Istituto Elettrotecnico Nazionale Galileo Ferraris

FINAL REPORT OF EUROMET.EM-K8.1 COMPARISON OF DC VOLTAGE RATIO

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IEN Technical Report 683

December 2004

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1. Introduction

Key comparison EUROMET.EM-K8 of DC voltage ratio was finalised in January 2004, with publication in the Key Comparison Data Base of the final report [1], of the document linking this comparison to key comparison CCEM-K8 [2, 3] and of the degrees of equivalence. In the mean time a follow-up comparison was organised, open to those participants in EUROMET.EM-K8 willing to improve their results. This comparison was named EUROMET.EM-K8.1.

The same travelling standard as in CCEM-K8, a Datron 4902S resistive divider, s/n 20335, was used in this comparison. The trimmers of the divider were adjusted in order to change the deviation of the divider's ratios from nominal value. More information about the travelling standard can be found in [3]. A technical protocol similar to those of the cited comparisons was adopted: the measurements of voltage ratios 1000 V / 10 V and 100 V / 10 V were mandatory while the measurements of voltage ratios 300 V / 10 V and 30 V / 10 V were optional. The measurements at reduced voltage (10 V / 0.1 V and 10 V / 1 V) were excluded from this comparison. The results for the mandatory ratios will be used to evaluate the degrees of equivalence of the participants; the results for the optional ratios are reported in Appendix F.

2. Participants and schedule

Four National Metrology Institutes, CMI from Czech Republic, SMU from Slovakia, UME from Turkey and NMi-VSL from the Netherlands, agreed to participate in comparison EUROMET.EM-K8.1. As for the other K8 comparisons, the pilot laboratory was the IEN. Table 1 lists the participants in chronological order and the periods of their measurements. In the same table the periods when the travelling standard was at the pilot laboratory are given. The exact dates of the pilot's measurements are reported, with all IEN measurement results, in Appendix A.

In March 2004, the pilot laboratory was informed by CMI about the decision to withdraw from the comparison. No measurement report had been received from this laboratory.

Table 1. List of participants and measurement dates.

Acronym	National Metrology Institute	Country	Standard at the laboratory	Mean date of measurement	Comment
IEN	Istituto Elettrotecnico Nazionale Galileo Ferraris - Pilot	Italy	28 Aug 2003 to 2 Oct 2003	-	Adjustment and initial measurements
CMI	Czech Metrology Institute	Czech Republic	10 Oct 2003 to 29 Oct 2003	-	withdrawn
SMU	Slovak Institute of Metrology	Slovakia	31 Oct 2003 to 13 Nov 2003	10 Nov 2003	
UME	Ulusal Metroloji Enstitüsü	Turkey	1 Dec 2003 to 7 Jan 2004	26 Dec 2003	

IEN	Pilot	Italy	16 Jan 2004 to 8 Feb 2004	-	
NMi-VSL	NMi Van Swinden Laboratorium B.V.	The Netherlands	10 Feb 2004 to 25 Feb 2004	20 Feb 2004	
IEN	Pilot	Italy	2 March 2004 to 23 March 2004	-	Final measurements

3. Behaviour of the travelling standard

The divider's trimmers were adjusted on 27 August 2003 and the behaviour of the different ratios was monitored up to 2 October 2003, when the standard was shipped to CMI. During this time and during the following comparison the divider has been drifting quite smoothly, as can be seen from the measurements of the basic ratios shown in Fig.1.

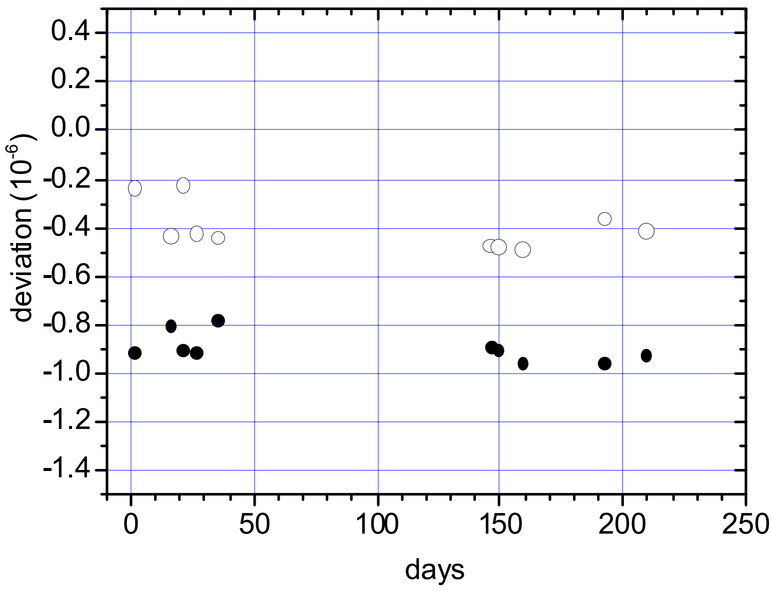


Fig.1. Behaviour of the basic ratios of the travelling standard, from the measurements of the pilot laboratory reduced to standard ambient conditions. Ratio 1000 V / 100 V: open circles. Ratio 100 V / 10 V: closed circles. Days are counted starting on 27 August 2003.

4. Measurements of the pilot laboratory and temperature and humidity coefficients

As in the other K8 comparisons, reference conditions for the measurements were a temperature of 23 °C and a relative humidity of 45 %. To evaluate the errors for deviations from these conditions, the temperature and humidity coefficients (C_T and C_H respectively) of the different ratios, shown in Table 2, were used. These coefficients were evaluated during comparison CCEM-

K8. In Table 2, the specification "after" refers to the measurements of the travelling standard carried out by the pilot laboratory after the change of drift occurred during CCEM-K8, as explained in [3].

Table 2. Temperature and humidity coefficients from [3], values "after", and regression parameters after (1).

r	C_T (10^{-6}/°C)	$u(C_T)$ (10^{-6}/°C)	C_H (10^{-6}/p.u.)	$u(C_H)$ (10^{-6}/p.u.)	D_0 (10^{-6})	$u(D_0)$ (10^{-6})	C_D (10^{-6}/day)	$u(C_D)$ (10^{-6}/day)	s (10^{-6})
1000/10 $_{after}$	-0.0259	0.0155	-0.0015	0.0013	-1.201	0.043	-0.00093	0.00035	0.086
100/10 $_{after}$	-0.2135	0.0140	-0.0095	0.0012	-0.851	0.025	-0.00042	0.00021	0.051
300/10 $_{after}$	-0.1665	0.0172	-0.0055	0.0014	-1.698	0.030	-0.00067	0.00024	0.060
30/10 $_{after}$	-0.0351	0.0119	-0.0075	0.0010	-1.340	0.038	-0.00058	0.00031	0.075

The whole set of IEN measurements is reported in Appendix A. The original measurements were first corrected for temperature and humidity and then interpolated following the equation:

$$d \equiv (r - r_N)/r_N = D_0 + C_D(t - t_0) \qquad (1)$$

where r is the ratio of interest, with nominal value r_N, D_0 is the deviation of the ratio from nominal at starting time t_0, C_D is the drift and t_0 is August 28th, 2003. Table 2 also reports the values of D_0, C_D and the standard deviation s of the regression. s will be assumed as the standard uncertainty contribution due to the instability of the travelling standard.

5. Measurement methods

IEN - pilot laboratory

IEN followed the same measurement method used in the other K8 comparisons. The divider calibrations were carried out by measuring the individual resistive sections: each section of the 10 V (0 V - 100 V) or of the 100 V (0 V - 1000 V) resistive chains of the divider was successively compared with a transfer resistor included in a Kelvin double bridge with lead compensation (Datron 4901). In this way the ratio of each section of the divider to the base section of the corresponding resistive chain can be evaluated. From these ratios all other ratios of interest for the comparison can be evaluated. The measurements were accurately timed to allow the divider to stabilise after application of the voltage. The measurement of the first section of the chain was repeated at the end of the process to correct for linear drifts.

SMU

A DC voltage source (Datron calibrator, model 4808) was used to apply the rated voltage to the relevant input terminals of the divider under test. The voltage at the output terminals was measured by compensation method using another DC voltage source (Datron model 4808) and a null detector Fluke 845AB. The waiting time before taking the measurement was 5 and 10 minutes, for ratios 100 V / 10 V and 1000 V / 10 V respectively. Both DC sources were calibrated. To calibrate the DC source applied at the input terminals of the divider under test, a reference divider was used. This method is one of those described in the Slovakian written standard STN 356211.

UME

Two measurement methods were used and the result given was the weighted mean of the two methods. In the first method the 10 individual resistive sections of the divider's resistive chains (10x10 kΩ and 10x100 kΩ) were measured by means of a Multifunction Transfer Standard (MTS) Datron 4950. In the second method a Fluke 5720 calibrator was used to energise the divider for 15 minutes before the measurements, then the voltage drops across the 10 kΩ or 100 kΩ resistors was measured by means of the same Datron 4950 MTS.

NMi-VSL

For the mandatory ratios, the unknown divider was compared with a Fluke 752A Reference Divider previously calibrated. The same input voltage was supplied in parallel to both dividers, using a Fluke 5440B DC Voltage Calibrator. A Fluke 721A Lead Compensator was used to avoid errors resulting from voltage drops in the connecting cables. The voltage difference between the 10 V taps of the two dividers was measured by means of a Fluke 845AB null detector. To compensate for thermal voltages, measurements with both current polarities were carried out. Waiting times of 25 minutes and 4 minutes were used for the ratios 1000 V / 10 V and 100 V / 10 V respectively.
For the optional ratios, 300 V / 10 V and 30 V / 10 V, the same method was used but the reference divider was a Fluke 720 Kelvin Varley.

6. Ratio 1000 V / 10 V: results

a) Participants results and differences from pilot

Table 3 reports the mean date of the measurements, the temperature and humidity conditions (for IEN the mean values for all the measurements are reported), the error ε due to temperature and humidity and evaluated by means of the coefficients reported in Table 2, and the uncertainty contributions $u(\varepsilon)$ given by eq. (3) of ref. [1]. For IEN the error ε is null because the interpolation is carried out on the corrected measurements (see par. 4). In the table, the uncertainties δT and δH of temperature and humidity are given as half width of a rectangular distribution.

Table 3. Ratio 1000 V / 10 V: error due to temperature and humidity

Lab	Date	T (°C)	δT (°C)	H (%)	δH (%)	$\varepsilon\,(T, H)$ (10^{-6})	$u(\varepsilon)$ (10^{-6})
SMU	10/11/2003	22.4	0.5	27	5	0.043	0.027
UME	26/12/2003	23.0	1.0	45	10	0.000	0.017
NMi-VSL	20/02/2004	22.5	0.5	41	3	0.019	0.013
IEN	-	23.2	0.5	36	5	-	0.015

Table 4 reports: the time t of the measurements in days, starting from 27 August 2003; the original result d; the result after correction for temperature and humidity $d_0 = d - \varepsilon$; the corresponding interpolated value, at standard ambient conditions, of the pilot laboratory $d_{0,P}$, given by eq. (1) with parameters D_0 and C_D from Table 2; the difference $\Delta = (d_0 - d_{0,P})$; the standard uncertainties (type A and type B) reported by the laboratory; the contribution $u(\varepsilon)$ to the standard uncertainty due to temperature and humidity; the contribution s to the standard uncertainty due to the transfer standard; the corresponding global standard uncertainty u_G. For IEN the contribution s of the transfer standard was evaluated by dividing the standard deviation of the regression (1) by $\sqrt{n}$, where n = 10 is the number of IEN measurements. All uncertainties are relative to the ratio.

Close to the uncertainty components, the corresponding degrees of freedom ν are reported; because the uncertainty contribution due to temperature and humidity, $u(\varepsilon)$, is small, the corresponding contribution of this component to ν_G is negligible already for $\nu_\varepsilon > 1$.

The uncertainty budget of each laboratory is given in Appendix E. The uncertainty budget of IEN is the same as in comparison CCEM-K8 [3].

Table 4. 1000 V / 10 V. Result and difference from the pilot laboratory

Lab	t (d)	d (10^{-6})	d_0 (10^{-6})	$d_{0,P}$ (10^{-6})	Δ (10^{-6})	u_A (10^{-6})	u_B (10^{-6})	$\nu_{A,B}$	$u(\varepsilon)$ (10^{-6})	ν_ε	s (10^{-6})	ν_s	u_G (10^{-6})	ν_G
SMU	75	-0.54	-0.583	-1.271	0.688	0.05	1.2	∞	0.027	>1	0.086	8	1.204	∞
UME	121	-1.35	-1.350	-1.314	-0.036	0.02	0.14	>10^4	0.017	>1	0.086	8	0.167	109
NMi-VSL	177	-1.55	-1.569	-1.366	-0.203	0.015	0.303	120	0.013	>1	0.086	8	0.316	128
IEN	-	-	-	-	0	0.053	0.103	598	0.015	>1	0.027	8	0.120	524

Fig. 2 shows a plot of the corrected laboratory results, d_0, with corresponding global standard uncertainties u_G , compared with the linear fit of the corrected IEN measurements.

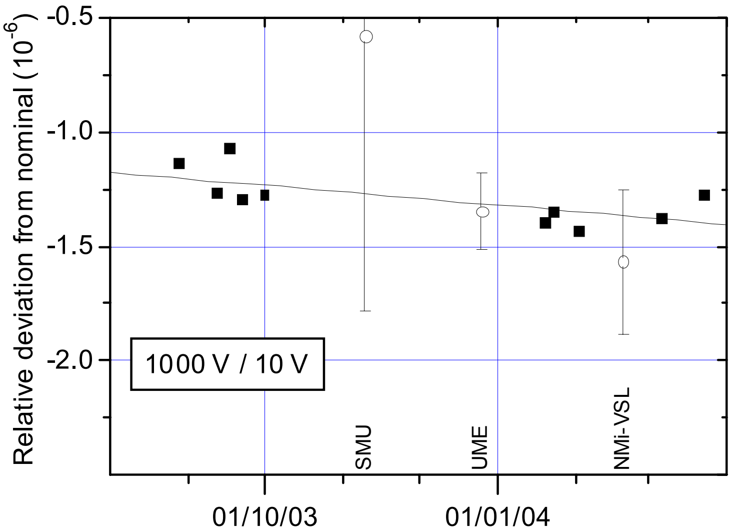


Fig. 2. Ratio 1000 V / 10 V: laboratory results, corrected to standard ambient conditions, corresponding global standard uncertainties and linearly interpolated IEN measurements.

b) <u>Degree of equivalence with respect to the KCRV</u>

To compare the result of a participant in EUROMET.EM-K8.1 with the results of the participants in the others K8 comparisons, all results must be referred to the same reference value, specifically that of CCEM-K8, which is by definition the Key Comparison Reference Value (KCRV).

If D_i is the difference between the result of laboratory i, participant in EUROMET.EM-K8.1, and the corresponding reference value R_F, and $D_{i,K}$ is the estimate of the difference between the result of the same laboratory and the KCRV, R_K, we can write:

$$D_{i,K} = D_i + (R_F - R_K) = \Delta_i - \Delta_{IEN} + (\Delta_{IEN,K} - R_K), \quad (2)$$

where the reference value in comparison EUROMET.EM-K8.1 is the IEN value Δ_{IEN} in this comparison, while the difference (R_F - R_K) is estimated by ($\Delta_{IEN,K} - R_K$), $\Delta_{IEN,K}$ being the IEN result in CCEM-K8.

The standard uncertainty $u(D_{i,K})$ associated with $D_{i,K}$ is given by:

$$\begin{aligned} u^2(D_{i,K}) &= [u_{i,A}^2 + u_{i,B}^2 + u_i^2(\varepsilon) + s_i^2] + u_{transfer}^2 + u^2(R_K) \\ &= u_{G,i}^2 + u_{transfer}^2 + u^2(R_K) \end{aligned} \quad (3)$$

where $u_{G,i}$ is the global standard uncertainty of laboratory i, given in Table 4, and $u_{transfer}$ represents the uncertainty for transferring the result of laboratory i to comparison CCEM-K8 through the linking laboratory IEN. $u_{transfer}$ is estimated as follows:

$$u_{transfer}^2 = s_{IEN,K}^2 + s_{IEN}^2 + 2u_{IEN,A}^2 + u_{IEN,K}^2(\varepsilon) + u_{IEN}^2(\varepsilon)\,, \quad (4)$$

where the index K refers to comparison CCEM-K8. The contributions $s_{IEN,K}$ and s_{IEN} are the standard deviations of the linear regressions of the IEN measurements divided by the square root of the number of measurements. In eq. (4) the contributions due to temperature and humidity for both comparisons have been reported, because they come mainly from the random uncertainty of temperature and humidity during the IEN measurements and are therefore essentially uncorrelated. $u_{IEN,A}$ is the combination of the type A or random components of the IEN uncertainty budgets reported in Tables D1 and E1 in the Appendixes D and E. Eq. (4) is based on the assumption that, in view of the methods used to calibrate the IEN travelling standard, a systematic change of the IEN results between the time of the CCEM-K8 comparison and the present comparison is negligible compared to the other uncertainty components in the same equation.

Table 5 reports, in the upper part, the values needed to evaluate eqs. (2), (3) and (4) and not already given in Table 4, and the resulting value of $u_{transfer}$. Close to each uncertainty value are the corresponding degrees of freedom. The lower part of the Table reports the requested degrees of equivalence with corresponding standard uncertainty, degrees of freedom and the expanded uncertainty $U(D_{i,K})$. In the calculation of $U(D_{i,K})$, the coverage factor is evaluated for a probability of 95%.

Table 5. Ratio 1000 V / 10 V. Values for calculation of eqs. (2), (3) and (4) and degrees of equivalence $D_{i,K}$ and $U(D_{i,K})$

$\Delta_{IEN,K}$ (10^{-6})	R_K (10^{-6})	$u(R_K)$ (10^{-6})	ν_{R_K}	$s_{IEN,K}$ (10^{-6})	$\nu_{s_{IEN,K}}$	$u_{IEN,A}$ (10^{-6})	$\nu_{IEN,A}$	$u_{IEN,K}(\varepsilon)$ (10^{-6})	$\nu_{IEN,K,\varepsilon}$	$u_{transfer}$ (10^{-6})	$\nu_{transfer}$
0.000	-0.048	0.062	11	0.018	22	0.053	25	0.010	3	0.084	67

Laboratory	$D_{i,K}$ (10^{-6})	$u(D_{i,K})$ (10^{-6})	$\nu_{D_{i,K}}$	$U(D_{i,K})$ (10^{-6})
SMU	0.736	1.209	$>10^5$	2.369
UME	0.012	0.198	162	0.390
NMi-VSL	-0.155	0.332	153	0.657

7. Ratio 100 V / 10 V: results

a) Participants results and differences from pilot

Table 6 reports the mean date of the measurements, the temperature and humidity conditions (for IEN the mean values for all the measurements are reported), the error ε due to temperature and humidity and evaluated by means of the coefficients reported in Table 2, and the uncertainty contribution $u(\varepsilon)$ given by eq. (3) of ref. [1]. For IEN the error ε is null because the interpolation is carried out on the corrected measurements. In the table, the uncertainties δT and δH of temperature and humidity are given as half width of a rectangular distribution.

Table 6. Ratio 100 V / 10 V: error due to temperature and humidity

Lab	Date	T (°C)	δT (°C)	H (%)	δH (%)	$\varepsilon(T, H)$ (10^{-6})	$u(\varepsilon)$ (10^{-6})
SMU	10/11/2003	22.4	0.5	27	5	0.299	0.071
UME	26/12/2003	23.0	1.0	45	10	0.000	0.135
NMi-VSL	20/02/2004	22.5	0.5	41	3	0.145	0.067
IEN	-	23.2	0.5	36	5	-	0.068

Table 7 reports: the time t of the measurements in days, starting from 27 August 2003; the original result d; the result after correction for temperature and humidity $d_0 = d - \varepsilon$; the corresponding interpolated value, at standard ambient conditions, of the pilot laboratory $d_{0,P}$, given by eq. (1) with parameters D_0 and C_D from Table 2; the difference $\Delta = (d_0 - d_{0,P})$; the standard uncertainties (type A and type B) reported by the laboratory; the contribution $u(\varepsilon)$ to the standard uncertainty due to temperature and humidity; the contribution s to the standard uncertainty due to the transfer standard; the corresponding global standard uncertainty u_G. For IEN the contribution s of the transfer standard was evaluated by dividing the standard deviation of the regression (1) by $\sqrt{n}$, where n = 10 is the number of IEN measurements. All uncertainties are relative to the ratio. Close to the uncertainty components, the corresponding degrees of freedom ν are reported; for temperature and humidity an uncertainty in the knowledge of $u(\varepsilon)$ of 20% is assumed (see eq. 13 in [3]).

The uncertainty budget of the laboratories is given in Appendix D. The uncertainty budget of IEN is the same as in comparison CCEM-K8 [3].

Table 7. 100 V / 10 V. Result and difference from the pilot laboratory

Lab	t (d)	d (10^{-6})	d_0 (10^{-6})	$d_{0,P}$ (10^{-6})	Δ (10^{-6})	u_A (10^{-6})	u_B (10^{-6})	$\nu_{A,B}$	$u(\varepsilon)$ (10^{-6})	ν_ε	s (10^{-6})	ν_s	u_G (10^{-6})	ν_G
SMU	75	-0.76	-1.059	-0.883	-0.176	0.03	1.2	∞	0.071	12	0.051	8	1.204	∞
UME	121	-1.05	-1.050	-0.902	-0.148	0.02	0.13	$>10^4$	0.135	12	0.051	8	0.195	50
NMi-VSL	177	-1.27	-1.415	-0.926	-0.489	0.020	0.138	190	0.067	12	0.051	8	0.163	155
IEN	-	-	-	-	0	0.043	0.095	502	0.068	12	0.016	8	0.126	120

Fig. 3 shows a plot of the corrected laboratory results, d_0, with corresponding global standard uncertainties u_G, compared with the linear fit of the corrected IEN measurements.

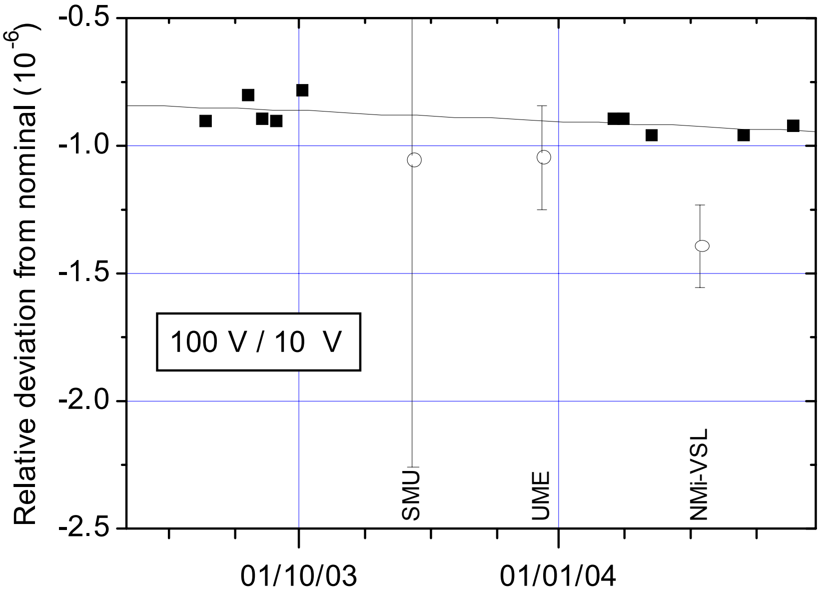


Fig. 3. Ratio 100 V / 10 V: laboratory results, corrected to standard ambient conditions, corresponding global standard uncertainties and linearly interpolated IEN measurements.

b) Degree of equivalence with respect to the KCRV

A procedure similar to the one followed for ratio 1000 V / 10 V leads to Table 8.

Table 8. Ratio 100 V / 10 V. Values for calculation of eqs. (2), (3) and (4) and degrees of equivalence $D_{i,\mathrm{K}}$ and $U(D_{i,\mathrm{K}})$

$\Delta_{\mathrm{IEN,K}}$ (10^{-6})	R_K (10^{-6})	$u(R_\mathrm{K})$ (10^{-6})	ν_{R_K}	$s_{\mathrm{IEN,K}}$ (10^{-6})	$\nu_{s_{\mathrm{IEN,K}}}$	$u_{\mathrm{IEN,A}}$ (10^{-6})	$\nu_{\mathrm{IEN,A}}$	$u_{\mathrm{IEN,K}}(\varepsilon)$ (10^{-6})	$\nu_{\mathrm{IEN,K},\varepsilon}$	u_{transfer} (10^{-6})	ν_{transfer}
0.000	-0.050	0.083	12	0.016	22	0.043	14	0.070	12	0.119	45

Laboratory	$D_{i,\mathrm{K}}$ (10^{-6})	$u(D_{i,\mathrm{K}})$ (10^{-6})	$\nu_{D_{i,\mathrm{K}}}$	$U(D_{i,\mathrm{K}})$ (10^{-6})
SMU	-0.126	1.212	∞	2.376
UME	-0.098	0.242	92	0.481
NMi-VSL	-0.439	0.217	172	0.429

8. Bilateral degrees of equivalence

The bilateral degrees of equivalence between one of the participants in EUROMET.EM-K8.1 (SMU, UME or NMi-VSL), laboratory *i*, and any other laboratory *j* that has participated in the same comparison or in comparisons CCEM-K8 or EUROMET.EM-K8 [3, 1], can be calculated by the difference of the degrees of equivalence of the two laboratories with respect to the key comparison reference value, with corresponding 95% uncertainty given by twice the root-sum-square of: the global standard uncertainty of laboratory *i*, the global standard uncertainty of laboratory *j* and, if laboratory *j* has participated in CCEM-K8 or EUROMET.EM-K8, the transfer standard uncertainty from EUROMET.EM-K8.1 to the relevant comparison.

If, for the transfer standard uncertainty to EUROMET.EM-K8, the same $u_{transfer}$ already evaluated for CCEM-K8 is used (see Tables 5 and 8), the error introduced by this approximation and by neglecting the degrees of freedom associated to the laboratory standard uncertainties, is lower than 5% for both ratios 1000 V / 10 V and 100 V / 10 V.

A particular case is that of CEM as participant in comparison CCEM-K8.1 [4], a follow-up of comparison CCEM-K8 also piloted by IEN. The bilateral degrees of equivalence of SMU, UME or NMi-VSL (laboratory *i*) with respect to CEM, can be calculated by the difference of the degrees of equivalence of the two laboratories with respect to the key comparison reference value, with corresponding 95% uncertainty given by twice the root-sum-square of four terms: the global standard uncertainty of laboratory *i*, the transfer standard uncertainty from EUROMET.EM-K8.1 to CCEM-K8, the transfer standard uncertainty from CCEM-K8.1 to CCEM-K8 and the global standard uncertainty of CEM. Because the two transfer uncertainties are practically identical, the value of $u_{transfer}$ given in Table 5 and 8 can be used for both. The error introduced by neglecting the degrees of freedom is still lower than 5% for both ratios 1000 V / 10 V and 100 V / 10 V.

9. Conclusions

Comparison EUROMET.EM-K8.1 on DC voltage ratio was organised to allow the participants in EUROMET.EM-K8 to improve their degrees of equivalence. Four laboratories participated, but one of them, namely CMI, withdrew before the release of the Draft A report.

In order to evaluate the new degrees of equivalence of the other participants, their results were linked to those of CCEM-K8 through the measurements of the pilot laboratory, which was also the pilot of CCEM-K8.

10. References

[1] G. Marullo Reedtz and R. Cerri, “Final Report of EUROMET.EM-K8 Comparison of DC Voltage Ratio (EUROMET project 449)”, IEN Technical Report 670, December 2003, published online in the *Key Comparison Data Base*: http://kcdb.bipm.fr

[2] G. Marullo Reedtz and R. Cerri, “ Linking the Results of Key Comparisons CCEM-K8 and EUROMET.EM-K8”, IEN Technical Report 679, rev. 17 May 2004, published online in the *Key Comparison Data Base*: http://kcdb.bipm.fr

[3] G. Marullo Reedtz and R. Cerri, “Final Report of CCEM-K8 Comparison of DC Voltage Ratio”, IEN Technical Report 653, November 2002, published online in the *Key Comparison Data Base*: http://kcdb.bipm.fr

[4] G. Marullo Reedtz and R. Cerri, “Final Report of CCEM-K8.1 Comparison of DC Voltage Ratio”, IEN Technical Report 678, May 2004, published online in the *Key Comparison Data Base*: http://kcdb.bipm.fr

APPENDIX A

Measurements of the pilot laboratory

Tables A1 and A2 report for each measurement the values of the basic ratios of the travelling divider, given as relative deviation *d* from nominal, the measurement date, the temperature *T*, the relative humidity *H* and the corrected values d_0 corresponding to standard ambient conditions (*T*= 23 °C, *H*= 45%). From the original values of the basic ratios, the ratios 1000 V / 10 V and 300 V / 10 V were calculated and then corrected for temperature and humidity. Table A3 reports for these ratios the same information as the previous tables. For temperature and humidity coefficients see Table 2 in the main report.

Table A1.
Ratios 1000 V / 100 V and 100 V / 10 V: IEN original values *d* and corrected values d_0 at standard ambient conditions.

Ratio 1000 V / 100 V					Ratio 100 V / 10 V (mandatory)				
d (10^{-6})	date	*T* (°C)	*H* (%)	$d_{0,\ 1000/100}$ (10^{-6})	*d* (10^{-6})	date	*T* (°C)	*H* (%)	$d_{0,\ 100/10}$ (10^{-6})
-0.180	28/08/03	23.0	52.0	-0.232	-0.973	28/08/03	23.0	52.0	-0.907
-0.498	12/09/03	22.7	43.8	-0.432	-0.765	12/09/03	22.9	44.1	-0.800
-0.225	17/09/03	22.9	47.9	-0.224	-0.849	17/09/03	22.7	47.9	-0.897
-0.376	22/09/03	23.0	50.8	-0.419	-0.925	22/09/03	22.8	51.7	-0.907
-0.423	01/10/03	22.6	58.2	-0.437	-0.867	01/10/03	22.8	59.5	-0.779
-0.608	20/01/04	23.2	22.3	-0.472	-0.763	20/01/04	23.4	22.0	-0.894
-0.610	23/01/04	23.2	23.0	-0.477	-0.714	23/01/04	23.1	23.2	-0.897
-0.485	02/02/04	24.1	16.5	-0.489	-0.933	02/02/04	24.1	17.0	-0.956
-0.464	06/03/04	23.4	22.1	-0.360	-0.894	06/03/04	23.8	21.3	-0.959
-0.444	23/03/04	23.7	23.0	-0.412	-0.812	23/03/04	23.6	20.1	-0.921

Table A2.
Ratios 300 V / 100 V and 30 V / 10 V: IEN original values *d* and corrected values d_0 at standard ambient conditions.

Ratio 300 V / 100 V					Ratio 30 V / 10 V (optional)				
d (10^{-6})	date	*T* (°C)	*H* (%)	$d_{0,\ 300/100}$ (10^{-6})	*d* (10^{-6})	date	*T* (°C)	*H* (%)	$d_{0,\ 30/10}$ (10^{-6})
-0.680	28/08/03	23.0	52.0	-0.706	-1.490	28/08/03	23.0	52.0	-1.438
-0.896	12/09/03	22.7	43.8	-0.877	-1.243	12/09/03	22.9	44.1	-1.254
-0.868	17/09/03	22.9	47.9	-0.873	-1.403	17/09/03	22.7	47.9	-1.394
-0.872	22/09/03	23.0	50.8	-0.893	-1.440	22/09/03	22.8	51.7	-1.398
-0.866	01/10/03	22.6	58.2	-0.893	-1.333	01/10/03	22.8	59.5	-1.233
-0.947	20/01/04	23.2	22.3	-0.872	-1.289	20/01/04	23.4	22.0	-1.447
-0.960	23/01/04	23.2	23.0	-0.887	-1.260	23/01/04	23.1	23.2	-1.419
-0.997	02/02/04	24.1	16.5	-0.948	-1.318	02/02/04	24.1	17.0	-1.488
-0.917	06/03/04	23.4	22.1	-0.850	-1.320	06/03/04	23.8	21.3	-1.472
-0.924	23/03/04	23.7	23.0	-0.877	-1.239	23/03/04	23.6	20.1	-1.405

Table A3.
Ratios 1000 V / 10 V and 300 V / 10 V: IEN original values *d* and corrected values d_0 at standard ambient conditions.

Ratio 1000 V / 10 V (mandatory)					Ratio 300 V / 10 V (optional)				
d (10^{-6})	date	T (°C)	H (%)	$d_{0,\ 1000/10}$ (10^{-6})	d (10^{-6})	date	T (°C)	H (%)	$d_{0,\ 300/10}$ (10^{-6})
-1.153	28/08/03	23.0	52.0	-1.142	-1.653	28/08/03	23.0	52.0	-1.614
-1.263	12/09/03	22.8	43.9	-1.270	-1.661	12/09/03	22.8	43.9	-1.702
-1.074	17/09/03	22.8	47.9	-1.076	-1.717	17/09/03	22.8	47.9	-1.740
-1.301	22/09/03	22.9	51.2	-1.294	-1.797	22/09/03	22.9	51.2	-1.780
-1.290	01/10/03	22.7	58.8	-1.278	-1.733	01/10/03	22.7	58.8	-1.712
-1.371	20/01/04	23.3	22.1	-1.399	-1.710	20/01/04	23.3	22.1	-1.788
-1.324	23/01/04	23.1	23.1	-1.354	-1.674	23/01/04	23.1	23.1	-1.773
-1.418	02/02/04	24.1	16.7	-1.432	-1.930	02/02/04	24.1	16.7	-1.897
-1.358	06/03/04	23.6	21.7	-1.380	-1.811	06/03/04	23.6	21.7	-1.849
-1.256	23/03/04	23.7	21.5	-1.275	-1.736	23/03/04	23.7	21.5	-1.759

APPENDIX B

Ratio 1000 V / 10 V: degree of equivalence with respect to the KCRV

Key comparison EUROMET.EM-K8.1

MEASURAND: DC voltage ratio 1000 V / 10 V
NOMINAL VALUE: 100
TRAVELLING STANDARD: voltage divider Datron 4902S, s/n 20335

Pilot laboratory: IEN

$d_{0,i}$: fractional difference from nominal value of ratio $x_{0,i}$, measured by laboratory *i* and corrected to standard ambient conditions; it is given by: $x_{0,i} = 100 \times (1 + d_{0,i})$
The fractional differences $d_{0,IEN}$, assigned by IEN to the ratio, are obtained by interpolation of the IEN measurement results to the measurement date of the participant laboratories.

$\Delta_i = (d_{0,i} - d_{0,IEN})$

$u_{G,i}$: global standard uncertainty of laboratory *i*

$\nu_{eff,i}$: number of effective degrees of freedom of laboratory *i*

Lab *i*	$d_{0,i}$ / 10^{-6}	$d_{0,IEN}$ / 10^{-6}	Δ_i / 10^{-6}	$u_{G,i}$ / 10^{-6}	$\nu_{eff,i}$	Mean date of measurements
SMU	-0.58	-1.27	0.69	1.20	∞	10/11/2003
UME	-1.35	-1.31	-0.04	0.17	109	26/12/2003
NMi-VSL	-1.57	-1.37	-0.20	0.31	128	20/02/2004
IEN	-	-	0.00	0.12	524	-

Key comparison EUROMET.EM-K8.1

MEASURAND: DC voltage ratio 1000 V / 10 V
NOMINAL VALUE: 100

The degree of equivalence D_i of laboratory *i*, with respect to the key comparison reference value Δ_R, is given by the estimated difference $(\Delta_i - \Delta_R)_{CCEM\text{-}K8}$ that the laboratory would have obtained if it had directly participated in comparison CCEM-K8, and by the corresponding 95% expanded uncertainty U_i.
The link to key comparison CCEM-K8 is given by IEN, who was the pilot laboratory in both comparisons.
It is:

$$D_i = (\Delta_i - \Delta_{IEN})_{EUROMET.EM\text{-}K8.1} + (\Delta_{IEN} - \Delta_R)_{CCEM\text{-}K8}$$

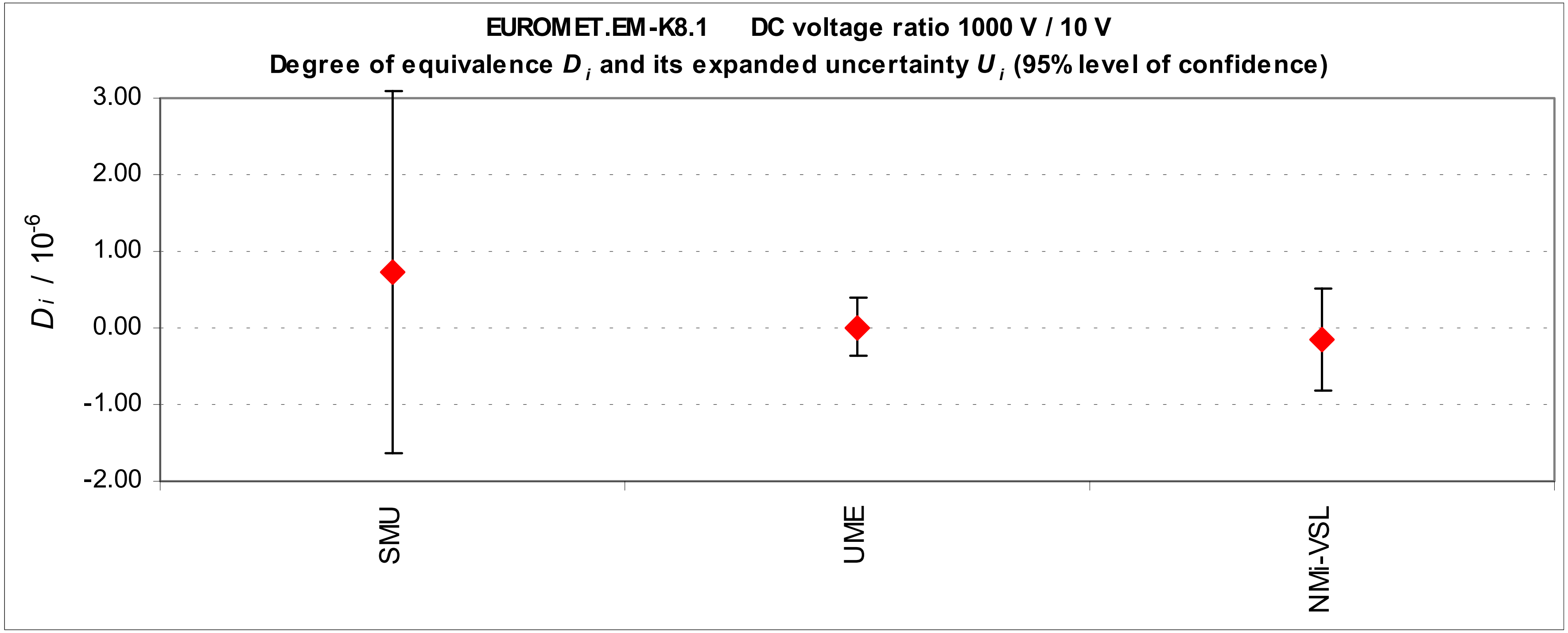
$$u(D_i) = (u^2_{G.i} + u^2_{transfer} + u^2(\Delta_R))^{1/2}$$

where $u_{transfer}$ represents the standard uncertainty of the link to CCEM-K8, evaluated in the final report as $u_{transfer} = 0.08\text{x}10^{-6}$. The degrees of freedom have negligible influence in the calculation of U_i.

The bilateral degrees of equivalence of laboratory *i*, with respect to any other laboratory participating in CCEM-K8 or EUROMET.EM-K8, can be calculated by the difference of the D_i values of the two laboratories, with corresponding approximated 95% uncertainty given by twice the root-sum-square of three terms: the global standard uncertainty of laboratory *i*, the transfer standard uncertainty $u_{transfer}$ and the global standard uncertainty of the other laboratory. The error of the approximated 95% uncertainty is estimated to be lower than 5%.

Degrees of equivalence with respect to the KCRV

Lab *i*	D_i /10^{-6}	U_i /10^{-6}
SMU	0.74	2.37
UME	0.01	0.39
NMi-VSL	-0.16	0.66


EUROMET.EM-K8.1 DC voltage ratio 1000 V / 10 V
Degree of equivalence D i and its expanded uncertainty U i (95% level of confidence)
3.00
2.00
1.00
0.00
-1.00
-2.00
D i / 10-6
SMU
UME
NMi-VSL

APPENDIX C

Ratio 100 V / 10 V: degree of equivalence with respect to the KCRV

Key comparison EUROMET.EM-K8.1

MEASURAND: DC voltage ratio 100 V / 10 V
NOMINAL
VALUE: 10
TRAVELLING STANDARD: voltage divider Datron 4902S, s/n
20335

Pilot laboratory: IEN

$d_{0,i}$: fractional difference from nominal value of ratio $x_{0,i}$, measured by laboratory *i* and corrected to standard ambient conditions; it is given by: $x_{0,i} = 10 \times (1 + d_{0,i})$
The fractional differences $d_{0,\mathrm{IEN}}$, assigned by IEN to the ratio, are obtained by interpolation of the IEN measurement results to the measurement date of the participant laboratories.

$\Delta_i = (d_{0,i} - d_{0,\mathrm{IEN}})$.

$u_{G,i}$: global standard uncertainty of laboratory *i*

$\nu_{\mathrm{eff},i}$: number of effective degrees of freedom of laboratory *i*

Lab *i*	$d_{0,i}$ / 10^{-6}	$d_{0,\mathrm{IEN}}$ / 10^{-6}	Δ_i / 10^{-6}	$u_{G,i}$ / 10^{-6}	$\nu_{\mathrm{eff},i}$	Mean date of measurements
SMU	-1.06	-0.88	-0.18	1.20	∞	10/11/03
UME	-1.05	-0.90	-0.15	0.20	50	26/12/03
NMi-VSL	-1.42	-0.93	-0.49	0.16	155	20/02/04
IEN	-	-	0.00	0.13	120	-

Key comparison EUROMET.EM-K8.1

MEASURAND: DC voltage ratio 100 V / 10 V
NOMINAL VALUE: 10

The degree of equivalence D_i of laboratory *i,* with respect to the key comparison reference value Δ_R, is given by the estimated difference $(\Delta_i - \Delta_R)_{CCEM\text{-}K8}$ that the laboratory would have obtained if it had directly participated in comparison CCEM-K8, and by the corresponding 95% expanded uncertainty U_i.
The link to key comparison CCEM-K8 is given by IEN, who was the pilot laboratory in both comparisons.
It is:

$$D_i = (\Delta_i - \Delta_{IEN})_{EUROMET.EM\text{-}K8.1} + (\Delta_{IEN} - \Delta_R)_{CCEM\text{-}K8}$$

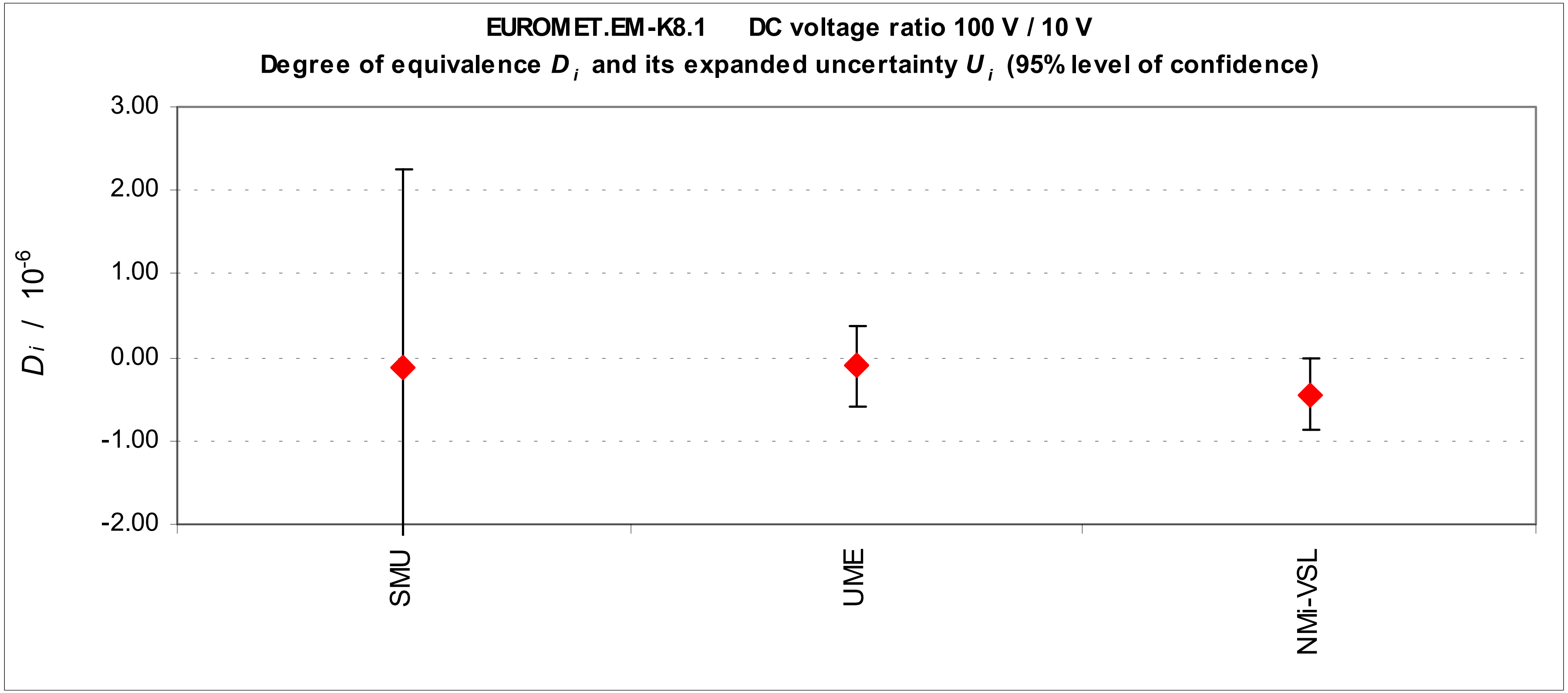
$$u(D_i) = (u^2_{G.i} + u^2_{transfer} + u^2(\Delta_R))^{1/2}$$

where $u_{transfer}$ represents the standard uncertainty of the link to CCEM-K8, evaluated in the final report as $u_{transfer} = 0.12 \times 10^{-6}$. The degrees of freedom have negligible influence in the calculation of U_i.

The bilateral degrees of equivalence of laboratory *i*, with respect to any other laboratory participating in CCEM-K8 or EUROMET.EM-K8, can be calculated by the difference of the D_i values of the two laboratories, with corresponding approximated 95% uncertainty given by twice the root-sum-square of three terms: the global standard uncertainty of laboratory *i,* the transfer standard uncertainty $u_{transfer}$ and the global standard uncertainty of the other laboratory. The error of the approximated 95% uncertainty is estimated to be lower than 5%.

Degrees of equivalence with respect to the KCRV

Lab *i*	D_i	U_i
	$/10^{-6}$	$/10^{-6}$
SMU	-0.13	2.38
UME	-0.10	0.48
NMi-VSL	-0.44	0.43


EUROMET.EM-K8.1 DC voltage ratio 100 V / 10 V
Degree of equivalence D i and its expanded uncertainty U i (95% level of confidence)
D i / 10-6
3.00
2.00
1.00
0.00
-1.00
-2.00
SMU
UME
NMi-VSL

APPENDIX D
Participant uncertainty budgets for ratio 100 V / 10 V

In the following the participants' uncertainty budgets for ratio 100 V / 10 V are given. For a description of the methods of measurement see par. 5 of the report.

IEN – pilot laboratory

The calibration of the ratio 100 V / 10 V was carried out by comparing each of the 10 resistive sections of the divider's 10 V chain with a transfer resistor, using a Kelvin double bridge with lead compensation. The equation of the measurement is reported in Appendix D of [3]. The uncertainty budget is also given in [3] but it is copied here for convenience.

Table D1. IEN relative uncertainty budget for the ratio 100 V / 10 V in units of 10^{-6}

Uncertainty component	Relative standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Relative standard uncertainty contribution $u_i(R)=c_i\,u(x_i)$	Degrees of freedom ν_i
u_A	0.043	gauss. / A	1	0.043	14
$u(\varepsilon)$	0.016	rect. / B	3	0.048	∞
$u(\gamma_1)$	0.008	rect. / B	9	0.071	∞
$u(\delta_C)$	0.005	rect. / B	3	0.014	∞
$u(\delta_D)$	0.006	rect. / B	3	0.017	∞
$u(\delta_L)$	0.001	rect. / B	3	0.003	∞
$u(\delta_S)$	0.006	rect. / B	3	0.017	∞
$u(\delta_G)$	0.009	rect. / B	3	0.028	∞
$\mathbf{R}_{100/10}$				$u(R) = 0.104$	$\nu_{\text{eff}} = 502$

The meaning of the symbols is as follows:

u_A repeatability of the measurement
$u(\gamma_1)$ imperfect balance of the first section of the divider;
$u(\varepsilon)$ correction of linear drifts of the measurement system;
$u(\delta_C)$ imperfect lead compensation;
$u(\delta_D)$ fluctuations of the detector;
$u(\delta_G)$ gain error of the detector;
$u(\delta_L)$ imperfect electrical insulation and guarding;
$u(\delta_S)$ insufficient stabilisation time after application of the voltage.

SMU

The unknown divider is compared indirectly with a reference divider. The calibrator used to apply the input voltage to the unknown divider and the one used to compensate the corresponding output voltage are both calibrated, the first one by using the reference divider.

Table D2. SMU relative uncertainty budget for ratio 100 V / 10 V

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Relative standard uncertainty contribution $u_i(R)$	Degrees of freedom v_i
R_S	1.0000000					
δR	-0.00000076	$1.2 \cdot 10^{-6}$	normal	1	$1.2 \cdot 10^{-6}$	$2.6 \cdot 10^{8}$
δ_{RC}	0	$3 \cdot 10^{-7}$	rectangular	1	$3 \cdot 10^{-7}$	
δ_{NI}	0	$5 \cdot 10^{-8}$	rectangular	1	$5 \cdot 10^{-8}$	
δ_{LR}	0	$1 \cdot 10^{-8}$	rectangular	1	$1 \cdot 10^{-8}$	
δ_{TA}	0	$1 \cdot 10^{-8}$	rectangular	1	$1 \cdot 10^{-8}$	
δ_{SH}	0	$5 \cdot 10^{-8}$	rectangular	1	$5 \cdot 10^{-8}$	
$\boldsymbol{R}_{100/10}$=	0.99999924				$u(R) = 1.2 \cdot 10^{-6}$	$v_{eff} = 2.6 \cdot 10^{8}$

Legend:

$R_{100/10}$ The established dividing ratio relative to the nominal ratio
R_S The relative nominal value of dividing ratio
δR The dividing ratio deviation measured by calibrator and zero indicator
δ_{RC} Correction to the calibrator stability
δ_{NI} Correction to the precision of the zero indicator
δ_{LR} Correction to the leakage
δ_{TA} Correction to the ambient temperature change
δ_{SH} Correction to the self heating

UME

The final result is weighted mean of the results obtained with two different methods: the measurement of the individual resistances of the divider's 10 V chain and the measurement of the individual voltage drops of the same chain. The final uncertainty is the weighted uncertainty of the two methods.

Table D3. UME Relative uncertainty budget for ratio 100V/10V in units of 10^{-6}
(Method: measuring the individual resistors)

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A, B)	Sensitivity coefficient c_i	Relative standard uncertainty contribution $u_i(R)$	Degrees of freedom ν_i
$\sum_{i=1}^{10} \frac{R_i}{R_1}$	9.999 989 9	0.023	normal /A	1	0.023	13
Wavetek 4950 MTS @10kΩ	0	0.058	rectangular /B	1	0.058	1E+09
Power coeff. of DUT(4902S)	0	0.144	rectangular /B	1	0.144	1E+09
$R_{100/10}$	**9.999 989 9**				**$u(R)$ = 0.157**	**ν_{eff}=28224**

Table D4. UME relative uncertainty budget for ratio 100V/10V in units of 10^{-6}
(Method: measuring the voltage drops across individual resistors)

Quantity Xi	Estimate x_i	Standard uncertainty $(x_i).10^{-6}$	Probability distribution	Sensitivity coefficient	Uncertainty contribution $u_i(R)$ in 10^{-6}	Degrees of freedom v_i
$R_{DUT} = \sum_{i=1}^{10} \frac{V_i}{V_1}$	9.999 988 5	0.031	normal / A	1	0.031	12
Wavetek 4950 MTS @10V	0	0.058	rectangular / B	1	0.058	1E+09
Stability of Calibrator @100V	0	0.231	rectangular / B	1	0.231	1E+09
$R_{100/10}$	**9.999 988 5**				**$u(R)$ = 0.240**	**ν_{eff}=43109**

NMi-VSL

The unknown divider was compared with a Fluke 752A Reference Divider previously calibrated, by applying the same input voltage to both dividers and by measuring the voltage difference at the 10 V outputs.
The equation of the measurement is:

$$R_x = R_s - \frac{R_s \cdot F_{\det}}{V_{out}} \cdot \left(\Delta V + V_{off} + V_{lc}\right)$$

where:

R_x is the ratio of the unknown divider;
R_s is the ratio of the reference divider with its uncertainty resulting from non linearity;
V_{out} is the nominal output voltage of the dividers;
$F_{\det}$ is the calibration factor for the null detector reading;
ΔV is the null detector reading;
V_{off} is the uncompensated thermal offset voltage;
V_{lc} is the influence of the imperfect lead compensation.

Table D5. NMi-VSL absolute uncertainty budget for ratio 100V/10V

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of eval. (A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(R)$	Degrees of freedom ν_i
R_s	10.000 000 0 V/V	1.15E-06 V/V	rectangular B	1	1.15E-06 V/V	100
ΔV	1.25E-05 V	5.77E-07 V	rectangular B	1.012 V^{-1}	5.84E-07 V/V	100
F_{det}	1.012	8.0E-03	rectangular B	3.0E-05 V/V	2.40E-07 V/V	100
V_{off}	0.000 000 V	2.89E-07 V	rectangular B	1.012 V^{-1}	2.92E-07 V/V	100
V_{lc}	0.000 000 V	2.89E-07 V	rectangular B	1.012 V^{-1}	2.92E-07 V/V	100
Reproducibility	0.000 000 V	1.96E-07 V/V	normal A	1	1.96E-07 V/V	16
$R_{x\ 100/10} =$	9.999 987 4 V/V			$u(R) =$	1.39E-06 V/V	$\nu_{eff} = 190$

APPENDIX E

Participant uncertainty budgets for ratio 1000 V / 10 V

In the following the participants' uncertainty budgets for ratio 1000 V / 10 V are given. For a description of the methods of measurement see par. 5 of the main report.

IEN – pilot laboratory

The value of the ratio 1000 V / 10 V was derived from the basic ratios 1000 V / 100 V and 100 V / 10 V. The method and the equation of the measurement for ratio 1000 V / 100 V is the same as that for ratio 100 V / 10 V. The uncertainty budget of ratio 1000 V / 100 V was already given in Appendix E of [3] but is copied here for convenience.

Table E1. IEN relative uncertainty budget for ratio 1000 V / 100 V in units of 10^{-6}

Uncertainty component	Relative standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Relative standard uncertainty contribution $u_i(R)=c_i\, u(x_i)$	Degrees of freedom ν_i
$u_{r,A}$	0.031	gauss. / A	1	0.031	13
$u_r(\varepsilon)$	0.004	rect. / B	3	0.011	∞
$u_r(\gamma_1)$	0.004	rect. / B	9	0.036	∞
$u_r(\delta_C)$	0.001	rect. / B	3	0.003	∞
$u_r(\delta_D)$	0.002	rect. / B	3	0.007	∞
$u_r(\delta_L)$	0.002	rect. / B	3	0.005	∞
$u_r(\delta_S)$	0.003	rect. / B	3	0.010	∞
$u_r(\delta_G)$	0.003	rect. / B	3	0.010	∞
$\mathbf{R}_{1000/100}$				$u(R)$ = 0.052	ν_{eff} = 101

Table E2. IEN relative uncertainty budget for the ratio 1000 V / 10 V in units of 10^{-6}

Uncertainty component	Relative standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Relative standard uncertainty contribution $u_i(R)=c_i\, u(x_i)$	Degrees of freedom ν_i
$u(R_{1000/100})$	0.052	approx. gauss. / B	1	0.052	101
$u(R_{100/10})$	0.104	approx. gauss. / B	1	0.104	502
$\mathbf{R}_{1000/10}$				$u(R)$ = 0.116	ν_{eff} = 598

In Table E1, the meaning of the symbols is as follows:

u_A repeatability of the measurement
$u(\gamma_1)$ imperfect balance of the first section of the divider;
$u(\varepsilon)$ correction of linear drifts of the measurement system;
$u(\delta_C)$ imperfect lead compensation;
$u(\delta_D)$ fluctuations of the detector;
$u(\delta_G)$ gain error of the detector;
$u(\delta_L)$ imperfect electrical insulation and guarding;
$u(\delta_S)$ insufficient stabilisation time after application of the voltage.

SMU

The unknown divider is compared indirectly with a reference divider. The calibrator used to apply the input voltage to the unknown divider and the one used to compensate the corresponding output voltage are both calibrated, the first one by using the reference divider.

Table E3. SMU relative uncertainty budget for ratio 1000 V / 10 V

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Relative standard uncertainty contribution $u_i(R)$	Degrees of freedom ν_i
R_S	1.0000000					
δR	-0.00000054	$1.2 \cdot 10^{-6}$	rectangular	1	$1.2 \cdot 10^{-6}$	$3.4 \cdot 10^{7}$
δ_{RC}	0	$3 \cdot 10^{-7}$	rectangular	1	$3 \cdot 10^{-7}$	
δ_{NI}	0	$5 \cdot 10^{-8}$	rectangular	1	$5 \cdot 10^{-8}$	
δ_{LR}	0	$1 \cdot 10^{-8}$	rectangular	1	$1 \cdot 10^{-8}$	
δ_{TA}	0	$1 \cdot 10^{-8}$	rectangular	1	$1 \cdot 10^{-8}$	
δ_{SH}	0	$5 \cdot 10^{-8}$	rectangular	1	$5 \cdot 10^{-8}$	
R $_{1000/10}$	0.99999946				$u(R) = 1.2 \cdot 10^{-6}$	$\nu_{eff} = 3.4 \cdot 10^{7}$

Legend:

$R_{1000/10}$	The established dividing ratio relative to the nominal ratio
R_S	The relative nominal value of dividing ratio
δR	The dividing ratio deviation measured by calibrator and zero indicator
δ_{RC}	Correction to the calibrator stability
δ_{NI}	Correction to the precision of the zero indicator
δ_{LR}	Correction to the leakage
δ_{TA}	Correction to the ambient temperature change
δ_{SH}	Correction to the self heating

UME

The final result is weighted mean of the results obtained with two different methods: the measurement of the individual resistances of the divider's 100 V chain and the measurement of the individual voltage drops of the same chain. The final uncertainty is the weighted uncertainty of the two methods.

Table E4. UME Relative uncertainty budget for ratio 1000V/10V in units of 10^{-6}
(Method: measuring the individual resistors)

Quantity Xi	Estimate x_i	Relative standard uncertainty $(x_i).10^{-6}$	Probability distribution	Sensitivity coefficient	Relative uncertainty contribution $u_i(R)$ in 10^{-6}	Degrees of freedom v_i
$R_{DUT} = \sum_{i=1}^{10} \frac{R'_i}{R_1}$	99.999872	0.025	normal / A	1	0.025	13
Wavetek 4950 MTS @10kΩ	0	0.058	rectangular / B	1	0.058	1E+09
Wavetek 4950 MTS @100kΩ	0	0.058	rectangular/B	1	0.058	1E+09
Power coeff. of DUT(4902S)	0	0.144	rectangular/B	1	0.144	1E+09
$R_{1000/10}$	**99.999 872**				**$u(R)$ = 0.168**	**v_{eff}=26510**

Table E5. UME Relative uncertainty budget for ratio 1000V/10V in units of 10^{-6}
(Method: measuring of voltage drops on individual resistors)

Quantity Xi	Estimate x_i	Relative standard uncertainty $(x_i).10^{-6}$	Probability distribution	Sensitivity coefficient	Relative uncertainty contribution $u_i(R)$ in 10^{-6}	Degrees of freedom v_i
$R_{DUT} = \sum_{i=1}^{10} \frac{V_i}{V_1}$	99.999 852	0.023	normal / A	1	0.023	11
Wavetek 4950 MTS @100V	0	0.058	rectangular / B	1	0.058	1E+09
Wavetek 4950 MTS @10V	0	0.058	rectangular / B	1	0.058	1E+09
Stability of Calibrator@1000V	0	0.231	rectangular / B	1	0.231	1E+09
$R_{1000/10}$	**99.999 852**				**$u(R)$ = 0.246**	**v_{eff}=143937**

NMi-VSL

The unknown divider was compared with a Fluke 752A Reference Divider previously calibrated, by applying the same input voltage to both dividers and by measuring the voltage difference at the 10 V outputs.
The equation of the measurement is:

$$R_x = R_s - \frac{R_s \cdot F_{\det}}{V_{out}} \cdot \left(\Delta V + V_{off} + V_{lc}\right)$$

where:

R_x is the ratio of the unknown divider;
R_s is the ratio of the reference divider with its uncertainty resulting from non linearity;
V_{out} is the nominal output voltage of the dividers;
$F_{\det}$ is the calibration factor for the null detector reading;
ΔV is the null detector reading;
V_{off} is the uncompensated thermal offset voltage;
V_{lc} is the influence of the imperfect lead compensation.

Table E6. NMi-VSL absolute uncertainty budget for ratio 1000V/10V

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of eval. (A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(R)$	Degrees of freedom ν_i
R_s	100.000 000 V/V	2.89E-05 V/V	rectangular B	1	2.89E-05 V/V	100
ΔV	1.53E-5 V	5.77E-07 V	rectangular B	10.12 V^{-1}	5.84E-06 V/V	100
F_{det}	1.012	8.0E-03	rectangular B	3.0E-04 V/V	2.40E-06 V/V	100
V_{off}	0.000 000 V	2.89E-07 V	rectangular B	10.12 V^{-1}	2.92E-06 V/V	100
V_{lc}	0.000 000 V	5.77E-07 V	rectangular B	10.12 V^{-1}	5.84E-06 V/V	100
Reproducibility	0.000 000 V	1.46E-06 V/V	normal A	1	1.46E-06 V/V	15
$R_{x\ 1000/10}$ =	99.999 845V/V			$u(R)$ =	3.03E-05 V/V	ν_{eff} = 120

APPENDIX F
Optional measurements

Only NMi-VSL carried out measurements of the optional ratios 300 V / 10 V and 30 V / 10 V. In the following the degrees of freedom will not be used, because they are quite high and do not have significant influence on the coverage factor.

Ratio 300 V / 10 V

The error ε due to deviations from standard ambient conditions is reported in Table F1, with the usual meaning of the symbols. The temperature and humidity coefficients used are those reported in Table 2 of the main report. For IEN the error ε is null because the interpolation of the IEN results is carried out on the corrected measurements.

Table F1. Ratio 300 V / 10 V: error due to temperature and humidity

Lab	Date	T (°C)	δT (°C)	H (%)	δH (%)	$\varepsilon (T, H)$ (10^{-6})	$u(\varepsilon)$ (10^{-6})
NMi-VSL	20/02/04	22.5	0.5	41	3	0.105	0.052
IEN	-	23.2	0.5	36	5	0	0.052

Table F2 reports the evaluation of the difference Δ of NMi-VSL with respect to the pilot laboratory and the evaluation of the global standard uncertainties u_G of NMi-VSL and IEN. The meaning of the symbols is the same as for Tables 4 and 7 in the main report.

Table F2. Ratio 300 V / 10 V. Result and difference from pilot laboratory

Lab	t (d)	d (10^{-6})	d_0 (10^{-6})	$d_{0,P}$ (10^{-6})	Δ (10^{-6})	u_A (10^{-6})	u_B (10^{-6})	$u(\varepsilon)$ (10^{-6})	s (10^{-6})	u_G (10^{-6})
NMi-VSL	177	-2.47	-2.575	-1.816	-0.759	0.12	1.292	0.052	0.060	1.300
IEN	-	-	-	-	0	0.047	0.104	0.052	0.019	0.127

Fig. F1 shows the result of NMi-VSL corrected to standard ambient conditions, d_0, with corresponding global standard uncertainty u_G , compared with the corrected IEN measurements.

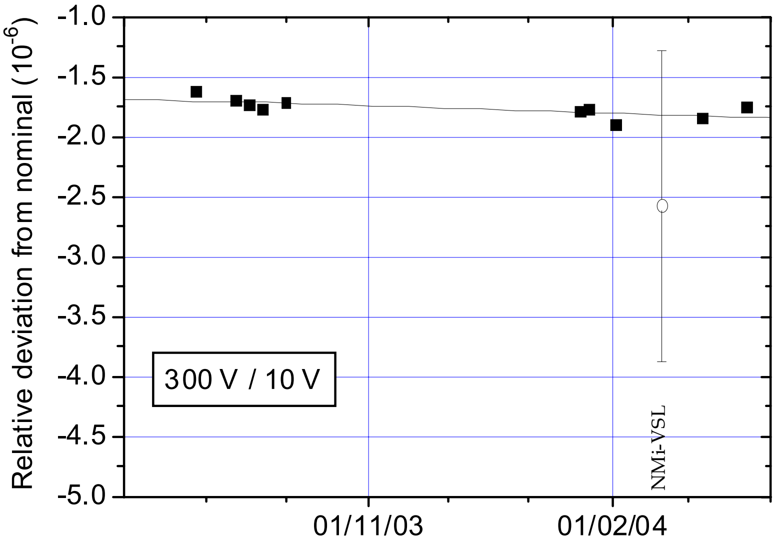


Fig. F1. Ratio 300 V / 10 V: result of NMi-VSL, corrected to standard ambient conditions, corresponding global standard uncertainty and linear interpolation of the corrected IEN measurements.

The agreement between the result of NMi-VSL and the one of the pilot laboratory can be evaluated in terms of compatibility index I_C. This index is defined as:

$$I_C = \frac{\Delta_{\text{NMi-VSL}} - \Delta_{\text{IEN}}}{U(\Delta_{\text{NMi-VSL}} - \Delta_{\text{IEN}})} \qquad \text{(F1)}$$

where $U(\Delta_{\text{NMi-VSL}} - \Delta_{\text{IEN}})$ is the expanded uncertainty (95% confidence level) of the difference between the two values. A coverage factor k=2 will be used. The measurements of the two laboratories are not correlated. It is found:

$$I_C = \frac{-0.759 - 0}{2\sqrt{1.300^2 + 0.127^2}} = -0.29 \qquad \text{(F2)}$$

Ratio 30 V / 10 V

The error ε due to deviations from standard ambient conditions is reported in Table F3, with the usual meaning of the symbols. The temperature and humidity coefficients used are those reported in Table 2 of the main report. For IEN the error ε is null because the interpolation of the IEN results is carried out on the corrected measurements.

Table F3. Ratio 30 V / 10 V: error due to temperature and humidity

Lab	Date	T (°C)	δT (°C)	H (%)	δH (%)	$\varepsilon(T, H)$ (10^{-6})	$u(\varepsilon)$ (10^{-6})
NMi-VSL	20/02/04	22.5	0.5	41	3	0.051	0.020
IEN	-	23.7	0.5	48	5	-	0.025

Table F4 reports the evaluation of the difference Δ of NMi-VSL with respect to the pilot laboratory and the evaluation of the global standard uncertainties u_G of NMi-VSL and IEN. The meaning of the symbols is the same as for Tables 4 and 7 in the main report.

Table F4. Ratio 30 V / 10 V. Results and differences from pilot laboratory

Lab	t (d)	d (10^{-6})	d_0 (10^{-6})	$d_{0,P}$ (10^{-6})	Δ (10^{-6})	u_A (10^{-6})	u_B (10^{-6})	$u(\varepsilon)$ (10^{-6})	s (10^{-6})	u_G (10^{-6})
NMi-VSL	177	-1.58	-1.631	-1.442	-0.189	0.065	0.182	0.020	0.075	0.208
IEN	-	-	-	-	0	0.031	0.112	0.025	0.024	0.121

Fig. F2 shows the result of NMi-VSL, corrected to standard ambient conditions, d_0, with corresponding global standard uncertainty u_G , compared with the corrected IEN measurements.

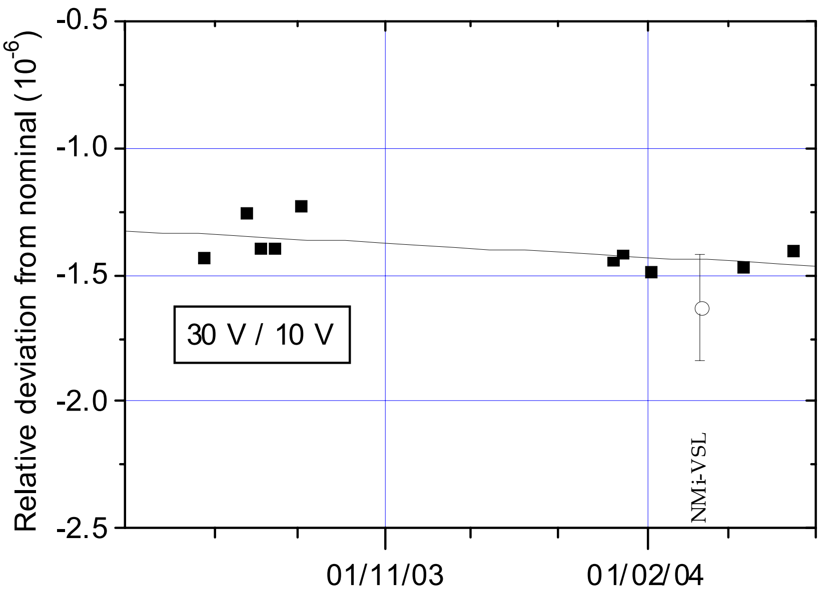


Fig. F2. Ratio 30 V / 10 V: result of NMi-VSL, corrected to standard ambient conditions, corresponding global standard uncertainty and linear interpolation of corrected IEN measurements.

Also in this case the agreement between NMi-VSL and pilot laboratory will be evaluated in terms of compatibility index I_C, adopting a coverage factor k=2. It is found:

$$I_C = \frac{-0.189 - 0}{2\sqrt{0.208^2 + 0.121^2}} = -0.39 \quad \text{(F3)}$$

APPENDIX G

Comparison protocol and schedule

G1) Technical Protocol
G2) Schedule
G3) Contact Persons

G1) Technical Protocol

EUROMET.EM-K8.1: COMPARISON OF DC VOLTAGE RATIO – FOLLOW-UP

Technical protocol

(September 23, 2003)

Purpose, participation and schedule

After approval of the Draft A report of EUROMET.EM-K8 by the participants, it was decided to organise a follow-up comparison to allow some participants to improve their results. The Istituto Elettrotecnico Nazionale (IEN, Italy), already pilot laboratory and co-ordinator of CCEM-K8 and EUROMET-K8, will also coordinate this follow-up and will assure the link with CCEM-K8, in order to evaluate the degrees of equivalence of the participants. The agreed schedule of the comparison is reported in Annex A. The list of the participant laboratories, the addresses of their contact persons and those for dispatching the travelling standard are reported in Annex B.

This protocol is essentially equivalent to the protocol of EUROMET-K8, but includes some improvements and better specifications. As the previous one, it is in agreement with the BIPM "Guidelines for CIPM key comparisons".

Travelling standard and uncertainty requirement

The travelling standard is the Datron 4902S voltage divider (s/n 20335) already used for the CCEM-K8 main exercise. It has dimensions 132x433x327 mm and a weight of 5 kg. This instrument can divide the maximum input voltage of 1000 V in multiples of 10 V, up to 100 V, and in multiples of 100 V up to 900 V. Adjustment trimmers are provided on the instrument, but they will be sealed. We do not intend to adjust the trimmers during the comparison.

The ratios to be measured are

- 1000 V / 10 V
- 100 V / 10 V

and, optionally

- 300 V / 10 V
- 30 V / 10 V

The goal of the comparison is to achieve, for the ratios 1000 V / 10 V and 100 V / 10 V, a relative standard uncertainty (combined type A and type B) of $5 \cdot 10^{-7}$ or less at k= 1 coverage factor.

The characterisation of the travelling standard has shown that, at this accuracy level, its temperature and humidity coefficients are not negligible, while drift in time and transport effects, if the standard is handled with care, are very low.

The circulation of the travelling standard

Given the experience already gained with the use of the travelling standard, in this follow-up each laboratory will have only two weeks to carry out the measurements and is expected to ship the standard to the next laboratory allowing less than one week for travel.

The laboratory's results should be sent to IEN within 30 days from the end of its measurements. If unforeseen circumstances prevent a laboratory from carrying out its measurements within the time allotted, it should contact the pilot laboratory to agree about a change in schedule.

A very solid enclosure, fitted with a digital thermometer / hygrometer, is provided for the divider so that it can be shipped as freight. This enclosure has dimensions 70x70x40 cm and a weight of about 30 kg, including the divider. Extreme temperatures or pressure changes as well as violent impacts should be avoided. After arrival the divider should be allowed to stabilise in a temperature and, possibly, humidity controlled room for at least three days before use. With the divider, a copy of its instruction manual, this technical protocol, a protective plexiglas plate for measurements on the 100 V sections and a number of forms, both on paper and in electronic version, will be sent. Each arrival and departure of the standard must be communicated to the pilot laboratory using the forms provided. While shipping the standard, the shipping checklist form should be carefully followed in order to include all the material received. Annex C should help the participant laboratory in following the right sequence of operations.

In case of damage or evident malfunctioning of the divider, the laboratory will report immediately to the pilot laboratory, which will give specific instructions.

The divider will normally be accompanied by an ATA carnet for non European-Union countries. As usual each participant laboratory is responsible for its own costs for the measurements, transportation and any customs charges as well as for any damage that may occur within its country.

Conditions and methods of measurement

The required and the optional ratios should be measured at the corresponding voltage terminals of the divider. All ratios should be measured at the nominal powers corresponding to the voltage ratio being measured.

The standard ambient condition for measurements is

temperature:	(23 ± 0.5) °C
relative humidity:	45% ± 5%

Room temperatures in the range (20 - 25) °C may also be used, while relative humidity should never exceed 70%. Corrections for deviations of temperature and humidity from the above standard condition will be applied by the pilot laboratory, which will also add the corresponding contribution to the uncertainty.

Any method can be used for calibrating the ratios, provided it is described in the measurement report. To allow enough time for the divider to stabilise following the application of the voltage, waiting times of 5 and 10 minutes respectively should be used when measuring the ratios 100 V / 10 V and 1000 V / 10 V; the actual waiting times must be reported. When measuring on 100 V sections, the given plexiglass plate preventing accidental access to the 10 V sections must be used.

Before the beginning of this follow-up comparison, the pilot laboratory has regulated some of the trimmers of the divider, to change the deviation from nominal of the ratios with respect to the values of the CCEM-K8 follow-up. These trimmers are covered by a tape and must not be touched in any way during the comparison.

Measurement uncertainty

For the mandatory ratios, all contributions to the uncertainty must be listed in an uncertainty budget organised in a table. A template for such a table is given in Appendix 1. The uncertainty calculations should be carried out according to the ISO "Guide to the expression of uncertainty in measurement" for a coverage factor k=1. The number of degrees of freedom must be reported.

Even though some contributions to the uncertainty are specific to each method of measurement, it may be useful to consider the following list to try to assure more comparable uncertainty evaluations. In the following list not all contributions apply to all methods:

1) reference divider
2) detector calibration
3) uncompensated voltage offset
4) poor lead compensation
5) stability of sources or reference voltages
6) leakage resistance
7) heating effects
8) reproducibility

The pilot laboratory will evaluate the contributions to the uncertainty from temperature and humidity, due both to their instability and to the corrections for reducing the results to the standard condition. The effect of pressure on the divider has been estimated negligible. The effect of leakage in the divider should be negligible if the guard circuit of the instrument is used.

Measurement reports of the laboratories

Within 30 days after finishing the measurements a report should be sent to the pilot laboratory. An early report helps in evaluating the behaviour of the travelling standard. A summary-of-results form is given in order to help summarising the essential information: it must be included in the report. In case of unforeseen difficulties, a preliminary and simplified report should be sent within 30 days to the pilot laboratory, while a conclusive report, which supersedes the previous one, should be sent within 60 days. The report should contain:

- a description of the method;
- the condition of measurement: values of temperature, humidity, pressure, with their limits of variation;
- the waiting times after application of the voltage;
- the results, with associated standard uncertainties (k = 1) and number of degrees of freedom, using the summary-of-results form;
- the detailed uncertainty budget for the two mandatory ratios, using the given templates.

Final report of the follow-up comparison

At the conclusion of the comparison, the pilot laboratory will prepare a short Draft A report, to be considered as an addendum with respect to the EUROMET.EM-K8. Draft A, which is confidential, will be sent to the participants for approval, at which time it will become Draft B and will be sent to the comparison support group together with a document reporting the link with respect to the main CCEM-K8 exercise. This link will be assured by the pilot laboratory.
The final report will be sent to the Euromet Electricity and Magnetism TC chairman, who will submit it to the CCEM Working Group on Low Frequency for final approval and publication of the results in the Key Comparison Data Base.

Co-ordinator and communications

The person responsible for the pilot laboratory is:

GianCarlo Marullo Reedtz — ph: +39 011 3919421
IEN — *fax: +39 011 346384*
Electrical Metrology — *e-mail: marullo@ien.it*
Strada delle Cacce 91
I 10135, Torino
Italy

Communication by e-mail is most welcome.

List of the Appendixes, Annexes and enclosed Forms

Appendix 1: Tables for uncertainty budgets
Appendix 2: Summary-of-results form
Annex A: Schedule
Annex B: Participants
Annex C: Timing

Enclosed Forms:

Receiving the standard Form
Shipping the standard Form for pilot
Shipping the standard Form for next laboratory
Shipping the standard checklist Form
Receiving the standard checklist Form

G2) Schedule

Period	Laboratory	Country
September 2003	**Pilot - Italy**	
October 6, 2003 – October 17, 2003	**CMI**	**Czech Republic**
October 27, 2003 – November 7, 2003	**SMU**	**Slovakia**
November 17, 2003 – November 28, 2003	**UME**	**Turkey**
December 2003	**Pilot - Italy**	
January 19, 2003 – January 30, 2003	**NMi-VSL**	**Netherlands**
February 2003	**Pilot - Italy**	

G3) Contact Persons

IEN, Italy (Pilot laboratory) **Mr. Giancarlo Marullo Reedtz** IEN, Electrical Metrology Strada delle Cacce 91 I 10135, TORINO ITALY	**NMi-VSL, The Netherlands** **Mr. Roland van Bemmelen** Nmi - Van Swinden Laboratorium PO Box 654, 2600 AR DELFT THE NETHERLANDS
CMI, Czech Republic **Mr. Jiri Streit** Czech Metrology Institute Okruzní 31 638 00 BRNO CZECH REPUBLIC	UME, Turkey **Ms. Saliha TURHAN** TÜBİTAK Ulusal Metroloji Enstitüsü(UME) PO Box 54 41470 GEBZE - KOCAELİ TURKEY
SMU, Slovakia **Dr. Peter Vrabcék** Director of Electricity Centre Slovak Institute of Metrology- SMU Karloveská 63 842 55 BRATISLAVA SLOVAKIA	