

Final Report

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

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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 k Ω , and 10 k Ω), 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

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.

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

Table 2. Comparison schedule

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.

Make	Model	Serial no.	Nominal value	Temperature coefficient α value	Temperature coefficient β value	Pressure coefficient
	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
Fluke	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

Table 3. Description of the travelling standards

3.2 Environmental conditions

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

Table 4. Environmental conditions by participants

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 k Ω) are calibrated by BIPM, France.

KEBS:

- The reference resistance standards (1 Ω and 10 $k\Omega)$ 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.

$$(y - y_0) = m(x - x_0)$$
 (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	- 0,0000001
5480006	10,000168	10,0001721	0,00000031
4805003	100,00216	100,00217	0,00000075
4810007	1000,0795	1000,0798	0,000023
4975043	10000,206	10000,207	0,0000075

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







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]:

$$R_{x} = R_{\gamma} (1 + \alpha (T_{x} - T_{\gamma}) + \beta (T_{x} - T_{\gamma})^{2})$$
(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]:

$$R_x = R_\gamma (1 + \gamma (P_x - P_\gamma)) \tag{3}$$

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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

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} \tag{4}$$

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

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

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:

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

Table 6. Comparison reference values (CRV)

5.3 Normalised error, E_n

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

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

$$D_i = \frac{R_x - R_{CRV}}{R_{CRV}} \times 1000000$$
 (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, $\mu\Omega/\Omega$. The calculated deviations are given in Table 8 below:

Travelling Standards	Deviation from CRV $(\mu\Omega/\Omega)$
1 Ω	0,51
10 Ω	0,55
100 Ω	0,59
1000 Ω	- 0,18
10000 Ω	- 0,03

Table 8. Deviations from CRV

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 <i>k=</i> 2,43 (μΩ/Ω)
21 June 2022	0,99994449				
22 June 2022	0,99994425				
23 June 2022	0,99994419	100 mA	23 June 2022	0,9999443	0,2
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 <i>k=</i> 2 (μΩ/Ω)
25 July 2022	0,99994467					
26 July 2022	0,99994467					
27 July 2022	0,99994465	100 mA	27 July 2022	0,9999447	0,9999445	1,5
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 $k=2 (\mu \Omega / \Omega)$
24 October 2022	0,99994315				
28 October 2022	0,99994314				
02 November 2022	0,99994311	100 mA	30 October 2022	0,99994312	0,07
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 <i>k=</i> 2 (μΩ/Ω)
21 June 2022	10,0001679				
22 June 2022	10,0001680				
23 June 2022	10,0001680	10 mA	23 June 2022	10,0001680	0,08
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 $k=2 (\mu\Omega/\Omega)$
25 July 2022	10,0001764					
26 July 2022	10,0001764					
27 July 2022	10,0001763	10 mA	27 July 2022	10,000176	10,000175	2,0
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 $k=2 (\mu\Omega/\Omega)$
24 October 2022	10,0001719				
28 October 2022	10,0001721				
02 November 2022	10,0001722	10 mA	30 October	10,0001721	0,08
03 November 2022	10,0001722		2022		
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 <i>k=</i> 2 (μΩ/Ω)
21 June 2022	100,00216				
22 June 2022	100,00216				
23 June 2022	100,00216	1 mA	23 June 2022	100,00216	0,3
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 <i>k=</i> 2 (μΩ/Ω)
25 July 2022	100,00223					
26 July 2022	100,00222					
27 July 2022	100,00222	1 mA	27 July 2022	100,00223	100,00222	2,0
28 July 2022	100,00223					
29 July 2022	100,00223					

		11 C	100.01		
Table 17. N	MISA's loop 2	results for	100Ω trave	elling standard	I: S/N 4805003

Measurement date	Measured Resistance (Ω)	Test Current	Average Date	Average Resistance (Ω)	Uncertainty of Measurement $k=2,11 (\mu\Omega/\Omega)$
24 October 2022	100,00214				
28 October 2022	100,00215		30		
02 November 2022	100,00219	1 mA	October	100,00217	0,4
03 November 2022	100,00219		2022		
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 <i>k=</i> 2 (μΩ/Ω)
21 June 2022	1000,0796				
22 June 2022	1000,0795				
23 June 2022	1000,0795	1 mA	23 June 2022	1000,0795	0,4
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 <i>k=</i> 2 (μΩ/Ω)
25 July 2022	1000,0794					
26 July 2022	1000,0794					
27 July 2022	1000,0795	1 mA	27 July 2022	1000,0795	1000,0794	1,4
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 $k=2 (\mu\Omega/\Omega)$
24 October 2022	1000,0796				
28 October 2022	1000,0797				
02 November 2022	1000,0800	1 mA	30 October	1000,0798	0,4
03 November 2022	1000,0800		2022		
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 23^{rd} 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 $k=2 (\mu \Omega / \Omega)$
21 June 2022	10000,206				
22 June 2022	10000,206				
23 June 2022	10000,206	100 µA	23 June 2022	10000,206	0,5
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 $k=2 (\mu\Omega/\Omega)$
25 July 2022	10000,205					
26 July 2022	10000,207					
27 July 2022	10000,206	100 µA	27 July 2022	10000,207	10000,207	1,5
28 July 2022	10000,207					
29 July 2022	10000,206					

Measurement date	Measured Resistance (Ω)	Average Date	Average Date	Average Resistance (Ω)	Uncertainty of Measurement <i>k=</i> 2 (μΩ/Ω)
24 October 2022	10000,205				
28 October 2022	10000,205		30		
02 November 2022	10000,208	100 µA	October	10000,207	0,5
03 November 2022	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 k Ω and 10 k Ω , 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

		NOCEDIAN										Certifi	cate No	AFRIMETS.EM-S3
		NCERTAIN	ITY BODO	JEII	WATRIX (UE	awi)						Proce	dure No	DCLF/R-0016
			Reference: Guide to t	he Expressio	n of Uncertainty in Measure	ment, issued	i by BIPM, IEC,	PCC, ISO, IUPAC, IL	IPAP, OML - ISO 1	995 (ISBN 9	2-87-10188-9)			
Description:	Standard resistor		Type & Serial		7424	A & 5040	014		Range:		1.0	0		Metrologist
			Number											M.Hiskola
	Mathematical Model:								R	UUT=Rn	neasured			
	Input Quantity	Estimated Input	Estimate	d	Probability			Standard	Sepalibility Co	Miclant	Standard	Ballability	Degrees of	
Symbol	(Source of Uncertainty)	Quantity	Uncertain	nty	Distribution	*-	factor	Uncertainty	Summing Co	A CONTRACTOR OF	Contribution	Renautry	Freedom	Remarks
	(X.)	(±4)		Unit	(8, 6, 1, 0)	•		U(XI)	ci	Unit	UI ()	%	۳	
	 standards and Reference Equipment (Un 	correlated) V									μΩ/Ω			
Std	Rstd calibration		1.700E-02	μΩγο	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	μΩγο	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	μΩγο	Rectangular 1/3		1.73	2.760E-03	1.000E+00		2.760E-03	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	μΩγο	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	μΩγο	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		1.400E-02	uQ/o	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	uOm	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
													<u> </u>	
				 									<u> </u>	
Res	Resolution of Standard / Equipment (if applicable)										100			
	 Standards and Reference Equipment (C 	orrelated) v						NOT	E! ONLY C	HANGE	BLUE CELLS -	- All OTHE	R CELLS (WHITE) ARE PROTECTED
	Unit Under Test / Calibration (Uncorr	elated) 🔻						NOT	E! ONLY C	HANGE	BLUE CELLS -	All OTHE	RCELLS	WHITE) ARE PROTECTED
Res	Resolution of UUT (If applicable)											100		
	Type "B" Evaluation Range of the results (Rectangular)											100		
Data	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 (Correl	lated) 🔻		-				NOT	E! ONLY C	HANGE	BLUE CELLS		RCELLS	WHITE) ARE PROTECTED
													<u> </u>	
												-		
About UBM		TOTAL	COMBINED	UNCER	TAINTY						μαγα			
			(Combined Uncertai	nty (Nor	mal)	▼ Level	of Confidence	,	3.342E-02	Ver	Infinite	Checked and Approved By:	
	Best Measurement Capability (Excluding UUT contribution)				Expanded Unc	ertainty		95,45	% K=2		6.69E-02	k =	2.00	
					Combined Lincertal	nty (Nee	mai)	▼ Level	of Confidence		6.692E-02	V	7 098815	
	Uncertainty of Measurement (Including UUT	contribution)	`	Emerginal critical da	and the second		- Level			0.0020-02		1.000010	
	_				Expanded Und	enanty		35,45	% K=2		1.63E-01	K =	2.43	

	UNCERTAINTY BUDGET MATRIX (UBM)													AFRIMETS.EM-83
		NCERTAIN	IT BOD	GET	WATRIA (UL	om)						Proce	dure No	DCLF\R-0018
			Reference Guide to t	he Ropress	n d'Uncertainty in Massur	anali, inte	d by SPM, IRC,	PCC, IBO, LIPAC, IL	PAP, DML - BO 1	NO DESIGN	0.0110100.0			
Description:	Standard resistor		Type & Serial		742/	A & 5480	0006		Range:		10	0		Metrologist
			Number											MJ lakola
	Mathematical Model:								R	UUT-R:	neasured			
Symbol	Input Quantity (Source of Uncertainty)	Estimated input Quantity	Estimate	2 2 2	Probability Distribution	k.	Divisor	Standard Uncertainty	Sensitivity Co	efficient	Standard Uncertainty	Reliability	Degrees of Freedom	Remarks
	<i>a</i> .,	6.2		Unit	(N, R, T, U)	•	THE R.F.	0.00	a	Unit	13.60	- 16		
	▼ Standards and Reference Equipment (Ur	correlated) V									uQQ			
524	Ratid calibration		1,700E-02	u0e	Normal k = 1		1.00	1,700E-02	1.000E+00		1,700E-02	100	infinite	From BPM calibration Certificate
	Pressure Lincertainty		1.4755-02	100	Normal k = 1	<u> </u>	1.00	1.475E-02	1.000E+00		1.4756-02	100	infinite	From BDM calibration Cartificate
	Dubl diff		4 7815-03	1000	Redena der sitt	<u> </u>	1.75	2 7805-03	1.00000-000	<u> </u>	2 7605-03	100	infinite	Control Charte
	POINT BUILD STREET		4.00005.000	pare	Normal k = 2	<u> </u>	2.00	2,0005,00	1.00000-100		20005-00	100	infinite	2010D analisation 1.10 ratio
	POTOD Security		4.000E-02	page	Normality 2		2.00	20000-02	1.00000400		2000042	100	infinite.	R010D exertingtion
	concorrently		3.0006-03	jane -	NOTTHE K = 2		200	25002-03	1.00000+00		25005-03	100	ininite Information	80100 determined evolution
	5010D Ratio error		2.1006-02	μοσ	Normal k • 1	<u> </u>	1.00	2.1006-02	1.00000+000	I —	2.1006-02	100	infinte	concordentmined experimentally
	60100 Bridge resolution	L	1.000E-03	μώο	Normal k = 2	L	2.00	5.000E-04	1.000E+00		5.000E-04	100	infinite	6010D specification
				L										
Res	Resolution of Standard / Equipment (if applicable)										100			
	Standards and Reference Equipment (C)	orrelated) V					•	NOT	EI ONLY C	HANG	BLUE CELLS	AILOTHE	R CELLS (WHITE) ARE PROTECTED
	Vinit Under Test / Calibration (Uncorr	elated) V						NOT		HANG	BLUE CELLS	AUOTHE	R CELLS (WHITE) ARE PROTECTED
						<u> </u>							<u> </u>	
Ren	Resolution of UUT (If applicable)					<u> </u>						100		
	Type "B" Evaluation Dance of the new the (Danteson for)					<u> </u>						100	<u> </u>	
Data	Type 10 Exclusion Fungle of the result (Hecking datr)		6 327E.03	-00	Normal K = 1		1.00	5 3275 (22	1.0005+00		23826.02		4	No of Designers
	The second secon	interfi =	3.3271-33	pract	A CONTRACT OF A		1.00	NOT	EL ONLY	HAND	BULLECEULS	All OTHE	B CELLER	WHITE ARE PROTECTED
	 One onder reach cambradon (Corre 	and) *						not	LI UNLIC		DEDE CELLS	- Au OTHE	n tetta (hing the morecret
						<u> </u>								
						<u> </u>							—	
Alexi USM		TOTA	COMBINED	UNCER	TAINTY						μΩΩ	T		
					ombined Uncertai	inty (Nor	mai)	V Level	of Confidence V	,	3.690E-02	V.	infinite	Checked and Approved By:
'	Best Measurement Capability (<u>Excluding</u> UUT contribution)				Expanded Unit	certainty		95,45	% K=2		7.39E-02	k=	2.00	
				(ombined Uncertai	inty (Nor	mai)	T Level	of Confidence		3.698E-02	V.	infinite	
	Uncertainty of Measurement (Including UUT	oontribution)		Expanded Unit	certainty		95,45	% K=2		7.40E-02	k=	2.00	

			-									Certific	ate No	AFRIMETS.EM-S3
	UN	CERTAIN	IY BUD	JE I	MAIRIX (U	BM)						Proces	lure No	DCLF/R-0016
		Refere	nce: Guide to the Ex	pression of	Uncertainty in Measuren	nent, issue	d by BIPM, IEC	, IFOC, ISO, IUPAC	, IUPAP, OIML - B	90 1995 (ISBN 92-67-10108-9)			
Description:	Standard resistor		Type & Serial		742A	8 480	5003		Range:		100	Ω		Metrologist
			Number											M.Hiakola
	Mathematical Model:								RL	IUT=Rr	measured			
	Input Quantity	Estimated	Estimat	ad	Buchability			Standard	Sensitiv	itv	Standard	_	Degrees	
Symbol	(Source of Uncertainty)	Quantity	Uncertai	nty	Distribution	Re-	Divisor	Uncertainty	Coeffici	ant	Contribution	Reliability	Freedom	Remarks
	α _θ	(5.)		Unit	(N, R, T, U)		Tactor	UCD	a	Unit	UI (0)	- 56		
	▼ Standards and Reference Equipment (U	ncorrelated)									uQ/Q			
214	Estil calibration		2 0005-01		Normal k = 2		2.00	1.0005-01	1 0005+00		10005-01	100	Infinite	Calculated UoM of Ristd
014	Pressure Coefficient		0.0005+00	pice o	Normal k = 2		2.00	0.0005+00	1.0005+00		0.0005+00	100	Infinito	Reference std calibrated at NMISA
			-1.10002-00	µuio uovo	Destangular da		4.73	-6.9425-00	1.0005+00		-6.9125-02	100	Infinite	Control Charles
			-1.180E-01	μικο	Nectangular 13		1.7.5	-0.013E-02	1.0002+00		-0.013E-02	100	Infinite	CONDO CINICO CONDO coacification 1:10 collo
	suruu enoge accuracy		4.000E-02	μΩνο	Normal k = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	ininite	so too specification 1:10 rado
	sono ineanty		5.000E-03	μΩνο	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	infinite	BUTUD specification
	6010D Ratio error		2.100E-02	μΩνο	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	μΩγο	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 (0)	Correlated)						NOTE	ONLY CH	ANGE	BLUE CELLS -		RCELLS	(WHITE) ARE PROTECTED
			<u> </u>	<u> </u>										
				<u> </u>										
	W Linit Linder Test / Collinstion / lineer	related) w						NOTE	-					
	 Onic onder Tesc/ Calibration (oncor 	related) 🔻						NOTE	ONLYCH	ANGE	BLUE CELLS -	AILOTHE	RCELLS	(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 (Correl	elated) 🔻						NOTE!	ONLY CH	ANGE	BLUE CELLS -	All OTHE	R CELLS	(WHITE) ARE PROTECTED
About UDM		COMBINED	UNCER	RTAINTY						u0/0	1			
				mbined Lincorte	inty (Ne	(Icon	The second	of Confidence		10455.04	v	Inflatio	Checked and Approved By:	
Be	Best Measurement Capability (Excluding UUT contribution)			<u> </u>	Expanded Unc	ertaint;	y Y	95,45	% K=2		2.49E-01	k=	2.00	Checked and Approved by.
					minine of the set of	and an approximate		T Locale	Confidence					4
u	ncertainty of Measurement (Including UUT	on)		unioined Uncertai	inty (NC	irmai)	▼ Level (a Contidenci	- •	1.245E-01	V.e	infinite		
Ŭ	,			Expanded Uno	ertaint	y	95,45	% K=2	2	2.49E-01	k =	2.00		

	UNCERTAINTY BUDGET MATRIX (UBM)													AFRIMETS.EM-S3
		CERTAIN	11 8000	JEI		(BMI)						Proces	lure No	DCLF/R-0016
		Name of	IDE: OUCH ID THE LA	pression of	Undersampy in measurem	e'1, 180.4	by serve, rac	, IPOC, 190, 1979C	TOPPOP, CIAL - D		GEN 82-61-10100-8)			Hatalaalat
Description:	Standard resistor		Type & Serial Number		742A	& 4810	0007		Range:		1000	Ω (Metrologist
														M.Hakola
	Mathematical Model:								RU	JUT=Rr	neasured			
	Input Quantity	Estimated	Estimat	be	Probability	ke.		Standard	Sensitiv	ity	Standard	Reliability	Degrees	
Symbol	(Source of Uncertainty)	Quantity	Uncertai	nty	Distribution		factor	Uncertainty	Coefficie	ent	Contribution	- Contacting	Freedom	Remarks
	αu	(x ₀)		Unit	(N, R, T, U)	•		U(A)	a	Unit	UI (9)	**	*	
	Standards and Reference Equipment (U	ncorrelated)	•								μΩ/Ω			
Std	Rstd calibration		3.000E-01	μΩγο	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	μΩγο	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	μΩγο	Rectangular 1/3		1.73	-6.468E-02	1.000E+00		-6.468E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	μΩγο	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	μΩγο	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	μΩγο	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	μΩγο	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 CH		BLUE CELLS -		R CELLS	(WHITE) ARE PROTECTED
	Unit Under Test / Calibration (Uncor	related) 🔻						NOTE	ONLY CH		BLUE CELLS -		RCEUS	(WHITE) ARE PROTECTED
									oner on				- OLLLO	
Rec	Resolution of LILIT (if applicable)											100		
Rea	Type "B" Evaluation, Range of the results (Rectangular)											100		
Data	Type 5" Evaluation Range of the resolds (rectangular)		9.6735-03		Normal K = 1		1.00	9 6735-03	1.0005+00		4 3365-03	100	4	No of Readings
	▼ Unit Under Test / Calibration /Com	elated) 💌	3.07 32-03	piper	control is a 1		1.00	NOTE	ONLY CH	ANCE	BULIE CELLS	All OTH	P CELLO	WHITE) ADE PROTECTED
					1			HOTE:	SHET CH	ANGE	DEDE OLLES -	All Offic	IN OLLES	
About UBM		TOTAL	COMBINED	UNCER	TAINTY						μΩ/Ω			· · · · · · · · · · · · · · · · · · ·
_	Part Management Complifies (Furthering 1997 and the time)				mbined Uncertai	inty (No	rmal)	▼ Level	of Confidence	•	1.659E-01	V.e	Infinite	Checked and Approved By:
Be	Best Measurement Capability (<u>Excluding</u> UUT contribution)				Expanded Unc	ertainty	(95,45	% K=2	2	3.32E-01	k =	2.00	
					mbined Uncertai	ntv (No	rmal)	▼ Level o	f Confidence	e 🔻	1.660E-01	V.z	Infinite	
U	Uncertainty of Measurement (Including UUT contribution)		on)	<u>َ</u>	Expanded Uno	ertainty	(95,45	% K=2	2	3.32E-01	k=	2.00	

	UNCERTAINTY BUDGET MATRIX (UBM) Certificate No													AFRIMETS.EM-S3
	01	CERTAIN	TY BODO	351		(BMI)						Proces	dure No	DCLF/R-0016
		Habers	NOR: GUIDE ID THE LA	pression of	Uncertainty in Measurer	erz, issue	d by siew, rec	2, IPOC, ISO, ISPAC	, IOPAP, OIML - I	90 1996 (GEN 82-67-10108-8)			Materialist
Description:	Standard resistor		Type & Serial Number		7424	8 497	5043		Range:		1000	ΩΩ		metroogra
														M. Hiakola
	Mathematical Model:								RL	JUT=Rr	neasured			
	Input Quantity	Estimated	Estimate	ad	Probability	ke.		Standard	Sensitiv	ity	Standard	Dallahilita	Degrees	
Symbol	(Source of Uncertainty)	Quantity	Uncertai	nty	Distribution	-	factor	Uncertainty	Coeffici	ent	Contribution	roenability	Freedom	Remarks
	(X.)	(x ₀)		Unit	(N, H, T, U)	•		U(A)	a	Unit	UI (9	- 56	*	
	Standards and Reference Equipment (U	ncorrelated)	•								μΩ/Ω			
Std	Rstd calibration		4.000E-01	μΩνο	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	μΩγο	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	μΩγο	Rectangular 1/3		1.73	-4.312E-02	1.000E+00		-4.312E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	μΩγο	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	μΩγο	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	μΩγο	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	μΩγο	Normal k = 2		2.00	5.000E-04	1.000E+00		5.000E-04	100	Infinite	6010D specification
				<u> </u>										
Dec	Pasolution of Standard / Equipment (Facolicable)			<u> </u>								100		
nes	Standards and Reference Equipment (Correlated)						NOTE	ONLYCH	ANCE	BUIE CELLS	AIL OTHE	DOFUS	(MH/TE) ADE DOOTECTED
	· clandardo and resoration Equipment (on orange ,						NOTE:	UNLIG	ANGL	DEUE CELLS	All Offic		(MILE) ARE PROTECTED
			<u> </u>	<u> </u>										
				<u> </u>										
				<u> </u>										
	 Unit Under Test / Calibration (Uncor 	related) 🔻						NOTE!	ONLYCH	IANGE	BLUE CELLS		R 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 (Correl	elated) 🔻						NOTE!	ONLY CH	ANGE	BLUE CELLS -	AII OTHE	R CELLS	(WHITE) ARE PROTECTED
About U.Day		TOTAL	COMBINED	UNCER	RTAINTY						u0/0	1		
	Į			0	ombined Lincerta	inty (Ne	imal)	▼ Level	of Confidence 1	•	2.0675-01	V.	Infinite	Checked and Annroved Rv
Be	Best Measurement Capability (Excluding UUT contribution)				Expanded Un	certaint	y y	95,45	% K=2	2	4.14E-01	k =	2.00	onevies and Approved by.
					antible and 1 line and a			F Levels	Continues					-
U	Incertainty of Measurement (Including UUT	on)	^۵	unioned uncerta	indy (INC	amai)	▼ Level 0	i coniideno	- •	2.068E-01	Vet	infinite	-	
					Expanded Unit	certaint	у	95,45	% K=2	2	4.14E-01	k =	2.00	

Appendix B: NMISA uncertainty budgets for loop 2

														AFRIMETS.EM-S3
	UN	CERTAIN	IT BODO	9E 1	MATRIA (U	ым)						Proces	dure No	DCLF\R-0016
		Reb	rence: Guide to the E	Apression o	f Uncertainty in Measurer	nent, issued	by BIPM, IEC,	IFCC, ISO, IUPAC,	IUPAP, OML - ISI	D 1995 (IS	an 92-67-10188-9)			_
Description:	Standard resistor		Type & Serial		742/	8 5040	0014		Range:		1.0	0		Metrologist
			Number											M.Hiakola
	Mathematical Model:								RL	JUT=Rr	neasured			
	Input Quantity	Estimated	Estimate	ıd	Probability			Standard	Sensitiv	rity	Standard		Degrees	
Symbol	(Source of Uncertainty)	Input Quantity	Uncertair	nty	Distribution		Divisor	Uncertainty	Coeffici	ent	Contribution	Reliability	Freedom	Remarks
	(X _i)	(= .)		Unit	(N, R, T, U)	•		U(33)	a	Unit	67.69	96		
	Standards and Reference Equipment (U)	ncorrelated)	•								μΩ/Ω			
Std	Rstd calibration		1.700E-02	μΩιο	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	μΩιο	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	μΩιο	Rectangular 13		1.73	2.760E-03	1.000E+00		2.760E-03	100	infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	μΩιο	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	μΩιο	Normal k = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	infinite	6010D specification
	6010D Ratio error		1.400E-02	μΩιο	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	μΩιο	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)									<u> </u>		100		
	Standards and Reference Equipment (Correlated)						NOTE	ONLY CH	ANGE	BULIE CELLS	All OTHE	RCEUS	(WHITE) ARE PROTECTED
		l						1012	CHL / Ch		DECE CELES			
										<u> </u>				
							<u> </u>			<u> </u>			<u> </u>	
										<u> </u>				
	Unit Under Test / Calibration (Uncor	related) 🔻						NOTE	ONLY CH	ANCE	BULIE CELLS	All OTHE	PCELLS	
		1						NOTE	ONL F Ch	ANDE	DEUE GELLS	All Office		(White) ARE PROTECTED
										<u> </u>			<u> </u>	
Per	Perclution of LEUT_ (If applicable)									<u> </u>		100		
THE R	Type 101 Cyphonics, Dance of the secular (Destruction)											100		
Deta	Type "B" Evaluation Range of the results (Rectangular)		4.0425.00		Manual Mar 4		4.000	4 0405 00	4.0005.00	<u> </u>	0.0045.00	100		No of Deadland
	Type A Evaluation Exp Std Deviation 'S	alated) T	1.9438-02	μικα	Normal K = 1		1.00	1.943E-02	1.000E+00		8.001E-03	A# 07.0	4	No of Readings 5
	Onic Onder Test / Calibration (Content	erated) +						NOTE	ONLYCH	ANGE	BLUE CELLS -	AIIOTHE	RCELLS	(WHITE) ARE PROTECTED
										<u> </u>			<u> </u>	
About UBM		TOTAL	COMBINED	UNCER	TAINTY						μΩ/Ω			
_			C	mbined Uncerta	inty (No	imal)	▼ Level	of Confidence	•	3.363E-02	Vett	infinite	Checked and Approved By:	
Be	Best Measurement Capability (Excluding UUT contribution)				Expanded Unit	ertainty	·	95,45	% K = 2	2	6.73E-02	k =	2.00	
				-						_				1
	incertainty of Measurement (Including UUT	on)	C	ombined Uncerta	inty (No	rmal)	▼ Level o	of Confidence	e 🔻	3.473E-02	Vett	infinite		
ľ	, or inclusion proclaming our				Expanded Unit	certainty	·	95,45	% K = 2	2	6.95E-02	k =	2.00	

		CEDTAIN		OFT		-						Certific	cate No	AFRIMETS.EM-63
	UN	CERTAIN	IT BUD	JEI	MATRIX (U	(BM)						Proces	dure No	DCLFIR-0016
		Rafere	now Guide to the Ex	pression of	Uncertainty in Measuren	nent, issue	d by BIPM, IEC	C, IFOC, ISO, IUPAC	, IUPAP, OML - I	SO 1995 (SBN 92-67-10166-9)			
Description:	Standard resistor		Type & Serial		7424	8 548	0006		Range:		10	0		Metrologist
			Number									-		M.Hiskola
	Mathematical Model:								RU	JUT=Rr	neacured			
	Input Quantity	Estimated	Estimat	ed	Bashability			Standard	Sensitiv	éty.	Standard	_	Degrees	
Symbol	(Source of Uncertainty)	Quantity	Uncertai	nty	Distribution	8-	Divisor	Uncertainty	Coeffici	ent	Contribution	Reliability	Freedom	Remarks
	αω	(5.)		Unit	(N, R, T, U)	•	Tactor	000	a	Unit	50			
	▼ Standards and Reference Equipment (Ur	noorrelated)	•								HO/D			
Std	Rstd calibration		1.700E-02	uQ/o	Normal k = 1		1.00	1.700E-02	1.000E+00		1.700E-02	100	Infinite	From BIPM calibration Certificate
	Pressure Lincertainty		1.522E-02	1000	Normal k = 1		1.00	1.522E-02	1,000E+00	<u> </u>	1 5225-02	100	Infinite	From BIPM calibration Certificate
	Batel det		4 7915-03		Rectangular 12		1.72	2 7605-02	1.0005+00	<u> </u>	2 7605-02	100	Infinite	Costrol Charts
			4.7012-05	jaca to	Hecangola 15		1.7.5	2.7002.05	1.0002.00	<u> </u>	2.7002.00	100	innnite	CONDUCTION IN THE CONDUCTION OF THE CONDUCTUAL O
	suruu enoge accuracy		4.000E-02	μανό	Normal K = 2		2.00	2.000E-02	1.000E+00		2.000E-02	100	innite	COLOD specification 1. To ratio
	6010D linearity		5.000E-03	μΩγο	Normal k = 2		2.00	2.500E-03	1.000E+00	<u> </u>	2.500E-03	100	Infinite	SUTUD specification
	6010D Ratio error		2.100E-02	μΩιο	Normal k = 1		1.00	2.100E-02	1.000E+00	<u> </u>	2.100E-02	100	Infinite	6010D determined experimentally
	6010D Bridge resolution		1.000E-03	μΩγο	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 (Control of the standards)	Correlated)						NOTE	ONLY CH		BLUE CELLS		RCELLS	(WHITE) ARE PROTECTED
				<u> </u>						<u> </u>				
L				<u> </u>						<u> </u>			<u> </u>	
	🖲 Unif Under Test / Calibration (Under	alafad) T						NOTE	01111/01			4.0 0 7.0	DOFULO	
	one onder reer/ campration (onder	elated) +						NOTE	ONLY CH	ANGE	BLUE CELLS	AIFOTHE	RCELLS	(WHITE) ARE PROTECTED
							•							
Res	Resolution of UUT (If applicable)											100	L	
Data	Type "B" Evaluation Range of the results (Rectangular)											100		
	Type "A" Evaluation Exp Std Deviation "s"		1.422E-02	μΩΩ	Normal K = 1		1.00	1.422E-02	1.000E+00		6.361E-03		4	No of Readings 5
	Unit Under Test / Calibration (Correl	elated) 🔻						NOTE	ONLY CH	ANGE	BLUE CELLS -	All OTHE	R CELLS	(WHITE) ARE PROTECTED
About UDM		ΤΟΤΑΙ	COMBINED	UNCER	TAINTY					-	μΩ/Ω	i		•
_					ombined Uncertai	inty (No	rmal)	▼ Level	of Confidence	•	3.709E-02	Ver	Infinite	Checked and Approved By:
Be	Best Measurement Capability (Excluding UUT contribution)				Expanded Und	ertaint	Y	96,46	96 K = 2	2	7.43E-02	k =	2.00	
				C/	mbined Uncertai	inty (No	rmal)	V Level	of Confidence		37635-02	V.	Infinite	ł
U	Incertainty of Measurement (Including UUT	contributi	on)		Expanded Und	ertaint	/	95,45	% K=2	2	7.64E-02	k =	2.00	
											1.042.42			

	UNCERTAINTY RUDGET MATRIX (URM)													AFRIMETS.EM-63
	UN	CERTAIN	IT BODO	JEI	MATRIX (U	(BMI)						Proces	dure No	DCLFIR-0016
		Refere	nos: Guide to the Ex	pression of	Uncertainty in Neasuren	ent, issue	d by BIPM, IEC	C, IPOC, ISO, IUPAC	UPAP, OML - I	SO 1995 (ISBN 92-67-101.08-9)			
Description:	Standard resistor		Type & Serial		7424	8 480	5003		Range:		100	0		Metrologist
			in a motor											M.Hiskola
	Mathematical Model:								RU	UT=Rr	neasured			
	Input Quantity	Estimated	Estimate	bel	Perduability			Standard	Sensitiv	ity	Standard		Degrees	
Symbol	(Source of Uncertainty)	Quantity	Uncertai	nty	Distribution	80-	Divisor	Uncertainty	Coefficie	ent	Contribution	Reliability	Freedom	Remarks
	αω	(5.)		Unit	(N, R, T, U)	•	Tactor	UCD	a	Unit	Ui (0)	- 26		
	▼ Standards and Reference Equipment (Ur	noorrelated)	•								μα/α			
Std	Rstd calibration		2.000E-01	uQ/o	Normal k = 2		2.00	1.000E-01	1.000E+00		1.000E-01	100	Infinite	Calculated UoM of Rstd
	Pressure Coefficient		0.0005+00	1000	Normal k = 2		2.00	0.000E+00	1.000E+00		0.0005+00	100	Infinite	Reference std calibrated at NMISA
	Batel det		-1.1805-01	-	Rectangular 13		173	-6.8135-02	1000E+00		-6.813E-02	100	Infinite	Control Charts
			1.1002.01	puto	Necessity 2		2.02	20005.02	1.0002.00	<u> </u>	2,0005,02	100	Internet	60100 specification 1-10 mile
	so too enoge accuracy		4.000E-02	jucaro.	Normal K = 2		2.00	2000E-02	1.000E+00		2.000E-02	100	inninite	CO-IDD specification
	6010D Inearty		5.000E-03	μΩγο	Normal K = 2		2.00	2.500E-03	1.000E+00		2.500E-03	100	infinite	So too specification
	6010D Ratio error		2.100E-02	μΩγο	Normal k = 1		1.00	2.100E-02	1.000E+00		2.100E-02	100	infinite	SUTUD determined experimentally
	6010D Bridge resolution		1.000E-03	μΩγο	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 (0	correlated) V	,					NOTE!	ONLY CH	ANGE	BLUE CELLS -		R CELLS	(WHITE) ARE PROTECTED
	V Linit Linder Test / Calibration (Lincon	related) ¥						NOTE	OWNER	ANCE	BULLE CELLS	All OTHE	PCELLS	ANNITE ARE PROTECTED
		0120027						NOTE	UNEFCH	ANGE	BLUE CELLS -	All OTHE	A CELLO	(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"		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 (Correl	elated) 🔻						NOTE!	ONLY CH	ANGE	BLUE CELLS -	All OTHE	R CELLS	(WHITE) ARE PROTECTED
About UEM		TOTAL	COMBINED	UNCER	TAINTY						μΩ/Ω	İ		
	•			Co	mbined Uncertai	nty (Ne	rmall	▼ Level	of Confidence 1	•	1.245E-01	Ver	Infinite	Checked and Approved By:
Be	Best Measurement Capability (Excluding UUT contribution)				Expanded Unc	ertaint	y	96,46	% K=2		2.49E-01	k =	2.00	
				00	mbined Uncertai	nty (No	rmaD	▼ Level :	of Confidence		16125-04	V -	24 6460	
U	Uncertainty of Measurement (Including UUT contribution)				- oncerta	and then		- Level (- connection		1.0126-01	· · · ·	24.3458	
			-		Expanded Unc	ertaint;	y	95,45	% K=2		3.40E-01	k =	2.11	

	LIN		Certific	ate No	AFRIMETS.EM-83									
	01	CENTAIN	11 8000									Proced	lure No	DCLF/R-0016
		Pathere	noe: Guide to the Ex	pression of	Uncertainty in Measurem	ent, issued	d by BIPM, IEC	C, IFOC, ISO, IUPAC	, IUPAP, OML - IS	iO 1995 (I	SBN 92-67-10108-9)			
Description:	Standard resistor		Type & Serial		742A	8 4810	0007		Range:		1000	0		Metrologist
			Number											M.Hiskola
	Mathematical Model:								RU	UT=Rn	neasured			
	Input Quantity	Estimated	Estimate	ed .	Bashability			Standard	Sensitiv	ity	Standard	_	Degrees	
Symbol	(Source of Uncertainty)	Quantity	Uncertai	nty	Distribution	ke-	Divisor	Uncertainty	Coefficie	ant	Uncertainty Contribution	Reliability	of	Remarks
	α _ω	(5.)		Unit	(N, R, T, U)		Tactor	UCD	a	Unit	U1 (1)	26		
	▼ Standards and Reference Equipment (Ur	noorrelated)	•					- 14			μανα			
Std	Rstd calibration		3.000E-01	μΩγο	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	uQ/o	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	1000	Rectangular 1/3		1.73	-6.468E-02	1.000E+00		-6.468E-02	100	Infinite	Control Charts
	60100 Bridge accuracy		4 0005-02	1000	Normal k = 2		2.00	2 0006-02	10005+00		2 0005-02	100	Infinite	6010D specification 1:10 ratio
	6010D linearty		5.0005-02	1000	Normal k = 2		2.00	2 5005-02	1,0005+00		2.5005-02	100	Infinite	6010D specification
	CO100 Incarty		3.0002-03	parts	Normal k = 2		4.00	2.0005.00	1.0002.400		2.5002-05	100	Infinite	6010D determined experimentally
	CO10D Ratio end		2.1002-02	puro	Normal k = 1		1.00	2.1002-02	1.0002+00		2.1002-02	100	Infinite	CO100 excellenting
	6010D Bridge resolution		1.0002-03	μωσ	Normal K = 2		2.00	5.0002-04	1.0002+00		5.0002-04	100	inninite	60100 specification
Res	Resolution of Standard / Equipment (if applicable)											100		
	Standards and Reference Equipment (0)	correlated) V						NOTE!	ONLY CH	ANGE	BLUE CELLS -	All OTHE	R CELLS	(WHITE) ARE PROTECTED
	Unit Under Test / Calibration (Uncorr	related) 🔻						NOTE!	ONLY CH	ANGE	BLUE CELLS -	All OTHE	R CELLS	(WHITE) ARE PROTECTED
Res	Resolution of UUT (If applicable)											100		
	Type "B" Evaluation Range of the results (Rectangular)											100		
Data	Type "A" Evaluation Exp Std Deviation "s"		1.808E-01	000	Normal K = 1		1.00	1.8085-01	1,000E+00		8.0865-02		4	No of Readings 5
	▼ Unit Under Test / Calibration /Corre	lated) V						NOTE	ONLYCH	ANGE	BLUE CELLS -	AILOTHE	RCELLS	(WHITE) ARE PROTECTED
About UDM		TOTAL	COMBINED	UNCER	TAINTY						μΩ/Ω			
-	Part Manuary Constilling (Fundadian UK) anatolis tion)				mbined Uncertai	nty (No	rmal)	V Level	of Confidence 1		1.659E-01	Vet	Infinite	Checked and Approved By:
Ве	Best Measurement Capability (<u>Excluding</u> UUT contribution)				Expanded Unc	ertaint)	,	96,46	% K=2		3.32E-01	k =	2.00	
					mblead Uncertai	eby (ble	cmall.	▼ Levels	Confidence		4.0455.02	v	400.000	
U	Uncertainty of Measurement (Including UUT contribution)				anoned oncertai	nty (NO	annan)	• Level o	a connidence	•	1.846E-01	*•#	108.599	
		-		Expanded Unc	ertaint)	Y	86,46	% K=2		3.73E-01	k =	2.02		

										Certificate No		AFRIMETS.EM-83		
	Defense Gride to the Dependence in a statistic in New York (SC 100 160 11040 11040 1104 0104 1100 100 100 100									Procedure No		DCLFIR-0016		
Internet of state of the suprementation of subsequences, and/or of suprementations, and/or of suprementations														
Description:	Standard resistor		Type & Serial Number	6 Serial 742A 8 4975043			Range:	10000 Q			Metrologist			
												M. Hiskola		
	Mathematical Model:			RUUT=Rmeasured										
	Input Quantity	Estimated	Estimate	ьd	Persbability			Standard	Sensitiv	ity	Standard	Degrees	Degrees	
Symbol	(Source of Uncertainty)	Quantity	Uncertai	inty Distribution		80-	Divisor	Uncertainty	Coefficie	ent	Contribution	Reliability	Freedom	Remarks
	αw	(cra)		Unit	(N, R, T, U)			UCU	a	Unit	U1 (s)	56		
	V Standards and Reference Equipment (Ur	noorrelated)	•								μα/α			
Std	Rstd calibration		4.000E-01	μΩγο	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	μΩγο	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	μΩτο	Rectangular 1/3		1.73	-4.312E-02	1.000E+00		-4.312E-02	100	Infinite	Control Charts
	6010D Bridge accuracy		4.000E-02	HQ/0	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	HO/2	Normal k = 2		2.00	2 500E-03	1.000E+00		2.500E-03	100	Infinite	6010D specification
	6010D Ratio error		2.100E-02	1000	Normal k = 1		1.00	2 100E-02	1.000E+00		2.100E-02	100	Infinite	6010D determined experimentally
	60100 Bridge resolution		1,000E-03	1000	Normal k = 2		2.00	5.000E-04	1,000E+00		5.000E-04	100	Infinite	6010D specification
				parts.										
Res	Resolution of Standard / Equipment (if applicable)							NOTE				100		
	▼ Standards and Reference Equipment (Correlated) ▼							NOTE!	ONLY CH	ANGE	BLUE CELLS -	AII OTHE	R CELLS	(WHITE) ARE PROTECTED
	Unit Under Test / Calibration (Uncor	related) 🔻						NOTE!	ONLY CH	ANGE	BLUE CELLS -	All OTHE	R 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 (Correl	elated) 🔻						NOTE!	ONLY CH	ANGE	BLUE CELLS -	All OTHE	R CELLS	(WHITE) ARE PROTECTED
About USM TOTAL COMBINED UNCERT					NCERTAINTY				Ī		•			
			Combined Uncertainty (Normal)			▼ Level	Level of Confidence V 2.067E-01		2.067E-01	Ver	Infinite	Checked and Approved By:		
Best Measurement Capability (Excluding UUT contribution)			Expanded Uncertainty 95			96,46	85,45 % K = 2 4.14E-01		k =	2.00				
				Combined Uncertainty (Normal)			▼ Level «	Level of Confidence V 2 2225-04		Ve	218 872	t		
U	Incertainty of Measurement (Including UUT	contributio	on)	Second difference in the second					4 475 44					
				Expanded Uncertainty			86,46 % K = 2		4.4/E-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	Probability	Sensitivity	Uncertainty	Degrees of freedom
		Standard	distribution	coefficient	Contribution	$artheta_i$
		Uncertainty			u _x	
		±				
1Ω Resistor Standard	1.00000178 Ω	0.40·10 ⁻⁶	Normal	1	0.40·10 ⁻⁶	×
(Rs)						
Drift of the 1 Ω resistor	$1.01 \cdot 10^{-6} \Omega$	0.59·10 ⁻⁶	Rectangular	1	0.59·10 ⁻⁶	×
(δRs)						
Repeatability (ESDM)		$12.0 \cdot 10^{-9}$	Normal	1	$12.0 \cdot 10^{-9}$	999
Temperature		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	8
Coefficient (δRτs)						
Combined uncertainty					$0.72 \cdot 10^{-6}$	
u _c						
Effective degrees of					$1.29 \cdot 10^{10}$	
freedom						
Expanded					1.44 · 10 ⁻⁶	
uncertainty U						

Quantity	Estimate	Relative Standard	Probability	Sensitivity	Uncertainty	Degrees of
		Uncertainty	distribution	coefficient	Contribution	freedom
		±			u _x	$artheta_i$
10 Ω Resistor	9.99998965 Ω	0.41·10 ⁻⁶	Normal	1	$0.41 \cdot 10^{-6}$	8
Standard (Rs)						
Drift of the 10 Ω	$15.5 \cdot 10^{-6} \Omega$	0.9· 10 ⁻⁶	Rectangular	1	0.9·10 ⁻⁶	8
resistor (δRs)						
Repeatability		$8.9 \cdot 10^{-9}$	Normal	1	$8.9 \cdot 10^{-9}$	999
(ESDM)						
Temperature		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	8
Coefficient (δR⊤s)						
Combined					$0.99 \cdot 10^{-6}$	
uncertainty u_c						
Effective degrees					$1.53 \cdot 10^{11}$	
of freedom						
Expanded					1.98 · 10 ⁻⁶	
uncertainty U						

Quantity	Estimate	Relative	Probability	Sensitivity	Uncertainty	Degrees of
		Standard	distribution	coefficient	Contributio	freedom
		Uncertainty			n	$artheta_i$
		±			u_x	
100 Ω Resistor	99.99976512 Ω	0.40· 10 ⁻⁶	Normal	1	0.40· 10 ⁻⁶	∞
Standard (Rs)						
Drift of the 100 Ω	$0.149 \cdot 10^{-3} \Omega$	0.9· 10 ⁻⁶	Rectangula	1	0.9·10 ⁻⁶	∞
resistor (δRs)			r			
Repeatability (ESDM)		$37.7 \cdot 10^{-9}$	Normal	1	$37.7 \cdot 10^{-9}$	999
Temperature	$5.0 \cdot 10^{-9}$	Rectangula	1	$5.0 \cdot 10^{-9}$	∞	
Coefficient (δR⊤s)			r			
Combined uncertainty					$0.99 \cdot 10^{-6}$	
u _c						
Effective degrees of				$4.75 \cdot 10^{8}$		
freedom						
Expanded				$1.98 \cdot 10^{-6}$		
uncertainty U						

Quantity	Estimate	Relative Standard	Probability	Sensitivit	Uncertainty	Degrees
		Uncertainty	distribution	у	Contribution	of
		±		coefficien	u_x	freedom
				t		ϑ_i
1 kΩ Resistor	0.99999625 kΩ	0.66· 10 ⁻⁶	Normal	1	0.66· 10 ⁻⁶	8
Standard (Rs)						
Drift of the 1 $k\Omega$	$0.11\cdot 10^{-6}$ k Ω	$63.5 \cdot 10^{-9}$	Rectangular	1	$63.5 \cdot 10^{-9}$	∞
resistor (δR _S)						
Repeatability		$32.4 \cdot 10^{-9}$	Normal	1	$32.4 \cdot 10^{-9}$	999
(ESDM)						
Temperature		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	∞
Coefficient (δR_{TS})						
Combined					$0.67 \cdot 10^{-6}$	
uncertainty u_c						
Effective degrees of					$1.83 \cdot 10^{8}$	
freedom						
Expanded					$1.34 \cdot 10^{-6}$	
uncertainty U						

Quantity	Estimate	Relative Standard	Probability distribution	Sensitivit	Uncertainty	Degrees
		Uncertainty		У	Contribution	of
		±		coefficien	u_x	freedom
				t		ϑ_i
10 kΩ Resistor	9.99997430 kΩ	0.66· 10 ⁻⁶	Normal	1	0.66· 10 ⁻⁶	8
Standard (Rs)						
Drift of the 10 k Ω	$5.22 \cdot 10^{-6} \text{ k}\Omega$	0.3·10 ⁻⁶	Rectangular	1	0.3·10 ⁻⁶	8
resistor (δRs)						
Repeatability		$73.7 \cdot 10^{-9}$	Normal	1	$73.7 \cdot 10^{-9}$	999
(ESDM)						
Temperature		$5.0 \cdot 10^{-9}$	Rectangular	1	$5.0 \cdot 10^{-9}$	∞
Coefficient (δR_{TS})						
Combined					$0.73 \cdot 10^{-6}$	
uncertainty u_c						
Effective degrees of					9.62 · 10 ⁶	
freedom						
Expanded					$1.46 \cdot 10^{-6}$	
uncertainty U						