0.7
		Type B	1.9	1.9	1.9	1.9	1.9
Uncertainty arising from voltage dependence :			0	0	0	0	0
Resulting standard uncertainty			**4.4**	**4.4**	**4.5**	**4.8**	**4.9**
Step n° 7	Voltage (V) :	**200**					
Measurement uncertainty :		Type A	0.4	0.3	0.3	0.4	0.3
		Type B	2	2	2	2	2
Uncertainty arising from voltage dependence :			0	2	2	5	5
Resulting standard uncertainty			**4.9**	**5.3**	**5.4**	**7.3**	**7.3**
Step n° 8	Voltage (V) :	**300**					
Measurement uncertainty :		Type A	0.3	0.3	0.3	0.3	0.3
		Type B	1.1	1.1	1.1	1.1	1.1
Uncertainty arising from voltage dependence :			1	4	4	8	8
Resulting standard uncertainty			**5.2**	**6.8**	**6.9**	**10.9**	**10.9**
Step n° 9	Voltage (V) :	**500**					
Measurement uncertainty :		Type A	0.4	0.3	0.4	0.2	0.2
		Type B	1.4	1.4	1.4	1.4	1.4
Uncertainty arising from voltage dependence :			2	7	7	14	14
Resulting standard uncertainty			**5.8**	**9.9**	**10**	**17.8**	**17.8**
Step n° 10	Voltage (V) :	**1000**					
Measurement uncertainty :		Type A	0.6	0.6	0.4	0.5	0.5
		Type B	2	2	2	2	2
Uncertainty arising from voltage dependence :			4	14	14	29	29
Resulting standard uncertainty			**7.4**	**17.3**	**17.4**	**34.1**	**34.1**

TRAVELLING STANDARDS		**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Measurement voltage (V) : 200						
Standard uncertainty of the reference standard :		4.9	5.3	5.4	7.3	7.3
Measurement uncertainty	Type A	0.2	0.7	0.9	0.6	0.6
	Type B	2	2	2	2	2
Resulting standard uncertainty (travelling standard)		5.3	5.8	5.9	7.6	7.6
Expanded uncertainty [k = 2] (travelling standard)		**10.6**	**11.6**	**11.8**	**15.2**	**15.2**
Measurement voltage (V) : 500						
Standard uncertainty of the reference standard :		5.8	9.9	10	17.8	17.8
Measurement uncertainty	Type A	0.3	0.4	0.4	0.2	0.5
	Type B	0.6	0.6	0.6	0.6	0.6
Resulting standard uncertainty (travelling standard)		5.9	10	10.1	17.9	17.9
Expanded uncertainty [k = 2] (travelling standard)		**11.8**	**20**	**20.2**	**35.8**	**35.8**
Measurement voltage (V) : 1000						
Standard uncertainty of the reference standard :		7.4	17.3	17.4	34.1	34.1
Measurement uncertainty	Type A	0.2	0.3	0.1	0.3	0.3
	Type B	0.8	0.8	0.8	0.8	0.8
Resulting standard uncertainty (travelling standard)		7.5	17.4	17.5	34.2	34.2
Expanded uncertainty [k = 2] (travelling standard)		**15**	**34.8**	**35**	**68.4**	**68.4**

Calculation of the uncertainties

The difference between the AC-DC differences d_x of the converter under test, and d_{ref} of the reference converter is given by (see the description of the measurement set up in [1]) :

$$d_x - d_{ref} = \frac{1}{n_{ref}}.[\frac{V_a}{V_c} - 1] - \frac{1}{n_x}.[\frac{k.V_a - V_{Da}}{k.V_c - V_{Dc}} - 1] = f(x_1, x_2, ...x_i, ...)$$

where :

- n_x (resp. n_{ref}) is a characteristic parameter of the converter under test (rep. reference) ;
- V_a (resp. V_c) is the measured output voltage of the reference converter in response to an AC (resp. DC) signal ;
- V_{da} (rsp. V_{Dc}) is a measured differential voltage between the outputs of both converters in response to an AC (resp. DC) signal ;
- k is the ratio of the resistive divider connected at the output of the converter under test.

For each measurement, the type B measurement uncertainty u_B is given by :

$$u_B = \sqrt{\sum_i [\frac{\partial f}{\partial x_i}]^2 . u_{Bi}^2}$$

where u_{Bi} is the uncertainty on x_i. The value of this component was taken equal to 5 parts in 10^3 for n_x and n_{ref}, 5 parts in 10^4 for k, V_a and V_c, and 5 parts in 10^6 for V_{Da} and V_{Dc}.

One determination of $d_x - d_{ref}$ is computed from a set of values of V_a, V_c, V_{da} and V_{Dc} measured during a sequence AC, DC+, DC-, AC, DC+, DC-, AC, DC+, DC-, AC, applied to the input of the converters, using a least mean square method, and then, can be associated with a standard deviation. The final value given for d_x is the weighted mean of four determinations $d_{x,i}$ (i = 1,…4), calculated using :

$$d_x = \frac{\sum_{i=1}^{i=4} d_{x,i} / u_{A,i}^2}{\sum_{i=1}^{i=4} 1/u_{A,i}^2}$$

where $u_{A,i}$ is the standard deviation calculated for $d_{x,i}$.
The type A uncertainty u_A, associated with d_x, is computed using :

$$u_A = \frac{\sum_{i=1}^{i=4} (d_{x,i} - d_x)^2 / u_{A,i}^2}{\sum_{i=1}^{i=4} 1/u_{A,i}^2}$$

The resulting standard uncertainty associated with d_x is finally given by :

$$u = \sqrt{u_A^2 + u_B^2 + u_{ref}^2 + u_{VoltDep}^2}$$

where u_{ref} is the uncertainty associated with the reference converter, and $u_{VoltDep}$, the uncertainty arising from the voltage level dependence (in the case of measurements performed in the frame of the step up procedure). This last uncertainty component was estimated from discrepancies observed between complementary measurements performed at two different voltage levels, assuming the same value of the AC-DC difference at both levels.

* * * * * * * * * *

[1] Andre POLETAEFF, “Automated Comparator for Accurate AC-DC Difference Measurement at the BNM-LCIE”, *IEEE Trans. Instr. Meas.*, vol 48, n° 2, April 1999.

UNCERTAINTY BUDGET FOR DANIAMet-AREPA (DENMARK)

Uncertainty.

The overall uncertainties of the measurement results are estimated in accordance with EAL-R2 / EA-4/02. It has been distinguished between category A and B uncertainties. The category A uncertainty is stated as the estimated value of the experimental standard deviation. Estimates of the category B uncertainties are based either on experience or on stated specifications of the manufactorers. Here the limits of errors are estimated. In this case a suitable population ditribution is assumed and the standard deviation is estimated by multiplying the error estimate with the corresponding factor.

The estimated uncertainties of the measured AC-DC differences are stated in table 2, whereas table 3 contains the complete uncertainty budget.

All the uncertainty contributions (u_i) listed in table 3 are uncorrelated, and so the standard uncertainty u is calculated as:

$$u = \sqrt{\sum u_i^2}$$

The expanded uncertainty U is determined by:

$$U = ku$$

where the coverage factor k for a coverage probability of 95% is found from the effective number of degrees of freedom ν_{eff} and a t-distribution:

$$\nu_{eff} = \frac{u^4}{\sum \frac{u_i^4}{\nu_i}}$$

Measured AC-DC voltage transfer difference in 10^{-6}					
Voltage	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
200 V	2	–1	–6	–26	–72
500 V	3	0	–4	–22	–60
1000 V	4	1	–1	–20	–58

Table 1: Measurement results.

Uncertainty of the AC-DC voltage transfer difference in 10^{-6}					
Voltage	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
200 V	11	11	11	11	26
500 V	21	21	21	21	41
1000 V	21	21	26	41	81

Table 2: Measurement uncertainties ($k = 2$).

Reason of deviation Standard Uncertainty u_i in 10^{-6}	Category	1kHz	10kHz	20kHz	50kHz	100kHz	Distribution Remarks
Fluke 792A traceability:	B						gaussian
200 V		5	5	5	5	12,5	
500 V		10	10	10	10	20	
1000 V		10	10	12,5	20	40	
Fluke 792A drift:	B						gaussian
200 V		2	2	2	3	5	
500 V		3	3	3	5	7	
1000 V		5	5	5	7	10	
Measurement set-up:	B						uniform
Stability, resolution, noise		2	2	2	2	2	
Standard deviation, $\nu_i > 12$:	A						gaussian
200 V		0,2	0,2	0,2	0,2	0,2	
500 V		0,1	0,1	0,1	0,1	0,2	
1000 V		0,2	0,2	0,2	- - -	- - -	
Standard uncertainty u:							$\nu_{eff} > 1000$
200 V		5,3	5,3	5,3	5,5	12,9	
500 V		10,3	10,3	10,3	10,5	20,5	
1000 V		10,5	10,5	12,9	20,5	40,5	
Expanded uncertainty U:							k = 2
200 V		11	11	11	11	26	
500 V		21	21	21	21	41	
1000 V		21	21	26	41	81	

Table 3: Uncertainty budget.

UNCERTAINTY BUDGET FOR NPL (UNITED KINGDOM)

All Type B contribtutions are considered to have infinite degrees of freedom and the divisor used is sqrt(3).

All Type A contributions are considered to have 10 Degrees of Freedom and the divisor used is 2.

	Divisor					
Frequency, kHz		**1**	**10**	**20**	**50**	**100**
SJTC Basic	Rectangular	0.00	0.00	0.00	0.00	1.00
900 ohm	Rectangular	0.00	0.00	0.00	0.00	1.00
Random Scatter from Results	Normal	1.50	1.50	1.50	1.50	1.50
MJTC Base Unc for 1 kHz	Rectangular	0.50	0.50	0.50	0.50	0.50
Cal of Freq Dependance of MJTC		1.58	1.58	1.58	1.58	2.12
Std Uncertainty / Sqrt (6)		0.65	0.65	0.65	0.65	0.87
Build up using MJTC's						
10V Level						
MJTC Uncertainty (3V)		0.65	0.65	0.65	0.65	0.87
Comparison Measurements	Rectangular	1.22	1.22	1.22	1.23	1.23
Bridge Scatter	Normal	1.00	1.00	1.00	1.00	1.00
Std Uncertainty for 10V		**1.71**	**1.71**	**1.71**	**1.71**	**1.81**
30V Level						
MJTC Uncertainty (10V)		**1.71**	**1.71**	**1.71**	**1.71**	**1.81**
Comparison Measurements	Rectangular	1.24	1.24	1.24	1.24	1.60
Bridge Scatter	Normal	1.00	1.00	1.00	1.00	1.00
Std Uncertainty for 30V		2.33	2.33	2.33	2.33	2.61
100V Level						
Cal uncertainty, *k* =2		**2.33**	**2.33**	**2.33**	**2.33**	**2.61**
Comparison Measurements	Rectangular	1.26	1.26	1.26	1.26	1.61
Resistor Voltage Coefficient	Rectangular	0.00	0.00	0.00	1.00	2.00
Bridge Scatter	Normal	2.00	2.00	2.00	2.00	2.00
Std Uncertainty for 100V		3.32	3.32	3.32	3.47	4.17
300V Level						
MJTC Uncertainty (100V)		3.32	3.32	3.32	3.47	4.17
Comparison Measurements	Rectangular	1.28	1.28	1.28	1.28	1.63
Resistor Voltage Coefficient	Rectangular	0.00	1.00	2.00	4.00	7.00
Bridge Scatter	Normal	3.00	3.00	3.00	3.00	3.00
Std Uncertainty for 300V		4.66	4.76	5.07	6.22	8.84

Comparison Measurements: Include contributions for bridge errors, Effect of T-Piece, Loss factor of heater, MJTC skin effect, Interseries adaptors, MJTC used at different levels.

Resistor Voltage Coefficient: Includes contribution for the range resistors as these are calibrated at a lower level and used at full rating.

All Type B contribtutions are considered to have infinite degrees of freedom and the divisor used is sqrt(3).

All Type A contributions are considered to have 10 Degrees of Freedom and the divisor used is 2.

200 V			**Divisor**					
Frequency, kHz				**1**	**10**	**20**	**50**	**100**
Build up using MJTC's								
Std Uncertainty for 100V				3.32	3.32	3.32	3.47	4.17
Cal of NPL SJTC								
NPL Basic Standards				**3.32**	**3.32**	**3.32**	**3.47**	**4.17**
Systematic Bridge Errors			Rectangular	1.22	1.22	1.22	1.22	1.22
Resistor Voltage Coefficient			Rectangular	0.00	0.00	2.00	4.00	7.00
Effect of T Piece			Rectangular	0.00	0.00	0.00	0.00	1.00
MJTC Different Levels			Rectangular	0.50	0.50	0.50	0.50	0.50
Interseries Adaptors			Rectangular	0.00	0.00	0.00	0.00	0.00
Bridge Scatter			Normal	3.00	3.00	3.00	3.00	3.00
Uncertainty of NPL Standards				**4.66**	**4.66**	**5.08**	**6.23**	**8.84**
Cal of Intercomparison Standard								
NPL SJTC Basic Uncertainty				**4.66**	**4.66**	**5.08**	**6.23**	**8.84**
Systematic Bridge Errors			Rectangular	1.22	1.22	1.22	1.22	1.22
Effect of T Piece			Rectangular	0.00	0.00	0.00	0.00	1.00
Bridge Scatter			Normal	3.00	3.00	4.00	4.00	4.00
Interseries Adaptors			Rectangular	0.00	0.00	0.00	0.00	1.00
Cal uncertainty, $k=2$				12	12	14	16	20
Degrees of Freedom				**2560**	**2560**	**1501**	**2560**	**6250**
Frequency (kHz)				**1**	**10**	**20**	**50**	**100**

All Type B contribtutions are considered to have infinite degrees of freedom and the divisor used is sqrt(3).						
All Type A contributions are considered to have 10 Degrees of Freedom and the divisor used is 2.						
500 V	**Divisor**					
Frequency, kHz		**1**	**10**	**20**	**50**	**100**
Build up using MJTC's						
Std Uncertainty for 300V		4.66	4.76	5.07	6.22	8.84
Cal of NPL SJTC						
NPL Basic Standards		**4.66**	**4.76**	**5.07**	**6.22**	**8.84**
Systematic Bridge Errors	Rectangular	1.22	1.22	1.22	1.22	1.22
Resistor Voltage Coefficient	Rectangular	0.00	1.00	3.00	7.50	15.00
Effect of T Piece	Rectangular	0.00	0.00	0.00	0.00	0.00
MJTC Different Levels	Rectangular	0.50	0.50	0.50	0.50	0.50
Interseries Adaptors	Rectangular	0.00	0.00	0.00	0.00	0.00
Bridge Scatter	Normal	3.00	3.00	3.00	3.00	3.00
Uncertainty of NPL Standards		**5.69**	**5.87**	**6.74**	**10.28**	**17.71**
Cal of Intercomparison Standard						
NPL SJTC Basic Uncertainty		**5.69**	**5.87**	**6.74**	**10.28**	**17.71**
Systematic Bridge Errors	Rectangular	1.22	1.22	1.22	1.22	1.22
Effect of T Piece	Rectangular	0.00	0.00	0.00	0.00	0.00
Bridge Scatter	Normal	1.00	1.00	1.00	1.00	1.00
Interseries Adaptors	Rectangular	0.00	0.00	0.00	0.00	1.00
Cal uncertainty, *k* =2		12	13	14	21	36
Degrees of Freedom		**207360**	**285610**	**384160**	**1944810**	**16796160**
Frequency (kHz)		**1**	**10**	**20**	**50**	**100**

All Type B contribtutions are considered to have infinite degrees of freedom and the divisor used is sqrt(3).

All Type A contributions are considered to have 10 Degrees of Freedom and the divisor used is 2.

1000 V	**Divisor**					
Frequency, kHz		**1**	**10**	**20**	**50**	**100**
Build up using MJTC's						
Std Uncertainty for 300V		4.66	4.76	5.07	6.22	8.84
Cal of NPL SJTC						
NPL Basic Standards		**4.66**	**4.76**	**5.07**	**6.22**	**8.84**
Systematic Bridge Errors	Rectangular	1.22	1.22	1.22	1.22	1.22
Resistor Voltage Coefficient	Rectangular	0.00	1.00	5.00	12.50	25.00
Effect of T Piece	Rectangular	0.00	0.00	0.00	0.00	0.00
MJTC Different Levels	Rectangular	0.50	0.50	0.50	0.50	0.50
Interseries Adaptors	Rectangular	0.00	0.00	0.00	0.00	0.00
Bridge Scatter	Normal	3.00	3.00	3.00	3.00	3.00
Uncertainty of NPL Standards		**5.69**	**5.87**	**7.84**	**14.34**	**26.72**
Cal of Intercomparison Standard						
NPL SJTC Basic Uncertainty		**5.69**	**5.87**	**7.84**	**14.34**	**26.72**
Systematic Bridge Errors	Rectangular	1.22	1.22	1.22	1.22	1.22
Effect of T Piece	Rectangular	0.00	0.00	0.00	0.00	0.00
Bridge Scatter	Normal	1.00	1.00	1.00	1.00	1.00
Interseries Adaptors	Rectangular	0.00	0.00	0.00	0.00	1.00
Cal uncertainty, *k*=2		12	13	16	29	54
Degrees of Freedom		**12960**	**17851**	**40960**	**442051**	**5314410**
Frequency (kHz)		**1**	**10**	**20**	**50**	**100**

UNCERTAINTY BUDGET FOR SP (SWEDEN)

1.Uncertainty of the travelling standard

It was observed that the ac-dc transfer difference of the travelling standard was changing during the warm up. The travelling standard was warmed up until steady state before measurement, but the final temperature of the travelling standard, and then also its ac-dc difference, will depend on how the TVC is supported. The support will influence the convection of heat.

The measured ac-dc transfer difference d_T of the travelling standard is determined as:

$$d_T = d_A + d_B + d_{Sr} + d_{Sd} + d_{STC} - d_{TTC} \qquad (7)$$

where

d_A	indicated ac-dc transfer difference between the standard and the travelling standard
d_B	correction for the error in the indicated ac-dc transfer difference due to the measurement set-up
d_{Sr}	ac-dc transfer difference of the standard of SP at the time and temperature of the determination
d_{Sd}	correction for the drift of the ac-dc transfer difference of the standard of SP
d_{STC}	correction due to the temperature of the ac-dc transfer difference of the standard of SP
d_{TTC}	correction due to the temperature of the ac-dc transfer difference of the travelling standard

The variance of the measured ac-dc transfer difference $u^2(d_T)$ is:

$$u^2(d_T) = u^2(d_A) + u^2(d_B) + u^2(d_{Sr}) + u^2(d_{Sd}) + u^2(d_{STC}) + u^2(d_{TTC}) \qquad (8)$$

Indicated ac-dc transfer difference (d_A): The indicated value is the mean of a set of determinations of the ac-dc transfer difference between the standard and the test. The standard uncertainty $u(d_A)$ is the standard deviation of the mean. Normal distribution.

Measurement set-up (d_B): The correction d_B is estimated to zero. The following sources of uncertainty are considered to contribute to the uncertainty of the correction: non-linearity and resolution of nV-amplifiers and DVMs, non-linearity of the drift in output voltages and back-off voltage sources and the uncertainty in the scale factors. Normal distribution.

Ac-dc transfer difference of the standard (d_S): The used ac-dc transfer differences of the standards were determined at the time and temperature of the voltage build-up in Jan-April 2001 and the above described determination at 200 V. Normal distribution.

Drift of the standard (d_{Sd}): The correction d_{Sd} is estimated to zero. The uncertainty due to the drift of the ac-dc transfer difference is estimated on the history of the standards and the time between this measurement and the voltage build-up. Rectangular distribution.

Temperature of the standard (d_{STC}): The correction d_{STC} is estimated to zero. The uncertainty is based on an estimate of the difference in temperature of the standard between the determination and the use of its ac-dc transfer differences and the temperature coefficient of the standard. Rectangular distribution.

Temperature of the travelling standard (d_{TTC}): The correction d_{TTC} is estimated to zero. The uncertainty is based on an estimate of the difference between the temperature of the travelling standard at our determination and an average temperature of all participants determinations and the influence of this temperature difference on the ac-dc transfer difference of the travelling standard. Rectangular distribution.

The uncertainties due to the following reasons are estimated to be negligible: T-connector and reference plane, difference in ac- and dc-voltage levels, reversal errors, non-pure spectra of ac- and dc-sources, common mode currents, potential difference between the output low and input low of TVCs, switching time and time constants of the TVCs, external fields and relative humidity in the laboratory.

The uncertainty budgets of the travelling standard at 200 V, 500 V and 1000V are given in table 7, 8 and 9. The standard deviations of the mean of the indicated ac-dc transfer differences are from table 2, 3 and 4.

Table 7. Uncertainty budget of the travelling standard at 200 V.

Quantity	u	Standard uncertainty in µV/V at the frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
Ac-dc diff of standard, 200 V	$u(d_S)$	3,2	3,6	4,4	6,0	9,0	117
Drift of standard	$u(d_{Sd})$	0,2	0,2	0,3	0,7	1,0	10
Temperature of standard	$u(d_{STC})$	0,0	0,1	0,1	0,2	0,4	10
Corr. measurement set-up	$u(d_B)$	0,6	0,6	0,6	0,6	0,6	10
Temperature of travelling std	$u(d_{TTC})$	0,0	0,1	0,1	0,2	0,4	10
Indicated ac-dc difference	$u(d_A)$	0,2	0,2	0,3	0,4	0,4	5
Standard uncertainty	$u(d_T)$	3,3	3,7	4,5	6,1	9,2	127
Expanded uncertainty	U = 2u	7	8	9	13	19	

Table 8. Uncertainty budget of the travelling standard at 500 V.

Quantity	u	Standard uncertainty in µV/V at the frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
Ac-dc diff of standard, 500 V	$u(d_S)$	3,7	4,0	4,8	6,5	10,0	121
Drift of standard	$u(d_{Sd})$	0,2	0,2	0,4	1,0	2,0	10
Temperature of standard	$u(d_{STC})$	0,0	0,1	0,2	0,5	1,0	10
Corr. measurement set-up	$u(d_B)$	0,9	0,9	0,9	0,9	0,9	10
Temperature of travelling std	$u(d_{TTC})$	0,0	0,1	0,2	0,5	1,0	10
Indicated ac-dc difference	$u(d_A)$	0,1	0,1	0,1	0,1	0,3	5
Standard uncertainty	$u(d_T)$	3,9	4,2	5,0	6,7	10,4	138
Expanded uncertainty	U = 2u	8	9	10	14	21	

Table 9. Uncertainty budget of the travelling standard at 1 kV.

Quantity	u	Standard uncertainty in µV/V at the frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
Ac-dc diff of standard, 1 kV	$u(d_S)$	4,1	4,4	5,1	7,0	10,5	143
Drift of standard	$u(d_{Sd})$	0,2	0,2	0,4	1,0	2,0	10
Temperature of standard	$u(d_{STC})$	0,1	0,2	0,4	1,0	2,0	10
Corr. measurement set-up	$u(d_B)$	0,9	0,9	0,9	0,9	0,9	10
Temperature of travelling std	$u(d_{TTC})$	0,1	0,2	0,4	1,0	2,0	10
Indicated ac-dc difference	$u(d_A)$	0,1	0,1	0,2	0,1	0,1	5
Standard uncertainty	$u(d_T)$	4,3	4,6	5,3	7,3	11,1	169
Expanded uncertainty	$U = 2u$	9	10	11	15	23	

Uncertainty budget for the voltage ac-dc transfer standards in SP

Voltage build-up

The primary standard for ac-dc transfer difference is a group of multijunction thermal converters (MJTC) of PTB type traceable to PTB. The ac-dc transfer difference of the MJTCs due to dc-effects has been evaluated by fast reversed dc (FRDC). The equivalence of the primary standard for ac-dc transfer difference maintained by SP to the standards of other national laboratories is verified by an international key comparison [2]. To establish traceability at higher voltage levels a method called phase controlled voltage build-up (PVB) is used [3]. This method allows a voltage build-up without introducing errors due to level dependence of the thermal converters used. The ac-dc transfer difference of a thermal voltage converter (TVC) is compared to two thermal voltage converters in series. Hence, the thermal converters are calibrated and used as reference at the same voltage level.

In the voltage build-up two thermal transfer standards (TTS) of type Fluke 792A are used as TTS1 and TTS2. From 4 V to 256 V a set of Holt 11 is used as TVC3. Above 256 V an early design of Fluke 792 range resistor in combination with a 400 O planar multijunction converter (PMJTC) of PTB type is used as TVC3. The ac-dc transfer difference of TTS1 at 2 V is determined by comparison to the primary standard.

The measurement procedure consists of three measurements for each step in the voltage build-up, fig. A1.

1. The ac-dc transfer difference of TTS2 is measured by a 1:1 comparison with TTS1 as the reference standard, using type N T-connector
2. The ac-dc transfer difference of TVC3 is measured by a 2:1 comparison with TTS1 and TTS2 in series as the reference standard, using special T-connector
3. The ac-dc transfer difference of TTS1 is measured by a 1:1 comparison with TVC3 as the reference standard, using special T-connector with output to TTS2 short circuited

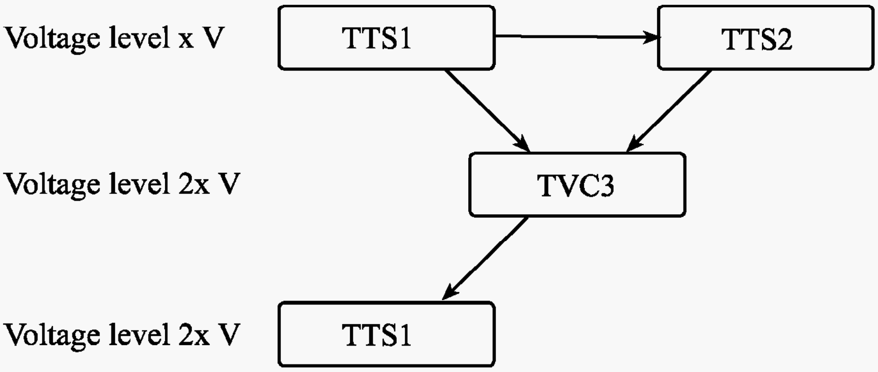


Fig. A1. Scheme for one step in the phase controlled voltage build-up using three thermal voltage converters.

The voltage build-up is made in a sequence 2 V, 4 V, 8 V, 16 V, 32 V, 64 V, 128 V, 256 V and then from 250 V to 500 V and 1000 V. The TVC3 calibrated at 256 V is used as reference at 250 V. This will introduce an error due to the level dependence of TVC3, which is considered in the uncertainty budget.

Uncertainty budget for the voltage build-up procedure

The model equations for the three measurements of a step in the voltage build-up procedure are based on the more detailed analysis of the 1:1 comparison and the 2:1 comparison in appendix B and C.

1. Comparison of TTS2 to TTS1

The measured ac-dc transfer difference d_{T2} of the test TTS2 at the voltage level x V is determined as:

$$d_{T2} = d_{A12} + d_{B12} + d_{S1} \qquad \text{(A1)}$$

where

d_{A12}	indicated ac-dc transfer difference between the standard TTS1 and the test TTS2
d_{B12}	correction for the error in the indicated ac-dc transfer difference due to the measurement set-up
d_{S1}	Ac-dc transfer difference of the standard TTS1

The variance of the measured ac-dc transfer difference $u^2(d_{T2})$ is

$$u^2(d_{T2}) = u^2(d_{A12}) + u^2(d_{B12}) + u^2(d_{S1}) \qquad \text{(A2)}$$

But the variance of interest in the next measurement is $u^2(d_{S12})$, which is the variance of the mean of d_{S1} and d_{S2}. As d_{S1} and d_{S2} are correlated the variance $u^2(d_{S12})$ is:

$$u^2(d_{S12}) = u^2(d_{A12})/4 + u^2(d_{B12})/4 + u^2(d_{S1}) \qquad \text{(A4)}$$

2. Comparison of TVC3 to TTS1 and TTS2 in series

The measured ac-dc transfer difference d_{T3} of the test TVC3 at the voltage level 2x V is determined as:

$$d_{T3} = d_{A123} + d_{B123} + d_a + d_g + d_{S12} \qquad \text{(A5)}$$

where

d_{A123}	indicated ac-dc transfer difference between the standards TTS1 and TTS2 in series and the test TVC3
d_{B123}	correction for the error in the indicated ac-dc transfer difference due to the PVB-measurement set-up, excluding phase angle error and guarding
d_a	correction for the error in the indicated ac-dc transfer difference due to phase angle error
d_g	correction for the error in the indicated ac-dc transfer difference due to guarding
d_{S12}	mean ac-dc transfer difference of the standards TTS1 and TTS2

The variance of the measured ac-dc transfer difference $u^2(d_{T3})$ is

$$u^2(d_{T3}) = u^2(d_{A123}) + u^2(d_{B123}) + u^2(d_a) + u^2(d_g) + u^2(d_{S12}) \qquad \text{(A6)}$$

3. Comparison of TTS1 to TVC3

The measured ac-dc transfer difference d_{T1} of the test TTS1 at the voltage level 2x V is determined as:

$$d_{T1} = d_{A31} + d_{B31} + d_c + d_{S3} + d_{TC} \qquad \text{(A7)}$$

where

d_{A31}	indicated ac-dc transfer difference between the standard TVC3 and the test TTS1
d_{B31}	correction for the error in the indicated ac-dc transfer difference due to the measurement set-up, excluding the T-connector and reference plane
d_c	correction for the error in the ac-dc transfer difference due to the T-connector and reference plane
d_{S3}	ac-dc transfer difference of the standard TVC3 at the temperature of the determination
d_{TC}	correction for the error in the ac-dc transfer difference of the standard TVC3 due to its temperature coefficient

The variance of the measured ac-dc transfer difference $u^2(d_{T1})$ is

$$u^2(d_{T1}) = u^2(d_{A31}) + u^2(d_{B31}) + u^2(d_c) + u^2(d_{S3}) + u^2(d_{TC}) \qquad \text{(A8)}$$

I the following uncertainty budget the uncertainty contributions are based on the calibration conditions given in appendix B and C and also:

- The maximum uncertainty due to non-linearity and resolution of a nV-amplifier and DVM is 5 nV and of a DVM 0,2 µV, rectangular distribution.
- The maximum uncertainty due to non-linear drift in the output is for Fluke 792A 0,15 µV/V below 100 V and 0,3 µV/V at 100 V and above and for other thermal converters 0,5 µV/V below 100 V and 1 µV/V at 100 V and above, rectangular distribution.
- The maximum drift in the output voltage from the time of determination of the scale factor to the time of the ac-dc transfer measurement is for Fluke 792A 0,05 % below 100 V, then 0,1 % up to 500 V and 0,15 % at 500 V and above and for other thermal converters 0,1 % below 50 V, then 0,15 % up to 250 V and 0,3 % at 250 V and above, rectangular distribution.
- The output voltages of the ac-sources are within 100 µV/V of the output voltages of the dc-sources.
- The measured ac-dc transfer differences are <100 µV/V.
- The phase angle error is <0,15° at 1 kHz and <0,2° at other frequencies, rectangular distribution.
- The maximum uncertainty due to the special T-connector is estimated to 3 µV/V at 4 V, 100 kHz, rectangular distribution.
- The uncertainty due to the temperature coefficient of TVC3 is estimated from warm-up measurements but in the range 64 V to 256 V there is also an uncertainty included due to a drift in the measured value of TVC3 during the voltage build-up measurements. The reason for this drift is unknown but can possibly be caused by changes of the humidity in the range resistors due to the repeated measurements (heat treatments) [4].
- Due to the change in voltage level of TVC3 from 256 V to 250 V an uncertainty contribution due to the level dependence is added in that step to the uncertainty due to the temperature coefficient of TVC3. The uncertainty contribution is evaluated in a similar way as the determination of the ac-dc transfer difference at 200 V.

Table A1. Uncertainty budget for the ac-dc transfer standards of SP based on the voltage build-up procedure.

Quantity	u	Standard uncertainties in uV/V at frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
1:1 comparison							
Ac-dc difference MJTC 2 V	$u(d_S)$	0,5	1,2	1,6	1,8	2,0	100
Measurement set-up	$u(d_B)$	0,3	0,3	0,3	0,3	0,3	10
Indicated ac-dc difference	$u(d_A)$	0,2	0,2	0,2	0,2	0,2	2
Ac-dc difference TTS1 2 V	$u(d_T)$	0,62	1,25	1,64	1,84	2,03	106
Standard uncertainty 2 V	$u(d_{2V})$	**0,7**	**1,3**	**1,7**	**1,9**	**2,1**	**106**

Quantity	u	Standard uncertainties in uV/V at frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
From 2 V to 4 V							
1:1 comparison							
Ac-dc difference TTS1 2 V	u(d_{S1})	0,7	1,3	1,7	1,9	2,1	106
Measurement set-up	u(d_{B12})	0,2	0,2	0,2	0,2	0,2	10
Indicated ac-dc difference	u(d_{A12})	0,2	0,2	0,2	0,2	0,2	2
Ac-dc difference TTS2 2 V	u(d_{T2})	0,75	1,33	1,72	1,92	2,12	109
2:1 comparison							
Ac-dc difference TTS1&TTS2 4 V	u(d_{S12})	0,71	1,31	1,71	1,91	2,10	106
Phase angle error	u(d_a)	0,3	0,5	0,5	0,5	0,5	10
Guarding	u(d_g)	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	u(d_{B123})	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	u(d_{A123})	0,2	0,2	0,2	0,2	0,2	2
Ac-dc difference TVC3 4 V	u(d_{T3})	0,90	1,48	1,88	2,25	2,98	44
1:1 comparison							
Ac-dc difference TVC3 4 V	u(d_{S3})	0,90	1,48	1,88	2,25	2,98	44
Temperature coefficient TVC3	u(d_{TC})	0	0,05	0,1	0,25	0,5	10
T-connector and reference plane	u(d_c)	0,2	0,6	0,9	1,4	2,0	10
Measurement set-up	u(d_{B31})	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	u(d_{A31})	0,2	0,2	0,2	0,2	0,2	2
Ac-dc difference TTS1 4 V	u(d_{T1})	1,02	1,66	2,13	2,70	3,65	52
Standard uncertainty 4 V	**u(d_{4V})**	**1,1**	**1,7**	**2,2**	**2,7**	**3,7**	**52**
From 4 V to 8 V							
1:1 comparison							
Ac-dc difference TTS1 4 V	u(d_{S1})	1,1	1,7	2,2	2,7	3,7	52
Measurement set-up	u(d_{B12})	0,2	0,2	0,2	0,2	0,2	10
Indicated ac-dc difference	u(d_{A12})	0,2	0,2	0,2	0,2	0,2	2
Ac-dc difference TTS2 4 V	u(d_{T2})	1,14	1,72	2,22	2,71	3,71	53
PVB							
Ac-dc difference TTS1&TTS2 4 V	u(d_{S12})	1,12	1,71	2,21	2,71	3,71	53
Phase angle error	u(d_a)	0,3	0,3	0,5	0,5	0,5	10
Guarding	u(d_g)	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	u(d_{B123})	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	u(d_{A123})	0,4	0,4	0,4	0,4	0,4	2
Ac-dc difference TVC3 8 V	u(d_{T3})	1,29	1,84	2,37	2,98	4,28	64
1:1 comparison							
Ac-dc difference TVC3 8 V	u(d_{S3})	1,29	1,84	2,37	2,98	4,28	64
T-connector and reference plane	u(d_{TC})	0,1	0,2	0,2	0,3	0,4	10
Temperature coefficient TVC3	u(d_c)	0	0,05	0,1	0,25	0,5	10
Measurement set-up	u(d_{B31})	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	u(d_{A31})	0,3	0,3	0,3	0,3	0,3	2
Ac-dc difference TTS1 8 V	u(d_{T1})	1,39	1,92	2,43	3,05	4,35	69
Standard uncertainty 8 V	**u(d_{8V})**	**1,4**	**2,0**	**2,5**	**3,1**	**4,4**	**69**

Quantity	u	Standard uncertainties in uV/V at frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
From 8 V to 16 V							
1:1 comparison							
Ac-dc difference TTS1 8 V	$u(d_{S1})$	1,4	2,0	2,5	3,1	4,4	69
Measurement set-up	$u(d_{B12})$	0,3	0,3	0,3	0,3	0,3	10
Indicated ac-dc difference	$u(d_{A12})$	0,3	0,3	0,3	0,3	0,3	2
Ac-dc difference TTS2 8 V	$u(d_{T2})$	1,46	2,04	2,54	3,13	4,42	70
2:1 comparison							
Ac-dc difference TTS1&TTS2 16 V	$u(d_{S12})$	1,42	2,01	2,51	3,11	4,41	69
Phase angle error	$u(d_{a})$	0,3	0,5	0,5	0,5	0,5	10
Guarding	$u(d_{g})$	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	$u(d_{B123})$	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	$u(d_{A123})$	0,4	0,4	0,4	0,4	0,4	2
Ac-dc difference TVC3 16 V	$u(d_{T3})$	1,56	2,16	2,65	3,35	4,90	81
1:1 comparison							
Ac-dc difference TVC3 16 V	$u(d_{S3})$	1,56	2,16	2,65	3,35	4,90	81
Temperature coefficient TVC3	$u(d_{TC})$	0	0,05	0,1	0,25	0,5	10
T-connector and reference plane	$u(d_{c})$	0,1	0,2	0,2	0,3	0,4	10
Measurement set-up	$u(d_{B31})$	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	$u(d_{A31})$	0,3	0,3	0,3	0,3	0,3	2
Ac-dc difference TTS1 16 V	$u(d_{T1})$	1,64	2,22	2,71	3,41	4,96	86
Standard uncertainty 16 V	**$u(d_{16V})$**	**1,7**	**2,3**	**2,8**	**3,5**	**5,0**	**86**
From 16 V to 32 V							
1:1 comparison							
Ac-dc difference TTS1 16 V	$u(d_{S1})$	1,7	2,3	2,8	3,5	5,0	86
Measurement set-up	$u(d_{B12})$	0,2	0,2	0,2	0,2	0,2	10
Indicated ac-dc difference	$u(d_{A12})$	0,3	0,3	0,3	0,3	0,3	2
Ac-dc difference TTS2 16 V	$u(d_{T2})$	1,74	2,33	2,82	3,52	5,01	86
PVB							
Ac-dc difference TTS1&TTS2 32 V	$u(d_{S12})$	1,72	2,31	2,81	3,51	5,01	86
Phase angle error	$u(d_{a})$	0,3	0,3	0,5	0,5	0,5	10
Guarding	$u(d_{g})$	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	$u(d_{B123})$	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	$u(d_{A123})$	0,4	0,4	0,4	0,4	0,4	2
Ac-dc difference TVC3 32 V	$u(d_{T3})$	1,84	2,41	2,94	3,73	5,44	98
1:1 comparison							
Ac-dc difference TVC3 32 V	$u(d_{S3})$	1,84	2,41	2,94	3,73	5,44	98
T-connector and reference plane	$u(d_{TC})$	0,1	0,1	0,1	0,2	0,2	10
Temperature coefficient TVC3	$u(d_{c})$	0	0,05	0,1	0,25	0,5	10
Measurement set-up	$u(d_{B31})$	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	$u(d_{A31})$	0,4	0,4	0,4	0,4	0,4	2
Ac-dc difference TTS1 32 V	$u(d_{T1})$	1,92	2,48	3,00	3,78	5,50	102
Standard uncertainty 32 V	**$u(d_{32V})$**	**2,0**	**2,5**	**3,0**	**3,8**	**5,5**	**102**

Quantity	u	Standard uncertainties in uV/V at frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
From 32 V to 64 V							
1:1 comparison							
Ac-dc difference TTS1 32 V	$u(d_{S1})$	2,0	2,5	3,0	3,8	5,5	102
Measurement set-up	$u(d_{B12})$	0,2	0,2	0,2	0,2	0,2	10
Indicated ac-dc difference	$u(d_{A12})$	0,4	0,4	0,4	0,4	0,4	2
Ac-dc difference TTS2 32 V	$u(d_{T2})$	2,05	2,54	3,03	3,83	5,52	104
2:1 comparison							
Ac-dc difference TTS1&TTS2 64 V	$u(d_{S12})$	2,01	2,51	3,01	3,81	5,50	103
Phase angle error	$u(d_a)$	0,3	0,5	0,5	0,5	0,5	10
Guarding	$u(d_g)$	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	$u(d_{B123})$	0,5	0,5	0,5	0,5	0,5	10
Indicated ac-dc difference	$u(d_{A123})$	0,5	0,5	1,0	1,5	2,0	2
Ac-dc difference TVC3 64 V	$u(d_{T3})$	2,16	2,66	3,27	4,27	6,23	81
1:1 comparison							
Ac-dc difference TVC3 64 V	$u(d_{S3})$	2,16	2,66	3,27	4,27	6,23	81
Temperature coefficient TVC3	$u(d_{TC})$	0,05	0,2	0,4	1,0	2,0	10
T-connector and reference plane	$u(d_c)$	0,1	0,1	0,1	0,1	0,1	10
Measurement set-up	$u(d_{B31})$	0,5	0,5	0,5	0,5	0,5	10
Indicated ac-dc difference	$u(d_{A31})$	0,5	0,5	1,0	1,5	2,0	2
Ac-dc difference TTS1 64 V	$u(d_{T1})$	2,27	2,76	3,48	4,66	6,86	79
Standard uncertainty 64 V	**$u(d_{64V})$**	**2,3**	**2,8**	**3,5**	**4,7**	**6,9**	**79**
From 64 V to 128 V							
1:1 comparison							
Ac-dc difference TTS1 64 V	$u(d_{S1})$	2,3	2,8	3,5	4,7	6,9	79
Measurement set-up	$u(d_{B12})$	0,2	0,2	0,2	0,2	0,2	10
Indicated ac-dc difference	$u(d_{A12})$	0,4	0,4	0,4	0,4	0,4	2
Ac-dc difference TTS2 64 V	$u(d_{T2})$	2,34	2,84	3,53	4,72	6,91	79
PVB							
Ac-dc difference TTS1&TTS2 128 V	$u(d_{S12})$	2,32	2,82	3,51	4,71	6,91	79
Phase angle error	$u(d_a)$	0,3	0,3	0,5	0,5	0,5	10
Guarding	$u(d_g)$	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	$u(d_{B123})$	0,7	0,7	0,7	0,7	0,7	10
Indicated ac-dc difference	$u(d_{A123})$	0,5	0,5	1,0	1,5	2,0	2
Ac-dc difference TVC3 128 V	$u(d_{T3})$	2,50	2,97	3,77	5,12	7,51	83
1:1 comparison							
Ac-dc difference TVC3 128 V	$u(d_{S3})$	2,50	2,97	3,77	5,12	7,51	83
T-connector and reference plane	$u(d_{TC})$	0,1	0,1	0,1	0,1	0,1	10
Temperature coefficient TVC3	$u(d_c)$	0,05	0,2	0,4	1,0	2,0	10
Measurement set-up	$u(d_{B31})$	0,7	0,7	0,7	0,7	0,7	10
Indicated ac-dc difference	$u(d_{A31})$	0,5	0,5	1,0	1,5	2,0	2
Ac-dc difference TTS1 128 V	$u(d_{T1})$	2,64	3,10	3,99	5,47	8,06	88
Standard uncertainty 128 V	**$u(d_{128V})$**	**2,7**	**3,1**	**4,0**	**5,5**	**8,1**	**88**

Quantity	u	Standard uncertainties in uV/V at frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
From 128 V to 250 V (256 V)							
1:1 comparison							
Ac-dc difference TTS1 128 V	$u(d_{S1})$	2,7	3,1	4,0	5,5	8,1	88
Measurement set-up	$u(d_{B12})$	0,3	0,3	0,3	0,3	0,3	10
Indicated ac-dc difference	$u(d_{A12})$	0,5	0,5	0,5	0,5	0,5	2
Ac-dc difference TTS2 128 V	$u(d_{T2})$	2,76	3,15	4,04	5,53	8,12	89
2:1 comparison							
Ac-dc difference TTS1&TTS2 256 V	$u(d_{S12})$	2,72	3,11	4,01	5,51	8,11	88
Phase angle error	$u(d_a)$	0,3	0,5	0,5	0,5	0,5	10
Guarding	$u(d_g)$	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	$u(d_{B123})$	0,7	0,7	0,7	0,7	0,7	10
Indicated ac-dc difference	$u(d_{A123})$	1,0	1,0	1,0	1,5	2,0	2
Ac-dc difference TVC3 256 V	$u(d_{T3})$	2,99	3,39	4,24	5,86	8,63	94
1:1 comparison							
Ac-dc difference TVC3 256 V	$u(d_{S3})$	2,99	3,39	4,24	5,86	8,63	94
Temperature coefficient TVC3	$u(d_{TC})$	0,2	0,4	0,7	1,5	2,7	10
T-connector and reference plane	$u(d_c)$	0,1	0,1	0,1	0,1	0,1	10
Measurement set-up	$u(d_{B31})$	0,7	0,7	0,7	0,7	0,7	10
Indicated ac-dc difference	$u(d_{A31})$	1,0	1,0	1,0	1,5	2,0	2
Ac-dc difference TTS1 250 V	$u(d_{T1})$	3,24	3,62	4,47	6,27	9,29	103
Standard uncertainty 250 V	$u(d_{250V})$	**3,3**	**3,7**	**4,5**	**6,3**	**9,3**	**103**
From 250 V to 500 V							
1:1 comparison							
Ac-dc difference TTS1 250 V	$u(d_{S1})$	3,3	3,7	4,5	6,3	9,3	103
Measurement set-up	$u(d_{B12})$	0,4	0,4	0,4	0,4	0,4	10
Indicated ac-dc difference	$u(d_{A12})$	1,0	1,0	1,0	1,5	2,0	2
Ac-dc difference TTS2 250 V	$u(d_{T2})$	3,47	3,85	4,63	6,49	9,52	102
PVB							
Ac-dc difference TTS1&TTS2 500 V	$u(d_{S12})$	3,39	3,78	4,56	6,39	9,41	107
Phase angle error	$u(d_a)$	0,3	0,3	0,5	0,5	0,5	10
Guarding	$u(d_g)$	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	$u(d_{B123})$	0,7	0,7	0,7	0,7	0,7	10
Indicated ac-dc difference	$u(d_{A123})$	0,5	0,5	0,5	0,5	0,5	2
Ac-dc difference TVC3 500 V	$u(d_{T3})$	3,51	3,89	4,69	6,55	9,67	117
1:1 comparison							
Ac-dc difference TVC3 500 V	$u(d_{S3})$	3,51	3,89	4,69	6,55	9,67	117
T-connector and reference plane	$u(d_{TC})$	0,1	0,1	0,1	0,1	0,1	10
Temperature coefficient TVC3	$u(d_c)$	0,05	0,1	0,2	0,5	1,0	10
Measurement set-up	$u(d_{B31})$	0,7	0,7	0,7	0,7	0,7	10
Indicated ac-dc difference	$u(d_{A31})$	0,5	0,5	0,5	0,5	0,5	2
Ac-dc difference TTS1 500 V	$u(d_{T1})$	3,61	3,99	4,77	6,62	9,76	121
Standard uncertainty 500 V	$u(d_{500V})$	**3,7**	**4,0**	**4,8**	**6,7**	**9,8**	**121**

Quantity	u	Standard uncertainties in uV/V at frequency					Eq. deg. freedom
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	
From 500 V to 1 kV							
1:1 comparison							
Ac-dc difference TTS1 500 V	u(d_{S1})	3,7	4,0	4,8	6,7	9,8	121
Measurement set-up	u(d_{B12})	0,5	0,5	0,5	0,5	0,5	10
Indicated ac-dc difference	u(d_{A12})	0,5	0,5	0,5	0,5	0,5	2
Ac-dc difference TTS2 500 V	u(d_{T2})	3,77	4,06	4,85	6,74	9,83	123
2:1 comparison							
Ac-dc difference TTS1&TTS2 1 kV	u(d_{S12})	3,72	4,02	4,81	6,71	9,81	122
Phase angle error	u(d_a)	0,3	0,5	0,5	0,5	0,5	10
Guarding	u(d_g)	0,1	0,2	0,4	1,0	2,0	10
Measurement set-up	u(d_{B123})	0,7	0,7	0,7	0,7	0,7	10
Indicated ac-dc difference	u(d_{A123})	1,0	1,0	1,0	1,0	1,0	2
Ac-dc difference TVC3 1 kV	u(d_{T3})	3,92	4,23	5,01	6,91	10,09	133
1:1 comparison							
Ac-dc difference TVC3 1 kV	u(d_{S3})	3,92	4,23	5,01	6,91	10,09	133
Temperature coefficient TVC3	u(d_{TC})	0,05	0,2	0,4	1,0	2,0	10
T-connector and reference plane	u(d_c)	0,1	0,1	0,1	0,1	0,1	10
Measurement set-up	u(d_{B31})	0,7	0,7	0,7	0,7	0,7	10
Indicated ac-dc difference	u(d_{A31})	0,5	0,5	0,5	0,5	0,5	2
Ac-dc difference TTS1 1 kV	u(d_{T1})	4,02	4,32	5,10	7,04	10,33	143
Standard uncertainty 1 kV	**u(d_{1kV})**	**4,1**	**4,4**	**5,1**	**7,1**	**10,4**	**143**

DETERMINATION OF THE UNCERTAINTY OF THE IEN STEP-UP

U. Pogliano G.C Bosco

The uncertainty of the basic reference group at 4 V is given by combination of:

- $u(x_1(f_i)$ estimated uncertainty of the mean value of the reference group at 3 V, which takes into account the uncertainty of ac-dc transfer difference of the multijunction.converters and the optimization of the measurement values in the reference group, obtained by least square adjustment.

$$u'(x_1(f_i)) = \sqrt{\frac{\sum_{i=1}^{N} R_i}{N - C + 1}} \tag{1}$$

where:
R_i is residual of the measurements
N number of independent measurements
C number of standards in the steps

- $u(x_2(f_i))$ uncertainty of the determination of the variation of the ac-dc transfer difference between 3 and 4 V.

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_1(f_i))$	0.4	0.6	0.7	1.1	1.7
$u(x_2(f_i))$	0.08	0.08	0.08	0.08	0.08

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u_C(Y)$	0.4	0.6	0.7	1.1	1.7

The uncertainty of the other steps are:

Step	**Voltage (V)**	
	Lower value	**Nominal value**
1	4	6
2	6	10
3	10	12
4	12	20
5	20	30
6	30	40
7	40	60
8	60	100
9	100	200
10	200	500
11	500	1000

The value of the ac-dc transfer difference in each step $Y_p(f_i)$ is given by:

$$Y_p(f_i) = X_{1,p}(f_i) + X_{2,p}(f_i) + X_{3,p}(f_i) + X_{4,p}(f_i) \tag{2}$$

where:

$X_{1,p}(f_i)$ is the ac-dc transfer difference of the converters at the lower voltage level in the previous step;

$X_{2,p}(fi)$ is the difference between the ac-dc transfer difference evaluated by the measurements and the optimization of the results;

$X_{3,p}(f_i)$ is the variation of the ac-dc transfer difference of the reference converter as function of the applied voltage in the transition between the lower value and the nominal value. This component, which is due only to the thermal element, is evaluated;

$X_{4,p}(f_i)$ is the variation of the ac-dc transfer difference of the reference converter as function of the applied voltage in the transition between the lower value and the nominal value. This component, which is due only to the resistor, has been estimated only for voltages higher than 100 V and has been assumed to be zero for other voltages.

In the 11 steps of the step-up procedure up to 1000 V the relation:

$$X_{1,p+1}(f_i) = Y_p(f_i) \tag{3}$$

is applied.

- $u(x_{2,p}(f_i))$ is evaluated on the basis of the measurements performed at that voltage level by applying to them the least square adjustment.
- $u(x_{3,p}(f_i))$ is evaluated by combination of the uncertainties in the determination of the ac-dc transfer differences of the thermal element in the two voltage levels.
- $u(x_{4,p}(f_i))$ due to the voltage dependence of the range resistors, is evaluated from the differences between the ac-dc transfer differences at nominal voltage and at reduced voltage in comparison with a thermal converter having a higher nominal voltage (for example the dependence of the 200 V thermal converters has been estimated from the difference between the ac-dc transfer differences of such converters at 200 V and at 100 V measured in comparison with a 500 V nominal voltage thermal converter). In this determination the variation of the power in all the converters and of the ac-dc transfer difference due to the thermal element have also been taken into account. The uncertainty of the voltage dependence on the 1000 V converter has been obtained by extrapolation assuming a behavior proportional to the power supplied to the converter.

Step 1 (form 4V to 6V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,1}(f_i))$	0.10	0.33	0.45	0.90	1.28
$u(x_{3,1}(f_i))$	0.14	0.14	0.14	0.14	0.14
$u(x_{4,1}(f_i))$	0.05	0.05	0.09	0.14	0.35

Step 2 (from 6V to 10V)

f_i	1kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,2}(f_i))$	0.06	0.21	0.27	0.26	0.30
$u(x_{3,2}(f_i))$	1.1	1.1	1.1	1.1	1.1
$u(x_{4,2}(f_i))$	0.05	0.05	0.09	0.13	0.33

Step 3 (from 10V to 12V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,3}(f_i))$	0.19	0.25	0.27	0.45	0.61
$u(x_{3,3}(f_i))$	0.26	0.26	0.26	0.26	0.26
$u(x_{4,3}(f_i))$	0.11	0.11	0.20	0.30	0.76

Step 4 (form 12V to 20V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,4}(f_i))$	0.14	0.33	0.37	0.36	0.35
$u(x_{3,4}(f_i))$	0.16	0.16	0.16	0.16	0.16
$u(x_{4,4}(f_i))$	0.19	0.19	0.35	0.52	1.3

Step 5 (form 20V a 30V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,5}(f_i))$	0.22	0.05	0.16	0.61	0.31
$u(x_{3,5}(f_i))$	0.82	0.82	0.82	0.82	0.82
$u(x_{4,5}(f_i))$	0.12	0.12	0.23	0.34	0.87

Step 6 (from 30V to 40V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,6}(f_i))$	0.20	0.43	0.61	0.89	1.14
$u(x_{3,6}(f_i))$	0.30	0.30	0.30	0.30	0.30
$u(x_{4,6}(f_i))$	0.51	0.51	0.95	1.4	3.6

Step 7 (from 40V to 60V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,7}(f_i))$	0.16	0.24	0.18	0.11	0.13
$u(x_{3,7}(f_i))$	0.14	0.14	0.14	0.14	0.14
$u(x_{4,7}(f_i))$	0.49	0.49	0.91	1.4	3.5

Step 8 (from 60V to 100V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,8}(f_i))$	0.40	0.10	0.13	0.61	0.78
$u(x_{3,8}(f_i))$	1.1	1.1	1.1	1.1	1.1
$u(x_{4,8}(f_i))$	0.47	0.47	0.87	1.3	3.3

Step 9 (from 100V to 200V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,9}(f_i))$	0.25	0.12	0.22	0.41	0.53
$u(x_{3,9}(f_i))$	0.25	0.25	0.25	0.25	0.25
$u(x_{4,9}(f_i))$	2.2	2.2	4.1	6.1	16

Step 10 (from 200V to 500V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,10}(f_i))$	0.33	0.17	0.34	1.3	2.1
$u(x_{3,10}(f_i))$	0.95	0.95	0.95	0.95	0.95
$u(x_{4,10}(f_i))$	1.5	1.5	2.9	4.3	11

Step 11 (from 500V to 1000V)

f_i	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
$u(x_{2,11}(f_i))$	1.3	1.4	1.3	2.1	2.2
$u(x_{3,11}(f_i))$	1.2	1.2	1.2	1.2	1.2
$u(x_{4,11}(f_i))$	5.5	5.5	10	15	31

The determination of the $u_{i,p}$ (fi) is obtained by collecting the different components on the basis of the first index j , which displays the type of the component.

For j = 2, $\overline{u_{2,p}}(f_i)$ are evaluated by the quadratic sum of the single components of the same index for the different steps.

$$\overline{u_{2,p}}(f_i)=\sqrt{\sum_{k=1}^{p}\left(u(X_{2,p}(f_i))\right)^2} \tag{4}$$

For j = 3, where the correlation for the steps that use the same thermoelement is assumed to be 1,

$$\overline{u_{3,p}}(f_i)=\sqrt{\sum_{t=1}^{nt}\left(\sum_{k=1}^{nl(t)}u(X_{3,t,k}(f_i))\right)^2} \tag{5}$$

where:
nt is the number of thermoelements used to reach the step *p;*
nl(t) is the number of steps where the same thermoelement *t* is used

For j = 3, where the correlation is 1 for the steps that use the same range resistors:

$$\overline{u_{4,p}}(f_i)=\sqrt{\sum_{r=1}^{nr}\left(\sum_{k=1}^{nl(r)}u(X_{4,r,k}(f_i))\right)^2} \tag{6}$$

where:
nr is the number of range resistor used to reach the step *p;*
nl(r) is the number of steps where the same range resistor *r* is used.

The total uncertainty at the step *p* and the frequency f_i is given by:

$$u_{c,p}(f_i)=\sqrt{(u_C(f_i))^2+(\overline{u_{2,p}}(f_i))^2+(\overline{u_{3,p}}(f_i))^2+(\overline{u_{4,p}}(f_i))^2} \tag{7}$$

$u_{c,p}(f_i)$ (parts in 10^6)						
f_i		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
p =1	6 V	0.46	0.74	0.82	1.5	2.2
p=2	10 V	1.2	1.3	1.4	1.8	2.5
p=3	12 V	1.2	1.4	1.5	2.0	2.8
p=4	20 V	1.3	1.5	1.6	2.1	3.2
p=5	30 V	2.0	2.1	2.2	2.7	3.7
p=6	40 V	2.2	2.4	2.7	3.5	6.4
p=7	60 V	2.3	2.5	3.0	3.9	7.7
p=8	100 V	3.3	3.4	3.8	4.7	8.7
p=9	200 V	4.2	4.3	6.2	8.7	20.6
p=10	500 V	4.6	4.6	6.9	9.8	23.3
p=11	1000 V	7.4	7.5	12.4	18.3	38.9

Extracts from:"COMPARISON CCEM-K9 High Voltage AC-DC transfer Report of the measurements at IEN" **U. Pogliano and G. C. Bosco,** IEN Report N. 624March 2001

7. UNCERTAINTIES

The uncertainties of the AC/DC transfer differences are evaluated in Table 8, Table 9 and Table 10.

Table 8 *Assigned uncertainties of the transfer differences at 200 V (1σ in parts in 10^6).*

Unc. components	**Type**	**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Reference standard		4.2	4.3	6.2	8.7	20.6
Repetitions of meas.	A	0.3	0.4	0.8	1.1	0.6
EMFs comparator	B	0.5	0.5	0.5	0.5	0.5
Measurement system additional uncertainty	B	0.5	0.8	1	2.5	5
Total uncertainty		**4.3**	**4.4**	**6.4**	**9.1**	**21.2**

Table 9 *Assigned uncertainties of the transfer differences at 500 V (1σ in parts in 10^6).*

Unc. components	**Type**	**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Reference standard		4.6	4.6	6.9	9.8	23.3
Repetitions of meas.	A	0.4	0.3	0.3	0.4	0.5
EMFs comparator	B	0.3	0.3	0.3	0.3	0.3
Measurement system additional uncertainty	B	0.5	0.8	1	2.5	5
Total uncertainty		**4.7**	**4.7**	**7.0**	**10.1**	**23.8**

Table 10 *Assigned uncertainties of the transfer differences at 1000 V (1σ in parts in 10^6).*

Unc. components	**Type**	**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Reference standard		7.4	7.5	12.4	18.3	38.9
Repetitions of meas.	A	0.1	0.4	0.2	0.3	0.6
EMFs comparator	B	0.1	0.1	0.1	0.1	0.1
Measurement system additional uncertainty	B	0.5	1.2	1.5	3.5	8
Total uncertainty		**7.4**	**7.6**	**12.5**	**18.6**	**39.7**

The uncertainty component due to the electromotive-force comparator was evaluated from the differences obtained by connecting the output of the same thermal converter to both channels and applying the usual measurement procedure. The additional component due to the system was evaluated by repeating the comparisons in different conditions, for example: using different type of T–connectors, changing the positions of the mechanical supports of the converters and using different cables.

UNCERTAINTY BUDGET FOR CEM (SPAIN)

Uncertainty of measurement.

An analysis of the uncertainties of measurement for the CEM-standards has been performed in accordance with the CIPM Recommendation 1 (CI-1981).

We enclose, tables 1, 2 and 3, an uncertainty budget with the reason of the deviation, type of distribution and standard deviations in 10^{-6} at measurement frequencies. We provide a list of type A and type B contributions. It also provides an overall uncertainty with the root squares of all contributions.

The study of the uncertainties contains all contributions from the PTB-MJTC basis; these reference values are based on the CCEM-K6.a. All type B contributions with rectangular distribution. We include the reference in the estimation of the uncertainty at level of 3 V. The standards for higher voltages are calibrated by a “step up” procedure with 10 steps. The uncertainties owing to the current level of the MJTC and owing to the voltage level of the voltage dropping resistors are correlated.

The calibration of the travelling standard is carried out by direct comparison against the CEM standards. Standard deviations smaller than 1 10^{-6} at 200 V and 500 V and up to 4 10^{-6} at 1000 V are obtained, which does not increase the uncertainty of the measurement results notably.

At the end we represent a combined value. All uncertainties are given at 1 σ. The degrees of freedom ν, for the uncertainty contribution of the 12 measurements is 11 (type A evaluation). The uncertainties obtained from a type B evaluation, dominate in the final combined standard uncertainty, and they can be treated as exactly known,

$\nu_i \longrightarrow \infty$, so the number of effective degrees of freedom of our results, $\nu_{eff} \longrightarrow \infty$, too ($\nu_{eff}$ >25000).

Uncertainty of the primary ac-dc voltage transfer standard. MJTC at 3V level

		Standard measurement uncertainty, u, in 10^{-6} at the frequencies,									
Influence quantity	u	10 Hz	20 Hz	40 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
Thomson effect.	$u(\delta_{TH})$	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Reactive components and loss factor of the heater	$u(\delta_{LGC})$	0	0	0	0,01	0,1	0,4	0,7	1	5	10
Low frequency effects	$u(\delta_{LF})$	2,5	1,5	1	0,1	0	0	0	0	0	0
Skin effect	$u(\delta_{Skin})$	0	0	0	0,01	0,01	0,01	0,01	0,1	2	5
Connectors and T	$u(\delta_{conn})$	0	0	0	0,5	0,5	0,5	0,6	0,7	1	3
Reference standard	**$u(\delta_S)$**	**2,5**	**1,5**	**1**	**0,5**	**0,5**	**0,6**	**1**	**1,2**	**5,5**	**11,6**

Table 1. $\mathbf{u^2(\delta_S) = u^2(\delta_{TH}) + u^2(\delta_{LGC}) + u^2(\delta_{Skin}) + u^2(\delta_{conn}) + u^2(\delta_{LF})}$

UNCERTAINTY BUDGET OF AC/DC VOLTAGE TRANSFER STANDARDS AT CEM

Reason of deviation	Standard uncertainty in 10^{-6} at the frequencies										Remarks/ distribution
	10 Hz	20 Hz	40 Hz	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz	
Standard uncertainty $u(\delta_s)$ (1σ) at 3 V level.	2,5	1,5	1	0,5	0,5	0,6	1	1,2	5,5	11,6	Reference
Step-up procedure. Standard deviations per step, change of transfer differences :											Worst case $\pm X/\sqrt{3}$ correl.
- With current level of the converters $u(\delta_n)$	1	0,8	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	
- With voltage $u(\delta s_i)$:											
up to 10 V	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1,5	1,5	
up to 30 V	2	1	1	1	1	1	1	1	2	2	
up to 100 V	2	1	1	1	1	1	1	1	-	-	
up to 300 V	3	2	1,5	1	1	1	2	3	-	-	
up to 500 V	5	4	3	1,5	1,5	2	4	6	-	-	
up to 1000 V	7	6	5	3	5	6	12	24	-	-	-----------------
Drift during measurement	2	1	0,5	0,5	0,5	0,5	0,5	0,5	1	2	$u(\delta_d)$
Comparison measurement	1,5	1	1	0,5	0,5	0,5	0,5	1	2	3	$u(\delta m)$
Standard uncertainty per additional steps $u(\delta c_i)$:											
to 5 V, 10 V	2,9	1,9	1,5	1,2	1,2	1,2	1,2	1,5	3	4,1	steps 1-2
20 V, 30 V	3,9	2,3	1,9	1,7	1,7	1,7	1,7	1,9	3,4	4,4	steps 3-4
50 V, 100 V	3,9	2,3	1,9	1,7	1,7	1,7	1,7	1,9	-	-	steps 5-6
200 V, 300 V	4,7	3,1	2,3	1,7	1,7	1,7	2,6	3,7	-	-	steps 7-8
500 V	6,5	5	3,7	2,1	2,1	2,6	4,6	6,6	-	-	step 9
1000 V	8,4	6,9	5,6	3,6	5,5	6,5	12,5	24,5	-	-	step 10
	$u(\delta_{ci}) = \sqrt{(u(\delta n) + u(\delta si))^2 + u(\delta d)^2 + u(\delta m)^2}$										
Total uncertainty $u(\delta_V)$ (1σ) of the standards :											
3 V	2,5	1,5	1	0,5	0,5	0,6	1	1,2	5,5	11,6	
5 V	3,8	2,4	1,8	1,3	1,3	1,3	1,6	1,9	6,3	12,3	1 step
10 V	6,3	4,1	3,2	2,5	2,5	2,5	2,6	3,2	8,1	14,2	2 steps
20 V	10	6,3	5	4,1	4,1	4,1	4,2	5	10,9	17,1	3 steps
30 V	13,8	8,5	6,9	5,8	5,8	5,8	5,9	6,9	-	-	4 steps
50 V	17,7	10,8	8,8	7,5	7,5	7,5	7,6	8,8	-	-	5 steps
100 V	21,5	13,1	10,6	9,2	9,2	9,2	9,3	10,7	-	-	6 steps
200 V	**26,2**	**16,2**	**12,9**	**10,9**	**10,9**	**10,9**	**11,8**	**14,4**	-	-	7 steps
300 V	30,9	19,3	15,2	12,6	12,6	12,6	14,4	18	-	-	8 steps
500 V	**37,4**	**24,2**	**18,9**	**14,7**	**14,7**	**15,2**	**19**	**24,6**	-	-	9 steps
1000 V	**45,8**	**31,1**	**24,5**	**18,3**	**20,2**	**21,7**	**31,5**	**49,1**	-	-	10 steps
	$u(\delta_V) = \sqrt{u(\delta s)^2 + (\sum u(\delta_{ci}))^2}$										

Table 2. Uncertainty budget of the ac-dc voltage transfer standards at CEM.

Uncertainty on the comparison of the reference of CEM with the travelling standard

Standard measurement uncertainty, u, in 10^{-6} at the frequencies,

	u	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
Reference standard	$u(\delta_V)$					
200 V		10,9	10,9	10,9	11,8	14,4
500 V		14,7	14,7	15,2	19	24,6
1000 V		18,3	20,2	21,7	31,5	49,1
Drift during measurements	$u(\delta_d)$	0,5	0,5	0,5	0,5	0,5
Comparison measurements	$u(\delta_C)$	0,5	0,5	0,5	0,5	1
standard deviation of the measurements	$u(\delta_A)$					
200 V		1	1	1	1	1
500 V		1	1	1	1	1
1000 V		2	3	3,2	3,,2	4
Standard meas. Uncertainty	$\mathbf{u(\delta_x)}$					
200 V		**11**	**11**	**11**	**12**	**14,4**
500 V		**14,8**	**14,8**	**15,2**	**19**	**24,6**
1000 V		**18,4**	**20,4**	**22**	**31,7**	**49,3**

Table 3. $\mathbf{u^2(\delta_x) = u^2(\delta_V) + u^2(\delta_d) + u^2(\delta_C) + u^2(\delta_A)}$

UNCERTAINTY BUDGET FOR PTB (GERMANY)

influence quantity	u	standard measurement uncertaintyies u in 10^{-6} at the frequencies				
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
MJTC at 5-V-level						
Thomson effect at dc	$u(\delta_{\mathrm{TH}})$	0,01	0,01	0,01	0,01	0,01
reactive components and loss factor of the heater	$u(\delta_{\mathrm{L,G,C}})$	0,00	0,02	0,02	0,05	0,13
skineffect	$u(\delta_{\mathrm{SKIN}})$	0,00	0,00	0,00	0,00	0,03
low frequency effect	$u(\delta_{\mathrm{LF}})$	0,00	0,00	0,00	0,00	0,00
connector and T	$u(\delta_{\mathrm{Connect}})$	0,00	0,10	0,10	0,30	0,50
measurements between different converters	$u(\delta_{\mathrm{d}})$	0,10	0,10	0,10	0,10	0,50
standard uncertainty 5-V	$u(\delta_{\mathrm{S\,5\text{-}V}})$	**0,1**	**0,1**	**0,1**	**0,3**	**0,7**
Step-up procedure						
10-V-level						
standard uncertainty 5 V	$u(\delta_{\mathrm{S\,5\,V}})$	0,1	0,1	0,1	0,3	0,7
comparison measurements	$u(\delta_{\mathrm{d}})$	0,1	0,1	0,1	0,1	0,5
resistor voltage coefficient	$u(\delta_{U\mathrm{voltage\ coefficient}})$	0,4	0,4	0,4	0,4	1,0
standard uncertainty 10 V	$u(\delta_{\mathrm{S\,10\,V}})$	**0,4**	**0,4**	**0,4**	**0,5**	**1,3**
20-V-level						
standard uncertainty 10 V	$u(\delta_{\mathrm{S\,10\,V}})$	0,4	0,4	0,4	0,5	1,3
comparison measurements	$u(\delta_{\mathrm{d}})$	0,1	0,1	0,1	0,1	0,5
resistor voltage coefficient	$u(\delta_{U\mathrm{voltage\ coefficient}})$	0,4	0,4	0,4	0,4	1,0
standard uncertainty 20 V	$u(\delta_{\mathrm{S\,20\,V}})$	**0,6**	**0,6**	**0,6**	**0,7**	**1,7**
100-V-level						
standard uncertainty 20 V	$u(\delta_{\mathrm{S\,20\,V}})$	0,6	0,6	0,6	0,7	1,7
comparison measurements	$u(\delta_{\mathrm{d}})$	0,1	0,1	0,1	0,1	0,5
resistor/converter combination	$u(\delta_{U\mathrm{standards}})$	1,9	1,9	1,9	1,9	1,9
resistor voltage coefficient	$u(\delta_{U\mathrm{voltage\ coefficient}})$	1,0	1,0	1,0	1,0	1,0
standard uncertainty 100 V	$u(\delta_{\mathrm{S\,100\,V}})$	**2,2**	**2,2**	**2,2**	**2,3**	**2,8**
200-V-level						
standard uncertainty 100 V	$u(\delta_{\mathrm{S\,100\,V}})$	2,2	2,2	2,2	2,3	2,8
comparison measurements	$u(\delta_{\mathrm{d}})$	0,1	0,1	0,1	0,1	0,5
resistor/converter combination	$u(\delta_{U\mathrm{standards}})$	1,2	1,2	1,2	1,2	2,8
resistor voltage coefficient	$u(\delta_{U\mathrm{volt.\ coefficient}})$	1,5	1,5	1,5	1,6	4,1
with high voltage amplifiers	$u(\delta_{U\mathrm{amplifiers}})$	2,3	2,3	2,9	3,5	9,0
standard uncertainty 200 V	$u(\delta_{\mathrm{S\,200\,V}})$	**3,7**	**3,7**	**4,1**	**4,6**	**11**

influence quantity	u	standard measurement uncertaintyies u in 10^{-6} at the frequencies				
		1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
500-V-level						
standard uncertainty 100 V	$u(\delta_{\mathrm{S\,100\,V}})$	2,2	2,2	2,2	2,3	2,8
comparison measurements	$u(\delta_{\mathrm{d}})$	0,1	0,1	0,1	0,1	0,5
resistor/converter combination	$u(\delta_{U\mathrm{standards}})$	0,5	0,5	0,5	1	4,5
resistor voltage coefficient	$u(\delta_{U\mathrm{volt.\ coefficient}})$	0,6	0,6	0,8	0,4	2,3
high voltage amplifiers	$u(\delta_{U\mathrm{amplifiers}})$	0,7	0,7	0,7	2,1	8,1
standard uncertainty 500 V	$\boldsymbol{u(\delta_{\mathrm{S\,500\,V}})}$	**2,5**	**2,5**	**2,5**	**3,3**	**10**
600-V-level						
standard uncertainty 500 V	$u(\delta_{\mathrm{S\,500\,V}})$	2,5	2,5	2,5	3,3	10
comparison measurements	$u(\delta_{\mathrm{d}})$	0,1	0,1	0,1	0,1	0,5
resistor/converter combination	$u(\delta_{U\mathrm{standards}})$	0,5	0,5	0,5	1	4,5
resistor voltage coefficient	$u(\delta_{U\mathrm{volt.\ coefficient}})$	0,6	0,6	0,8	0,4	2,3
high voltage amplifiers	$u(\delta_{U\mathrm{amplifiers}})$	0,9	0,9	0,8	2,1	8,8
standard uncertainty 600 V	$\boldsymbol{u(\delta_{\mathrm{S\,600\,V}})}$	**2,7**	**2,7**	**2,8**	**4,0**	**14**
1000-V-level						
standard uncertainty 500 V	$u(\delta_{\mathrm{S\,500\,V}})$	2,5	2,5	2,5	3,3	10,0
comparison measurements	$u(\delta_{\mathrm{d}})$	0,1	0,1	0,1	0,1	0,5
resistor/converter combination	$u(\delta_{U\mathrm{standards}})$	0,5	0,5	0,5	1	4,5
resistor voltage coefficient	$u(\delta_{U\mathrm{volt.\ coefficient}})$	0,4	0,4	0,9	0,3	5,5
high voltage amplifiers	$u(\delta_{U\mathrm{amplifiers}})$	1,0	1,0	1,0	3,2	4,7
standard uncertainty 1000 V	$\boldsymbol{u(\delta_{\mathrm{S\,1000\,V}})}$	**2,7**	**2,7**	**2,9**	**4,7**	**13**

As at 100 kHz the standard measurement uncertainty at 600 V is larger than at 1000 V, the larger value is taken for the uncertainty at 1000 V.

All uncertainties are calculated as a mean of more than 40 measurements. Therefore the degrees of freedom can be taken as large enough to use k=2 for the calculation of the expanded measurement uncertainty at a confidence level of 95 %.

Table III. Standard measurement uncertainties

voltage	standard measurement uncertainties u in 10^{-6} at the frequencies				
	1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
200 V, 500 V	4	4	4	5	11
1000 V	4	4	4	5	15

UNCERTAINTY BUDGET FOR VSL (THE NETHERLANDS)

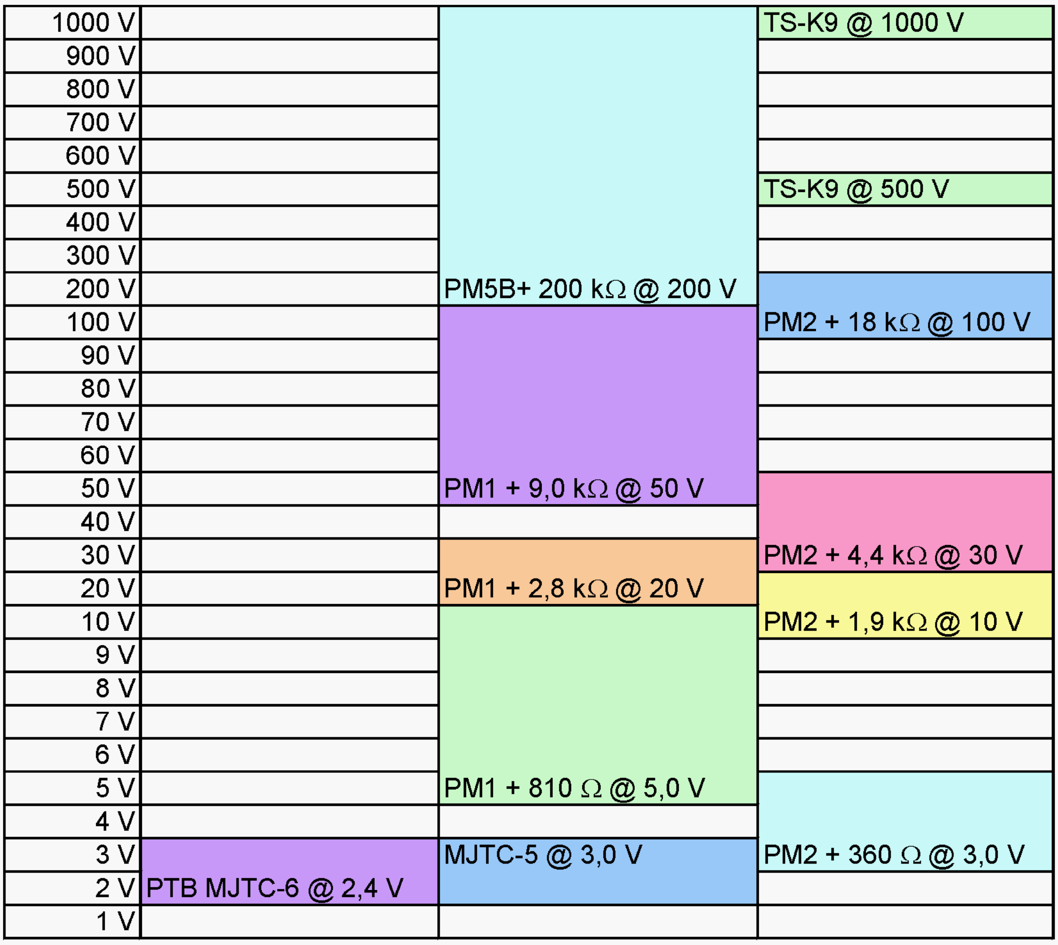
Detailed uncertainty budget for CCEM-K9

Institute: **NMi VSL B.V.**

Date: **25 August 2004**
By: **E.F. Dierikx and J.T. Dessens**

Measurements performed in May / June 2001

The AC/DC transfer difference of thermal voltage converters up to 1000 V in the frequency range from 1 kHz to 100 kHz is determined by a step-up method. The starting point of this step-up is a multi junction thermal converter (MJTC-6) with a nominal input voltage of 2.4 V, which has been calibrated at PTB. Two 1 V planar multi junction thermal converters (PM1 and PM2) are used to step-up from 3 V to 200 V by using different range resistors as shown in the diagram below. The whole range from 200 V up to 1000 V is covered by PM5B (a 2V PMJTC) in combination with a Fluke 792 range resistor of about 200 kΩ.



1000 V			TS-K9 @ 1000 V
900 V			
800 V			
700 V			
600 V			
500 V			TS-K9 @ 500 V
400 V			
300 V			
200 V		PM5B+ 200 kΩ @ 200 V	
100 V			PM2 + 18 kΩ @ 100 V
90 V			
80 V			
70 V			
60 V			
50 V		PM1 + 9,0 kΩ @ 50 V	
40 V			
30 V			PM2 + 4,4 kΩ @ 30 V
20 V		PM1 + 2,8 kΩ @ 20 V	
10 V			PM2 + 1,9 kΩ @ 10 V
9 V			
8 V			
7 V			
6 V			
5 V		PM1 + 810 Ω @ 5,0 V	
4 V			
3 V		MJTC-5 @ 3,0 V	PM2 + 360 Ω @ 3,0 V
2 V	PTB MJTC-6 @ 2,4 V		
1 V			

Figure 1 Schematic diagram of the AC-DC transfer difference step-up from 3 V up to 1000 V at NMi-VSL

For each step, the AC-DC transfer difference, $\delta_{\mathrm{x,step(i)}}$ is calculated by:

$$\delta_{\mathrm{x,step}(i)} = \delta_{\mathrm{x,step}(i-1)} + \delta_{\mathrm{lev}} + \delta_{\mathrm{diff}}$$

where, for each step:

$\delta_{\mathrm{x,step}(i)}$:	is the unknown AC-DC difference from the converter/resistor combination under test.
$\delta_{\mathrm{x,step}(i\text{-}1)}$:	is the known reference AC-DC difference from the converter/resistor combination in the previous step.
δ_{lev}:	is the voltage/current level dependence of the reference converter/resistor combination.
δ_{diff}:	is the measured AC-DC difference between the reference and the unknown.

The uncertainty in each step, u_{x} is given by the root sum square of the individual contributions:

$$u_{\mathrm{x}} = \sqrt{u_{\mathrm{ref}}^2 + u_{\mathrm{lev}}^2 + u_{\mathrm{diff}}^2 + u_{\mathrm{std}}^2}$$

where

u_{ref}: is the uncertainty of the reference converter (or converter/resistor combination)
For PTB-MJTC-6, the uncertainties are given on the PTB calibration certificate. The effective degrees of freedom ν_{ref} for PTB-MJTC-6 are estimated to be at least 1000. For all other steps, the uncertainty in de reference and the corresponding values of ν_{ref} are obtained from the previous step.

u_{lev}: is the voltage and current level dependence of the converter and range resistor.
For measurements below 30 V, this contribution is estimated to be very small; < 0.1 µV/V at all frequencies. In the range from 30 V up to 200 V, u_{lev} is typical 1 µV/V or 2 µV/V. Above 200 V the contributions are somewhat higher, but less than 10 µV/V. All of the values have been estimated from experience with these standards.
ν_{lev} is estimated to be at least 1000 for all steps.

u_{diff}: is the combined uncertainty of contributions resulting from the AC/DC difference measurement. This contains contributions for:

- drift during the measurements
- sensitivity measurement
- output voltage readout
- temperature
- reproducibility
- electromagnetic interference
- t-connector
- systematic effects from the set-up (sources, amplifiers, grounding, guarding, etc.)

All these contributions are estimate by a type B evaluation with a rectangular distribution. The combined uncertainty of these contributions is expected to have a more or less normal distribution. ν_{diff} is estimated to be at least 1000.

u_{std}: is the standard deviation of the mean of the measured values.
This contribution is estimated by a type A evaluation with a normal distribution.
In the step-up from 3 V up to 200 V each measurement is repeated at least 5 times, so $\nu_{\mathrm{std}} > 4$. The measurements of the travelling standard at 500 V and 1000 V were each repeated more than 7 times, so in the last step $\nu_{\mathrm{std}} > 6$.

A table for these different uncertainty contributions at each step is given below.
The total effective degrees of freedom ν_{eff} have been calculated for each step by the Welch-Satterthwaite formula according to the GUM. Only the values for ν_{eff} in the measurements at 500 V and 1000 V are shown in the table below.

Table 1 Uncertainty budget table for the NMi-VSL AC-DC difference step-up from 3 V up to 1000 V. All values are expressed as standard uncertainties in μV/V (k = 1) unless specified otherwise.

					1 kHz	10 kHz	20 kHz	50 kHz	100 kHz			
Applied Voltage V	Thermal converter	Range resistor Ω	Max. Voltage V		unc. k = 1 μV/V	unc. k = 1 μV/V	unc. k = 1 μV/V	unc. k = 1 μV/V	unc. k = 1 μV/V			
2.4	MJTC-6		3		0.5	0.5	1.0	1.0	2.5			
3	MJTC-5		3		0.5	0.5	1.0	1.0	2.5	type B	normal	u_ref
					1	1	2	2	5	k=2		
					1	1	1	2	3	type B	rectangular	u_diff
					0.1	0.1	0.1	0.1	0.1	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
3	PM2	360	5		1.5	1.5	1.7	2.5	4.0	type B	normal	u_ref
					3.0	3.0	3.5	4.9	8.1	k=2		
					1	1	1	2	3	type B	rectangular	u_diff
					0.1	0.1	0.1	0.1	0.1	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
5	PM1	810	10		2.1	2.1	2.2	3.3	5.1	type B	normal	u_ref
					4.1	4.1	4.5	6.6	10.3	k=2		
					1	1	1	2	3	type B	rectangular	u_diff
					0.1	0.1	0.1	0.1	0.1	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
10	PM2	1k9	20		2.5	2.5	2.7	4.0	6.0	type B	normal	u_ref
					5.0	5.0	5.3	8.0	12.0	k=2		
					1	1	1	2	3	type B	rectangular	u_diff
					0.1	0.1	0.1	0.1	0.1	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
20	PM1	2k8	30		2.9	2.9	3.0	4.6	6.8	type B	normal	u_ref
					5.8	5.8	6.0	9.2	13.6	k=2		
					1	1	1	2	3	type B	rectangular	u_diff
					1	1	1	2	2	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
30	PM2	4k4	50		3.4	3.4	3.5	5.5	7.8	type B	normal	u_ref
					6.7	6.7	6.9	11.0	15.5	k=2		
					1	1	1	2	3	type B	rectangular	u_diff
					1	1	1	2	2	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
50	PM1	9k0	100		3.8	3.8	3.9	6.2	8.6	type B	normal	u_ref
					7.6	7.6	7.8	12.5	17.2	k=2		
					1	1	1	2	3	type B	rectangular	u_diff
					1	1	1	2	2	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
100	PM2	18k	200		4.2	4.2	4.2	6.9	9.4	type B	normal	u_ref
					8.3	8.3	8.5	13.9	18.8	k=2		
					1	1	1	2	3	type B	rectangular	u_diff
					1	1	1	2	2	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
200	PM5B	200k	1000		4.5	4.5	4.6	7.6	10.1	type B	normal	u_ref
					9.0	9.0	9.2	15.1	20.2	k=2		

					1 kHz	10 kHz	20 kHz	50 kHz	100 kHz			
Applied Voltage V	Thermal converter	Range resistor Ω	Max. Voltage V		unc. k = 1 µV/V	unc. k = 1 µV/V	unc. k = 1 µV/V	unc. k = 1 µV/V	unc. k = 1 µV/V			
	PM5B	200k	1000		4.5	4.5	4.6	7.6	10.1	type B	normal	u_ref
					2	2	6	7	14	type B	rectangular	u_diff
					3	3	5	5	10	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
500	TS-K9		1000		5.9	5.9	9.1	11.5	20.0	type B	normal	u_ref
					517	517	1682	3237	3106	ν_eff		
					11.7	11.7	18.2	23.0	40.0	k=2		
					15.0	15.0	20.0	25.0	40.0	Reported unc. k = 2		
	PM5B	200k	1000		4.5	4.5	4.6	7.6	10.1	type B	normal	u_ref
					4	4	7	13	17	type B	rectangular	u_diff
					5	5	6	7	9	type B	rectangular	u_lev
					1	1	1	1	1	type A	normal	u_std
1000	TS-K9		1000		7.9	7.9	10.3	16.6	21.8	type B	normal	u_ref
					1621	1621	2199	2333	2426	ν_eff		
					15.8	15.8	20.7	33.2	43.5	k=2		
					20.0	20.0	25.0	35.0	50.0	Reported unc. k = 2		

The tables below were submitted to the pilot laboratory in the original measurement report from NMi-VSL. However, there was a mistake in the uncertainties for the reference standard for the measurement of TS-K9 at 1000 V. (The total uncertainties and expanded uncertainties were correct in the original table). The table below give the correct values for the uncertainty in the reference standard. (The total uncertainties k = 1 are slightly different from the values above, probably due to rounding errors.)

Travelling standard: TS-K9 at 500 V

Contribution of:	Unc. f: 1 kHz	Unc. f: 10 kHz	Unc. f: 20 kHz	Unc. f: 50 kHz	Unc. f: 100 kHz	Type A or B	Shape
St. dev. of mean	< 1	< 1	< 1	< 1	< 1	A	N
Reference standard	5	5	5	9	11	B	N
Level dependence	3	3	5	5	10	B	R
Measurement set-up	2	2	10	10	20	B	R
Connectors	2	2	4	4	10	B	R
Reproducibility	1	1	1	3	5	B	R

total unc (*k*=1):	5.7	5.7	8.6	11.5	18.2
exp. unc (*k*=2):	11.3	11.3	17.1	23.0	36.4
Reported uncertainty (*k*=2)	15	15	20	25	40

Travelling standard: TS-K9 at 1000 V

Contribution of:	Unc. f: 1 kHz	Unc. f: 10 kHz	Unc. f: 20 kHz	Unc. f: 50 kHz	Unc. f: 100 kHz	Type A or B	Shape
St. dev. of mean	< 1	< 1	< 1	< 1	< 1	A	N
Reference standard	5	5	5	9	11	B	N
Level dependence	8	8	8	12	15	B	R
Measurement set-up	4	4	10	20	25	B	R
Connectors	2	2	4	4	10	B	R
Reproducibility	1	1	1	3	5	B	R

total unc (*k*=1):	7.4	7.4	9.3	16.5	21.4
exp. unc (*k*=2):	14.7	14.7	18.6	33	42.3
Reported uncertainty (*k*=2)	20	20	25	35	50

AC-DC Voltage Transfer Standards at INTI (Argentina)

1. INTORDUCTION

The AC-DC voltage transfer at INTI is based on the scheme shown in Figure 1. At 1,5 V four PTB Thin-film multijunction thermal converters (PMJTCs) [1,2], are the basis of the system. In this step-up procedure the only assumption made is that the ac-dc transfer difference of each standard remains constant along its voltage range, from the reduced voltage at which it is calibrated against the neighbouring standard to its higher rated voltage. At low frequencies, a LF-design is compensated for level independence and fulfils this requirement [3]. At higher voltages and frequencies, this assumption needs a careful analysis. The high sensitivity of the PMJTC allows big steps in the step-up calibration and many steps in-between which leads to an overdetermined system to check the validity of the assumptions used in the step-up and diminishes its uncertainty.

2. AC-DC TRANSFER DIFFERENCES OF THE BASIC SET AT 1,5 V.

The ac-dc transfer differences of each PMJTC of the basic system at 1,5 V are determined in three different ways depending on the frequency range.

2.1 Low frequencies (10 Hz $\leq f \leq$ 100 Hz); U = 1,5 V

At this low frequencies the ac-dc transfer differences for each PMJTC are determined individually using the LF-PMJTC with negligible low frequency ac-dc transfer differences as standard.

2.2 2.2 Medium frequencies (100 Hz $< f \leq$ 20 kHz); U = 1,5 V

At these frequencies the four PMJTC are compared with the scheme shown in Figure 2

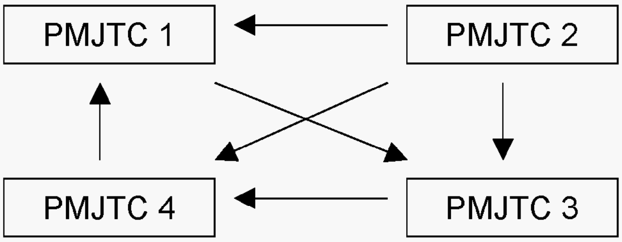


Figure 2 Comparisons at 1,5 V

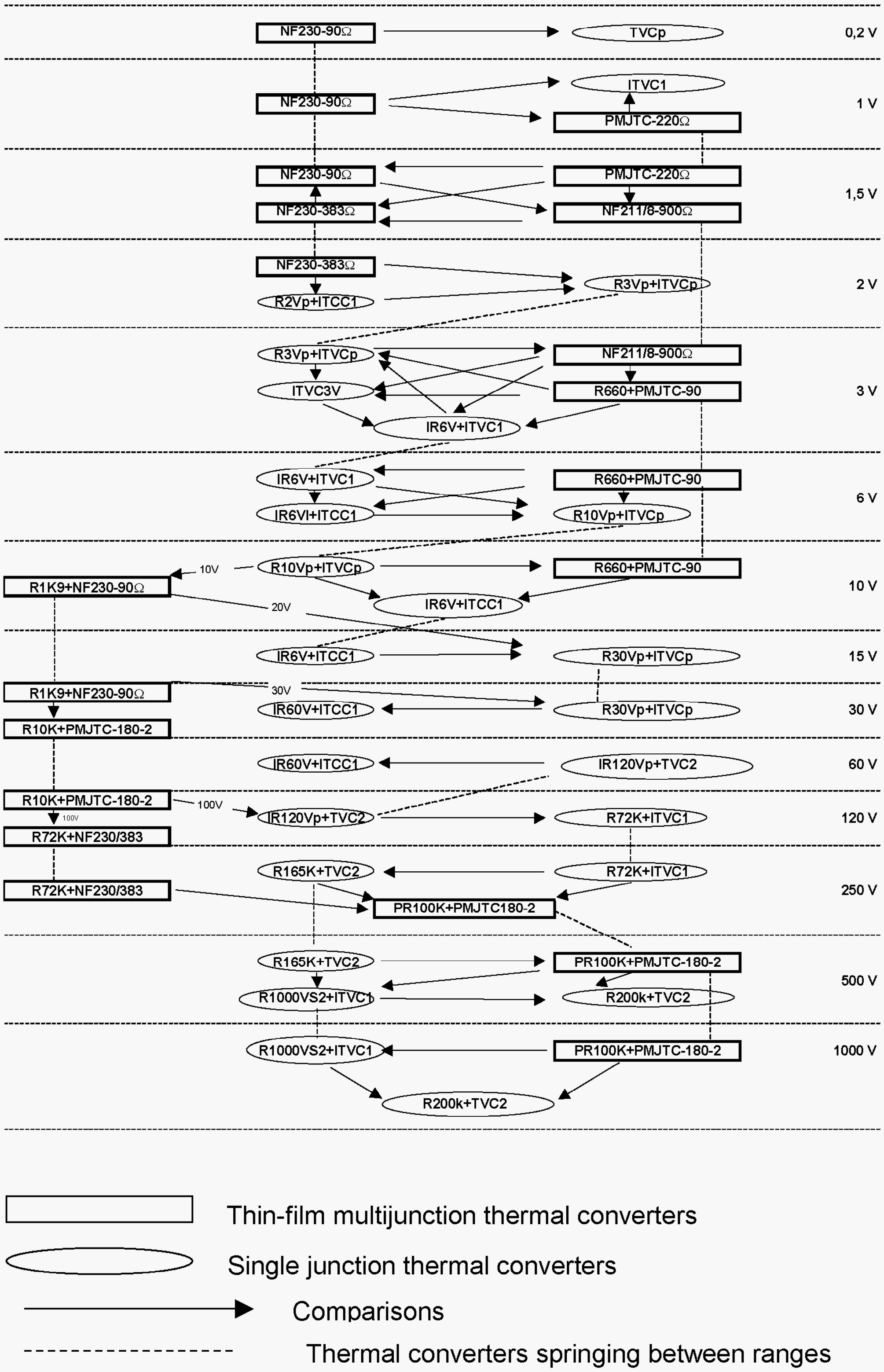


Figure 1. Voltage Step-up

The mean value of the ac-dc transfer difference of the four PMJTC is taken as zero. Hence, the following system of equations results

$$\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & 1 \\ 1 & 0 & 0 & -1 \\ -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix} = \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ 0 \end{bmatrix} \tag{2.1}$$

that is to say

$$[\mathrm{A}] \cdot [\delta] = [\mathrm{B}] \tag{2.2}$$

where *a,b,c,d,e* and *f* are the measured ac-dc transfer differences. The best solution [δ'] is obtained using a modified least squares method. It will be shown that in this method the comparison statistic uncertainty is included in the system. The lack of agreement of the fitting process is also included in the uncertainty calculation.

2.3 High frequencies (20 kHz < *f* ≤ 1 MHz); *U* = 1,5 V

At these frequencies the value assigned in a calibration against the PTB standards is used for each PMJTC. The comparisons shown in Figure 2 are also performed to allow for the uncertainty calculation. Therefore, the system of equations is

$$\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & 1 \\ 1 & 0 & 0 & -1 \\ -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix} = \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ \delta_{1PTB} \\ \delta_{2PTB} \\ \delta_{2PTB} \\ \delta_{3PTB} \end{bmatrix} \tag{2.3}$$

3. STEP-UP PROCESS

3.1 Voltages up to 250 V

At each other voltage level the same idea as at 1,5 V is used. At frequencies below 100 Hz, the thermal converters are calibrated against the improved LF-PMJTC with appropriate range resistors. For higher frequencies a system is built in which the same converters are compared and more than one of them which were calibrated at a lower voltage are taken as reference. Using the least squares method the values for the new converters are assigned. For instance, at 6 V we get (see the comparison scheme in Figure 1).

$$\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & 1 & -1 \\ -1 & 0 & 0 & 1 \\ -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \delta_{IR6V+ITVC1} \\ \delta_{R640+PMJTC-90} \\ \delta_{R10Vp+ITVCp} \\ \delta_{IR6VI+ITCC1} \end{bmatrix} = \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ \delta_{IR6V+ITVC1-LV} \\ \delta_{R640+PMJTC-90-LV} \end{bmatrix} \qquad (3.1)$$

where *a,b,c,d,e,* and *f* are the results of the comparisons and $\delta_{\ldots\text{-LV}}$ are the values obtained for these thermal converters at lower voltages.

3.2 U ≥ 250 V

A planar thin-film resistor of 100 kΩ together with a PMJTC with R_H=180 Ω is used as standard up to 1000 V. It is calibrated at 250 V and no voltage dependence is assumed. A study of the influence of the shield in the voltage dependence was carried out, in order to checkout this hypothesis [4]. Two other standards, R1000Vs2+ITVC1 and R200k+TVC2, are used to calculate the comparisons uncertainty at these voltage levels, according to the method described above.

4. Uncertainty calculations

At each step in the step-up procedure the measured differences δ_d of the ac-dc transfer differences of the unknown δ_x and the known standard δ_s has to be added to the transfer difference of the standard δ_s to get the transfer difference of the unknown δ_x

$$\delta_x = \delta_d + \delta_s \qquad (4.1)$$

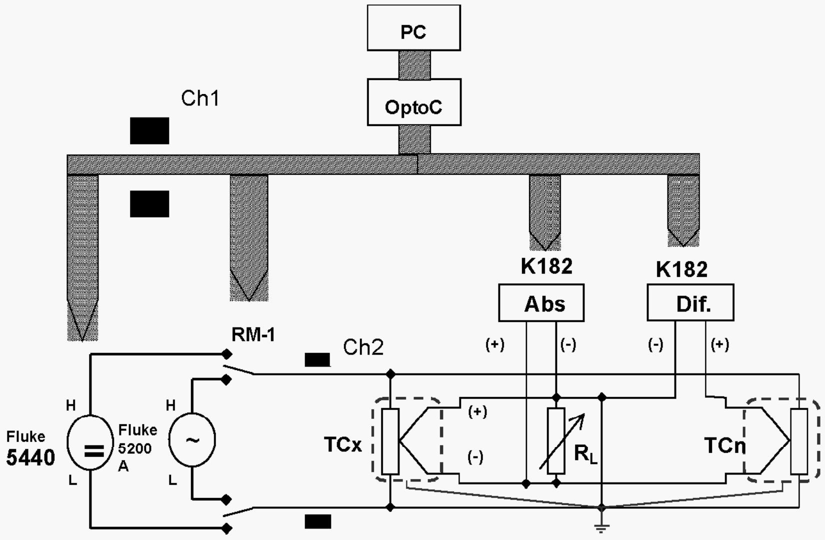
Using the difference method to measure δ_d, the differences of the output voltages of both converters are measured with one nanovoltmeter and, with a second nanovoltmeter the output voltage of the unknown is measured (see Figure 3). δ_d can be evaluated as

$$\delta_d = \frac{1}{n_s \cdot U_{odcx}} \cdot \left(\left(U_{oacs} - U_{oacx} \right) - \left(U_{odcs} - U_{odcx} \right) \right) - C \tag{4.2}$$

n_s is the exponent of the standard, U_{odcx} and U_{oacx} the output voltages of the unknown and U_{odcs} and U_{oacs} the output voltages of the standard with dc and ac input voltages respectively. The correction term C is

$$C = \frac{1}{n_x} \cdot \frac{U_{oacx} - U_{odcx}}{U_{odcx}} \cdot \left(\frac{n_s - n_x}{n_x} + \frac{U_{odcs} - U_{odcx}}{U_{odcx}} + \frac{n_s - n_x}{n_x} \cdot \frac{U_{odcs} - U_{odcx}}{U_{odcx}} \right) \tag{4.3}$$

where n_x is the exponent of the unknown, $\frac{U_{oacx} - U_{odcx}}{U_{odcx}}$ the relative difference between the output voltages of the unknown with dc and ac input (adjusted to <20 μV/V), and $\frac{U_{odcs} - U_{odcx}}{U_{odcx}}$ the relative difference between the output voltages of both converters at dc. This is adjusted to <5 mV/V by an adjustable resistor, which loads the output voltage of that converter which has the larger one.



Fluke 5440B = Fluke 5440B DC calibrator

RM-1 = computer controlled mercury relays

TCx = unknown thermal converter

R_L = loading resistor

K182 = Keithley 182 nanovoltmeter

Fluke 5200 = Fluke 5200 AC calibrator

Ch1, Ch2 = coaxial chokes

TCn = standard thermal converter

TCn = standard thermal converter

OptoC = IOTECH Optocoupler

Figure 3. Schematics of the comparison of two thermal converters

4.1 Uncertainty budget

The standard measurement uncertainty of the ac-dc transfer difference of the unknown $u(\delta_X)$ at each voltage step in the step-up chain needs to be calculated from (4.1) as

$$u^2(\delta_x) = u^2(\delta_s) + u^2(\delta_d) \tag{4.4}$$

At 1,5 V and below 100 Hz, $u(\delta_s)$ is the standard uncertainty of the low frequency PMJTC. Between 100 Hz and 20 kHz the standard uncertainty of the mean for the ac-dc transfer differences in the four converters is taken as zero (see 2.1). Above 20 kHz the standard uncertainty obtained in the PTB calibration is taken for $u(\delta_s)$.

At other voltage levels the standard uncertainty obtained in the previous step for the thermal converter that makes the spring is taken as $u(\delta_s)$.

The standard uncertainty of the measured difference between both converters $u(\delta_d)$ is

$$u^2(\delta_d) = u_A^2(\delta_d) + u_C^2(\delta_d) + u_M^2(\delta_d) \tag{4.5}$$

where

u_A = type A standard uncertainty. It is the standard deviation of the mean calculated from a set of determinations of δ_d,

u_C = standard uncertainty of the comparison according to eq. (4.2),

u_M = standard uncertainty due to the method (scheme) used to determine the transfer difference of the converter.

Calculation of $u_C(\delta_d)$. We can rewrite eq.(4.2) as

$$\delta_d = \frac{1}{n_s \cdot U_{odcx}} \cdot \left(Udif_{ac} - Udif_{dc} \right) - C \tag{4.6}$$

where $Udif_{ac}$ and $Udif_{dc}$ are the voltages measured by the difference nanovoltmeter with ac and dc input voltages resp. The combined uncertainty is

$$\begin{aligned} u_c^2(\delta_d) = {} & \left(\frac{\partial\delta_d}{\partial n_s}\right)^2 \cdot u^2(n_s) + \left(\frac{\partial\delta_d}{\partial U_{odcx}}\right)^2 \cdot u^2(U_{odcx}) + \left(\frac{\partial\delta_d}{\partial Udif_{ac}}\right)^2 \cdot u^2(Udif_{ac}) + \\ & + \left(\frac{\partial\delta_d}{\partial Udif_{dc}}\right)^2 \cdot u^2(Udif_{dc}) + 2 \cdot \left(\frac{\partial\delta_d}{\partial Udif_{ac}}\right) \cdot \left(\frac{\partial\delta_d}{\partial Udif_{dc}}\right) \cdot u(Udif_{ac}) \cdot u(Udif_{dc}) \cdot \\ & \cdot r(Udif_{ac}, Udif_{dc}) + \left(\frac{\partial\delta_d}{\partial C}\right)^2 \cdot u^2(C) \end{aligned} \tag{4.7}$$

As $Udif_{\mathrm{ac}}$ and $Udif_{\mathrm{dc}}$ are measured with the same instrument within a few minutes they are correlated with $r(Udif_{\mathrm{ac}}, Udif_{\mathrm{dc}}) = 1$. Therefore, the sum of the third, fourth and fifth term in (4.7) equals

$$\left(\frac{1}{n_{\mathrm{s}} \cdot U_{\mathrm{odcx}}}\right)^2 \cdot \left(u(Udif_{\mathrm{ac}}) - u(Udif_{\mathrm{dc}})\right)^2 \tag{4.8}$$

The measuring sequence is ac_1, dc_+, ac_2, dc_-, ac_3, with 60 s waiting time after switching. Hence, the mean

$$\overline{Udif_{ac}} = \frac{1}{3} \cdot \left(Udif_{ac1} + Udif_{ac2} + Udif_{ac3}\right) \tag{4.9}$$

corresponds to the time when ac_2 is measured ($t = t_2$). For the same moment we calculate the mean

$$\overline{Udif_{dc}} = \frac{1}{2} \cdot \left(Udif_{dc+} + Udif_{dc-}\right) \tag{4.10}$$

Therefore, this sequence corrects for a linear drift of the output voltage. Moreover, if the drift differs slightly from the linear approach, we can assume that this uncertainty contribution is the same at ac and dc and they cancel each other in (4.8). Thus,

$$u\left(\overline{Udif_{dc}}\right) \cong u\left(Udif_{dc}\right) \text{ and } u\left(\overline{Udif_{ac}}\right) \cong u\left(Udif_{ac}\right) \tag{4.11}$$

For C the expectation is taken as zero. A measurement is taken as a good one, if: a) the relative difference between the output voltages at ac and dc of the unknown remains <20 µV/V, b) the relative difference between the output voltages of both converters remains <5 mV/V due to the adjustment with the load resistor. If, moreover, the exponents of both converters agree within 0.01, then C will be <0.15 µV/V. This value is taken into the uncertainty budget with a rectangular distribution, i.e. $u(C) \cong 0.1$ µV/V. Therefore, we get from (4.7)

$$u_{\mathrm{c}}^2(\delta_{\mathrm{d}}) = \left(\frac{Udif_{\mathrm{ac}} - Udif_{\mathrm{dc}}}{U_{\mathrm{odcx}} \cdot n_{\mathrm{s}}^2}\right)^2 \cdot u^2(n_{\mathrm{s}}) + \left(\frac{Udif_{\mathrm{ac}} - Udif_{\mathrm{dc}}}{n_{\mathrm{s}} \cdot U_{\mathrm{odcx}}^2}\right)^2 \cdot u^2(U_{\mathrm{odcx}}) + \left(\frac{1}{n_{\mathrm{s}} \cdot U_{\mathrm{odcx}}}\right)^2 \cdot \left(u(Udif_{\mathrm{ac}}) - u(Udif_{\mathrm{dc}})\right)^2 + u^2(C) \tag{4.12}$$

$u(n_{\mathrm{s}})$ is the uncertainty of the exponent of the standard, which is $5 \cdot 10^{-3}$ if only PMJTCs are used. $u(U_{\mathrm{odcx}})$ is the uncertainty in the measurement of the absolute voltage of the unknown, $(u(Udif_{\mathrm{ac}})-u(Udif_{\mathrm{dc}}))$ corresponds to the uncertainty of the linearity in the nanovoltmeter that measures the difference and, $u(C)$ is the standard uncertainty of the correction term C.

Calculation of u_M. A rigorous evaluation of the standard uncertainty of the transfer difference of the unknown is possible if the behaviour of the standards in the step-up chain is considered and comparison schemes are arranged as described. For instance, if TVCs are compared with the scheme shown in Figure 2, standards in the step-up chain for higher voltages are compared at different voltage levels against each other. These measurements include the level dependence of the PMJTCs and of the resistors but also the uncertainty due to the voltage sources at different voltage levels and the comparison circuit. For instance, at 6 V:

$$\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & 1 & -1 \\ -1 & 0 & 0 & 1 \\ -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \delta_{IR6V+ITVC1} \\ \delta_{R660+PMJTC-90} \\ \delta_{R10Vp+ITVCp} \\ \delta_{IR6VI+ITCC1} \end{bmatrix} = \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ \delta_{IR6V+ITVC1-LV} \\ \delta_{R660+PMJTC-90-LV} \end{bmatrix}$$

$$[\mathbf{A}]\cdot[\delta]=[\mathbf{B}] \tag{4.13}$$

If we take IR6V+ITVC1 and R660+PMJC-90 as the known standards and built-up against them, the above system of equations results, where *a,b,c,d,e* and *f* are the measured ac-dc transfer differences (using eq. 1.2), and $\delta_{\mathrm{IR6V+ITVC1\text{-}LV}}$ and $\delta_{\mathrm{R660+PMJTC\text{-}90\text{-}LV}}$ are the known ac-dc transfer differences determined in the previous step. The best solution of eq. (4.13) is obtained using the least squares method. The solution is the vector δ′ that minimizes

$$\xi=(\mathbf{A}\cdot\delta'-\mathbf{B})^{t}\cdot(\mathbf{A}\cdot\delta'-\mathbf{B})=\min \tag{4.14}$$

This leads to

$$\delta'=(\mathbf{A}^{t}\cdot\mathbf{A})^{-1}\cdot\mathbf{A}^{t}\cdot\mathbf{B}=\mathbf{C}\cdot\mathbf{B} \tag{4.15}$$

The standard uncertainty associated to the measurement process $u_{\mathrm{M}}(\delta_{\mathrm{d}})$ can be calculated as

$$u_{\mathrm{M}}(\delta_{\mathrm{d}})=\sqrt{\frac{(\mathbf{A}\cdot\delta'-\mathbf{B})^{t}\cdot(\mathbf{A}\cdot\delta'-\mathbf{B})}{\nu}} \tag{4.19}$$

where ν is the degree of freedom associated with the process, i.e. 4 in our example.

In order to calculate the standard uncertainty of δ' we need to calculate its covariance matrix, that is regarding eq. (3.16):

$$cov(\delta') = \mathbf{C} \cdot cov(\mathbf{B}) \cdot \mathbf{C}^t \qquad (4.17)$$

***cov* (B)** is the covariance matrix of **B**. Its diagonal terms are the variances of *a,b,c,d* and *f*, calculated using eqs. (4.5), (4.12) and (4.16), and the square of the standard uncertainty of $\delta_{IR6V+ITVC1\text{-}LV}$ and $\delta_{R660+PMJTC\text{-}90\text{-}LV}$ calculated in the previous step or, for the basic set, calculated with eq. (4.5). If more than one known standard is used in the scheme, special attention should be paid to the correlation between them because they come from previous steps in the built-up process and all relate to the basic standard at 1,5 V. Also the voltage or current level dependence of the resistors can be correlated. If no correlation exists, ***cov*(B)** is a diagonal matrix, but due to the process, ***cov*(δ')** will not be a diagonal matrix and the uncertainties of the unknowns will be correlated.

Thus, if a scheme as the one described here is used, the combined standard uncertainty of the unknown δ_{x_i} can be calculated as

$$u(\delta_{x_i}) = \sqrt{cov(\delta'(i,i))} \qquad (4.18)$$

where *cov*(δ'(*i,i*)) is the i diagonal term of ***cov*(δ').** The terms of ***cov*(δ')** out of the diagonal are the covariances between the transfer differences of the unknowns due to the correlation that comes out of the process.

5. RESULTS

Table 1 shows the ac-dc voltage transfer difference of the basic and working standards determined with the described procedure. Table 2 depicts their standard uncertainties.

REFERENCES

[1] M. Klonz, T. Weimann, 1989, "Accurate thin film multijunction thermal converter on a Silicon chip," IEEE Trans. Instrum. Meas., vol. 38, pp.335-337.

[2] M. Klonz, T. Weimann, 1991,"Increasing the Time-Constant of a Thin Film Multijunction Thermal Converter for Low Frequency Application," IEEE Trans. Instrum. Meas., vol. 40, No.2.

[3] H. Laiz , 1999, "Low Frequency Behaviour of Thin-Film Multijunction Thermal," Thesis TU Braunschweig, PTB-Bericht-E-63.

[4] M. Klonz, T. Spiegel, H. Laiz, E. Kessler, 1999, "A 1000-V Resistor for AC-DC transfer," IEEE Trans. Instrum. Meas., vol. 48, No.2..

TABLE 1: AC-DC voltage transfer differences of the basic and working standards

Voltage	Standard	Frequency in kHz														
		0.01	0.02	0.03	0.04	0.5	1	10	20	50	70	100	200	500	700	1000
0.2	PMJTC-90ohm	0.4	-0.5	-0.2	0	-0.1	0.5	0.2	-2.5	-4	-5	-9	-12	0	10	32
1.5	230-90ohm	13.2	4.4	1.2	0.3	0.1	0.1	0.6	1.1	5.6	9	10	13	30	40	57
	PMJTC-180ohm	4.3	1	0.5	0	0.1	0.1	0.1	0.2	2.6	4	3.4	1.6	2.5	2	4
	230-383ohm	4.3	1.8	1.1	0.8	0.1	0.1	0	-0.4	0.8	1	0	-4	-17	-30	-51
	211/8-900ohm	5	2.6	2	1	-0.3	-0.3	-0.7	-0.6	-0.7	-2	-4.5	-12	-47	-81	-144
3	211/8-900ohm	13.1	6	3.2	1	-0.3	-0.3	-0.7	-0.6	-0.7	-2	-4.5	-12	-47	-81	-144
	R3Vp+ITVCp	10.1	4.4	3.4	2.2	0.2	0.3	1.1	2	6.5	8.7	10.8	16.7	28	32	45
	ITVC3V	26	8	3	1.4	0.4	-0.1	-0.5	0	1	0	-1	-3	-4	-2	-6
	IR6V+ITVC1	7.1	9	0.7	1	0.6	0.3	2.8	4.4	11.2	14.5	20	38	110	183	304
	R660+PMJTC-90ohm	1.5	0	0	1	-0.4	-0.4	0.5	3.8	15.2	21.1	24.9	41	84	110	162
6	IR6V+ITVC1	-4	0	-2	1	0.6	0.3	2.8	4.4	11.2	14.5	20	38	110	183	304
	R660+PMJTC-90ohm	2.3	1.2	-0.2	0	-0.4	-0.4	0.5	3.8	15.2	21.1	24.9	41	84	110	162
	IR6VI+ITCC1	5.2	2.3	2	1.6	2.3	2.2	4.6	4.6	8	8	8	9	9	16	15
	R10Vp+TVCp	3	1.2	0.2	0.2	-0.3	-0.2	0.4	1.8	2.4	3.8	0	2	4	3	7
10	R660+PMJTC-90ohm	4.2	1.4	0.6	0	-0.4	-0.4	0.5	3.8	15.2	21.1	24.9	41	84	110	162
	R10Vp+TVCp	9	2.4	1	0.2	-0.3	-0.2	0.4	1.8	2.4	3.8	0	2	4	3	7
	IR6V+ITCC1	1.2	1.4	1	1	1.5	1.4	2	4	5	3	-1	-4.6	-12	-28	-34
	R1k9+230-90ohm	2	0	-0.6	-1	-0.8	-1	-0.6	1	2.5	3	3	6	15	29	62
20	R1k9+230-90ohm	9	3	1.7	0.4	-0.8	-1	-0.6	1	2.5	3	3	6	15	29	62
	R10k+180-2	0	0	0	0	-1	-1	0	1	1	1	-2				
30	R30Vp+TVCp	2	1	1	1	0	0	0.5	2	2	1	-3				
60	IR60V+ITVC1	9	5	5	1	0	-1	-1	3	0	3	2				
100	R10k+180-2	12	3	2	0	-1	-1	0	1	1	1	-2				
120	IR120V+TVC2	-10	-4	-2	-2	1	1	0	3	2	-5	-20				
300	R72k+ITVC1	1.5	1	0	1	1	0	0	7	23	30	52				
	R72k+230-383	6	4	3	3	-1	0	1	4	13	22	40				
	PR100k+180-2	1	1	0	0.5	-1	2	3	2	-8	-18	-38				
500	R1000Vs2+ITVC1	-2	-3	-4	-3	-8	-9	-15	-11	-11	-8	-5				
	R200k+TVC2	9	5	3	4	-1	1	-1	12	65	120	240				
	PR100k+180-2	3	2	0	0.5	-1	2	3	2	-8	-18	-38				
700	PR100k+180-2	6	2	2	1	-1	2	3	2	-8	-18	-38				
1000	R1000Vs2+ITVC1	15	0	-4	-3	-8	-12	-24	-22	-32	-24	-40				
	R200k+TVC2	43	12	7	6	-1	0	2	10	66	122	245				
	PR100k+180-2	13	3.5	2.5	1	-1	2	3	2	-8	-18	-38				

PMTCs	▨

TABLE 2: Standard uncertainties of the AC-DC voltage transfer differences of the basic and working standards

Voltage in V	Standard	Frequency in kHz														
		0.01	0.02	0.03	0.04	0.5	1	10	20	50	70	100	200	500	700	1000
0.2	PMJTC-90ohm	2	2	2	2	2	2	2	2	4	6	7	9	13	16	20
1.5	230-90ohm	2	2	1.5	1	0.5	0.5	0.5	1	1	2	3	5	7	11	15
	PMJTC-180ohm	2	2	1.5	1	0.5	0.5	0.5	1	1	2	3	5	7	11	15
	230-383ohm	2	2	1.5	1	0.5	0.5	0.5	1	1	2	3	5	7	11	15
	211/8-900ohm	2	2	1.5	1	0.5	0.5	0.5	1	1	2	3	5	7	11	15
3	211/8-900ohm	2	2	1.5	1	0.6	0.6	1	1.2	2.5	3	5	7	11	12	15
	R3Vp+ITVCp	3	2	2	1	1	1	1	2	3	3	5	7	11	12	15
	ITVC3V	3	2	2	1.5	1	1	1	2	3	3	5	7	11	12	15
	IR6V+ITVC1	3	2	2	2	1.5	1.5	1.5	2	3	4	6	8	13	15	20
	R660+PMJTC-90ohm	1.5	1.5	1.5	1	0.6	0.6	1	1.2	2.5	3	5	7	11	12	15
6	IR6V+ITVC1	4	2	2	1	1	1	2	2	3	5	7	10	15	17	20
	R660+PMJTC-90ohm	1.5	1.5	1.5	1	1	1	1.5	1.5	3	5	6	8	12	15	17
	IR6VI+ITCC1	4	2	2	1	1	1	2	2	3	5	7	10	15	17	20
	R10Vp+TVCp	3	2	1.5	1	1	1	1.5	1.5	3	5	6	8	12	15	17
10	R660+PMJTC-90ohm	1.5	1.5	1.5	1.5	1.5	1.5	2	2	4	6	7	8	13	16	19
	R10Vp+TVCp	3	2.5	2	1.5	1.5	1.5	2	2	4	6	7	8	13	16	19
	IR6V+ITCC1	4	3	2	2	2	2	2	2	4	6	8	10	15	17	20
	R1k9+230-90ohm	3	2.5	2	1.5	1.5	1.5	2	2	4	6	7	8	13	16	19
20	R1k9+230-90ohm	4	3	3	2	2	2	3	3	5	7	8	9	14	18	22
	R10k+180-2	4	3	3	2	2	2	3	3	5	7	8				
30	R30Vp+TVCp	4	3	3	2	2	2	3	3	5	7	8				
60	IR60V+ITVC1	8	5	4	3	3	3	4	4	6	8	9				
100	R10k+180-2	6	5	4	4	4	4	5	5	7	9	10				
120	IR120V+TVC2	10	6	5	4	4	4	5	5	7	9	10				
300	R72k+ITVC1	12	7	6	5	5	5	5	6	8	10	12				
	R72k+230-383	7	6	6	5	5	5	5	6	8	10	12				
	PR100k+180-2	7	6	6	5	5	5	5	6	8	10	12				
500	R1000Vs2+ITVC1	13	7	6	6	6	6	8	8	8	12	15				
	R200k+TVC2	13	7	6	6	6	6	8	8	8	12	15				
	PR100k+180-2	8	7	6	6	6	6	6	7	9	11	14				
700	PR100k+180-2	9	8	7	6	6	6	7	8	10	12	16				
1000	R1000Vs2+ITVC1	13	8	7	7	7	7	10	12	17	20	25				
	R200k+TVC2	13	8	7	7	7	7	10	12	17	20	25				
	PR100k+180-2	10	8	7	7	7	7	8	10	12	15	20				

PMTCs	▨

CCEM-K9 Key International Comparison of AC-DC Transfer Standards at High Voltages

Detailed Uncertainty Budget of the National Measurement Institute of Australia (NMIA)

1. Uncertainty of NMIA Reference Standards

Table 1

Influence Quantity	*u*	Standard Measurement Uncertainties in μV/V				
		1 kHz	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
6 V						
Reference Uncertainty (4V)	$u(\delta_{REF})$	1.00	1.24	1.33	2.18	2.85
Random Uncertainty	$u(\delta_{RND})$	0.04	0.11	0.08	0.28	0.37
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.57	0.57	0.57	0.57	0.71
Measurement Setup	$u(\delta_{d})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at 6 V		**1.36**	**1.57**	**1.65**	**2.44**	**3.35**
10 V						
Reference Uncertainty	$u(\delta_{REF})$	1.36	1.57	1.65	2.44	3.35
Random Uncertainty (1)	$u(\delta_{RND1})$	0.13	0.18	0.16	0.12	0.27
Random Uncertainty (2)	$u(\delta_{RND2})$	0.30	0.30	0.30	0.30	0.30
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.57	0.57	0.57	0.57	0.71
Measurement Setup	$u(\delta_{d})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at 10 V		**1.67**	**1.86**	**1.94**	**2.69**	**3.80**
12 V						
Reference Uncertainty	$u(\delta_{REF})$	1.67	1.86	1.94	2.69	3.80
Random Uncertainty	$u(\delta_{RND})$	0.11	0.22	0.07	0.09	0.29
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.57	0.57	0.57	0.57	0.71
Measurement Setup	$u(\delta_{d})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at 12 V		**1.91**	**2.10**	**2.17**	**2.89**	**4.18**
20 V						
Reference Uncertainty	$u(\delta_{REF})$	1.91	2.10	2.17	2.89	4.18
Random Uncertainty (1)	$u(\delta_{RND1})$	0.11	0.11	0.09	0.16	0.23
Random Uncertainty (2)	$u(\delta_{RND2})$	0.10	0.10	0.10	0.10	0.10
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.57	0.57	0.57	0.57	0.71
Measurement Setup	$u(\delta_{d})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at 20 V		**2.12**	**2.31**	**2.38**	**3.09**	**4.53**

Table 1 (continued)

Influence Quantity	***u***	**Standard Measurement Uncertainties in µV/V**				
		1 kHz	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
30 V						
Reference Uncertainty	$u(\delta_{REF})$	2.12	2.31	2.38	3.09	4.53
Random Uncertainty (1)	$u(\delta_{RND1})$	0.34	0.16	0.12	0.21	0.55
Random Uncertainty (2)	$u(\delta_{RND2})$	0.40	0.40	0.40	0.40	0.40
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.57	0.57	0.57	0.57	0.71
Measurement Setup	$u(\delta_{d})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at 30 V		**2.37**	**2.54**	**2.61**	**3.30**	**4.90**
40 V						
Reference Uncertainty	$u(\delta_{REF})$	2.37	2.54	2.61	3.30	4.90
Random Uncertainty	$u(\delta_{RND})$	0.11	0.17	0.19	0.18	0.15
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.85	0.85	0.85	1.41	2.12
Measurement Setup	$u(\delta_{d})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at 40 V		**2.62**	**2.78**	**2.86**	**3.71**	**5.57**
60 V						
Reference Uncertainty	$u(\delta_{REF})$	2.62	2.78	2.86	3.71	5.57
Random Uncertainty (1)	$u(\delta_{RND1})$	0.11	0.17	0.19	0.46	0.45
Random Uncertainty (2)	$u(\delta_{RND2})$	0.10	0.10	0.10	0.10	0.10
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.85	0.85	0.85	1.41	2.12
Measurement Setup	$u(\delta_{d})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at 60 V		**2.85**	**3.02**	**3.09**	**4.10**	**6.18**
100 V						
Reference Uncertainty	$u(\delta_{REF})$	2.85	3.02	3.09	4.10	6.18
Random Uncertainty (1)	$u(\delta_{RND1})$	0.11	0.09	0.07	0.13	0.11
Random Uncertainty (2)	$u(\delta_{RND2})$	0.40	0.40	0.40	0.40	0.40
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.85	0.85	0.85	1.41	2.12
Measurement Setup	$u(\delta_{d})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at 100 V		**3.09**	**3.25**	**3.33**	**4.45**	**6.74**

Table 1 (continued)

Influence Quantity	***u***	**Standard Measurement Uncertainties in μV/V**				
		1 kHz	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
120 V						
Reference Uncertainty	$u(\delta_{\mathrm{REF}})$	3.09	3.25	3.33	4.45	6.74
Random Uncertainty	$u(\delta_{\mathrm{RND}})$	0.35	0.20	0.45	0.30	0.20
Connectors	$u(\delta_{\mathrm{conn}})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{\mathrm{VC}})$	0.85	0.85	0.85	1.41	2.12
Measurement Setup	$u(\delta_{\mathrm{d}})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at	**120 V**	**3.30**	**3.45**	**3.55**	**4.76**	**7.24**
200 V						
Reference Uncertainty	$u(\delta_{\mathrm{REF}})$	3.30	3.45	3.55	4.76	7.24
Random Uncertainty (1)	$u(\delta_{\mathrm{RND1}})$	0.25	0.05	0.05	0.16	0.21
Random Uncertainty (2)	$u(\delta_{\mathrm{RND2}})$	0.10	0.10	0.10	0.10	0.10
Connectors	$u(\delta_{\mathrm{conn}})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{\mathrm{VC}})$	0.85	0.85	0.85	1.41	2.12
Measurement Setup	$u(\delta_{\mathrm{d}})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at	**200 V**	**3.49**	**3.64**	**3.74**	**5.05**	**7.71**
300 V						
Reference Uncertainty	$u(\delta_{\mathrm{REF}})$	3.49	3.64	3.74	5.05	7.71
Random Uncertainty (1)	$u(\delta_{\mathrm{RND1}})$	0.30	0.20	0.25	0.10	0.15
Random Uncertainty (2)	$u(\delta_{\mathrm{RND2}})$	0.50	0.50	0.50	0.50	0.50
Connectors	$u(\delta_{\mathrm{conn}})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{\mathrm{VC}})$	0.85	0.85	0.85	1.41	2.12
Measurement Setup	$u(\delta_{\mathrm{d}})$	0.71	0.71	0.71	0.71	1.41
Standard Uncertainty at	**300 V**	**3.71**	**3.85**	**3.96**	**5.35**	**8.17**
400 V						
Reference Uncertainty	$u(\delta_{\mathrm{REF}})$	3.71	3.85	3.96	5.35	8.17
Random Uncertainty	$u(\delta_{\mathrm{RND}})$	0.05	0.50	0.15	0.10	0.10
Connectors	$u(\delta_{\mathrm{conn}})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{\mathrm{VC}})$	0.85	0.85	1.41	2.83	4.24
Measurement Setup	$u(\delta_{\mathrm{d}})$	1.41	1.41	1.41	2.12	2.83
Standard Uncertainty at	**400 V**	**4.07**	**4.23**	**4.45**	**6.44**	**9.66**

Table 1 (continued)

Influence Quantity	u	**Standard Measurement Uncertainties in μV/V**				
		1 kHz	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
500 V						
Reference Uncertainty	$u(\delta_{REF})$	4.07	4.23	4.45	6.44	9.66
Random Uncertainty (1)	$u(\delta_{RND1})$	0.05	0.45	0.20	0.35	0.75
Random Uncertainty (2)	$u(\delta_{RND2})$	0.10	0.10	0.10	0.10	0.10
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.85	0.85	1.41	2.83	4.24
Measurement Setup	$u(\delta_{d})$	1.41	1.41	1.41	2.12	2.83
Standard Uncertainty at	**500 V**	**4.39**	**4.57**	**4.90**	**7.38**	**10.97**
600 V						
Reference Uncertainty	$u(\delta_{REF})$	4.39	4.57	4.90	7.38	10.97
Random Uncertainty	$u(\delta_{RND})$	0.25	0.20	0.25	0.15	0.10
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.85	2.12	2.83	4.95	7.07
Measurement Setup	$u(\delta_{d})$	1.41	1.41	1.41	2.12	2.83
Standard Uncertainty at	**600 V**	**4.70**	**5.24**	**5.84**	**9.15**	**13.37**
800 V						
Reference Uncertainty	$u(\delta_{REF})$	4.70	5.24	5.84	9.15	13.37
Random Uncertainty	$u(\delta_{RND})$	0.10	0.10	0.20	0.25	0.07
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	0.85	2.12	2.83	4.95	7.07
Measurement Setup	$u(\delta_{d})$	1.41	1.41	1.41	2.12	2.83
Standard Uncertainty at	**800 V**	**4.98**	**5.84**	**6.66**	**10.64**	**15.41**
1000 V						
Reference Uncertainty	$u(\delta_{REF})$	4.98	5.84	6.66	10.64	15.41
Random Uncertainty	$u(\delta_{RND})$	0.20	0.05	0.10	0.70	0.55
Connectors	$u(\delta_{conn})$	0.14	0.28	0.35	0.57	0.71
Voltage Coefficient	$u(\delta_{VC})$	1.41	3.54	4.24	8.49	11.31
Measurement Setup	$u(\delta_{d})$	1.41	1.41	1.41	2.83	5.66
Standard Uncertainty at	**1000 V**	**5.38**	**6.98**	**8.03**	**13.93**	**19.95**

2. Uncertainty of CCEM-K9 Measurements

Table 2

Influence Quantity	u	Standard Measurement Uncertainties in μV/V				
		1 kHz	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
200 V						
Reference Uncertainty	$u(\delta_{REF})$	3.5	3.6	3.7	5.1	7.7
Random Uncertainty	$u(\delta_{RND})$	0.1	0.1	0.1	0.1	0.1
IUT Drift	$u(\delta_{IUT})$	0.6	0.6	1.2	1.7	4.6
Temperature/Humidity	$u(\delta_{T\text{-}RH})$	0.2	0.2	0.2	0.3	0.3
Measurement Setup	$u(\delta_{d})$	0.2	0.2	0.2	0.3	0.3
Standard Uncertainty at 200 V		**3.6**	**3.7**	**3.9**	**5.4**	**9.0**
95% Uncertainty at 200 V		**7**	**7**	**8**	**11**	**18**
500 V						
Reference Uncertainty	$u(\delta_{REF})$	4.4	4.6	4.9	7.4	11.0
Random Uncertainty	$u(\delta_{RND})$	0.1	0.1	0.1	0.1	0.1
IUT Drift	$u(\delta_{IUT})$	0.6	0.6	1.2	1.2	3.5
Temperature/Humidity	$u(\delta_{T\text{-}RH})$	0.2	0.2	0.2	0.5	0.7
Measurement Setup	$u(\delta_{d})$	0.2	0.2	0.2	0.3	0.3
Standard Uncertainty at 500 V		**4.4**	**4.6**	**5.0**	**7.5**	**11.5**
95% Uncertainty at 500 V		**9**	**9**	**10**	**15**	**23**
1000 V						
Reference Uncertainty	$u(\delta_{REF})$	5.4	7.0	8.0	13.9	20.0
Random Uncertainty	$u(\delta_{RND})$	0.1	0.1	0.1	0.1	0.1
IUT Drift	$u(\delta_{IUT})$	0.6	0.6	1.2	1.2	3.5
Temperature/Humidity	$u(\delta_{T\text{-}RH})$	0.2	0.3	0.5	1.5	2.5
Measurement Setup	$u(\delta_{d})$	0.2	0.2	0.2	0.3	0.5
Standard Uncertainty at 1000 V		**5.4**	**7.0**	**8.1**	**14.1**	**20.4**
95% Uncertainty at 1000 V		**11**	**14**	**16**	**28**	**41**

Ilya Budovsky
27 August 2004

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National Research Council Canada
Institute for the National Measurement Standards

Comparison CCEM K-9
High Voltage AC-DC Transfer Difference
Detailed Uncertainty Budget of the 1 V to 1000 V Step-Up Procedure

Level/Standard Influence Quantity	u	Type	Standard measurement uncertainty in parts of 10^6 Frequency				
			1 kHz	10 kHz	20 kHz	50 kHz	100 kHz
1 V level							
MJTC/CTVC NRC primary standard	$u(\delta_{PS})$	A+B	0.3	0.6	0.6	0.6	1.1
4 V level							
1 V MJTC primary std.	$u(\delta_S)$	A+B	0.3	0.6	0.6	0.6	1.1
standard deviation	$u(\delta_A)$	B	0.2	0.2	0.2	0.2	0.3
ac-dc comparator	$u(\delta_B)$	A	0.8	0.8	0.8	0.8	2.8
standard uncertainty 4 V		A+B	**0.9**	**1.0**	**1.0**	**1.0**	**3.0**
8 V level							
4 V MJTC working std.	$u(\delta_S)$	A+B	0.9	1.0	1.0	1.0	3.0
standard deviation	$u(\delta_A)$	A	0.1	0.1	0.1	0.1	0.1
ac-dc comparator	$u(\delta_B)$	B	0.8	0.8	0.8	0.8	0.9
standard uncertainty 8 V		A+B	**1.3**	**1.3**	**1.3**	**1.3**	**3.1**
16 V level							
8 V MJTC working std.	$u(\delta_S)$	A+B	1.3	1.3	1.3	1.3	3.1
standard deviation	$u(\delta_A)$	A	0.1	0.1	0.1	0.1	0.2
ac-dc comparator	$u(\delta_B)$	B	0.8	0.8	0.9	0.9	0.9
TVC level dependence	$u(\delta_I)$	B	0.6	0.6	0.6	0.6	0.6
standard uncertainty 16 V		A+B	**1.6**	**1.6**	**1.6**	**1.7**	**3.3**
20 V level							
16 V SJTC working std.	$u(\delta_S)$	A+B	1.6	1.6	1.6	1.7	3.3
standard deviation	$u(\delta_A)$	A	0.3	0.3	0.3	0.3	0.3
ac-dc comparator	$u(\delta_B)$	B	1.5	1.5	1.7	1.7	2.1
TVC level dependence	$u(\delta_I)$	B	0.8	0.8	0.8	0.8	0.8
standard uncertainty 20 V		A+B	**2.4**	**2.4**	**2.5**	**2.6**	**4.0**

50 V level							
20 V SJTC working std.	u(δ_S)	A+B	2.4	2.4	2.5	2.6	4.0
standard deviation	u(δ_A)	A	0.3	0.3	0.3	0.3	0.3
ac-dc comparator	u(δ_B)	B	0.8	0.8	0.8	1.3	3.8
TVC level dependence	u(δ_I)	B	1.2	1.2	1.2	1.2	1.2
standard uncertainty 50 V		A+B	**2.8**	**2.8**	**2.9**	**3.1**	**5.6**
100 V level							
50 V SJTC working std.	u(δ_S)	A+B	2.8	2.8	2.9	3.1	5.6
standard deviation	u(δ_A)	A	0.3	0.3	0.3	0.3	0.4
ac-dc comparator	u(δ_B)	B	1.3	1.4	1.4	1.5	4.9
TVC level dependence	u(δ_I)	B	1.5	1.5	1.5	1.5	1.5
standard uncertainty 100 V		A+B	**3.1**	**3.2**	**3.3**	**3.4**	**6.6**
200 V level							
100 V SJTC working std.	u(δ_S)	A+B	3.1	3.2	3.3	3.4	6.6
standard deviation	u(δ_A)	A	0.3	0.3	0.3	0.3	0.3
ac-dc comparator	u(δ_B)	B	0.9	0.9	0.9	0.9	3.6
TVC level dependence	u(δ_I)	B	1.0	1.0	1.0	1.0	1.0
standard uncertainty 200 V		A+B	**3.4**	**3.5**	**3.5**	**3.7**	**7.6**
HV working std. at 200 V							
200 V LV working std.	u(δ_S)	A+B	3.4	3.5	3.5	3.7	7.6
standard deviation	u(δ_A)	A	1.2	0.7	0.6	0.8	1.0
comparison linearity	u(δ_B)	B	0.9	0.9	0.9	1.5	3.5
station difference	u($\delta_{station}$)	B	1.2	1.2	1.7	2.3	2.6
standard uncertainty 200 V		A+B	**3.9**	**3.8**	**4.0**	**4.7**	**8.8**
HV working std. at 350 V							
200 V HV working std.	u(δ_S)	A+B	3.9	3.8	4.0	4.7	8.8
standard deviation	u(δ_A)	A	0.2	0.4	0.2	0.1	0.1
ac-dc comparator	u(δ_B)	B	0.8	0.9	0.9	1.2	1.8
TVC level dependence	u(δ_I)	B	0.6	0.6	0.6	0.6	0.6
standard uncertainty 350 V		A+B	**4.0**	**4.0**	**4.2**	**4.9**	**9.0**
Travelling Standard 92 PTB/IPHT MJTC 1997 + Fluke resistor S/N 034							
200 V							
200 V HV working std.	u(δ_S)	A+B	3.4	3.5	3.5	3.7	7.6
standard deviation	u(δ_A)	A	0.1	0.1	0.1	0.1	0.1
ac-dc comparator	u(δ_B)	B	0.9	0.9	0.9	1.0	2.4
station difference	u($\delta_{station}$)	B	1.2	1.2	1.8	2.3	2.6
lack of closure	u($\delta_{closure}$)	B	2.6	2.6	2.9	5.2	7.5
Standard uncertainty	u(δ_{TS})	A+B	**4.5**	**4.6**	**4.9**	**6.9**	**11.3**
Expanded unc. (k=2)	U(δ_{TS})		**9.0**	**9.2**	**9.8**	**13.8**	**22.6**

500 V							
350 V HV working std.	$u(\delta_S)$	A+B	4.0	4.0	4.2	4.9	9.0
standard deviation	$u(\delta_A)$	A	0.1	0.0	0.0	0.0	0.1
ac-dc comparator	$u(\delta_B)$	B	0.8	0.8	0.9	0.9	0.8
TVC level dependence	$u(\delta_I)$	B	1.2	1.2	1.2	1.2	1.2
heater resistance change	$u(\delta_{heater})$	B	0.0	0.0	0.0	0.3	1.2
working std stability	$u(\delta_{stab})$	B	0.6	0.6	0.6	1.2	7.0
residual level dependence	$u(\delta_{level})$	B	1.2	1.2	1.2	1.2	2.3
lack of closure	$u(\delta_{closure})$	B	2.6	2.6	2.9	5.2	7.5
Standard uncertainty	$u(\delta_{TS})$	A+B	**5.2**	**5.1**	**4.5**	**7.5**	**14**
Expanded unc. (k=2)	$U(\delta_{TS})$		**10.4**	**10.2**	**9.0**	**15**	**28**
Travelling Standard OFMET SJTC US6 + OFMET 1000 V R1000/E							
500 V							
350 V HV working std.	$u(\delta_S)$	A+B	4.0	4.0	4.2	4.9	9.0
standard deviation	$u(\delta_A)$	A	0.7	0.5	0.3	0.5	1.0
ac-dc comparator	$u(\delta_B)$	B	0.5	0.5	0.5	0.5	0.5
TVC level dependence	$U(\delta_I)$	B	0.6	0.6	0.6	0.6	1.2
heater resistance change	$u(\delta_{heater})$	B	0.0	0.0	0.0	0.3	0.4
working std stability	$u(\delta_{stab})$	B	0.6	0.6	0.6	1.2	7.0
residual level dependence	$u(\delta_{level})$	B	1.2	1.2	1.2	1.2	2.3
lack of closure	$u(\delta_{closure})$	B	0.6	0.6	0.6	0.6	1.7
Standard uncertainty	$u(\delta_{TS})$	A+B	**4.4**	**4.3**	**4.5**	**5.3**	**11.8**
Expanded unc. (k=2)	$U(\delta_{TS})$		**8.8**	**8.6**	**9.0**	**10.6**	**23.6**
1000 V							
350 V HV working std.	$u(\delta_S)$	A+B	4.0	4.0	4.2	4.9	9.0
standard deviation	$u(\delta_A)$	A	0.7	0.9	0.4	0.5	1.0
ac-dc comparator	$u(\delta_B)$	B	0.5	0.5	0.5	0.5	0.5
TVC level dependence	$U(\delta_I)$	B	1.2	1.2	1.2	1.2	1.7
heater resistance change	$u(\delta_{heater})$	B	0.0	0.0	0.0	0.6	0.9
working std stability	$u(\delta_{stab})$	B	0.6	0.6	0.6	1.2	7.0
residual level dependence	$u(\delta_{level})$	B	1.2	1.2	2.3	2.3	3.7
lack of closure	$u(\delta_{closure})$	B	0.6	0.6	0.6	0.6	1.7
Standard uncertainty	$u(\delta_{TS})$	A+B	**4.5**	**4.5**	**4.5**	**5.3**	**11.8**
Expanded unc. (k=2)	$U(\delta_{TS})$		**9.0**	**9.0**	**9.0**	**10.6**	**23.6**

Explanation of used designations:

$u(\delta_{PS})$ – type A+B, uncertainty of the NRC primary reference standard.
$u(\delta_S)$ – type A+B, uncertainty of the reference standard at the previous voltage level.
$u(\delta_A)$ – type A, standard deviation of the measurement, evaluated at every step.
$u(\delta_B)$ – type B, ac-dc comparator; measurement uncertainty due to the measurement setup, proportional to the ac-dc differences of the compared devices.
$u(\delta_I)$ – type B, TVC level change uncertainty; the uncertainty due to the level change of ac-dc current transfer difference of the SJTC δ_I, arising when a TVC

and a range resistor are calibrated at a lower voltage and used at a higher voltage.

$u(\delta_{stab})$ – type B – working standard stability uncertainty; standard uncertainty assigned to the instability of the working standard.

$u(\delta_{station})$ – type B, station uncertainty, standard uncertainty assigned to the variability of measurements at different test stations. See below note on NRC HV working standards.

$u(\delta_{closure})$ – type B, closure uncertainty; standard uncertainty assigned to the variability of measurements of the travelling standard compared to different converters. See below note on Traveling standards tests.

$u(\delta_{heater})$ – type B, heater resistance change uncertainty; standard uncertainty assigned to correction for of the SJTC heater resistance change. See below note on NRC voltage level dependence of HV working standards.

$u(\delta_{level})$ – type B, the residual voltage level dependence uncertainty. See below note on NRC voltage level dependence of HV working standards.

$u(\delta_{TS})$ – standard uncertainty of the traveling standard.

$U(\delta_{TS})$ – expanded uncertainty of the traveling standard.

NRC Test Systems

NRC ac-dc transfer standards and comparators have been described in detail in the following publications:

R.F. Clark, P.S. Filipski, D.C. Paulusse, “Improvements in the NRC AC-DC Transfer Capabilities,” *IEEE Trans. Instrum. Meas.*, vol. 46, April 1997, pp. 365 - 368.

P.S. Filipski, R.F. Clark, D.C. Paulusse, “Calorimetric Thermal Voltage Converter as a Wideband Calculable Standard of AC-DC Difference,” *IEEE Trans. Instrum. Meas.*, vol. 48, April 1999, pp. 387-390.

P.S. Filipski, R. Rinfret, “An Automated AC-DC Transfer Calibration System,” *IEEE Trans. Instrum. Meas.*, vol. 49, April 2000, pp. 279-284.

Three different measurement setups, called Station 0, 1 and 2, were used in these tests. The low voltage tests, up to 200 V, were performed on Stations 1 and 2; the high voltage tests were performed only on Station 0. The main characteristics of the stations are as follows.

Station 0
AC Source – Fluke model 5200A with 5215 HV amplifier,
DC Source – Keithley model 2410 1100 V SourceMeter,
Meters: - HP model 34420A nanovoltmeters,
Measurement sequence : AC –DC N - AC –DC R – AC.

Station 1
AC/DC Source – Fluke model 5700 calibrator,
Meters: HP model 34420A nanovoltmeters,
Measurement sequence: AC-(Aux DC)-DC N-(Aux DC)-DC R-(Aux DC)-AC.

Station 2
AC/DC Source – Fluke model 5720 calibrator,
Meters - Keithley model 182 digital voltmeters,
Measurement sequence: AC-(Aux DC)-DC N-(Aux DC)-DC R-(Aux DC)-AC.

where Aux DC is an auxiliary DC source. The converters under test are switched to the auxiliary source during the short period (2-3 s) of an internal range switching of an AC/DC calibrator.

The waiting time after voltage switching was 45 s.

NRC Primary Standards of AC-DC Difference

The primary NRC standard of the ac-dc transfer difference is a group standard consisting of four 20-mA Multijunction Thermal Converters (MJTC). The average value of the group ac-dc transfer difference, at 1 kHz and 1 V, is assumed to be zero with a standard uncertainty of $u(\delta_{\mathrm{MJTC}}) = 0.21$ µV/V. The frequency characteristics of these converters are estimated to be flat up to 7 kHz. Above this frequency, up to 100 MHz, the primary value of the ac-dc difference is being derived from an NRC designed Calorimetric Thermal Voltage Converter (CTVC).

Uncertainties of the NRC Primary standards $u(\delta_{\mathrm{PS}})$ have been evaluated for the comparison CCEM-K6a (CCE 92-3) with results reported in Metrologia, 1997, vol. 34, pp. 291-292.

NRC Buildup procedure

The NRC working standards were evaluated for the purpose of this comparison using the following build-up procedure. The first working standard used in the procedure was a 4 V/10 mA (400 Ω heater resistance) Multijunction Thermal Converter (MJTC) designated as V4-GM10-1N. It has been calibrated at 1 V using one of the primary standard MJTCs and a CTVC. The following table shows steps of the build-up procedure used to calibrate 200 V working standard VS2e&R4S1.

Steps of the buildup procedure to calibrate 200 V working standard VS2e&R4S1.

Step #	Reference converter	Test converter	Test voltage
1	V4-GM10-1N	V8-GM10-5IR	3.6 V
2	V8-GM10-5IR	VS2e&R2S1	8 V
3	VS2e&R2S1	V1STO288&R3S1	16 V
4	V1STO288&R3S1	F792A#1@22 V	20 V
5	F792A#1@22 V	VS2e&R3S1	20 V
6	VS2e&R3S1	V1STO288&R4S1	48 V
7	V1STO288&R4S1	F792A#1@220 V	99 V
8	F792A#1@220 V	VS2e&R4S1	99 V

where:

V8-GM10-5IR – Multijunction Thermal Converter,
V1STO288&R3S1 - 1-V thermal converter V1STO288, used with a range resistor R3S1,
VS2e&R4S1 - 2-V SJTC thermal converter VS2e used with a range resistor R4S1,
F792A#1@220 V - Fluke model F792A S/N 5405002 used at the range of 220 V.

NRC HV working standards

NRC HV working standards were calibrated by a step-up procedure starting from the calibration results of VS2e&R4S1 working standard.

The primary 500 V working standard is designated VS500#3 and consists of a 2.5-mA SJTC and a Fluke HV 200 kΩ resistor designated FR#1 (part of Fluke791A#1 - Fluke model 792A S/N 5405002). The primary 1000 V working standard is designated VS1000#2 and consists of a dedicated 5 mA SJTC and a Fluke HV 200 kΩ resistor designated FR#2 (part of F792A S/N 6680001).

For consistency verification purposes additional working standards were used, VS500#1&FR#1 and F792#1A@1000V. The working standards were calibrated as follows.

Step-up procedure for calibrating high voltage working standards.

	Reference converter	Test converter	Test voltage
Primary working standards calibrations			
1	VS2e&R4S1	VS500#3	200 V
2	VS500#3	VS1000#2	350 V
Auxiliary working standards calibrations			
3	VS2e&R4S1	VS500#1	200 V
5	VS1000#2	F792A#1@1000 V	200 V
6	VS1000#2	F792A#1@1000 V	500 V
7	VS1000#2	F792A#1@1000 V	1000 V
8	VS1000#2	VS500#1	500 V

Working standard VS500#3 has been compared to VS2e&R4S1 on all three stations. The differences between these comparisons indicate presence of a systematic component, probably originating in differences in the design of sources, meters, wiring and grounding arrangements of the stations. The value of the ac-dc difference of the tested converter has been calculated as the average of the tests on all stations and u($\delta_{station}$) has been assigned as the uncertainty of the average.

Traveling Standards Tests

In the following tables the travelling standards were designated as:
TS500V - 92 PTB/IPHT MJTC 1997 + Fluke resistor S/N 034
TS1000V - OFMET SJTC US6 + OFMET 1000 V R1000/E

Traveling standard tests.

	Reference converter	Test converter	Test voltage

Traveling Standard TS500V			
1	VS2e&R4S1	TS500V	200 V
2	VS500#3	TS500V	200 V
3	VS500#1	TS500V	200 V
4	VS500#1	TS500V	500 V
6	F792A#1@1000 V	TS500V	500 V
Traveling Standard TS1000V			
7	VS1000#2	TS1000V	500 V
8	F792A#1@1000 V	TS1000V	500 V
9	VS1000#2	TS1000V	1000 V
10	F792A#1@1000 V	TS1000V	1000 V

Traveling standard TS500V has been compared to three different converters, VS2e&R4S1, VS500#3 and VS500#1 with different results. The differences between these comparisons cannot be explained by random variations and indicate presence of a systematic error component. Separate tests on different converters, designed at NRC, have indicated that this relatively large lack of closure was related to the PTB MJTC with high output resistance. The value of the ac-dc difference of tested converter has been calculated as the average of the tests against the three converters and $u(\delta_{closure})$ was assigned as the uncertainty of this average.

Note on voltage level dependence of NRC high voltage working standards

NRC high voltage working standards, VS500#3 and VS1000#2, consist of single junction thermal converters and Fluke model F792A HV resistors. They are calibrated at 200 V and 350 V respectively and used at 500 V and 1000 V. Three uncertainty components were associated with their voltage level change: the uncertainty due to the level change of ac-dc current transfer of the SJTC, $u(\delta_I)$, the uncertainty due to the heater resistance change, $u(\delta_{heater})$, and the residual voltage level change uncertainty, $u(\delta_{level})$.

The heater resistance change uncertainty takes into account changing of the current distribution between the heater and a parallel residual capacitance. (This change for some converters can be significant, e.g. 28 µV/V at 100 kHz for HV auxiliary working standard VS500#1.) The working standard SJTC heater resistor, R_{heater}, forms, together with the range resistor, R_{range}, and a residual capacitance, $C_{residual}$, (combined capacitance of the input of the TVC and output of the range resistor), a type-T $R_{range}C_{residual}R_{heater}$ divider. When the heater resistance changes with the current level, the parameters of this divider also change, thus changing the current flowing to the heater. This change has been estimated and corrected at 50 kHz and 100 kHz, uncertainty of this correction was designated $u(\delta_{heater})$. This error was assumed negligible for low value range resistors and at lower frequencies.

The last component, $u(\delta_{level})$, was evaluated by comparing results of NRC calibrations of a F792A transfer standard at low voltage range, 22 V, and the highest voltage range, 1000 V. It was assumed that the change in the F792A ac-dc difference with voltage level should be similar at both ranges and that lack of this similarity is due to the unaccounted for systematic errors in the HV working standards. The residual voltage level dependence uncertainty takes into account this divergence of voltage level change at different ranges.

The assumption that the ac-dc difference of F792A transfer standard changes similarly at low ranges and the highest range assumes that for both ranges the range resistors do not change either with the voltage level or with the dissipated power, thus temperature. *NRC has no direct means to verify lack of voltage level dependence of NRC HV working standards, but this assumption was confirmed by several indirect tests conducted over the years.* In particular, the F792 resistors based working standards were compared with standards, designed at NRC, based on resistors of other manufacturers. In these tests no significant voltage or power level dependence of the Fluke F792A HV resistors was discovered, which lead to their adoption in HV working standards. NRC standards were also compared with standards of other NMIs both in bilateral comparisons as well as in formal comparison CCE 92-4. Results of these comparisons also appear to confirm correctness of the above assumptions.

UNCERTAINTY BUDGET FOR VNIIM (RUSSIA)

STEP UP PROCEDURE			**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
PRIMARY STANDARD	**Voltage (V):**	**1**					
(VNIIM 1V MJTC)	**Standard uncertainty**		1.5	1.5	3.0	5.0	5.0
Step #1	Voltage (V):	**2**					
Measurement uncertainty:		Type A	0.2	0.2	0.7	0.7	1.0
		Type B	0.8	0.8	1.0	1.5	1.5
Uncertainty arising from voltage dependence:			0.5	0.5	1.0	3.0	4.0
Resulting standard uncertainty:			1.8	1.8	3.4	6.1	6.7
Step #2	Voltage (V):	**3**					
Measurement uncertainty:		Type A	0.2	0.2	0.7	0.7	1.0
		Type B	1.0	1.0	1.0	1.5	1.5
Uncertainty arising from voltage dependence:			0.5	0.5	1.0	3.0	4.0
Resulting standard uncertainty:			2.1	2.1	3.8	7.0	8.0
Step #3	Voltage (V):	**5**					
Measurement uncertainty:		Type A	0.2	0.2	0.7	0.7	1.0
		Type B	1.0	1.0	1.0	1.5	1.5
Uncertainty arising from voltage dependence:			0.7	0.7	1.0	3.0	4.0
Resulting standard uncertainty:			2.4	2.4	4.1	7.8	9.1
Step #4	Voltage (V):	**10**					
Measurement uncertainty:		Type A	0.2	0.2	0.7	0.7	1.0
		Type B	1.0	1.0	1.0	1.5	1.5
Uncertainty arising from voltage dependence:			1.0	1.0	1.0	3.0	4.0
Resulting standard uncertainty:			2.8	2.8	4.4	8.5	10.1
Step #5	Voltage (V):	**20**					
Measurement uncertainty:		Type A	0.3	0.3	1.0	1.0	1.5
		Type B	1.0	1.0	1.0	2.0	2.0
Uncertainty arising from voltage dependence:			1.5	1.5	1.0	4.0	5.0
Resulting standard uncertainty:			3.4	3.4	4.7	9.7	11.5
Step #6	Voltage (V):	**30**					
Measurement uncertainty:		Type A	0.4	0.4	1.0	1.0	1.5
		Type B	1.0	1.0	1.5	2.0	2.0
Uncertainty arising from voltage dependence:			1.8	1.8	1.5	4.0	5.0
Resulting standard uncertainty:			4.0	4.0	5.3	10.7	12.8
Step #7	Voltage (V):	**50**					
Measurement uncertainty:		Type A	0.4	0.4	1.0	1.0	1.5
		Type B	1.0	1.0	1.5	2.5	2.0
Uncertainty arising from voltage dependence:			2.0	2.0	2.0	4.0	6.0
Resulting standard uncertainty:			4.6	4.6	5.9	11.7	14.4
Step #8	Voltage (V):	**100**					
Measurement uncertainty:		Type A	0.4	0.4	1.0	1.5	2.0
		Type B	1.5	1.5	2.0	3.0	3.0
Uncertainty arising from voltage dependence:			2.0	2.0	4.0	4.0	8.0

Resulting standard uncertainty:		5.3	5.3	7.5	12.8	16.9
Step #9 Voltage (V): **200**						
Measurement uncertainty:	Type A	0.4	0.4	1.5	1.5	2.0
	Type B	1.5	1.5	2.0	3.0	3.0
Uncertainty arising from voltage dependence:		2.0	2.0	4.0	5.0	9.0
Resulting standard uncertainty:		5.9	5.9	8.7	14.2	19.5
Step #10 Voltage (V): **300**						
Measurement uncertainty:	Type A	0.5	0.5	1.5	2.0	3.0
	Type B	1.8	1.8	2.0	3.0	3.0
Uncertainty arising from voltage dependence:		2.4	2.4	4.0	6.0	12.0
Resulting standard uncertainty:		6.6	6.6	9.8	15.8	23.3
Step #11 Voltage (V): **500**						
Measurement uncertainty:	Type A	0.5	0.5	2.0	2.0	3.0
	Type B	2.1	2.1	2.0	3.0	3.0
Uncertainty arising from voltage dependence:		3.0	3.0	5.0	8.0	16.0
Resulting standard uncertainty:		7.6	7.6	11.0	18.1	28.6
Step #12 Voltage (V): **700**						
Measurement uncertainty:	Type A	0.7	0.7	2.0	3.0	4.0
	Type B	2.3	2.3	3.0	3.0	3.0
Uncertainty arising from voltage dependence:		3.0	3.0	5.0	8.0	20.0
Resulting standard uncertainty:		8.5	8.5	12.6	20.2	35.3
Step #13 Voltage (V): **1000**						
Measurement uncertainty:	Type A	1.0	1.0	2.0	4.0	5.0
	Type B	2.5	2.5	3.0	4.0	5.0
Uncertainty arising from voltage dependence:		3.0	3.0	5.0	8.0	30.0
Resulting standard uncertainty:		9.4	9.4	14.0	22.5	46.9

TRAVELLING STANDARDS		**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Measurement voltage (V):	**200**					
Standard uncertainty of the reference standard:		5.9	5.9	8.7	14.2	19.5
Measurement uncertainty:	Type A	1.4	1.5	1.5	1.5	1.7
	Type B	0.8	1.2	5.0	5.0	4.5
Resulting standard uncertainty (travelling standard):		6.16	6.2	10.1	15.1	20.07
Expanded uncertainty [k=2] (travelling standard)		12.3	12.4	20.2	30.2	40.1
Measurement voltage (V):	**500**					
Standard uncertainty of the reference standard:		7.6	7.6	11.0	18.1	28.6
Measurement uncertainty:	Type A	1.6	2.6	2.6	2.6	3.0
	Type B	2.5	2.5	5.0	8.5	9.0
Resulting standard uncertainty (travelling standard):		8.2	8.4	12.3	20.2	30.13
Expanded uncertainty [k=2] (travelling standard)		16.4	16.8	24.6	40.4	60.3
Measurement voltage (V):	**1000**					
Standard uncertainty of the reference standard:		9.4	9.4	14.0	22.5	46.9
Measurement uncertainty:	Type A	1.6	2.5	6.1	6.2	7.3
	Type B	3.4	4.0	5.5	11.0	17.0
Resulting standard uncertainty (travelling standard):		10.1	10.3	16.2	25.8	50.4
Expanded uncertainty [k=2] (travelling standard)		20.2	20.6	32.4	51.6	101

UNCERTAINTY BUDGET FOR METAS (SWITZERLAND)

Institute : METAS / Marc Flueli 19 August 2004
Country : Switzerland All uncertainty values in microV/V étalon:

STEP-UP PROCEDURE		**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**	
PRIMARY STANDARD	**Voltage (V) :** 2.8						MJTC #115 (MJ2
	Standard uncertainty :	**0.5**	**0.5**	**1.0**	**1.0**	**2.5**	
Step n° 1	**Voltage (V) :** 3.2						RS2+US3
Measurement uncertainty		0.2	0.3	0.3	0.2	0.2	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**0.8**	**0.8**	**1.2**	**1.5**	**4.3**	
Step n° 2	**Voltage (V) :** 5.6						RS3+US4
Measurement uncertainty		0.6	0.6	0.4	0.4	0.4	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**1.1**	**1.2**	**1.4**	**2.0**	**5.5**	
Step n° 3	**Voltage (V) :** 10						RS4+US5
Measurement uncertainty		0.5	0.8	0.5	0.3	0.5	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**1.4**	**1.5**	**1.6**	**2.3**	**6.5**	
Step n° 4	**Voltage (V) :** 18						RS5+US2
Measurement uncertainty		0.6	0.5	0.4	0.4	0.6	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**1.6**	**1.7**	**1.7**	**2.6**	**7.4**	
Step n° 5	**Voltage (V) :** 32						RS7+US4
Measurement uncertainty		0.5	0.3	0.4	0.6	0.5	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**1.7**	**1.8**	**1.9**	**2.9**	**8.2**	
Step n° 6	**Voltage (V) :** 56						RS9+US2
Measurement uncertainty		0.6	0.5	0.9	0.8	0.6	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**1.9**	**2.0**	**2.1**	**3.2**	**8.9**	
Step n° 7	**Voltage (V) :** 100						RS10+US3
Measurement uncertainty		0.7	0.6	0.6	0.5	0.5	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**2.1**	**2.2**	**2.3**	**3.5**	**9.6**	
Step n° 8	**Voltage (V) :** 178						RS11+US4
Measurement uncertainty		0.3	0.5	0.5	0.3	0.6	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**2.2**	**2.3**	**2.4**	**3.7**	**10.2**	
Step n° 9	**Voltage (V) :** 316						RS13+US2
Measurement uncertainty		0.7	0.9	0.6	0.4	0.7	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**2.4**	**2.5**	**2.6**	**3.9**	**10.8**	
Step n° 10	**Voltage (V) :** 562						RS15+US4
Measurement uncertainty		0.5	0.5	0.5	0.3	0.6	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**2.5**	**2.6**	**2.7**	**4.0**	**11.4**	
Step n° 11	**Voltage (V) :** 1000						RS17+US2
Measurement uncertainty		0.5	0.3	0.6	1.0	1.7	
Uncertainty arising from voltage dependence		0.6	0.6	0.6	1.2	3.5	
Resulting standard uncertainty		**2.6**	**2.7**	**2.8**	**4.3**	**12.0**	

TRAVELLING STANDARDS		**1 kHz**	**10 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Measurement voltage (V) : 200						
Standard uncertainty of reference standard		2.4	2.5	2.6	3.9	10.8
Measurement uncertainty ………………	Type A	1.0	1.0	1.0	1.0	1.0
	Type B	0.1	0.1	0.1	0.2	0.3
Resulting standard uncertainty (travelling standard)		2.6	2.8	2.8	4.0	11
Number of effective degrees of freedom		(34)	(31)	(40)	(20)	(13)
Expended uncertainty [U95] (travelling standard)		**6**	**6**	**6**	**9**	**24**
Measurement voltage (V) : 500						
Standard uncertainty of reference standard		2.5	2.6	2.7	4.0	11.4
Measurement uncertainty ………………	Type A	1.0	1.0	1.0	1.0	1.0
	Type B	1.0	0.2	0.2	0.3	0.3
Resulting standard uncertainty (travelling standard)		2.9	2.9	2.9	4.2	12
Number of effective degrees of freedom		(31)	(29)	(36)	(19)	(15)
Expended uncertainty [U95] (travelling standard)		**6**	**6**	**6**	**9**	**26**
Measurement voltage (V) : 1000				0.0		
Standard uncertainty of reference standard		2.6	2.7	2.8	4.3	12.0
Measurement uncertainty ………………	Type A	1.0	1.0	1.0	1.0	1.0
	Type B	0.1	0.1	0.1	0.2	0.3
Resulting standard uncertainty (travelling standard)		2.9	3.0	3.0	4.5	13
Number of effective degrees of freedom		(29)	(31)	(33)	(19)	(17)
Expended uncertainty [U95] (travelling standard)		**6**	**7**	**7**	**10**	**28**

UNCERTAINTY BUDGET FOR NIST (USA)

The uncertainties of the measurement processes are listed in Tables 2 through 6. The components are identified as either Type A, those evaluated by statistical means, or Type B, those evaluated by other means. The various elements have been combined as the square root of the sum-of-the-squares (RSS), and the final values are given with a coverage factor k =1. All values are in µV/V of the applied voltage.

Table 2. Standard uncertainty contributions for 1 kHz.

1 kHz	FL034-PTB/IPHT 1997-92		R1000E-US6	
	200 V	500 V	500 V	1000 V
(1) Primary standard MJTCs	0.25	0.25	0.25	0.25
(2) Comparison of Reference 10 V TVC to primary standard	0.42	0.42	0.42	0.42
(3) RSS for 10 V Reference & build-up including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in build-up = 0.49				
(3a) 10 V to 20 V RSS of (2) and 0.49	0.65	0.65	0.65	0.65
(3b) 20 V to 30 V RSS of (3a) and 0.49	0.82	0.82	0.82	0.82
(3c) 30 V to 50 V RSS of (3b) and 0.49	0.95	0.95	0.95	0.95
(3d) 50 V to 100 V RSS of (3c) and 0.49	1.07	1.07	1.07	1.07
(4) RSS for Reference Build-up 200 V to 500 V including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in the build-up = 1.85				
(4a) 100 V to 200 V RSS of (3d) and 1.85	2.14	2.14	2.14	2.14
(4b) 200 V to 300 V RSS of (4a) and 1.85		2.83	2.83	2.83
(4c) 300 V to 500 V RSS of (4b) and 1.85		3.39	3.39	3.39
(5) RSS for Transfer from 500 V to 600 V including pooled standard deviation for crossover between TVC sets, Type B contributions for comparator, and type B uncertainties for TVCs				
Uncertainty for this transfer measurement = 2.47				
Reference TVC at 600 V RSS of (4c) and 2.47				4.19
(6) RSS for Build-up 600 V to 1000 V including pooled standard deviation, type B contributions for comparator, and Type B contributions for TVCs				
Uncertainty for this step in the build-up = 2.59				
(7) Reference TVC at 1000 V RSS of (5) and 2.59				4.93
(8) RSS for Type B contributions for test TVC including comparator system, e.g. detectors, sources; test TVC, e.g. self-heating, ac effects				
(9) Summary of Type B uncertainties for test TVC	1.5	2.5	2.5	4.1
(10) Pooled standard deviation for measurement of test TVC	1.1	1.8	3.5	5.5
Combined standard uncertainties, *k*=1 RSS of elements (4), (9), (10) for 200 V and 500 V RSS of elements (7), (9), (10) for 1000 V	**2.8**	**4.6**	**5.5**	**8.5**

Table 3. Standard uncertainty contributions for 10 kHz.

10 kHz	FL034-PTB/IPHT 1997-92		R1000E-US6	
	200 V	500 V	500 V	1000 V
(1) Primary standard MJTCs	0.27	0.27	0.27	0.27
(2) Comparison of Reference10 V TVC to primary standard	0.54	0.54	0.54	0.54
(3) RSS for 10 V Reference & build-up including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in the build-up = 0.52				
(3a) 10 V to 20 V RSS of (2) and 0.52	0.75	0.75	0.75	0.75
(3b) 20 V to 30 V RSS of (3a) and 0.52	0.92	0.92	0.92	0.92
(3c) 30 V to 50 V RSS of (3b) and 0.52	1.05	1.05	1.05	1.05
(3d) 50 V to 100 V RSS of (3c) and 0.52	1.18	1.18	1.18	1.18
RSS for Reference Build-up 200 V to 500 V including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in the build-up = 1.78				
(4a) 100 V to 200 V RSS of (3d) and 1.78	2.14	2.14	2.14	2.14
(4b) 200 V to 300 V RSS of (4a) and 1.78		2.78	2.78	2.78
(4c) 300 V to 500 V RSS of (4b) and 1.78		3.31	3.31	3.31
(5) RSS for Transfer from 500 V to 600 V including pooled standard deviation for crossover between TVC sets, type B contributions for comparator , and Type B uncertainties for TVCs				
Uncertainty for this step in the build-up = 2.58				
Reference TVC at 600 V RSS of (4c) and 2.58				4.20
(6) RSS for Build-up 600 V to 1000 V including pooled standard deviation, Type B contributions for comparator, and type B contributions for TVCs				
Uncertainty for this step in the build-up = 3.23				
(7) Reference TVC at 1000 V RSS of (5) and 3.23				5.30
(8) RSS for Type B contributions for test TVC including comparator system, e.g. detectors, sources; test TVC, e.g. self-heating, ac effects				
(9) Summary of Type B uncertainties for test TVC	1.5	2.5	2.5	4.1
(10) Pooled standard deviation for measurement of test TVC	1.2	2.3	3.2	5.3
Combined standard uncertainties, *k*=1 RSS of elements (4), (9), (10) for 200 V and 500 V RSS of elements (7), (9), (10) for 1000 V	**2.9**	**4.8**	**5.3**	**8.5**

Table 4. Standard uncertainty contributions for 20 kHz.

20 kHz	FL034-PTB/IPHT 1997-92		R1000E-US6	
	200 V	500 V	500 V	1000 V
(1) Primary standard MJTCs	0.27	0.27	0.27	0.27
(2) Comparison of Reference10 V TVC to primary standard	0.60	0.60	0.60	0.60
(3) RSS for 10 V Reference & build-up including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncetainty for each step in build-up = 0.56				
(3a) 10 V to 20 V RSS of (2) and 0.56	0.82	0.82	0.82	0.82
(3b) 20 V to 30 V RSS of (3a) and 0.56	0.99	0.99	0.99	0.99
(3c) 30 V to 50 V RSS of (3b) and 0.56	1.14	1.14	1.14	1.14
(3d) 50 V to 100 V RSS of (3c) and 0.56	1.27	1.27	1.27	1.27
RSS for Reference Build-up 200 V to 500 V including pooled standard deviation, type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in build-up = 1.81				
(4a) 100 V to 200 V RSS of (3d) and 1.81	2.21	2.21	2.21	2.21
(4b) 200 V to 300 V RSS of (4a) and 1.81		2.85	2.85	2.85
(4c) 300 V to 500 V RSS of (4b) and 1.81		3.38	3.38	3.38
(5) RSS for Transfer from 500 V to 600 V including pooled standard deviation for crossover between TVC sets, Type B contributions for comparator, and type B uncertainties for TVCs				
Uncertainty for this step in the build-up = 2.65				
Reference TVC at 600 V RSS of (4c) and 2.65				4.29
(6) RSS for Build-up 600 V to 1000 V including pooled standard deviation, type B contributions for comparator, and Type B contributions for TVCs				
Uncertainty for this step in the build-up = 3.52				
(7) Reference TVC at 1000 V RSS of (5) and 3.52				5.55
(8) RSS for Type B contributions for test TVC including comparator system, e.g. detectors, sources; test TVC, e.g. self-heating, ac effects				
(9) Summary of Type B uncertainties for test TVC	1.5	2.5	2.5	4.1
(10) Pooled standard deviation for measurement of test TVC	1.4	2.6	3.7	4.3
Combined standard uncertainties, *k*=1 RSS of elements (4), (9), (10) for 200 V and 500 V RSS of elements (7), (9), (10) for 1000 V	**3.0**	**4.9**	**5.6**	**8.1**

Table 5. Standard uncertainty contributions for 50 kHz.

50 kHz	FL034-PTB/IPHT 1997-92		R1000E-US6	
	200 V	500 V	500 V	1000 V
(1) Primary standard MJTCs	0.27	0.27	0.27	0.27
(2) Comparison of Reference10 V TVC to primary standard	0.96	0.96	0.96	0.96
(3) RSS for 10 V Reference & build-up including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in build-up = 0.63				
(3a) 10 V to 20 V RSS of (2) and 0.63	1.15	1.15	1.15	1.15
(3b) 20 V to 30 V RSS of (3a) and 0.63	1.31	1.31	1.31	1.31
(3c) 30 V to 50 V RSS of (3b) and 0.63	1.45	1.45	1.45	1.45
(3d) 50 V to 100 V RSS of (3c) and 0.63	1.58	1.58	1.58	1.58
(4) RSS for Reference Build-up 200 V to 500 V including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in build-up = 1.88				
(4a) 100 V to 200 V RSS of (3d) and 1.88	2.46	2.46	2.46	2.46
(4b) 200 V to 300 V RSS of (4a) and 1.88		3.09	3.09	3.09
(4c) 300 V to 500 V RSS of (4b) and 1.88		3.62	3.62	3.62
(5) RSS for Transfer from 500 V to 600 V including pooled standard deviation for crossover between TVC sets, Type B contributions for comparator, and type B uncertainties for TVCs				
Uncertainty for this step in the build-up = 3.98				
Reference TVC at 600 V RSS of (4c) and 2.98				5.38
(6) RSS for Build-up 600 V to 1000 V including pooled standard deviation, type B contributions for comparator, and Type B contributions for TVCs				
Uncertainty for this step in the build-up = 3.77				
(7) Reference TVC at 1000 V RSS of (5) and 3.77				6.57
(8) RSS for Type B contributions for test TVC including comparator system, e.g. detectors, sources; test TVC, e.g. self-heating, ac effects				
(9) Summary of Type B uncertainties for test TVC	2.4	5.1	5.1	7.5
(10) Pooled standard deviation for measurement of test TVC	1.9	1.9	3.1	4.0
Combined standard uncertainties, *k*=1 RSS of elements (4), (9), (10) for 200 V and 500 V RSS of elements (7), (9), (10) for 1000 V	**3.9**	**6.5**	**7.0**	**10.7**

Table 6. Standard uncertainty contributions for 100 kHz.

100 kHz	FL034-PTB/IPHT 1997-92		R1000E-US6	
	200 V	500 V	500 V	1000 V
(1) Primary standard MJTCs	0.27	0.27	0.27	0.27
(2) Comparison of Reference10 V TVC to primary standard	1.38	1.38	1.38	1.38
(3) RSS for 10 V Reference & build-up including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in build-up = 0.73				
(3a) 10 V to 20 V RSS of (2) and 0.73	1.56	1.56	1.56	1.56
(3b) 20 V to 30 V RSS of (3a) and 0.73	1.73	1.73	1.73	1.73
(3c) 30 V to 50 V RSS of (3b) and 0.73	1.88	1.88	1.88	1.88
(3d) 50 V to 100 V RSS of (3c) and 0.73	2.01	2.01	2.01	2.01
(4) RSS for Reference Build-up 200 V to 500 V including pooled standard deviation, Type B contributions for the comparator, and type B contributions for TVCs				
Uncertainty for each step in build-up = 2.61				
(4a) 100 V to 200 V RSS of (3d) and 2.61	3.30	3.30	3.30	3.30
(4b) 200 V to 300 V RSS of (4a) and 2.61		4.21	4.21	4.21
(4c) 300 V to 500 V RSS of (4b) and 2.61		4.95	4.95	4.95
(5) RSS for Transfer from 500 V to 600 V including pooled standard deviation for crossover between TVC sets, Type B contributions for comparator, and type B uncertainties for TVCs				
Uncertainty for this step in the build-up = 6.91				
Reference TVC at 600 V RSS of (4c) and 6.91				8.50
(6) RSS for Build-up 600 V to 1000 V including pooled standard deviation, type B contributions for comparator, and Type B contributions for TVCs				
Uncertainty for this step in the build-up = 7.03				
(7) Reference TVC at 1000 V RSS of (5) and 7.03				11.03
(8) RSS for Type B contributions for test TVC including comparator system, e.g. detectors, sources; test TVC, e.g. self-heating, ac effects				
(9) Summary of Type B uncertainties for test TVC	4.0	6.5	6.5	8.8
(10) Pooled standard deviation for measurement of test TVC	1.5	1.9	3.4	3.9
Combined standard uncertainties, *k*=1 RSS of elements (4), (9), (10) for 200 V and 500 V RSS of elements (7), (9), (10) for 1000 V	**5.4**	**8.4**	**8.9**	**14.6**

UNCERTAINTY BUDGET FOR NIM (CHINA)

The uncertainty components and the combination of uncertainty of NIM's voltage thermal converters are listed in Table IV.

Table IV. Uncertainty budget of ac-dc voltage thermal converters of NIM (k=1)

Uncertainty contribution		Standard uncertainty in 10^{-6} at frequency				
		1kHz	10kHz	20kHz	50kHz	100kHz
PMJTC at 1.5V Calibrated by PTB	u_s	1.0	1.0	1.0	1.5	1.5
Step-up Procedure Voltage dependence of the resistors						
2V	u_{R1}	1.0	1.0	1.0	1.0	1.0
3V	u_{R2}	1.0	1.0	1.0	1.0	1.0
5V	u_{R3}	1.0	1.0	1.0	1.0	1.0
10V	u_{R4}	1.0	1.0	1.0	1.0	1.0
20V	u_{R5}	1.0	1.0	1.0	1.0	1.0
30V	u_{R6}	1.0	1.0	1.0	1.0	1.0
50V	u_{R7}	1.0	1.0	1.0	1.0	2.0
100V	u_{R8}	1.0	1.0	1.0	2.0	2.0
200V	u_{R9}	1.0	1.0	1.0	2.0	2.0
300V	u_{R10}	2.0	2.0	2.0	3.0	5.0
500V	u_{R11}	2.0	2.0	2.0	5.0	8.0
1000V	u_{R12}	2.0	2.0	4.0	8.0	10.0
Comparison	s_{comp}	1.0	1.0	1.0	1.0	1.0
Drift	s_{drift}	1.0	1.0	1.0	1.0	1.0
Standard uncertainty of step:						
1V to 2V	u_{step1}	1.7	1.7	1.7	1.7	1.7
2V to 3V	u_{step2}	1.7	1.7	1.7	1.7	1.7
3V to 5V	u_{step3}	1.7	1.7	1.7	1.7	1.7
5V to 10V	u_{step4}	1.7	1.7	1.7	1.7	1.7
10V to 20V	u_{step5}	1.7	1.7	1.7	1.7	1.7
20V to 30V	u_{step6}	1.7	1.7	1.7	1.7	1.7
30V to 50V	u_{step7}	1.7	1.7	1.7	1.7	2.4
50V to 100V	u_{step8}	1.7	1.7	1.7	2.4	2.4
100V to 200V	u_{step9}	1.7	1.7	1.7	2.4	2.4
200V to 300V	u_{step10}	1.7	1.7	2.4	3.3	5.2
300V to 500V	u_{step11}	2.4	2.4	2.4	5.2	8.1
500V to 1000V	u_{step12}	2.4	2.4	4.2	8.1	10.1
Standard uncertainty Of the voltage TC	u_N					
2V	u_{2V}	2.0	2.0	2.0	2.3	2.3
3V	u_{3V}	2.6	2.6	2.6	2.9	2.9
5V	u_{5V}	3.2	3.2	3.2	3.4	3.4
10V	u_{10V}	3.6	3.6	3.6	3.8	3.8
20V	u_{20V}	4.0	4.0	4.0	4.2	4.2
30V	u_{30V}	4.4	4.4	4.4	4.5	4.5
50V	u_{50V}	4.7	4.7	4.7	4.8	5.1
100V	u_{100V}	5.0	5.0	5.0	5.4	5.7
200V	u_{200V}	5.3	5.3	5.3	5.9	6.2
300V	u_{300V}	7.0	7.0	7.7	9.3	11.4
500V	u_{500V}	9.5	9.5	10.2	14.4	19.5
1000V	u_{1000V}	11.9	11.9	14.4	22.6	29.6

$$u_{stepi} = \sqrt{u_{Ri}^2 + s_{comp}^2 + s_{drift}^2}$$

$$u_N = \sqrt{u_s^2 + \sum_{i=i}^{n} u_{stepi}^2} \qquad N \leq 200V$$

$$u_N = \sqrt{u_s^2 + \sum_{i=1}^{9} u_{stepi}^2} + \sum_{i=10}^{n} u_{stepi} \qquad 200V < N \leq 1000V$$

(n is the number of steps to reach N)

The uncertainty on the comparison of the reference of NIM with the traveling standards are listed in Table V and Table VI. The standard uncertainty of the measurement results are calculated as:

$$u_C = \sqrt{S_x^2 + u_N^2 + u_{SR}^2 + u_{ST}^2}$$

Table V. Uncertainty on the comparison of the reference of NIM with the traveling standards (NIST/PTB 500V)

		u_x	Standard uncertainty in 10^{-6} at the frequencies					
			1kHz	10kHz	20kHz	50kHz	100kHz	Degrees of freedom
NIST/PTB 500V								
Standard Deviation of comparison	200V	s_x	0.7	0.5	0.4	0.7	0.6	18
Standard uncertainty of NIM's 200V standard		u_N	5.3	5.3	5.3	5.9	6.2	
Stability of Reference		u_{SR}	1.0	1.0	1.0	1.0	1.0	
Stability of travelling standard		u_{ST}	1.0	1.0	1.0	1.0	2.0	
Standard uncertainty of Measurement Results		u_C	**5.5**	**5.5**	**5.5**	**6.1**	**6.6**	
NIST/PTB 500V								
Standard Deviation of comparison	500V	s_x	1.0	0.8	1.1	0.8	1.1	18
Standard uncertainty of NIM's 500V standard		u_N	9.5	9.5	10.2	14.4	19.5	
Stability of Reference		u_{SR}	1.0	1.0	1.0	1.0	1.0	
Stability of travelling standard		u_{ST}	1.0	1.0	1.0	1.0	2.0	
Standard uncertainty of Measurement Results		u_C	**9.6**	**9.6**	**10.4**	**14.5**	**19.7**	

Table VI. Uncertainty on the comparison of the reference of NIM with the traveling standards (OFMET 1000V)

		u_x	Standard uncertainty in 10^{-6} at the frequencies					
			1kHz	10kHz	20kHz	50kHz	100kHz	Degrees of freedom
OFMET 1000V								
Standard Deviation of comparison	500V	s_x	0.9	1.3	1.5	1.0	1.3	18
Standard uncertainty of NIM's 500V standard		u_N	9.5	9.5	10.2	14.4	19.5	
Stability of Reference		u_{SR}	1.0	1.0	1.0	1.0	1.0	
Stability of traveling standard		u_{ST}	2.0	2.0	2.0	2.0	3.0	
Standard uncertainty of Measurement Results		u_C	**9.8**	**9.8**	**10.6**	**14.6**	**19.8**	
OFMET 1000V								
Standard Deviation of comparison	1000V	s_x	0.7	1.1	1.1	1.1	1.0	18
Standard uncertainty of NIM's 1000V standard		u_N	11.9	11.9	14.4	22.6	29.6	
Stability of Reference		u_{SR}	1.0	1.0	1.0	1.0	1.0	
Stability of travelling standard		u_{ST}	2.0	2.0	2.0	2.0	3.0	
Standard uncertainty of Measurement Results		u_C	**12.1**	**12.2**	**14.6**	**22.7**	**29.8**	