Final Report

CCEM-K10 Key Comparison of Resistance Standards at 100 Ω

B. Schumacher
Physikalisch-Technische Bundesanstalt
Braunschweig, Germany

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1. Introduction

At the 22^{nd} CCEM meeting in Sèvres, France, on 14 September 2000, it was decided to start an international CIPM key comparison CCEM K-10 ”Resistance at 100 Ω” with the Physikalisch-Technische Bundesanstalt (PTB) as the pilot laboratory. This comparison checks the ability of the participants to scale from the quantized Hall resistance to 100 Ω. The reason why a 100 Ω key comparison has not been proposed up to now is that the knowledge of the transport behaviour of 100 Ω resistors was not sufficient to assure a meaningful comparison. As a result of EUROMET project 435 it has been shown that 100 Ω standard resistors are available that allow a comparison at a very low level of uncertainty ($< 10^{-8}$, 2σ)[1]. The same resistors were used in this comparison. The travelling standards for this comparison were kindly supplied by the National Physical Laboratory (NPL), United Kingdom, and by TEGAM, Geneva; Ohio, USA.

2. Participants and schedule

The pilot laboratory, 10 NMIs, and the BIPM agreed to participate in the comparison. During the time of the comparison 3 NMIs withdraw due to personal or technical problems. One laboratory asked to repeat their measurements towards the end of the comparison due to temperature problems occurred at the first set of measurements. Table 1 lists all participant laboratories in chronological order and the period of their measurements. The last column indicates the main events occurred during the comparison.

Acronym	*National Metrology Institute*	*Country*	*Standards at the lab.*	*Mean Date of Measurement*	*Comment*
PTB	Physikalisch-Technische Bundesanstalt (Pilot)		15. Feb. 2001		initial characterisation of the standards
		Germany	to	9. May 2001	
			18. Jul. 2001		
NIST	National Institute of Standards and Technology		1. Aug. 2001		
		U.S.A.	to	19. Aug. 2001	
			24. Aug. 2001		
NRC	National Research Council		27. Aug. 2001		
		Canada	to	18. Sept. 2001	
			26. Sep.2001		
BIPM	International Bureau of Weights and Measures		5. Oct. 2001		air/oil-bath failure, all standards involved
		International	to	16. Oct. 2001	
			28. Oct. 2001		
PTB	Physikalisch-Technische Bundesanstalt (Pilot)		29. Oct. 2001		
		Germany	to	25. Nov. 2001	
			15. Jan. 2002		
MIKES	Centre for Metrology and Accreditation		16. Jan. 2002		change in drift rate of Tinsley #919
		Finland	to	9. Feb. 2002	
			13. Feb. 2002		
CSIRO/ NML	CSIRO National Measurement Laboratory		25. Feb. 2002		
		Australia	to	6. Mar. 2002	
			15. Mar. 2002		
PTB	Physikalisch-Technische Bundesanstalt (Pilot)		30. Mar. 2002		
		Germany	to	5. May 2002	
			31. May 2002		

METAS	Swiss Federal Office of Metrology and Accreditation		5. Jun. 2002		
		Switzerland	to	11. Jul. 2002	
			23. Jul. 2002		
PTB	Physikalisch-Technische Bundesanstalt (Pilot),		29. Jul. 2002		
		Germany	to	20. Sep. 2002	
			14. Nov. 2002		
AIST	National Institute of Advanced Industrial Science and Technology		2. Dec. 2002		
		Japan	to	18. Dec. 2002	
			7. Jan. 2003		
BIPM	International Bureau of Weights and Measures		31. Jan 2003		
		International	to	15. Feb. 2003	
			26. Feb. 2003		
PTB	Physikalisch-Technische Bundesanstalt (Pilot)		3. Mar. 2003		
		Germany	to	18. Mar. 2003	
			2. Apr. 2003		
NIM	National Institute of Metrology		10. Apr. 2003		
		China	to	26. Apr. 2003	
			8. May 2003		
PTB	Physikalisch-Technische Bundesanstalt (Pilot)		16. May 2003		
		Germany	to	2. Aug. 2003	
			18. Aug. 2003		

Table 1: Participants list and schedule

3. Transfer standards and required measurements

The chosen travelling standards were commercially available resistors with common four terminal connectors:

- Standard Resistor 100 Ω Tinsley 5685A, S/N 267 919,
- Standard Resistor 100 Ω Tinsley 5685A, S/N 262 767,
- Standard Resistor 100 Ω Tinsley 5685A, S/N 268 168,
- Standard Resistor 100 Ω Tegam SR 102, S/N A 2030397.

The required measurand was the value of the resistance at DC, based on the conventional value of the von Klitzing constant $R_{\text{K-90}}$=25 812,807 Ω. The preferred measurement conditions were:

- direct comparison with the QHR using a CCC bridge,
- aimed uncertainty less than $2{\cdot}10^{-8}$ (95% confidence level),
- current through the resistor 5 mA,
- ambient temperature (23,00 ± 0,05) °C for the Tinsley resistors in oil, (23,00 ± 0,20) °C for the Tegam resistor in air);

Together with the results of the resistance measurements, the resistance temperature and ambient pressure were required.

4. Measurements of the pilot laboratory

The temperature and pressure coefficients have been determined, and are listed in the table 2 below. The Tinsley resistors showed no significant pressure coefficient. With these values and the provided temperature and pressure data, all results have been corrected to nominal conditions which are 23,000°C and 1013,25 hPa.

Resistor	α_{23} / 10^{-9}K^{-1}	$u(\alpha_{23})$ / 10^{-9}K^{-1}	β / 10^{-9}K^{-2}	$u(\beta)$ / 10^{-9}K^{-2}	p_k / 10^{-9}hPa^{-1}	$u(pk)$ / 10^{-9}hPa^{-1}
267 919	-483,4	2,1	-79,1	2	0,01	0,03
262 767	-35,7	2,1	-79,3	2	0,00	0,02
268 168	-635,6	2,1	-76,3	2	0,04	0,02
A 2030397	79,5	2,1	-22,7	2	-0,29	0,13

Table 2: Temperature and pressure coefficients of the resistors, used in the comparison.

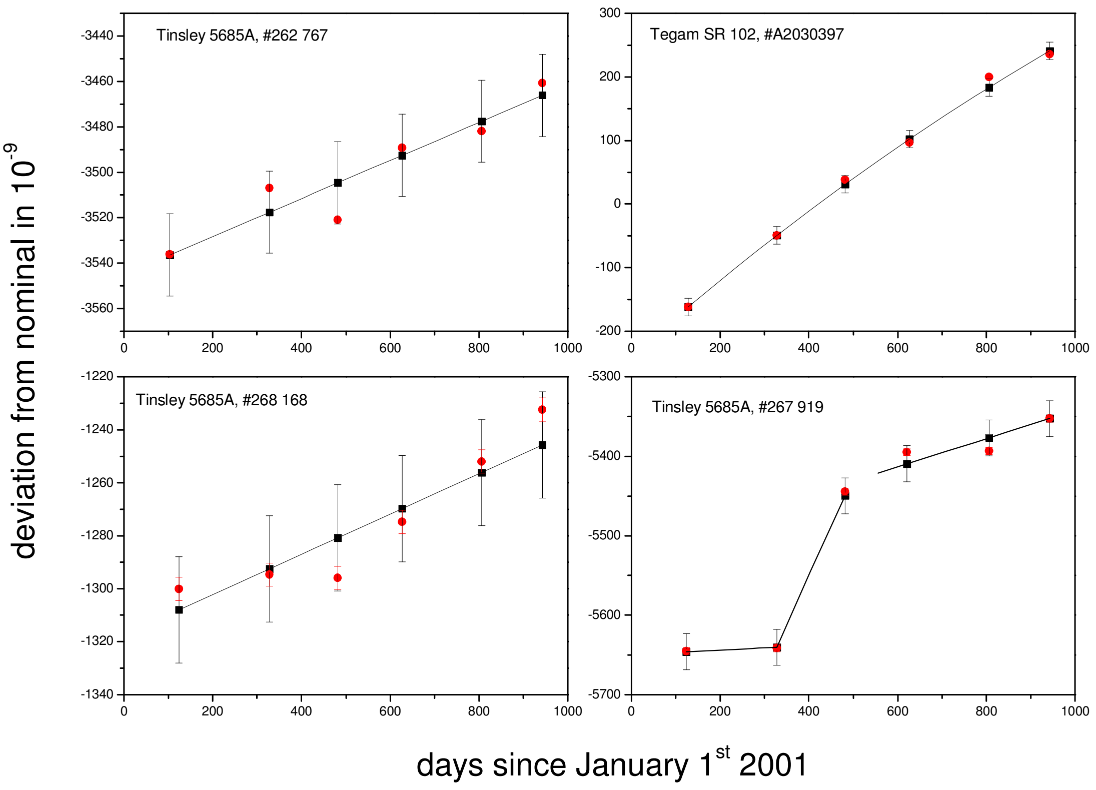


Figure 1: Measurements of the travelling standards by the pilot laboratory and drift behavior. The red circles represent the mean of the results of the pilot during the individual measurement periods. The black squares are the values calculated from the drift analysis with the residual as uncertainty bar.

All resistors have repeatedly been measured by the pilot laboratory. Due to transportation effects, the overall drift of the standards is different from the drift during the period in the laboratory. Therefore, for each resistor, all measurements of a laboratory are combined to a mean result given for a mean date. This result is taken from a linear regression analysis and the residual of the fit is included in the laboratory's uncertainty.

The results of the pilot laboratory are shown in the figures above. The determined drift rate is based on all individual measurements of the pilot laboratory. For the resistors #262 767 and #268 168 the drift behavior can be described by a linear equation,

- $R(\#262\ 767) = 100\cdot(1-(3545{,}0179-0{,}08374\cdot t)\cdot 10^{-9})\ \Omega$
- $R(\#268\ 168) = 100\cdot(1-(1317{,}420-0{,}0760\cdot t)\cdot 10^{-9})\ \Omega$

where t is the number of days since January 1st 2001. The standard deviations of the residuals for the fits are $8{,}81\cdot 10^{-9}$ and $9{,}76\cdot 10^{-9}$ respectively. For resistor #268 168 a model with two linear segments was considered, but it had no advantage over the single linear fit. The Tegam SR102 is fitted with a second order regression line, which is an approximation of a possible exponential drift behavior.

- $R(\#2030397) = 100\cdot(1-(238{,}139-0{,}61144\cdot t+1{,}096\cdot 10^{-4}\cdot t^2)\cdot 10^{-9})\ \Omega$.

where t is the number of days since January 1st 2001. The standard deviation of the residuals for the fit is $6{,}77\cdot 10^{-9}$. The resistor Tinsley #267 919 showed a strong instability after a transportation. The drastic change in the drift behavior is accounted for by a description with three different linear equations.

- $R(\#267\ 919) = 100\cdot(1-(5649{,}247-0{,}0271\cdot t)\cdot 10^{-9})\ \Omega$, 2001-05-05 < t < 2001-11-25
- $R(\#267\ 919) = 100\cdot(1-(6036{,}324-1{,}217\cdot t)\cdot 10^{-9})\ \Omega$, 2001-11-25 < t < 2002-04-28
- $R(\#267\ 919) = 100\cdot(1-(5519{,}095-0{,}177\cdot t)\cdot 10^{-9})\ \Omega$, 2002-04-28 < t < 2003-08-02

The standard deviation of the residuals for the fit is $11{,}1\cdot 10^{-9}$.

5. Measurement Methods

The methods of measurement carried out by the participants are described briefly

PTB, NRC, NIST, METAS, AIST, NIM:

The measurements at these institutes were made using their cryogenic current comparator bridge. All four resistors were measured against the QHR i=2 plateau. At METAS also measurements against the QHR i=4 plateau were made.

BIPM:

First participation**:**

The measurements were made using the BIPM cryogenic dc current comparator bridge. All four resistors were measured against the QHR i=2 plateau.

Second participation:

The three Tinsley resistors were compared with a BIPM 100 Ω reference standard using a substitution method in a cryogenic current comparator bridge. The measuring current in the Tinsley resistors was 0,5 mA. The 100 Ω reference standard is known in terms of the BIPM realization of the ohm based on the quantum Hall effect.

The Tegam resistor was compared with the BIPM 100 Ω reference standard by a method of substitution using a room-temperature current comparator operating at 1 Hz. The measuring current in the Tegam resistor was 5 mA. The frequency dependence has been evaluated and corrected for.

MIKES:

The resistors were measured against the MIKES QHR standard using an AC cryogenic current comparator bridge. The measurements were performed in the frequency range from 0,1 Hz to 0,3 Hz with current values of 2,6 mA and 5 mA (rms value). No significant frequency dependence has been found so the values are considered to be equal to the DC values

CSIRO-NML:

The standards were compared against the NML as-maintained resistance unit (four 1 Ω resistors) using a Warshawsky bridge and the NML 100 element Hamon build-up resistor (10kΩ BUR). The 1 Ω resistors were measured against the QHR using a potentiometric system and an 83 element Hamon build-up resistor (QHR BUR).

6. Results

6.1 Participant results and differences from pilot

Due to similarities in the measurement objects and procedures, for the calculation of the reference value a similar procedure as for CCEM-K2 is chosen[2]. In the long run all resistors show a linear drift behavior. Also the drift during the respective periods in the laboratories is linear. Due to unforeseeable transport effects the drift during the time in the laboratory is different from the overall drift. Hence, for the evaluation all short term drifts have been accounted for by a linear regression on the participant measurement results. A single value, for each resistor and for each participant, is calculated at the mean date of the participant measurements, based on the corresponding regression, and is used for further analysis. The uncertainty of this value is calculated from the Type A and Type B uncertainties from the uncertainty budget, and the residual standard deviation of the regression (also considered as Type A). Values and uncertainties for each laboratory are listed in Table A-1.

The drift behavior of the standards is then analyzed, taking all the results of the pilot laboratory into account. For the resistors Tinsley #268 168 and #262 767 a single linear regression is chosen, for the Tegam #2030397 a polynomial of second order is chosen and for the Tinsley 267 919 a fit consisting of three linear fits is chosen. The Tinsley #267 919 suffered from a bad travel experience, that caused an extreme change in drift rate.

In a next step, for each participant and for each resistor, the difference between the single value and the corresponding value deduced from the fit to the pilot measurement results is calculated.

$$D_i = x_i - V_r \tag{1}$$

This eliminates the drift from the results. Then, for each participant (a total of 15 participations), the weighted mean, D_{iCOMB}, of the four differences is calculated using weights proportional to $1/\sigma_r^2(j)$ where $\sigma_r(j)$ are the standard deviations of the residuals in the pilot fits for the four resistors.

For some laboratories, outlier values of D_{i} have been excluded from the set of four values normally used to calculate the weighted mean D_{iCOMB}. A value of D_{i} for a particular resistor and a particular laboratory is regarded as an outlier if it differs more than 4 σ from the mean of all D_{i} values corresponding to that resistor. Here σ is the standard deviation of that respective mean. Not more than one outlier per participant is excluded to leave a minimum of three components in each weighted mean D_{iCOMB}. The values regarded as outliers are marked in table A-3 with an asterisk.

The expanded relative uncertainty (k=2) for the D_{iCOMB} is defined as

$$U_{i\mathrm{COMB}} = 2 \cdot \sqrt{\mathrm{VAR}\left[D_{i\mathrm{COMB}}\right]} \qquad .(2)$$

where the variance of the D_{iCOMB} are defined as follows:

- non-pilot laboratory

$$Var\left[D_{i,comb}\right] = \sigma^2_{x,B,i} + \sigma^2_{x,A,i} \cdot \frac{\sum_{j=1}^{4} \frac{1}{\sigma_r^4(j)}}{\left(\sum_{j=1}^{4} \frac{1}{\sigma_r^2(j)}\right)^2} + \frac{1 + \frac{1}{n} + \frac{(t_i - \bar{t}_{PTB})^2}{\sum_{k=1}^{n} (t_{PTB,k} - \bar{t}_{PTB})^2}}{\sum_{j=1}^{4} \frac{1}{\sigma_r^2(j)}} \qquad (3)$$

- pilot laboratory (has measured *n* times)

$$Var\left[D_{PTB,comb}\right] = \sigma^2_{x,B,PTB} + \frac{\sigma^2_{x,A,PTB}}{n} \cdot \frac{\sum_{j=1}^{4} \frac{1}{\sigma_r^4(j)}}{\left(\sum_{j=1}^{4} \frac{1}{\sigma_r^2(j)}\right)^2} \qquad (4)$$

The σ_{xA} is the root sum square of the participants type A uncertainty, stated in the budget as the random contribution of the measurement, and the residual of the linear regression fit of the repeated measurement in the participants laboratory. The $\sigma_{\mathrm{x,B}}$ includes the type B uncertainties as listed in the uncertainty budget and those contributions designated as type A, which are attributed to the measurement set up. The D_{iCOMB} for the BIPM is the arithmetic mean of its individual measurements. Each U_{iCOMB} includes the variance of each resistor and thus a part of the transport uncertainty is included. The values used to calculate U_{iCOMB} are listed in table A-2. An additional transport uncertainty $u_{\mathrm{T}} = 3{,}5 \cdot 10^{-9}$ is included in U_{iCOMB}. This value is chosen that the results and uncertainties fulfill the χ^2 criteria. The measurement results and the differences from the fit are listed in table A-3 and shown for each resistor in figures A-1 to A-4.

6.2 Key comparison reference value and its uncertainty

The key comparison reference value, X_{KCRV}, and the uncertainty of the key comparison reference value, U_{KCRV}, is determined from the weighted mean of the D_{iCOMB} with the U_{iCOMB} used as weight. In this calculation the mean value for the pilot laboratory is taken. The values are calculated as follows:

$$X_{\mathrm{KCRV}} = U^2_{\mathrm{KCRV}} \cdot \sum_{i=1}^{10} \frac{D_{iCOMB}}{U^2_{iCOMB}}, \quad U_{KCRV} = \frac{1}{\sqrt{\sum_{i=1}^{10} \frac{1}{U^2_{i\mathrm{COMB}}}}} \qquad (5)$$

$$X_{\mathrm{KCRV}} = -0{,}14 \cdot 10^{-9}, \; U_{\mathrm{KCRV}} = 4{,}57 \cdot 10^{-9} \qquad (6)$$

6.3 Degree of equivalence with respect to the KCRV

The degree of equivalence is shown in Table B-4. The equivalence with the key comparison reference value and its uncertainty is calculated as follows

$$D_{iKCRV} = D_{iCOMB} - X_{KCRV} \tag{7}$$

$$U_{iKCRV} = \sqrt{U_{iCOMB}^2 - U_{KCRV}^2} \; . \tag{8}$$

The differences between the laboratories results and the key comparison reference value are shown in figure B-5.

7. Effect of correlation among the laboratory differences

Each laboratory has its own independent realization of the Quantum Hall resistance standard, from which the values for the resistors are derived, so there is no apparent source of correlation in the results.

8. Conclusion

This comparison is limited by the transport behavior of the resistors. Although the resistors have been thoroughly evaluated in EUROMET project 435, there is still the chance of unexpected jumps in resistance value. On the other hand, it could be shown that the equivalence between the laboratories and the KCRV is better than $2 \cdot 10^{-8}$. All uncertainties (except CSIRO) are significantly greater than the laboratory's claims due to the added transport uncertainty of the resistors. So these results are limited by the transportability of the resistors and not by the capability of the participants. The scatter of the results with respect to the KCRV is more or less arbitrary. Therefore a degree of equivalence between pairs of laboratories is not meaningful.

9. References

[1] B. Schumacher et al. "Transport Behavior of Commercially Available 100-Ω Resistors", IEEE-**IM** 50,242-246.

[2] D.G. Jarrett and R.F. Dziuba, "CCEM-K2 Key Comparison of 10-MΩ and 1-GΩ Resistance Standards", IEEE-IM **52**, 474-477.

[3] Nien Fan Zhang et al., "Statistical analysis of key comparisons with linear trends", Metrologia **41** (2004) 231-237.

Appendix A

Measurement results

Appendix A: Measurement Results

Table A-1

Summary of all results, calculated for a mean date. The corresponding uncertainty is the one calculated from the participants uncertainty budget.

		Tegam no. 2030397		Tinsley no. 267 919		Tinsley no. 262 767		Tinsley no. 268 168	
institute	mean date	result ($\cdot 10^{-9}$)	U_i ($\cdot 10^{-9}$)	result ($\cdot 10^{-9}$)	U_i ($\cdot 10^{-9}$)	result ($\cdot 10^{-9}$)	U_i ($\cdot 10^{-9}$)	result ($\cdot 10^{-9}$)	U_i ($\cdot 10^{-9}$)
PTB	09.05.2001	-161,67	2,6	-5645,89	3,0	-3536,39	2,6	-1308,00	3,4
NIST	19.08.2001	-94,62	6,2	-5645,94	6,6	-3522,26	3,2	-1284,52	5,4
NRC	18.09.2001	-29,88	7,2	-5646,39	7,4	-3538,3	6,8	-1314,16	7,7
BIPM	16.10.2001	-26,88	4,5	-5636,89	4,6	-3537,06	5,2	-1284,8	4,6
PTB	25.11.2001	-49,38	2,6	-5640,37	3,0	-3517,55	2,6	-1292,49	3,4
MIKES	09.02.2002	3,93	11,3	-5531,44	14,4	-3494,17	11,3	-1283,73	15,9
CSIRO	06.03.2002	0,04	64,6	-5530	62,6	-3520	62,6	-1279,99	62,6
PTB	28.04.2002	31,11	2,6	-5449,77	3,0	-3504,66	2,6	-1280,79	3,4
METAS	11.07.2002	64,65	2,3	-5417,4	3,6	-3525,00	2,3	-1290,6	4,3
PTB	20.09.2002	102,15	2,6	-5409,48	3,0	-3492,51	2,6	-1269,77	3,4
AIST	11.12.2002	132,93	15,7	-5388	13,8	-3485	12,7	-1288,01	14,5
BIPM	15.02.2003	211,27	14,2	-5386,1	15,7	-3487,19	15,7	-1251,06	15,7
PTB	18.03.2003	183,48	2,6	-5376,83	3,0	-3477,52	2,6	-1256,16	3,4
NIM	24.04.2003	221,7	1,4	-5390,42	1,5	-3474,19	1,5	-1259,28	1,8
PTB	02.08.2003	240,99	2,6	-5352,65	3,0	-3466,05	2,6	-1245,75	3,4

Table A-2

List of the uncertainty components σ_A and σ_B, used in the evaluation:

	weighted mean		Tinsley no. 268 168		Tinsley no. 267 919		Tegam no. 2030397		Tinsley no. 262 767	
institute	$\sigma_{A,i}$ $(\cdot 10^{-9})$	$\sigma_{B,i}$ $(\cdot 10^{-9})$	σ_A $(\cdot 10^{-9})$	σ_B $(\cdot 10^{-9})$	σ_A $(\cdot 10^{-9})$	σ_B $(\cdot 10^{-9})$	σ_A $(\cdot 10^{-9})$	σ_B $(\cdot 10^{-9})$	σ_A $(\cdot 10^{-9})$	σ_B $(\cdot 10^{-9})$
PTB	8,5	1,3	11,1	1,4	9,8	1,6	6,8	1,2	8,8	1,2
NIST	4,7	1,3	4,5	1,6	3,9	1,6	6,2	1,1	2,8	1,3
NRC	4,0	2,3	5,0	2,3	3,1	2,5	3,8	2,3	4,2	2,1
BIPM	5,4	2,0	7,5	2,0	7,1	2,0	4,5	2,0	4,0	2,0
MIKES	4,9	6,0	4,8	6,9	5,0	7,7	5,8	5,3	3,4	5,3
CSIRO	9,0	30,4	9,0	30,0	9,0	30,0	9,0	31,0	9,0	30,0
METAS	0,4	1,4	0,4	1,8	0,4	2,1	0,4	1,1	0,4	1,1
AIST	2,3	6,8	2,3	6,5	2,3	6,9	2,3	7,5	2,3	5,9
BIPM	3,4	7,3	4,5	7,6	2,0	7,6	2,5	6,8	5,3	7,6
NIM	0,8	0,3	1,2	0,5	0,7	0,6	0,7	0,2	0,8	0,2

For each resistor, the σ_A is the root sum square of the participants type A uncertainty, stated in the budget as the random contribution of the measurement, and the residual of the linear regression fit of the repeated measurement in the participants laboratory. The σ_B is taken from the uncertainty budget, including the contributions designated as type A, which belong to the measurement set up.

Table A-3

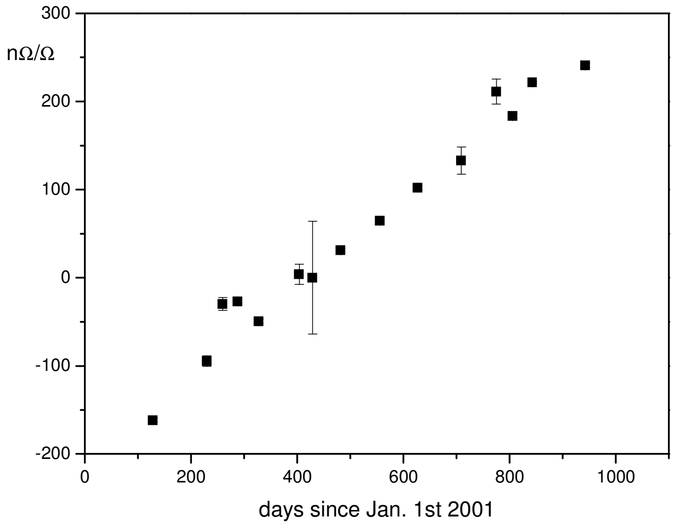
Summary of reference values V_r and the differences D_i of the laboratories, all values are in 10^{-9}:

		Tegam no. 2030397		Tinsley no. 267 919		Tinsley no. 262 767		Tinsley no. 268 168		weighted mean		
institute	mean date	V_r	D_i	V_r	D_i	V_r	D_i	V_r	D_i	$D_{i\text{-comb}}$	$U_{i\text{-comb}}$	$U_{i\text{-comb,T}}$
PTB	09.05.2001	-161,67	0	-5645,89	0	-3536,39	0	-1308,00	0	0,00	4,56	8,4
NIST	19.08.2001	-103,31	8,69	-5643,03	-2,91	-3525,76	3,50	-1299,94	15,42	6,99	11,63	13,6
NRC	18.09.2001	-86,57	*56,69	-5642,21	-4,18	-3523,25	-15,05	-1297,66	-16,50	-12,73	11,81	13,7
BIPM	16.10.2001	-71,13	*44,25	-5641,46	4,57	-3520,90	-16,16	-1295,53	10,73	-1,86	12,13	14,0
PTB	25.11.2001	-49,38	0	-5640,37	0	-3517,55	0	-1292,49	0	0,00	4,56	8,4
MIKES	09.02.2002	-9,01	12,94	-5544,69	13,25	-3511,19	17,02	-1286,72	2,99	12,01	16,23	17,7
CSIRO	06.03.2002	4,00	-3,96	-5514,27	-15,73	-3509,09	-10,91	-1284,82	4,83	-5,70	61,65	62,1
PTB	28.04.2002	31,11	0	-5449,77	0	-3504,66	0	-1280,79	0	0,00	4,56	8,4
METAS	11.07.2002	67,94	-3,29	-5420,96	3,56	-3498,46	*-26,54	-1275,16	-15,44	-5,07	9,77	12,0
PTB	20.09.2002	102,15	0	-5409,48	0	-3492,51	0	-1269,77	0	0,00	4,56	8,4
AIST	11.12.2002	140,28	-7,35	-5393,95	5,95	-3485,65	0,65	-1263,54	*-24,47	-2,42	16,88	18,3
BIPM	15.02.2003	169,90	*41,37	-5382,30	-3,80	-3480,12	-7,07	-1258,52	7,46	-1,39	17,89	19,2
PTB	18.03.2003	183,48	0	-5376,83	0	-3477,52	0	-1256,16	0	0,00	4,56	8,4
NIM	24.04.2003	199,42	22,28	-5370,30	-20,12	-3474,34	0,15	-1253,35	-5,93	4,92	10,11	12,3
PTB	02.08.2003	240,99	0	-5352,65	0	-3466,05	0	-1245,75	0	0,00	4,56	8,4
PTB_{mean}	13.07.2002									0	4,56	8,4

* denotes outliers, not included in the evaluation

$U_{i\text{-comb,T}}$ is the root sum square of $U_{i\text{-comb}}$ and the additional transport uncertainty ($7 \cdot 10^{-9}$, chosen to fulfill the χ^2 criteria)

Figure A-1: Results and differences for Tegam SR102, no. 2030397



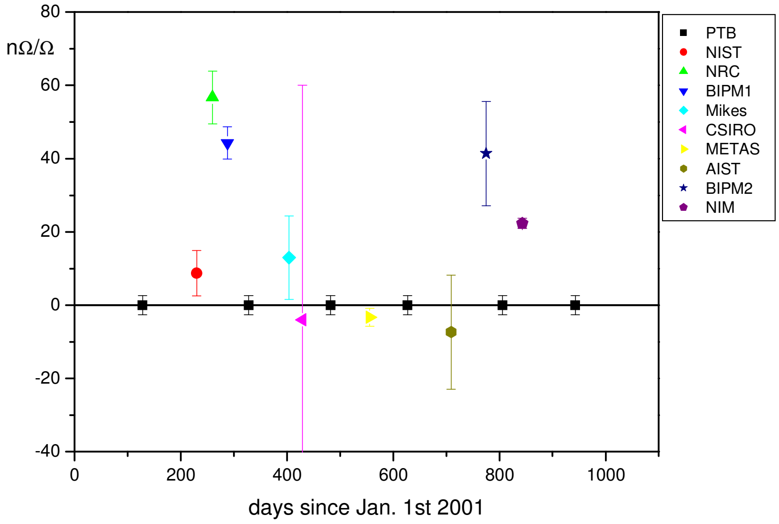
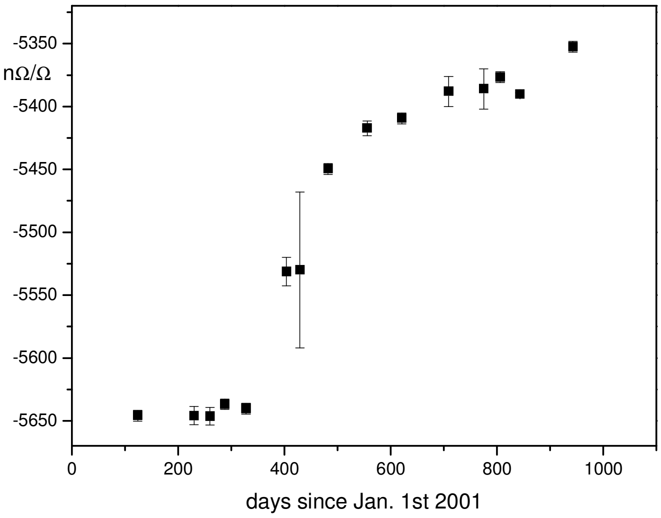


Figure A-2: Results and differences for Tinsley 5685A, no. 267 919



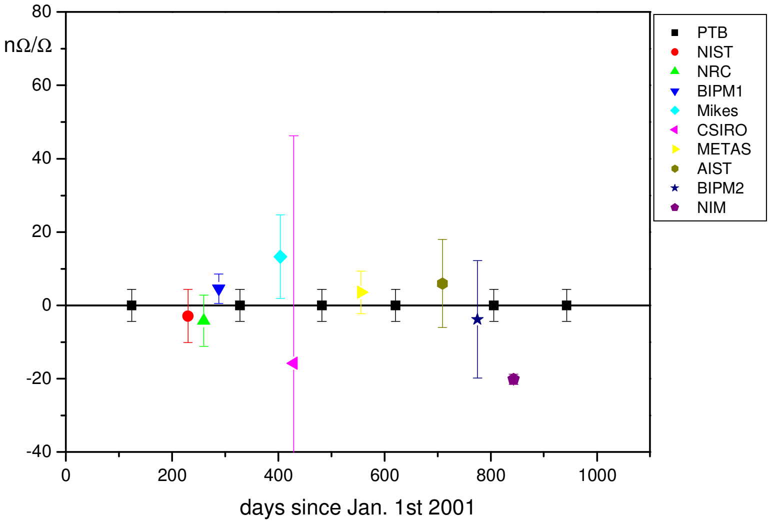
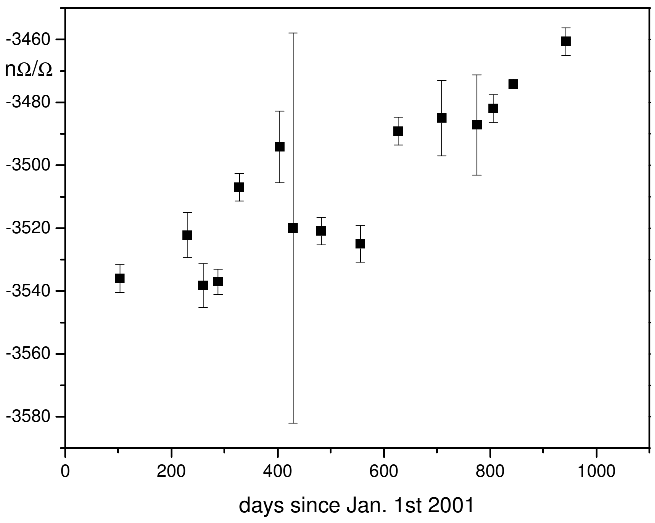


Figure A-3: Results and differences for Tinsley 5685A, no. 262 767



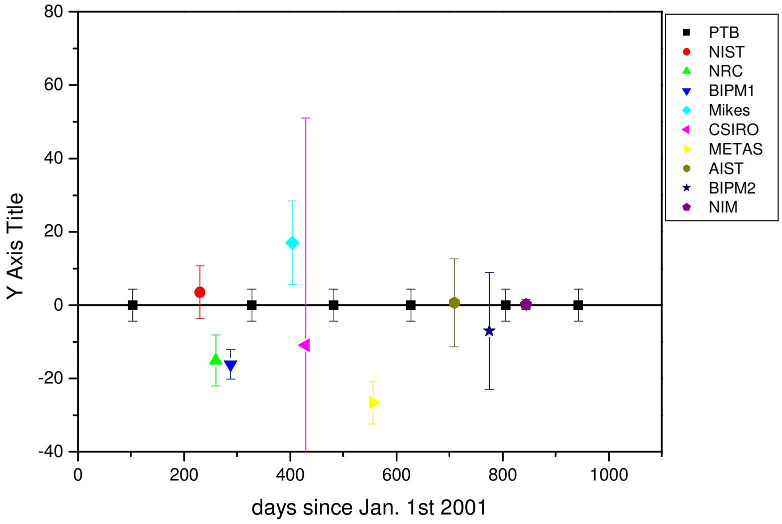
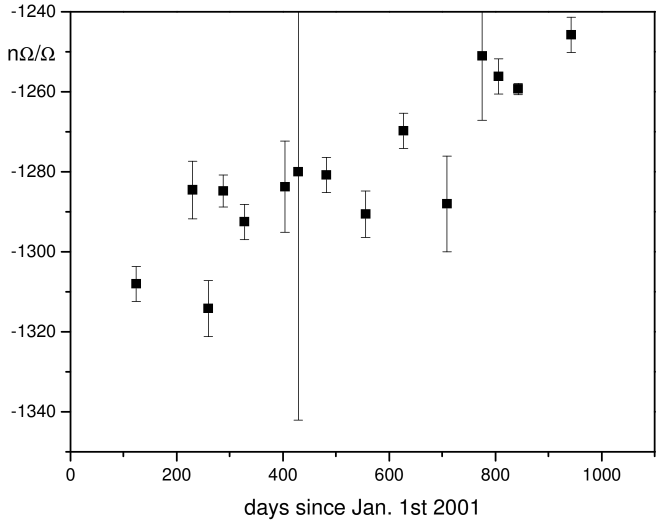
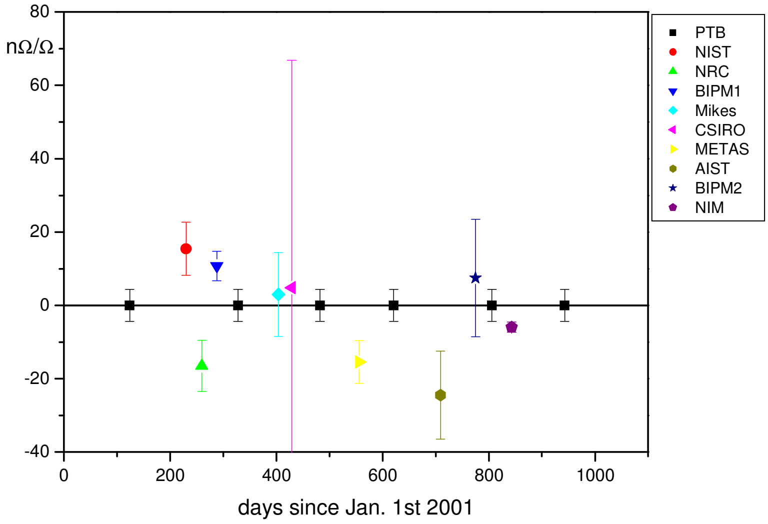


Figure A-4: Results and differences for Tinsley 5685A, no. 268 168





Appendix B

Degree of equivalence

Table B-4: Equivalence with respect to the KCRV at 100 Ω (k=2)

Laboratoy	KCRV	
	D_{iKCRV}	U_{iKCRV}
	$\cdot 10^{-9}$	
PTB	0,14	7,0
NIST	7,13	12,8
NRC	-12,59	12,9
BIPM	-1,48	18,7
MIKES	12,15	17,1
CSIRO	-5,56	61,9
METAS	-4,93	11,1
AIST	-2,28	17,7
NIM	5,07	11,4

All uncertainties (except CSIRO) are significantly greater than the laboratory's claims due to the added transport uncertainty of the resistors. So these results are limited by the transportability of the resistors and not by the capability of the participants.

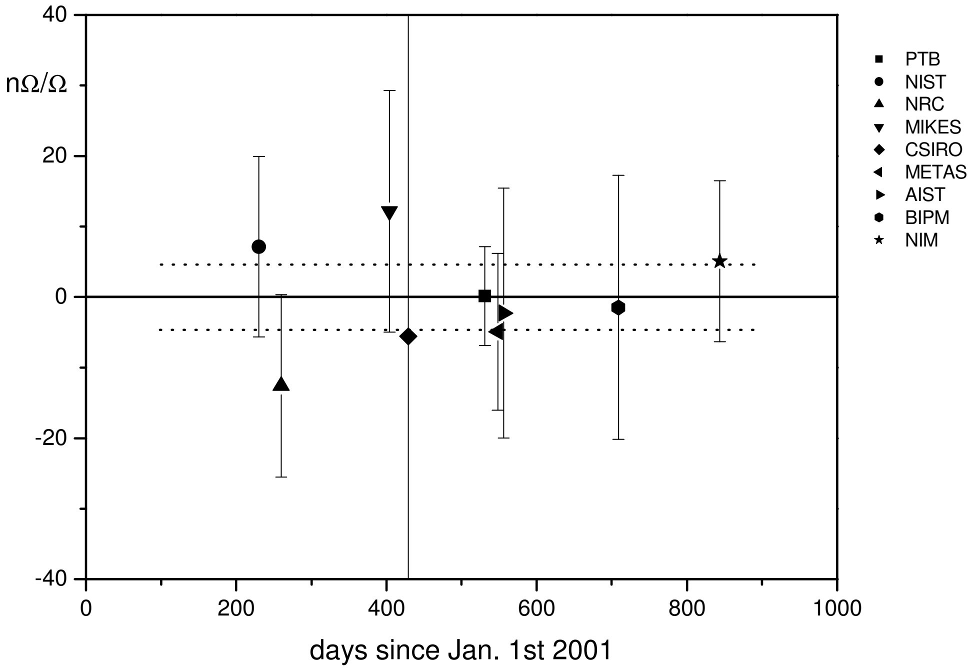


Figure B-5: Differences D_{iKCRV} and associated uncertainties U_{iKCRV} , related to the key comparison reference value and its uncertainty (dotted lines). The scatter of the results with respect to the KCRV is arbitrary and is mainly due to the stability of the travelling standards and not due to the participants measurement capabilities.

Appendix C

Technical protocol

Physikalisch-Technische Bundesanstalt 2001-06-25

CIPM key comparison CCEM K-10
”100 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 key comparisons chosen and organised by the Consultative Committees of the CIPM working closely together with the Regional Metrology Organisations (RMO's).

At the CCEM WGKC meeting in Sèvres, France, on 20 September 2000, it was decided that an international CIPM key comparison CCEM K-10 of "Resistance at 100 Ω" would start with the Physikalisch-Technische Bundesanstalt (PTB) as the pilot laboratory. As far as DC resistance is concerned there are three sets of key comparisons:

- On-site comparison of QHR (quantized Hall resistance) based resistance standards, including scaling at the level of 1 Ω, 100 Ω and 10 kΩ,
- 1 Ω and 10 kΩ resistors,
- 10 MΩ and 1GΩ resistors.

The on-site comparison of QHR based standards is very time consuming and it is hardly possible to perform more than one comparison a year. A 100 Ω key comparison would allow participation of a large number of laboratories in a relatively short time period, although at a slightly higher level of uncertainty. For those laboratories having a QHR system and a cryogenic current comparator (CCC) this comparison checks the operation of the QHR standard and the CCC. The reason why a 100 Ω key comparison has not been proposed up to now is that the knowledge of the transport behaviour of 100 Ω resistors was not sufficient to assure a meaningful comparison. As a result of Euromet project 435 it has been shown that 100 Ω standard resistors are available that allow a comparison at a very low level of uncertainty ($< 10^{-8}$, 2σ)[1].

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 in different national institutes. This technical protocol was prepared following the Guidelines for CIPM key comparisons.

2 The travelling standards

The resistors are commercially available types with common four terminal connectors.

- Standard Resistor 100 Ω Tinsley 5685A, S/N 267 919,
- Standard Resistor 100 Ω Tinsley 5685A, S/N 262 767,
- Standard Resistor 100 Ω Tinsley 5685A, S/N 268 168,
- Standard Resistor 100 Ω Tegam SR 102, S/N A 2030397,

3 Organisation

Following the Guidelines for CIPM key comparisons two institutes from the provisional list of participant were nominated by the CCEM in September 2000 to help the pilot laboratory with the organisation. These are the NIST (R. Elmquist) and the BIPM (F. Delahaye). In the following the pilot laboratory and the helping laboratories will be denominated "the organisation group". The BIPM and the chairman of the CCEM Working Group act as observers of this key comparison and will be regularly informed about the progress of this comparison.

In September 2000 the members of the CCEM Working Group had been informed about the comparison. At that opportunity eighteen laboratories (including the pilot laboratory) showed interest to take part in the comparison. Due to a lack of sufficiently stable travelling standards and keeping in mind that a key comparison should link the regional metrological organisations (RMO) in a reasonable time period (less than two years) it was the consensus of the organising group to reduce the number of participants to twelve. Each RMO is represented in the proposed time schedule given below. The RMO's are asked to organise regional comparisons that then are linked to this key comparison.

3.1 Participants

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

Dr. Bernd Schumacher
Physikalisch-Technische Bundesanstalt (PTB)
Laboratory for DC quantities (2.12)
Letters: P.O.Box. 33 45, - 38023 Braunschweig, GERMANY
Parcels: Bundesallee 100, 38116 Braunschweig, GERMANY
Tel.: +49 531 592 2122, Fax: +49 531 592 2105, E-mail:
Bernd.Schumacher@PTB.DE

The addresses of the two colleagues helping the co-ordinator with the organisation:

Dr. Randolph Elmquist
National Institute of Standards and Technology
E-mail: randolph.elmquist@nist.gov

Mr. Francois Delahaye
Bureau International des Poids et Mesures
E-mail: fdelahaye@bipm.org

A list of all participating institutes and contact persons with their addresses is enclosed in chapter 8, page 9 with Table I.

3.2 Time schedule

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

In all loops an ATA carnet will accompany the package. For the measurements in each laboratory a period of four weeks is allowed, including time necessary for transportation. It is intended to re-measure the standards at certain intervals in the pilot laboratory to establish a drift rate for the standards and to detect transport problems. The time period in the pilot laboratory is extended to cover small delays in the circulation of the standards.

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

Key Comparison CCEM K-10
(2001-06-18)

Institution	Country	Start date	Time for measurement and transportation
PTB (initial meas.)	Germany	until August 2001	
NIST	U.S.A	August 2001	4 weeks
NRC	Canada	September 2001	4 weeks
BIPM	International	October 2001	4 weeks
PTB (pilot)	Germany	November 2001	8 weeks
MIKES	Finland	January 2002	4 weeks
CSIRO/NML	Australia	February 2002	4 weeks
CSIR/NML	South Africa	March 2002	4 weeks
PTB (pilot)	Germany	April 2002	8 weeks
CEM	Spain	June 2002	4 weeks
METAS	Switzerland	July 2002	4 weeks
SMU	Slovakia	August 2002	4 weeks
PTB (pilot)	Germany	September 2002	8 weeks

NIM	China	October 2002	4 weeks
AIST	Japan	November 2002	4 weeks
PTB (final meas.)	Germany	December 2002	8 weeks
End of meas.	Germany	January 2003	

3.3 Transportation

Transportation is on each laboratory's own responsibility and cost. The resistors will be shipped in a suitcase, approximate dimensions are 70*50*20 cm^3, weight 20 kg. 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.

The package will be accompanied by an ATA carnet to accelerate customs procedures. The value of the four standards with the data logger is about 15.000,-- €.

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 package contains the following items:

Packing list:

- Standard Resistor 100 Ω Tinsley 5685A, S/N 267 919,
- Standard Resistor 100 Ω Tinsley 5685A, S/N 262 767,
- Standard Resistor 100 Ω Tinsley 5685A, S/N 268 168,
- Standard Resistor 100 Ω Tegam SR 102, S/N A 2030397,
- Ambient conditions recorder. This recorder is used to monitor the ambient conditions of the standard resistors during transport. Please leave this recorder in the shipping case.
- Instruction Manual.

After the receipt of the package the suitcase and the standards inside the case 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, based on the conventional value of the von Klitzing constant $R_{K\text{-}90}$=25 812.807 Ω. In practice, DC means that the waiting time between the end of a current reversal and the start of data acquisition should not be shorter than 5 s. Choice is left to the participants to either carry out a guarded measurement where the resistor case is used as a guard, or leave the resistor floating with respect to the case, or connect one point of the resistor to its case. The solution 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.

The measurements should be carried out with these preferred conditions:

- direct comparison with the QHR using a CCC bridge,
- aimed uncertainty less than $2 \cdot 10^{-8}$ (95% confidence level),
- current through the resistor 5 mA,
- ambient temperature (23,00 ± 0,05) °C for the Tinsley resistors in oil, (23,00 ± 0,20) °C for the Tegam resistor in air); the deviation of the temperature from nominal should not exceed the given limit.

The resistance temperature and ambient pressure should be recorded and reported as well as the height of oil above the top plate of the Tinsley resistors in the oil bath. If known, the density of the oil in the oil bath should be reported. The temperature of the Tegam SR102 should preferably be measured in the thermometer well. These resistors have a huge thermal time constant (several hours)! The measurements should be made at different dates during the period in the laboratory. The temperature and pressure coefficients of the standards have been determined to allow for corrections. They are intentionally not provided with this protocol.

5 Uncertainty of measurement

Since this comparison is a CIPM key 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 A6). 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.

6 Measurement report

The individual results with date, pressure, height of oil above the top plate, temperature, measurement current and the standard uncertainty should be reported to the pilot laboratory. 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 BIPM Guidelines will be followed.

References

[1] B. Schumacher et al., “Transport Behaviour of Commercially Available 100 Ω Standard Resistors”, to be published in IEEE Trans. Instrum. Meas.

[2] European co-operation for accreditation (EA) – publication references EA-4/02 ”Expression of the uncertainty of measurement in calibration”, Dec. 1999

8. List of participants

Name	Institute	Akronym	Adress	Land	Telefon	Telefax	E-mail
Prof. Zhang Zhonghua	National Institue of Metrology	NIM	18, Bei San Huan Dong Lu, 100013 Beijing	China	+86 10 6421 1631	+86 10 6421 8703	zzh@public.bta.net.cn
Dr Beat Jeckelmann	Metrology and Accreditation Switzerland	metas	Lindenweg 50, CH-3003 Bern-Wabern	Switzer-land	+41 31 323 3297	+41 31 323 3210	beat.jeckelmann@metas.ch
Dr Haruo Yoshida	National Metrology Institue of Japan	NMIJ	1-1-4 Umezono, Tsukuba-shi, 305-8568 Ibaraki	Japan	+81 298 61 5247	+81 298 61 5592	yoshida-h@aist.go.jp
Mr Erik Dressler	CSIR – National Metrology Laboratory	CSIR / NML	Building 5, P.O. Box 395, 0001 Pretoria	South Africa	+27 12 841 4342	+27 12 841 2131	redressl@csir.co.za
Dr Thomas Witt	Bureau International des Poids et Mesures	BIPM	Pavillon de Breteuil, 92312 Sèvres cedex	France	+33 1 45 07 70 97	+33 1 45 34 20 21	tjwitt@bipm.org
Francois Delahaye	Bureau International des Poids et Mesures	BIPM	Pavillon de Breteuil, 92312 Sèvres cedex	France	+33 1 45 07 70 07	+33 1 45 34 20 21	fdelahaye@bipm.org
Mr Miguel Neira	Centro Espanol de Metrologia	CEM	Calle del Alfar, 2, 28760 Tres Cantos – Madrid	Spain	+34 91 807 4773	+34 91 807 4807	mneira@mfom.es
Dr Brian Ricketts	National Measurement Laboratory CSIRO	NML CSIRO	Bradfield Road, West Lindfield, PO Box 218, NSW 2070 Lindfield	Australia	+61 2 9413 7730	+61 2 9413 7202	brianr@tip.csiro.au
Dr. Panu Helistö	VTT Automation Centre for Metrology and Accreditation	mikes	Otakaari 7 B, P.O. Box 1304, Fin – 02044 VTT Espoo	Finland	+358 9 456 6419	+358 9 456 7029	panu.helisto@mikes.fi
Dr. Barry Wood	National Research Council of Canada / INMS	NRC	Bldg. M-35, 1500 Montreal Road, K1A 0R6 Ottawa, Ontario	Canada	+1 613 990 9225	+1 613 952 1394	barry.wood@nrc.ca

Dave Inglis	National Research Council of Canada / INMS	NRC	Bldg. M-35, 1500 Montreal Road, K1A 0R6 Ottawa, Ontario	Canada	+1 613 990 9225	+1 613 952 1394	dave.inglis@nrc.ca
Dr William E. Anderson	National Institute of Standards and Technology	NIST	100 Bureau Drive, Building 220, Room B358 MS 8100, Maryland 20899-8100, Gaithersburg	United States	+1 301 975 2220	+1 301 975 4091	william.anderson@nist.gov
Dr Randolph E. Elmquist	National Institute of Standards and Technology	NIST	100 Bureau Drive, Building 220, Room B266 MS 8100, Maryland 20899-8112, Gaithersburg	United States	+1 301 975 6591	+1 301 975 4091	randolph.elmquist@nist.gov
Dr. Peter Vrabcek	Slovak Institute of Metrology	SMU	Karlovesk 63, 842 55 Bratislava, Slovakia	Slovakia	+4217 60294 385	+4217 65429 592	vrabcek@smu.gov.sk
Dr. Bernd Schumacher	Physikalisch Technische Bundesanstalt, FL 2.12	PTB	Bundesallee 100, 38116 Braunschweig	Germany	+49 531 592 2122	+49 531 592 2105	bernd.schumacher@ptb.de

CCEM key comparison receipt form
Annex 1
Telefax Telefax Telefax

(Please pass on immediately!)

To Physikalisch-Technische Bundesanstalt (PTB)
Laboratory of DC-quantities (2.12) att.: Dr. Bernd Schumacher
Post Box 3345 D-38023 Braunschweig GERMANY
FAX No. : +49 531 592 2105
e-mail: bernd.schumacher@ptb.de

From: (participating laboratory):

Fax: International +
Pages (total): 1
In the case of faulty reproduction, please call:

Re: **CIPM key comparison CCEM.K-10 - Receipt of travelling standards**
Date:

We confirm having received the travelling standards of the CCEM-K-10 CIPM key comparison on...................................

After visual inspection:

€ No damage of the suitcase and the travelling standards has been noticed

€ the following damage(s) must be reported(if possible add a picture):
....
....

Date: Signature

Telefax Telefax Telefax

(Please pass on immediately!)

To: Physikalisch-Technische Bundesanstalt (PTB)
Laboratory of DC-quantities (2.12) att.: Dr. Bernd Schumacher
Post Box 3345 D-38023 Braunschweig GERMANY
FAX No. : +49 531 592 2105
e-mail: bernd.schumacher@ptb.de

From: (participating laboratory):

Fax: International +
Pages (total): 1
In the case of faulty reproduction, please call:
Re: **CIPM key comparison CCEM.K-10 - Sending off of travelling standards**
Date:

We have informed the next participant on.............................that we will send the travelling standards to them next time.

We confirm having sent the travelling standards of the CCEM-K10 CIPM key comparison on................................to the next participant.

Additional informations:

....
..

....
...

Date:.......................... Signature:...

CCEM key comparison –measurement results
(Annex 3)

List of the principal components of the uncertainty budget to be evaluated (for those participants using the QHR as a reference standard and a CCC):

Imperfect quantization of the Hall resistance
Uncertainties associated with the CCC bridge:
- winding ratio
- leakage resistance
- bridge balancing
- possible noise rectification

Uncertainty of the temperature measurement
Uncertainty of the pressure measurement
Uncertainty of measurement of type A

Proposed scheme for an uncertainty budget for R_X

Quantity X_i	estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution / method of evaluation(A,B)	Sensitivity coefficient c_i	Uncertainty contribution $u_i(R_x)$	Degree of freedom ν_i
R_X						ν_{eff}

Appendix D

Uncertainty Budgets of the Participants

1. PTB

Mathematical model:

$$R_{100} = R_\mathrm{H} \cdot V_\mathrm{CCC} \cdot k_\mathrm{leak} \cdot k_\mathrm{bridge}$$

Table D-1: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	$R_\mathrm{K-90}/2$	0	rect/B	1	0	
V_CCC	$N_\mathrm{S}/N_\mathrm{P}$	$0,83\cdot10^{-9}$	rect/B	1	$0,83\cdot10^{-9}$	inf
k_leak	1	$0,1\cdot10^{-9}$	rect/B	1	$0,1\cdot10^{-9}$	inf
k_bridge	1	$0,8\cdot10^{-9}$	rect/B	1	$0,8\cdot10^{-9}$	inf
k_Temp	1	$0,14\cdot10^{-9}$	rect/B	1	$0,14\cdot10^{-9}$	inf
k_press	1	$0,02\cdot10^{-9}$	rect/B	1	$0,02\cdot10^{-9}$	inf
k_read	1	$0,5\cdot10^{-9}$	normal/A	1	$0,5\cdot10^{-9}$	9
R_{100}	100 Ω				$1,3\cdot10^{-9}$	411
		RSS of Type A uncertainties			$0,5\cdot10^{-9}$	
		RSS of Type B uncertainties			$1,2\cdot10^{-9}$	

Table D-2: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	$R_\mathrm{K-90}/2$	0	rect/B	1	0	inf
V_CCC	$N_\mathrm{S}/N_\mathrm{P}$	$0,83\cdot10^{-9}$	rect/B	1	$0,83\cdot10^{-9}$	inf
k_leak	1	$0,1\cdot10^{-9}$	rect/B	1	$0,1\cdot10^{-9}$	inf
k_bridge	1	$0,8\cdot10^{-9}$	rect/B	1	$0,8\cdot10^{-9}$	inf
k_Temp	1	$0,84\cdot10^{-9}$	rect/B	1	$0,84\cdot10^{-9}$	inf
k_read	1	$0,5\cdot10^{-9}$	normal/A	1	$0,5\cdot10^{-9}$	9
R_{100}	100 Ω				$1,5\cdot10^{-9}$	729
		RSS of Type A uncertainties			$0,5\cdot10^{-9}$	
		RSS of Type B uncertainties			$1,4\cdot10^{-9}$	

Table D-3: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	$R_\mathrm{K-90}/2$	0	rect/B	1	0	inf
V_CCC	$N_\mathrm{S}/N_\mathrm{P}$	$0,83\cdot10^{-9}$	rect/B	1	$0,83\cdot10^{-9}$	inf
k_leak	1	$0,1\cdot10^{-9}$	rect/B	1	$0,1\cdot10^{-9}$	inf
k_bridge	1	$0,8\cdot10^{-9}$	rect/B	1	$0,8\cdot10^{-9}$	inf
k_Temp	1	$6\cdot10^{-11}$	rect/B	1	$0,06\cdot10^{-9}$	inf
k_read	1	$0,5\cdot10^{-9}$	normal/A	1	$0,5\cdot10^{-9}$	9
R_{100}	100 Ω				$1,3\cdot10^{-9}$	411
		RSS of Type A uncertainties			$0,5\cdot10^{-9}$	
		RSS of Type B uncertainties			$1,2\cdot10^{-9}$	

Table D-4: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K\text{-}90}}/2$	0	rect/B	1	0	inf
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$0,83\cdot10^{-9}$	rect/B	1	$0,83\cdot10^{-9}$	inf
k_{leak}	1	$0,1\cdot10^{-9}$	rect/B	1	$0,1\cdot10^{-9}$	inf
k_{bridge}	1	$0,8\cdot10^{-9}$	rect/B	1	$0,8\cdot10^{-9}$	inf
k_{Temp}	1	$1,1\cdot10^{-9}$	rect/B	1	$1,1\cdot10^{-9}$	inf
k_{read}	1	$0,5\cdot10^{-9}$	normal/A	1	$0,5\cdot10^{-9}$	9
R_{100}	100 Ω				$1,7\cdot10^{-9}$	1200
		RSS of Type A uncertainties			$0,5\cdot10^{-9}$	
		RSS of Type B uncertainties			$1,6\cdot10^{-9}$	

2. NIST

Mathematical model:

$$R_{100} = R_{\mathrm{H}} \cdot V_{\mathrm{CCC}} \cdot k_{\mathrm{leak}} \cdot k_{\mathrm{bridge}} \cdot k_{\mathrm{noise}}$$

Table D-5: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K\text{-}90}}/2$	$9\cdot10^{-5}$ Ω	rect/B	1/129	$7\cdot10^{-8}$ Ω	inf
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$4\cdot10^{-12}$	rect/B	12 906 Ω	$5\cdot10^{-8}$ Ω	inf
k_{leak}	1	$6\cdot10^{-10}$	rect/B	100 Ω	$6\cdot10^{-8}$ Ω	inf
k_{bridge}	1	$5\cdot10^{-10}$	rect/B	100 Ω	$5\cdot10^{-8}$ Ω	inf
k_{noise}	1	$3\cdot10^{-10}$	rect/B	100 Ω	$3\cdot10^{-8}$ Ω	inf
k_{Temp}	1	$1,4\cdot10^{-10}$	rect/B	100 Ω	$1,4\cdot10^{-8}$ Ω	inf
k_{press}	1	$1,7\cdot10^{-11}$	rect/B	100 Ω	$0,2\cdot10^{-8}$ Ω	inf
k_{read}	1	$2,9\cdot10^{-9}$	normal/A	100 Ω	$29\cdot10^{-8}$ Ω	6
R_{100}	100 Ω				$31\cdot10^{-8}$ Ω	8
		RSS of Type A uncertainties			$29\cdot10^{-8}$ Ω	
		RSS of Type B uncertainties			$8,8\cdot10^{-8}$ Ω	

Table D-6: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K\text{-}90}}/2$	$9\cdot10^{-5}$ Ω	rect/B	1/129	$7\cdot10^{-8}$ Ω	inf
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$4\cdot10^{-12}$	rect/B	12 906 Ω	$5\cdot10^{-8}$ Ω	inf
k_{leak}	1	$6\cdot10^{-10}$	rect/B	100 Ω	$6\cdot10^{-8}$ Ω	inf
k_{bridge}	1	$5\cdot10^{-10}$	rect/B	100 Ω	$5\cdot10^{-8}$ Ω	inf
k_{noise}	1	$3\cdot10^{-10}$	rect/B	100 Ω	$3\cdot10^{-8}$ Ω	inf
k_{Temp}	1	$8,4\cdot10^{-10}$	rect/B	100 Ω	$8,4\cdot10^{-8}$ Ω	inf
k_{read}	1	$2,9\cdot10^{-9}$	normal/A	100 Ω	$29\cdot10^{-8}$ Ω	8
R_{100}	100 Ω				$33\cdot10^{-8}$ Ω	13
		RSS of Type A uncertainties			$29\cdot10^{-8}$ Ω	
		RSS of Type B uncertainties			$14,6\cdot10^{-8}$ Ω	

Table D-7: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K-90}}/2$	$9\cdot10^{-5}$ Ω	rect/B	1/129	$7\cdot10^{-8}$ Ω	inf
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$4\cdot10^{-12}$	rect/B	12 906 Ω	$5\cdot10^{-8}$ Ω	inf
k_{leak}	1	$6\cdot10^{-10}$	rect/B	100 Ω	$6\cdot10^{-8}$ Ω	inf
k_{bridge}	1	$5\cdot10^{-10}$	rect/B	100 Ω	$5\cdot10^{-8}$ Ω	inf
k_{noise}	1	$3\cdot10^{-10}$	rect/B	100 Ω	$3\cdot10^{-8}$ Ω	inf
k_{Temp}	1	$6\cdot10^{-11}$	rect/B	100 Ω	$0{,}6\cdot10^{-8}$ Ω	inf
k_{read}	1	$1\cdot10^{-9}$	normal/A	100 Ω	$10\cdot10^{-8}$ Ω	7
R_{100}	100 Ω				$16\cdot10^{-8}$ Ω	46
		RSS of Type A uncertainties			$10\cdot10^{-8}$ Ω	
		RSS of Type B uncertainties			$12\cdot10^{-8}$ Ω	

Table D-8: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K-90}}/2$	$9\cdot10^{-5}$ Ω	rect/B	1/129	$7\cdot10^{-8}$ Ω	inf
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$4\cdot10^{-12}$	rect/B	12 906 Ω	$5\cdot10^{-8}$ Ω	inf
k_{leak}	1	$6\cdot10^{-10}$	rect/B	100 Ω	$6\cdot10^{-8}$ Ω	inf
k_{bridge}	1	$5\cdot10^{-10}$	rect/B	100 Ω	$5\cdot10^{-8}$ Ω	inf
k_{noise}	1	$3\cdot10^{-10}$	rect/B	100 Ω	$3\cdot10^{-8}$ Ω	inf
k_{Temp}	1	$11\cdot10^{-10}$	rect/B	100 Ω	$11\cdot10^{-8}$ Ω	inf
k_{read}	1	$2{,}2\cdot10^{-9}$	normal/A	100 Ω	$22\cdot10^{-8}$ Ω	6
R_{100}	100 Ω				$27\cdot10^{-8}$ Ω	14
		RSS of Type A uncertainties			$22\cdot10^{-8}$ Ω	
		RSS of Type B uncertainties			$16{,}3\cdot10^{-8}$ Ω	

3. NRC

Using relative uncertainties, all sensitivity coefficients are 1.

Table D-9: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	0	$0{,}3\cdot10^{-9}$	normal/B	1	$0{,}3\cdot10^{-9}$	4,9
V_{CCC}	0	$1{,}7\cdot10^{-9}$	normal/A	1	$1{,}7\cdot10^{-9}$	19
k_{leak}	-0,001	$1\cdot10^{-9}$	normal/B	1	$1\cdot10^{-9}$	4,9
k_{bridge}	0	$0{,}3\cdot10^{-9}$	normal/A	1	$0{,}3\cdot10^{-9}$	15
k_{Temp}	0	$0{,}46\cdot10^{-9}$	rect/B	1	$0{,}46\cdot10^{-9}$	inf
k_{press}	0	$0{,}86\cdot10^{-9}$	rect/B	1	$0{,}86\cdot10^{-9}$	inf
k_{read}	-0,0388	$2{,}8\cdot10^{-9}$	normal/A	1	$2{,}8\cdot10^{-9}$	8
R_{100}	-0,0398				$3{,}6\cdot10^{-9}$	20
		RSS of Type A uncertainties			$3{,}3\cdot10^{-9}$	
		RSS of Type B uncertainties			$1{,}4\cdot10^{-9}$	

Table D-10: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	0	$0,3\cdot10^{-9}$	normal/B	1	$0,3\cdot10^{-9}$	4,9
V_{CCC}	0	$1,7\cdot10^{-9}$	normal/A	1	$1,7\cdot10^{-9}$	19
k_{leak}	-0,001	$1\cdot10^{-9}$	normal/B	1	$1\cdot10^{-9}$	4,9
k_{bridge}	0	$0,3\cdot10^{-9}$	normal/A	1	$0,3\cdot10^{-9}$	15
k_{Temp}	0	$1,1\cdot10^{-9}$	rect/B	1	$1,1\cdot10^{-9}$	inf
k_{read}	-5,6427	$2,9\cdot10^{-9}$	normal/A	1	$2,9\cdot10^{-9}$	8
R_{100}	-5,6437				$3,7\cdot10^{-9}$	20
		RSS of Type A uncertainties			$3,4\cdot10^{-9}$	
		RSS of Type B uncertainties			$1,5\cdot10^{-9}$	

Table D-11: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	0	$0,3\cdot10^{-9}$	normal/B	1	$0,3\cdot10^{-9}$	4,9
V_{CCC}	0	$1,7\cdot10^{-9}$	normal/A	1	$1,7\cdot10^{-9}$	19
k_{leak}	-0,001	$1\cdot10^{-9}$	normal/B	1	$1\cdot10^{-9}$	4,9
k_{bridge}	0	$0,3\cdot10^{-9}$	normal/A	1	$0,3\cdot10^{-9}$	15
k_{Temp}	0	$0,08\cdot10^{-9}$	rect/B	1	$0,08\cdot10^{-9}$	inf
k_{read}	-3,5373	$2,7\cdot10^{-9}$	normal/A	1	$2,7\cdot10^{-9}$	8
R_{100}	-3,5383				$3,4\cdot10^{-9}$	18
		RSS of Type A uncertainties			$3,2\cdot10^{-9}$	
		RSS of Type B uncertainties			$1,0\cdot10^{-9}$	

Table D-12: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	0	$0,3\cdot10^{-9}$	normal/B	1	$0,3\cdot10^{-9}$	4,9
V_{CCC}	0	$1,7\cdot10^{-9}$	normal/A	1	$1,7\cdot10^{-9}$	19
k_{leak}	-0,001	$1\cdot10^{-9}$	normal/B	1	$1\cdot10^{-9}$	4,9
k_{bridge}	0	$0,3\cdot10^{-9}$	normal/A	1	$0,3\cdot10^{-9}$	15
k_{Temp}	0	$1,5\cdot10^{-9}$	rect/B	1	$1,5\cdot10^{-9}$	inf
k_{read}	-1,3067	$2,9\cdot10^{-9}$	normal/A	1	$2,9\cdot10^{-9}$	8
R_{100}	-1,3077				$3,8\cdot10^{-9}$	22
		RSS of Type A uncertainties			$3,4\cdot10^{-9}$	
		RSS of Type B uncertainties			$1,8\cdot10^{-9}$	

4. BIPM (Direct measurement in terms of R_K with CCC bridge)

Using relative uncertainties, all sensitivity coefficients are 1.

Table D-13: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
V_CCC	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_leak	0	$0{,}2\cdot10^{-9}$	triangular/B	1	$0{,}2\cdot10^{-9}$	inf
k_bridge	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_noise	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_Temp	0	$0{,}03\cdot10^{-9}$	triangular/B	1	$0{,}03\cdot10^{-9}$	inf
k_press	0	$0{,}06\cdot10^{-9}$	triangular/B	1	$0{,}06\cdot10^{-9}$	inf
k_read	$-0{,}0381\cdot10^{-6}$	$1\cdot10^{-9}$	normal/A	1	$1\cdot10^{-9}$	19
R_{100}	$-0{,}0381\cdot10^{-6}$				$2{,}2\cdot10^{-9}$	445
		RSS of Type A uncertainties			$1\cdot10^{-9}$	
		RSS of Type B uncertainties			$2{,}0\cdot10^{-9}$	

Table D-14: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
V_CCC	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_leak	0	$0{,}2\cdot10^{-9}$	triangular/B	1	$0{,}2\cdot10^{-9}$	inf
k_bridge	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_noise	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_Temp	0	$0{,}2\cdot10^{-9}$	triangular/B	1	$0{,}2\cdot10^{-9}$	inf
k_read	$-5{,}6191\cdot10^{-6}$	$1{,}1\cdot10^{-9}$	normal/A	1	$1{,}1\cdot10^{-9}$	6
R_{100}	$-5{,}6191\cdot10^{-6}$				$2{,}3\cdot10^{-9}$	115
		RSS of Type A uncertainties			$1{,}1\cdot10^{-9}$	
		RSS of Type B uncertainties			$2{,}0\cdot10^{-9}$	

Table D-15: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
V_CCC	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_leak	0	$0{,}2\cdot10^{-9}$	triangular/B	1	$0{,}2\cdot10^{-9}$	inf
k_bridge	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_noise	0	$1\cdot10^{-9}$	triangular/B	1	$1\cdot10^{-9}$	inf
k_Temp	0	$0{,}01\cdot10^{-9}$	triangular/B	1	$0{,}01\cdot10^{-9}$	inf
k_read	$-3{,}5486\cdot10^{-6}$	$1{,}7\cdot10^{-9}$	normal/A	1	$1{,}7\cdot10^{-9}$	6
R_{100}	$-3{,}5486\cdot10^{-6}$				$2{,}6\cdot10^{-9}$	38
		RSS of Type A uncertainties			$1{,}7\cdot10^{-9}$	
		RSS of Type B uncertainties			$2{,}0\cdot10^{-9}$	

Table D-16: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	0	$1 \cdot 10^{-9}$	triangular/B	1	$1 \cdot 10^{-9}$	inf
V_{CCC}	0	$1 \cdot 10^{-9}$	triangular/B	1	$1 \cdot 10^{-9}$	inf
k_{leak}	0	$0{,}2 \cdot 10^{-9}$	triangular/B	1	$0{,}2 \cdot 10^{-9}$	inf
k_{bridge}	0	$1 \cdot 10^{-9}$	triangular/B	1	$1 \cdot 10^{-9}$	inf
k_{noise}	0	$1 \cdot 10^{-9}$	triangular/B	1	$1 \cdot 10^{-9}$	inf
k_{Temp}	0	$0{,}26 \cdot 10^{-9}$	triangular/B	1	$0{,}26 \cdot 10^{-9}$	inf
k_{read}	$-1{,}2682 \cdot 10^{-6}$	$1{,}1 \cdot 10^{-9}$	normal/A	1	$1{,}1 \cdot 10^{-9}$	6
R_{100}	$-1{,}2682 \cdot 10^{-6}$				$2{,}3 \cdot 10^{-9}$	115
		RSS of Type A uncertainties			$1{,}1 \cdot 10^{-9}$	
		RSS of Type B uncertainties			$2{,}0 \cdot 10^{-9}$	

5. MIKES

Mathematical model:

$$R_{100} = R_H \cdot V_{CCC}$$

V_{CCC} includes windings, leakage and other bridge errors.

Table D-17: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	$R_{K-90}/2$	$1 \cdot 10^{-9}$	rect/B	1	$1 \cdot 10^{-9}$	inf
V_{CCC}	N_S/N_P	$5{,}2 \cdot 10^{-9}$	rect/B	1	$5{,}2 \cdot 10^{-9}$	inf
k_{Temp}	1	$0{,}72 \cdot 10^{-9}$	rect/B	1	$0{,}72 \cdot 10^{-9}$	inf
k_{press}	1	$0{,}29 \cdot 10^{-9}$	rect/B	1	$0{,}29 \cdot 10^{-9}$	inf
k_{read}	1	$2 \cdot 10^{-9}$	normal/A	1	$2 \cdot 10^{-9}$	5
R_{100}	100 Ω				$5{,}7 \cdot 10^{-9}$	330
		RSS of Type A uncertainties			$2 \cdot 10^{-9}$	
		RSS of Type B uncertainties			$5{,}4 \cdot 10^{-9}$	

Table D-18: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	$R_{K-90}/2$	$1 \cdot 10^{-9}$	rect/B	1	$1 \cdot 10^{-9}$	inf
V_{CCC}	N_S/N_P	$5{,}2 \cdot 10^{-9}$	rect/B	1	$5{,}2 \cdot 10^{-9}$	inf
k_{Temp}	1	$4{,}4 \cdot 10^{-9}$	rect/B	1	$4{,}4 \cdot 10^{-9}$	inf
k_{read}	1	$2 \cdot 10^{-9}$	normal/A	1	$2 \cdot 10^{-9}$	5
R_{100}	100 Ω				$7{,}2 \cdot 10^{-9}$	840
		RSS of Type A uncertainties			$2 \cdot 10^{-9}$	
		RSS of Type B uncertainties			$6{,}9 \cdot 10^{-9}$	

Table D-19: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K-90}}/2$	$1\cdot10^{-9}$	rect/B	1	$1\cdot10^{-9}$	inf
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$5{,}2\cdot10^{-9}$	rect/B	1	$5{,}2\cdot10^{-9}$	inf
k_{Temp}	1	$0{,}32\cdot10^{-9}$	rect/B	1	$0{,}32\cdot10^{-9}$	inf
k_{read}	1	$2\cdot10^{-9}$	normal/A	1	$2\cdot10^{-9}$	5
R_{100}	100 Ω				$5{,}7\cdot10^{-9}$	330
		RSS of Type A uncertainties			$2\cdot10^{-9}$	
		RSS of Type B uncertainties			$5{,}3\cdot10^{-9}$	

Table D-20: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K-90}}/2$	$1\cdot10^{-9}$	rect/B	1	$1\cdot10^{-9}$	inf
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$5{,}2\cdot10^{-9}$	rect/B	1	$5{,}2\cdot10^{-9}$	inf
k_{Temp}	1	$5{,}7\cdot10^{-9}$	rect/B	1	$5{,}7\cdot10^{-9}$	inf
k_{read}	1	$2\cdot10^{-9}$	normal/A	1	$2\cdot10^{-9}$	5
R_{100}	100 Ω				$8\cdot10^{-9}$	1280
		RSS of Type A uncertainties			$2\cdot10^{-9}$	
		RSS of Type B uncertainties			$7{,}8\cdot10^{-9}$	

6. CSIRO

Mathematical model:

$$R_{100} = 100 \cdot \Omega_{\mathrm{LAB}}$$

Table D-21: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_1 to Ω_{LAB}	1	$17{,}4\cdot10^{-9}$	normal/B	1	$17{,}4\cdot10^{-9}$	7
QHR to R_1	1	$23{,}9\cdot10^{-9}$	normal/B	1	$23{,}9\cdot10^{-9}$	12
Ω_{LAB} to R_{100}	100	$4{,}5\cdot10^{-9}$	normal/B	1	$4{,}5\cdot10^{-9}$	13
k_{Temp}	1	$8\cdot10^{-9}$	rect/B	1	$8\cdot10^{-9}$	inf
k_{press}	1	$0{,}28\cdot10^{-9}$	rect/B	1	$0{,}28\cdot10^{-9}$	inf
k_{read}	1	$9\cdot10^{-9}$	normal/A	1	$9\cdot10^{-9}$	4
R_{100}	100 Ω				$32\cdot10^{-9}$	25
		RSS of Type A uncertainties			$9\cdot10^{-9}$	
		RSS of Type B uncertainties			$31\cdot10^{-9}$	

Table D-22: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_1 to Ω_{LAB}	1	$17{,}4\cdot10^{-9}$	normal/B	1	$17{,}4\cdot10^{-9}$	7
QHR to R_1	1	$23{,}9\cdot10^{-9}$	normal/B	1	$23{,}9\cdot10^{-9}$	12
Ω_{LAB} to R_{100}	100	$4{,}5\cdot10^{-9}$	normal/B	1	$4{,}5\cdot10^{-9}$	13
k_{Temp}	1	$2{,}8\cdot10^{-9}$	rect/B	1	$2{,}8\cdot10^{-9}$	inf
k_{read}	1	$9\cdot10^{-9}$	normal/A	1	$9\cdot10^{-9}$	4
R_{100}	100 Ω				$31\cdot10^{-9}$	22
		RSS of Type A uncertainties			$9\cdot10^{-9}$	
		RSS of Type B uncertainties			$30\cdot10^{-9}$	

Table D-23: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_1 to Ω_{LAB}	1	$17,4\cdot 10^{-9}$	normal/B	1	$17,4\cdot 10^{-9}$	7
QHR to R_1	1	$23,9\cdot 10^{-9}$	normal/B	1	$23,9\cdot 10^{-9}$	12
Ω_{LAB} to R_{100}	100	$4,5\cdot 10^{-9}$	normal/B	1	$4,5\cdot 10^{-9}$	13
k_{Temp}	1	$0,2\cdot 10^{-9}$	rect/B	1	$0,2\cdot 10^{-9}$	inf
k_{read}	1	$9\cdot 10^{-9}$	normal/A	1	$9\cdot 10^{-9}$	4
R_{100}	100 Ω				$31\cdot 10^{-9}$	22
		RSS of Type A uncertainties			$9\cdot 10^{-9}$	
		RSS of Type B uncertainties			$30\cdot 10^{-9}$	

Table D-24: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_1 to Ω_{LAB}	1	$17,4\cdot 10^{-9}$	normal/B	1	$17,4\cdot 10^{-9}$	7
QHR to R_1	1	$23,9\cdot 10^{-9}$	normal/B	1	$23,9\cdot 10^{-9}$	12
Ω_{LAB} to R_{100}	100	$4,5\cdot 10^{-9}$	normal/B	1	$4,5\cdot 10^{-9}$	13
k_{Temp}	1	$3,7\cdot 10^{-9}$	rect/B	1	$3,7\cdot 10^{-9}$	inf
k_{read}	1	$9\cdot 10^{-9}$	normal/A	1	$9\cdot 10^{-9}$	4
R_{100}	100 Ω				$31\cdot 10^{-9}$	22
		RSS of Type A uncertainties			$9\cdot 10^{-9}$	
		RSS of Type B uncertainties			$30\cdot 10^{-9}$	

7. METAS

Mathematical model:

$$R_{100} = R_{\text{H}} \cdot V_{\text{CCC}} \cdot k_{\text{leak}} \cdot k_{\text{bridge}} \cdot k_{\text{noise}}$$

Table D-25: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
V_{CCC}	$N_{\text{S}}/N_{\text{P}}$	$0,1\cdot 10^{-9}$	normal/A	1	$0,1\cdot 10^{-9}$	10
k_{leakS}	1	$0,59\cdot 10^{-9}$	normal/A	1	$0,59\cdot 10^{-9}$	5
k_{leakG}	1	$0,39\cdot 10^{-9}$	normal/A	1	$0,39\cdot 10^{-9}$	5
k_{divider}	1	$0,41\cdot 10^{-9}$	normal/A	1	$0,41\cdot 10^{-9}$	10
k_{GainV}	1	$0,22\cdot 10^{-9}$	rect/B	1	$0,22\cdot 10^{-9}$	inf
k_{GainS}	1	$0,29\cdot 10^{-9}$	rect/B	1	$0,29\cdot 10^{-9}$	inf
k_{uncomp0}	1	$0,58\cdot 10^{-9}$	rect/B	1	$0,58\cdot 10^{-9}$	inf
k_{Temp}	1	$0,23\cdot 10^{-9}$	rect/B	1	$0,23\cdot 10^{-9}$	inf
k_{press}	1	$0,29\cdot 10^{-9}$	rect/B	1	$0,29\cdot 10^{-9}$	inf
k_{read}	1	$0,4\cdot 10^{-9}$	normal/A	1	$0,4\cdot 10^{-9}$	9
R_{100}	100 Ω				$1,2\cdot 10^{-9}$	60
		RSS of Type A uncertainties			$0,9\cdot 10^{-9}$	
		RSS of Type B uncertainties			$0,8\cdot 10^{-9}$	

Table D-26: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$0{,}1\cdot10^{-9}$	normal/A	1	$0{,}1\cdot10^{-9}$	10
k_{leakS}	1	$0{,}59\cdot10^{-9}$	normal/A	1	$0{,}59\cdot10^{-9}$	5
k_{leakG}	1	$0{,}39\cdot10^{-9}$	normal/A	1	$0{,}39\cdot10^{-9}$	5
k_{divider}	1	$0{,}41\cdot10^{-9}$	normal/A	1	$0{,}41\cdot10^{-9}$	10
k_{GainV}	1	$0{,}22\cdot10^{-9}$	rect/B	1	$0{,}22\cdot10^{-9}$	inf
k_{GainS}	1	$0{,}29\cdot10^{-9}$	rect/B	1	$0{,}29\cdot10^{-9}$	inf
k_{uncomp0}	1	$0{,}58\cdot10^{-9}$	rect/B	1	$0{,}58\cdot10^{-9}$	inf
k_{Temp}	1	$1{,}4\cdot10^{-9}$	rect/B	1	$1{,}4\cdot10^{-9}$	inf
k_{read}	1	$0{,}4\cdot10^{-9}$	normal/A	1	$0{,}4\cdot10^{-9}$	9
R_{100}	100 Ω				$1{,}8\cdot10^{-9}$ □	300
		RSS of Type A uncertainties			$0{,}9\cdot10^{-9}$	
		RSS of Type B uncertainties			$1{,}6\cdot10^{-9}$	

Table D-27: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$0{,}1\cdot10^{-9}$	normal/A	1	$0{,}1\cdot10^{-9}$	10
k_{leakS}	1	$0{,}59\cdot10^{-9}$	normal/A	1	$0{,}59\cdot10^{-9}$	5
k_{leakG}	1	$0{,}39\cdot10^{-9}$	normal/A	1	$0{,}39\cdot10^{-9}$	5
k_{divider}	1	$0{,}41\cdot10^{-9}$	normal/A	1	$0{,}41\cdot10^{-9}$	10
k_{GainV}	1	$0{,}22\cdot10^{-9}$	rect/B	1	$0{,}22\cdot10^{-9}$	inf
k_{GainS}	1	$0{,}29\cdot10^{-9}$	rect/B	1	$0{,}29\cdot10^{-9}$	inf
k_{uncomp0}	1	$0{,}58\cdot10^{-9}$	rect/B	1	$0{,}58\cdot10^{-9}$	inf
k_{Temp}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	inf
k_{read}	1	$0{,}4\cdot10^{-9}$	normal/A	1	$0{,}4\cdot10^{-9}$	9
R_{100}	100 Ω				$1{,}2\cdot10^{-9}$	60
		RSS of Type A uncertainties			$0{,}9\cdot10^{-9}$	
		RSS of Type B uncertainties			$0{,}7\cdot10^{-9}$	

Table D-28: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$0{,}1\cdot10^{-9}$	normal/A	1	$0{,}1\cdot10^{-9}$	10
k_{leakS}	1	$0{,}59\cdot10^{-9}$	normal/A	1	$0{,}59\cdot10^{-9}$	5
k_{leakG}	1	$0{,}39\cdot10^{-9}$	normal/A	1	$0{,}39\cdot10^{-9}$	5
k_{divider}	1	$0{,}41\cdot10^{-9}$	normal/A	1	$0{,}41\cdot10^{-9}$	10
k_{GainV}	1	$0{,}22\cdot10^{-9}$	rect/B	1	$0{,}22\cdot10^{-9}$	inf
k_{GainS}	1	$0{,}29\cdot10^{-9}$	rect/B	1	$0{,}29\cdot10^{-9}$	inf
k_{uncomp0}	1	$0{,}58\cdot10^{-9}$	rect/B	1	$0{,}58\cdot10^{-9}$	inf
k_{Temp}	1	$1{,}8\cdot10^{-9}$	rect/B	1	$1{,}8\cdot10^{-9}$	inf
k_{read}	1	$0{,}4\cdot10^{-9}$	normal/A	1	$0{,}4\cdot10^{-9}$	9
R_{100}	100 Ω				$2{,}1\cdot10^{-9}$	560
		RSS of Type A uncertainties			$0{,}9\cdot10^{-9}$	
		RSS of Type B uncertainties			$1{,}9\cdot10^{-9}$	

8. AIST

Mathematical model:

$$R_{100} = R_{\mathrm{H}} \cdot V_{\mathrm{CCC}} \cdot k_{\mathrm{leak}} \cdot k_{\mathrm{bridge}} \cdot k_{\mathrm{noise}}$$

Table D-29: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K-90}}/2$	$1{,}7\cdot10^{-5}$ Ω	rect/B	1/129	$0{,}13\cdot10^{-6}$ Ω	3
N_2	16	$1{,}8\cdot10^{-10}$	rect/B	6,25 Ω	$0{,}001\cdot10^{-6}$ Ω	3
I_1	30 µA	$2{,}4\cdot10^{-9}$	rect/B	107 Ω	$0{,}27\cdot10^{-6}$ Ω	9
I_3	20 µA	$3{,}2\cdot10^{-10}$	rect/B	1614 Ω	$0{,}5\cdot10^{-6}$ Ω	39
ΔV	0	$1\cdot10^{-10}$	rect/B	258 Ω	$0{,}015\cdot10^{-6}$ Ω	inf
ΔAT	0	$1{,}4\cdot10^{-10}$	normal/A	1614 Ω	$0{,}23\cdot10^{-6}$ Ω	inf
k_{Temp}	0	$4{,}6\cdot10^{-9}$	rect/B	100 Ω	$0{,}46\cdot10^{-6}$ Ω	inf
k_{press}	0	$0{,}83\cdot10^{-9}$	rect/B	100 Ω	$0{,}083\cdot10^{-6}$ Ω	inf
R_{100}	100 Ω				$0{,}78\cdot10^{-6}$ Ω	72
		RSS of Type A uncertainties			$0{,}23\cdot10^{-6}$ Ω	
		RSS of Type B uncertainties			$0{,}75\cdot10^{-6}$ Ω	

Table D-30: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K-90}}/2$	$1{,}7\cdot10^{-5}$ Ω	rect/B	1/129	$0{,}13\cdot10^{-6}$ Ω	3
N_2	16	$1{,}8\cdot10^{-10}$	rect/B	6,25 Ω	$0{,}001\cdot10^{-6}$ Ω	3
I_1	30 µA	$2{,}4\cdot10^{-9}$	rect/B	107 Ω	$0{,}27\cdot10^{-6}$ Ω	9
I_3	20 µA	$3{,}2\cdot10^{-10}$	rect/B	1614 Ω	$0{,}5\cdot10^{-6}$ Ω	39
ΔV	0	$1\cdot10^{-10}$	rect/B	258 Ω	$0{,}015\cdot10^{-6}$ Ω	inf
ΔAT	0	$1{,}4\cdot10^{-10}$	normal/A	1614 Ω	$0{,}23\cdot10^{-6}$ Ω	inf
k_{Temp}	0	$2{,}8\cdot10^{-9}$	rect/B	100 Ω	$0{,}28\cdot10^{-6}$ Ω	inf
R_{100}	100 Ω				$0{,}69\cdot10^{-6}$ Ω	44
		RSS of Type A uncertainties			$0{,}23\cdot10^{-6}$ Ω	
		RSS of Type B uncertainties			$0{,}58\cdot10^{-6}$ Ω	

Table D-31: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K-90}}/2$	$1{,}7\cdot10^{-5}$ Ω	rect/B	1/129	$0{,}13\cdot10^{-6}$ Ω	3
N_2	16	$1{,}8\cdot10^{-10}$	rect/B	6,25 Ω	$0{,}001\cdot10^{-6}$ Ω	3
I_1	30 µA	$2{,}4\cdot10^{-9}$	rect/B	107 Ω	$0{,}27\cdot10^{-6}$ Ω	9
I_3	20 µA	$3{,}2\cdot10^{-10}$	rect/B	1614 Ω	$0{,}5\cdot10^{-6}$ Ω	39
ΔV	0	$1\cdot10^{-10}$	rect/B	258 Ω	$0{,}015\cdot10^{-6}$ Ω	inf
ΔAT	0	$1{,}4\cdot10^{-10}$	normal/A	1614 Ω	$0{,}23\cdot10^{-6}$ Ω	inf
k_{Temp}	0	$0{,}21\cdot10^{-9}$	rect/B	100 Ω	$0{,}021\cdot10^{-6}$ Ω	inf
R_{100}	100 Ω				$0{,}63\cdot10^{-6}$ Ω	31
		RSS of Type A uncertainties			$0{,}23\cdot10^{-6}$ Ω	
		RSS of Type B uncertainties			$0{,}58\cdot10^{-6}$ Ω	

Table D-32: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	$R_{K-90}/2$	$1,7\cdot10^{-5}$ Ω	rect/B	1/129	$0,13\cdot10^{-6}$ Ω	3
N_2	16	$1,8\cdot10^{-10}$	rect/B	6,25 Ω	$0,001\cdot10^{-6}$ Ω	3
I_1	30 µA	$2,4\cdot10^{-9}$	rect/B	107 Ω	$0,27\cdot10^{-6}$ Ω	9
I_3	20 µA	$3,2\cdot10^{-10}$	rect/B	1614 Ω	$0,5\cdot10^{-6}$ Ω	39
ΔV	0	$1\cdot10^{-10}$	rect/B	258 Ω	$0,015\cdot10^{-6}$ Ω	inf
ΔAT	0	$1,4\cdot10^{-10}$	normal/A	1614 Ω	$0,23\cdot10^{-6}$ Ω	inf
k_{Temp}	0	$3,7\cdot10^{-9}$	rect/B	100 Ω	$0,37\cdot10^{-6}$ Ω	inf
R_{100}	100 Ω				$0,73\cdot10^{-6}$ Ω	55
		RSS of Type A uncertainties			$0,23\cdot10^{-6}$ Ω	
		RSS of Type B uncertainties			$0,69\cdot10^{-6}$ Ω	

9. BIPM (Measurements in terms of a reference 100 Ω resistance, R_{100B})

Using relative uncertainties, all sensitivity coefficients are 1.

Table D-33: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{100B}	100 Ω	$3\cdot10^{-9}$	triangular/B	1	$3\cdot10^{-9}$	inf
k_{drift}	1	$3\cdot10^{-9}$	triangular/B	1	$3\cdot10^{-9}$	inf
k_{bridge}	1	$2\cdot10^{-9}$	triangular/B	1	$2\cdot10^{-9}$	inf
$k_{ac\text{-}dc}$	1	$5\cdot10^{-9}$	triangular/B	1	$5\cdot10^{-9}$	inf
k_{Temp}	1	$0,03\cdot10^{-9}$	triangular/B	1	$0,03\cdot10^{-9}$	inf
k_{press}	1	$0,01\cdot10^{-9}$	triangular/B	1	$0,01\cdot10^{-9}$	inf
k_{read}	1	$2\cdot10^{-9}$	normal/A	1	$2\cdot10^{-9}$	10
R_{100}	100 Ω				$7,1\cdot10^{-9}$	1600
		RSS of Type A uncertainties			$2\cdot10^{-9}$	
		RSS of Type B uncertainties			$6,9\cdot10^{-9}$	

Table D-34: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{100B}	100 Ω	$3\cdot10^{-9}$	triangular/B	1	$3\cdot10^{-9}$	inf
k_{drift}	1	$3\cdot10^{-9}$	triangular/B	1	$3\cdot10^{-9}$	inf
k_{bridge}	1	$4\cdot10^{-9}$	triangular/B	1	$4\cdot10^{-9}$	inf
k_{noise}	1	$5\cdot10^{-9}$	triangular/B	1	$5\cdot10^{-9}$	inf
k_{Temp}	1	$0,2\cdot10^{-9}$	triangular/B	1	$0,2\cdot10^{-9}$	inf
k_{read}	1	$2\cdot10^{-9}$	normal/A	1	$2\cdot10^{-9}$	10
R_{100}	100 Ω				$7,9\cdot10^{-9}$	2400
		RSS of Type A uncertainties			$2\cdot10^{-9}$	
		RSS of Type B uncertainties			$7,7\cdot10^{-9}$	

Table D-35: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{100B}	100 Ω	$3\cdot10^{-9}$	triangular/B	1	$3\cdot10^{-9}$	inf
k_{drift}	1	$3\cdot10^{-9}$	triangular/B	1	$3\cdot10^{-9}$	inf
k_{bridge}	1	$4\cdot10^{-9}$	triangular/B	1	$4\cdot10^{-9}$	inf
k_{noise}	1	$5\cdot10^{-9}$	triangular/B	1	$5\cdot10^{-9}$	inf
k_{Temp}	1	$0{,}01\cdot10^{-9}$	triangular/B	1	$0{,}01\cdot10^{-9}$	inf
k_{read}	1	$2\cdot10^{-9}$	normal/A	1	$2\cdot10^{-9}$	10
R_{100}	100 Ω				$7{,}9\cdot10^{-9}$	2400
		RSS of Type A uncertainties			$2\cdot10^{-9}$	
		RSS of Type B uncertainties			$7{,}7\cdot10^{-9}$	

Table D-36: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{100B}	100 Ω	$3\cdot10^{-9}$	triangular/B	1	$3\cdot10^{-9}$	inf
k_{drift}	1	$3\cdot10^{-9}$	triangular/B	1	$3\cdot10^{-9}$	inf
k_{bridge}	1	$4\cdot10^{-9}$	triangular/B	1	$4\cdot10^{-9}$	inf
k_{noise}	1	$5\cdot10^{-9}$	triangular/B	1	$5\cdot10^{-9}$	inf
k_{Temp}	1	$0{,}26\cdot10^{-9}$	triangular/B	1	$0{,}26\cdot10^{-9}$	inf
k_{read}	1	$2\cdot10^{-9}$	normal/A	1	$2\cdot10^{-9}$	10
R_{100}	100 Ω				$7{,}9\cdot10^{-9}$	2400
		RSS of Type A uncertainties			$2\cdot10^{-9}$	
		RSS of Type B uncertainties			$7{,}7\cdot10^{-9}$	

10. NIM

Mathematical model:

$$R_{100} = R_H \cdot V_{CCC} \cdot k_{leak} \cdot k_{bridge} \cdot k_{noise}$$

Table D-37: uncertainty for Tegam SR102 #A2030397

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_H	$R_{K-90}/2$	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	8
V_{CCC}	N_S/N_P	$0{,}01\cdot10^{-9}$	rect/B	1	$0{,}01\cdot10^{-9}$	12
k_{leak}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	12
k_{bridge}	1	$0{,}01\cdot10^{-9}$	rect/B	1	$0{,}01\cdot10^{-9}$	12
k_{noise}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	12
k_{Temp}	1	$0{,}07\cdot10^{-9}$	rect/B	1	$0{,}07\cdot10^{-9}$	inf
k_{press}	1	$0{,}02\cdot10^{-9}$	rect/B	1	$0{,}02\cdot10^{-9}$	inf
k_{read}	1	$0{,}67\cdot10^{-9}$	normal/A	1	$0{,}67\cdot10^{-9}$	5
R_{100}	100 Ω				$0{,}69\cdot10^{-9}$	6
		RSS of Type A uncertainties			$0{,}67\cdot10^{-9}$	
		RSS of Type B uncertainties			$0{,}17\cdot10^{-9}$	

Table D-38: uncertainty for Tinsley 5685A #267919

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K\text{-}90}}/2$	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	8
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$0{,}01\cdot10^{-9}$	rect/B	1	$0{,}01\cdot10^{-9}$	12
k_{leak}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	12
k_{bridge}	1	$0{,}06\cdot10^{-9}$	rect/B	1	$0{,}06\cdot10^{-9}$	12
k_{noise}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	12
k_{Temp}	1	$0{,}42\cdot10^{-9}$	rect/B	1	$0{,}42\cdot10^{-9}$	inf
k_{read}	1	$0{,}62\cdot10^{-9}$	normal/A	1	$0{,}62\cdot10^{-9}$	5
R_{100}	100 Ω				$0{,}77\cdot10^{-9}$	12
		RSS of Type A uncertainties			$0{,}62\cdot10^{-9}$	
		RSS of Type B uncertainties			$0{,}46\cdot10^{-9}$	

Table D-39: uncertainty for Tinsley 5685A #262767

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K\text{-}90}}/2$	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	8
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$0{,}01\cdot10^{-9}$	rect/B	1	$0{,}01\cdot10^{-9}$	12
k_{leak}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	12
k_{bridge}	1	$0{,}04\cdot10^{-9}$	rect/B	1	$0{,}04\cdot10^{-9}$	12
k_{noise}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	12
k_{Temp}	1	$0{,}03\cdot10^{-9}$	rect/B	1	$0{,}03\cdot10^{-9}$	inf
k_{read}	1	$0{,}72\cdot10^{-9}$	normal/A	1	$0{,}72\cdot10^{-9}$	5
R_{100}	100 Ω				$0{,}74\cdot10^{-9}$	6
		RSS of Type A uncertainties			$0{,}72\cdot10^{-9}$	
		RSS of Type B uncertainties			$0{,}18\cdot10^{-9}$	

Table D-40: uncertainty for Tinsley 5685A #268168

Quantity	estimate	standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	Degree of Freedom
R_{H}	$R_{\mathrm{K\text{-}90}}/2$	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	8
V_{CCC}	$N_{\mathrm{S}}/N_{\mathrm{P}}$	$0{,}01\cdot10^{-9}$	rect/B	1	$0{,}01\cdot10^{-9}$	12
k_{leak}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	12
k_{bridge}	1	$0{,}02\cdot10^{-9}$	rect/B	1	$0{,}02\cdot10^{-9}$	12
k_{noise}	1	$0{,}1\cdot10^{-9}$	rect/B	1	$0{,}1\cdot10^{-9}$	12
k_{Temp}	1	$0{,}55\cdot10^{-9}$	rect/B	1	$0{,}55\cdot10^{-9}$	inf
k_{read}	1	$0{,}68\cdot10^{-9}$	normal/A	1	$0{,}68\cdot10^{-9}$	5
R_{100}	100 Ω				$0{,}89\cdot10^{-9}$	15
		RSS of Type A uncertainties			$0{,}68\cdot10^{-9}$	
		RSS of Type B uncertainties			$0{,}58\cdot10^{-9}$	