Supplementary Comparison EURAMET.EM-S32
Comparison of Resistance Standards at 1 TΩ and 100 TΩ

Final Report

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Abstract

Resistance standards with values in the TΩ range play an important role in electrical instrumentation. The calibration of such standards is, thus, a service offered by many metrology institutes. The techniques used to measure very high resistance values differ quite substantially from the calibration techniques applied in the lower resistance ranges. For this reason, the EURAMET technical committee for electricity and magnetism decided in 2008 to organise for the first time a supplementary comparison of resistance at 1 TΩ and 100 TΩ based on well characterized travelling standards.

Eighteen European National Metrology Institutes participated in the comparison. With some exceptions, the results supplied by the participants agree reasonably well with the comparison reference value within the expanded uncertainty.

As observed in other resistance comparisons, the characteristics of the standards used as transport artefacts ultimately limit the accuracy of comparisons in this field. The transport behaviour is difficult to model and introduces an undesired bias in the laboratory results. The transport uncertainties are at the level of the uncertainties claimed by some of the participants and, thus, limit the meaningfulness of the comparison results.

Another remarkable observation is the big difference in the uncertainty statements made by the participants; even in cases there similar measurement systems were used. The results of the comparison allow the participants to critically review their measurement procedures and uncertainty models.

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1. Introduction

Resistance standards with values in the TΩ range play an important role in electrical instrumentation. The calibration of such standards is, thus, a service offered by many metrology institutes. The techniques used to measure very high resistance values differ quite substantially from the calibration techniques applied in the lower resistance ranges. For this reason, the key comparisons carried out so far in the field of DC resistance do not cover the high end of the scale in the TΩ range. The EURAMET technical committee for electricity and magnetism, thus, decided in 2008 to organise a supplementary comparison of resistance at 1 TΩ and 100 TΩ, based on well characterized travelling standards.

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:

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2.2 List of participants

Eighteen EURAMET NMIs participated in the comparison.

No	Country	Institute	Acronym
1	Switzerland	Federal Institute of Metrology	METAS
2	Slovakia	Slovak Institute of Metrology	SMU
3	Germany	Physikalisch-Technische Bundesanstalt	PTB
4	Slovenia	Slovenian Institute of Quality and Metrology	MIRS-SIQ
5	Greece	Hellenic Institute of Metrology	EIM
6	Italy	Istituto Nazionale di Ricerca Metrologica	INRIM
7	Finland	Centre for Metrology and Accreditation	MIKES
8	Sweden	Technical Research Institute of Sweden	SP
9	Romania	National Institute of Metrology	INM
10	Bulgaria	Bulgarian Institute of Metrology – National Centre of Metrology	BIM-NCM
11	Netherlands	Van Swinden Laboratorium	VSL
12	Poland	Central Office of Measures	GUM
13	Czech Republic	Czech Metrology Institute	CMI

No	Country	Institute	Acronym
14	Portugal	Instituto Português da Qualidade	IPQ
15	Spain	Spanish Centre of Metrology	CEM
16	Belgium	Service de la Métrologie	SMD
17	France	Laboratoire National de Métrologie et d'Essais	LNE
18	Turkey	TÜBİTAK Ulusal Metroloji Enstitüsü	UME

Table 1: Participants

2.3 Organisation and comparison schedule

The comparison was carried out in one measurement loop. The circulation of the standards started in April 2009 and was completed in July 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 three times during the loop 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	SMU	Slovakia	14. April to 14. May 2009
13	CMI[1)]	Czech Republic	15. May to 10. June 2009
3	PTB	Germany	15. June to 14. July 2009
1	**Pilot (METAS)**	Switzerland	24. July to 17. August 2009
4	MIRS-SIQ	Slovenia	21. August to 18. Sept. 2009
5	EIM	Greece	28. Sept. to 23. Oct. 2009
6	INRIM	Italy	26. Oct. to 26. Nov. 2009
7	MIKES	Finland	27. Nov. to 23. Dec. 2009
15	CEM[1)]	Spain	5. Jan. to 2. Feb. 2010
16	SMD[1)]	Belgium	8. Feb. to 4. March 2010
8	SP	Sweden	5. March to 6. April 2010
1	**Pilot (METAS)**	Switzerland	12. April to 4. May 2010
9	INM	Romania	10. May to 11. June 2010
10	BIM-NCM	Bulgaria	15. June to 26. July 2010
11	VSL	Netherlands	28. July to 8. Sept. 2010
12	GUM	Poland	14. Sept. to 13. Oct. 2010
1	**Pilot (METAS)**	Switzerland	18. Oct. to 12. Nov. 2010
13	CMI	Czech Republic	15. Nov. to 13. Dec. 2010
14	IPQ	Portugal	14. Dec. 2010 to 27. Jan. 2011
15	CEM	Spain	28. Jan. to 24. Feb. 2011
16	SMD	Belgium	2. March to 24. March 2011
17	LNE	France	26. March to 5 May 2011
18	UME	Turkey	18 May to 13 July 2011
1	**Pilot (METAS)**	Switzerland	20. July 2011 to April 2012

Table 2: Comparison schedule
[1)] CMI, CEM and SMD have repeated the measurements towards the end of the loop. Only the report for the 2nd measurement was sent to the pilot and taken into account in the analysis.

2.4 Unexpected incidents

Problems with one of the 100 TΩ standards (standard no 6, SN 1100625) were reported by CEM in February 2011 and by UME in May 2011. In both cases it turned out that one of the wires connecting the inner box with the resistive element to the N-type connector, mounted on the outer box of the standard, was broken. These failures were most probably caused by a displacement of the inner box with respect to the outer box during transport. In both cases, the participants opened the outer box and re-soldered the broken wire to the N-connector.

3. Travelling standard and measurement instructions

3.1 Description of the standards

Two different types of travelling standards were used:

1. Standard air resistor, model 9331G, manufactured by Measurements International (one 1 TΩ standard and one 100 TΩ standard).
   The schematic of the standard is shown in Fig. 1. The standard has an inner and an outer enclosure. The inner enclosure, filled with dry Argon gas, contains the resistive element. Glass to metal seals, at both ends of the inner enclosure, are used to connect the resistor to the input connectors. The two ends of the inner box are isolated from each other. They can be driven by guard potentials applied to the shields of the input connectors (N-type). These connectors are electrically isolated from the outer enclosure. A terminal is provided to connect the outer box to the ground potential.

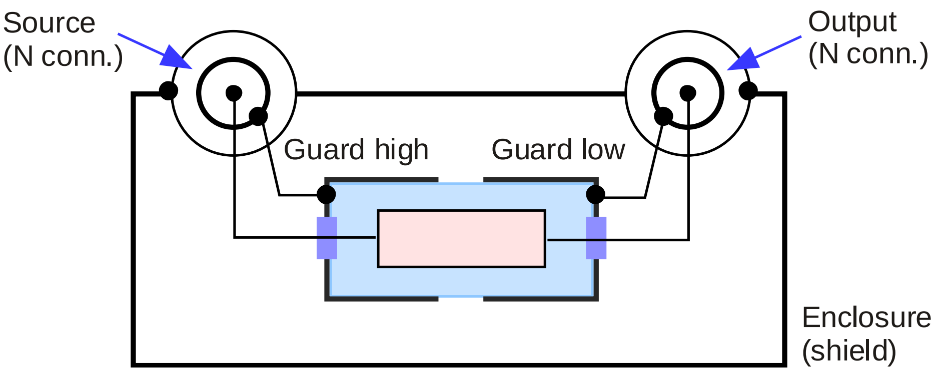

Figure 1: MI 9331 G standard (1 TΩ and 100 TΩ)

2. Standard air resistor, model 9337, manufactured by Guildline (two 1 TΩ standards and two 100 TΩ standards). These standards were kindly provided by Guildline Instruments Limited CA for this comparison.
   The schematic is shown in Fig. 2. The required resistance value is achieved by the use of a resistance divider network. Assuming that the output terminal and the shield are at the same potential, the resistance R_x between the source and output terminal is given by:

$$R_x = R_i + R_o\left(1 + \frac{R_i}{R_d}\right)$$

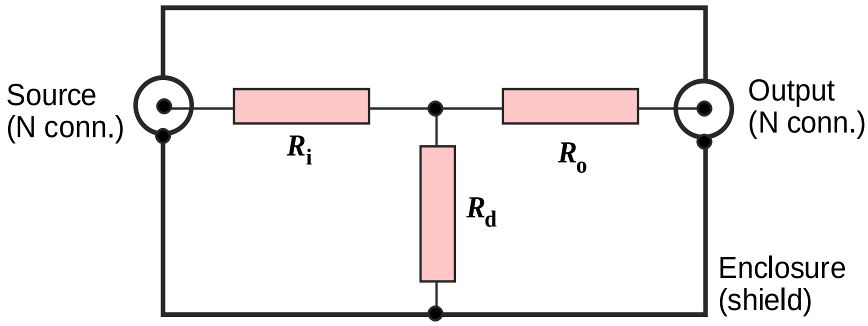

Figure 2: Guildline 9337standard (1 TΩ and 100 TΩ)

The comparison was carried out with three 1 TΩ and three 100 TΩ standards (see Table 3).

R	Std-ind. *a*	Standards
1 TΩ	1	Guildline 9937, SN 69573
	2	Guildline 9937, SN 69574
	3	MI 9331G, SN 1101180
100 TΩ	4	Guildline 9937, SN 69640
	5	Guildline 9937, SN 69641
	6	MI 9331G, SN 1100625

Table 3: List of travelling standards

3.2 Quantities to be measured and conditions of measurement

- Resistance of the 1 TΩ standards at the following conditions:
  test voltage: V_{test} = 500 V and 1000 V (both polarities)
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

- Resistance of the 100 TΩ standards at the following conditions:
  test voltage: V_{test} = 500 V and 1000 V (both polarities)
  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

4.1 Active arm Wheatstone bridge

An active arm Wheatstone bridge [1] was used by the majority of the participants (METAS, PTB, EIM, INRIM (for 100 TΩ), MIKES, SP, VSL, CEM, UME). Below, a short description of the METAS set-up is given.

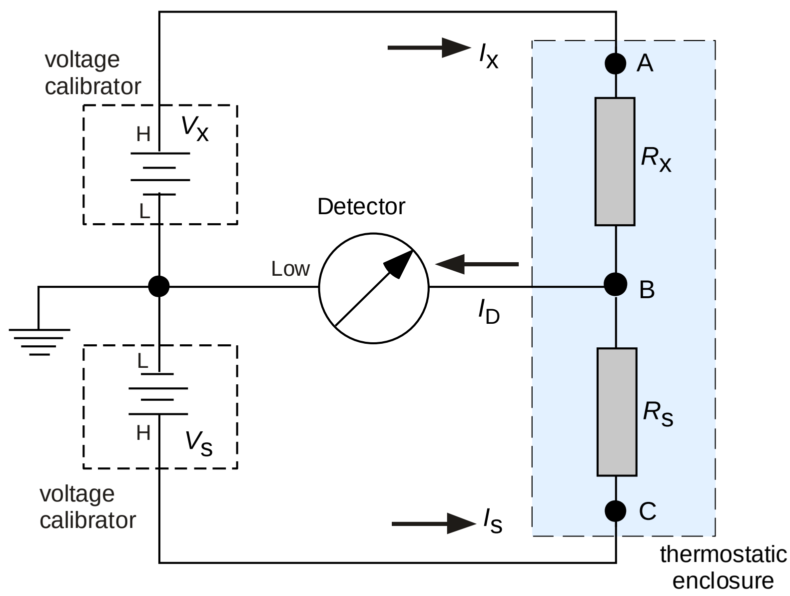

Figure 3: Schematics of the active arm Wheatstone bridge

The principle of the bridge is shown in Fig. 3. The current seen by the detector (feedback electrometer) is given by:

$$I_D = I_x + I_s = \frac{V_x}{R_x} + \frac{V_s}{R_s}$$

$$\text{bridge balanced}: I_D = 0 \quad \Rightarrow \quad R_x = -\frac{V_x}{V_s} \cdot R_s$$

At fixed voltage V_x, the voltage V_s is varied until the reading of the detector corresponds to the reading at zero voltage ($V_x = V_s = 0$). The measurement is repeated at reversed polarity.

The detector reading I_m is given by: $I_m = \frac{1}{k}(I_x + I_s) + I_0$

k: correction factor (instrument, reduction of the sensitivity due to leaks).
I_0: offset reading of the detector

$$I_0 = I_{m0} - \frac{V_{x-0}}{R_x} - \frac{V_{s-0}}{R_s}$$

V_{x-0}, V_{s-0}: voltage at the output of the sources at zero set-voltage
I_{m0}: detector reading with sources in zero position (active zero).

$$k \cdot (I_m - I_0) = I_x + I_s = \frac{V_x}{R_x} + \frac{V_s}{R_s}$$

$$k \cdot \Delta I_m = \frac{1}{R_s}\left(\frac{V_x}{r} + V_s\right); \; r = \frac{R_x}{R_s}$$

V_x remains constant and is set to the nominal value. Two measurements are carried out for each polarity to determine the balance point: The first measurement close to the balance and the second using a predefined voltage offset:

$$\Delta I_{m1} = \frac{1}{kR_S}\left(\frac{V_X}{r} + V_{s1}\right); \; \Delta I_{m2} = \frac{1}{kR_S}\left(\frac{V_X}{r} + V_{s2}\right);$$

$$\Delta I_{m2} - \Delta I_{m1} = \frac{1}{kR_S}(V_{s2} - V_{s1}) \Rightarrow k = \frac{1}{R_S}\frac{(V_{s2} - V_{s1})}{\Delta I_{m2} - \Delta I_{m1}} = \alpha \frac{1}{R_S}$$

The voltage V_{sb} at bridge balance is given by:

$V_{sb} = V_{s1} - \alpha \cdot \Delta I_{m1};$ The resistance ratio to be determined is thus: $\boxed{r = -\frac{V_x}{V_{sb}}}$

Due to differences in the RC components in the two arms of the bridge, the settling of the detector after a change in the test voltage may take a long time. For this reason, the influence of the settling time on the value of the unknown resistor is systematically determined for each R_x/R_s pair. An example of such a study is shown in Fig. 4. The resistance change as a function of the settling time t is given by:

$$\Delta R/R(t) = a_0 + a_e \exp(-t/\tau)$$

a_0: Deviation form nominal after complete stabilisation
τ: Time constant

The value of the device under test is always taken as the value extrapolated to complete stabilization.

From the reports of the participants it is not clear, if all participants have reported the DC value of the standards which is the value after complete stabilisation (no remaining RC components in the measured signal). Some of the discrepancies in the results (see Sect. 6.3) may be a consequence of insufficient stabilisation.

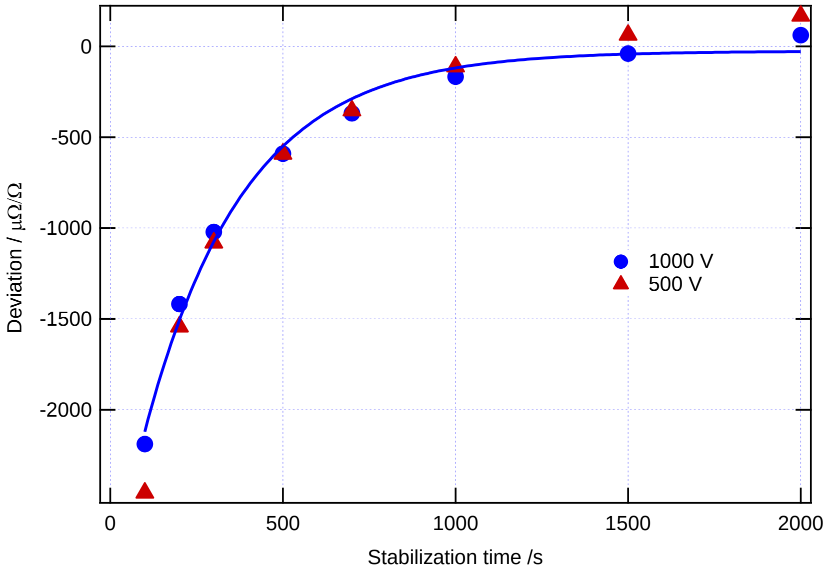

Figure 4: Influence of the stabilization time for a 100 TΩ to 1 TΩ comparison (100 TΩ standard = standard no. 6). The stabilization time is the time span between the moment when the voltage is set (or removed) and the start of the current measurement.

4.2 Integration Method

The integration method [2] schematically depicted in Fig. 5 was used at GUM, INM, IPQ, LNE, SIQ and SMD. At LNE a home-made set-up was used whereas a commercial bridge ("Teraohmmeter") was in operation at the other institutes.

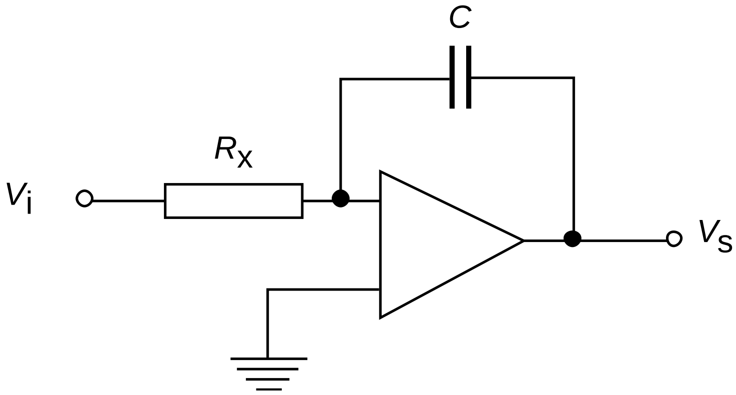

Figure 5: Principle of the integration method.

In the integration method, the current I_x flowing through the unknown resistor R_x is given by:

$$I_x = -C\frac{dV_s}{dt},$$

where C is a well characterized standard capacitor and dV_s/d_t is a linearly changing voltage which has to be measured. The unknown resistor is then:

$$R_x = \frac{V_i + e_i}{I_x},$$

where V_i is a stable reference voltage and e_i denotes the residual input voltage of the integration bridge. The measurements should be performed at both polarities of V_i.

4.3 Other methods

- Method used at BIM-NCM, CMI and SMU: measurements carried out with a calibrated electrometer and a voltage.
- INRIM, measurements at 1 TΩ: method based on a digital voltmeter and a DC voltage calibrator, see [3, 4] for details.

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 dependence of the travelling standards was determined at the pilot laboratory. The temperature was varied around 23 °C.

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

$$R_a(T) = R_{nom-a} \cdot \left(1 + \delta_{nom}(T_{nom}) + \alpha_a (T - T_{nom})\right), \qquad (5.1)$$

where a is the index for the standard and $\delta_{nom}(T_{nom})$ the relative deviation from the nominal value at nominal temperature.

The temperature coefficients were determined by a least-squares fit to the data. The fit results are listed in Table 4.

Standard Index a		α_a (ppm/K)	Standard Index a		α_a (ppm/K)
1 TΩ			**100 TΩ**		
1	69573	42 ± 7	4	69640	-100 ± 250
2	69574	37 ± 7	5	69641	47 ± 70
3	1101180	70 ± 5	6	1100625	-3950 ± 150

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

According to the protocol, the measurements were supposed to be carried out at two fixed voltage values (500 V and 1000 V). Nevertheless, slightly different test voltages were applied by some of the participants. To make the corresponding values useable for the comparison, voltage correction terms had to be applied. For this purpose, the fitted voltage dependence determined by the pilot laboratory was used. The voltage dependence can be described by the following model:

$$R_a(V) = R_{nom-a} \cdot \left(1 + \delta_{nom}(V = 0) + \gamma_{1-a} V + \gamma_{2-a} V^2\right) \qquad (5.2)$$

The voltage coefficients were determined by a least-square fit to the data. The fit results are listed in Table 5.

Standard Index a	SN	γ_{1-a} (ppm/V)	γ_{2-a} (ppm/V^2)	Standard Index a	SN	γ_{1-a} (ppm/V)	γ_{2-a} (ppm/V^2)
1 TΩ				**100 TΩ**			
1	69573	0	(-1.31±0.05)10^{-4}	4	69640	0	(-1.35±0.02)10^{-3}
2	69574	0	(-1.47±0.03)10^{-4}	5	69641	-0.077 ± 0.028	0
3	1101180	0	(-4.53±0.15)10^{-5}	6	1100625	-101.0 ± 0.5	(-1.59±0.04)10^{-5}

Table 5: 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, three times during the loop and at the end were used to establish the drift behaviour of the standards.

When left in stable conditions, resistance standards drift in a linear fashion over short time periods and with a slowly decaying drift rate over longer time periods. A smooth fitting line (straight line, polynomial of low order or straight line with additional exponential component) can be used in most cases to fit the drift behaviour. During transport, standards may suffer from mechanical shocks or from temperature shocks. As a consequence, step like changes in the resistance value may occur which are unpredictable. In some cases, the step like changes decay over periods of days or weeks and the resistance values returns to a value close to the original value. Often however, the original value is not restored, and in some cases, even the drift rate changes as a consequence of the shock.

These effects often limit the meaningfulness of comparisons. In the case when the pilot data cannot be fitted by a smooth fitting line which is a reasonable continuation of the drift behaviour observed before the start of the comparison loop, assumptions on the transport effects have to be made.

First of all, an overall drift has to be determined from the results of the pilot laboratory. These results may have a bias with respect to a reference value; but this bias is the same for all the pilot measurements. The pilot data, thus indicate, the real change in the resistance value between clearly defined points in time. The value of the standard in between these points is not known. To first order, it is reasonable to construct a smooth fitting line that goes through all the pilot data points. There is equal probability that in between the pilot data points, the real position of the value was below or above this fitting curve. It is also possible to choose an overall smooth fitting line which in case of transport effects does not go through the pilot data points. In absence of knowledge about the real effect of the travel incidents, it is, however, not possible to argue that such a solution would be any better than the piecewise fitting method.

Base on these considerations, the following model was used to fit the measurements. A piecewise fitting was applied, if a smooth fitting line over the whole period of the comparison was not appropriate:

$$R_a(t) = R_{nom}\left(1 + p_{a,0-Vi} + p_{a,1}(t-t_0) + p_{a,2}(t-t_0)^2 + p_{a,3}(t-t_0)^3\right) = R_{nom}\left(1 + f(t)\right) \quad (5.3)$$

with:

- $p_{a,i}$: fitting parameters for standard no a
- V_i: test voltage i = 1: V = 500 V; i = 2: V = 1000 V.
- t_0: reference date

In this model, it is assumed that the drift behaviour is the same for the two test voltages. This assumption was checked by carefully measuring the voltage dependence of the standards before and after the comparison loop, and by an analysis of the residuals to the fitted curves.

In the following, the drift behaviour of the travelling standards is described individually. For clarity the offset terms $p_{a,i\text{-}V_i}$ were subtracted in the graphs. Only the time dependent part of the drift functions is, thus, shown. The reference date used in the graphs is 1 January 2009.

5.2.1 1 TΩ standards

***Standard a* = 1**

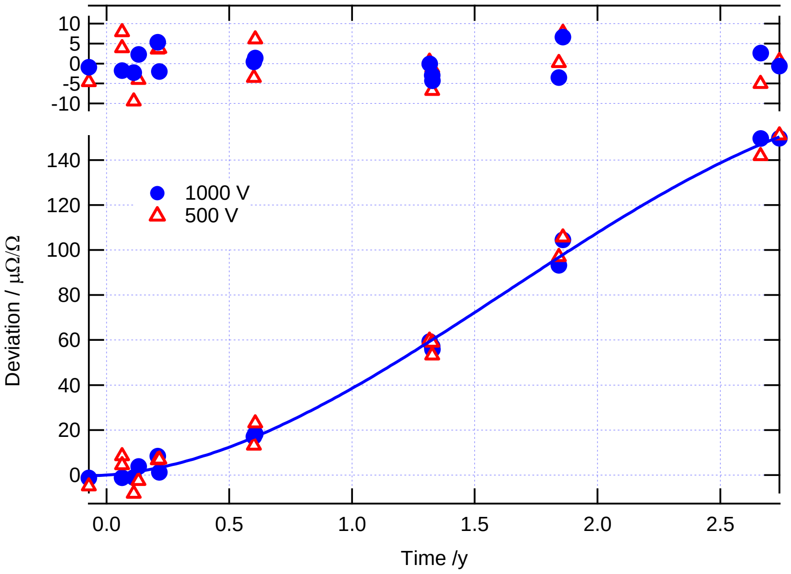

Figure 6: Drift behaviour of the 1 TΩ standard *a* = 1. The residuals to the fit are shown in the upper part of the figure.

The drift behaviour can be described by a polynomial of third order. The residuals show no systematic structure and the voltage dependence did not change during the measurement period.

***Standard a* = 2**

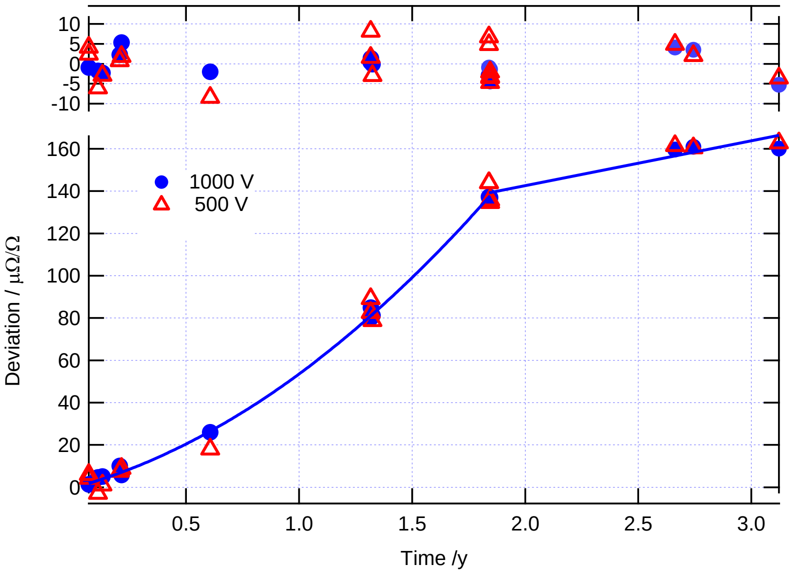

Figure 7: Drift behaviour of the 1 TΩ standard *a* = 2.

For this standard, it was not possible to fit a smooth drift curve throughout the whole period of the comparison. The data suggest that an incident after the fourth measurement at the pilot laboratory caused a change in the drift behaviour. It was decided to use a polynomial fit of second order to fit the first part up to t =1.8 y and a line fit for the second part. Because of the change in the drift behaviour after t =1.8 y, an important deviation of the actual resistance value form the linear model used for this period may be possible. The values reported by the participants for this standard and this period have, thus, to be analysed more carefully.

***Standard a* = 3**

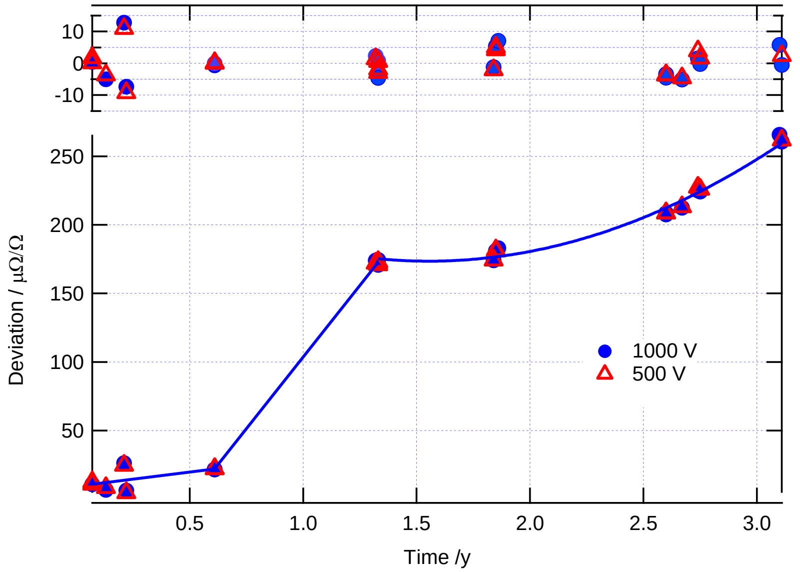

Figure 8: Drift behaviour of the 1 TΩ standard a = 3.

Again, it is not possible to have one smooth drift curve over the whole period. For this standard, a travel incident must have occurred between t = 0.6 y and t = 1.3 y. A piecewise linear fit is chosen for the two first parts until t = 1.3 y and a 2nd order polynomial fit from t = 1.3 y until the end of the comparison.

5.2.2 100 TΩ standards

***Standard a* = 4**

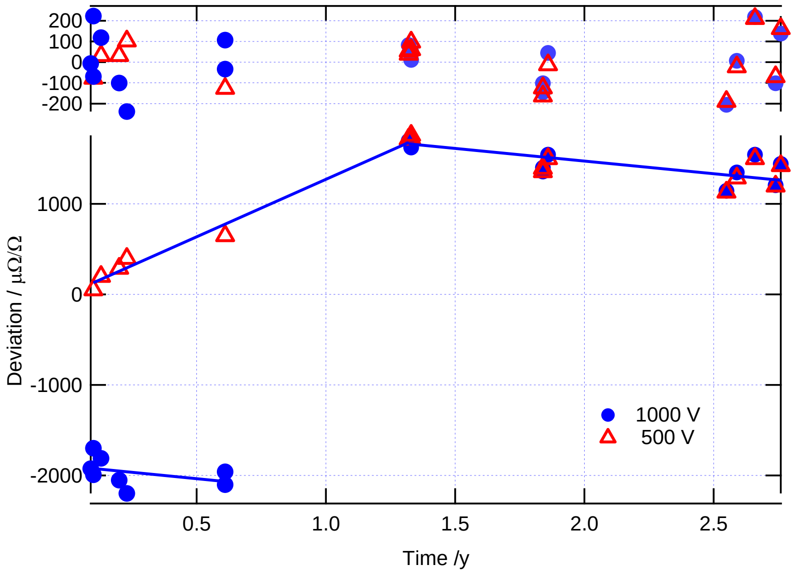

Figure 9: Drift behaviour of the 100 TΩ standard *a* = 4.

For this standard, the voltage dependence changed during the comparison. As can be seen in Figure 9, the difference between the resistance value at a test voltage of 500 V and the value at 1000 V drastically changed between *t* = 0.6 y and *t* = 1.3 y. The difference remained stable after *t* = 1.3 y. As an illustration, the voltage dependences measured before and after the loop are shown in Fig. 10. No explanation for the observed changes was found.

A line fit was chosen for the 500 V data between *t* = 0.6 y and *t* = 1.3 y. The behaviour at 1000 V in this period cannot be safely predicted and the corresponding data reported by the participants will, thus, have to be checked carefully. The 500 V as well as the 1000 V data for the period after *t* = 1.3 y is fitted by a 2nd straight line.

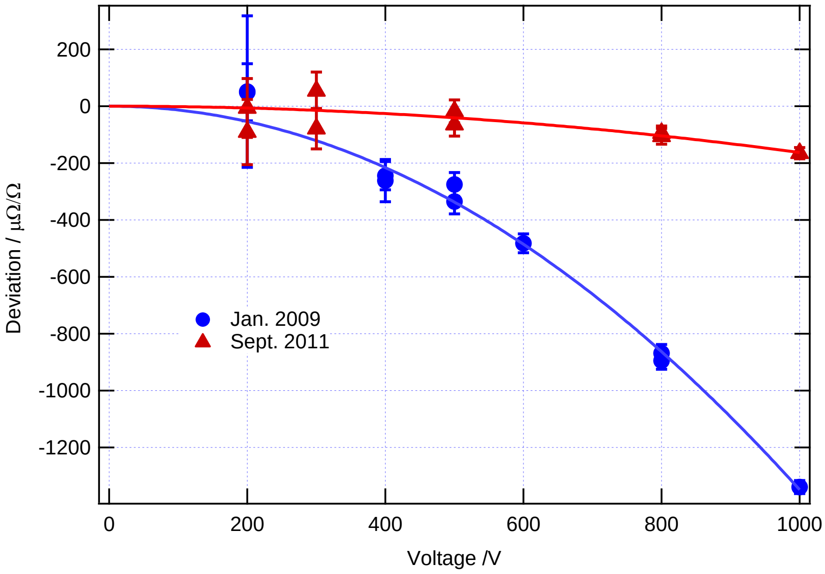

Figure 10: Voltage dependence of the 100 TΩ standard *a* = 4, before and after the comparison.

Standard *a* = 5

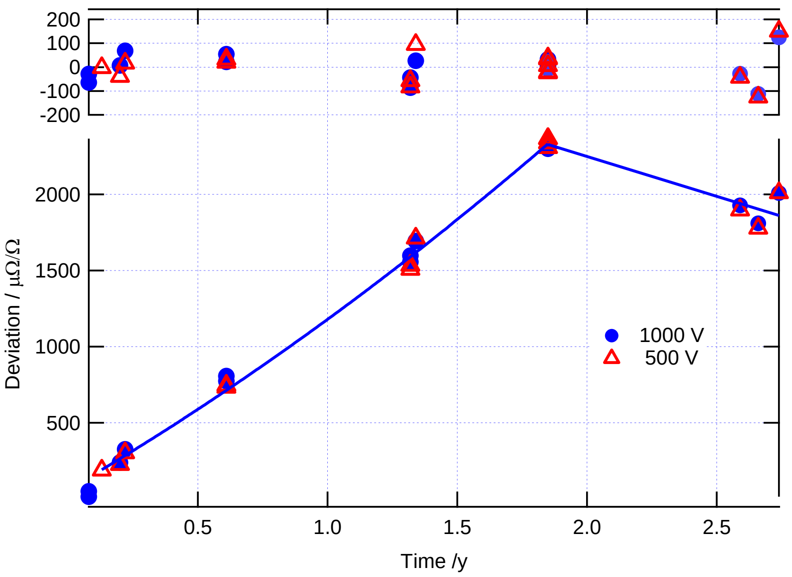

Figure 11: Drift behaviour of the 100 TΩ standard *a* = 5.

As for other standards, it was not possible to fit a smooth drift curve over the whole period of the comparison. The data suggest that an incident after the fourth measurement at the pilot laboratory caused a change in the drift behaviour. It was decided to use a polynomial fit of second order to fit the first part up to *t* =1.8 y and a line fit for the second part. Because of the change in the drift behaviour after *t* =1.8 y, an important deviation of the actual resistance value form the linear model used for this period may be possible. The values reported by the participants for this standard and this period have, thus, to be analysed more carefully.

Standard *a* = 6

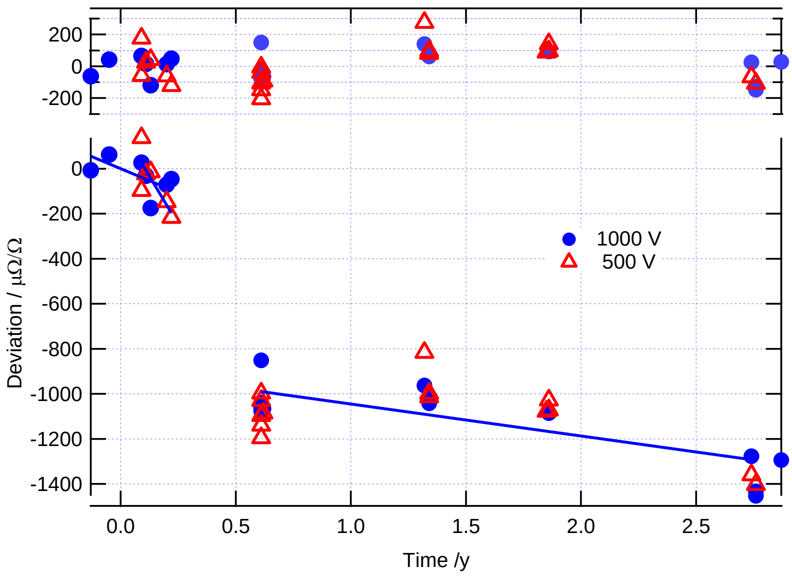

Figure 12: Drift behaviour of the 100 TΩ standard *a* = 6.

For this standard, a deviation from the expected behaviour is observed right after the beginning of the loop. Due to the drastic change in the period from *t* = 0.2 y to *t* = 0.6 y, the data in this period is not taken into account in the analysis. From t = 0.6 y to the end of the comparison, a straight line fit is chosen.

5.2.3 Summary fit parameters

Standard Index a		*Fit part*	t_0	$P_{a,0\text{-Vi}}$ (ppm)	$P_{a,1}$ (ppm/y)	$P_{a,2}$ (ppm/y^2)	$P_{a,3}$ (ppm/y^3)
1 TΩ							
1	69573	1	1 Jan 2009	-535.9 ± 1.8 -626.5 ± 1.9	7.0 ± 8.3	39.2 ± 8.0	-7.9 ± 1.9
2	69574	1	1 Jan 2009	-351.4 ± 2.2 -455.0 ± 2.6	29.1 ± 5.5	24.8 ± 2.9	-
		2	1 Nov 2010	-213.0 ± 2.2 -316.6 ± 2.2	21.2 ± 2.6	-	-
3	1101180	1	1 Jan 2009	-1459.8 ± 4.7 -1491.6 ± 6.6	21.4 ± 13.5	-	-
		2	1 Aug 2009	-1452.6 ± 3.3 -1484.4 ± 5.2	210.4 ± 2.6	-	-
		3	1 May 2010	-1293.6 ± 3.0 -1325.4 ± 2.9	-17.6 ± 6.9	36.7 ± 3.7	-
100 TΩ							
4	69640	1	1 Jan 2009	-131 ± 55	1269 ± 90	-	-
		2	27 Apr 2010	1511 ± 55 1372 ± 55	-253 ± 50	-	-
5	69641	1	1 Jan 2009	-1729 ± 32 -1883 ± 30	1176 ± 79	41 ± 39	-
		2	1 Nov 2010	592 ± 60 443 ± 60	-494 ± 80	-	-
6	1100625	1	1 Jan 2009	-54909 ± 53 -93674 ± 41	-428 ± 267	-	-
		2	11 Aug 2009	-55899 ± 37 -94676 ± 39	-142 ± 27	-	-

Table 6: Fit parameters describing the drift behaviour of the travelling standards. V_1 = 500 V, V_2 = 1000 V

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 see 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
- Humidity
- Test voltage

Each result reported by the participants can be expressed as:

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

- 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:

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

- $u_{s\text{-}p\text{-}a}$: 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 7. The term $u^*_{\text{r-p,a}}$ describes the scatter of the normalized individual results. This term is introduced in Sect. 6.2.3 below. The term in the last column is a combined term describing the non-statistical uncertainty components. It is calculated as:

$$u_{s-p}{}^2 = \frac{1}{3}\sum_i u_{s-p-a}{}^2 \text{, } i = 1, 2, 3 \text{ for } 1\ \mathrm{T\Omega} \text{ and } i = 4, 5, 6 \text{ for } 100\ \mathrm{T\Omega}. \qquad (6.3)$$

p	Lab	***a* = 1** $u_{r\text{-}p,a}$ (ppm)	$u^*_{\text{r-p,a}}$ (ppm)	$u_{s\text{-}p,a}$ (ppm)	***a* = 2** $u_{r\text{-}p,a}$ (ppm)	$u^*_{\text{r-p,a}}$ (ppm)	$u_{s\text{-}p,a}$ (ppm)	***a* = 3** $u_{r\text{-}p,a}$ (ppm)	$u^*_{\text{r-p,a}}$ (ppm)	$u_{s\text{-}p,a}$ (ppm)	$u_{s\text{-}p}$ (ppm)
1	METAS	1.3	1.3	19.2	1.1	1.1	19.2	1.0	1.0	19.2	19.2
2	SMU	180.0	41.9	2544.0	160.0	55.5	2480.0	419.0	202.8	2588.0	2537.7
3	PTB	220.0	39.3	40.0	220.0	36.2	40.0	220.0	89.8	90.0	61.4
4	MIRS/SIQ	77.0	77.6	1150.0	70.0	71.2	1150.0	56.0	59.0	1150.0	1150.0
5	EIM	13.0	4.1	23.0	11.0	8.7	22.0	25.0	42.3	27.0	24.1
6	INRIM	4.0	2.7	100.0	4.0	2.2	100.0	3.7	8.4	100.0	100.0
7	MIKES	3.1	1.5	33.0	2.2	1.1	33.0	11.8	4.9	33.0	33.0
8	SP	2.3	2.3	33.2	2.3	1.1	33.2	14.8	17.0	33.2	33.2
9	INM										
10	NCM	16.0	85.1	612.0	14.0	36.8	612.0	14.0	4.6	733.0	654.8
11	VSL	6.0	4.8	13.0	7.0	4.3	13.0	14.0	5.5	13.0	13.0
12	GUM	2.0	12.8	1155.0	4.6	19.3	1155.0	1.7	24.4	1155.0	1155.0
13	CMI	7.1	6.7	114.8	7.1	11.1	114.8	7.1	7.2	114.8	114.8
14	IPQ	1216.0	15.2	1155.0	2022.0	16.2	1155.0	2105.0	28.9	1155.0	1155.0
15	CEM	8.9	6.9	10.0	8.7	4.7	10.0	12.0	7.9	10.0	10.0
16	SMD	67.1	57.7	264.0	77.6	80.0	267.0	54.9	54.0	264.0	265.0
17	LNE	1.6	1.6	10.6	1.6	1.6	10.6	1.3	1.3	10.6	10.6
18	UME	16.3	17.7	21.3	6.9	8.0	23.1	11.2	11.3	21.5	22.0

Table 7a: Combined standard uncertainties reported by the laboratories for 1 TΩ standards and V = 500 V.

p	Lab	***a* = 1**			***a* = 2**			***a* = 3**			
		$u_{r-p,a}$ (ppm)	$u^*_{\mathrm{r-p,a}}$ (ppm)	$u_{s-p,a}$ (ppm)	$u_{r-p,a}$ (ppm)	$u^*_{\mathrm{r-p,a}}$ (ppm)	$u_{s-p,a}$ (ppm)	$u_{r-p,a}$ (ppm)	$u^*_{\mathrm{r-p,a}}$ (ppm)	$u_{s-p,a}$ (ppm)	u_{s-p} (ppm)
1	METAS	1.0	0.8	19.2	1.0	0.8	19.2	1.1	0.8	19.2	19.2
2	SMU										
3	PTB	220.0	43.5	43.0	220.0	43.0	43.0	220.0	119.5	120.0	77.7
4	MIRS/SIQ	75.0	75.4	1150.0	69.0	70.2	1150.0	54.0	56.5	1150.0	1150.0
5	EIM	10.0	16.9	21.0	10.0	20.2	21.0	21.0	33.8	24.0	22.0
6	INRIM	2.8	2.2	60.0	2.0	6.3	60.0	2.5	4.9	60.0	60.0
7	MIKES	4.2	2.5	31.0	1.4	1.4	31.0	11.1	4.6	31.0	31.0
8	SP	1.1	1.0	21.8	2.2	1.1	21.8	15.2	17.4	21.8	21.8
9	INM	3.0	3.2	57.0	3.0	2.1	57.0	3.0	3.0	57.0	57.0
10	NCM	8.7	61.1	612.0	4.5	52.8	612.0	15.0	373.6	679.0	635.1
11	VSL	5.0	1.5	12.0	7.0	2.1	12.0	16.0	7.3	12.0	12.0
12	GUM	2.3	17.8	1155.0	5.4	10.9	1155.0	2.2	22.2	1155.0	1155.0
13	CMI	7.1	4.4	84.7	7.1	4.8	84.7	7.1	4.3	84.7	84.7
14	IPQ	1215.0	8.9	1155.0	2017.0	9.7	1155.0	1518.0	35.4	1155.0	1155.0
15	CEM	5.7	9.2	6.9	4.8	7.6	6.9	3.7	3.0	6.9	6.9
16	SMD	51.6	41.6	261.0	63.8	66.3	263.0	53.1	46.0	261.0	261.7
17	LNE	1.7	1.7	10.5	1.1	1.1	10.5	0.7	0.7	10.5	10.5
18	UME	23.1	27.7	22.5	4.5	3.8	20.4	9.9	8.3	21.2	21.4

Table 7b: Combined standard uncertainties reported by the laboratories for 1 TΩ standards and *V* = 1000 V.

p	Lab	***a* = 4**			***a* = 5**			***a* = 6**			
		$u_{r-p,a}$ (ppm)	$u^*_{\mathrm{r-p,a}}$ (ppm)	$u_{s-p,a}$ (ppm)	$u_{r-p,a}$ (ppm)	$u^*_{\mathrm{r-p,a}}$ (ppm)	$u_{s-p,a}$ (ppm)	$u_{r-p,a}$ (ppm)	$u^*_{\mathrm{r-p,a}}$ (ppm)	$u_{s-p,a}$ (ppm)	u_{s-p} (ppm)
1	METAS	30	28	90	30	18	90	50	27	90	90
2	SMU	2740	1880	20610	2980	1456	20650	5000	4236	21040	20768
3	PTB	650	1095	1091	650	1168	944	650	2308	1643	1262
4	MIRS/SIQ	318	326	2885	147	155	2885	314	363	2885	2885
5	EIM	393	486	584	582	215	694	984	889	785	693
6	INRIM	30	45	330	33	56	330	44	125	330	330
7	MIKES	384	207	503	146	97	503	200	61	503	503
8	SP	75	87	349	17	44	349	536	42	349	349
9	INM										
10	NCM	181	4528	2040	976	3015	2040	801	3528	2030	2037
11	VSL	120	74	106	69	58	116	240	109	180	138
12	GUM	113	46	2887	110	165	2887	106	1639	2887	2887
13	CMI	112	182	3998	112	179	3998	112	246	3998	3998
14	IPQ	1790	710	2890	2010	13	2890	2110	1263	2890	2890
15	CEM	300	150	72	540	128	72	770	503	72	72
16	SMD	1657	1657	2410	1910	1910	2600				2047
17	LNE	126	126	27	142	142	27				22
18	UME	51	51	297	36	66	297	70	88	330	308

Table 7c: Combined standard uncertainties reported by the laboratories for 100 TΩ standards and *V* = 500 V.

p	Lab	*a* = 4			*a* = 5			*a* = 6			
		$u_{r\text{-}p,a}$ (ppm)	$u^*_{\text{r-p,a}}$ (ppm)	$u_{s\text{-}p,a}$ (ppm)	$u_{r\text{-}p,a}$ (ppm)	$u^*_{\text{r-p,a}}$ (ppm)	$u_{s\text{-}p,a}$ (ppm)	$u_{r\text{-}p,a}$ (ppm)	$u^*_{\text{r-p,a}}$ (ppm)	$u_{s\text{-}p,a}$ (ppm)	$u_{s\text{-}p}$ (ppm)
1	METAS	30	30	90	30	14	90	50	19	90	90
2	SMU										
3	PTB	650	953	739	650	1057	826	650	1721	1707	1175
4	MIRS/SIQ	92	279	2885	62	95	2885	327	273	2885	2885
5	EIM	320	304	371	393	609	437	254	600	297	373
6	INRIM	20	16	330	16	30	330	25	50	330	330
7	MIKES	300	167	511	28	24	511	237	84	511	511
8	SP	31	29	234	47	49	234	1025	26	234	234
9	INM	1100	1107	1529	1100	1086	1529	90	163	1529	1529
10	NCM	75	1253	2010	471	849	2000	422	15077	2020	2010
11	VSL	48	52	99	20	42	108	180	74	159	125
12	GUM	101	61	2887	175	202	2887	157	6130	2887	2887
13	CMI	71	105	3849	71	96	3849	71	132	3849	3849
14	IPQ	1010	424	2890	1160	813	2890	1230	333	2890	2890
15	CEM	140	171	77	310	562	77	210	264	77	77
16	SMD	1510	1510	2350	1342	1342	2220				1858
17	LNE	91	91	22	92	92	22				18
18	UME	28	44	255	31	53	255	31	56	278	263

Table 7d: Combined standard uncertainties reported by the laboratories for 100 TΩ standards and V = 1000 V.

6.2 Normalization of the results

6.2.1 Correction to standard 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:

$$O_{c-p,a,m} = O_{p,a,m} - \alpha_a\left(T_{p,a,m} - T_{nom}\right) - \gamma_{1-a}\left(V_{p,a,m} - V_{nom}\right) - \gamma_{2-a}\left(V^2_{p,a,m} - V^2_{nom}\right) \tag{6.4}$$

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

$$\begin{aligned} u_{TV-p,a}{}^2 = {} & \left(\alpha \cdot u\left(T_{p,a}\right)\right)^2 + \left(u(\alpha)\cdot\left(\overline{T}_{p,a} - T_{nom}\right)\right)^2 + \left(u(\alpha)\cdot u\left(T_m\right)\right)^2 + \\ & \left(u\left(\gamma_{1-a}\right)\cdot\left(\overline{V}_{p,a} - V_{nom}\right)\right)^2 + \left(u\left(\gamma_{2-a}\right)\cdot\left(\overline{V}^2_{p,a} - V^2_{nom}\right)\right)^2 \end{aligned} \tag{6.5}$$

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 measurement conditions are listed in Table 8.

p	Lab	***a* = 1** *T* (°C)	*u*(*T*) (°C)	*V* (V)	***a* = 2** *T* (°C)	*u*(*T*) (°C)	*V* (V)	***a* = 3** *T* (°C)	*u*(*T*) (°C)	*V* (V)
1	METAS	23.00	0.05	500.000	23.00	0.05	500.00	23.00	0.05	500.00
2	SMU	23.10	0.20	400.000	23.10	0.20	400.00	23.13	0.20	400.00
3	PTB	22.99	0.10	499.990	22.98	0.10	499.99	22.98	0.10	499.99
4	MIRS/SIQ	23.01	0.05	500.000	22.97	0.05	500.00	22.94	0.05	500.00
5	EIM	23.00	0.02	499.456	23.00	0.02	499.55	23.00	0.02	498.94
6	INRIM	22.82	0.05	499.995	22.83	0.05	500.00	22.82	0.05	500.00
7	MIKES	22.82	0.20	500.000	22.83	0.20	500.00	22.81	0.20	500.00
8	SP	22.99	0.05	500.000	22.97	0.05	500.00	22.99	0.05	500.00
9	INM									
10	NCM	22.96	0.02	500.000	22.96	0.02	500.00	22.98	0.02	500.00
11	VSL	22.95	0.01	500.000	22.95	0.01	500.00	22.97	0.01	500.00
12	GUM	22.93	0.10	500.000	22.78	0.10	500.00	22.82	0.10	500.00
13	CMI	23.00	0.20	500.000	23.00	0.20	500.00	23.00	0.20	500.00
14	IPQ	22.93	0.02	500.000	22.93	0.03	500.00	23.06	0.03	500.00
15	CEM	23.03	0.04	500.000	22.99	0.01	500.00	23.02	0.01	500.00
16	SMD	23.03	0.04	500.000	23.03	0.00	500.00	23.03	0.04	500.00
17	LNE	23.00	0.20	500.000	23.00	0.20	500.00	23.00	0.20	500.00
18	UME	23.07	0.05	500.000	23.08	0.05	500.00	23.10	0.06	500.00

Table 8a: Measurement conditions for 1 TΩ standards and *V* = 500 V.

p	Lab	***a* = 1** *T* (°C)	*u*(*T*) (°C)	*V* (V)	***a* = 2** *T* (°C)	*u*(*T*) (°C)	*V* (V)	***a* = 3** *T* (°C)	*u*(*T*) (°C)	*V* (V)
1	METAS	23.00	0.05	1000.00	23.00	0.05	1000.00	23.00	0.05	1000.00
2	SMU									
3	PTB	22.99	0.10	999.96	22.98	0.10	999.96	22.99	0.10	999.96
4	MIRS/SIQ	23.00	0.05	1000.00	22.94	0.05	1000.00	22.95	0.05	1000.00
5	EIM	23.00	0.02	998.89	23.00	0.02	999.11	23.00	0.02	997.89
6	INRIM	22.82	0.05	999.99	22.82	0.05	999.99	22.83	0.05	999.99
7	MIKES	22.82	0.20	1000.00	22.82	0.20	1000.00	22.82	0.20	1000.00
8	SP	22.99	0.05	1000.00	22.97	0.05	1000.00	22.99	0.05	1000.00
9	INM	22.95	0.04	1000.00	22.95	0.04	1000.00	22.90	0.04	1000.00
10	NCM	22.96	0.01	1000.00	22.96	0.01	1000.00	22.97	0.02	1000.00
11	VSL	22.95	0.01	1000.00	22.95	0.00	1000.00	22.97	0.01	1000.00
12	GUM	22.80	0.10	1000.00	22.98	0.10	1000.00	23.12	0.10	1000.00
13	CMI	23.00	0.20	1000.00	23.00	0.20	1000.00	23.00	0.20	1000.00
14	IPQ	22.95	0.02	1000.00	22.99	0.02	1000.00	23.07	0.02	1000.00
15	CEM	23.04	0.04	1000.00	23.00	0.01	1000.00	23.02	0.01	1000.00
16	SMD	23.03	0.04	1000.00	23.03	0.04	1000.00	23.03	0.04	1000.00
17	LNE	23.00	0.20	1000.00	23.00	0.20	1000.00	23.00	0.20	1000.00
18	UME	23.07	0.05	1000.00	23.08	0.05	1000.00	23.10	0.05	1000.00

Table 8b: Measurement conditions for 1 TΩ standards and *V* = 1000 V.

p	Lab	***a* = 4**			***a* = 5**			***a* = 6**		
		T (°C)	*u*(*T*) (°C)	*V* (V)	*T* (°C)	*u*(*T*) (°C)	*V* (V)	*T* (°C)	*u*(*T*) (°C)	*V* (V)
1	METAS	23.00	0.05	500.00	23.00	0.05	500.00	23.00	0.05	500.00
2	SMU	23.10	0.20	400.00	23.10	0.20	400.00	23.13	0.20	400.00
3	PTB	22.98	0.10	499.99	23.00	0.10	499.99	23.00	0.10	499.99
4	MIRS/SIQ	23.04	0.05	500.00	22.99	0.05	500.00	23.06	0.05	500.00
5	EIM	23.00	0.02	538.84	23.00	0.02	538.22	23.00	0.02	506.41
6	INRIM	22.99	0.05	500.00	22.97	0.05	500.00	22.96	0.05	500.00
7	MIKES	22.80	0.20	500.00	22.83	0.20	500.00	22.80	0.20	500.00
8	SP	22.99	0.05	500.00	22.99	0.05	500.00	22.98	0.05	500.00
9	INM									
10	NCM	22.94	0.01	500.00	22.94	0.01	500.00	22.96	0.01	500.00
11	VSL	22.95	0.00	500.00	22.95	0.01	500.00	22.97	0.01	500.00
12	GUM	22.72	0.10	500.00	22.95	0.10	500.00	22.89	0.10	500.00
13	CMI	23.00	0.20	500.00	23.00	0.20	500.00	23.00	0.20	500.00
14	IPQ	22.90	0.02	500.00	22.99	0.01	500.00	23.02	0.02	500.00
15	CEM	23.07	0.01	500.00	23.07	0.01	500.00	23.05	0.05	500.00
16	SMD	23.06	0.04	500.00	23.05	0.04	500.00	0.00	0.00	0.00
17	LNE	23.00	0.20	500.00	23.00	0.20	500.00	0.00	0.00	0.00
18	UME	23.09	0.03	500.00	23.09	0.04	500.00	23.09	0.02	500.00

Table 8c: Measurement conditions for 100 TΩ standards and *V* = 500 V.

p	Lab	***a* = 4**			***a* = 5**			***a* = 6**		
		T (°C)	*u*(*T*) (°C)	*V* (V)	*T* (°C)	*u*(*T*) (°C)	*V* (V)	*T* (°C)	*u*(*T*) (°C)	*V* (V)
1	METAS	23.00	0.05	1000.00	23.00	0.05	1000.00	23.00	0.05	1000.00
2	SMU									
3	PTB	22.97	0.10	999.96	23.00	0.10	999.96	23.00	0.10	999.96
4	MIRS/SIQ	23.08	0.05	1000.00	23.05	0.05	1000.00	23.05	0.05	1000.00
5	EIM	23.00	0.02	1000.78	23.00	0.02	999.45	23.00	0.02	1024.72
6	INRIM	22.99	0.05	1000.00	22.97	0.05	1000.00	22.96	0.05	1000.00
7	MIKES	22.79	0.20	1000.00	22.84	0.20	1000.00	22.80	0.20	1000.00
8	SP	22.99	0.05	1000.00	22.99	0.05	1000.00	22.98	0.05	1000.00
9	INM	22.99	0.04	1000.00	22.99	0.04	1000.00	23.00	0.04	1000.00
10	NCM	22.95	0.01	1000.00	22.94	0.01	1000.00	22.96	0.01	1000.00
11	VSL	22.94	0.00	1000.00	22.94	0.00	1000.00	22.97	0.01	1000.00
12	GUM	22.96	0.10	1000.00	23.03	0.10	1000.00	23.04	0.10	1000.00
13	CMI	23.00	0.20	1000.00	23.00	0.20	1000.00	23.00	0.20	1000.00
14	IPQ	22.91	0.01	1000.00	22.98	0.02	1000.00	23.01	0.02	1000.00
15	CEM	23.07	0.01	1000.00	23.07	0.01	1000.00	23.05	0.05	1000.00
16	SMD	23.03	0.04	1000.00	23.05	0.04	1000.00			
17	LNE	23.00	0.20	1000.00	23.00	0.20	1000.00			
18	UME	23.08	0.03	1000.00	23.08	0.05	1000.00	23.09	0.02	1000.00

Table 8d: Measurement conditions for 100 TΩ standards and *V* = 1000 V.

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:

$$M_{p,a,m} = O_{c-p,a,m} - f\left(t_{p,a,m}\right) \tag{6.6}$$

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

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

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

$$M_{p,a} = \frac{1}{N_{p,a}} \sum_m M_{p,a,m} \tag{6.7}$$

6.2.3 Repeatability of results

In a ***third step***, the uncertainties $u_{\mathrm{r\text{-}p,a,m}}$, 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

$$s^2_{\mathrm{int}-p,a} = \frac{1}{N^2_{p,a}} \sum_m u^2_{r-p,a,m} \tag{6.8}$$

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

$$s^2_{ext-p,a} = \frac{1}{\left(N_{p,a}-1\right)N_{p,a}} \sum_m \left(M_{p,a,m} - M_{p,a}\right)^2 . \tag{6.9}$$

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

$$u^*_{r-p,a} = \max\left(s_{\mathrm{int}-p,a}, s_{ext-p,a}\right). \tag{6.10}$$

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:

$$u_{rs-p,a}{}^2 = \max\left(u_{r-p,a}, u^*_{r-p,a}\right)^2 + u_{TV-p,a}{}^2 + u_{tr-a}{}^2 . \tag{6.11}$$

The last component describes the uncertainty contribution due to transport effects (see next paragraph).

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

6.2.4 Transport uncertainties

The piecewise fitting, applied to model the drift of the standards, does not give any information on the uncertainty component which has to be attributed to the drift correction applied to the results reported by the participants. This is the disadvantage of this approach. To reasonably estimate the transport uncertainties, the following procedure was chosen:

The standards were measured before and after the loop and three times during the loop. For every of these five measurement periods a mean value $\overline{M}_{1,a,i}$ (i = 1 to 5) is calculated for every standard. A smooth fitting line (straight line or 2nd order polynomial) is then fitted for every standard through the five data points. The residuals to the fit curve are an average measure for the step-like changes which may have occurred during transport. The transport uncertainty for standard a is then estimated as

$$u_{tr-a}^{\ 2} = \frac{\sum \left(\overline{M}_{1,a,i} - f_a(t_i)\right)^2}{(5 - \nu_a)} \text{ , where} \qquad (6.12)$$

f_a it the overall fitting curve and ν the number of degrees of freedom (=2 for straight line and 3 for 2nd order polynomial).

The method is illustrated in Fig. 13; the resulting values for the transport uncertainties are listed in Table 9.

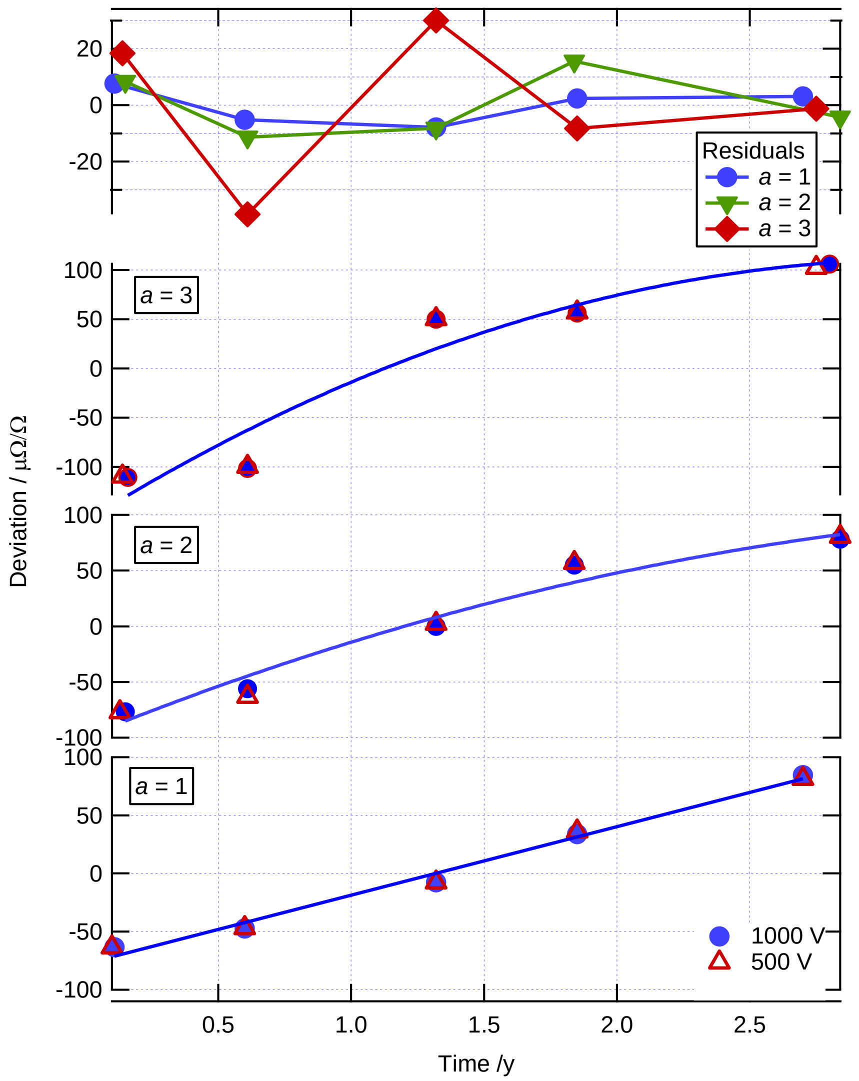

Figure 13a: Determination of the transport uncertainties for the 1 TΩ standards.

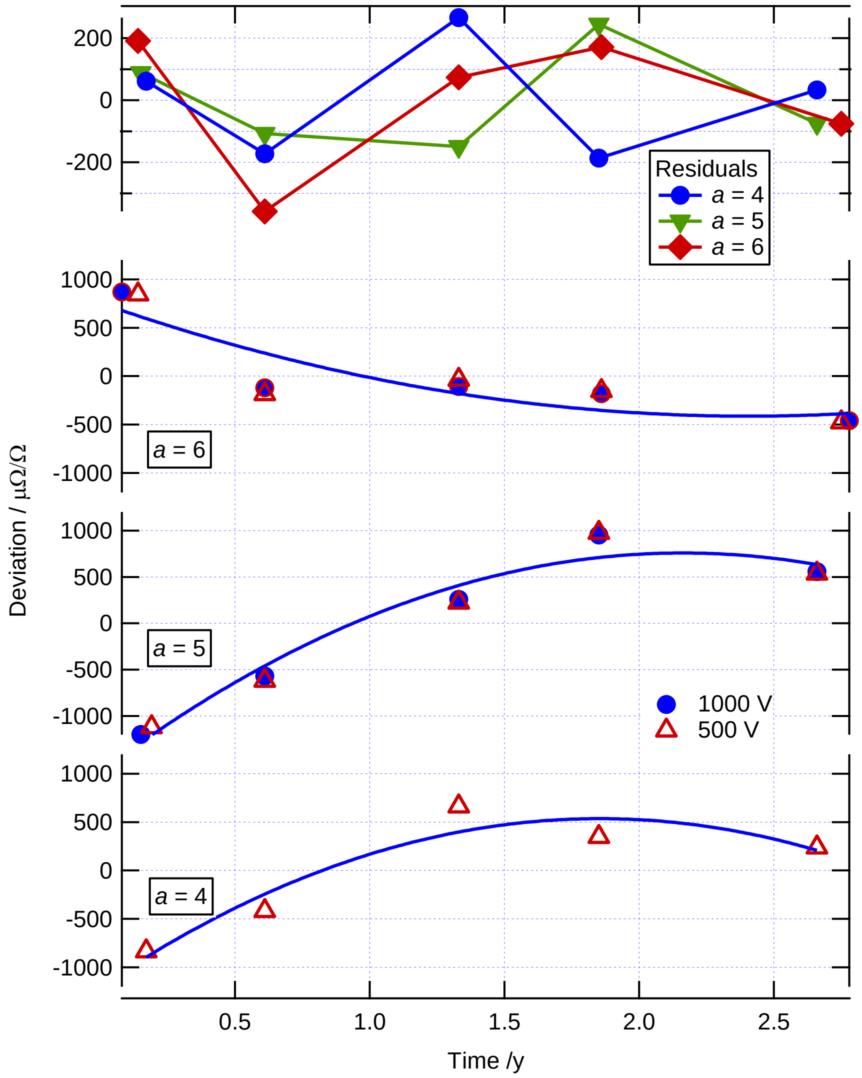

Figure 13b: Determination of the transport uncertainties for the 100 TΩ standards.

Standard	*a*	u_{tr-a} (ppm)	Standard	*a*	u_{tr-a} (ppm)
1 TΩ	1	10	100 TΩ	4	270
	2	19		5	270
	3	37		6	400

Table 9: Transport variability attributed to the artefacts.

6.2.5 Combination of the results for the same nominal value

In the final step, the three results obtained for the same nominal value have to be combined.

At 1 TΩ, the values of all three standards are considered in the combined result. For 100 TΩ, it was decided to remove the standard no 6 from the calculation of the combined result, for the following reasons:

- Standard no 6 was repaired on several occasions during the comparison loop;

- its time dependence is unusually long and this was not properly taken into account by many participants;
- it was not measured by all of the participants.

The combined result is, thus, calculated as the weighted mean from the individual values as:

$$M_p = \frac{\sum_a \frac{M_{p,a}}{u_{rs-p,a}^2}}{\sum_a \frac{1}{u_{rs-p,a}^2}}, \; a = 1 \text{ to } 3 \text{ at } 1\ \mathrm{T\Omega};\ a = 4 \text{ and } 5 \text{ at } 100\ \mathrm{T\Omega} \qquad (6.13)$$

The internal and external standard deviations are given by:

$$u_{rs-p-\mathrm{int}} = \sqrt{\frac{1}{\sum_a \frac{1}{u_{rs-p,a}^2}}},$$

$$u_{rs-p-ext} = \sqrt{\frac{\sum_a \frac{\left(M_{p,a} - M_p\right)^2}{u_{rs-p,a}^2}}{\left(n_a - 1\right)\sum_a \frac{1}{u_{rs-p,a}^2}}} \qquad (6.14)$$

with n_a number of standards of the same nominal value considered for the weighted mean.

The combined uncertainty of the combined results is finally:

$$u\left(M_p\right) = \sqrt{\max\left(u_{rs-p-\mathrm{int}}, u_{rs-p-ext}\right)^2 + u_{s-p}^2}, \qquad (6.15)$$

where $u_{s\text{-}p}$ is the type B uncertainty component as given in Table 7.

The combined results M_p and the corresponding uncertainties are listed in Table 10 below.

p	Lab	a = 1 $M_{p,a}$ (ppm)	$u_{\text{rs-p,a}}$ (ppm)	a = 2 $M_{p,a}$ (ppm)	$u_{\text{rs-p,a}}$ (ppm)	a = 3 $M_{p,a}$ (ppm)	$u_{\text{rs-p,a}}$ (ppm)	Combination M_p (ppm)	$u_{\text{rs-p-int}}$ (ppm)	$u_{\text{rs-p-ext}}$ (ppm)	$u(M_p)$ (ppm)
1	METAS	0.0	10.3	0.0	19.1	0.0	37.2	0.0	8.8	0.0	21.1
2	SMU	-915.7	180.5	-931.7	161.3	1631.4	420.9	-731.7	115.6	477.5	2582.3
3	PTB	216.7	220.3	243.9	220.9	-314.2	223.2	51.7	127.8	180.9	191.0
4	MIRS/SIQ	49.5	78.3	67.1	73.7	-98.9	69.7	0.2	42.5	54.1	1151.3
5	EIM	29.5	16.4	29.8	22.0	-101.9	56.2	22.8	12.8	20.6	31.7
6	INRIM	94.0	11.1	96.3	19.5	121.0	38.1	96.1	9.3	4.5	100.4
7	MIKES	2.4	13.6	-7.2	20.6	47.3	41.3	2.8	10.9	9.1	34.8
8	SP	21.4	10.5	0.1	19.2	-75.1	40.9	12.1	9.0	15.2	36.5
9	INM										
10	NCM	479.9	85.7	37.0	41.4	1112.4	39.6	587.4	27.1	361.1	747.8
11	VSL	58.3	11.7	55.9	20.3	-40.4	39.6	51.7	9.8	16.7	21.1
12	GUM	-829.4	16.8	-685.8	27.4	-886.9	44.9	-799.1	13.6	47.4	1156.0
13	CMI	109.1	14.9	93.8	23.2	101.3	40.2	104.4	12.0	4.8	115.4
14	IPQ	151.4	1216.0	98.1	2022.1	385.0	2105.3	186.0	934.0	71.2	1485.4
15	CEM	-18.8	13.5	-45.9	20.9	5.7	38.9	-24.2	10.9	10.4	14.8
16	SMD	23.2	67.9	7.4	82.2	-100.5	66.3	-28.3	41.1	40.6	268.2
17	LNE	21.6	13.2	30.8	20.5	31.1	39.6	24.8	10.7	3.1	15.1
18	UME	-30.5	20.5	4.3	20.7	-53.4	38.9	-18.2	13.6	14.8	26.5

Table 10a: Normalized results for the 1 TΩ standards, V = 500 V.

p	Lab	a = 1 $M_{p,a}$ (ppm)	$u_{\text{rs-p,a}}$ (ppm)	a = 2 $M_{p,a}$ (ppm)	$u_{\text{rs-p,a}}$ (ppm)	a = 3 $M_{p,a}$ (ppm)	$u_{\text{rs-p,a}}$ (ppm)	Combination M_p (ppm)	$u_{\text{rs-p-int}}$ (ppm)	$u_{\text{rs-p-ext}}$ (ppm)	$u(M_p)$ (ppm)
1	METAS	0.0	10.3	0.0	19.1	0.0	37.2	0.0	8.8	0.0	21.1
2	SMU										
3	PTB	242.2	220.3	267.5	220.9	-313.2	223.2	68.4	127.8	188.7	204.1
4	MIRS/SIQ	42.5	76.1	36.8	72.7	-124.9	67.6	-22.4	41.5	56.4	1151.4
5	EIM	59.1	19.7	86.0	27.8	-109.9	50.2	51.5	15.3	37.5	43.5
6	INRIM	91.8	10.7	69.2	20.1	105.0	37.5	87.9	9.1	7.1	60.7
7	MIKES	-5.6	13.8	-14.7	20.5	35.4	41.1	-5.3	11.1	8.5	32.9
8	SP	16.7	10.3	-3.6	19.2	-81.8	41.0	7.8	8.9	15.2	26.6
9	INM	31.0	10.6	14.2	19.3	-199.6	37.2	13.7	9.0	38.1	68.5
10	NCM	757.3	62.0	325.6	56.1	1503.3	375.5	531.9	41.3	169.0	657.2
11	VSL	58.4	11.2	48.3	20.3	-26.9	40.3	51.4	9.5	13.8	20.0
12	GUM	-911.3	20.9	-714.4	22.2	-981.2	43.7	-836.5	14.4	74.7	1157.4
13	CMI	84.8	14.9	72.4	21.6	83.1	40.2	81.0	11.7	3.9	85.5
14	IPQ	180.4	1215.0	171.2	2017.1	173.7	1518.5	176.6	858.5	2.7	1439.1
15	CEM	-21.9	13.7	-39.4	20.5	15.8	37.2	-23.6	10.9	10.1	20.0
16	SMD	365.9	52.6	355.0	69.0	234.3	64.8	324.3	35.1	41.2	264.9
17	LNE	71.1	13.2	100.5	20.4	33.0	39.6	76.4	10.7	12.5	20.0
18	UME	-55.7	29.5	-14.9	19.6	-57.9	38.5	-32.1	15.0	14.5	26.1

Table 10b: Normalized results for the 1 TΩ standards, V = 1000 V.

p	Lab	***a* = 4** $M_{p,a}$ (ppm)	$u_{rs-p,a}$ (ppm)	***a* = 5** $M_{p,a}$ (ppm)	$u_{rs-p,a}$ (ppm)	***a* = 6** $M_{p,a}$ (ppm)	$u_{rs-p,a}$ (ppm)	Combination M_p (ppm)	$u_{rs-p-int}$ (ppm)	$u_{rs-p-ext}$ (ppm)	$u(M_p)$ (ppm)
1	METAS	0	272	0	272	0	449	0	192	0	212
2	SMU	200	2754	1277	2992	67280	5078	694	2026	537	20866
3	PTB	6676	1128	6886	1199	-2651	2376	6775	822	105	1506
4	MIRS/SIQ	1119	423	1700	311	518	575	1496	251	277	2898
5	EIM	-538	556	112	642	-3457	1065	-259	420	322	810
6	INRIM	434	274	751	276	854	463	591	194	158	383
7	MIKES	-612	475	78	308	-1033	909	-126	258	315	594
8	SP	662	284	1100	274	-4220	699	889	197	219	412
9	INM										
10	NCM	-4490	4536	-2905	3027	113454	3551	-3394	2518	732	3239
11	VSL	367	296	182	279	-2741	468	269	203	92	245
12	GUM	6379	302	18818	317	46202	1733	12308	219	6213	6851
13	CMI	816	330	1049	324	-1015	920	934	231	117	4005
14	IPQ	2501	1810	-488	2028	3076	2149	1176	1351	1485	3249
15	CEM	-3332	404	-3721	604	-2372	890	-3453	336	180	343
16	SMD	-2213	1679	-2147	1929			-2185	1266	33	2407
17	LNE	-118	303	-338	306			-227	215	110	216
18	UME	241	276	-68	278	-2202	422	88	196	154	365

Table 10c: Normalized results for the 100 TΩ standards, V = 500 V.
The results for standard no a = 6 were not taken into account in the calculation (see text).

p	Lab	***a* = 4** $M_{p,a}$ (ppm)	$u_{rs-p,a}$ (ppm)	***a* = 5** $M_{p,a}$ (ppm)	$u_{rs-p,a}$ (ppm)	***a* = 6** $M_{p,a}$ (ppm)	$u_{rs-p,a}$ (ppm)	Combination M_p (ppm)	$u_{rs-p-int}$ (ppm)	$u_{rs-p-ext}$ (ppm)	$u(M_p)$ (ppm)
1	METAS	5	272	0	272	1	447	3	192	3	212
2	SMU										
3	PTB	6828	991	6764	1091	-2463	1811	6799	734	32	1385
4	MIRS/SIQ	-563	389	1713	286	-185	553	913	231	1087	3083
5	EIM	988	419	1510	666	-2058	726	1136	354	236	514
6	INRIM	345	271	904	272	675	449	624	192	280	433
7	MIKES	-813	411	-264	272	-1210	918	-432	227	253	570
8	SP	587	272	1230	274	-4018	1119	906	193	322	398
9	INM	5128	1139	5479	1133	-5223	460	5304	803	175	1727
10	NCM	-7424	1282	-2389	891	176488	15083	-4030	732	2360	3100
11	VSL	346	275	210	273	-2378	441	277	194	68	231
12	GUM	4432	290	23684	337	35166	6156	12610	220	9516	9945
13	CMI	4455	294	4248	287	2636	896	4349	206	103	3854
14	IPQ	13176	1046	13264	1191	94850	1295	13214	786	43	2995
15	CEM	-1952	320	-2543	624	-3196	518	-2075	285	240	295
16	SMD	-1908	1534	-1678	1369			-1780	1021	114	2121
17	LNE	4	290	-206	286			-103	204	105	204
18	UME	193	274	14	275	-2248	416	104	194	90	327

Table 10d: Normalized results for the 100 TΩ standards, V = 1000 V.
The result for standard no a = 6 was not taken into account in the calculation (see text).

To check the consistency of the normalized results obtained for the three standards with the same nominal value, the following pairwise differences were calculated.

$$D_{2,1} = \frac{M_{p,2} - M_{p,1}}{\sqrt{u_{rs-p,2}{}^2 + u_{rs-p,1}{}^2}}, \qquad D_{3,1} = \frac{M_{p,3} - M_{p,1}}{\sqrt{u_{rs-p,3}{}^2 + u_{rs-p,1}{}^2}}, \tag{6.16}$$

and in a similar fashion $D_{4,5}$ for the 100 TΩ standards. The normalized differences are plotted in Fig. 14.

Ideally, the standard deviation of the normalized differences should be around 1. As can be seen in Fig. 14, this condition is reasonably well met. In addition, no systematic excursions of the pairwise differences from the zero line occur. This is a good indication that the chosen fitting models and the values for the transport uncertainties are appropriate.

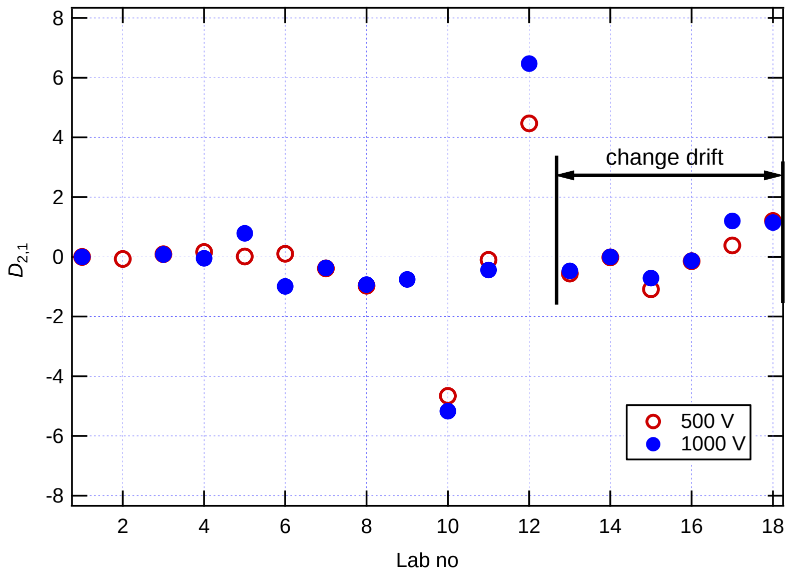

Figure 14a: Normalized differences between standard no 2 and standard no 1 at 1 TΩ. The region in the plot marked “changed drift” indicated the region where an unexpected change in the drift rate of standard no 2 must have occurred. No systematic effect can be seen in the *D* values for this region.

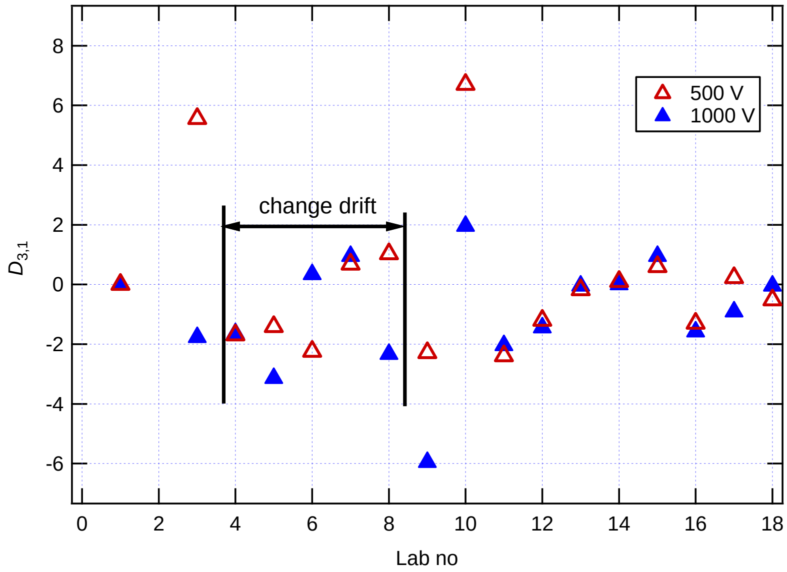

Figure 14b: Normalized differences between standard no 3 and standard no 1 at 1 TΩ. The region in the plot marked "changed drift" indicated the region where an unexpected change in the drift rate of standard no 3 must have occurred. No systematic effect can be seen in the *D* values for this region.

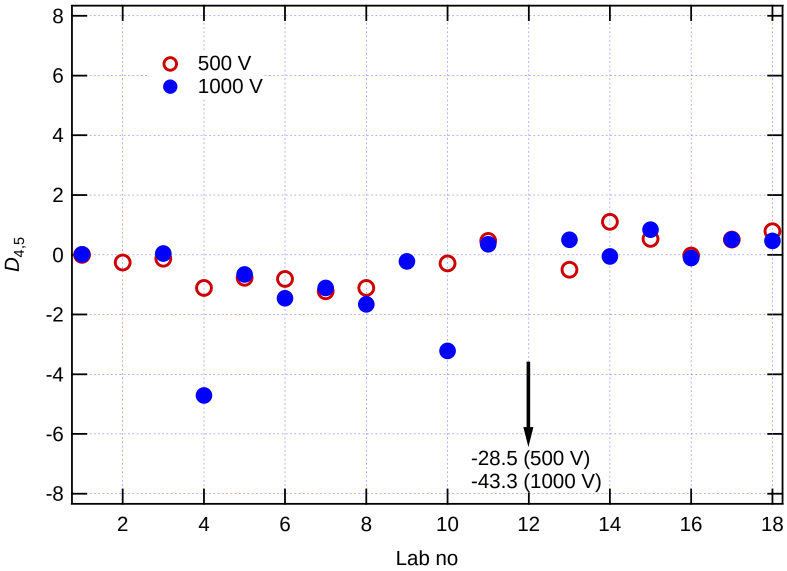

Figure 14c: Normalized differences between standard no 4 and standard no 5 at 100 TΩ. The outliers are not situated in the period where a change of the drift behaviour of the standards was observed.

6.3 Comparison reference value and degrees of equivalence DoE

The method proposed in [5] is used to calculate the comparison reference value CRV.

The CRV is calculated as the weighted mean value from the participants results M_p as follows:

$$CRV = \frac{\sum_p f_{CRV-p} \cdot \frac{M_p}{u(M_p)^2}}{\sum_p \frac{f_{CRV-p}}{u(M_p)^2}}, \qquad (6.17)$$

where $f_{\mathrm{CRV\text{-}p}}$ is a flag indicating if the result of participant *p* is taken into account in the calculation of the CRV or not. It takes the values 1 or 0. For the first attempt, $f_{\mathrm{CRV\text{-}p}}$ is set to 1 for all participants.

The uncertainty of the CRV is given by:

$$u(CRV)=\sqrt{\frac{1}{\sum_p \frac{f_{CRV-p}}{u(M_p)^2}}}, \tag{6.18}$$

The degree of equivalence, DoE, with the CRV and its uncertainty are then calculated as:

$$DoE_p=(M_p-CRV)$$
$$u(DoE_p)=\sqrt{u(M_p)^2+(1-2\cdot f_{CRV-p})\cdot u(CRV)^2} \tag{6.19}$$
$$U(DoE_p)=2\cdot u(DoE_p)$$

The normalized degree of equivalence may be defined as:

$$E_{n-p}=\frac{DoE_p}{U(DoE_p)} \tag{6.20}$$

To check for the consistency of the result, a chi-square test is performed:

$$\chi_{obs}{}^2=\sum_p \frac{f_{CRV-p}\cdot (M_p-CRV)^2}{u(M_p)^2} \tag{6.21}$$

The chi-square test is considered as passed if, for $\nu = n - 1$ degrees of freedom, the probability *P* for χ_{obs}^2 is greater than 5%. Here, *n* is the number of participants with $f_{\mathrm{CRV\text{-}p}} = 1$. *P* is calculated from the integral χ^2 distribution function.

The CRVs and the chi-square test results are listed in Table 11. Depending on the test results, the conditions for the calculation of the CRVs were modified as described below.

1 TΩ, 500 V:

The chi-square test is passed with the complete data set ($f_{\mathrm{CRV\text{-}p}} = 1$ for all participants).

1 TΩ, 1000 V:

The test is not passed. No clear outliers can be identified in this data set. The inconsistency is caused by the results with the smallest uncertainties. Possible reasons for this may be:

- Step-like changes in the value of the transport standards which recovered before the measurement period carried out by the next participant in the loop.
- Underestimation of uncertainty components for the participants with the lowest uncertainty claims.

Because it is not possible to identify the reason for the inconsistency in an unequivocal way, it was decided to introduce a lower limit, $u(M)_{\mathrm{lim}}$, for the overall uncertainty $u(M_{\mathrm{p}})$ (eq. 6.15) as follows:

$$u(M_p)=\max\left(\sqrt{\max(u_{rs-p-\mathrm{int}},u_{rs-p-ext})^2+u_{s-p}{}^2};u(M)_{\lim}\right), \tag{6.22}$$

The value for $u(M)_{\mathrm{lim}}$ was gradually increased from zero until the chi-square test passed. This was the case for $u(M)_{\mathrm{lim}}$ = 20 ppm.

100 TΩ, 500 V:

The test is not passed if all results are included. In contrast to the situation just described, the inconsistency in this case is not caused by the results with the smallest uncertainties but by a few clearly identifiable outliers. For this reason, the following procedure was chosen: Outliers are removed one by one from the calculation of the CRV, starting with the participant with the highest E_n value. The test is passed if participants p = 3 and 15 are removed ($f_{CRV-3} = f_{CRV-15} = 0$).

100 TΩ, 1000 V:

Again, the test is not passed if all results are included. The situation is similar as for 100 TΩ, 500 V, and thus, the same procedure is applied. The test is passed if participants p = 3, 9, 14 and 15 are removed ($f_{CRV-3} = f_{CRV-9} = f_{CRV-14} = f_{CRV-15} = 0$).

Resistance Voltage (V)	**Action on data**	**CRV (ppm)**	***u*(CRV) (ppm)**	**ν**	**χ_{obs}^2**	***P* in %**
	1 TΩ					
500 V	Complete data set	8.0	7.5	16	14.4	57.1
1000 V	Complete data set	18.6	7.1	16	36.7	0.2
1000 V	Increase lower limit for $u(M_p)$ to 20 ppm	16.5	8.2	16	25.8	5.6
	100 TΩ					
500 V	Complete data set	-187	103	16	133	0.0
500 V	Remove p = 3, 15 from CRV calculation	102	108	14	14.3	43.0
1000 V	Complete data set	-15	97	16	122.3	0.0
1000 V	Remove p = 3, 9, 14, 15 from CRV calculation	166	104	12	17.3	13.9

Table 11: CRVs and results of the chi-square test.

The final values for the degrees of equivalence are presented in Table 12 and Figure 15.

p	Lab	500 V				1000 V			
		DoE (ppm)	U(DoE) (ppm)	E_n	f_{CRV-p}	DoE (ppm)	U(DoE) (ppm)	E_n	f_{CRV-p}
1	METAS	-8	39	0.2	1	-16	39	0.4	1
2	SMU	-740	5164	0.1	1				
3	PTB	44	382	0.1	1	52	408	0.1	1
4	MIRS/SIQ	-8	2302	0.0	1	-39	2303	0.0	1
5	EIM	15	62	0.2	1	35	85	0.4	1
6	INRIM	88	200	0.4	1	71	120	0.6	1
7	MIKES	-5	68	0.1	1	-22	64	0.3	1
8	SP	4	71	0.1	1	-9	51	0.2	1
9	INM					-3	136	0.0	1
10	NCM	579	1496	0.4	1	515	1314	0.4	1
11	VSL	44	40	1.1	1	35	36	1.0	1
12	GUM	-807	2312	0.3	1	-853	2315	0.4	1
13	CMI	96	230	0.4	1	64	170	0.4	1
14	IPQ	178	2971	0.1	1	160	2878	0.1	1
15	CEM	-32	25	1.3	1	-40	36	1.1	1
16	SMD	-36	536	0.1	1	308	530	0.6	1
17	LNE	17	26	0.6	1	60	36	1.6	1
18	UME	-26	51	0.5	1	-49	50	1.0	1

Table 12a: Degrees of equivalence at 1 TΩ.

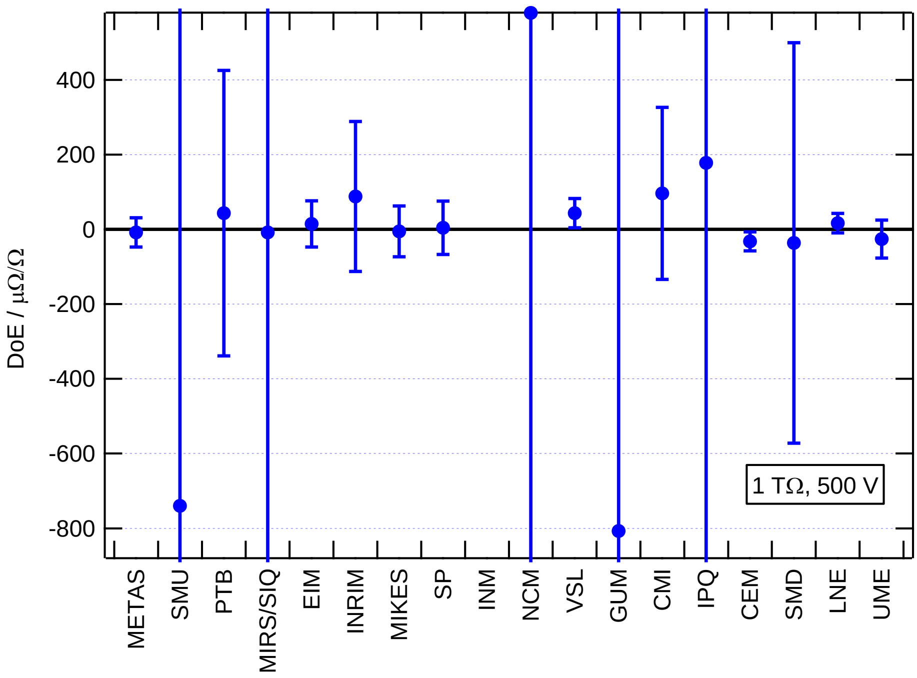

Figure 15a: Degrees of equivalence with respect to the CRV at 1 TΩ, 500 V.

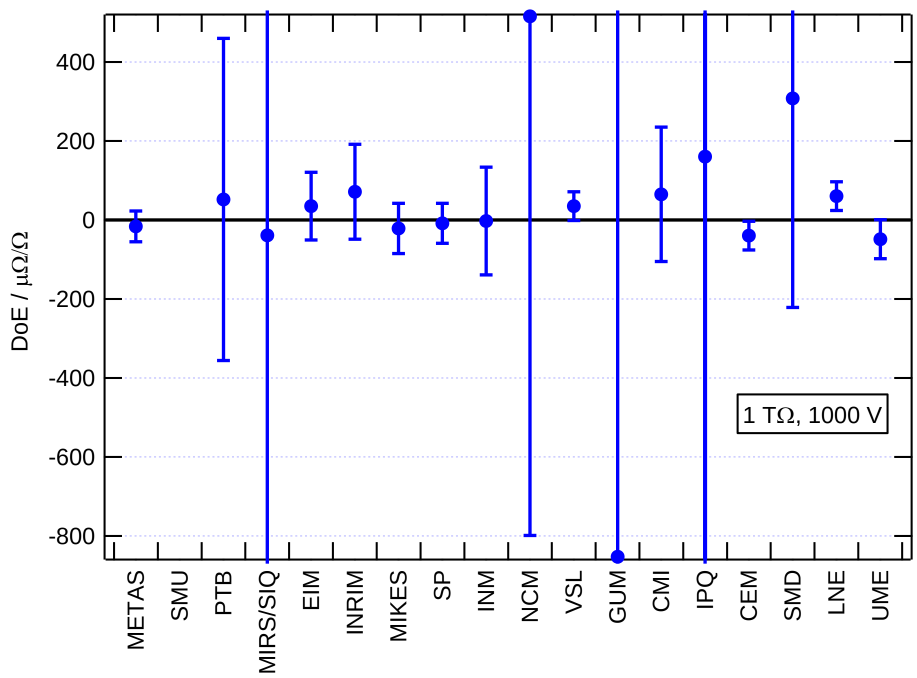

Figure 15b: Degrees of equivalence with respect to the CRV at 1 TΩ, 1000 V.

p	Lab	500 V DoE (ppm)	500 V U(DoE) (ppm)	500 V E_n	500 V f_{CRV-p}	1000 V DoE (ppm)	1000 V U(DoE) (ppm)	1000 V E_n	1000 V f_{CRV-p}
1	METAS	-102	365	0.3	1	-164	371	0.4	1
2	SMU	592	41732	0.0	1				
3	PTB	6673	3020	2.2	0	6633	2778	2.4	0
4	MIRS/SIQ	1394	5793	0.2	1	747	6162	0.1	1
5	EIM	-361	1605	0.2	1	970	1008	1.0	1
6	INRIM	489	735	0.7	1	458	840	0.5	1
7	MIKES	-228	1167	0.2	1	-598	1121	0.5	1
8	SP	787	795	1.0	1	740	768	1.0	1
9	INM					5138	3460	1.5	0
10	NCM	-3496	6473	0.5	1	-4196	6196	0.7	1
11	VSL	167	440	0.4	1	111	412	0.3	1
12	GUM	12206	13700	0.9	1	12444	19888	0.6	1
13	CMI	832	8006	0.1	1	4183	7706	0.5	1
14	IPQ	1074	6495	0.2	1	13048	5993	2.2	0
15	CEM	-3555	720	4.9	0	-2242	625	3.6	0
16	SMD	-2287	4809	0.5	1	-1946	4236	0.5	1
17	LNE	-329	374	0.9	1	-269	352	0.8	1
18	UME	-14	698	0.0	1	-63	620	0.1	1

Table 12b: Degrees of equivalence at 100 TΩ.

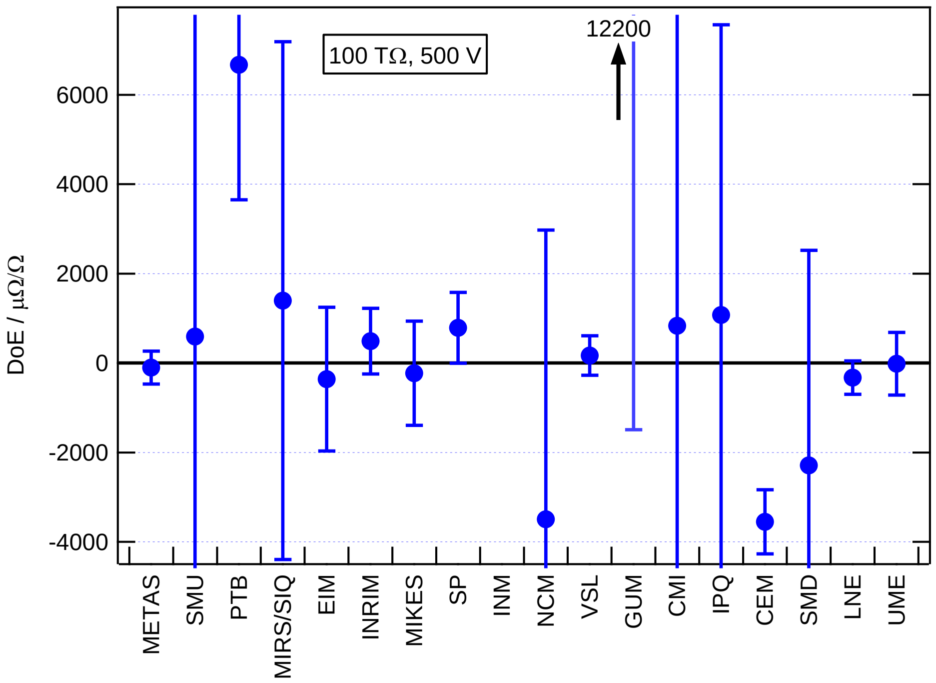

Figure 15c: Degrees of equivalence with respect to the CRV at 100 TΩ, 500 V.

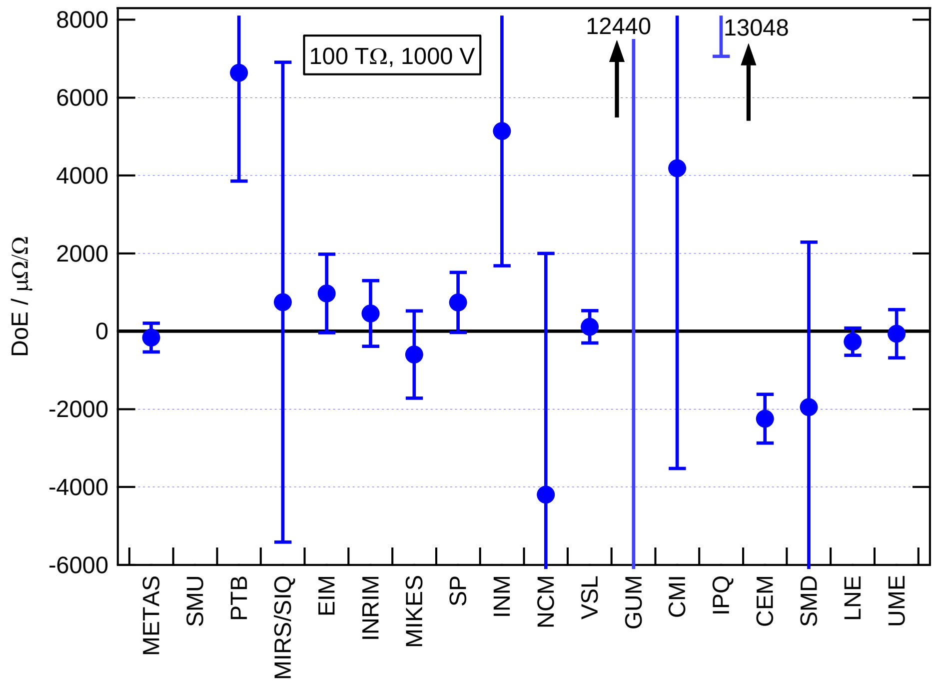

Figure 15d: Degrees of equivalence with respect to the CRV at 100 TΩ, 1000 V.

7. Summary and conclusions

Eighteen European National Metrology Institutes participated in the comparison EURAMET.EM-S32 aimed at evaluating the degrees of equivalence of the measurements of 1 TΩ and 100 TΩ resistance standards. This was the first comparison exercise carried out in this range of resistance in the framework of EURAMET. With some exceptions, the results supplied by the participants agree reasonably well with the comparison reference value within the expanded uncertainty. 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.

As observed in other resistance comparisons, the characteristics of the standards used as transport artefacts ultimately limit the accuracy of comparisons in this field. Besides the uniform drift behaviour in time, step-like resistance changes may occur during transport due to temperature shocks or mechanical shocks. Such behaviour is difficult to model and introduces an undesired bias in the laboratory results. The transport uncertainties are at the level of the uncertainties claimed by some of the participants and, thus, limit the meaningfulness of the comparison results.

Another remarkable observation is the big difference in the uncertainty statements made by the participants; even in cases there similar measurement systems were used. The poor consistency of some of the measurements may indicate that some laboratories have underestimated their uncertainties. At this high end of the resistance scale, long stabilization times are needed to bring transient signals to an acceptable level; uncompensated offset effects may have unwanted effects and –due to the big temperature coefficient of the device under test- the temperature of the resistive element itself has to be known very accurately. Based on the results of this comparison, some of the participants may want to review their measurement procedures and uncertainty models.

9. Participant's comments

In this Section, comments made by participants related to their results, are reported.

VSL, Netherlands (participant no 11)

VSL recognized that in their measurements for the comparison, the resistance values for positive and negative measurement voltage did not agree with each other to the level normal at resistance values of 100 GΩ and below (see Annex A of this report and [6]). For measurements at these lower resistance values, such an agreement was found to be a good indicator for getting the lowest uncertainties [6].

Therefore, immediately after the measurements for the comparison were finished, and before the appearance of the draft A report, a study was started aimed to improve this situation. It finally appeared that moving the ground location of the setup from the input of the null-detector to the central cable connection box had the desired effect. Now not only the resistance values for positive and negative measurement voltage agree within the noise of the measurements, but furthermore the noise in the measurements decreased with more than a factor 5 and also the stabilization times became significantly shorter. With this improvement, VSL is of the opinion that systematic errors in the VSL setup for resistance measurements above 100 GΩ have been significantly reduced with respect to the situation during the measurements for the comparison.

VSL concludes that its uncertainties reported in this comparison at 1 TΩ were slightly underestimated due to the effects shown in Annex A of this comparison report, but that these uncertainties are representative for the present configuration of the VSL measurement setup. This will be verified with an additional bilateral check with METAS.

CEM, Spain (participant no 15)

Following the reception of the Draft A report, CEM has analysed its measurements on 100 TΩ, searching for the reasons of the discrepancy found for this value. This analysis has shown the following:

- The stabilization time for the standards was too short, only about 5 minutes. Comparing this with the stabilization time shown in the report for a sample standard, it's clearly insufficient.
- No correction for voltage coefficient was applied to the standard resistor used as reference, due to be a new standard not characterized yet in its behaviour respect to voltage. By error, an uncertainty component to cover this fact was not included in the measurement report.

CEM thinks both discoveries could explain, totally or in part, the discrepancy in 100 TΩ measurements.

11. References

[1] L. C.A. Henderson, A new technique for the automatic measurement of high value resistors, J. Phys. E: Sci. Instrum. 20, pp. 492-495, 1987.

[2] S. H. Tsao, An accurate, semiautomatic technique of measuring high resistances, IEEE Trans. Instrum. Meas., 16, no 3, pp. 220-225, 1967.

[3] F. Galliana, P.P. Capra, E. Gasparotto, “Metrological management of the high dc resistance scale at INRIM” Measurement 42, pp. 314-321, 2009.

[4] F. Galliana, P.P. Capra, E. Gasparotto: Evaluation of two different methods to calibrate ultra-high value resistors at INRIM”, IEEE Trans. Meas., Vol. 60, no.6, pp. 965- 970, 2011.

[5] Cox M. G., The evaluation of key comparison data, Metrologia, vol. 39, no. 6, p. 589, 2002.

[6] G. Rietveld and J.H.N. van der Beek, “Automated High-Ohmic Resistance Bridge with Voltage and Current Null-detection”, IEEE Trans. Instr. & Meas., Vol. 62, no. 6, pp. 1760-1765, 2013.

Annexes

A. Optional measurements
B. Measurement results reported by participants
C. Uncertainty budgets as declared by the participants
D. Technical Protocol

Annex A: Optional Measurements

Dependence on the polarity of the test voltage

According to the protocol, the mean resistance value determined form measurements at both polarities of the test voltage had to be reported for the travelling artefacts. If available, the participants were asked to indicate the difference in the resistance value between positive and negative test voltage. This difference is defined as:

$$d_{pos-neg} = \frac{R_{pos} - R_{neg}}{R_{nom}} , \qquad \text{(A1)}$$

where R_{pos} and R_{neg} are the values determined at positive and negative test voltage respectively.

Depending on the type of standard, substantial values for $d_{pos\text{-}neg}$ may be observed. However, non-zero values for $d_{pos\text{-}neg}$ may also be an artefact of the measurement procedure and result from uncompensated offset effects. For traditional standards (type 1 Sect. 3.1), offset effects can be distinguished from voltage polarity differences by repeating the measurements in a reversed connection scheme (output terminal of standard connected to the source and source terminal connected to the output). However this scheme is not possible for T-network standards (type 2 Sect. 3.1), as these standards are not fully symmetric.

Fig. A1 and A2 show the $d_{pos\text{-}neg}$ values reported by the participants. No further analysis of these data was carried out.

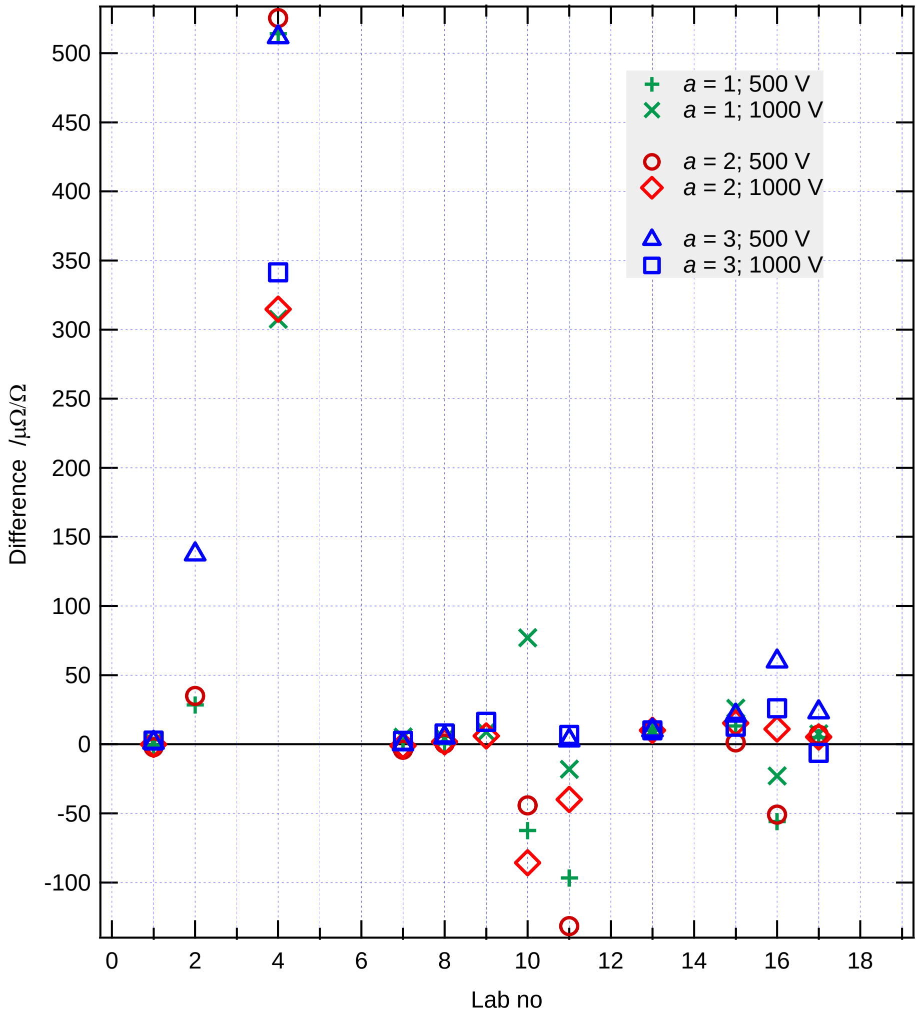

Figure A1: Differences $d_{\text{pos-neg}}$ for the 1 TΩ standards.

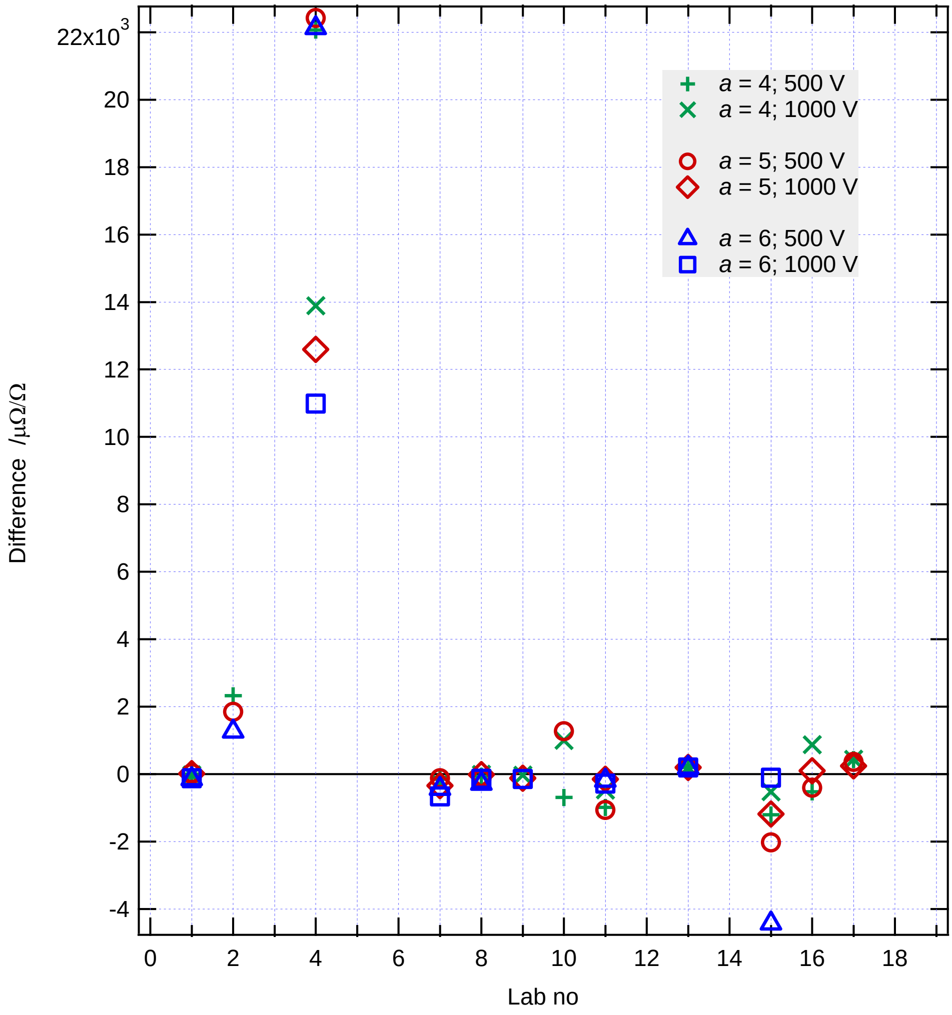

Figure A2: Differences $d_{\text{pos-neg}}$ for the 100 TΩ standards.

Annex B: Raw Results

B.1 1 TΩ

B.1.1 1 TΩ standard no 69573, a = 1, 500 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p* = 1 METAS**															
1	05.12.08	23.00	0.05	45	500	both	-540.8	5.3	-5.0	-26.1			-540.8	-536.2	-4.6
2	23.01.09	23.00	0.05	45	500	both	-527.4	5.3	0.1	22.8			-527.4	-535.3	7.9
3	24.01.09	23.00	0.05	45	500	both	-531.4	5.3	-0.4	23.0			-531.4	-535.3	3.9
4	10.02.09	23.00	0.05	45	500	both	-544.1	5.3	-2.2	40.5			-544.1	-534.6	-9.5
5	17.02.09	23.00	0.05	45	500	both	-538.4	5.3	-2.4	47.6			-538.4	-534.3	-4.1
6	18.03.09	23.00	0.05	45	500	both	-529.2	5.3	0.6	76.3			-529.2	-532.8	3.5
7	20.03.09	23.00	0.05	45	500	both	-528.9	5.3	2.5	78.3			-528.9	-532.6	3.7
8	07.08.09	23.00	0.05	45	500	both	-522.7	5.3	-4.2	218.9			-522.7	-519.3	-3.4
9	10.08.09	23.00	0.05	45	500	both	-512.8	5.3	0.7	221.0			-512.8	-519.0	6.2
10	26.04.10	23.00	0.05	45	500	both	-476.0	5.3	-5.0	480.5			-476.0	-476.8	0.7
11	30.04.10	23.00	0.05	45	500	both	-482.6	5.3	8.3	484.4			-482.6	-476.0	-6.5
12	30.04.10	23.00	0.05	45	500	both	-476.9	5.3	-2.7	484.5			-476.9	-476.0	-0.9
13	04.11.10	23.00	0.05	45	500	both	-438.9	5.3	-2.0	672.5			-438.9	-439.4	0.5
14	10.11.10	23.00	0.05	45	500	both	-430.2	5.3	1.2	678.4			-430.2	-438.2	8.0
15	31.08.11	23.00	0.05	45	500	both	-394.0	5.3	-1.3	972.5			-394.0	-388.4	-5.6
16	28.09.11	23.00	0.05	45	500	both	-384.8	5.3	1.3	1000.5			-384.8	-384.9	0.1
***p* = 2, SMU**															
1	22.04.09	23.10	0.20	38	400	both	-1501.0	34.0	30.0	111.0	-4.2	-11.8	-1517.0	-530.3	-986.6
2	28.04.09	23.00	0.20	35	400	both	-1344.0	37.0	32.0	117.0	0.0	-11.8	-1355.8	-529.9	-825.9
3	06.05.09	23.10	0.20	40	400	both	-1501.0	18.0	22.0	125.0	-4.2	-11.8	-1517.0	-529.2	-987.8
4	14.05.09	23.20	0.20	37	400	both	-1371.0	34.0	30.0	133.0	-8.4	-11.8	-1391.2	-528.5	-862.7
***p* = 3, PTB**															
1	25.06.09	23.00	0.10	45	500	both	-370.0	16.2		175.0	0.0	0.0	-370.0	-524.4	154.4
2	01.07.09	22.97	0.10	52	500	both	-240.0	18.0		181.0	1.3	0.0	-238.7	-523.7	285.0
3	06.07.09	23.00	0.10	47	500	both	-380.0	14.3		186.0	0.0	0.0	-380.0	-523.2	143.2
4	08.07.09	22.97	0.10	45	500	both	-240.0	32.8		188.0	1.3	0.0	-238.7	-522.9	284.2
***p* = 4, SIQ**															
1	05.09.09	22.86	0.05	46	500	both	-393.0	13.0	442.0	247.0	5.9	0.0	-387.1	-515.6	128.5
2	08.09.09	22.93	0.05	43	500	both	-327.0	14.0	438.0	250.0	2.9	0.0	-324.1	-515.2	191.2
3	10.09.09	23.19	0.05	43	500	both	-365.0	6.0	474.0	252.0	-8.0	0.0	-373.0	-515.0	142.0
4	13.09.09	23.07	0.05	49	500	both	-754.0	11.0	604.0	255.0	-2.9	0.0	-756.9	-514.5	-242.4
5	17.09.09	23.00	0.05	45	500	both	-486.0	12.0	612.0	259.0	0.0	0.0	-486.0	-514.0	28.0
***p* = 5, EIM**															
1	29.09.09	23.00	0.02	40	499	both	-489.0	8.1		271.0	0.0	-0.1	-489.1	-512.3	23.2
2	06.10.09	23.00	0.02	40	499	both	-473.0	7.5		278.0	0.0	-0.1	-473.1	-511.3	38.2
3	09.10.09	23.00	0.02	40	499	both	-480.0	6.8		281.0	0.0	-0.1	-480.1	-510.9	30.8
4	14.10.09	23.00	0.02	40	499	both	-472.0	7.3		286.0	0.0	-0.1	-472.1	-510.1	38.1
5	20.10.09	23.00	0.02	40	499	both	-492.0	7.8		292.0	0.0	-0.1	-492.1	-509.2	17.2
***p* = 6, INRIM**															
1	16.11.09	22.83	0.05	40	499.995	both	-426.5	7.1		319.0	7.2	0.0	-419.3	-505.1	85.8
2	17.11.09	22.82	0.05	40	499.995	both	-412.8	4.1		320.0	7.7	0.0	-405.2	-504.9	99.8
3	18.11.09	22.82	0.05	40	499.995	both	-417.2	3.6		321.0	7.7	0.0	-409.5	-504.8	95.3

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
4	23.11.09	22.81	0.05	40	499.995	both	-412.9	2.8		326.0	7.9	0.0	-405.0	-504.0	99.0
5	25.11.09	22.82	0.05	40	499.995	both	-421.4	2.4		328.0	7.7	0.0	-413.6	-503.7	90.0
p = 7, MIKES															
1	01.12.09	22.82	0.20	39	500	both	-508.7	2.5	2.8	334.0	7.7	0.0	-500.9	-502.7	1.8
2	06.12.09	22.83	0.20	39	500	both	-508.7	1.3	2.6	339.0	7.0	0.0	-501.8	-501.9	0.1
3	13.12.09	22.81	0.20	23	500	both	-503.3	1.8	-0.8	346.0	7.9	0.0	-495.4	-500.8	5.4
p = 8, SP															
1	09.03.10	23.01	0.05	47	500	both	-466.5	1.8	1.9	432.0	-0.2	0.0	-466.7	-485.8	19.0
2	18.03.10	22.98	0.05	46	500	both	-465.9	1.3	-0.8	441.0	0.7	0.0	-465.2	-484.1	18.9
3	19.03.10	22.97	0.05	45	500	both	-456.8	2.5	-3.5	442.5	1.1	0.0	-455.7	-483.9	28.2
4	24.03.10	22.98	0.05	45	500	both	-464.5	1.4	4.6	447.5	1.0	0.0	-463.6	-483.0	19.4
p = 9, INM															
1															
p = 10, NCM															
1	25.06.10	22.89	0.01	52	500	pos	211.9	19.6		540.0	4.6	0.0	216.6	-465.3	681.9
2	29.06.10	22.88	0.01	51	500	pos	137.6	17.1		544.0	5.0	0.0	142.6	-464.5	607.2
3	06.07.10	22.98	0.04	52	500	both	71.5	27.9	-195.9	551.0	0.8	0.0	72.3	-463.2	535.5
4	14.07.10	23.06	0.01	52	500	both	68.0	8.2	71.2	559.0	-2.5	0.0	65.5	-461.6	527.1
5	19.07.10	23.01	0.01	52	500	pos	-371.6	1.5		564.0	-0.4	0.0	-372.0	-460.6	88.6
6	20.07.10	22.95	0.01	49	500	neg	-23.4	1.2		565.0	2.1	0.0	-21.3	-460.4	439.2
p = 11, VSL															
1	30.07.10	22.95	0.01	46	500	both	-395.0	11.0	-112.0	575.6	2.0	0.0	-393.0	-458.4	65.4
2	30.07.10	22.95	0.01	45	500	both	-406.7	11.9	-88.8	575.9	2.0	0.0	-404.7	-458.3	53.6
3	31.07.10	22.95	0.01	46	500	both	-400.5	13.2	-98.9	576.2	2.1	0.0	-398.4	-458.2	59.8
4	31.07.10	22.95	0.01	46	500	both	-405.2	13.6	-105.0	576.5	2.1	0.0	-403.0	-458.2	55.2
5	31.07.10	22.95	0.01	46	500	both	-407.5	16.0	-95.8	576.8	2.1	0.0	-405.4	-458.1	52.7
6	18.08.10	22.95	0.01	46	500	both	-395.3	15.3	-101.6	594.6	2.2	0.0	-393.1	-454.6	61.5
7	31.08.10	22.96	0.03	44	500	both	-393.1	8.3	-77.1	607.8	1.9	0.0	-391.2	-452.0	60.8
8	01.09.10	22.94	0.01	45	500	both	-397.5	17.2	-95.5	608.1	2.5	0.0	-395.0	-452.0	57.0
p = 12, GUM															
1	06.10.10	22.80	0.10	43	500	both	-1234.3	3.1		643.0	8.4	0.0	-1225.9	-445.1	-780.8
2	07.10.10	23.00	0.10	44	500	both	-1335.4	5.4		644.0	0.0	0.0	-1335.4	-444.9	-890.5
3	07.10.10	22.90	0.10	43	500	both	-1267.4	4.1		644.0	4.2	0.0	-1263.2	-444.9	-818.3
4	07.10.10	23.00	0.10	42	500	both	-1298.2	4.2		644.0	0.0	0.0	-1298.2	-444.9	-853.2
5	07.10.10	23.00	0.10	41	500	both	-1257.5	4.6		644.0	0.0	0.0	-1257.5	-444.9	-812.6
6	07.10.10	22.90	0.10	42	500	both	-1256.6	4.2		644.0	4.2	0.0	-1252.4	-444.9	-807.5
7	12.10.10	23.00	0.10	40	500	both	-1252.8	3.9		649.0	0.0	0.0	-1252.8	-443.9	-808.9
8	12.10.10	22.80	0.10	54	500	both	-1316.0	4.1		649.0	8.4	0.0	-1307.6	-443.9	-863.7
p = 13, CMI															
1	24.11.10	23.00	0.20	40	500	both	-330.0	5.0	10.0	692.0	0.0	0.0	-330.0	-435.6	105.6
2	29.11.10	23.00	0.20	40	500	both	-320.0	5.0	10.0	697.0	0.0	0.0	-320.0	-434.6	114.6
3	03.12.10	23.00	0.20	40	500	both	-310.0	5.0	10.0	701.0	0.0	0.0	-310.0	-433.8	123.8
4	10.12.10	23.00	0.20	40	500	both	-340.0	5.0	10.0	708.0	0.0	0.0	-340.0	-432.5	92.5
p = 14, IPQ															
1	14.12.10	23.38	0.01	64	500		-245.5	10.5		712.7	-15.9	0.0	-261.4	-431.6	170.2

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
2	12.01.11	22.27	0.02	52	500		-268.9	21.1		741.5	30.7	0.0	-238.2	-426.2	187.9
3	12.01.11	23.07	0.02	52	500		-254.3	13.3		741.7	-2.9	0.0	-257.2	-426.1	168.9
4	21.01.11	22.95	0.03	41	500		-312.5	15.8		750.5	2.0	0.0	-310.5	-424.5	114.0
5	24.01.11	22.98	0.01	38	500		-308.6	15.7		753.7	0.9	0.0	-307.7	-423.9	116.2
p = 15, CEM															
1	08.02.11	23.01	0.04	38	500	both	-450.4	4.0	40.6	768.0	-0.4	0.0	-450.9	-421.2	-29.6
2	09.02.11	23.01	0.04	38	500	both	-441.5	3.9	-33.6	769.0	-0.4	0.0	-441.9	-421.1	-20.8
3	22.02.11	23.08	0.04	39	500	both	-421.2	2.9	33.0	782.0	-3.5	0.0	-424.7	-418.7	-6.0
p = 16, SMD															
1	12.03.11	23.03	0.04	34	500	both	-391.0	57.7	-56.0	800.0	-1.2	0.0	-392.2	-415.5	23.2
p = 17, LNE															
1	08.04.11	23.00	0.20	44	500	both	-389.1	1.6	4.8	827.0	0.0	0.0	-389.1	-410.7	21.6
p = 18, UME															
1	30.05.11	23.04	0.07	47	500	both	-456.5	7.3		879.5	-1.8	0.0	-458.2	-402.0	-56.2
2	03.06.11	23.07	0.03	48	500	both	-397.9	18.0		883.4	-2.8	0.0	-400.7	-401.4	0.7
3	10.06.11	23.10	0.08	48	500	both	-392.6	7.9		890.4	-4.4	0.0	-397.0	-400.3	3.2
4	23.06.11	23.10	0.05	46	500	both	-481.4	34.8		903.4	-4.0	0.0	-485.5	-398.3	-87.2
5	28.06.11	23.06	0.02	44	500	both	-407.8	8.5		908.4	-2.6	0.0	-410.4	-397.5	-12.9

B.1.2 1 TΩ standard no 69573, *a* = 1, 1000 V

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
p = 1 METAS															
1	05.12.08	23.00	0.05	45	1000.00	both	-627.8	3.1	2.8	-26.3			-627.8	-626.8	-1.0
2	23.01.09	23.00	0.05	45	1000.00	both	-627.7	3.1	3.1	22.9			-627.7	-625.9	-1.8
3	10.02.09	23.00	0.05	45	1000.00	both	-627.6	3.1	1.3	40.5			-627.6	-625.2	-2.3
4	17.02.09	23.00	0.05	45	1000.00	both	-622.7	3.1	-2.0	47.7			-622.7	-624.9	2.2
5	18.03.09	23.00	0.05	45	1000.00	both	-618.1	3.1	1.0	76.4			-618.1	-623.4	5.3
6	20.03.09	23.00	0.05	45	1000.00	both	-625.3	3.1	-1.1	78.4			-625.3	-623.3	-2.0
7	07.08.09	23.00	0.05	45	1000.00	both	-609.4	3.1	2.2	218.9			-609.4	-609.9	0.5
8	10.08.09	23.00	0.05	45	1000.00	both	-608.2	3.1	2.6	221.1			-608.2	-609.6	1.5
9	26.04.10	23.00	0.05	45	1000.00	both	-567.2	3.1	0.2	480.6			-567.2	-567.4	0.2
10	30.04.10	23.00	0.05	45	1000.00	both	-569.4	3.1	2.3	484.4			-569.4	-566.6	-2.8
11	30.04.10	23.00	0.05	45	1000.00	both	-570.7	3.1	4.1	484.6			-570.7	-566.6	-4.1
12	04.11.10	23.00	0.05	45	1000.00	both	-533.3	3.1	-0.8	672.6			-533.3	-530.0	-3.4
13	10.11.10	23.00	0.05	45	1000.00	both	-522.0	3.1	3.2	678.5			-522.0	-528.8	6.9
14	31.08.11	23.00	0.05	45	1000.00	both	-476.9	3.1	3.5	972.6			-476.9	-479.0	2.1
15	28.09.11	23.00	0.05	45	1000.00	both	-476.8	3.1	1.1	1000.6			-476.8	-475.5	-1.3
p = 2, SMU															
1															
p = 3, PTB															
1	26.06.09	23.01	0.10	48	999.96	both	-410.0	13.9		176.0	-0.4	0.0	-410.4	-614.9	204.5
2	01.07.09	22.97	0.10	53	999.96	both	-340.0	11.6		181.0	1.3	0.0	-338.8	-614.3	275.6
3	06.07.09	23.00	0.10	47	999.96	both	-470.0	23.2		186.0	0.0	0.0	-470.0	-613.8	143.8

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
4	08.07.09	22.97	0.10	45	999.96	both	-270.0	10.2		188.0	1.3	0.0	-268.8	-613.6	344.8
***p* = 4, SIQ**															
1	05.09.09	22.94	0.05	46	1000.00	both	-494.0	10.0	244.0	247.0	2.5	0.0	-491.5	-606.3	114.8
2	08.09.09	22.85	0.05	43	1000.00	both	-423.0	8.0	290.0	250.0	6.3	0.0	-416.7	-605.9	189.2
3	10.09.09	23.19	0.05	43	1000.00	both	-461.0	3.0	284.0	252.0	-8.0	0.0	-469.0	-605.6	136.6
4	13.09.09	22.95	0.05	45	1000.00	both	-842.0	5.0	362.0	255.0	2.1	0.0	-839.9	-605.2	-234.7
5	17.09.09	23.05	0.05	43	1000.00	both	-596.0	13.0	358.0	259.0	-2.1	0.0	-598.1	-604.6	6.5
***p* = 5, EIM**															
1	30.09.09	23.00	0.02	40	998.86	both	-570.0	5.0		272.0	0.0	-0.3	-570.3	-602.8	32.5
2	06.10.09	23.00	0.02	40	998.92	both	-513.0	4.4		278.0	0.0	-0.3	-513.3	-601.9	88.6
3	09.10.09	23.00	0.02	40	998.92	both	-518.0	4.0		281.0	0.0	-0.3	-518.3	-601.5	83.2
4	14.10.09	23.00	0.02	40	998.92	both	-515.0	3.8		286.0	0.0	-0.3	-515.3	-600.7	85.5
5	20.10.09	23.00	0.02	40	998.85	both	-594.0	3.2		292.0	0.0	-0.3	-594.3	-599.9	5.6
***p* = 6, INRIM**															
1	16.11.09	22.82	0.05	40	999.99	both	-504.6	2.2		319.0	7.6	0.0	-497.0	-595.7	98.8
2	17.11.09	22.82	0.05	40	999.99	both	-512.1	1.9		320.0	7.7	0.0	-504.3	-595.6	91.2
3	18.11.09	22.82	0.05	40	999.99	both	-514.5	6.9		321.0	7.7	0.0	-506.7	-595.4	88.7
4	23.11.09	22.82	0.05	40	999.99	both	-508.0	1.6		326.0	7.6	0.0	-500.3	-594.6	94.3
5	25.11.09	22.82	0.05	40	999.99	both	-515.8	1.4		328.0	7.6	0.0	-508.2	-594.3	86.1
6															
***p* = 7, MIKES**															
1	01.12.09	22.81	0.20	39	1000.00	both	-605.9	0.7	6.0	334.0	8.0	0.0	-597.9	-593.3	-4.6
2	06.12.09	22.85	0.20	39	1000.00	both	-609.3	0.9	11.2	339.0	6.5	0.0	-602.8	-592.5	-10.3
3	13.12.09	22.82	0.20	23	1000.00	both	-600.9	2.7	-1.2	346.0	7.7	0.0	-593.2	-591.4	-1.8
***p* = 8, SP**															
1	09.03.10	23.00	0.05	47	1000.00	both	-560.9	1.1	5.5	432.0	-0.2	0.0	-561.1	-576.4	15.3
2	18.03.10	22.98	0.05	46	1000.00	both	-559.8	1.2	5.9	441.1	0.7	0.0	-559.1	-574.8	15.6
3	19.03.10	22.98	0.05	45	1000.00	both	-555.9	1.4	0.4	442.5	1.0	0.0	-555.0	-574.5	19.5
4	24.03.10	22.98	0.05	45	1000.00	both	-558.0	1.5	4.2	447.5	0.7	0.0	-557.4	-573.6	16.2
***p* = 9, INM**															
1	20.05.10	22.91	0.04	42	1000.00	both	-530.0	3.0	4.2	504.0	3.8	0.0	-526.2	-562.9	36.7
2	20.05.10	22.95	0.04	43	1000.00	both	-520.0		5.2	504.0	2.1	0.0	-517.9	-562.9	45.0
3	20.05.10	22.94	0.04	44	1000.00	both	-540.0		6.2	504.0	2.5	0.0	-537.5	-562.9	25.4
4	20.05.10	22.94	0.04	44	1000.00	both	-520.0		7.2	504.0	2.5	0.0	-517.5	-562.9	45.4
5	20.05.10	22.93	0.04	44	1000.00	both	-530.0		8.2	504.0	2.9	0.0	-527.1	-562.9	35.9
6	21.05.10	22.93	0.04	47	1000.00	both	-540.0		9.2	505.0	2.9	0.0	-537.1	-562.7	25.7
7	21.05.10	22.97	0.04	49	1000.00	both	-530.0		10.2	505.0	1.3	0.0	-528.7	-562.7	34.0
8	21.05.10	22.96	0.04	49	1000.00	both	-540.0		11.2	505.0	1.7	0.0	-538.3	-562.7	24.4
9	21.05.10	22.98	0.04	49	1000.00	both	-550.0		12.2	505.0	0.8	0.0	-549.2	-562.7	13.6
10	21.05.10	22.98	0.04	49	1000.00	both	-540.0		13.2	505.0	0.8	0.0	-539.2	-562.7	23.6
***p* = 10, NCM**															
1	29.06.10	22.88	0.01	49	1000.00	pos	378.6	18.3	-	544.0	5.0	0.0	383.6	-555.2	938.8
2	07.07.10	22.98	0.01	50	1000.00	both	165.2	3.3	13.4	552.0	0.8	0.0	166.0	-553.6	719.6
3	14.07.10	23.06	0.02	51	1000.00	both	144.4	9.8	85.5	559.0	-2.5	0.0	141.9	-552.2	694.1
4	15.07.10	22.92	0.01	48	1000.00	both	121.2	15.1	132.0	560.0	3.4	0.0	124.6	-552.0	676.6

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p* = 11, VSL**															
1	01.08.10	22.95	0.01	45	1000.00	both	-493.8	6.0	-22.9	577.0	2.1	0.0	-491.6	-548.7	57.1
2	01.08.10	22.95	0.01	46	1000.00	both	-494.4	4.1	-20.6	577.3	2.0	0.0	-492.4	-548.6	56.3
3	01.08.10	22.95	0.01	46	1000.00	both	-492.5	3.9	-19.0	577.6	2.2	0.0	-490.3	-548.6	58.3
4	01.08.10	22.95	0.01	46	1000.00	both	-495.4	6.4	-17.0	577.9	2.2	0.0	-493.3	-548.5	55.3
5	19.08.10	22.97	0.01	46	1000.00	both	-488.6	2.7	-16.9	595.6	1.4	0.0	-487.1	-545.1	57.9
6	26.08.10	22.95	0.02	46	1000.00	both	-483.7	1.0	-18.2	602.6	2.1	0.0	-481.6	-543.7	62.1
7	31.08.10	22.94	0.01	45	1000.00	both	-485.1	3.1	-12.7	608.0	2.6	0.0	-482.5	-542.6	60.1
8	01.09.10	22.94	0.01	45	1000.00	both	-484.7	3.3	-17.9	608.3	2.6	0.0	-482.2	-542.6	60.4
9															
***p* = 12, GUM**															
1	06.10.10	22.80	0.10	43	1000.00	both	-1514.5	5.9	-	643.0	8.4	0.0	-1506.1	-535.7	-970.3
2	06.10.10	22.80	0.10	44	1000.00	both	-1504.7	4.3		643.0	8.4	0.0	-1496.3	-535.7	-960.6
3	06.10.10	22.80	0.10	44	1000.00	both	-1516.3	6.2		643.0	8.4	0.0	-1507.9	-535.7	-972.1
4	06.10.10	22.80	0.10	43	1000.00	both	-1521.1	5.4		643.0	8.4	0.0	-1512.7	-535.7	-977.0
5	06.10.10	22.70	0.10	43	1000.00	both	-1380.4	5.6		643.0	12.6	0.0	-1367.8	-535.7	-832.0
6	06.10.10	22.90	0.10	42	1000.00	both	-1396.0	2.6		643.0	4.2	0.0	-1391.8	-535.7	-856.0
7	07.10.10	22.80	0.10	43	1000.00	both	-1413.0	4.8		644.0	8.4	0.0	-1404.6	-535.5	-869.1
8	07.10.10	22.80	0.10	43	1000.00	both	-1423.8	5.1		644.0	8.4	0.0	-1415.4	-535.5	-879.9
9	12.10.10	22.80	0.10	53	1000.00	both	-1472.6	4.3		649.0	8.4	0.0	-1464.2	-534.6	-929.6
10	12.10.10	22.80	0.10	54	1000.00	both	-1409.7	9.0		649.0	8.4	0.0	-1401.3	-534.6	-866.7
***p* = 13, CMI**															
1	24.11.10	23.00	0.20	40	1000.00	both	-440.0	5.0	10.0	692.0	0.0	0.0	-440.0	-526.2	86.2
2	29.11.10	23.00	0.20	40	1000.00	both	-440.0	5.0	10.0	697.0	0.0	0.0	-440.0	-525.2	85.2
3	03.12.10	23.00	0.20	40	1000.00	both	-430.0	5.0	10.0	701.0	0.0	0.0	-430.0	-524.5	94.5
4	10.12.10	23.00	0.20	40	1000.00	both	-450.0	5.0	10.0	708.0	0.0	0.0	-450.0	-523.1	73.1
***p* = 14, IPQ**															
1	14.12.10	23.40	0.02	64	1000.00		-330.5	3.7		712.7	-16.9	0.0	-347.4	-522.2	174.8
2	12.01.11	22.33	0.03	52	1000.00		-353.2	6.3		741.5	28.1	0.0	-325.0	-516.8	191.8
3	12.01.11	23.07	0.02	52	1000.00		-304.9	6.0		741.7	-2.9	0.0	-307.8	-516.7	208.9
4	21.01.11	22.95	0.03	41	1000.00		-350.6	8.8		750.5	2.0	0.0	-348.6	-515.1	166.5
5	24.01.11	23.02	0.01	38	1000.00		-353.6	9.4		753.7	-0.8	0.0	-354.4	-514.5	160.1
***p* = 15, CEM**															
1	08.02.11	23.01	0.04	38	1000.00	both	-518.5	3.3	26.7	768.0	-0.6	0.0	-519.1	-511.9	-7.2
2	09.02.11	23.01	0.04	38	1000.00	both	-531.1	2.3	14.2	769.0	-0.4	0.0	-531.5	-511.7	-19.9
3	22.02.11	23.08	0.04	39	1000.00	both	-544.6	2.2	37.4	782.0	-3.5	0.0	-548.1	-509.3	-38.7
***p* = 16, SMD**															
1	12.03.11	23.03	0.04	34	1000.00	both	-139.0	41.6	-23.0	800.0	-1.2	0.0	-140.2	-506.1	365.9
***p* = 17, LNE**															
1	08.04.11	23.00	0.20	44	1000.00	both	-430.2	1.7	7.4	827.0	0.0	0.0	-430.2	-501.3	71.1
***p* = 18, UME**															
1	30.05.11	23.04	0.07	47	1000.00	both	-627.6	8.4		879.6	-1.8	0.0	-629.4	-492.6	-136.8
2	03.06.11	23.07	0.03	48	1000.00	both	-524.1	11.2		883.4	-2.8	0.0	-526.9	-492.0	-34.9
3	10.06.11	23.10	0.08	48	1000.00	both	-546.4	1.5		890.4	-4.4	0.0	-550.8	-490.9	-59.9
4	23.06.11	23.10	0.05	46	1000.00	both	-564.3	66.8		903.4	-4.0	0.0	-568.3	-488.9	-79.5
5	28.06.11	23.06	0.02	44	1000.00	both	-453.2	8.0		908.5	-2.6	0.0	-455.8	-488.1	32.3

B.1.3 1 TΩ standard no 69574, *a* = 2, 500 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p* = 1, METAS**															
1	26.01.09	23.00	0.05	45	500	both	-347.2	5.0	-3.7	25.4			-347.2	-349.2	2.0
2	26.01.09	23.00	0.05	45	500	both	-345.4	5.0	-8.1	25.6			-345.4	-349.2	3.8
3	10.02.09	23.00	0.05	45	500	both	-354.3	5.0	-4.1	40.6			-354.3	-347.8	-6.5
4	17.02.09	23.00	0.05	45	500	both	-350.4	5.0	3.6	47.7			-350.4	-347.1	-3.3
5	17.03.09	23.00	0.05	45	500	both	-343.9	5.0	-2.0	75.7			-343.9	-344.3	0.4
6	20.03.09	23.00	0.05	45	500	both	-342.5	5.0	-4.0	78.6			-342.5	-343.9	1.4
7	10.08.09	23.00	0.05	45	500	both	-333.4	5.0	-1.5	221.4			-333.4	-324.6	-8.8
8	26.04.10	23.00	0.05	45	500	both	-268.8	5.0	-1.8	480.7			-268.8	-270.0	1.3
9	26.04.10	23.00	0.05	45	500	both	-262.2	5.0	-2.6	480.9			-262.2	-270.0	7.8
10	29.04.10	23.00	0.05	45	500	both	-272.6	5.0	1.3	483.5			-272.6	-269.3	-3.3
11	03.11.10	23.00	0.05	45	500	both	-207.4	5.0	-4.0	671.5			-207.4	-213.9	6.5
12	05.11.10	23.00	0.05	45	500	both	-216.8	5.0	1.7	673.4			-216.8	-213.3	-3.4
13	05.11.10	23.00	0.05	45	500	both	-215.6	5.0	-6.0	673.5			-215.6	-213.3	-2.3
14															
15	03.11.10	23.00	0.05	45	500	both	-207.4	5.0	-4.0	671.5			-207.4	-212.9	5.5
16	05.11.10	23.00	0.05	45	500	both	-216.8	5.0	1.7	673.4			-216.8	-212.8	-4.0
	05.11.10	23.00	0.05	45	500	both	-215.6	5.0	-6.0	673.5			-215.6	-212.8	-2.8
	30.08.11	23.00	0.05	45	500	both	-189.9	5.0	-1.3	971.5			-189.9	-195.5	5.7
	29.09.11	23.00	0.05	45	500	both	-191.0	5.0	-3.8	1001.5			-191.0	-193.8	2.8
	14.02.12	23.00	0.05	45	500	both	-188.6	5.0	2.8	1139.5			-188.6	-185.8	-2.8
***p* = 2, SMU**															
1	22.04.09	23.10	0.20	38	400	both	-1314.0	31.0	28.0	111.0	-3.7	-13.2	-1330.9	-340.2	-990.7
2	28.04.09	23.00	0.20	36	400	both	-1289.0	171.0	45.0	117.0	0.0	-13.2	-1302.2	-339.5	-962.7
3	06.05.09	23.10	0.20	41	400	both	-1303.0	117.0	35.0	125.0	-3.7	-13.2	-1319.9	-338.5	-981.4
4	14.05.09	23.20	0.20	37	400	both	-1109.0	74.0	32.0	133.0	-7.3	-13.2	-1129.6	-337.5	-792.1
***p* = 3, PTB**															
1	26.06.09	23.01	0.10	48	500	both	-130.0	10.8		176.0	-0.4	0.0	-130.4	-331.6	201.2
2	01.07.09	22.97	0.10	53	500	both	-60.0	49.5		181.0	1.1	0.0	-58.9	-330.8	271.9
3	06.07.09	22.98	0.10	46	500	both	-160.0	9.1		186.0	0.7	0.0	-159.3	-330.1	170.8
4	09.07.09	22.94	0.10	45	500	both	0.0	39.3		189.0	2.2	0.0	2.2	-329.6	331.8
***p* = 4, SIQ**															
1	04.09.09	22.82	0.05	45	500	both	-203.0	8.0	473.0	246.0	6.6	0.0	-196.4	-320.5	124.1
2	08.09.09	22.86	0.05	42	500	both	-79.0	14.0	457.0	250.0	5.1	0.0	-73.9	-319.8	245.9
3	11.09.09	22.99	0.05	48	500	both	-204.0	12.0	477.0	253.0	0.4	0.0	-203.6	-319.3	115.6
4	12.09.09	22.98	0.05	43	500	both	-503.0	5.0	585.0	254.0	0.7	0.0	-502.3	-319.1	-183.2
5	17.09.09	23.19	0.05	45	500	both	-278.0	12.0	635.0	259.0	-7.0	0.0	-285.0	-318.2	33.3
***p* = 5, EIM**															
1	30.09.09	23.00	0.02	40	500	both	-269.0	3.6		272.0	0.0	-0.1	-269.1	-315.9	46.8
2	06.10.09	23.00	0.02	40	500	both	-285.0	3.0		278.0	0.0	-0.1	-285.1	-314.8	29.7
3	09.10.09	23.00	0.02	40	500	both	-285.0	3.5		281.0	0.0	-0.1	-285.1	-314.3	29.2
4	15.10.09	23.00	0.02	40	500	both	-268.0	7.2		287.0	0.0	-0.1	-268.1	-313.1	45.1
5	20.10.09	23.00	0.02	40	500	both	-314.0	7.0		292.0	0.0	-0.1	-314.1	-312.2	-1.9
***p* = 6, INRIM**															
1	05.11.09	22.81	0.05	45	499.995	both	-224.2	2.6		308.0	6.8	0.0	-217.4	-309.1	91.8

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
2	14.11.09	22.82	0.05	40	499.995	both	-215.0	2.8		317.0	6.7	0.0	-208.3	-307.4	99.1
3	19.11.09	22.88	0.05	40	499.995	both	-212.4	6.0		322.0	4.6	0.0	-207.9	-306.4	98.5
4	20.11.09	22.82	0.05	40	499.995	both	-222.6	3.5		323.0	6.7	0.0	-216.0	-306.2	90.2
5	21.11.09	22.82	0.05	40	499.995	both	-211.0	4.8		324.0	6.7	0.0	-204.3	-306.0	101.7
***p* = 7, MIKES**															
1	02.12.09	22.83	0.20	39	500	both	-316.4	2.3	-10.2	335.0	6.2	0.0	-310.2	-303.8	-6.4
2	07.12.09	22.82	0.20	39	500	both	-318.2	1.1	-0.3	340.0	6.7	0.0	-311.5	-302.7	-8.8
3	15.12.09	22.83	0.20	39	500	both	-313.7	2.2	-1.8	348.0	6.3	0.0	-307.5	-301.1	-6.4
***p* = 8, SP**															
1	09.03.10	22.94	0.05	46	500	both	-287.3	2.0	0.4	432.6	2.1	0.0	-285.2	-282.1	-3.1
2	10.03.10	22.95	0.05	46	500	both	-283.3	2.7	1.9	433.0	1.7	0.0	-281.6	-281.9	0.3
3	18.03.10	22.98	0.05	45	500	both	-278.7	1.0	2.2	441.5	0.6	0.0	-278.1	-279.9	1.8
4	24.03.10	22.99	0.05	46	500	both	-277.3	1.2	-2.3	448.0	0.5	0.0	-276.8	-278.3	1.5
***p* = 9, INM**															
1															
***p* = 10, NCM**															
1	25.06.10	22.89	0.01	52	500	pos	-117.6	20.1	-	540.0	4.0	0.0	-113.6	-254.1	140.5
2	29.06.10	22.88	0.01	51	500	pos	-152.7	23.1	-	544.0	4.4	0.0	-148.3	-252.9	104.6
3	06.07.10	22.98	0.04	52	500	both	-193.0	10.1	39.6	551.0	0.7	0.0	-192.3	-250.9	58.7
4	14.07.10	23.06	0.01	52	500	both	-200.9	14.8	-128.2	559.0	-2.2	0.0	-203.1	-248.7	45.6
5	19.07.10	23.01	0.01	52	500	pos	-358.2	4.3	-	564.0	-0.4	0.0	-358.6	-247.2	-111.3
6	20.07.10	22.95	0.01	49	500	neg	-265.0	0.6	-	565.0	1.8	0.0	-263.2	-246.9	-16.2
***p* = 11, VSL**															
1	02.08.10	22.95	0.00	46	500	both	-197.0	14.2	-141.8	578.7	1.8	0.0	-195.2	-242.9	47.7
2	02.08.10	22.96	0.00	46	500	both	-187.8	9.5	-150.5	578.9	1.6	0.0	-186.1	-242.9	56.7
3	18.08.10	22.95	0.00	45	500	both	-184.1	9.3	-136.3	594.9	1.7	0.0	-182.4	-238.1	55.7
4	19.08.10	22.96	0.00	46	500	both	-180.2	8.4	-118.2	595.4	1.6	0.0	-178.5	-238.0	59.4
5	30.08.10	22.96	0.03	45	500	both	-179.6	8.4	-124.1	607.0	1.6	0.0	-177.9	-234.4	56.5
6	31.08.10	22.94	0.00	46	500	both	-176.9	12.4	-118.9	607.5	2.2	0.0	-174.7	-234.3	59.6
***p* = 12, GUM**															
1	05.10.10	22.80	0.10	50	500	both	-1055.8	6.7	-	642.0	7.3	0.0	-1048.5	-223.5	-825.0
2	05.10.10	22.80	0.10	55	500	both	-919.0	3.4		642.0	7.3	0.0	-911.7	-223.5	-688.2
3	05.10.10	22.80	0.10	54	500	both	-908.1	3.7		642.0	7.3	0.0	-900.7	-223.5	-677.2
4	05.10.10	22.70	0.10	54	500	both	-883.8	4.7		642.0	11.0	0.0	-872.8	-223.5	-649.3
5	05.10.10	22.80	0.10	53	500	both	-860.6	2.8		642.0	7.3	0.0	-853.2	-223.5	-629.7
6	05.10.10	22.80	0.10	47	500	both	-875.8	3.2		642.0	7.3	0.0	-868.5	-223.5	-645.0
7	06.10.10	22.70	0.10	44	500	both	-947.5	6.1		643.0	11.0	0.0	-936.5	-223.2	-713.3
8	12.10.10	22.80	0.10	44	500	both	-908.8	3.8		649.0	7.3	0.0	-901.5	-221.3	-680.2
9	12.10.10	22.80	0.10	44	500	both	-892.5	5.4		649.0	7.3	0.0	-885.2	-221.3	-664.0
***p* = 13, CMI**															
1	24.11.10	23.00	0.20	40	500	both	-110.0	5.0	10.0	692.0	0.0	0.0	-110.0	-211.7	101.7
2	29.11.10	23.00	0.20	40	500	both	-140.0	5.0	10.0	697.0	0.0	0.0	-140.0	-211.4	71.4
3	03.12.10	23.00	0.20	40	500	both	-90.0	5.0	10.0	701.0	0.0	0.0	-90.0	-211.2	121.2
4	10.12.10	23.00	0.20	40	500	both	-130.0	5.0	10.0	708.0	0.0	0.0	-130.0	-210.8	80.8

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p* = 14, IPQ**															
1	12.01.11	22.66	0.01	52	500		-85.3	18.6		741.5	12.3	0.0	-72.9	-208.9	135.9
2	20.01.11	23.04	0.02	45	500		-92.7	36.3		749.7	-1.5	0.0	-94.3	-208.4	114.1
3	21.01.11	22.99	0.05	42	500		-133.6	1.3		750.4	0.2	0.0	-133.4	-208.3	75.0
4	25.01.11	23.02	0.01	40	500		-140.0	16.0		754.4	-0.6	0.0	-140.7	-208.1	67.5
***p* = 15, CEM**															
1	10.02.11	23.00	0.01	38	500	both	-258.0	4.7	21.8	770.0	0.2	0.0	-257.8	-207.2	-50.6
2	11.02.11	22.99	0.01	38	500	both	-248.5	1.9	-19.0	771.0	0.2	0.0	-248.3	-207.1	-41.2
***p* = 16, SMD**															
1	12.03.11	23.03	0.00	34	500	both	-197.0	80.0	-51.0	800.0	-1.1	0.0	-198.1	-205.5	7.4
***p* = 17, LNE**															
1	04.04.11	23.00	0.20	44	500	both	-173.3	1.6	7.0	823.0	0.0	0.0	-173.3	-204.1	30.8
***p* = 18, UME**															
1	26.05.11	23.03	0.08	48	500	both	-203.0	12.4		875.4	-1.1	0.0	-204.1	-201.1	-3.0
2	27.05.11	23.05	0.04	48	500	both	-173.9	5.4		876.5	-1.8	0.0	-175.7	-201.0	25.3
3	07.06.11	23.11	0.05	47	500	both	-195.5	11.0		887.5	-3.9	0.0	-199.4	-200.4	1.0
4	17.06.11	23.08	0.04	48	500	both	-189.7	19.1		897.3	-3.1	0.0	-192.7	-199.8	7.1
5	20.06.11	23.08	0.04	48	500	both	-197.0	29.3		900.4	-2.8	0.0	-199.8	-199.6	-0.1
6	22.06.11	23.11	0.04	45	500	both	-199.5	28.2		902.4	-4.1	0.0	-203.7	-199.5	-4.2

B.1.4 1 TΩ standard 69574, *a* = 2, 1000 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p* =1, METAS**															
1	26.01.09	23.00	0.05	45	1000.0	both	-453.7	3.0	-0.8	25.5			-453.7	-452.8	-0.9
2	10.02.09	23.00	0.05	45	1000.0	both	-450.4	3.0	0.8	40.7			-450.4	-451.4	1.0
3	17.02.09	23.00	0.05	45	1000.0	both	-449.9	3.0	2.1	47.8			-449.9	-450.7	0.8
4	17.03.09	23.00	0.05	45	1000.0	both	-444.9	3.0	-0.7	75.7			-444.9	-447.8	3.0
5	20.03.09	23.00	0.05	45	1000.0	both	-449.2	3.0	-1.7	78.6			-449.2	-447.5	-1.6
6	10.08.09	23.00	0.05	45	1000.0	both	-429.0	3.0	-2.9	221.5			-429.0	-428.2	-0.8
7	26.04.10	23.00	0.05	45	1000.0	both	-375.0	3.0	-0.5	480.8			-375.0	-373.6	-1.4
8	26.04.10	23.00	0.05	45	1000.0	both	-370.1	3.0	0.3	480.9			-370.1	-373.6	3.5
9	29.04.10	23.00	0.05	45	1000.0	both	-373.8	3.0	2.1	483.5			-373.8	-372.9	-0.9
10	03.11.10	23.00	0.05	45	1000.0	both	-317.7	3.0	-0.7	671.6			-317.7	-317.5	-0.2
11	05.11.10	23.00	0.05	45	1000.0	both	-318.1	3.0	0.2	673.5			-318.1	-316.9	-1.2
12															
13	03.11.10	23.00	0.05	45	1000.0	both	-317.7	3.0	-0.7	671.6			-317.7	-316.5	-1.2
14	05.11.10	23.00	0.05	45	1000.0	both	-318.1	3.0	0.2	673.5			-318.1	-316.4	-1.7
15	30.08.11	23.00	0.05	45	1000.0	both	-295.3	3.0	0.7	971.5			-295.3	-299.1	3.8
16	29.09.11	23.00	0.05	45	1000.0	both	-294.1	3.0	-2.1	1001.5			-294.1	-297.4	3.3
	14.02.12	23.00	0.05	45	1000.0	both	-294.9	3.0	1.2	1139.5			-294.9	-289.4	-5.6
***p* = 2, SMU**															
1															

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p* = 3, PTB**															
1	26.06.09	23.01	0.10	48	1000.0	both	-220.0	11.8		176.0	-0.4	0.0	-220.4	-435.1	214.8
2	01.07.09	22.97	0.10	53	1000.0	both	-140.0	19.3		181.0	1.1	0.0	-138.9	-434.4	295.5
3	07.07.09	22.98	0.10	46	1000.0	both	-250.0	5.8		187.0	0.7	0.0	-249.3	-433.5	184.2
4	09.07.09	22.94	0.10	45	1000.0	both	-60.0	38.6		189.0	2.2	0.0	-57.8	-433.2	375.4
***p* = 4, SIQ**															
1	04.09.09	22.85	0.05	44	1000.0	both	-316.0	10.0	271.0	246.0	5.5	0.0	-310.5	-424.1	113.6
2	08.09.09	22.81	0.05	42	1000.0	both	-253.0	10.0	295.0	250.0	7.0	0.0	-246.0	-423.4	177.3
3	11.09.09	22.90	0.05	45	1000.0	both	-305.0	8.0	277.0	253.0	3.7	0.0	-301.3	-422.9	121.5
4	12.09.09	22.97	0.05	43	1000.0	both	-638.0	11.0	352.0	254.0	1.1	0.0	-636.9	-422.7	-214.2
5	17.09.09	23.19	0.05	43	1000.0	both	-429.0	18.0	379.0	259.0	-7.0	0.0	-436.0	-421.8	-14.1
***p* = 5, EIM**															
1	30.09.09	23.00	0.02	40	999.1	both	-309.0	2.7		272.0	0.0	-0.3	-309.3	-419.5	110.2
2	06.10.09	23.00	0.02	40	999.1	both	-309.0	1.7		278.0	0.0	-0.3	-309.3	-418.4	109.1
3	09.10.09	23.00	0.02	40	999.1	both	-316.0	2.1		281.0	0.0	-0.3	-316.3	-417.8	101.6
4	15.10.09	23.00	0.02	40	999.1	both	-313.0	3.5		287.0	0.0	-0.3	-313.3	-416.7	103.5
5	21.10.09	23.00	0.02	40	999.0	both	-410.0	5.3		293.0	0.0	-0.3	-410.3	-415.6	5.3
***p* = 6, INRIM**															
1	05.11.09	22.82	0.05	45	999.99	both	-347.3	2.6		308.0	6.6	0.0	-340.7	-412.7	72.0
2	14.11.09	22.82	0.05	40	999.99	both	-325.9	1.3		317.0	6.7	0.0	-319.2	-411.0	91.7
3	19.11.09	22.82	0.05	40	999.99	both	-361.6	2.1		322.0	6.6	0.0	-355.0	-410.0	55.0
4	20.11.09	22.82	0.05	40	999.99	both	-353.7	1.9		323.0	6.7	0.0	-347.0	-409.8	62.8
5	21.11.09	22.82	0.05	40	999.99	both	-351.8	2.0		324.0	6.7	0.0	-345.1	-409.6	64.4
6															
***p* = 7, MIKES**															
1	02.12.09	22.82	0.20	39	1000.0	both	-425.9	0.6	-1.1	335.0	6.4	0.0	-419.5	-407.4	-12.1
2	07.12.09	22.81	0.20	39	1000.0	both	-428.3	0.8	-0.8	340.0	6.9	0.0	-421.4	-406.3	-15.1
3	15.12.09	22.82	0.20	39	1000.0	both	-428.3	0.4	-1.5	348.0	6.7	0.0	-421.7	-404.7	-17.0
4															
***p* = 8, SP**															
1	09.03.10	22.95	0.05	46	1000.0	both	-392.5	1.1	2.1	432.5	1.8	0.0	-390.8	-385.6	-5.1
2	10.03.10	22.95	0.05	46	1000.0	both	-392.9	1.7	3.7	433.0	1.7	0.0	-391.2	-385.5	-5.7
3	18.03.10	22.98	0.05	45	1000.0	both	-385.4	1.4	-0.7	441.5	0.6	0.0	-384.7	-383.5	-1.3
4	25.03.10	22.99	0.05	46	1000.0	both	-384.8	0.7	1.5	448.0	0.5	0.0	-384.3	-381.9	-2.4
***p* = 9, INM**															
1	20.05.10	22.91	0.04	42	1000.0	both	-360.0	3.0	1.5	504.0	3.3	0.0	-356.7	-367.5	10.8
2	20.05.10	22.95	0.04	43	1000.0	both	-350.0	3.0	2.5	504.0	1.8	0.0	-348.2	-367.5	19.3
3	20.05.10	22.94	0.04	44	1000.0	both	-350.0	3.0	3.5	504.0	2.2	0.0	-347.8	-367.5	19.7
4	20.05.10	22.94	0.04	44	1000.0	both	-370.0	3.0	4.5	504.0	2.2	0.0	-367.8	-367.5	-0.3
5	20.05.10	22.93	0.04	44	1000.0	both	-360.0	3.0	5.5	504.0	2.6	0.0	-357.4	-367.5	10.1
6	21.05.10	22.93	0.04	47	1000.0	both	-350.0	3.0	6.5	505.0	2.6	0.0	-347.4	-367.2	19.8
7	21.05.10	22.97	0.04	49	1000.0	both	-360.0	3.0	7.5	505.0	1.1	0.0	-358.9	-367.2	8.3
8	21.05.10	22.96	0.04	49	1000.0	both	-350.0	3.0	8.5	505.0	1.5	0.0	-348.5	-367.2	18.7
9	21.05.10	22.98	0.04	49	1000.0	both	-350.0	3.0	9.5	505.0	0.7	0.0	-349.3	-367.2	18.0
10	21.05.10	22.98	0.04	49	1000.0	both	-350.0	3.0	10.5	505.0	0.7	0.0	-349.3	-367.2	18.0

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
p = 10, NCM															
1	29.06.10	22.88	0.01	49	1000.0	pos	87.1	9.1	-	544.0	4.4	0.0	91.5	-356.5	448.0
2	07.07.10	22.98	0.01	50	1000.0	both	-164.8	36.8	-320.7	552.0	0.7	0.0	-164.1	-354.2	190.2
3	14.07.10	23.06	0.02	51	1000.0	both	-19.2	3.9	34.1	559.0	-2.2	0.0	-21.4	-352.2	330.8
4	15.07.10	22.92	0.01	48	1000.0	both	-21.6	3.4	29.2	560.0	2.9	0.0	-18.7	-352.0	333.3
p = 11, VSL															
1	03.08.10	22.95	0.00	45	1000.0	both	-304.5	3.7	-37.4	579.2	1.8	0.0	-302.7	-346.4	43.7
2	03.08.10	22.95	0.00	46	1000.0	both	-301.5	4.6	-34.9	579.5	1.7	0.0	-299.8	-346.3	46.5
3	19.08.10	22.95	0.00	46	1000.0	both	-293.4	4.4	-35.4	595.2	1.7	0.0	-291.6	-341.6	49.9
4	31.08.10	22.94	0.00	44	1000.0	both	-290.1	6.7	-43.0	607.2	2.2	0.0	-287.8	-337.9	50.1
5	31.08.10	22.94	0.00	45	1000.0	both	-288.5	3.8	-49.5	607.6	2.0	0.0	-286.5	-337.8	51.3
p = 12, GUM															
1	05.10.10	23.10	0.10	42	1000.0	both	-1015.6	5.5		642.0	-3.7	0.0	-1019.3	-327.1	-692.2
2	05.10.10	23.00	0.10	42	1000.0	both	-1047.0	6.3		642.0	0.0	0.0	-1047.0	-327.1	-719.9
3	05.10.10	23.00	0.10	43	1000.0	both	-1032.7	3.7		642.0	0.0	0.0	-1032.7	-327.1	-705.6
4	05.10.10	22.80	0.10	51	1000.0	both	-1078.7	6.0		642.0	7.3	0.0	-1071.3	-327.1	-744.2
5	05.10.10	22.80	0.10	50	1000.0	both	-1072.9	5.1		642.0	7.3	0.0	-1065.6	-327.1	-738.5
6	06.10.10	22.80	0.10	42	1000.0	both	-1080.8	7.1		643.0	7.3	0.0	-1073.4	-326.8	-746.7
7	06.10.10	23.20	0.10	44	1000.0	both	-1031.9	4.5		643.0	-7.3	0.0	-1039.3	-326.8	-712.5
8	12.10.10	23.10	0.10	44	1000.0	both	-976.6	3.9		649.0	-3.7	0.0	-980.2	-324.9	-655.4
p = 13, CMI															
1	24.11.10	23.00	0.20	40	1000.0	both	-240.0	5.0	10.0	692.0	0.0	0.0	-240.0	-315.3	75.3
2	29.11.10	23.00	0.20	40	1000.0	both	-250.0	5.0	10.0	697.0	0.0	0.0	-250.0	-315.0	65.0
3	03.12.10	23.00	0.20	40	1000.0	both	-230.0	5.0	10.0	701.0	0.0	0.0	-230.0	-314.8	84.8
4	10.12.10	23.00	0.20	40	1000.0	both	-250.0	5.0	10.0	708.0	0.0	0.0	-250.0	-314.4	64.4
p = 14, IPQ															
1	15.12.10	23.23	0.01	51	1000.0		-115.5	3.7		713.0	-8.3	0.0	-123.7	-314.1	190.4
2	12.01.11	22.67	0.01	52	1000.0		-173.6	10.4		741.5	12.1	0.0	-161.5	-312.4	150.9
3	20.01.11	23.04	0.02	45	1000.0		-119.9	16.7		749.7	-1.5	0.0	-121.4	-312.0	190.6
4	21.01.11	22.99	0.05	42	1000.0		-167.0	1.2		750.4	0.2	0.0	-166.8	-311.9	145.1
5	25.01.11	23.02	0.01	40	1000.0		-131.8	8.7		754.4	-0.6	0.0	-132.5	-311.7	179.2
p = 15, CEM															
1	10.02.11	23.00	0.01	38	1000.0	both	-342.8	3.0	16.0	770.0	0.2	0.0	-342.6	-310.8	-31.8
2	11.02.11	22.99	0.01	38	1000.0	both	-358.0	1.6	14.4	771.0	0.2	0.0	-357.8	-310.7	-47.1
p = 16, SMD															
1	12.03.11	23.03	0.04	34	1000.0	both	47.0	66.3	11.0	800.0	-1.1	0.0	45.9	-309.1	355.0
p = 17, LNE															
1	04.04.11	23.00	0.20	44	1000.0	both	-207.3	1.1	5.3	823.0	0.0	0.0	-207.3	-307.7	100.5
p = 18, UME															
1	26.05.11	23.03	0.08	48	1000.0	both	-323.0	3.1		875.4	-1.1	0.0	-324.1	-304.7	-19.4
2	27.05.11	23.05	0.04	48	1000.0	both	-326.8	2.5		876.6	-1.8	0.0	-328.6	-304.6	-24.0
3	07.06.11	23.11	0.05	47	1000.0	both	-323.5	3.1		887.6	-3.9	0.0	-327.3	-304.0	-23.4
4	17.06.11	23.08	0.04	48	1000.0	both	-300.5	0.5		897.4	-3.1	0.0	-303.6	-303.4	-0.2
5	20.06.11	23.08	0.04	48	1000.0	both	-314.0	5.5		900.4	-2.8	0.0	-316.8	-303.2	-13.6
6	22.06.11	23.11	0.04	45	1000.0	both	-307.7	11.0		902.4	-4.1	0.0	-311.8	-303.1	-8.7

B.1.5 1 TΩ standard no 1101180, *a* = 3, 500 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p* =1, METAS**															
1	27.01.09	23.00	0.05	45	500.0	both	-1456.4	4.3	1.0	26.4			-1456.4	-1458.3	1.8
2	27.01.09	23.00	0.05	45	500.0	both	-1458.0	4.3	1.0	26.6			-1458.0	-1458.3	0.2
3	17.02.09	23.00	0.05	45	500.0	both	-1460.6	4.3	1.8	47.5			-1460.6	-1457.0	-3.6
4	17.03.09	23.00	0.05	45	500.0	both	-1444.3	4.3	2.5	75.5			-1444.3	-1455.4	11.1
5	20.03.09	23.00	0.05	45	500.0	both	-1464.3	4.3	1.7	78.8			-1464.3	-1455.2	-9.1
6	10.08.09	23.00	0.05	45	500.0	both	-1446.8	4.3	1.3	221.7			-1446.8	-1446.8	0.0
7															
8	10.08.09	23.00	0.05	45	500.0	both	-1446.8	4.3	1.3	221.7			-1446.8	-1447.1	0.2
9	27.04.10	23.00	0.05	45	500.0	both	-1296.9	4.3	0.1	481.3			-1296.9	-1297.4	0.5
10	29.04.10	23.00	0.05	45	500.0	both	-1295.7	4.3	0.8	483.8			-1295.7	-1296.0	0.3
11	29.04.10	23.00	0.05	45	500.0	both	-1298.1	4.3	2.1	483.9			-1298.1	-1295.9	-2.2
12															
13	29.04.10	23.00	0.05	45	500.0	both	-1296.5	4.3	2.1	483.9			-1296.5	-1293.5	-3.0
14	04.11.10	23.00	0.05	45	500.0	both	-1294.6	4.3	0.6	672.4			-1294.6	-1293.0	-1.7
15	08.11.10	23.00	0.05	45	500.0	both	-1287.2	4.3	-0.3	676.8			-1287.2	-1292.7	5.6
16	09.11.10	23.00	0.05	45	500.0	both	-1288.1	4.3	1.1	677.0			-1288.1	-1292.7	4.7
17	08.08.11	23.00	0.05	45	500.0	both	-1260.2	4.3	0.6	949.5			-1260.2	-1256.7	-3.6
18	09.08.11	23.00	0.05	45	500.0	both	-1260.3	4.3	1.4	950.6			-1260.3	-1256.4	-3.8
19	31.08.11	23.00	0.05	45	500.0	both	-1255.8	4.3	0.6	972.8			-1255.8	-1251.7	-4.2
20	29.09.11	23.00	0.05	45	500.0	both	-1241.6	4.3	0.6	1001.8			-1241.6	-1245.1	3.4
21	30.09.11	23.00	0.05	45	500.0	both	-1243.0	4.3	-0.3	1002.9			-1243.0	-1244.8	1.8
22	10.02.12	23.00	0.05	45	500.0	both	-1207.1	4.3	1.2	1135.3			-1207.1	-1208.6	1.5
***p* = 2, SMU**															
1	22.04.09	23.20	0.20	38	400.0	both	43.0	419.0	150.0	111.0	-13.9	-4.1	25.0	-1453.3	1478.3
2	28.04.09	23.00	0.20	34	400.0	both	153.0	478.0	135.0	117.0	0.0	-4.1	148.9	-1452.9	1601.9
3	05.05.09	23.10	0.20	41	400.0	both	312.0	312.0	120.0	124.0	-7.0	-4.1	301.0	-1452.5	1753.5
4	12.05.09	23.20	0.20	37	400.0	both	258.0	396.0	145.0	131.0	-13.9	-4.1	240.0	-1452.1	1692.1
***p* = 3, PTB**															
1	25.06.09	23.00	0.10	45	499.99	both	-1530.0	7.4		175.0	0.0	0.0	-1530.0	-1449.5	-80.5
2	30.06.09	22.96	0.10	51	499.99	both	-1970.0	4.1		180.0	2.8	0.0	-1967.2	-1449.2	-518.0
3	06.07.09	22.99	0.10	46	499.99	both	-1770.0	3.2		186.0	0.7	0.0	-1769.3	-1448.9	-320.4
4	09.07.09	22.95	0.10	45	499.99	both	-1790.0	4.9		189.0	3.5	0.0	-1786.5	-1448.7	-337.8
***p* = 4, SIQ**															
1	04.09.09	22.82	0.05	48	500.0	both	-1448.0	7.0	513.0	246.0	12.5	0.0	-1435.5	-1433.0	-2.4
2	08.09.09	22.81	0.05	43	500.0	both	-1410.0	11.0	428.0	250.0	13.2	0.0	-1396.8	-1430.7	34.0
3	11.09.09	22.88	0.05	45	500.0	both	-1597.0	34.0	501.0	253.0	8.4	0.0	-1588.6	-1429.0	-159.6
4	12.09.09	23.04	0.05	42	500.0	both	-1720.0	26.0	573.0	254.0	-2.8	0.0	-1722.8	-1428.4	-294.3
5	17.09.09	23.15	0.05	45	500.0	both	-1487.0	30.0	543.0	259.0	-10.4	0.0	-1497.4	-1425.6	-71.9
***p* = 5, EIM**															
1	28.09.09	23.00	0.02	40	499.0	both	-1406.0	8.7		270.0	0.0	0.0	-1406.0	-1419.2	13.2
2	05.10.09	23.00	0.02	40	498.9	both	-1646.0	31.5		277.0	0.0	0.0	-1646.0	-1415.2	-230.9
3	12.10.09	23.00	0.02	40	498.9	both	-1552.0	6.3		284.0	0.0	0.0	-1552.0	-1411.1	-140.9
4	15.10.09	23.00	0.02	40	498.9	both	-1523.0	18.4		287.0	0.0	0.0	-1523.0	-1409.4	-113.6
5	21.10.09	23.00	0.02	40	499.0	both	-1443.0	24.1		293.0	0.0	0.0	-1443.0	-1406.0	-37.1
***p* = 6, INRIM**															
1	17.11.09	22.82	0.05	40	499.995	both	-1258.5	4.4		320.0	12.6	0.0	-1245.9	-1390.4	144.5

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
2	18.11.09	22.82	0.05	40	499.995	both	-1269.0	2.8		321.0	12.2	0.0	-1256.8	-1389.8	133.0
3	20.11.09	22.82	0.05	40	499.995	both	-1277.6	4.2		323.0	12.2	0.0	-1265.4	-1388.7	123.3
4	21.11.09	22.83	0.05	40	499.995	both	-1298.9	2.6		324.0	11.9	0.0	-1287.0	-1388.1	101.1
5	22.11.09	22.83	0.05	40	499.995	both	-1296.6	4.3		325.0	12.1	0.0	-1284.5	-1387.5	103.0
***p* = 7, MIKES**															
1	30.11.09	22.84	0.20	39	500.0	both	-1355.5	0.6	0.1	333.0	11.5	0.0	-1344.1	-1382.9	38.9
2	08.12.09	22.83	0.20	39	500.0	both	-1337.5	0.5	0.6	341.0	12.1	0.0	-1325.4	-1378.3	52.9
3	14.12.09	22.80	0.20	23	500.0	both	-1349.4	0.3	0.0	347.0	13.6	0.0	-1335.8	-1374.8	39.1
4	17.12.09	22.79	0.20	39	500.0	both	-1329.2	1.0	0.0	350.0	14.4	0.0	-1314.8	-1373.1	58.3
***p* = 8, SP**															
1	18.03.10	22.98	0.05	45	500.0	both	-1363.0	1.2	7.5	442.0	1.1	0.0	-1361.9	-1320.1	-41.8
2	25.03.10	22.99	0.05	45	500.0	both	-1403.1	1.5	7.1	448.5	0.9	0.0	-1402.2	-1316.3	-85.9
3	01.04.10	22.99	0.05	45	500.0	both	-1410.8	1.6	0.2	455.5	0.7	0.0	-1410.1	-1312.3	-97.8
***p* = 9, INM**															
1															
***p* = 10, NCM**															
1	19.07.10	23.01	0.01	52	500.0	pos	-178.2	1.6	-	564.0	-0.7	0.0	-178.9	-1295.7	1116.8
2	20.07.10	22.95	0.02	49	500.0	neg	-191.2	9.0	-	565.0	3.5	0.0	-187.7	-1295.7	1108.0
***p* = 11, VSL**															
1	04.08.10	22.98	0.01	45	500.0	both	-1363.7	3.2	3.9	580.5	1.7	0.0	-1362.0	-1295.7	-66.3
2	20.08.10	22.97	0.01	45	500.0	both	-1338.7	1.7	2.6	596.3	2.4	0.0	-1336.3	-1295.6	-40.7
3	22.08.10	22.96	0.01	46	500.0	both	-1338.5	1.9	3.2	598.4	2.6	0.0	-1335.9	-1295.5	-40.4
4	26.08.10	22.97	0.01	45	500.0	both	-1333.1	2.3	2.3	602.2	1.9	0.0	-1331.2	-1295.5	-35.7
5	03.09.10	22.97	0.01	45	500.0	both	-1328.2	1.4	1.8	610.6	2.3	0.0	-1325.9	-1295.3	-30.6
6	04.09.10	22.97	0.01	45	500.0	both	-1326.4	1.2	2.9	611.9	2.4	0.0	-1324.0	-1295.3	-28.7
***p* = 12, GUM**															
1	04.10.10	22.90	0.10	43	500.0	both	-2258.6	5.3	-	641.6	7.0	0.0	-2251.6	-1294.4	-957.2
2	04.10.10	22.80	0.10	43	500.0	both	-2207.6	5.1		641.6	13.9	0.0	-2193.7	-1294.4	-899.3
3	04.10.10	22.80	0.10	43	500.0	both	-2187.6	3.6		641.6	13.9	0.0	-2173.7	-1294.4	-879.3
4	04.10.10	22.80	0.10	41	500.0	both	-2202.2	2.3		641.7	13.9	0.0	-2188.3	-1294.4	-893.9
5	12.10.10	22.80	0.10	41	500.0	both	-2112.8	3.6		649.6	13.9	0.0	-2098.8	-1294.1	-804.8
***p* = 13, CMI**															
1	24.11.10	23.00	0.20	40	500.0	both	-1170.0	5.0	10.0	692.0	0.0	0.0	-1170.0	-1291.8	121.8
2	29.11.10	23.00	0.20	40	500.0	both	-1200.0	5.0	10.0	697.0	0.0	0.0	-1200.0	-1291.5	91.5
3	03.12.10	23.00	0.20	40	500.0	both	-1190.0	5.0	10.0	701.0	0.0	0.0	-1190.0	-1291.2	101.2
4	10.12.10	23.00	0.20	40	500.0	both	-1200.0	5.0	10.0	708.0	0.0	0.0	-1200.0	-1290.7	90.7
***p* = 14, IPQ**															
1	12.01.11	23.30	0.05	52	500.0		-893.7	17.0		741.5	-20.7	0.0	-914.4	-1287.9	373.5
2	21.01.11	22.92	0.02	42	500.0		-881.0	14.8		750.6	5.6	0.0	-875.4	-1287.0	411.6
3	24.01.11	23.17	0.03	37	500.0		-964.8	17.5		753.6	-11.8	0.0	-976.6	-1286.7	310.2
4	26.01.11	22.84	0.01	37	500.0		-852.9	17.5		755.6	11.0	0.0	-841.9	-1286.5	444.6
***p* = 15, CEM**															
1	02.02.11	23.02	0.01	36	500.0	both	-1287.2	2.4	26.0	762.0	-1.4	0.0	-1288.6	-1285.9	-2.7
2	03.02.11	23.02	0.01	37	500.0	both	-1273.1	3.8	40.9	763.0	-1.3	0.0	-1274.3	-1285.8	11.4

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
3	04.02.11	23.02	0.01	38	500.0	both	-1294.9	3.1	55.2	764.0	-1.6	0.0	-1296.5	-1285.7	-10.8
4	07.02.11	23.03	0.01	37	500.0	both	-1258.7	2.2	-38.7	767.0	-1.7	0.0	-1260.4	-1285.3	24.9
***p* = 16, SMD**															
1	12.03.11	23.03	0.04	34	500.0	both	-1380.0	54.0	60.0	800.0	-2.0	0.0	-1382.0	-1281.5	-100.5
***p* = 17, LNE**															
1	12.04.11	23.00	0.20	44	500.0	both	-1246.2	1,3	23.3	831.0	0.0	0.0	-1246.2	-1277.4	31.1
***p* = 18, UME**															
1	31.05.11	23.06	0.09	47	500.0	both	-1264.4	3.4		880.4	-4.5	0.0	-1268.9	-1269.7	0.8
2	02.06.11	23.12	0.09	48	500.0	both	-1333.5	2.6		882.0	-8.4	0.0	-1341.9	-1269.4	-72.5
3	06.06.11	23.09	0.04	48	500.0	both	-1302.9	1.8		886.4	-6.1	0.0	-1309.0	-1268.7	-40.3
4	07.06.11	23.11	0.05	47	500.0	both	-1345.6	2.8		887.0	-7.3	0.0	-1353.0	-1268.5	-84.4
5	16.06.11	23.15	0.04	46	500.0	both	-1293.6	21.3		896.4	-10.3	0.0	-1303.9	-1266.9	-37.0
6	21.06.11	23.11	0.05	47	500.0	both	-1320.6	16.4		901.3	-7.6	0.0	-1328.3	-1266.0	-62.3
7	27.06.11	23.07	0.03	45	500.0	both	-1337.9	35.5		907.4	-4.8	0.0	-1342.7	-1264.9	-77.8

B.1.6 1 TΩ standard no1101180, *a* = 3, 1000 V

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p* =1, METAS**															
1	27.01.09	23.00	0.05	45	1000.0	both	-1490.0	4.8	0.3	26.5			-1490.0	-1490.1	0.1
2	17.02.09	23.00	0.05	45	1000.0	both	-1494.1	4.8	2.5	47.5			-1494.1	-1488.9	-5.3
3	17.03.09	23.00	0.05	45	1000.0	both	-1474.6	4.8	3.8	75.5			-1474.6	-1487.2	12.7
4	20.03.09	23.00	0.05	45	1000.0	both	-1494.5	4.8	3.1	78.7			-1494.5	-1487.0	-7.5
5	10.08.09	23.00	0.05	45	1000.0	both	-1479.2	4.8	2.6	221.8			-1479.2	-1478.6	-0.5
6															
7	10.08.09	23.00	0.05	45	1000.0	both	-1479.2	4.8	2.6	221.8			-1479.2	-1478.9	-0.3
8	27.04.10	23.00	0.05	45	1000.0	both	-1326.8	4.8	1.5	481.4			-1326.8	-1329.2	2.4
9	29.04.10	23.00	0.05	45	1000.0	both	-1326.3	4.8	4.2	483.8			-1326.3	-1327.8	1.5
10	29.04.10	23.00	0.05	45	1000.0	both	-1330.0	4.8	2.8	484.0			-1330.0	-1327.7	-2.2
11															
12	29.04.10	23.00	0.05	45	1000.0	both	-1330.0	4.8	2.8	484.0			-1330.0	-1325.4	-4.6
13	04.11.10	23.00	0.05	45	1000.0	both	-1326.6	4.8	2.3	672.4			-1326.6	-1324.8	-1.8
14	08.11.10	23.00	0.05	45	1000.0	both	-1319.8	4.8	2.7	676.9			-1319.8	-1324.6	4.8
15	09.11.10	23.00	0.05	45	1000.0	both	-1317.9	4.8	2.2	677.1			-1317.9	-1324.6	6.6
16	08.08.11	23.00	0.05	45	1000.0	both	-1293.3	4.8	2.7	949.6			-1293.3	-1288.5	-4.8
17	09.08.11	23.00	0.05	45	1000.0	both	-1292.2	4.8	2.8	950.6			-1292.2	-1288.3	-4.0
18	31.08.11	23.00	0.05	45	1000.0	both	-1288.3	4.8	2.6	972.9			-1288.3	-1283.5	-4.7
19	29.09.11	23.00	0.05	45	1000.0	both	-1275.7	4.8	2.5	1001.9			-1275.7	-1276.9	1.2
20	30.09.11	23.00	0.05	45	1000.0	both	-1276.6	4.8	2.5	1003.0			-1276.6	-1276.6	0.0
21	08.02.12	23.00	0.05	45	1000.0	both	-1235.1	4.8	2.5	1133.1			-1235.1	-1241.2	6.0
22	10.02.12	23.00	0.05	45	1000.0	both	-1240.2	4.8	2.5	1135.4			-1240.2	-1240.4	0.3
***p* = 2, SMU**															
1															
***p* = 3, PTB**															
1	25.06.09	23.00	0.10	45	1000.0	both	-1550.0	2.6		175.0	0.0	0.0	-1550.0	-1481.4	-68.6
2	30.06.09	22.96	0.10	51	1000.0	both	-2120.0	9.3		180.0	2.8	0.0	-2117.2	-1481.1	-636.1
3	06.07.09	23.00	0.10	47	1000.0	both	-1800.0	2.2		186.0	0.0	0.0	-1800.0	-1480.7	-319.3

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
4	10.07.09	22.99	0.10	43	1000.0	both	-1710.0	14.7		190.0	0.7	0.0	-1709.3	-1480.5	-228.8
***p* = 4, SIQ**															
1	04.09.09	22.84	0.05	47	1000.0	both	-1523.0	8.0	306.0	246.0	11.1	0.0	-1511.9	-1464.9	-47.0
2	08.09.09	22.87	0.05	42	1000.0	both	-1465.0	10.0	272.0	250.0	9.0	0.0	-1456.0	-1462.6	6.6
3	11.09.09	22.99	0.05	43	1000.0	both	-1669.0	35.0	356.0	253.0	0.7	0.0	-1668.3	-1460.9	-207.4
4	12.09.09	23.04	0.05	42	1000.0	both	-1759.0	35.0	389.0	254.0	-2.8	0.0	-1761.8	-1460.3	-301.5
5	17.09.09	23.01	0.05	43	1000.0	both	-1532.0	45.0	384.0	259.0	-0.7	0.0	-1532.7	-1457.4	-75.3
***p* = 5, EIM**															
1	29.09.09	23.00	0.02	40	997.9	both	-1519.0	19.5		271.0	0.0	-0.2	-1519.2	-1450.5	-68.7
2	05.10.09	23.00	0.02	40	997.8	both	-1628.0	26.2		277.0	0.0	-0.2	-1628.2	-1447.0	-181.2
3	12.10.09	23.00	0.02	40	997.8	both	-1630.0	18.8		284.0	0.0	-0.2	-1630.2	-1443.0	-187.2
4	15.10.09	23.00	0.02	40	997.9	both	-1544.0	6.4		287.0	0.0	-0.2	-1544.2	-1441.3	-102.9
5	16.10.09	23.00	0.02	40	998.0	both	-1450.0	4.1		288.0	0.0	-0.2	-1450.2	-1440.7	-9.5
***p* = 6, INRIM**															
1	17.11.09	22.82	0.05	40	999.99	both	-1322.3	5.0		320.0	12.3	0.0	-1310.0	-1422.2	112.2
2	18.11.09	22.82	0.05	40	999.99	both	-1316.6	1.5		321.0	12.2	0.0	-1304.4	-1421.7	117.2
3	20.11.09	22.83	0.05	40	999.99	both	-1328.0	2.0		323.0	11.7	0.0	-1316.2	-1420.5	104.3
4	21.11.09	22.83	0.05	40	999.99	both	-1329.7	1.7		324.0	12.0	0.0	-1317.8	-1419.9	102.2
5	22.11.09	22.83	0.05	39	999.99	both	-1342.6	2.1		325.0	12.1	0.0	-1330.5	-1419.4	88.9
***p* = 7, MIKES**															
1	30.11.09	22.84	0.20	39	1000.0	both	-1399.3	0.4	2.6	333.0	10.8	0.0	-1388.4	-1414.7	26.3
2	08.12.09	22.83	0.20	39	1000.0	both	-1383.8	0.4	3.0	341.0	12.0	0.0	-1371.8	-1410.1	38.4
3	14.12.09	22.81	0.20	39	1000.0	both	-1389.7	0.3	2.3	347.0	13.0	0.0	-1376.7	-1406.7	30.0
4	17.12.09	22.78	0.20	39	1000.0	both	-1372.9	0.5	1.9	350.0	15.0	0.0	-1357.9	-1405.0	47.1
***p* = 8, SP**															
1	19.03.10	22.98	0.05	45	1000.0	both	-1400.8	0.6	5.8	442.0	1.1	0.0	-1399.6	-1351.9	-47.7
2	25.03.10	22.99	0.05	45	1000.0	both	-1442.0	0.6	5.8	448.5	1.0	0.0	-1440.9	-1348.2	-92.8
3	01.04.10	22.99	0.05	45	1000.0	both	-1449.7	0.5	11.7	455.5	0.8	0.0	-1448.9	-1344.1	-104.8
***p* = 9, INM**															
1	18.05.10	22.91	0.04	42	1000.0	both	-1530.0	3.0	11.7	502.0	6.3	0.0	-1523.7	-1326.2	-197.5
2	18.05.10	22.90	0.04	43	1000.0	both	-1550.0	3.0	12.7	502.0	7.0	0.0	-1543.0	-1326.2	-216.9
3	18.05.10	22.88	0.04	43	1000.0	both	-1530.0	3.0	13.7	502.0	8.4	0.0	-1521.6	-1326.2	-195.5
4	19.05.10	22.90	0.04	44	1000.0	both	-1520.0	3.0	14.7	503.0	7.0	0.0	-1513.0	-1326.2	-186.8
5	19.05.10	22.90	0.04	43	1000.0	both	-1520.0	3.0	15.7	503.0	7.0	0.0	-1513.0	-1326.2	-186.8
6	19.05.10	22.89	0.04	43	1000.0	both	-1540.0	3.0	16.7	503.0	7.7	0.0	-1532.3	-1326.2	-206.1
7	19.05.10	22.89	0.04	43	1000.0	both	-1530.0	3.0	17.7	503.0	7.7	0.0	-1522.3	-1326.2	-196.1
8	19.05.10	22.90	0.04	43	1000.0	both	-1530.0	3.0	18.7	503.0	7.0	0.0	-1523.0	-1326.2	-196.8
9	19.05.10	22.90	0.04	43	1000.0	both	-1540.0	3.0	19.7	503.0	7.0	0.0	-1533.0	-1326.2	-206.8
10	19.05.10	22.90	0.04	43	1000.0	both	-1540.0	3.0	20.7	503.0	7.0	0.0	-1533.0	-1326.2	-206.8
***p* = 10, NCM**															
1	19.07.10	23.01	0.03	52	1000.0	pos	-197.2	0.7	-	564.0	-0.7	0.0	-197.9	-1327.5	1129.6
2	21.07.10	22.92	0.01	52	1000.0	pos	543.8	9.4	-	566.0	5.6	0.0	549.4	-1327.6	1876.9
***p* = 11, VSL**															
1	06.08.10	22.98	0.01	45	1000.0	both	-1383.7	1.5	7.8	582.0	1.5	0.0	-1382.2	-1327.5	-54.6
2	21.08.10	22.97	0.01	46	1000.0	both	-1357.0	0.9	6.9	597.5	2.4	0.0	-1354.6	-1327.4	-27.2

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
3	23.08.10	22.97	0.01	46	1000.0	both	-1352.1	2.9	6.2	599.4	2.4	0.0	-1349.7	-1327.4	-22.3
4	03.09.10	22.97	0.01	45	1000.0	both	-1344.3	1.5	6.6	610.1	2.2	0.0	-1342.1	-1327.2	-15.0
5	04.09.10	22.97	0.01	45	1000.0	both	-1344.9	1.4	6.3	611.3	2.4	0.0	-1342.5	-1327.2	-15.3
***p* = 12, GUM**															
1	04.10.10	23.20	0.10	42	1000.0	both	-2322.1	5.7	-	641.0	-13.9	0.0	-2336.1	-1326.3	-1009.8
2	04.10.10	23.10	0.10	42	1000.0	both	-2299.4	6.2		641.0	-7.0	0.0	-2306.4	-1326.3	-980.1
3	04.10.10	23.10	0.10	42	1000.0	both	-2299.0	4.3		641.0	-7.0	0.0	-2305.9	-1326.3	-979.6
4	04.10.10	22.90	0.10	43	1000.0	both	-2270.8	3.0		641.0	7.0	0.0	-2263.8	-1326.3	-937.5
5	05.10.10	23.20	0.10	43	1000.0	both	-2379.5	6.1		642.0	-13.9	0.0	-2393.4	-1326.2	-1067.1
6	12.10.10	23.20	0.10	43	1000.0	both	-2224.9	3.4		649.0	-13.9	0.0	-2238.8	-1326.0	-912.8
***p* = 13, CMI**															
1	24.11.10	23.00	0.20	40	1000.0	both	-1230.0	5.0	10.0	692.0	0.0	0.0	-1230.0	-1323.6	93.6
2	29.11.10	23.00	0.20	40	1000.0	both	-1240.0	5.0	10.0	697.0	0.0	0.0	-1240.0	-1323.3	83.3
3	03.12.10	23.00	0.20	40	1000.0	both	-1240.0	5.0	10.0	701.0	0.0	0.0	-1240.0	-1323.0	83.0
4	10.12.10	23.00	0.20	40	1000.0	both	-1250.0	5.0	10.0	708.0	0.0	0.0	-1250.0	-1322.5	72.5
***p* = 14, IPQ**															
1	15.12.10	23.31	0.01	51	1000.0		-1069.9	11.0		713.5	-21.8	0.0	-1091.7	-1322.1	230.4
2	12.01.11	23.14	0.04	52	1000.0		-1030.0	31.7		741.5	-9.6	0.0	-1039.7	-1319.7	280.1
3	21.01.11	22.92	0.02	42	1000.0		-1222.2	12.5		750.6	5.6	0.0	-1216.6	-1318.9	102.3
4	24.01.11	23.14	0.03	37	1000.0		-1206.1	14.9		753.6	-9.6	0.0	-1215.7	-1318.6	102.8
5	26.01.11	22.84	0.01	37	1000.0		-1176.3	9.7		755.6	11.1	0.0	-1165.2	-1318.4	153.1
***p* = 15, CEM**															
1	02.02.11	23.02	0.01	37	1000.0	both	-1300.2	1.5	19.3	762.0	-1.3	0.0	-1301.5	-1317.7	16.2
2	03.02.11	23.02	0.01	37	1000.0	both	-1307.4	1.5	21.8	763.0	-1.4	0.0	-1308.8	-1317.6	8.8
3	04.02.11	23.02	0.01	38	1000.0	both	-1300.9	3.9	-6.9	764.0	-1.5	0.0	-1302.4	-1317.5	15.1
4	07.02.11	23.03	0.01	37	1000.0	both	-1292.2	2.6	16.4	767.0	-1.7	0.0	-1294.0	-1317.2	23.2
***p* = 16, SMD**															
1	12.03.11	23.03	0.04	34	1000.0	both	-1077.0	46.0	26.0	800.0	-2.0	0.0	-1079.0	-1313.4	234.3
***p* = 17, LNE**															
1	12.04.11	23.00	0.20	44	1000.0	both	-1276.2	0.7	-6.3	831.0	0.0	0.0	-1276.2	-1309.2	33.0
***p* = 18, UME**															
1	31.05.11	23.06	0.09	47	1000.0	both	-1326.7	2.6		880.5	-4.5	0.0	-1331.2	-1301.5	-29.7
2	06.06.11	23.09	0.04	48	1000.0	both	-1357.6	3.2		886.4	-6.1	0.0	-1363.6	-1300.5	-63.1
3	07.06.11	23.11	0.05	47	1000.0	both	-1379.5	8.8		887.0	-7.3	0.0	-1386.8	-1300.4	-86.5
4	16.06.11	23.15	0.04	46	1000.0	both	-1328.4	28.1		896.4	-10.3	0.0	-1338.6	-1298.7	-39.9
5	21.06.11	23.11	0.05	47	1000.0	both	-1352.6	22.4		901.4	-7.6	0.0	-1360.3	-1297.8	-62.4
6	27.06.11	23.07	0.03	45	1000.0	both	-1357.8	4.4		907.5	-4.8	0.0	-1362.6	-1296.7	-65.9

B.2 100 TΩ

B.2.1 100 TΩ standard no 69640, *a* = 4, 500 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=1, METAS**															
1	06.02.09	23.00	0.05	45	500	both	-81	115	-112	36.8			-81	-4	-78
2	18.02.09	23.00	0.05	45	500	both	67	115	-29	48.3			67	36	30
3	16.03.09	23.00	0.05	45	500	both	155	115	2	74.4			155	127	28
4	24.03.09	23.00	0.05	45	500	both	264	115	-75	82.4			264	155	109
5	12.08.09	23.00	0.05	45	500	both	516	115	13	223.3			516	645	-129
7	27.04.10	23.00	0.05	45	500	both	1583	115	-9	481.5			1583	1543	40
8															
9	27.04.10	23.00	0.05	45	500	both	1583	115	-9	481.5			1583	1510	72
10	30.04.10	23.00	0.05	45	500	both	1624	115	6	484.8			1624	1508	116
11	01.05.10	23.00	0.05	45	500	both	1586	115	15	485.0			1586	1508	78
12	04.11.10	23.00	0.05	45	500	both	1260	115	60	672.8			1260	1378	-118
13	05.11.10	23.00	0.05	45	500	both	1221	115	6	673.0			1221	1378	-156
14	10.11.10	23.00	0.05	45	500	both	1366	115	7	678.6			1366	1374	-8
15	21.07.11	23.00	0.05	45	500	both	997	115	48	931.7			997	1198	-201
16	04.08.11	23.00	0.05	45	500	both	1154	115	50	945.3			1154	1189	-35
17	29.08.11	23.00	0.05	45	500	both	1367	115	-15	970.8			1367	1171	196
18	28.09.11	23.00	0.05	45	500	both	1063	115	72	1000.8			1063	1150	-87
19	03.10.11	23.00	0.05	45	500	both	1290	115	-8	1006.0			1290	1147	144
***p*=2, SMU**															
1	22.04.09	23.10	0.20	38	400	both	-1477	2830	1800	111.0	10	-123	-1590	255	-1844
2	28.04.09	23.00	0.20	35	400	both	1061	2840	2500	117.0	0	-123	938	275	663
3	06.05.09	23.10	0.20	40	400	both	666	5740	2800	125.0	10	-123	553	303	250
4	14.05.09	23.20	0.20	37	400	both	2164	2740	2200	133.0	20	-123	2061	331	1730
***p*=3, PTB**															
1	24.06.09	22.98	0.10	42	500	both	7600	300		174.0	-2	0	7598	474	7124
2	29.06.09	23.01	0.10	48	500	both	6100	300		179.0	1	0	6101	491	5610
3	02.07.09	23.01	0.10	52	500	both	11100	300		182.0	1	0	11101	501	10600
4	07.07.09	22.97	0.10	46	500	both	4600	300		187.0	-3	0	4597	519	4078
5	09.07.09	22.93	0.10	45	500	both	6500	800		189.0	-7	0	6493	526	5967
***p*=4, SIQ**															
1	07.09.09	23.13	0.05	41	500	both	2033	471	16068	249.0	13	0	2046	734	1312
2	09.09.09	23.18	0.05	42	500	both	2871	249	24308	251.0	18	0	2889	741	2148
3	12.09.09	22.95	0.05	44	500	both	1582	401	23776	254.0	-5	0	1577	752	825
4	14.09.09	22.89	0.05	42	500	both	920	589	23237	256.0	-11	0	909	759	150
5	16.09.09	23.06	0.05	44	500	both	1920	253	22935	258.0	6	0	1926	766	1160
***p*=5, EIM**															
1	01.10.09	23.00	0.02	40	539	both	1469	111		273.0	0	55	1524	818	706
2	07.10.09	23.00	0.02	40	539	both	388	317		279.0	0	55	443	839	-396
3	08.10.09	23.00	0.02	40	539	both	579	298		280.0	0	55	634	842	-208
4	13.10.09	23.00	0.02	40	539	both	296	387		285.0	0	55	351	860	-509
5	19.10.09	23.00	0.02	40	539	both	-1456	392		291.0	0	55	-1401	881	-2282
***p*=6, INRIM**															
1	16.11.09	22.98	0.05	40	500	both	1400	31		319.0	-2	0	1398	978	420

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
2	17.11.09	22.99	0.05	40	500	both	1576	45		320.0	-1	0	1575	981	594
3	22.11.09	23.02	0.05	40	500	both	1359	26		325.0	2	0	1361	999	362
4	23.11.09	23.01	0.05	40	500	both	1341	28		326.0	1	0	1342	1002	340
5	24.11.09	22.96	0.05	40	500	both	1465	18		327.0	-4	0	1461	1006	455
***p*=7, MIKES**															
1	28.11.09	22.77	0.20	39	500	both	730	28	-274	331.0	-23	0	707	1020	-312
2	03.12.09	22.81	0.20	39	500	both	682	46	-121	336.0	-19	0	662	1037	-375
3	11.12.09	22.81	0.20	39	500	both	539	33	-84	344.0	-19	0	519	1065	-545
4	22.12.09	22.81	0.20	39	500	both	-95		-90	355.0	-19	0	-114	1103	-1217
***p*=8, SP**															
1	10.03.10	23.01	0.05	47	500	both	2416	209	-348	434.0	1	0	2417	1378	1039
2	15.03.10	23.00	0.05	47	500	both	2044	82	380	438.0	0	0	2044	1392	652
3	23.03.10	22.97	0.05	45	500	both	2077	151	-306	446.5	-3	0	2074	1421	653
4	23.03.10	22.97	0.05	45	500	both	2064	102	-389	447.0	-3	0	2061	1423	638
5	31.03.10	23.00	0.06	47	500	both	2057	123	198	454.1	0	0	2057	1448	609
6	04.04.10	22.99	0.05	46	500	both	1846	61	108	459.0	-1	0	1845	1465	381
***p*=9, INM**															
1															
***p*=10, NCM**															
1	07.07.10	22.98	0.01	49	500	pos	-2997	2260	-	552.0	-2	0	-2999	1461	-4460
2	08.07.10	22.97	0.01	52	500	neg	-10295	1080	-	553.0	-3	0	-10298	1461	-11759
3	10.07.10	22.94	0.01	52	500	pos	14382	47	-	555.0	-6	0	14376	1459	12917
4	12.07.10	22.90	0.01	46	500	neg	-9210	153	-	557.0	-10	0	-9220	1458	-10678
5	13.07.10	22.90	0.01	50	500	both	-7003	161	-692	558.0	-10	0	-7013	1457	-8470
***p*=11, VSL**															
1	16.08.10	22.95	0.00	46	500	both	1747	165	-909	593.0	-5	0	1742	1433	309
2	24.08.10	22.94	0.00	46	500	both	1884	127	-1064	600.8	-6	0	1878	1428	450
3	07.09.10	22.95	0.01	45	500	both	1764	78	-986	614.7	-5	0	1759	1418	341
***p*=12, GUM**															
1	28.09.10	22.80	0.10	43	500	both	7809	62		635.0	-20	0	7789	1404	6385
2	01.10.10	22.70	0.10	43	500	both	7809	158		638.0	-30	0	7779	1402	6377
3	01.10.10	22.70	0.10	43	500	both	7809	101		638.0	-30	0	7779	1402	6377
4	01.10.10	22.70	0.10	43	500	both	7809	122		638.0	-30	0	7779	1402	6377
5	01.10.10	22.70	0.10	43	500	both	7809	91		638.0	-30	0	7779	1402	6377
6	01.10.10	22.70	0.10	43	500	both	7809	120		638.0	-30	0	7779	1402	6377
***p*=13, CMI**															
1	24.11.10	23.00	0.20	40	500	both	1700	50	200	692.0	0	0	1700	1364	336
2	29.11.10	23.00	0.20	40	500	both	2100	50	200	697.0	0	0	2100	1361	739
3	03.12.10	23.00	0.20	40	500	both	2400	50	200	701.0	0	0	2400	1358	1042
4	10.12.10	23.00	0.20	40	500	both	2500	50	200	708.0	0	0	2500	1353	1147
***p*=14, IPQ**															
1	16.12.10	23.23	0.01	46	500		6377	1145		714.5	23	0	6400	1349	5051
2	17.01.11	22.49	0.02	51	500		3114	1278		746.6	-51	0	3063	1327	1736
3	17.01.11	22.42	0.01	52	500		3963	1376		746.7	-58	0	3906	1327	2579
4	18.01.11	23.08	0.02	50	500		1963	1130		747.4	8	0	1971	1326	645

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
5	18.01.11	23.11	0.01	49	500		2297	1430		747.6	11	0	2308	1326	982
6	20.01.11	23.09	0.02	45	500		5331	1221		749.4	9	0	5339	1325	4015
***p*=15, CEM**															
1	14.02.11	23.07	0.01	37	500	both	-2183	117	-1160	774.0	7	0	-2175	1308	-3483
2	15.02.11	23.07	0.01	38	500	both	-1882	88	-1244	775.0	7	0	-1875	1307	-3182
***p*=16, SMD**															
1	12.03.11	23.06	0.04	35	500	both	-930	1657	-520	800.0	6	0	-924	1290	-2213
***p*=17, LNE**															
1	20.04.11	23.00	0.20	44	500	both	1145	126	429	839.0	0	0	1145	1263	-118
***p*=18, UME**															
1	03.06.11	23.07	0.03	48	500	both	1450	18		883.6	7	0	1457	1232	225
2	04.06.11	23.05	0.01	49	500	both	1331	120		884.2	5	0	1335	1231	104
3	16.06.11	23.15	0.04	46	500	both	1741	212		896.6	15	0	1756	1223	533
4	17.06.11	23.08	0.04	48	500	both	1428	129		897.1	8	0	1436	1222	214
5	24.06.11	23.08	0.03	48	500	both	1442	165		905.0	8	0	1450	1217	233
6	25.06.11	23.08	0.01	47	500	both	1484	165		905.3	8	0	1491	1217	275
7	26.06.11	23.07	0.01	45	500	both	1392	164		906.3	7	0	1399	1216	183
8	01.07.11	23.10	0.05	46	500	both	1591	67		911.0	10	0	1601	1213	389
9	11.07.11	23.09	0.02	47	500	both	1205	141		921.4	9	0	1214	1205	9

B.2.2 100 TΩ standard no 69640, *a* = 4, 1000 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=1, METAS**															
1	03.02.09	23.00	0.05	45	1000.00	both	-2196	128	-75	33.9			-2196	-2211	15
2	06.02.09	23.00	0.05	45	1000.00	both	-2262	128	-121	36.7			-2262	-2213	-50
3	06.02.09	23.00	0.05	45	1000.00	both	-1970	128	-97	36.9			-1970	-2213	243
4	18.02.09	23.00	0.05	45	1000.00	both	-2082	128	-198	48.4			-2082	-2220	138
5	16.03.09	23.00	0.05	45	1000.00	both	-2322	128	-157	74.5			-2322	-2237	-85
	24.03.09	23.00	0.05	45	1000.00	both	-2468	128	-107	82.4			-2468	-2242	-226
7	12.08.09	23.00	0.05	45	1000.00	both	-2371	128	104	223.4			-2371	-2332	-38
8	12.08.09	23.00	0.05	45	1000.00	both	-2231	128	-9	223.6			-2231	-2333	102
9															
10	27.04.10	23.00	0.05	45	1000.00	both	1427	128	43	481.6			1427	1372	55
11	30.04.10	23.00	0.05	45	1000.00	both	1392	128	35	484.9			1392	1369	23
12	01.05.10	23.00	0.05	45	1000.00	both	1352	128	26	485.2			1352	1369	-17
13	04.11.10	23.00	0.05	45	1000.00	both	1086	128	26	672.9			1086	1239	-153
14	05.11.10	23.00	0.05	45	1000.00	both	1129	128	22	673.2			1129	1239	-109
15	10.11.10	23.00	0.05	45	1000.00	both	1272	128	-7	678.7			1272	1235	37
16	21.07.11	23.00	0.05	45	1000.00	both	872	128	19	931.8			872	1059	-187
17	04.08.11	23.00	0.05	45	1000.00	both	1076	128	18	945.5			1076	1050	26
18	29.08.11	23.00	0.05	45	1000.00	both	1272	128	27	970.9			1272	1032	240
19	28.09.11	23.00	0.05	45	1000.00	both	935	128	-17	1000.9			935	1012	-77
20	03.10.11	23.00	0.05	45	1000.00	both	1171	128	3	1005.9			1171	1008	163
***p*=2, SMU**															
1															

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=3, PTB**															
1	25.06.09	22.98	0.10	42	999.96	both	5300	300		175.0	-2	0	5298	-2301	7599
2	29.06.09	23.01	0.10	48	999.96	both	5200	300		179.0	1	0	5201	-2304	7505
3	02.07.09	22.98	0.10	54	999.96	both	5900	300		182.0	-2	0	5898	-2306	8204
4	07.07.09	22.97	0.10	46	999.96	both	1700	300		187.0	-3	0	1697	-2309	4006
5	09.07.09	22.93	0.10	45	999.96	both	4400	500							
***p*=4, SIQ**															
1	07.09.09	23.22	0.05	38	1000.00	both	-228	435	15192	249.0	22	0	-206	596	-802
2	09.09.09	23.16	0.05	41	1000.00	both	-22	606	12472	251.0	16	0	-6	603	-609
3	12.09.09	22.96	0.05	43	1000.00	both	228	558	14247	254.0	-4	0	224	613	-389
4	14.09.09	22.99	0.05	42	1000.00	both	170	612	13637	256.0	-1	0	169	620	-451
***p*=5, EIM**															
1	01.10.09	23.00	0.02	40	1001.02	both	1211	262		273.0	0	3	1214	679	535
2	07.10.09	23.00	0.02	40	999.87	both	966	361		279.0	0	0	966	700	266
3	08.10.09	23.00	0.02	40	1000.63	both	1462	238		280.0	0	2	1464	703	760
4	13.10.09	23.00	0.02	40	1001.08	both	2201	154		285.0	0	3	2204	721	1483
5	19.10.09	23.00	0.02	40	1001.29	both	2634	273		291.0	0	4	2638	742	1896
***p*=6, INRIM**															
1	16.11.09	22.98	0.05	40	1000.00	both	1218	30		319.0	-2	0	1216	839	377
2	17.11.09	22.99	0.05	40	1000.00	both	1211	29		320.0	-1	0	1210	843	368
3	22.11.09	23.02	0.05	40	1000.00	both	1164	12		325.0	2	0	1165	860	305
4	23.11.09	23.01	0.05	40	1000.00	both	1169	16		326.0	1	0	1170	863	306
5	24.11.09	22.96	0.05		1000.00	both	1239	11		327.0	-4	0	1235	867	368
***p*=7, MIKES**															
1	28.11.09	22.76	0.20	39	1000.00	both	447	38	-427	331.0	-24	0	423	881	-458
2	03.12.09	22.80	0.20	39	1000.00	both	299	23	-135	336.0	-20	0	279	898	-619
3	11.12.09	22.81	0.20	39	1000.00	both	-37	34	-278	344.0	-19	0	-56	926	-982
4	22.12.09	22.80	0.20	39	1000.00	both	-207	22	-200	355.0	-20	0	-227	964	-1192
***p*=8, SP**															
1	10.03.10	23.00	0.05	47	1000.00	both	1821	117	129	434.0	0	0	1821	1239	582
2	15.03.10	23.00	0.05	47	1000.00	both	1791	68	45	438.1	0	0	1791	1253	537
3	23.03.10	22.97	0.05	45	1000.00	both	1882	74	3	446.5	-3	0	1880	1283	597
4	24.03.10	22.97	0.05	45	1000.00	both	1942	43	-79	447.0	-3	0	1939	1284	655
5	31.03.10	22.99	0.06	47	1000.00	both	1968	30	-116	454.1	-1	0	1967	1309	658
6	05.04.10	22.99	0.05	46	1000.00	both	1818	60	-31	459.0	-1	0	1816	1326	490
***p*=9, INM**															
1	27.05.10	22.95	0.04	58	1000.00	both	3940	1100	-31	511.0	-5	0	3935	1351	2584
2	04.06.10	23.03	0.04	53	1000.00	both	9340	1100	-30	519.0	3	0	9343	1346	7997
3	07.06.10	23.03	0.04	51	1000.00	both	8040	1100	-29	522.0	3	0	8043	1344	6700
4	08.06.10	23.02	0.04	53	1000.00	both	4140	1100	-28	523.0	2	0	4142	1343	2799
5	09.06.10	22.97	0.04	58	1000.00	both	4040	1100	-27	524.0	-3	0	4037	1342	2695
6	10.06.10	22.96	0.04	58	1000.00	both	9340	1100	-26	525.0	-4	0	9336	1341	7995
***p*=10, NCM**															
1	08.07.10	22.97	0.01	54	1000.00	pos	-4278	673	-	553.0	-3	0	-4281	1322	-5603
2	09.07.10	22.93	0.01	53	1000.00	neg	-10775	428	-	554.0	-7	0	-10782	1321	-12104
3	13.07.10	22.90	0.01	53	1000.00	pos	-4752	16	-	558.0	-10	0	-4762	1319	-6081

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
4	14.07.10	22.94	0.01	52	1000.00	neg	-6615	4	-	559.0	-6	0	-6621	1318	-7939
5	25.07.10	22.99	0.01	47	1000.00	both	-4081	115	997	570.0	-1	0	-4082	1310	-5392
***p*=11, VSL**															
1	17.08.10	22.93	0.00	45	1000.00	both	1669	109	-561	593.4	-7	0	1662	1294	368
2	25.08.10	22.94	0.00	45	1000.00	both	1674	55	-372	601.2	-6	0	1668	1289	379
3	08.09.10	22.95	0.00	46	1000.00	both	1575	97	-471	615.2	-6	0	1569	1279	290
***p*=12, GUM**															
1	28.09.10	23.20	0.10	47	1000.00	both	5974	81		635.0	20	0	5994	1265	4729
2	28.09.10	23.20	0.10	47	1000.00	both	5598	90		635.0	20	0	5618	1265	4353
3	28.09.10	23.10	0.10	49	1000.00	both	5570	84		635.0	10	0	5580	1265	4315
4	29.09.10	22.80	0.10	48	1000.00	both	5814	139		636.0	-20	0	5794	1264	4529
5	29.09.10	22.80	0.10	48	1000.00	both	5768	86		636.0	-20	0	5748	1264	4484
6	29.09.10	22.80	0.10	48	1000.00	both	5556	85		636.0	-20	0	5536	1264	4272
7	29.09.10	22.80	0.10	47	1000.00	both	5625	123		636.0	-20	0	5605	1264	4341
***p*=13, CMI**															
1	24.11.10	23.00	0.20	40	1000.00	both	5400	50	200	692.0	0	0	5400	1226	4174
2	29.11.10	23.00	0.20	40	1000.00	both	5700	50	200	697.0	0	0	5700	1222	4478
3	03.12.10	23.00	0.20	40	1000.00	both	5900	50	200	701.0	0	0	5900	1219	4681
4	10.12.10	23.00	0.20	40	1000.00	both	5700	50	200	708.0	0	0	5700	1215	4485
***p*=14, IPQ**															
1	16.12.10	23.24	0.01	46	1000.00		15579	99		714.5	24	0	15603	1210	14393
2	17.01.11	22.48	0.02	51	1000.00		13650	78		746.6	-52	0	13598	1188	12410
3	17.01.11	22.42	0.01	52	1000.00		14345	76		746.7	-58	0	14287	1188	13099
4	18.01.11	23.11	0.01	50	1000.00		13349	93		747.4	11	0	13360	1187	12173
5	18.01.11	23.11	0.01	49	1000.00		13639	679		747.6	11	0	13650	1187	12462
6	20.01.11	23.11	0.02	45	1000.00		15696	74		749.4	11	0	15707	1186	14521
***p*=15, CEM**															
1	14.02.11	23.07	0.01	37	1000.00	both	-962	52	-267	774.0	7	0	-955	1169	-2123
2	15.02.11	23.07	0.01	38	1000.00	both	-620	47	-784	775.0	7	0	-613	1168	-1781
***p*=16, SMD**															
1	12.03.11	23.03	0.04	34	1000.00	both	-760	1510	870	800.0	3	0	-757	1151	-1908
***p*=17, LNE**															
1	20.04.11	23.00	0.20	44	1000.00	both	1127	91	442	839.0	0	0	1127	1124	4
***p*=18, UME**															
1	03.06.11	23.07	0.03	48	1000.00	both	1164	78		883.8	7	0	1170	1093	78
2	04.06.11	23.05	0.01	49	1000.00	both	1214	69		884.0	5	0	1218	1093	126
3	05.06.11	23.05	0.02	47	1000.00	both	1340	118		885.0	5	0	1345	1092	254
4	16.06.11	23.15	0.04	46	1000.00	both	1235	136		896.7	15	0	1250	1084	166
5	17.06.11	23.08	0.04	48	1000.00	both	1104	129		897.2	8	0	1113	1083	29
6	24.06.11	23.08	0.03	48	1000.00	both	1249	159		904.8	8	0	1257	1078	179
7	25.06.11	23.08	0.01	47	1000.00	both	1214	54		905.1	8	0	1222	1078	144
8	26.06.11	23.07	0.01	45	1000.00	both	1285	103		906.4	7	0	1293	1077	216
9	27.06.11	23.07	0.03	45	1000.00	both	1325	74		907.1	7	0	1332	1077	256
10	30.06.11	23.09	0.02	46	1000.00	both	1449	268		910.8	9	0	1457	1074	383
11	08.07.11	23.10	0.05	46	1000.00	both	1380	289		918.5	10	0	1390	1069	321

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
12	11.07.11	23.09	0.02	47	1000.00	both	1220	146		921.5	9	0	1230	1067	163

B.2.3 100 TΩ standard no 69641, *a* = 5, 500 V

m	Date	T (°C)	u(T) (°C)	H (%)	V (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	Tcorr (ppm)	Vcorr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=1, METAS**															
1	18.02.09	23.00	0.05	45	500.00	both	-1539	71	76	48.5			-1539	-1572	33
2	16.03.09	23.00	0.05	45	500.00	both	-1503	71	74	74.7			-1503	-1486	-17
3	23.03.09	23.00	0.05	45	500.00	both	-1427	71	62	81.8			-1427	-1463	37
4	12.08.09	23.00	0.05	45	500.00	both	-996	71	-46	223.7			-996	-993	-3
5	12.08.09	23.00	0.05	45	500.00	both	-982	71	77	223.9			-982	-992	10
	27.04.10	23.00	0.05	45	500.00	both	-194	71	42	481.7			-194	-105	-89
7	27.04.10	23.00	0.05	45	500.00	both	-221	71	31	481.9			-221	-105	-116
8	03.05.10	23.00	0.05	45	500.00	both	-17	71	46	487.4			-17	-85	69
9	05.11.10	23.00	0.05	45	500.00	both	609	71	41	673.8			609	582	27
10	06.11.10	23.00	0.05	45	500.00	both	578	71	-1	674.1			578	583	-4
11	06.11.10	23.00	0.05	45	500.00	both	637	71	-6	674.3			637	584	54
12															
13	06.11.10	23.00	0.05	45	500.00	both	578	71	-1	674.1			578	586	-7
14	06.11.10	23.00	0.05	45	500.00	both	637	71	-6	674.3			637	585	52
15	04.08.11	23.00	0.05	45	500.00	both	169	71	41	945.7			169	218	-49
16	30.08.11	23.00	0.05	45	500.00	both	49	71	-5	971.8			49	182	-134
17	27.09.11	23.00	0.05	45	500.00	both	282	71	57	999.8			282	144	138
***p*=2, SMU**															
1	22.04.09	23.10	0.20	38	400.00	both	-332	1870	1200	111.0	-5	-8	-344	-1368	1023
2	28.04.09	23.00	0.20	36	400.00	both	-896	3960	2500	117.0	0	-8	-904	-1348	444
3	06.05.09	23.10	0.20	41	400.00	both	-41	2980	2200	125.0	-5	-8	-53	-1321	1268
4	14.05.09	23.20	0.20	37	400.00	both	1095	2420	1500	133.0	-9	-8	1078	-1295	2373
***p*=3, PTB**															
1	24.06.09	23.07	0.10	41	499.99	both	4300	300		174.0	-3	0	4297	-1159	5456
2	29.06.09	23.01	0.10	48	499.99	both	6100	300		179.0	0	0	6100	-1142	7242
3	02.07.09	22.98	0.10	52	499.99	both	8900	300		182.0	1	0	8901	-1132	10033
4	08.07.09	22.97	0.10	45	499.99	both	3700	300		188.0	1	0	3701	-1112	4814
5	09.07.09	22.97	0.10	45	499.99	both	4400	300							
***p*=4, SIQ**															
1	02.09.09	22.89	0.05	46	500.00	both	405	169	16381	244.0	5	0	410	-924	1335
2	07.09.09	22.94	0.05	41	500.00	both	1150	473	24807	249.0	3	0	1153	-908	2060
3	12.09.09	22.95	0.05	43	500.00	both	1128	114	25006	254.0	2	0	1130	-891	2021
4	14.09.09	23.10	0.05	42	500.00	both	727	517	23001	256.0	-5	0	722	-884	1606
5	16.09.09	23.07	0.05	44	500.00	both	602	258	22919	258.0	-3	0	599	-877	1476
***p*=5, EIM**															
1	01.10.09	23.00	0.02	40	538.49	both	-802	748		273.0	0	3	-799	-826	27
2	07.10.09	23.00	0.02	40	538.27	both	-411	304		279.0	0	3	-408	-806	398
3	13.10.09	23.00	0.02	40	537.94	both	-1297	556		285.0	0	3	-1294	-786	-508
4	16.10.09	23.00	0.02	40	538.10	both	-786	346		288.0	0	3	-783	-775	-8
5	21.10.09	23.00	0.02	40	538.30	both	-111	279		293.0	0	3	-108	-758	650
***p*=6, INRIM**															

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
1	01.11.09	22.88	0.05	45	500.00	both	-17	35		304.0	6	0	-12	-721	709
2	17.11.09	22.98	0.05	40	500.00	both	117	41		320.0	1	0	118	-666	784
3	20.11.09	22.99	0.05	40	500.00	both	-33	32		323.0	0	0	-33	-656	624
4	21.11.09	23.02	0.05	40	500.00	both	235	22		324.0	-1	0	234	-653	887
***p*=7, MIKES**															
1	29.11.09	22.84	0.20	39	500.00	both	-384	27	-238	332.0	7	0	-377	-625	248
2	05.12.09	22.83	0.20	39	500.00	both	-540	14	-115	338.0	8	0	-531	-605	73
3	12.12.09	22.83	0.20	39	500.00	both	-675	27	-4	345.0	8	0	-667	-581	-86
***p*=8, SP**															
1	23.03.10	22.98	0.05	45	500.00	both	856	91	-441	446.1	1	0	857	-230	1087
2	27.03.10	22.99	0.05	46	500.00	both	948	135	-274	450.2	1	0	949	-216	1165
3	28.03.10	22.99	0.05	45	500.00	both	891	108	192	451.1	0	0	891	-213	1104
4	29.03.10	22.99	0.05	46	500.00	both	881	89	-40	452.1	0	0	882	-209	1091
5	31.03.10	22.99	0.05	45	500.00	both	852	45	-210	455.0	0	0	852	-199	1052
***p*=9, INM**															
1															
***p*=10, NCM**															
1	07.07.10	22.98	0.01	49	500.00	pos	425	1818	-	552.0	1	0	426	143	282
2	08.07.10	22.97	0.01	52	500.00	neg	-7434	229	-	553.0	1	0	-7433	147	-7580
3	10.07.10	22.94	0.01	52	500.00	pos	7704	44	-	555.0	3	0	7707	154	7553
4	12.07.10	22.90	0.01	46	500.00	neg	-6915	117	-	557.0	5	0	-6910	161	-7071
5	13.07.10	22.90	0.01	50	500.00	both	-7549	870	1269	558.0	5	0	-7545	165	-7709
***p*=11, VSL**															
1	17.08.10	22.95	0.00	46	500.00	both	404	111	-1122	593.9	3	0	407	293	114
2	23.08.10	22.94	0.00	46	500.00	both	610	108	-970	599.9	3	0	613	315	298
3	06.09.10	22.95	0.01	45	500.00	both	496	80	-1093	613.8	2	0	498	365	134
***p*=12, GUM**															
1	01.10.10	23.20	0.10	42	500.00	both	19918	118		638.0	-9	0	19909	452	19457
2	30.09.10	22.90	0.10	42	500.00	both	19484	115		637.0	5	0	19488	448	19040
3	30.09.10	22.90	0.10	42	500.00	both	19360	99		637.0	5	0	19365	448	18916
4	30.09.10	22.90	0.10	42	500.00	both	19004	88		637.0	5	0	19009	448	18560
5	30.09.10	22.90	0.10	42	500.00	both	19057	116		637.0	5	0	19062	448	18613
6	30.09.10	22.90	0.10	42	500.00	both	18766	118		637.0	5	0	18771	448	18322
***p*=13, CMI**															
1	24.11.10	23.00	0.20	40	500.00	both	1300	50	200	692.0	0	0	1300	561	739
2	29.11.10	23.00	0.20	40	500.00	both	1600	50	200	697.0	0	0	1600	555	1045
3	03.12.10	23.00	0.20	40	500.00	both	2100	50	200	701.0	0	0	2100	549	1551
4	10.12.10	23.00	0.20	40	500.00	both	1400	50	200	708.0	0	0	1400	540	860
***p*=14, IPQ**															
1	16.12.10	23.16	0.01	47	500.00		3	1		714.7	-7	0	-4	531	-535
2	17.01.11	22.48	0.02	52	500.00		5	2		746.5	24	0	29	487	-458
3	18.01.11	23.12	0.01	50	500.00		7	1		747.7	-6	0	2	486	-484
4	20.01.11	23.09	0.02	46	500.00		3	1		749.5	-4	0	-1	483	-485
5	25.01.11	23.11	0.01	40	500.00		4	1		754.6	-5	0	-1	476	-477

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=15, CEM**															
1	16.02.11	23.08	0.01	38	500.00	both	-3398	114	-3231	776.0	-4	0	-3402	448	-3849
2	17.02.11	23.07	0.01	38	500.00	both	-3143	104	-818	777.0	-3	0	-3146	446	-3592
***p*=16, SMD**															
1	12.03.11	23.05	0.04	35	500.00	both	-1730	1910	-400	800.0	-2	0	-1732	415	-2147
***p*=17, LNE**															
1	14.04.11	23.00	0.20	44	500.00	both	32	142	364	833.0	0	0	32	370	-338
***p*=18, UME**															
1	07.06.11	23.11	0.05	47	500.00	both	237	134		887.0	-5	0	232	297	-65
2	23.06.11	23.10	0.05	46	500.00	both	355	256		903.7	-5	0	351	275	76
3	24.06.11	23.08	0.03	48	500.00	both	79	169		904.0	-4	0	75	274	-199
4	28.06.11	23.06	0.02	44	500.00	both	245	100		908.6	-3	0	242	268	-25
5	06.07.11	23.09	0.05	46	500.00	both	187	53		916.3	-4	0	183	257	-75
6	11.07.11	23.09	0.02	47	500.00	both	190	108		921.7	-4	0	186	250	-64
7	12.07.11	23.11	0.03	47	500.00	both	133	283		922.2	-5	0	128	250	-121

B.2.4 100 TΩ standard no 69641, *a* = 5, 1000 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=1, METAS**															
1	30.01.09	23.00	0.05	45	1000.00	both	-1867	59	-9	29.6			-1867	-1787	-79
2	31.01.09	23.00	0.05	45	1000.00	both	-1831	59	-8	30.8			-1831	-1783	-48
3	16.03.09	23.00	0.05	45	1000.00	both	-1642	59	-5	74.8			-1642	-1640	-2
4	23.03.09	23.00	0.05	45	1000.00	both	-1556	59	-23	81.7			-1556	-1617	61
5	12.08.09	23.00	0.05	45	1000.00	both	-1075	59	-6	223.8			-1075	-1146	71
	12.08.09	23.00	0.05	45	1000.00	both	-1108	59	73	224.0			-1108	-1146	38
7	27.04.10	23.00	0.05	45	1000.00	both	-326	59	12	481.8			-326	-259	-67
8	28.04.10	23.00	0.05	45	1000.00	both	-284	59	17	482.0			-284	-258	-26
9	03.05.10	23.00	0.05	45	1000.00	both	-188	59	40	487.5			-188	-239	51
10	05.11.10	23.00	0.05	45	1000.00	both	424	59	20	674.0			424	429	-4
11	06.11.10	23.00	0.05	45	1000.00	both	418	59	46	674.2			418	429	-12
12	06.11.10	23.00	0.05	45	1000.00	both	448	59	13	674.4			448	430	18
13															
14	06.11.10	23.00	0.05	45	1000.00	both	418	59	46	674.2			418	436	-18
15	06.11.10	23.00	0.05	45	1000.00	both	448	59	13	674.4			448	435	12
16	04.08.11	23.00	0.05	45	1000.00	both	46	59	43	945.9			46	68	-22
17	30.08.11	23.00	0.05	45	1000.00	both	-72	59	24	971.9			-72	33	-105
18	27.09.11	23.00	0.05	45	1000.00	both	127	59	18	999.9			127	-5	133
***p*=2, SMU**															
1															
***p*=3, PTB**															
1	24.06.09	23.07	0.10	41	999.96	both	4600	700		174.0	-3	0	4597	-1313	5909
2	29.06.09	23.01	0.10	48	999.96	both	6500	1100		179.0	0	0	6500	-1296	7796
3	03.07.09	22.98	0.10	52	999.96	both	7800	600		183.0	1	0	7801	-1283	9084
4	08.07.09	22.97	0.10	45	999.96	both	3000	100		188.0	1	0	3001	-1266	4267
5	10.07.09	22.99	0.10	42	999.96	both	6100	300							

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=4, SIQ**															
1	02.09.09	23.18	0.05	45	1000.00	both	600	38	10430	244.0	-8	0	592	-1078	1670
2	07.09.09	22.89	0.05	43	1000.00	both	471	272	12065	249.0	5	0	476	-1061	1537
3	12.09.09	22.94	0.05	42	1000.00	both	766	134	13744	254.0	3	0	769	-1044	1813
4	14.09.09	23.11	0.05	42	1000.00	both	826	242	13391	256.0	-5	0	821	-1038	1858
5	16.09.09	23.14	0.05	43	1000.00	both	664	275	13344	258.0	-7	0	657	-1031	1688
***p*=5, EIM**															
1	01.10.09	23.00	0.02	40	997.75	both	-1763	118		273.0	0	0	-1763	-980	-783
2	05.10.09	23.00	0.02	40	999.60	both	600	137		277.0	0	0	600	-967	1566
3	07.10.09	23.00	0.02	40	1000.33	both	1519	474		279.0	0	0	1519	-960	2479
4	13.10.09	23.00	0.02	40	999.93	both	1654	598		285.0	0	0	1654	-939	2593
5	19.10.09	23.00	0.02	40	999.65	both	778	207		291.0	0	0	778	-919	1697
***p*=6, INRIM**															
1	01.11.09	22.88	0.05	45	1000.00	both	59	17		304.0	6	0	65	-875	939
2	17.11.09	22.98	0.05	40	1000.00	both	138	25		320.0	1	0	139	-820	959
3	20.11.09	22.99	0.05	40	1000.00	both	86	15		323.0	0	0	86	-810	896
4	21.11.09	23.02	0.05	40	1000.00	both	17	10		324.0	-1	0	16	-806	822
***p*=7, MIKES**															
1	29.11.09	22.86	0.20	39	1000.00	both	-1038	17	-653	332.0	7	0	-1031	-779	-252
2	05.12.09	22.83	0.20	39	1000.00	both	-997	38	-152	338.0	8	0	-989	-758	-231
3	12.12.09	22.83	0.20	39	1000.00	both	-1052	20	-230	345.0	8	0	-1044	-734	-310
***p*=8, SP**															
1	23.03.10	22.98	0.05	45	1000.00	both	836	71	116	446.1	1	0	837	-384	1221
2	27.03.10	22.99	0.05	46	1000.00	both	919	35	-116	450.2	1	0	919	-370	1289
3	28.03.10	22.99	0.05	45	1000.00	both	919	40	-25	451.1	0	0	920	-366	1286
4	29.03.10	22.99	0.05	46	1000.00	both	947	57	75	452.1	1	0	948	-363	1311
5	31.03.10	22.99	0.05	45	1000.00	both	690	42	-126	455.0	0	0	690	-353	1043
***p*=9, INM**															
1	27.05.10	22.95	0.04	58	1000.00	both	1690	1100	-126	511.0	2	0	1692	-156	1848
2	04.06.10	23.03	0.04	53	1000.00	both	8440	1100	-125	519.0	-1	0	8439	-128	8566
3	07.06.10	23.03	0.04	51	1000.00	both	8240	1100	-124	522.0	-1	0	8239	-117	8356
4	08.06.10	23.02	0.04	53	1000.00	both	3390	1100	-123	523.0	-1	0	3389	-113	3502
5	09.06.10	22.97	0.04	58	1000.00	both	4740	1100	-122	524.0	1	0	4741	-110	4851
6	10.06.10	22.96	0.04	58	1000.00	both	5640	1100	-121	525.0	2	0	5642	-106	5748
***p*=10, NCM**															
1	08.07.10	22.97	0.01	54	1000.00	pos	-3410	279	-	553.0	1	0	-3409	-7	-3402
2	09.07.10	22.93	0.01	53	1000.00	neg	124	524	-	554.0	3	0	127	-3	131
3	13.07.10	22.90	0.01	53	1000.00	pos	-2865	5	-	558.0	5	0	-2860	11	-2871
4	14.07.10	22.94	0.01	52	1000.00	neg	-3403	2	-	559.0	3	0	-3400	15	-3415
***p*=11, VSL**															
1	18.08.10	22.94	0.00	46	1000.00	both	425	54	-162	594.4	3	0	428	141	286
2	24.08.10	22.94	0.00	45	1000.00	both	362	61	-210	600.4	3	0	365	163	202
3	07.09.10	22.95	0.00	45	1000.00	both	351	50	-90	614.3	3	0	354	213	141

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=12, GUM**															
1	29.09.10	23.10	0.10	44	1000.00	both	24844	186		636.0	-5	0	24839	291	24548
2	29.09.10	23.10	0.10	44	1000.00	both	24294	103		636.0	-5	0	24289	291	23998
3	29.09.10	23.00	0.10	44	1000.00	both	24361	167		636.0	0	0	24361	291	24070
4	29.09.10	23.00	0.10	44	1000.00	both	23848	175		636.0	0	0	23848	291	23558
5	29.09.10	23.00	0.10	44	1000.00	both	23518	69		636.0	0	0	23518	291	23227
6	29.09.10	23.00	0.10	42	1000.00	both	23419	296		636.0	0	0	23419	291	23128
7	30.09.10	23.00	0.10	42	1000.00	both	23553	128		637.0	0	0	23553	295	23259
***p*=13, CMI**															
1	24.11.10	23.00	0.20	40	1000.00	both	4500	50	200	692.0	0	0	4500	412	4088
2	29.11.10	23.00	0.20	40	1000.00	both	4700	50	200	697.0	0	0	4700	405	4295
3	03.12.10	23.00	0.20	40	1000.00	both	4900	50	200	701.0	0	0	4900	400	4500
4	10.12.10	23.00	0.20	40	1000.00	both	4500	50	200	708.0	0	0	4500	390	4110
***p*=14, IPQ**															
1	16.12.10	23.17	0.01	47	1000.00		15189	159		714.7	-8	0	15180	381	14799
2	17.01.11	22.48	0.01	52	1000.00		15103	281		746.5	24	0	15127	338	14789
3	18.01.11	23.14	0.01	50	1000.00		12483	142		747.7	-7	0	12476	336	12140
4	20.01.11	23.02	0.03	46	1000.00		14275	123		749.5	-1	0	14274	334	13940
5	25.01.11	23.11	0.01	40	1000.00		10983	116		754.6	-5	0	10977	327	10651
***p*=15, CEM**															
1	16.02.11	23.08	0.01	38	1000.00	both	-1679	70	-1767	776.0	-4	0	-1683	298	-1981
2	17.02.11	23.07	0.01	38	1000.00	both	-2805	29	-603	777.0	-3	0	-2808	297	-3105
***p*=16, SMD**															
1	12.03.11	23.05	0.04	35	1000.00	both	-1410	1342	100	800.0	-2	0	-1412	265	-1678
***p*=17, LNE**															
1	14.04.11	23.00	0.20	44	1000.00	both	15	92	239	833.0	0	0	15	221	-206
***p*=18, UME**															
1	30.05.11	23.04	0.07	47	1000.00	both	-23	278		879.8	-2	0	-25	157	-182
2	31.05.11	23.06	0.09	47	1000.00	both	175	331		880.1	-3	0	172	157	15
3	06.06.11	23.09	0.04	48	1000.00	both	8	160		886.8	-4	0	4	148	-144
4	07.06.11	23.11	0.05	47	1000.00	both	265	44		887.2	-5	0	260	147	113
5	23.06.11	23.10	0.05	46	1000.00	both	190	110		903.8	-5	0	185	125	61
6	24.06.11	23.08	0.03	48	1000.00	both	268	109		904.2	-4	0	264	124	140
7	28.06.11	23.06	0.02	44	1000.00	both	188	56		908.8	-3	0	185	118	67
8	29.06.11	23.09	0.03	44	1000.00	both	92	64		909.2	-4	0	88	118	-30
9	06.07.11	23.09	0.05	46	1000.00	both	48	148		916.5	-4	0	44	108	-64
10	11.07.11	23.09	0.02	47	1000.00	both	208	238		921.8	-4	0	204	100	103
11	12.07.11	23.11	0.03	47	1000.00	both	177	127		922.0	-5	0	172	100	72

B.2.5 100 TΩ standard no 1100625, *a* = 6, 500 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=1, METAS**															
1	02.02.09	23.00	0.05	45	500.00	both	-54772	123	-147	32.4			-54772	-54947	175
2	02.02.09	23.00	0.05	45	500.00	both	-55006	123	-129	32.7			-55006	-54948	-59

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
3	10.02.09	23.00	0.05	45	500.00	both	-54932	123	-134	40.3			-54932	-54956	24
4	18.02.09	23.00	0.05	45	500.00	both	-54924	123	-137	48.7			-54924	-54966	43
5	13.03.09	23.00	0.05	45	500.00	both	-55056	123	-160	71.5			-55056	-54993	-63
	23.03.09	23.00	0.05	45	500.00	both	-55126	123	-130	81.4			-55126	-55005	-121
7															
8	11.08.09	23.00	0.05	45	500.00	both	-55906	123	-179	222.3			-55906	-55899	-7
9	11.08.09	23.00	0.05	45	500.00	both	-56104	123	-138	222.5			-56104	-55899	-205
10	11.08.09	23.00	0.05	45	500.00	both	-56049	123	-160	222.9			-56049	-55900	-149
11	12.08.09	23.00	0.05	45	500.00	both	-56005	123	-137	223.1			-56005	-55900	-106
12	13.08.09	23.00	0.05	45	500.00	both	-55938	123	-181	224.3			-55938	-55900	-38
13	13.08.09	23.00	0.05	45	500.00	both	-55995	123	-122	224.6			-55995	-55900	-94
14	28.04.10	23.00	0.05	45	500.00	both	-55725	123	-111	482.3			-55725	-56000	275
15	03.05.10	23.00	0.05	45	500.00	both	-55907	123	-136	487.8			-55907	-56002	96
16	04.05.10	23.00	0.05	45	500.00	both	-55923	123	-149	488.1			-55923	-56003	80
17	08.11.10	23.00	0.05	45	500.00	both	-55987	123	-118	676.4			-55987	-56076	89
18	09.11.10	23.00	0.05	45	500.00	both	-55981	123	-233	677.7			-55981	-56076	95
19	10.11.10	23.00	0.05	45	500.00	both	-55937	123	-141	678.8			-55937	-56077	140
20	26.09.11	23.00	0.05	45	500.00	both	-56268	123	-152	998.8			-56268	-56201	-68
21	04.10.11	23.00	0.05	45	500.00	both	-56312	123	-168	1006.7			-56312	-56204	-108
***p*=2, SMU**															
1	22.04.09	23.20	0.20	38	400.00	both	28904	3140	1200	111.0	790	-8671	21023	-55039	76062
2	28.04.09	23.00	0.20	34	400.00	both	26549	5000	1500	117.0	0	-8671	17878	-55046	72924
3	05.05.09	23.10	0.20	41	400.00	both	14339	5780	1100	124.0	395	-8671	6063	-55055	61117
4	12.05.09	23.20	0.20	37	400.00	both	11833	6510	1250	131.0	790	-8671	3952	-55063	59015
***p*=3, PTB**															
1	23.06.09	23.07	0.10	41	499.99	both	-56100	300		173.0	277	-1	-55824	-55112	-712
2	26.06.09	23.01	0.10	50	499.99	both	-64700	300		176.0	40	-1	-64661	-55115	-9546
3	03.07.09	22.98	0.10	55	499.99	both	-54800	300		183.0	-79	-1	-54880	-55124	244
4	08.07.09	22.97	0.10	45	499.99	both	-55600	300		188.0	-119	-1	-55719	-55130	-590
5	10.07.09	22.99	0.10	43	499.99	both	-55800	300							
***p*=4, SIQ**															
1	09.09.09	22.96	0.05	42	500.00	both	-54770	398	19844	251.0	-158	0	-54928	-55910	982
2	11.09.09	23.05	0.05	44	500.00	both	-55885	902	24001	253.0	198	0	-55687	-55911	224
3	13.09.09	23.02	0.05	42	500.00	both	-55549	560	22610	255.0	79	0	-55470	-55912	442
4	16.09.09	23.19	0.05	44	500.00	both	-56241	905	22062	258.0	751	0	-55490	-55913	423
***p*=5, EIM**															
1	02.10.09	23.00	0.02	40	505.78	both	-61579	1110		274.0	0	491	-61088	-55919	-5168
2	08.10.09	23.00	0.02	40	505.67	both	-61132	985		280.0	0	482	-60650	-55922	-4728
3	14.10.09	23.00	0.02	40	506.04	both	-61225	937		286.0	0	513	-60712	-55924	-4788
4	19.10.09	23.00	0.02	40	507.34	both	-57542	519		291.0	0	624	-56918	-55926	-992
5	21.10.09	23.00	0.02	40	507.22	both	-58149	651		293.0	0	613	-57536	-55927	-1609
***p*=6, INRIM**															
1	27.10.09	22.87	0.05	45	500.00	both	-54909	34		299.0	-508	0	-55417	-55929	512
2	18.11.09	22.99	0.05	40	500.00	both	-54803	56		321.0	-43	0	-54846	-55938	1092
3	21.11.09	23.00	0.05	40	500.00	both	-55096	48		324.0	-3	0	-55098	-55939	840
4	22.11.09	22.99	0.05	40	500.00	both	-54933	36		325.0	-35	0	-54969	-55939	970

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	$t\text{-}t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=7, MIKES**															
1	27.11.09	22.79	0.20	39	500.00	both	-56037		-570	330.0	-827	0	-56864	-55941	-923
2	04.12.09	22.82	0.20	39	500.00	both	-56403	48	-340	337.0	-728	0	-57131	-55944	-1187
3	10.12.09	22.81	0.20	39	500.00	both	-56263	18	-408	343.0	-755	0	-57018	-55946	-1072
4	21.12.09	22.77	0.20	39	500.00	both	-55973	30	-409	354.0	-926	0	-56899	-55950	-949
***p*=8, SP**															
1	16.03.10	22.98	0.05	46	500.00	both	-60026	209	-88	439.1	-84	0	-60110	-55983	-4127
2	22.03.10	22.97	0.05	47	500.00	both	-60085	54	-516	445.1	-105	0	-60190	-55986	-4204
3	30.03.10	22.98	0.05	46	500.00	both	-60150	92	42	453.0	-64	0	-60214	-55989	-4225
4	02.04.10	22.99	0.05	46	500.00	both	-60255	34	-292	456.2	-51	0	-60306	-55990	-4316
5	02.04.10	22.99	0.05	46	500.00	both	-60146	53	-450	457.0	-49	0	-60195	-55990	-4204
6	04.04.10	22.99	0.05	46	500.00	both	-60191	70	-393	458.0	-45	0	-60236	-55991	-4246
***p*=9, INM**															
1															
***p*=10, NCM**															
1	07.07.10	22.98	0.01	49	500.00	pos	62892	1200		552.0	-79	0	62813	-56027	118840
2	08.07.10	22.97	0.01	52	500.00	neg	54644	270		553.0	-119	0	54525	-56028	110553
3	10.07.10	22.94	0.01	52	500.00	pos	68476	263		555.0	-237	0	68239	-56029	124267
4	12.07.10	22.90	0.01	49	500.00	neg	52929	76		557.0	-395	0	52534	-56029	108563
5	26.07.10	22.99	0.01	47	500.00	pos	49051	24		571.0	-40	0	49012	-56035	105047
***p*=11, VSL**															
1	10.08.10	22.97	0.01	46	500.00	both	-58814	387	-67	586.7	-130	0	-58944	-56041	-2903
2	14.08.10	22.97	0.01	46	500.00	both	-58851	264	-244	590.5	-103	0	-58953	-56042	-2911
3	28.08.10	22.96	0.01	45	500.00	both	-58785	140	-173	604.6	-154	0	-58939	-56048	-2891
4	30.08.10	22.96	0.01	45	500.00	both	-58545	156	-213	606.6	-146	0	-58691	-56049	-2643
5	08.09.10	22.98	0.01	46	500.00	both	-58321	70	-262	615.7	-87	0	-58408	-56052	-2356
***p*=12, GUM**															
1	30.09.10	23.00	0.10	42	500.00	both	-13800	118		637.0	0	0	-13800	-56060	42261
2	30.09.10	22.90	0.10	42	500.00	both	-13614	115		637.0	-395	0	-14009	-56060	42051
3	30.09.10	22.90	0.10	42	500.00	both	-13588	99		637.0	-395	0	-13983	-56060	42077
4	30.09.10	22.90	0.10	42	500.00	both	-13284	88		637.0	-395	0	-13679	-56060	42381
5	30.09.10	22.90	0.10	42	500.00	both	-13282	116		637.0	-395	0	-13677	-56060	42383
6	30.09.10	22.90	0.10	42	500.00	both	-13026	118		637.0	-395	0	-13421	-56060	42640
7	30.09.10	22.80	0.10	42	500.00	both	-13028	84		637.0	-790	0	-13818	-56060	42243
8	08.10.10	23.00	0.10	42	500.00	both	-2226	101		645.0	0	0	-2226	-56063	53837
9	08.10.10	22.90	0.10	42	500.00	both	-2585	98		645.0	-395	0	-2981	-56063	53083
10	08.10.10	22.80	0.10	44	500.00	both	-2716	89		645.0	-790	0	-3506	-56063	52557
11	08.10.10	22.80	0.10	42	500.00	both	-2570	124		645.0	-790	0	-3360	-56063	52703
***p*=13, CMI**															
1	24.11.10	23.00	0.20	40	500.00	both	-57500	50	200	692.0	0	0	-57500	-56082	-1418
2	29.11.10	23.00	0.20	40	500.00	both	-57500	50	200	697.0	0	0	-57500	-56084	-1416
3	03.12.10	23.00	0.20	40	500.00	both	-56900	50	200	701.0	0	0	-56900	-56085	-815
4	10.12.10	23.00	0.20	40	500.00	both	-56500	50	200	708.0	0	0	-56500	-56088	-412
***p*=14, IPQ**															
1	16.12.10	22.81	0.04	45	500.00		-50343	955		714.4	-739	0	-51082	-56090	5009
2	20.01.11	23.01	0.01	45	500.00		-54146	1359		749.5	34	0	-54112	-56104	1992

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
3	20.01.11	23.02	0.01	48	500.00		-56171	1290		749.6	86	0	-56084	-56104	20
4	26.01.11	23.23	0.01	36	500.00		-51744	1277		755.4	923	0	-50821	-56106	5285
***p*=15, CEM**															
1	23.02.11	23.10	0.05	39	500.00	both	-58790	317	-3227	783.0	383	0	-58406	-56117	-2289
2	24.02.11	23.09	0.05	39	500.00	both	-60292	129	-4764	784.0	371	0	-59921	-56117	-3803
3	25.02.11	23.00	0.05	39	500.00	both	-58008	182	-4635	785.0	4	0	-58005	-56118	-1887
4	28.02.11	23.00	0.05	37	500.00	both	-57629	138	-5077	788.0	0	0	-57629	-56119	-1510
5															
***p*=16, SMD**															
1															
***p*=17, LNE**															
1															
***p*=18, UME**															
1	28.06.11	23.06	0.02	44	500.00	both	-58476	235		908.1	244	0	-58231	-56166	-2066
2	01.07.11	23.10	0.05	46	500.00	both	-58971	356		911.7	393	0	-58578	-56167	-2411
3	02.07.11	23.09	0.01	48	500.00	both	-58663	82		912.1	346	0	-58317	-56167	-2149
4	03.07.11	23.08	0.01	46	500.00	both	-58803	257		913.2	319	0	-58484	-56168	-2316
5	05.07.11	23.09	0.03	47	500.00	both	-58511	330		915.0	360	0	-58150	-56168	-1982
6	09.07.11	23.09	0.01	48	500.00	both	-58678	139		919.0	369	0	-58309	-56170	-2139
7	10.07.11	23.09	0.01	47	500.00	both	-58840	206		920.0	359	0	-58481	-56170	-2311
8	11.07.11	23.09	0.02	47	500.00	both	-58789	273		921.0	374	0	-58415	-56171	-2244

B.2.6 100 TΩ standard no 1100625, *a* = 6, 1000 V

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=1, METAS**															
1	13.11.08	23.00	0.05	45	1000.00	both	-93682	85	-170	-48.4			-93682	-93617	-64
2	12.12.08	23.00	0.05	45	1000.00	both	-93611	85	-142	-19.6			-93611	-93651	40
3	02.02.09	23.00	0.05	45	1000.00	both	-93648	85	-116	32.5			-93648	-93712	64
4	10.02.09	23.00	0.05	45	1000.00	both	-93705	85	-94	40.4			-93705	-93721	16
5	18.02.09	23.00	0.05	45	1000.00	both	-93849	85	-114	48.8			-93849	-93731	-117
	13.03.09	23.00	0.05	45	1000.00	both	-93745	85	-143	71.5			-93745	-93758	13
7	23.03.09	23.00	0.05	45	1000.00	both	-93720	85	-130	81.4			-93720	-93769	49
8															
9	11.08.09	23.00	0.05	45	1000.00	both	-94750	85	-150	222.4			-94750	-94676	-74
10	11.08.09	23.00	0.05	45	1000.00	both	-94526	85	-169	222.5			-94526	-94676	150
11	11.08.09	23.00	0.05	45	1000.00	both	-94714	85	-122				-94714	-94676	-38
12	12.08.09	23.00	0.05	45	1000.00	both	-94737	85	-123	223.2			-94737	-94676	-61
13	13.08.09	23.00	0.05	45	1000.00	both	-94730	85	-86	224.4			-94730	-94677	-54
14	13.08.09	23.00	0.05	45	1000.00	both	-94739	85	-135	224.7			-94739	-94677	-63
15	28.04.10	23.00	0.05	45	1000.00	both	-94637	85	-104	482.5			-94637	-94777	140
16	03.05.10	23.00	0.05	45	1000.00	both	-94716	85	-97	487.9			-94716	-94779	63
17	04.05.10	23.00	0.05	45	1000.00	both	-94699	85	-106	488.2			-94699	-94779	80
18	09.11.10	23.00	0.05	45	1000.00	both	-94759	85	-30	677.9			-94759	-94853	93
19	26.09.11	23.00	0.05	45	1000.00	both	-94951	85	-103	998.9			-94951	-94977	26
20	04.10.11	23.00	0.05	45	1000.00	both	-95127	85	-99	1006.9			-95127	-94980	-146
21	05.10.11	23.00	0.05	45	1000.00	both	-95107	85	-118	1007.3			-95107	-94981	-126

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r\text{-}p,a,m}$ (ppm)	D_{pol} (ppm)	t-t_{ref} (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c\text{-}p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
22	13.11.11	23.00	0.01	45	1000.00	both	-94968	85	-124	1046.7			-94968	-94996	28
***p*=2, SMU**															
1															
***p*=3, PTB**															
1	23.06.09	23.07	0.10	41	999.96	both	-95300	300		173.0	277	-2	-95026	-93877	-1149
2	29.06.09	22.98	0.10	47	999.96	both	-103100	300		179.0	-79	-2	-103181	-93884	-9297
3	03.07.09	22.98	0.10	55	999.96	both	-93900	300		183.0	-79	-2	-93981	-93888	-93
4	08.07.09	22.97	0.10	45	999.96	both	-95000	300		188.0	-119	-2	-95121	-93894	-1226
5	10.07.09	22.99	0.10	43	999.96	both	-94400	300		190.0	-40	-2	-94442	-93897	-545
***p*=4, SIQ**															
1	04.09.09	23.09	0.05	48	1000.00	both	-96051	190	8008	246.0	356	0	-95695	-94685	-1011
2	09.09.09	22.81	0.05	42	1000.00	both	-94013	413	10283	251.0	-751	0	-94764	-94687	-77
3	11.09.09	23.02	0.05	46	1000.00	both	-95318	1016	12051	253.0	79	0	-95239	-94688	-551
4	13.09.09	23.17	0.05	42	1000.00	both	-95022	535	12606	255.0	672	0	-94350	-94688	338
5	16.09.09	23.18	0.05	43	1000.00	both	-95024	584	11970	258.0	711	0	-94313	-94690	377
***p*=5, EIM**															
1	02.10.09	23.00	0.02	40	1025.47	both	-97951	269		274.0	0	1752	-96199	-94696	-1503
2	08.10.09	23.00	0.02	40	1022.88	both	-100555	183		280.0	0	1575	-98980	-94698	-4282
3	14.10.09	23.00	0.02	40	1024.14	both	-98647	155		286.0	0	1661	-96986	-94700	-2285
4	20.10.09	23.00	0.02	40	1025.39	both	-97785	271		292.0	0	1747	-96038	-94703	-1336
5	22.10.09	23.00	0.02	40	1025.74	both	-97357	111		294.0	0	1771	-95586	-94704	-883
***p*=6, INRIM**															
1	27.10.09	22.87	0.05	45	1000.00	both	-93624	10		299.0	-508	0	-94132	-94706	573
2	18.11.09	22.99	0.05	40	1000.00	both	-94048	47		321.0	-43	0	-94090	-94714	624
3	21.11.09	23.00	0.05	40	1000.00	both	-94013	27		324.0	-3	0	-94016	-94715	699
4	22.11.09	22.99	0.05	40	1000.00	both	-93876	18		325.0	-35	0	-93911	-94716	805
***p*=7, MIKES**															
1	27.11.09	22.79	0.20	39	1000.00	both	-94924		-1258	330.0	-842	0	-95767	-94718	-1049
2	04.12.09	22.82	0.20	39	1000.00	both	-95426	19	-366	337.0	-728	0	-96154	-94720	-1433
3	10.12.09	22.81	0.20	39	1000.00	both	-95202	18	-394	343.0	-755	0	-95957	-94723	-1235
4	21.12.09	22.77	0.20	39	1000.00	both	-94947	57	-607	354.0	-904	0	-95851	-94727	-1124
***p*=8, SP**															
1	16.03.10	22.98	0.05	46	1000.00	both	-98599	69	-61	439.1	-90	0	-98688	-94760	-3928
2	22.03.10	22.97	0.05	47	1000.00	both	-98605	48	-188	445.2	-108	0	-98714	-94762	-3951
3	30.03.10	22.99	0.05	46	1000.00	both	-98728	57	5	453.1	-55	0	-98783	-94765	-4017
4	02.04.10	22.99	0.05	46	1000.00	both	-98784	36	-148	456.2	-56	0	-98841	-94767	-4074
5	03.04.10	22.99	0.05	46	1000.00	both	-98781	26	-269	457.1	-51	0	-98831	-94767	-4065
6	04.04.10	22.99	0.05	46	1000.00	both	-98796	34	-145	458.1	-45	0	-98841	-94767	-4074
***p*=9, INM**															
1	18.05.10	22.90	0.04	41	1000.00	both	-99990	90	-145	502.0	-395	0	-100385	-94784	-5601
2	25.05.10	22.98	0.04	53	1000.00	both	-100220	90	-144	509.0	-79	0	-100299	-94787	-5512
3	26.05.10	23.04	0.04	56	1000.00	both	-100230	90	-143	510.0	158	0	-100072	-94787	-5284
4	26.05.10	23.04	0.04	56	1000.00	both	-99940	90	-142	510.0	158	0	-99782	-94787	-4994
5	26.05.10	23.06	0.04	56	1000.00	both	-99750	90	-141	510.0	237	0	-99513	-94787	-4725

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
***p*=10, NCM**															
1	09.07.10	22.93	0.01	53	1000.00	neg	97037	396		554.0	-277	0	96760	-94805	191565
2	26.07.10	22.98	0.01	48	1000.00	pos	66678	45		571.0	-79	0	66599	-94811	161411
***p*=11, VSL**															
1	13.08.10	22.97	0.01	45	1000.00	both	-97249	206	-345	589.5	-119	0	-97368	-94818	-2549
2	15.08.10	22.97	0.01	45	1000.00	both	-97249	90	-242	591.6	-103	0	-97351	-94819	-2532
3	27.08.10	22.96	0.01	46	1000.00	both	-96903	33	-240	603.7	-146	0	-97049	-94824	-2225
4	29.08.10	22.96	0.01	46	1000.00	both	-97056	115	-367	605.7	-154	0	-97211	-94825	-2386
5	09.09.10	22.98	0.01	45	1000.00	both	-96930	43	-210	616.3	-95	0	-97024	-94829	-2196
***p*=12, GUM**															
1	28.09.10	23.20	0.10	47	1000.00	both	-56564	154		635.0	790	0	-55774	-94836	39062
2	28.09.10	23.10	0.10	47	1000.00	both	-58015	186		635.0	395	0	-57620	-94836	37216
3	28.09.10	23.10	0.10	47	1000.00	both	-57887	103		635.0	395	0	-57492	-94836	37344
4	28.09.10	23.10	0.10	47	1000.00	both	-57605	167		635.0	395	0	-57210	-94836	37626
5	28.09.10	23.10	0.10	47	1000.00	both	-57971	175		635.0	395	0	-57576	-94836	37261
6	07.10.10	23.20	0.10	41	1000.00	both	-89890	69		644.0	790	0	-89100	-94840	5739
7	07.10.10	22.80	0.10	44	1000.00	both	-35157	296		644.0	-790	0	-35948	-94840	58892
8	07.10.10	22.80	0.10	44	1000.00	both	-34876	128		644.0	-790	0	-35666	-94840	59173
9	07.10.10	22.80	0.10	44	1000.00	both	-34903	111		644.0	-790	0	-35693	-94840	59147
10	12.10.10	23.10	0.10	44	1000.00	both	-89602	110		649.0	395	0	-89206	-94841	5635
11	13.10.10	23.10	0.10	43	1000.00	both	-85505	100		650.0	395	0	-85110	-94842	9732
***p*=13, CMI**															
1	24.11.10	23.00	0.20	40	1000.00	both	-92500	50	200	692.0	0	0	-92500	-94858	2358
2	29.11.10	23.00	0.20	40	1000.00	both	-92000	50	200	697.0	0	0	-92000	-94860	2860
3	03.12.10	23.00	0.20	40	1000.00	both	-92400	50	200	701.0	0	0	-92400	-94862	2462
4	10.12.10	23.00	0.20	40	1000.00	both	-92000	50	200	708.0	0	0	-92000	-94864	2864
***p*=14, IPQ**															
1	16.12.10	22.81	0.02	45	1000.00		-84	0		714.4	-742	0	-827	-94867	94040
2	20.01.11	23.00	0.02	45	1000.00		-88	1		749.5	9	0	-79	-94881	94801
3	20.01.11	23.02	0.01	48	1000.00		-88	1		749.6	96	0	8	-94881	94889
4	26.01.11	23.22	0.01	36	1000.00		-86	0		755.4	872	0	786	-94883	95668
***p*=15, CEM**															
1	23.02.11	23.10	0.05	39	1000.00	both	-97907	162	1559	783.0	383	0	-97524	-94894	-2630
2	24.02.11	23.09	0.05	39	1000.00	both	-98163	36	-120	784.0	371	0	-97792	-94894	-2898
3	25.02.11	23.00	0.05	39	1000.00	both	-98695	38	-1566	785.0	4	0	-98691	-94894	-3797
4	28.02.11	23.00	0.05	37	1000.00	both	-98355	57	-287	788.0	0	0	-98355	-94895	-3459
***p*=16, SMD**															
1															
***p*=17, LNE**															
1															
***p*=18, UME**															
1	27.06.11	23.07	0.03	45	1000.00	both	-97389	214		907.9	273	0	-97116	-94942	-2174
2	28.06.11	23.06	0.02	44	1000.00	both	-97435	294		908.2	244	0	-97191	-94942	-2249
3	01.07.11	23.10	0.05	46	1000.00	both	-97370	240		911.9	393	0	-96977	-94944	-2034
4	02.07.11	23.09	0.01	48	1000.00	both	-97538	32		912.2	346	0	-97192	-94944	-2248

m	Date	*T* (°C)	u(T) (°C)	*H* (%)	*V* (V)	polarity	$O_{p,a,m}$ (ppm)	$u_{r-p,a,m}$ (ppm)	D_{pol} (ppm)	$t-t_{ref}$ (d)	*T*corr (ppm)	*V*corr (ppm)	$O_{c-p,a,m}$ (ppm)	$f(t_p,a,m)$ (ppm)	$M_{p,a,m}$ (ppm)
5	03.07.11	23.08	0.01	46	1000.00	both	-97645	40		913.0	319	0	-97326	-94944	-2382
6	04.07.11	23.09	0.02	47	1000.00	both	-97574	73		914.2	364	0	-97211	-94944	-2266
7	05.07.11	23.09	0.03	47	1000.00	both	-97549	120		915.2	360	0	-97189	-94945	-2244
8	08.07.11	23.09	0.02	46	1000.00	both	-97552	277		918.8	367	0	-97185	-94946	-2239
9	09.07.11	23.09	0.01	48	1000.00	both	-97580	84		919.2	369	0	-97211	-94946	-2264
10	10.07.11	23.09	0.01	47	1000.00	both	-97604	91		920.2	359	0	-97245	-94947	-2298
11	11.07.11	23.09	0.02	47	1000.00	both	-97653	268		921.2	374	0	-97279	-94947	-2332

Annex C: Uncertainty budgets

01 METAS

1 TΩ standards

The measurement consists in a 100:1 comparison ($r_{100:1}$) against a reference standard R_s (10 GΩ). R_s is calibrated against a 100 MΩ standard using the same double source Wheatstone bridge. The step-up to 100 MΩ is carried out using a cryogenic current comparator up to 1 MΩ and then a Hamon device from 1 MΩ to 100 MΩ. The model for the measurements with the modified Wheatstone bridge can be simplified to:

$$R_x = r_{100:1} \cdot R_s \cdot \prod k_i$$

k_i are correction factors. The corresponding uncertainties (grouped together according to the main influence factors) are given below.

Quantity X_i	Standard uncertainty $u(x_i)/x_i$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R)/R$ µΩ/Ω	Degree of freedom ν_i
Step-up QHR to 100 MΩ	1.5	normal A	1	1.5	25
100 MΩ reference standard: stability, temperature and loading effects	0.5	normal A	1	0.5	60
Voltage dependence 100 MΩ reference	1.0	normal A	1	1.0	10
Bridge, 10 GΩ to 100 MΩ ratio: voltage ratio calibration + stability	9.8	normal A	1	9.8	20
10 GΩ reference standard: stability, temperature and loading effects	5.0	normal A	1	5.0	60
Voltage dependence 10 GΩ reference	1.0	normal A	1	1.0	10
Bridge, 1 TΩ to 10 GΩ ratio: voltage ratio calibration + stability	9.8	normal A	1	9.8	20
Uncompensated offset effects (burden voltage, zero stability detector..)	10.0	rectangular B	1	10.0	1000
Stabilization time	6.7	rectangular B	1	6.7	1000
Temperature dependence DUT	0.0*)	rectangular B	1	0.0	1000
Reproducibility R_x measurement	1.3	normal A	1	1.3	16
	Combined standard uncertainty:			19.2	µΩ/Ω
	Effective degrees of freedom:			143	
	Expanded uncertainty (95% coverage factor):			38.4	µΩ/Ω

*) The temperature dependence of the device under test is taken into account in the analysis (see report)

100 TΩ standards

The measurement consists in a 100:1 comparison ($r_{100:1}$) against a reference standard R_s (1 TΩ). The step-up to 1 TΩ is described above in the heading of the 1 TΩ budget. The model for the measurements with the modified Wheatstone bridge can be simplified to:

$$R_x = r_{100:1} \cdot R_s \cdot \prod k_i$$

k_i are correction factors. The corresponding uncertainties (grouped together according to the main influence factors) are given below.

Quantity X_i	Standard uncertainty $u(x_i)/\ x_i$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R)/R$ µΩ/Ω	Degree of freedom ν_i
Step-up 1 TΩ	19.2	normal A	1	19.2	140
1 TΩ reference standard: stability, temperature and loading effects	7.0	normal A	1	7.0	60
Voltage dependence 1 TΩ reference	10.0	normal A	1	10.0	10
Bridge, 100 TΩ to 1 TΩ ratio: voltage ratio calibration + stability	9.8	normal A	1	9.8	20
Uncompensated offset effects (burden voltage, zero stability detector..)	58.0	rectangular B	1	58.0	1000
Stabilization time	64.0	rectangular B	1	64.0	1000
Temperature dependence DUT	0.0*)	rectangular B	1	0.0	1000
Reproducibility R_x measurement	30.0	normal A	1	30.0	16
	Combined standard uncertainty:			94.7	µΩ/Ω
	Effective degrees of freedom:			1004	
	Expanded uncertainty (95% coverage factor):			189.5	µΩ/Ω

*) The temperature dependence of the device under test is taken into account in the analysis (see report)

02 SMU

Typical uncertainty budget for 1 TΩ - MI 9331G, Ser. No.: 1101180

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u(R_i)$	Degree of freedom ν_i
R_s	996,2 GΩ	$1{,}14 \cdot 10^{-3}$	B	1,0	$1{,}14 \cdot 10^{-3}$	∞
δR_s	- 0,5 GΩ	$2{,}89 \cdot 10^{-4}$	B	1,0	$2{,}89 \cdot 10^{-4}$	50
δR_{sT}	0,0 GΩ	$5{,}78 \cdot 10^{-4}$	B	1,0	$5{,}78 \cdot 10^{-4}$	30
δR_{sH}	0,0 GΩ	$2{,}89 \cdot 10^{-4}$	B	1,0	$2{,}89 \cdot 10^{-4}$	30
δR_{xT}	0,0 GΩ	$5{,}78 \cdot 10^{-4}$	B	1,0	$5{,}78 \cdot 10^{-4}$	30
δR_{xH}	0,0 GΩ	$2{,}89 \cdot 10^{-4}$	B	1,0	$2{,}89 \cdot 10^{-4}$	30
$\delta R_{x\,U\,400\,V}$	400 V	$3{,}76 \cdot 10^{-4}$	B	1,0	$3{,}76 \cdot 10^{-4}$	∞
$\delta R_{x\,6517A}$	1 000,000 GΩ	$2{,}02 \cdot 10^{-3}$	B	1,0	$2{,}02 \cdot 10^{-3}$	∞
R_x	1 000,043 GΩ	$4{,}19 \cdot 10^{-4}$	A (u_A)		$4{,}19 \cdot 10^{-4}$	100
		Combined relative standard uncertainty:			$2{,}588 \cdot 10^{-3}$	
		Effective degrees of freedom:			100	
		Expanded relative uncertainty (95% coverage factor):			$5{,}2 \cdot 10^{-3}$ (5,2 GΩ)	

where:

- R_s: *is value of reference resistor 1 TΩ,*
- δR_s: *is the relative error of the reference resistor due to its drift,*
- δR_{sT}, δR_{xT}: *are relative error due to uncorrected temperature instabilities reference and measurement resistor,*
- δR_{sH}, δR_{xH}: *are relative error due to uncorrected humidity reference and measurement resistor and leakage effects,*
- $\delta R_{x\,U\,400\,V}$: *is the relative error due to uncorrected voltage,*
- $\delta R_{x\,6517A}$: *is uncertainty of high resistance meter,*
- u_A: *is uncertainty type A of measurements.*

Typical uncertainty budget for 100 TΩ - MI 9331G, Ser. No.: 1100625

Quantity X_i	Estimate x_i	Relative standard uncertainty $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution $u(R_i)$	Degree of freedom ν_i
R_s	96,98 TΩ	$2,31 \cdot 10^{-1}$	B	1,0	$2,31 \cdot 10^{-1}$	∞
δR_s	0,3 TΩ	$1,73 \cdot 10^{-1}$	B	1,0	$1,73 \cdot 10^{-1}$	50
δR_{sT}	0,0 TΩ	$8,67 \cdot 10^{-2}$	B	1,0	$8,67 \cdot 10^{-2}$	30
δR_{sH}	0,0 TΩ	$2,89 \cdot 10^{-2}$	B	1,0	$2,89 \cdot 10^{-2}$	30
δR_{xT}	0,0 TΩ	$5,78 \cdot 10^{-2}$	B	1,0	$5,78 \cdot 10^{-2}$	30
δR_{xH}	0,0 TΩ	$1,73 \cdot 10^{-2}$	B	1,0	$1,73 \cdot 10^{-2}$	30
$\delta R_{x\ U\ 400\ V}$	400 V	$3,70 \cdot 10^{-2}$	B	1,0	$3,70 \cdot 10^{-2}$	∞
$\delta R_{x\ 6517A}$	100,000 TΩ	2,02	B	1,0	2,02	∞
R_x	102,6549 TΩ	$5,00 \cdot 10^{-1}$	A (u_A)		$5,00 \cdot 10^{-1}$	100
		Combined relative standard uncertainty:			2,104	
		Effective degrees of freedom:			100	
		Expanded relative uncertainty (95% coverage factor):			4,2 (4,2 TΩ)	

Where:

- R_s: *is value of reference resistor 100 TΩ,*
- δR_s: *is the relative error of the reference resistor due to its drift,*
- δR_{sT}, δR_{xT}: *are relative error due to uncorrected temperature instabilities reference and measurement resistor,*
- δR_{sH}, δR_{xH}: *are relative error due to uncorrected humidity reference and measurement resistor and leakage effects,*
- $\delta R_{x\ U\ 400\ V}$: *is the relative error due to uncorrected voltage,*
- $\delta R_{x\ 6517A}$: *is uncertainty of high resistance meter,*
- u_A: *is uncertainty type A measurements.*

03 PTB

1 TΩ, 500 V

Model Equation:
$R_x=R_n \cdot V \cdot k_D \cdot k_T \cdot (-U_x/U_n \cdot 1/(1-((I_B) \cdot R_n \cdot k_D \cdot k_T)/U_n))$

List of Quantities:

Quantity	Unit	Definition
R_x	Ω	unknown resistor
R_n	Ω	standard resistor
V	1	reproducibility of the ratio
k_D	1	drift of the standard resistor
k_T	1	temperature dependance of the standard resistor
U_x	V	voltage across R_x
U_n	V	voltage across R_n
I_B	A	residual bridge balance current

Uncertainty Budgets:
***R_x*: unknown resistor**

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
R_n	$100.0000 \cdot 10^9$ Ω	$6.00 \cdot 10^6$ Ω	normal	10	$60 \cdot 10^6$ Ω	7.9 %
V	1.0000000 1	$40.0 \cdot 10^{-6}$ 1	normal	$1.0 \cdot 10^{12}$	$40 \cdot 10^6$ Ω	3.5 %
k_D	1.0000000 1	$17.3 \cdot 10^{-6}$ 1	rectangular	$1.0 \cdot 10^{12}$	$17 \cdot 10^6$ Ω	0.7 %
k_T	1.0000000 1	$11.5 \cdot 10^{-6}$ 1	rectangular	$1.0 \cdot 10^{12}$	$12 \cdot 10^6$ Ω	0.3 %
U_x	500.000000 V	$250 \cdot 10^{-6}$ V	normal	$2.0 \cdot 10^9$	$500 \cdot 10^3$ Ω	0.0 %
U_n	-50.000000 V	$160 \cdot 10^{-6}$ V	normal	$20 \cdot 10^9$	$3.2 \cdot 10^6$ Ω	0.0 %
I_B	$500 \cdot 10^{-15}$ A	$100 \cdot 10^{-15}$ A	normal	$-2.0 \cdot 10^{21}$	$-200 \cdot 10^6$ Ω	87.6 %
R_x	$999.001 \cdot 10^9$ Ω	$213 \cdot 10^6$ Ω				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
R_x	$999.00 \cdot 10^9$ Ω	$440 \cdot 10^6$ Ω	2.07	95% (t-table 95.45%)

100 TΩ, 500 V

Uncertainty Budget:
R_x: unknown resistor

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
R_n	$1.00191 \cdot 10^{12}$ Ω	$250 \cdot 10^{6}$ Ω	normal	94	$24 \cdot 10^{9}$ Ω	17.0 %
V	1.000000 1	$400 \cdot 10^{-6}$ 1	normal	$95 \cdot 10^{12}$	$38 \cdot 10^{9}$ Ω	43.6 %
k_D	1.0000000 1	$17.3 \cdot 10^{-6}$ 1	rectangular	$95 \cdot 10^{12}$	$1.6 \cdot 10^{9}$ Ω	0.0 %
k_T	1.00000000 1	$6.93 \cdot 10^{-6}$ 1	rectangular	$95 \cdot 10^{12}$	$660 \cdot 10^{6}$ Ω	0.0 %
U_x	499.980000 V	$250 \cdot 10^{-6}$ V	normal	$190 \cdot 10^{9}$	$47 \cdot 10^{6}$ Ω	0.0 %
U_n	-5.298700 V	$150 \cdot 10^{-6}$ V	normal	$18 \cdot 10^{12}$	$2.7 \cdot 10^{9}$ Ω	0.2 %
I_B	$-2.62 \cdot 10^{-15}$ A	$2.00 \cdot 10^{-15}$ A	normal	$-18 \cdot 10^{24}$	$-36 \cdot 10^{9}$ Ω	39.0 %
R_x	$94.5861 \cdot 10^{12}$ Ω	$57.3 \cdot 10^{9}$ Ω				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
R_x	$94.59 \cdot 10^{12}$ Ω	$1.3 \cdot 10^{-3}$ (relativ)	2.07	95% (t-table 95.45%)

04 MIRS-SIQ

Mathematical model

The resistance of the resistor under calibration, *Rx*, is obtained from (Eq. 8):

Eq. 8: $$R_X = R_S + K\_s + K\_r\,,$$

where:

K_s correction of the indicated resistance on the teraohmmeter due to its specification,

K_r correction of the indicated resistance on the teraohmmeter due to its resolution.

Resistance measured with the teraohmmeter (R_s)

The resistance measured with the teraohmmeter R_s is combined resistance measured as positive and negative resistance of the resistor under calibration. This model of measurement is repeated several times and from these results the repeatability is calculated as standard deviation with equations (Eq. 9):

Eq. 9: $$u\_A = \sqrt{\frac{\sum_{i=1}^{n}\left(R_{S\_i} - \overline{R_S}\right)^2}{n \cdot (n-1)}}$$ - normal distribution.

The difference between positive and negative measurement has no uncertainty, because it is part of our measurement method and the standard deviation of it is already included in the calculation of the *u_A* (Eq. 9).

Correction of measured resistance due to uncertainty from teraohmmeter's specifications (*K_s*)

The teraohmmeters is operated within the specified working temperature and has a valid calibration according to prescribed recalibration interval with compliant with specification status, meaning that for all measured points compliance with specified limit of error minus uncertainty of measurement was confirmed.

Rectangular probability distribution is assumed for this type of uncertainty.

Correction of the measured resistance on the teraohmmeter due to its resolution (*K_r*)

The uncertainty due to the resolution is negligible according to the uncertainty due to the repeatability and therefore not taken into account in further calculations.

Calculation of uncertainty budget

1 TΩ Guildline 9337 G, SN 69573 (500V)

Mathematical model of measurement:

$$R_X = R_S + K\_s$$

measured value		
Rs	0,99954	TΩ
StDev	77	μΩ/Ω

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribution	Div.	Sensitivity coefficient *ci*		Uncertainty contribution *ui(y)*	Degree of freedom *vi*
Rs	0,99954 TΩ	0,0001 TΩ	normal	1	1	A	0,0001 TΩ	4
K_s	0 TΩ	0,0012 TΩ	rectangular	1,73	1	B	0,0012 TΩ	1E+99
Rx	0,99954 TΩ	Combined standard uncertainty:					0,0012 TΩ	
		Effective degrees of freedom:					2,0E+05	
		Expanded uncertainty (95% coverage factor):					0,0023 TΩ	
		Relative expanded uncertainty (95% coverage factor):					0,23 %	

1 TΩ Guildline 9337 G, SN 69573 (1000V)

Mathematical model of measurement:

$$R_X = R_S + K\_s$$

measured value		
Rs	0,99944	TΩ
StDev	75	μΩ/Ω

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribution	Div.	Sensitivity coefficient *ci*		Uncertainty contribution *ui(y)*	Degree of freedom *vi*
Rs	0,99944 TΩ	0,0001 TΩ	normal	1	1	A	0,0001 TΩ	4
K_s	0 TΩ	0,0012 TΩ	rectangular	1,73	1	B	0,0012 TΩ	1E+99
Rx	0,99944 TΩ	Combined standard uncertainty:					0,0012 TΩ	
		Effective degrees of freedom:					2,3E+05	
		Expanded uncertainty (95% coverage factor):					0,0023 TΩ	
		Relative expanded uncertainty (95% coverage factor):					0,23 %	

100 TΩ Guildline 9337 G, SN 69640 (500V)

Mathematical model of measurement:

$$R_X = R_S + K\_s$$

measured value		
Rs	99,998	TΩ
StDev	318	µΩ/Ω

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribution	Div.	Sensitivity coefficient *ci*		Uncertainty contribution *ui(y)*	Degree of freedom *vi*
Rs	99,998 TΩ	0,03 TΩ	normal	1	1	A	0,03 TΩ	4
K_s	0 TΩ	0,29 TΩ	rectangular	1,73	1	B	0,29 TΩ	1E+99
Rx	99,998 TΩ	Combined standard uncertainty:					0,29 TΩ	
		Effective degrees of freedom:					2,8E+04	
		Expanded uncertainty (95% coverage factor):					0,58 TΩ	
		Relative expanded uncertainty (95% coverage factor):					0,58 %	

100 TΩ Guildline 9337 G, SN 69640 (1000V)

Mathematical model of measurement:

$$R_X = R_S + K\_s$$

measured value		
Rs	100,000	TΩ
StDev	92	µΩ/Ω

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribution	Div.	Sensitivity coefficient *ci*		Uncertainty contribution *ui(y)*	Degree of freedom *vi*
Rs	100,000 TΩ	0,01 TΩ	normal	1	1	A	0,01 TΩ	3
K_s	0 TΩ	0,29 TΩ	rectangular	1,73	1	B	0,29 TΩ	1E+99
Rx	100,000 TΩ	Combined standard uncertainty:					0,29 TΩ	
		Effective degrees of freedom:					2,9E+06	
		Expanded uncertainty (95% coverage factor):					0,58 TΩ	
		Relative expanded uncertainty (95% coverage factor):					0,58 %	

05 EIM

R_x Serial Number 69573 (1T, 500 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 $u(R_i)$		Degrees of freedom v_i
R_s	1,000 608 432	TΩ	19,511 864	MΩ	Normal B	1		$1{,}9 \cdot 10^{7}$	Ω	inf
k_T	1		$1{,}15 \cdot 10^{-6}$		rectangular B	$1 \cdot 10^{12}$	Ω	$1{,}2 \cdot 10^{6}$	Ω	inf
k_D	1		$4{,}43 \cdot 10^{-6}$		rectangular B	$1 \cdot 10^{12}$	Ω	$4{,}4 \cdot 10^{6}$	Ω	inf
E_s	-499,999 750	V	$7{,}25 \cdot 10^{-4}$	V	normal	$2 \cdot 10^{9}$	Ω/V	$1{,}4 \cdot 10^{6}$	Ω	9
E_x^+	499,449 520	V	$7{,}24 \cdot 10^{-4}$	V	normal	$1 \cdot 10^{9}$	Ω/V	$7{,}2 \cdot 10^{5}$	Ω	9
ΔI_0^+	$1{,}5167 \cdot 10^{-13}$	A	$6{,}65 \cdot 10^{-15}$	A	normal B	$-1 \cdot 10^{21}$	Ω/A	$-6{,}6 \cdot 10^{6}$	Ω	inf
E_x^-	-499,454 329	V	$7{,}24 \cdot 10^{-4}$	V	normal B	$-1 \cdot 10^{9}$	Ω/V	$-7{,}2 \cdot 10^{5}$	Ω	9
ΔI_0^-	$1{,}4768 \cdot 10^{-13}$	A	$6{,}62618 \cdot 10^{-15}$	A	normal B	$1 \cdot 10^{21}$	Ω/A	$6{,}6 \cdot 10^{6}$	Ω	inf
Bridge	1		$3{,}8856 \cdot 10^{-15}$	A	rectangular B	$1 \cdot 10^{21}$	Ω/A	$3{,}9 \cdot 10^{6}$	Ω	5
Repeat	1		$7{,}81 \cdot 10^{-15}$	A	normal A	$1 \cdot 10^{21}$	Ω/A	$7{,}8 \cdot 10^{6}$	Ω	81
					Type B uncertainty			22 521 517	Ω	
					Type A uncertainty			7 811 784	Ω	
R_{xj} =	999 508 215 285	Ω			Combined standard uncertainty			26 057 042	Ω	
					Effective degrees of freedom			138		
					Expanded uncertainty (95% covarage factor):			**52 275 644**	Ω	
$\overline{R_x}$ =	**999 518 983 760**	**Ω**			Type A uncertainty of the mean			**7 520 833**	Ω	400
					Reproducibility of the mean			**10 522 678**	Ω	4
					Combined standard uncertainty of the mean			**25 971 300**	Ω	
					Effective degrees of freedom			148		
					Expanded uncertainty (95% coverage factor):			**51 942 599**	Ω (k=2)	
								52 µΩ/Ω		

R_x Serial Number 69640 (100 T, 500 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 $u(R_i)$	Degrees of freedom v_i
R_s	92,857 771 359 223 TΩ	1 810, 726 MΩ	Normal B	1	$2{,}0 \cdot 10^{9}$ Ω	inf
k_T	1	$1{,}15 \cdot 10^{-6}$	rectangular B	$1 \cdot 10^{14}$ Ω	$1{,}2 \cdot 10^{8}$ Ω	inf
k_D	1	$4{,}43 \cdot 10^{-6}$	rectangular B	$1 \cdot 10^{14}$ Ω	$4{,}4 \cdot 10^{8}$ Ω	inf
E_s	-499,999 750 V	$7{,}25 \cdot 10^{-4}$ V	normal	$2 \cdot 10^{11}$ Ω/V	$1{,}5 \cdot 10^{8}$ Ω	9
E_x^+	538,543 625 V	$7{,}81 \cdot 10^{-4}$ V	normal	$9 \cdot 10^{10}$ Ω/V	$7{,}3 \cdot 10^{7}$ Ω	9
ΔI_0^+	$-2{,}6723 \cdot 10^{-14}$ A	$4{,}20 \cdot 10^{-15}$ A	normal B	$-9 \cdot 10^{24}$ Ω/A	$-3{,}9 \cdot 10^{10}$ Ω	inf
E_x^-	-538,662 150 V	$7{,}81 \cdot 10^{-4}$ V	normal B	$-9 \cdot 10^{10}$ Ω/V	$-7{,}2 \cdot 10^{7}$ Ω	9
ΔI_0^-	$-2{,}6697 \cdot 10^{-14}$ A	$4{,}20 \cdot 10^{-15}$ A	normal B	$9 \cdot 10^{24}$ Ω/A	$3{,}9 \cdot 10^{10}$ Ω	inf
Bridge	1	$2{,}08 \cdot 10^{-15}$ A	rectangular B	$9 \cdot 10^{24}$ Ω/A	$1{,}9 \cdot 10^{10}$ Ω	5
Repeat	1	$4{,}21 \cdot 10^{-15}$ A	normal A	$9 \cdot 10^{24}$ Ω/A	$3{,}9 \cdot 10^{10}$ Ω	80
			Type B uncertainty		**58 382 957 480** Ω	
			Type A uncertainty		38 735 285 542 Ω	
R_{xj} =	100 029 628 920 809 Ω		Combined standard uncertainty		75 788 788 166 Ω	
			Effective degrees of freedom		132	
			Expanded uncertainty (95% covarage factor):		151 577 576 332 Ω	
$\overline{R_x}$ =	**100 038 792 919 669 Ω**		Type A uncertainty of the mean		**26 711 514 926** Ω	596
			Reproducibility of the mean		**28 895 472 683** Ω	4
			Combined standard uncertainty of the mean		**70 406 129 671** Ω	
			Effective degrees of freedom		140 Ω	
			Expanded uncertainty (95% coverage factor):		**140 812 259 343** Ω	
					1408 µΩ/Ω	

06 INRIM

Measurement model (DMM-cal method) 1 TΩ

The value of R_x is given by:

$$R_x = \frac{V_x}{I_x} = (V_{out} - V_s)\frac{R_S}{V_s} = R_s(\frac{V_{out}}{V_S} - 1) \cong [(\frac{V_{out} + k_{cal-cal} + k_{Cal-acc}}{V_s + k_{DMM-cal} + k_{load} + k_{DMM-acc} + k_{term-bias}} - 1)(R_S k_{drift} k_T)]k_{leak}$$

Where:

V_{out}	is the voltage supplied by the dc calibrator. As uncertainty contribution for this input quantity, its mid-term instability as declared by the manufacturer, was taken into account;
V_s	is the voltage on R_s read by the DMM;
$k_{drift} \cong 1$	is a corrective term to take into account the drift of R_S;
$k_T \cong 1$	is a corrective term to take into account the instability of R_s due to temperature instability;
$k_{load} \cong 0$ V	is a corrective term to take into account the error due to the DMM input impedance;
$k_{DMM-cal} \cong 0$ V	is a corrective term to take into account the error in the calibration of the DMM;
$k_{DMM-acc} \cong 0$ V	is a corrective term to take into account the accuracy of the DMM as declared by the manufacturer;
$k_{cal-cal} \cong 0$ V	is a corrective term to take into account the error in the calibration of the dc voltage calibrator;
$k_{cal-acc} \cong 0$ V	is a corrective term to take into account the accuracy of the calibrator as declared by the manufacturer;
$k_{term-bias} \cong 0$ V	is a corrective term to take into account the error of the DMM due to thermal and offset voltages and bias current residual effects to polarity inversion;
$k_{leak} \cong 1$	is a corrective term to take into account the error due to the leakages;
$k_{repeat} \cong 1$	is a corrective term to take into account the repeatability of R_x;
$k_{Ax} \cong 1$	is a corrective term to take into account the instability of R_x due to instability of environment conditions during the measurements.

Table 1- uncertainties budget at 1 TΩ at 500 V - DMM-cal method.

Unc. source	Quantity X_i	Estimate x_i	$u(x_i)$	Distrib.	c_i	$u_i(R_x)$	. ν_i
R_s	R_s	≅ 10 MΩ	19.5 Ω	normal B	99999	1.9×10^{6} Ω	∞
drift	k_{drift}	1	5.8×10^{-8}	Rect B	1.0×10^{12} Ω	5.8×10^{4} Ω	50
Temp on R_s	k_T	1	5.8×10^{-8}	Rect B	1.0×10^{12} Ω	5.8×10^{4} Ω	50
load	k_{load}	≅ 0 V	2.9×10^{-8} V	Rect B	2×10^{14} Ω/V	5.8×10^{6} Ω	50
DMM-calibration	$k_{DMM-cal}$	≅ 0 V	1.2×10^{-7} V	Rect B	2×10^{14} Ω/V	2.4×10^{7} Ω	∞
DMM-accuracy	$k_{DMM-acc}$	≅ 0 V	2.5×10^{-8} V	Rect B	2×10^{14} Ω/V	4.9×10^{6} Ω	∞
Repeat V_s	V_s	≅ mV	1.5×10^{-8} V	Normal A	2×10^{14} Ω/V	3.0×10^{6} Ω	342
Instab V_{out}	V_{out}	≅ 500 V	2.3×10^{-4} V	Rect B	2×10^{9} Ω/V	4.6×10^{5} Ω	∞
Calibrator calibration	$k_{cal-cal}$	≅ 0 V	2.6×10^{-3} V	Rect B	2×10^{9} Ω/V	5.2×10^{6} Ω	∞
Calibrator accuracy	$k_{cal-acc}$	≅ 0 V	8.9×10^{-4} V	Rect B	2×10^{9} Ω/V	1.8×10^{6} Ω	∞
Residual ftem, bias curr	$k_{term-bias}$	≅ 0 V	4.6×10^{-7} V	Rect B	2×10^{14} Ω/V	9.2×10^{7} Ω	5
leakage	k_{leak}	1	5.8×10^{-6}	Rect B	1.0×10^{12} Ω	5.8×10^{6} Ω	∞
Repeat R_x	k_{repeat}	1	5.0×10^{-6}	Normal A	1.0×10^{12} Ω	5.0×10^{6} Ω	342
Temp on R_x	k_{Ax}	1	2.9×10^{-5}	Rect B	1.0×10^{12} Ω	2.9×10^{7} Ω	50
R_x	R_x	≅ 1 TΩ					
		$u_c(R_x)$	combined	Standard	uncertainty	**1.0×10^{8} Ω**	
			effective	degrees of	freedom	283	
		$U(R_x)$	Expanded	Uncert.	2 δ	**2.0×10^{8} Ω**	k = 2

Measurement model (modified Wheatstone bridge method) 100 TΩ

The value of R_x is given by:

$$R_x \cong R_s[(k_{drift}k_T k_V)(\frac{V_x + k_{calhi-acc} + k_{calhi-cal} - V_b}{(V_s + k_{callo-acc} + k_{callo-cal} - V_b})]k_{\det}k_{\text{int}}k_{repeat}k_{conn}k_{leak}k_{Ax}$$

where:

R_s is the standard resistor;

V_x is the voltage supplied by the Hi calibrator. As uncertainty contribution for this input quantity, its mid-term instability, as declared by the manufacturer was taken into account;

V_s is the voltage supplied by the Lo calibrator at the balance of the bridge. For this input quantity its type A uncertainty was taken into account;

$k_{\text{drift}} \cong 1$ is a corrective term to take into account the drift of R_s;

$k_T \cong 1$ is a corrective term to take into account the instability of R_s due to instability of environment conditions;

$k_V \cong 1$ is a corrective term to take into account the voltage dependence of R_s ;

$k_{\det} \cong 1$ is a corrective term to take into account the resolution of the detector as declared by the manufacturer;

$k_{\text{int}} \cong 1$ is a corrective term to take into account the interpolation of the readings of the detector;

$k_{repeat} \cong 1$ is a corrective term to take into account the repeatability of R_x;

$k_{Ax} \cong 1$ is a corrective term to take into account the instability of R_x due to instability of environment conditions

$k_{conn} \cong 1$ is a corrective term to take into account the error due to the connections;

$k_{\text{leak}} \cong 1$ is a corrective term to take into account the error due to the leakages;

$k_{calhi-cal} \cong 0$ V is a corrective term to take into account the uncertainty of the calibration of the high calibrator;

$k_{calhi-acc} \cong 0$ V is a corrective term to take into account the accuracy of the high calibrator as declared by the manufacturer;

$k_{callo-cal} \cong 0$ V is a corrective term to take into account the uncertainty of the calibration of the low calibrator;

$k_{callo-acc} \cong 0$ V is a corrective term to take into account the accuracy of the low calibrator as declared by the manufacturer;

V_b is the estimate of the voltage burden of the detector and of the residual offset and thermal voltages to polarity inversion.

Table 2 - Uncertainties budget at 100 TΩ 500 V -modified Wheatstone Bridge

Jnc. source	Quantity X_i	x_i	$u(x_i)$	distrib.	c_i	$u_i(R_x)$	ν_i
R_s	R_s	≅ 1 TΩ	9.5×10^{7} Ω	normal B	100	9.5×10^{9} Ω	∞
drift	k_{drift}	1	5.8×10^{-6}	Rect B	1.0×10^{14} Ω	5.8×10^{8} Ω	50
Temp on R_s	k_T	1	5.8×10^{-5}	Rect B	1.0×10^{14} Ω	5.8×10^{9} Ω	50
Voltage ependence R_s	k_V	1	6.2×10^{-5}	Rect B	1.0×10^{14} Ω	6.2×10^{9} Ω	50
detector	k_{det}	1	1.4×10^{-5}	Rect B	1.0×10^{14} Ω	1.4×10^{9} Ω	∞
nterpolation	k_{int}	1	5.8×10^{-6}	Rect B	1.0×10^{14} Ω	5.8×10^{8} Ω	50
Repeat R_x	k_{repeat}	1	2.5×10^{-5}	Normal A	1.0×10^{14} Ω	2.5×10^{9} Ω	217
connections	k_{conn}	1	5.8×10^{-5}	Rect B	1.0×10^{14} Ω	5.8×10^{9} Ω	∞
leakage	k_{leak}	1	5.8×10^{-5}	Rect B	1.0×10^{14} Ω	5.8×10^{9} Ω	∞
Temp on R_x	k_{Ax}	1	2.9×10^{-4}	Rect B	1.0×10^{14} Ω	2.9×10^{10} Ω	50
Hi calibrator calibration	$k_{calhi-cal}$	≅ 0 V	1.7×10^{-3} V	Rect B	2.0×10^{11} Ω/V	3.5×10^{8} Ω	∞
Hi calibrator accuracy	$k_{calhi-acc}$	≅ 0 V	6.9×10^{-4} V	Rect B	2.0×10^{11} Ω/V	1.4×10^{8} Ω	∞
Instab V_x	V_x	≅ – 500 V	2.3×10^{-4} V	Rect B	2.0×10^{11} Ω/V	4.6×10^{7} Ω	∞
Repeat V_s	V_s	≅ 5 V	1.4×10^{-4} V	Normal A	2.0×10^{13}Ω/V	2.7×10^{9} Ω	217
Lo calibrator calibration	$k_{callo-cal}$	≅ 0 V	1.7×10^{-6} V	Rect B	2.0×10^{13}Ω/V	3.5×10^{7} Ω	∞
Lo calibrator accuracy	$k_{callo-acc}$	≅ 0 V	5.8×10^{-6} V	Rect B	2.0×10^{13}Ω/V	1.2×10^{8} Ω	∞
Voltage burden	V_b	1.0×10^{-6} V	1.2×10^{-6} V	Normal B	2.0×10^{13}Ω/V	2.3×10^{7} Ω	∞
	R_x	≅ 100 TΩ					
		$\boldsymbol{u_c(R_x)}$	combined	Standard	uncertainty	**3.3 ×10^10 Ω**	
			effective	degrees of	freedom	**160**	
		$\boldsymbol{U(R_x)}$	Expanded	Uncert.	2 δ	**6.6 ×10^10 Ω**	k = 2

07 MIKES

MIKES uncertainty budget for sn. 1101180 (1 TΩ) at 1000 V.

Quantity X_i	Estimate x_i	unit	Standard uncertainty $u(x_i)$ k=1	Probability distribution / method of evaluation (A,B)	Sensitivity coefficient c_i	Uncertainty contribution u_i	unit	Degrees of freedom v_i
$U_{x\text{-}pos\text{-}cal}$	999.9982	V	0.0009	normal, B	4.99E+08	4.354E+05	Ω	inf.
$U_{x\text{-}neg\text{-}cal}$	-999.9988	V	0.0009	normal, B	-4.99E+08	-4.348E+05	Ω	inf.
$u_{ref\text{-}pos\text{-}cal}$	0.999999	V/V	4.8E-07	normal, B	-4.99E+11	-2.412E+05	Ω	inf.
$u_{ref\text{-}neg\text{-}cal}$	0.999999	V/V	4.7E-07	normal, B	-4.99E+11	-2.366E+05	Ω	inf.
$U_{ref\text{-}pos\text{-}meas}$	99.86072	V	0.00004	normal, A	-5.00E+09	-2.094E+05	Ω	15
$U_{ref\text{-}neg\text{-}meas}$	-99.86048	V	0.00006	normal, A	5.00E+09	3.124E+05	Ω	15
$R_{ref\text{-}cal}$	9.97223E+10	Ω	3.09E+06	normal, B	1.00E+01	3.096E+07	Ω	inf.
k_{rep}	1.000000	Ω/Ω	1.1E-05	normal, A	9.99E+11	1.105E+07	Ω	3
t_{amb}	22.82	°C	0.14	normal, B	5.69E+06	7.962E+05	Ω	inf.
$t_{ref\text{-}cal}$	22.91	°C	0.14	normal, B	-5.68E+06	-7.958E+05	Ω	inf.
$k_{ref\text{-}temp}$	5.7E+06	Ω/°C	7.E+05	normal, B	-8.59E-02	-5.996E+04	Ω	inf.
			Total Type A uncertainty			**1.106E+07**	**Ω**	**3.007E+00**
			Total Type B uncertainty			**3.099E+07**	**Ω**	**inf.**
R_x	**9.98613E+11**	**Ω**	**Combined standard uncertainty**			**3.290E+07**	**Ω**	
From nominal	**-1387**	**ppm**				**33**	**ppm**	
			Effective degrees of freedom					**236**
			Expanded unc. k = 2 (95 % coverage factor)			**66**	**ppm**	

MIKES uncertainty budget for sn. 69640 (100 TΩ) at 500 V.

Quantity X_i	Estimate x_i	unit	Standard uncertainty $u(X_i)$ k=1	Probability distribution / method of evaluation (A,B)	Sensitivity coefficient c_i	Uncertainty contribution u_i	unit	Degrees of freedom ν_i
$U_{x\text{-}pos\text{-}cal}$	500.0000	V	0.0005	normal, B	1.00E+11	5.450E+07	Ω	inf.
$U_{x\text{-}neg\text{-}cal}$	-500.0004	V	0.0005	normal, B	-1.00E+11	-5.440E+07	Ω	inf.
$u_{ref\text{-}pos\text{-}cal}$	1.000000	V/V	8.0E-07	normal, B	-5.00E+13	-3.996E+07	Ω	inf.
$u_{ref\text{-}neg\text{-}cal}$	0.999999	V/V	7.9E-07	normal, B	-5.00E+13	-3.963E+07	Ω	inf.
$U_{ref\text{-}pos\text{-}meas}$	51.43710	V	0.00251	normal, A	-9.72E+11	-2.436E+09	Ω	15
$U_{ref\text{-}neg\text{-}meas}$	-51.44442	V	0.00322	normal, A	9.72E+11	3.127E+09	Ω	15
$R_{ref\text{-}cal}$	1.02929E+13	Ω	5.18E+09	normal, B	9.72E+00	5.032E+10	Ω	inf.
k_{rep}	1.000000	Ω/Ω	3.8E-04	normal, A	1.00E+14	3.816E+10	Ω	3
t_{amb}	22.80	°C	0.14	normal, B	-2.06E+08	-2.878E+07	Ω	inf.
$t_{ref\text{-}cal}$	22.91	°C	0.14	normal, B	2.06E+08	2.883E+07	Ω	inf.
$k_{ref\text{-}temp}$	-2.1E+08	Ω/°C	7.E+08	normal, B	-1.52E-01	-1.125E+08	Ω	inf.
			Total Type A uncertainty			**3.837E+10**	**Ω**	**3.065E+00**
			Total Type B uncertainty			**5.032E+10**	**Ω**	**inf.**
R_x	**1.00046E+14**	**Ω**	**Combined standard uncertainty**			**6.328E+10**	**Ω**	
From nominal	**464**	**ppm**				**633**	**ppm**	
			Effective degrees of freedom					**22.7**
			Expanded unc. k = 2.13 (95 % coverage factor)			**1347**	**ppm**	

08 SP

The value of the unknown resistance is obtained from the relationship:

$$R_x = R_s \cdot r \cdot (1+\delta r) \cdot (1+\delta_{res}) \cdot (1+\delta_{bal}) \cdot (1+\delta R_{xbal})$$

where:

R_x - the value of the unknown resistance

R_s - the value of the reference resistance

r - the measured voltage ratio

δr - correction for the error in the voltage ratio due to calibration and stability of the voltage ratio

δ_{res} - correction for the error due to the resolution of the detector

δ_{bal} - correction for the error in the balancing procedure of the bridge due to leakage and not compensated offset effects in the detector

δR_{xbal} - correction for the error due to the change in the voltage over the unknown resistance during the bridge balancing process due to the voltage dependence (calculated from the difference between the values at 500 V and 1000 V respectively) of the unknown resistance

Based on the model equation the relative standard uncertainty of the measured resistance u(R_x)/ R_x can be determined as:

$$\left(\frac{u(R_x)}{R_x}\right)^2 = \left(\frac{u(R_s)}{R_s}\right)^2 + \left(\frac{u(r)}{r}\right)^2 + u^2(\delta r) + u^2(\delta_{res}) + u^2(\delta_{bal}) + u^2(\delta R_{xbal})$$

where:

u(R_s) - uncertainty in the value of the reference resistance due to step-up from QHR, stability, temperature and voltage dependence

u(r) - standard deviation of the mean of the measured voltage ratio

$u(\delta r)$ - uncertainty in the voltage ratio due to calibration and stability of the voltage ratio

$u(\delta_{res})$ - uncertainty due to the resolution of the detector

$u(\delta_{bal})$ - uncertainty in the balancing procedure of the bridge due to leakage and not compensated offset effects in the detector

$u(\delta R_{xbal})$ - uncertainty due to the change in the voltage over the unknown resistance during the bridge balancing process due to the voltage dependence (calculated from the difference between the values at 500 V and 1000 V respectively) of the unknown resistance

Uncertainty budget for 1 TΩ (Guildline 9337 G, s/n 69573) at **500 V**

Quantity X_i	Estimate x_i	Relative standard uncertainty, (10^{-6}) $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution, (10^{-6}) $u(R_i)$	Degree of freedom ν_i
R_s	1 GΩ	11.5	rectangular / B	1	11.5	∞
r	1000	2.3	normal / A	1	2.3	3
δr	0	11.5	rectangular / B	1	11.5	∞
δ_{res}	0	0.1	rectangular / B	1	0.1	∞
δ_{bal}	0	28.9	rectangular / B	1	28.9	∞
δR_{xbal}	0	0.1	rectangular / B	1	0.1	∞
R_x	1 TΩ					
		Combined standard uncertainty:			34 µΩ/Ω	
		Effective degrees of freedom:			1809	
		Expanded uncertainty (95% coverage factor):			69 µΩ/Ω	

Uncertainty budget for 1 TΩ (Guildline 9337 G, s/n 69573) at **1000 V**

Quantity X_i	Estimate x_i	Relative standard uncertainty, (10^{-6}) $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution, (10^{-6}) $u(R_i)$	Degree of freedom ν_i
R_s	1 GΩ	11.5	rectangular / B	1	11.5	∞
r	1000	1.1	normal / A	1	1.1	3
δr	0	11.5	rectangular / B	1	11.5	∞
δ_{res}	0	0.1	rectangular / B	1	0.1	∞
δ_{bal}	0	14.4	rectangular / B	1	14.4	∞
δR_{xbal}	0	0.1	rectangular / B	1	0.1	∞
R_x	1 TΩ					
		Combined standard uncertainty:			22 µΩ/Ω	
		Effective degrees of freedom:			2949	
		Expanded uncertainty (95% coverage factor):			45 µΩ/Ω	

Uncertainty budget for 100 TΩ (Guildline 9337 G, s/n 69641) at **500 V**

Quantity X_i	Estimate x_i	Relative standard uncertainty, (10^{-6}) $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution, (10^{-6}) $u(R_i)$	Degree of freedom ν_i
R_s	1 TΩ	34.6	rectangular / B	1	34.6	∞
r	100	17.3	normal / A	1	17.3	4
δr	0	11.5	rectangular / B	1	11.5	∞
δ_{res}	0	11.5	rectangular / B	1	11.5	∞
δ_{bal}	0	346.4	rectangular / B	1	346.4	∞
δR_{xbal}	0	0.2	rectangular / B	1	0.2	∞
R_x	100 TΩ					
		Combined standard uncertainty:			349 μΩ/Ω	
		Effective degrees of freedom:			1029	
		Expanded uncertainty (95% coverage factor):			699 μΩ/Ω	

Uncertainty budget for 100 TΩ (Guildline 9337 G, s/n 69641) at **1000 V**

Quantity X_i	Estimate x_i	Relative standard uncertainty, (10^{-6}) $u(x_i)$	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient c_i	Relative uncertainty contribution, (10^{-6}) $u(R_i)$	Degree of freedom ν_i
R_s	1 TΩ	34.6	rectangular / B	1	34.6	∞
r	100	46.9	normal / A	1	46.9	4
δr	0	11.5	rectangular / B	1	11.5	∞
δ_{res}	0	5.8	rectangular / B	1	5.8	∞
δ_{bal}	0	230.9	rectangular / B	1	230.9	∞
δR_{xbal}	0	0.5	rectangular / B	1	0.5	∞
R_x	100 TΩ					
		Combined standard uncertainty:			239 μΩ/Ω	
		Effective degrees of freedom:			804	
		Expanded uncertainty (95% coverage factor):			479 μΩ/Ω	

09 INM

Resistance standard at 1 TΩ, MI 9331G, serial no. **1101180**
The test voltage was 1000 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 $u(R_i)$	Degree of freedom ν_i
R_S	0.99624 TΩ	0.03 GΩ	Normal/B	1	0.03 GΩ	∞
$\bar{r}$	+0.00223 TΩ	0.003 GΩ	Normal/A	1	0.003 GΩ	9
δR_{SD}	0	0.035 GΩ	Rectangular/B	1	0.035 GΩ	2
δR_{ST}	0	0.023 GΩ	Rectangular/B	1	0.023 GΩ	2
δR_{XT}	0	0.023 GΩ	Rectangular/B	-1	0.023 GΩ	2
δR_L	0	0.004 GΩ	Triangular/B	1	0.004 GΩ	50
R_x	**0.99847 TΩ**					
		Combined standard uncertainty:			0.057 GΩ	
		Effective degrees of freedom:			10	
		Expanded uncertainty (95% coverage factor):			**0.13 GΩ**	

Resistance standard at 100 TΩ, MI 9331G, serial no. **1100625**
The test voltage was 1000 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 $u(R_i)$	Degree of freedom ν_i
R_S	94.384 TΩ	0.010 TΩ	Normal/B	1	0.010 TΩ	∞
$\bar{r}$	-4.387 TΩ	0.010 TΩ	Normal/A	1	0.010 TΩ	4
δR_{SD}	0	0.138 TΩ	Rectangular/ B	1	0.138 TΩ	2
δR_{ST}	0	0.046 TΩ	Rectangular/ B	1	0.046 TΩ	2
δR_{XT}	0	0.046 TΩ	Rectangular/ B	-1	0.046 TΩ	2
δR_L	0	0.003 TΩ	Triangular/B	1	0.003 TΩ	50
R_x	**89.997 TΩ**					
		Combined standard uncertainty:			0.153 TΩ	
		Effective degrees of freedom:			3	
		Expanded uncertainty (95% coverage factor):			**0.49 TΩ**	

10 BIM-NCM

The mean values of the MI 9331 G and Guildline 9337 G resistance measurements are given in the following tables.

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, voltage dependence of the reference resistor of 1T G9337) are included;

δR_{dr} – drift of the reference resistor;

δR_v – voltage dependence of the reference resistor is estimated to be 0, because reference resistors are calibrated at 500 V and 1000 V with the exception of the above mentioned in R_s contribution.;

δR_{ts} – temperature dependence of the reference resistor (including temperature correction of digital thermometer);

r_h– humidity influence on the reference resistor and DUT;

r_{res} – correction factor from DEM resolution;

$\bar{r} = R_X/R_S$ – mean value of ratio of the DUT and reference resistors;

r_{stab} – stability of the DEM;

r_{leak} – effects of leakage from cables, reference resistor, DUT and DEM (residual effects after leakage compensation of DEM);

r_{offs} – gain and offset-effects. Uncertainty contribution of this influence is estimated to be negligible, because of the used method of substitution and the closeness of measured values of reference resistor and DUT;

r_{config} – effects of configuration of the connections, estimated to be greater than effects of leakage currents;

δR_{tx} – correction due to temperature effects of DUT.

Traveling Standard Guildline 9337G, SN 69574, 1 TΩ, 1000 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	0,999 75 TΩ	6,00E-04 TΩ	Normal/B	1,000 3	6,00E-04 TΩ	50
δR_{dr}	0,0 TΩ	2,43E-05 TΩ	Rectangular/B	1,000 3	2,43E-05 TΩ	infinity
δR_{ts}	0,0 TΩ	1,73E-05 TΩ	Rectangular/B	1,000 3	1,73E-05 TΩ	infinity
r_h	0,0	3,46E-05	Rectangular/B	1,000 1 TΩ	3,46E-05 TΩ	infinity
r_{res}	1	4,08E-07	Triangular/B	1,000 1 TΩ	4,08E-07 TΩ	infinity
$\bar{r}$	1,00029638	4,47E-06	Normal/A	0,999 75 TΩ	4,47E-06 TΩ	63
r_{stab}	0,0	4,04E-05	Rectangular/B	1,000 1 TΩ	4,04E-05 TΩ	infinity
r_{leak}	0,0	5,77E-05	Rectangular/B	1,000 1 TΩ	5,77E-05 TΩ	infinity
r_{config}	0,0	8,66E-05	Rectangular/B	1,000 1 TΩ	8,66E-05 TΩ	infinity
δR_{tx}	0,0 TΩ	1,73E-05 TΩ	Rectangular/B	-1	-1,73E-05 TΩ	infinity
R_X	1,000 1 TΩ					
		Combined standard uncertainty:			0,000 612 TΩ	
		Effective degrees of freedom:			54	
		Expanded uncertainty (95% coverage factor):			0,001 3 TΩ	

Traveling Standard Guildline 9337G, SN 69640, 100 TΩ, 1000 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	100,342 TΩ	1,90E-01 TΩ	Normal/B	1,00	1,90E-01 TΩ	50
δR_{dr}	0,0 TΩ	4,79E-03 TΩ	Rectangular/B	1,00	4,79E-03 TΩ	infinity
δR_{ts}	0,0 TΩ	4,62E-03 TΩ	Rectangular/B	1,00	4,62E-03 TΩ	infinity
r_h	0,0	6,93E-05	Rectangular/B	100,58 TΩ	6,97E-03 TΩ	infinity
r_{res}	1	4,08E-05	Triangular/B	100,58 TΩ	4,11E-03 TΩ	infinity
$\overline{r}$	1,0023557	7,52E-05	Normal/A	100,34 TΩ	7,55E-03 TΩ	45
r_{stab}	0,0	5,77E-05	Rectangular/B	100,58 TΩ	5,81E-03 TΩ	infinity
r_{leak}	0,0	3,46E-04	Rectangular/B	100,58 TΩ	3,48E-02 TΩ	infinity
r_{config}	0,0	5,20E-04	Rectangular/B	100,58 TΩ	5,23E-02 TΩ	infinity
δR_{tx}	0,0 TΩ	4,62E-03 TΩ	Rectangular/B	-1	-4,62E-03 TΩ	infinity
R_X	100,58 TΩ					
		Combined standard uncertainty:			0,201 TΩ	
		Effective degrees of freedom:			62	
		Expanded uncertainty (95% coverage factor):			0,41 TΩ	

11 VSL

The following model equation is the basis for the uncertainty budget of the 1 TΩ and 100 TΩ resistors:

$$R_{DUT} = R_{ref} * (1 + \delta R_{refpwr} + \delta R_{refT}) * r * (1 + \delta r_{Vcal} + \delta r_{Vdrift} + \delta r_{Vlin})$$

$$* (1 + \delta r_{null} + \delta r_{bridgesens}) * (1 + \delta r_{closure} + \delta r_{leak} + \delta r_{decay})$$

Quantity	**Definition**
R_{DUT}	Value of DUT
R_{ref}	Value of reference resistor, determined at certain T and V
δR_{refpwr}	Power and/or voltage effect of reference resistor: calibration and use not always at the same voltage (1:10 step up method)
δR_{refT}	Temperature effect of reference resistor: calibration and use not always at same temperature. Includes non-equilibrium temperature of resistor and temperature sensor.
r	Measured ratio with adapted Wheatstone bridge (value at average date)
δr_{Vcal}	Combined uncertainty of voltage calibration with HP 3458A DVM
δr_{Vdrift}	Drift in EDC voltage sources since last voltage calibration
δr_{Vlin}	Linearity of voltage sources (including specified non-linearity of the HP 3458A)
δr_{null}	Gain error of null-detector
$\delta r_{bridgesens}$	Effect of bridge sensitivity
$\delta r_{closure}$	Measured closure: 100M - 1G - 10G – 100M and 10G - 100G - 1T - 10G
δr_{leak}	Effect of leakage in bridge, cables, reference resistor and DUT
δr_{decay}	Effect of insufficient wait times (25 % of measured difference between initial and final „circuit zero“ readings).

This results in the following uncertainty budget for the 1T MIL 9331G resistor with serial number 1101180 measured at 500 V:

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
R_{ref}	$99.589400 \cdot 10^{9}$	$822 \cdot 10^{3}$	normal	10	$8.2 \cdot 10^{6}$
δR_{refpwr}	0.0	$289 \cdot 10^{-9}$	rectangular	$1.0 \cdot 10^{12}$	$290 \cdot 10^{3}$
δR_{refT}	0.0	$1.15 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$1.2 \cdot 10^{6}$
r	10.027790	$136 \cdot 10^{-6}$	normal	$100 \cdot 10^{9}$	$14 \cdot 10^{6}$
δr_{Vcal}	0.0	$3.80 \cdot 10^{-6}$	normal	$1.0 \cdot 10^{12}$	$3.8 \cdot 10^{6}$
δr_{Vdrift}	0.0	$1.44 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$1.4 \cdot 10^{6}$
δr_{Vlin}	0.0	$1.15 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$1.2 \cdot 10^{6}$
δr_{null}	0.0	$1.15 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$1.2 \cdot 10^{6}$
$\delta r_{bridgesens}$	0.0	$1.44 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$1.4 \cdot 10^{6}$
$\delta r_{closure}$	0.0	$3.58 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$3.6 \cdot 10^{6}$
δr_{leak}	0.0	$5.77 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$5.8 \cdot 10^{6}$
δr_{decay}	0.0	$4.04 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$4.0 \cdot 10^{6}$
R_{DUT}	$998.6616 \cdot 10^{9}$	$18.3 \cdot 10^{6}$			

With as final result: $R_{1T\_MIL9331G\ sn.1101180}$ = (0.998 662 ± 0.000 037) TΩ (k = 2)

For the 1T GL 9337G resistor with serial number 69.573 measured at 1000 V this results in the following uncertainty budget:

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
R_{ref}	$99.589071 \cdot 10^{9}$	$789 \cdot 10^{3}$	normal	10	$7.9 \cdot 10^{6}$
δR_{refpwr}	0.0	$289 \cdot 10^{-9}$	rectangular	$1.0 \cdot 10^{12}$	$290 \cdot 10^{3}$
δR_{refT}	0.0	$1.15 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$1.2 \cdot 10^{6}$
r	10.0363340	$48.0 \cdot 10^{-6}$	normal	$100 \cdot 10^{9}$	$4.8 \cdot 10^{6}$
δr_{Vcal}	0.0	$4.50 \cdot 10^{-6}$	normal	$1.0 \cdot 10^{12}$	$4.5 \cdot 10^{6}$
δr_{Vdrift}	0.0	$981 \cdot 10^{-9}$	rectangular	$1.0 \cdot 10^{12}$	$980 \cdot 10^{3}$
δr_{Vlin}	0.0	$1.50 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$1.5 \cdot 10^{6}$
δr_{null}	0.0	$577 \cdot 10^{-9}$	rectangular	$1.0 \cdot 10^{12}$	$580 \cdot 10^{3}$
$\delta r_{bridgesens}$	0.0	$1.73 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$1.7 \cdot 10^{6}$
$\delta r_{closure}$	0.0	$3.58 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$3.6 \cdot 10^{6}$
δr_{leak}	0.0	$5.77 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$5.8 \cdot 10^{6}$
δr_{decay}	0.0	$2.60 \cdot 10^{-6}$	rectangular	$1.0 \cdot 10^{12}$	$2.6 \cdot 10^{6}$
R_{DUT}	$999.5092 \cdot 10^{9}$	$12.9 \cdot 10^{6}$			

With as final result: $R_{1T\_GL\ 9337G\ sn.69.573}$ = (0.999 509 ± 0.000 026) TΩ (k = 2)

The uncertainty budget for the other Guildline 1 TΩ resistor is essentially equal.

For the 100T MIL 9331G resistor with serial number 1100625 measured at 500 V this results in the following uncertainty budget:

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
R_{ref}	$998.6430\cdot10^{9}$	$25.0\cdot10^{6}$	normal	94	$2.4\cdot10^{9}$
δR_{refpwr}	0.0	$14.4\cdot10^{-6}$	rectangular	$94\cdot10^{12}$	$1.4\cdot10^{9}$
δR_{refT}	0.0	$11.5\cdot10^{-6}$	rectangular	$94\cdot10^{12}$	$1.1\cdot10^{9}$
r	94.2616	0.0240	normal	$1.0\cdot10^{12}$	$24\cdot10^{9}$
δr_{Vcal}	0.0	$3.70\cdot10^{-6}$	normal	$94\cdot10^{12}$	$350\cdot10^{6}$
δr_{Vdrift}	0.0	$4.39\cdot10^{-6}$	rectangular	$94\cdot10^{12}$	$410\cdot10^{6}$
δr_{Vlin}	0.0	$1.21\cdot10^{-6}$	rectangular	$94\cdot10^{12}$	$110\cdot10^{6}$
δr_{null}	0.0	$11.5\cdot10^{-6}$	rectangular	$94\cdot10^{12}$	$1.1\cdot10^{9}$
$\delta r_{bridgesens}$	0.0	$86.6\cdot10^{-6}$	rectangular	$94\cdot10^{12}$	$8.2\cdot10^{9}$
$\delta r_{closure}$	0.0	0.0	rectangular	0.0	0.0
δr_{leak}	0.0	$86.6\cdot10^{-6}$	rectangular	$94\cdot10^{12}$	$8.2\cdot10^{9}$
δr_{decay}	0.0	$92.4\cdot10^{-6}$	rectangular	$94\cdot10^{12}$	$8.7\cdot10^{9}$
R_{DUT}	$94.1337\cdot10^{12}$	$28.2\cdot10^{9}$			

With as final result: $R_{100T\_MIL9331G\ sn.1100625}$ = (94.13 ± 0.06) TΩ (*k* = 2)

For the 100T GL 9337G resistor with serial number 69.640 measured at 1000 V this results in the following uncertainty budget:

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution
R_{ref}	$998.6430\cdot10^{9}$	$25.0\cdot10^{6}$	normal	100	$2.5\cdot10^{9}$
δR_{refpwr}	0.0	$14.4\cdot10^{-6}$	rectangular	$100\cdot10^{12}$	$1.4\cdot10^{9}$
δR_{refT}	0.0	$11.5\cdot10^{-6}$	rectangular	$100\cdot10^{12}$	$1.2\cdot10^{9}$
r	100.27660	$4.80\cdot10^{-3}$	normal	$1.0\cdot10^{12}$	$4.8\cdot10^{9}$
δr_{Vcal}	0.0	$4.00\cdot10^{-6}$	normal	$100\cdot10^{12}$	$400\cdot10^{6}$
δr_{Vdrift}	0.0	$5.48\cdot10^{-6}$	rectangular	$100\cdot10^{12}$	$550\cdot10^{6}$
δr_{Vlin}	0.0	$1.21\cdot10^{-6}$	rectangular	$100\cdot10^{12}$	$120\cdot10^{6}$
δr_{null}	0.0	$11.5\cdot10^{-6}$	rectangular	$100\cdot10^{12}$	$1.2\cdot10^{9}$
$\delta r_{bridgesens}$	0.0	$14.4\cdot10^{-6}$	rectangular	$100\cdot10^{12}$	$1.4\cdot10^{9}$
$\delta r_{closure}$	0.0	0.0	rectangular	0.0	0.0
δr_{leak}	0.0	$86.6\cdot10^{-6}$	rectangular	$100\cdot10^{12}$	$8.7\cdot10^{9}$
δr_{decay}	0.0	$37.5\cdot10^{-6}$	rectangular	$100\cdot10^{12}$	$3.8\cdot10^{9}$
R_{DUT}	$100.1405\cdot10^{12}$	$11.2\cdot10^{9}$			

With as final result: $R_{100T\_GL\ 9337G\ sn.69.640}$ = (100.141 ± 0.022) TΩ (*k* = 2)

12 GUM

Rx – 1 TΩ

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_{Xm}	998544799098,0	2304218,7	Normal/A	1	4216 868,6	72
R_T	0	43867879,2	Uniform/B	1	43867879,2	Infinity
R_R	0	576510,1	Uniform/B	1	576510,1	Infinity
R_O	0	1153020217,1	Uniform/B	1	1153020217,1	Infinity
R_X	998 500 000 000					
		Combined standard uncertainty: / TΩ	0,0012			
		Effective degrees of freedom:			90	
		Expanded uncertainty (95% coverage factor): / TΩ			0,0024	

Rx – 100 TΩ

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_{Xm}	99057096218182	10441118481	Normal/A	1	10441118481	99
R_T	0	6515017699	Uniform/B	1	6515017699	Infinity
R_R	0	571906412	Uniform/B	1	571906412	Infinity
R_O	0	285953205834	Uniform/B	1	285953205834	Infinity
R_X	99 060 000 000 000					
		Combined standard uncertainty: / TΩ	0,58			
		Effective degrees of freedom:			99	
		Expanded uncertainty (95% coverage factor): / TΩ			0,58	

R_{Xm} – mean resistance of measured resistor
R_T – correction related to Guildline 6500 temperature error
R_R – correction related to Guildline 6500 resolution
R_O – correction related to teraohmmeter accuracy
R_X – measured resistance (rounded to 2 significant digits)

$R_X = R_{Xm} + R_T + R_R + R_O$

13 CMI

Example 1 TΩ, SN 69573, 1000 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 [TΩ] $u(R_i)$	Degree of freedom ν_i
R_S	0.999 37 TΩ	6 x 10^{-5} TΩ	normal	1.000	6 x 10^{-5}	∞
δ R_{SD}	+2 x 10^{-5} TΩ	5 x 10^{-5} / √ 3 TΩ	rectangular	1.000	2.9 x 10^{-5}	∞
δ L	5 x 10^{-5} / √ 3 TΩ	5 x 10^{-5} / √ 3 TΩ	rectangular	1.000	2.9 x 10^{-5}	∞
δ STD	2 x 10^{-5} / √ 3 TΩ	2 x 10^{-5} / √ 3 TΩ	rectangular	1.000	1.2 x 10^{-5}	∞
δ R_T	0 TΩ	2 x 10^{-5} / √ 3 TΩ	rectangular	1.000	1.2 x 10^{-5}	∞
δ R_{RH}	0 TΩ	2 x 10^{-5} / √ 3 TΩ	rectangular	1.000	1.2 x 10^{-5}	∞
δ R_L	0 TΩ	5 x 10^{-5} / √ 3 TΩ	rectangular	1.000	2.9 x 10^{-5}	∞
δ R_C	0 TΩ	5 x 10^{-5} / √ 3 TΩ	rectangular	1.000	2.9 x 10^{-5}	∞
repeatability R_{XM}	0.998 97 TΩ	0.5 x 10^{-5} TΩ	normal	1.000	0.5 x 10^{-5}	14
repeatability R_{SM}	0.998 78 TΩ	0.5 x 10^{-5} TΩ	normal	-1.000	0.5 x 10^{-5}	14
R_X	0.999 56 TΩ					
		Combined relative standard uncertainty:			8.63 x 10^{-5}	
		Effective degrees of freedom:			1 242 485	
		Expanded relative uncertainty (95% coverage factor):			17 x 10^{-5}	

The uncertainties of the high-resistance standards of 1 TΩ and 100 TΩ have been derived from reference high-resistance standard resistors of CMI (1TΩ - MI 9331S - 1030710 and 100 TΩ - MI 9331S - 1050116) whose values have been established once a year in the very high-ohmic laboratory of electrical resistance of CMI.

The principle of the method employed to establish the values of the reference resistors and corresponding uncertainties consists in successive calibration of the constant of the Keithley 6517B in the picoammeter mode using the Ohm's method with the help of a DATRON 4808 source.

The procedure starts from the 1 GΩ reference high-resistance and complete scale of reference resistors up to 100 TΩ is then built by successive calibrations of the constant of the picoammeter. The best uncertainties could be achieved for 1000 V, slightly worse at 500 V and the worst at 100 V.

In our very high-ohmic laboratory we then take the same K 6517B and calibrate other standard resistors of the same nominal values as the reference ones, using the comparative method (1:1) with K 6517B in the standard digital teraohmmeter mode.

In calculating the uncertainty of the comparative method, dominant contribution comes from the uncertainty of the corresponding reference standard and from its time instability. The influence of an error of the teraohmmeter has been suppressed by the use of the comparative method and it can be neglected if the measurement takes part in a short time after the reference scale has been established.

Equation used for evaluation of the uncertainty of an unknown resistance:

$R_X = R_S + \delta R_{SD} + R_{XM} - R_{SM} + \delta L + \delta R_{STD} + \delta R_T + \delta R_{RH} + \delta R_L + \delta R_C$

where R_X - unknown resistance
R_{XM} - mean value of measured unknown resistance (4 measurements: 24.11. ÷ 10.12.2010)

R_S - resistance of the reference standard
R_{SM} - mean value of measured reference standard (4 measurements: 24.11. ÷ 10.12.2010)

1. Type A evaluation of standard uncertainty (repeatability of R_X): $u_{A1} = 0.5 \times 10^{-5}$ TΩ (500 V and 1000 V)
   Type A evaluation of standard uncertainty (repeatability of R_S): $u_{A2} = 0.5 \times 10^{-5}$ TΩ (500 V and 1000 V)

2. The sources of error for the estimated Type B standard uncertainties are subdivised into three main categories:

I. Reference standard

δR_{SD} - drift in value of the reference standard since its last calibration was estimated from its calibration history to be $+2 \times 10^{-5}$ with deviation within $\pm 5 \times 10^{-5}$

II. Measurement system (K 6517B)

δL - error of linearity of the Keithley 6517B

δSTD - error caused by short term drift of the Keithley 6517B

III. Others components

δR_T - error of R_X and R_S due to a temperature deviation of the ambient environment (air)

δR_{RH} - error of R_X and R_S due to a relative humidity

δR_L - error of R_X and R_S due to leakage currents

δR_C - error due to a connection

1000 V:

$$u_B = \sqrt{(u_{B1})^2 + (u_{B2})^2 + ... + (u_{Bn})^2} \approx \sqrt{73.96 \times 10^{-10}}$$

$$u_C = \sqrt{(u_{A1})^2 + (u_{A2})^2 + (u_B)^2}$$

$$u_C = \sqrt{74.46 \times 10^{-10}} = 8.63 \times 10^{-5}$$

Expanded uncertainty:
$U = k \times u_C = 2 \times 8.63 \times 10^{-5} \approx 17 \times 10^{-5}$

R_X = 0.999 56 TΩ ± 17 x 10^{-5} TΩ (k=2)

Example 100 TΩ, SN 69641, 1000 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 [GΩ] $u(R_i)$	Degree of freedom ν_i
R_S	84.01 TΩ	24.5 x 10^{-2} TΩ	normal	1.000	24.5 x 10^{-2}	∞
δ R_{SD}	+20 x 10^{-2} TΩ	50 x 10^{-2} / √ 3 TΩ	rectangular	1.000	28.9 x 10^{-2}	∞
δ L	5 x 10^{-2} / √ 3	5 x 10^{-2} / √ 3 TΩ	rectangular	1.000	2.9 x 10^{-2}	∞
δ STD	2 x 10^{-2} / √ 3	2 x 10^{-2} / √ 3 TΩ	rectangular	1.000	1.2 x 10^{-2}	∞
δ R_T	0 TΩ	2 x 10^{-2} / √ 3 TΩ	rectangular	1.000	1.2 x 10^{-2}	∞
δ R_{RH}	0 TΩ	2 x 10^{-6} / √ 3 TΩ	rectangular	1.000	1.2 x 10^{-2}	∞
δ R_L	0 TΩ	5 x 10^{-6} / √ 3 TΩ	rectangular	1.000	2.9 x 10^{-2}	∞
δ R_C	0 TΩ	5 x 10^{-6} / √ 3 TΩ	rectangular	1.000	2.9 x 10^{-2}	∞
repeatability R_{XM}	100.38 TΩ	0.5 x 10^{-2} TΩ	normal	1.000	0.5 x 10^{-2}	14
repeatability R_{SM}	83.92 TΩ	0.5 x 10^{-2} TΩ	normal	-1.000	0.5 x 10^{-2}	14
R_X	100.47 TΩ					
		Combined relative standard uncertainty:			38.28 x 10^{-2}	
		Effective degrees of freedom:			480 989 654	
		Expanded relative uncertainty (95% coverage factor):			77 x 10^{-2}	

Equation used for evaluation of the uncertainty of an unknown resistance:
$R_X = R_S + \delta R_{SD} + R_{XM} - R_{SM} + \delta L + \delta R_{STD} + \delta R_T + \delta R_{RH} + \delta R_L + \delta R_C$

where R_X - unknown resistance
R_{XM} - mean value of measured unknown resistance (4 measurements: 24.11. ÷ 10.12.2010)

R_S - resistance of the reference standard
R_{SM} - mean value of measured reference standard (4 measurements: 24.11. ÷ 10.12.2010)

1. Type A evaluation of standard uncertainty (repeatability of R_X): $u_{A1} = 0.5 \times 10^{-2}$ TΩ (500 V)
   Type A evaluation of standard uncertainty (repeatability of R_S): $u_{A2} = 1 \times 10^{-2}$ TΩ (500 V)
   Type A evaluation of standard uncertainty (repeatability of R_X): $u_{A1} = 0.5 \times 10^{-2}$ TΩ (1000 V)
   Type A evaluation of standard uncertainty (repeatability of R_S): $u_{A2} = 0.5 \times 10^{-2}$ TΩ (1000 V)

2. The sources of error for the estimated Type B standard uncertainties are subdivised into three main categories:

<u>I. Reference standard</u>

δR_{SD} - drift in value of the reference standard since its last calibration was estimated from its calibration history to be +20 x 10^{-2} with deviation within ± 50 x 10^{-2}

<u>II. Measurement system (K 6517B)</u>

δL - error of linearity of the Keithley 6517B

δ STD - error caused by short term drift of the Keithley 6517B

<u>III. Others components</u>

δR_T - error of R_X and R_S due to a temperature deviation of the ambient environment (air)

δR_{RH} - error of R_X and R_S due to a relative humidity

δR_L - error of R_X and R_S due to leakage currents

δR_C - error due to a connection

1000 V:

$$u_B = \sqrt{(u_{B1})^2 + (u_{B2})^2 + ... + (u_{Bn})^2} \approx \sqrt{1465.01 \times 10^{-4}}$$

$$u_C = \sqrt{(u_{A1})^2 + (u_{A2})^2 + (u_B)^2}$$

$$u_C = \sqrt{1465.51 \times 10^{-4}} = 38.28 \times 10^{-2}$$

Expanded uncertainty:
$U = k \times u_C = 2 \times 38.28 \times 10^{-2} \approx 77 \times 10^{-2}$
R_X = 100.47 TΩ ± 77 x 10^{-2} TΩ (k=2)

14 IPQ

1 TΩ uncertainty budget - combined type A and type B uncertainties

1 Tohm - 500 V

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribuition / method of evaluation (A	Sensitivity coefficient *ci*	Uncertainty contribution $(ui(Rx))^2$	Degree of freedom ν_i
Measuring set-up	**9,99722E+11**	1,15E-03	B / rectangular	1	1,33E-06	50
Experimental standard deviation of the mean	-	2,11E-05	A / normal	1	4,44E-10	4
Standard uncertainty of temperature	-	1,22E-03	A / normal	1	1,48E-06	4
***R** x*	**9,99722E+11**					
					ν_{eff}=	1,36E+01

Combined standard uncertainty, *uc (R x)* =	1,7E-03	
	1,7	**mΩ/Ω**
Effective degrees of freedom=	2,2E+00	
Expanded uncertainty (95% coverage factor) =	3,7E-03	
	3,7	**mΩ/Ω**

1 Tohm - 1000 V

Quantity *Xi*	Estimate *xi*	Standard uncertainty *u(xi)*	Probability distribuition / method of evaluation (A	Sensitivity coefficient *ci*	Uncertainty contribution $(ui(Rx))^2$	Degree of freedom ν_i
Measuring set-up	**9,99661E+11**	1,15E-03	B / rectangular	1	1,33E-06	50
Experimental standard deviation of the mean	-	9,39E-06	A / normal	1	8,81E-11	4
Standard uncertainty of temperature	-	1,21E-03	A / normal	1	1,48E-06	4
***R** x*	**9,99661E+11**					
					ν_{eff}=	1,36E+01

Combined standard uncertainty, *uc (R x)* =	1,7E-03	
	1,7	**mΩ/Ω**
Effective degrees of freedom=	2,2E+00	
Expanded uncertainty (95% coverage factor) =	3,7E-03	
	3,7	**mΩ/Ω**

100 TΩ uncertainty budget - combined type A and type B uncertainties.

100 Tohm - 500 V

Quantity Xi	Estimate xi	Standard uncertainty $u(xi)$	Probability distribuition / method of evaluation (A	Sensitivity coefficient ci	Uncertainty contribution $(ui(Rx))^2$	Degree of freedom $\nu\iota$
Measuring set-up	**9,99947E+13**	2,89E-03	B / rectangular	1	8,33E-06	50
Experimental standard deviation of the mean	-	1,36E-03	A / normal	1	1,85E-06	3
Standard uncertatinty of temperature	-	1,62E-03	A / normal	1	2,61E-06	3
R $_{x}$	**9,99947E+13**					
					ν_{eff}=	3,41E+01

Combined standard uncertainty, $uc\ (R_x)$ =	3,6E-03	
	3,6	**mΩ/Ω**
Effective degrees of freedom=	2,1E+00	
Expanded uncertainty (95% coverage factor) =	7,4E-03	
	7,4	**mΩ/Ω**

100 Tohm - 1000 V

Quantity Xi	Estimate xi	Standard uncertainty $u(xi)$	Probability distribuition / method of evaluation (A	Sensitivity coefficient ci	Uncertainty contribution $(ui(Rx))^2$	Degree of freedom $\nu\iota$
Measuring set-up	**9,99913E+13**	2,89E-03	B / rectangular	1	8,33E-06	50
Experimental standard deviation of the mean	-	7,58E-04	A / normal	1	5,75E-07	3
Standard uncertatinty of temperature	-	9,65E-04	A / normal	1	9,32E-07	3
R $_{x}$	**9,99913E+13**					
					ν_{eff}=	5,41E+01

Combined standard uncertainty, $uc\ (R_x)$ =	3,1E-03	
	3,1	**mΩ/Ω**
Effective degrees of freedom=	2,0E+00	
Expanded uncertainty (95% coverage factor) =	6,4E-03	
	6,4	**mΩ/Ω**

15 CEM

In the analysis of uncertainty for this comparison, the following mathematical model is considered. For all standards:

$$R_x = rR_s\left(1+\alpha\delta_T+\beta\delta_T{}^2\right)+\delta_L \tag{1}$$

, where the symbols have the following meanings:

- R_x: Value of the travelling standard, relative to Quantum Hall Resistance.
- r: Measured ratio of 1 TΩ to 100 GΩ standard resistor.
- R_s: Value of 100 GΩ or 10 TΩ standard.
- α: Temperature coefficient of the corresponding standard.
- β: Temperature coefficient of the corresponding standard.
- δ_T: Temperature difference between measures.
- δ_L: Correction to R_x due to leakage currents.

With the following expression for uncertainty:

$$\frac{u^2(R_x)}{(R_x)^2}=\frac{u^2(r)}{(r)^2}+\frac{u^2(R_s)}{(R_s)^2}+\frac{\delta_T{}^2u^2(\alpha)}{\left(1+\alpha\delta_T+\beta\delta_T{}^2\right)^2}+\frac{(\alpha+2\beta\delta_T)^2u^2(\delta_T)}{\left(1+\alpha\delta_T+\beta\delta_T{}^2\right)^2}+\frac{\delta_T{}^4u^2(\beta)}{\left(1+\alpha\delta_T+\beta\delta_T{}^2\right)^2}+u^2(\delta_L) \tag{4}$$

The results individualized for every resistor are presented in separated tables.

Test voltage: V_{test} = 500 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 $u(R_i)$	Degree of freedom ν_i
r	9,984 88	1,1E-05	A	1	1,07E-05	5
Rs	1,000 243 4 E+11	9,9 E-06	B	1	9,86E-06	7
α	1,40E-05	5,00E-07	B	0,021	1,05E-08	∞
β	-1,30E-06	5,00E-08	B	0,000	2,21E-11	∞
δ_T	0,021	0,011	A	1,39E-05	1,48E-07	5
δ_L	0,0	3,00E-06	B	1	3,00E-06	∞
R_x	9,987 32 E+11					
		Combined standard uncertainty:			*1,49E-05*	
		Effective degrees of freedom:			*12*	
		Expanded uncertainty (95% coverage factor):			*3,2E-05*	

Test voltage: V_{test} = -500 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 $u(R_i)$	Degree of freedom ν_i
r	9,984 66	2,1E-05	A	1	2,08E-05	5
Rs	1,000 243 4 E+11	9,9 E-06	B	1	9,86E-06	7
α	1,40E-05	5,00E-07	B	0,020	1,02E-08	∞
β	-1,30E-06	5,00E-08	B	0,000	2,10E-11	∞
δ_T	0,020	0,011	A	1,39E-05	1,50E-07	5
δ_L	0,0	3,00E-06	B	1	3,00E-06	∞
R_x	9,987 09 E+11					
		Combined standard uncertainty:			*2,32E-05*	
		Effective degrees of freedom:			*7*	
		Expanded uncertainty (95% coverage factor):			*5,5E-05*	

Test voltage: V_{test} = 1000 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 $u(R_i)$	Degree of freedom ν_i
r	9,984 63	2,9E-06	A	1	2,88E-06	4
Rs	1,000 245 4 E+11	6,20E-06	B	1	6,20E-06	7
α	1,40E-05	5,00E-07	B	0,021	1,06E-08	∞
β	-1,30E-06	5,00E-08	B	0,000	2,24E-11	∞
δ_T	0,021	0,011	A	1,39E-05	1,48E-07	4
δ_L	0,0	3,00E-06	B	1	3,00E-06	∞
R_x	9,987 08 E+11					
		Combined standard uncertainty:			*7,47E-06*	
		Effective degrees of freedom:			*13*	
		Expanded uncertainty (95% coverage factor):			*1,6E-05*	

Test voltage: V_{test} = -1000 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 $u(R_i)$	Degree of freedom ν_i
r	9,984 48	5,3E-06	A	1	5,35E-06	5
Rs	1,000 245 4 E+11	6,20E-06	B	1	6,20E-06	7
α	1,40E-05	5,00E-07	B	0,021	1,03E-08	∞
β	-1,30E-06	5,00E-08	B	0,000	2,14E-11	∞
δ_T	0,021	0,011	A	1,39E-05	1,48E-07	5
δ_L	0,0	3,00E-06	B	1	3,00E-06	∞
R_x	9,986 93 E+11					
		Combined standard uncertainty:			*8,72E-06*	
		Effective degrees of freedom:			*15*	
		Expanded uncertainty (95% coverage factor):			*1,9E-05*	

16 SMD

Calibration of 1 TΩ resistor; SN: 69573 - at 500 V by a transfer method using a high resistance meter.

Model Equation:

$Runk=Rs*(READunkP+READunkN)/(READsP+READsN)+\delta driftRs+\delta TRs+\delta TRunk+\delta VRs+\delta VRunk+\delta noise+\delta Leak+\delta resol$

List of Quantities:

Quantity	Unit	Definition
Runk	TΩ	Calculated value of the unknown resistor
Rs	TΩ	Value of the standard resistor from last calibration certificate
READunkP	TΩ	Mean value of the measurement results for positive voltage of the unknown resistor
READunkN	TΩ	Mean value of the measurement results for negative voltage of the unknown resistor
READsP	TΩ	Mean value of the measurement results for positive voltage of the standard resistor
READsN	TΩ	Mean value of the measurement results for negative voltage of the standard resistor
δdriftRs	TΩ	Drift contribution of the standard resistor
δTRs	TΩ	Temperature contribution of the standard resistor
δTRunk	TΩ	Temperature contribution of the unknown resistor
δVRs	TΩ	Voltage contribution of the standard resistor
δVRunk	TΩ	Voltage contribution of the unknown resistor
δnoise	TΩ	Noise contribution (cables, electromagnetic interference, etc)
δLeak	TΩ	Contribution of the limited insulation
δresol	TΩ	Contribution of the instrument resolution on the measurement result indication

Uncertainty Budget:

Runk: Calculated value of the unknown resistor

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
Rs	0.999900 TΩ	$250\cdot10^{-6}$ TΩ	normal	1.0	$250\cdot10^{-6}$ TΩ	89.4 %
READunkP	0.9995434 TΩ	$64.9\cdot10^{-6}$ TΩ	normal	0.50	$32\cdot10^{-6}$ TΩ	1.5 %
READunkN	0.9995508 TΩ	$50.4\cdot10^{-6}$ TΩ	normal	0.50	$25\cdot10^{-6}$ TΩ	0.9 %
READsP	0.9998627 TΩ	$56.1\cdot10^{-6}$ TΩ	normal	-0.50	$-28\cdot10^{-6}$ TΩ	1.1 %
READsN	0.9998126 TΩ	$84.8\cdot10^{-6}$ TΩ	normal	-0.50	$-42\cdot10^{-6}$ TΩ	2.6 %
δdriftRs	0.0 TΩ	$28.9\cdot10^{-6}$ TΩ	rectangular	1.0	$29\cdot10^{-6}$ TΩ	1.2 %
δTRs	0.0 TΩ	$28.9\cdot10^{-6}$ TΩ	rectangular	1.0	$29\cdot10^{-6}$ TΩ	1.2 %
δTRunk	0.0 TΩ	$28.9\cdot10^{-6}$ TΩ	rectangular	1.0	$29\cdot10^{-6}$ TΩ	1.2 %
δVRs	0.0 TΩ	$462\cdot10^{-9}$ TΩ	rectangular	1.0	$460\cdot10^{-9}$ TΩ	0.0 %
δVRunk	0.0 TΩ	$462\cdot10^{-9}$ TΩ	rectangular	1.0	$460\cdot10^{-9}$ TΩ	0.0 %
δnoise	0.0 TΩ	$17.3\cdot10^{-6}$ TΩ	rectangular	1.0	$17\cdot10^{-6}$ TΩ	0.4 %
δLeak	0.0 TΩ	$17.3\cdot10^{-6}$ TΩ	rectangular	1.0	$17\cdot10^{-6}$ TΩ	0.4 %
δresol	0.0 TΩ	$577\cdot10^{-9}$ TΩ	rectangular	1.0	$580\cdot10^{-9}$ TΩ	0.0 %
Runk	0.999609 TΩ	$264\cdot10^{-6}$ TΩ				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
Runk	0.99961 TΩ	$530\cdot10^{-6}$ TΩ	2.00	95% (t-table 95.45%)

Calibration of 100 TΩ resistor, SN: 69641 - at 1000 V by a transfer method using a high resistance meter.

Uncertainty Budget:

Runk: Calculated value of the unknown resistor

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
Rs	100.124 TΩ	0.170 TΩ	normal	1.0	0.17 TΩ	58.5 %
READunkP	100.571 TΩ	0.177 TΩ	normal	0.50	0.088 TΩ	15.9 %
READunkN	99.6656 TΩ	0.0855 TΩ	normal	0.50	0.043 TΩ	3.7 %
READsP	100.833 TΩ	0.191 TΩ	normal	-0.50	-0.095 TΩ	18.4 %
READsN	99.9353 TΩ	0.0832 TΩ	normal	-0.50	-0.041 TΩ	3.5 %
δdriftRs	0.0 TΩ	$2.89 \cdot 10^{-3}$ TΩ	rectangular	1.0	$2.9 \cdot 10^{-3}$ TΩ	0.0 %
δTRs	0.0 TΩ	$2.89 \cdot 10^{-3}$ TΩ	rectangular	1.0	$2.9 \cdot 10^{-3}$ TΩ	0.0 %
δVRs	0.0 TΩ	$46.2 \cdot 10^{-6}$ TΩ	rectangular	1.0	$46 \cdot 10^{-6}$ TΩ	0.0 %
δVRunk	0.0 TΩ	$46.2 \cdot 10^{-6}$ TΩ	rectangular	1.0	$46 \cdot 10^{-6}$ TΩ	0.0 %
δTRunk	0.0 TΩ	$2.89 \cdot 10^{-3}$ TΩ	rectangular	1.0	$2.9 \cdot 10^{-3}$ TΩ	0.0 %
δnoise	0.0 TΩ	$1.15 \cdot 10^{-3}$ TΩ	rectangular	1.0	$1.2 \cdot 10^{-3}$ TΩ	0.0 %
δLeak	0.0 TΩ	$1.73 \cdot 10^{-3}$ TΩ	rectangular	1.0	$1.7 \cdot 10^{-3}$ TΩ	0.0 %
δresol	0.0 TΩ	$57.7 \cdot 10^{-6}$ TΩ	rectangular	1.0	$58 \cdot 10^{-6}$ TΩ	0.0 %
Runk	99.859 TΩ	0.222 TΩ				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
Runk	99.86 TΩ	0.44 TΩ	2.00	95% (t-table 95.45%)

17 LNE

The resistance value measured by means of the LNE integration bridge is given by the relation :

$$R_x = \frac{U_e + e_i}{\bar{I}_x} \quad (1)$$

with :

$$\bar{I}_x = (C+\gamma)\cdot(1-k_\omega)\cdot\frac{k_M \cdot \Delta\overline{w}_n}{T} + \frac{1}{\rho}\cdot(e_i - \frac{S}{2\cdot N}) - I_0 \quad (2)$$

Where :

U_e standard DC voltage source,

e_i input residual voltage of the integration bridge,

$\bar{I}_x$ mean value of the current measured during a cycle,

C is the value of the standard capacitance and its corrections,

γ is the correction term related to the stray capacitances,

k_ω, ρ represent the correction factors related to stray capacitances and resistances,

$\Delta w = k_M \cdot \Delta\overline{w}_n$ is the variation of the output voltage of the integration bridge measured by a calibrated digital voltmeter over a cycle,

k_M represents the gain of the calibrated voltmeter,

$\Delta\overline{w}_n$ represents the mean value of the voltage differences measured during a cycle,

T is the sampling period of the output voltage measurements,

S is a correction term related to the output voltage during the charge of the integration capacity,

N is the number of measurements on a cycle (the integration capacity and the maximum output voltage are chosen to have about 100 measures on a cycle),

I_0 is the residual current.

Taking into account the uncertainties of I_x components and the type A uncertainties of the measured resistance leads to the final relation of the combined uncertainty :

$$\frac{u_c^2(R_x)}{R_x} = \frac{u_c^2(U_e) + u_c^2(e_i)}{U_e^2} + \frac{u_c^2(I_x)}{I_x^2} + \frac{u_A^2(R_x)}{R_x} \quad (3)$$

A numerical example is provided for the uncertainty budget of 1 TΩ resistor measured at 500 V, positive polarity.

The uncertainty budget related to the measured current $\boldsymbol{I_x}$ is resumed in the following table :

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$
k_M	0.9999984	1.30x10^{-6} -	5.0x10^{-10} -	6.52x10^{-16}
(C+γ)	1.0x10^{-9} F	1.03x10^{-14} F	0.5 A.F^{-1}	5.17x10^{-15}
T	1.0 s	8.50x10^{-7} s	5.0x10^{-10} A.s^{-1}	4.25x10^{-16}
(1-kω)	1.0	1.00x10^{-10} -	5.0x10^{-10} -	5.00x10^{-20}
$\Delta\overline{w}_n$	0.5 V	0.0 V	1.0x10^{-9} A.V^{-1}	0.00
$\frac{1}{\rho}$	-1.55x10^{-17} S	6.70x10^{-18} S	2.21x10^{-4} V	1.48x10^{-21}
e_i	2.21x10^{-4} V	1.00x10^{-6} V	-1.55x10^{-17} S	-1.55x10^{-23}
S	0.0 V	4.3 V	-7.73x10^{-20} S	-3.32x10^{-19}
I_0	0 A	1.00x10^{-16} A	1.0 -	1.00x10^{-16}
I_x	5.00x10^{-10} A			
		Combined standard uncertainty:		5.23x10^{-15} A

The uncertainty budget for 1 TΩ resistance standard, model MI SN 9331 G and 500V

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
U_e	500.0 V	7.97x10^{-4} V	Normal/B	2.00x10^{-3} V^{-1}	1.59x10^{-6}	∞
e_i	2.21x10^{-4} V	1.00x10^{-6} V	Normal/B	2.00x10^{-3} V^{-1}	2.00x10^{-9}	∞
I_x	5.00x10^{-10} A	5.23x10^{-15} A	Normal/B	2.00x10^{9} A^{-1}	1.05x10^{-5}	∞
R_x	9.98765x10^{11} Ω	8.57x10^{5} Ω	Normal/A	1.00x10^{-12} Ω^{-1}	8.57x10^{-7}	10
		Combined standard uncertainty:			1.06x10^{-5}	
		Effective degrees of freedom:			2.33x10^{8}	
		Expanded uncertainty (95% coverage factor): k=2			2.12x10^{-5}	

A second numerical example is provided for the uncertainty budget of 100 TΩ resistor (model Guildline SN 69640) measured at 1000 V, negative polarity.

The main components that change the uncertainty budget refer to the standard voltage source, the capacity value, the internal and external conductance of the integration bridge.

The uncertainty budget related to the measured current I_x is resumed in the following table :

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$
k_M	0.9999984	1.30×10^{-6} -	-1.0×10^{-11} -	1.30×10^{-17}
$(C+\gamma)$	1.0×10^{-11} F	1.91×10^{-16} F	-1.0 $A.F^{-1}$	-1.91×10^{-16}
T	1.0 s	8.50×10^{-7} s	-1.0×10^{-11} $A.s^{-1}$	-8.50×10^{-18}
$(1-k\omega)$	1.0	1.00×10^{-10} -	-1.0×10^{-11} -	-9.99×10^{-22}
$\Delta\overline{w}_n$	-1.0 V	0.0 V		0.00
$\frac{1}{\rho}$	-6.45×10^{-17} S	1.20×10^{-17} S	2.21×10^{-4} V	2.65×10^{-21}
e_i	2.21×10^{-4} V	1.00×10^{-6} V	-6.45×10^{-17} S	-6.45×10^{-23}
S	0.0 V	4.3 V	-3.22×10^{-19} S	-1.39×10^{-18}
I_0	0.0 A	1.00×10^{-16} A	1.0 -	1.00×10^{-16}
I_x	-9.99×10^{-12} A			
		Combined standard uncertainty:		2.16×10^{-16} A

The uncertainty budget for 100 TΩ resistance standard (model GUILDLINE SN 69640) and -1000V

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
U_e	-1000.0 V	8.37×10^{-4} V	Normal/B	-1.00×10^{-3} V^{-1}	-8.37×10^{-7}	∞
e_i	2.21×10^{-4} V	1.00×10^{-6} V	Normal/B	-1.00×10^{-3} V^{-1}	-1.00×10^{-9}	∞
I_x	-9.99×10^{-12} A	2.17×10^{-16} A	Normal/B	-1.00×10^{11} A^{-1}	-2.17×10^{-5}	∞
R_x	1.00091×10^{14} Ω	7.89×10^{9} Ω	Normal/A	9.99×10^{-15} Ω^{-1}	7.88×10^{-5}	100
		Combined standard uncertainty:			8.17×10^{-5}	
		Effective degrees of freedom:			1.16×10^{8}	
		Expanded uncertainty (95% coverage factor): k=2			1.63×10^{-4}	

18 UME

Model Function :

$$R_X = \frac{(R_S + \delta R_{Sdrf} + \delta R_{STemp} + \delta R_{Svolt}) \times (V_X + \delta V_{Xdrf})}{(V_S + \delta V_{Sdrf})} - \delta R_{XTemp} + \delta R_{Xleakage}$$

Model Function Explanations

R_X	Resistance value of the unknown resistor
R_S	Resistance value of the reference resistor traceable to Quantum Hall Resistance
δR_{Sdrf}	Correction due to the drift of the reference resistor since its last calibration
δR_{STemp}	Correction due to temperature related resistance variation of the reference resistor
δR_{Svolt}	Correction due to voltage related resistance variation of the reference resistor
V_X	Applied unknown voltage value on unknown resistor
δV_{Xdrf}	Correction due to the drift of the DC voltage measurement device (multimeter) since its last calibration
V_S	Applied reference voltage value on reference resistor
δV_{Sdrf}	Correction due to the drift of the DC voltage measurement device (multimeter) since its last calibration
δR_{Xtemp}	Correction due to temperature related resistance variation of the unknown resistor
$\delta R_{Xleakage}$	Correction due to leakage and noise effects of the bridge

1 Tohm Guildline 9337 Serial No : **69574** / Measurement Voltage : **500 V**

Quantity	Estimate	Standard uncertainty	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient	Uncertainty contribution	Degree of freedom
X_i	x_i	$u(x_i)$		c_i	$u(R_i)$	ν_i
R_s	1,00E+09 ohm	1,20E+04 ohm	Normal / B	1000	6,00E+06 ohm	1000
δR_{sdrf}	0	5,00E+03 ohm	Rect. / B	1000	2,89E+06 ohm	100
$\delta R_{stemp.}$	0	8,00E+03 ohm	Rect. / B	1000	4,62E+06 ohm	1000
δR_{svolt}	0	1,00E+03 ohm	Rect. / B	1000	5,77E+05 ohm	20
V_s	0,50 V	1,00E-06 V	Normal / B	-2,00E+12 ohm/V	-1,00E+06 ohm	1000
δV_{sdrf}	0	1,90E-06 V	Rect. / B	-2,00E+12 ohm/V	-2,19E+06 ohm	1000
V_x	500,00 V	1,25E-03 V	Normal / B	2,00E+09 ohm/V	1,25E+06 ohm	1000
δV_{xdrf}	0	2,75E-03 V	Rect. / B	2,00E+09 ohm/V	3,18E+06 ohm	1000
δR_{xtemp}	0	3,00E+07 ohm	Rect. / B	-1	-1,73E+07 ohm	1000
$\delta R_{xleakage}$	0	2,12E+07 ohm	Rect. / B	1	1,22E+07 ohm	10
Repeatibility of measurements		6,94E+06 ohm	Normal / A	1	6,94E+06 ohm	5
R_x	1,00E+12 ohm					
		Combined standard uncertainty:			***24,1 µΩ/Ω***	
		Effective degrees of freedom:			***121***	
		Expanded uncertainty (95,45 % coverage factor):			***49 µΩ/Ω***	

100 Tohm Guildline 9337 Serial No : **69640**/ Measurement Voltage : **1000 V**

Quantity	Estimate	Standard uncertainty	Probability distribution /method of evaluation (A, B)	Sensitivity coefficient	Uncertainty contribution	Degree of freedom
X_i	x_i	$u(x_i)$		c_i	$u(R_i)$	ν_i
R_s	1,00E+13 ohm	1,73E+09 ohm	Normal / B	10	8,64E+09 ohm	1000
δR_{sdrf}	0	5,00E+08 ohm	Rect. / B	10	2,89E+09 ohm	100
$\delta R_{stemp.}$	0	1,00E+09 ohm	Rect. / B	10	5,77E+09 ohm	1000
δR_{svolt}	0	1,00E+09 ohm	Rect. / B	10	5,77E+09 ohm	20
V_s	100,00 V	2,00E-04 V	Normal / B	-1,00E+12 ohm/V	-1,00E+08 ohm	1000
δV_{sdrf}	0	4,90E-04 V	Rect. / B	-1,00E+12 ohm/V	-2,83E+08 ohm	1000
V_x	1000,00 V	2,50E-03 V	Normal / B	1,00E+11 ohm/V	1,25E+08 ohm	1000
δV_{xdrf}	0	5,00E-03 V	Rect. / B	1,00E+11 ohm/V	2,89E+08 ohm	1000
δR_{xtemp}	0	8,00E+09 ohm	Rect. / B	-1	-4,62E+09 ohm	1000
$\delta R_{xleakage}$	0	3,80E+10 ohm	Rect. / B	1	2,19E+10 ohm	10
Repeatibility of measurements		2,83E+09 ohm	Normal / A	1	2,83E+09 ohm	11
R_x	1,00E+14 ohm					
		Combined standard uncertainty:			***257,0 µΩ/Ω***	
		Effective degrees of freedom:			***19***	
		Expanded uncertainty (95,45 % coverage factor):			***550 µΩ/Ω***	

Annex D

Supplementary Comparison EURAMET.EM-S32
Comparison of Resistance Standards at 1 TΩ and 100 TΩ

TECHNICAL PROTOCOL

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Contents

1. Introduction

Resistance standards with values in the TΩ range play an important role in electrical instrumentation. The calibration of such standards is, thus, a service offered by many metrology institutes. The techniques used to measure very high resistance values differ quite substantially from the calibration techniques applied in the lower resistance ranges. For this reason, the key comparisons carried out so far in the field of dc resistance do not cover the high end of the scale in the TΩ range. The EURAMET technical committee for electricity and magnetism, thus, decided in 2008 to organise a supplementary comparison of resistance at 1 TΩ and 100 TΩ, based on well characterized travelling standards.

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

Two different types of travelling standards are used:

1. Standard air resistor, model 9331G, manufactured by Measurements International (one 1 TΩ standard and one 100 TΩ standard).
   The schematic of the standard is shown in Fig. 1. The standard has an inner and an outer enclosure. The inner enclosure, filled with dry Argon gas, contains the resistive element. Glass to metal seals at both ends of the inner enclosure are used to connect the resistor to the input connectors. The two ends of the inner box are isolated from each other. They can be driven by guard potentials applied to the shields of the input connectors (N-type). These connectors are electrically isolated from the outer enclosure. A terminal is provided to connect the outer box to the ground potential.

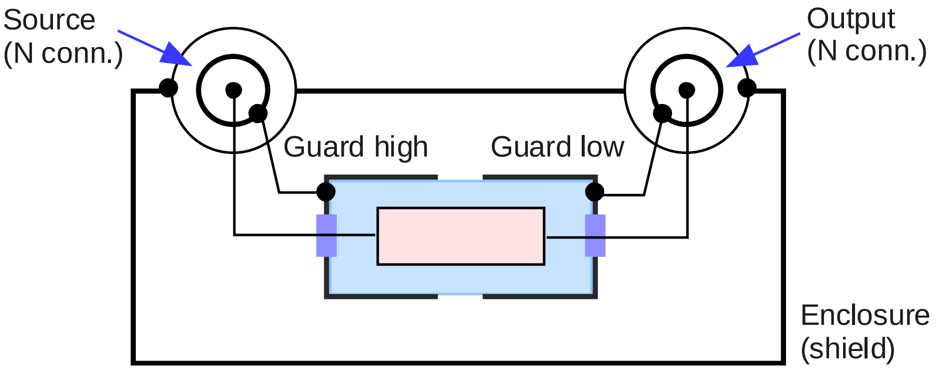

Figure 1: MI 9331 G standard (1 TΩ and 100 TΩ)

2. Standard air resistor, model 9337, manufactured by Guildline (two 1 TΩ standards and two 100 TΩ standards). These standards were kindly provided by Guildline Instruments Limited CA for this comparison.
   The schematic is shown in Fig. 2. The required resistance value is achieved by the use of a resistance divider network. Assuming that the output terminal and the shield are on the same potential, the resistance R_x between the source and output terminal is given by:

$$R_x = R_i + R_o\left(1 + \frac{R_i}{R_d}\right)$$

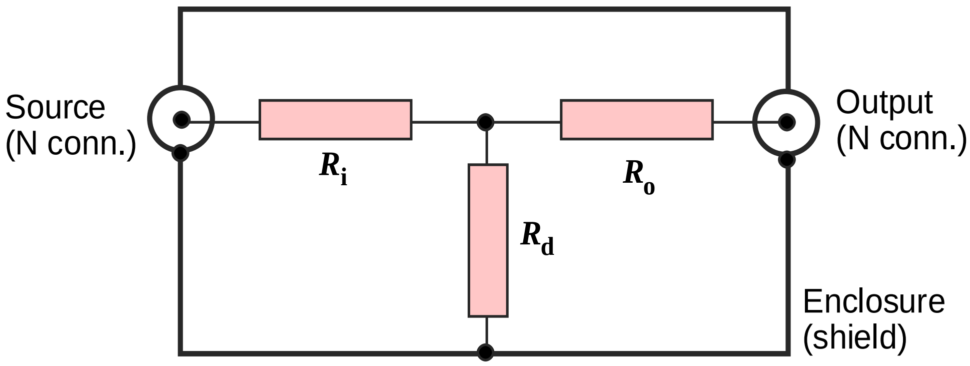

Figure 2: Guildline 9337standard (1 TΩ and 100 TΩ)

The comparison is carried out in one single loop with three 1 TΩ and three 100 TΩ standards.

2.2 Quantities to be measured

- Resistance of the 1 TΩ standards at the following conditions:
  test voltage: V_{test} = 500 V and 1000 V (both polarities)
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

- Resistance of the 100 TΩ standards at the following conditions:
  test voltage: V_{test} = 500 V and 1000 V (both polarities)
  ambient temperature: (23 ± 0.2) °C
  relative humidity: (50 ± 10) %

2.3 Method of computation of the Reference value

The comparison reference value (CRV) will be evaluated following the principles laid down in [1]. 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) using the sensitivity coefficients determined by the pilot laboratory;
- For the calculation of the CRV and the degrees of equivalence, a constraint least-square optimization process will be used;
- If for a result, the uncertainty contribution due to the traceability to another NMI amounts to a substantial part of the overall uncertainty value, the result is not taken into account in the calculation of the CRV.

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 following institutes announced the interest to participate in the comparison.

No	Country	Institute	Acronym
1	Belgium	Service de la Métrologie	SMD
2	Bulgaria	Bulgarian Institute of Metrology	NCM
3	Czech Re-public	Czech Metrology Institute	CMI
4	Finland	Centre for Metrology and Accreditation	MIKES
5	France	Laboratoire National de Métrologie et d'Essais	LNE
6	Germany	Physikalisch-Technische Bundesanstalt	PTB
7	Greece	Hellenic Institute of Metrology	EIM
8	Italy	Istituto Nazionale di Ricerca Metrologica	INRIM
9	Netherlands	Van Swinden Laboratorium	VSL
10	Poland	Central Office of Measures	GUM
11	Portugal	Instituto Português da Qualidade	IPQ
12	Romania	National Institute of Metrology	INM
13	Slovakia	Slovak Institute of Metrology	SMU
14	Slovenia	Slovenian Institute of Quality and Metrology	SIQ
15	Spain	Spanish Centre of Metrology	CEM
16	Sweden	Technical Research Institute of Sweden	SP
17	Switzerland	Federal Office of Metrology	METAS
18	Turkey	Ulusal Metroloji Enstitüsü	UME

Table 1: Participants

3.3 Time schedule

The comparison is carried out in one loop. The circulation of the standards starts in March 2009 and is planned to end in December 2010. The detailed time schedule for the comparison is given in Appendix A2.

A period of 4.5 weeks is allowed for the measurements in each laboratory, including the time necessary for transportation. It is intended to re-measure the standards at certain intervals 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 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 cases contain the following items:

Packing list

- Three 1 TΩ standard resistors:
  - MI 9331 G, SN 1101180
  - Guildline 9337 G, SN 69573
  - Guildline 9337 G, SN 69574
- Three 100 TΩ standard resistors:
  - MI 9331 G, SN 1100625
  - Guildline 9337 G, SN 69640
  - Guildline 9337 G, SN 69641
- 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.

4.2 Measurement performance

Pre- conditioning: The standards should be installed in a thermostatic air bath, regulated at the working temperature, at least 24 h before starting 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: 1 TΩ: V_{test} = 500 V and 1000 V; if possible in both polarities
100 TΩ: V_{test} = 500 V and 1000 V; if possible in both polarities

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. For the Guildline standards, the resistance value to be determined is the resistance between the source and the output terminal for the case when the output terminal is at the same potential as the outer enclosure of the standard.

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 measuring 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
- Humidity
- 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 together with an EXCEL worksheet containing the detailed measurement (see Appendix 4) are also to 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. If the deadline for sending in the results is not kept, the laboratory concerned may be excluded from the comparison.
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 MI standards, 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

No	Name	e-Mail	Institute	Acronym	Address	Country	Telephone	Telefax
1	Jonas Marlein	jo-nas.marlein@economie.fgov.be; jac-ques.nicolas@economie.fgov.be	Federal Public Ser-vice Economy	SMD	DG Quality and Safety - Service Scientific Metrolo-gy (SMD) 1000 Brussels	Belgium	+32 2 277 9375	+32 2 277 5405
2	Andrey Tenev	a.tenev@bim.government.bg	Bulgarian Institute of Metrology National Centre of Metrology	NCM	52 B, G.M Dimitrov Blvd. 1040 Sofia	Bulgaria	+359 2 9702721	+359 2 9702735
3	Petr Chrobok	pchrobok@cmi.cz	Czech Metrology Institute	CMI	Radiova 3 10200 Praha 10	Czech Re-public	+420 266 020 117	+420 272 704 852
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8	Flavio Galliana	f.galliana@inrim.it	Istituto Nazionale di Ricerca Metrologica	INRIM	Strada della Cacce, 91 10135 Torino	Italy	+39 011 3919336	+39 011 346384
9	Gerd Rietveld	Grietveld@vsl.nl	VSL Dutch Metrolo-gy Institute	VSL	Thijsseweg 11 2629 JA Delft	Netherlands	+31 15 269 1645	+31 15 261 2971
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No	Name	e-Mail	Institute	Acronym	Address	Country	Telephone	Telefax
11	Isabel Godinho	igodinho@mail.ipq.pt	Instituto Português da Qualidade	IPQ	Metrologia Cientifica e Aplicada (LCM) Instituto Português da Qualidade Rua António Gião 2 2829-513 Caparica	Portugal	+351 212 948 166	+351 212 948 188
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A2 Schedule of the measurements

Period	Start date	End date	Laboratory
1	16.04.09	17.05.09	SMU
2	18.05.09	17.06.09	CMI
3	18.06.09	19.07.09	PTB
	20.07.09	19.08.09	Pilot laboratory
4	20.08.09	20.09.09	MIRS/SIQ
5	21.09.09	21.10.09	EIM
6	22.10.09	22.11.09	INRIM
7	23.11.09	23.12.09	MIKES
8	04.01.10	03.02.10	CEM
9	04.02.10	07.03.10	SMD
10	08.03.10	07.04.10	SP
	08.04.10	09.05.10	Pilot laboratory
11	10.05.10	09.06.10	INM
12	10.06.10	26.07.10	BIM-NCM
13	28.07.10	11.09.10	VSL
14	12.09.10	13.10.10	GUM
	18.10.10	12.11.10	Pilot laboratory
15	15.11.10	13.12.10	CMI
16	14.12.10	27.01.11	IPQ
17	28.01.11	24.02.11	CEM
18	02.03.11	24.03.11	SMD
19	26.03.11	05.05.11	LNE
20	18.05.11	13.07.11	UME
			Pilot laboratory

A3 Typical scheme for an uncertainty budget

Quantity X_i	Estimate x_i	Standard un-certainty $u(x_i)$	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. uncert. T (°C)[1)]	Test voltage (V)	Humidity (%)	Measurement result: Deviation from nominal value (µΩ/Ω)	Type A uncertainty (µΩ/Ω)

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

A5 Confirmation note of receipt

T e l e f a x   T e l e f a x   T e l e f a x

(Please pass on immediately!)

To: Federal Office of Metrology
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:

Re: Euramet supplementary comparison EURAMET.EM-S32 - Receipt of travelling standards

Date: ....

We confirm having received the travelling standards

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

T e l e f a x   T e l e f a x   T e l e f a x

(Please pass on immediately!)

To: Federal Office of Metrology
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:

Re: **Euramet supplementary comparison EURAMET.EM-S32 -**

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
on................................to the next participant.

Additional informations:

....

....

....

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