Final Report

AFRIMETS.EM-S3: Bilateral comparison between NMISA and KEBS on Resistance Standards at 1 Ω, 10 Ω, 100 Ω, 1 kΩ and 10 kΩ

Authors
Marcus Hlakola[1], Michael Khoza[1],Grace Ateka[2] & Kobur Kiplagat Ngeno[2]

[1]National Metrology Institute of South Africa (NMISA), South Africa
[2]Kenya Bureau of Standards (KEBS), Kenya

CONTENTS

1 Introduction 3
2 Organisation of the comparison 3
2.1 Participants 3
2.2 Measurement schedule 4
2.3 Unexpected incidents 4
3 Travelling standards and required measurement 4
3.1 Description of travelling standards 4
3.2 Environmental conditions 5
3.3 Measurement methods 5
3.4 Traceability 6
3.5 Connection setup 6
3.6 Deviation(s) from the protocol 6
4 Stability of the travelling standards 7
5 Discussion of comparison results 10
5.1 Temperature and atmospheric pressure corrections 10
5.2 Calculation of comparison reference value, CRV 11
5.3 Normalised error, $\boldsymbol{En}$ 12
5.4 Deviation from CRV 12
5.5 Participants reported results 13
6 Summary and conclusions 23
7 References 23
Appendix A: NMISA uncertainty budgets for loop 1 24
Appendix B: NMISA uncertainty budgets for loop 2 29
Appendix C: KEBS uncertainty budgets 34

1 Introduction

This is a follow-up comparison between NMISA and KEBS of AFRIMETS.EM-S1 (Resistance standards at 1 Ω, 10 Ω, 100 Ω, 1 kΩ, and 10 kΩ), published in KCDB in February 2022. This follow-up comparison uses a different set of standard resistors from the main comparison. After completion of the supplementary comparison (AFRIMETS.EM-S1), KEBS was not satisfied with their comparison results because they did not support their required measurement capabilities. KEBS purchased a new resistance measurement system as part of the corrective action and requested a follow-up bilateral comparison with NMISA.

This report describes the detailed findings and results of the comparison in terms of behaviour of travelling standards, methods used by participants and measurement results.

2 Organisation of the comparison

2.1 Participants

Table 1. List of participants

Country	Institute	Acronym	Contact person	e-mail address	Shipping address
South Africa	National Metrology Institute of South Africa (Pilot)	NMISA	Marcus Hlakola	mhlakola@nmisa.org	Building 5, CSIR Scientia campus, Meiring Naude Road, Pretoria, 0001, South Africa
Kenya	Kenya Bureau of Standards	KEBS	Grace Ateka	atekag@kebs.org	Popo Road, Off Mombasa Road, Nairobi, Kenya

2.2 Measurement schedule

The artefacts were circulated between the participants in the order listed in Table 2 below.

Table 2. Comparison schedule

Institute	Measurement date
NMISA	21-25 June 2022
KEBS	25-29 July 2022
NMISA	24 October 2022-04 November 2022

2.3 Unexpected incidents

No incidents involving the travelling standards were reported.

3 Travelling standards and required measurement

3.1 Description of travelling standards

The travelling standards are described in Table 3 below.

Table 3. Description of the travelling standards

Make	Model	Serial no.	Nominal value	Temperature coefficient α value	Temperature coefficient β value	Pressure coefficient
Fluke	742A-1	5040014	1 Ω	0,1E-6/K	- 0,036E-6/K^2	- 0,17E-9/hPa
	742A-10	5480006	10 Ω	0,042E-6/K	- 0,055E-6/K^2	- 0,171E-9/hPa
	742A-100	4805003	100 Ω	- 0,01E-6/K	- 0,046E-6/K^2	- 0,185E-9/hPa
	742A-1k	4810007	1 kΩ	0,00E-6/K	- 0,032E-6/K^2	- 0,157E-9/hPa
	742A-10k	4975043	10 kΩ	0,03E-6/K	- 0,008E-6/K^2	- 0,11E-9/hPa

3.2 Environmental conditions

Table 4. Environmental conditions by participants

	Temperature	Relative Humidity	Atmospheric pressure
NMISA	23,03 °C	52,9 %	871 hPa
KEBS	21,8 °C	49,5 %	840 hPa

3.3 Measurement methods

NMISA

- The 4-terminal resistance of the comparison standards was measured using Measurement International, 6010D automated resistance measurement system.
- The travelling standards were connected in accordance with the connection setup explained in 3.4.
- The standards were kept in a temperature-controlled air bath throughout the duration of the measurements

KEBS

- The laboratory standard and the travelling standard were connected as per the connection setup explained in 3.4.
- The resistance measurement system (6625A) was configured such that the automatic resistance bridge was comparing the laboratory resistance standard with the same nominal value as the travelling standard.
- The travelling standard resistors were configured on the Guildline bridgeworks software using the nominal resistance values.
- The current values used for resistance measurements were configured as per the technical protocol specifications for each resistance standard.
- A total of one thousand (1000) measurements were taken for each resistance value, with the first two hundred (200) readings allowed for stabilization. The mean readings were automatically computed by the software.
- All the six (6) measurements were configured to run sequentially while the environmental conditions were recorded on a data logger.

- Resistance measurements were taken continuously while varying time for each reading until a suitable setting was achieved.

3.4 Traceability

NMISA:

- The reference resistance standards (1 Ω and 10 kΩ) are calibrated by BIPM, France.

KEBS:

- The reference resistance standards (1 Ω and 10 kΩ) are calibrated by UME, Turkey

3.5 Connection setup

The travelling standards were connected to the laboratory resistance measurement systems as per the diagram below. The current terminals C1 and C2 were connected to the resistance standard CURRENT terminals and the potential terminals P1 and P2 were connected to the SENSE terminals of the resistor standards

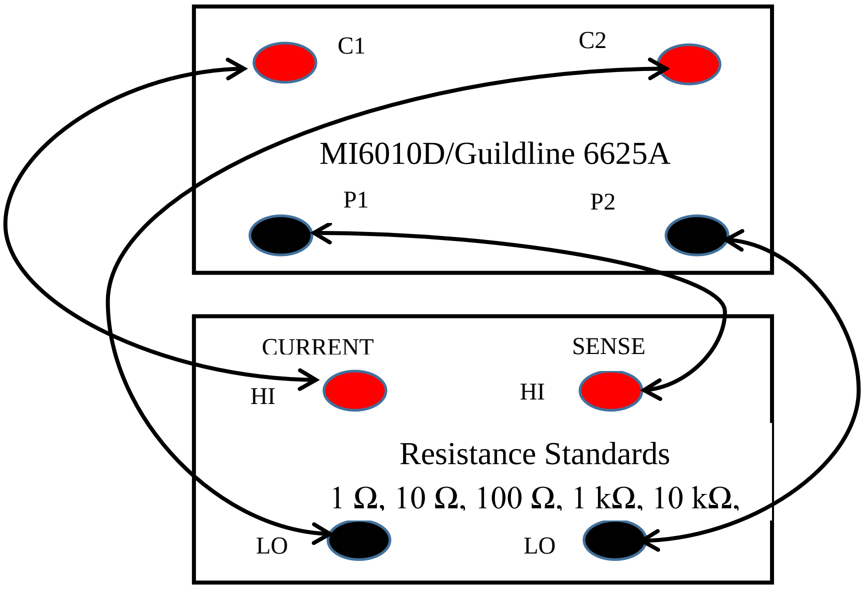

Figure 1: Schematic diagram of the measurement setups

3.6 Deviation(s) from the protocol

There were no deviations from both participants, the measurements were undertaken as per the protocol [1]

4 Stability of the travelling standards

The stabilities of the travelling standards are determined from NMISA measurements dated from 21 June 2022 to 04 November 2022. The linear fit equation (1) below used to calculate the drifts of the travelling standards.

$$(y - y_0) = m(x - x_0) \qquad (1)$$

Where:

x is the loop 1 NMISA measurement date
x_0 is the loop 2 NMISA measurement date
y is the loop 1 NMISA resistance value
y_0 is the loop 2 NMISA resistance value
m is the calculated drift of the resistance per day

For each of the travelling standards, x_0, y_0 and m are given in Table 5 below.

Table 5. Parameters for behaviour of travelling standards

Travelling standard	$y(\Omega)$	$y_0(\Omega)$	$m(\Omega/day)$
5040014	0,99994426	0,99994312	- 0,00000001
5480006	10,000168	10,0001721	0,000000031
4805003	100,00216	100,00217	0,000000075
4810007	1000,0795	1000,0798	0,0000023
4975043	10000,206	10000,207	0,0000075

The behaviour of the travelling standards using the NMISA measurements are plotted on the graphs below.

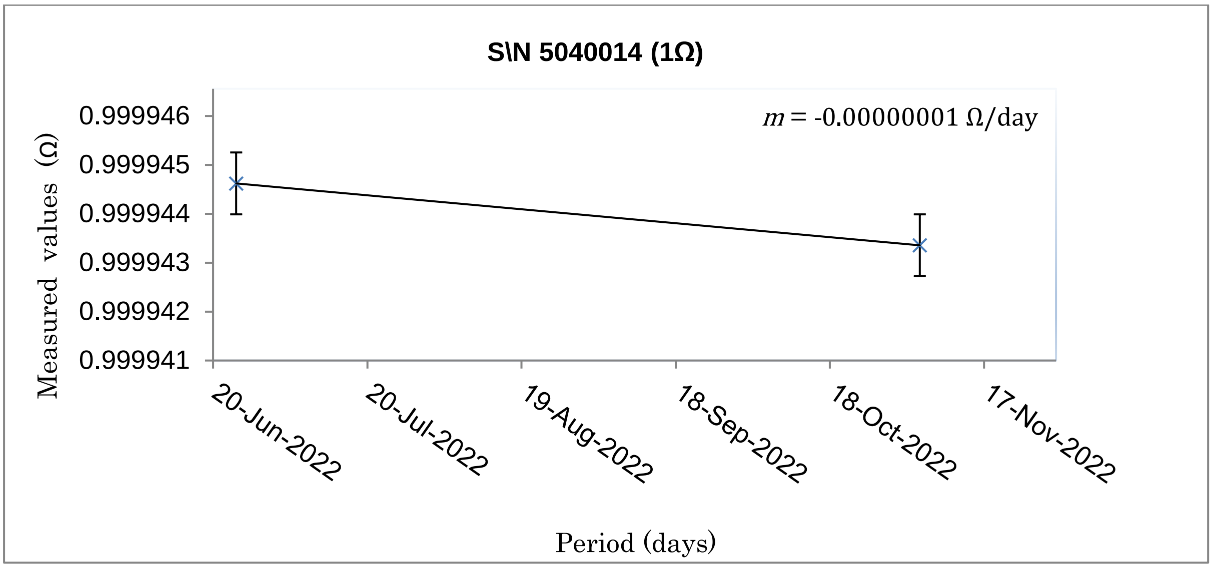

Figure 2. Stability of 1 Ω travelling standard: S/N 5040014

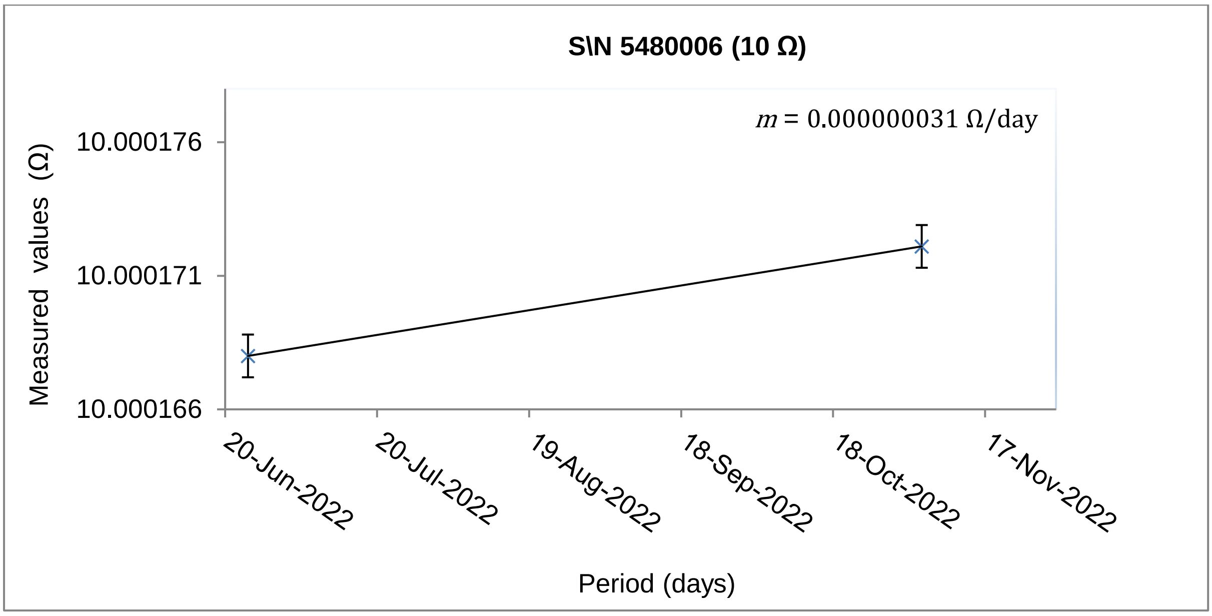

Figure 3. Stability of 10 Ω travelling standard: S/N 5480006

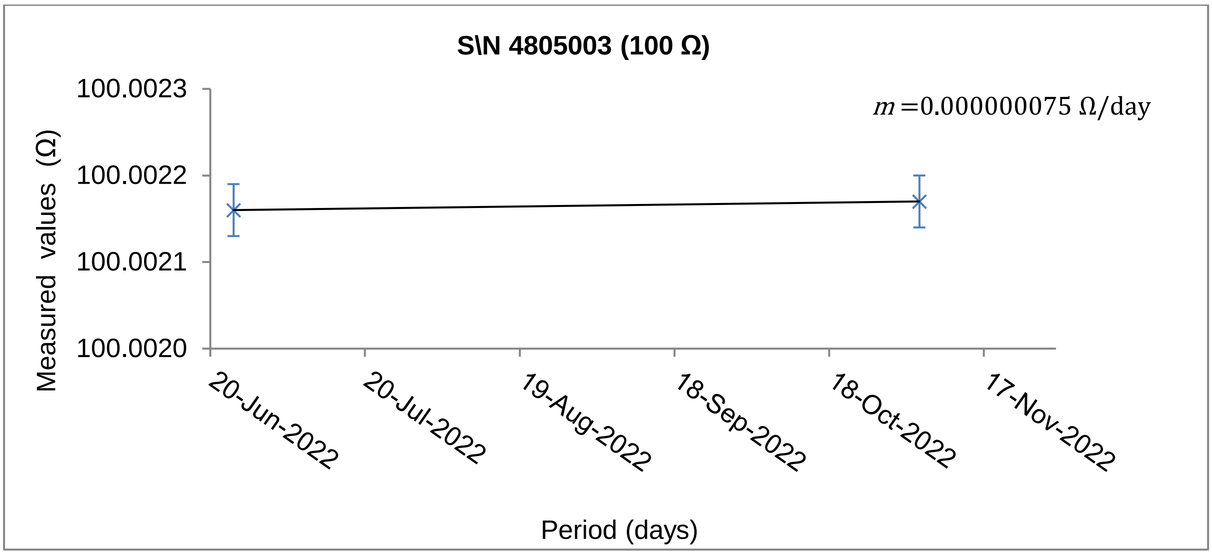

Figure 4. Stability of 100 Ω travelling standard: S/N 4805003

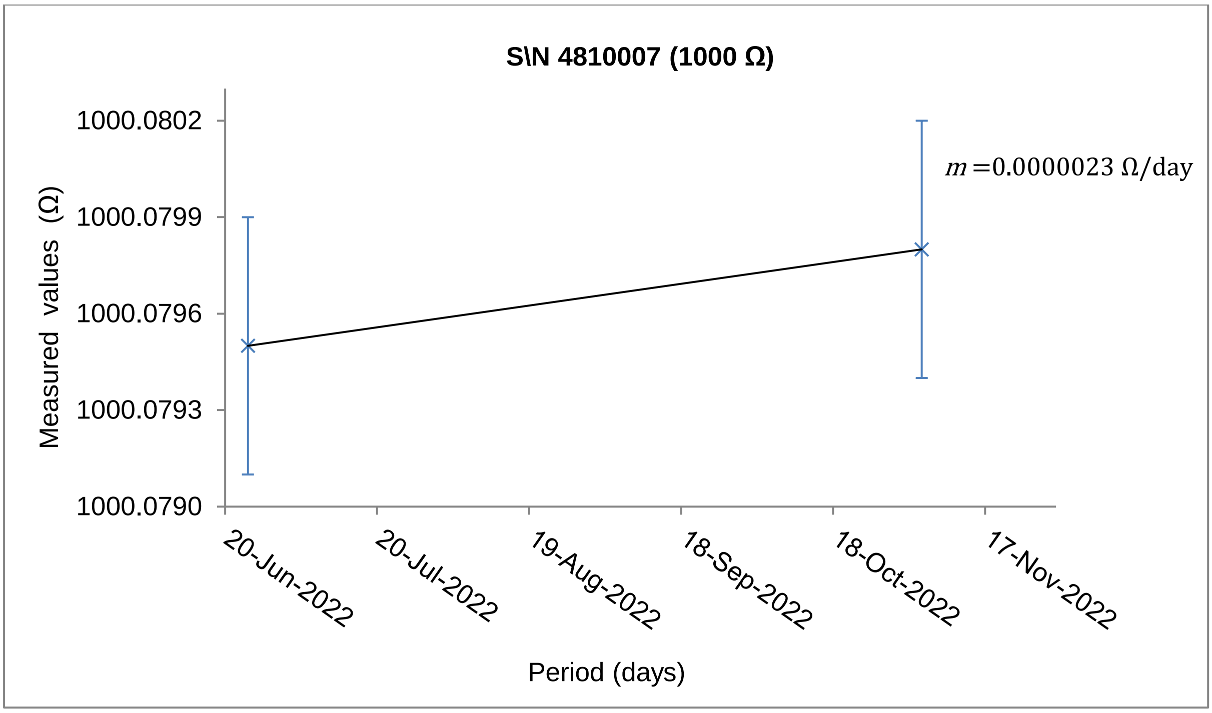

Figure 5. Stability of 1 000 Ω travelling standard: S/N 4810007

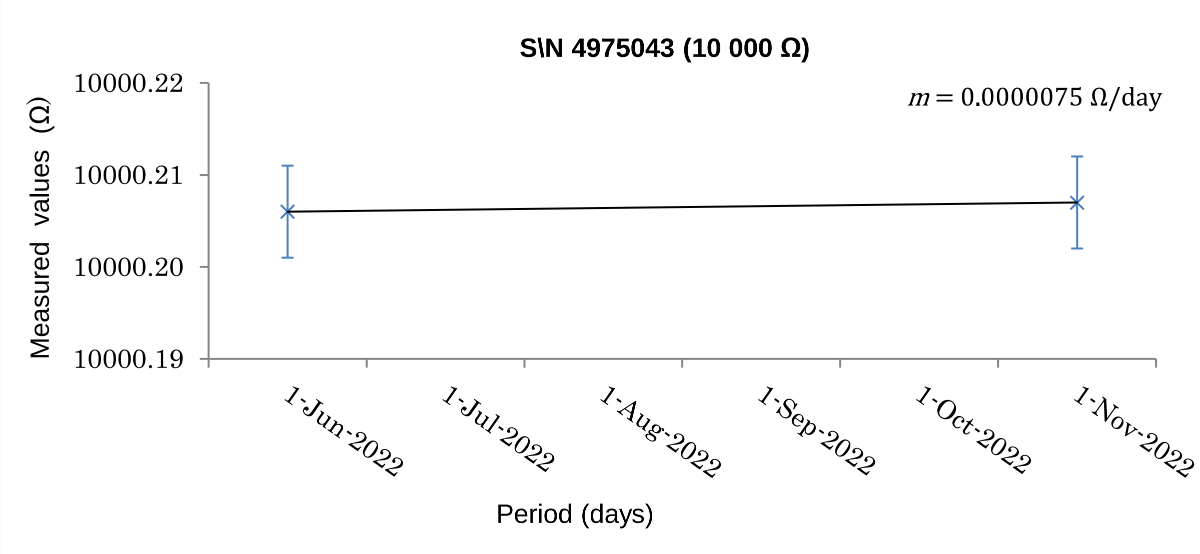

Figure 6. Stability of 10 000 Ω travelling standard: S/N 4975043

The stability checks show that only the 1 Ω and 10 Ω travelling standards drifted significantly throughout the comparison period.

5 Discussion of comparison results

5.1 Temperature and atmospheric pressure corrections

The values reported by KEBS were corrected for temperature and atmospheric pressure in line with the comparison reference values (CRV). The reported values were corrected for temperature variations using equation 2 below [2]:

$$R_x = R_\gamma(1 + \alpha(T_x - T_\gamma) + \beta(T_x - T_\gamma)^2) \qquad (2)$$

Where:

- R_x is corrected reported resistance of KEBS to NMISA's reported temperature T_x
- T_x is the reference temperature as reported by NMISA
- R_γ is the resistance reported by KEBS at temperature T_γ
- T_γ is the temperature reported by KEBS
- α and β are temperature coefficients listed in Table 3

For atmospheric pressure corrections, equation 3 below was used [2]:

$$R_x = R_\gamma(1 + \gamma(P_x - P_\gamma) \qquad (3)$$

Where:

R_x is corrected reported resistance of KEBS to NMISA's reported atmospheric pressure P_x

P_x is the reference atmospheric pressure reported by NMISA

R_γ is the resistance reported by KEBS at atmospheric pressure P_γ

P_γ is the atmospheric pressure reported by KEBS

γ is pressure coefficient listed in Table 3

5.2 Calculation of comparison reference value, CRV

According to the protocol, the comparison reference value is to be determined from the average of NMISA's measurements. The comparison reference value (CRV) is determined as

$$\bar{X} = \frac{\sum_{i=1}^{N} x_i}{N} \qquad (4)$$

Where:

$\bar{X}$ is the arithmetic mean of NMISA measurements from loop 1, Xi is the measurements performed by NMISA and N is the number of measurements performed by NMISA for loop 1. The reference values are drift corrected to the average date of KEBS measurements using equation 5

$$R_x = \bar{X} + (R_{dft} \times D_y) \qquad (5)$$

Where:

R_x is the drift corrected reference value

$\bar{X}$ is the calculated average of NMISA's loop 1.

R_{dft} is the calculated drift per day of the travelling standard since initial measurement.

D_y is the period lapsed in days between the average date of NMISA's loop 1 measurements and KEBS measurement average date

The CRVs and their uncertainties (k = 2) are as shown the Table 6 below:

Table 6. Comparison reference values (CRV)

Travelling Standards	**Test Current**	**Reference value**	**Uncertainty (*k*=2)**
1 Ω	100 mA	0,9999440 Ω	0,2 µΩ/Ω
10 Ω	10 mA	10,0001691 Ω	0,08 µΩ/Ω
100 Ω	1 mA	100,00216 Ω	0,3 µΩ/Ω
1000 Ω	1 mA	1000,0796 Ω	0,4 µΩ/Ω
10000 Ω	100 µA	10000,206 Ω	0,5 µΩ/Ω

5.3 Normalised error, $\boldsymbol{E_n}$

The normalised errors of the corrected reported values were calculated using equation (6),

$$E_n = \frac{R_x - R_{CRV}}{\sqrt{(U_{Rx})^2 + (U_{CRV})^2}} \qquad (6)$$

where:

E_n is the normalised error.

R_x is KEBS corrected reported value.

R_{CRV} is the comparison reference value provided by NMISA.

U_{Rx} is KEBS reported uncertainty.

U_{CRV} is the uncertainty of the reference value by NMISA.

The calculated normalised errors are given in Table 7

Table 7. Calculated Normalised Errors

Travelling Standards	**Normalised Error, $\boldsymbol{E_n}$**
1 Ω	0,34
10 Ω	0,28
100 Ω	0,29
1000 Ω	- 0,12
10000 Ω	0,02

5.4 Deviation from CRV

The deviation from CRV, D_i is determined the using the equation (7).

$$D_i = \frac{R_x - R_{CRV}}{R_{CRV}} \times 1000000 \qquad (7)$$

Where R_x is the corrected reported value by KEBS and R_{CRV} is the comparison reference value. The D_i is expressed in relative, μΩ/Ω. The calculated deviations are given in Table 8 below:

Table 8. Deviations from CRV

Travelling Standards	**Deviation from CRV** (µΩ/Ω)
1 Ω	0,51
10 Ω	0,55
100 Ω	0,59
1000 Ω	- 0,18
10000 Ω	- 0,03

5.5 Participants reported results

Table 9. NMISA's loop 1 results for 1 Ω travelling standard: S/N 5040014

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement *k*=2,43 (µΩ/Ω)
21 June 2022	0,99994449	100 mA	23 June 2022	0,9999443	0,2
22 June 2022	0,99994425				
23 June 2022	0,99994419				
24 June 2022	0,99994419				
25 June 2022	0,99994418				

Table 10. KEBS results for 1 Ω travelling standard: S/N 5040014

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Corrected Resistance (Ω)	Uncertainty of Measurement *k*=2 (µΩ/Ω)
25 July 2022	0,99994467	100 mA	27 July 2022	0,9999447	0,9999445	1,5
26 July 2022	0,99994467					
27 July 2022	0,99994465					
28 July 2022	0,99994466					
29 July 2022	0,99994461					

Table 11. NMISA's loop 2 results for 1 Ω travelling standard: S/N 5040014

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
24 October 2022	0,99994315	100 mA	30 October 2022	0,99994312	0,07
28 October 2022	0,99994314				
02 November 2022	0,99994311				
03 November 2022	0,99994311				
04 November 2022	0,99994310				

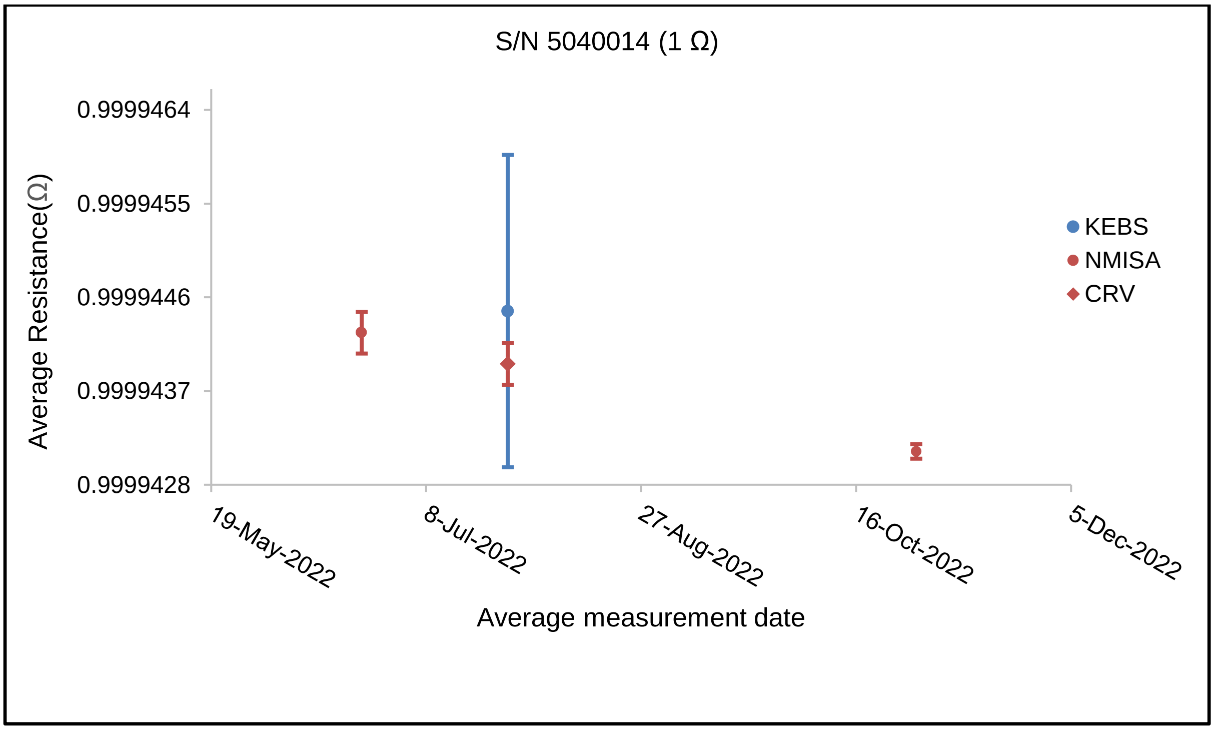

Figure 7. Results for 1 Ω travelling standard: S/N 5040014. NMISA measurements are for 2 loops, first loop on the 23rd of June 2022 and second loop on the 30th of October 2022

Table 12. NMISA’s loop 1 results for 10 Ω travelling standard: S/N 5480006

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
21 June 2022	10,0001679	10 mA	23 June 2022	10,0001680	0,08
22 June 2022	10,0001680				
23 June 2022	10,0001680				
24 June 2022	10,0001681				
25 June 2022	10,0001681				

Table 13. KEBS Results for 10 Ω travelling standard: S/N 5480006

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Corrected Resistance (Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
25 July 2022	10,0001764	10 mA	27 July 2022	10,000176	10,000175	2,0
26 July 2022	10,0001764					
27 July 2022	10,0001763					
28 July 2022	10,0001762					
29 July 2022	10,0001764					

Table 14. NMISA's loop 2 results for 10 Ω travelling standard: S/N 5480006

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
24 October 2022	10,0001719	10 mA	30 October 2022	10,0001721	0,08
28 October 2022	10,0001721				
02 November 2022	10,0001722				
03 November 2022	10,0001722				
04 November 2022	10,0001723				

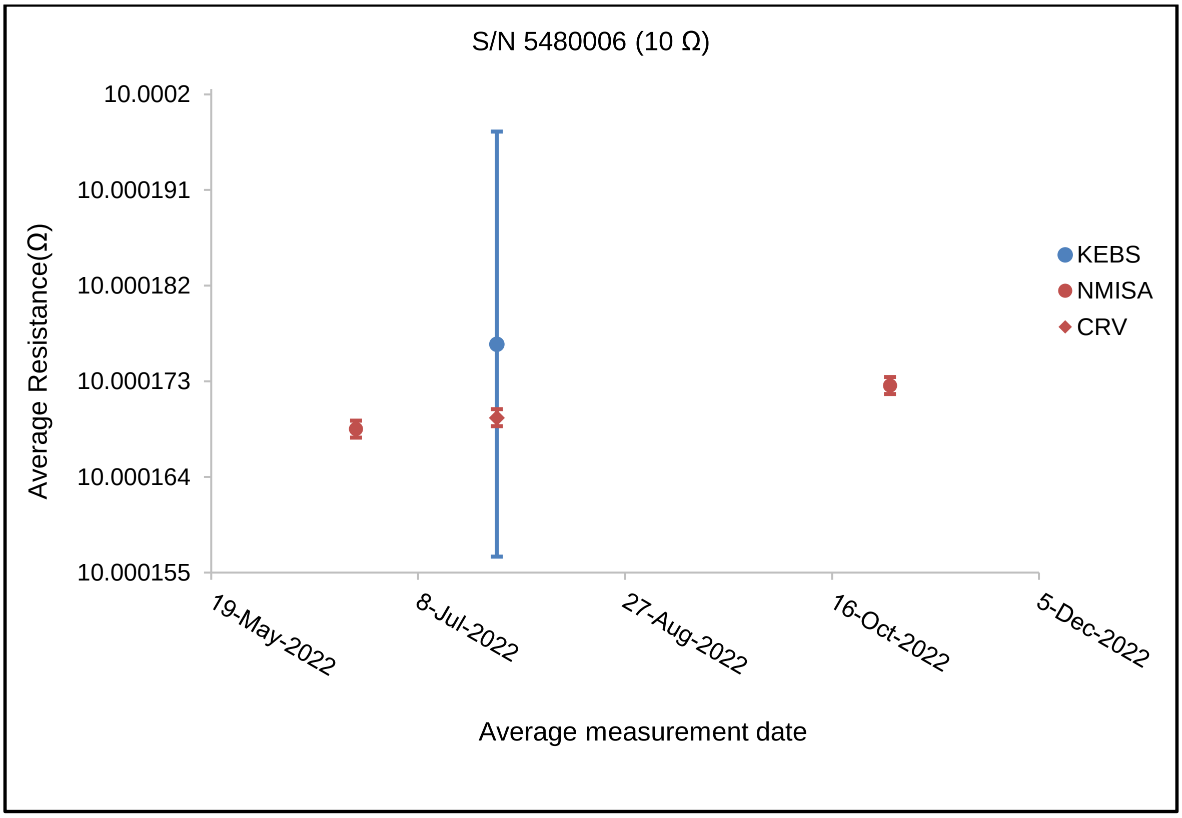

Figure 8. Results for 10 Ω travelling standard: S/N 5480006. NMISA measurements are for 2 loops, first loop on the 23rd of June 2022 and second loop on the 30th of October 2022

Table 15. NMISA’s loop 1 results for 100 Ω travelling standard: S/N 4805003

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
21 June 2022	100,00216	1 mA	23 June 2022	100,00216	0,3
22 June 2022	100,00216				
23 June 2022	100,00216				
24 June 2022	100,00216				
25 June 2022	100,00216				

Table 16. KEBS results for 100 Ω travelling standard: S/N 4805003

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Corrected Resistance (Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
25 July 2022	100,00223	1 mA	27 July 2022	100,00223	100,00222	2,0
26 July 2022	100,00222					
27 July 2022	100,00222					
28 July 2022	100,00223					
29 July 2022	100,00223					

Table 17. NMISA's loop 2 results for 100 Ω travelling standard: S/N 4805003

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement *k*=2,11 (μΩ/Ω)
24 October 2022	100,00214	1 mA	30 October 2022	100,00217	0,4
28 October 2022	100,00215				
02 November 2022	100,00219				
03 November 2022	100,00219				
04 November 2022	100,00219				

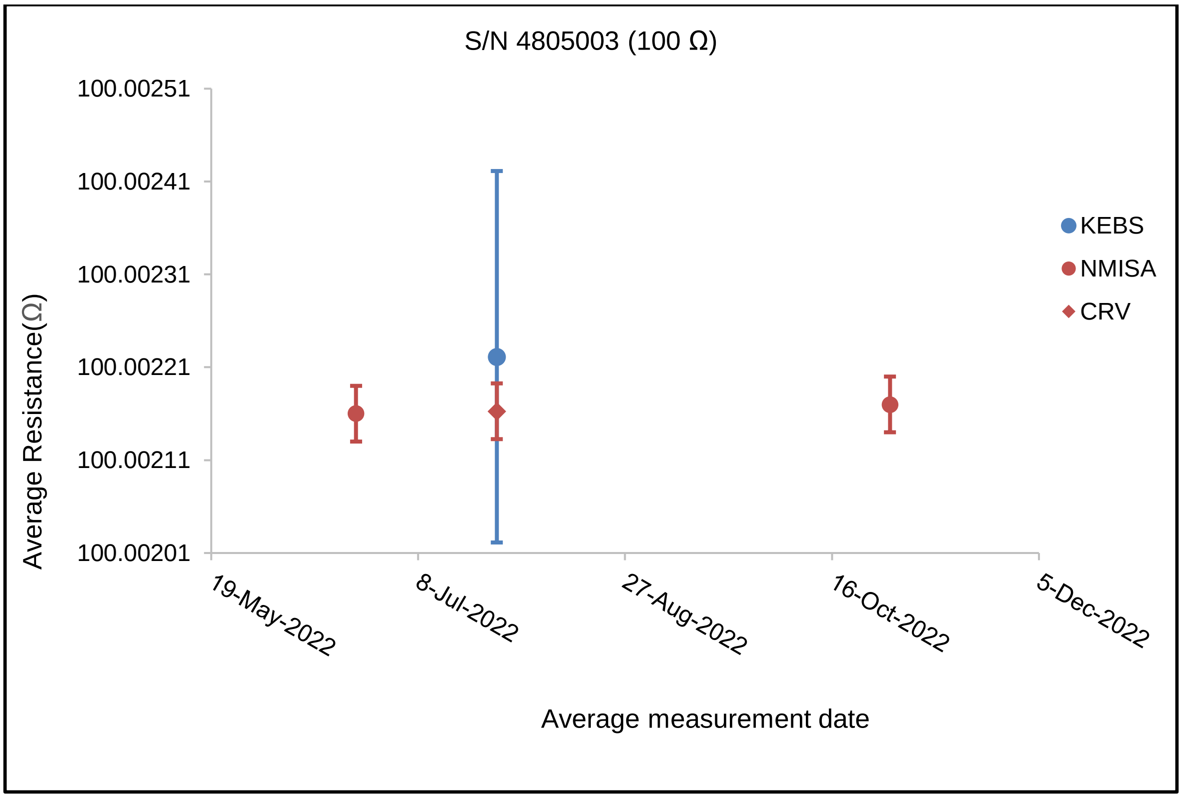

Figure 9. Results for 100 Ω travelling standard: S/N 4805003. NMISA measurements are for 2 loops, first loop on the 23rd of June 2022 and second loop on the 30th of October 2022

Table 18. NMISA's loop 1 results for 1000 Ω travelling standard: S/N 4810007

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance(Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
21 June 2022	1000,0796	1 mA	23 June 2022	1000,0795	0,4
22 June 2022	1000,0795				
23 June 2022	1000,0795				
24 June 2022	1000,0795				
25 June 2022	1000,0795				

Table 19. KEBS results for 1000 Ω travelling standard: S/N 4810007

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Corrected Resistance(Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
25 July 2022	1000,0794	1 mA	27 July 2022	1000,0795	1000,0794	1,4
26 July 2022	1000,0794					
27 July 2022	1000,0795					
28 July 2022	1000,0795					
29 July 2022	1000,0795					

Table 20. NMISA's loop 2 results for 1000 Ω travelling standard: S/N 4810007

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement *k*=2 (μΩ/Ω)
24 October 2022	1000,0796	1 mA	30 October 2022	1000,0798	0,4
28 October 2022	1000,0797				
02 November 2022	1000,0800				
03 November 2022	1000,0800				
04 November 2022	1000,0800				

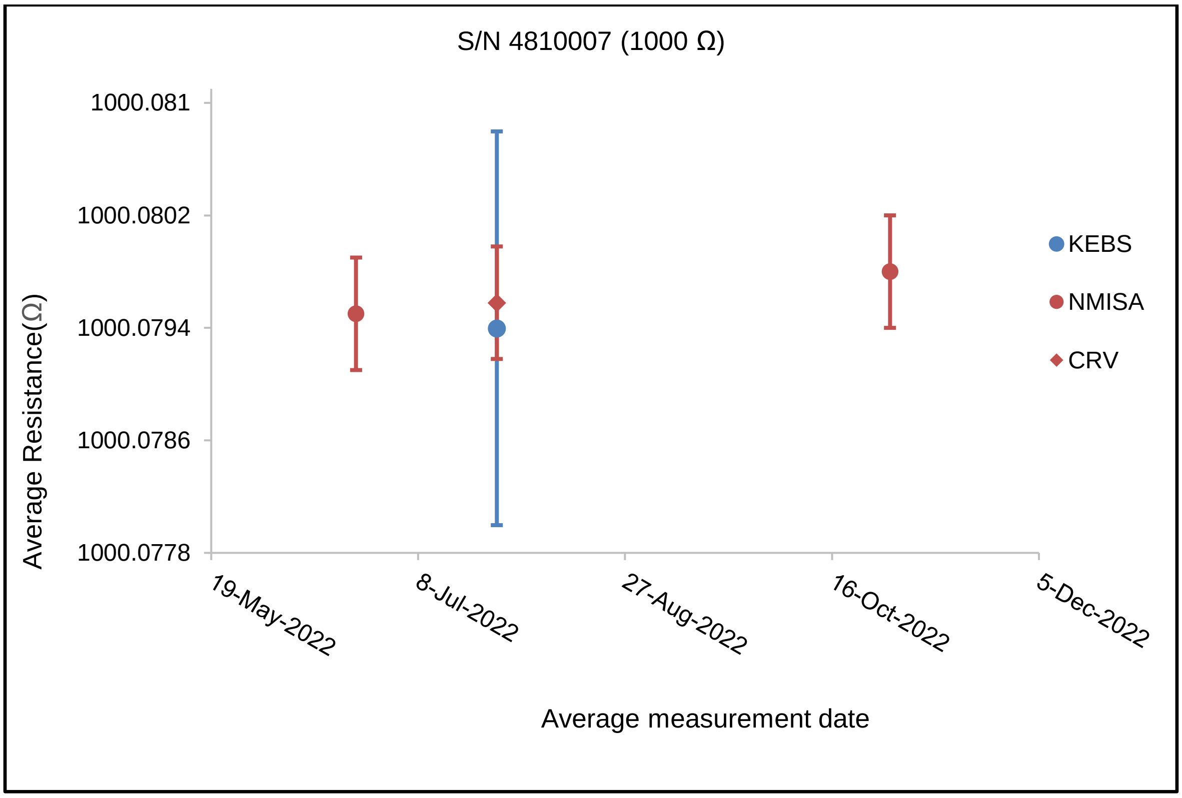

Figure 10. Results for 1 000 Ω travelling standard: S/N 4810007. NMISA measurements are for 2 loops, first loop on the 23rd of June 2022 and second loop on the 30th of October 2022

Table 21. NMISA’s loop 1 results for 10000 Ω travelling standard: S/N 4975043

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement *k*=2 (µΩ/Ω)
21 June 2022	10000,206	100 µA	23 June 2022	10000,206	0,5
22 June 2022	10000,206				
23 June 2022	10000,206				
24 June 2022	10000,206				
25 June 2022	10000,206				

Table 22. KEBS results for 10000 Ω travelling standard: S/N 4975043

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Corrected Resistance (Ω)	Uncertainty of Measurement *k*=2 (µΩ/Ω)
25 July 2022	10000,205	100 µA	27 July 2022	10000,207	10000,207	1,5
26 July 2022	10000,207					
27 July 2022	10000,206					
28 July 2022	10000,207					
29 July 2022	10000,206					

Table 23. NMISA's loop 2 results for 10000 Ω travelling standard: S/N 4975043

Measurement date	Measured Resistance (Ω)	Average Date	Average Date	Average Resistance (Ω)	Uncertainty of Measurement k=2 (μΩ/Ω)
24 October 2022	10000,205	100 μA	30 October 2022	10000,207	0,5
28 October 2022	10000,205				
02 November 2022	10000,208				
03 November 2022	10000,208				
04 November 2022	10000,208				

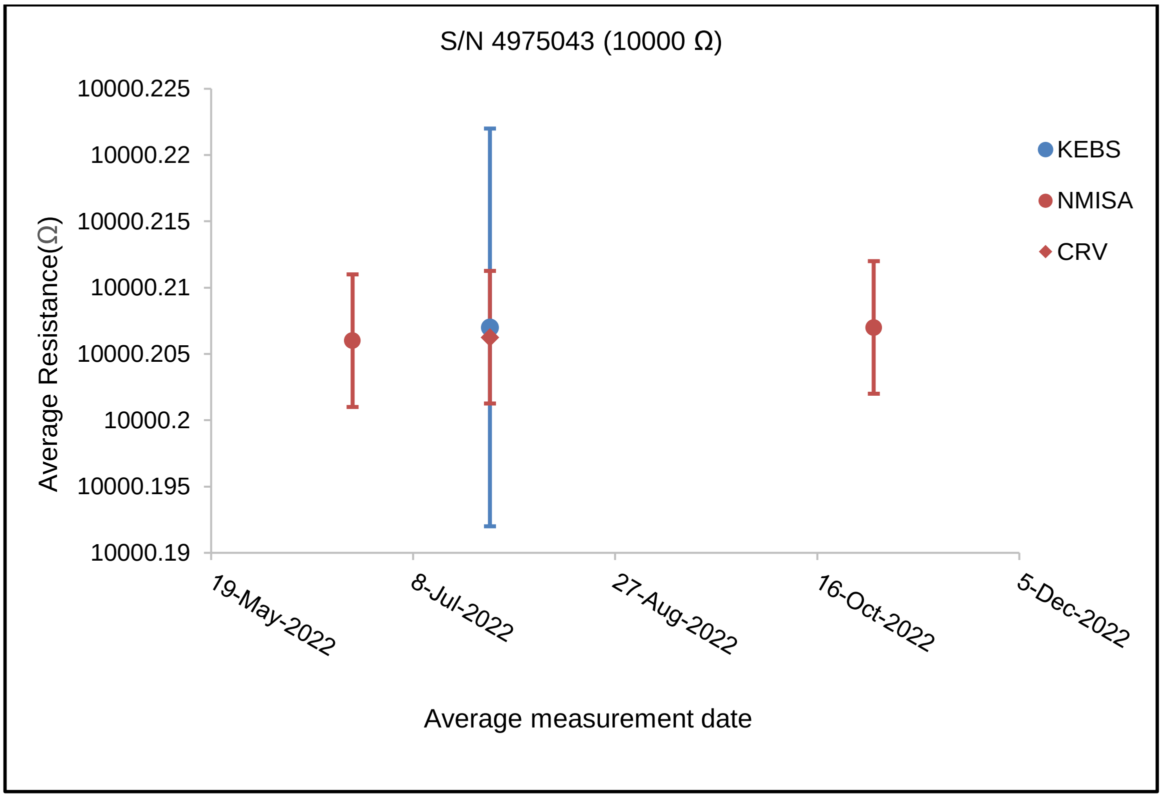

Figure 11. Results for 10 000 Ω travelling standard: S/N 4975043. NMISA measurements are for 2 loops, first loop on the 23rd of June 2022 and second loop on the 30th of October 2022

6 Summary and conclusions

The comparison was successfully carried out between NMISA and KEBS as a follow-up to AFRIMETS.EM-S1. The measurements commenced in June 2022 and were completed in November 2022. There were no deviations from the technical protocol. The stability checks were conducted to analyse the effect of transportation and mechanical shocks on the travelling standards,1 Ω & 10 Ω travelling standards were found to have drifted significantly throughout the comparison period. There is a good agreement and correlation between KEBS and NMISA results to within stated uncertainties. The normalised errors for all the measurement points are less than 1 and this confirms satisfactory comparison results.

7 References

[1] Technical Protocol, AFRIMETS.EM-S3: Bilateral comparison between NMISA and KEBS on Resistance Standards at 1 Ω, 10 Ω, 100 Ω, 1 kΩ and 10 kΩ, Version 1.0, April 2022.

[2] Characteristics of precision 1Ω standard resistors influencing transport behaviour and the uncertainty of key comparisons. G R Jones, B J Pritchard and R E Elmquist, Metrologia 46 (2009) 503–5111

Appendix A: NMISA uncertainty budgets for loop 1

UNCERTAINTY BUDGET MATRIX (UBM)		Certificate No	AFRIMETS.EM-S3
		Procedure No	DCLF\R-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	Type & Serial Number	742A & 5040014	Range:	1 Ω	Metrologist M.Hlakola
Mathematical Model:	RUUT=Rmeasured					

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(X_i)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom v	Remarks
▼ Standards and Reference Equipment (Uncorrelated) ▼											µΩ/Ω			
Std	Rstd calibration		1.700E-02	µΩ/Ω	Normal k = 1		1.00	1.700E-02	1.000E+00		1.700E-02	100	Infinite	From BIPM calibration Certificate
	Pressure Uncertainty		1.475E-02	µΩ/Ω	Normal k = 1		1.00	1.475E-02	1.000E+00		1.475E-02	100	Infinite	From BIPM calibration Certificate
	Rstd drift		4.781E-03	µΩ/Ω	Rectangular √3		1.73	2.760E-03	1.000E+00		2.760E-03	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	µΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	Infinite	6010D specification 1:1 ratio
	6010D linearity		5.000E-03	µΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		1.400E-02	µΩ/Ω	Normal k = 1		1.00	1.400E-02	1.000E+00		1.400E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	µΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
Res	Resolution of Standard / Equipment (If applicable)											100		
▼ Standards and Reference Equipment (Correlated) ▼								NOTE! *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*						
▼ Unit Under Test / Calibration (Uncorrelated) ▼								NOTE! *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*						
Res	Resolution of UUT (If applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		1.296E-01	µΩ/Ω	Normal K = 1		1.00	1.296E-01	1.000E+00		5.798E-02		4	No of Readings 5
▼ Unit Under Test / Calibration (Correlated) ▼								NOTE! *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*						

About UBM	TOTAL COMBINED UNCERTAINTY		µΩ/Ω			
Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	3.342E-02	V_{eff}	Infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	6.69E-02	k =	2.00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	6.692E-02	V_{eff}	7.098815	
	Expanded Uncertainty	95,45 % K = 2	1.63E-01	k =	2.43	

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	AFRIMETS.EM-S3
	Procedure No	DCLF\R-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	Type & Serial Number	742A & 5480006	Range:	10 Ω	Metrologist: M.Hlakola

Mathematical Model: RUUT=Rmeasured

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k=	Divisor factor	Standard Uncertainty $u(x_i)$	Sensitivity Coefficient c_i	Unit	Standard Uncertainty Contribution $u_i(y)$	Reliability %	Degrees of Freedom ν	Remarks
▼ Standards and Reference Equipment (Uncorrelated) ▼											µΩ/Ω			
Std	Rstd calibration		1.700E-02	µΩ/Ω	Normal k = 1		1.00	1.700E-02	1.000E+00		1.700E-02	100	infinite	From BIPM calibration Certificate
	Pressure Uncertainty		1.475E-02	µΩ/Ω	Normal k = 1		1.00	1.475E-02	1.000E+00		1.475E-02	100	infinite	From BIPM calibration Certificate
	Rstd drift		4.781E-03	µΩ/Ω	Rectangular √3		1.73	2.760E-03	1.000E+00		2.760E-03	100	infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	µΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	infinite	6010D specification 1:10 ratio
	6010D linearity		5.000E-03	µΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	infinite	6010D specification
	6010D Ratio error		2.100E-02	µΩ/Ω	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	µΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	infinite	6010D specification
Res	Resolution of Standard / Equipment (If applicable)											100		
▼ Standards and Reference Equipment (Correlated) ▼								NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
▼ Unit Under Test / Calibration (Uncorrelated) ▼								NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
Res	Resolution of UUT (If applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		5.327E-03	µΩ/Ω	Normal K = 1		1.00	5.327E-03	1.000E+00		2.382E-03		4	No of Readings 5
▼ Unit Under Test / Calibration (Correlated) ▼								NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
About UBM	TOTAL COMBINED UNCERTAINTY										µΩ/Ω			

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	3.690E-02	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	7.39E-02	k =	2.00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	3.698E-02	V_{eff}	infinite	
	Expanded Uncertainty	95,45 % K = 2	7.40E-02	k =	2.00	

UNCERTAINTY BUDGET MATRIX (UBM)

Certificate No	AFRIMETS.EM-S3
Procedure No	DCLF\R-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	Type & Serial Number	742A & 4605003	Range:	100 Ω	Metrologist: M.Hlakola

Mathematical Model: RUUT=Rmeasured

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(Xi)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom ν	Remarks
▼ Standards and Reference Equipment (Uncorrelated) ▼											µΩ/Ω			
Std	Rstd calibration		2.000E-01	µΩ/Ω	Normal k = 2		2.00	1.000E-01	1.000E+00		1.000E-01	100	Infinite	Calculated UoM of Rstd
	Pressure Coefficient		0.000E+00	µΩ/Ω	Normal k = 2		2.00	0.000E+00	1.000E+00		0.000E+00	100	Infinite	Reference std calibrated at NMISA
	Rstd drift		-1.180E-01	µΩ/Ω	Rectangular √3		1.73	-6.813E-02	1.000E+00		-6.813E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	µΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	Infinite	6010D specification 1:10 ratio
	6010D linearity		5.000E-03	µΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	µΩ/Ω	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	µΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
Res	Resolution of Standard / Equipment (if applicable)											100		
▼ Standards and Reference Equipment (Correlated) ▼								NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
▼ Unit Under Test / Calibration (Uncorrelated) ▼								NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
Res	Resolution of UUT (if applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		7.114E-03	µΩ/Ω	Normal K = 1		1.00	7.114E-03	1.000E+00		3.181E-03		4	No of Readings 5
▼ Unit Under Test / Calibration (Correlated) ▼								NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					

About UBM	TOTAL COMBINED UNCERTAINTY		µΩ/Ω			
Best Measurement Capability (<u>Excluding</u> UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	1.245E-01	V_{eff}	Infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	2.49E-01	k =	2.00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	1.245E-01	V_{eff}	Infinite	
	Expanded Uncertainty	95,45 % K = 2	2.49E-01	k =	2.00	

UNCERTAINTY BUDGET MATRIX (UBM)			Certificate No	AFRIMETS.EM-S3
			Procedure No	DCLF\R-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	**Type & Serial Number**	742A & 4810007	**Range:**	1000 Ω	**Metrologist**
						M.Hlakola

Mathematical Model: RUUT=Rmeasured

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(Xi)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom ν	Remarks
	▼ Standards and Reference Equipment (Uncorrelated) ▼										µΩ/Ω			
Std	Rstd calibration		3.000E-01	µΩ/Ω	Normal k = 2		2.00	1.500E-01	1.000E+00		1.500E-01	100	Infinite	Calculated UoM of Rstd
	Pressure Coefficient		0.000E+00	µΩ/Ω	Normal k = 2		2.00	0.000E+00	1.000E+00		0.000E+00	100	Infinite	Reference std calibrated at NMISA
	Rstd drift		-1.120E-01	µΩ/Ω	Rectangular √3		1.73	-6.468E-02	1.000E+00		-6.468E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	µΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	Infinite	6010D specification 1:10 ratio
	6010D linearity		5.000E-03	µΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	µΩ/Ω	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	µΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
Res	Resolution of Standard / Equipment (if applicable)											100		
	▼ Standards and Reference Equipment (Correlated) ▼							**NOTE!**	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
	▼ Unit Under Test / Calibration (Uncorrelated) ▼							**NOTE!**	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
Res	Resolution of UUT (if applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		9.673E-03	µΩ/Ω	Normal K = 1		1.00	9.673E-03	1.000E+00		4.326E-03		4	No of Readings 5
	▼ Unit Under Test / Calibration (Correlated) ▼							**NOTE!**	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					

About UBM	**TOTAL COMBINED UNCERTAINTY**			µΩ/Ω		
Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	1.659E-01	V_{eff}	Infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	3.32E-01	k =	2.00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	1.660E-01	V_{eff}	Infinite	
	Expanded Uncertainty	95,45 % K = 2	3.32E-01	k =	2.00	

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	AFRIMETS.EM-S3
	Procedure No	DCLF\R-0016

Reference: Guide to the Expression of Uncertainty in Measurement; issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	Type & Serial Number	742A & 4975043	Range:	10000 Ω	Metrologist: M. Hlakola

Mathematical Model: RUUT=Rmeasured

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(Xi)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom ν	Remarks
	▼ Standards and Reference Equipment (Uncorrelated) ▼										µΩ/Ω			
Std	Rstd calibration		4.000E-01	µΩ/Ω	Normal k = 2		2.00	2.000E-01	1.000E+00		2.000E-01	100	Infinite	Calculated UoM of Rstd
	Pressure Coefficient		0.000E+00	µΩ/Ω	Normal k = 2		2.00	0.000E+00	1.000E+00		0.000E+00	100	Infinite	Reference std calibrated at NMISA
	Rstd drift		-7.468E-02	µΩ/Ω	Rectangular √3		1.73	-4.312E-02	1.000E+00		-4.312E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	µΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	Infinite	6010D specification 1:10 ratio
	6010D linearity		5.000E-03	µΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	µΩ/Ω	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	µΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
Res	Resolution of Standard / Equipment (if applicable)											100		
	▼ Standards and Reference Equipment (Correlated) ▼							NOTE!	ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					
	▼ Unit Under Test / Calibration (Uncorrelated) ▼							NOTE!	ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					
Res	Resolution of UUT (if applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		1.460E-02	µΩ/Ω	Normal K = 1		1.00	1.460E-02	1.000E+00		6.531E-03		4	No of Readings 5
	▼ Unit Under Test / Calibration (Correlated) ▼							NOTE!	ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					

About UBM	TOTAL COMBINED UNCERTAINTY		µΩ/Ω			
Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	2.067E-01	V_{eff}	Infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	4.14E-01	k =	2.00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	2.068E-01	V_{eff}	Infinite	
	Expanded Uncertainty	95,45 % K = 2	4.14E-01	k =	2.00	

Appendix B: NMISA uncertainty budgets for loop 2

UNCERTAINTY BUDGET MATRIX (UBM)		Certificate No	AFRIMETS.EM-S3
		Procedure No	DCLF\R-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	**Type & Serial Number**	742A & 5040014	**Range:**	1 Ω	**Metrologist**
						M.Hlakola
Mathematical Model:	RUUT=Rmeasured					

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(Xi)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom ν	Remarks
	▼ Standards and Reference Equipment (Uncorrelated) ▼										μΩ/Ω			
Std	Rstd calibration		1.700E-02	μΩ/Ω	Normal k = 1		1.00	1.700E-02	1.000E+00		1.700E-02	100	infinite	From BIPM calibration Certificate
	Pressure Uncertainty		1.522E-02	μΩ/Ω	Normal k = 1		1.00	1.522E-02	1.000E+00		1.522E-02	100	infinite	From BIPM calibration Certificate
	Rstd drift		4.781E-03	μΩ/Ω	Rectangular √3		1.73	2.760E-03	1.000E+00		2.760E-03	100	infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	μΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	infinite	6010D specification 1:1 ratio
	6010D linearity		5.000E-03	μΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	infinite	6010D specification
	6010D Ratio error		1.400E-02	μΩ/Ω	Normal k = 1		1.00	1.400E-02	1.000E+00		1.400E-02	100	infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	μΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	infinite	6010D specification
Res	Resolution of Standard / Equipment (If applicable)											100		
	▼ Standards and Reference Equipment (Correlated) ▼							**NOTE!**	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
	▼ Unit Under Test / Calibration (Uncorrelated) ▼							**NOTE!**	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
Res	Resolution of UUT (If applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		1.943E-02	μΩ/Ω	Normal K = 1		1.00	1.943E-02	1.000E+00		8.691E-03		4	No of Readings 5
	▼ Unit Under Test / Calibration (Correlated) ▼							**NOTE!**	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					

About UBM	**TOTAL COMBINED UNCERTAINTY**		μΩ/Ω			
Best Measurement Capability (<u>Excluding</u> UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	3.363E-02	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	**95,45 % K = 2**	**6.73E-02**	**k =**	**2.00**	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	3.473E-02	V_{eff}	infinite	
	Expanded Uncertainty	**95,45 % K = 2**	**6.95E-02**	**k =**	**2.00**	

UNCERTAINTY BUDGET MATRIX (UBM)		Certificate No	AFRIMETS.EM-S3
		Procedure No	DCLF\R-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	Type & Serial Number	742A & 5480006	Range:	10 Ω	Metrologist
						M.Hlakola
Mathematical Model:	RUUT=Rmeasured					

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(X_i)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom v	Remarks
	▼ Standards and Reference Equipment (Uncorrelated) ▼										µΩ/Ω			
Std	Rstd calibration		1.700E-02	µΩ/Ω	Normal k = 1		1.00	1.700E-02	1.000E+00		1.700E-02	100	Infinite	From BIPM calibration Certificate
	Pressure Uncertainty		1.522E-02	µΩ/Ω	Normal k = 1		1.00	1.522E-02	1.000E+00		1.522E-02	100	Infinite	From BIPM calibration Certificate
	Rstd drift		4.781E-03	µΩ/Ω	Rectangular √3		1.73	2.760E-03	1.000E+00		2.760E-03	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	µΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	Infinite	6010D specification 1:10 ratio
	6010D linearity		5.000E-03	µΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	µΩ/Ω	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	µΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
Res	Resolution of Standard / Equipment (if applicable)											100		
	▼ Standards and Reference Equipment (Correlated) ▼							NOTE!	ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					
	▼ Unit Under Test / Calibration (Uncorrelated) ▼							NOTE!	ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					
Res	Resolution of UUT (if applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		1.422E-02	µΩ/Ω	Normal K = 1		1.00	1.422E-02	1.000E+00		6.361E-03		4	No of Readings 5
	▼ Unit Under Test / Calibration (Correlated) ▼							NOTE!	ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					

About UBM	TOTAL COMBINED UNCERTAINTY			µΩ/Ω			
Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼		3.709E-02	V_{eff}	Infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 %	K = 2	7.42E-02	k =	2.00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼		3.763E-02	V_{eff}	Infinite	
	Expanded Uncertainty	95,45 %	K = 2	7.64E-02	k =	2.00	

UNCERTAINTY BUDGET MATRIX (UBM)

Certificate No	AFRIMETS.EM-S3
Procedure No	DCLF\R-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	Type & Serial Number	742A & 4805003	Range:	100 Ω	Metrologist: M.Hlakola

Mathematical Model: RUUT=Rmeasured

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(X_i)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom v	Remarks
	▼ Standards and Reference Equipment (Uncorrelated) ▼										µΩ/Ω			
Std	Rstd calibration		2.000E-01	µΩ/Ω	Normal k = 2		2.00	1.000E-01	1.000E+00		1.000E-01	100	Infinite	Calculated UoM of Rstd
	Pressure Coefficient		0.000E+00	µΩ/Ω	Normal k = 2		2.00	0.000E+00	1.000E+00		0.000E+00	100	Infinite	Reference std calibrated at NMISA
	Rstd drift		-1.180E-01	µΩ/Ω	Rectangular √3		1.73	-6.813E-02	1.000E+00		-6.813E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	µΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	Infinite	6010D specification 1:10 ratio
	6010D linearity		5.000E-03	µΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	µΩ/Ω	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	µΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
Res	Resolution of Standard / Equipment (if applicable)											100		
	▼ Standards and Reference Equipment (Correlated) ▼							NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
	▼ Unit Under Test / Calibration (Uncorrelated) ▼							NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
Res	Resolution of UUT (if applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
Data	Type "A" Evaluation Exp Std Deviation "s"		2.290E-01	µΩ/Ω	Normal K = 1		1.00	2.290E-01	1.000E+00		1.024E-01		4	No of Readings 5
	▼ Unit Under Test / Calibration (Correlated) ▼							NOTE!	*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					

About UBM	TOTAL COMBINED UNCERTAINTY		µΩ/Ω			
Best Measurement Capability (<u>Excluding</u> UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	1.245E-01	V_{eff}	Infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	**2.49E-01**	**k =**	**2.00**	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	1.612E-01	V_{eff}	24.5458	
	Expanded Uncertainty	95,45 % K = 2	**3.40E-01**	**k =**	**2.11**	

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	AFRIMETS.EM-S3
	Procedure No	DCLF/R-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	Type & Serial Number	742A & 4810007	Range:	1000 Ω	Metrologist: M.Hlakola

Mathematical Model: RUUT=Rmeasured

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(Xi)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom ν	Remarks
	▼ Standards and Reference Equipment (Uncorrelated) ▼										μΩ/Ω			
Std	Rstd calibration		3.000E-01	μΩ/Ω	Normal k = 2		2.00	1.500E-01	1.000E+00		1.500E-01	100	Infinite	Calculated UoM of Rstd
	Pressure Coefficient		0.000E+00	μΩ/Ω	Normal k = 2		2.00	0.000E+00	1.000E+00		0.000E+00	100	Infinite	Reference std calibrated at NMISA
	Rstd drift		-1.120E-01	μΩ/Ω	Rectangular √3		1.73	-6.468E-02	1.000E+00		-6.468E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	μΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	Infinite	6010D specification 1:10 ratio
	6010D linearity		5.000E-03	μΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	μΩ/Ω	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	μΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
Res	Resolution of Standard / Equipment (if applicable)											100		
	▼ Standards and Reference Equipment (Correlated) ▼								NOTE! ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					
	▼ Unit Under Test / Calibration (Uncorrelated) ▼								NOTE! ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					
Res	Resolution of UUT (if applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
Data	Type "A" Evaluation Exp Std Deviation "s"		1.808E-01	μΩ/Ω	Normal K = 1		1.00	1.808E-01	1.000E+00		8.086E-02		4	No of Readings 5
	▼ Unit Under Test / Calibration (Correlated) ▼								NOTE! ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED					

About UBM	TOTAL COMBINED UNCERTAINTY		μΩ/Ω			
Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	1.659E-01	V_{eff}	Infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	3.32E-01	k =	2.00	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	1.846E-01	V_{eff}	108.599	
	Expanded Uncertainty	95,45 % K = 2	3.73E-01	k =	2.02	

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	AFRIMETS.EM-S3
	Procedure No	DCLFIR-0016

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995 (ISBN 92-67-10188-9)

Description:	Standard resistor	Type & Serial Number	742A & 4975043	Range:	10000 Ω	Metrologist
						M. Hlakola

Mathematical Model: RUUT=Rmeasured

Symbol	Input Quantity (Source of Uncertainty) (X_i)	Estimated Input Quantity (x_i)	Estimated Uncertainty	Unit	Probability Distribution (N, R, T, U)	k= ▼	Divisor factor	Standard Uncertainty $U(Xi)$	Sensitivity Coefficient Ci	Unit	Standard Uncertainty Contribution $Ui(y)$	Reliability %	Degrees of Freedom v	Remarks
	▼ Standards and Reference Equipment (Uncorrelated) ▼										µΩ/Ω			
Std	Rstd calibration		4.000E-01	µΩ/Ω	Normal k = 2		2.00	2.000E-01	1.000E+00		2.000E-01	100	Infinite	Calculated UoM of Rstd
	Pressure Coefficient		0.000E+00	µΩ/Ω	Normal k = 2		2.00	0.000E+00	1.000E+00		0.000E+00	100	Infinite	Reference std calibrated at NMISA
	Rstd drift		-7.468E-02	µΩ/Ω	Rectangular √3		1.73	-4.312E-02	1.000E+00		-4.312E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	µΩ/Ω	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	Infinite	6010D specification 1:10 ratio
	6010D linearity		5.000E-03	µΩ/Ω	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	µΩ/Ω	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	µΩ/Ω	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
Res	Resolution of Standard / Equipment (If applicable)											100		
	▼ Standards and Reference Equipment (Correlated) ▼							NOTE!	***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					
	▼ Unit Under Test / Calibration (Uncorrelated) ▼							NOTE!	***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					
Res	Resolution of UUT (If applicable)											100		
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		1.827E-01	µΩ/Ω	Normal K = 1		1.00	1.827E-01	1.000E+00		8.171E-02		4	No of Readings 5
	▼ Unit Under Test / Calibration (Correlated) ▼							NOTE!	***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					

About UBM	TOTAL COMBINED UNCERTAINTY		µΩ/Ω			
Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	2.067E-01	V_{eff}	Infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	**4.14E-01**	k =	**2.00**	
Uncertainty of Measurement (Including UUT contribution)	Combined Uncertainty (Normal)	▼ Level of Confidence ▼	2.222E-01	V_{eff}	218.872	
	Expanded Uncertainty	95,45 % K = 2	**4.47E-01**	k =	**2.01**	

Appendix C: KEBS uncertainty budgets

In the uncertainty budget, all the uncertainty contributors and the associated standard uncertainties were included. The calculations were done according to the "Guide to the Expression of Uncertainty in Measurement". Each uncertainty contributor was combined using sum square root (SSR) method to get the combined uncertainty, u_c. The confidence level was taken at 95.45% ($k = 2$), hence the expanded uncertainty, U, was taken as:

$$U = k \ x \ u_c = 2u_c$$

The effective number of degrees of freedom, ϑ_{eff}, was finally calculated. This was obtained by using Welch-Satterthwaite equation, that is;

$$\vartheta_{eff} = \frac{u_c^4}{\sum_{i=1}^{i=n} \frac{u_i^4}{\vartheta_i}}$$

where:

u_c – combined uncertainty

u_i – uncertainty for each uncertainty contributor

ϑ_i – degrees of freedom for each uncertainty contributor

Quantity	Estimate	Relative Standard Uncertainty ±	Probability distribution	Sensitivity coefficient	Uncertainty Contribution u_x	Degrees of freedom ϑ_i
1 Ω Resistor Standard (R_S)	1.00000178 Ω	$0.40 \cdot 10^{-6}$	Normal	1	$0.40 \cdot 10^{-6}$	∞
Drift of the 1 Ω resistor (δR_S)	$1.01 \cdot 10^{-6}$ Ω	$0.59 \cdot 10^{-6}$	Rectangular	1	$0.59 \cdot 10^{-6}$	∞
Repeatability (ESDM)		$12.0 \cdot 10^{-9}$	Normal	1	$12.0 \cdot 10^{-9}$	999
Temperature Coefficient (δR_{TS})		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	∞
Combined uncertainty u_c					$0.72 \cdot 10^{-6}$	
Effective degrees of freedom					$1.29 \cdot 10^{10}$	
Expanded uncertainty $\boldsymbol{U}$					$\mathbf{1.44 \cdot 10^{-6}}$	

Quantity	Estimate	Relative Standard Uncertainty ±	Probability distribution	Sensitivity coefficient	Uncertainty Contribution u_x	Degrees of freedom ϑ_i
10 Ω Resistor Standard (R_S)	9.99998965 Ω	$0.41 \cdot 10^{-6}$	Normal	1	$0.41 \cdot 10^{-6}$	∞
Drift of the 10 Ω resistor (δR_S)	$15.5 \cdot 10^{-6}$ Ω	$0.9 \cdot 10^{-6}$	Rectangular	1	$0.9 \cdot 10^{-6}$	∞
Repeatability (ESDM)		$8.9 \cdot 10^{-9}$	Normal	1	$8.9 \cdot 10^{-9}$	999
Temperature Coefficient (δR_{TS})		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	∞
Combined uncertainty u_c					$0.99 \cdot 10^{-6}$	
Effective degrees of freedom					$1.53 \cdot 10^{11}$	
Expanded uncertainty $\boldsymbol{U}$					$\mathbf{1.98 \cdot 10^{-6}}$	

Quantity	Estimate	Relative Standard Uncertainty ±	Probability distribution	Sensitivity coefficient	Uncertainty Contribution u_x	Degrees of freedom ϑ_i
100 Ω Resistor Standard (R_S)	99.99976512 Ω	$0.40 \cdot 10^{-6}$	Normal	1	$0.40 \cdot 10^{-6}$	∞
Drift of the 100 Ω resistor (δR_S)	$0.149 \cdot 10^{-3}$ Ω	$0.9 \cdot 10^{-6}$	Rectangular	1	$0.9 \cdot 10^{-6}$	∞
Repeatability (ESDM)		$37.7 \cdot 10^{-9}$	Normal	1	$37.7 \cdot 10^{-9}$	999
Temperature Coefficient (δR_{TS})		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	∞
Combined uncertainty u_c					$0.99 \cdot 10^{-6}$	
Effective degrees of freedom					$4.75 \cdot 10^{8}$	
Expanded uncertainty $\boldsymbol{U}$					$\mathbf{1.98 \cdot 10^{-6}}$	

Quantity	Estimate	Relative Standard Uncertainty ±	Probability distribution	Sensitivity coefficient	Uncertainty Contribution u_x	Degrees of freedom ϑ_i
1 kΩ Resistor Standard (R_S)	0.99999625 kΩ	$0.66 \cdot 10^{-6}$	Normal	1	$0.66 \cdot 10^{-6}$	∞
Drift of the 1 kΩ resistor (δR_S)	$0.11 \cdot 10^{-6}$ kΩ	$63.5 \cdot 10^{-9}$	Rectangular	1	$63.5 \cdot 10^{-9}$	∞
Repeatability (ESDM)		$32.4 \cdot 10^{-9}$	Normal	1	$32.4 \cdot 10^{-9}$	999
Temperature Coefficient (δR_{TS})		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	∞
Combined uncertainty u_c					$0.67 \cdot 10^{-6}$	
Effective degrees of freedom					$1.83 \cdot 10^{8}$	
Expanded uncertainty $\boldsymbol{U}$					$\mathbf{1.34 \cdot 10^{-6}}$	

Quantity	Estimate	Relative Standard Uncertainty ±	Probability distribution	Sensitivity coefficient	Uncertainty Contribution u_x	Degrees of freedom ϑ_i
10 kΩ Resistor Standard (R_S)	9.99997430 kΩ	$0.66 \cdot 10^{-6}$	Normal	1	$0.66 \cdot 10^{-6}$	∞
Drift of the 10 kΩ resistor (δR_S)	$5.22 \cdot 10^{-6}$ kΩ	$0.3 \cdot 10^{-6}$	Rectangular	1	$0.3 \cdot 10^{-6}$	∞
Repeatability (ESDM)		$73.7 \cdot 10^{-9}$	Normal	1	$73.7 \cdot 10^{-9}$	999
Temperature Coefficient (δR_{TS})		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	∞
Combined uncertainty u_c					$0.73 \cdot 10^{-6}$	
Effective degrees of freedom					$9.62 \cdot 10^{6}$	
Expanded uncertainty U					$\mathbf{1.46 \cdot 10^{-6}}$	