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Report on

Comparison of resistance measurement between DFM and SPI, Lithuania at 100 Ω and 10 kΩ

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Abstract: This report describes a pilot comparison of resistance measurements performed between Danish Fundamental Metrology(DFM), Lyngby, Denmark, and Semiconductor Physics Institute (SPI), Vilnius, Lithuania, at resistance values 100 Ω and 10kΩ.

Dansk resumé: Denne rapport beskriver en pilotsammenligning af måling af resistans mellem Dansk Fundamental Metrologi (DFM), Lyngby, Danmark, og Semiconductor Physics Institute (SPI), Vilnius, Litauen, ved resistans værdier 100 Ω og 10 kΩ.

1 Introduction

For many years ties between the metrology systems of Denmark and Lithuania has been in place. In recent years personnel of DFM has visited the metrology institutions of Lithuania, assessed their facilities and measurement capabilities, provide advice on possible developments and carried out training activities. With the establishment of the national laboratories in the various fields of measurement it is therefore a natural development to perform comparisons of measurement capabilities.

In Denmark, Danish Fundamental Metrology (DFM) is appointed as national primary laboratory for DC electricity, including resistance. In Lithuania, the Semiconductor Physics Institute (SPI) is appointed as national laboratory for resistance.

In 2003 the EUROMET Key Comparison EM.K10 (EUROMET project 636) on 100 Ω resistance was started, and because both institutes, DFM and SPI, are participants, a pilot comparison of resistance measurements at 100 Ω and also 10 kΩ was initiated between the two institutes in connection with a training visit, to build confidence in the measurement systems.

The comparison was performed in the period May 2003 till February 2004. The measurement objects were two Tinsley wire wound standard resistors type 5865B, a 100 Ω unit S/N 274889 belonging to DFM, and a 10 kΩ unit S/N 279892 belonging to SPI.

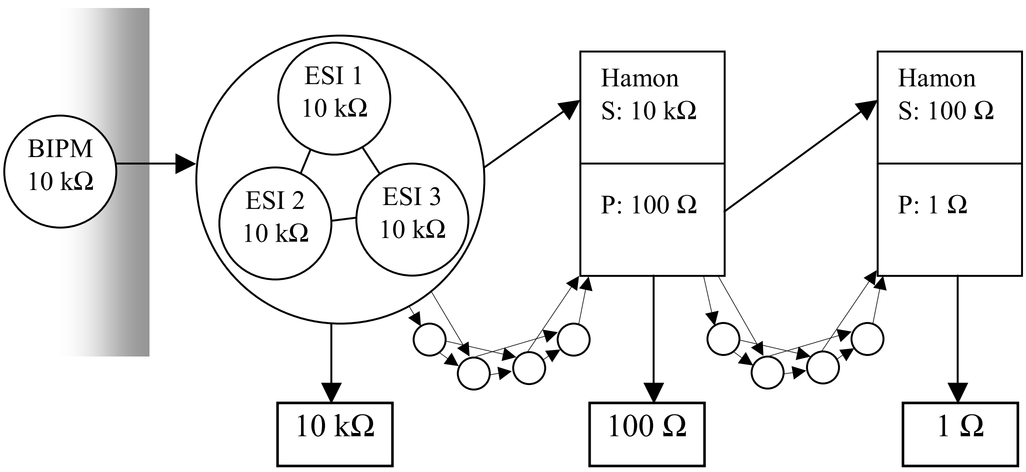
The resistors were initially measured at DFM in May 2003, then transported to SPI in Vilnius, Lithuania, and measured from May until October 2003. The 100 Ω resistor was returned 29 October 2003, the 10 kΩ resistor was received at DFM 15 December 2003 and returned back to SPI 7 February 2004.

2 Measurement setups

2.1 DFM

DFM achieves at present its traceability for resistance from BIPM. A set of three ESI SR104 10 kΩ resistors serve as DFM reference standards, and each of these are in turn calibrated by BIPM over a three year period. The resistors in the group are intercompared using the procedure described below.

Scaling over the range 1 Ω to 10 kΩ is achieved primarily via two Hamon transfer devices, Guildline 9350/1kΩ and Guildline 9350/10Ω. The scaling is independently checked via a set of thermalised resistors[1] in a 1:2:5 sequence schematically illustrated below. Working standards at 10 kΩ, 100 Ω, etc. are used as check standards.



[1] Vishay VHP100 resistors mounted in a copper block combined with a regulated resistive heater maintaining a constant temperature.

Resistance ratio measurements are performed using a Guildline 6675A Direct Current Comparator Bridge. The resistors being compared are connected to independent channels of a Measurement International 4220A Four-Terminal Matrix Scanner. The A and B outputs of the scanner are connected as RS and RX on the resistance bridge. Interconnections are made by single core silver-plated copper, twisted pair, screened cable, as a potential pair and a current pair. A reference potential point is located near the scanner case terminal. The "Guard" and "Ground" connections on the resistance bridge are connected to the reference potential point via the screen of the interconnecting cables. The case of the ESI and Hamon transfer resistors is connected to the reference potential via the screen of the potential carrying interconnecting cable. The screen of the current carrying cable is connected to the reference point at the scanner side.

A measurement program connects the resistors in question via the scanner to the resistance bridge, set up the measurement parameters of the bridge, start the measurement, and read the resistance ratios measured by the bridge.

Temperature measurements, Pt 100 sensor readings, as well as recording of the environmental conditions are performed using an Agilent 34970A DMM scanner mainframe with an Agilent 34901A input module.

2.2 SPI

The source of traceability for the SPI reference standards – a 1 Ω Tinsley 5685A standard resistor and a 10 kΩ Tegam SR 104 standard resistor – is presently from the Czech Metrology Institute, CMI. The history of SPI reference standards values and their temporal variations are known from calibrations at NPL and CMI for the 1 Ω reference, and the Tegam manufacturers certificate, calibration at CMI, and from periodic measurements at SPI, for the 10 kΩ reference.

During the period of measurement at SPI all standard resistors except the 10 kΩ SPI reference standard were maintained in a Hart Scientific 7015 oil bath at (23.00 ± 0.01) °C. The 10 kΩ Tegam SR 104 reference standard was maintained at room temperature (22 ± 1) °C.

The standard resistors were connected in 4 terminal configuration, and resistors cases were used as a guard. Measurement current was used such that not to exceed a load of 1 mW.

A direct current comparator bridge MI 6010Q and low-thermal MI 4220A scanner were used in the measurements. An automated high resistance bridge 6000B was used for 10 kΩ resistance measurements during the final stage in February 2004.

The room temperature was monitored by an ALMEMO 2290-4 thermohygrobarometer with uncertainty 0.2 °C. The temperature in the oil bath was measured by a platinum resistance thermometer, and the value read from an Agilent 3458A DVM with a combined uncertainty of 0.005 °C.

3 Measurement methods

3.1 DFM

Comparison of two or more nominally equal resistors is performed by measurement of each possible ratio combination and subsequent least squares fitting of the relative deviation from the nominal value and a constant bridge ratio error.

The basic model for the ratio reading r_I of the Guildline 6675A bridge is

$$r_I = \frac{R_X}{R_S} + \delta r$$

where R_X and R_S are the resistances of the two resistors, and δr is the bridge ratio error, which is assumed constant in time, but, by experience, depends on the resistance value and the measurement current.

Writing $R_i = R_{nom}(1+\varepsilon_i)$ where R_{nom} is the nominal resistance value and ε_i is the relative deviation from the nominal value, the equation above becomes:

$$r_I = \frac{R_X}{R_S} + \delta r = \frac{R_{nom}(1+\varepsilon_X)}{R_{nom}(1+\varepsilon_S)} + \delta r = (1+\varepsilon_X)(1-\varepsilon_S) + \delta r + o(\varepsilon^2) \approx 1 + \varepsilon_X - \varepsilon_S + \delta r$$

Because ε is typically less than 10^{-5}, we have ignored the second order and higher terms. Writing the bridge reading as $r_I = 1 + \Delta$, we get the relation for an individual measurement:

$$\Delta = \varepsilon_X - \varepsilon_S + \delta r$$

From a sequence of *m* measurements of the possible ratios between *N* resistors, we wish to determine the values of the ε's and δ*r*. This is performed by a least-squares analysis by minimizing the following expression for χ^2:

$$\chi^2 = \left(\overline{\overline{X}} \cdot \begin{Bmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_N \\ \delta r \end{Bmatrix} - \overline{\Delta} \right)^2$$

where the ε_i is the relative deviation of each of the *N* standards, and each row in the $(m+1)\times(N+1)$-dimensional matrix $\overline{\overline{X}}$, the design matrix, is of the form $\{-1 \quad 1 \quad 0 \quad \cdots \quad 1\}$, i.e. a "+1" in the column corresponding to the resistor in the R_X position, and a "–1" for R_S, and a "1" in the final column, for δ*r*. One row is added to this system of equations of the form $\{1 \quad 0 \quad \cdots \quad 0 \quad 0\}$, with the corresponding element in $\overline{\Delta}$ equal to the calibrated value of the appropriate reference resistor in the form of its the relative deviation from the nominal value.

The measurement result is then determined from a least squares fit of the parameters using the standard procedure, from which also the standard uncertainties of the parameters are determined. For the latter, the standard deviation of the residuals is used to determine the value of the covariance matrix.

Four resistors and measurement of all possible ratios, gives 12 measurements and 4 parameters (the value of one resistor, the reference, or e.g. the average, is fixed, leaving three independent ε_i plus δ*r*), thus 8 degrees of freedom.

3.2 SPI

Measurement of two nominally equal resistors is performed by 1:1 comparison between the SPI reference standard (R_s) and the unknown standard resistor (R_x) by measurement of the corresponding resistance ratio. Measurement results of the 1:1 comparison are determined as the mean value of 150 bridge ratio readings, where only the last 140 readings are considered for the average. Ratio measurements are taken in two configurations of the resistors placed in turn at the position of standard (R_s) and unknown (R_x) on the bridge. A bridge offset, δ*r*, is estimated as

$$\delta r = \frac{1}{2}\left(\frac{R_x}{R_s} - \frac{1}{\frac{R_s}{R_x}} \right)$$, where R_s and R_x are reference and unknown resistors,

for each compared resistor pair. Estimated bridge offset is subtracted from the ratio measurement result to achieve maximum bridge accuracy. This method was used for 10 kΩ standard resistor measurements.

100 Ω standard resistors were measured by 10:1 scaling using an intermediate SPI 10 Ω Tinsley 5685A standard resistor. The measurement results of the 10:1 comparisons are taken in two steps: 1 Ω reference standard to 10 Ω intermediate standard and 10 Ω intermediate standard to 100 Ω unknown resistor. Measurement results are determined as the mean values of 150 bridge 10:1 ratio readings, where only the last 140 readings are considered for the average. The results are corrected for bridge offset, taken from the bridge 10:1 ratio calibration certificate (METAS calibration certificate, 2003).

The measurements are made at different dates during the period in SPI. The results obtained for the 100 Ω resistor and the 10 kΩ resistor are represented in Figure 1 and Figure 2 respectively.

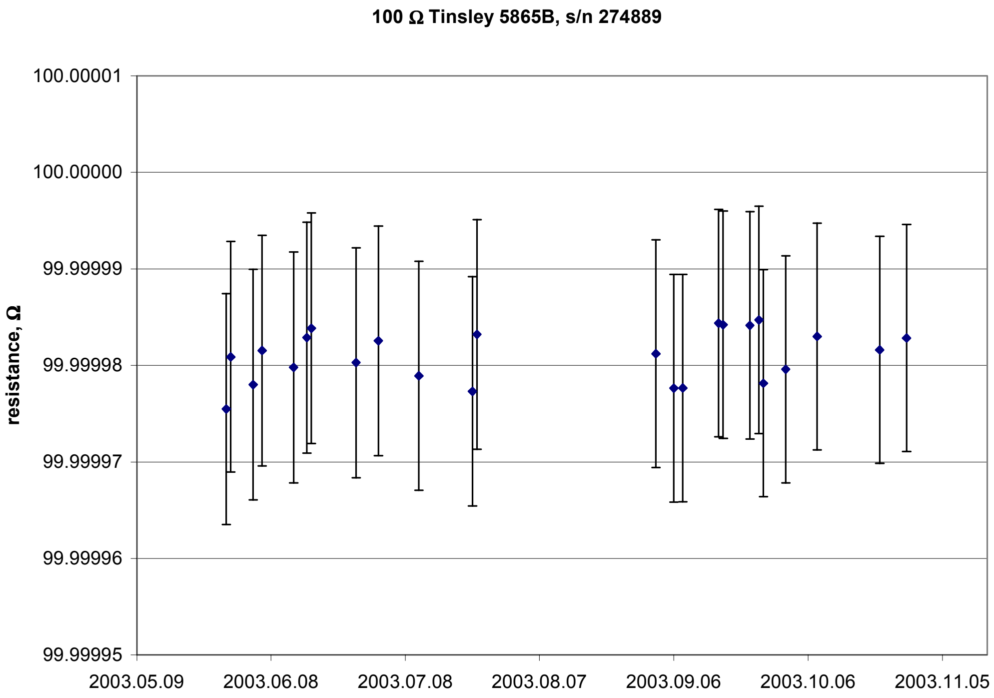


Figure 1. Measurements at SPI of the 100 Ω standard resistor s/n 274889. Error bars represent the expanded uncertainty of the individual measurements using k=2.

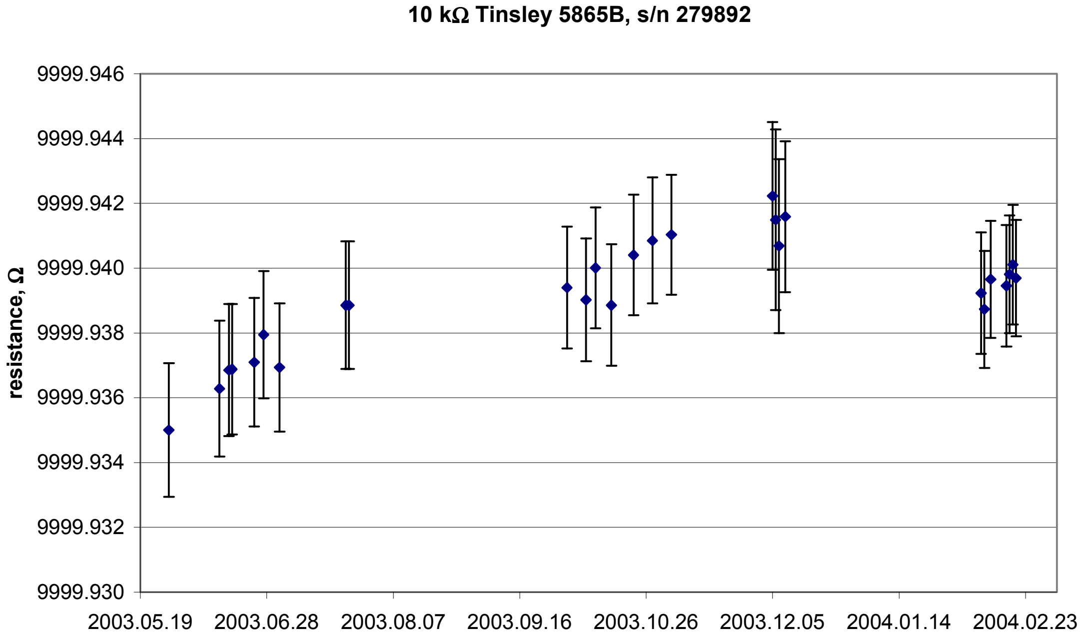


Figure 2. Measurements at SPI of the 10 kΩ standard resistor s/n 279892. Error bars represent the expanded uncertainty of the individual measurements using k=2.

4 Comparison measurements

The DFM ESI reference resistor and the Hamon transfer device are measured in air, in a passive, insulated box.

For the measurements at DFM in May 2003, the two Tinsley wire-wound resistors were placed in an oil bath at nominal 23 °C. The average temperature in the oil bath was measured to be 22,992 °C, $s(T) \sim 3$ mK; the combined standard uncertainty is estimated to be 5 mK.

For the measurements at DFM in December 2003, the 10 kΩ Tinsley resistor was placed in air, while the 100 Ω resistor was kept in a temperature regulated aluminium block at 25 °C.

For all measurements at SPI, the resistors are maintained in an oil bath at (23.00 ± 0.01) °C.

4.1 Measurement results on 10 kΩ Tinsley 5865B, S/N 279892:

Measurements at DFM were performed over the course of three days. The reference resistor was calibrated at BIPM in March 2002 and the value at the date of measurement estimated from the calibration history.

The average value of S/N 279892 at 2003-05-21 was found as

$$R_{892} = 10\ \text{k}\Omega \cdot (1 - 6{,}288 \cdot 10^{-6}) = 9\,999{,}937\ 12\ \Omega$$
$$u(R_{892}) = 0{,}000\ 89\ \Omega$$

SPI measured the resistor 20 times at regular intervals in the period from May 2003 to December 2003. From the measurement data, a clear relative drift of magnitude 0,08 10^{-6}/month is observed during the period. The relative deviation from nominal varies from approximately –6,3 10^{-6} in May 2003 to –5,9 10^{-6} in December. To facilitate a comparison, the average value is found as

$$R_{892} = 10\ \text{k}\Omega \cdot (1 - 6{,}098 \cdot 10^{-6}) = 9\,999{,}939\ 02\ \Omega$$
$$u(R_{892}) = 0{,}000\ 41\ \Omega$$

For the second measurement at DFM, 2003-12-15, traceability is achieved from a second reference resistor calibrated at BIPM June 2003, and the average value for the SPI 10 kΩ resistor was found as

R_{892}	$= 10\ \text{k}\Omega \cdot (1 - 6{,}229 \cdot 10^{-6}) = 9\ 999{,}937\ 71\ \Omega$
$u(R_{892})$	$= 0{,}000\ 89\ \Omega$

Comparing the two DFM measurement values no significant change is observed from the May value.

It is noted, that there is very good agreement between the SPI value obtained in the beginning of the period, May-June, but the drift observed at SPI could not be confirmed by the DFM measurements. However, regarding the SPI average value there is agreement, although marginal, within the uncertainties between the values of DFM and SPI.

After the resistor returned to SPI in February 2004, additional measurements were performed using another 6000B bridge. The reason of the change was the observation of unstable operation of 6010Q bridge in January 2004. Afterwards, the 6010Q bridge failed to operate and was removed from the measurement setup for repair at the manufacturers.

As can be seen from Figure 2, the February 2004 measurements by 6000B bridge show no significant drift from the July – September values. Omitting the December 2003 measurement results as possibly influenced by 6010Q bridge errors, the revised average value for the SPI 10 kΩ resistor was found as

R_{892}	$= 10\ \text{k}\Omega \cdot (1 - 6{,}157 \cdot 10^{-6}) = 9\ 999{,}938\ 74\ \Omega$
$u(R_{892})$	$= 0{,}000\ 36\ \Omega$

The difference in the resistance values at 10 kΩ of DFM and SPI thus becomes:

$$\Delta R = 1{,}3\ \text{m}\Omega, \quad \text{with } U(\Delta R) = 1{,}9\ \text{m}\Omega.$$

Uncertainty budgets, 10 kΩ

DFM

The DFM uncertainty budget is based on the following model equation:

$$\varepsilon_X = \underbrace{\varepsilon_{ref,A} + \varepsilon_{ref,B} + \delta\varepsilon}_{\varepsilon_S} + \delta_{T,S} + \left(r + \delta r_S + \delta r_C\right) - \delta_{T,X}$$

where ε_X is the relative deviation from nominal (RDN) of the unknown resistor, ε_S is the RDN of the reference resistor, containing the value obtained from BIPM (type-A and type-B components) and the drift since calibration. The term $\delta_{T,S}$ is the temperature correction of the reference, r is the ratio as measured, δr_S is the specification of the current comparator bridge, δr_C is the correction of the bridge error, and $\delta_{T,X}$ is the temperature correction of the unknown resistor.

The value of the resistance is derived using the least squares technique described above, for which the uncertainty calculation is impractical to put in the standard form. The uncertainty budget is therefore constructed over the values determined for the unknown, the bridge error and the ratios measured.

The uncertainty budget for the May measurement becomes:

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$
1	ε_S, Rel. dev. from nominal of standard (10^{-6})	Normal	0,972	0,015	7	1	0,0151
2	$\delta_{T,S}$, Temp deviation standard ±0,1 °C (10^{-6})	Rectangular	0,000	0,017	infinity	1	0,0170
3	r, Ratio deviation as determined (10^{-6})	Normal	–7,336	0,060	43	1	0,0600
4	δr_S, Specification for Guildline bridge (10^{-6})	Rectangular	0,000	0,058	infinity	1	0,0577
5	δr_C, Correction of bridge error (10^{-6})	Normal	0,076	0,021	30	1	0,0210
6	$\delta_{T,X}$, Temp deviation standard ±0,01 °C (10^{-6})	Rectangular	0,000	0,005	infinity		
y	ε_X, Rel. dev. from nom. of unknown (10^{-6})	Normal	–6,288	0,089	infinity		

We estimate a correlation of our result for the 10 kΩ resistor to the BIPM working standards of **r = 0,17** (estimated from the quoted type-B relative uncertainty of BIPM of $1{,}5\cdot 10^{-8}$.)

SPI

The SPI uncertainty budget is based on the following model equation:

$$R_x = ((R_s + (dtR_s - dR_s)\, r_{xs}\, d_r / 1000) - dtR_x / 1000$$

where R_x and R_s are the unknown and reference standard resistances respectively, dR_s is drift of R_s since last calibration, dtR_s and dtR_x are the temperature corrections for the reference and the unknown standards respectively, r_{xs} is ratio as measured, d_r is bridge linearity error.

The uncertainty budget for the July 23 measurements becomes:

i	**Quantity (unit)**	**Distribution**	***Xi***	***u(xi)***	***ϖi***	***ci***	***ui(y)***
1	Rs, reference standard (Ohm)	Rectangular	10000.0053	0.000866	infinity	0.9999934	0.000866
2	dRs, drift of Rs since last calibration (mOhm)	Rectangular	0.86	0.283	infinity	-0.001	-0.000283
3	dtRs, temperature correction, reference (mOhm)	Rectangular	0	0.156	infinity	0.001	0.000156
4	r_xs, ratio unknown/reference (relative)	Normal	0.99999344	0.000000033	150	10000.004	0.00033
5	d_r, bridge linearity error (relative)	Rectangular	1	2.89E-09	infinity	9999.939	2.89E-05
6	dtRx, temperature correction, unknown (mOhm)	Rectangular	0	0.0577	infinity	-0.001	-5.77E-05
y	Rx, resistance of unknown (Ohm)	Normal	9999.93886	0.000984	infinity		
		Conf. level =	95.45%	k =	2.000003		
		Result =	9999.9389	U =	0.002		

Estimation of uncertainty components:

- reference standard value uncertainty is determined from the calibration certificate. The most recent 10 kΩ reference value was obtained using the value of the SPI 100 Ω standard resistor calibrated with the QHR at CMI and the experimental results of the 100 Ω – 1 kΩ – 10 kΩ transfer by means of the 6010Q bridge. The combined uncertainty is estimated by

$$u(R_s) = \sqrt{u(R_{100\Omega})^2 + s(trans)^2}$$

- where $u(R_{100})$ is uncertainty taken from 100 Ω resistor calibration certificate, and $s(trans)$ is standard deviation of 100 Ω to 10 kΩ value transfer via the intermediate 1 kΩ resistor by means of 10:1 ratio measurements on 6010Q bridge;
- the uncertainty of the drift of reference standard is estimated from the linear regression taking into account lower and upper limits of the drift determined by the calibration uncertainties of the previous and the last calibrations;
- the uncertainty due to bridge linearity error is taken from the bridge specification;

- the uncertainty of bridge 1:1 ratio measurements is determined from the experimental standard deviation of 140 individual ratio measurements;
- the uncertainty due to temperature of the resistors maintained in oil bath is estimated taking into account temperature instability inside the bath 0.01 °C and the resistor temperature coefficients taken from their calibration certificates ($1 \cdot 10^{-6}$ °C^{-1} for the SPI 279892 resistor). The room temperature instability of ±1 °C and the temperature coefficients $\alpha = 0$ °C^{-1}, $\beta = 0.028 \cdot 10^{-6}$ °C^{-2} were used to estimate the value of the SPI 10 kΩ Tegam SR104 reference temperature correction uncertainty.

4.2 Measurement results on 100 Ω Tinsley 5865B, S/N 274889:

This 100 Ω resistor is usually maintained at DFM in a thermostatted environment at 25 °C. For the purpose of the comparison, the resistor was placed in an oil bath at 23 °C together with the 10 kΩ resistor described below. Prior to the change in temperature, the value at 25 °C was measured, so to determine the offset of the resistance value between the two temperatures. The difference was determined to $\Delta R_{25\text{–}23} = 139$ μΩ.

DFM result 2003-05-21:

$$R_{889} = 100\ \Omega \cdot (1 - 0{,}23 \cdot 10^{-6}) = 99{,}999\ 977\ \Omega$$
$$u(R_{889}) = 19\ \mu\Omega$$

SPI performed 25 determinations of the value of the 100 Ω resistor over the period from May to October 2003. The average value is found as:

$$R_{889} = 100\ \Omega \cdot (1 - 0{,}190 \cdot 10^{-6}) = 99{,}999\ 981\ 0\ \Omega,\ s = 3{,}0\ \mu\Omega$$
$$u(R_{889}) = 13\ \mu\Omega$$

The DFM result of 2004-01-22 at 25 °C was referred to 23 °C by applying the correction determined in Spring 2003 and the result becomes:

$$R_{889,25} = 100\ \Omega \cdot (1 + 1{,}20 \cdot 10^{-6})$$
$$R_{889,23} = 100\ \Omega \cdot (1 - 0{,}19 \cdot 10^{-6}) = 99{,}999\ 981\ \Omega$$
$$u(R_{889}) = 19\ \mu\Omega$$

Comparing the DFM values with the SPI value we find excellent agreement. The difference in the resistance values at 100 Ω of DFM and SPI thus becomes:

$$\Delta R = 2\ \mu\Omega, \quad \text{with } U(\Delta R) = 26\ \mu\Omega.$$

Uncertainty budgets, 100 Ω

The DFM uncertainty budget is based on the following model equation:

$$\varepsilon_X = \varepsilon_S + \delta\varepsilon_{SP} + \delta_{T,S} + (r + \delta r_S + \delta r_C) - \delta_{T,X}$$

where ε_X is the relative deviation from nominal (RDN) of the unknown resistor, ε_S is the RDN of the reference/transfer resistor and $\delta\varepsilon_{SP}$ is the series-parallel transfer error. The term $\delta_{T,S}$ is the temperature correction of the reference, r is the ratio as measured, δr_S is the specification of the current comparator bridge, δr_C is the correction of the bridge error, and $\delta_{T,S}$ is the temperature correction of the unknown resistor.

I	**Quantity (unit)**	**Distribution**	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$
1	ε_S, Rel. dev. from nominal of standard (10^{-6})	Normal	-13,268	0,089	30	1	0,089
2	$\delta\varepsilon_{SP}$, Series-parallel transfer error (10^{-6})	Rectangular	0,000	0,058	infinity	1	0,058
3	$\delta_{T,S}$, Temp deviation standard ±0,1 °C (10^{-6})	Rectangular	0,000	0,080	infinity	1	0,080
4	r, Ratio deviation as determined (10^{-6})	Normal	18,877	0,030	30	1	0,030
5	δr_S, Specification for Guildline bridge (10^{-6})	Rectangular	0,000	0,058	infinity	1	0,058
6	δr_C, Correction of bridge error (10^{-6})	Normal	0,008	0,010	30	1	0,010
7	$\delta_{T,X}$, Temp deviation standard ±0,01 °C (10^{-6})	Rectangular	0,000	0,005	infinity		–0,005
Y	ε_X, Rel. dev. from nom. of unknown (10^{-6})	Normal	0,225	0,148	75		

The SPI uncertainty budget is based on the following model equation:

$$R_x = ((R_s + dtR_s + dR_s)\, r_{10:1}/(d_{r1} + 1)\, r_{100:10}/(d_{r2} + 1)\, d_{r3}\, d_{r3} - dtR_x$$

where R_x and R_s are unknown and reference standard resistance respectively, dR_s is drift of R_s since last calibration, dtR_s and dtR_x are temperature corrections for reference and unknown standard respectively, $r_{10:1}$ is 10:1 measured ratio of the intermediate standard to the reference standard, $r_{100:10}$ is 100:10 measured ratio of the unknown standard to the intermediate standard, d_{r1}, d_{r2}, and d_{r3} are bridge 10:1 ratio error, 100:10 ratio error and bridge linearity error respectively.

The uncertainty budget for the July 23 measurements becomes:

i	**Quantity (unit)**	**Distribution**	***xi***	***u(xi)***	***ϖi***	***ci***	***ui(y)***
1	Rs, reference standard (Ohm)	Rectangular	0.9999999	5.77E-08	infinity	99.999984	5.77E-06
2	dRs, drift of Rs since last calibration (Ohm)	Rectangular	3.5E-08	7.51E-09	infinity	99.999984	7.51E-07
3	dtRs, temperature correction, reference (Ohm)	Rectangular	0	5.77E-09	infinity	99.999984	5.77E-07
4	r_10:1, ratio intermediate/reference (relative)	Normal	9.99996805	0.000000051	150	10.00003	5.1E-07
5	er1, bridge 10:1 ratio error (relative)	Rectangular	0	4.62E-09	infinity	-99.999976	-4.62E-07
6	r_100:10, ratio unknown/intermediate (relative)	Normal	10.0000303	0.000000024	150	9.9999674	2.4E-07
7	er2, bridge 100:10 ratio error (relative)	Rectangular	0	4.62E-09	infinity	-99.999976	-4.62E-07
8	er3, bridge linearity error (relative)	Rectangular	1	2.89E-09	infinity	199.99995	5.77E-07
9	dtRx, temperature correction, unknown (Ohm)	Rectangular	0	5.77E-09	infinity	-0.9999997	-5.77E-09
10							
y	Rx, resistance of unknown (Ohm)	Normal	99.9999773	5.94E-06	infinity		
		Conf. level =	95.45%	k =	2.000003		
		Result =	99.999977	U =	0.000012		

Estimation of uncertainty components is analogous to the 10 kΩ case with the only difference: the bridge 10:1 and 100:10 ratio measurements errors are taken from the bridge calibration certificate (METAS, 2003).

5 Conclusions

A comparison of resistance measurements at 10 kΩ and 100 Ω has been performed between DFM and SPI during 2003. Excellent agreement was found at 100 Ω with a relative difference between the two institutes of $(2 \pm 26)\cdot 10^{-8}$. Good agreement was found at 10 kΩ, with a relative difference between the two institutes of $(13 \pm 19)\cdot 10^{-8}$. A systematic drift in the value of the 10 kΩ resistor observed at SPI could not be confirmed by DFM.

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