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Bilateral Comparison of 1 Ω Standards (ongoing BIPM key comparison BIPM.EM-K13.a) between the KRISS, Republic of Korea and the BIPM, June 2003

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Bilateral Comparison of 1 Ω Standards
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A comparison of the 1 Ω reference standards of the BIPM and the Korea Research Institute of Standard and Science (KRISS), Daejeon, Republic of Korea, was carried out from April to September 2003. Three BIPM 1 Ω travelling standards, BIV202, BIV203 and BIV205 were shipped to the KRISS by air courier. The BIPM measurements were carried out at 23 °C by comparison with a 100 Ω reference resistor whose value is known with respect to the BIPM Quantized Hall Resistance (QHR) standard. The measuring current in the 1 Ω resistors was 50 mA. The KRISS measurements were carried out at 25 °C by comparison to the KRISS QHR standard in four steps involving transfer resistors of 10 Ω, 100 Ω and 1 kΩ. For each step, measurements were carried out using a commercially available, direct current comparator resistance bridge, MI 6010Q[1]. The measuring current used was 50mA. Further information about the KRISS measurement system is given in Annex 1.

The reference temperature to which all measurements were referred is 23°C. The pressure coefficients of the three travelling standards are negligible.

Figures 1, 2 and 3 show the measured values obtained for the three standards by the two laboratories. A linear least-squares fit to the BIPM values is used to calculate the BIPM values for the reference date, 23 June 2003, the mean date of the KRISS measurements. Each KRISS value is the unweighted mean of the results of KRISS measurements carried out on a given day (from 1 to 4 results per day, each result being itself an average of three to five individual 15 minute measurements). The uncertainty bars correspond to the type A standard uncertainties of the unweighted means. The KRISS value at the reference date is the weighted mean of the seven KRISS results; each weight is proportional to the square of the reciprocal of the type A standard uncertainty.

[1] In this report, commercial equipment are identified in order to adequately specify certain standards or procedures. In no case does such identification imply recommendation or endorsement by the KRISS or the BIPM, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Table 1 lists the results and the component uncertainty contributions for the comparison KRISS/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 KRISS.

The following elements are listed in Table 1:

(1) The mean resistance value R_{KRISS} of each resistor measured by the KRISS;
(2) The type A uncertainty due to the instability of the resistors and the measuring equipment of the KRISS, computed as the standard uncertainty of the weighted mean for each resistor;
(3) The type B uncertainty component due the measuring equipment of the KRISS;
(4-6) The corresponding quantities (1-3) for the BIPM;
(7) The difference ($R_{\mathrm{KRISS}} - R_{\mathrm{BIPM}}$) for each resistor;
(8) The clearly uncorrelated (type A) part of the uncertainty;
(9) The result of the comparison which is the unweighted mean of the differences of the calibration results for the different standards;
(10) The *expected* type A transfer uncertainty, x', based on the type A uncertainties of the individual results;
(11) The *a posteriori* transfer uncertainty, x, which is the standard deviation of the mean of the three different results. As x is larger than x', the former is retained as an estimation of the type A transfer uncertainty;
(12) The total uncertainty of the comparison, which is the root-sum-square of the type A transfer uncertainty and of type B uncertainties, including the uncertainty corresponding to the temperature correction from 25 °C to 23 °C.

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 KRISS, at the KRISS, R_{KRISS}, and that assigned by the BIPM, at the BIPM, R_{BIPM}, for the reference date is

$$R_{\mathrm{KRISS}} - R_{\mathrm{BIPM}} = 0.031\ \mu\Omega\ ;\ u_{\mathrm{c}} = 0.042\ \mu\Omega \quad \text{on 2003/06/23},$$

where u_{c} is the total standard uncertainty of the comparison. For both participants, the combined uncertainties are largely dominated by type B uncertainties for which the numbers of degrees of freedom are infinite. Thus, to a good approximation, the value of the coverage factor, k, corresponding to a 95 % confidence level is 2.

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.

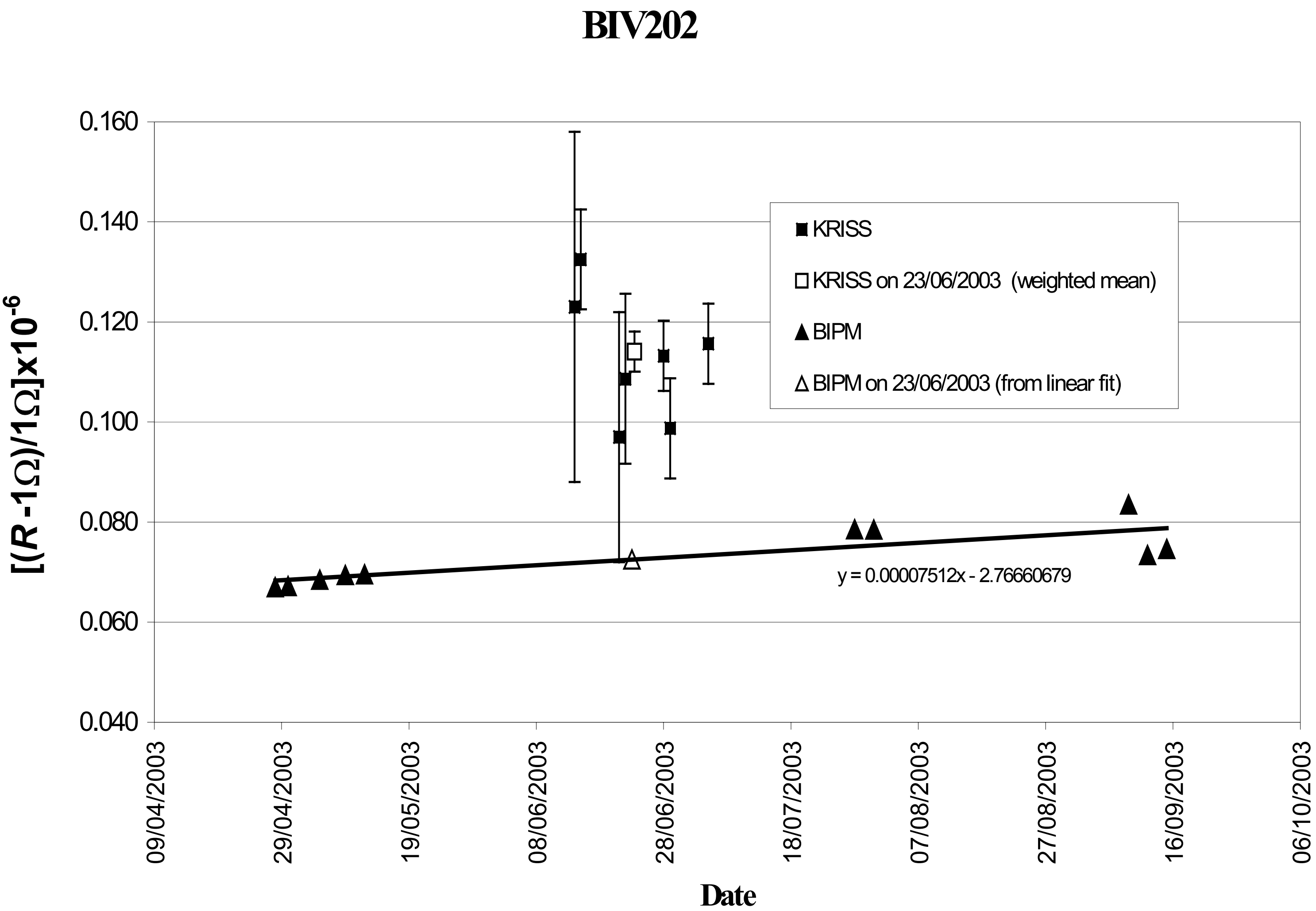

Figure 1. Relative deviation from the nominal 1 Ω value of the resistance of BIV202 vs time: a linear least-squares fit to the BIPM measurements (full line) and the weighted mean of the KRISS measurements. Uncertainty bars correspond to standard uncertainties of type A only. For each individual BIPM result, the type A standard uncertainty is about 3 parts in 10^9.

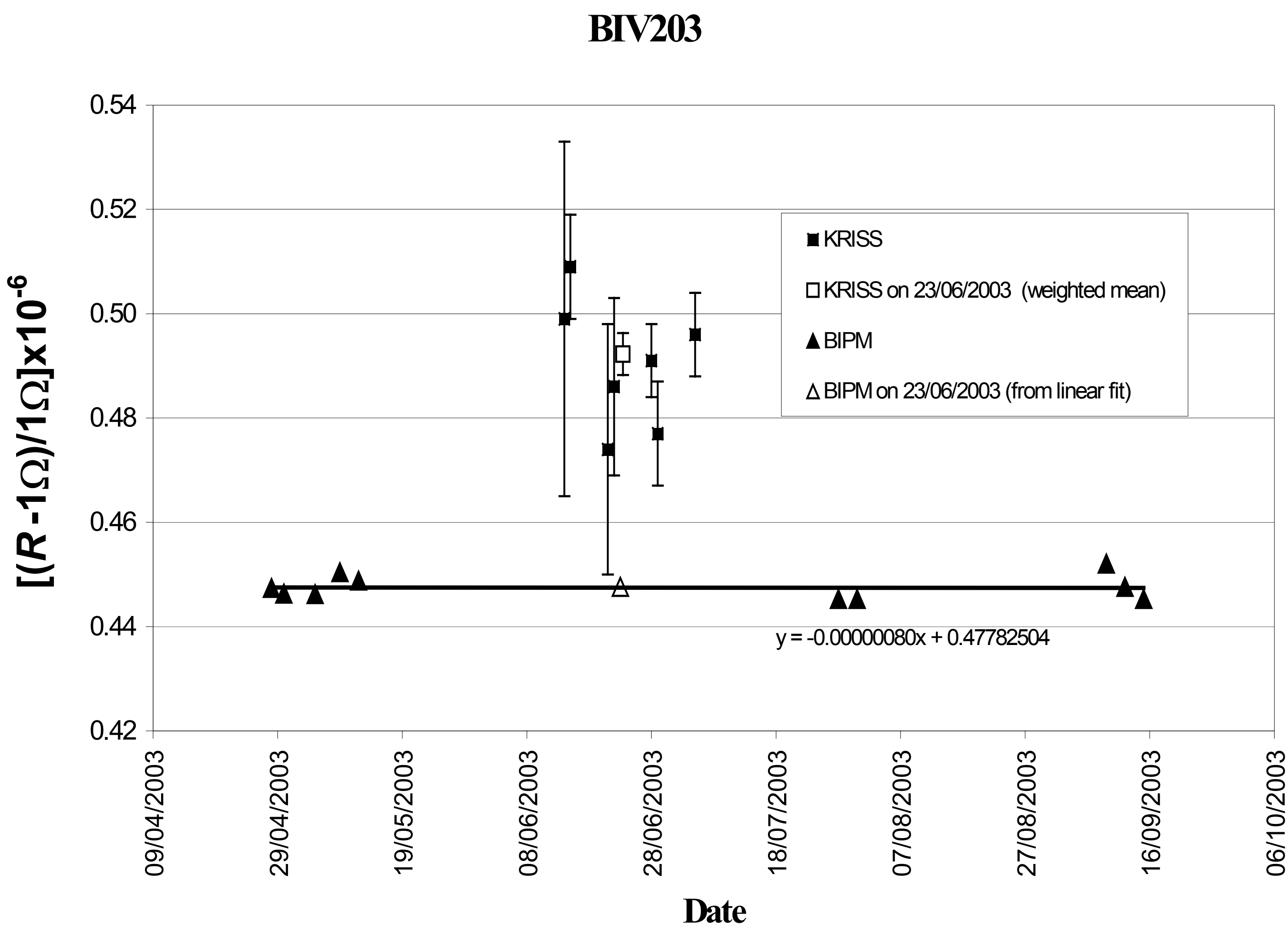

Figure 2. Relative deviation from the nominal 1 Ω value of the resistance of BIV203 vs time: a linear least-squares fit to the BIPM measurements (full line) and the weighted mean of the KRISS measurements. Uncertainty bars correspond to standard uncertainties of type A only. For each individual BIPM result, the type A standard uncertainty is about 3 parts in 10^9.

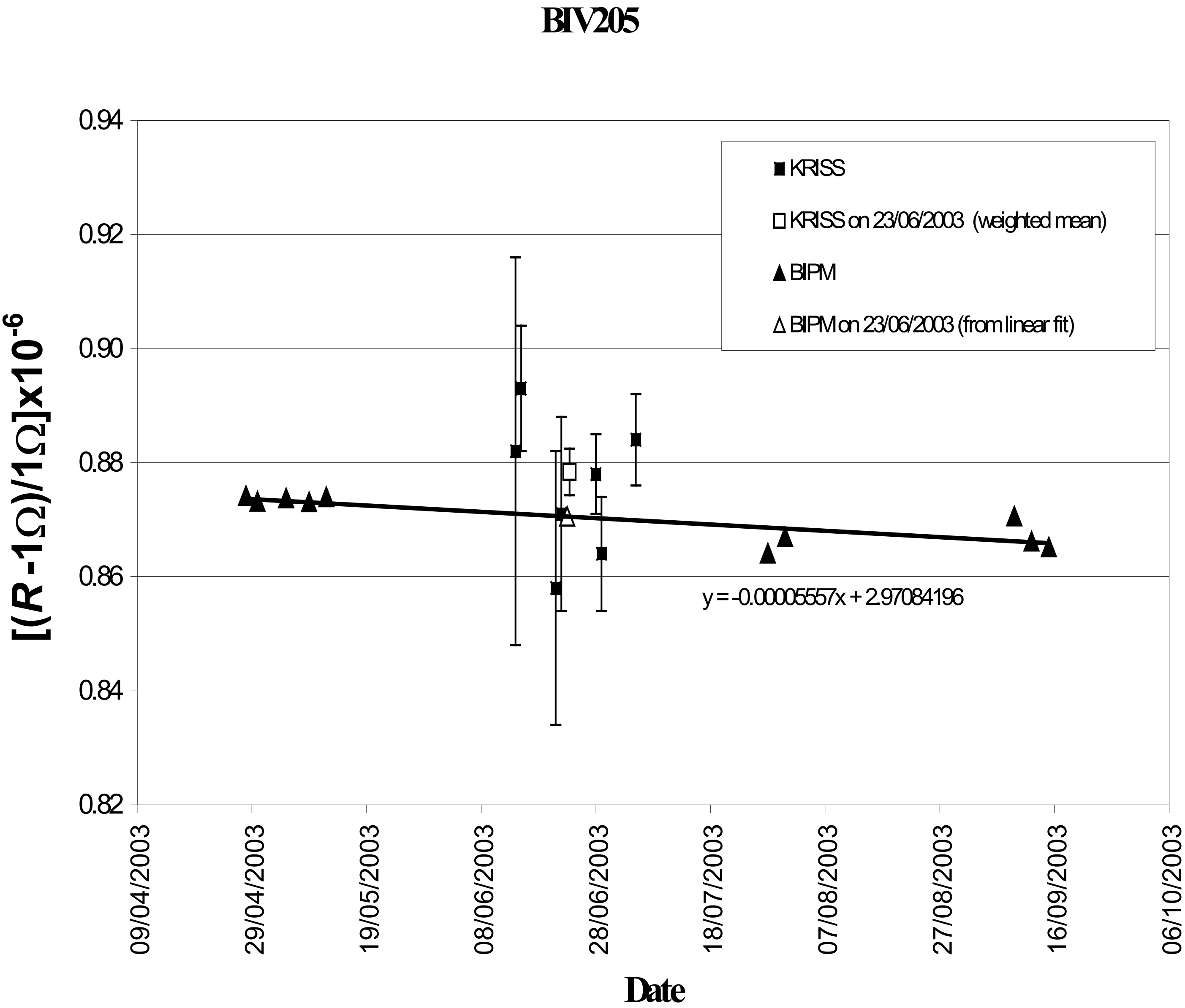

Figure 3. Relative deviation from the nominal 1 Ω value of the resistance of BIV205 vs time: a linear least-squares fit to the BIPM measurements (full line) and the weighted mean of the KRISS measurements. Uncertainty bars correspond to standard uncertainties of type A only. For each individual BIPM result, the type A standard uncertainty is about 3 parts in 10^9.

Table 1. Results of the KRISS/BIPM bilateral comparison of 1 Ω standards using three BIPM travelling standards: reference date 23 June 2003. Uncertainties are 1-σ estimates.
The combined type A uncertainty is $w=[r^2+t^2]^{1/2}$, the *expected* transfer uncertainty is $x'=[w_{202}^2+w_{203}^2+w_{205}^2]^{1/2}/3$, the *a posteriori* transfer uncertainty is x, the standard deviation of the mean $< R_{\mathrm{KRISS}} - R_{\mathrm{BIPM}} >$, and the total combined uncertainty is $y=[s_1^2+s_2^2+u^2+x^2]^{1/2}$.

			BIV202	BIV203	BIV205	
1	KRISS	$(R - 1\ \Omega)$/ μΩ	0.114	0.492	0.878	
2		Type A uncertainty/ μΩ	0.004	0.004	0.004	r
3		Type B uncertainty / μΩ		0.037		s_1
		Temperature-correction uncertainty/μΩ (from 25°C to 23°C)		0.005		s_2
4	BIPM	$(R - 1\ \Omega)$/μΩ	0.073	0.448	0.871	
5		Type A uncertainty/ μΩ	0.002	0.002	0.002	t
6		Type B uncertainty/ μΩ		0.016		u
7		$(R_{\mathrm{KRISS}} - R_{\mathrm{BIPM}})$/ μΩ	0.041	0.044	0.007	
8		Combined type A uncertainty/ μΩ	0.005	0.005	0.005	w
9		$< R_{\mathrm{KRISS}} - R_{\mathrm{BIPM}} >$/ μΩ	0.031			
10		Expected type A transfer uncertainty/ μΩ	0.003			x'
11		s_{M} of difference for 3 resistors/ μΩ	0.012			x
12		Total uncertainty in comparison / μΩ	0.042			y

Table 2. Estimated type B standard uncertainties, relative to the nominal value, for 1 Ω calibrations with the BIPM equipment.

Measurement of the 100 Ω reference in terms of $R_{\mathrm{K-90}}$	3×10^{-9}
Extrapolation of the value of the reference resistance at the date of the measurements, including residual temperature and pressure effects	13×10^{-9}
Measurement of the 1Ω/100 Ω ratio using a cryogenic current comparator	9×10^{-9}
rss total	16×10^{-9}

Table 3. Estimated type B standard uncertainties, relative to the nominal value, for 1 Ω calibrations with the KRISS equipment.

QHR(2)-ground leakage	10×10^{-9}
QHR device leakage	9×10^{-9}
QHR device temperature correction	20×10^{-9}
QHR(2)/1 kΩ ratio correction	20×10^{-9}
QHR(2)/1 kΩ ratio leakage	10×10^{-9}
Bridge ratio (10:1) correction	17×10^{-9}
rss total	37×10^{-9}

Annex 1:

Description of the KRISS measurement system

1. Measurement period : 2003/06/14 to 2003/07/05

2. Measurement method : the 10:1 ratio of the DCC bridge is used to compare the QHR (step i=2) with the BIPM 1 Ω standards via transfer standard resistors of 1 kΩ, 100 Ω and10 Ω.

3. Number of measurements: each reported value is the average of 3 to 5 individual measurements (about 15 minutes for one individual measurement) of the BIPM 1 Ω standards (SN 64202, 64203 and 64205). All the measurements were carried out between 6 P.M. and 6 A.M. on the next morning.

4. QHR device : certified by NRC of Canada, operated at 77 µA and at a temperature between 1.2 K and 1.5 K, with an uncertainty level of less than $1x10^{-8}$.

5. Contact resistance and longitudinal resistivity of the device (step 2 at about 7.3 T), with a current of 77 µA and at a temperature close to 1.5 K:
   1) contact resistance : less than 0.1 Ω for the source and drain terminals, less than 3 Ω for the 4 other potential terminals,
   2) longitudinal resistivity : less than 0.2 mΩ.

6.Transfer standard resistors (Tinsley 5685A, special type) : their relative power and temperature coefficients are about $0.002x10^{-6}$/mW and $0.5x10^{-6}$/K, respectively. Their relative resistance stability is about $0.5x10^{-6}$/year. Power and temperature effects are negligible for this comparison because the transfer standard resistors are used with power lower than 1 mW and at a temperature stable to within 0.005 K.

7. DCC bridge : MI 6010Q certified by METAS (Switzerland) , which has a 10 to 1 ratio relative uncertainty lower than $0.02x10^{-6}$ (k=2).

8. Temperature of the oil bath used : 25.000 °C ± 0.005 °C.

9. Measurement current : 50 mA (1 Ω)