Bilateral Comparison of 10 kΩ Standards

between the CMI, Czech Republic and the BIPM, April 2000

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A comparison of the 10 kΩ reference standards of the BIPM and the Czech Metrological Institute, (CMI), Prague, Czech Republic, was carried out in April 2000. Two BIPM 10 kΩ travelling standards, B10K07 and B10K11, were transported by automobile. The CMI measurements were carried out by comparison with the CMI 10 kΩ standard by means of a commercial direct current comparator resistance bridge. The CMI reference standard and its temporal variation are known in terms of R_{K-90} by means of previous regular calibrations at the BIPM. The BIPM measurements of the travelling standards were carried out by comparison with BIPM 10 kΩ reference standards using a Warshawsky bridge. The BIPM 10 kΩ reference standards are calibrated in terms of a 100 Ω reference standard calibrated in terms of the BIPM realization of the quantized Hall resistance standard. Results of all measurements were corrected to 23 °C and 101325 Pa for the dependence of the resistances of the travelling standards on ambient temperature and pressure.

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 CMI measurements, from linear least-squares fits. Those of the CMI are calculated from the mean of the measured values.

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

The following elements are listed in Table 1:

(1) the mean resistance value R_{CMI} of each resistor measured by the CMI;
(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 CMI. 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 ($R_{CMI} - R_{BIPM}$) 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;

(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.) If the *a posteriori* uncertainty is significantly different from the type-A uncertainty, as is the case here, we assume either that a standard has changed in an unusual way (but the BIPM measurement results before and after transporting the travelling standards, Figure 1 and Figure 2, show no evidence of this) or that some factors listed in the type-B uncertainty budget for the CMI can give rise to residual errors that differ among the travelling standards. The correlations between the type-B uncertainties when measuring different standards are unknown.

The final results of the comparison are presented as the difference between the value assigned to a 10 kΩ standard by each laboratory. The difference between the value assigned by the CMI, at the CMI, R_{CMI}, and that assigned by the BIPM, at the BIPM, R_{BIPM}, for the reference date is

$$R_{\mathrm{CMI}} - R_{\mathrm{BIPM}} = 1.2\ \mathrm{m\Omega}\ ;\ u_{\mathrm{c}} = 2.0\ \mathrm{m\Omega}\ \text{on } 2000/04/19,$$

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

This is a 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.

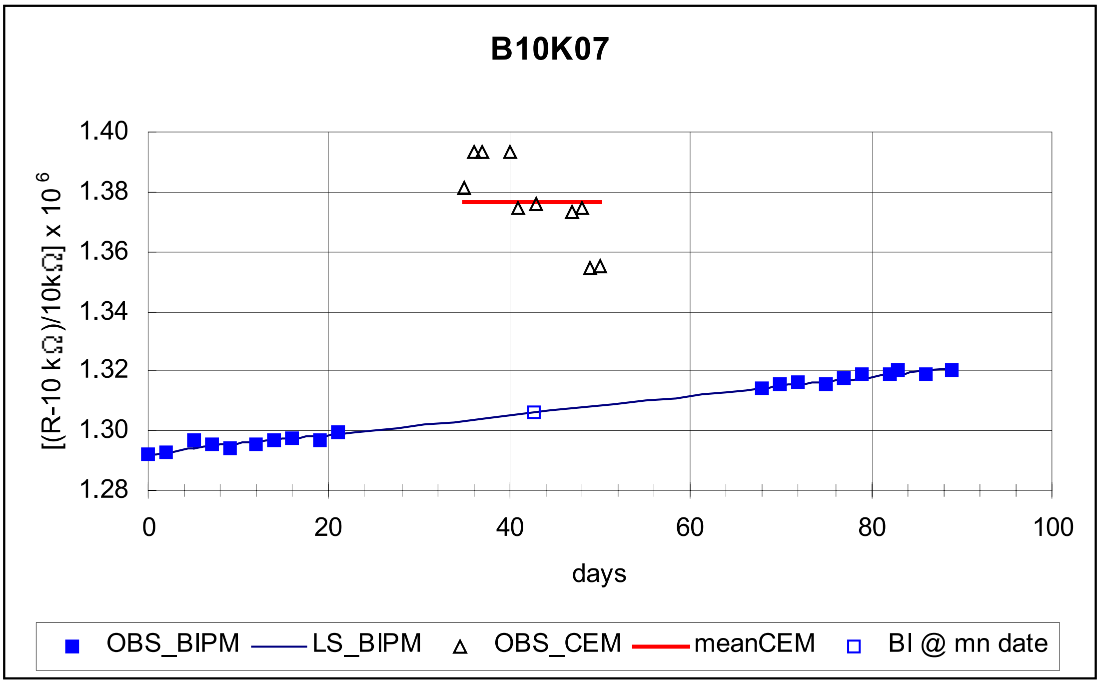

Figure 1. Relative deviation from the nominal 10 kΩ value of the resistance of B10K07 vs time: a linear least-squares fit (LS) to the BIPM measurements and the mean of the CMI measurements.

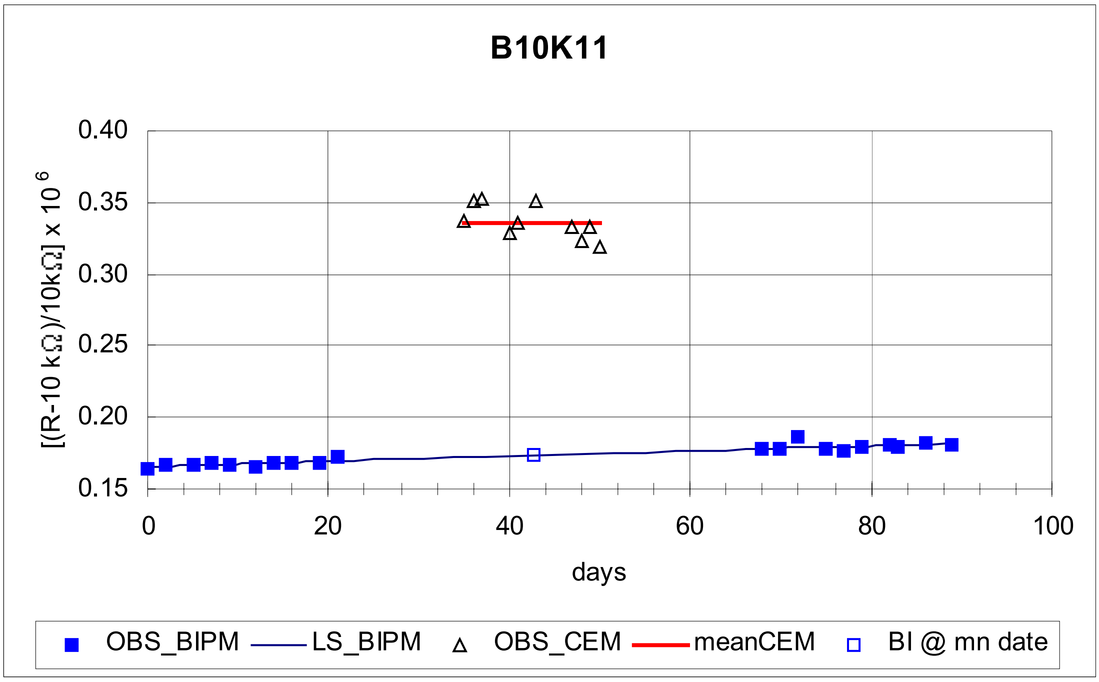

Figure 2. Relative deviation from the nominal 10 kΩ value of the resistance of B10K11 vs time: a linear least-squares fit (LS) to the BIPM measurements and the mean of the CMI measurements.

Table 1. Results of the CMI/BIPM bilateral comparison of 10 kΩ standards using two BIPM travelling standards: mean date 19 April 2000. Uncertainties are 1-σ estimates.
The combined type-A uncertainty is $w=[r^2+t^2]^{1/2}$, the expected transfer uncertainty is $x=[w_{07}^2+w_{11}^2]^{1/2}/2$ and the total combined uncertainty is $y=[s^2+u^2+x^2]^{1/2}$.

			B10K07	B10K11	
1	CMI	(R – 10 000 Ω)/mΩ	13.77	3.36	
2		type-A uncertainty/ mΩ	0.08	0.09	r
3		type-B uncertainty/ mΩ	2.0		s
4	BIPM	(R – 10 000 Ω)/mΩ	13.06	1.73	
5		type-A uncertainty/ mΩ	0.007	0.006	t
6		type-B uncertainty/ mΩ	0.15		u
7		($R_{CMI} - R_{BIPM}$)/ mΩ	0.71	1.63	
8		combined type-A uncertainty/ mΩ	0.08	0.09	w
9		$< R_{CMI} - R_{BIPM} >$/ mΩ	1.17		
10	expected type-A transfer uncertainty/ mΩ		0.06		x
11	s_M of difference for 2 resistors/ mΩ		0.46		
12	total uncertainty in comparison / mΩ		2.01		y

Table 2. Estimated type-B standard uncertainties, relative to the nominal value, for 10 kΩ calibrations with the BIPM equipment. A relative uncertainty of 1×10^{-8} corresponds to 0.1 mΩ.

Realization of $R_H(2)$	2×10^{-9}
Ratio of resistance of transfer resistor to $R_H(2)$	6×10^{-9}
DC/AC difference (at 1 Hz) of transfer resistor	2×10^{-9}
Comparison of transfer resistor to reference resistors	5×10^{-9}
Imprecision in the values of the reference resistors (including uncertainties in extrapolated resistance values and residual power, temperature and pressure effects)	10×10^{-9}
Comparison of the travelling standards to the reference resistor	5×10^{-9}
Uncertainty in the temperature correction for the travelling standard	2×10^{-9}
Uncertainty in the pressure correction for the travelling standard	4×10^{-9}
rss total	15×10^{-9}

Table 3. Estimated standard uncertainties, relative to the nominal value, for 10 kΩ calibrations with the CMI equipment. A relative uncertainty of 1×10^{-8} corresponds to 0.1 mΩ. Asterisks (*) indicate components that are either completely correlated or probably significantly correlated when measuring different travelling standards.

Calibrated value of the reference standard*	1.5×10^{-8}
Drift of the reference standard*	5.8×10^{-8}
Detector, measurement of resistance ratio of travelling resistor to tare	11.6×10^{-8}
Detector, measurement of resistance ratio of reference resistor to tare*	11.6×10^{-8}
Stability of tare resistor and turns ratio	5.8×10^{-8}
Linearity of turns ratio	5.8×10^{-8}
Residual temperature effects on resistance of standard and unknown	0.6×10^{-8}
Residual power effects on resistance of standard and unknown	0.6×10^{-8}
Leakage resistance effects on resistance of standard and unknown	2.9×10^{-8}
Transport effect on previous calibration of reference resistor*	1.2×10^{-8}
Influence of connection	1.2×10^{-8}
rss total	20×10^{-8}