Istituto Elettrotecnico Nazionale Galileo Ferraris

FINAL REPORT OF CCEM-K8.1
COMPARISON OF DC VOLTAGE RATIO

Giancarlo Marullo Reedtz and Roberto Cerri

Electrical Metrology Department
Istituto Elettrotecnico Nazionale G. Ferraris
Strada delle Cacce 91, I-10135, Torino, Italy

IEN Technical Report 678

May 2004

Table of Contents

1. Introduction

Comparison CCEM-K8 of DC voltage ratio was finalised in January 2003, with publication of the final report and of the tables of the degrees of equivalence in the Key Comparison Data Base [1]. In the mean time a follow-up comparison was organised, open to those participants in CCEM-K8 willing to improve their results. This comparison was named CCEM-K8.1.

The same travelling standard as in CCEM-K8, a Datron 4902S resistive divider, s/n 20335, was used in this comparison, but 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 [1]. A technical protocol similar to the one of CCEM-K8 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

Two National Metrology Institutes, CEM from Spain and CSIR-NML from South Africa, agreed to participate in comparison CCEM-K8.1. As for CCEM-K8, the comparison was co-ordinated by 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.

After receiving the measurement report from CSIR, their ratio values being quite far from those obtained by the pilot laboratory, CSIR was requested to carefully check their results. After some time and before the Draft A report was released, CSIR asked to withdraw from the comparison. Then, in the following, only the results of CEM will be reported.

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	17 Jul 2002 to 13 Nov 2002	-	Adjustment and initial measurements
CEM	Centro Espanol de Metrologia	Spain	15 Nov 2002 to 4 Dec 2002	25 Nov 2002	
IEN	Pilot	Italy	6 Dec 2002 to 17 Jan 2003	-	
CSIR	Council for Scientific and Industrial Research - National Measurement Laboratory	South Africa	28 Jan 2003 to 17 Feb 2003	5 Feb 2003	Temperature excursion from -8 °C to +40 °C during travel back to IEN
IEN	Pilot	Italy	25 Feb 2003 to 1 Apr 2003	-	Final measurements

3. Behaviour of the travelling standard

The divider's trimmers were regulated on 17 July 2002 and the behaviour of the different ratios was monitored up to the beginning of November 2002, when the standard was shipped to CEM. During this time and during the following comparison the divider has been drifting quite regularly as shown in Fig.1. During the last travel from CSIR to IEN, the divider was submitted to a quite strong thermal shock, from -8°C to +40°C, apparently without significant effects on the values of the ratios.

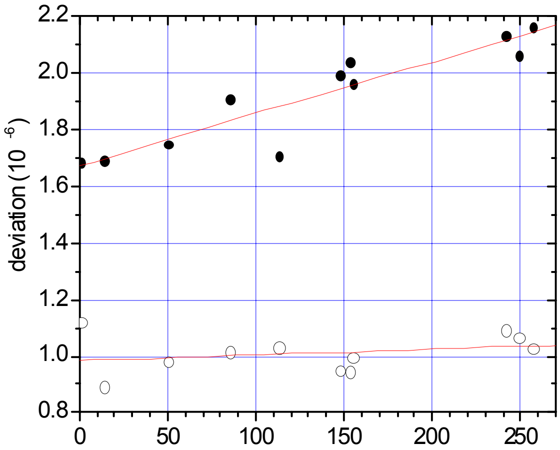


Fig.1. Behaviour of the basic ratios of the travelling standard, from the measurements of the pilot laboratory reduced to standard ambient conditions. Ratio 1000 V / 100 V: open circles. Ratio 100 V / 10 V: closed circles. Days are counted starting on 18 July 2002

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

As in CCEM-K8, 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 [1].

Table 2. Temperature and humidity coefficients from [1], values "after".

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})
$1000/10_{\text{after}}$	-0.0259	0.0155	-0.0015	0.0013	2.687	0.040	0.00191	0.00025	0.072
$100/10_{\text{after}}$	-0.2135	0.0140	-0.0095	0.0012	1.673	0.042	0.00183	0.00026	0.076
$300/10_{\text{after}}$	-0.1665	0.0172	-0.0055	0.0014	2.106	0.054	0.00209	0.00034	0.097
$30/10_{\text{after}}$	-0.0351	0.0119	-0.0075	0.0010	2.741	0.038	0.00215	0.00024	0.068

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 July 18th, 2002. 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 CCEM-K8. 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.

CEM

Differently from CCEM-K8 [1], the method used in this comparison was based on the measurement of the voltage ratios of successive sections of the divider using a dual source bridge, as shown in Figure 2. The voltage sources are two high accuracy DC calibrators. In the normal process of calibration at CEM, all the successive 10 V / 10 V and 100 V / 100 V ratios are measured with the described method. Due to the short time available for the comparison follow up, an abbreviated procedure was used, measuring only the following ratios: $r_1 = R_1/R_2$, $r_2 = R_2/R_3$, $r_3 = (R_2+R_3)/(R_4+R_5)$ and $r_4 = (R_1+R_2+R_3+R_4+R_5)/(R_6+R_7+R_8+R_9+R_{10})$. Combining these measurements, it is possible to evaluate the mandatory ratios (100 V / 10 V and 1000 V / 10 V) and additionally the optional ratios 30 V / 10 V and 300 V / 10 V. The measurements are repeated after interchanging the voltage sources.

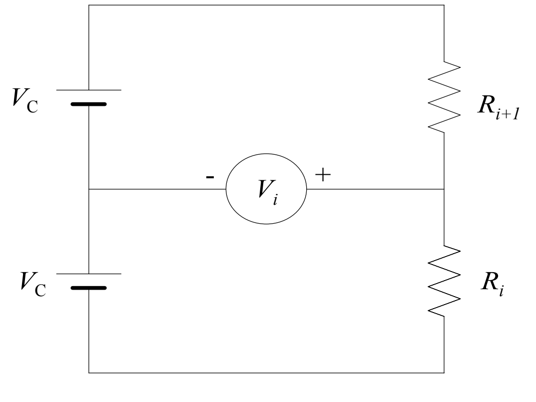


Fig. 2. Scheme of the measurement system used at CEM

CEM has reported that a comparison with their reference divider was also carried out. The travelling standard and the CEM reference divider (another Datron 4902S) were successively connected to a DC calibrator and their 10 V outputs were compared with a 10 V Zener reference. However, the measurements by this method were not reported, due to a drift change in the ratio value of the reference divider.

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. (2) 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})
CEM	25/11/2002	23.9	0.2	38	2	-0.013	0.017
IEN	-	22.6	0.5	42.6	5	0	0.011

Table 4 reports: the time t of the measurements in days, starting from 18 July 2002; 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 $d_{0,\mathrm{P}}$, given by eq. (1) with parameters D_0 and C_D from Table 2; the difference $\Delta = (d_0 - d_{0,\mathrm{P}})$; 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 = 11 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.

The uncertainty budget of each laboratory is given in Appendix E. The uncertainty budget of IEN is the same as in comparison CCEM-K8 [1].

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

Lab	t (d)	d (10^{-6})	d_0 (10^{-6})	$d_{0,\mathrm{P}}$ (10^{-6})	Δ (10^{-6})	u_A (10^{-6})	u_B (10^{-6})	$\nu_{\mathrm{A,B}}$	$u(\varepsilon)$ (10^{-6})	ν_ε	s (10^{-6})	ν_s	u_G (10^{-6})	ν_G
CEM	130	3.340	3.353	2.935	0.418	0.029	0.155	>10^4	0.017	2	0.072	9	0.174	296
IEN	-	-	-	-	0	0.053	0.104	598	0.011	2	0.022	9	0.119	590

Fig. 3 shows a plot of the corrected CEM result, $d_{0,\mathrm{CEM}}$, with corresponding global standard uncertainty u_{G}, compared with the linear fit of the corrected IEN measurements.

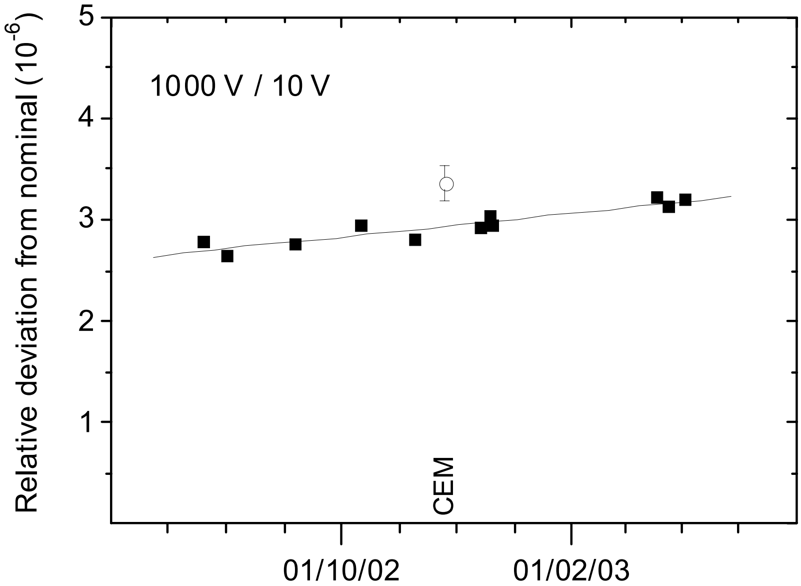


Fig. 3. Ratio 1000 V / 10 V: CEM result, corrected to standard ambient conditions, corresponding global standard uncertainty and linearly interpolated IEN results.

b) Degree of equivalence with respect to the KCRV

To compare the result of CEM in CCEM-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, which has participated in CCEM-K8.1, and the corresponding reference value R_{F}, and $D_{i,\mathrm{K}}$ is the estimate of the difference between the result of the same laboratory and the KCRV, R_{K}, we can write:

$$D_{i,\mathrm{K}} = D_i + (R_{\mathrm{F}} - R_{\mathrm{K}}) = \Delta_i - \Delta_{\mathrm{IEN}} + (\Delta_{\mathrm{IEN,\,K}} - R_{\mathrm{K}}), \tag{2}$$

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

The standard uncertainty associated with $D_{i,\mathrm{K}}$ is given by:

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

where $u_{\mathrm{G},i}$ 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:

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

where the index K refers to comparison CCEM-K8. The contributions $s_{\mathrm{IEN,K}}$ 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. $u_{\mathrm{IEN,A}}$ 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.

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 degree of equivalence of CEM with the corresponding standard uncertainty, the degrees of freedom and the expanded uncertainty $U(D_{i,K})$. In the calculation of $U(D_{i,K})$, the expansion factor is evaluated for a probability of 95%.

Table 5. Ratio 1000 V / 10 V. Values for calculation of eqs. (2), (3) and (4)

$\Delta_{\mathrm{IEN,K}}$ (10^{-6})	R_{K} (10^{-6})	$u(R_{\mathrm{K}})$ (10^{-6})	$\nu_{R_{\mathrm{K}}}$	$s_{\mathrm{IEN,K}}$ (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	-0.048	0.062	11	0.018	22	0.053	25	0.010	3	0.081	65

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})
CEM	0.466	0.202	324	0.398

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. (2) 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})
CEM	25/11/2002	23.9	0.2	38	2	-0.126	0.031
IEN	-	22.6	0.5	42.7	5	0	0.068

Table 7 reports: the time t of the measurements in days, starting from 18 July 2002; 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 $d_{0,\mathrm{P}}$, 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 = 11 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.

The uncertainty budget of the laboratories is given in Appendix D. The uncertainty budget of IEN is the same as in comparison CCEM-K8 [1].

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
CEM	130	1.937	2.063	1.911	0.152	0.011	0.116	>10^4	0.031	2	0.076	9	0.142	100
IEN	-	-	-	-	0	0.043	0.095	502	0.068	2	0.023	9	0.126	23

Fig. 4 shows a plot of the corrected CEM result, $d_{0,CEM}$, with corresponding global standard uncertainty u_G, compared with the linear fit of the corrected IEN measurements.

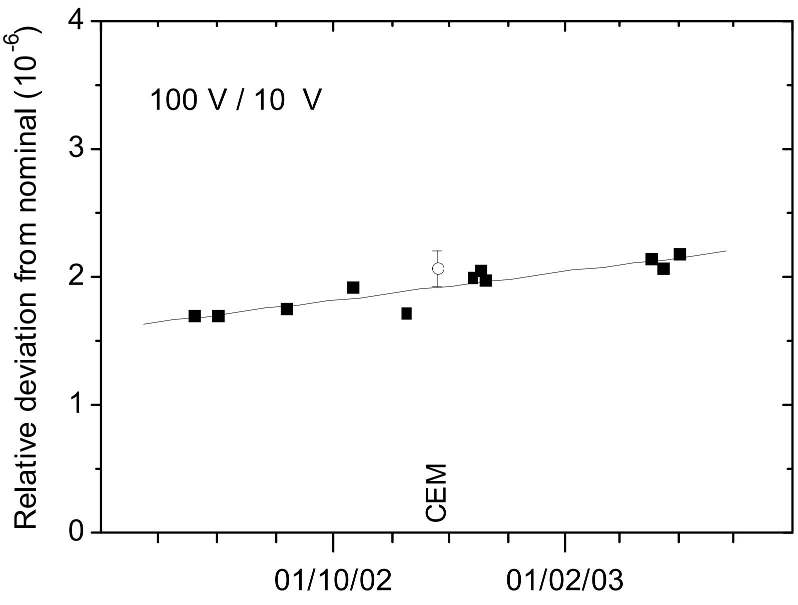


Fig. 4. Ratio 100 V / 10 V: CEM result, corrected to standard ambient conditions, corresponding global standard uncertainty and linearly interpolated IEN results.

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)

$\Delta_{\mathrm{IEN,K}}$ (10^{-6})	R_{K} (10^{-6})	$u(R_{\mathrm{K}})$ (10^{-6})	$\nu_{R_{\mathrm{K}}}$	$s_{\mathrm{IEN,K}}$ (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	-0.050	0.083	12	0.016	22	0.043	14	0.070	12	0.118	14

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})
CEM	0.202	0.203	76	0.404

8. Bilateral degrees of equivalence

The bilateral degrees of equivalence between a laboratory *i* participating in CCEM-K8.1 and any other laboratory *j*, participating in comparisons CCEM-K8 or EUROMET.EM-K8 [2], 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 three terms: the global standard uncertainty of laboratory *i*, the transfer standard uncertainty from CCEM-K8.1 to the other comparison and the global standard uncertainty of laboratory *j*.

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

9. Conclusions

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

In order to evaluate the new degrees of equivalence of the other participant, CEM, its 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 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

[2] 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

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})
1.005	19/07/02	21.9	58.0	1.118	1.794	19/07/02	21.9	58.0	1.683
0.975	01/08/02	23.2	50.1	0.893	1.654	01/08/02	22.9	49.9	1.690
1.045	06/09/02	23.2	49.0	0.981	1.704	06/09/02	22.9	52.0	1.749
1.143	11/10/02	23.2	57.6	1.015	1.768	11/10/02	23.0	58.9	1.906
0.816	08/11/02	22.3	34.6	1.032	2.019	08/11/02	22.1	31.4	1.706
0.693	13/12/02	22.1	34.0	0.951	2.270	13/12/02	22.1	35.6	1.993
0.863	18/12/02	22.8	39.0	0.947	2.184	18/12/02	22.6	38.6	2.040
0.863	20/12/02	22.7	34.9	0.997	2.107	20/12/02	22.8	34.6	1.962
0.900	17/03/03	22.6	29.7	1.093	2.347	17/03/03	22.6	29.9	2.129
0.895	24/03/03	22.6	32.0	1.066	2.257	24/03/03	22.6	32.4	2.063
1.014	01/04/03	22.8	49.1	1.027	2.181	01/04/03	22.8	48.4	2.164

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})
0.585	19/07/02	21.9	58.0	0.591	2.684	19/07/02	21.9	58.0	2.743
0.388	01/08/02	23.2	50.1	0.358	2.748	01/08/02	22.9	49.9	2.783
0.408	06/09/02	23.2	49.0	0.384	2.706	06/09/02	22.9	52.0	2.755
0.489	11/10/02	23.2	57.6	0.434	2.896	11/10/02	23.0	58.9	3.001
0.334	08/11/02	22.3	34.6	0.408	3.034	08/11/02	22.1	31.4	2.902
0.331	13/12/02	22.1	34.0	0.417	3.222	13/12/02	22.1	35.6	3.121
0.383	18/12/02	22.8	39.0	0.415	3.231	18/12/02	22.6	38.6	3.170
0.388	20/12/02	22.7	34.9	0.440	3.146	20/12/02	22.8	34.6	3.061
0.473	17/03/03	22.6	29.7	0.549	3.408	17/03/03	22.6	29.9	3.282
0.465	24/03/03	22.6	32.0	0.531	3.304	24/03/03	22.6	32.4	3.197
0.539	01/04/03	22.8	49.1	0.535	3.276	01/04/03	22.8	48.4	3.293

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})
2.799	19/07/02	21.9	58.0	2.790	2.379	19/07/02	21.9	58.0	2.268
2.629	01/08/02	23.1	50.0	2.639	2.042	01/08/02	23.1	50.0	2.085
2.749	06/09/02	23.0	50.5	2.758	2.112	06/09/02	23.0	50.5	2.149
2.911	11/10/02	23.1	58.2	2.934	2.257	11/10/02	23.1	58.2	2.348
2.835	08/11/02	22.2	33.0	2.796	2.353	08/11/02	22.2	33.0	2.154
2.962	13/12/02	22.1	34.8	2.923	2.601	13/12/02	22.1	34.8	2.394
3.047	18/12/02	22.7	38.8	3.029	2.567	18/12/02	22.7	38.8	2.483
2.970	20/12/02	22.7	34.8	2.947	2.495	20/12/02	22.7	34.8	2.394
3.247	17/03/03	22.6	29.8	3.214	2.820	17/03/03	22.6	29.8	2.672
3.152	24/03/03	22.6	32.2	3.123	2.722	24/03/03	22.6	32.2	2.590
3.195	01/04/03	22.8	48.8	3.195	2.720	01/04/03	22.8	48.8	2.702

APPENDIX B

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

Key comparison CCEM-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 x0,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 difference $d_{0,\mathrm{IEN}}$, assigned by IEN to the ratio, is obtained by interpolation of the IEN measurement results to the measurement date of the participant laboratory.

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

$u_{\mathrm{G},i}$: 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}	$u_{\mathrm{G},i}$ / 10^{-6}	$\nu_{\mathrm{eff},i}$	Mean date of measurements
CEM	3.35	2.94	0.42	0.17	296	2002/11/25
IEN	-	-	0.00	0.12	590	-

Key comparison CCEM-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:

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

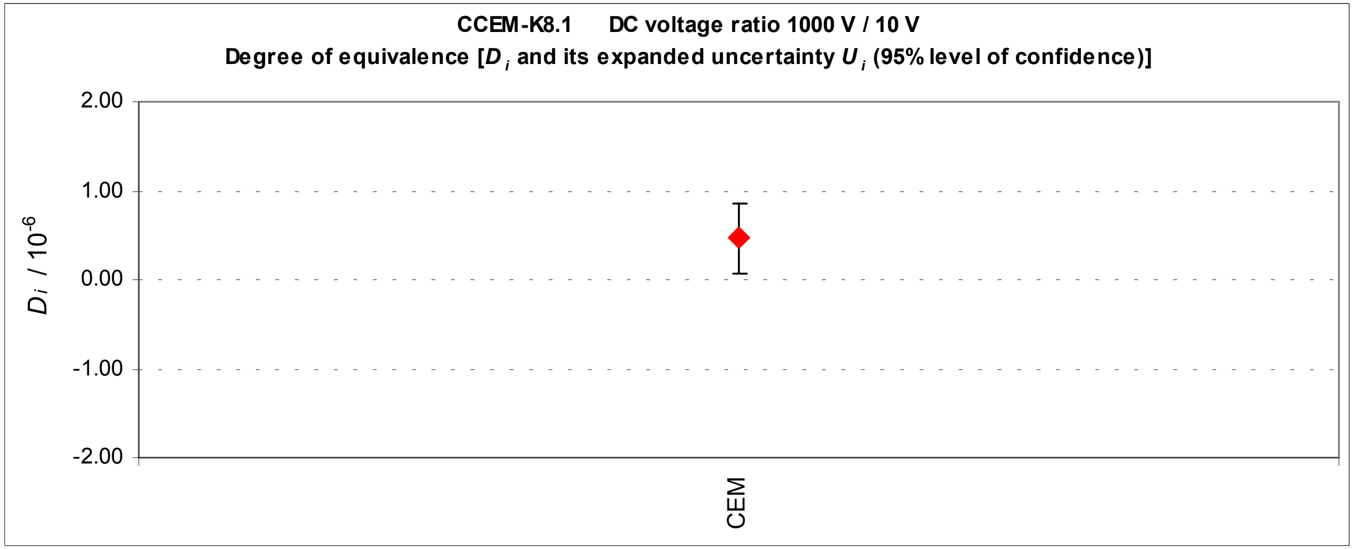
$$u(D_i) = (u^2_{G.i} + u^2_{transfer} + u^2(\Delta_R))^{1/2}$$

where $u_{transfer}$ represents the standard uncertainty of the link to CCEM-K8, evaluated in the final report as $u_{transfer} = 0.08\times10^{-6}$. The degrees of freedom are taken into account 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 95% uncertainty given, within an approximation of 5% or better, 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.

Degrees of equivalence for CCEM-K8.1

Lab i	D_i /10^{-6}	U_i /10^{-6}
CEM	0.47	0.40


CCEM-K8.1 DC voltage ratio 1000 V / 10 V
Degree of equivalence [D i and its expanded uncertainty U i (95% level of confidence)]
2.00
1.00
0.00
-1.00
-2.00
Di / 10-6
CEM

APPENDIX C

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

Key comparison CCEM-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 x (1 + $d_{0,i}$)
The fractional difference $d_{0,\mathrm{IEN}}$, assigned by IEN to the ratio, is obtained by interpolation
of the IEN measurement results to the measurement date of the participant laboratory.

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

$u_{\mathrm{G},i}$: 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}	$u_{\mathrm{G},i}$ / 10^{-6}	$\nu_{\mathrm{eff},i}$	Mean date of measurements
CEM	2.06	1.91	0.15	0.14	100	2002/11/25
IEN	-	-	0.00	0.13	23	-

Key comparison CCEM-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:

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

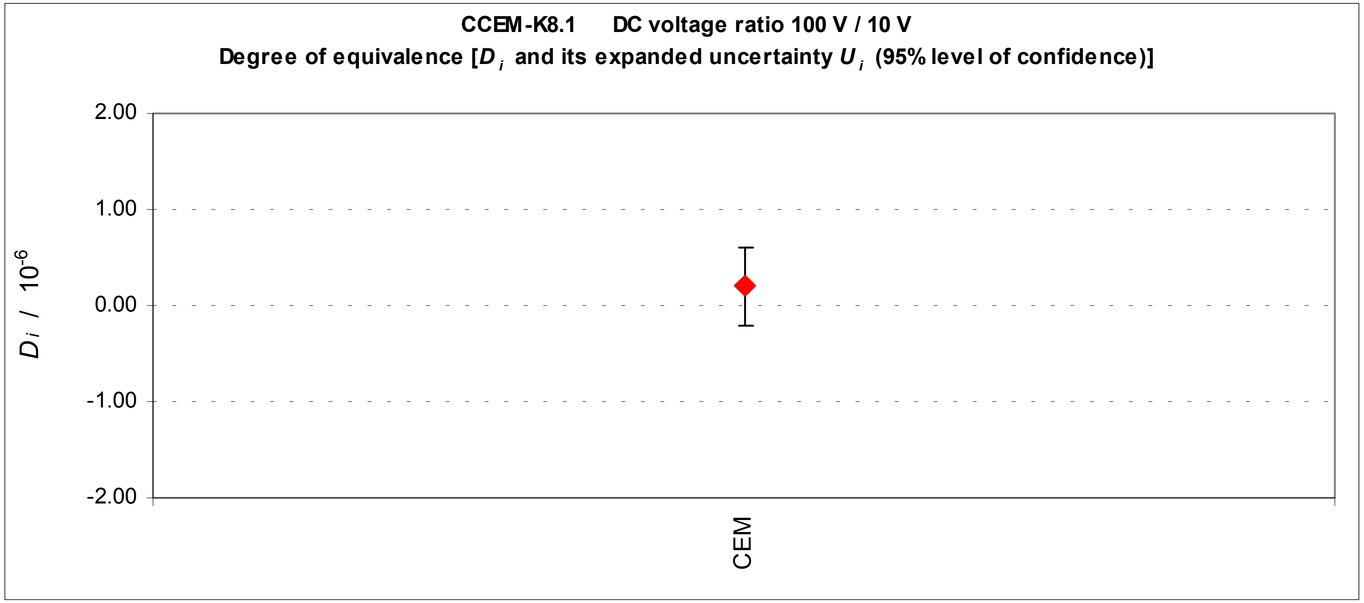
$$u(D_i) = (u^2_{G.i} + u^2_{transfer} + u^2(\Delta_R))^{1/2}$$

where $u_{transfer}$ represents the standard uncertainty of the link to CCEM-K8, evaluated in the final report as $u_{transfer} = 0.12\times10^{-6}$. The degrees of freedom are taken into account 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 95% uncertainty given, within an approximation of 10% or better, 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.

Degrees of equivalence for CCEM-K8.1

Lab *i*	D_i $/10^{-6}$	U_i $/10^{-6}$
CEM	0.20	0.40


CCEM-K8.1 DC voltage ratio 100 V / 10 V
Degree of equivalence [D_i and its expanded uncertainty U_i (95% level of confidence)]
2.00
1.00
0.00
-1.00
-2.00
D_i / 10^{-6}
CEM

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 main report.

IEN – pilot laboratory

The equation of the measurement is reported in Appendix D of [1]. The uncertainty budget is also given in [1] 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	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	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
$u(\gamma_l)$ 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.

CEM

The mathematical model equation of the measurement is:

$$r_{100-10} = 10\left(\begin{matrix} 1 + \frac{4}{5}\left(\overline{\delta}_1 + \delta_{1stsb} + \delta_{1cab}\right) + \frac{2}{5}\left(\overline{\delta}_2 + \delta_{2stab} + \delta_{2cab}\right) + \frac{2}{5}\left(\overline{\delta}_3 + \delta_{3stab} + \delta_{3cab}\right) + \\ \frac{1}{2}\left(\overline{\delta}_4 + \delta_{4stab} + \delta_{4cab}\right) + \delta_{leak} + \delta_{cont} \end{matrix}\right) \quad \text{(D1)}$$

where the meaning of the symbols is:
r_{100-10}: Ratio 100 V: 10 V of the travelling standard.

$\overline{\delta_i}$: Average of the relative deviations of the ratio *i*.
δ_{istab}: Correction of the ratio *i* due to insufficient stabilisation time.
δ_{icab}: Correction of the ratio *i* due to imperfect cable compensation.
δ_{leak}: Correction of the ratio *i* due to leakage across insulation.
δ_{cont}: Correction of the ratio *i* due to contact resistance.

The terms δ_{leak} and δ_{cont} are corrections due to collective effects, being the other terms sources of error in the measurements of the individual ratios. The uncertainty budget is expressed in Table D2:

Table D2. CEM absolute uncertainty budget for the ratio 100 V / 10 V

Quantity X_i	Estimate x_i ($\times 10^{-6}$)	Standard uncertainty ($\times 10^{-6}$)	Probability distribution / method of evaluation	Sensitivity coefficient c_i	Standard uncertainty contribution ($\times 10^{-6}$)	Degrees of freedom ν_i
$\overline{\delta_1}$	4.73	0.010	Gauss/A	8	0.080	∞
δ_{1stab}	0	0.006	Rectangular/B	8	0.048	∞
δ_{1cab}	0	0.05	Rectangular/B	8	0.020	∞
$\overline{\delta_2}$	-0.10	0.010	Gauss/A	4	0.040	∞
δ_{2stab}	0	0.006	Rectangular/B	4	0.060	∞
δ_{2cab}	0	0.05	Rectangular/B	4	0.20	∞
$\overline{\delta_3}$	0.33	0.015	Student/A	4	0.06	5
δ_{3stab}	0	0.006	Rectangular/B	4	0.024	∞
δ_{3cab}	0	0.025	Rectangular/B	4	0.1	∞
$\overline{\delta_4}$	-3.88	0.020	Student/A	5	0.1	5
δ_{4stab}	0	0.006	Rectangular/B	5	0.030	∞
δ_{4cab}	0	0.01	Rectangular/B	5	0.5	∞
δ_{leak}	0	0.1	Rectangular/B	10	1	∞
δ_{cont}	0	0.01	Rectangular/B	10	0.1	∞
r_{100-10}	10.00001937				1.16	79406

CEM reported the following remark: *"The low number of degrees of freedom in the measurement of δ_3 and δ_4 is due to the abbreviated procedure used in this comparison. The measurement of δ_1 and δ_3 is the same used in our usual procedure of calibration and can be considered having a very high number of degrees of freedom."*

APPENDIX E

Participant uncertainty budgets for ratio 1000 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 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 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 [1] 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	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	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	∞
$R_{1000/100}$				$u(R)$ = 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	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	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
$R_{1000/10}$				$u(R)$ = 0.116	ν_{eff} = 598

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

u_A repeatability of the measurement
$u(\gamma_I)$ 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.

CEM

The mathematical model equation of the measurement is:

$$r_{1000-10} = 10 r_{100-10} \left(\begin{array}{l} 1 + \frac{4}{5}\left(\bar{\delta}_1 + \delta_{1stsb} + \delta_{1cab}\right) + \frac{2}{5}\left(\bar{\delta}_2 + \delta_{2stab} + \delta_{2cab}\right) + \frac{2}{5}\left(\bar{\delta}_3 + \delta_{3stab} + \delta_{3cab}\right) + \\ \frac{1}{2}\left(\bar{\delta}_4 + \delta_{4stab} + \delta_{4cab}\right) + \delta_{leak} + \delta_{cont} \end{array} \right) \quad \text{(E1)}$$

where the meaning of the symbols is as follows:

$r_{1000\text{-}10}$: Ratio 1000 V: 10 V of the travelling standard.
$r_{100\text{-}10}$: Ratio 100 V: 10 V of the travelling standard.
$\bar{\delta}_i$: Average of the relative deviations of ratio *i*.
δ_{istab}: Correction of ratio *i* due to insufficient stabilisation time.
δ_{icab}: Correction of ratio *i* due to imperfect cable compensation.
δ_{leak}: : Correction of ratio *i* due to leakage across insulation.
δ_{cont}: Correction of ratio *i* due to contact resistance.

The uncertainty budget is expressed in Table E3.

Table E3. CEM absolute uncertainty budget for ratio 1000 V / 10 V

Quantity X_i	Estimate x_i	Standard uncertainty ($\times 10^{-6}$)	Probability distribution / method of evaluation	Sensitivity coefficient c_i	Standard uncertainty contribution ($\times 10^{-6}$)	Degrees of freedom ν_i
$r_{100\text{-}10}$	10.000 019 37	1.1	Gauss/A+B	10	11.5	79406
$\bar{\delta}_1$	0.683×10^{-6}	0.021	Student/A	80	1.6	5
δ_{1stab}	0	0.006	Rectangular/B	80	0.048	∞
δ_{1cab}	0	0.005	Rectangular/B	80	0.40	∞
$\bar{\delta}_2$	0.336×10^{-6}	0.045	Student/A	40	1.8	5
δ_{2stab}	0	0.006	Rectangular/B	40	0.24	∞
δ_{2cab}	0	0.005	Rectangular/B	40	0.20	∞
$\bar{\delta}_3$	0.724×10^{-6}	0.030	Student/A	40	1.2	5
δ_{3stab}	0	0.006	Rectangular/B	40	0.024	∞
δ_{3cab}	0	0.0025	Rectangular/B	40	0.1	∞
$\bar{\delta}_4$	0.877×10^{-6}	0.020	Student/A	50	1	5
δ_{4stab}	0	0.006	Rectangular/B	50	0.30	∞
δ_{4cab}	0	0.001	Rectangular/B	50	0.05	∞
δ_{leak}	0	0.1	Rectangular/B	100	10	∞
δ_{cont}	0	0.001	Rectangular/B	100	0.1	∞
$r_{1000\text{-}10}$	100.000334				15.5	13666

CEM reported the following remark: *"In this case, the reported type A uncertainty for all δ_i corrections is not based on our historical data, because the instability of standard looks greater than the ours. For this, few degrees of freedom are reported and the Student's distribution is used."*

APPENDIX F

Optional measurements

In the following the results for ratios 300 V / 10 V and 30 V / 10 V will be reported. To simplify the treatment, the degrees of freedom will not be considered.

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})
CEM	25/11/02	23.9	0.2	38	2	-0.111	0.027
IEN	-	22.6	0.5	42.6	5	0	0.051

Table F2 reports the evaluation of the difference Δ of CEM with respect to the pilot laboratory and the evaluation of the global standard uncertainties u_G of CEM 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})
CEM	130	2.503	2.614	2.378	0.237	0.023	0.154	0.027	0.097	0.185
IEN	-	-	-	-	0	0.047	0.104	0.051	0.029	0.128

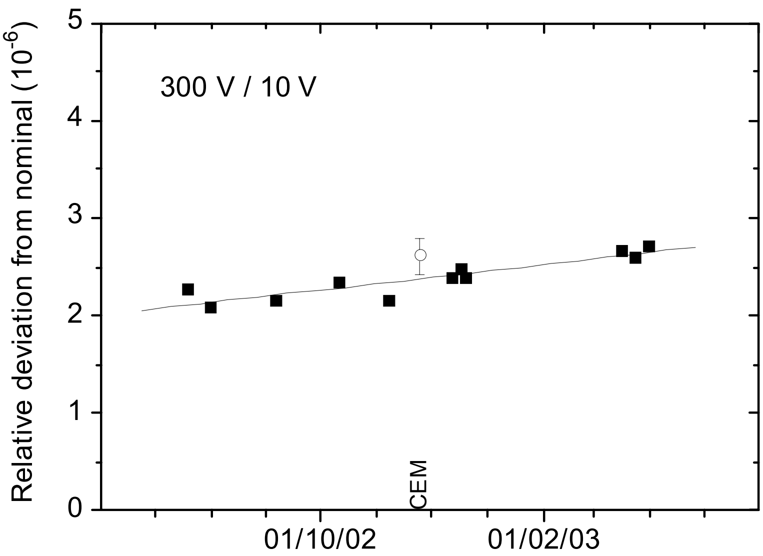


Fig. F1. Ratio 300 V / 10 V: CEM result, corrected to standard ambient conditions, corresponding global standard uncertainty and linear interpolation of the corrected IEN measurements.

Fig. F1 shows the CEM result, corrected to standard ambient conditions, $d_{0,\mathrm{CEM}}$, with corresponding global standard uncertainty u_G , compared with the corrected IEN measurements.

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

$$I_C = \frac{\Delta_{\mathrm{CEM}} - \Delta_{\mathrm{IEN}}}{U(\Delta_{\mathrm{CEM}} - \Delta_{\mathrm{IEN}})} \tag{F1}$$

where $U(\Delta_{\mathrm{CEM}} - \Delta_{\mathrm{IEN}})$ is the expanded uncertainty (95% confidence level) of the difference between the value of CEM and the value of IEN. An expansion factor k=2 will be used. The measurements of the two laboratories are not correlated. It is found:

$$I_C = \frac{0.237 - 0}{2\sqrt{0.185^2 + 0.128^2}} = 0.53 \tag{F2}$$

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})
CEM	25/11/02	23.9	0.2	38	2	0.021	0.016
IEN	-	22.6	0.5	42.7	5	0	0.025

Table F4 reports the evaluation of the difference Δ of CEM with respect to the pilot laboratory and the evaluation of the global standard uncertainties u_G of CEM 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})
CEM	130	3.12	3.099	3.021	0.079	0.007	0.102	0.016	0.068	0.124
IEN	-	-	-	-	0	0.031	0.112	0.025	0.021	0.121

Fig. F2 shows the CEM result, corrected to standard ambient conditions, $d_{0,\mathrm{CEM}}$, with corresponding global standard uncertainty u_G , compared with the corrected IEN measurements.

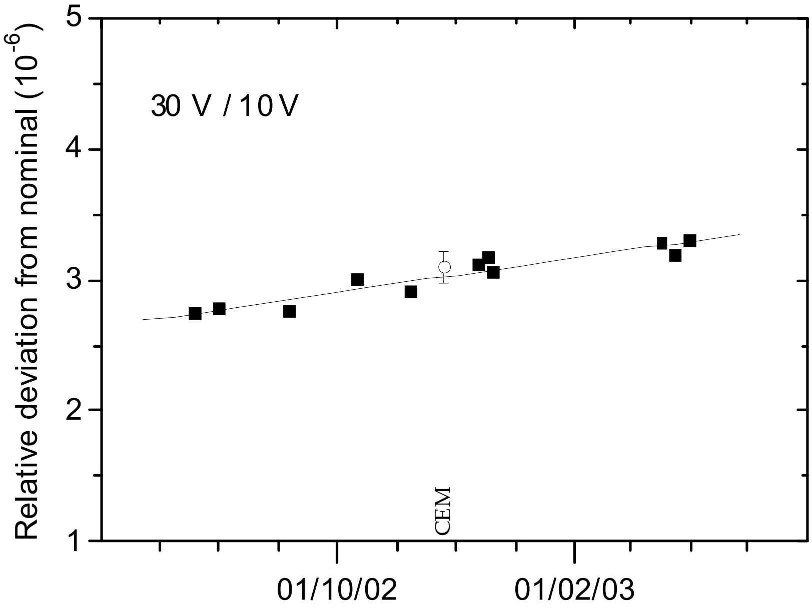


Fig. F2. Ratio 30 V / 10 V: CEM result, corrected to standard ambient conditions, corresponding global standard uncertainty and linear interpolation of corrected IEN measurements.

Also in this case the agreement between the result of CEM and the result of the pilot laboratory will be evaluated in terms of compatibility index I_C, adopting an expansion factor k=2. It is found:

$$I_{\mathrm{C}} = \frac{0.079 - 0}{2\sqrt{0.124^2 + 0.121^2}} = 0.23 \qquad \text{(F3)}$$

APPENDIX G

Comparison protocol and schedule

G1) Technical Protocol
G2) Schedule
G3) Contact Persons

G1) Technical Protocol

CCEM-K8.1: COMPARISON OF DC VOLTAGE RATIO
(Follow-up of CCEM-K8)

(November 8, 2002)

Purpose, participation and schedule

After approval of the Draft A report of CCEM-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, will also coordinate the follow-up. 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 CCEM-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 pilot 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 main exercise. 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 CCEM-K8 already approved final report. 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 given by the pilot laboratory.
The final report should be ready for approval by the CCEM Working Group on Low Frequency at its next meeting in November 2003.

Co-ordinator and communications

The person responsible for the pilot laboratory is:

GianCarlo Marullo Reedtz, IEN, Electrical Metrology, Strada delle Cacce 91, I 10135, Torino
Italy

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
Shipping the standard checklist Form
Receiving the standard checklist Form

G2) Schedule

Period	Laboratory	Country
July 2002 – November 11, 2002	**Pilot - Italy**	
November 15, 2002 – December 2, 2002	**CEM**	**Spain**
December 10, 2002 – January 10, 2003	**Pilot - Italy**	
January 28, 2003 – February 17, 2003	**CSIR-NML**	**South Africa**
February 25, 2003 – March 31, 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

CEM, Spain
Mr. Felix Raso
Centro Espagnol de Metrologia (CEM)
Calle del Alfar 2
E-28760 TRES CANTOS - MADRID
SPAIN
.

CSIR-NML, South Africa
Mr. Eddie Tarnow
National Metrology Laboratory
CSIR
P.O. Box 395
PRETORIA
0001
SOUTH AFRICA