Georgian National Agency for Standards and Metrology

Metrology Institute

Electricity Reference Division

FINAL

REPORT

COOMET project no. 571/GE/12

COOMET.EM-S17 supplementary comparison on 10 Ω and 100 kΩ
Resistance standards

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May 2013

Abstract:

This report presents the results of the bilateral comparison on10 Ω and 100 kΩ resistance standards performed by the national metrology institutes of Georgia (GEOSTM) and Germany (PTB).

Content

1. Introduction

In the Mutual Recognition Arrangement (MRA) it is stated that the metrological equivalence of national measurement standards will be determined by a set of comparisons chosen and organised by the Consultative Committees or the Regional Metrology Organisations (RMO's). The results of this COOMET supplementary comparison will be used to support the CMC claims of GEOSTM in the field of resistance.

From August 2012 to March 2013, the national institutes of Georgia (GEOSTM) and Germany (PTB) performed a supplementary comparison on 10 Ω and 100 kΩ resistance standards. This comparison allows for a clear and unequivocal comparison of the measurement results and will show the equivalence of measuring results obtained with the measurement systems for resistance in the participating national metrology institutes.

2. Participants and schedule

2.1 List of participants

Two laboratories participated in this comparison. They are listed in Table 1.

Participant 1 (Pilot laboratory)	Participant 2
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Table 1: List of participants

2.2 Comparison schedule

The comparison took place from August 2012 to March 2013, details are given in table 2.

Institution	Country	Start date	Time for measurement and transportation
PTB	Germany	2 August 2012	12 weeks
GEOSTM	Georgia	23 October to 15 November 2012	4 weeks
PTB (final meas.)	Germany	21 January to 13 March 2013	12 weeks

Table 2: Circulation Time Schedule

2.3 Organisation of the comparison

Following the Guidelines for Comparisons the pilot laboratory was supported by the other participant in organizing the comparison. The travelling standards were provided by PTB and transported by courier in special containers.

3. Travelling standards and measurement instructions

3.1 Description of the travelling standards

For this comparison two resistance values have been chosen, 10 Ω and 100 kΩ. The resistors are commercially available types with common four terminal connectors.

- Standard Resistor 10 Ω FLUKE 742A-10, S/N 1063004,
- Standard Resistor 100 kΩ FLUKE 742A-100k, S/N 6280001.

3.2 Measurement instructions

The measurand is the value of the resistance at DC. The measurement methods which has been adopted and the measurement results together with a detailed calculation of the uncertainty of measurement are given in Annexes A and B for both participants. After installation of the resistors, a minimum settling time of one day is required. The measurements should be carried out with these preferred conditions:

- current through the resistor 10 mA for 10 Ω and 100 μA for 100kΩ,
- ambient temperature (23,00 ± 1) °C.

The resistance temperature has been recorded and reported. The measurements have been made at different dates during the period in the laboratory. For the correction of the influence of temperature the temperature coefficients of the standards have been taken from the manufacturers specifications.

4. Methods of measurement

Different measurement methods were used in the comparison. GEOSTM applied a direct measurement method using a calibrated digital multimeter and a modified substitution method using the reference resistance standards of GEOSTM and making use of the linearity of the DMM. PTB used two different methods, a substitution method using a DC current comparator bridge for 10 Ω and a potentiometric bridge to compare the 100 kΩ transfer standard against a 10 kΩ reference standard. Details are given in the Measurement Reports of GEOSTM and PTB in Annexes A and B.

5. Behaviour of the travelling standards

PTB measured the travelling standards before and after the circulation (see figures 1a and 1b). From these measurements the drift and stability of the travelling standards have been evaluated.

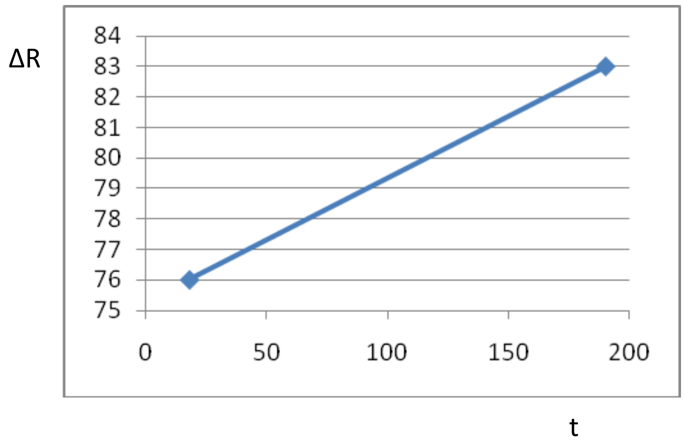

Fig.1a: Change with time of the 10 Ω transfer standard

t time in days from the start of the comparison

ΔR Deviation from nominal in μΩ

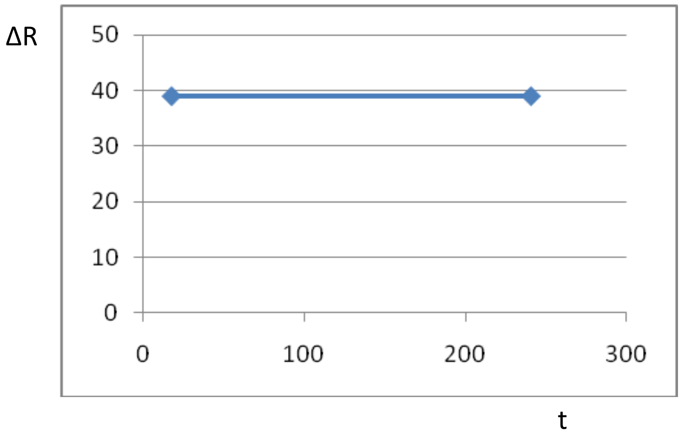

Fig.1b: Change with time of the 100 kΩ transfer standard

t time in days from the start of the comparison

Deviation from nominal is ΔR*0,01in Ω

While the 100 kΩ transfer standard did not change between the first and second measurement at PTB, the linear regression for the 10 Ω transfer standard is given by

$R_{ref10}(t) = 10{,}000076*(1+0{,}000314*t)$ Ω, with t in days. (1)

Hereby the value $R_{ref10}(t)$ denotes the value R_{ref10}, as it would have been measured by PTB at the time t with t=0 for the 2nd of August 2012.

6. Measurement results

6.1 Results of the participating institutes

The pilot laboratory performed measurements over the period from 23 October to 15 November 2012. As the maximum temperature changes are smaller than 1 K and the largest temperature coefficient of the standards is smaller than $0{,}2\cdot10^{-6}$/K, the largest change in resistance will be below $0{,}2\cdot10^{-6}$ and can be neglected compared with the standard uncertainty of the measurement. Therefore no correction of temperature has been made. The results are given in tables 4a and 4b.

Resistance Standard 10 Ω PTB, S/N 1063004

Mean date of measurement	Method of measurement	Measurement result in Ω	Uncertainty in μΩ/Ω
04.11.2012	direct	10,000105	11

04.11.2012	substitution	10,000115	12

Table 4a: The results of GEOSTM for 10 Ω

Resistance Standard 100 kΩ PTB, S/N 6280001

Mean date of measurement	Method of measurement	Measurement result in kΩ	Uncertainty in μΩ/Ω
04.11.2012	direct	100,00040	8,7
04.11.2012	substitution	100,00051	8,3

Table 4b: The results of GEOSTM for 100 kΩ

The results reported by PTB are given in tables 5a and 5b.

Resistance Standard 10 Ω PTB S/N 1063004

Date of measurement	Measurement result in Ω	Uncertainty in μΩ/Ω
02.08.2012	10,000 076	0,3
21.01.2013	10,000 083	0,3

Table 5a: The results of PTB for 10 Ω

Resistance Standard 100 kΩ PTB S/N 6280001

Date of measurement	Measurement result in Ω	Uncertainty in μΩ/Ω
3.8.2012	100 000,39	0,3
13.3.2013	100 000,39	0,3

Table 5b: The results of PTB for 100 kΩ

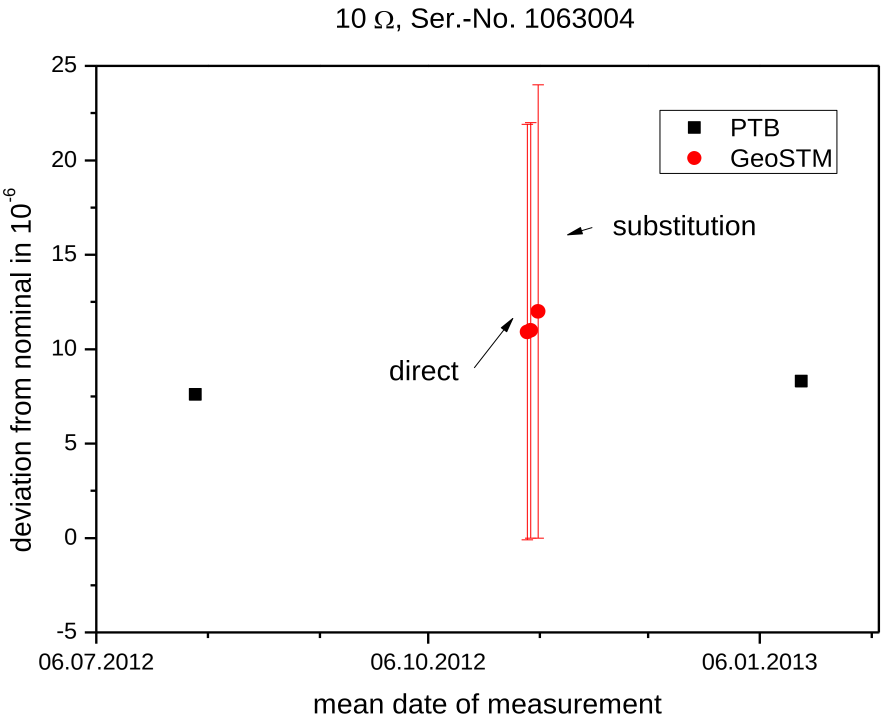

Fig. 2a. Combined results for 10 Ω

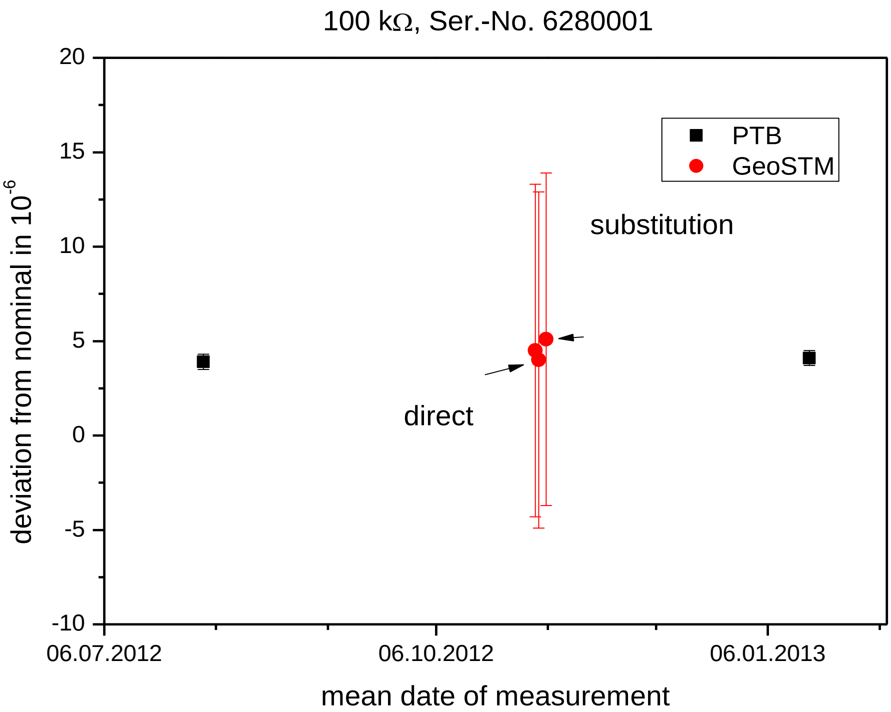

Fig. 2b. Combined results for 100 kΩ

6.2 Calculation of the E_n value

The E_n-value is defined as

$$En = \frac{|R_{CALPTB} - R_{CALGEO}|}{\sqrt{U_{PTB}^2 + U_{GEO}^2}}$$

To calculate the E_n-value for the comparison, the measurement results obtained from PTB must be recalculated to the mean date of the GEOSTM measurements. For the 10 Ω resistor this can be done using equation (1). The calculation for the value of R_{ref10} at the mean date of the GEOSTM measurements (t=96) yields R_{ref10}(t=96)=10,000080 Ω , which is in very good agreement with the values obtained by GEOSTM for the direct measurement method and the substitution method.

R_{10}	PTB value, Ω	PTB uncertainty, μΩ	GEOSTM value, Ω	GEOSTM uncertainty, μΩ	E_n-value
direct	10,000080	3	10,000105	110	0,23
substitution	10,000080	3	10,000115	120	0,30

Table 6a. En-values for 10 Ω

$R_{100\ k}$	PTB value, kΩ	PTB uncertainty, Ω	GEOSTM value, kΩ	GEOSTM uncertainty, Ω	E_n-value
direct	100,00039	0,03	100,00040	0,87	0,01
substitution	100,00039	0,03	100,00051	0,83	0,14

Table 6b. E_n-values for 100 kΩ

The E_n-values which are much smaller than 1 show, that GEOSTM can perform resistance measurements well in between the claimed expanded uncertainties.

7. Conclusions

A bilateral resistance comparison has been performed by GEOSTM and PTB to justify the CMC claims of GEOSTM. The differences of the results at GEOSTM and PTB are very small and lie well within the combined standard uncertainties of the measurements and therewith support the CMC claims of GEOSTM for resistance.

Appendix A:

Measurement Report of GEOSTM

RMO Supplementary Comparison COOMET.EM17

COOMET project No. 571/GE/12

Comparison of Resistance Standards

Measurement report

Manana Gelovani

Georgian Agency for Standards and Metrology (GEOSTM), Tbilisi

The standard resistors were measured at GEOSTM from October 2012 to November 2012. The resistors were measured at PTB in August 2012 and March 2013.

1. Measurand

The measurand is the quantity DC resistance at 10 Ω and at 100 kΩ.

2. Measurement procedure and Traceability scheme

The measurements were made using GEOSTM's set-up for the calibration of standard resistors.

The National Standards of GEOSTM were calibrated by PTB and therewith are traceable to PTB's realisations of the unit of resistance, based on the Quantum Hall resistance standard.

3. Measurement set-up for the calibration standard resistors

Two different measurement methods have been used in the comparison, a direct measurement method using a calibrated digital multimeter and a modified substitution method using the resistance standards of GEOSTM and making use of the linearity of the DMM.

All measurements were carried out at a room temperature of 23.0 °C ± 1 K. The measurement current for the 10 Ω resistor was 10 mA and 100 μA for the 100 kΩ resistor.

The measurement uncertainty includes a contribution for the short term instability of the standards. All quantities are considered to be uncorrelated. The uncertainty of calibration of the reference resistors performed by PTB is so small, that correlation must not be taken into account

4. Results

4.1. Resistance Standard 10 Ω, PTB S/N 1063004

	Date	Result value of comparison, Ω	Dev. from nom. value, Ω	Std. dev., Ω	Exp. MU, Ω
Direct measurements					
1	23.10.12	10,000105	0,0001048	$2{,}5\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
2	24.10.12	10,000113	0,0001125	$2{,}4\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
3	24.10.12	10,000110	0,0001097	$1{,}9\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
4	25.10.12	10,000106	0,0001057	$3{,}4\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
5	01.11.12	10,000102	0,0001019	$2{,}6\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
6	02.11.12	10,000069	0,0000691	$2{,}6\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
7	05.11.12	10,000115	0,0001150	$2{,}4\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
8	07.11.12	10,000101	0,0001013	$2{,}0\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
9	08.11.12	10,000106	0,0001064	$2{,}0\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
10	09.11.12	10,000087	0,0000875	$3{,}0\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
11	12.11.12	10,000118	0,0001184	$3{,}1\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
12	14.11.12	10,000119	0,0001188	$2{,}0\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
13	15.11.12	10,000118	0,0001179	$2{,}9\cdot10^{-6}$	$1{,}1\cdot10^{-4}$
Substitution measurements					
1	24.10.12	10,000113	0,0001133	$2{,}5\cdot10^{-6}$	$1{,}2\cdot10^{-4}$
2	25.10.12	10,000109	0,0001091	$2{,}0\cdot10^{-6}$	$1{,}2\cdot10^{-4}$
3	02.11.12	10,000120	0,0001198	$2{,}0\cdot10^{-6}$	$1{,}2\cdot10^{-4}$
4	05.11.12	10,000113	0,0001133	$2{,}5\cdot10^{-6}$	$1{,}2\cdot10^{-4}$
5	09.11.12	10,000116	0,0001165	$1{,}7\cdot10^{-6}$	$1{,}2\cdot10^{-4}$
6	12.11.12	10,000116	0,0001161	$2{,}1\cdot10^{-6}$	$1{,}2\cdot10^{-4}$
7	13.11.12	10,000109	0,0001093	$2{,}0\cdot10^{-6}$	$1{,}2\cdot10^{-4}$
8	14.11.12	10,000116	0,0001156	$2{,}2\cdot10^{-6}$	$1{,}2\cdot10^{-4}$
9	15.11.12	10,000126	0,0001261	$3{,}0\cdot10^{-6}$	$1{,}2\cdot10^{-4}$

4.2. Resistance Standard 100 kΩ, PTB S/N 6280001

	Date	Result value of comparison, kΩ	Dev. from nom. value, kΩ	Std. dev., Ω	Exp. MU, Ω
Direct measurements					
1	23.10.12	100,00037	0,000374	$5,2{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
2	24.10.12	100,00043	0,000434	$1,2{\cdot}10^{-2}$	$8,3{\cdot}10^{-1}$
3	25.10.12	100,00041	0,000415	$1,1{\cdot}10^{-2}$	$8,3{\cdot}10^{-1}$
4	01.11.12	100,00033	0,000330	$1,5{\cdot}10^{-1}$	$8,3{\cdot}10^{-1}$
5	02.11.12	100,00034	0,000343	$4,8{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
6	05.11.12	100,00035	0,000352	$4,2{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
7	07.11.12	100,00033	0,000326	$1,1{\cdot}10^{-2}$	$8,3{\cdot}10^{-1}$
8	08.11.12	100,00043	0,000430	$1,3{\cdot}10^{-2}$	$8,3{\cdot}10^{-1}$
9	09.11.12	100,00026	0,000263	$4,8{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
10	13.11.12	100,00047	0,000470	$4,7{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
11	14.11.12	100,00054	0,000542	$6,3{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
12	15.11.12	100,00054	0,000536	$5,2{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
Substitution measurements					
1	24.10.12	100,00046	0,000462	$6,1{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
2	25.10.12	100,00047	0,000468	$1,4{\cdot}10^{-2}$	$8,3{\cdot}10^{-1}$
3	02.11.12	100,00054	0,000540	$8,3{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
4	05.11.12	100,00046	0,000462	$6,1{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
5	09.11.12	100,00052	0,000520	$6,0{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
6	12.11.12	100,00054	0,000537	$6,5{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
7	13.11.12	100,00046	0,000465	$1,2{\cdot}10^{-2}$	$8,3{\cdot}10^{-1}$
8	14.11.12	100,00049	0,000493	$6,5{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$
9	15.11.12	100,00063	0,000627	$8,6{\cdot}10^{-3}$	$8,3{\cdot}10^{-1}$

5. Detailed uncertainty budget

5.1. Mathematical model for calibration of resistance using the direct method:

Model Equation:

$R_{CAL} = R_{IND} + \Delta R_{IND} + \delta R_{IND} + \delta R_{stab} + \delta R_{proc} + \delta R_{temp}$

List of Quantities:

Quantity	Unit	Definition
R_{CAL}	Ω	Value of the resistor to be calibrated
R_{IND}	Ω	indicated value of resistance meter
ΔR_{IND}	Ω	correction of indicated value according to the last calibration certificate for the resistance meter
δR_{IND}	Ω	standard deviation of measurements
δR_{CAL}	Ω	Uncertainty of calibration of the resistance meter
δR_{stab}	Ω	long-term stability of the resistance meter (specification)
δR_{proc}	Ω	additional influences of the calibration procedure (e.g. connection)
δR_{temp}	Ω	influence of temperature on the DUT

Uncertainty Budget for 10 Ω:

Quantity	Value, Ω	Standard Uncertainty, μΩ	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution, μΩ	Index, %
R_{IND}	10,00041500	0.0				
ΔR_{IND}	-0,0000010	0.0				
δR_{IND}	0,0	2,5	9	1,0	2,5	0,2
δR_{CAL}	0,0	5,5	50	1,0	5,5	1,0
δR_{stab}	0,0	54	50	1,0	54	98,6
δR_{proc}	0,0	0.0	∞	1,0	0.0	0,0
δR_{temp}	0,0	2,3	∞	1,0	2,3	0,2
R_{CAL}	10,000414	55	52			

Uncertainty Budget for 100 kΩ:

Quantity	Value, kΩ	Standard Uncertainty, Ω	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution, Ω	Index, %
R_{IND}	100,00037	0.0				
ΔR_{IND}	-0,000010	0.0				
δR_{IND}	0,0	$5{,}2\cdot10^{-3}$	9	1,0	$5{,}2\cdot10^{-3}$	0,0
δR_{CAL}	0,0	0,05	50	1,0	0,05	1,5
δR_{stab}	0,0	0,41	50	1,0	0,41	98,3
δR_{proc}	0,0	0.0	∞	1,0	0.0	0,0
δR_{temp}	0,0	0,02	∞	1,0	0,02	0,2
R_{CAL}	100,00036	$4{,}1\cdot10^{-1}$	52			

Results:

Quantity	Value, Ω	Expanded Uncertainty, Ω	Coverage factor	Coverage
R_{CAL}	10,000105	$1{,}1\cdot10^{-4}$	2.00	95%
R_{CAL}	100000,40	$8{,}3\cdot10^{-1}$	2.00	95%

5.2. Mathematical model for calibration of resistance using the substitution method:

Model Equation:

$$R_{CAL}=(R_{Ref}+\Delta R_{Ref}+\delta R_{Ref}+\delta R_{Refdrift}+\delta R_{Reftemp})*(Ind_{RCAL}+\delta Ind_{RCAL})/(Ind_{Rref}+\delta Ind_{Rref})+\delta R_{CALtemp}$$

List of Quantities:

Quantity	Unit	Definition
R_{CAL}	Ω	Value of the resistor to be calibrated
R_{Ref}	Ω	Value of the reference standard resistor
ΔR_{Ref}	Ω	Correction to be applied to the reference standard resistor from the calibration of the reference resistor
δR_{Ref}	Ω	Calibration uncertainty from last certificate
$\delta R_{Refdrift}$	Ω	Drift of the reference resistor since its last calibration or the 1-year specification
$\delta R_{Reftemp}$	Ω	Influence of temperature on the reference resistor
Ind_{RCAL}	Ω	Indicated value for the resistor under calibration
δInd_{RCAL}	Ω	short term stability and nonlinearity of the DMM for R_{CAL}
Ind_{Ref}	Ω	Indicated value for the reference resistor
δInd_{Rref}	Ω	Short term stability and nonlinearity of the DMM for R_{Ref}
$\delta R_{CALtemp}$	Ohm	Influence of temperature on the calibrated resistor

Uncertainty Budget for 10 Ω:

Quantity	Value, Ω	Standard Uncertainty, μΩ	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution, μΩ	Index, %
R_{Ref}	1,0000000					
ΔR_{Ref}	0,0000002					
δR_{Ref}	0,0	0,3	50	10	3	1
$\delta R_{Refdrift}$	0,0	2,89	∞	10	29	19
$\delta R_{Reftemp}$	0,0	0,23	∞	10	2,3	1
Ind_{RCAL}	10,0000102	5	9	10	50	37
δInd_{RCAL}	0,0	0,45	9	10	4,5	2
Ind_{Ref}	1,00000020	5	9	10	50	37
δInd_{Rref}	0,0	0,45	9	10	4.5	2
$\delta R_{CALtemp}$	0,0	2,3	∞	1,0	2,3	1
R_{CAL}	10,0000100	77,0	100			

Uncertainty Budget for 100 kΩ:

Quantity	Value, kΩ	Standard Uncertainty, Ω	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution, Ω	Index, %
R_{Ref}	10,0000000					
ΔR_{Ref}	0,000007					
δR_{Ref}	0,0	$3{\cdot}10^{-3}$	50	10	0,03	1
$\delta R_{Refdrift}$	0,0	0,04	∞	10	0,4	13
$\delta R_{Reftemp}$	0,0	0,002	∞	10	0,02	0,5
Ind_{RCAL}	100,00052	0,15	9	10	1,5	50
δInd_{RCAL}	0,0	0,06	9	10	0,6	17
Ind_{Ref}	10,0000070	0,006	9	10	0,06	2
δInd_{Rref}	0,0	0,06	9	-10	0,6	17
$\delta R_{CALtemp}$	0,0	0,02	∞	1,0	0,02	0,5
R_{CAL}	100,00052	1,77	100			

Results:

Quantity	Value, Ω	Expanded Uncertainty, Ω	Coverage factor	Coverage
R_{CAL}	10,000115	$1,2{\cdot}10^{-4}$	2.00	95%
R_{CAL}	100000,51	$8,3{\cdot}10^{-1}$	2.00	95%

MananaGelovani

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6. December 2012

Appendix B:

Measurement Report of PTB

RMO Supplementary Comparison COOMET.EM

Comparison of Resistance Standards

Measurement report

Bernd Schumacher

Physikalisch-TechnischeBundesanstalt, Braunschweig

The standard resistors were measured at PTB in August 2012 and in March 2013. The resistors were sent to GEOSTM in October 2012 and received back in December 2012.

1. Measurand

The measurand is the quantity DC resistance at 10 Ω and at 100 kΩ.

2. Measurement procedure and Traceability scheme

The measurements were made using PTB's set-up for the calibration of standard resistors.

All measurements are traceable to PTB's realisations of the unit of resistance, based on the Quantum Hall resistance standard.

3. Measurement set-up for the calibration standard resistors

The 10 Ω standard resistor was calibrated using a direct current transformer bridge in comparison to a known reference resistor of value 10 Ω.

The 100 kΩ standard resistor was calibrated using a potentiometric bridge in comparison to a known reference resistor of value 10 kΩ.

All measurements were carried out in an air-bath at 23.00 °C +/- 0.05 K. The measurement current for the 10 Ω resistor was 10 mA, the 100 kΩ resistor was measured at a voltage of 10 V.

The measurement uncertainty includes a contribution for the short term instability of the standards.

All quantities are considered to be uncorrelated.

4. Results

Resistance Standard 10 Ω PTB S/N 1063004

Date of measurement	Measurement result in Ω	Uncertainty in μΩ/Ω
2.8.2012	10,000 076	0,3
21.1.2013	10,000 083	0,3

Resistance Standard 100 kΩ PTB S/N 6280001

Date of measurement	Measurement result in Ω	Uncertainty in μΩ/Ω
3.8.2012	100 000,39	0,3
13.3.2013	100 000,39	0,3

5. Detailed uncertainty budget

Model Equation for 10 Ω:

$R_x=V*V_r*R_n*k_d*k_T*k_p*k_i$

List of Quantities:

Quantity	Unit	Definition
R_x	Ohm	result
V		nominal bridge ratio
V_r		measured ratio
R_n	Ohm	reference resistor
k_d		drift
k_T		temperature dependence
k_p		pressure dependence
k_i		isolation

Uncertainty Budgets:

R_x: result

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
V	1.0000000000	$57.7 \cdot 10^{-9}$	∞	rectangular	10	$580 \cdot 10^{-9}$ Ohm	34.8 %
V_r	1.0000000000	$20.0 \cdot 10^{-9}$	5	normal	10	$200 \cdot 10^{-9}$ Ohm	4.2 %
R_n	10.0000000 Ohm	$500 \cdot 10^{-9}$ Ohm	100	normal	1.0	$500 \cdot 10^{-9}$ Ohm	26.1 %
k_d	1.0000000000	$57.7 \cdot 10^{-9}$	∞	rectangular	10	$580 \cdot 10^{-9}$ Ohm	34.8 %
k_T	1.00000000000	$1.15 \cdot 10^{-9}$	∞	rectangular	10	$12 \cdot 10^{-9}$ Ohm	0.0 %
k_p	1.0	0.0	∞	rectangular	0.0	0.0 Ohm	0.0 %
k_i	1.0	$577 \cdot 10^{-15}$	∞	rectangular	10	$5.8 \cdot 10^{-12}$ Ohm	0.0 %
R_x	10.0000000 Ohm	$978 \cdot 10^{-9}$ Ohm	980				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
R_x	10.0000000 Ohm	$200 \cdot 10^{-9}$ (relativ)	2.00	95% (normal)

Model Equation for 100 kΩ:

$R_x = R_N * V * k_V * k_T * k_D$

List of Quantities:

Quantity	Unit	Definition
Rx	Ohm	result
RN	Ohm	reference resistor
V		Bridge ratio
kV		Divider uncertainty
kT		temperature dependence
kD		drift

Uncertainty Budgets:

Rx: result

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
RN	$100.00000000 \cdot 10^{3}$ Ohm	$5.00 \cdot 10^{-3}$ Ohm	100	normal	1.0	$5.0 \cdot 10^{-3}$ Ohm	21.2 %
V	1.0000000000	$50.0 \cdot 10^{-9}$	9	normal	$100 \cdot 10^{3}$	$5.0 \cdot 10^{-3}$ Ohm	21.2 %
kV	1.0000000000	$10.0 \cdot 10^{-9}$	1500	normal	$100 \cdot 10^{3}$	$1.0 \cdot 10^{-3}$ Ohm	0.8 %
kT	1.0000000000	$57.7 \cdot 10^{-9}$	∞	rectangular	$100 \cdot 10^{3}$	$5.8 \cdot 10^{-3}$ Ohm	28.3 %
kD	1.0000000000	$57.7 \cdot 10^{-9}$	∞	rectangular	$100 \cdot 10^{3}$	$5.8 \cdot 10^{-3}$ Ohm	28.3 %
Rx	$100.00000 \cdot 10^{3}$ Ohm	0.0108 Ohm	180				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
Rx	$100.000000 \cdot 10^{3}$ Ohm	$220 \cdot 10^{-9}$ (relativ)	2.00	95% (t-table 95.45%)

Bernd Schumacher

Physikalisch-Technische Bundesanstalt,
Braunschweig 6. May 2013

Appendix C:

Technical Protocol

GEOSTM **2012-10-22**

COOMET comparison COOMET.EM-571/GE/12

”10 Ω and 100 k Ω Standard Resistor”

Technical protocol

Content

1 Introduction

In the Mutual Recognition Arrangement (MRA) it is stated that the metrological equivalence of national measurement standards will be determined by a set of comparisons chosen and organised by the Consultative Committees of the CIPM working closely together with the Regional Metrology Organisations (RMO's). The results of this COOMET comparison will be used for evaluation (determination, identification) of equivalence of national standards and an estimation of calibration and measuring capabilities of the participant countries, and development of quality management system of participant NMI.

The procedures outlined in this document are intended to allow for a clear and unequivocal comparison of the measurement results and to show the equivalence of measuring results obtained with various quantized Hall resistance systems or other measurement systems for resistance in different national institutes. This technical protocol was prepared following the Guidelines for Euromet key comparisons.

2 The travelling standards

For this comparison two resistance values have been chosen, 10 Ω and 100 kΩ. The resistors are commercially available types with common four terminal connectors.

- Standard Resistor 10 Ω FLUKE 742A-10, S/N 1063004,
- Standard Resistor 100 kΩFLUKE 742A-100k, S/N 6280001.

3 Organisation

Following the Guidelines for COOMET bilateral comparisons one institute from the provisional list of participant were nominated to help the pilot laboratory with the organisation. This is Physikalisch-TechnischeBundesanstaltPTB (B. Schumacher). In the following the pilot laboratory and the helping laboratory will be denominated "the organisation group". The TC chairman of the COOMET EM Working Group will be regularly informed about the progress of this comparison.

3.1 Participants

The address of the co-ordinator of the pilot laboratory is:

Ms.MananaGelovani

Georgian National Agency for Standards and Metrology (GEOSTM)

Electrical Reference Division (02)

Letters: Chargali str., 67, - 0178 Tbilisi, GEORGIA

Parcels: Chargali str., 67, - 0178 Tbilisi, GEORGIA

Tel.: +995 32 260 66 53, Fax: +995 32 261 35 00, E-mail: elmetrology@yahoo.com

A list of all participating institutes and contact persons with their addresses is enclosed in chapter 8 with Table I.

3.2 Time schedule

The time schedule for the comparison is given in the table below.

For the measurements in each laboratory a period of four weeks is allowed, including time necessary for transportation.

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 will still be possibility for carrying out measurements once again 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.

If an ATA carnet is used, it must be used properly. 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 with the device in the package. In some cases it is possible to attach the carnet to the package. The carnet must be saved in the laboratory very carefully because a loss of the carnet may cause a serious delay in the comparison schedule.

Circulation Time Schedule

Comparison COOMET. EM-571/GE/12

(2012-10-22)

Institution	Country	Start date	Time for measurement and transportation
PTB	Germany	July 2012	12 weeks
GeoSTM	Georgia	October 2012	4 weeks
PTB (final meas.)	Germany	November 2012	4 weeks

3.3 Transportation

Transportation is on each laboratory’s own responsibility and cost. The resistors will be shipped in appropriate boxes. Shipping using courier services is accepted as an alternative to transportation by hand. The shipment should be arranged in a way that the time for transport is as short as possible, preferably day to day courier service. This means that customs procedures, where appropriate, have to be examined in advance of the transport. Particular care should be taken to avoid the shipping cases being exposed to extreme temperatures, e.g. left standing on the airport.

After arrival of the package, please, inform the pilot laboratory of this by completing and returning a form (confirmation note of receipt *(Annex A1))* by e-mail or fax.

Immediately after having completed the measurements, the package is to be transported to the next participant. It is advisable to prepare and organise this transportation beforehand. Please, inform the pilot laboratory again about the details of sending the package to the next participant (use the dispatch note (Annex *A2*)) - and also inform the next participant by e-mail or Fax.

3.4 Unpacking, handling, packing

The packages contain the following items:

Packing list:

- Standard Resistor 10 Ω FLUKE 742A-10, S/N 1063004,
- Standard Resistor 100 kΩFLUKE 742A-100k, S/N 6280001,
- Instruction Manual.

After the receipt of the package the box and the standards inside the box have to be inspected for any damage or dirt.
When the measurements have been finished ensure that the package is complete (see list above) before sending it in the original transportation suitcase to the next participant.

3.5 Failure with a travelling standard

Should one of the travelling standards be damaged during the comparison the pilot laboratory must be informed immediately.

3.6 Financial aspects, insurance

Each participating laboratory covers the costs of the measurement, transportation and eventual customs formalities as well as for any damage that may have occurred 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

The measurand is the value of the resistance at DC. The measurement method which is adopted should be mentioned in reporting the results. Together with the measurement results, a short description of the individual measuring methods used must be included for the final report.

After installation of the resistors in their respective thermostats a minimum settling time of one day is required. The measurements should be carried out with these preferred conditions:

- current through the resistor 10 mA for 10 Ω and 100 μA for 100k Ω,
- ambient temperature (23,00 ± 1) °C; the deviation of the temperature from nominal should not exceed the given limit.

The resistance temperature and ambient pressure should be recorded and reported. The measurements should be made at different dates during the period in the laboratory. The temperature coefficients of the standards have been determined to allow for corrections. They are intentionally not provided with this protocol. In case this information is needed for evaluation of the individual measurements it will be provided on request.

5 Uncertainty of measurement

Since this comparison is a Coomet comparison all participants must provide their results with the associated uncertainty of measurement and a complete uncertainty budget including the degrees of freedom (see Annex A3). The uncertainty must be evaluated at a level of one standard uncertainty. The uncertainty of measurement of the measuring results must be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement* (GUM). A list of the principal components of the uncertainty budget to be evaluated by each participant is included in this technical protocol (annex A3).

6 Measurement report

The individual results with date, temperature, measurement current and the standard uncertainty should be reported to the pilot laboratory (please use the attached summary of results sheet, annex A4). Furthermore, a short description of the measuring set-up used and a detailed evaluation of the uncertainty of measurement are to be reported. Preliminary results can be send by email. In any case, a printed and signed report of the results must be sent by mail. In case of any differences, the paper forms are considered to be the valid version.

The reports should be sent to the pilot laboratory no later than six weeks after the measurements have been completed. No information about differences of the reported results with respect to others will be communicated before the completion of the comparison, unless larger deviations of particular laboratories results and the preliminary reference results obtained by the pilot laboratory have been observed. In this case the laboratory in question will be contacted.

7 Report of the comparison

Within 3 months after completion of the circulation, the organisation group will prepare a first draft report and send it to the participants for comments. In this report an overview about the different measuring systems and a proposed key comparison reference value will be included. Subsequently, the procedure outlined in the CCEM Guidelines will be followed.

8. List of participants

Name	Institute	Acronym	Address	Land	Telephone	Telefax	E-mail
Bernd Schumacher	PhysikalischTechnischeBundesanstalt, AG 2.11	PTB	Bundesallee 100, 38116 Braunschweig	Germany	+49 531 592 2110	+49 531 592 2105	bernd.schumacher@ptb.de

COOMET comparison –Confirmation for receipt **(Annex 1)**

Confirmation for receipt		
Date of arrival		
NMI		
Name of person responsible		
Travelling standard 1 (100 Ω)	**Not Damaged**	**Damaged**
Travelling standard 2(100 kΩ)	**Not Damaged**	**Damaged**
Notes		

COOMET comparison –Confirmation for dispatch **(Annex 2)**

Confirmation for dispatch	
Date of dispatch	
NMI	
Name of person responsible	
Shipment information	
Notes	

Coomet comparison –measurement results **(Annex 3)**

List of the principal components of the uncertainty budget to be evaluated

For those participants using another measurement system and a reference resistor:

Uncertainties associated with the measurement system

Uncertainty associated with the reference resistor:

- calibration uncertainty (please note the institution that performed the calibration as a possible source of correlation)
- uncertainty due to drift

For all participants:

Uncertainty of the temperature measurement

Uncertainty of measurement of type A

Proposed scheme for an uncertainty budget for R_X

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 $u_i(R_x)$	Degree of freedom ν_i
R_X						ν_{eff}

Summary of results form (one sheet per standard) ***(*****Annex 4)**

Standard serial no.:

Standard Serial no.	Date of measurement	Ambient temperature	Uncertainty of ambient temperature	Measurement result	Standard uncertainty of measurement