BUREAU INTERNATIONAL
DES POIDS ET MESURES

Bilateral comparison of 1 Ω and 10 kΩ standards (ongoing BIPM key comparisons BIPM.EM-K13.a and 13.b) between the NIM (The People's Republic of China) and the BIPM

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Final Report

B. Rolland[*], M. Stock[*]
L. Yunfeng[**], Z. Jianting[**], H. Qing[**]
[*] Bureau International des Poids et Mesures (BIPM), Sèvres, France
[**] National Institute of Metrology (NIM), Beijing, The People's Republic of China

1 Introduction

A comparison of values assigned to 1 Ω and 10 kΩ resistance standards was carried out between the BIPM and the NIM (The People's Republic of China) in the period August 2018 to February 2019. Two 1 Ω and two 10 kΩ BIPM travelling standards were calibrated first at the BIPM, then at the NIM and again at the BIPM after their return. The measurement periods are referred to as:

'Before' measurements at the BIPM: October 2018 – November 2018
NIM measurements: November 2018 – December 2018
'After' measurements at the BIPM: January 2019 – February 2019

This report is organised as follows: details of the travelling standards used are listed in Section 2. The results of the BIPM measurements are given in Section 3, and the calibration reports provided by the NIM are summarized in Section 4; these two sections include the uncertainty budgets for each laboratory. Finally, the two sets of measurements are compared and analysed in Section 5. The uncertainties arising from the transfer of the standards between the two laboratories are estimated and included at this point. The final results of the comparisons are given in the form of the degrees of equivalence (deviations from the KCRV and associated uncertainties) between the NIM and the BIPM for measurements of 1 Ω and 10 kΩ resistance standards.

This report covers the comparison of both 1 Ω standards (BIPM.EM-K13.a) and 10 kΩ standards (BIPM.EM-K13.b). The measurements of these two different resistance values are analysed separately, but are reported together here as the two comparisons were carried out simultaneously.

2 Travelling Standards

Four travelling standards provided by the BIPM were used for this comparison. The two 1 Ω standards are of CSIRO type, with working labels BIV193 (manufacturer's serial number S-64193) and BIV207 (manufacturer's serial number S-64207). The two 10 kΩ standards are TEGAM S104 type, and have the working labels B10k08 (manufacturer's serial number K201039730104) and B10k11 (serial number K205039730104). The standards were shipped by regular air freight between the laboratories.

All measurements are corrected to a reference temperature of 23.000 °C and reference pressure 1013.25 hPa using the known coefficients of the standards, given in Table 1.
According to the protocol, the NIM did not apply pressure and temperature corrections to its results, but supplied the raw values and the measured temperature and pressure. An additional power effect correction has been evaluated by the NIM and the BIPM to correct for the difference of applied current between the NIM and the BIPM on the 10 kΩ standards.
The corrections were applied in the analysis made by the BIPM.

	Relative temperature coefficients		Relative pressure coefficients
Standard #	α_{23} / (10^{-6}/K)	β / (10^{-6}/K²)	γ / (10^{-9}/hPa)
BIV193	− 0.0042	− 0.0012	− 0.170
BIV207	− 0.0094	+ 0.0001	− 0.250
B10k08	− 0.0100	− 0.0230	− 0.162
B10k11	− 0.0700	− 0.0270	− 0.350

Table 1: Temperature and pressure coefficients of the travelling standards.

3 Measurements at the BIPM

The BIPM measurements are traceable to the quantum Hall resistance (QHR) standard via different measurement bridges and working standards for the two nominal values. In all cases, values are based on the conventional value of the von Klitzing constant, R_{K-90} = 25812.807 Ω. (The standard uncertainty associated with the use of R_{K-90}, which has a relative value of 1×10^{-7}, has not been included).

The 1 Ω measurements were carried out by comparison with a 100 Ω reference resistor (identifier BI100-3) whose value is calibrated against the BIPM QHR standard regularly (at least once every 6 months). The comparison was performed using a DC cryogenic current comparator operating with 50 mA current in the 1 Ω resistors.

The 1 Ω travelling standards were kept in a temperature controlled oil bath at a temperature which is close (within a few mK) to the reference temperature of 23 °C. The oil temperature close to each standard was determined by means of a calibrated Standard Platinum Resistance Thermometer (SPRT) in conjunction with thermocouples placed in the thermal well of each resistor. The air pressure in the laboratory was recorded using a calibrated manometer at the time of each measurement.

The ‘dc’ resistance value (or ratio) measured with the BIPM CCC-bridge results from a current signal passing through the resistors having polarity reversals with a waiting time between polarity inversions, cf. Figure 1. The polarity reversal frequency is of the order of 3 mHz (340 s cycle period) and the measurements are sampled only during 100 s before the change of polarity.

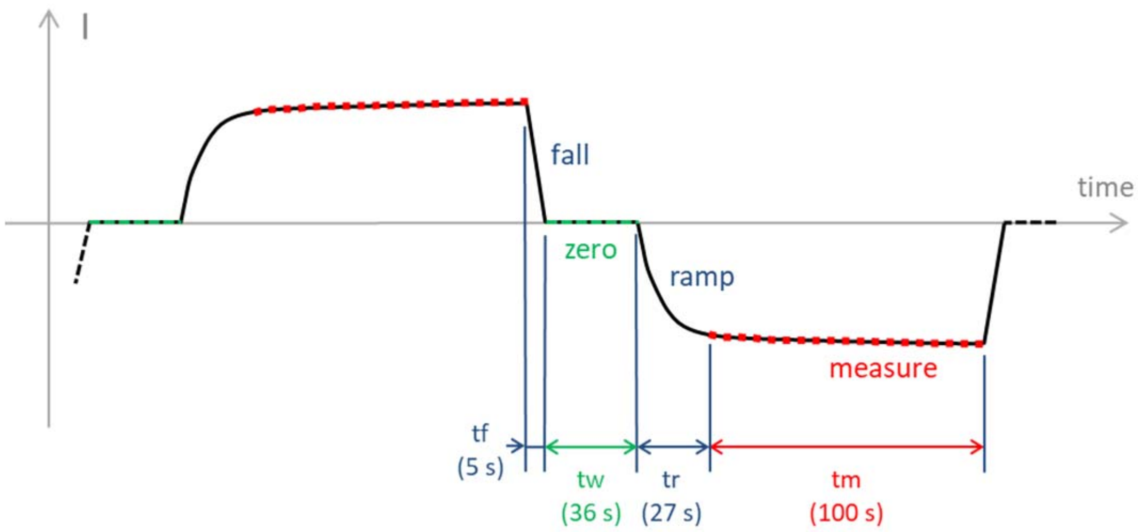

Figure 1: Schematic representation of the reference current signal with polarity reversals used in the BIPM CCC-bridge. The reversal cycle comprises a waiting time of about 36 s at zero current (green dotted line). The red dotted line corresponds to the sampling time period.

The travelling standards were measured 11 times during the period labelled ‘before’ (October 2018 – November 2018) and 11 times during the period labelled ‘after’ (January 2019 – February 2019).

The individual BIPM measurement data are plotted in Figures 2 and 3 of Section 5 (after application of the temperature and pressure corrections). The mean results are summarized in Table 2 and the uncertainty budget in Table 3. The dispersion of each group of measurements is estimated by the standard deviation.

BIPM	**Relative difference from nominal 1 Ω value / 10^{-6}**					
Standard #	BEFORE	Std dev. u_{1B}	AFTER	Std dev. u_{1A}	INTERPOLATED ON 10-12-2018	Std dev.
BIV193	− 5.184	0.010	− 5.173	0.010	− 5.179	0.007
BIV207	− 0.490	0.008	− 0.554	0.006	− 0.522	0.005

Table 2: Summary of BIPM calibrations of the 1 Ω standards.

Source of uncertainty	**relative standard uncertainty /10^{-9}**
Imperfect realisation of R_{K-90}	2
Calibration of the BIPM 100 Ω reference (BI100-3) against R_{K-90}	3
Interpolation / extrapolation of the value of BI100-3	13
Measurement of the (1Ω / BI100-3) ratio	8
Temperature correction for the 1 Ω standard	2
Pressure correction for the 1 Ω standard	3
Combined uncertainty u_2	**16**

Table 3: BIPM uncertainty budget for the calibration of the 1 Ω travelling standards.

The 10 kΩ measurements were carried out by comparison with a set of two 10 kΩ reference resistors (identifiers B10K1 and B10K2) which are calibrated regularly (at least once every 6 months) against the BIPM QHR standard. The comparison was performed using a Warshawsky bridge operating with a 0.1 mA DC current (i.e. at a measurement voltage of 1 V).

The 10 kΩ travelling standards were kept in a temperature-controlled air bath at a temperature which is close to the reference temperature of 23 °C (within 0.05 °C). The temperature of the standards was determined by means of a calibrated platinum resistance thermometer, in conjunction with thermocouples placed in the thermal well of each resistor. The air pressure in the laboratory was recorded using a calibrated manometer at the time of each measurement. The relative humidity in the air bath was not monitored, but the laboratory air conditioning system controls the relative humidity to 50 % (± 10 %).

The travelling standards were measured 11 times during the period labelled 'before' (October 2018 – November 2018) and 8 times during the period labelled 'after' (January 2019 – February 2019). The individual BIPM measurement data are plotted in Figures 4 and 5 of Section 5 (after application of the temperature and pressure correction). The mean results are summarized in Table 4 and the uncertainty budget in Table 5. The dispersion of each group of measurements is estimated by the standard deviation.

BIPM	**Relative difference from nominal 10 kΩ value / 10^{-6}**					
Standard #	BEFORE	Std dev. u_{1B}	AFTER	Std dev. u_{1A}	INTERPOLATED ON 11-12-2018	Std dev.
B10k08	+ 0.982	0.004	+ 1.012	0.002	+ 0.996	0.002
B10k11	+ 1.127	0.003	+ 1.139	0.003	+ 1.133	0.002

Table 4: Summary of BIPM calibrations of the 10 kΩ standards.

Source of uncertainty	**relative standard uncertainty / 10^{-9}**
Imperfect realization of R_{K-90}	2
Calibration of the BIPM 100 Ω reference (BI100-3) against R_{K-90}	3
Link 100 Ω / 10 000 Ω	5
Link 10 000 Ω / (mean reference B10K1-B10K2)	7
Extrapolation of mean value of 10 kΩ reference	8
Measurement of the voltage applied to the bridge	5
Measurements of the bridge unbalance voltage	5
Leakage resistances	1
Temperature correction for travelling standard	3
Pressure correction for travelling standard	2
Combined uncertainty u_2	**15**

Table 5: BIPM uncertainty budget for the calibration of the 10 kΩ travelling standards.

4 Measurements at the NIM

4.1 Method of calibration:

NIM uses the quantum hall resistance (QHR) standard with the cryogenic current comparator (CCC) bridge to carry out this bilateral comparison. The steps were like this: the QHR standard was compared to a 100 Ω reference standard with CCC turn ratio 4001/31, which was then compared to the 10 kΩ BIPM comparison standards (the CCC turn ratio 3200/32) and the 1 Ω BIPM comparison standards (the CCC turn ratio 400/4). The QHR standard was compared to the 100 Ω reference standard every measurement day. The direct current with reversal applied to the 100 Ω, 10 kΩ and 1 Ω is 5 mA, 50 μA and 50 mA respectively.

Parameters	**Resistance Ratio**
	$R_H(2)/100\ \Omega$
Numbers of turns N_1/N_2	4001/31
Voltage drop (I_1R_1) (V)	0.5
Relative standard uncertainty contributions	
CCC windings ratio ($\times 10^{-9}$)	0.19
Compensation ratio ($\times 10^{-9}$)	0.023
Correction of $R_H(2)$ for finite dissipation ($\times 10^{-9}$)	0.1
Leakage resistances ($\times 10^{-9}$)	0.1
*Pressure fluctuation ($\times 10^{-9}$)	/
ΔTemperature fluctuation ($\times 10^{-9}$)	/
Bridge voltage ΔU measurement ($\times 10^{-9}$)	0.2
Combined type-B std. uncertainty u_B ($\times 10^{-9}$)	**0.31**

Table 6: Uncertainty Budget for the Calibration of the 100 Ω Reference Resistance Standard

Note:
NIM has two QHR standard systems including CCC bridges, which are placed in different campus, 40 km each other. Comparisons between the two systems have demonstrated quite good consistency.

*The relative uncertainty caused by the pressure fluctuation (rectangular distribution assumed) is from the 100 Ω reference resistor pressure coefficient, which is below 0.2×10^{-9}/hPa (obtained by experiments), within 2 hPa peak-peak change during the measuring time.

ΔThe relative uncertainty caused by the temperature fluctuation (rectangular distribution assumed) is from the 100 Ω reference resistor temperature coefficient, which is below 0.08×10^{-6}/ ℃, within 3 mK peak-peak change during the measuring time.

4.2 Operating conditions:

The 1 Ω travelling standards (No. 64193 & 64207) were maintained in a mineral oil bath maintained at 23.000 °C as measured by a calibrated SPRT and thermometer bridge.

Current value: 50 mA on 1 Ω standards.

One 10 kΩ travelling standard (No. B10K08) was measured in a commercial air bath (MI 9300A) maintained at 23.00 °C as measured by a calibrated SPRT (Fluke 5683) all the measuring time.

Another 10 kΩ travelling standard (No. B10K11) was measured in a homemade air bath maintained at 23.000 °C as measured by a calibrated SPRT (another Fluke 5683) all the measuring time.

Considering the recommended current value 100 µA on 10 kΩ standards, while NIM uses the current value 50 µA, NIM made experiments to estimate the power coefficient contribution between the different powers applied to the 10 kΩ travelling standard. The results on the effect of 100 µA current evaluated compared to 50 µA current measuring are reported in Section 4.4 below.

Humidity: Relative humidity in the laboratory averaged 42%.

The 'dc' resistance value (or ratio) measured with the NIM-CCC bridge results from a current signal passing through the resistors with a polarity reversal frequency of 10 mHz (100 s cycle period) and the measurements are sampled only during 25 s before the change of polarity.

4.3 NIM results at 1 Ω:

The 1 Ω travelling standards were measured 12 times in the period November 2018 – December 2018. Table 7 gives the mean values at the mean date of 10 December 2018, before application of temperature and pressure corrections. The repeatability is estimated by the standard deviation of the series of measurements. The pressure of the mineral oil exerts on the resistors has been considered, which is about 7.6 hPa.

Standard #	Relative difference from nominal 1 Ω value /10^{-6}	Std dev. /10^{-6}	Mean temperature / °C	Mean atmospheric pressure / hPa
BIV193	− 5.133	0.004	23.000	1020.7
BIV207	− 0.551	0.003	23.000	1020.9

Table 7: Summary of NIM 1 Ω calibrations.

Corrections for temperature and pressure:

The value $R(23)$ of the resistance corrected for T_0= 23 °C is:

$$\mathrm{R}(23) = R(T) \times [1 - \alpha_{23}(T - T_0) - \beta(T - T_0)^2]$$

where $R(T)$ is the resistance of the standard at temperature T.

The value $R(1013.25)$ of the resistance corrected for P_0= 1013.25 hPa is:

$$\mathrm{R}(1013.25) = R(P) \times [1 - \gamma(P - P_0)]$$

where $R(P)$ is the resistance of the standard at pressure P.

A correction for a possible dependence on the duty-cycle has not been evaluated.

The NIM results are corrected to the reference temperature and the reference pressure using the coefficients α_{23}, β and γ shown in Table 1.

Reference temperature = 23.000°C Reference pressure = 1013.25 hPa		
	Relative corrections $/10^{-6}$	
Standard #	For temperature	For pressure
BIV193	+ 0.000	+ 0.001
BIV207	+ 0.000	+ 0.002

Table 8: Corrections applied to the NIM 1 Ω results.

The uncertainties on temperature and pressure measurements at the NIM are 0.001 °C and 1 hPa respectively. Taking into account the differences from the reference temperature and reference pressure, and the uncertainties associated with the coefficients, the relative standard uncertainties u_{Temp} and u_{Press} associated with the temperature and pressure corrections applied by the BIPM are estimated to be $u_{\text{Temp}} < 0.001 \times 10^{-6}$ and $u_{\text{Press}} < 0.001 \times 10^{-6}$ leading to a combined relative standard uncertainty $u_3 = 0.001 \times 10^{-6}$.

Uncertainty Budget Provided by the NIM:

Uncertainties associated with the value of 1 Ω measurement

Parameters	**Resistance Ratio**
	100 Ω/1 Ω
Numbers of turns N_1/N_2	400/4
Voltage drop (I_1R_1) (V)	0.05
Relative standard uncertainty contributions	
CCC windings ratio ($\times 10^{-9}$)	0.19
Compensation ratio ($\times 10^{-9}$)	0.031
Leakage resistances ($\times 10^{-9}$)	<0.01
*Pressure fluctuation ($\times 10^{-9}$)	0.12
ΔTemperature fluctuation ($\times 10^{-9}$)	0.1
Bridge voltage ΔU measurement ($\times 10^{-9}$)	0.619
Combined type-B std. uncertainty u_{B} ($\times 10^{-9}$)	**0.67**

Table 9: Summary of the NIM uncertainty budget for 1 Ω.

Note:

*The relative uncertainty caused by the pressure fluctuation (rectangular distribution assumed) is from the 100 Ω reference resistor pressure coefficient, which is below 0.2×10^{-9}/hPa (obtained by experiments), within 2 hPa peak-peak change during the measuring time.

ΔThe relative uncertainty caused by the temperature fluctuation (rectangular distribution assumed) is from the 100 Ω reference resistor temperature coefficient, which is below 0.08×10^{-6}/ ℃, within 3 mK peak-peak change during the measuring time.

NIM After corrections	Relative difference from nominal value / 10^{-6}	Relative standard uncertainties		
		Repeatability u_1 / 10^{-6}	Systematic u_2 / 10^{-6}	Corrections u_3 / 10^{-6}
BIV193	− 5.132	0.004	0.001	0.001
BIV207	− 0.549	0.003	0.001	0.001

Table 10: Summary of the NIM results at 1 Ω, after corrections.

Note: The distinction between 'systematic' and 'repeatability' is made in Tables 10 and 14 because our model is that the latter can reasonably be reduced by taking an average across several transfer standards. The former cannot be reduced in this way. (This does not correspond exactly to the more usual division into Type A and Type B components).

4.4 NIM results at 10 kΩ:

The 10 kΩ travelling standards were measured 12 times in the period November 2018 – December 2018. Table 11 gives the mean values at the mean date of 11 December 2018, before application of temperature and pressure corrections. The repeatability is estimated by the standard deviation of the series of measurements.

Standard #	Relative difference from nominal 10 kΩ value /10^{-6}	Std dev. /10^{-6}	Mean temperature / °C	Mean atmospheric pressure / hPa
B10k08	+ 0.977	0.004	22.999	1014.5
B10k11	+ 1.149	0.004	23.000	1015.0

Table 11: Summary of NIM 10 kΩ calibrations.

Corrections for temperature and pressure:

The value $R(23)$ of the resistance corrected for T_0= 23 °C is:

$$\mathrm{R}(23) = R(T) \times [1 - \alpha_{23}(T - T_0) - \beta(T - T_0)^2]$$

where $R(T)$ is the resistance of the standard at temperature T.

The value $R(1013.25)$ of the resistance corrected for P_0= 1013.25 hPa is:

$$\mathrm{R}(1013.25) = R(P) \times [1 - \gamma(P - P_0)]$$

where $R(P)$ is the resistance of the standard at pressure P.

Corrections for power difference:

From BIPM experiments: the power coefficient of B10k08 and B10k11 from 100 µA to 50 µA is − 1 ×10^{-9} / mW with a standard uncertainty u_{Power} = 3 × 10^{-9} / mW.

From NIM experiments: the power coefficient of B10k08 under the current of 100 µA to 50 µA is − 0.6 ×10^{-9} / mW with a standard uncertainty of u_{Power} = 2.0 × 10^{-9} / mW.

The power coefficient of B10k11 under the current of 100 µA to 50 µA is – 2.4 ×10^{-9} / mW with a standard uncertainty of u_{Power} = 2.0 × 10^{-9} / mW.

The power difference in the 10 kΩ travelling standards between the NIM (50 µA) and the BIPM (100 µA) is 75 µW. Since the difference is smaller than the dispersion, there is no correction applied to the power effect.

A correction for a possible dependence on the duty-cycle has not been evaluated.

The NIM results are corrected to the reference temperature, the reference pressure and the power difference using the coefficients α_{23}, β and γ shown in Table 1 and the power coefficient determined before.

Reference temperature = 23.000°C Reference pressure = 1013.25 hPa			
	Relative corrections /10^{-6}		
Standard #	For temperature	For pressure	For power effect
B10k08	+ 0.000	+ 0.000	− 0.000
B10k11	+ 0.000	+ 0.001	− 0.000

Table 12: Corrections applied to the NIM 10 kΩ results.

The uncertainties on temperature and pressure measurements at the NIM are 0.010 °C and 1 hPa respectively. Taking into account the differences from the reference temperature, reference pressure and power difference, and the uncertainties associated with the coefficients, the relative standard uncertainties u_{Temp}, u_{Press} and u_{Power} associated with the temperature and pressure corrections applied by the BIPM are estimated to be $u_{\mathrm{Temp}} < 0.001 \times 10^{-6}$, $u_{\mathrm{Press}} < 0.001 \times 10^{-6}$ and $u_{\mathrm{Power}} = 0.002 \times 10^{-6}$ leading to a combined relative standard uncertainty $u_3 = 0.002 \times 10^{-6}$.

Uncertainty Budget Provided by the NIM:

Parameters	**Resistance Ratio**
	10 k Ω/100 Ω
Numbers of turns N_1/N_2	3200/32
Voltage drop (I_1R_1) (V)	0.5
Relative standard uncertainty contributions	
CCC windings ratio (×10^{-9})	0.19
Compensation ratio (×10^{-9})	0.01
Leakage resistances (×10^{-9})	0.1
*Pressure fluctuation (×10^{-9})	0.12
ΔTemperature fluctuation (×10^{-9})	0.1
Bridge voltage ΔU measurement (×10^{-9})	0.152
Combined type-B std. uncertainty u_{B} (×10^{-9})	**0.31**

Table13: Summary of the NIM uncertainty budget for 10 kΩ.

Note:
*The relative uncertainty caused by the pressure fluctuation (rectangular distribution assumed) is from the 100 Ω reference resistor pressure coefficient, which is below 0.2 × 10^{-9}/hPa (obtained by experiments), within 2 hPa peak-peak change during the measuring time.
ΔThe relative uncertainty caused by the temperature fluctuation (rectangular distribution assumed) is from the 100 Ω reference resistor temperature coefficient, which is below 0.08×10^{-6}/ ℃, within 3 mK peak-peak change during the measuring time.

NIM After corrections	**Relative difference from nominal value / 10^{-6}**	**Relative standard uncertainties**		
		Repeatability u_1 / 10^{-6}	Systematic u_2 / 10^{-6}	Corrections u_3 / 10^{-6}
B10k08	+ 0.977	0.004	0.001	0.002
B10k11	+ 1.150	0.004	0.001	0.002

Table 14: Summary of the NIM results at 10 kΩ, after corrections.

Note: The distinction between ‘systematic’ and ‘repeatability’ is made in Tables 10 and 14 because our model is that the latter can reasonably be reduced by taking an average across several transfer standards. The former cannot be reduced in this way. (This does not correspond exactly to the more usual division into Type A and Type B components).

5 Comparison NIM - BIPM

The individual measurement results for each of the four standards are shown in Figures 2 to 5 below. The plots also show the mean value of the NIM measurements with the uncertainty bar corresponding to the expanded uncertainty ($k = 2$) of the comparison U_c provided below, and a linear fit to the BIPM before and after measurements. We assume that the value of each standard is subject to a simple linear drift during the period of the comparison. Inspection of Figures 2 to 5 indicates that this is an appropriate model. Both 1 Ω standards and 10 kΩ standards fit this model well. We treat the 1 Ω and 10 kΩ results as two separate cases.

Within this model, the result of the comparison for a given standard is the difference between the mean of the NIM measurements and the interpolated value of the linear fit to the BIPM measurements on the mean date of the NIM measurements.

The difference between the NIM and the BIPM calibrations of a given standard R_i can be written as:

$$\Delta_i = R_{\mathrm{NIM},i} - R_{\mathrm{BIPM},i}$$

If two standards are used, the mean of the differences is:

$$\Delta_{\mathrm{NIM-BIPM}} = \frac{1}{2}\sum_{i=1}^{2}\left(R_{\mathrm{NIM},i} - R_{\mathrm{BIPM},i}\right)$$

For each standard, the uncertainty u_1 associated with the interpolated BIPM value is calculated from the linear fit; u_2 is the uncertainty arising from the combined contributions associated with the BIPM measurement facility and the traceability, as described in Table 3 or 5. This component is assumed to be strongly correlated between calibrations performed in the same period.

For a single standard, the BIPM uncertainty $u_{\mathrm{BIPM},\,i}$ is obtained from: $u^2_{\mathrm{BIPM},i} = u^2_{1,i} + u^2_{2,i}$. When the mean (for two standards) of the NIM − BIPM relative difference is calculated, the BIPM contribution to the uncertainty is:

$$u^2_{\mathrm{BIPM}} = \sum_{i=1}^{2}\frac{u^2_{1,i}}{2^2} + u^2_2$$

Similarly, for the NIM measurements, we expect the uncertainty components u_2 and u_3 of Tables 10 and 14 to be correlated between standards, and u_1 to be uncorrelated. We therefore calculate the total uncertainty as:

$$u^2_{\mathrm{NIM}} = \sum_{i=1}^{2}\frac{u^2_{1,i}}{2^2} + u^2_2 + u^2_3$$

Uncertainty associated with the transfer

Changes in the values of the standards due to the effects of transport can add an extra uncertainty component to a comparison. In this case, from inspection of the BIPM ‘before’ and ‘after’ measurements in Figures 2 to 5, we can see that any such effects are negligible compared to the overall uncertainty of the comparison, and for simplicity we do not include any extra uncertainty components.

Results at 1 Ω

The differences between the values assigned by the NIM, R_{NIM}, and those assigned by the BIPM, R_{BIPM}, to each of the two travelling standards on the mean date of the NIM measurements are shown in Table 15.

NIM − BIPM	
Standard #	$10^6 \times (R_{\mathrm{NIM}} - R_{\mathrm{BIPM}}) / (1\ \Omega)$
BIV193	+ 0.047
BIV207	− 0.027
mean	**+ 0.010**

Table 15: Differences for the two 1 Ω travelling standards.

The mean difference between the NIM and the BIPM calibrations is:

$$(\boldsymbol{R}_{\mathbf{NIM}} - \boldsymbol{R}_{\mathbf{BIPM}}) / (1\ \Omega) = +0.010 \times 10^{-6}$$

The relative combined standard uncertainty of the comparison, u_{C}, is:

$$u_c^2 = u_{BIPM}^2 + u_{\mathrm{NIM}}^2$$

where $u_{\mathrm{BIPM}} = 0.017 \times 10^{-6}$,
$u_{\mathrm{NIM}} = 0.003 \times 10^{-6}$,

Giving: $\boldsymbol{u}_{\mathbf{C}} = \mathbf{0.017 \times 10^{-6}}$

The final result of the comparison is presented as a degree of equivalence, composed of the deviation, D, between the NIM and the BIPM for values assigned to 1 Ω resistance standards, and its expanded relative uncertainty (expansion factor $k = 2$, corresponding to a confidence level of 95 %), U_{C}

$$\boldsymbol{D} = (\boldsymbol{R}_{\mathbf{NIM}} - \boldsymbol{R}_{\mathbf{BIPM}}) / 1\ \Omega = +0.010 \times 10^{-6}$$

$$\boldsymbol{U}_{\mathbf{C}} = \mathbf{0.034 \times 10^{-6}}$$

The difference between the NIM and the BIPM calibration results is within the expanded uncertainty.

Results at 10 kΩ

The difference between the value assigned by the NIM, R_{NIM}, and those assigned by the BIPM, R_{BIPM}, to each of the two travelling standards on the mean date of the NIM measurements are shown in Table 16.

NIM − BIPM	
Standard #	$10^6 \times (R_{\mathrm{NIM}} - R_{\mathrm{BIPM}}) / (10\ \mathrm{k}\Omega)$
B10k08	− 0.019
B10k11	+ 0.017
mean	**− 0.001**

Table 16: Differences for the two 10 kΩ travelling standards.

The mean difference between the NIM and the BIPM calibrations is:

$$(R_{\mathrm{NIM}} - R_{\mathrm{BIPM}}) / (10\ \mathrm{k}\Omega) = -0.001 \times 10^{-6}$$

The relative combined standard uncertainty of the comparison, u_{C}, is:

$$u_c^2 = u_{BIPM}^2 + u_{\mathrm{NIM}}^2$$

where $u_{\mathrm{BIPM}} = 0.015 \times 10^{-6}$,
$u_{\mathrm{NIM}} = 0.004 \times 10^{-6}$,

Giving: $\boldsymbol{u_{\mathrm{C}} = 0.016 \times 10^{-6}}$

The final result of the comparison is presented as a degree of equivalence, composed of the deviation, D, between the NIM and the BIPM for the value assigned to 10 kΩ resistance standards, and its expanded relative uncertainty (expansion factor $k = 2$, corresponding to a confidence level of 95 %), U_{C}

$$D = (R_{\mathrm{NIM}} - R_{\mathrm{BIPM}}) / 10\ \mathrm{k}\Omega = -0.001 \times 10^{-6}$$

$$U_{\mathrm{C}} = 0.032 \times 10^{-6}$$

The difference between the NIM and the BIPM calibration results is within the expanded uncertainty.

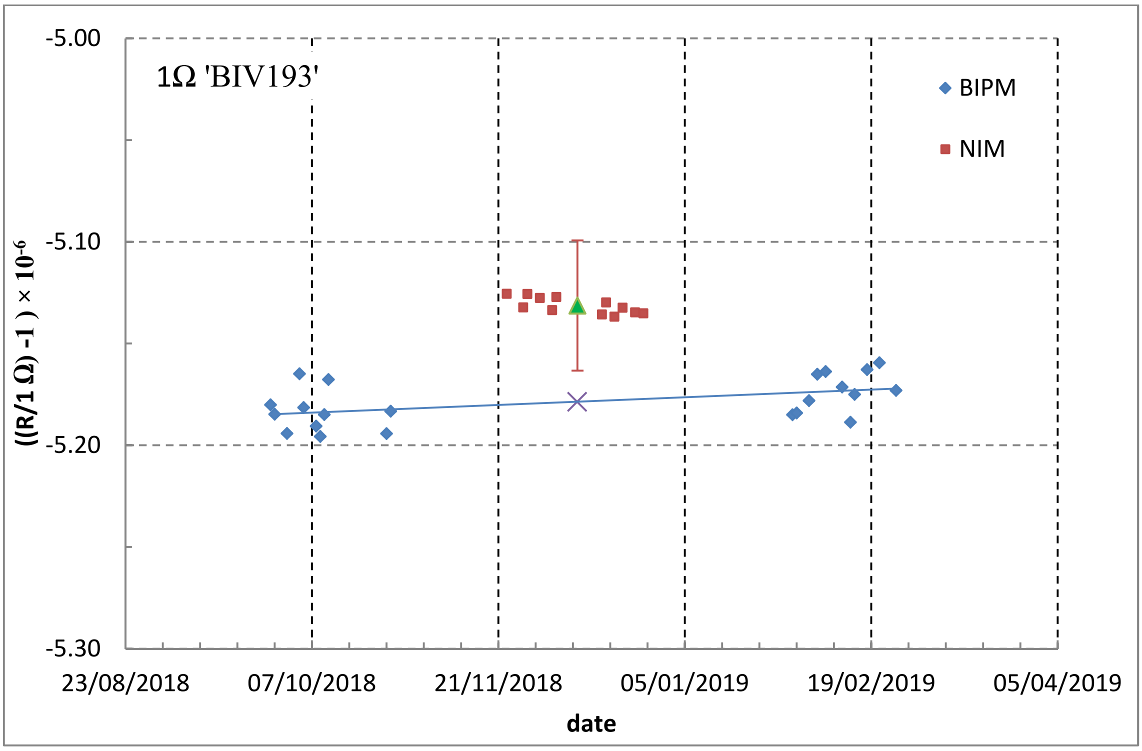

Figure 2: results for 1 Ω standard BIV193;
Uncertainty bar shows the combined expanded uncertainty of the comparison on the mean NIM results

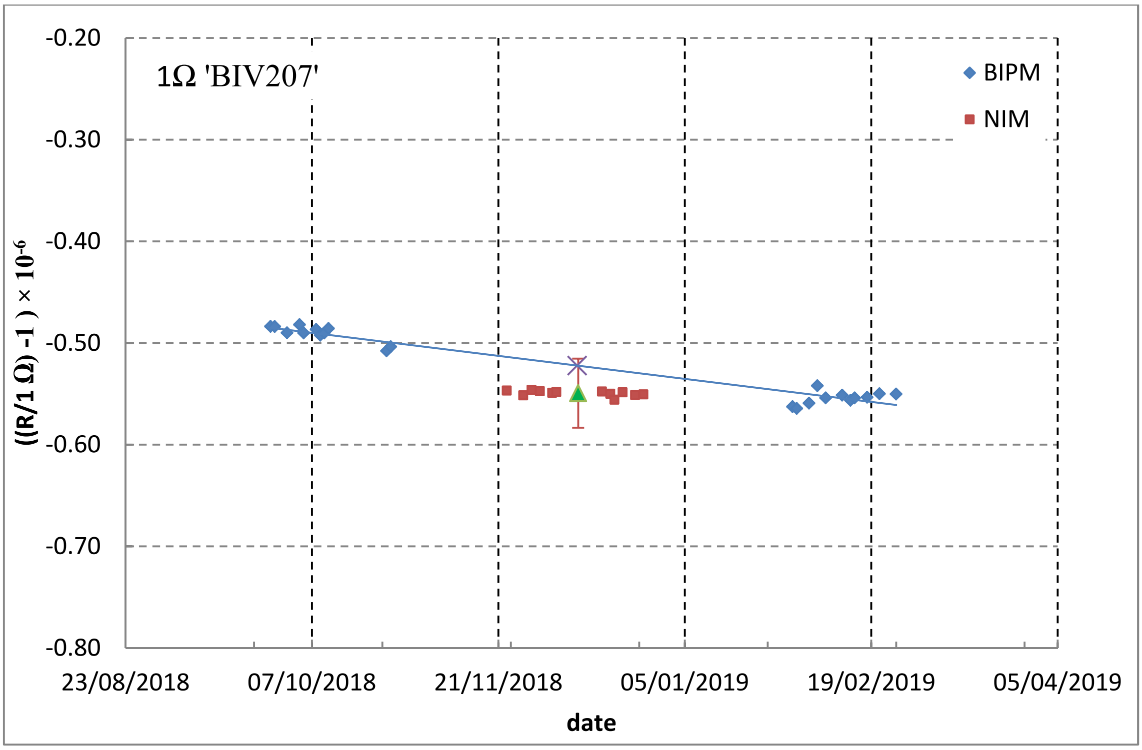

Figure 3: results for 1 Ω standard BIV207

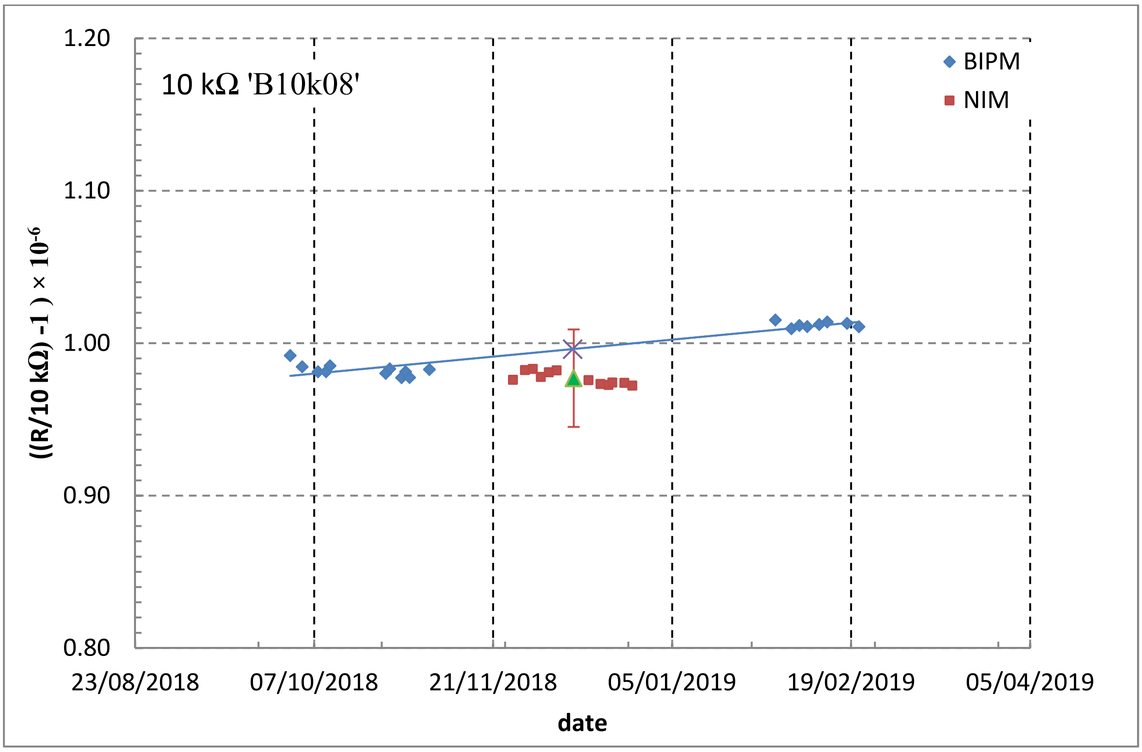

Figure 4: results for 10 kΩ standard B10k08
Uncertainty bar shows the combined expanded uncertainty of the comparison on the mean NIM results

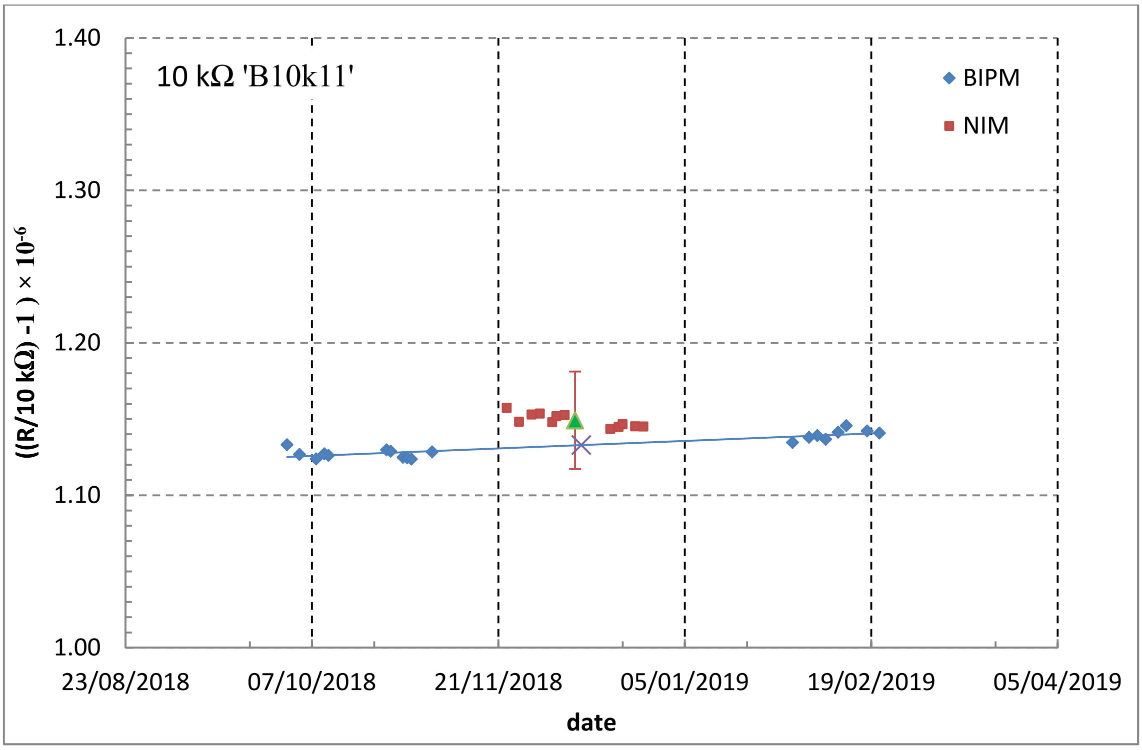

Figure 5: results for 10 kΩ standard B10k11