RMO Key Comparison EURAMET.EM-K2.1
Comparison of Resistance Standards at 10 MΩ and 1 GΩ

Final Report

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Abstract

Four National Metrology Institutes, among them three EURAMET members, participated in the follow-up comparison EURAMET.EM-K2.1. The comparison aimed at evaluating the degrees of equivalence of the measurements of 10 MΩ and 1 GΩ resistance standards. Through the pilot laboratory, the results are linked to comparisons EUROMET.EM-K2 and CCEM-K2 respectively. At 1 GΩ, all results supplied by the participants agreed with the comparison reference value within the expanded uncertainty. At 10 MΩ, a slight disagreement with the KCRV for three of the four participants was observed.

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1. Introduction

After approval of the draft B report of the RMO key comparison EUROMET.EM-K2, it was decided to organise a follow-up comparison to allow new participants to join in and to allow some participants of EUROMET.EM-K2 to improve their results. The Federal Institute of Metrology METAS, already pilot laboratory and co-ordinator of EUROMET.EM-K2, coordinated this follow-up and assures the link to CCEM-K2.

The comparison protocol is essentially equivalent to the protocol of EUROMET.EM-K2. It was prepared following the CCEM guidelines for planning, organizing, conducting and reporting key, supplementary and pilot comparisons.

2. Participants and organisation of the comparison

2.1 Co-ordinator and members of the support group

The pilot laboratory for the comparison was the Federal Institute of Metrology (METAS).

Co-ordinator:

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Support group, appointed by the EURAMET technical committee for electricity and magnetism:

Dr Bernd Schumacher, Physikalisch-Technische Bundesanstalt (PTB), DE;
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Dr Gert Rietveld, VSL, NL:
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2.2 List of participants

Five EURAMET NMIs and one non-EURAMET NMI participated in the comparison. IPQ performed measurements but withdrew afterwards from the comparison before the analysis of the comparison results was carried out.

No	Country	Institute	Acronym
1	Switzerland	Federal Institute of Metrology	METAS*)
2	Portugal	Portuguese Institute for Quality	IPQ**)
3	Poland	Central Office of Measures	GUM
4	Croatia	Croatian Metrology Institute - Primary Electromagnetic Laboratory	HMI/FER-PEL
5	Bulgaria	Bulgarian Institute of Metrology	BIM
6	Egypt	National Institute of Standards	NIS

Table 1: Participants
*) METAS participated in CCEM-K2 and EUROMET.EM-K2 and assures the link to the CCEM key comparison.
**) IPQ performed the measurements but withdrew from the comparison before the draft A report was issued.

2.3 Organisation and comparison schedule

The comparison was carried out in one measurement loop. The circulation of the standards started in March 2010 and was completed in February 2011. The detailed time schedule for the comparison is given in Table 2.

A period of four weeks was allowed for the measurements in each laboratory, including the time necessary for transportation. The standards were re-measured in the middle and at the end of the loop by the pilot laboratory to establish a drift rate for the standards and to detect resistance changes related to transport.

Loop A

No *p*	Institute	Country	Dates: arrival to dispatch of standards
1	**Pilot (METAS)**	Switzerland	
2	IPQ	Portugal	30 March to 3 May 2010
3	GUM	Poland	12 May to 10 June 2010
4	HMI/FER-PEL	Croatia	29 June to 16 July 2010
5	BIM	Bulgaria	23 July to 10 Sept 2010
	Pilot (METAS)	Switzerland	15 Sept to 1 Nov 2010
6	NIS	Egypt	23 Nov to 16 Feb 2011
	Pilot (METAS)	Switzerland	

Table 2: Comparison schedule

2.4 Unexpected incidents

No travel incidents or problems were reported by the participants. When the standards returned to the pilot in September 2010 after the first comparison sequence, it was realized that at least one of the 10 MΩ standards (Serial number 47225) must have been used in an oil bath by one of the participants. As a consequence, the resistance value measured for this standard was not as expected. The standard was opened, carefully cleaned and reassembled. This procedure induced another step-change in the value (see Sect. 5 below).

3. Travelling standard and measurement instructions

3.1 Description of the standards

10 MΩ

Two different types of travelling standards (one resistor each) were used:

1. MI 9331, SN 1050109
   Standard manufactured by Measurements International (CA), Model 9331. The resistance element is hermetically sealed in a metal container. The four resistor terminations of the standards are tellurium copper binding posts. A separate ground terminal is included for screening.
2. Guildline 9930, SN 47225
   Standard manufactured by Guildline Instruments, model 9330. The resistance element is suspended in oil in a hermetically sealed metal container. This container is mounted inside a metal box. The two resistor terminations of the standard are coaxial N-type connectors mounted on the top panel of the enclosure. The resistor container, the outer box and the shields of the coaxial N-connectors are joined together.

1 GΩ

Two travelling standards of the same type were used:

1. MI 9331S, SN 1010802 and MI 9331S, SN 1100036
   Standards manufactured by Measurements International (CA), Model 9331S (based on NIST design). The resistance elements are housed in a double shielded enclosure. The two resistor terminations of the standards are N-type coaxial connectors mounted directly on the outer enclosure. The inner enclosure containing the resistive element is connected to the guard terminal. For one of the standards, this terminal is isolated from the outer enclosure and may be operated either in floating mode, in a grounded mode, or driven at a guard potential. For the 2nd standard, the guard terminal is connected to the outer enclosure.

The standards 10 MΩ, SN 1050109, and 1 GΩ, SN 1100036, were already used in the comparison EUROMET.EM-K2. Their values were deliberately offset by means of trim resistors after this comparison. In this way, an extrapolation of their value based on the results of EUROMET.EM-K2 is not possible.

R	Std-ind. *a*	Standards
10 MΩ	1	MI 9331, SN 1050109
	2	Guildline 9330, SN 47225
1 GΩ	3	MI 9331S, SN 1010802
	4	MI 9331S, SN 1100036

Table 3: List of travelling standards

3.2 Quantities to be measured and conditions of measurement

- Resistance of the 10 MΩ standards at the following conditions:
  test voltage: $V_{test} \leq 100$ V; preferably 10 V
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

- Resistance of the 1 GΩ standards at the following conditions:
  test voltage: $V_{test} \leq 100$ V; preferably 100 V
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

3.3 Measurement instructions

Pre- conditioning: The standards were to be installed in a thermostatic air bath, regulated at the chosen working temperature, at least 24 h before starting the measurements.

Measurements: It was expected that the measurements would be repeated several times during the whole period allocated to the participating laboratory.

Method: The measurement method was not specified. It was assumed that every participant uses its normal measurement method. The method and the traceability

scheme had to be described in the measurement report.
The choice of the ground/guard configuration was left to the participants.

3.4 Deviations from the protocol

The comparison was carried out as described in the protocol. Except to the modifications in the comparison schedule, no adjustments of the protocol were necessary.

4. Methods of measurement

The following measurement methods and step-up procedures were applied by the participants:

METAS (see also [1])

- 10 MΩ: Potentiometric resistance bridge (MI 6000B). Reference standards up to 1 MΩ calibrated in terms of the quantized Hall resistance (QHR) using a cryogenic current comparator (CCC). Ratio accuracy of potentiometric bridge checked with Hamon devices up to 100 MΩ.
- 1 GΩ: Active arm Wheatstone bridge; reference standards at 1 MΩ, 10 MΩ and 100 MΩ calibrated with potentiometric system and CCC resp., traceable to QHR.

GUM

- 10 MΩ and 1 GΩ: Potentiometric resistance bridge (MI 6000B). Step-up from 100 Ω using the same bridge. 100 Ω standards calibrated against QHR using a CCC.

HMI/FER-PEL

- Active arm Wheatstone bridge. 1:1 comparison against reference standards calibrated at PTB

BIM-NCM

- 10 MΩ and 1 GΩ: Potentiometric resistance bridge (MI 6000B). 10:1 comparisons against 1 MΩ and 100 MΩ standards resp. The traceability is provided by calibration of 10 kΩ resistor SR 104, SN J1-0824605 at BIPM with Certificate No 78/19 Oct 2009. Step-up from 10 kΩ using the potentiometric resistance bridge (MI 6000B).

NIS

- 10 MΩ: Potentiometric resistance bridge (home-made). 1:1 comparisons against reference standard; step-up from 10 kΩ standard calibrated at BIPM using Hamon networks.

5. Repeated measurements of the pilot institute, behaviour of the travelling standards

5.1 Temperature and voltage dependence

Before starting the measurement loops, the temperature and voltage dependences of the travelling standards were determined at the pilot laboratory. The temperature was varied around 23 °C. The voltage was varied between 5 V and 90 V for the 10 MΩ standards and between 10 V and 1000 V for the 1 GΩ standards respectively.

The temperature (T) dependence around 23 °C and the voltage (V) dependence can be described by the following model:

$$R_a(T,V) = R_a(T_{nom}, V_{nom}) \cdot (1 + \alpha_a(T - T_{nom}) + \gamma_a(V - V_{nom})), \tag{5.1}$$

where a is the index for the standard.

The temperature coefficients (α) and the voltage coefficient (γ) were determined by a least-squares fit to the data. The fit results are listed in Table 4.

Standard Index a		T_{nom} (°C)	α_a (ppm/K)	V_{nom} (V)	γ_a (ppm/V)
10 MΩ					
1	1050109	23	0.74± 0.05	10	(-1.2 ± 1.0) 10^{-3}
2	47225		1.27 ± 0.04		(-1.2 ± 2.4) 10^{-4}
1 GΩ					
3	1010802	23	14.7± 3.3	100	(3.9 ± 1.0) 10^{-3}
4	1100036		1.2 ± 0.3		(2.9 ± 0.5) 10^{-3}

Table 4: Temperature and voltage coefficients of the travelling standards. The uncertainties are one-standard-deviations.

5.2 Drift behaviour of the standards

The measurements carried out at the pilot laboratory before starting the comparison, in the middle of the loop and at the end were used to establish the drift behaviour of the standards.

Due to relaxation effects in the metal used to fabricate a standard, its resistance value changes in time. Step-like resistance changes are observed after temperature shocks or mechanical shocks. After a long stabilization time and over short or medium-term time periods, a polynomial fit up to order two is usually sufficient to describe the resistance change over time.

Following these considerations, the following model was used to fit the measurements:

$$R_a(t) = R_{nom}\left(1 + p_{a,0} + p_{a,1}(t - t_0) + p_{a,2}(t - t_0)^2\right) = R_{nom}(1 + f(t)) \tag{5.2}$$

The reference date t_0 was chosen as 1 January 2010, 00:00 h. The fit results are listed in Table 5 and plotted in Figures 1 to 4. With one exception (10 MΩ standard no 2), the fit residuals are randomly distributed and the scatter around zero corresponds well with the type A standard deviation attributed to the individual measurement points.

For the 10 MΩ standard no 2, a rapid change of its value was observed by the pilot laboratory after the first part of the measurement loop (see Fig. 2a). The values were far off the expected drift line. In addition, it was realized that the standard must have been used in an oil bath (see Sect. 2.4) by one of the participants. As a consequence, the standard was opened and cleaned, and then assembled in a slightly modified way. The subsequent measurements by the pilot before and after the second part of the loop showed a satisfactory and stable behaviour of the standard after this operation (see Fig. 2b). As described in Sect. 6.2.4 below, the data for this standard measured in the *first part* of the loop (participants 3 to 5) were not used in the evaluation of the degrees of equivalence.

Standard Index a		$P_{a,0}$ (ppm)	$P_{a,1}$ (ppm/y)	$P_{a,2}$ (ppm/y^2)
10 MΩ				
1	1050109	29.605 ± 0.043	4.80 ± 0.12	-1.014 ± 0.062
2a	47225	237.14 ± 0.14	8.61 ± 1.12	0, fixed
2b	47225	107.07 ± 0.62	10.2 ± 1.2	-3.10 ± 0.54
1 GΩ				
3	1010802	-851.9 ± 0.4	2.44 ± 0.36	0, fixed
4	1100036	-0.57 ± 0.18	1.15 ± 0.22	0, fixed

Table 5: Fit parameters describing the drift behaviour of the travelling standards
Reference date t_0: 1 January 2010, 00:00 h

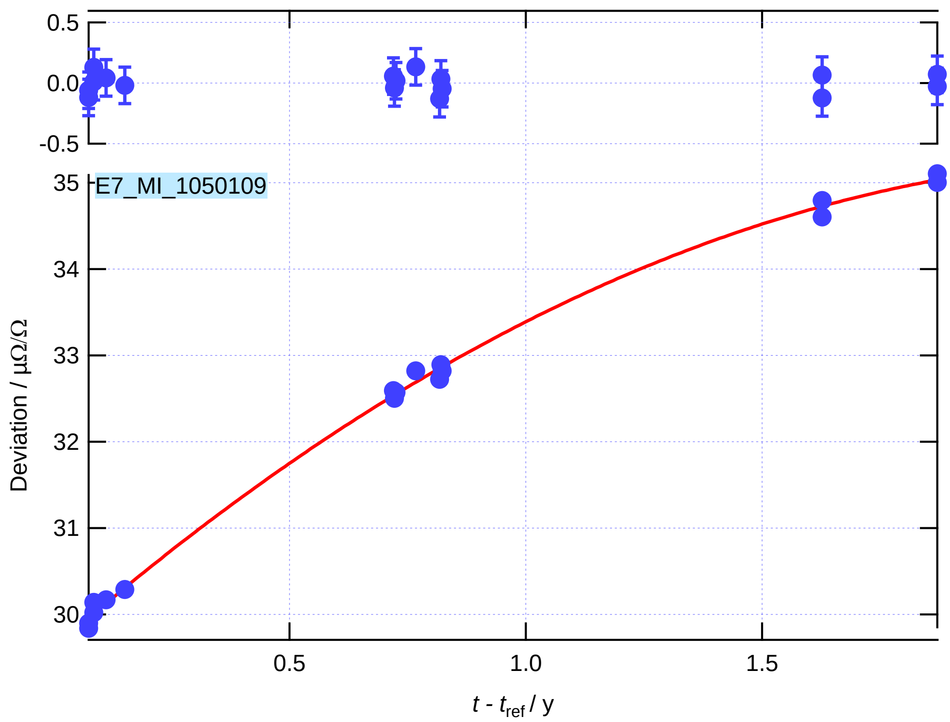

Figure 1: Drift behaviour of the 10 MΩ standard a = 1. The residuals to the fit are shown in the upper part of the figure.

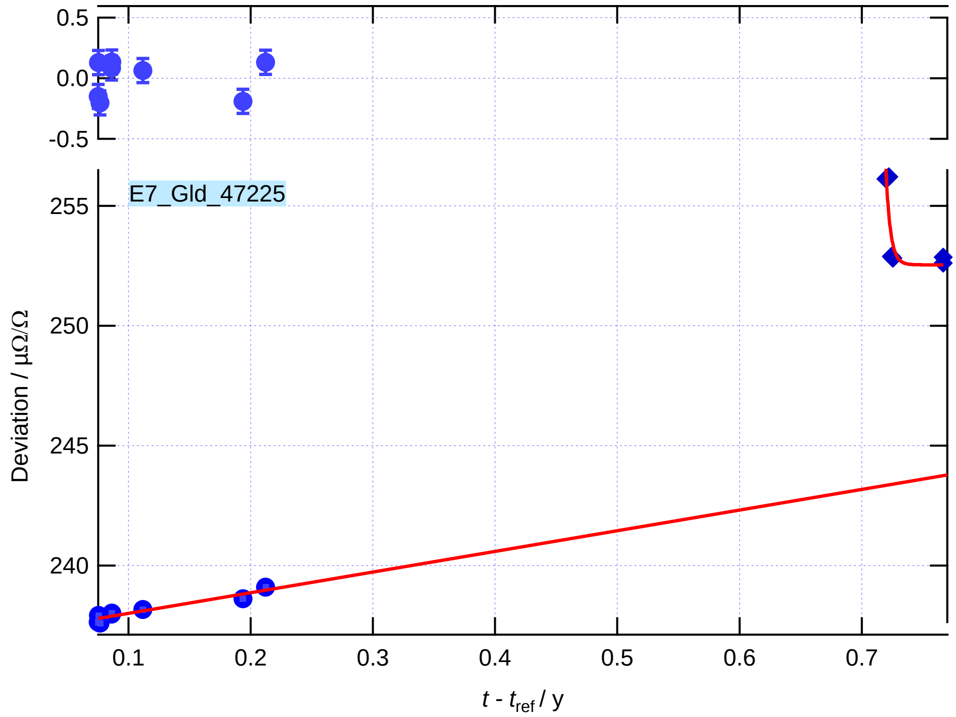

Figure 2a: Drift behaviour of the 10 MΩ standard a = 2 for the first part of the loop.

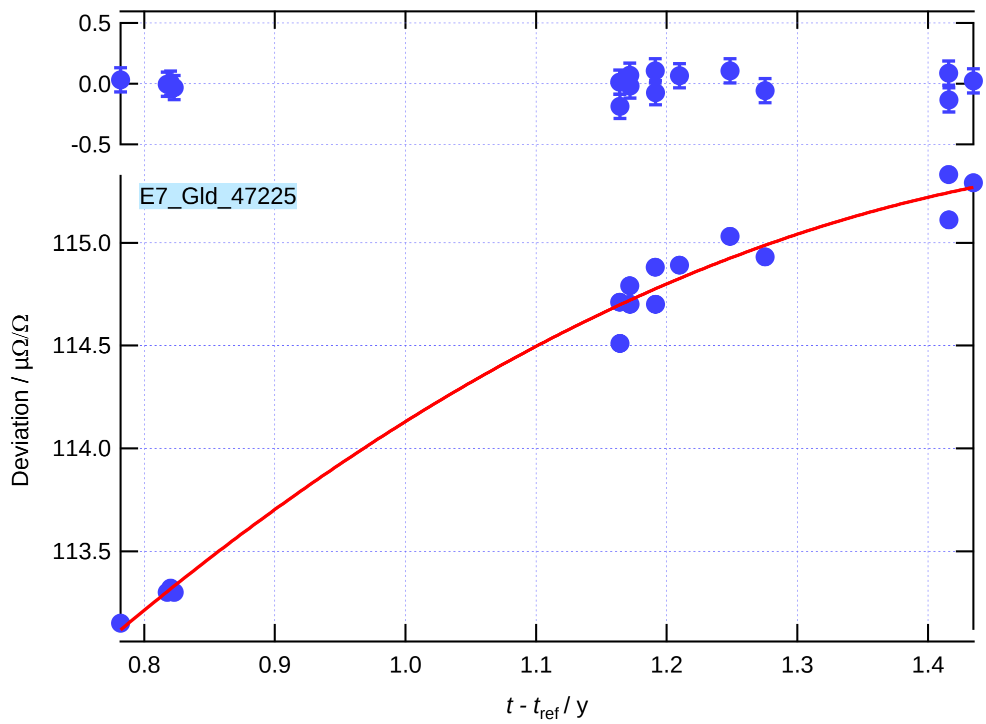

Figure 2b: Drift behaviour of the 10 MΩ standard a = 2 for the second part of the loop.

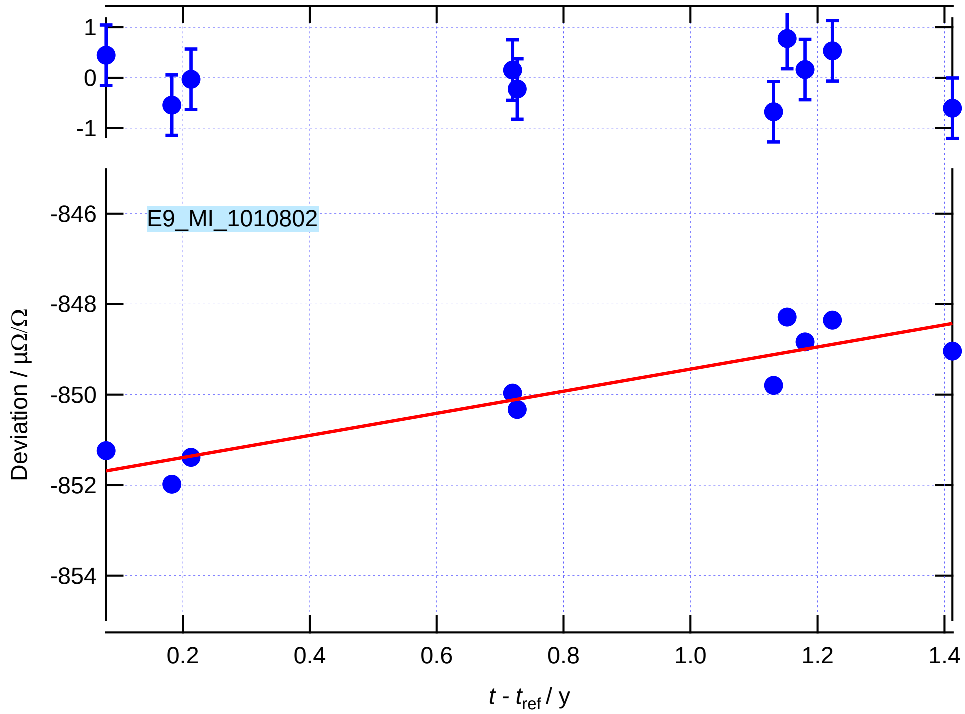

Figure 3: Drift behaviour of the 1 GΩ standard a = 3. The residuals to the fit are shown in the upper part of the figure.

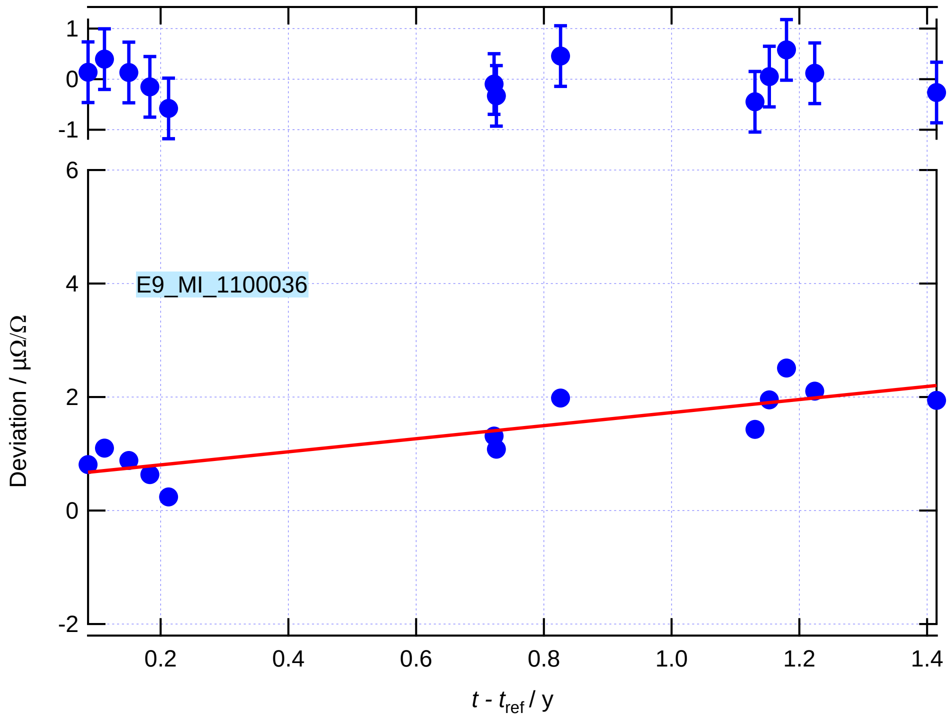

Figure 4: Drift behaviour of the 1 GΩ standard a = 4.

6. Analysis of comparison data set

6.1 Results of the participating institutes

The participants were asked to do as many measurements as deemed reasonable distributed in time over the whole period allocated to the laboratory. This should allow to detect a departure of the drift behaviour from the overall drift model fitted by the pilot laboratory. For each measurement point the following information was reported:

- Date of the measurement
- Resistance value
- Repeatability of the result (type A standard deviation of the measurement)
- Temperature including its uncertainty
- Test voltage

Each result reported by the participants can be expressed as:

$$R_{p,a,m} = R_{nom}\left(1+O_{p,a,m}\right) = R_{nom}\left(1+O\left(t_{p,a,m}, T_{p,a,m,} V_{p,a,m}\right)\right), \text{ with} \qquad (6.1)$$

- p: Index for the participant
- a: Index for the artefact
- m: Index for the measurement of artefact a at participant p
- $O_{p,a,m}$: Deviation from the nominal value, reported for time $t_{p,a,m}$, temperature $T_{p,a,m}$ and test voltage $V_{p,a,m}$

Furthermore, the following nomenclature is used, unless otherwise noted: $N_{p,a}$ is the number of measurements done by participant p with artefact a, N_p is the number of all measurements done by participant p.

The values $O_{p,a,m}$ and the associated standard deviations, $u_{r\text{-}p,a,m}$, are given in Annex A.

In addition to the individual results, mean values for every resistor and combined standard uncertainties were reported. The mean values were not used in the analysis (see Sect. 6.2). The reported combined uncertainties, $u_{c\text{-}p,a}$, for participant p and artefact a can be expressed as:

$$u_{c-p,a}{}^2 = u_{s-p}{}^2 + u_{r-p,a}{}^2, \text{ where:} \qquad (6.2)$$

- $u_{s\text{-}p}$: Combined standard uncertainty of the measurement set-up (step-up procedure, bridge…)
- $u_{r\text{-}p,a}$: Component related to the repeatability of the measurement; typically the standard deviation of the mean of the series of measurements performed.

The reported uncertainty values are listed in Table 6.

p	**Laboratory**	10 MΩ			1 GΩ		
		$u_{\text{c-p,a}}$ (ppm)	$u_{\text{r-p,a}}$ (ppm)	$u_{\text{s-p}}$ (ppm)	$u_{\text{c-p,a}}$ (ppm)	$u_{\text{r-p,a}}$ (ppm)	$u_{\text{s-p}}$ (ppm)
3	GUM	0.62	0.50	0.37	1.6	1.3	1.0
4	HMI/FER-PEL	0.88	0.14	0.87	4.4	1.6	4.1
5	BIM	1.45	0.26	1.43	8.7	2.8	8.2
6	NIS	47.00	3.80	46.85	-	-	-

Table 6: Combined uncertainties reported by the laboratories

6.2 Normalization of the results

6.2.1 Correction to standard ambient conditions

In a ***first step***, temperature and voltage corrections were applied to the reported results. The corrected results (expressed as deviation from the nominal resistance value) are given by:

$$O_{c-p,a,m} = O_{p,a,m} - \alpha_a \left(T_{p,a,m} - T_{nom}\right) - \gamma\left(V_{p,a,m} - V_{nom}\right) \tag{6.3}$$

The uncertainty of the mean correction term for every participant and standard may be expressed as:

$$u_{TV-p,a}{}^2 = \left(\alpha \cdot u\left(T_{p,a}\right)\right)^2 + \left(u(\alpha)\cdot\left(T_{p,a} - T_{nom}\right)\right)^2 + \left(u(\alpha)\cdot u\left(T_{p,a}\right)\right)^2 + \left(u(\gamma)\cdot\left(\overline{V}_{p,a} - V_{nom}\right)\right)^2 \tag{6.4}$$

Most of the measurements were carried out close to the nominal temperature. For this reason, also the second order term of the Taylor expansion was taken into account in the uncertainty expression. The resulting uncertainty components are listed in Tables 7 and 8.

p	**Lab**	***T* (°C)**	**V (V)**	***u*(*T*) (°C)**	**$u_{TV-p,1}$ (ppm)**	**$u_{TV-p,2}$ (ppm)**
1	METAS	23.00	10.0	0.03	0.022	0.038
3	GUM	23.02	9.1	0.10	0.074	0.127
4	HMI/FER-PEL	23.03	50.0	0.05	0.055	0.064
5	BIM	22.98	90.0	0.01	0.080	0.023
6	NIS	22.88	20.0	0.10	0.075	0.127

Table 7: Averaged measurement conditions for the 10 MΩ standards. Uncertainty contributions due to the temperature/voltage correction.

p	**Lab**	***T* (°C)**	**V (V)**	***u*(*T*) (°C)**	**$u_{TV-p,3}$ (ppm)**	**$u_{TV-p,4}$ (ppm)**
1	METAS	23.00	100.0	0.05	0.753	0.062
3	GUM	23.00	90.9	0.10	1.507	0.124
4	HMI/FER-PEL	23.01	100.0	0.05	0.754	0.062
5	BIM	22.98	90.0	0.01	0.165	0.015
6	NIS	Not measured				

Table 8: Averaged measurement conditions for the 1 GΩ standards. Uncertainty contributions due to the temperature/voltage correction.

6.2.2 Drift correction

In a ***second step***, the time dependence of the standards and an offset term, taken from the results of the pilot laboratory, are removed from the results:

$$M_{p,a,m} = O_{c-p,a,m} - f\left(t_{p,a,m}\right) \tag{6.5}$$

f(t) is the model function fitted to the results of the pilot laboratory (see Sect. 5.2.)

The normalized results $M_{p,a,m}$ are given in Annex A.

The mean value for every participant and every standard is calculated as:

$$M_{p,a} = \frac{1}{N_{p,a}} \sum_m M_{p,a,m} \tag{6.6}$$

6.2.3 Repeatability of results

In a ***third step***, the uncertainties $u_{\text{r-p,a,m}}$, which are related to the repeatability and which were indicated by the participants for each measured value were checked against the variation of the normalized results. If necessary, a corrected value based on the observed scatter of the data was determined. This was done the following way:

For every participant and artefact, the internal standard deviation of the arithmetic mean was calculated as

$$s^2_{\text{int}-p,a} = \frac{1}{N^2_{p,a}} \sum_m u^2_{r-p,a,m} \tag{6.7}$$

This value can be compared to the external standard deviation calculated from the scatter of the individual results as

$$s^2_{ext-p,a} = \frac{1}{(N_{p,a}-1)N_{p,a}} \sum_m \left(M_{p,a,m} - M_{p,a}\right)^2 . \tag{6.8}$$

The standard deviation $u^*_{\text{r-p,a}}$ for the mean value was chosen as:

$$u^*_{r-p,a} = \max\left(s_{\text{int}-p,a}, s_{ext-p,a}, u_{r-p,a}\right). \tag{6.9}$$

The combined uncertainty component $u_{rs\text{-}p,a}$ linked to the reproducibility of the result for a particular standard can finally be expressed as:

$$u_{rs-p,a}{}^2 = u^*_{r-p,a}{}^2 + u_{TV-p,a}{}^2 + u_{tr-a}{}^2 . \tag{6.10}$$

The last component ($u_{\text{tr-a}}$) describes the uncertainty contribution due to transport effects. Based on the experience made during the comparison EUROMET.EM-K2 [1] with similar standards and a large number of participants and standards, the values listed in Table 9 were attributed to the standards.

Standard	a	$u_{tr\text{-}a}$ (ppm)	Standard	a	$u_{tr\text{-}a}$ (ppm)
10 MΩ	1	0.50	1 GΩ	3	1.50
	2	0.50		4	1.50

Table 9: Base transport variability attributed to the artefacts.

The normalized results $M_{\text{p,a}}$ and the corresponding uncertainty components linked to reproducibility are listed in Tables 10 and 11.

p	Laboratory	a =1 $N_{\text{p,1}}$	$M_{\text{p,1}}$ (ppm)	$u^*_{\text{r-p,1}}$ (ppm)	$u_{\text{rs-p,1}}$ (ppm)	a =2 $N_{\text{p,2}}$	$M_{\text{p,2}}$ (ppm)	$u^*_{\text{r-p,2}}$ (ppm)	$u_{\text{rs-p,2}}$ (ppm)
1	METAS	17	0.00	0.04	0.50	8	0.00	0.08	0.51
3	GUM	6	2.20	0.50	0.71	10	5.02	0.50	0.72
4	HMI/FER-PEL	9	4.00	0.14	0.52	9	4.37	0.14	0.52
5	BIM-NCM	5	1.99	1.55	1.63	4	1.62	1.59	1.66
6	NIS	21	-8.08	3.80	3.83	20	-69.02	3.80	3.83

Table 10: Uncertainty contributions due to the reproducibility of the measurements for the 10 MΩ standards.

p	Laboratory	a =3 $N_{p,3}$	$M_{p,3}$ (ppm)	$u^*_{r\text{-}p,3}$ (ppm)	$u_{rs\text{-}p,3}$ (ppm)	a =4 $N_{p,2}$	$M_{p,4}$ (ppm)	$u^*_{r\text{-}p,4}$ (ppm)	$u_{rs\text{-}p,4}$ (ppm)
1	METAS	10	0.0	0.2	1.7	13	0.0	0.2	1.5
3	GUM	7	4.9	1.3	2.5	12	-3.9	1.3	2.0
4	HMI/FER-PEL	9	-24.5	1.4	2.2	9	14.2	1.6	2.2
5	BIM-NCM	8	213.2	92.0	92.0	5	-6.3	44.7	44.7
6	NIS								

Table 11: Uncertainty contributions due to the reproducibility of the measurements for the 1 GΩ standards.

The normalized results for the two 10 MΩ standards and the two 1 GΩ standards are shown in Figures 5 and 6 respectively. For every participant, the two values measured for the same nominal value should agree within the uncertainty component $u_{rs\text{-}p,a}$. This is not the case for lab number 6 at 10 MΩ and lab number 4 at 1 GΩ. Reasons for discrepancies may be:

- Differences in ground-guard configurations and/or leakage effects between the standards which are not properly accounted for in the set-ups of the participants.
- Step-like changes in the value of a transport standard which recovered before the start of the measurement period carried out by the next participant in the loop. In such a case, a clear time dependence of the individual measurement values $M_{p,a,m}$ from the overall drift behaviour should be visible. This is not the case (see Appendix A).

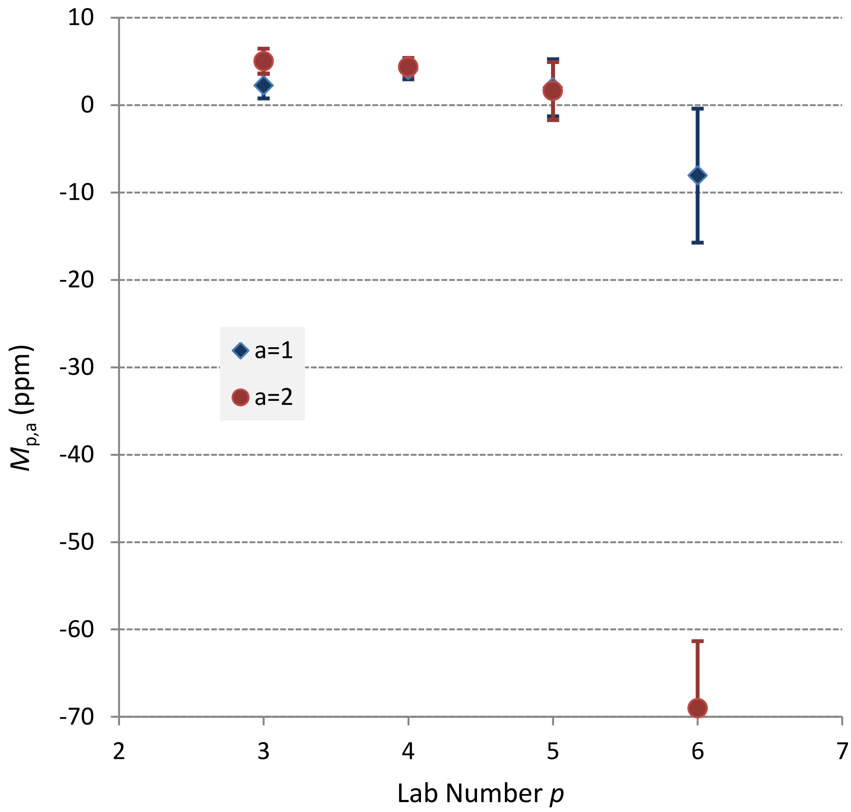

Figure 5: Normalized results for the 10 MΩ standards. The uncertainty bars represent the expanded reproducibility component $2u_{rs-p,a}$

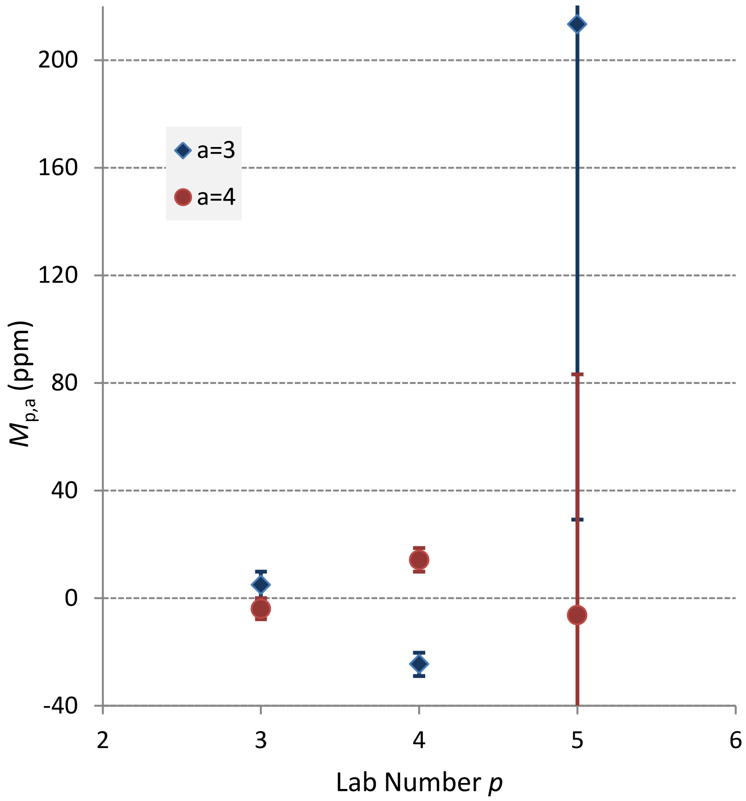

Figure 6: Normalized results for the 1 GΩ standards. The uncertainty bars represent the expanded reproducibility component $2u_{rs-p,a}$

6.2.4 Combination of results for the same nominal value

In the final step, the two results obtained for the same nominal resistance value have to be combined. The following procedure was applied:

10 MΩ

Due to the step change of the standard number two in the first part of the comparison loop, two separate cases have to be considered:

- Participants number 3, 4 and 5: The results in Figure 5 for standard number 2 are based on a linear extrapolation of the values measured by the pilot laboratory before the start of the loop. As can be seen, these results agree quite well with the results of standard number one. This may indicate that the step change of the value of standard number 2 may have occurred during the transport form participant number 5 to the pilot laboratory. Despite this observation, it is not safe to base comparison results on extrapolated fit results and it was, thus, decided to exclude the results of standard number two from the calculation for the first part of the loop. The combined normalized result and its uncertainty component due to reproducibility at 10 MΩ for participants *p*= 3, 4, 5 is then given by:

$$M_p^{10M} = M_{p,1} \qquad u_{rs-p}^{10M} = u_{rs-p,1} \tag{6.11}$$

- Participants number 6: In this case, no anomaly in the drift behaviour of standard number two can be observed (see Fig. 2b). The combined result is thus calculated as the mean value from the normalized results from the standards number one and two:

$$M_p^{10M} = \frac{1}{2}\left(M_{p,1} + M_{p,2}\right) \tag{6.12}$$

To check the consistency of the two values $M_{p,1}$ and $M_{p,2}$, a *t*-test is performed. The two results are based on $N_{p,1}$ and $N_{p,2}$ individual results. The uncertainty components describing the reproducibility of the results are given by $u_{rs\text{-}p,1}$ and $u_{rs\text{-}p,2}$. Then the *t*-value is given by:

$$t_p = \frac{\left|M_{p,1} - M_{p,2}\right|}{\sqrt{u_{rs-p,1}^{\;2} + u_{rs-p,2}^{\;2}}} \tag{6.13}$$

The number of degrees of freedom is: $\nu = N_{p,1} + N_{p,2} - 2$.

A common procedure is to declare the two mean values as consistent if the probability (calculated from the *t*-distribution) for a *t*-value greater than the calculated one is at least 5%. The results for the *t*-test are summarized in Table 12. As expected (see Sect. 6.2.3) the *t*-test is not passed for participant 6 at 10 MΩ. As it is not possible to decide, if this inconsistency is caused by an unknown systematic error in the measurement set-up or by an undiscovered step-change in one of the travelling standards, it is decided to increase the uncertainty component in such a way that the *t*-test is passed. The corresponding multiplication factor is denoted by *k* in Table 12. The uncertainty component of the combined result (6.12) due to reproducibility is thus:

$$u_{rs-p}^{10\mathrm{M}} = k \cdot \left(\frac{1}{2}\sqrt{u_{rs-p,1}^{\;2} + u_{rs-p,2}^{\;2}}\right). \tag{6.14}$$

p	Laboratory	*t*-test t_p	ν	L	k	Mean values M_p (ppm)	$u_{rs\text{-}p}$
3	GUM	Not applicable				2.20	0.71
4	HMI/FER-PEL					4.00	0.52
5	BIM-NCM					1.99	1.63
6	NIS	11.24	39	2.02	5.56	-38.55	15.06

Table 12: Combined normalized results at 10 MΩ and t-test values. *L* is the *t*-value where the probability to have a *t*-value with a higher value is equal to 5%. The *t*-test is passed if $t_p \leq L$.

1 GΩ

No anomalies are present in the drift behaviour of the two 1 GΩ standards. For this reason, the results of both standards are taken into account for all participants, analogue to (6.12) to (6.14):

$$M_p^{1G} = \frac{1}{2}\left(M_{p,3} + M_{p,4}\right)$$
$$u_{rs-p}^{1G} = k \cdot \left(\frac{1}{2}\sqrt{\left(u_{rs-p,3}^{\;2} + u_{rs-p,4}^{\;2}\right)}\right) \tag{6.15}$$

p	Laboratory	*t*-test t_p	ν	L	k	Mean values M_p (ppm)	u_{rs-p}
3	GUM	2.79	17	1.02	2.72	0.5	4.3
4	HMI/FER-PEL	12.59	16	1.03	12.27	-5.2	18.9
5	BIM-NCM	2.15	11	1.04	2.06	103.5	105.4

Table 13: Combined normalized results at 1 GΩ and t-test values. L is the t-value where the probability to have a t-value with a higher value is equal to 5%. The t-test is passed if $t_p \leq L$.

6.3 Degrees of equivalence DoE

As this comparison is a follow-up of EUROMET.EM-K2 with a small number of participants, no comparison reference value is calculated. The results of the participants are linked to the Comparison Reference Value (CRV) of EUROMET.EM-K2 through the results of the pilot laboratory. For METAS, the degrees of equivalence to the CRV in this comparison are [1]:

10 MΩ: $d_1^{10\mathrm{M}}$ = 0.49 µΩ/Ω, expanded uncertainty (k=2): $U(d_1^{10\mathrm{M}})$ = 0.57 µΩ/Ω

1 GΩ: $d_1^{1\mathrm{G}}$ = -1.4 µΩ/Ω, expanded uncertainty (k=2): $U(d_1^{1\mathrm{G}})$ = 5.6 µΩ/Ω

DoE at 10 MΩ

The DoEs are calculated as follows:

$$\begin{aligned} d_p &= M_p^{10M} + d_1^{10\mathrm{M}} \\ u(d_p)^2 &= \left(u_{rs-p}^{10M}\right)^2 + \left(u_{s-p}^{10\mathrm{M}}\right)^2 + u_{rs-1}^{\ 2} + u\left(d_1^{10\mathrm{M}}\right)^2 \end{aligned} \tag{6.16}$$

The combined uncertainty of the DoE contains the following contributions:

u_{rs-p}: Reproducibility component; see eq. (6.14)

u_{s-p}: Combined standard uncertainty of the measurement set-up (step-up procedure, bridge…) for participant p; see eq. (6.2)

u_{rs-1}: Reproducibility component of pilot laboratory

$u(d_1^{10\mathrm{M}})$: Uncertainty of the DoE of the pilot lab to the CRV in EUROMET.EM-K2. This uncertainty also includes u_{s-1}.

DoE at 1 GΩ

Analogue to (6.14), we may write:

$$\begin{aligned} d_p &= M_p^{1G} + d_1^{1\mathrm{G}} \\ u(d_p)^2 &= \left(u_{rs-p}^{1G}\right)^2 + \left(u_{s-p}^{1\mathrm{G}}\right)^2 + u_{rs-1}^{\ 2} + u\left(d_1^{1\mathrm{G}}\right)^2 \end{aligned} \tag{6.17}$$

The DoEs are summarized in Table 14 and Figures 7 and 8 resp.

p	Laboratory	**10 MΩ** d_p=DoE (ppm)	U_{DoE} (ppm)	**1 GΩ** d_p=DoE (ppm)	U_{DoE} (ppm)
3	GUM	2.7	2.0	-0.9	10.7
4	HMI/FER-PEL	4.5	2.3	-6.6	39.1
5	BIM-NCM	2.5	4.5	102.0	211.5
6	NIS	-38.1	98.4		

Table 14: The degree of equivalence DoE is the difference between a laboratory result and the comparison reference value. The uncertainty U_{doe} is the combined expanded uncertainty with a coverage factor of k = 2.

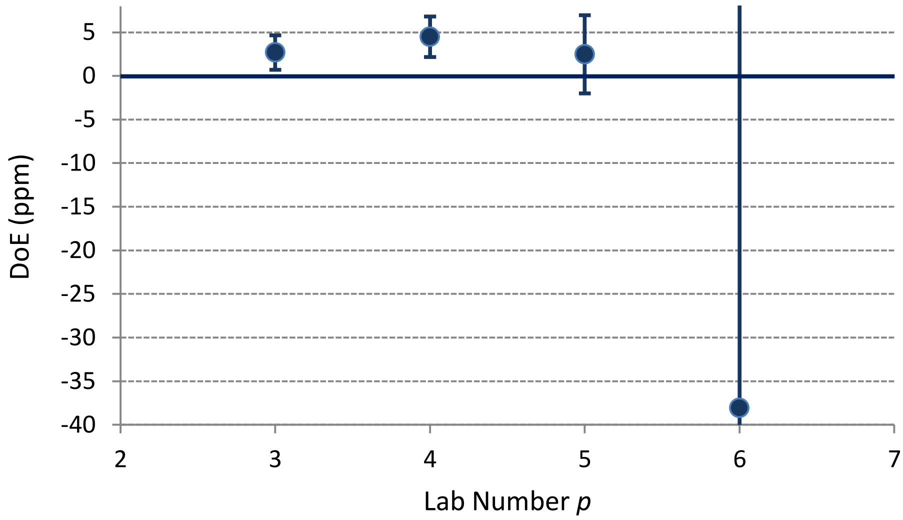

Figure 7: Unilateral degrees of equivalence with respect to the CRV at 10 MΩ.

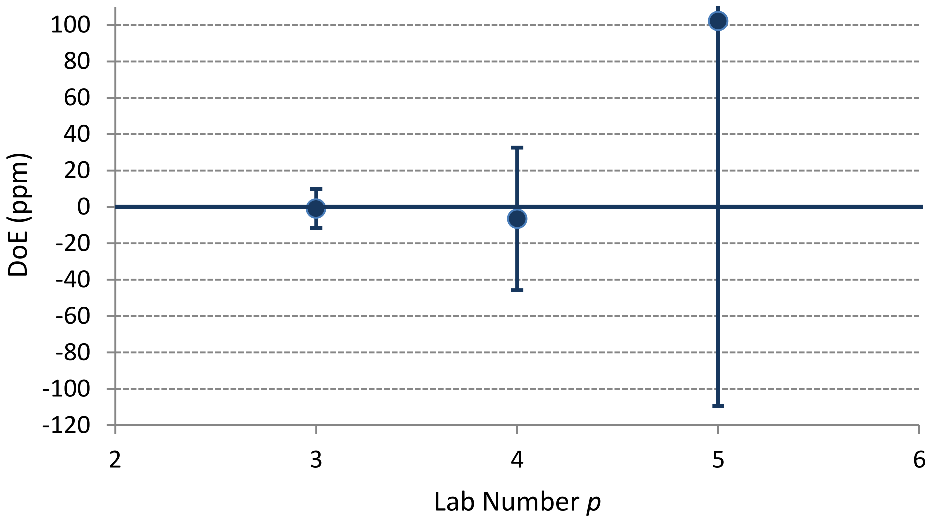

Figure 8: Unilateral degrees of equivalence with respect to the CRV at 1 GΩ.

6.4 Linking the results of EURAMET.EM-K2.1 with CCEM-K2 and degrees of equivalence

The purpose of this linking step is to determine unilateral degrees of equivalence with respect to the Key Comparison Reference Value (KCRV). The values should represent best estimates of what would have been the results of the laboratories had they actually participated in the CCEM comparison.

The linking procedure is the same as applied in the comparison EUROMET.EM-K2 (see [1] for details). It is assumed that the linking laboratories (LNE, METAS, NPL, PTB, VSL, VNIIM) performed similarly in the CCEM and in the RMO comparison. The difference between the unilateral DoE d_i in the CCEM and RMO comparison can thus be taken as the correction Δ_i which needs to be applied to the RMO values.

$$\Delta_i = d_i^{CCEM} - d_i^{RMO} \tag{6.18}$$

with i indicating the linking laboratory.

The correction to the DoEs of those who participated exclusively in the RMO comparison can then be written as

$$d_p^{CCEM} = d_p^{RMO} + \Delta$$

with uncertainties

$$u^2\left(d_p^{CCEM}\right) = u^2\left(d_p^{RMO}\right) + u^2(\Delta) \tag{6.19}$$

In the analysis made in [1], the following correction factors Δ with their standard uncertainties were determined:

10 MΩ:	**Δ = (0.54 ± 0.81) µΩ/Ω**
1 GΩ:	**Δ = (-1.43 ± 2.97) µΩ/Ω**

Using these values, the unilateral degrees of equivalence with respect to the KCRV are calculated as listed in Table 15.

p	Laboratory	10 MΩ d_p^{CCEM}=DoE (ppm)	U_{DoE} (ppm)	1 GΩ d_p^{CCEM} =DoE (ppm)	U_{DoE} (ppm)
3	GUM	3.2	2.6	-2.4	12.2
4	HMI/FER-PEL	5.0	2.8	-8.0	39.6
5	BIM-NCM	3.0	4.8	100.6	211.5
6	NIS	-37.5	98.4		

Table 15: Degree of equivalence with respect to the KCRV (CCEM-K2). The uncertainty U_{doe} is the combined expanded uncertainty with a coverage factor of k = 2.

7. Summary and conclusions

Four National Metrology Institutes, among them three EURAMET members, participated in the follow-up comparison EURAMET.EM-K2.1. The comparison aimed at evaluating the degrees of equivalence of the measurements of 10 MΩ and 1 GΩ resistance standards. At 1 GΩ, all results supplied by the participants agreed with the comparison reference value within the expanded uncertainty. At 10 MΩ, a slight disagreement with the KCRV for three of the four participants was observed.

In several cases it was observed that the normalized results for the two standards of the same nominal value were not consistent with each other. This may be an indication for imperfections in the measurement set-up and/or the measurement procedures. Based on this finding, the corresponding participants should check their set-up and the uncertainty analysis.

The analysis of the comparison results with respect to the CMC claims of the participating institutes and the measures to be taken in the case of inconsistencies are described in a separate executive report.

8. References

[1] B. Jeckelmann and M. Zeier, Final report on RMO key comparison EUROMET.EM-K2: Comparison of resistance standards at 10 MΩ and 1 GΩ, Metrologia 47 Tech. Suppl. 01006, 2010.

Annexes

A. Measurement results reported by the participants
B. Uncertainty budgets as declared by the participants
C. Technical protocol

Annex A: Raw Results

A1 10 MΩ

A1.1 10 MΩ standard MI 1050109, *a* = 1

p	Meas #	Date	$T_{p,1,m}$ (°C)	*u*(T) (°C)	$V_{p,1,m}$ (V)	Humidity (%)	$O_{p,1,m}$ (ppm)	$u_{r\text{-}p,1,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,1,m})$ (ppm)	$M_{p,1,m}$ (ppm)
1	**METAS,CH**										
	1	28.01.10	23.15	0.03	10.0	45.0	30.01	0.16	-0.11	29.96	-0.06
	2	28.01.10	23.15	0.03	18.2	46.0	29.94	0.16	-0.10	29.96	-0.12
	3	01.02.10	23.17	0.03	20.0	47.0	30.13	0.16	-0.11	30.01	0.01
	4	01.02.10	23.17	0.03	40.0	48.0	30.23	0.16	-0.09	30.01	0.13
	5	10.02.10	22.98	0.03	40.0	49.0	30.12	0.16	0.05	30.13	0.04
	6	25.02.10	23.02	0.03	10.0	50.0	30.30	0.16	-0.01	30.31	-0.02
	7	20.09.10	23.30	0.03	10.0	53.0	32.80	0.16	-0.22	32.53	0.05
	8	21.09.10	23.13	0.03	10.0	54.0	32.60	0.16	-0.10	32.54	-0.04
	9	22.09.10	23.04	0.03	10.0	55.0	32.59	0.16	-0.03	32.55	0.02
	10	07.10.10	22.98	0.03	10.0	57.0	32.81	0.16	0.01	32.69	0.13
	11	26.10.10	23.09	0.03	10.0	58.0	32.78	0.16	-0.07	32.85	-0.13
	12	27.10.10	23.06	0.03	10.0	59.0	32.93	0.16	-0.04	32.86	0.03
	13	28.10.10	23.07	0.03	10.0	60.0	32.87	0.16	-0.05	32.87	-0.04
	14	17.08.11	23.43	0.03	10.0	60.0	34.91	0.16	-0.32	34.72	-0.13
	15	17.08.11	23.03	0.03	18.2	56.0	34.80	0.16	-0.01	34.72	0.06
	16	14.11.11	22.99	0.03	10.0	60.0	34.99	0.16	0.01	35.03	-0.03
	17	14.11.11	22.98	0.03	18.2	56.0	35.08	0.16	0.02	35.03	0.07
3	**GUM, Poland**										
	1	10.05.10	23.00	0.10	9.1	46.8	33.36	0.25	0.00	31.17	2.19
	2	12.05.10	23.00	0.10	9.1	40.6	33.37	0.13	0.00	31.20	2.18
	3	14.05.10	23.10	0.10	9.1	40.2	33.54	0.24	-0.08	31.22	2.25
	4	18.05.10	23.00	0.10	9.1	44.3	33.46	0.22	0.00	31.26	2.20
	5	20.05.10	23.00	0.10	9.1	44.6	33.52	0.34	0.00	31.28	2.23
	6	22.05.10	23.10	0.10	9.1	42.8	33.54	0.25	-0.08	31.31	2.16
4	**HMI/FER-PEL Croatia**										
	1	14.07.10	23.01	0.05	50.0	57.3	35.94	0.14	0.04	31.87	4.12
	2	14.07.10	23.02	0.05	50.0	57.3	35.55	0.13	0.03	31.87	3.71
	3	14.07.10	23.03	0.05	50.0	56.2	35.62	0.17	0.03	31.87	3.78
	4	14.07.10	23.04	0.05	50.0	56.4	35.77	0.14	0.02	31.87	3.93
	5	15.07.10	23.02	0.05	50.0	57.1	35.95	0.14	0.03	31.88	4.11
	6	15.07.10	23.03	0.05	50.0	57.6	36.07	0.13	0.03	31.88	4.22
	7	15.07.10	23.04	0.05	50.0	56.7	35.65	0.10	0.02	31.88	3.80
	8	15.07.10	23.05	0.05	50.0	55.9	35.92	0.15	0.01	31.88	4.06
	9	15.07.10	23.05	0.05	50.0	55.5	36.13	0.16	0.01	31.88	4.26
5	**BIM-NCM, Bulgaria**										
	1	12.08.10	22.98	0.01	90.0	49.5	*35.40*	*7.60*	0.11		
	2	13.08.10	22.98	0.01	90.0	52.3	35.00	0.95	0.11	32.17	2.94
	3	24.08.10	22.98	0.01	90.0	43.4	34.10	0.43	0.11	32.27	1.94
	4	25.08.10	22.98	0.01	90.0	43.8	33.90	0.66	0.11	32.28	1.73
	5	26.08.10	22.98	0.01	90.0	48.3	33.80	0.89	0.11	32.29	1.62
	6	27.08.10	22.98	0.01	90.0	50.3	33.90	0.57	0.11	32.30	1.71

6	**NIS, Egypt**										
	1	22.12.10	22.90	0.10	20.0	50.0	25.82	3.90	0.09	33.31	-7.40
	2	23.12.10	22.80	0.10	20.0	55.0	26.84	4.10	0.16	33.32	-6.32
	3	26.12.10	22.90	0.10	20.0	54.0	26.62	3.10	0.09	33.34	-6.64
	4	27.12.10	22.80	0.10	20.0	57.0	27.23	4.30	0.16	33.35	-5.96
	5	28.12.10	22.80	0.10	20.0	52.0	25.62	4.70	0.16	33.36	-7.58
	6	29.12.10	23.10	0.10	20.0	56.0	27.03	3.70	-0.06	33.36	-6.40
	7	30.12.10	23.10	0.10	20.0	55.0	26.60	2.40	-0.06	33.37	-6.83
	8	03.01.11	22.80	0.10	20.0	55.0	26.43	5.70	0.16	33.40	-6.81
	9	04.01.11	22.80	0.10	20.0	50.0	26.29	3.50	0.16	33.41	-6.96
	10	05.01.11	22.80	0.10	20.0	49.0	24.59	2.80	0.16	33.42	-8.67
	11	10.01.11	22.90	0.10	20.0	49.0	24.51	3.20	0.09	33.45	-8.86
	12	11.01.11	22.90	0.10	20.0	49.0	24.13	2.20	0.09	33.46	-9.25
	13	12.01.11	22.80	0.10	20.0	49.0	23.37	2.50	0.16	33.47	-9.94
	14	13.01.11	22.90	0.10	20.0	57.0	25.99	2.30	0.09	33.48	-7.40
	15	16.01.11	22.90	0.10	20.0	57.0	25.82	2.30	0.09	33.50	-7.59
	16	18.01.11	22.80	0.10	20.0	55.0	23.98	3.30	0.16	33.51	-9.37
	17	19.01.11	23.00	0.10	20.0	56.0	24.33	3.30	0.01	33.52	-9.18
	18	20.01.11	22.80	0.10	20.0	57.0	24.67	3.60	0.16	33.53	-8.70
	19	23.01.11	23.20	0.10	20.0	48.0	22.65	4.10	-0.14	33.55	-11.04
	20	24.01.11	22.90	0.10	20.0	55.0	24.67	5.90	0.09	33.56	-8.80
	21	26.01.11	22.80	0.10	20.0	53.0	23.42	3.50	0.16	33.57	-9.99

A1.2 10 MΩ standard Guildline 47225, *a* = 2

p	Meas #	Date	$T_{p,2,m}$ (°C)	u(T) (°C)	$V_{p,2,m}$ (V)	Humidity (%)	$O_{p,2,m}$ (ppm)	$u_{r\text{-}p,2,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,2,m})$ (ppm)	$M_{p,2,m}$ (ppm)
1	**METAS,CH**										
	1	28.01.10	23.15	0.03	18.2	46.0	237.82	0.20	-0.19	237.79	-0.15
	2	28.01.10	23.15	0.03	10.0	47.0	238.11	0.20	-0.19	237.79	0.13
	3	29.01.10	23.16	0.03	90.9	48.0	237.79	0.20	-0.19	237.80	-0.20
	4	01.02.10	23.17	0.03	20.0	49.0	238.18	0.20	-0.21	237.88	0.08
	5	01.02.10	23.17	0.03	40.0	50.0	238.23	0.20	-0.21	237.88	0.13
	6	10.02.10	22.98	0.03	30.0	51.0	238.14	0.20	0.03	238.10	0.07
	7	12.03.10	23.03	0.03	10.0	53.0	238.66	0.20	-0.04	238.81	-0.19
	8	19.03.10	23.06	0.03	10.0	54.0	239.18	0.20	-0.07	238.97	0.13
	9	20.09.10	23.30	0.03	10.0	55.0	*256.48*	0.20	-0.38		
	10	21.09.10	23.15	0.03	10.0	55.0	*256.38*	0.20	-0.19		
	11	22.09.10	23.12	0.03	10.0	55.0	*253.03*	0.20	-0.15		
	12	22.09.10	23.04	0.03	10.0	56.0	*252.85*	0.20	-0.05		
	13	07.10.10	23.02	0.03	10.0	57.0	*252.87*	0.20	-0.02		
	14	07.10.10	23.00	0.03	18.2	58.0	*252.60*	0.20	0.00		
	Fit 2b										
	1	13.10.10	23.00	0.03	10.0	61.0	113.15	0.20	0.00	113.12	0.03
	2	26.10.10	23.09	0.03	10.0	62.0	113.41	0.20	-0.11	113.31	-0.01
	3	27.10.10	23.09	0.03	10.0	63.0	113.44	0.20	-0.12	113.32	0.00
	4	28.10.10	23.09	0.03	10.0	64.0	113.42	0.20	-0.12	113.33	-0.03
	5	01.03.11	22.99	0.03	10.0	64.0	114.69	0.20	0.02	114.70	0.01
	6	01.03.11	22.98	0.03	18.2	58.0	114.49	0.20	0.02	114.70	-0.19
	7	04.03.11	22.99	0.03	10.0	64.0	114.78	0.20	0.02	114.72	0.07
	8	04.03.11	22.99	0.03	18.2	58.0	114.68	0.20	0.02	114.72	-0.03
	9	11.03.11	22.99	0.03	10.0	64.0	114.86	0.20	0.02	114.78	0.10
	10	11.03.11	22.98	0.03	18.2	58.0	114.67	0.20	0.02	114.78	-0.08

	11	18.03.11	22.99	0.03	18.2	58.0	114.87	0.20	0.02	114.83	0.06
	12	01.04.11	23.06	0.03	18.2	58.0	115.11	0.20	-0.08	114.93	0.10
	13	11.04.11	23.06	0.03	18.2	58.0	115.01	0.20	-0.08	114.99	-0.06
	14	01.06.11	23.00	0.03	18.2	58.0	115.33	0.20	0.00	115.25	0.08
	15	01.06.11	23.00	0.03	10.0	64.0	115.10	0.20	0.00	115.25	-0.14
	16	08.06.11	23.02	0.03	18.2	58.0	115.32	0.20	-0.02	115.27	0.02
3	**GUM, Poland**										
	1	10.05.10	23.00	0.10	9.1	46.0	245.46	0.29	0.00	240.19	5.26
	2	12.05.10	23.00	0.10	9.1	41.6	245.49	0.18	0.00	240.24	5.25
	3	14.05.10	22.90	0.10	9.1	40.4	245.27	0.24	0.13	240.29	5.11
	4	18.05.10	23.00	0.10	9.1	47.3	245.30	0.32	0.00	240.38	4.92
	5	20.05.10	23.00	0.10	9.1	43.5	245.39	0.23	0.00	240.43	4.96
	6	22.05.10	23.00	0.10	9.1	42.5	245.21	0.25	0.00	240.48	4.73
	7	24.05.10	23.10	0.10	9.1	50.1	245.68	0.23	-0.13	240.53	5.03
	8	25.05.10	23.10	0.10	9.1	42.4	245.70	0.28	-0.13	240.55	5.02
	9	26.05.10	23.00	0.10	9.1	45.0	245.52	0.19	0.00	240.57	4.95
	10	28.05.10	23.00	0.10	9.1	40.1	245.59	0.25	0.00	240.62	4.97
4	**HMI/FER-PEL Croatia**										
	1	14.07.10	23.01	0.05	50.0	57.3	246.01	0.18	-0.01	241.74	4.27
	2	14.07.10	23.02	0.05	50.0	57.3	246.60	0.17	-0.02	241.74	4.85
	3	14.07.10	23.03	0.05	50.0	56.2	246.74	0.24	-0.03	241.74	4.97
	4	14.07.10	23.04	0.05	50.0	56.4	245.61	0.20	-0.04	241.74	3.83
	5	15.07.10	23.02	0.05	50.0	57.1	246.47	0.19	-0.02	241.76	4.69
	6	15.07.10	23.03	0.05	50.0	57.6	246.44	0.19	-0.03	241.76	4.65
	7	15.07.10	23.04	0.05	50.0	56.7	245.68	0.14	-0.04	241.76	3.88
	8	15.07.10	23.05	0.05	50.0	55.9	245.93	0.19	-0.05	241.76	4.11
	9	15.07.10	23.05	0.05	50.0	55.5	245.88	0.23	-0.06	241.76	4.06
5	**BIM-NCM, Bulgaria**										
	1	12.08.10	22.98	0.01	90.0	50.1	*228.3*	*5.30*	0.03		
	2	13.08.10	22.98	0.01	90.0	53.2	*225.3*	*3.22*	0.03		
	3	24.08.10	22.98	0.01	90.0	43.4	245.1	0.40	0.03	242.71	2.43
	4	25.08.10	22.98	0.01	90.0	43.8	244.3	0.89	0.03	242.73	1.60
	5	26.08.10	22.98	0.01	90.0	48.3	244.1	0.75	0.03	242.76	1.38
	6	27.08.10	22.98	0.01	90.0	50.3	243.8	0.51	0.03	242.78	1.06
6	**NIS, Egypt**										
	1	22.12.10	22.9	0.1	20.0	50.0	46.89	3.30	0.13	114.02	-67.00
	2	23.12.10	22.8	0.1	20.0	55.0	46.29	2.70	0.26	114.03	-67.49
	3	26.12.10	22.9	0.1	20.0	54.0	45.75	2.20	0.13	114.07	-68.19
	4	27.12.10	22.8	0.1	20.0	57.0	45.99	2.23	0.26	114.08	-67.83
	5	28.12.10	22.8	0.1	20.0	52.0	45.02	3.93	0.26	114.09	-68.81
	6	29.12.10	23.1	0.1	20.0	56.0	46.28	2.86	-0.13	114.10	-67.95
	7	30.12.10	23.1	0.1	20.0	55.0	46.23	8.04	-0.13	114.11	-68.01
	8	03.01.11	22.8	0.1	20.0	55.0	45.98	6.04	0.26	114.15	-67.92
	9	04.01.11	22.8	0.1	20.0	50.0	45.64	3.60	0.26	114.17	-68.27
	10	05.01.11	22.8	0.1	20.0	49.0	45.39	2.10	0.26	114.18	-68.53
	11	09.01.11	22.9	0.1	20.0	50.0	45.24	3.80	0.13	114.22	-68.85
	12	10.01.11	22.9	0.1	20.0	49.0	44.85	3.04	0.13	114.23	-69.25
	13	11.01.11	22.9	0.1	20.0	49.0	43.91	4.20	0.13	114.24	-70.20
	14	12.01.11	22.8	0.1	20.0	49.0	44.90	4.02	0.25	114.25	-69.09
	15	13.01.11	22.9	0.1	20.0	57.0	43.36	2.22	0.13	114.26	-70.77
	16	18.01.11	22.8	0.1	20.0	55.0	43.22	2.42	0.25	114.31	-70.84
	17	19.01.11	23.00	0.10	20.0	56.0	44.03	1.20	0.00	114.32	-70.29

	18	20.01.11	22.8	0.1	20.0	57.0	43.51	2.90	0.25	114.33	-70.57
	19	24.01.11	22.9	0.1	20.0	55.0	44.22	4.60	0.13	114.37	-70.02
	20	26.01.11	22.8	0.1	20.0	53.0	43.62	2.20	0.25	114.39	-70.51

A2 1 GΩ

A2.1 1 GΩ standard MI 1010802, *a* = 3

p	Meas #	Date	$T_{p,3,m}$ (°C)	*u*(T) (°C)	$V_{p,3,m}$ (V)	Humidity (%)	$O_{p,3,m}$ (ppm)	$u_{r-p,2,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,3,m})$ (ppm)	$M_{p,3,m}$ (ppm)
1	**METAS,CH**										
	1	29.01.10	23.07	0.05	100.0	57.0	-850.15	0.60	-1.09	-851.69	0.45
	2	08.03.10	23.14	0.05	100.0	58.0	-849.98	0.60	-2.00	-851.43	-0.54
	3	19.03.10	23.06	0.05	100.0	59.0	-850.47	0.60	-0.93	-851.36	-0.03
	4	20.09.10	23.04	0.05	100.0	60.0	-849.44	0.60	-0.53	-850.12	0.15
	5	23.09.10	23.05	0.05	100.0	61.0	-849.59	0.60	-0.74	-850.11	-0.22
	6	17.02.11	23.01	0.05	100.0	62.0	-849.66	0.60	-0.15	-849.12	-0.68
	7	25.02.11	22.99	0.05	100.0	62.0	-848.46	0.60	0.17	-849.07	0.78
	8	07.03.11	22.99	0.05	100.0	62.0	-848.97	0.60	0.13	-849.00	0.16
	9	23.03.11	23.00	0.05	100.0	62.0	-848.37	0.60	0.01	-848.89	0.53
	10	31.05.11	23.03	0.05	100.0	62.0	-848.53	0.60	-0.51	-848.43	-0.61
3	**GUM, Poland**										
	1	13.05.10	22.90	0.10	90.9	44.7	-847.20	2.50	1.51	-851.00	5.30
	2	17.05.10	23.00	0.10	90.9	40.8	-846.50	1.80	0.04	-850.97	4.51
	3	19.05.10	23.00	0.10	90.9	41.2	-846.40	2.30	0.04	-850.96	4.59
	4	21.05.10	23.00	0.10	90.9	49.4	-845.50	1.10	0.04	-850.94	5.48
	5	25.05.10	23.10	0.10	90.9	47.2	-845.40	1.90	-1.43	-850.92	4.08
	6	27.05.10	23.00	0.10	90.9	43.5	-845.30	2.40	0.04	-850.90	5.64
	7	31.05.10	23.00	0.10	90.9	44.9	-846.40	2.60	0.04	-850.88	4.51
4	**HMI/FER-PEL Croatia**										
	1	07.07.10	22.99	0.05	100.0	54.3	-873.31	1.60	0.22	-850.63	-22.46
	2	07.07.10	22.93	0.05	100.0	54.8	-872.35	1.99	1.10	-850.63	-20.61
	3	07.07.10	23.05	0.05	100.0	54.4	-867.70	2.10	-0.74	-850.63	-17.81
	4	08.07.10	23.02	0.05	100.0	53.5	-875.85	1.55	-0.29	-850.62	-25.53
	5	08.07.10	23.02	0.05	100.0	53.5	-880.65	1.94	-0.29	-850.62	-30.32
	6	08.07.10	23.02	0.05	100.0	53.5	-874.58	1.65	-0.29	-850.62	-24.25
	7	09.07.10	23.02	0.05	100.0	54.9	-879.67	1.98	-0.29	-850.62	-29.35
	8	09.07.10	23.02	0.05	100.0	55.0	-877.62	1.92	-0.29	-850.62	-27.30
	9	09.07.10	23.03	0.05	100.0	54.5	-873.46	2.05	-0.44	-850.62	-23.29
5	**BIM-NCM, Bulgaria**										
	1	19.08.10	22.98	0.01	90.0	41.4	-955.80	20.00	0.33	-850.34	-105.12
	2	20.08.10	22.98	0.01	90.0	43.2	-872.80	31.00	0.33	-850.34	-22.13
	3	27.08.10	22.98	0.01	90.0	48.4	-519.20	60.00	0.33	-850.29	331.42
	4	28.08.10	22.98	0.01	90.0	50.6	-309.60	61.00	0.33	-850.28	541.02
	5	29.08.10	22.98	0.01	90.0	52.3	-278.90	59.00	0.33	-850.28	571.71
	6	01.09.10	22.98	0.01	90.0	52.1	-867.70	54.00	0.33	-850.26	-17.11
	7	02.09.10	22.98	0.01	90.0	51.6	-730.80	60.00	0.33	-850.25	119.78
	8	03.09.10	22.98	0.01	90.0	50.8	-564.60	59.00	0.33	-850.24	285.97

A2.2 1 GΩ standard MI 1100036, *a* = 4

p	Meas #	Date	$T_{p,4,m}$ (°C)	*u*(T) (°C)	$V_{p,4,m}$ (V)	Humidity (%)	$O_{p,4,m}$ (ppm)	$u_{r-p,4,m}$ (ppm)	T,V-corr (ppm)	$f(t_{p,4,m})$ (ppm)	$M_{p,4,m}$ (ppm)
1	**METAS,CH**										
	1	01.02.10	22.99	0.05	100.0	45.0	0.80	0.60	0.02	0.67	0.14
	2	10.02.10	22.99	0.05	100.0	45.0	1.08	0.60	0.02	0.70	0.40
	3	24.02.10	22.97	0.05	100.0	45.0	0.85	0.60	0.03	0.75	0.14
	4	08.03.10	23.13	0.05	100.0	45.0	0.79	0.60	-0.16	0.78	-0.15
	5	19.03.10	22.99	0.05	100.0	45.0	0.23	0.60	0.01	0.82	-0.58
	6	21.09.10	22.94	0.05	100.0	45.0	1.24	0.60	0.07	1.41	-0.09
	7	22.09.10	22.93	0.05	100.0	45.0	0.99	0.60	0.09	1.41	-0.33
	8	29.10.10	22.98	0.05	100.0	45.0	1.95	0.60	0.02	1.52	0.45
	9	17.02.11	22.96	0.05	100.0	45.0	1.38	0.60	0.05	1.88	-0.44
	10	25.02.11	22.98	0.05	100.0	45.0	1.93	0.60	0.02	1.90	0.05
	11	07.03.11	23.02	0.05	100.0	45.0	2.53	0.60	-0.03	1.93	0.57
	12	23.03.11	22.97	0.05	100.0	45.0	2.07	0.60	0.03	1.98	0.11
	13	01.06.11	22.98	0.05	100.0	45.0	1.91	0.60	0.02	2.20	-0.26
3	**GUM, Poland**										
	1	11.05.10	23.00	0.10	90.9	40.0	-3.05	1.90	0.03	0.98	-4.00
	2	13.05.10	22.90	0.10	90.9	44.1	-3.70	1.10	0.15	0.99	-4.54
	3	14.05.10	23.00	0.10	90.9	48.2	-2.82	2.30	0.03	0.99	-3.79
	4	17.05.10	23.10	0.10	90.9	41.3	-2.42	1.80	-0.09	1.00	-3.52
	5	19.05.10	23.00	0.10	90.9	43.0	-3.33	1.50	0.03	1.01	-4.31
	6	21.05.10	23.00	0.10	90.9	49.0	-2.56	1.40	0.03	1.02	-3.55
	7	24.05.10	23.00	0.10	90.9	45.6	-2.81	0.90	0.03	1.02	-3.81
	8	25.05.10	22.90	0.10	90.9	48.9	-3.13	1.60	0.15	1.03	-4.01
	9	27.05.10	23.10	0.10	90.9	43.0	-2.56	0.90	-0.09	1.03	-3.69
	10	28.05.10	23.00	0.10	90.9	47.1	-2.73	1.50	0.03	1.04	-3.74
	11	31.05.10	23.00	0.10	90.9	45.6	-2.75	1.60	0.03	1.05	-3.77
	12	01.06.10	23.00	0.10	90.9	44.4	-3.40	1.20	0.03	1.05	-4.42
4	**HMI/FER-PEL Croatia**										
	1	07.07.10	22.99	0.05	100.0	54.3	17.72	2.01	0.02	1.16	16.57
	2	07.07.10	22.93	0.05	100.0	54.8	11.94	2.50	0.09	1.16	10.87
	3	07.07.10	23.05	0.05	100.0	54.4	21.81	2.03	-0.06	1.16	20.59
	4	08.07.10	23.02	0.05	100.0	53.5	7.10	1.83	-0.02	1.17	5.91
	5	08.07.10	23.02	0.05	100.0	53.5	16.38	2.28	-0.02	1.17	15.19
	6	08.07.10	23.02	0.05	100.0	53.5	15.76	1.77	-0.02	1.17	14.57
	7	09.07.10	23.02	0.05	100.0	54.9	9.92	2.38	-0.02	1.17	8.73
	8	09.07.10	23.02	0.05	100.0	55.0	19.38	2.35	-0.02	1.17	18.19
	9	09.07.10	23.03	0.05	100.0	54.5	18.58	2.53	-0.04	1.17	17.37
5	**BIM-NCM, Bulgaria**										
	1	19.08.10	22.98	0.01	90.0	41.2	-110.20	15.00	0.05	1.30	-111.45
	2	20.08.10	22.98	0.01	90.0	44.6	-98.90	43.00	0.05	1.30	-100.15
	3	01.09.10	22.98	0.01	90.0	52.1	-0.50	2.50	0.05	1.34	-1.79
	4	02.09.10	22.98	0.01	90.0	51.6	68.40	21.00	0.05	1.34	67.11
	5	03.09.10	22.98	0.01	90.0	50.8	116.20	11.00	0.05	1.35	114.91

Annex B: Uncertainty budgets

1 METAS

See report comparison EUROMET.EM-K2:

B. Jeckelmann and M. Zeier, Final report on RMO key comparison EUROMET.EM-K2: Comparison of resistance standards at 10 MΩ and 1 GΩ, Metrologia 47 Tech. Suppl. 01006, 2010.

3 GUM

Rx – 10 MΩ

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(Ri)$ / Ω	Degree of freedom ν_i
r_x	10,000298697	0,00000496	Normal/A	999946,78	4,96	40
R_T	0	1,73	Uniform/B	1	1,73	Infinity
R_L	0	0,0058	Uniform/B	1	0,0058	Infinity
R_S	999946,78	0,30	Normal/A	1	0,30	40
R_D	0		Uniform/B	1	1,15	Infinity
R_X	999997100					
		Combined standard uncertainty: / Ω			6,2	
		Effective degrees of freedom:			80	
		Expanded uncertainty (95% coverage factor): / Ω			12,4	

r_x – mean ratio of measured resistor
R_T –temperature correction
R_L –linearity correction
R_S – value of reference standard resistor
R_D – short term drift correction

$R_X = r_x * R_S + R_T + R_L + R_D$

Rx – 1 GΩ

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(Ri)$ / Ω	Degree of freedom ν_i
r_x	10,00028682	0,00001258	Normal/A	99996838	1258,3	48
R_T	0	288,7	Uniform/B	1	288,7	Infinity
R_L	0	5,8	Uniform/B	1	5,8	Infinity
R_S	99996838	790	Normal/A	1	790	40
R_D	0	14	Uniform/B	1	115	Infinity
R_X	999997100					
		Combined standard uncertainty: / kΩ			1,6	
		Effective degrees of freedom:			85	
		Expanded uncertainty (95% coverage factor): / kΩ			3,2	

r_x – mean ratio of measured resistor
R_T –temperature correction
R_L –linearity correction
R_S – value of reference standard resistor
R_D – short term drift correction

$R_X = r_x * R_S + R_T + R_L + R_D$

4 HMI/FER-PEL

The detailed uncertainty budget is presented separately for two resistance levels, but the basic relation by which the unknown resistance R_X is determined for this comparison is the same for both levels:

$$R_X = R_{REF} \cdot r_U \cdot (1 + k_d + m_d), \quad (8)$$

where the quantities which determine the final measurement result are:

Quantity	Description
R_{REF}	The laboratory reference standard used for comparison
r_U	Measured resistance ratio during comparison of the unknown R_X to the reference R_{REF}
k_d	Correction of the unity voltage ratio of voltages U_1 and U_2 during adjustment of the measurement set-up for actual measurement
m_d	Millivoltmeter offset, thermoelectric voltages and other influences estimated from the analysis of the measurement set-up

Therefore, the contributions to the combined uncertainty are:

- $u(R_{REF})$ – uncertainty of the estimated value of reference resistor R_{REF} for the mean date of comparison;
- $u(r_U)$ – uncertainty of the measured resistance ratio r_U (standard deviation of the mean value for the mean date of comparison);
- $u(k_d)$ – uncertainty of the correction of unity voltage ratio (on levels 50 V and 100 V), which is determined from the measurements performed prior and after the comparison procedure;
- $u(m_d)$ – uncertainty contribution due to millivoltmeter offset, thermoelectric voltages and other influences estimated from the analysis of the measurement set-up and performed measurements in the past.

10 MΩ

The analysis is given for the resistance standard Guildline 9930 (R_A). For the resistance standard MI 9331 (R_B) the only difference is standard uncertainty $u(r_U) = 0{,}07 \cdot 10^{-6}$, which leads to the combined standard uncertainty of 8,7 Ω, effective degrees of freedom of 100, and expanded uncertainty (95% coverage factor) of 17,2 Ω.

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty Contribution $u(R_i)$	Degree of freedom ν_i
$R_{REF-10M}$	10 MΩ	5 Ω	normal	1	5 Ω	11
r_U	1	$0{,}14 \cdot 10^{-6}$	normal	10 MΩ	1,4 Ω	8
k_d	0	$0{,}5 \cdot 10^{-6}$	rectangular	10 MΩ	5 Ω	∞
m_d	0	$0{,}5 \cdot 10^{-6}$	rectangular	10 MΩ	5 Ω	∞
R_x	10 MΩ					
		Combined standard uncertainty:			8,8 Ω	
		Effective degrees of freedom:			103	
		Expanded uncertainty (95% coverage factor):			17,4 Ω	

1 GΩ

The analysis is given for the resistance standard R_C (SN 1100036). For the resistance standard R_D (SN 1010802) the only difference is standard uncertainty $u(r_U) = 1{,}3 \cdot 10^{-6}$, which leads to the combined standard uncertainty of 4,3 kΩ, effective degrees of freedom of 10, and expanded uncertainty (95% coverage factor) of 9,4 kΩ.

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty Contribution $u(R_i)$	Degree of freedom ν_i
R_{REF-1G}	1 GΩ	4 kΩ	normal	1	4 kΩ	8
r_U	1	$1{,}6 \cdot 10^{-6}$	normal	1 GΩ	1,6 kΩ	8
k_d	0	$0{,}5 \cdot 10^{-6}$	rectangular	1 GΩ	0,5 kΩ	∞
m_d	0	$0{,}5 \cdot 10^{-6}$	rectangular	1 GΩ	0,5 kΩ	∞
R_x	1 GΩ					
		Combined standard uncertainty:			4,4 kΩ	
		Effective degrees of freedom:			11	
		Expanded uncertainty (95% coverage factor):			9,6 kΩ	

5 BIM-NCM

The detailed uncertainty budgets with the different sources of uncertainty and their values for one standard of each nominal value are given in the tables below.

The resistance *R* of the unknown resistor is obtained from the relationship with:

R_s – resistance of the reference resistor. In this uncertainty contribution the influences from step-up procedure (bridge's ratios error, linearity) are included;
δR_{dr} – drift of the reference resistor;
δR_v – voltage dependence of the reference resistor, used at two different voltages during the step-up chain;
δR_{ts} – temperature dependence of the reference resistor (including temperature correction of digital thermometer);
r_{bridge} – correction factor from bridge's ratio error and linearity for DUT measurement against lab. standard;
$\bar{r}$ - measured ratio of the bridge;
r_{stab} – stability of the bridge;
r_{leak} – effects of leakage from cables, reference resistor, DUT and bridge;
δR_{tx} – correction due to temperature effects of DUT.

Traveling Standard MI 9331, SN 1050109, 10 MΩ, 90,9 V

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution/method of evaluation (A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(R_x)$	Degree of freedom ν_i
R_s	1,000 0378 9 MΩ	1,75E-07 MΩ	Normal/B	10	1,75E-06 MΩ	50
δR_{dr}	0 MΩ	2,96E-08 MΩ	Rectangular/B	10	2,96E-07 MΩ	infinity
δR_v	0 MΩ	5,77E-07 MΩ	Rectangular/B	10	5,77E-06 MΩ	infinity
δR_{ts}	0 MΩ	5,77E-08 MΩ	Rectangular/B	10	5,77E-07 MΩ	infinity
r_{bridge}	1	1,15E-07	Rectangular/B	10 MΩ	1,15E-06 MΩ	infinity
$\bar{r}$	9,999 966 63	2,58E-06	Normal/A	1 MΩ	2,58E-06 MΩ	84
r_{stab}	0	1,15E-07	Rectangular/B	10 MΩ	1,15E-06 MΩ	infinity
r_{leak}	0	1,27E-06	Rectangular/B	10 MΩ	1,27E-05 MΩ	infinity
δR_{tx}	0 MΩ	3,46E-07 MΩ	Rectangular/B	-1	-3,46E-07 MΩ	infinity
R_X	10,000 346 MΩ					
		Combined standard uncertainty:			0,000 014 5 MΩ	
		Effective degrees of freedom:			infinity	
		Expanded uncertainty (95% coverage factor):			0,000 029 MΩ	

Traveling Standard MI 9331S, SN 1100036, 1 GΩ, 90,9 V

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution/method of evaluation (A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(R_x)$	Degree of freedom ν_i
R_s	0,100 000 73 GΩ	1,50E-07 GΩ	Normal/B	10	1,50E-06 GΩ	50
δR_{dr}	0 GΩ	7,88E-08 GΩ	Rectangular/B	10	7,88E-07 GΩ	infinity
δR_v	0 GΩ	1,73E-07 GΩ	Rectangular/B	10	1,73E-06 GΩ	infinity
δR_{ts}	0 GΩ	5,77E-09 GΩ	Rectangular/B	10	5,77E-08 GΩ	infinity
r_{bridge}	1	3,46E-06	Rectangular/B	1 GΩ	3,46E-06 GΩ	infinity
$\bar{r}$	9,999 877	2,80E-05	Normal/A	0,1 GΩ	2,80E-06 GΩ	95
r_{stab}	0	1,15E-07	Rectangular/B	1 GΩ	1,15E-07 GΩ	infinity
r_{leak}	0	6,93E-06	Rectangular/B	1 GΩ	6,93E-06 GΩ	infinity
δR_{tx}	0 GΩ	2,89E-07 GΩ	Rectangular/B	-1	-2,89E-07 GΩ	infinity
R_X	0,999 995 00 GΩ					
		Combined standard uncertainty:			0,000 008 67 GΩ	
		Effective degrees of freedom:			infinity	
		Expanded uncertainty (95% coverage factor):			0,000 017 GΩ	

6 NIS

Uncertainty budget for the Calibration of 10Mohm MI 9331, SN 1050109

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A ,B)	Sensitivity Coefficient c_i	Uncertainty Contribution $u(R_i)$	Degree of Freedom ν_i
Repeatability of R_x	38 Ω	38 Ω	Normal/A	1	37 Ω	∞
Calibration of R_s	190 Ω	95 Ω	Normal/B	1	95 Ω	∞
Drift of R_s	300 Ω	173.2 Ω	Rectangular/ B	1	173.2 Ω	∞
Voltage coefficient of R_s	0.6 Ω	0.35 Ω	Rectangular/ B	1	0.35Ω	∞
Temp. Coefficient of R_s	20.8 Ω	12 Ω	Rectangular/ B	1	12 Ω	∞
Power Coefficient of R_s	0.05 Ω	0.03 Ω	Rectangular/ B	1	0.03 Ω	∞
Resolution of R_x	5 Ω	2.9 Ω	Rectangular/ B	1	2.9 Ω	∞
DVM Cal. Cert. of V_s	8 µV	4 µV	Normal/B	1 MΩ/V	4 Ω	∞
Instability of Bias of V_s	519.6 µV	300 µV	Rectangular/ B	1 MΩ/V	300 Ω	∞
DVM Cal. Cert. of V_x	8 µV	4 µV	Normal/B	1 MΩ/V	4 Ω	∞
Instability of Bias of V_x	519.6 µV	300 µV	Rectangular/ B	1 MΩ/V	300 Ω	∞
Ratio Accuracy	4.4 µV	2.2 µV	Normal/B	1 MΩ/V	2.2 Ω	∞
R_x	10.000450 14 MΩ					
		Combined standard uncertainty:			**470 Ω**	
		Effective degrees of freedom:			**∞**	
		Expanded uncertainty (95% coverage factor):			**940 Ω**	

Report, Annex C

RMO Key Comparison EURAMET.EM-K2.1
Comparison of Resistance Standards at 10 MΩ and 1 GΩ: Follow-Up

TECHNICAL PROTOCOL

Beat Jeckelmann

Federal Office of Metrology METAS
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1. Introduction

After approval of the draft B report of the RMO key comparison EUROMET.EM-K2, it was decided to organise a follow-up comparison to allow new participants to join in and to allow some participants of EUROMET.EM-K2 to improve their results. The Federal Office of Metrology METAS, already pilot laboratory and co-ordinator of EUROMET.EM-K2, will also coordinate this follow-up and will assure the link to CCEM-K2.

This protocol is essentially equivalent to the protocol of EUROMET.EM-K2. The procedures outlined in this document should allow for a clear and unequivocal comparison of the measurement results. The protocol was prepared following the CCEM guidelines for planning, organizing, conducting and reporting key, supplementary and pilot comparisons.

2. Travelling standards

2.1 Description of the standards

10 MΩ

Two different types of travelling standards (one resistor each) are used:

1. Standard Resistor manufactured by Guildline Instruments, model 9330. The resistance element is suspended in oil in a hermetically sealed metal container. This container is mounted inside a metal box. The two resistor terminations of the standard are coaxial N-type connectors mounted on the top panel of the enclosure. The resistor container, the outer box and the shields of the coaxial N-connectors are joined together.
2. Standards manufactured by Measurements International (CA), Model 9331. The resistance elements are hermetically sealed in metal containers. The four resistor terminations of the standards are tellurium copper binding posts. A separate ground terminal is included for screening.

1 GΩ

Two travelling standards of the same type are used:

1. Standards manufactured by Measurements International (CA), Model 9331S (based on NIST design). The resistance elements are housed in a double shielded enclosure. The two resistor terminations of the standards are N-type coaxial connectors mounted directly on the outer enclosure. The inner enclosure containing the resistive element is connected to the guard terminal. For one of the standards, this terminal is isolated from the outer enclosure and may be operated either in floating mode, in a grounded mode, or driven at a guard potential. For the 2nd standard, the guard terminal is connected to the outer enclosure.

In the comparison, two 10 MΩ and two 1 GΩ standards will be circulated:

- 10 MΩ: Guildline 9930, SN 47225
  MI 9331, SN 1050109
- 1 GΩ: MI 9331S, SN 1100036
  MI 9331S, SN 1010802

The standards 10 MΩ, SN 1050109, and 1 GΩ, SN 1100036, were already used in the comparison EUROMET.EM-K2. Their values were deliberately offset by means of trim resistors after this comparison. In this way a extrapolation of their value based on the results of EUROMET.EM-K2 will not be possible.

2.2 Quantities to be measured

- Resistance of the 10 MΩ standards at the following conditions:
  test voltage: $V_{test} \leq 100$ V; preferably 10 V
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

- Resistance of the 1 GΩ standards at the following conditions:
  test voltage: $V_{test} \leq 100$ V; preferably 100 V
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

2.3 Method of computation of the Reference value

The proposed principles of the analysis are:

- The results obtained by the pilot laboratory will be used to determine the drift behaviour of the travelling standards;
- The results provided by the participants will be corrected to the nominal temperature (23 °C) and nominal voltage using the sensitivity coefficients determined by the pilot laboratory;
- The results of the participants will be linked to the comparison EUROMET.EM-K2 through the results of the pilot laboratory obtained in the comparison EUROMET.EM-K2 and this follow-up loop.

3. Organisation

3.1 Co-ordinator and members of the support group

The pilot laboratory for the comparison is the Federal Office of Metrology METAS

Co-ordinator and contact person for technical questions:
Dr Beat Jeckelmann
Tel.: +41 31 323 3297; e-mail: beat.jeckelmann@metas.ch

Organizational matters:
Mrs Beatrice Steiner
Tel.: +41 31 323 3430; e-mail: beatrice.steiner@metas.ch

Support group:
Dr Bernd Schumacher, Physikalisch-Technische Bundesanstalt (PTB), DE;
e-mail: bernd.schumacher@ptb.de

Dr Gert Rietveld, Van Swinden Laboratorium VSL, NL:
e-mail: grietveld@vsl.nl

3.2 Participants

The participating institutes are listed in the following table. The contact details are given in Appendix A1.

No	Country	Institute	Acronym
1	Bulgaria	Bulgarian Institute of Metrology	BIM
2	Croatia	Faculty of Electrical Engineering and Computing, Primary Electromagnetic Laboratory	FER-PEL
3	Egypt	National Institute for Standards	NIS
5	Poland	Central Office of Measures	GUM
5	Portugal	Portugese Institute for Quality	IPQ
6	Switzerland	Federal Office of Metrology	METAS

Table 1: Participants

3.3 Time schedule

The comparison is carried out in one loop. The circulation of the standards starts in April 2010 and is planned to end in February 2011. The detailed time schedule for the comparison is given in Appendix A2.

A period of five weeks is allowed for the measurements in each laboratory, including the time necessary for transportation. The standards will be measured before and after the circulation in the pilot laboratory to establish a drift rate for the standards and to detect transport problems.

In agreeing with the proposed circulation time schedule, each participating laboratory confirms that it is capable to perform the measurements in the limited time period allocated in the time schedule. If, for some reasons, the measurement facility is not ready or custom clearance should take too much time, the laboratory is requested to contact immediately the co-ordinator in the pilot laboratory. According to the arrangement made in this special case the travelling standards must be eventually sent directly to the next participant before the measurement has been finished or even without performing any measurements. In such a case, there is a possibility to carry out the measurements at the end of the comparison.

If a delay occurs, the pilot laboratory shall inform the participants and revise - if necessary - the time schedule, or skip one country and put it at the end of the circulation.

3.4 Transportation

- Transportation is at each laboratory’s own responsibility and cost. Due to the time constraints, a recognised courier service (e.g. UPS, DHL..) guaranteeing an adequate delivery time, inclusive of the time for customs procedure, should be used. Where appropriate, customs procedures have to be examined in advance of the transport. *The courier service has to be informed that the transport case should not be exposed to extreme temperatures or mechanical shocks*.
- In some countries, the case will be transported with an ATA carnet for customs clearance. Upon each movement of the package, the person organising the transit must ensure that the carnet is presented to customs on leaving the country, and upon its arrival in the country of destination. When the package is sent unaccompanied, the carnet must be included with the other forwarding documents so that the handling agent can obtain customs clearance. *In no case should the carnet be packed inside the case*. In some cases it is possible to attach the carnet to the case. The

carnet must be stored in the laboratory very carefully because a loss of the carnet may cause a serious delay in the comparison schedule.

- On receipt of the case, the participant shall inform the pilot laboratory by sending the receipt form given in Appendix A5 by fax or e-mail.
- Immediately after the completion of the measurements, the case is to be transported to the next participant. It is advisable to organise this transport beforehand. The pilot laboratory has to be informed through the form given in Appendix A6 about the dispatch of the case. The next participant should be informed as well.

3.5 Unpacking, handling, packing

The transport case contains the following items:

- Two 10 MΩ standard resistors:
    - Guildline 9930, SN 47225
    - MI 9331, SN 1050109
- Two 1 GΩ standard resistors:
    - MI 9331S, SN 1100036
    - MI 9331S, SN 1010802
- Two N-to-binding-post adapters
- Ambient conditions recorder. This recorder is used to monitor the temperature of the standards during transport.
- Instruction manual

On receipt of the case, unpack the standards carefully and check for any damage and the completeness of the audit pack according to the packing list. The ambient conditions recorder should not be removed from the transport case. If possible, the transport case should be stored in the laboratory. Any damage of the standards or missing item shall be reported on the receipt form to be sent to the co-ordinator.

Before sending the case out, check the packing list and ensure everything is enclosed. The standards should be packed in the original transport case as illustrated in the instruction manual. *Ensure that the ATA carnet (where applicable) is packed outside the case for easy access by customs*.

3.6 Failure of the travelling standard

Should one of the standards be damaged during the comparison, the pilot laboratory has to be informed immediately.

3.7 Financial aspects, insurance

Each participating laboratory covers the costs of the measurements, transportation and eventual customs formalities as well as for any damage that may occur within its country. The overall costs for the organisation of the comparison are covered by the organising pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during transportation.

4. Measurement instructions

4.1 Test before measurements

No initial tests are required. However, depending on the measurement set-up it may be necessary to measure the isolation resistance between the resistive elements and the case of the standards.

4.2 Measurement performance

Pre- conditioning:	The standards should be installed in a thermostatic air bath, regulated at the chosen working temperature, at least 24 h before staring the measurements.
Measurand:	Resistance value of the travelling standards at DC, expressed in terms of the conventional value of the von Klitzing constant R_{K-90} = 25812.807 Ω.
Test voltage:	10 MΩ: $V_{test} \leq 100$ V; preferably 10 V 1 GΩ: $V_{test} \leq 100$ V; preferably 100 V
Temperature:	(23 ± 0.2) °C; the temperature should not exceed the given limits.
Humidity:	(50 ± 10) %.
Measurements:	The measurements should be repeated several times during the whole period allocated to the participating laboratory.

4.3 Method of measurement

The measurement method is not specified. It is assumed that every participant uses its normal measurement method. The method and the traceability scheme have to be described in the measurement report (see below).

The choice of the ground/guard configuration is left to the participants. Sect. 2.1 describes the internal configuration of the ground/guard terminals in the resistance standards.

5. Uncertainty of measurement

5.1 Main uncertainty components

A detailed uncertainty budget in accordance with the ISO Guide to the Expression of Uncertainty in Measurement shall be reported for one resistor of each nominal value.

To have a comparable uncertainty evaluation, a list of principal uncertainty contributions is given. Depending on the measurement methods, this list may vary:

- Step-up procedure
- Reference standard (drift, temperature and voltage dependence)
- Measuring set-up (stability, gain and offset-effects, configuration)
- Leakage effects
- Temperature
- Reproducibility

5.2 Scheme to report the uncertainty budget

A proposed scheme for the uncertainty budget is given in Annex A3.

6. Measurement report

Each participant is asked to submit a printed and signed report by mail within **6 weeks** after completing the measurements. A copy of the report may also be sent by e-mail. In the case of differences between electronic and paper versions of the report, the signed paper form is considered to be the valid version. The report should contain at least the following (see also Appendix A4):

- Description of the measuring set-up including the ground/guard configuration. (If a two-terminal method is used in the case of the 10 MΩ MI standard, the connection scheme should be reported);
- Traceability scheme. If the traceability to the SI is provided by another NMI, the name of the NMI has to be stated (needed to identify possible sources of correlation);
- Description of the measurement procedure;
- The measurement results: Mean resistance value for every standard and the corresponding mean date of measurement; individual results in the form described in Appendix A4;
- The test voltages chosen for the measurements;
- The ambient conditions of the measurement: the temperature and humidity with limits of variation;
- A complete uncertainty budget in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement, including degrees of freedom for every component and calculation of the coverage factor. Such an analysis is a prerequisite to be considered in the calculation of the comparison reference value. It is also an essential part of the final report which will appear in the BIPM Key Comparison Database.

The pilot laboratory will inform a participating laboratory if there is a large deviation between the results of the laboratory and the preliminary reference values. No other information will be communicated before the completion of the circulation.

7. Report of the comparison

The pilot laboratory will prepare the draft A report within three months after completion of the circulation. This report will be prepared with the aid of the support group and will be sent to all participants for comments.

References

[1] B. Jeckelmann and M. Zeier, Analysis of measurement comparison EUROMET.EM-K2, Conference on precision electromagnetic measurements (CPEM), 8-13 June 2008, Broomfield, CO, USA; conference digest p. 144.

Annexes

A1 Detailed list of participants

Name	Institute	Acronym	Address	Country	Telephone	Telefax	e-mail
Andrey Tenev	Bulgarian Institute of Metrology	BIM	52B G. M. Dimitrov Blvd. BG-1040 SOFIA	Bulgaria	+359 29 70 27 21	+359 29 70 27 35	a.tenev@bim.government.bg
Damir Ilic	University of Zagreb, Faculty of Electrical Engineering and Computing; Primary Electromagnetic Laboratory	FER-PEL	Unska 3 HR-10000 Zagreb	Croatia	+385 1 612 9753	+385 1 612 9571	damir.ilic@fer.hr
Nadia Nassif Tadros	National Institute for Standards	NIS	Tersa Street, El-Haram El-Giza 136 Giza Code No 12211	Egypt		+202 338 67451	nntadros@yahoo.com
Edyta Dudek	Central Office of Measures	GUM	ul. Elektoralna 2 PL-00-950 Warszawa	Poland	+48 22 581 9462	+48 22 581 9499	dc.standards@gum.gov.pl
Maria Isabel Godinho	Portugese Institute for Quality	IPQ	Rua Antonio Giã 2, PT-2829-513 Caparica	Portugal	+351 21 294 8166	+351 21 294 8101	igodinho@mail.ipq.pt
Beat Jeckelmann	Federal Office of Metrology	METAS	Lindenweg 50 3003 Bern-Wabern	Switzerland	+41 31 32 33 297	+41 31 32 33 210	beat.jeckelmann@metas.ch

A2 Schedule of the measurements

Institute	Country	Start date	Time for measurements and transport
Pilot (metas)	Switzerland	until April 2010	
Period 1, IPQ	Portugal	5 April to 9 May 2010	5 weeks
Period 2, GUM	Poland	10 May to 13 June 2010	5 weeks
Period 3, FER-PEL	Croatia	14 June to 18 July 2010	5 weeks
Period 4, BIM	Bulgaria	19 July to 10 Sept. 2010	7 weeks
Pilot (metas)	Switzerland	15 Sept. to 30 Oct 2010	6 weeks
Period 5, NIS	Egypt	20 Nov 2010 to 15 Feb 2011	12 weeks
Pilot (metas)	Switzerland	from March 2011	-

A3 Typical scheme for an uncertainty budget

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degree of freedom ν_i
R_x						
		Combined standard uncertainty:				
		Effective degrees of freedom:				
		Expanded uncertainty (95% coverage factor):				

The detailed uncertainty has to be provided in this form for one standard of each nominal value.

A4 Layout of the measurement report

1. Measurand
2. Measurement set-up and traceability scheme
3. Measurement procedure
4. Results
   a. Ambient conditions
      Temperature: mean value, uncertainty and range of variation
      Humidity: mean value, uncertainty and range of variation
   b. Test voltage
   c. Mean date of measurement
   d. Mean resistance value, combined standard uncertainty
5. Detailed uncertainty budget

Detailed results

These results have to be supplied using the xls mask supplied by the coordinator

Standard Serial No

Date	Temperature T (°C)	Stand. un-cert. T (°C)[1)]	Test voltage (V)	Humidity (%)	Measurement result: Deviation from nominal value (μΩ/Ω)	Type A uncer-tainty (μΩ/Ω)

[1)] Combined standard uncertainty (incl. type B components)

A5 Confirmation note of receipt

To be sent by telefax or e-mail

(Please pass on immediately!)

To: Federal Office of Metrology METAS
attn.: Mrs. Beatrice Steiner

Lindenweg 50, CH-3003 Bern-Wabern, Switzerland

FAX No. : +41 31 323 3210
e-mail: beatrice.steiner@metas.ch

From: (participating laboratory):

....

....

....

Fax: International +

Pages (total): 1

In the case of faulty reproduction, please call:

EURAMET key comparison EURAMET.EM-K2.1 - Receipt of travelling standards

Date: ....

We confirm having received the travelling standards of the EURAMET.EM-K2.1 key comparison

on ....

After visual inspection:

☐ No damage of the suitcase and the travelling standards has been noticed

☐ the following damage(s) must be reported(if possible add a picture):

....

....

....

Date: .... Signature: ....

A6 Confirmation note of dispatch

To be sent by telefax or e-mail

(Please pass on immediately!)

To: Federal Office of Metrology METAS
attn.: Mrs. Beatrice Steiner

Lindenweg 50, CH-3003 Bern-Wabern, Switzerland

FAX No. : +41 31 323 3210
e-mail: beatrice.steiner@metas.ch

From: (participating laboratory):

....

....

....

Fax: International +

Pages (total): 1

In the case of faulty reproduction, please call:

EURAMET key comparison EURAMET.EM-K2.1-
Dispatch of travelling standards

Date: ....

We have informed the next participant on..............................that we will send the travelling standards to them.

We confirm having sent the travelling standards of the EURAMET.EM-K2.1 key comparison on.................................to the next participant.

Additional informations:

....

....

....

Date: .... Signature: ....