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Bilateral Comparison of 1 Ω Standards between NML, Ireland and the BIPM, March 2002

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A comparison of the 1 Ω reference standards of the BIPM and the National Metrology Laboratory, (NML), Dublin, Ireland was carried out from February to June 2002. Two BIPM 1 Ω travelling standards, BIV202 and BIV203, were shipped to the NML by air courier. The BIPM measurements were carried out by comparison with 100 Ω reference resistors whose values are known with respect to the BIPM Quantized Hall Resistance (QHR) standard. The current in the 1 Ω resistors during the measurements was 50 mA. The combined standard uncertainty of the link from the travelling standards to the QHR is 15 nΩ. The NML carried out measurements of the travelling standards by a substitution method using a current comparator resistance bridge. The NML resistance standard is maintained with respect to R_{K-90} by means of periodic calibrations and comparisons with the BIPM and by extrapolation of the secular behaviour of its reference group. The measuring current used was 30mA. The uncertainty arising from the two different measuring currents at the BIPM and at the NML (50 mA and 30 mA) is believed to be negligible. The reference temperature is 23°C. The NML measurements, carried out near 20 °C, and those of the BIPM, carried out near 23 °C, are referred to the reference temperature. Results of all measurements were corrected to 101325 Pa for the pressure dependence of the resistance.

Figures 1 and 2 show the measured values obtained for the two standards by the two laboratories. The BIPM values and uncertainties are calculated for the reference date, the mean date of the NML measurements (18 March 2002), from linear least-squares fits. Those of the NML are calculated from the mean of the measured values.

Table 1 lists the results and the component uncertainty contributions for the comparison NML/BIPM. Table 2 lists the uncertainties associated with maintenance and measuring equipment at the BIPM and Table 3 lists the uncertainties associated with maintenance and measuring equipment at the NML.

The following elements are listed in Table 1:

(1) the mean resistance value R_{NML} of each resistor measured by the NML;
(2) the type-A uncertainty due to the instability of the resistors and the measuring equipment, computed as the standard uncertainty of the mean value;
(3) the type-B uncertainty component due the measuring equipment of the NML. This uncertainty is partially correlated between the different travelling standards used for a comparison and the contributions that are completely or at least partially correlated are indicated by asterisks (*) in Table 3 ;
(4-6) the corresponding quantities for the BIPM;
(7) the difference ($R_{NML} - R_{BIPM}$) for each resistor, and (8) the clearly uncorrelated (type-A) part of the uncertainty;
(9) the result of the comparison which is the mean of the differences of the calibration results for the different standards;
the uncertainty of the transfer, estimated by two methods:
(10) the standard deviation of the mean value of the results, from the different resistors, counting only the type-A uncertainties of the individual results;
(11) the *a posteriori* uncertainty, which is the standard deviation of the mean of the two different results, s_M;
(12) the total uncertainty of the comparison, which is the root-sum-square of the type-A and type-B uncertainties.

In Table 1, the type-A uncertainties are negligible compared to the estimated type-B uncertainties. We compare these with the *a posteriori* uncertainty estimated by the standard deviation of the mean of the results from the two travelling standards, line 11. (With only two travelling standards, the uncertainty of the standard deviation of the mean is comparable to the value of the standard deviation of the mean itself.) The two estimates are in satisfactory agreement but, as usual, the larger of the two estimates is taken as the type-A uncertainty. It should be noted that the return measurements at the BIPM indicate that the resistance of BIV202 is about 0.10 μΩ lower than the value one would have anticipated based on the behaviour of the resistance before shipment. Although a linear least-squares fit is used in Fig.1, it is clear that the actual resistance change with time may have been non-linear.

The final results of the comparison are presented as the difference between the value assigned to a 1 Ω standard by each laboratory. The difference between the value assigned by the NML, at the NML, R_{NML}, and that assigned by the BIPM, at the BIPM, R_{BIPM}, for the reference date is

$$R_{\mathrm{NML}} - R_{\mathrm{BIPM}} = -0.07\ \mu\Omega\ ;\ u_{\mathrm{c}} = 0.23\ \mu\Omega \text{ on } 2002/03/18,$$

where u_{c} is the combined type-A and type-B standard uncertainty from both laboratories.

This is a most satisfactory result. The difference between the values assigned to the travelling standards by the two laboratories is less than the standard uncertainty associated with the difference.

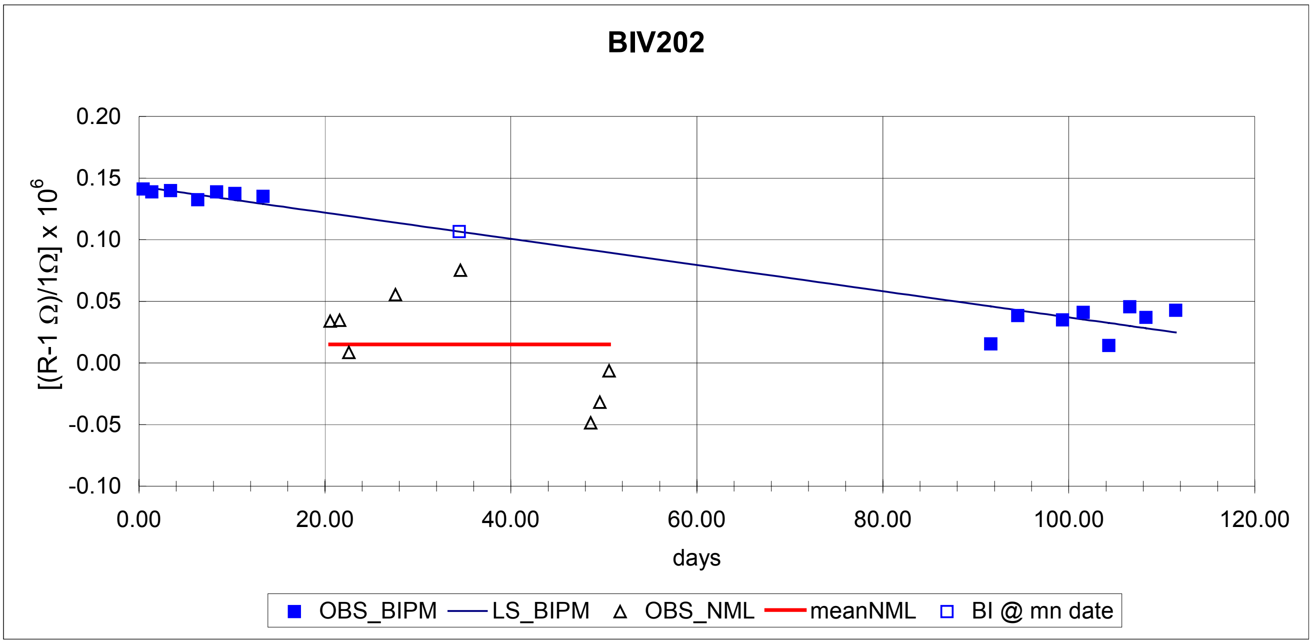

Figure 1. Relative deviation from the nominal 1 Ω value of the resistance of BIV202 vs time: a linear least-squares fit (LS) to the BIPM measurements and the mean of the NML measurements.

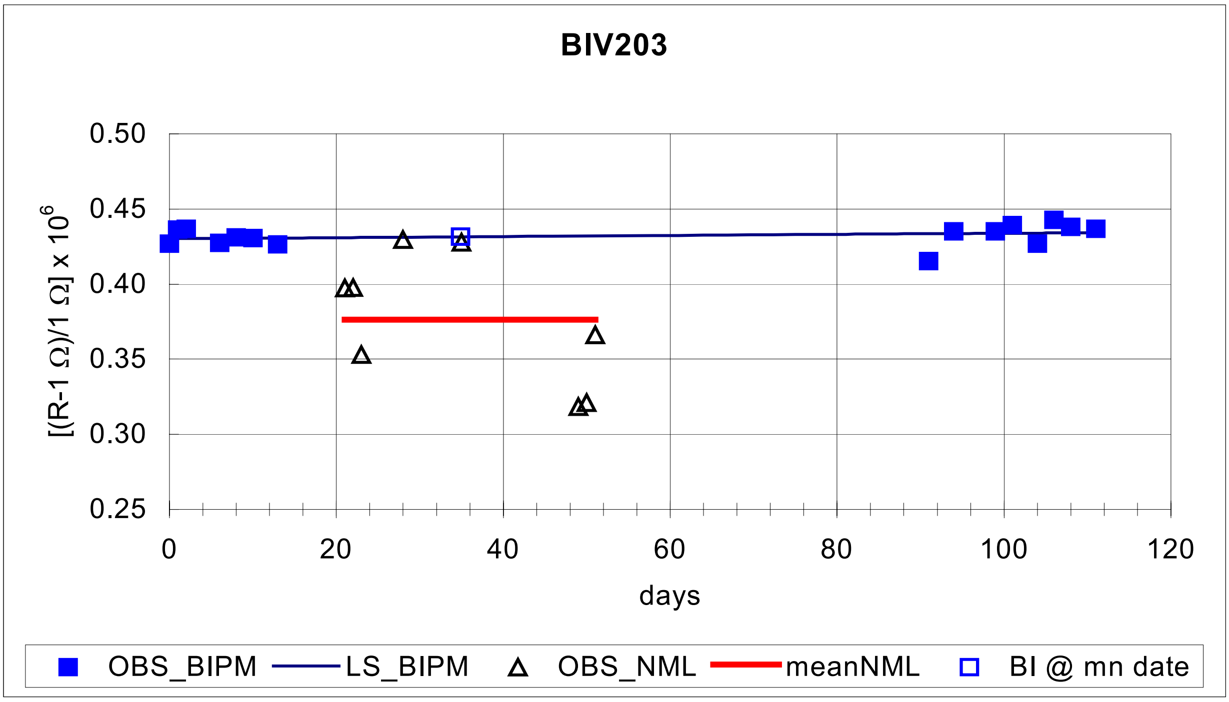

Figure 2. Relative deviation from the nominal 1 Ω value of the resistance of BIV203 vs time: a linear least-squares fit (LS) to the BIPM measurements and the mean of the NML measurements.

Table 1. Results of the NML/BIPM bilateral comparison of 1 Ω standards using two BIPM travelling standards: mean date 18 March 2002. Uncertainties are 1-σ estimates. The combined type-A uncertainty is $w=[r^2+t^2]^{1/2}$, the expected transfer uncertainty is $x=[w_{202}{}^2+w_{203}{}^2]^{1/2}/2$ and the total combined uncertainty is $y=[s^2+u^2+x^2]^{1/2}$.

			BIV202	BIV203	
1	NML	$(R-1\ \Omega)/\ \mu\Omega$	0.015	0.376	
2		type-A uncertainty/ μΩ	0.015	0.016	r
3		type-B uncertainty/ μΩ	0.23		s
4	BIPM	$(R-1\ \Omega)/\mu\Omega$	0.107	0.432	
5		type-A uncertainty/ μΩ	0.003	0.002	t
6		type-B uncertainty/ μΩ	0.015		u
7		$(R_{\mathrm{NML}}-R_{\mathrm{BIPM}})/\ \mu\Omega$	−0.092	−0.056	
8		combined type-A uncertainty/ μΩ	0.015	0.016	w
9		$< R_{\mathrm{NML}}-R_{\mathrm{BIPM}} >/\ \mu\Omega$	−0.074		
10		expected type-A transfer uncertainty/ μΩ	0.011		
11		s_{M} of difference for 2 resistors/ μΩ	0.018		x
12		total uncertainty in comparison / μΩ	0.23		y

Table 2. Estimated type-B standard uncertainties, relative to the nominal value, for 1 Ω calibrations with the BIPM equipment. A relative uncertainty of 1×10^{-9} corresponds to 0.001 μΩ.

Realization of $R_H(2)$	2×10^{-9}
Ratio of resistance of 100 Ω transfer resistor to $R_H(2)$	4×10^{-9}
DC/AC difference (at 1 Hz) of transfer resistor	1×10^{-9}
Imprecision in the values of the reference resistors (including uncertainties in extrapolated resistance values and residual power, temperature and pressure effects)	11×10^{-9}
Comparison of the travelling standards to the reference resistor (ratio 1 Ω/100 Ω)	5×10^{-9}
Uncertainty in the temperature correction for the travelling standard	1×10^{-9}
Uncertainty in the pressure correction for the travelling standard	4×10^{-9}
rss total	14×10^{-9}

Table 3. Estimated standard uncertainties, relative to the nominal value, for 1 Ω calibrations with the NML equipment. A relative uncertainty of 1×10^{-8} corresponds to 0.01 μΩ. Asterisks (*) indicate components that are either completely correlated or probably significantly correlated when measuring different travelling standards.

Calibrated value of the 1 Ω reference standard*	15×10^{-8}
Bridge ratio	17×10^{-8}
Effects of temperature	0×10^{-8}
rss total	23×10^{-8}