EURAMET Project 1341

Comparison on Calibration of Multimeter

Measurements Report of TÜBİTAK UME

TÜBİTAK UME

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PARTICIPANT INSTITUTE

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1. PERIOD OF MEASUREMENTS

Turn	Measurement Periods
1	02.03.2015 - 13.03.2015
2	20.04.2015 - 23.04.2015
3	16.06.2015 - 30.06.2015
4	18.08.2015 – 25.08.2015
5	19.10.2015 – 20.10.2015
6	23.02.2016 - 06.05.2016
7	28.07.2016 - 05.08.2016
8	07.11.2016 – 11.11.2016

2. AMBIENT CONDITIONS

Temperature : (23 ± 1) °C

Relative Humidity : (45 ± 10) %rh

3. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Calibrator	Fluke	5720A	7215201	TÜBİTAK UME
DC Current Shunt	Guildline	9211A	57970	TÜBİTAK UME
Multimeter	HP	3458A	2823A15436	TÜBİTAK UME

Name	Manufacturer	Model No	Serial No	Traceability
AC-DC Transfer Standard	Fluke	792A	6130002	TÜBİTAK UME
AC-DC Current Shunt/ AC-DC Transfer Standard	Fluke/Fluke	A40-1 A (0.5Ω) / 792A	3820095/ 6130002	TÜBİTAK UME
AC-DC Current Shunt/ AC-DC Transfer Standard	Fluke/Fluke	A40-10 mA (87 Ω) / 792A	3820009/ 6130002	TÜBİTAK UME
Multimeter	HP	3458A	2823A15077	TÜBİTAK UME

4. MEASUREMENT METHOD

After each arrival of the travelling standard to TUBITAK UME, the travelling standard was allowed to stabilise for 24 hours with the power turned on before measurements were performed.

DC Voltage

DC voltage function of the travelling standard was calibrated by direct measurement method; The known DC voltages generated by the characterized multifunction calibrator were applied to the travelling standard and the readings of the travelling standard were recorded.

A settling time of more than 5 min for 100 mV, 10 V & 100 V and 10 min for 1000 V were allowed before starting measurements.

The errors of the travelling standard were determined using the formula (1) given below:

$$\text{Error} = \frac{\text{Measured Value (reading of Travelling Standard)} - \text{Applied Value}}{\text{Applied Value}} \qquad (1)$$

During the measurement, the travelling standard was set to the configurations below:

Resolution 7; Filter ON; Fast OFF; Front Input; Internal Guard

DC Current

DC current function of the travelling standard was calibrated by using the DC Current Shunt which is connected to the travelling standard in series. The voltage drop on the DC Current Shunt was measured with a reference multimeter and the applied current was calculated using the resistance of the Shunt and the measured voltage. The errors of the travelling standard were determined using the equation (1).

A settling time of more than 5 min for 100 µA & 10 mA and 30 min for 1 A were allowed before starting measurements.

During the measurement, the travelling standard was set to the configurations below:

Resolution 7; Filter ON; Fast OFF; Front Input; Internal Guard

DC Resistance

DC resistance function of the travelling standard was calibrated by the characterized multifunction calibrator. The errors of the travelling standard were determined using the equation (1).

A settling time of more than 5 min were allowed before starting measurements.

During the measurement, the travelling standard was set to the configurations below:

10 Ω	10 kΩ	1 MΩ
TrueΩ Resolution 7 4-Wire Low Current OFF Filter ON Fast OFF Front Input Internal Guard	TrueΩ Resolution 7 4-Wire Low Current OFF & ON Filter ON Fast OFF Front Input Internal Guard	Normal Ω Resolution 7 4-Wire Low Current OFF Filter ON Fast OFF Front Input Internal Guard

AC Voltage

AC voltage function of the travelling standard was calibrated by AC-DC transfer method. At each test frequency, first AC voltage from a calibrator was applied to the parallel connected AC-DC Transfer Standard and the travelling standard, and then DC voltage of the calibrator was adjusted to produce as close as possible output on the transfer standard to those produced by test AC voltage. After initial adjustment, measurement cycles continued by applying AC and DC voltages to the transfer standard and the travelling standard in a sequence: AC, DC-, DC+, AC. First, error of the AC voltage was calculated then the errors of the travelling standard were determined using the formula (1).

A settling time of more than 5 min was allowed before starting measurements.

During the measurement, the travelling standard was set to the configurations below:

Resolution 6; Transfer ON; AC Coupled; RMS Filter 100 Hz (RMS Filter 40 Hz for measurement points at 55 Hz); Front Input, Internal Guard

AC Current

AC current function of the travelling standard was calibrated by sets of AC/DC current shunt & AC/DC transfer standard. AC/DC current shunts were connected in series with the travelling standard and the voltage drops across these current shunts were measured by AC/DC transfer standard. The applied AC current was calculated from DC current measured by the travelling standard and the determined AC/DC current transfer difference. The error of the travelling standard was determined by comparing the reading of the standard to the applied AC current using the formula (1).

A settling time of more than 5 min for 10 mA and 30 min for 1 A were allowed before starting measurements.

During the measurement, the travelling standard was set to the configurations below:

Resolution 6; AC Coupled; RMS Filter 100 Hz; Front Input, Internal Guard

MEASUREMENT RESULTS

During the comparison, the travelling standard was measured by TÜBİTAK UME at beginning and end of each loop which consist of no more than 3 institutes in order to monitor the performance of the travelling standard. The values reported by TÜBİTAK UME is the average of 8 measurements performed by TÜBİTAK UME. The all measurements results of TÜBİTAK UME and the drift of the travelling standard, evaluated from these results are given in Appendix A.

DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 mV	+ 100 mV	99.99984 mV	100.00005 mV	2.1 µV/V	2.9 µV/V
20 V	+ 10 V	9.999994 V	10.000036 V	4.2 µV/V	0.8 µV/V
200 V	+ 100 V	100.00000 V	99.99978 V	-2.2 µV/V	1.1 µV/V
1000 V	+ 1000 V	1000.0013 V	999.9998 V	-1.5 µV/V	1.4 µV/V

DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 µA	+ 100 µA	100.00007 µA	99.99922 µA	-8 µA/A	10 µA/A
20 mA	+ 10 mA	9.999962 mA	10.000191 mA	23 µA/A	10 µA/A
2 A	+ 1 A	1.0000216 A	0.9998975 A	-124 µA/A	12 µA/A

DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
20 Ω	TrueΩ	10 Ω	10.000164 Ω	10.000309 Ω	14.5 µΩ/Ω	1.3 µΩ/Ω
20 kΩ	TrueΩ	10 kΩ	9.999882 kΩ	9.999972 kΩ	9.0 µΩ/Ω	3.0 µΩ/Ω
	TrueΩ LoI	10 kΩ	9.999885 kΩ	9.999984 kΩ	9.9 µΩ/Ω	3.0 µΩ/Ω
2 MΩ	Normal Ω	1 MΩ	0.9999520 MΩ	0.9999612 MΩ	9.2 µΩ/Ω	6.0 µΩ/Ω

AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Voltage	Frequency				
200 mV	100 mV	55 Hz	100.0000 mV	100.0000 mV	0.000 mV/V	0.040 mV/V
	100 mV	1 kHz	100.0000 mV	100.0044 mV	0.044 mV/V	0.040 mV/V
20 V	10 V	55 Hz	10.00000 V	10.00050 V	0.050 mV/V	0.011 mV/V
	10 V	1 kHz	10.00000 V	10.00095 V	0.095 mV/V	0.010 mV/V
	10 V	100 kHz	10.00000 V	10.00065 V	0.065 mV/V	0.016 mV/V
200 V	100 V	55 Hz	100.0000 V	99.9988 V	-0.012 mV/V	0.015 mV/V
	100 V	1 kHz	100.0000 V	100.0028 V	0.028 mV/V	0.018 mV/V

AC CURRENT

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Current	Frequency				
20 mA	10 mA	300 Hz	10.00000 mA	10.00057 mA	0.057 mA/A	0.020 mA/A
	10 mA	1 kHz	10.00000 mA	10.00074 mA	0.074 mA/A	0.020 mA/A
2 A	1 A	300 Hz	1.000000 A	0.999902 A	-0.098 mA/A	0.035 mA/A
	1 A	1 kHz	1.000000 A	0.999967 A	-0.033 mA/A	0.035 mA/A

[1] *Expanded uncertainty corresponding to the coverage probability of approximately 95 %.*

5. UNCERTAINTY BUDGET

5.1. Uncertainty Budget for DC Voltage

Model Function:

$$E = V_{ix} - V_s + \delta V_{ix} - \delta V_s - \delta V_{emf}$$

Table 1. Uncertainty budget for 100 mV

Quantity X_i		**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** ν_i
V_{ix}	Voltage, indicated by the UUT	100.00005 mV	0.01 µV	Normal	1	0.01 µV	9
V_s	The voltage, generated by the reference calibrator	99.99984 mV	0.07 µV	Normal	-1	0.07 µV	100
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.00000 mV	0.003 µV	Rectangular	1	0.00 µV	100
δV_s	Correction of the voltage, generated by the calibrator (drift etc.)	0.00000 mV	0.12 µV	Rectangular	-1	0.12 µV	100
δV_{emf}	Voltage correction due to the residual emf voltages	0.00000 mV	0.05 µV	Rectangular	1	0.05 µV	100
E_x	The error of UUT	**0.00021 mV**				**Combined Uncertainty, $u(E_x)$**	0.14 µV
						Effective Degrees of Freedom, ν_{eff}	200
		2.1 µV/V				**Coverage Factor, k**	2.01
						Expanded Uncertainty, $U(E_x)$	0.29 µV
							2.9 µV/V

Table 2. Uncertainty budget for 10 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the UUT	10.000036 V	0.16 µV	Normal	1	0.16 µV	9
V_s	The voltage, generated by the calibrator	9.999994 V	2.50 µV	Normal	-1	2.50 µV	100
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.000000 V	0.29 µV	Rectangular	1	0.29 µV	100
δV_s	Correction of the voltage, generated by the calibrator (drift etc.)	0.000000 V	2.89 µV	Rectangular	-1	2.89 µV	100
δV_{emf}	Voltage correction due to the residual emf voltages	0.000000 V	0.05 µV	Rectangular	1	0.05 µV	100
E_x	The error of UUT	0.000042 V	**Combined Uncertainty, $u(E_x)$**				3.8 µV
			Effective Degrees of Freedom, v_{eff}				199
		4.2 µV/V	**Coverage Factor, k**				2.01
			Expanded Uncertainty, $U(E_x)$				7.7 µV
							0.8 µV/V

Table 3. Uncertainty budget for 100 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	Voltage, indicated by the UUT	99.99978 V	2.2 µV	Normal	1	2.2 µV	9
V_s	The voltage, generated by the calibrator	100.00000 V	40 µV	Normal	-1	40.0 µV	100
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.00000 V	2.9 µV	Rectangular	1	2.9 µV	100
δV_s	Correction of the voltage, generated by the calibrator (drift etc.)	0.00000 V	40.4 µV	Rectangular	-1	40.4 µV	100
δV_{emf}	Voltage correction due to the residual emf voltages	0.00000 V	0.05 µV	Rectangular	1	0.05 µV	100
E_x	The error of UUT	-0.00022 V				**Combined Uncertainty, $u(E_x)$**	57 µV
						Effective Degrees of Freedom, ν_{eff}	202
		-2.2 µV/V				**Coverage Factor, k**	2.01
						Expanded Uncertainty, $U(E_x)$	0.11 mV
							1.1 µV/V

Table 4. Uncertainty budget for 1000 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	Voltage, indicated by the UUT	999.9998 V	22 µV	Normal	1	22 µV	9
V_s	The voltage, generated by the calibrator	1000.0013 V	400 µV	Normal	-1	400 µV	100
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.0000 V	29 µV	Rectangular	1	29 µV	100
δV_s	Correction of the voltage, generated by the calibrator (drift etc.)	0.0000 V	577 µV	Rectangular	-1	577 µV	100
δV_{emf}	Voltage correction due to the residual emf voltages	0.0000 V	0.05 µV	Rectangular	1	0.05 µV	100
E_x	The error of UUT	-0.0015 V	**Combined Uncertainty, $u(E_x)$**				703 µV
			Effective Degrees of Freedom, ν_{eff}				179
		-1.5 µV/V	**Coverage Factor, k**				2.01
			Expanded Uncertainty, $U(E_x)$				1.4 mV
							1.4 µV/V

5.2. Uncertainty Budget for DC Current

Model Function:

$$E_x = I_{ix} - \frac{V_{DVM} + \delta V_{DVM} + \delta V_{DVMX} + \delta V_{EMF}}{R_S + \delta R_S + \delta R_p} + \delta I_{ix} + \delta I_L$$

Table 5. Uncertainty budget for 100 µA

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I_{ix}	Current, indicated by the UUT	99.99922 µA	0.000001 µA	Normal	1	0.00000 µA	9
V_{DVM}	Voltage indicated by the reference voltmeter	99.99876 mV	0.00003 mV	Normal	0.001 Ω^{-1}	0.00003 µA	9
δV_{DVM}	Correction of Voltmeter	0.00000 mV	0.00025 mV	Normal	0.001 Ω^{-1}	0.00025 µA	100
δV_{DVMX}	Correction of Voltmeter due to its drift	0.00000 mV	0.00038 mV	Rectangular	0.001 Ω^{-1}	0.00038 µA	100
δV_{EMF}	Correction due to uncompensated emf voltages	0.00000 mV	0.00005 mV	Rectangular	0.001 Ω^{-1}	0.00005 µA	100
R_S	Resistance of the DC current shunt	999.987 Ω	0.0015 Ω	Normal	-0.1 µV/Ω^2	0.00015 µA	100
δR_S	Correction due to drift of the DC current shunt	0.000 Ω	0.0012 Ω	Rectangular	-0.1 µV/Ω^2	0.00012 µA	100
δR_p	Correction due to power coefficient of DC current shunt	0.000 Ω	0.0000 Ω	Rectangular	-0.1 µV/Ω^2	0.00000 µA	100
δI_{ix}	Correction due to finite resolution of UUT	0.00000 µA	0.000029 µA	Rectangular	1	0.00003 µA	100
δI_L	Correction due to finite input impedance of the reference voltmeter	0.00000 µA	0.00001 µA	Rectangular	1	0.00001 µA	100
E_x	The error of UUT	-0.0008 µA	**Combined Uncertainty, $u(E_x)$**				0.00049µA
			Effective Degrees of Freedom, ν_{eff}				243
		-8 µA/A	**Coverage Factor, k**				2.01
			Expanded Uncertainty, $U(E_x)$				0.0010 µA
							10 µA/A

Table 7. Uncertainty budget for ±10 mA

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current, indicated by the UUT	10.000191 mA	0.0000009 mA	Normal	1	0.000001 mA	9
V_{DVM}	Voltage indicated by the reference voltmeter	99.99962 mV	0.00003 mV	Normal	0.1 Ω^{-1}	0.000003 mA	9
δV_{DVM}	Correction of Voltmeter	0.00000 mV	0.00025 mV	Normal	0.1 Ω^{-1}	0.000025 mA	100
δV_{DVMX}	Correction of Voltmeter due to its drift	0.00000 mV	0.00038 mV	Rectangular	0.1 Ω^{-1}	0.000038 mA	100
δV_{EMF}	Correction due to uncompensated emf voltages	0.00000 mV	0.00005 mV	Rectangular	0.1 Ω^{-1}	0.000005 mA	100
R_S	Resistance of the DC current shunt	10.00000 Ω	0.000015 Ω	Normal	-0.001 V/Ω^2	0.000015 mA	100
δR_S	Correction due to drift of the DC current shunt	0.00000 Ω	0.000009 Ω	Rectangular	-0.001 V/Ω^2	0.000009 mA	100
δR_p	Correction due to power coefficient of DC current shunt	0.00000 Ω	0.000000 Ω	Rectangular	-0.001 V/Ω^2	0.000000 mA	100
δI_{ix}	Correction due to finite resolution of UUT	0.000000 mA	0.0000029 mA	Rectangular	1	0.000003 mA	100
δI_L	Correction due to finite input impedance of the reference voltmeter	0.000000 mA	0.00000001 mA	Rectangular	1	0.000000 mA	100
E_x	The error of UUT	0.00023 mA	**Combined Uncertainty, $u(E_x)$**				0.00005 mA
			Effective Degrees of Freedom, v_{eff}				232
		23 µA/A	**Coverage Factor, k**				2.01
			Expanded Uncertainty, $U(E_x)$				0.00010 mA **10 µA/A**

Table 8. Uncertainty budget for ±1 A

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I_{ix}	Current, indicated by the UUT	0.9998975 A	0.0000001 A	Normal	1	0.0000001 A	9
V_{DVM}	Voltage indicated by the reference voltmeter	100.00632 mV	0.00003 mV	Normal	10 Ω^{-1}	0.0000003 A	9
δV_{DVM}	Correction of Voltmeter	0.00000 mV	0.00025 mV	Normal	10 Ω^{-1}	0.0000025 A	100
δV_{DVMX}	Correction of Voltmeter due to its drift	0.00000 mV	0.00038 mV	Rectangular	10 Ω^{-1}	0.0000038 A	100
δV_{EMF}	Correction due to uncompensated emf voltages	0.00000 mV	0.00005 mV	Rectangular	10 Ω^{-1}	0.0000005 A	100
R_S	Resistance of the DC current shunt	0.100004 Ω	0.0000003 Ω	Normal	-10 V/Ω^2	0.0000030 A	100
δR_S	Correction due to drift of the DC current shunt	0.000000 Ω	0.0000002 Ω	Rectangular	-10 V/Ω^2	0.0000017 A	100
δR_p	Correction due to power coefficient of DC current shunt	0.000000 Ω	0.0000000 Ω	Rectangular	-10 V/Ω^2	0.0000000 A	100
δI_{ix}	Correction due to finite resolution of UUT	0.000000 A	0.00000003 A	Rectangular	1	0.0000000 A	100
δI_L	Correction due to finite input impedance of the reference voltmeter	0.000000 A	0.00000000 A	Rectangular	1	0.0000000 A	100
E_x	The error of UUT	-0.000124 A				**Combined Uncertainty, $u(E_x)$**	0.000006 A
						Effective Degrees of Freedom, ν_{eff}	326
		-124 μA/A				**Coverage Factor, k**	2.01
						Expanded Uncertainty, $U(E_x)$	0.000012 A
							12 μA/A

5.3. Uncertainty Budget for DC Resistance

Model Function:

$$E = R_{ix} - R_s + \delta R_{ix} - \delta R_s$$

Table 9. Uncertainty budget for 10 Ω TrueΩ

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	Resistance, indicated by the UUT	10.000309 Ω	0.0000013 Ω	Normal	1	1.3E-06 Ω	9
R_s	The resistance applied by the reference calibrator	10.000164 Ω	0.0000020 Ω	Normal	-1	2.0E-06 Ω	100
δR_{ix}	Correction of the indicated resistance due to the finite resolution of the UUT	0.000000 Ω	0.0000003 Ω	Rectangular	1	2.9E-07 Ω	100
δR_s	Drift of reference calibrator	0.000000 Ω	0.0000058 Ω	Rectangular	-1	5.8E-06 Ω	100
E_x	The error of UUT	0.000145 Ω				**Combined Uncertainty, $u(E_x)$**	0.0000063 Ω
						Effective Degrees of Freedom, v_{eff}	132
		14.5 µΩ/Ω				**Coverage Factor, k**	2.02
						Expanded Uncertainty, $U(E_x)$	0.000013 Ω
							1.3 µΩ/Ω

Table 10. Uncertainty budget for 10 kΩ TrueΩ

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
R_{ix}	Resistance, indicated by the UUT	9.999972 kΩ	0.0000006 kΩ	Normal	1	5.7E-07 kΩ	9
R_s	The resistance applied by the reference calibrator	9.999882 kΩ	0.0000150 kΩ	Normal	-1	1.5E-05 kΩ	100
δR_{ix}	Correction of the indicated resistance due to the finite resolution of the UUT	0.000000 kΩ	0.0000003 kΩ	Rectangular	1	2.9E-07 kΩ	100
δR_s	Drift of reference calibrator	0.000000 kΩ	0.0000006 kΩ	Rectangular	-1	5.8E-07 kΩ	100
E_x	The error of UUT	0.000090 kΩ	**Combined Uncertainty, $u(E_x)$**				0.015 Ω
			Effective Degrees of Freedom, ν_{eff}				101
		9.0 µΩ/Ω	**Coverage Factor, k**				2.03
			Expanded Uncertainty, $U(E_x)$				0.030 Ω
							3.0 µΩ/Ω

Table 11. Uncertainty budget for 10 kΩ TrueΩ LoI

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	Resistance, indicated by the UUT	9.999984 kΩ	0.0000011 kΩ	Normal	1	1.1E-06 kΩ	9
R_s	The resistance applied by the reference calibrator	9.999885 kΩ	0.0000150 kΩ	Normal	-1	1.5E-05 kΩ	100
δR_{ix}	Correction of the indicated resistance due to the finite resolution of the UUT	0.000000 kΩ	0.0000003 kΩ	Rectangular	1	2.9E-07 kΩ	100
δR_s	Drift of reference calibrator	0.000000 kΩ	0.0000006 kΩ	Rectangular	-1	5.8E-07 kΩ	100
E_x	The error of UUT	0.000099 kΩ	**Combined Uncertainty, $u(E_x)$**				0.015 Ω
			Effective Degrees of Freedom, v_{eff}				101
		9.9 µΩ/Ω	**Coverage Factor, k**				2.03
			Expanded Uncertainty, $U(E_x)$				0.030 Ω
							3.0 µΩ/Ω

Table 12. Uncertainty budget for 1 MΩ NormalΩ

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	Resistance, indicated by the UUT	0.9999612 MΩ	0.00003 kΩ	Normal	1	3.2E-08 MΩ	9
R_s	The resistance applied by the reference calibrator	0.9999520 MΩ	0.00275 kΩ	Normal	-1	2.8E-06 MΩ	100
δR_{ix}	Correction of the indicated resistance due to the finite resolution of the UUT	0.0000000 MΩ	0.00003 kΩ	Rectangular	1	2.9E-08 MΩ	100
δR_s	Drift of reference calibrator	0.0000000 MΩ	0.00115 kΩ	Rectangular	-1	1.2E-06 MΩ	100
E_x	The error of UUT	0.0000092 MΩ				**Combined Uncertainty, $u(E_x)$**	0.0030 kΩ
						Effective Degrees of Freedom, v_{eff}	134
		9.2 µΩ/Ω				**Coverage Factor, k**	2.02
						Expanded Uncertainty, $U(E_x)$	0.0060 kΩ
							6.0 µΩ/Ω

5.4. Uncertainty Budget for AC Voltage

Model Function:

$$E_x = V_{ix} + \delta V_{ix} - (V_{DC} + \delta V_{DC}) \times (1 + \delta_{AC-DC} + \delta_{REF} + \delta_{drift} + \delta_{set-up} + \delta_{conn})$$

Table 13. Uncertainty budget for 100 mV, 55 Hz

Quantity X_i		**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** ν_i
V_{ix}	AC Voltage, indicated by the UUT	100.0000 mV	7.91 µV/V	Normal	1	7.91 µV/V	9
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.0000 mV	0.29 µV/V	Rectangular	1	0.29 µV/V	100
V_{DC}	DC Voltage, indicated by the UUT	99.99832 mV	0.16 µV/V	Normal	1	0.16 µV/V	9
δV_{DC}	Correction of DC voltage reading of the UUT	0.00021 mV	1.5 µV/V	Normal	1	1.45 µV/V	100
δ_{AC-DC}	Measured AC/DC voltage transfer difference	-7.3 µV/V	1.2 µV/V	Normal	1	1.15 µV/V	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	22 µV/V	5.0 µV/V	Normal	1	5.00 µV/V	9
δ_{drift}	Correction due to drift of AC/DC transfer standard	0.0 µV/V	2.9 µV/V	Rectangular	1	2.89 µV/V	4
δ_{set-up}	Correction due to AC/DC transfer system	0.0 µV/V	11.5 µV/V	Rectangular	1	11.55 µV/V	100
δ_{conn}	Correction due to frequency dependency of the connection elements	0.0 µV/V	11.5 µV/V	Rectangular	1	11.55 µV/V	100
E_x	The error of UUT	**0.0000 mV**	**Combined Uncertainty, $u(E_x)$**				19.1 µV/V
			Effective Degrees of Freedom, ν_{eff}				153
		-0.000 mV/V	**Coverage Factor, k**				2.02
			Expanded Uncertainty, $U(E_x)$				**39 µV/V**
							0.040 mV/V

Table 14. Uncertainty budget for 100 mV, 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	AC Voltage, indicated by the UUT	100.0044 mV	6.32 µV/V	Normal	1	6.32 µV/V	9
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.0000 mV	0.29 µV/V	Rectangular	1	0.29 µV/V	100
V_{DC}	DC Voltage, indicated by the UUT	99.9951 mV	0.16 µV/V	Normal	1	0.16 µV/V	9
δV_{DC}	Correction of DC voltage reading of the UUT	0.00021 mV	1.5 µV/V	Normal	1	1.45 µV/V	100
$\delta_{AC\text{-}DC}$	Measured AC/DC voltage transfer difference	39.7 µV/V	1.2 µV/V	Normal	1	1.15 µV/V	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	7.0 µV/V	5.0 µV/V	Normal	1	5.00 µV/V	9
δ_{drift}	Correction due to drift of AC/DC transfer standard	0.0 µV/V	2.9 µV/V	Rectangular	1	2.89 µV/V	4
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0.0 µV/V	12.7 µV/V	Rectangular	1	12.70 µV/V	100
δ_{conn}	Correction due to frequency dependency of the connection elements	0.0 µV/V	11.5 µV/V	Rectangular	1	11.55 µV/V	100
E_x	The error of UUT	**0.0044 mV**	**Combined Uncertainty, $u(E_x)$**				19.3 µV/V
			Effective Degrees of Freedom, v_{eff}				196
		0.044 mV/V	**Coverage Factor, k**				2.01
			Expanded Uncertainty, $U(E_x)$				**39 µV/V**
							0.040 mV/V

Table 15. Uncertainty budget for 10 V, 55 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	AC Voltage, indicated by the UUT	10.00050 V	2.21 µV/V	Normal	1	2.21 µV/V	9
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.00000 V	0.29 µV/V	Rectangular	1	0.29 µV/V	100
V_{DC}	DC Voltage, indicated by the UUT	9.999417 V	0.06 µV/V	Normal	1	0.06 µV/V	9
δV_{DC}	Correction of DC voltage reading of the UUT	0.000042 V	0.4 µV/V	Normal	1	0.40 µV/V	100
$\delta_{AC\text{-}DC}$	Measured AC/DC voltage transfer difference	49.1 µV/V	0.6 µV/V	Normal	1	0.58 µV/V	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	5.0 µV/V	2.5 µV/V	Normal	1	2.50 µV/V	9
δ_{drift}	Correction due to drift of AC/DC transfer standard	0.0 µV/V	1.2 µV/V	Rectangular	1	1.15 µV/V	4
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0.0 µV/V	2.9 µV/V	Rectangular	1	2.89 µV/V	100
δ_{conn}	Correction due to frequency dependency of the connection elements	0.0 µV/V	2.9 µV/V	Rectangular	1	2.89 µV/V	100
E_x	The error of UUT	**0.00050 V**				**Combined Uncertainty, $u(E_x)$**	5.5 µV/V
						Effective Degrees of Freedom, ν_{eff}	100
		0.050 mV/V				**Coverage Factor, k**	2.03
						Expanded Uncertainty, $U(E_x)$	**11 µV/V**
							0.011 mV/V

Table 16. Uncertainty budget for 10 V, 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	AC Voltage, indicated by the UUT	10.00095 V	0.63 μV/V	Normal	1	0.63 μV/V	9
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.00000 V	0.29 μV/V	Rectangular	1	0.29 μV/V	100
V_{DC}	DC Voltage, indicated by the UUT	9.999008 V	0.06 μV/V	Normal	1	0.06 μV/V	9
δV_{DC}	Correction of DC voltage reading of the UUT	0.000042 V	0.40 μV/V	Normal	1	0.40 μV/V	100
$\delta_{AC\text{-}DC}$	Measured AC/DC voltage transfer difference	94.0 μV/V	0.17 μV/V	Normal	1	0.17 μV/V	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	1.0 μV/V	2.5 μV/V	Normal	1	2.50 μV/V	9
δ_{drift}	Correction due to drift of AC/DC transfer standard	0.0 μV/V	1.2 μV/V	Rectangular	1	1.15 μV/V	4
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0.0 μV/V	2.9 μV/V	Rectangular	1	2.89 μV/V	100
δ_{conn}	Correction due to frequency dependency of the connection elements	0.0 μV/V	2.9 μV/V	Rectangular	1	2.89 μV/V	100
E_x	The error of UUT	**0.00095 V**	**Combined Uncertainty, $u(E_x)$**				5.0 μV/V
			Effective Degrees of Freedom, v_{eff}				100
		0.095 mV/V	**Coverage Factor, k**				2.03
			Expanded Uncertainty, $U(E_x)$				**10 μV/V**
							0.010 mV/V

Table 17. Uncertainty budget for 10 V, 100 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	AC Voltage, indicated by the UUT	10.00065 V	0.63 µV/V	Normal	1	0.63 µV/V	9
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.00000 V	0.29 µV/V	Rectangular	1	0.29 µV/V	100
V_{DC}	DC Voltage, indicated by the UUT	9.999260 V	0.06 µV/V	Normal	1	0.06 µV/V	9
δV_{DC}	Correction of DC voltage reading of the UUT	0.000042 V	0.40 µV/V	Normal	1	0.40 µV/V	100
$\delta_{AC\text{-}DC}$	Measured AC/DC voltage transfer difference	52.8 µV/V	1.15 µV/V	Normal	1	1.15 µV/V	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	17 µV/V	2.5 µV/V	Normal	1	2.50 µV/V	9
δ_{drift}	Correction due to drift of AC/DC transfer standard	0.0 µV/V	2.9 µV/V	Rectangular	1	2.89 µV/V	4
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0.0 µV/V	3.5 µV/V	Rectangular	1	3.46 µV/V	100
δ_{conn}	Correction due to frequency dependency of the connection elements	0.0 µV/V	5.8 µV/V	Rectangular	1	5.77 µV/V	100
E_x	The error of UUT	**0.00065 V**	**Combined Uncertainty, $u(E_x)$**				7.9 µV/V
			Effective Degrees of Freedom, ν_{eff}				110
		0.065 mV/V	**Coverage Factor, k**				2.02
			Expanded Uncertainty, $U(E_x)$				**16 µV/V**
							0.016 mV/V

Table 18. Uncertainty budget for 100 V, 55 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	AC Voltage, indicated by the UUT	99.9988 V	2.53 µV/V	Normal	1	2.53 µV/V	9
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.0000 V	0.29 µV/V	Rectangular	1	0.29 µV/V	100
V_{DC}	DC Voltage, indicated by the UUT	100.00060 V	0.06 µV/V	Normal	1	0.06 µV/V	9
δV_{DC}	Correction of DC voltage reading of the UUT	-0.00022 V	0.55 µV/V	Normal	1	0.55 µV/V	100
$\delta_{AC\text{-}DC}$	Measured AC/DC voltage transfer difference	-7.8 µV/V	0.58 µV/V	Normal	1	0.58 µV/V	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	4.0 µV/V	5.0 µV/V	Normal	1	5.00 µV/V	9
δ_{drift}	Correction due to drift of AC/DC transfer standard	0.0 µV/V	1.7 µV/V	Rectangular	1	1.73 µV/V	4
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0.0 µV/V	2.9 µV/V	Rectangular	1	2.89 µV/V	100
δ_{conn}	Correction due to frequency dependency of the connection elements	0.0 µV/V	2.9 µV/V	Rectangular	1	2.89 µV/V	100
E_x	The error of UUT	**-0.0012 V**				**Combined Uncertainty, $u(E_x)$**	7.2 µV/V
						Effective Degrees of Freedom, ν_{eff}	35
		-0.012 mV/V				**Coverage Factor, k**	2.08
						Expanded Uncertainty, $U(E_x)$	**15 µV/V**
							0.015 mV/V

Table 19. Uncertainty budget for 100 V, 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	AC Voltage, indicated by the UUT	100.0028 V	0.32 µV/V	Normal	1	0.32 µV/V	9
δV_{ix}	Correction of the indicated voltage due to the finite resolution of the UUT	0.0000 V	0.29 µV/V	Rectangular	1	0.29 µV/V	100
V_{DC}	DC Voltage, indicated by the UUT	99.99675 V	0.06 µV/V	Normal	1	0.06 µV/V	9
δV_{DC}	Correction of DC voltage reading of the UUT	-0.00022 V	0.55 µV/V	Normal	1	0.55 µV/V	100
$\delta_{AC\text{-}DC}$	Measured AC/DC voltage transfer difference	31.7 µV/V	0.58 µV/V	Normal	1	0.58 µV/V	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	3.0 µV/V	7.5 µV/V	Normal	1	7.50 µV/V	9
δ_{drift}	Correction due to drift of AC/DC transfer standard	0.0 µV/V	0.9 µV/V	Rectangular	1	0.87 µV/V	4
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0.0 µV/V	2.9 µV/V	Rectangular	1	2.89 µV/V	100
δ_{conn}	Correction due to frequency dependency of the connection elements	0.0 µV/V	1.7 µV/V	Rectangular	1	1.73 µV/V	100
E_x	The error of UUT	**0.0028 V**	**Combined Uncertainty, $u(E_x)$**				8.3 µV/V
			Effective Degrees of Freedom, ν_{eff}				14
		0.028 mV/V	**Coverage Factor, k**				2.21
			Expanded Uncertainty, $U(E_x)$				**18 µV/V**
							0.018 mV/V

5.5. Uncertainty Budget for AC Current

Model Function:

$$E_x = I_{ix} + \delta I_{ix} - (I_{DC} + \delta I_{DC}) \times (1 + \delta_{AC-DC} + \delta_{REF} + \delta_{drift} + \delta_{set-up})$$

Table 20. Uncertainty budget for 10 mA, 300 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I_{ix}	AC current, indicated by the UUT	10.00057 mA	0.95 µA/A	Normal	1	0.9 µA/A	9
δI_{ix}	Correction of the indicated current due to the finite resolution of the UUT	0.00000 mA	0.29 µA/A	Rectangular	1	0.3 µA/A	100
I_{DC}	DC current, indicated by the UUT	9.99933 mA	0.09 µA/A	Normal	1	0.1 µA/A	9
δI_{DC}	Correction of DC current reading of the UUT	0.00023 mA	5.0 µA/A	Normal	1	5.0 µA/A	100
δ_{AC-DC}	Measured AC/DC current transfer difference	40.8 µA/A	1.15 µA/A	Normal	1	1.2 µA/A	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	3 µA/A	5.5 µA/A	Normal	1	5.5 µA/A	4
δ_{drift}	Correction due to drift of AC/DC transfer standard	0 µA/A	2.9 µA/A	Rectangular	1	2.9 µA/A	100
δ_{set-up}	Correction due to AC/DC transfer system	0 µA/A	4.6 µA/A	Rectangular	1	4.6 µA/A	100
E_x	The error of UUT	**0.00057 mA**				**Combined Uncertainty, $u(E_x)$**	9.3 µA/A
						Effective Degrees of Freedom, ν_{eff}	32
		57 µA/A				**Coverage Factor, k**	2.08
						Expanded Uncertainty, $U(E_x)$	20 µA/A
							0.020 mA/A

Table 21. Uncertainty budget for 10 mA, 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I_{ix}	AC current, indicated by the UUT	10.00074 mA	0.32 µA/A	Normal	1	0.3 µA/A	9
δI_{ix}	Correction of the indicated current due to the finite resolution of the UUT	0.00000 mA	0.29 µA/A	Rectangular	1	0.3 µA/A	100
I_{DC}	DC current, indicated by the UUT	9.99917 mA	0.09 µA/A	Normal	1	0.1 µA/A	9
δI_{DC}	Correction of DC current reading of the UUT	0.00023 mA	5.0 µA/A	Normal	1	5.0 µA/A	100
$\delta_{AC\text{-}DC}$	Measured AC/DC current transfer difference	60 µA/A	0.58 µA/A	Normal	1	0.6 µA/A	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	0 µA/A	5.5 µA/A	Normal	1	5.5 µA/A	4
δ_{drift}	Correction due to drift of AC/DC transfer standard	0 µA/A	2.9 µA/A	Rectangular	1	2.9 µA/A	100
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0 µA/A	4.6 µA/A	Rectangular	1	4.6 µA/A	100
E_x	The error of UUT	**0.00074 mA**	**Combined Uncertainty, $u(E_x)$**				9.2 µA/A
			Effective Degrees of Freedom, ν_{eff}				30
		74 µA/A	**Coverage Factor, k**				2.09
			Expanded Uncertainty, $U(E_x)$				20 µA/A
							0.020 mA/A

Table 22. Uncertainty budget for 1 A, 300 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I_{ix}	AC current, indicated by the UUT	0.999902 A	1.90 µA/A	Normal	1	1.9 µA/A	9
δI_{ix}	Correction of the indicated current due to the finite resolution of the UUT	0.000000 A	0.29 µA/A	Rectangular	1	0.3 µA/A	100
I_{DC}	DC current, indicated by the UUT	1.000093 A	0.13 µA/A	Normal	1	0.1 µA/A	9
δI_{DC}	Correction of DC current reading of the UUT	-0.000124 A	6.0 µA/A	Normal	1	6.0 µA/A	100
$\delta_{AC\text{-}DC}$	Measured AC/DC current transfer difference	26.9 µA/A	0.87 µA/A	Normal	1	0.9 µA/A	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	4 µA/A	10.5 µA/A	Normal	1	10.5 µA/A	4
δ_{drift}	Correction due to drift of AC/DC transfer standard	0 µA/A	5.8 µA/A	Rectangular	1	5.8 µA/A	100
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0 µA/A	8.7 µA/A	Rectangular	1	8.7 µA/A	100
E_x	The error of UUT	**-0.000098 A**	**Combined Uncertainty, $u(E_x)$**				16.1 µA/A
			Effective Degrees of Freedom, ν_{eff}				22
		-98 µA/A	**Coverage Factor, k**				2.13
			Expanded Uncertainty, $U(E_x)$				35 µA/A
							0.035 mA/A

Table 23. Uncertainty budget for 1 A, 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I_{ix}	AC current, indicated by the UUT	0.999967 A	1.90 µA/A	Normal	1	1.9 µA/A	9
δI_{ix}	Correction of the indicated current due to the finite resolution of the UUT	0.000000 A	0.29 µA/A	Rectangular	1	0.3 µA/A	100
I_{DC}	DC current, indicated by the UUT	1.000033 A	0.13 µA/A	Normal	1	0.1 µA/A	9
δI_{DC}	Correction of DC current reading of the UUT	-0.000124 A	6.0 µA/A	Normal	1	6.0 µA/A	100
$\delta_{AC\text{-}DC}$	Measured AC/DC current transfer difference	92.3 µA/A	0.69 µA/A	Normal	1	0.7 µA/A	3
δ_{REF}	AC/DC transfer difference of the AC/DC transfer standard	-1 µA/A	10.5 µA/A	Normal	1	10.5 µA/A	4
δ_{drift}	Correction due to drift of AC/DC transfer standard	0 µA/A	5.8 µA/A	Rectangular	1	5.8 µA/A	100
$\delta_{set\text{-}up}$	Correction due to AC/DC transfer system	0 µA/A	8.7 µA/A	Rectangular	1	8.7 µA/A	100
E_x	The error of UUT	**-0.000033 A**	**Combined Uncertainty, $u(E_x)$**				16.1 µA/A
			Effective Degrees of Freedom, ν_{eff}				21
		-33 µA/A	**Coverage Factor, *k***				2.13
			Expanded Uncertainty, $U(E_x)$				35 µA/A
							0.035 mA/A

Appendix A: Drift of the Travelling Standard

Function	Range of Travelling Std.	Measurement Point	Drift per Day	Drift Uncertainty (*k*=1)
DC Voltage	200 mV	100 mV	0.000759 µV/V	0.25 µV/V
	20 V	10 V	0.000277 µV/V	0.14 µV/V
	200 V	100 V	-0.001938 µV/V	0.17 µV/V
	1000 V	1000 V	-0.002353 µV/V	0.20 µV/V
DC Current	200 µA	100 µA	-0.00273 µA/A	0.74 µA/A
	20 mA	10 mA	0.00329 µA/A	0.58 µA/A
	2 A	1 A	-0.03609 µA/A	1.8 µA/A
AC Voltage	200 mV	100 mV @ 55 Hz	-0.01005 µV/V	2.2 µV/V
		100 mV @ 1 kHz	-0.00648 µV/V	2.2 µV/V
	20 V	10 V @ 55 Hz	0.00009 µV/V	0.58 µV/V
		10 V @ 1 kHz	0.00129 µV/V	0.71 µV/V
		10 V @ 100 kHz	-0.03399 µV/V	6.2 µV/V
	200 V	100 V @ 55 Hz	-0.00278 µV/V	1.1 µV/V
		100 V @ 1 kHz	-0.00179 µV/V	1.2 µV/V
AC Current	20 mA	10 mA @ 300 Hz	0.01317 µA/A	1.7 µA/A
		10 mA @ 1 kHz	0.01273 µA/A	1.4 µA/A
	2 A	1 A @ 300 Hz	-0.02973 µA/A	2.3 µA/A
		1 A @ 1 kHz	-0.03034 µA/A	3.7 µA/A
DC Resistance	20 Ω (TrueΩ)	10 Ω	0.003143 µΩ/Ω	0.27 µΩ/Ω
	20 kΩ (TrueΩ)	10 kΩ	0.002281 µΩ/Ω	0.30 µΩ/Ω
		10 kΩ (LOI)	0.002708 µΩ/Ω	0.30 µΩ/Ω
	2 MΩ (Normal)	1 MΩ	0.005075 µΩ/Ω	0.18 µΩ/Ω

1. PARTICIPANT INSTITUTE

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2. PERIOD OF MEASUREMENTS

The measurements were carried out from March 17, 2015 to March 23, 2015.

3. AMBIENT CONDITIONS

Temperature : (23 ± 1) °C

Relative Humidity : (45 ± 10) % rh

4. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Digital multimeter	**FLUKE**	**8508A**	**136561138**	**SIQ, Slovenia**
Calibrator	**FLUKE**	**5520A**	**1343003**	**MBM, Montenegro**

5. MEASUREMENT METHOD

This method uses a high precision digital multimeter, manufacturer FLUKE, type 8508A and calibrator, manufacturer FLUKE, type 5520A. At first we measure voltage, current or resistance with our reference multimeter and after that, we measure voltage, current or resistance with multimeter under test.

6. MEASUREMENT RESULTS

DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 mV	+ 100 mV	99.99912 mV	99.99848 mV	-6.4 µV/V	5.9 µV/V
20 V	+ 10 V	10.000019 V	10.000086 V	6.7 µV/V	1.1 µV/V
200 V	+ 100 V	100.00023 V	100.000092 V	-1.4 µV/V	5.3 µV/V
1000 V	+ 1000 V	999.99382 V	999.99534 V	1.5 µV/V	5.9 µV/V

DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 µA	+ 100 µA	99.99269 µA	99.99111 µA	-0.016 mA/A	0.018 mA/A
20 mA	+ 10 mA	9.99998 mA	10.00029 mA	0.031 mA/A	0.005 mA/A
1 A	+ 1 A	1.000137 A	0.999887 A	-0.25 mA/A	0.09 mA/A

DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
20 Ω	TrueΩ	10 Ω	10.000081 Ω	10.00025 Ω	0.02 mΩ/Ω	0.01 mΩ/Ω
20 kΩ	TrueΩ	10 kΩ	9.999956 kΩ	10.000143 kΩ	0.019 mΩ/Ω	0.008 mΩ/Ω
	TrueΩ LoI	10 kΩ	9.999993 kΩ	10.000098 kΩ	0.011 mΩ/Ω	0.009 mΩ/Ω
2 MΩ	Normal Ω	1 MΩ	1.000003 MΩ	1.000009 MΩ	0.006 mΩ/Ω	0.086 mΩ/Ω

AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99.99861 mV	99.99873 mV	0.00 mV/V	0.16 mV/V
	100 mV	1 kHz	99.99802 mV	100.00301 mV	0.05 mV/V	0.14 mV/V
20 V	10 V	55 Hz	10.00065 V	10.00087 V	0.02 mV/V	0.11 mV/V
	10 V	1 kHz	10.00073 V	10.00085 V	0.01 mV/V	0.12 mV/V
	10 V	100 kHz	10.00006 V	9.99979 V	-0.03 mV/V	0.72 mV/V
200 V	100 V	55 Hz	100.00615 V	100.00177 V	-0.04 mV/V	0.11 mV/V
	100 V	1 kHz	100.00077 V	100.00018 V	-0.01 mV/V	0.09 mV/V

AC CURRENT

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Current	Frequency				
20 mA	10 mA	300 Hz	9.999748 mA	10.001142 mA	0.14 mA/A	0.49 mA/A
	10 mA	1 kHz	10.000422 mA	10.001345 mA	0.09 mA/A	0.49 mA/A
1 A	1 A	300 Hz	1.000132 A	1.000033 A	-0.10 mA/A	0.82 mA/A
	1 A	1 kHz	1.000124 A	0.999964 A	-0.2 mA/A	1.1 mA/A

[1] *Expanded uncertainty corresponding to the coverage probability of approximately 95 %.*

7. UNCERTAINTY BUDGET

7.1. DC Voltage

Model Function:

Error (Ex)=Vix+δVres-Vs-δVs-δVd-δVcs

Table 1. Uncertainty budget for 100 mV

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	99,99848 mV	0,05 µV/V	Normal	1	0,05 µV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,0000 mV	0,03 µV/V	Rectangular	1	0,03 µV/V	1E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	99,99892 mV	0,20 µV/V	Normal	-1	-0,20 µV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,0002 mV	1,00 µV/V	Normal	-1	-1,00 µV/V	1E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,0000 mV	2,75 µV/V	Normal	-1	-2,75 µV/V	1E+99
δV_{cs}	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,0000 mV	0,07 µV/V	Normal	-1	-0,07 µV/V	99
Error (E_x)		-0,00064 mV -6,4 µV/V	**Combined Uncertainty, $u(E_x)$**				2,9 µV/V
			Effective Degrees of Freedom, v_{eff}				4,2E+05
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**5,9 µV/V**

Table 2. Uncertainty budget for 10 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	10,000086 V	0,03 µV/V	Normal	1	0,03 µV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,00000 V	0,03 µV/V	Rectangular	1	0,03 µV/V	1E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	10,00003 V	0,02 µV/V	Normal	-1	-0,02 µV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,000011 V	0,50 µV/V	Normal	-1	-0,50 µV/V	1E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,00000 V	0,20 µV/V	Normal	-1	-0,20 µV/V	1E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,00000 V	0,02 µV/V	Normal	-1	-0,02 µV/V	99
Error (E_x)		0,00007 V 6,7 µV/V	**Combined Uncertainty, $u(E_x)$**				0,54 µV/V
			Effective Degrees of Freedom, v_{eff}				1,6E+06
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**1,1 µV/V**

Table 3. Uncertainty budget for 100 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	100,0000 92 V	0,03 µV/V	Normal	1	0,03 µV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,00000 V	0,03 µV/V	Rectangular	1	0,03 µV/V	1E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	100,0001 7 V	0,03 µV/V	Normal	-1	-0,03 µV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,00006 V	1,0 µV/V	Normal	-1	-1,00 µV/V	1E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,00000 V	2,5 µV/V	Normal	-1	-2,5 µV/V	1E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,00000 V	0,01 µV/V	Normal	-1	-0,01 µV/V	99
Error (E_x)		-0,00014 V -1,4 µV/V	**Combined Uncertainty, $u(E_x)$**				2,6 µV/V
			Effective Degrees of Freedom, v_{eff}				5,6E+08
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**5,3 µV/V**

Table 4. Uncertainty budget for 1000 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	999,9953 4 V	0,05 µV/V	Normal	1	0,05 µV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,0000 V	0,03 µV/V	Rectangular	1	0,03 µV/V	1E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	999,9953 2 V	0,04 µV/V	Normal	-1	-0,04 µV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,0015 V	1,00 µV/V	Normal	-1	-1,0 µV/V	1E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,0000 V	2,7 µV/V	Normal	-1	-2,7 µV/V	1E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,0000 V	0,02 µV/V	Normal	-1	-0,02 µV/V	99
Error (E_x)		0,0015 V 1,5 µV/V	**Combined Uncertainty, $u(E_x)$**				2,9 µV/V
			Effective Degrees of Freedom, v_{eff}				8,7E+07
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**5,9 µV/V**

7.2. DC Current

Model Function:

Error (Ex)=Iix+δIres-Is-δIs-δId-δIcs

Table 5. Uncertainty budget for 100 µA

Quantity X_i		**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** v_i
I_{ix}	Current, indicated by the DMM under test, FLUKE 8508A	99,99111 µA	0,0001 mA/A	Normal	1	0,00005 mA/A	9
δI_{res}	Correction of the indicated current due to the finite resolution of the DMM	0,00000 µA	0,00003 mA/A	Rectangular	1	0,00003 mA/A	1E+99
I_s	Current, indicated by the reference DMM, FLUKE 8508A	99,99269 µA	0,0001 mA/A	Normal	-1	-0,00006 mA/A	9
δI_s	Current correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,00000 µA	0,004 mA/A	Normal	-1	-0,004 mA/A	1E+99
δI_d	Correction of the indicated current due to drift of the reference DMM, FLUKE 8508A	0,00000 µA	0,008 mA/A	Normal	-1	-0,008 mA/A	1,00E+99
δIcs	Correction of the indicated current due to short term stablity of calibrator FLUKE 5520A	0,00000 µA	0,00004 mA/A	Normal	-1	-0,00004 mA/A	99
Error (E_x)		-0,0016 µA -0,016 mA/A	**Combined Uncertainty, $u(E_x)$**				0,01 mA/A
			Effective Degrees of Freedom, v_{eff}				2,9E+09
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,018 mA/A**

Table 6. Uncertainty budget for 10 mA

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current, indicated by the DMM under test, FLUKE 8508A	10,00029 mA	0,00004 mA/A	Normal	1	0,00004 mA/A	9
δI_{res}	Correction of the indicated current due to the finite resolution of the DMM	0,00000 mA	0,00003 mA/A	Rectangular	1	0,00003 mA/A	1E+99
I_s	Current, indicated by the reference DMM, FLUKE 8508A	10,00004 mA	0,00006 mA/A	Normal	-1	-0,00006 mA/A	9
δI_s	Current correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,00006 mA	0,003 mA/A	Normal	-1	-0,003 mA/A	1E+99
δI_d	Correction of the indicated current due to drift of the reference DMM, FLUKE 8508A	0,00000 mA	0,009 mA/A	Normal	-1	-0,009 mA/A	1,00E+99
δIcs	Correction of the indicated current due to short term stablity of calibrator FLUKE 5520A	0,00000 mA	0,0001 mA/A	Normal	-1	-0,0001 mA/A	99
Error (E_x)		0,00031 mA 0,031 mA/A	**Combined Uncertainty, $u(E_x)$**				0,003 mA/A
			Effective Degrees of Freedom, v_{eff}				1,9E+07
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,005 mA/A**

Table 7. Uncertainty budget for 1 A

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current, indicated by the DMM under test, FLUKE 8508A	0,999887 A	0,0002 mA/A	Normal	1	0,000 mA/A	9
δI_{res}	Correction of the indicated current due to the finite resolution of the DMM	0,000000 A	0,00003 mA/A	Rectangular	1	0,000 mA/A	1E+99
I_s	Current, indicated by the reference DMM, FLUKE 8508A	1,000097 A	0,0001 mA/A	Normal	-1	0,000 mA/A	9
δI_s	Current correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,000040 A	0,05 mA/A	Normal	-1	-0,05 mA/A	1E+99
δI_d	Correction of the indicated current due to drift of the reference DMM, FLUKE 8508A	0,000000 A	0,09 mA/A	Normal	-1	-0,09 mA/A	1,00E+99
δIcs	Correction of the indicated current due to short term stablity of calibrator FLUKE 5520A	0,000000 A	0,0002 mA/A	Normal	-1	0,000 mA/A	99
Error (E_x)		-0,00025 A -0,25 mA/A	**Combined Uncertainty, $u(E_x)$**				0,045 mA/A
			Effective Degrees of Freedom, v_{eff}				3,9E+10
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,09 mA/A**

7.3. DC Resistance

Model Function:

Error (Ex)=Rix+δRres-Rs-δRs-δRd-δRcs

Table 8. Uncertainty budget for 10 Ω TrueΩ

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	Resistance, indicated by the DMM under test, FLUKE 8508A	10,00025 Ω	0,0001 mΩ/Ω	Normal	1	0,0001 mΩ/Ω	9
δR_{res}	Correction of the indicated resistance due to the finite resolution of the DMM	0,000000 Ω	0,00003 mΩ/Ω	Rectangular	-1	-0,00003 mΩ/Ω	1E+99
R_s	Resistance, indicated by the reference DMM, FLUKE 8508A	10,000101 Ω	0,0002 mΩ/Ω	Normal	-1	-0,0002 mΩ/Ω	9
δR_s	Resistance correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,000020 Ω	0,0005 mΩ/Ω	Normal	-1	-0,0005 mΩ/Ω	1E+99
δR_d	Correction of the indicated resistance due to drift of the reference DMM, FLUKE 8508A	0,000000 Ω	0,0052 mΩ/Ω	Normal	-1	-0,005 mΩ/Ω	1E+99
δRcs	Correction of the indicated current due to short term stablity of calibrator FLUKE 5520A	0,000000 Ω	0,0002 mΩ/Ω	Normal	-1	-0,0002 mΩ/Ω	99
Error (E_x)		0,0002 Ω 0,02 mΩ/Ω	**Combined Uncertainty, $u(E_x)$**				0,005 mΩ/Ω
			Effective Degrees of Freedom, v_{eff}				7,1E+06
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,01 mΩ/Ω**

Table 9. Uncertainty budget for 10 kΩ TrueΩ

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
R_{ix}	Resistance, indicated by the DMM under test, FLUKE 8508A	10,000143 kΩ	0,00004 kΩ	Normal	1	0,00004 mΩ/Ω	9
δR_{res}	Correction of the indicated resistance due to the finite resolution of the DMM	0,000000 kΩ	0,00003 kΩ	Rectangular	1	0,00003 mΩ/Ω	1E+99
R_s	Resistance, indicated by the reference DMM, FLUKE 8508A	9,999966 kΩ	0,0003 kΩ	Normal	-1	-0,0003 mΩ/Ω	9
δR_s	Resistance correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,000010 kΩ	0,0005 kΩ	Normal	-1	-0,001 mΩ/Ω	1E+99
δR_d	Correction of the indicated resistance due to drift of the reference DMM, FLUKE 8508A	0,000000 kΩ	0,0040 kΩ	Normal	-1	-0,004 mΩ/Ω	1,00E+99
δRcs	Correction of the indicated current due to short term stablity of calibrator FLUKE 5520A	0,000000 kΩ	0,0002 kΩ	Normal	-1	-0,0002 mΩ/Ω	99
Error (E_x)		0,00019 kΩ 0,019 mΩ/Ω				**Combined Uncertainty, $u(E_x)$**	0,004 mΩ/Ω
						Effective Degrees of Freedom, ν_{eff}	2,3E+05
						Coverage Factor, k	2
						Expanded Uncertainty, $U(E_x)$	**0,008 mΩ/Ω**

Table 10. Uncertainty budget for 10 kΩ TrueΩ LoI

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	Resistance, indicated by the DMM under test, FLUKE 8508A	10,000098 kΩ	0,0003 kΩ	Normal	1	0,0003 mΩ/Ω	9
δR_{res}	Correction of the indicated resistance due to the finite resolution of the DMM	0,000000 kΩ	0,00003 kΩ	Rectangular	1	0,00003 mΩ/Ω	1E+99
R_s	Resistance, indicated by the reference DMM, FLUKE 8508A	10,000003 kΩ	0,0002 kΩ	Normal	1	0,0002 mΩ/Ω	9
δR_s	Resistance correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,000010 kΩ	0,0005 kΩ	Normal	1	0,001 mΩ/Ω	1E+99
δR_d	Correction of the indicated resistance due to drift of the reference DMM, FLUKE 8508A	0,000000 kΩ	0,0045 kΩ	Normal	-1	-0,004 mΩ/Ω	1,00E+99
δRcs	Correction of the indicated current due to short term stablity of calibrator FLUKE 5520A	0,000000 kΩ	0,0003 kΩ	Normal	-1	-0,0003 mΩ/Ω	99
Error (E_x)		0,0001 kΩ 0,011 mΩ/Ω	**Combined Uncertainty, $u(E_x)$**				0,005 mΩ/Ω
			Effective Degrees of Freedom, v_{eff}				2,6E+05
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,009 mΩ/Ω**

Table 11. Uncertainty budget for 1 MΩ Normal

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	Resistance, indicated by the DMM under test, FLUKE 8508A	1,000009 MΩ	0,00008 MΩ	Normal	1	0,00008 mΩ/Ω	9
δR_{res}	Correction of the indicated resistance due to the finite resolution of the DMM	0,0000000 MΩ	0,00003 MΩ	Rectangular	1	0,00003 mΩ/Ω	1E+99
R_s	Resistance, indicated by the reference DMM, FLUKE 8508A	1,000001 MΩ	0,00007 MΩ	Normal	-1	-0,00007 mΩ/Ω	9
δR_s	Resistance correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,0000015 MΩ	0,00075 MΩ	Normal	-1	-0,001 mΩ/Ω	1E+99
δR_d	Correction of the indicated resistance due to drift of the reference DMM, FLUKE 8508A	0,0000000 MΩ	0,043 MΩ	Normal	-1	-0,043 mΩ/Ω	1,00E+99
δRcs	Correction of the indicated current due to short term stablity of calibrator FLUKE 5520A	0,0000000 MΩ	0,00009 MΩ	Normal	-1	-0,00009 mΩ/Ω	99
Error (E_x)		0,000006 MΩ 0,006 mΩ/Ω				**Combined Uncertainty, $u(E_x)$**	0,04 mΩ/Ω
						Effective Degrees of Freedom, v_{eff}	4,3E+11
						Coverage Factor, k	2
						Expanded Uncertainty, $U(E_x)$	**0,086 mΩ/Ω**

7.4. AC Voltage

Model Function:

Error (Ex)=Vix+δVres+δVc-Vs-δVs-δVd-δVcs

Table 12. Uncertainty budget for 100 mV @ 55 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	99,99873 mV	0,001 mV/V	Normal	1	0,001 mV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,0000 mV	0,0003 mV/V	Rectangular	1	0,0003 mV/V	1,00E+99
δVc	Correction of the indicated voltage due to connection	0,0000 mV	0,0005 mV/V	Rectangular	1	0,001 mV/V	1,00E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	99,99661 mV	0,002 mV/V	Normal	-1	-0,002 mV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,0020 mV	0,030 mV/V	Normal	-1	-0,030 mV/V	1,00E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,0000 mV	0,075 mV/V	Normal	-1	-0,075 mV/V	1,00E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,0000 mV	0,001 mV/V	Normal	-1	-0,001 mV/V	99
Error (E_x)		0,00012 mV 0,001 mV/V	**Combined Uncertainty, $u(E_x)$**				0,081 mV/V
			Effective Degrees of Freedom, v_{eff}				5,7E+07
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,16 mV/V**

Table 13. Uncertainty budget for 100 mV @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	100,00301 mV	0,003 mV/V	Normal	1	0,003 mV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,0000 mV	0,0003 mV/V	Rectangular	1	0,0003 mV/V	1,00E+99
δVc	Correction of the indicated voltage due to connection	0,0000 mV	0,002 mV/V	Rectangular	1	0,002 mV/V	1,00E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	100,00002 mV	0,002 mV/V	Normal	-1	-0,002 mV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,0020 mV	0,03 mV/V	Normal	-1	-0,03 mV/V	1,00E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,0000 mV	0,06 mV/V	Normal	-1	-0,06 mV/V	1,00E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,0000 mV	0,0009 mV/V	Normal	-1	-0,001 mV/V	99
Error (E_x)		0,005 mV 0,05 mV/V	**Combined Uncertainty, $u(E_x)$**				0,07 mV/V
			Effective Degrees of Freedom, ν_{eff}				2,4E+06
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,14 mV/V**

Table 14. Uncertainty budget for 10 V @ 55 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	10,00087 V	0,001 mV/V	Normal	1	0,0009 mV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,00000 V	0,0003 mV/V	Rectangular	1	0,0003 mV/V	1,00E+99
δVc	Correction of the indicated voltage due to connection	0,00000 V	0,0029 mV/V	Rectangular	1	0,003 mV/V	1,00E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	10,00065 V	0,001 mV/V	Normal	-1	-0,0009 mV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,00000 V	0,015 mV/V	Normal	-1	-0,02 mV/V	1,00E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,00000 V	0,053 mV/V	Normal	-1	-0,05 mV/V	1,00E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,00000 V	0,001 mV/V	Normal	-1	-0,0005 mV/V	99
Error (E_x)		0,00022 V 0,02 mV/V	**Combined Uncertainty, $u(E_x)$**				0,05 mV/V
			Effective Degrees of Freedom, v_{eff}				6,2E+07
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,11 mV/V**

Table 15. Uncertainty budget for 10 V @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	10,00085 V	0,001 mV/V	Normal	1	0,001 mV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,00000 V	0,0003 mV/V	Rectangular	1	0,0003 mV/V	1,00E+99
δVc	Correction of the indicated voltage due to connection	0,00000 V	0,04 mV/V	Rectangular	1	0,04 mV/V	1,00E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	10,00053 V	0,001 mV/V	Normal	-1	-0,001 mV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,00020 V	0,015 mV/V	Normal	-1	-0,02 mV/V	1,00E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,00000 V	0,04 mV/V	Normal	-1	-0,04 mV/V	1,00E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,00000 V	0,0004 mV/V	Normal	-1	-0,0004 mV/V	99
Error (E_x)		0,00012 V 0,01 mV/V	**Combined Uncertainty, $u(E_x)$**				0,06 mV/V
			Effective Degrees of Freedom, v_{eff}				8,0E+07
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,12 mV/V**

Table 16. Uncertainty budget for 10 V @ 100 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	9,99979 V	0,002 mV/V	Normal	1	0,002 mV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,00000 V	0,0003 mV/V	Rectangular	1	0,0003 mV/V	1,00E+99
δVc	Correction of the indicated voltage due to connection	0,00000 V	0,058 mV/V	Rectangular	1	0,06 mV/V	1,00E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	10,00006 V	0,002 mV/V	Normal	-1	-0,002 mV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,00000 V	0,05 mV/V	Normal	-1	-0,050 mV/V	1,00E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,00000 V	0,35 mV/V	Normal	-1	-0,35 mV/V	1,00E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,00000 V	0,0007 mV/V	Normal	-1	-0,001 mV/V	99
Error (E_x)		-0,00027 V -0,03 mV/V	**Combined Uncertainty, $u(E_x)$**				0,36 mV/V
			Effective Degrees of Freedom, ν_{eff}				6,4E+09
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,72 mV/V**

Table 17. Uncertainty budget for 100 V @ 55 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	100,00177 V	0,002 mV/V	Normal	1	0,002 mV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,00000 V	0,0003 mV/V	Rectangular	1	0,0003 mV/V	1,00E+99
δVc	Correction of the indicated voltage due to connection	0,00000 V	0,0005 mV/V	Rectangular	1	0,0005 mV/V	1,00E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	100,0032 V	0,002 mV/V	Normal	-1	-0,002 mV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,00300 V	0,02 mV/V	Normal	-1	-0,02 mV/V	1,00E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,00000 V	0,05 mV/V	Normal	-1	-0,05 mV/V	1,00E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,00000 V	0,001 mV/V	Normal	-1	-0,001 mV/V	99
Error (E_x)		-0,004 V -0,04 mV/V	**Combined Uncertainty, $u(E_x)$**				0,06 mV/V
			Effective Degrees of Freedom, ν_{eff}				6,9E+06
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,11 mV/V**

Table 18. Uncertainty budget for 100 V @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage, indicated by the DMM under test, FLUKE 8508A	100,00018 V	0,0004 mV/V	Normal	1	0,0004 mV/V	9
δV_{res}	Correction of the indicated voltage due to the finite resolution of the DMM	0,00000 V	0,0003 mV/V	Rectangular	1	0,0003 mV/V	1,00E+99
δVc	Correction of the indicated voltage due to connection	0,00000 V	0,0008 mV/V	Rectangular	1	0,001 mV/V	1,00E+99
V_s	Voltage, indicated by the reference DMM, FLUKE 8508A	100,00077 V	0,0006 mV/V	Normal	-1	-0,001 mV/V	9
δV_s	Voltage correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,00000 V	0,02 mV/V	Normal	-1	-0,02 mV/V	1,00E+99
δV_d	Correction of the indicated voltage due to drift of the reference DMM, FLUKE 8508A	0,00000 V	0,04 mV/V	Normal	-1	-0,04 mV/V	1,00E+99
δVcs	Correction of the indicated voltage due to short time stability of calibrator, FLUKE 5520A	0,00000 V	0,0006 mV/V	Normal	-1	-0,001 mV/V	99
Error (E_x)		-0,00059 V -0,01 mV/V				**Combined Uncertainty, $u(E_x)$**	0,05 mV/V
						Effective Degrees of Freedom, v_{eff}	2,6E+08
						Coverage Factor, k	2
						Expanded Uncertainty, $U(E_x)$	**0,09 mV/V**

7.5. AC Current

Model Function:

Error (Ex)=Iix+δIres+δIc-Is-δIs-δId-δIcs

Table 19. Uncertainty budget for 10 mA @ 300 Hz

Quantity X_i		**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** v_i
I_{ix}	Current, indicated by the DMM under test, FLUKE 8508A	10,001142 mA	0,0006 mA/A	Normal	1	0,001 mA/A	9
δI_{res}	Correction of the indicated current due to the finite resolution of the DMM	0,000000 mA	0,0003 mA/A	Rectangular	1	0,000 mA/A	1,00E+99
δIc	Correction of the indicated current due to connection	0,000000 mA	0,0043 mA/A	Rectangular	1	0,004 mA/A	1,00E+99
I_s	Current, indicated by the reference DMM, FLUKE 8508A	10,001048 mA	0,0009 mA/A	Normal	-1	-0,001 mA/A	9
δI_s	Current correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,001300 mA	0,06 mA/A	Normal	-1	-0,055 mA/A	1,00E+99
δI_d	Correction of the indicated current due to drift of the reference DMM, FLUKE 8508A	0,000000 mA	0,24 mA/A	Normal	-1	-0,240 mA/A	1,00E+99
δIcs	Correction of the indicated current due to short time stability of calibrator, FLUKE 5520A	0,000000 mA	0,002 mA/A	Normal	-1	-0,002 mA/A	99
Error (E_x)		0,0014 mA 0,14 mA/A	**Combined Uncertainty, $u(E_x)$**				0,25 mA/A
			Effective Degrees of Freedom, v_{eff}				1,5E+10
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,49 mA/A**

Table 20. Uncertainty budget for 10 mA @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current, indicated by the DMM under test, FLUKE 8508A	10,001345 mA	0,0009 mA/A	Normal	1	0,001 mA/A	9
δI_{res}	Correction of the indicated current due to the finite resolution of the DMM	0,000000 mA	0,0003 mA/A	Rectangular	1	0,0003 mA/A	1,00E+99
δIc	Correction of the indicated current due to connection	0,000000 mA	0,03 mA/A	Rectangular	1	0,03 mA/A	1,00E+99
I_s	Current, indicated by the reference DMM, FLUKE 8508A	10,001022 mA	0,001 mA/A	Normal	-1	-0,001 mA/A	9
δI_s	Current correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,000600 mA	0,05 mA/A	Normal	-1	-0,05 mA/A	1,00E+99
δI_d	Correction of the indicated current due to drift of the reference DMM, FLUKE 8508A	0,000000 mA	0,24 mA/A	Normal	-1	-0,24 mA/A	1,00E+99
δIcs	Correction of the indicated current due to short time stability of calibrator, FLUKE 5520A	0,000000 mA	0,001 mA/A	Normal	-1	-0,001 mA/A	99
Error (E_x)		0,00092 mA 0,09 mA/A	**Combined Uncertainty, $u(E_x)$**				0,25 mA/A
			Effective Degrees of Freedom, v_{eff}				3,7E+10
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,49 mA/A**

Table 21. Uncertainty budget for 1 A @ 300 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current, indicated by the DMM under test, FLUKE 8508A	1,000033 A	0,002 mA/A	Normal	1	0,002 mA/A	9
δI_{res}	Correction of the indicated current due to the finite resolution of the DMM	0,000000 A	0,0003 mA/A	Rectangular	1	0,003 mA/A	1,00E+99
δIc	Correction of the indicated current due to connection	0,000000 A	0,05 mA/A	Rectangular	1	0,05 mA/A	1,00E+99
I_s	Current, indicated by the reference DMM, FLUKE 8508A	1,000202 A	0,002 mA/A	Normal	-1	-0,002 mA/A	9
δI_s	Current correction obtain from the calibration of the reference DMM, FLUKE 8508A	-0,000070 A	0,07 mA/A	Normal	-1	-0,07 mA/A	1,00E+99
δI_d	Correction of the indicated current due to drift of the reference DMM, FLUKE 8508A	0,000000 A	0,40 mA/A	Normal	-1	-0,40 mA/A	1,00E+99
δIcs	Correction of the indicated current due to short time stability of calibrator, FLUKE 5520A	0,000000 A	0,002 mA/A	Normal	-1	-0,002 mA/A	99
Error (E_x)		-0,0001 A -0,10 mA/A	**Combined Uncertainty, $u(E_x)$**				0,4 mA/A
			Effective Degrees of Freedom, v_{eff}				4,8E+09
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**0,82 mA/A**

Table 22. Uncertainty budget for 1 A @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current, indicated by the DMM under test, FLUKE 8508A	0,999964 A	0,002 mA/A	Normal	1	0,002 mA/A	9
δI_{res}	Correction of the indicated current due to the finite resolution of the DMM	0,000000 A	0,0003 mA/A	Rectangular	1	0,0003 mA/A	1,00E+99
δIc	Correction of the indicated current due to connection	0,000000 A	0,4 mA/A	Rectangular	1	0,4 mA/A	1,00E+99
I_s	Current, indicated by the reference DMM, FLUKE 8508A	1,000124 A	0,003 mA/A	Normal	-1	-0,003 mA/A	9
δI_s	Current correction obtain from the calibration of the reference DMM, FLUKE 8508A	0,000000 A	0,1 mA/A	Normal	-1	-0,1 mA/A	1,00E+99
δI_d	Correction of the indicated current due to drift of the reference DMM, FLUKE 8508A	0,000000 A	0,4 mA/A	Normal	-1	-0,4 mA/A	1,00E+99
δIcs	Correction of the indicated current due to short time stability of calibrator, FLUKE 5520A	0,000000 A	0,001 mA/A	Normal	-1	-0,001 mA/A	99
Error (E_x)		-0,0002 A -0,2 mA/A	**Combined Uncertainty, $u(E_x)$**				0,5 mA/A
			Effective Degrees of Freedom, v_{eff}				5,5E+09
			Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				**1,1 mA/A**

BOSNA I HERCEGOVINA
INSTITUT ZA MJERITELJSTVO
BOSNE I HERCEGOVINE

БОСНА И ХЕРЦЕГОВИНА
ИНСТИТУТ ЗА МЕТРОЛОГИЈУ
БОСНЕ И ХЕРЦЕГОВИНЕ

BOSNIA AND HERZEGOVINA
INSTITUTE OF METROLOGY
OF BOSNIA AND HERZEGOVINA

REPORT OF INTERCOMPARISON

EURAMET Project No 1341- Comparison on Calibration of Multimeter

Issued by :
Laboratory for electrical quantity
Institute of Metrology of Bosnia and Herzegovina

Sarajevo, Jun 2015.

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of Bosnia and Herzegovina
Laboratory for electrical quantity

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Description:	Comparison on Calibration of Multimeter
Project:	EURAMET Project No 1341
Type:	DMM Fluke 8508A
Serial Number:	969656608
Date of receipt:	24-3-2015
Date of measurement:	From 30-3-2015 to 06-04-2015

Date of issue:	Measurements Performed by :	Report Approved By:
10 Jun 2015	Milojevic Vladimir Srdjan Calija Calibration engineer	Jasmina Loncarevic Head of Laboratory for electrical quantities

Laboratory Condition

Ambient Conditions	
Temperature	23±1°C
Relative Humidity	50±10 %

Reference standards used in intercomparison

Reference standards	Serial No.
Reference DMM 8508A/01	154961897
Multifunctional calibrator 5720A	1560210
Set of reference resistors Fluke 742 A 10 Ω , 100Ω, 1kΩ	1481018;1602001;1602002
Reference resistors SR 104 Tegam 10 kΩ	J1-1121629
AC Current shunt SIQ -10 mA	SIQ12067

1. Calibration DC and AC Voltage:

IMBIH reference method used in this intercomparison for calibration DC voltage is **substitution method**. Our reference multimeter DMM Fluke 8508A/01 has been used as reference standard and multifunctional calibrator Fluke 5720A as source of DC volatage. Our reference multimeter is traceable to Slovenian Istitute for Quality (SIQ).

The calibration of the digital multimeter (UUT) was carried out at the points indicated by intercomparison protocol during 5 days in period of 30 Mart - 6 April 2015.

Twenty (20) repeated observations of DC (AC) voltage per each day have been take in account for evalvation mean value (1) and experimental standard uncertanty according to formula (2).

The results are checked in terms of consistency based on the F-test and they prove to belong to a same population. According to that, final mean value (3) have been obtained as weighted mean of all measurement sets as well as weighted standard uncertainty (4). Weights have been taken in account as the reciprocal of the variance of the each sets.

$$\bar{X}_i = \frac{\sum_{i=1}^{20} X_i}{n} \quad (1)$$

$$\sigma_{\bar{X}i} = \sqrt{\frac{\sum_{i=1}^{20} (\bar{X} - X_i)^2}{n(n-1)}} \quad (2)$$

$$\bar{X} = \frac{\sum_{k=1}^{5} \frac{\bar{X}_k}{\sigma_{X_k}^2}}{\sum_{k=1}^{5} \frac{1}{\sigma_{X_k}^2}} \qquad (3)$$

$$\sigma_{\bar{X}} = \sqrt{\frac{1}{\sum_{k=1}^{5} \frac{1}{\sigma_{X_k}^2}}} \qquad (4)$$

Where:
$\bar{X}_i$ - mean value of *i* th set of measurement
$\sigma_{\bar{X}i}$- standard uncertainty of i-th sets of measurement
$\bar{X}$ - weighted mean value
$\sigma_{\bar{X}}$-weighted standard uncertainty

❖ *Uncertainty evaluation*

The measurement uncertainty reported in the tables 1 and 3 have been obtained taking into account all contributing factors to uncertainty which affecting the measurement. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k, which corresponds to a coverage probability of approximately 95 %.

Mathematical model used for evaluation of error and uncertainty of DC and AC voltage :

$$E = V_{ix} + \delta V_{ixres} - \left(V_{iS} + \delta V_{S_{res}} + \delta V_{Scal} + \delta V_{S_{spec}}\right) + \delta V_{STS-MFC}$$

- **E** –Measurement error of the DMM-UUT
- **V_{ix}** -Voltage, indicated by the UUT-DMM
- **δV_{ixres}** -Correction of the indicated voltage due to the finite resolution of the DMM-UUT
- **V_{iS}** -Voltage, indicated by the Ref-DMM 8508A
- **δV_{Sres}** -Correction of the indicated voltage due to the finite resolution of the Ref-DMM 8508A
- **δV_{Sspec}** -Correction of the measured voltage by the the Ref-DMM due to specification (90 day)
- **δV_{Scal}** –Correction due to last calibration of Ref DMM
- **$\delta V_{STS-MFC}$** –Correction due to Short term stability of voltage source (multifunctional calibrator's 24 h specification)

2. Calibration of resistance

Method used in this intecomparison for calibration resistances is **direct method for value 10 Ω and 10 kΩ using our set of refrerence resistors Fluke 742A as reference standard, since for 1 MΩ we used substitution method and refrerence multimeter DMM Fluke 8508A/01 as reference standard** . Our reference resistors are traceable to Czech Metrology Institute and multimetre is traceable to Slovenian Istitute for Quality (SIQ).
The calibration of the digital multimeter (UUT) was carried out at the points indicated by intercomparison protocol during 5 days in period of 30 Mart - 6 April 2015.
Ten observations for direct and twenty for substitution method of resistace per each day have been take in account for evalvation mean value (1) and experimental standard uncertanty according to formula (2). Standard resistors during measurement have been placed in temerature stabilized air bath with temperure stability ±0.05°C.
The results are checked in terms of consistency based on the F-test and they prove to belong to a same population. According to that, final mean value (3) have been obtained as weighted mean of all measurement sets as wel as weighted standard uncertainty (4)

❖ *Uncertainty evaluation*

The measurement uncertainty reported in the table 5 have been obtained taking into account all contributing factors to uncertainty which affecting the measurement. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k, which corresponds to a coverage probability of approximately 95 %.

Mathematical models used for evaluation of error and uncertainty of resistance for direct and substitution method are :

Direct method:

$$E = R_{ix} + \delta R_{ixres} - \left(R'_S + \delta R_{drift} + \delta R'_{Scal} + \delta R_{S_{temp}}\right)$$

Substitution method:

$$E = R_{ix} + \delta R_{ixres} - \left(R''_{iS} + \delta R_{S_{res}} + \delta R''_{Scal} + \delta R_{S_{spec}}\right)$$

- **E** -Measurement error of the DMM-UUT
- $\mathbf{R_{ix}}$ -Resistance, indicated by the UUT-DMM
- $\mathbf{\delta R_{ixres}}$ -Correction of the indicated resistance due to the finite resolution of the DMM-UUT
- $\mathbf{R'_S}$ –Resistance of standard resistors

- **R''$_{iS}$** resistance indicated by the Ref-DMM
- **δR$_{Sdrift}$** -Correction of the resistance of standard resistors due to drift
- **δR'$_{Scal}$** - Correction due to last calibration of standard resistors
- **δR$_{Stemp}$** –Correction of resistance of standard resistors due to temperature change
- **δR$_{Sres}$** -Correction of the indicated resistance due to the finite resolution of the Ref-DMM
- **δR$_{Sspec}$** -Correction of the measured resistance by the the Ref-DMM due to specification (90 day)
- **δR''$_{Scal}$** –Correction due to last calibration of Ref DMM

3. Calibration of DC current

IMBIH reference methods used for calibration DC current are **indirect method using Ohm's low for value (100 µA ; 10 mA) and substitution method for value (1 A)**. Set of refrerence resistors Fluke 742A DMM and DMM Fluke 8508A/01 for indirect method and in case of susbstitution method refrerence multimeter DMM Fluke 8508A/01 have been used as reference standards. Our reference resistors are traceable to Czech Metrology Institute and DMM is traceable to Slovenian Istitute for Quality (SIQ).

The calibration of the digital multimeter (UUT) was carried out at the points indicated by intercomparison protocol during 5 days in period of 30 Mart - 6 April 2015.

Ten observations for indirect and twenty for substitution method of current per each day have been take in account for evalvation mean value (1) and experimetal standard uncertanty according to formula (2). Final mean value (3) have been obtained as weighted mean of all measurement sets as wel as weighted standard uncertainty (4).

Standard resistors during measurement have been placed on conditions which exist in laboratory (t=23±1°C and H=50±10%). Nominal value of resistors was chosen in such way that disipated power is less then 10 mW.

❖ *Uncertainty evalvation*

The measurement uncertainty reported in the table 2 have been obtained taking into account all contributing factors to uncertainty which affecting the measurement. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k, which corresponds to a coverage probability of approximately 95 %.

Mathematical model used for evaluation of error and uncertainty of DC current for substitution method is :

$$E = I_{ix} + \delta I_{ixres} - \left(I_{iS} + \delta I_{S_{res}} + \delta I_{S_{cal}} + \delta I_{S_{spec}} \right) + \delta I_{StsMFC}$$

- ***E*** - Measurement error of the DMM-UUT
- I_{ix} -Current, indicated by the DMM-UUT
- I_S -Current, indicated by the Ref-DMM 8508A
- δI_{ixres} -Correction of the indicated current due to the finite resolution of the DMM-UUT
- δI_{Sres} -Correction of the indicated current due to the finite resolution of the Ref-DMM 8508A
- δI_{Scal} –Correction due to last calibration of Ref DMM
- δI_{Sspec} -Correction of the measured current by the the Ref-DMM due to specification (90 day)
- δI_{StsMFC} –Correction due to short term stability of current source (multifunctional calibrator's 24 h specification)

Mathematical model used for evaluation of error and uncertainty of DC current for indirect method is:

$$E_X = I_{iX} + \delta I_{iX} - \frac{V_{iS} + \delta V_{Sspec} + \delta V_{Sresx} + \delta V_{load}}{R_S + \delta R_{drift} + \delta R_{Power} + \delta R_{temp}}$$

Ex -Measurement error of the DMM-UUT

I_{ix} -Current indicated by the UUT-DMM

δI_{ix} -Correction of indicated current due to finite resolution of the UUT-DMM

V_{iS} -Voltage indicated by the reference voltmeter

δV_{Sspec} Correction of indicated voltage due to specification (1 year absolute specification)

δV_{Sresx} -Correction due to finite resolution of the reference voltmeter

δV_{load} -Correction of voltage due to finite input impedance of the reference voltmeter

R_S -Resistance of the standard resistors stated in the calibration certificate

δR_{Drift} -Correction due to drift of standard resistors since its last calibration

δR_{Power} -Correction of resistance of the standard resistor due to power coefficient

δR_{temp} -Correction of resistance of the standard resistor due to change of temperature

4. Calibration of AC current

IMBIH reference methods used for calibration AC current are **substitution method for value (1 A 300 Hz and 1 kHz) and indirect method using reference current shunt for value (10 mA 300 Hz and 1 kHz).** Refrerence current shunt SIQ-10 mA and DMM Fluke 8508A/01 for indirect method and in case of susbstitution method reference multimeter DMM Fluke 8508A/01 have been used as reference standards. Our reference current shunt and Ref DMM are traceable Slovenian Istitute for Quality (SIQ).

The calibration of the digital multimeter (UUT) was carried out at the points indicated by intercomparison protocol during 5 days in period of 30 Mart - 6 April 2015.

Twenty observation of current per each day have been taken in account for evalvation mean value (1) and experimental standard uncertanty according to formula (2). Final mean value (3) have been obtained as weighted mean of all measurement sets as wel as weighted standard uncertainty (4). Standard current shunt during measurement have been placed on conditions which exist in laboratory (t=23±1°C and H=50±10%).

The measurement uncertainty reported in the table 4 have been obtained taking into account all contributing factors to uncertainty which affecting the measurement. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k, which corresponds to a coverage probability of approximately 95 %.

Mathematical model used for evaluation error and uncertainty of AC current for substitution method is:

$$E = I_{ix} + \delta I_{ixres} - \left(I_{iS} + \delta I_{S_{res}} + \delta I_{S_{cal}} + \delta I_{S_{spec}}\right) + \delta I_{StsMFC}$$

- ***E*** - Measurement error of the DMM-UUT
- I_{ix} -Current, indicated by the DMM-UUT
- I_{iS} -Current, indicated by the Ref-DMM 8508A
- δI_{ixres} -Correction of the indicated current due to the finite resolution of the DMM-UUT
- δI_{Sres} -Correction of the indicated current due to the finite resolution of the Ref-DMM
- δI_{Scal} –Correction due to last calibration of Ref DMM
- δI_{Sspec} -Correction of the measured current by the the Ref-DMM due to specification (90 day)
- δI_{StsMFC} – Correction due to short term stability of current source (multifunctional calibrator's 24 h specification)

Mathematical model used for evualvation error and uncertainty of AC current for indirect method via the AC current shun is:

$$E_X = I_{iX} + \delta I_{iX} - \left[\frac{V_{iS} + \delta V_{Sspec} + \delta V_{Sresx}}{R_S + \delta R_{Drift} + \delta R_{Power} + \delta R_{temp}} \cdot (1 + \delta_{AC-DC} + \delta_{drift}) \cdot (1 - \delta_{load})\right]$$

Ex The error of indication of the UUT-DMM

I_{ix} Current indicated by the UUT -DMM

V_{iS} Voltage indicated by the reference voltmeter

δV_{Sspec} Voltage correction due to specification of the voltmeter (1 year spec.)

δV_{Sresx} Correction od voltage due to finite resolution of the reference voltmeter

R_S DC resistance of the current shunt, stated in the calibration certificate

δR_{Drift} Correction due to drift of the reference of the DC current shunt since its last calibration

δR_{temp} Correction of DC resistance of the reference current shunt due to change of temperature

$\boldsymbol{\delta R_{Power}}$ Correction of DC resistance of the reference current shunt due to power coefficient

$\boldsymbol{\delta I_{ix}}$ Correction of indicated current due to finite resolution of the UUT-DMM

$\boldsymbol{\delta_{Load}}$ Correction of circuit loading due to finite input impedance of the reference voltmeter

$\boldsymbol{\delta_{AC\text{-}DC}}$ AC-DC difference of current shunt

$\boldsymbol{\delta_{drift}}$ Correction due to drift of AC-DC difference of the current shunt since its last calibration

1. MEASUREMENT RESULTS

Table 1. DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 mV	+ 100 mV	100,001 09 mV	99,999 99 mV	-11,0 µV/V	5,6 µV/V
20 V	+ 10 V	9,999 976 V	10,000 029 V	5,3 µV/V	2,4 µV/V
200 V	+ 100 V	99,999 76 V	99,999 61V	-1,6 µV/V	4,1 µV/V
1000 V	+ 1000 V	999,999 7 V	999,996 4 V	-3,3 µV/V	4,5 µV/V

Table 2. DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 µA	+ 100 µA	100,002 81 µA	100,000 73 µA	-20,8 µA/A	5,5 µA/A
20 mA	+ 10 mA	10,000 044 mA	10,000 244 mA	20,0 µA/A	3,4 µA/A
1 A	+ 1 A	1,000 059 3 A	0,999 920 7 A	-138,7 µA/A	171,5 µA/A

Table 3. AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99,990 2 mV	99,994 7 mV	45 µV/V	194 µV/V
	100 mV	1 kHz	99,994 7 mV	99,998 9 mV	42 µV/V	180 µV/V
20 V	10 V	55 Hz	10,000 21 V	10,000 53 V	33 µV/V	109 µV/V
	10 V	1 kHz	10,000 05 V	10,000 95 V	90 µV/V	91 µV/V
	10 V	100 kHz	10,000 54 V	10,000 58 V	4 µV/V	714 µV/V
200 V	100 V	55 Hz	100,001 2 V	99,998 0 V	-33 µV/V	115 µV/V
	100 V	1 kHz	99,999 3 V	100,001 8 V	25 µV/V	98 µV/V

Table 4. AC CURRENT

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty
	Current	Frequency				
20 mA	10 mA	300 Hz	10,000 08	10,000 57	49 µA/A	86 µA/A
	10 mA	1 kHz	9,999 76	10,000 69	93 µA/A	86 µA/A
1 A	1 A	300 Hz	1,000 017 A	0,999 920 A	-97 µA/A	843 µA/A
	1 A	1 kHz	1,000 105 A	1,000 071 A	-35 µA/A	843 µA/A

Table 5. DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
20 Ω	TrueΩ	10 Ω	10,000 122 Ω	10,000 262 Ω	14 µΩ/Ω	1,2 µΩ/Ω
20 kΩ	TrueΩ	10 kΩ	10,000 003 kΩ	10,000 090 kΩ	8,7 µΩ/Ω	1,2 µΩ/Ω
	TrueΩ LoI	10 kΩ	10,000 003 kΩ	10,000 101 kΩ	9,8 µΩ/Ω	1,2 µΩ/Ω
2 MΩ	Normal Ω	1 MΩ	1,000 014 1 MΩ	1,000 021 7 MΩ	7,7 µΩ/Ω	5,2 µΩ/Ω

2. BUDGETS OF MEASURMENT UNCERTAINTY

1. DC Voltage results

DC Voltage 100 mV

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (mV)	100,001 09	7,41E-06	normal	-1	-7,41E-06	19
Resolution of Ref DMM (mV)	0	2,89E-06	rectangular	-1	-2,89E-06	inf
90 day specification for Ref DMM (mV)	0	1,20E-04	normal	-1	-1,20E-04	inf
Correction due to last calibration of Ref DMM (mV)	0	1,00E-04	normal	-1	-1,00E-04	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (mV)	0	2,31E-04	normal	1	2,31E-04	inf
Voltage idicated by UUT-DMM (mV)	99,999 99	6,29E-06	normal	1	6,29E-06	19
Resolution of UUT- DMM (mV)	0	2,89E-06	rectagular	1	2,89E-06	inf
Error Ex (mV)	-0,00110	Combined Uncertainty, u(Ex) (mV)				2,79E-04
		Effective degrees of freedom, veff				2,51E+07
Error Ex (µV/V)	-11,0	Coverage Factor, k				2
		Expanded uncertainty U(Ex) (µV/V)				5,6

DC Voltage 10 V

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (V)	9,999 976	2,19E-07	normal	-1	-2,19E-07	19
Resolution of Ref DMM (V)	0	2,89E-07	rectangular	-1	-2,89E-07	inf
90 day specification for Ref DMM (V)	0	9,00E-06	normal	-1	-9,00E-06	inf
Correction due to last calibration of Ref DMM (V)	0	5,00E-06	normal	-1	-5,00E-06	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (V)	0	6,50E-06	normal	1	6,50E-06	inf
Voltage idicated by UUT-DMM (V)	10,000 029	5,03E-07	normal	1	5,03E-07	19
Resolution of UUT- DMM (V)	0	2,89E-07	rectagular	1	2,89E-07	inf
Error Ex (V)	0,000 053	Combined Uncertainty, u(Ex) (V)				1,22E-05
		Effective degrees of freedom, veff				6,33E+06
Error Ex (µV/V)	5,3	Coverage Factor, k				2
		Expanded uncertainty U(Ex) (µV/V)				2,4

DC Voltage 100 V

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (V)	99,999 76	2,46E-06	normal	-1	-2,46E-06	19
Resolution of Ref DMM (V)	0	2,89E-06	rectangular	-1	-2,89E-06	inf
90 day specification for Ref DMM (V)	0	1,50E-04	normal	-1	-1,50E-04	inf
Correction due to last calibration of Ref DMM (V)	0	1,00E-04	normal	-1	-1,00E-04	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (V)	0	9,81E-05	normal	1	9,81E-05	inf
Voltage idicated by UUT-DMM (V)	99,999 61	4,09E-06	normal	1	4,09E-06	19
Resolution of UUT- DMM (V)	0	2,89E-06	rectagular	1	2,89E-06	inf
Error Ex (V)	-0,000 16	Combined Uncertainty, u(Ex) (V)				2,05E-04
		Effective degrees of freedom, veff				1,07E+08
Error Ex (µV/V)	-1,6	Coverage Factor, k				2
		Expanded uncertainty U(Ex) (µV/V)				4,1

DC Voltage 1000 V

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (V)	999,999 7	2,30E-05	normal	-1	-2,30E-05	19
Resolution of Ref DMM (V)	0	2,89E-05	rectangular	-1	-2,89E-05	inf
90 day specification for Ref DMM (V)	0	1,55E-03	normal	-1	-1,55E-03	inf
Correction due to last calibration of Ref DMM (V)	0	1,00E-03	normal	-1	-1,00E-03	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (V)	0	1,27E-03	normal	1	1,27E-03	inf
Voltage idicated by UUT-DMM (V)	999,996 4	5,74E-05	normal	1	5,74E-05	19
Resolution of UUT- DMM (V)	0	2,89E-05	rectagular	1	2,89E-05	inf
Error Ex (V)	-0,003 3	Combined Uncertainty, u(Ex) (V)				2,24E-03
		Effective degrees of freedom, veff				4,30E+07
Error Ex (µV/V)	-3,3	Coverage Factor, k				2
		Expanded uncertainty U(Ex) (µV/V)				4,5

2. DC Current results

DC 100 uA

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci		Uncertaity contribution ui(Ex)		Degrees of freedom vi
Voltage indicated by Ref DMM (mV)	100,003 23	1,62E-05	normal	-1	1/kΩ	-1,62E-05	μA	19
Resolution of Ref DMM (mV)	0	2,89E-06	rectangular	-1	1/kΩ	-2,89E-06	μA	inf
Absolute (1 year) specification of Ref DMM (mV)	0	2,75E-04	normal	-1	1/kΩ	-2,75E-04	μA	inf
Loading voltage of Ref DMM (mV)	0	5,77E-06	rectangular	-1	1/kΩ	-5,77E-06	μA	inf
Standard resistor Rs (kΩ)	1,000 004 27	5,00E-07	normal	-100	$mV/k\Omega^2$	-5,00E-05	μA	inf
Correction due to drift of standard resistor (kΩ)	0	1,15E-07	rectagular	-100	$mV/k\Omega^2$	-1,15E-05	μA	inf
Correction due to temperature change of standard resistor (kΩ)	0	1,73E-07	rectagular	-100	$mV/k\Omega^2$	-1,73E-05	μA	inf
Current indicated by UUT-DMM (μA)	100,000 73	9,55E-06	normal	1	μA	9,55E-06	μA	19
Resolution of UUT- DMM (μA)	0	2,89E-06	rectagular	1	μA	2,89E-06	μA	inf
Error Ex (μA)	**-0,002 08**	**Combined Uncertainty, u(Ex) (μA)**						**2,76E-04**
		Effective degrees of freedom, veff						**1,43E+06**
Error Ex (μA/A)	**-20,8**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (μA/A)						**5,5**

10 mA

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci		Uncertaity contribution ui(Ex)		Degrees of freedom vi
Voltage indicated by Ref DMM (V)	1,000 006 4	6,96E-08	normal	-0,01	1/Ω	-6,96E-07	mA	19
Resolution of Ref DMM (V)	0	2,89E-08	rectangular	-0,01	1/Ω	-2,89E-07	mA	inf
Absolute (1 year) specification of Ref DMM (V)	0	1,70E-06	normal	-0,01	1/Ω	-1,70E-05	mA	inf
Loading voltage of Ref DMM (V)	0	5,77E-09	rectangular	-0,01	1/Ω	-5,77E-08	mA	inf
Standard resistor Rs (Ω)	100,000 202 1	5,00E-05	normal	-0,0001	V/Ω^2	-5,00E-06	mA	inf
Correction due to drift of standard resistor (Ω)	0	1,15E-05	rectagular	-0,0001	V/Ω^2	-1,15E-06	mA	inf
Correction due to temperature change of standard resistor (Ω)	0	1,15E-05	rectagular	-0,0001	V/Ω^2	-1,15E-06	mA	inf
Current indicated by UUT-DMM (mA)	10,000 244	9,76E-07	normal	1	mA	9,76E-07	mA	19
Resolution of UUT- DMM (mA)	0	2,89E-07	rectagular	1	mA	2,89E-07	mA	inf
Error Ex (mA)	**0,000 200**	**Combined Uncertainty, u(Ex) (mA)**						**1,71E-05**
		Effective degrees of freedom, veff						**1,42E+06**
Error Ex (μA/A)	**20,0**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (μA/A)						**3,4**

DC Current 1 A

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Current indicated by Ref DMM (A)	1,000 059 3	8,49E-08	normal	-1	-8,49E-08	19
Resolution of Ref DMM (A)	0	2,89E-08	rectangular	-1	-2,89E-08	inf
90 day specification for Ref DMM(A)	0	7,05E-05	normal	-1	-7,05E-05	inf
Correction due to last calibration of Ref DMM (A)	0	4,50E-05	normal	-1	-4,50E-05	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (A)	0	1,90E-05	normal	-1	-1,90E-05	inf
Current idicated by UUT-DMM (A)	0,999 920 7	8,67E-08	normal	1	8,67E-08	19
Resolution of UUT- DMM (A)	0	2,89E-08	rectagular	1	2,89E-08	inf
Error Ex (A)	**-0,000 138 7**	**Combined Uncertainty, u(Ex) (A)**				**8,58E-05**
		Effective degrees of freedom, veff				**9,50E+12**
Error Ex (μA/A)	**-138,7**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (μA/A)				**171,5**

3. AC Voltage results

AC Voltage 100 mV 55 Hz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (mV)	99,990 2	2,80E-04	normal	-1	-2,80E-04	19
Resolution of Ref DMM (mV)	0	2,89E-05	rectangular	-1	-2,89E-05	inf
90 day specification for Ref DMM (mV)	0	7,00E-03	normal	-1	-7,00E-03	inf
Correction due to last calibration of Ref DMM (mV)	0	3,00E-03	normal	-1	-3,00E-03	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (mV)	0	6,00E-03	normal	1	6,00E-03	inf
Voltage idicated by UUT-DMM (mV)	99,994 7	2,06E-04	normal	1	2,06E-04	19
Resolution of UUT- DMM (mV)	0	2,89E-05	rectagular	1	2,89E-05	inf
Error Ex (mV)	**0,004 5**	**Combined Uncertainty, u(Ex) (mV)**				**9,70E-03**
		Effective degrees of freedom, veff				**2,12E+07**
Error Ex (μV/V)	**45**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (μV/V)				**194**

AC Voltage 100 mV 1 kHz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (mV)	99,994 7	2,05E-04	normal	-1	-2,05E-04	19
Resolution of Ref DMM (mV)	0	2,89E-05	rectangular	-1	-2,89E-05	inf
90 day specification for Ref DMM (mV)	0	6,00E-03	normal	-1	-6,00E-03	inf
Correction due to last calibration of Ref DMM (mV)	0	3,00E-03	normal	-1	-3,00E-03	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (mV)	0	6,00E-03	normal	1	6,00E-03	inf
Voltage idicated by UUT-DMM (mV)	99,998 9	2,52E-04	normal	1	2,52E-04	19
Resolution of UUT- DMM (mV)	0	2,89E-05	rectagular	1	2,89E-05	inf
Error Ex (mV)	**0,004 2**	**Combined Uncertainty, u(Ex) (mV)**				**9,01E-03**
		Effective degrees of freedom, veff				**2,14E+07**
Error Ex (μV/V)	**42**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (μV/V)				**180**

AC Voltage 10 V 55 Hz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (V)	10,000 21	9,93E-06	normal	-1	-9,93E-06	19
Resolution of Ref DMM (V)	0	2,89E-06	rectangular	-1	-2,89E-06	inf
90 day specification for Ref DMM (V)	0	5,00E-04	normal	-1	-5,00E-04	inf
Correction due to last calibration of Ref DMM (V)	0	1,50E-04	normal	-1	-1,50E-04	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (V)	0	1,50E-04	normal	1	1,50E-04	inf
Voltage idicated by UUT-DMM (V)	10,000 53	1,09E-05	normal	1	1,09E-05	19
Resolution of UUT- DMM (V)	0	2,89E-06	rectagular	1	2,89E-06	inf
Error Ex (V)	**0,000 33**	**Combined Uncertainty, u(Ex) (V)**				**5,43E-04**
		Effective degrees of freedom, veff				**7,01E+07**
Error Ex (μV/V)	**33**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (μV/V)				**109**

AC Voltage 10 V 1 kHz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (V)	10,000 05	4,83E-06	normal	-1	-4,83E-06	19
Resolution of Ref DMM (V)	0	2,89E-06	rectangular	-1	-2,89E-06	inf
90 day specification for Ref DMM (V)	0	4,00E-04	normal	-1	-4,00E-04	inf
Correction due to last calibration of Ref DMM (V)	0	1,50E-04	normal	-1	-1,50E-04	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (V)	0	1,50E-04	normal	1	1,50E-04	inf
Voltage idicated by UUT-DMM (V)	10,000 95	5,48E-06	normal	1	5,48E-06	19
Resolution of UUT- DMM (V)	0	2,89E-06	rectagular	1	2,89E-06	inf
Error Ex (V)	**0,000 90**	**Combined Uncertainty, u(Ex) (V)**				**4,53E-04**
		Effective degrees of freedom, veff				**5,53E+08**
Error Ex (µV/V)	**90**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**91**

AC Voltage 10 V 100 kHz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (V)	10,000 54	4,75E-06	normal	-1	-4,75E-06	19
Resolution of Ref DMM (V)	0	2,89E-06	rectangular	-1	-2,89E-06	inf
90 day specification for Ref DMM (V)	0	3,50E-03	normal	-1	-3,50E-03	inf
Correction due to last calibration of Ref DMM (V)	0	5,00E-04	normal	-1	-5,00E-04	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (V)	0	5,00E-04	normal	1	5,00E-04	inf
Voltage idicated by UUT-DMM (V)	10,000 58	5,37E-06	normal	1	5,37E-06	19
Resolution of UUT- DMM (V)	0	2,89E-06	rectagular	1	2,89E-06	inf
Error Ex (V)	**0,000 04**	**Combined Uncertainty, u(Ex) (V)**				**3,57E-03**
		Effective degrees of freedom, veff				**2,30E+12**
Error Ex (µV/V)	**4**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**714**

AC Voltage 100 V 55 Hz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (V)	100,001 2	9,90E-05	normal	-1	-9,90E-05	19
Resolution of Ref DMM (V)	0	2,89E-05	rectangular	-1	-2,89E-05	inf
90 day specification for Ref DMM (V)	0	5,00E-03	normal	-1	-5,00E-03	inf
Correction due to last calibration of Ref DMM (V)	0	2,00E-03	normal	-1	-2,00E-03	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (V)	0	2,05E-03	normal	1	2,05E-03	inf
Voltage idicated by UUT-DMM (V)	99,998 0	1,05E-04	normal	1	1,05E-04	19
Resolution of UUT- DMM (V)	0	2,89E-05	rectagular	1	2,89E-05	inf
Error Ex (V)	**-0,003 3**	**Combined Uncertainty, u(Ex) (V)**				**5,76E-03**
		Effective degrees of freedom, veff				**9,62E+07**
Error Ex (µV/V)	**-33**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**115**

AC Voltage 100 V 1 kHz						
Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Voltage indicated by Ref DMM (V)	99,999 3	4,90E-05	normal	-1	-4,90E-05	19
Resolution of Ref DMM (V)	0	2,89E-05	rectangular	-1	-2,89E-05	inf
90 day specification for Ref DMM (V)	0	4,00E-03	normal	-1	-4,00E-03	inf
Correction due to last calibration of Ref DMM (V)	0	2,00E-03	normal	-1	-2,00E-03	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (V)	0	2,05E-03	normal	1	2,05E-03	inf
Voltage idicated by UUT-DMM (V)	100,001 8	4,91E-05	normal	1	4,91E-05	19
Resolution of UUT- DMM (V)	0	2,89E-05	rectagular	1	2,89E-05	inf
Error Ex (V)	**0,002 5**	**Combined Uncertainty, u(Ex) (V)**				**4,92E-03**
		Effective degrees of freedom, veff				**9,62E+08**
Error Ex (µV/V)	**25**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**98**

4. Results of AC current

10 mA 300 Hz								
Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci		Uncertaity contribution ui(Ex)		Degrees of freedom vi
Voltage indicated by Ref DMM (V)	0,999 918	7,38E-07	normal	-0,01	1/Ω	-7,38E-06	mA	19
Resolution of Ref DMM (V)	0	2,89E-07	rectangular	-0,01	1/Ω	-2,89E-06	mA	inf
Absolute (1 year) specification of Ref DMM (V)	0	4,25E-05	normal	-0,01	1/Ω	-4,25E-04	mA	inf
Correction due to Loading of Ref DMM (1-δload)	1,0001	5,00E-06	rectangular	-0,01	V/Ω	-5,00E-05	mA	inf
DC resistance of current shunts Rs (Ω)	100,000 934	7,50E-05	normal	-0,0001	V/Ω^2	-7,50E-06	mA	inf
Correction due to drift of shunt resistance (Ω)	0	2,89E-05	rectagular	-0,0001	V/Ω^2	-2,89E-06	mA	inf
Correction due to temperature change of shunt resistance (Ω)	0	2,31E-05	rectagular	-0,0001	V/Ω^2	-2,31E-06	mA	inf
AC-DC difference of current shunt	0,999 999	5,50E-06	normal	-0,01	V/Ω	-5,50E-05	mA	inf
Drift of AC-DC difference of current shunt	0	5,77E-07	rectangular	-0,01	V/Ω	-5,77E-06	mA	inf
Current indicated by UUT-DMM (mA)	10,000 57	2,28E-05	normal	1	mA	2,28E-05	mA	19
Resolution of UUT- DMM (mA)	0	5,77E-06	rectagular	1	mA	5,77E-06	mA	inf
Error Ex (mA)	**0,000 49**	**Combined Uncertainty, u(Ex) (mA)**						**4,32E-04**
		Effective degrees of freedom, veff						**2,43E+06**
Error Ex (µA/A)	**49**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (µA/A)						**86**

10 mA 1 kHz								
Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci		Uncertaity contribution ui(Ex)		Degrees of freedom vi
Voltage indicated by Ref DMM (V)	0,999 882	7,51E-07	normal	-0,01	1/Ω	-7,51E-06	mA	19
Resolution of Ref DMM (V)	0	2,89E-07	rectangular	-0,01	1/Ω	-2,89E-06	mA	inf
Absolute (1 year) specification of Ref DMM (V)	0	4,25E-05	normal	-0,01	1/Ω	-4,25E-04	mA	inf
Correction due to Loading of Ref DMM (1-δload)	1,0001	5,00E-06	rectangular	-0,01	V/Ω	-5,00E-05	mA	inf
DC resistance of current shunts Rs (Ω)	100,000 934	7,50E-05	normal	-0,0001	V/Ω^2	-7,50E-06	mA	inf
Correction due to drift of shunt resistance (Ω)	0	2,89E-05	rectagular	-0,0001	V/Ω^2	-2,89E-06	mA	inf
Correction due to temperature change of shunt resistance (Ω)	0	2,31E-05	rectagular	-0,0001	V/Ω^2	-2,31E-06	mA	inf
AC-DC difference of current shunt	1,000 004	5,50E-06	normal	-0,01	V/Ω	-5,50E-05	mA	inf
Drift of AC-DC difference of current shunt	0	5,77E-07	rectangular	-0,01	V/Ω	-5,77E-06	mA	inf
Current indicated by UUT-DMM (mA)	10,000 69	9,17E-06	normal	1	mA	9,17E-06	mA	19
Resolution of UUT- DMM (mA)	0	5,77E-06	rectagular	1	mA	5,77E-06	mA	inf
Error Ex (mA)	**0,000 93**	**Combined Uncertainty, u(Ex) (mA)**						**4,32E-04**
		Effective degrees of freedom, veff						**6,45E+07**
Error Ex (µA/A)	**93**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (µA/A)						**86**

AC Currente 1 A 300 Hz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Current indicated by Ref DMM (A)	1,000 017	2,59E-06	normal	-1	-2,59E-06	19
Resolution of Ref DMM (A)	0	2,89E-07	rectangular	-1	-2,89E-07	inf
90 day specification for Ref DMM (A)	0	4,00E-04	normal	-1	-4,00E-04	inf
Correction due to last calibration of Ref DMM (A)	0	1,50E-05	normal	-1	-1,50E-05	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (A)	0	1,33E-04	normal	-1	-1,33E-04	inf
Current idicated by UUT-DMM (A)	0,999 920	2,42E-06	normal	1	2,42E-06	19
Resolution of UUT- DMM (A)	0	2,89E-07	rectagular	1	2,89E-07	inf
Error Ex (A)	**-0,000 097**	**Combined Uncertainty, u(Ex) (A)**				**4,22E-04**
		Effective degrees of freedom, veff				**7,52E+09**
Error Ex (μA/A)	**-97**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (μA/A)				**843**

AC Currente 1 A 1kHz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Current indicated by Ref DMM (A)	1,000 105	2,08E-06	normal	-1	-2,08E-06	19
Resolution of Ref DMM (A)	0	2,89E-07	rectangular	-1	-2,89E-07	inf
90 day specification for Ref DMM (A)	0	4,00E-04	normal	-1	-4,00E-04	inf
Correction due to last calibration of Ref DMM (A)	0	1,50E-05	normal	-1	-1,50E-05	inf
Correction due to Short Trem stability of Multifuctional Calibrator (24 h) (A)	0	1,33E-04	normal	-1	-1,33E-04	inf
Current idicated by UUT-DMM (A)	1,000 071	2,48E-06	normal	1	2,48E-06	19
Resolution of UUT- DMM (A)	0	2,89E-07	rectagular	1	2,89E-07	inf
Error Ex (A)	**-0,000 035**	**Combined Uncertainty, u(Ex) (A)**				**4,22E-04**
		Effective degrees of freedom, veff				**1,06E+10**
Error Ex (μA/A)	**-35**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (μA/A)				**843**

5. Results of DC resistance

10 Ω True Ohm

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Standard Resistors (Ω)	10,000 122	5,00E-06	normal	-1	-5,00E-06	9
Correction of Standard Resistors due to drift from last calibration (Ω)	0	1,15E-06	rectangular	-1	-1,15E-06	inf
Correction of Standard Resistors due to temperature change (Ω)	0	3,00E-08	rectagular	-1	-3,00E-08	inf
Resistance indicated by UUT-DMM (Ω)	10,000 262	8,01E-07	normal	1	8,01E-07	9
Resolution of UUT- DMM (Ω)	0	2,89E-07	rectagular	1	2,89E-07	inf
Error Ex (Ω)	**0,000 140**	**Combined Uncertainty, u(Ex) (Ω)**				**5,20E-06**
		Effective degrees of freedom, veff				**10,54**
Error Ex (μΩ/Ω)	**14,0**	**Coverage Factor, k**				**2,28**
		Expanded uncertainty U(Ex) (μΩ/Ω)				**1,2**

10 kΩ True Ohm

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Standard Resistors (kΩ)	10,000 003	5,00E-06	normal	-1	-5,00E-06	9
Correction of Standard Resistors due to drift from last calibration (kΩ)	0	1,15E-06	rectangular	-1	-1,15E-06	inf
Correction of Standard Resistors due to temperature change (kΩ)	0	3,00E-09	rectagular	-1	-3,00E-09	inf
Resistance indicated by UUT-DMM (kΩ)	10,000 090	3,38E-07	normal	1	3,38E-07	9
Resolution of UUT- DMM (kΩ)	0	2,89E-07	rectagular	1	2,89E-07	inf
Error Ex (Ω)	**0,000 087**	**Combined Uncertainty, u(Ex) (kΩ)**				**5,15E-06**
		Effective degrees of freedom, veff				**10,14**
Error Ex (μΩ/Ω)	**8,7**	**Coverage Factor, k**				**2,28**
		Expanded uncertainty U(Ex) (μΩ/Ω)				**1,2**

10 kΩ True Ohm LoI

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Standard Resistors (kΩ)	10,000 003	5,00E-06	normal	-1	-5,00E-06	9
Correction of Standard Resistors due to drift from last calibration (kΩ)	0	1,15E-06	rectangular	-1	-1,15E-06	inf
Correction of Standard Resistors due to temperature change (kΩ)	0	3,00E-09	rectagular	-1	-3,00E-09	inf
Resistance indicated by UUT-DMM (kΩ)	10,000 101	6,96E-07	normal	1	6,96E-07	9
Resolution of UUT- DMM (kΩ)	0	2,89E-07	rectagular	1	2,89E-07	inf
Error Ex (Ω)	**0,000 098**	**Combined Uncertainty, u(Ex) (kΩ)**				**5,19E-06**
		Effective degrees of freedom, veff				**10,42**
Error Ex (μΩ/Ω)	**9,8**	**Coverage Factor, k**				**2,28**
		Expanded uncertainty U(Ex) (μΩ/Ω)				**1,2**

1 MΩ

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertaity contribution ui(Ex)	Degrees of freedom vi
Resistance idicated by Ref DMM (MΩ)	1,000 014 1	3,06E-08	normal	-1	-3,06E-08	19
Resolution of Ref DMM (MΩ)	0	2,89E-08	rectangular	-1	-2,89E-08	inf
90 day specification for Ref DMM (MΩ)	0	2,50E-06	normal	-1	-2,50E-06	inf
Correction due to last calibration of Ref DMM (MΩ)	0	7,50E-07	normal	-1	-7,50E-07	inf
Voltage idicated by UUT-DMM (MΩ)	1,000 021 7	2,89E-08	normal	1	2,89E-08	19
Resolution of UUT- DMM (MΩ)	0	2,89E-08	rectagular	1	2,89E-08	inf
Error Ex (MΩ)	**0,000 007 7**	**Combined Uncertainty, u(Ex) (kΩ)**				**2,61E-06**
		Effective degrees of freedom, veff				**5,62E+08**
Error Ex (μΩ/Ω)	**7,7**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (μΩ/Ω)				**5,2**

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2. PERIOD OF MEASUREMENTS

18 – 26 May 2015

3. AMBIENT CONDITIONS

Temperature : (23 ± 1) °C

Relative Humidity : (50 ± 15) % rh

4. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Multifunction Calibrator	**Fluke**	**5730A**	**2941503**	**UME, Turkey G1LV-0033 / 09.04.2015**

5. MEASUREMENT METHOD

Direct comparison against multifunction calibrator

6. MEASUREMENT RESULTS

AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Voltage	Frequency				
200 mV	100 mV	55 Hz	100.0005 mV	99.9947 mV	-58 µV/V	128 µV/V
	100 mV	1 kHz	100.0004 mV	99.9989 mV	-15 µV/V	128 µV/V
20 V	10 V	55 Hz	10.00008 V	10.00056 V	48 µV/V	42 µV/V
	10 V	1 kHz	10.00004 V	10.00096 V	92 µV/V	42 µV/V
	10 V	100 kHz	9.99987 V	10.00032 V	45 µV/V	107 µV/V
200 V	100 V	55 Hz	100.0001 V	99.9990 V	-11 µV/V	51 µV/V
	100 V	1 kHz	100.0001 V	100.0028 V	27 µV/V	51 µV/V

AC CURRENT

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Current	Frequency				
20 mA	10 mA	300 Hz	10.00009 mA	10.00063 mA	54 µA/A	134 µA/A
	10 mA	1 kHz	10.00006 mA	10.00076 mA	70 µA/A	132 µA/A
1 A	1 A	300 Hz	0.999970 A	0.999911 A	-59 µA/A	287 µA/A
	1 A	1 kHz	0.999965 A	0.999984 A	19 µA/A	274 µA/A

[1] *Expanded uncertainty corresponding to the coverage probability of approximately 95 %.*

7. UNCERTAINTY BUDGET

7.1. DC Voltage

7.2. DC Current

7.3. DC Resistance

7.4. AC Voltage

Model Function:

$$E_x = \overline{V_x} - (V_C + V_{drift}) + V_{res}$$

E_x = absolute error of 8508; for report, it has to be reported as relative error to V_{nom}

$\overline{V_x}$ = indicated value; its estimate is aritmethic mean of 20 indications of DMM 8508, associated contribution to combined uncertainty is experimental standard deviation of their mean

V_c = applied voltage value, measured at the calibrator output; its estimate and contribution to combined uncertainty are extracted from calibration certificate data of calibrator

V_{drift} = value which accounts for drift of the value of the voltage at the calibrator output since its last calibration; its estimate is zero, contribution to combined uncertainty is extracted from calibrator specifications for relative accuracy for 90 days (2 months passed since last calibration)

V_{res} = value which accounts for DMM 8508 finite resolution; its estimate is zero, contribution to combined uncertainty is $1/2\sqrt{3}$ of value corresponding to last digit of DMM indication

Table 4. Uncertainty budget for 100 mV / 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
$\overline{V_x}$	99.9947 mV	0.00014 mV	normal	1	0.00014 mV	19
V_c	100.0005 mV	0.0015 mV	normal	-1	0.0015 mV	∞
V_{drift}	0 mV	0.00625 mV	normal	-1	0.00625 mV	∞
V_{res}	0 mV	0.00003 mV	rectangular	1	0.00003 mV	∞
Error (E_x)	-0.0058 mV	**Combined Uncertainty, $u(E_x)$**				0.0064 mV
		Effective Degrees of Freedom, ν_{eff}				>50
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**0.0128 mV**

As absolute values, the results are: error E_x = - 0.0058 mV, with an expanded uncertainty (k = 2) $U(Ex)$ = 0.0128 mV

As relative values to nominal value of 100 mV, the results are:
E_x = - 58 µV/V; $U(Ex)$ = 128 µV/V

7.5. AC Current

Model Function:

$$E_x = \overline{I_x} - \left(I_C + I_{drift}\right) + I_{res}$$

Similar to voltage model but quantities are currents. Meanings of variable indexes are same.

Table 5. Uncertainty budget for 10 mA / 1 kHz

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** ν_i
$\overline{I_x}$	10.00076 mA	0.000004 mA	normal	1	0.000004 mA	19
I_c	10.00006 mA	0.00020 mA	normal	-1	0.00020 mA	∞
I_{drift}	0 mA	0.000625 mA	normal	-1	0.000625 mA	∞
I_{res}	0 mA	0.000003 mA	rectangular	1	0.000003 mA	∞
Error (E_x)	0.00070 mA	**Combined Uncertainty, $u(E_x)$**				0.00066 mA
		Effective Degrees of Freedom, ν_{eff}				>50
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**0.00132 mA**

As absolute values, the results are: error E_x = 0.00070 mA, with an expanded uncertainty (k = 2) $U(Ex)$ = 0.00132 mA

As relative values to nominal value of 10 mA, the results are:

E_x = 70 µA/A; $U(Ex)$ = 132 µA/A

1. PARTICIPANT INSTITUTE

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2. PERIOD OF MEASUREMENTS

Measurements were taken in period of 2015-07-27 to 2015-07-31.

3. AMBIENT CONDITIONS

Temperature : (23 ± 1) ºC
Relative humidity : (45 ± 10) % rh

4. THE MEASUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
DC Voltage standard	FLUKE	7001	47001	Local primary Josephson DC voltage standard.
Digital multimeter	AGILENT	3458A	US28030263	Keysignt Technologies, issued 2014-10-09, certificate number 1-5559727843-1; Local adjustment of DC voltage (10 V).
Reference divider	FLUKE	752A	8410019	Adjusted before measurements to meet manufacturers specification.
AC/DC transfer standard	FLUKE	792A	8295002	Czech Metrology Institute, issued 2008-08-29, certificate number 6011-KL-V576-08.
Multifunction calibrator	FLUKE	5720A	9500204	Adjusted locally.
10 Ohm standard resistor	TINSLEY	5685A	279942	Calibrated locally against 1 Ohm standard resistor (Czech Metrology Institute, issued 2012-11-05, certificate number 1011-KL-A00043-12).
10 kilo Ohm standard resistor	TEGAM	SR104	K201090230104	Czech Metrology Institute, issued 2012-11-05, certificate number 1011-KL-A00044-12.
1 mega Ohm standard resistor	TINSLEY	5615B	279523	Calibrated locally against 100 kOhm > 10 kOhm standard resistors (Czech Metrology Institute, issued 2012-11-05, certificate number 1011-KL-A00044-12).

5. MEASUREMENT METHOD

For 100 mV DC voltage, a direct measurement of reference standard was used (10 V FLUKE 7001 Zener voltage standard connected to FLUKE 752A reference divider, set at ratio 1:100). For 10 V DC voltage, a direct measurement of 10 V FLUKE 7001 Zener voltage standard was used. All resistance measurements were done by direct measurement of standard resistors.

For other measurements FLUKE 5720A calibrator was used. To determine applied value for DC voltage (100 V and 1000 V), DC current and AC current, a reference multimeter was used (AGILENT 3458A). Applied value calculated as average of two values (one before measurement with traveling standard, onother after). Each value calculated as average of 30 readings. 100 and 1000 V DC output of calibrator were divided by FLUKE 752A set at ratio 1:10 and 1:100 respectively and measured with AGILENT 3458A reference DMM at 10 volt range. All DC current and AC current values were measured directly from calibrator output.

For AC voltages, a calibrator output was measured using FLUKE 792A AC/DC transfer standard and then adjusted to output exact nominal voltage. Adjusted calibrator output then measured with traveling standard directly.

6. MEASUREMENT RESULTS

DC VOLTAGE

Range of 8508A	Nominal value	Applied value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 mV	+100 mV	99,99882 mV	99,99880 mV	$-2{,}0 \cdot 10^{-7}$	$5{,}1 \cdot 10^{-6}$
20 V	+10 V	9,999882 V	9,999926 V	$4{,}4 \cdot 10^{-6}$	$1{,}0 \cdot 10^{-6}$
200 V	+100 V	100,00007 V	99,99996 V	$-1{,}1 \cdot 10^{-6}$	$1{,}5 \cdot 10^{-6}$
1000V	+1000 V	1000,0027 V	1000,0021 V	$-6{,}0 \cdot 10^{-7}$	$1{,}4 \cdot 10^{-6}$

DC CURRENT

Range of 8508A	Nominal value	Applied value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 µA	+100 µA	100,00027 µA	99,99949 µA	$-7{,}8 \cdot 10^{-6}$	$3{,}4 \cdot 10^{-5}$
20 mA	+10 mA	9,999962 mA	10,000199 mA	$2{,}37 \cdot 10^{-5}$	$2{,}8 \cdot 10^{-5}$
1 A	+1 A	0,9999564 A	0,9998687 A	$-8{,}77 \cdot 10^{-5}$	$1{,}2 \cdot 10^{-4}$

DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal value	Applied value	Reading of 8508A	Error of 8508A	Uncertainty[1]
20 Ω	TrueΩ	10 Ω	9,999975 Ω	10,000115 Ω	$1{,}4 \cdot 10^{-5}$	$1{,}1 \cdot 10^{-6}$
20 kΩ	TrueΩ	10 kΩ	10,000011 k Ω	10,000100 kΩ	$8{,}9 \cdot 10^{-6}$	$1{,}1 \cdot 10^{-6}$
	TrueΩ LoI	10 kΩ	10,000011 k Ω	10,000111 kΩ	$1{,}0 \cdot 10^{-5}$	$1{,}3 \cdot 10^{-6}$
2 MΩ	Normal Ω	1 MΩ	0,9999582 MΩ	0,9999673 MΩ	$9{,}1 \cdot 10^{-6}$	$1{,}7 \cdot 10^{-6}$

AC VOLTAGE

Range of 8508A	Nominal value		Applied voltage	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Voltage	Frequency				
200 mV	100 mV	55 Hz	100,0000 mV	99,9945 mV	$-5{,}5 \cdot 10^{-5}$	$1{,}4 \cdot 10^{-4}$
	100 mV	1 kHz	100,0000 mV	99,9991 mV	$-9{,}0 \cdot 10^{-6}$	$1{,}3 \cdot 10^{-4}$
20 V	10 V	55 Hz	10,00000 V	10,00062 V	$6{,}2 \cdot 10^{-5}$	$4{,}4 \cdot 10^{-5}$
	10 V	1 kHz	10,00000 V	10,00106 V	$1{,}06 \cdot 10^{-4}$	$4{,}3 \cdot 10^{-5}$
	10 V	100 kHz	10,00000 V	10,00081 V	$8{,}1 \cdot 10^{-5}$	$3{,}3 \cdot 10^{-4}$
200 V	100 V	55 Hz	100,0000 V	99,9990 V	$-1{,}0 \cdot 10^{-5}$	$5{,}7 \cdot 10^{-5}$
	100 V	1 kHz	100,0000 V	100,0033 V	$3{,}3 \cdot 10^{-5}$	$5{,}2 \cdot 10^{-5}$

AC CURRENT

Range of 8508A	Nominal value		Applied current	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Current	Frequency				
20 mA	10 mA	300 Hz	10,00062 mA	10,00052 mA	$-1{,}0 \cdot 10^{-5}$	$5{,}7 \cdot 10^{-4}$
	10 mA	1 kHz	10,00051 mA	10,00066 mA	$1{,}5 \cdot 10^{-5}$	$5{,}5 \cdot 10^{-4}$
1 A	1 A	300 Hz	1,000073 A	0,999901 A	$-1{,}72 \cdot 10^{-4}$	$1{,}2 \cdot 10^{-3}$
	1 A	1 kHz	1,000121 A	0,999989 A	$-1{,}32 \cdot 10^{-4}$	$1{,}2 \cdot 10^{-3}$

[1]*Expanded uncertainty corresponding to the coverage probability of approximately 95%.*

7. UNCERTAINTY BUDGET

7.1. DC voltage

Model function (100 mV DC):

$$Y = \frac{((X_3 + X_4) - (X_1 \cdot X_2)) + X_5}{(X_1 \cdot X_2)}$$

Table 1. Uncertainty budget for 100 mV

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(E_x)$	Degrees of freedom (DoF) ν_i
X_1: 10 V Zener reference standard, V	9,999881922	$5{,}0 \cdot 10^{-8}$	Normal	-0,100001	$-5{,}0 \cdot 10^{-9}$	148
X_2: 752A reference divider ratio	0,01	$2{,}5 \cdot 10^{-8}$	Normal	-99,99998	$-2{,}5 \cdot 10^{-6}$	infinity
X_3: Measurement result, V	0,09999880	$2{,}98 \cdot 10^{-8}$	Normal	10,000118	$2{,}98 \cdot 10^{-7}$	29
X_4: Resolution of the traveling standard, V	0	$2{,}89 \cdot 10^{-9}$	Rectangular	10,000118	$2{,}89 \cdot 10^{-8}$	infinity
X_5: Repeatability of results, V	0	$4{,}04 \cdot 10^{-8}$	Rectangular	10,000118	$4{,}04 \cdot 10^{-7}$	infinity
Error E_x	$-2 \cdot 10^{-7}$				**Combined Uncertainty, $u(E_x)$**	$2{,}55 \cdot 10^{-6}$
					Effective Degrees of Freedom, ν_{eff}	infinity
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	$5{,}10 \cdot 10^{-6}$

Model function (10 V DC):

$$Y = \frac{((X_2 + X_3) - X_1) + X_4}{X_1}$$

Table 2. Uncertainty budget for 10 V

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(E_x)$	Degrees of freedom (DoF) v_i
X_1: 10 V Zener reference standard, V	9,999881922	$5{,}0 \cdot 10^{-6}$	Normal	-0,100002	$-5{,}0 \cdot 10^{-7}$	148
X_2: Measurement result, V	9,999926	$5{,}51 \cdot 10^{-7}$	Normal	0,1000012	$5{,}51 \cdot 10^{-8}$	29
X_3: Resolution of the traveling standard, V	0	$2{,}89 \cdot 10^{-7}$	Rectangular	0,1000012	$2{,}89 \cdot 10^{-8}$	infinity
X_4: Repeatability of results, V	0	$5{,}77 \cdot 10^{-7}$	Rectangular	0,1000012	$5{,}77 \cdot 10^{-8}$	infinity
Error E_x	$4{,}4 \cdot 10^{-6}$	**Combined Uncertainty, $u(E_x)$**				$5{,}0 \cdot 10^{-7}$
		Effective Degrees of Freedom, v_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$1{,}0 \cdot 10^{-6}$

Model function (100 V DC):

$$Y = \frac{((X_6 + X_7) - (X_5 \cdot X_2 + X_1 + X_3 + X_4)) + X_8}{(X_5 \cdot X_2 + X_1 + X_3 + X_4)}$$

Table 3. Uncertainty budget for 100 V

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(E_x)$	Degrees of freedom (DoF) ν_i
X_1: 10 V Zener reference standard, V	0	$5{,}0 \cdot 10^{-5}$	Normal	-0,01	$-5{,}0 \cdot 10^{-7}$	148
X_2: 752A reference divider ratio	10	$1{,}0 \cdot 10^{-6}$	Normal	-0,1	$-1{,}0 \cdot 10^{-7}$	infinity
X_3: 5720A calibrator stability at 100V, V	0	$4{,}5 \cdot 10^{-5}$	Normal	-0,01	$-4{,}5 \cdot 10^{-7}$	infinity
X_4: Applied voltage, V	0	$9{,}35 \cdot 10^{-7}$	Normal	-0,01	$-9{,}35 \cdot 10^{-9}$	29
X_5: Reference DMM accuracy, V	10,000007	$2{,}75 \cdot 10^{-6}$	Normal	-0,1	$-2{,}75 \cdot 10^{-7}$	infinity
X_6: Measurement result, V	99,99996	$5{,}10 \cdot 10^{-6}$	Normal	0,01	$5{,}10 \cdot 10^{-8}$	29
X_7: Resolution of the traveling standard, V	0	$2{,}89 \cdot 10^{-6}$	Rectangular	0,01	$2{,}89 \cdot 10^{-8}$	infinity
X_8: Repeatability of results, V	0	$5{,}77 \cdot 10^{-6}$	Rectangular	0,01	$5{,}77 \cdot 10^{-8}$	infinity
Error E_x	$-1{,}1 \cdot 10^{-6}$				**Combined Uncertainty, $u(E_x)$**	$7{,}4 \cdot 10^{-7}$
					Effective Degrees of Freedom, ν_{eff}	infinity
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	$1{,}5 \cdot 10^{-6}$

Model function (1000 V DC):

$$Y = \frac{((X_6 + X_7) - (X_5 \cdot X_2 + X_1 + X_3 + X_4)) + X_8}{(X_5 \cdot X_2 + X_1 + X_3 + X_4)}$$

Table 4. Uncertainty budget for 1000 V

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(E_x)$	Degrees of freedom (DoF) ν_i
X_1: 10 V Zener reference standard, V	0	$5{,}0 \cdot 10^{-4}$	Normal	-0,001	$-5{,}0 \cdot 10^{-7}$	148
X_2: 752A reference divider ratio	100	$2{,}5 \cdot 10^{-6}$	Normal	-0,01	$-2{,}5 \cdot 10^{-8}$	infinity
X_3: 5720A calibrator stability at 1000V, V	0	$3{,}5 \cdot 10^{-4}$	Normal	-0,001	$-3{,}5 \cdot 10^{-7}$	infinity
X_4: Applied voltage, V	0	$7{,}40 \cdot 10^{-7}$	Normal	-0,001	$-7{,}40 \cdot 10^{-10}$	29
X_5: Reference DMM accuracy, V	10,000027	$2{,}75 \cdot 10^{-6}$	Normal	-0,1	$-2{,}75 \cdot 10^{-7}$	infinity
X_6: Measurement result, V	1000,0021	$5{,}71 \cdot 10^{-5}$	Normal	0,001	$5{,}71 \cdot 10^{-8}$	29
X_7: Resolution of the traveling standard, V	0	$2{,}89 \cdot 10^{-5}$	Rectangular	0,001	$2{,}89 \cdot 10^{-8}$	infinity
X_8: Repeatability of results, V	0	$1{,}12 \cdot 10^{-4}$	Rectangular	0,001	$1{,}12 \cdot 10^{-7}$	infinity
Error E_x	$-6{,}0 \cdot 10^{-7}$	**Combined Uncertainty, $u(E_x)$**				$6{,}83 \cdot 10^{-7}$
		Effective Degrees of Freedom, ν_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$1{,}4 \cdot 10^{-6}$

7.2. DC current

Model function (100 µA DC):

$$Y = \frac{\left(\left(X_2 + X_3\right) - \left(X_1 + X_4 + X_5 + X_6\right)\right) + X_7}{\left(X_1 + X_4 + X_5 + X_6\right)}$$

Table 5. Uncertainty budget for 100 µA

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: Applied current, A	$100{,}00027 \cdot 10^{-6}$	$4{,}57 \cdot 10^{-11}$	Normal	-9999,895	$-4{,}57 \cdot 10^{-7}$	29
X_2: Measured current, A	$99{,}99949 \cdot 10^{-6}$	$2{,}64 \cdot 10^{-11}$	Normal	9999,973	$2{,}64 \cdot 10^{-7}$	29
X_3: Resolution of traveling standard, A	0	$2{,}89 \cdot 10^{-12}$	Rectangular	9999,973	$2{,}89 \cdot 10^{-8}$	infinity
X_4: Reference DMM accuracy, A	0	$1{,}15 \cdot 10^{-9}$	Normal	-9999,895	$-1{,}15 \cdot 10^{-5}$	infinity
X_5: Reference DMM last calibration, A	0	$1{,}00 \cdot 10^{-9}$	Normal	-9999,895	$-1{,}00 \cdot 10^{-5}$	infinity
X_6: 5720A calibrator stability at 100 µA, A	0	$7{,}50 \cdot 10^{-10}$	Normal	-9999,895	$-7{,}50 \cdot 10^{-6}$	infinity
X_7: Repeatability of results, A	0	$4{,}04 \cdot 10^{-11}$	Rectangular	9999,973	$4{,}04 \cdot 10^{-7}$	infinity
Error E_x	$-7{,}8 \cdot 10^{-6}$				**Combined Uncertainty,** $u(E_x)$	$1{,}7 \cdot 10^{-5}$
					Effective Degrees of Freedom, ν_{eff}	infinity
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	$3{,}4 \cdot 10^{-5}$

Model function (10 mA DC):

$$Y = \frac{((X_2 + X_3) - (X_1 + X_4 + X_5 + X_6)) + X_7}{(X_1 + X_4 + X_5 + X_6)}$$

Table 6. Uncertainty budget for 10 mA

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(E_x)$	Degrees of freedom (DoF) ν_i
X_1: Applied current, A	0,009999962	$2,88 \cdot 10^{-9}$	Normal	-100,0028	$-2,88 \cdot 10^{-7}$	29
X_2: Measured current, A	0,010000199	$1,07 \cdot 10^{-9}$	Normal	100,00038	$1,07 \cdot 10^{-7}$	29
X_3: Resolution of traveling standard, A	0	$2,89 \cdot 10^{-10}$	Rectangular	100,00038	$2,89 \cdot 10^{-8}$	infinity
X_4: Reference DMM accuracy, A	0	$1,00 \cdot 10^{-7}$	Normal	-100,0028	$-1,00 \cdot 10^{-5}$	infinity
X_5: Reference DMM last calibration, A	0	$8,50 \cdot 10^{-8}$	Normal	-100,0028	$-8,50 \cdot 10^{-6}$	infinity
X_6: 5720A calibrator stability at 10 mA, A	0	$5,00 \cdot 10^{-8}$	Normal	-100,0028	$-5,00 \cdot 10^{-6}$	infinity
X_7: Repeatability of results, A	0	$8,08 \cdot 10^{-9}$	Rectangular	100,00038	$8,08 \cdot 10^{-7}$	infinity
Error E_x	$2,37 \cdot 10^{-5}$	**Combined Uncertainty, $u(E_x)$**				$1,4 \cdot 10^{-5}$
		Effective Degrees of Freedom, ν_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$2,8 \cdot 10^{-5}$

Model function (1 A DC):

$$Y = \frac{\left(\left(X_2 + X_3\right) - \left(X_1 + X_4 + X_5 + X_6\right)\right) + X_7}{\left(X_1 + X_4 + X_5 + X_6\right)}$$

Table 7. Uncertainty budget for 1 A

Quantity X_i	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(E_x)$	Degrees of freedom (DoF) ν_i
X_1: Applied current, A	0,9999564	$3{,}55 \cdot 10^{-7}$	Normal	-0,999956	$-3{,}55 \cdot 10^{-7}$	29
X_2: Measured current, A	0,9998687	$1{,}85 \cdot 10^{-7}$	Normal	1,0000436	$1{,}85 \cdot 10^{-7}$	29
X_3: Resolution of traveling standard, A	0	$2{,}89 \cdot 10^{-8}$	Rectangular	1,0000436	$2{,}89 \cdot 10^{-8}$	infinity
X_4: Reference DMM accuracy, A	0	$5{,}50 \cdot 10^{-5}$	Normal	-0,999956	$-5{,}50 \cdot 10^{-5}$	infinity
X_5: Reference DMM last calibration, A	0	$2{,}15 \cdot 10^{-5}$	Normal	-0,999956	$-2{,}15 \cdot 10^{-5}$	infinity
X_6: 5720A calibrator stability at 1A, A	0	$8{,}00 \cdot 10^{-6}$	Normal	-0,999956	$-8{,}00 \cdot 10^{-6}$	infinity
X_7: Repeatability of results, A	0	$1{,}67 \cdot 10^{-6}$	Rectangular	1,0000436	$1{,}67 \cdot 10^{-6}$	infinity
Error E_x	$-8{,}77 \cdot 10^{-5}$	**Combined Uncertainty, $u(E_x)$**				$6{,}0 \cdot 10^{-5}$
		Effective Degrees of Freedom, ν_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$1{,}2 \cdot 10^{-4}$

7.3. DC resistance

Model function (10 Ohms):

$$Y = \frac{((X_3 + X_4) - (X_1 + X_2)) + X_5}{(X_1 + X_2)}$$

Table 8. Uncertainty budget for 10 Ohms

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 Ohm reference resistor, Ohm	9,999975317	$5,00 \cdot 10^{-6}$	Normal	-0,100002	$-5,00 \cdot 10^{-7}$	54
X_2: Temperature correction of reference resistor, Ohm	0	$2,89 \cdot 10^{-7}$	Rectangular	-0,100002	$-2,89 \cdot 10^{-8}$	infinity
X_3: Measurement result, Ohm	10,000115	$1,82 \cdot 10^{-6}$	Normal	0,1000002	$1,82 \cdot 10^{-7}$	29
X_4: Resolution of traveling standard, Ohm	0	$2,89 \cdot 10^{-7}$	Rectangular	0,1000002	$2,89 \cdot 10^{-8}$	infinity
X_5: Repeatability of results, Ohm	0	$8,49 \cdot 10^{-7}$	Rectangular	0,1000002	$8,49 \cdot 10^{-8}$	infinity
Error E_x	$1,4 \cdot 10^{-5}$	**Combined Uncertainty,** $u(E_x)$				$5,4 \cdot 10^{-7}$
		Effective Degrees of Freedom, ν_{eff}				71,33266
		Coverage Factor, k				2,0357
		Expanded Uncertainty, $U(E_x)$				$1,1 \cdot 10^{-6}$

Model function (10 kOhms):

$$Y = \frac{((X_3 + X_4) - (X_1 + X_2)) + X_5}{(X_1 + X_2)}$$

Table 9. Uncertainty budget for 10 kOhms

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 kOhm reference resistor, Ohm	10000,011	$5{,}00 \cdot 10^{-3}$	Normal	-0.0001	$-5{,}00 \cdot 10^{-7}$	54
X_2: Temperature correction of reference resistor, Ohm	0	$1{,}15 \cdot 10^{-4}$	Rectangular	-0.0001	$-1{,}15 \cdot 10^{-8}$	infinity
X_3: Measurement result, Ohm	10000,1	$2{,}22 \cdot 10^{-3}$	Normal	0.0001	$2{,}22 \cdot 10^{-7}$	29
X_4: Resolution of traveling standard, Ohm	0	$2{,}89 \cdot 10^{-4}$	Rectangular	0.0001	$2{,}89 \cdot 10^{-8}$	infinity
X_5: Repeatability of results, Ohm	0	$8{,}26 \cdot 10^{-4}$	Rectangular	0.0001	$8{,}26 \cdot 10^{-8}$	infinity
Error E_x	$8{,}9 \cdot 10^{-6}$	**Combined Uncertainty,** $u(E_x)$				$5{,}5 \cdot 10^{-7}$
		Effective Degrees of Freedom, ν_{eff}				75,96887
		Coverage Factor, k				2,0334
		Expanded Uncertainty, $U(E_x)$				$1{,}1 \cdot 10^{-6}$

Model function (10 kOhms, LoI):

$$Y = \frac{((X_3 + X_4) - (X_1 + X_2)) + X_5}{(X_1 + X_2)}$$

Table 10. Uncertainty budget for 10 kOhms LoI

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 kOhm reference resistor, Ohm	10000,011	$5,00 \cdot 10^{-3}$	Normal	-0.0001	$-5,00 \cdot 10^{-7}$	54
X_2: Temperature correction of reference resistor, Ohm	0	$1,15 \cdot 10^{-4}$	Rectangular	-0.0001	$-1,15 \cdot 10^{-8}$	infinity
X_3: Measurement result, Ohm	10000,111	$3,59 \cdot 10^{-3}$	Normal	0.0001	$3,59 \cdot 10^{-7}$	29
X_4: Resolution of traveling standard, Ohm	0	$2,89 \cdot 10^{-4}$	Rectangular	0.0001	$2,89 \cdot 10^{-8}$	infinity
X_5: Repeatability of results, Ohm	0	$8,83 \cdot 10^{-4}$	Rectangular	0.0001	$8,83 \cdot 10^{-8}$	infinity
Error E_x	$1,0 \cdot 10^{-5}$	**Combined Uncertainty, $u(E_x)$**				$6,22 \cdot 10^{-7}$
		Effective Degrees of Freedom, ν_{eff}				86,854070
		Coverage Factor, k				2,0292
		Expanded Uncertainty, $U(E_x)$				$1,3 \cdot 10^{-6}$

Model function (1 MOhm):

$$Y = \frac{\left(\left(X_3 + X_4\right) - \left(X_1 + X_2\right)\right) + X_5}{\left(X_1 + X_2\right)}$$

Table 11. Uncertainty budget for 1 MOhm

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 1 MOhm reference resistor, Ohm	999958,18	0,8	Normal	$-1 \cdot 10^{-6}$	$-8{,}00 \cdot 10^{-7}$	23
X_2: Temperature correction of reference resistor, Ohm	0	$3{,}46 \cdot 10^{-2}$	Rectangular	$-1 \cdot 10^{-6}$	$-3{,}46 \cdot 10^{-8}$	infinity
X_3: Measurement result, Ohm	999967,3	$2{,}01 \cdot 10^{-1}$	Normal	$1 \cdot 10^{-6}$	$2{,}01 \cdot 10^{-7}$	29
X_4: Resolution of traveling standard, Ohm	0	$2{,}89 \cdot 10^{-2}$	Rectangular	$1 \cdot 10^{-6}$	$2{,}89 \cdot 10^{-8}$	infinity
X_5: Repeatability of results, Ohm	0	$5{,}77 \cdot 10^{-2}$	Rectangular	$1 \cdot 10^{-6}$	$5{,}77 \cdot 10^{-8}$	infinity
Error E_x	$9{,}1 \cdot 10^{-6}$	**Combined Uncertainty,** $u(E_x)$				$8{,}28 \cdot 10^{-7}$
		Effective Degrees of Freedom, ν_{eff}				26,323916
		Coverage Factor, k				2,0996
		Expanded Uncertainty, $U(E_x)$				$1{,}7 \cdot 10^{-6}$

7.4. AC voltage

Model function (100 mV@ 55 Hz):

$$Y = \frac{((X_5 + X_6) - (X_2 + X_1 + X_3 + X_4)) + X_7}{(X_2 + X_1 + X_3 + X_4)}$$

Table 12. Uncertainty budget for 100 mV @55 Hz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 V Zener reference standard, V	0	$3,00 \cdot 10^{-8}$	Normal	-9,99945	$-3,00 \cdot 10^{-7}$	148
X_2: Calibrator output, V	0,1	$6,25 \cdot 10^{-6}$	Normal	-9,99945	$-6,25 \cdot 10^{-5}$	infinity
X_3: Calibrator stability, V	0	$1,60 \cdot 10^{-6}$	Normal	-9,99945	$-1,60 \cdot 10^{-5}$	infinity
X_4: 792A transfer standard, V	0	$1,75 \cdot 10^{-6}$	Normal	-9,99945	$-1,75 \cdot 10^{-5}$	infinity
X_5: Measurement result, V	0,0999945	$1,53 \cdot 10^{-6}$	Normal	10	$1,53 \cdot 10^{-5}$	29
X_6: Resolution of traveling standard, V	0	$2,89 \cdot 10^{-8}$	Rectangular	10	$2,89 \cdot 10^{-7}$	infinity
X_7: Repeatability of results, V	0	$1,73 \cdot 10^{-7}$	Rectangular	10	$1,73 \cdot 10^{-6}$	infinity
Error E_x	$-5,5 \cdot 10^{-5}$	**Combined Uncertainty,** $u(E_x)$				$6,9 \cdot 10^{-5}$
		Effective Degrees of Freedom, ν_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$1,4 \cdot 10^{-4}$

Model function (100 mV@ 1 kHz):

$$Y = \frac{((X_5 + X_6) - (X_2 + X_1 + X_3 + X_4)) + X_7}{(X_2 + X_1 + X_3 + X_4)}$$

Table 13. Uncertainty budget for 100 mV @1 kHz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 V Zener reference standard, V	0	$3{,}00 \cdot 10^{-8}$	Normal	-9,99991	$-3{,}00 \cdot 10^{-7}$	148
X_2: Calibrator output, V	0,1	$6{,}25 \cdot 10^{-6}$	Normal	-9,99991	$-6{,}25 \cdot 10^{-5}$	infinity
X_3: Calibrator stability, V	0	$1{,}60 \cdot 10^{-6}$	Normal	-9,99991	$-1{,}60 \cdot 10^{-5}$	infinity
X_4: 792A transfer standard, V	0	$1{,}75 \cdot 10^{-6}$	Normal	-9,99991	$-1{,}75 \cdot 10^{-5}$	infinity
X_5: Measurement result, V	0,0999991	$7{,}03 \cdot 10^{-7}$	Normal	10	$7{,}03 \cdot 10^{-6}$	29
X_6: Resolution of traveling standard, V	0	$2{,}89 \cdot 10^{-8}$	Rectangular	10	$2{,}89 \cdot 10^{-7}$	infinity
X_7: Repeatability of results, V	0	$1{,}73 \cdot 10^{-8}$	Rectangular	10	$1{,}73 \cdot 10^{-7}$	infinity
Error E_x	$-9{,}0 \cdot 10^{-6}$				**Combined Uncertainty,** $u(E_x)$	$6{,}7 \cdot 10^{-5}$
					Effective Degrees of Freedom, ν_{eff}	infinity
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	$1{,}3 \cdot 10^{-4}$

Model function (10 V@ 55 Hz):

$$Y = \frac{((X_5 + X_6) - (X_2 + X_1 + X_3 + X_4)) + X_7}{(X_2 + X_1 + X_3 + X_4)}$$

Table 14. Uncertainty budget for 10 V @55 Hz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 V Zener reference standard, V	0	$3,00 \cdot 10^{-6}$	Normal	-0,100006	$-3,00 \cdot 10^{-7}$	148
X_2: Calibrator output, V	10	$2,00 \cdot 10^{-4}$	Normal	-0,100006	$-2,00 \cdot 10^{-5}$	infinity
X_3: Calibrator stability, V	0	$6,40 \cdot 10^{-5}$	Normal	-0,100006	$-6,40 \cdot 10^{-6}$	infinity
X_4: 792A transfer standard, V	0	$6,00 \cdot 10^{-5}$	Normal	-0,100006	$-6,00 \cdot 10^{-6}$	infinity
X_5: Measurement result, V	10,00062	$2,90 \cdot 10^{-5}$	Normal	0,1	$2,90 \cdot 10^{-6}$	29
X_6: Resolution of traveling standard, V	0	$2,89 \cdot 10^{-6}$	Rectangular	0,1	$2,89 \cdot 10^{-7}$	infinity
X_7: Repeatability of results, V	0	$1,35 \cdot 10^{-6}$	Rectangular	0,1	$1,35 \cdot 10^{-7}$	infinity
Error E_x	$6,2 \cdot 10^{-5}$	**Combined Uncertainty,** $u(E_x)$				$2,2 \cdot 10^{-5}$
		Effective Degrees of Freedom, ν_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$4,4 \cdot 10^{-5}$

Model function (10 V@ 1 kHz):

$$Y = \frac{\left(\left(X_5 + X_6\right) - \left(X_2 + X_1 + X_3 + X_4\right)\right) + X_7}{\left(X_2 + X_1 + X_3 + X_4\right)}$$

Table 15. Uncertainty budget for 10 V @1 kHz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 V Zener reference standard, V	0	$3{,}00 \cdot 10^{-6}$	Normal	-0,100011	$-3{,}00 \cdot 10^{-7}$	148
X_2: Calibrator output, V	10	$2{,}00 \cdot 10^{-4}$	Normal	-0,100011	$-2{,}00 \cdot 10^{-5}$	infinity
X_3: Calibrator stability, V	0	$6{,}40 \cdot 10^{-5}$	Normal	-0,100011	$-6{,}40 \cdot 10^{-6}$	infinity
X_4: 792A transfer standard, V	0	$5{,}00 \cdot 10^{-5}$	Normal	-0,100011	$-5{,}00 \cdot 10^{-6}$	infinity
X_5: Measurement result, V	10,00106	$1{,}65 \cdot 10^{-5}$	Normal	0,1	$1{,}65 \cdot 10^{-6}$	29
X_6: Resolution of traveling standard, V	0	$2{,}89 \cdot 10^{-6}$	Rectangular	0,1	$2{,}89 \cdot 10^{-7}$	infinity
X_7: Repeatability of results, V	0	$5{,}77 \cdot 10^{-6}$	Rectangular	0,1	$5{,}77 \cdot 10^{-7}$	infinity
Error E_x	$1{,}06 \cdot 10^{-4}$				**Combined Uncertainty,** $u(E_x)$	$2{,}15 \cdot 10^{-5}$
					Effective Degrees of Freedom, ν_{eff}	infinity
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	$4{,}3 \cdot 10^{-5}$

Model function (10 V@ 100 kHz):

$$Y = \frac{((X_5 + X_6) - (X_2 + X_1 + X_3 + X_4)) + X_7}{(X_2 + X_1 + X_3 + X_4)}$$

Table 16. Uncertainty budget for 10 V @100 kHz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 V Zener reference standard, V	0	$3{,}00 \cdot 10^{-6}$	Normal	-0,100008	$-3{,}00 \cdot 10^{-7}$	148
X_2: Calibrator output, V	10	$1{,}65 \cdot 10^{-3}$	Normal	-0,100008	$-1{,}65 \cdot 10^{-4}$	infinity
X_3: Calibrator stability, V	0	$1{,}58 \cdot 10^{-4}$	Normal	-0,100008	$-1{,}58 \cdot 10^{-5}$	infinity
X_4: 792A transfer standard, V	0	$7{,}50 \cdot 10^{-5}$	Normal	-0,100008	$-7{,}50 \cdot 10^{-6}$	infinity
X_5: Measurement result, V	10,00081	$1{,}22 \cdot 10^{-5}$	Normal	0,1	$1{,}22 \cdot 10^{-6}$	29
X_6: Resolution of traveling standard, V	0	$2{,}89 \cdot 10^{-6}$	Rectangular	0,1	$2{,}89 \cdot 10^{-7}$	infinity
X_7: Repeatability of results, V	0	$1{,}73 \cdot 10^{-5}$	Rectangular	0,1	$1{,}73 \cdot 10^{-6}$	infinity
Error E_x	$8{,}1 \cdot 10^{-5}$	**Combined Uncertainty,** $u(E_x)$				$1{,}66 \cdot 10^{-5}$
		Effective Degrees of Freedom, ν_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$3{,}3 \cdot 10^{-4}$

Model function (100 V@ 55 Hz):

$$Y = \frac{((X_5 + X_6) - (X_2 + X_1 + X_3 + X_4)) + X_7}{(X_2 + X_1 + X_3 + X_4)}$$

Table 17. Uncertainty budget for 100 V @55 Hz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** v_i
X_1: 10 V Zener reference standard, V	0	$3{,}00 \cdot 10^{-5}$	Normal	-0,01	$-3{,}00 \cdot 10^{-7}$	148
X_2: Calibrator output, V	100	$2{,}3 \cdot 10^{-3}$	Normal	-0,01	$-2{,}30 \cdot 10^{-5}$	infinity
X_3: Calibrator stability, V	0	$6{,}40 \cdot 10^{-4}$	Normal	-0,01	$-6{,}40 \cdot 10^{-6}$	infinity
X_4: 792A transfer standard, V	0	$1{,}50 \cdot 10^{-3}$	Normal	-0,01	$-1{,}50 \cdot 10^{-5}$	infinity
X_5: Measurement result, V	99,9990	$2{,}95 \cdot 10^{-4}$	Normal	0,01	$2{,}95 \cdot 10^{-6}$	29
X_6: Resolution of traveling standard, V	0	$2{,}89 \cdot 10^{-5}$	Rectangular	0,01	$2{,}89 \cdot 10^{-7}$	infinity
X_7: Repeatability of results, V	0	$5{,}77 \cdot 10^{-5}$	Rectangular	0,01	$5{,}77 \cdot 10^{-7}$	infinity
Error E_x	$-1{,}0 \cdot 10^{-5}$	**Combined Uncertainty,** $u(E_x)$				$2{,}84 \cdot 10^{-5}$
		Effective Degrees of Freedom, v_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$5{,}7 \cdot 10^{-5}$

Model function (100 V@ 1 kHz):

$$Y = \frac{\left(\left(X_5 + X_6\right) - \left(X_2 + X_1 + X_3 + X_4\right)\right) + X_7}{\left(X_2 + X_1 + X_3 + X_4\right)}$$

Table 18. Uncertainty budget for 100 V @1 kHz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: 10 V Zener reference standard, V	0	$3{,}00 \cdot 10^{-5}$	Normal	-0,01	$-3{,}00 \cdot 10^{-7}$	148
X_2: Calibrator output, V	100	$2{,}3 \cdot 10^{-3}$	Normal	-0,01	$-2{,}30 \cdot 10^{-5}$	infinity
X_3: Calibrator stability, V	0	$6{,}40 \cdot 10^{-4}$	Normal	-0,01	$-6{,}40 \cdot 10^{-6}$	infinity
X_4: 792A transfer standard, V	0	$1{,}00 \cdot 10^{-3}$	Normal	-0,01	$-1{,}00 \cdot 10^{-5}$	infinity
X_5: Measurement result, V	100,0033	$1{,}55 \cdot 10^{-4}$	Normal	0,01	$1{,}55 \cdot 10^{-6}$	29
X_6: Resolution of traveling standard, V	0	$2{,}89 \cdot 10^{-5}$	Rectangular	0,01	$2{,}89 \cdot 10^{-7}$	infinity
X_7: Repeatability of results, V	0	$5{,}77 \cdot 10^{-5}$	Rectangular	0,01	$5{,}77 \cdot 10^{-7}$	infinity
Error E_x	$3{,}3 \cdot 10^{-5}$				**Combined Uncertainty,** $u(E_x)$	$2{,}59 \cdot 10^{-5}$
					Effective Degrees of Freedom, ν_{eff}	infinity
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	$5{,}2 \cdot 10^{-5}$

7.5. AC current

Model function (10 mA @ 300 Hz):

$$Y = \frac{((X_2 + X_3) - (X_1 + X_4 + X_5 + X_6)) + X_7}{(X_1 + X_4 + X_5 + X_6)}$$

Table 19. Uncertainty budget for 10 mA @300 Hz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: Applied current, A	0,01000062	$1{,}71 \cdot 10^{-8}$	Normal	-99,9928	$-1{,}71 \cdot 10^{-6}$	29
X_2: Measured current, A	0,01000052	$2{,}45 \cdot 10^{-8}$	Normal	99,9938	$2{,}45 \cdot 10^{-6}$	29
X_3: Resolution of traveling standard, A	0	$2{,}89 \cdot 10^{-9}$	Rectangular	99,9938	$2{,}89 \cdot 10^{-7}$	infinity
X_4: Reference DMM accuracy, A	0	$2{,}5 \cdot 10^{-6}$	Normal	-99,99281	$-2{,}5 \cdot 10^{-4}$	infinity
X_5: Reference DMM last calibration, A	0	$1{,}35 \cdot 10^{-6}$	Normal	-99,9928	$-1{,}35 \cdot 10^{-4}$	infinity
X_6: 5720A calibrator stability, A	0	$1{,}65 \cdot 10^{-7}$	Normal	-99,9928	$-1{,}65 \cdot 10^{-5}$	infinity
X_7: Repeatability of results, A	0	$6{,}35 \cdot 10^{-8}$	Rectangular	99,9938	$6{,}35 \cdot 10^{-6}$	infinity
Error E_x	$-1{,}0 \cdot 10^{-5}$	**Combined Uncertainty,** $u(E_x)$				$2{,}85 \cdot 10^{-4}$
		Effective Degrees of Freedom, ν_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$5{,}7 \cdot 10^{-4}$

Model function (10 mA @ 1 kHz):

$$Y = \frac{((X_2 + X_3) - (X_1 + X_4 + X_5 + X_6)) + X_7}{(X_1 + X_4 + X_5 + X_6)}$$

Table 20. Uncertainty budget for 10 mA @1 kHz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** v_i
X_1: Applied current, A	0,01000051	$1,78 \cdot 10^{-8}$	Normal	-99,9964	$-1,78 \cdot 10^{-6}$	29
X_2: Measured current, A	0,01000066	$1,35 \cdot 10^{-8}$	Normal	99,9949	$1,35 \cdot 10^{-6}$	29
X_3: Resolution of traveling standard, A	0	$2,89 \cdot 10^{-9}$	Rectangular	99,9949	$2,89 \cdot 10^{-7}$	infinity
X_4: Reference DMM accuracy, A	0	$2,5 \cdot 10^{-6}$	Normal	-99,99641	$-2,5 \cdot 10^{-4}$	infinity
X_5: Reference DMM last calibration, A	0	$1,0 \cdot 10^{-6}$	Normal	-99,9964	$-1,0 \cdot 10^{-4}$	infinity
X_6: 5720A calibrator stability, A	0	$5,0 \cdot 10^{-7}$	Normal	-99,9964	$-5,0 \cdot 10^{-5}$	infinity
X_7: Repeatability of results, A	0	$5,77 \cdot 10^{-8}$	Rectangular	99,9949	$5,77 \cdot 10^{-6}$	infinity
Error E_x	$1,5 \cdot 10^{-5}$	**Combined Uncertainty,** $u(E_x)$				$2,74 \cdot 10^{-4}$
		Effective Degrees of Freedom, v_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$5,5 \cdot 10^{-4}$

Model function (1 A @ 300 Hz):

$$Y = \frac{((X_2 + X_3) - (X_1 + X_4 + X_5 + X_6)) + X_7}{(X_1 + X_4 + X_5 + X_6)}$$

Table 21. Uncertainty budget for 1 A @300 Hz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: Applied current, A	1,000073	$1,52 \cdot 10^{-6}$	Normal	-0,999755	$-1,52 \cdot 10^{-6}$	29
X_2: Measured current, A	0,999901	$6,80 \cdot 10^{-6}$	Normal	0,999927	$6,80 \cdot 10^{-6}$	29
X_3: Resolution of traveling standard, A	0	$2,89 \cdot 10^{-7}$	Rectangular	0,999927	$2,89 \cdot 10^{-7}$	infinity
X_4: Reference DMM accuracy, A	0	$6,0 \cdot 10^{-4}$	Normal	-0,999755	$-6,0 \cdot 10^{-4}$	infinity
X_5: Reference DMM last calibration, A	0	-	Normal	-	-	infinity
X_6: 5720A calibrator stability, A	0	$2,75 \cdot 10^{-5}$	Normal	-0,999755	$-2,75 \cdot 10^{-5}$	infinity
X_7: Repeatability of results, A	0	$4,62 \cdot 10^{-6}$	Rectangular	0,999927	$4,62 \cdot 10^{-6}$	infinity
Error E_x	$-1,72 \cdot 10^{-4}$	**Combined Uncertainty,** $u(E_x)$				$6,0 \cdot 10^{-4}$
		Effective Degrees of Freedom, ν_{eff}				infinity
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				$1,2 \cdot 10^{-3}$

Model function (1 A @ 1 kHz):

$$Y = \frac{((X_2 + X_3) - (X_1 + X_4 + X_5 + X_6)) + X_7}{(X_1 + X_4 + X_5 + X_6)}$$

Table 22. Uncertainty budget for 1 A @1 kHz

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(E_x)$	**Degrees of freedom (DoF)** ν_i
X_1: Applied current, A	1,000121	$1{,}24 \cdot 10^{-6}$	Normal	-0,999747	$-1{,}24 \cdot 10^{-6}$	29
X_2: Measured current, A	0,999989	$7{,}41 \cdot 10^{-6}$	Normal	0,999879	$7{,}41 \cdot 10^{-6}$	29
X_3: Resolution of traveling standard, A	0	$2{,}89 \cdot 10^{-7}$	Rectangular	0,999879	$2{,}89 \cdot 10^{-7}$	infinity
X_4: Reference DMM accuracy, A	0	$6{,}0 \cdot 10^{-4}$	Normal	-0,999747	$-6{,}0 \cdot 10^{-4}$	infinity
X_5: Reference DMM last calibration, A	0	-	Normal	-	-	infinity
X_6: 5720A calibrator stability, A	0	$5{,}0 \cdot 10^{-5}$	Normal	-0,999747	$-5{,}0 \cdot 10^{-5}$	infinity
X_7: Repeatability of results, A	0	$5{,}2 \cdot 10^{-6}$	Rectangular	0,999879	$5{,}2 \cdot 10^{-6}$	infinity
Error E_x	$-1{,}32 \cdot 10^{-4}$				**Combined Uncertainty,** $u(E_x)$	$6{,}0 \cdot 10^{-4}$
					Effective Degrees of Freedom, ν_{eff}	infinity
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	$1{,}2 \cdot 10^{-3}$

Instituto Português da Qualidade

REPÚBLICA PORTUGUESA
ECONOMIA

REPORT

Portuguese Participation
on
“Comparison on Calibration of Multimeter”

EURAMET Project No 1341

Luís Ribeiro
Vitor Cabral

December 2015

1. Introduction

This report is intended to present a summary of the results of Portuguese participation in the EURAMET Project No 1341: “Comparison on Calibration of Multimeter”.

Portugal has been scheduled to participate between 2015-09-03 and 2015.09.11.

2. PARTICIPANT INSTITUTE

Institute	IPQ – Instituto Português da Qualidade Laboratório Nacional de Metrologia
Contact Person	Luís Ribeiro
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Address	Rua António Gião 2 PT - 2829-513 Caparica, Portugal

3. PERIOD OF MEASUREMENTS

2015-09-03 to 2015-09-10

4. Travelling Standard

The travelling standard was an 8½ digit multimeter, Fluke 8508A Reference Multimeter, serial number 969656608, supplied by TÜBİTAK UME.

It was received on 2015-08-28 from:
Saliha TURHAN
TÜBİTAK ULUSAL METROLOJİ ENSTİTÜSÜ
Gebze Yerleşkesi
P.K. 54 41470
Gezbe Kocaeli

under carnet at nr. TR-0024368

It was shipped on 2015-09-11 to:

Stanislava Kroneva Petrovska
Bureau of Metrology (BoM)
Bull. Jane Sandanski 109 a
MK-1000 Skopje R.
FYR Macedonia

5. Measurement Quantities and Points

The quantities measured were DC voltage, DC current, AC voltage, AC current and DC resistance in the points defined in the technical protocol.

Measurement quantities & points and the configuration of Fluke 8508A

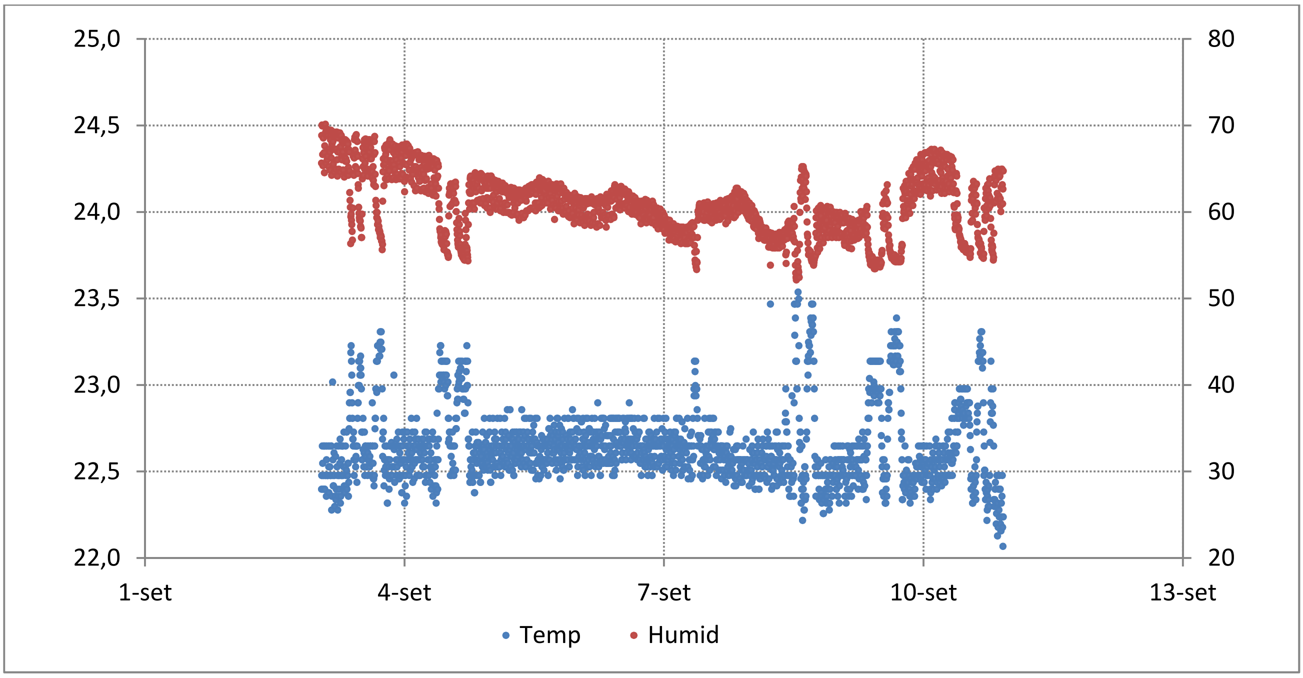
Quantity	Measurement Point	Range of 8508A	Configuration of 8508A
DC Voltage	100 mV	200 mV	Resolution 7 Filter ON Fast OFF Front Input
	10 V	20 V	
	100 V	200 V	
	1000 V	1000 V	
DC Current	100 µA	200 µA	Resolution 7 Filter ON Fast OFF Front Input
	10 mA	20 mA	
	1 A	2 A	
AC Voltage	100 mV @ 55 Hz[†]	200 mV	Resolution 6 Transfer ON AC Coupled RMS Filter 100 Hz ([†]RMS Filter 40 Hz @ 55 Hz) Front Input
	100 mV @ 1 kHz		
	10 V @ 55 Hz[†]	20 V	
	10 V @ 1 kHz		
	10 V @ 100 kHz		
	100 V @ 55 Hz[†]	200 V	
	100 V @ 1 kHz		
AC Current	10 mA @ 300 Hz	20 mA	Resolution 6 AC Coupled RMS Filter 100 Hz Front Input
	10 mA @ 1 kHz		
	1 A @ 300 Hz	2 A	
	1 A @ 1 kHz		
DC Resistance	10 Ω	20 Ω	TrueΩ ([‡] Normal Ω for 1 MΩ) Resolution 7 4-Wire Low Current OFF ([‡]Low Current ON) Filter ON Fast OFF Front Input
	10 kΩ	20 kΩ	
	10 kΩ[‡]		
	1 MΩ[‡]	2 MΩ	

6. AMBIENT CONDITIONS

The limits founded in the overall period are covered by the following limits:

Temperature : (23 ± 1) °C

Relative Humidity : (61 ± 9) % rh



7. MEASUREMENT RESULTS

7.1. DC VOLTAGE

The measurement method was based on a direct measurement of a standard cell or a standardized multifunction calibrator output.

THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Reference standard	FLUKE	7001	44323	Josephson Effect
Multifunction calibrator	FLUKE	5720A	8657201	Josephson effect
Resistance Divider	FLUKE	720A	4395008	Josephson effect

MEASUREMENT RESULTS

Range of 8508A	Nominal Value		Applied Value	Reading of 8508A	Error of 8508A (ppm)	Uncertainty (ppm)
200 mV	100 mV		100,00000 mV	99,999878 mV	-1,22	1,3
20 V	10 V		9,999850 V	9,9998897 V	3,96	0,22
200 V	100 V		100,00000 V	99,99987 V	-1,31	1,8
1000 V	1000 V		1000,0000 V	1000,00236 V	2,36	2,4

7.2. DC CURRENT

The measurement method was based on a direct measurement of a DC current provided by a multifunction calibrator standardized by means of a standard resistance.

THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Multifunction calibrator	FLUKE	5720	8657201	BIPM
Standard Resistor, 10 kΩ	ESI	SR104	J207119030104	BIPM
Standard Resistor, 10 Ω	TINSLEY	5685A	7002/08	BIPM
Standard Resistor, 0.1 Ω	TINSLEY	3504C	183610	BIPM
Reference multimeter	AGILENT	3458A	MY45041453	Josephson Effect

MEASUREMENT RESULTS

Range of 8508A	Nominal Value		Applied Value	Reading of 8508A	Error of 8508A (ppm)	Uncertainty (ppm)
200 µA	100 µA		99,999020 µA	99,997927 µA	-10,92	0,73
20 mA	10 mA		9,9999863 mA	10,000200 mA	21,41	0,68
1 A	1 A		1,0000021 A	0,9998865 A	-115,6	1,3

7.3. AC VOLTAGE

The measurement method was based on a direct measurement of an AC voltage provided by a multifunction calibrator standardized by thermal converters with resistive adapters after characterization of the equivalent DC output.

THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Multifunction calibrator	FLUKE	5720	8657201	Josephson effect
Thermal converters	PTB		TC90	PTB
Resistive adapters	IPQ			PTB

MEASUREMENT RESULTS

Range of 8508A	Nominal Value		Applied Value	Reading of 8508A	Error of 8508A (ppm)	Uncertainty (ppm)
	Voltage	Frequency				
200 mV	100 mV	55 Hz	100,0000 mV	99,99890 mV	-11,0	18
	100 mV	1 kHz	100,0000 mV	100,00205 mV	20,5	18
20 V	10 V	55 Hz	10,0000 V	10,00056 V	56,0	12
	10 V	1 kHz	10,0000 V	10,000993 V	99,3	8,8
	10 V	100 kHz	10,0000 V	10,000735 V	73,4	14
200 V	100 V	55 Hz	100,000 V	99,9979 V	-21,1	23
	100 V	1 kHz	100,000 V	100,0018 V	18,1	19

7.4. AC CURRENT

The measurement method was based on a direct measurement of an AC current provided by a multifunction calibrator standardized by thermal converters with resistive shunts after characterization of the equivalent DC output.

THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Multifunction calibrator	FLUKE	5720	8657201	Josephson effect
Thermal converters	PTB		TC05	PTB
Resistive adapters	FLUKE	A40 20 mA	4730003	PTB
Resistive adapters	FLUKE	A40 2 A	4550001	PTB

MEASUREMENT RESULTS

Range of 8508A	Nominal Value		Applied Value	Reading of 8508A	Error of 8508A (ppm)	Uncertainty (ppm)
	Voltage	Frequency				
20 mA	10 mA	300 Hz	9,9999863 mA	10,00056 mA	56,9	52
	10 mA	1 kHz	9,9999863 mA	10,00068 mA	69,8	52
2 A	1 A	300 Hz	1,0000021 A	0,99993 A	-76,5	117
	1 A	1 kHz	1,0000021 A	1,00002 A	14,6	117

7.5. DC RESISTANCE

The measurement method was based on a direct measurement of standard resistors with the multimeter under calibration.

THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Standard Resistor, 10 Ω	Guildline	9330	57499	BIPM
Standard Resistor, 10 kΩ	ESI	SR104	J207119030104	BIPM
Standard Resistor, 1 MΩ	Guildline	9330	58180	BIPM

MEASUREMENT RESULTS

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
20 Ω	TrueΩ	10 Ω	10,0003531 Ω	10,000488 Ω	13,49 ppm	0,69 ppm
20 kΩ	TrueΩ	10 kΩ	9.999,9906 Ω	10.000,0827 Ω	9,21 ppm	0,63 ppm
	TrueΩ LoI	10 kΩ	9.999,9906 Ω	10.000,0843 Ω	9,37 ppm	0,63 ppm
2 MΩ	Normal Ω	1 MΩ	1000080,93 Ω	1000096,8 Ω	15,9 ppm	1,6 ppm

8. UNCERTAINTY BUDGET

The uncertainty of measurement was calculated according to the JCGM 100 "Guide to the Expression of Uncertainty in Measurement" [3] for the coverage probability of approximately 95 %.

1.1. DC Voltage

Model Function:

$$E = I + \Delta I - (U * \Delta U)$$

or

$$E = I + \Delta I - U$$

Where:

E Error of the multimeter
I Multimeter reading
ΔI Correction of the multimeter reading error due to the finite resolution
U Reference value
ΔU Resistive divider

Uncertainty budget for 100 mV

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I	0,09999988 V	2,2E-08 V	Normal	1	2,2E-08 V	105
ΔI	0 V	2,9E-10 V	Rectangular	1	2,9E-10 V	50
U	1,000001 V	5,8E-08 V	Rectangular	-0,0999999 V	-5,8E-09 V	50
ΔU	0,0999999 V	5,8E-08 V	Rectangular	-1,000001 V	-5,8E-08 V	50
Error (E_x)	-1,2E-07 V				**Combined Uncertainty, $u(E_x)$**	6,2E-08 V
					Effective Degrees of Freedom, v_{eff}	66
					Coverage Factor, k	2,04
					Expanded Uncertainty, $U(E_x)$	1,3E-07 V

Uncertainty budget for 10 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I	9,9998899 V	9,5E-07 V	Normal	1	9,5E-07 V	187
ΔI	0 V	2,9E-08 V	Rectangular	1	2,9E-08 V	50
U	9,9998501 V	5,8E-07 V	Rectangular	1	5,8E-07 V	50
Error (E_x)	4,0E-05 V				**Combined Uncertainty, $u(E_x)$**	1,1E-06 V
					Effective Degrees of Freedom, v_{eff}	233
					Coverage Factor, k	2,01
					Expanded Uncertainty, $U(E_x)$	2,2E-06 V

Uncertainty budget for 100 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	99,99987 V	1,7E-05 V	Normal	1	1,7E-05 V	168
ΔI	0 V	2,9E-07 V	Rectangular	1	2,9E-07 V	50
U	100,0 V	8,7E-05 V	Rectangular	1	8,7E-05 V	50
Error (E_x)	-1,3E-04 V	**Combined Uncertainty, *u(E_x)***				8,8E-05 V
		Effective Degrees of Freedom, ν_{eff}				54
		Coverage Factor, *k*				2,05
		Expanded Uncertainty, *U(E_x)*				1,8E-04 V

Uncertainty budget for 1000 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	1000,0024 V	1,7E-04 V	Normal	1	1,7E-04 V	87
ΔI	0 V	2,9E-06 V	Rectangular	1	2,9E-06 V	50
U	1000,0 V	1,2E-03 V	Rectangular	1	1,2E-03 V	50
Error (E_x)	2,36E-03 V	**Combined Uncertainty, $u(E_x)$**				1,2E-03 V
		Effective Degrees of Freedom, ν_{eff}				52
		Coverage Factor, *k*				2,05
		Expanded Uncertainty, $U(E_x)$				2,4E-03 V

1.2. DC Current

Model Function:

$$E = I + \Delta I - (U/R)$$

Where:

E Error of the multimeter
I Multimeter reading
ΔI Correction of the multimeter reading error due to the finite resolution
U Voltage reference value
R Standard resistance value

Uncertainty budget for 100 µA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I	9,9998E-05 A	2,5E-11 A	Normal	1	2,5E-11 A	74
ΔI	0 A	2,9E-12 A	Rectangular	1	2,9E-12 A	50
U	0,9999892 A	5,8E-08 A	Rectangular	-1,0E-04 Ω^{-1}	-5,8E-12 A	50
R	9999,990 Ω	2,5E-03 Ω	Rectangular	1,0E-08 V Ω^{-2}	2,5E-11 A	50
Error (E_x)	-1,09E-09 A				Combined Uncertainty, $u(E_x)$	3,6E-11 A
					Effective Degrees of Freedom, v_{eff}	127
					Coverage Factor, k	2,02
					Expanded Uncertainty, $U(E_x)$	7,3E-11 A

Uncertainty budget for 10 mA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I	1,0000E-02 A	1,4E-09 A	Normal	1	1,4E-09 A	79
ΔI	0 A	2,9E-10 A	Rectangular	1	2,9E-10 A	50
U	0,1000000 A	5,8E-09 A	Rectangular	-1,0E-01 Ω^{-1}	-5,8E-10 A	50
R	10,000 Ω	3,0E-06 Ω	Rectangular	1,0E-03 V Ω^{-2}	3,0E-09 A	50
Error (E_x)	2,14E-07 A				Combined Uncertainty, $u(E_x)$	3,3E-09 A
					Effective Degrees of Freedom, v_{eff}	77
					Coverage Factor, k	2,03
					Expanded Uncertainty, $U(E_x)$	6,8E-09 A

Uncertainty budget for 1 A

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I	9,9989E-01 A	2,3E-07 A	Normal	1	2,3E-07 A	134
ΔI	0 A	2,9E-08 A	Rectangular	1	2,9E-08 A	50
U	0,0999966 A	5,8E-09 A	Rectangular	-1,0E+01 Ω^{-1}	-5,8E-08 A	50
R	0,100 Ω	5,8E-08 Ω	Rectangular	1,0E+01 V Ω^{-2}	5,8E-07 A	50
Error (E_x)	-1,16E-04 A				Combined Uncertainty, $u(E_x)$	6,3E-07 A
					Effective Degrees of Freedom, v_{eff}	68
					Coverage Factor, k	2,04
					Expanded Uncertainty, $U(E_x)$	1,3E-06 A

1.3. AC Voltage

Model Function:

$$E = I + \Delta I - (U + \Delta U)$$

Where:

E Error of the multimeter
I Multimeter reading
ΔI Correction of the multimeter reading error due to the finite resolution
U Voltage reference value corresponding to the DC caractherization
ΔU Coretion due to the AC/DC transfer

Uncertainty budget for 100 mV 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	0,0999989 V	5,3E-07 V	Normal	1	5,3E-07 V	106
ΔI	0 V	2,9E-08 V	Rectangular	1	2,9E-08 V	50
U	0,1000000 V	6,6E-07 V	Rectangular	1	6,6E-07 V	50
ΔU		2,8E-07 V	Rectangular	1	2,9E-07 V	50
Error (E_x)	-1,1E-06 V				Combined Uncertainty, $u(E_x)$	9,0E-07 V
					Effective Degrees of Freedom, ν_{eff}	137
					Coverage Factor, k	2,02
					Expanded Uncertainty, $U(E_x)$	1,8E-06 V

Uncertainty budget for 100 mV 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	0,1000021 V	5,7E-07 V	Normal	1	5,7E-07 V	104
ΔI	0 V	2,9E-08 V	Rectangular	1	2,9E-08 V	50
U	0,1 V	6,6E-07 V	Rectangular	1	6,6E-07 V	50
ΔU		2,3E-07 V	Rectangular	1	2,3E-07 V	50
Error (E_x)	2,05E-06 V				Combined Uncertainty, $u(E_x)$	9,1E-07 V
					Effective Degrees of Freedom, ν_{eff}	136
					Coverage Factor, k	2,02
					Expanded Uncertainty, $U(E_x)$	1,8E-06 V

Uncertainty budget for 10 V 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	10,000560 V	3,3E-05 V	Normal	1	3,3E-05 V	60
ΔI	0 V	2,9E-06 V	Rectangular	1	2,9E-06 V	50
U	10,0 V	2,3E-05 V	Rectangular	1	2,3E-05 V	50
ΔU		4,0E-05 V	Rectangular	1	4,0E-05 V	50
Error (E_x)	5,60E-04 V	**Combined Uncertainty, $u(E_x)$**				5,7E-05 V
		Effective Degrees of Freedom, ν_{eff}				134
		Coverage Factor, *k*				2,02
		Expanded Uncertainty, $U(E_x)$				1,2E-04 V

Uncertainty budget for 10 V 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	10,000994 V	1,3E-05 V	Normal	1	1,3E-05 V	90
ΔI	0 V	2,9E-06 V	Rectangular	1	2,9E-06 V	50
U	10,0 V	2,3E-05 V	Rectangular	1	2,3E-05 V	50
ΔU		3,5E-05 V	Rectangular	1	3,5E-05 V	50
Error (E_x)	9,93E-04 V	**Combined Uncertainty, $u(E_x)$**				4,3E-05 V
		Effective Degrees of Freedom, ν_{eff}				102
		Coverage Factor, *k*				2,02
		Expanded Uncertainty, $U(E_x)$				8,8E-05 V

Uncertainty budget for 10 V 100 kHz

X_i	x_i	Uncertainty $u(x_i)$	Distribution	Coefficient c_i	Contribution $u_i(E_x)$	ν_i
I	10,000735 V	1,4E-05 V	Normal	1	1,4E-05 V	101
ΔI	0 V	2,9E-06 V	Rectangular	1	2,9E-06 V	50
U	10,0 V	2,3E-05 V	Rectangular	1	2,3E-05 V	50
ΔU		6,4E-05 V	Rectangular	1	6,4E-05 V	50
Error (E_x)	7,35E-04 V	**Combined Uncertainty, $u(E_x)$**				6,9E-05 V
		Effective Degrees of Freedom, ν_{eff}				68
		Coverage Factor, *k*				2,04
		Expanded Uncertainty, $U(E_x)$				1,4E-04 V

Uncertainty budget for 100 V 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	99,9979 V	3,1E-04 V	Normal	1	3,1E-04 V	127
ΔI	0 V	2,9E-05 V	Rectangular	1	2,9E-05 V	50
U	100,0 V	5,2E-05 V	Rectangular	1	5,2E-05 V	50
ΔU		1,1E-03 V	Rectangular	1	1,1E-03 V	50
Error (E_x)	-2,11E-03 V				**Combined Uncertainty, $u(E_x)$**	1,1E-03 V
					Effective Degrees of Freedom, ν_{eff}	58
					Coverage Factor, k	2,04
					Expanded Uncertainty, $U(E_x)$	2,3E-03 V

Uncertainty budget for 100 V 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	100,0019 V	1,1E-04 V	Normal	1	1,1E-04 V	150
ΔI	0 V	2,9E-05 V	Rectangular	1	2,9E-05 V	50
U	100,0 V	5,2E-05 V	Rectangular	1	5,2E-05 V	50
ΔU		9,2E-04 V	Rectangular	1	9,2E-04 V	50
Error (E_x)	1,81E-03 V				**Combined Uncertainty, $u(E_x)$**	9,3E-04 V
					Effective Degrees of Freedom, ν_{eff}	52
					Coverage Factor, k	2,05
					Expanded Uncertainty, $U(E_x)$	1,9E-03 V

1.4. AC Current

Model Function:

$$E = I + \Delta I - (Q + \Delta Q)$$

Where:

E Error of the multimeter
I Multimeter reading
ΔI Correction of the multimeter reading error due to the finite resolution
Q Current reference value corresponding to the DC caractherization
ΔQ Corretion due to the AC/DC transfer

Uncertainty budget for 10 mA 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	0,01000056 A	2,6E-08 A	Normal	1	2,6E-08 A	256
ΔI	0 A	2,9E-09 A	Rectangular	1	2,9E-09 A	50
Q	0,00999998 A	2,3E-07 A	Rectangular	1	2,3E-07 A	50
ΔQ		1,2E-07 A	Rectangular	1	1,2E-07 A	50
Error (E_x)	5,69E-07 A				Combined Uncertainty, $u(E_x)$	2,5E-07 A
					Effective Degrees of Freedom, ν_{eff}	76
					Coverage Factor, k	2,03
					Expanded Uncertainty, $U(E_x)$	5,2E-07 A

Uncertainty budget for 10 mA 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	0,01000068 A	1,6E-08 A	Normal	1	1,6E-08 A	162
ΔI	0 A	2,9E-09 A	Rectangular	1	2,9E-09 A	50
Q	0,009999986 A	2,3E-07 A	Rectangular	1	2,3E-07 A	50
ΔQ		1,2E-07 A	Rectangular	1	1,2E-07 A	50
Error (E_x)	6,98E-07 A				Combined Uncertainty, $u(E_x)$	2,5E-07 A
					Effective Degrees of Freedom, ν_{eff}	75
					Coverage Factor, k	2,03
					Expanded Uncertainty, $U(E_x)$	5,26E-07 A

Uncertainty budget for 1 A 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	0,999926 A	7,4E-06 A	Normal	1	7,4E-06 A	172
ΔI	0	2,9E-07 A	Rectangular	1	2,9E-07 A	50
Q	1,0000022 A	5,3E-05 A	Rectangular	1	5,3E-05 A	50
ΔQ		2,1E-05 A	Rectangular	1	2,1E-05 A	50
Error (E_x)	-7,65E-05 A				Combined Uncertainty, $u(E_x)$	5,6E-05 A
					Effective Degrees of Freedom, ν_{eff}	67
					Coverage Factor, k	2,04
					Expanded Uncertainty, $U(E_x)$	1,2E-04 A

Uncertainty budget for 1 A 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	1,000017 A	7,7E-06	Normal	1	7,7E-06 A	202
ΔI	0 A	2,9E-07	Rectangular	1	2,9E-07 A	50
Q	1,0000022 A	5,3E-05	Rectangular	1	5,3E-05 A	50
ΔQ		2,1E-05		1	2, E-05 A	50
Error (E_x)	1,46E-05 A	**Combined Uncertainty, $u(E_x)$**				5,6E-05 A
		Effective Degrees of Freedom, ν_{eff}				67
		Coverage Factor, k				2,04
		Expanded Uncertainty, $U(E_x)$				1,2E-04 A

1.5. DC Resistance

Model Function:

$$E = I + \Delta I - (R + \Delta R)$$

Where:

E Error of the multimeter
I Multimeter reading
ΔI Correction of the multimeter reading error due to the finite resolution
R True value of the standard resistor
ΔR Coretion of the standard resistor error due to the temperature

$$\Delta R = R \times \alpha(23°\mathrm{C} - t) + R \times \beta(23°\mathrm{C} - t)^2$$

Where:

α temperature coefficient of the standard resistor, °C^{-1}
β temperature coefficient of the standat resistor, °C^{-2}
t temperature of the standard resistor

Uncertainty budget for 10 Ω

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	10,00048 Ω	2,0E-07 Ω	Normal	1	2,0E-07 Ω	99
ΔI	0 Ω	2,9E-07 Ω	Rectangular	1	2,9E-07 Ω	∞
R	10,0003524 Ω	2,97E-06 Ω	t-student	-1	2,97E-06 Ω	30
t	22,981 °C	0,037 °C	Rectangular	3,9E-05 Ω°C^{-1}	1,45E-06 Ω	∞
Error (E_x)	134,9E-06 Ω	**Combined Uncertainty, $u(E_x)$**				3,3E-06 Ω
		Effective Degrees of Freedom, ν_{eff}				47
		Coverage Factor, k				2,1
		Expanded Uncertainty, $U(E_x)$				6,9E-06 Ω

Uncertainty budget for 10 kΩ

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	10000,0827 Ω	1,4E-04 Ω	Normal	1	1,4E-04 Ω	99
ΔI	0 Ω	2,9E-04 Ω	Rectangular	1	2,9E-04 Ω	∞
R	9999,9904 Ω	2,50E-03 Ω	t-student	-1	2,50E-03 Ω	6
t	22,629 °C	0,046 °C	Rectangular	4,1E-04 Ω°C^{-1}	1,9E-05 Ω	∞
Error (E_x)	0,0921 Ω	**Combined Uncertainty, $u(E_x)$**				0,0025 Ω
		Effective Degrees of Freedom, ν_{eff}				6,4
		Coverage Factor, k				2,5
		Expanded Uncertainty, $U(E_x)$				0,0063 Ω

Uncertainty budget for 10 kΩ LoI

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	10000,0843 Ω	3,4E-04 Ω	Normal	1	3,4E-04 Ω	99
ΔI	0 Ω	2,9E-04 Ω	Rectangular	1	2,9E-04 Ω	∞
R	9999,9904 Ω	2,50E-03 Ω	t-student	-1	2,50E-03 Ω	7
t	22,698 °C	0,043 °C	Rectangular	4,4E-04 Ω°C^{-1}	1,9E-05 Ω	∞
Error (E_x)	0,0937 Ω	**Combined Uncertainty, $u(E_x)$**				0,0025 Ω
		Effective Degrees of Freedom, ν_{eff}				6,6
		Coverage Factor, k				2,5
		Expanded Uncertainty, $U(E_x)$				0,0063 Ω

Uncertainty budget for 1 MΩ

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I	1000096,8Ω	5,7E-03 Ω	Normal	1	5,7E-03 Ω	99
ΔI	0 Ω	2,89E-02 Ω	Rectangular	1	2,89E-02 Ω	∞
R	1000080,93 Ω	7,374E-01 Ω	t-student	-1	7,374E-01 Ω	16
t	23,221°C	0,032 °C	Rectangular	0 Ω°C^{-1}	0 Ω	∞
Error (E_x)	15,9 Ω	**Combined Uncertainty, $u(E_x)$**				0,74 Ω
		Effective Degrees of Freedom, ν_{eff}				16
		Coverage Factor, k				2,2
		Expanded Uncertainty, $U(E_x)$				1,6 Ω

Bureau of metrology
Republia of Macedonia

1. PARTICIPANT INSTITUTE

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2. PERIOD OF MEASUREMENTS

From 21.09.2015 to 28.09.2015

3. AMBIENT CONDITIONS

Temperature : (23 ± 1) °C

Relative Humidity : (46 ± 5) % rh

4. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Multifunctional Calibrator	**Wavetek-Datron**	**4808**	**29276**	**EIM, Greece**

5. MEASUREMENT METHOD

Direct method

6. MEASUREMENT RESULTS

DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 mV	+ 100 mV	99.999574 mV	99.99799 mV	-16 µV/V	21 µV/V
20 V	+ 10 V	10.0000466 V	10.000039 V	-0.8 µV/V	13 µV/V
200 V	+ 100 V	100.00013 V	99.99946 V	-6.7 µV/V	14 µV/V
1000 V	+ 1000 V	999.998522 V	999.9941 V	-4.4 µV/V	15 µV/V

DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 µA	+ 100 µA	99.999329 µA	99.99925 µA	-1 µA/A	146 µA/A
20 mA	+ 10 mA	10.0001815 mA	10.000179 mA	-0.3 µA/A	72 µA/A
1 A	+ 1 A	1.00002388 A	0.9998825 A	-141 µA/A	204 µA/A

DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
20 Ω	TrueΩ	10 Ω	10.0002137 Ω	10.00024 Ω	3 µΩ/Ω	45 µΩ/Ω
20 kΩ	TrueΩ	10 kΩ	10.0004207 kΩ	10.000389 kΩ	-3 µΩ/Ω	23 µΩ/Ω
	TrueΩ LoI	10 kΩ	10.0004207 kΩ	10.000408 kΩ	-1 µΩ/Ω	23 µΩ/Ω
2 MΩ	Normal Ω	1 MΩ	1.00007704 MΩ	1.0000733 MΩ	-4 µΩ/Ω	42 µΩ/Ω

AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99.99805 mV	99.9975 mV	-6 μV/V	232 μV/V
	100 mV	1 kHz	99.99146 mV	100.0023 mV	108 μV/V	223 μV/V
20 V	10 V	55 Hz	10.000246 V	10.00020 V	-5 μV/V	144 μV/V
	10 V	1 kHz	10.000423 V	10.00073 V	31 μV/V	137 μV/V
	10 V	100 kHz	10.001553 V	10.00117 V	-38 μV/V	958 μV/V
200 V	100 V	55 Hz	100.00355 V	99.9983 V	-52 μV/V	276 μV/V
	100 V	1 kHz	100.00370 V	100.0025 V	-12 μV/V	269 μV/V

AC CURRENT

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Current	Frequency				
20 mA	10 mA	300 Hz	10.001917 mA	10.00058 mA	-134 μA/A	647 μA/A
	10 mA	1 kHz	10.001926 mA	10.00085 mA	-108 μA/A	647 μA/A
1 A	1 A	300 Hz	1.0001116 A	0.999902 A	-210 μA/A	1498 μA/A
	1 A	1 kHz	1.0001466 A	0.999892 A	-255 μA/A	1498 μA/A

[1] *Expanded uncertainty corresponding to the coverage probability of approximately 95 %.*

7. UNCERTAINTY BUDGET

The model function is the same for all quantities.
Model Function:

$$E_x = (X_{ix} + \delta X_{ix}) - (X_s + \delta X_s)$$

X_{ix}	DMM reading
x_s	The value applied by the reference calibrator
δX_s	Drift from the reference calibrator
δX_{ix}	The finite resolution of DMM

7.1. DC Voltage

Model Function:

$$E_x = (V_{ix} + \delta V_{ix}) - (V_s + \delta V_s)$$

Table 1. Uncertainty budget for 100 mV

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Vix	99.99799 mV	0.05 μV/V	Normal	1	0.05 μV/V	9
δVix	99.99957 mV	8.00 μV/V	Normal	-1	8.00 μV/V	50
Vs	0.00000 mV	6.93 μV/V	Rectangular	-1	6.93 μV/V	∞
δVs	0.00000 mV	0.03 μV/V	Rectangular	1	0.03 μV/V	∞
Error (E_x)	**-16 μV/V**	**Combined Uncertainty, $u(E_x)$**				10.58 μV/V
		Effective Degrees of Freedom, ν_{eff}				153.20
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**21 μV/V**

Table 2. Uncertainty budget for 10 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Vix	10.000039 V	0.02 μV/V	Normal	1	0.02 μV/V	9
δVix	10.000047 V	6.00 μV/V	Normal	-1	6.00 μV/V	50
Vs	0.000000 V	1.91 μV/V	Rectangular	-1	1.91 μV/V	∞
δVs	0.000000 V	0.03 μV/V	Rectangular	1	0.03 μV/V	∞
Error (E_x)	**-0.8 μV/V**	**Combined Uncertainty, $u(E_x)$**				6.30 μV/V
		Effective Degrees of Freedom, v_{eff}				60.65
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**13 μV/V**

Table 3. Uncertainty budget for 100 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Vix	99.99946 V	0.33 μV/V	Normal	1	0.33 μV/V	9
δVix	100.00013 V	6.00 μV/V	Normal	-1	6.00 μV/V	50
Vs	0.000000 V	3.18 μV/V	Rectangular	-1	3.18 μV/V	∞
δVs	0.00000 V	0.03 μV/V	Rectangular	1	0.03 μV/V	∞
Error (E_x)	**-6.7 μV/V**	**Combined Uncertainty, $u(E_x)$**				6.80 μV/V
		Effective Degrees of Freedom, v_{eff}				82.42
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**14 μV/V**

Table 4. Uncertainty budget for 1000 V

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** ν_i
Vix	999.9941 V	0.06 µV/V	Normal	1	0.06 µV/V	9
δVix	999.9985 V	6.00 µV/V	Normal	-1	6.00 µV/V	50
Vs	0.000000 V	4.33 µV/V	Rectangular	-1	4.33 µV/V	∞
δVs	0.0000 V	0.03 µV/V	Rectangular	1	0.03 µV/V	∞
Error (E_x)	**-4.4 µV/V**				**Combined Uncertainty, $u(E_x)$**	7.40 µV/V
					Effective Degrees of Freedom, ν_{eff}	115.66
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	**15 µV/V**

7.2. DC Current

Model Function:

$$E_x = (I_{ix} + \delta I_{ix}) - (I_s + \delta I_s)$$

Table 5. Uncertainty budget for 100 µA

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** ν_i
Iix	99.99925 µA	0.33 µA/A	Normal	1	0.33 µA/A	9
δIix	99.99933 µA	22.50 µA/A	Normal	-1	22.50 µA/A	50
Is	0.00000 µA	69.28 µA/A	Rectangular	-1	69.28 µA/A	∞
δIs	0.00000 µA	0.03 µA/A	Rectangular	1	0.03 µA/A	∞
Error (E_x)	**-1 µA/A**				**Combined Uncertainty, $u(E_x)$**	72.8 µA/A
					Effective Degrees of Freedom, ν_{eff}	5492.72
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	**146 µA/A**

Table 6. Uncertainty budget for 10 mA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Iix	10.000179 mA	0.04 µA/A	Normal	1	0.04 µA/A	9
δIix	10.000182 mA	21.5 µA/A	Normal	-1	21.5 µA/A	50
Is	0.000000 mA	28.87 µA/A	Rectangular	-1	28.87 µA/A	∞
δIs	0.000000 mA	0.03 µA/A	Rectangular	1	0.03 µA/A	∞
Error (E_x)	**-0.3 µA/A**				**Combined Uncertainty, $u(E_x)$**	36.0 µA/A
					Effective Degrees of Freedom, v_{eff}	392.87
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	**72 µV/V**

Table 6. Uncertainty budget for 1 A

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Iix	0.9998825 A	0.23 µA/A	Normal	1	0.23 µA/A	9
δIix	1.0000239 A	75.00 µA/A	Normal	-1	75.00 µA/A	50
Is	0.0000000 A	69.28 µA/A	Rectangular	-1	69.28 µA/A	∞
δIs	0.0000000 A	0.03 µA/A	Rectangular	1	0.03 µA/A	∞
Error (E_x)	**-141 µA/A**				**Combined Uncertainty, $u(E_x)$**	102.1 µA/A
					Effective Degrees of Freedom, v_{eff}	171.73
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	**204 µV/V**

7.3. DC Resistance

Model Function:

$$E_x = (R_{ix} + \delta R_{ix}) - (R_s + \delta R_s)$$

Table 7. Uncertainty Budget for 10 Ω TrueΩ

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Rix	10.000240 Ω	0.06 µΩ/Ω	Normal	1	0.06 µΩ/Ω	9
δRix	10.000214 Ω	17.50 µΩ/Ω	Normal	-1	17.50 µΩ/Ω	50
Rs	0.000000 Ω	14.43 µΩ/Ω	Rectangular	-1	14.43 µΩ/Ω	∞
δRs	0.000000 Ω	0.30 µΩ/Ω	Rectangular	1	0.30 µΩ/Ω	∞
Error (E_x)	**3 µΩ/Ω**				**Combined Uncertainty, $u(E_x)$**	22.7 µΩ/Ω
					Effective Degrees of Freedom, v_{eff}	141.16
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	**45 µΩ/Ω**

Table 8. Uncertainty Budget for 10 kΩ TrueΩ

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Rix	10.000389 kΩ	0.02 µΩ/Ω	Normal	1	0.02 µΩ/Ω	9
δRix	10.000421 kΩ	10.00 µΩ/Ω	Normal	-1	10.00 µΩ/Ω	50
Rs	0.000000 kΩ	5.20 µΩ/Ω	Rectangular	-1	5.20 µΩ/Ω	∞
δRs	0.000000 kΩ	0.03 µΩ/Ω	Rectangular	1	0.03 µΩ/Ω	∞
Error (E_x)	**-3 µΩ/Ω**				**Combined Uncertainty, $u(E_x)$**	11.3 µΩ/Ω
					Effective Degrees of Freedom, v_{eff}	80.70
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	**23 µΩ/Ω**

Table 9. Uncertainty Budget for 10 kΩ TrueΩ LoI

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** ν_i
Rix	10.000408 kΩ	0.10 μΩ/Ω	Normal	1	0.10 μΩ/Ω	9
δRix	10.000421 kΩ	10.00 μΩ/Ω	Normal	-1	10.00 μΩ/Ω	50
Rs	0.000000 kΩ	5.20 μΩ/Ω	Rectangular	-1	5.20 μΩ/Ω	∞
δRs	0.000000 kΩ	0.03 μΩ/Ω	Rectangular	1	0.03 μΩ/Ω	∞
Error (E_x)	**-1 μΩ/Ω**	**Combined Uncertainty, $u(E_x)$**				11.3 μΩ/Ω
		Effective Degrees of Freedom, ν_{eff}				80.71
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**23 μΩ/Ω**

Table 10. Uncertainty Budget for 1 MΩ Normal

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** ν_i
Rix	1.0000733 MΩ	0.17 μΩ/Ω	Normal	1	0.17 μΩ/Ω	9
δRix	1.0000770 MΩ	15.00 μΩ/Ω	Normal	-1	15.00 μΩ/Ω	50
Rs	0.0000000 MΩ	14.43 μΩ/Ω	Rectangular	-1	14.43 μΩ/Ω	∞
δRs	0.0000000 MΩ	0.03 μΩ/Ω	Rectangular	1	0.03 μΩ/Ω	∞
Error (E_x)	**-4 μΩ/Ω**	**Combined Uncertainty, $u(E_x)$**				20.8 μΩ/Ω
		Effective Degrees of Freedom, ν_{eff}				185.39
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**42 μΩ/Ω**

7.4. AC Voltage

Model Function:

$$E_x = (V_{ix} + \delta V_{ix}) - (V_s + \delta V_s)$$

Table 11. Uncertainty Budget for 100 mV @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Vix	99.9975 mV	2.2 µV/V	Normal	1	2.2 µV/V	9
δVix	99.99805 mV	70.0 µV/V	Normal	-1	70.0 µV/V	50
Vs	0.0000 mV	92.4 µV/V	Rectangular	-1	92.4 µV/V	∞
δVs	0.0000 mV	0.3 µV/V	Rectangular	1	0.3 µV/V	∞
Error (E_x)	**-6 µV/V**	**Combined Uncertainty, $u(E_x)$**				115.93 µV/V
		Effective Degrees of Freedom, ν_{eff}				376.1
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**232 µV/V**

Table 12. Uncertainty Budget for 100 mV @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Vix	100.0023 mV	1.7 µV/V	Normal	1	1.7 µV/V	9
δVix	99.9915 mV	70.0 µV/V	Normal	-1	70.0 µV/V	50
Vs	0.0000 mV	86.6 µV/V	Rectangular	-1	86.6 µV/V	∞
δVs	0.0000 mV	0.3 µV/V	Rectangular	1	0.3 µV/V	∞
Error (E_x)	**108 µV/V**	**Combined Uncertainty, $u(E_x)$**				111.37 µV/V
		Effective Degrees of Freedom, ν_{eff}				320.33
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**223 µV/V**

Table 13. Uncertainty Budget for 10 V @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Vix	10.00020 V	1.7 µV/V	Normal	1	1.7 µV/V	9
δVix	10.00025 V	55.5 µV/V	Normal	-1	55.5 µV/V	50
Vs	0.00000 V	46.2 µV/V	Rectangular	-1	46.2 µV/V	∞
δVs	0.00000 V	0.3 µV/V	Rectangular	1	0.3 µV/V	∞
Error (E_x)	**-5 µV/V**				**Combined Uncertainty, $u(E_x)$**	72.23 µV/V
					Effective Degrees of Freedom, ν_{eff}	143.42
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	**144 µV/V**

Table 14. Uncertainty Budget for 10 V @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Vix	10.00073 V	0.8 µV/V	Normal	1	0.8 µV/V	9
δVix	10.00042 V	55.5 µV/V	Normal	-1	55.5 µV/V	50
Vs	0.00000 V	40.4 µV/V	Rectangular	-1	40.4 µV/V	∞
δVs	0.00000 V	0.3 µV/V	Rectangular	1	0.3 µV/V	∞
Error (E_x)	**31 µV/V**				**Combined Uncertainty, $u(E_x)$**	68.66 µV/V
					Effective Degrees of Freedom, ν_{eff}	117.10
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	**137 µV/V**

Table 15. Uncertainty Budget for 10 V @ 100 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Vix	10.00117 V	1.0 µV/V	Normal	1	1.0 µV/V	9
δVix	10.00155 V	475.0 µV/V	Normal	-1	475.0 µV/V	50
Vs	0.00000 V	63.5 µV/V	Rectangular	-1	63.5 µV/V	∞
δVs	0.00000 V	0.3 µV/V	Rectangular	1	0.3 µV/V	∞
Error (E_x)	**-38 µV/V**	**Combined Uncertainty, $u(E_x)$**				479.23 µV/V
		Effective Degrees of Freedom, ν_{eff}				51.80
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**958 µV/V**

Table 16. Uncertainty Budget for 100 V @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Vix	99.9983 V	4.0 µV/V	Normal	1	4.0 µV/V	9
δVix	100.0035 V	130.0 µV/V	Normal	-1	130.0 µV/V	50
Vs	0.0000 V	46.2 µV/V	Rectangular	-1	46.2 µV/V	∞
δVs	0.0000 V	0.3 µV/V	Rectangular	1	0.3 µV/V	∞
Error (E_x)	**-52 µV/V**	**Combined Uncertainty, $u(E_x)$**				138.02 µV/V
		Effective Degrees of Freedom, ν_{eff}				63.53
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**276 µV/V**

Table 17. Uncertainty Budget for 100 V @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Vix	100.0026 V	1.1 µV/V	Normal	1	1.1 µV/V	9
δVix	100.0037 V	130.0 µV/V	Normal	-1	130.0 µV/V	50
Vs	0.0000 V	34.6 µV/V	Rectangular	-1	34.6 µV/V	∞
δVs	0.0000 V	0.3 µV/V	Rectangular	1	0.3 µV/V	∞
Error (E_x)	**-12 µV/V**	**Combined Uncertainty, $u(E_x)$**				134.54 µV/V
		Effective Degrees of Freedom, v_{eff}				57.36
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**269 µV/V**

7.5. AC Current

Model Function:

$$E_x = (I_{ix} + \delta I_{ix}) - (I_s + \delta I_s)$$

Table 18. Uncertainty Budget for 10 mA @ 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Iix	10.00058 mA	1.5 µA/A	Normal	1	1.5 µA/A	9
δIix	10.00192 mA	302.4 µA/A	Normal	-1	302.4 µA/A	50
Is	0.000000 mA	115.5 µA/A	Rectangular	-1	115.5 µA/A	∞
δIs	0.000000 mA	0.3 µA/A	Rectangular	1	0.3 µA/A	∞
Error (E_x)	**-134 µA/A**	**Combined Uncertainty, $u(E_x)$**				323.7 µA/A
		Effective Degrees of Freedom, v_{eff}				65.64
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**647 µA/A**

Table 19. Uncertainty budget for 10 mA @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Iix	10.00085 mA	1.4 µA/A	Normal	1	1.4 µA/A	9
δIix	10.001926 mA	302.4 µA/A	Normal	-1	302.4 µA/A	50
Is	0.000000 mA	115.5 µA/A	Rectangular	-1	115.5 µA/A	∞
δIs	0.000000 mA	0.3 µA/A	Rectangular	1	0.3 µA/A	∞
Error (E_x)	**-108 µA/A**	**Combined Uncertainty, $u(E_x)$**				323.7 µA/A
		Effective Degrees of Freedom, ν_{eff}				65.64
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**647 µA/A**

Table 20. Uncertainty Budget for 1 A @ 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
Iix	0.999902 A	2.8 µA/A	Normal	1	2.8 µA/A	9
δIix	1.0001116 A	712.4 µA/A	Normal	-1	712.4 µA/A	50
Is	0.0000000 A	230.9 µA/A	Rectangular	-1	230.9 µA/A	∞
δIs	0.0000000 A	0.3 µA/A	Rectangular	1	0.3 µA/A	∞
Error (E_x)	**-210 µA/A**	**Combined Uncertainty, $u(E_x)$**				748.9 µA/A
		Effective Degrees of Freedom, ν_{eff}				61.06
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**1498 µA/A**

Table 21. Uncertainty budget for 1 A @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Iix	0.999892 A	3.1 µA/A	Normal	1	3.1 µA/A	9
δIix	1.000147 A	712.4 µA/A	Normal	-1	712.4 µA/A	50
Is	0.0000000 A	230.9 µA/A	Rectangular	-1	230.9 µA/A	∞
δIs	0.0000000 A	0.3 µA/A	Rectangular	1	0.3 µA/A	∞
Error (E_x)	**-255 µA/A**	**Combined Uncertainty, $u(E_x)$**				748.9 µA/A
		Effective Degrees of Freedom, v_{eff}				61.06
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				**1498 µA/A**

1. PARTICIPANT INSTITUTE

Institute	AS Metrosert
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2. PERIOD OF MEASUREMENTS

29.10.2015…03.11.2015

3. AMBIENT CONDITIONS

Temperature : (23,0 ± 1,5) °C

Relative Humidity : (45 ± 10) % rh

4. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Voltage standard	**Fluke**	**7000**	**863148193**	**VTT, Finland**
Resistance standard 1 Ω	**Tinsley**	**5685A**	**280233**	**VTT, Finland**
Resistance standard 10 Ω	**Tinsley**	**5685A**	**280082**	**VTT, Finland**
Resistance standard 1 kΩ	**Tinsley**	**5685B**	**280260**	**VTT, Finland**
Resistance standard 10 kΩ	**Tinsley**	**5685B**	**274915**	**VTT, Finland**
Resistance standard 1 MΩ	**ZP**	**P4010**	**250**	**Metrosert**
Reference voltage divider	**Fluke**	**752A**	**2981001**	**-**
AC/DC transfer standard	**Fluke**	**792A**	**8600001**	**SP, Sweden**
AC/DC shunt 10 mA	**Fluke**	**A40**	**85860001**	**SP, Sweden**
AC/DC shunt 1 A	**Fluke**	**A40**	**85860009**	**SP, Sweden**

(continued) THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
100 A range extender	**MI**	**6011B**	**11000128**	**-**
Nanovoltmeter	**Agilent**	**34420A**	**MY42003613**	**Metrosert**
Calibrator	**Fluke**	**5720A**	**9781214**	**Metrosert**

5. MEASUREMENT METHOD

The multimeter Fluke 8508A-01 S/N 969656608 has been calibrated in accordance to Technical Protocol of Comparison on Calibration of Multimeter Rev. 2 provided by TÜBITAK UME and Metrosert's calibration guides based on the EURAMET Calibration Guide EURAMET cg-15. The multimeter has been calibrated against the reference standards at DCV, RES and DCI functions, and against the calibrator Fluke 5720A at DCV, ACV and ACI functions. Before calibration of the multimeter, the corresponding output values of the calibrator have been calibrated against the reference standards.

DC Voltage
At the measurement point 10 V, the multimeter has been calibrated directly against the reference voltage standard Fluke 7000. The measurement points 100 mV, 100 V and 1000 V have been calibrated against the calibrator Fluke 5720A. Before calibration of the multimeter, the corresponding output values of the calibrator have been calibrated against the 10 V output of the voltage standard Fluke 7000 using the reference voltage divider Fluke 752A.

Resistance
At the measurement points 10 Ω, 10 kΩ and 1 MΩ, the multimeter has been calibrated directly against the standard resistors, maintained in thermostats at stable temperature.

DC Current
At the measurement points 100 µA, 10 mA and 1A, the multimeter has been calibrated against the calibrator Fluke 5720A. Before calibration of the multimeter, the corresponding output values of the calibrator have been calibrated by measuring the voltage across the standard resistors. At the 1 A value, the MI 100 A range extender has been used on its 10:1 current ratio to divide current of the calibrator from 1 A to 100 mA to be supplied to the 1 Ω standard resistor.

AC Voltage
At the AC voltage measurement points, the multimeter has been calibrated against the calibrator Fluke 5720A. Before calibration of the multimeter, the corresponding output values of the calibrator have been calibrated by using the AC/DC transfer standard Fluke 792A.

AC Current

At the AC current measurement points, the multimeter has been calibrated against the calibrator Fluke 5720A. Before calibration of the multimeter, the corresponding output values of the calibrator have been calibrated by using the AC/DC transfer standard Fluke 792A and AC/DC current shunts Fluke A40.

MEASUREMENT RESULTS

DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 mV	+ 100 mV	99,99961 mV	100,00004 mV	4,3 µV/V	5,9 µV/V
20 V	+ 10 V	9,999870 V	9,999911 V	4,1 µV/V	1,0 µV/V
200 V	+ 100 V	99,99994 V	99,99972 V	-2,2 µV/V	2,1 µV/V
1000 V	+ 1000 V	1000,0004 V	999,9980 V	-2,4 µV/V	2,1 µV/V

DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 µA	+ 100 µA	100,00073 µA	99,99960 µA	-11,3 µA/A	9,6 µA/A
20 mA	+ 10 mA	9,999913 mA	10,000181 mA	26,8 µA/A	9,5 µA/A
1 A	+ 1 A	0,9999973 A	0,9998770 A	-120,3 µA/A	11,7 µA/A

DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
20 Ω	TrueΩ	10 Ω	10,000011 Ω	10,000151 Ω	14,0 µΩ/Ω	1,0 µΩ/Ω
20 kΩ	TrueΩ	10 kΩ	10,000145 kΩ	10,000233 kΩ	8,8 µΩ/Ω	1,0 µΩ/Ω
	TrueΩ LoI	10 kΩ	10,000145 kΩ	10,000245 kΩ	10,0 µΩ/Ω	1,0 µΩ/Ω
2 MΩ	Normal Ω	1 MΩ	1,0000637 MΩ	1,0000742 MΩ	10,5 µΩ/Ω	9,3 µΩ/Ω

AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99,9996 mV	99,9946 mV	-50 µV/V	59 µV/V
	100 mV	1 kHz	99,9996 mV	99,9992 mV	-4 µV/V	59 µV/V
20 V	10 V	55 Hz	9,99983 V	10,00035 V	52 µV/V	58 µV/V
	10 V	1 kHz	9,99992 V	10,00090 V	98 µV/V	58 µV/V
	10 V	100 kHz	10,00033 V	10,00146 V	113 µV/V	117 µV/V
200 V	100 V	55 Hz	100,0006 V	99,9991 V	-15 µV/V	59 µV/V
	100 V	1 kHz	100,0007 V	100,0033 V	26 µV/V	59 µV/V

AC CURRENT

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Current	Frequency				
20 mA	10 mA	300 Hz	9,99992 mA	10,00049 mA	57 µA/A	17 µA/A
	10 mA	1 kHz	9,99987 mA	10,00059 mA	72 µA/A	17 µA/A
1 A	1 A	300 Hz	0,999987 A	0,999896 A	-91 µA/A	24 µA/A
	1 A	1 kHz	0,999983 A	0,999973 A	-10 µA/A	24 µA/A

[1] *Expanded uncertainty corresponding to the coverage probability of approximately 95 %.*

6. UNCERTAINTY BUDGET

6.1. DC Voltage

The combined uncertainty for calibration of the DMM at the DCV function is given by the following equation:

$$u^2(E_x) = u^2(V_{ix}) + u^2(V_s) + u^2(\delta V_{load}) + u^2(V_{std}) + u^2(r_{div}) + u^2(V_{diff}) + u^2(\delta V_g) + u^2(\delta V_{th}) + u^2(\delta V_{ix})$$

where the uncertainty components of the input quantities X_i are the following:

Vix	DMM reading
Vs	The voltage applied by the reference calibrator
δVload	Loading the reference calibrator
Vstd	The voltage of the voltage standard
rdiv	The ratio of voltage divider
Vdiff	Voltage difference between output of the voltage divider and output of the calibrator
δVg	The gain error of the nanovoltmeter
δVth	Thermal EMF
δVix	The finite resolution of DMM

Table 1. Uncertainty budget for 100 mV

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** ν_i
V_{ix}	100,00004 mV	0,02 µV/V	normal	1	0,02 µV/V	49
V_s	99,99961 mV	1,73 µV/V	rectangular	1	1,73 µV/V	∞
δV_{load}	0,00000 mV	0,23 µV/V	rectangular	1	0,23 µV/V	∞
V_{std}	9,999870 V	0,50 µV/V	normal	1	0,50 µV/V	∞
r_{div}	100:1 V/V	0,29 µV/V	rectangular	1	0,29 µV/V	∞
V_{diff}	-0,00091 mV	0,03 µV/V	normal	1	0,03 µV/V	49
δV_g	0,00000 mV	0,12 µV/V	rectangular	1	0,12 µV/V	∞
δV_{th}	0,00000 mV	2,31 µV/V	rectangular	1	2,31 µV/V	∞
δV_{ix}	0,00001 mV	0,03 µV/V	rectangular	1	0,03 µV/V	∞
Error (E_x)	4,3 µV/V				**Combined Uncertainty, $u(E_x)$**	2,96 µV/V
					Effective Degrees of Freedom, ν_{eff}	∞
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	5,92 µV/V

Table 2. Uncertainty budget for 10 V

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** v_i
V_{ix}	9,999911 V	0,06 µV/V	normal	1	0,06 µV/V	49
V_{std}	9,999870 V	0,50 µV/V	normal	1	0,50 µV/V	∞
δV_{th}	0,000000 V	0,02 µV/V	rectangular	1	0,02 µV/V	∞
δV_{ix}	0,000001 V	0,03 µV/V	rectangular	1	0,03 µV/V	∞
Error (E_x)	4,1 µV/V	**Combined Uncertainty, $u(E_x)$**				0,50 µV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				1,00 µV/V

Table 3. Uncertainty budget for 100 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	99,99972 V	0,01 μV/V	normal	1	0,01 μV/V	49
V_s	99,99994 V	0,87 μV/V	rectangular	1	0,87 μV/V	∞
δV_{load}	0,00000 V	0,23 μV/V	rectangular	1	0,23 μV/V	∞
V_{std}	9,999870 V	0,50 μV/V	normal	1	0,50 μV/V	∞
r_{div}	10:1 V/V	0,12 μV/V	rectangular	1	0,12 μV/V	∞
δV_{ix}	0,00001 V	0,03 μV/V	rectangular	1	0,03 μV/V	∞
Error (E_x)	-2,3 μV/V	**Combined Uncertainty, $u(E_x)$**				1,03 μV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				2,06 μV/V

Table 4. Uncertainty budget for 1000 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	999,9980 V	0,01 μV/V	normal	1	0,01 μV/V	49
V_s	1000,0004 V	0,87 μV/V	rectangular	1	0,87 μV/V	∞
δV_{load}	0,00000 V	0,23 μV/V	rectangular	1	0,23 μV/V	∞
V_{std}	9,999870 V	0,50 μV/V	normal	1	0,50 μV/V	∞
r_{div}	100:1 V/V	0,29 μV/V	rectangular	1	0,29 μV/V	∞
δV_{ix}	0,0001 V	0,03 μV/V	rectangular	1	0,03 μV/V	∞
Error (E_x)	-2,4 μV/V	**Combined Uncertainty, $u(E_x)$**				1,07 μV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				2,14 μV/V

6.2. DC Current

The combined uncertainty for calibration of the DMM at the DCI function is given by the following equation:

$$u^2(E_x) = u^2(I_{ix}) + u^2(I_s) + u^2(\delta I_{std}) + u^2(\delta I_{load}) + u^2(\delta I_v) + u^2(\delta I_{vt}) + u^2(\delta I_{ix}) + u^2(\delta I_{ext})$$

where the uncertainty components of the input quantities X_i are the following:

I_{ix} -DMM reading,
I_s -the current applied by the reference calibrator,
δI_{std} -current variation due to standard resistor,
δI_{load} -current variation due to voltmeter input impedance,
δI_v -current variation due to voltmeter uncertainty,
δI_{vt} -current variation due to thermal EMF,
δI_{ix} -the finite resolution of DMM,
δI_{ext} -current variation due to range extender (applies at 1 A only).

V_{ix}	DMM reading
V_s	The voltage applied by the reference calibrator
δV_{load}	Loading the reference calibrator
V_{std}	The voltage of the voltage standard
r_{div}	The ratio of voltage divider
V_{diff}	Voltage difference between output of the voltage divider and output of the calibrator
δV_g	The gain error of the nanovoltmeter
δV_{th}	Thermal EMF
δV_{ix}	The finite resolution of DMM

Table 5. Uncertainty budget for 100 µA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
I_{ix}	99,99960 µA	0,10 µA/A	normal	1	0,10 µA/A	49
I_s	100,00073 µA	2,89 µA/A	rectangular	1	2,89 µA/A	∞
δI_{std}	0,00000 µA	0,50 µA/A	normal	1	0,50 µA/A	∞
δI_{load}	0,00000 µA	0,58 µA/A	rectangular	1	0,58 µA/A	∞
δI_v	0,00000 µA	2,95 µA/A	normal	1	2,95 µA/A	∞
δI_{vt}	0,00000 µA	2,31 µA/A	rectangular	1	2,31 µA/A	∞
δI_{ix}	0,00001 µA	0,03 µA/A	rectangular	1	0,03 µA/A	∞
Error (E_x)	-11,3 µA/A	**Combined Uncertainty, $u(E_x)$**				4,79 µA/A
		Effective Degrees of Freedom, ν_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				9,58 µA/A

Table 6. Uncertainty budget for 10 mA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	10,000181 mA	0,02 µA/A	normal	1	0,02 µA/A	49
I_s	9,999913 mA	2,89 µA/A	rectangular	1	2,89 µA/A	∞
δI_{std}	0,000000 mA	0,50 µA/A	normal	1	0,50 µA/A	∞
δI_{load}	0,000000 mA	0,01 µA/A	rectangular	1	0,01 µA/A	∞
δI_v	0,000000 mA	2,95 µA/A	normal	1	2,95 µA/A	∞
δI_{vt}	0,000000 mA	2,31 µA/A	rectangular	1	2,31 µA/A	∞
δI_{ix}	0,000001 mA	0,03 µA/A	rectangular	1	0,03 µA/A	∞
Error (E_x)	26,9 µA/A	**Combined Uncertainty, $u(E_x)$**				4,76 µA/A
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				9,52 µA/A

Table 7. Uncertainty budget for 1 A

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	0,9998770 A	1,73 µA/A	rectangular	1	1,73 µA/A	49
I_s	0,9999973 A	2,89 µA/A	rectangular	1	2,89 µA/A	∞
δI_{ext}	0,0000000 A	2,89 µA/A	rectangular	1	2,89 µA/A	∞
δI_{std}	0,0000000 A	0,50 µA/A	normal	1	0,50 µA/A	∞
δI_{load}	0,0000000 A	0,01 µA/A	rectangular	1	0,01 µA/A	∞
δI_v	0,0000000 A	2,95 µA/A	normal	1	2,95 µA/A	∞
δI_{vt}	0,0000000 A	2,31 µA/A	rectangular	1	2,31 µA/A	∞
δI_{ix}	0,0000001 A	0,03 µA/A	rectangular	1	0,03 µA/A	∞
Error (E_x)	-120,3 µA/A	**Combined Uncertainty, $u(E_x)$**				5,83 µA/A
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				11,66 µA/A

6.3. DC Resistance

The combined uncertainty for calibration of the DMM at the RESISTANCE function is given by the following equation:

$$u^2(E_x) = u^2(R_{ix}) + u^2(R_s) + u^2(\delta R_t) + u^2(\delta R_{ix})$$

where the uncertainty components of the input quantities X_i are the following:

- R_{ix} -DMM reading,
- R_s -the resistance value applied by the standard resistor,
- δR_t -effect of the temperature of thermostat,
- δR_{ix} -the finite resolution of DMM.

Table 8. Uncertainty Budget for 10 Ω TrueΩ

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	10,000151 Ω	0,03 μΩ/Ω	normal	1	0,03 μΩ/Ω	49
R_s	10,000011 Ω	0,50 μΩ/Ω	normal	1	0,50 μΩ/Ω	∞
δR_t	0,000000 Ω	0,06 μΩ/Ω	rectangular	1	0,06 μΩ/Ω	∞
δR_{ix}	0,000001 Ω	0,03 μΩ/Ω	rectangular	1	0,03 μΩ/Ω	∞
Error (E_x)	14,0 μΩ/Ω	**Combined Uncertainty, $u(E_x)$**				0,51 μΩ/Ω
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				1,02 μΩ/Ω

Table 9. Uncertainty Budget for 10 kΩ TrueΩ

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	10,000233 kΩ	0,01 μΩ/Ω	normal	1	0,01 μΩ/Ω	49
R_s	10,000145 kΩ	0,50 μΩ/Ω	normal	1	0,50 μΩ/Ω	∞
δR_t	0,000000 kΩ	0,06 μΩ/Ω	rectangular	1	0,06 μΩ/Ω	∞
δR_{ix}	0,000001 kΩ	0,03 μΩ/Ω	rectangular	1	0,03 μΩ/Ω	∞
Error (E_x)	8,8 μΩ/Ω	**Combined Uncertainty, $u(E_x)$**				0,50 μΩ/Ω
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				1,00 μΩ/Ω

Table 10. Uncertainty Budget for 10 kΩ TrueΩ LoI

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** v_i
R_{ix}	10,000245 kΩ	0,03 μΩ/Ω	normal	1	0,03 μΩ/Ω	49
R_s	10,000145 kΩ	0,50 μΩ/Ω	normal	1	0,50 μΩ/Ω	∞
δR_t	0,000000 kΩ	0,06 μΩ/Ω	rectangular	1	0,06 μΩ/Ω	∞
δR_{ix}	0,000001 kΩ	0,03 μΩ/Ω	rectangular	1	0,03 μΩ/Ω	∞
Error (E_x)	10,0 μΩ/Ω	**Combined Uncertainty, $u(E_x)$**				0,51 μΩ/Ω
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				1,02 μΩ/Ω

Table 11. Uncertainty Budget for 10 MΩ

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom (DoF)** v_i
R_{ix}	1,0000742 MΩ	0,01 μΩ/Ω	normal	1	0,01 μΩ/Ω	49
R_s	1,0000637 MΩ	4,50 μΩ/Ω	normal	1	4,50 μΩ/Ω	∞
δR_t	0,0000000 MΩ	1,15 μΩ/Ω	rectangular	1	1,15 μΩ/Ω	∞
δR_{ix}	0,0000001 MΩ	0,03 μΩ/Ω	rectangular	1	0,03 μΩ/Ω	∞
Error (E_x)	10,5 μΩ/Ω	**Combined Uncertainty, $u(E_x)$**				4,65 μΩ/Ω
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				9,30 μΩ/Ω

6.4. AC Voltage

The combined uncertainty for calibration of the DMM at the ACV function is given by the following equation:

$$u^2(E_x) = u^2(V_{ix}) + u^2(V_s) + u^2(\delta_{acdc}) + u^2(\delta V_{acdc\_Lstab}) + u^2(V_{std}) + u^2(\delta V_{th}) + u^2(V_{acdc\_AC}) + u^2(V_{acdc\_DC}) + u^2(\delta V_{load}) + u^2(\delta V_{ix})$$

where the uncertainty components of the input quantities X_i are the following:

V_{ix}	-DMM reading,
V_s	-the voltage applied by the reference calibrator,
δ_{acdc}	-AC-DC transfer standard,
δV_{acdc_Lstab}	-long term stability of AC-DC transfer standard,
V_{std}	-the voltage of the voltage standard,
δV_{th}	-thermal EMF,
V_{acdc_AC}	-AC voltage applied to AC-DC transfer standard,
V_{acdc_DC}	-DC voltage applied to AC-DC transfer standard,
δV_{load}	-loading the reference calibrator,
δV_{ix}	-the finite resolution of DMM.

Table 12. Uncertainty Budget for 100 mV @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	99,9946 mV	1,1 µV/V	normal	1	1,1 µV/V	49
V_s	99,9996 mV	2,9 µV/V	rectangular	1	2,9 µV/V	∞
δ_{acdc}	16,0 µV/V	4,5 µV/V	normal	1	4,5 µV/V	∞
δV_{acdc_Lstab}	0,0 µV/V	0,6 µV/V	rectangular	1	0,6 µV/V	∞
V_{std}	99,9996 mV	3,0 µV/V	normal	1	3,0 µV/V	∞
δV_{th}	0,0000 mV	2,3 µV/V	rectangular	1	2,3 µV/V	∞
V_{acdc_AC}	100,0000 mV	0,3 µV/V	normal	1	0,3 µV/V	49
V_{acdc_DC}	100,0000 mV	0,1 µV/V	normal	1	0,1 µV/V	49
δV_{load}	0,0000 mV	28,9 µV/V	rectangular	1	0,3 µV/V	∞
δV_{ix}	0,0001 mV	0,3 µV/V	rectangular	1	0,3 µV/V	∞
Error (E_x)	-49,2 µV/V				**Combined Uncertainty, $u(E_x)$**	29,6 µV/V
					Effective Degrees of Freedom, ν_{eff}	∞
					Coverage Factor, k	2
					Expanded Uncertainty, $U(E_x)$	59,3 µV/V

Table 13. Uncertainty Budget for 100 mV @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	99,9992 mV	0,8 µV/V	normal	1	0,8 µV/V	49
V_s	99,9996 mV	2,9 µV/V	rectangular	1	2,9 µV/V	∞
δ_{acdc}	0,0 µV/V	4,5 µV/V	normal	1	4,5 µV/V	∞
δV_{acdc_Lstab}	0,0 µV/V	0,6 µV/V	rectangular	1	0,6 µV/V	∞
V_{std}	99,9996 mV	3,0 µV/V	normal	1	3,0 µV/V	∞
δV_{th}	0,0000 mV	2,3 µV/V	rectangular	1	2,3 µV/V	∞
V_{acdc_AC}	100,0000 mV	0,1 µV/V	normal	1	0,1 µV/V	49
V_{acdc_DC}	100,0000 mV	0,1 µV/V	normal	1	0,1 µV/V	49
δV_{load}	0,0000 mV	28,9 µV/V	rectangular	1	28,9 µV/V	∞
δV_{ix}	0,0001 mV	0,3 µV/V	rectangular	1	0,3 µV/V	∞
Error (E_x)	-3,6 µV/V	**Combined Uncertainty, $u(E_x)$**				29,6 µV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				59,2 µV/V

Table 14. Uncertainty Budget for 10 V @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	10,00035 V	1,1 µV/V	normal	1	1,1 µV/V	49
V_s	9,99983 V	2,9 µV/V	rectangular	1	2,9 µV/V	∞
δ_{acdc}	7,0 µV/V	2,5 µV/V	normal	1	2,5 µV/V	∞
δV_{acdc_Lstab}	0 µV/V	0,6 µV/V	rectangular	1	0,6 µV/V	∞
V_{std}	9,99999 V	0,6 µV/V	normal	1	0,6 µV/V	∞
V_{acdc_AC}	10,00000 V	0,6 µV/V	normal	1	0,6 µV/V	49
V_{acdc_DC}	10,00000 V	0,1 µV/V	normal	1	0,1 µV/V	49
δV_{load}	0,00000 V	28,9 µV/V	rectangular	1	28,9 µV/V	∞
δV_{ix}	0,00001 V	0,3 µV/V	rectangular	1	0,3 µV/V	∞
Error (E_x)	52,3 µV/V	**Combined Uncertainty, $u(E_x)$**				29,2 µV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				58,3 µV/V

Table 15. Uncertainty Budget for 10 V @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	10,00090 V	0,4 µV/V	normal	1	0,4 µV/V	49
V_s	9,99992 V	2,9 µV/V	rectangular	1	2,9 µV/V	∞
δ_{acdc}	3,0 µV/V	2,5 µV/V	normal	1	2,5 µV/V	∞
δV_{acdc_Lstab}	0,0 µV/V	0,6 µV/V	rectangular	1	0,6 µV/V	∞
V_{std}	9,99999 V	0,6 µV/V	normal	1	0,6 µV/V	∞
V_{acdc_AC}	10,00000 V	0,2 µV/V	normal	1	0,2 µV/V	49
V_{acdc_DC}	10,00000 V	0,1 µV/V	normal	1	0,1 µV/V	49
δV_{load}	0,00000 V	28,9 µV/V	rectangular	1	28,9 µV/V	∞
δV_{ix}	0,00001 V	0,3 µV/V	rectangular	1	0,3 µV/V	∞
Error (E_x)	98,0 µV/V	**Combined Uncertainty, $u(E_x)$**				29,1 µV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				58,3 µV/V

Table 16. Uncertainty Budget for 10 V @ 100 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	10,00146 V	3,4 µV/V	normal	1	3,4 µV/V	49
V_s	10,00033 V	5,8 µV/V	rectangular	1	5,8 µV/V	∞
δ_{acdc}	13,0 µV/V	3,5 µV/V	normal	1	3,5 µV/V	∞
δV_{acdc_Lstab}	0,0 µV/V	0,6 µV/V	rectangular	1	0,6 µV/V	∞
V_{std}	9,99999 V	0,6 µV/V	normal	1	0,6 µV/V	∞
V_{acdc_AC}	10,00000 V	0,2 µV/V	normal	1	0,2 µV/V	49
V_{acdc_DC}	10,00000 V	0,1 µV/V	normal	1	0,1 µV/V	49
δV_{load}	0,00000 V	57,7 µV/V	rectangular	1	57,7 µV/V	∞
δV_{ix}	0,00001 V	0,3 µV/V	rectangular	1	0,3 µV/V	∞
Error (E_x)	113,4 µV/V	**Combined Uncertainty, $u(E_x)$**				58,2 µV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				116,5 µV/V

Table 17. Uncertainty Budget for 100 V @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	99,9991 V	0,9 μV/V	normal	1	0,9 μV/V	49
V_s	100,0006 V	5,8 μV/V	rectangular	1	5,8 μV/V	∞
δ_{acdc}	10,0 μV/V	3,5 μV/V	normal	1	3,5 μV/V	∞
δV_{acdc_Lstab}	0,0 μV/V	0,6 μV/V	rectangular	1	0,6 μV/V	∞
V_{std}	99,9997 V	1,0 μV/V	normal	1	1,0 μV/V	∞
V_{acdc_AC}	100,0000 V	0,6 μV/V	normal	1	0,6 μV/V	49
V_{acdc_DC}	100,0000 V	0,2 μV/V	normal	1	0,2 μV/V	49
δV_{load}	0,00000 V	28,9 μV/V	rectangular	1	28,9 μV/V	∞
δV_{ix}	0,00001 V	0,3 μV/V	rectangular	1	0,3 μV/V	∞
Error (E_x)	-15,2 μV/V	**Combined Uncertainty, $u(E_x)$**				29,7 μV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				59,4 μV/V

Table 18. Uncertainty Budget for 100 V @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	100,0033 V	0,5 μV/V	normal	1	0,5 μV/V	49
V_s	100,0007 V	5,8 μV/V	rectangular	1	5,8 μV/V	∞
δ_{acdc}	5,0 μV/V	3,5 μV/V	normal	1	3,5 μV/V	∞
δV_{acdc_Lstab}	0,0 μV/V	0,6 μV/V	rectangular	1	0,6 μV/V	∞
V_{std}	99,9997 V	1,0 μV/V	normal	1	1,0 μV/V	∞
V_{acdc_AC}	100,0000 V	0,6 μV/V	normal	1	0,6 μV/V	49
V_{acdc_DC}	100,0000 V	0,2 μV/V	normal	1	0,2 μV/V	49
δV_{load}	0,00000 V	28,9 μV/V	rectangular	1	28,9 μV/V	∞
δV_{ix}	0,00001 V	0,3 μV/V	rectangular	1	0,3 μV/V	∞
Error (E_x)	26,2 μV/V	**Combined Uncertainty, $u(E_x)$**				29,7 μV/V
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				59,4 μV/V

6.5. AC Current

The combined uncertainty for calibration of the DMM at the ACI function is given by the following equation:

$$u^2(E_x) = u^2(I_{ix}) + u^2(I_s) + u^2(\delta_{acdc}) + u^2(\delta I_{acdc\_Lstab}) + u^2(I_{std}) + u^2(I_{acdc\_AC}) + u^2(I_{acdc\_DC}) + u^2(\delta I_{ix})$$

where the uncertainty components of the input quantities X_i are the following:

I_{ix} -DMM reading,

I_s -the current applied by the reference calibrator,

δ_{acdc} -AC-DC transfer standard,

δI_{acdc_Lstab} -long term stability of AC-DC transfer standard,

I_{std} -DC current of the current source,

I_{acdc_AC} -AC current applied to AC-DC transfer standard,

I_{acdc_DC} -DC current applied to AC-DC transfer standard,

δI_{ix} -the finite resolution of DMM.

Table 19. Uncertainty Budget for 10 mA @ 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	10,00049 mA	0,4 µA/A	normal	1	0,4 µA/A	49
I_s	9,99992 mA	5,8 µA/A	rectangular	1	5,8 µA/A	∞
δ_{acdc}	17,0 µA/A	3,5 µA/A	normal	1	3,5 µA/A	∞
δI_{acdc_Lstab}	0,0 µA/A	0,6 µA/A	rectangular	1	0,6 µA/A	∞
I_{std}	10,00000 mA	4,8 µA/A	normal	1	4,8 µA/A	∞
I_{acdc_AC}	10,00000 mA	0,3 µA/A	normal	1	0,3 µA/A	29
I_{acdc_DC}	10,00000 mA	0,1 µA/A	normal	1	0,1 µA/A	29
δI_{ix}	0,00001 mA	0,3 µA/A	rectangular	1	0,3 µA/A	∞
Error (E_x)	57,0 µA/A	**Combined Uncertainty, $u(E_x)$**				8,3 µA/A
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				16,6 µA/A

Table 20. Uncertainty Budget for 10 mA @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	10,00059 mA	0,3 µA/A	normal	1	0,3 µA/A	49
I_s	9,99987 mA	5,8 µA/A	rectangular	1	5,8 µA/A	∞
I_{acdc}	10,0 µA/A	3,5 µA/A	normal	1	3,5 µA/A	∞
δI_{acdc_Lstab}	0,0 µA/A	0,6 µA/A	rectangular	1	0,6 µA/A	∞
I_{std}	10,00000 mA	4,8 µA/A	normal	1	4,8 µA/A	∞
I_{acdc_AC}	10,00000 mA	0,3 µA/A	normal	1	0,3 µA/A	29
I_{acdc_DC}	10,00000 mA	0,1 µA/A	normal	1	0,1 µA/A	29
δI_{ix}	0,00001 mA	0,3 µA/A	rectangular	1	0,3 µA/A	∞
Error (E_x)	72,0 µA/A	**Combined Uncertainty, $u(E_x)$**				8,3 µA/A
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				16,6 µA/A

Table 21. Uncertainty Budget for 1 A @ 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	0,999896 A	0,8 µA/A	normal	1	0,8 µA/A	49
I_s	0,999987 A	8,7 µA/A	rectangular	1	8,7 µA/A	∞
I_{acdc}	16,0 µA/A	5,0 µA/A	normal	1	5,0 µA/A	∞
δI_{acdc_Lstab}	0,0 µA/A	2,3 µA/A	rectangular	1	2,3 µA/A	∞
I_{std}	1,000000 A	5,8 µA/A	normal	1	5,8 µA/A	∞
I_{acdc_AC}	1,000000 A	0,4 µA/A	normal	1	0,4 µA/A	29
I_{acdc_DC}	1,000000 A	0,2 µA/A	normal	1	0,2 µA/A	29
δI_{ix}	0,000001 A	0,3 µA/A	rectangular	1	0,3 µA/A	∞
Error (E_x)	-91,5 µA/A	**Combined Uncertainty, $u(E_x)$**				11,8 µA/A
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				23,6 µA/A

Table 22. Uncertainty Budget for 1 A @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	0,999973 A	0,9 µA/A	normal	1	0,9 µA/A	49
I_s	0,999983 A	8,7 µA/A	rectangular	1	8,7 µA/A	∞
I_{acdc}	8,0 µA/A	5,0 µA/A	normal	1	5,0 µA/A	∞
δI_{acdc_Lstab}	0,0 µA/A	2,3 µA/A	rectangular	1	2,3 µA/A	∞
I_{std}	1,000000 A	5,8 µA/A	normal	1	5,8 µA/A	∞
I_{acdc_AC}	1,000000 A	0,4 µA/A	normal	1	0,4 µA/A	29
I_{acdc_DC}	1,000000 A	0,2 µA/A	normal	1	0,2 µA/A	29
δI_{ix}	0,000001 A	0,3 µA/A	rectangular	1	0,3 µA/A	∞
Error (E_x)	-10,5 µA/A	**Combined Uncertainty, $u(E_x)$**				11,9 µA/A
		Effective Degrees of Freedom, v_{eff}				∞
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				23,8 µA/A

EURAMET Project No 1341

Comparison on Calibration of Multimeter

Report of the measurements at GUM
9 - 18 November 2015

Acronym of Institute: GUM
Główny Urząd Miar - Central Office of Measure
2 Elektoralna Str.
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Poland
By: Patryk Bruszewski
Date: 30. Nov. 2016
Measurements performed in November 2015

1. PARTICIPANT INSTITUTE

Institute	Central Office of Measures (Główny Urząd Miar - GUM)
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2. PERIOD OF MEASUREMENTS

9 - 18 November 2015

3. AMBIENT CONDITIONS

Temperature : (23 ± 1) °C

Relative Humidity : (40 ± 20) % rh

4. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
DC Standard	Fluke	732B	9125701	GUM
Reference divider	Fluke	752A	862001	GUM
Resistance standard	Fluke	742A-10	8588001	GUM
Resistance standard	Fluke	742A-10k	8585001	GUM
Resistance standard	Fluke	742A-10M	8574001	GUM
Resistance standard	Ohm-Labs	MCS	14245	GUM
Calibrator	Fluke	5720A	8586205	GUM
Reference Mustimeter	Fluke	8508A	969656420	GUM
AC/DC Transfer standard	Fluke	792A	8680001	PTB
AC/DC current transfer standard (thermoelement)	Holt	PN/ 84506	0943500001688	PTB
AC/DC current shunt	Holt	HCS1	81554	PTB
AC/DC current shunt	Holt	HCS1	81667-002	PTB

5. MEASUREMENT METHODS

Measurements of DC Voltage, AC Voltage, AC Current and Resistance were made by direct comparison of indications method. For measurements AC Voltage and AC Current, the source (calibrator type 5720A) was characterized by using the thermal ACDC standards, in order to improve the uncertainties of the source, as showed on figure 4 and 5 (step 1) and in short time were made measurements of multimeter by using characterized source.

Measurements of DC current were made by the technical method of electrical current measurement (voltmeter method with shunt resistor).

All measurements were made in repeated series, where the number of measurements ≥ 10.

Schemes of measurement systems and connections are shown at Fig. 1 to Fig. 5.

5.1. DC Voltage

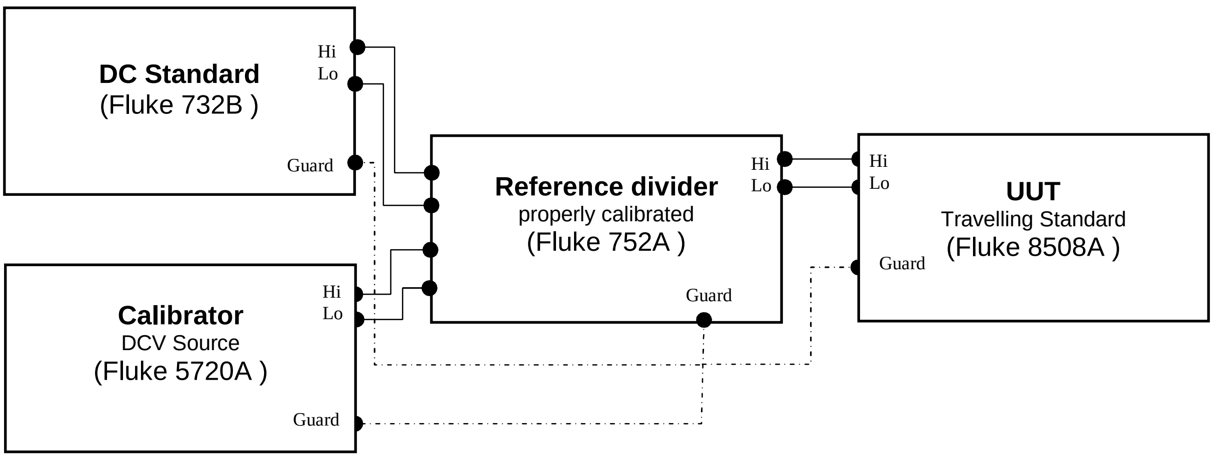

Fig. 1. Scheme of measurement systems and connections for DC Voltage ranges.

5.2. DC Current

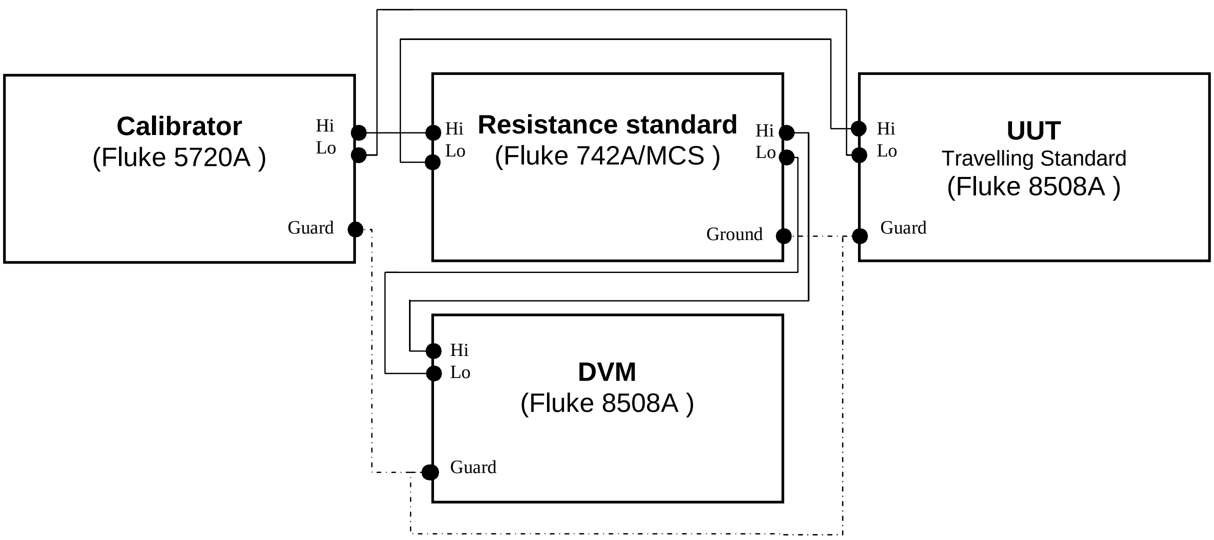

Fig. 2. Scheme of measurement systems and connections for DC Current ranges.

5.3. DC Resistance

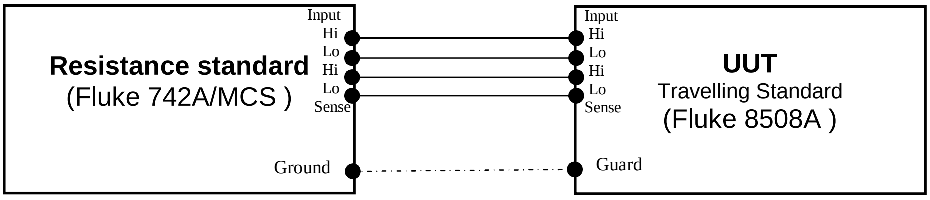

Fig. 3. Scheme of measurement systems and connections for DC Resistance ranges.

5.4. AC Voltage

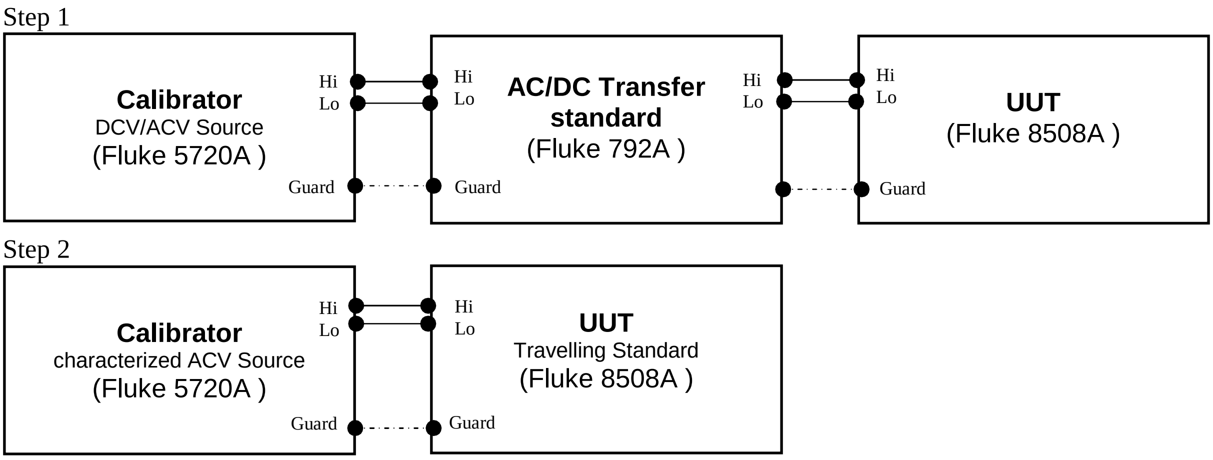

Fig. 4. Scheme of measurement systems and connections for AC Voltage ranges.

5.5. AC Current

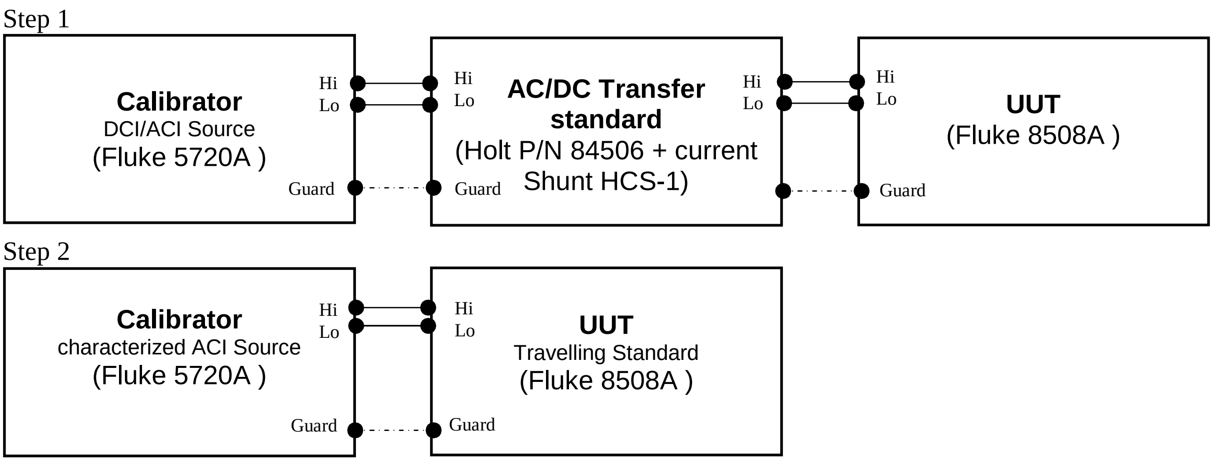

Fig. 5. Scheme of measurement systems and connections for AC Current ranges.

6. MEASUREMENT RESULTS

DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value [2]	Reading of 8508A[2]	Error of 8508A [2, 3]	Uncertainty [1, 2]
200 mV	+ 100 mV	100,00000	100,00017	0,00017	0,00045
20 V	+ 10 V	10,000001	10,000038	0,000037	0,000014
200 V	+ 100 V	100,00011	99,99988	-0,00023	0,00021
1000 V	+ 1000 V	1000,0032	1000,0013	-0,0019	0,0025

DC CURRENT

Range of 8508A	Nominal Value	Applied Value [2]	Reading of 8508A[2]	Error of 8508A[3]	Uncertainty [1, 2]
200 µA	+ 100 µA	99,9987	99,9977	-0,0010	0,0004
20 mA	+ 10 mA	9,99995	10,00020	0,00022	0,00004
1 A	+ 1 A	1,0000010	0,9998818	-0,0001192	0,0000236

DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value [2]	Reading of 8508A[2]	Error of 8508A [2, 3]	Uncertainty [1, 2]
20 Ω	TrueΩ	10 Ω	9,999794	9,999908	0,000114	0,000021
20 kΩ	TrueΩ	10 kΩ	10,000180	10,000289	0,000109	0,000019
	TrueΩ LoI	10 kΩ	10,000180	10,000295	0,000115	0,000019
2 MΩ	Normal Ω	1 MΩ	1,0000023	1,0000121	0,0000098	0,0000015

AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage [2]	Reading of 8508A [2]	Error of 8508A [2, 3]	Uncertainty [1, 2]
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99,9999	99,9944	-0,0055	0,0021
	100 mV	1 kHz	99,9992	99,9984	-0,0008	0,0021
20 V	10 V	55 Hz	10,00005	10,00056	0,00051	0,00011
	10 V	1 kHz	10,00003	10,00096	0,00093	0,00011
	10 V	100 kHz	9,99989	10,00106	0,00117	0,00022
200 V	100 V	55 Hz	99,9993	99,9985	-0,0008	0,0012
	100 V	1 kHz	99,9990	100,0021	0,0031	0,0012

AC CURRENT

Range of 8508A	Nominal Value		Applied Current [2]	Reading of 8508A [2]	Error of 8508A [2, 3]	Uncertainty [1, 2]
	Current	Frequency				
20 mA	10 mA	300 Hz	10,00010	10,00051	0,00041	0,00021
	10 mA	1 kHz	10,00003	10,00064	0,00061	0,00021
1 A	1 A	300 Hz	1,000026	0,999916	-0,000110	0,000033
	1 A	1 kHz	1,000051	1,000004	-0,000047	0,000033

[1] *Expanded uncertainty corresponding to the coverage probability of approximately 95 %.*
[2] *The units of measure of the electrical quantities values are the same as the units shown in nominal value columns.*
[3] The *Errors of 8508A are determined by equation:*

Error = Measured Value (reading of Traveling Standard) – Applied Value

7. UNCERTAINTY BUDGET

Model Function

Measurement equation for direct comparison of indications method.

Indication error ΔW of calibrated multimeter for measured value of quantity is determined by measurement equation:

$$\Delta W = W_Z - W_O + \delta_1 W_Z - \delta_2 W_O$$

where:

W_Z – the measured value of quantity – indicated by calibrated multimeter,

W_O – reference value of quantity, determined as standard indication,

$\delta_1 W_Z$ – correction of W_Z – due to multimeter resolution,

$\delta_2 W_O$ – correction of W_O determined in one of the ways described below:

a) resulting from the maximum permissible measurement error contained in standard (calibrator) specification and confirmed in its certificate of calibration. Correction value in result is assumed as zero and measurement uncertainty is expanded to a randomized value of these errors. W_O value is then assumed directly as standard (calibrator) regulation value

b) resulting from such components as:

- reference to external standards based on calibration certificate or comparative measurements to reference standards performed before and after calibration,
- drift since the last calibration or short-term stability,
- offset,
- resolution,
- nonlinearity,
- temperature coefficient,
- interaction between multimeter and standard etc.

Measurement equation for technical method of electrical current measurement.

Indication error of calibrated multimeter ΔW, that is difference between the measured value of quantity indicated by calibrated multimeter W_Z and reference value of current source W_O, is determined by measurement equation:

$$\Delta W = W_Z - W_O + \delta_1 W_Z$$

where:

$\delta_1 W_Z$ – correction of W_Z – due to multimeter resolution,

Reference value of current source W_O is determined by technical method – standard voltmeter measures voltage drop due to current flowing through standard resistance. Reference value of current source W_O is then determined based on Ohm's law:

$$W_O = \frac{V_O + \delta_1 V_O + \delta_2 V_O}{R_C + \delta_4 R_O + \delta_t R_O}$$

where:

V_O – voltage drop value on standard resistance due to current flowing through it measured by standard voltmeter,

$\delta_1 V_O$ – correction of V_O – due to standard voltmeter resolution,

$\delta_2 V_O$ – correction of W_O determined in one of the ways described below:

a) resulting from the maximum permissible measurement error contained in standard voltmeter specification and confirmed in its certificate of calibration. Correction value in result is assumed as zero and measurement uncertainty is expanded to a randomized value of these errors. W_O value is then assumed directly as voltmeter (standard multimeter) regulation value,

b) resulting from such components as:

- reference to external standards based on calibration certificate or comparative measurements to reference standards performed before and after calibration,
- drift since the last calibration or short-term stability,
- offset,
- resolution,
- nonlinearity,
- temperature coefficient,
- load influence on the voltmeter (standard multimeter) etc.

R_C – measuring system resistance, through that current of measuring intermediate device flows. R_C is determined by equation:

$$R_C = \frac{R_O \cdot R_V}{R_O + R_V}$$

because

$$R_O << R_V$$

than

$$R_C = R_O$$

where:

R_O – value of resistance current shunt calibrated at constant current or impedance calibrated

at alternating current,

R_V – value of input resistance of standard voltmeter DC or input impedance of standard voltmeter AC. Effect of that resistance (impedance) is negligibly small.

$\delta_4 R_O$ – correction of R_O – due to resistor long term stability,

$\delta_t R_O$ – correction of R_O – due to temperature coefficient of standard resistance, related to difference between ambient temperature from certificate of calibration of standard resistor and this ambient temperature at which calibration by technical method is performed. When resistance value corrections due to temperature coefficient are negligibly small, they aren't taken into account at uncertainty estimation,

Uncertainty equation detailed form of i-th measurement for direct comparison of the indications method is the following:

$$u(\Delta W) = \sqrt{c_1^2 u^2(W_Z) + c_2^2 u^2(W_O) + c_3^2 u^2(\delta_1 W_Z) + c_4^2 u^2(\delta_2 W_O)}$$

where: $c_1 \div c_4$ – sensitivity coefficients:

$$c_1 = \frac{\partial \Delta W}{\partial W_Z} = 1; \quad c_2 = \frac{\partial \Delta W}{\partial W_O} = -1; \quad c_3 = \frac{\partial \Delta W}{\partial \delta_1 W_Z} = 1; \quad c_4 = \frac{\partial \Delta W}{\partial \delta_2 W_O} = -1;$$

and also:

$u^2(W_Z)$ – variance of W_Z,

$u^2(W_O)$ – variance of W_O,

$u^2(\delta_1 W_Z)$ –variance of correction $\delta_1 W_Z$,

$u^2(\delta_2 W_O)$ – variance of correction $\delta_2 W_O$,

Uncertainty equation detailed formula of i-th measurement for technical method of electrical current measurement is the following:

$$u(\Delta W) = \sqrt{c_1^2 u^2(W_Z) + c_2^2 u^2(W_O) + c_3^2 u^2(\delta_1 W_Z)}$$

where:

$$u(W_O) = \sqrt{c_4^2 u^2(V_O) + c_5^2 u^2(\delta_1 V_O) + c_6^2 u^2(\delta_2 V_O) + c_7^2 u^2(R_O) + c_8^2 u^2(\delta_4 R_O) + c_9^2 u^2(\delta_t R_O)}$$

and:

$c1 \div c9$ – sensitivity coefficients:

$$c_1 = \frac{\partial \Delta W}{\partial W_Z} = 1; \quad c_2 = \frac{\partial \Delta W}{\partial W_O} = -1; \quad c_3 = \frac{\partial \Delta W}{\partial \delta_1 W_Z} = 1; \quad c_4 = \frac{\partial W_O}{\partial V_O} = \frac{1}{R_O + \delta_4 R_O + \delta_t R_O};$$

$$c_5 = \frac{\partial W_O}{\partial \delta_1 V_O} = \frac{1}{R_O + \delta_4 R_O + \delta_t R_O}; \qquad c_6 = \frac{\partial W_O}{\partial \delta_2 V_O} = \frac{1}{R_O + \delta_4 R_O + \delta_t R_O};$$

$$c_7 = \frac{\partial W_O}{\partial R_O} = -\frac{V_O + \delta_1 V_O + \delta_2 V_O}{(R_O + \delta_4 R_O + \delta_t R_O)^2}; \qquad c_8 = \frac{\partial W_O}{\partial \delta_4 R_O} = -\frac{V_O + \delta_1 V_O + \delta_2 V_O}{(R_O + \delta_4 R_O + \delta_t R_O)^2};$$

$$c_9 = \frac{\partial W_O}{\partial \delta_t R_O} = -\frac{V_O + \delta_1 V_O + \delta_2 V_O}{(R_O + \delta_4 R_O + \delta_t R_O)^2};$$

and also:

$u2(W_Z)$ – variance of W_Z,

$u2(W_O)$ – variance of W_O,

$u2(\delta_1 W_Z)$ – variance of correction $\delta_1 W_Z$,

$u2(V_O)$ – variance of correction V_O,

$u2(\delta_1 V_O)$ – variance of correction $\delta_1 V_O$,

$u2(R_O)$ – variance of correction R_C,

$u2(\delta_4 R_O)$ - variance of correction $\delta_4 R_O$,

$u2(\delta_t R_O)$ - variance of correction $\delta_t R_O$,

Table 1. Uncertainty budget for direct comparison of indications method

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$
W_Z	w_Z	$u(W_Z)$	normal	1	$c_1 \cdot u(W_Z)$
W_O	w_O	$u(W_O)$	normal	-1	$c_2 \cdot u(W_O)$
$\delta_1 W_Z$	$\delta_1 w_Z$	$u(\delta_1 W_Z)$	rectangular	1	$c_3 \cdot u(\delta_1 W_Z)$
$\delta_2 W_O$	$\delta_2 w_O$	$u(\delta_2 W_O)$	rectangular	-1	$c_4 \cdot u(\delta_2 W_O)$
Error (E_x)	δw			**Combined Uncertainty, $u(E_x)$**	$u(\Delta W)$
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	**2**
				Expanded Uncertainty, $U(E_x)$	$U(\Delta W) = k\, u(\Delta W)$

Table 2. Uncertainty budget for direct comparison of for technical method of electrical current measurement

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$
W_Z	w_Z	$u(W_Z)$	normal	1	$c_1 \cdot u(W_Z)$
$\delta_1 W_Z$	$\delta_1 w_Z$	$u(\delta_1 W_Z)$	rectangular	1	$c_3 \cdot u(\delta_1 W_Z)$
V_O	v_O	$u(V_O)$	normal	$\frac{1}{R_O + \delta_4 R_O + \delta_t R_O}$	$c_4 \cdot u(V_O)$
$\delta_1 V_O$	$\delta_1 v_O$	$u(\delta_1 V_O)$	rectangular	$\frac{1}{R_O + \delta_4 R_O + \delta_t R_O}$	$c_5 \cdot u(\delta_1 V_O)$
$\delta_2 V_O$	$\delta_2 v_O$	$u(\delta_2 V_O)$	rectangular	$\frac{1}{R_O + \delta_4 R_O + \delta_t R_O}$	$c_6 \cdot u(\delta_2 V_O)$
R_O	r_O	$u(R_O)$	normal	$-\frac{V_O + \delta_1 V_O + \delta_2 V_O}{(R_O + \delta_4 R_O + \delta_t R_O)^2}$	$c_7 \cdot u(R_O)$
$\delta_4 R_O$	$\delta_4 r_O$	$u(\delta_4 R_O)$	rectangular	$-\frac{V_O + \delta_1 V_O + \delta_2 V_O}{(R_O + \delta_4 R_O + \delta_t R_O)^2}$	$c_8 \cdot u(\delta_4 R_O)$
$\delta_t R_O$	$\delta_t r_O$	$u(\delta_t R_O)$	rectangular	$-\frac{V_O + \delta_1 V_O + \delta_2 V_O}{(R_O + \delta_4 R_O + \delta_t R_O)^2}$	$c_9 \cdot u(\delta_t R_O)$
Error (E_x)	δw			**Combined Uncertainty, $u(E_x)$**	$u(\Delta W)$
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	**2**
				Expanded Uncertainty, $U(E_x)$	$U(\Delta W) = k\, u(\Delta W)$

7.1. *DC Voltage*

Table 1. Uncertainty budget for 100 mV

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$
W_Z	100,00017	4,77E-05	normal	1	4,77E-05
W_O	100,00000	1,04E-04	normal	-1	-1,04E-04
$\delta_1 W_Z$	0,00000	2,89E-06	rectangular	1	2,89E-06
$\delta_2 W_O$	0,00000	1,91E-04	rectangular	-1	-1,91E-04
Error (E_x)	0,00017			**Combined Uncertainty, $u(E_x)$**	0,000223
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,000445

Table 2. Uncertainty budget for 10 V

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$
W_Z	10,000038	1,64E-06	normal	1	1,64E-06
W_O	10,000001	5,79E-06	normal	-1	-5,79E-06
$\delta_1 W_Z$	0,000000	2,89E-07	rectangular	1	2,89E-07
$\delta_2 W_O$	0,000000	3,18E-06	rectangular	-1	-3,18E-06
Error (E_x)	0,000037			**Combined Uncertainty, $u(E_x)$**	0,0000068
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,0000136

Table 3. Uncertainty budget for 100 V

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$
W_Z	99,99988	5,89E-05	normal	1	5,89E-05
W_O	100,00011	6,93E-05	normal	-1	-6,93E-05
$\delta_1 W_Z$	0,00000	2,89E-06	rectangular	1	2,89E-06
$\delta_2 W_O$	0,00000	5,20E-05	rectangular	-1	-5,20E-05
Error (E_x)	-0,00023			**Combined Uncertainty, $u(E_x)$**	0,000105
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,000210

Table 4. Uncertainty budget for 1000 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	1000,0013	7,98E-04	normal	1	7,98E-04
W_O	1000,0032	8,66E-04	normal	-1	-8,66E-04
$\delta_1 W_Z$	0,0000	2,89E-05	rectangular	1	2,89E-05
$\delta_2 W_O$	0,0000	4,04E-04	rectangular	-1	-4,04E-04
Error (E_x)	-0,0019			**Combined Uncertainty, u(E_x)**	0,00125
				Effective Degrees of Freedom, v_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, U(E_x)	0,00249

7.2. *DC Current*

Table 5. Uncertainty budget for 100 µA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	9,99977E-05	3,17E-11	normal	1,0000E+00	3,17E-11
$\delta_1 W_Z$	0	2,89E-11	rectangular	1,0000E+00	2,89E-11
V_O	1,0000055	2,89E-08	normal	9,9998E-05	2,89E-12
$\delta_1 V_O$	0	2,89E-08	rectangular	9,9998E-05	2,89E-12
$\delta_2 V_O$	0	1,70E-06	rectangular	9,9998E-05	1,70E-10
R_O	10000,1802	7,00E-04	normal	-9,9997E-09	-7,00E-12
$\delta_4 R_O$	0	9,47E-03	rectangular	-9,9997E-09	-9,47E-11
$\delta_t R_O$	0	4,60E-08	rectangular	-9,9997E-09	-4,60E-16
Error (E_x)	-1,048E-09			**Combined Uncertainty, *u(E_x)***	1,994E-10
				Effective Degrees of Freedom, v_{eff}	∞
				Coverage Factor, *k*	2
				Expanded Uncertainty, *U(E_x)*	3,989E-10

Table 6. Uncertainty budget for 10 mA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	1,000017E-02	2,52E-09	normal	1,00E+00	2,52E-09
$\delta_1 W_Z$	0	2,89E-09	rectangular	1,00E+00	2,89E-09
V_O	0,9999765	2,89E-08	normal	-1,00E-02	-2,89E-10
$\delta_1 V_O$	0	2,89E-08	rectangular	-1,00E-02	-2,89E-10
$\delta_2 V_O$	0	1,70E-06	rectangular	-1,00E-02	-1,70E-08
R_O	99,9981533	2,90E-06	normal	1,00E-04	2,90E-10
$\delta_4 R_O$	0	7,33E-05	rectangular	1,00E-04	7,33E-09
$\delta_t R_O$	0	4,00E-09	rectangular	1,00E-04	4,00E-13a
Error (E_x)	2,203E-07			**Combined Uncertainty, $u(E_x)$**	1,891E-08
				Effective Degrees of Freedom, v_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	3,782E-08

Table 7. Uncertainty budget for 1 A

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	0,9998818	1,32E-06	normal	1,00E+00	1,32E-06
$\delta_1 W_Z$	0	2,89E-08	rectangular	1,00E+00	2,89E-08
V_O	1,0000142	2,89E-08	normal	-1,00E+00	-2,89E-08
$\delta_1 V_O$	0	2,89E-08	rectangular	-1,00E+00	-2,89E-08
$\delta_2 V_O$	0	1,70E-06	rectangular	-1,00E+00	-1,70E-06
R_O	1,00001317	2,90E-08	normal	1,00E+00	2,90E-08
$\delta_4 R_O$	0	1,15E-05	rectangular	1,00E+00	1,15E-05
$\delta_t R_O$	0	1,22E-06	rectangular	1,00E+00	1,22E-06
Error (E_x)	-1,192E-04			**Combined Uncertainty, $u(E_x)$**	1,180E-05
				Effective Degrees of Freedom, v_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	2,360E-05

7.3. DC Resistance

Table 8. Uncertainty budget for 10 Ω

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$
W_Z	9,999908	5,03E-06	normal	1	5,03E-06
W_O	9,999794	3,70E-07	normal	-1	-3,70E-07
$\delta_1 W_Z$	0,000000	2,89E-07	rectangular	1	2,89E-07
$\delta_2 W_O$	0,000000	8,89E-06	rectangular	-1	-8,89E-06
Error (E_x)	0,000114			**Combined Uncertainty, $u(E_x)$**	0,0000102
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,0000205

Table 9. Uncertainty budget for 10 kΩ - low Current OFF

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$
W_Z	10,000289	1,10E-06	normal	1	1,10E-06
W_O	10,000180	7,00E-07	normal	-1	-7,00E-07
$\delta_1 W_Z$	0,000000	2,89E-07	rectangular	1	2,89E-07
$\delta_2 W_O$	0,000000	9,47E-06	rectangular	-1	-9,47E-06
Error (E_x)	0,000109			**Combined Uncertainty, $u(E_x)$**	0,0000096
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,0000191

Table 10. Uncertainty budget for 10 kΩ - low Current ON

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Distribution**	**Sensitivity Coefficient** c_i	**Uncertainty Contribution** $u_i(E_x)$
W_Z	10,000295	7,28E-07	normal	1	7,28E-07
W_O	10,000180	7,00E-07	normal	-1	-7,00E-07
$\delta_1 W_Z$	0,000000	2,89E-07	rectangular	1	2,89E-07
$\delta_2 W_O$	0,000000	9,47E-06	rectangular	-1	-9,47E-06
Error (E_x)	0,000115			**Combined Uncertainty, $u(E_x)$**	0,0000095
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,0000191

Table 11. Uncertainty budget for 1 MΩ

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	1,0000121	6,86E-08	normal	1	6,86E-08
W_O	1,0000023	1,50E-07	normal	-1	-1,50E-07
$\delta_1 W_Z$	0,0000000	2,89E-07	rectangular	1	2,89E-07
$\delta_2 W_O$	0,0000000	6,87E-07	rectangular	-1	-6,87E-07
Error (E_x)	0,0000098	Combined Uncertainty, $u(E_x)$			0,00000076
		Effective Degrees of Freedom, ν_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,00000153

7.4. AC Voltage

Table 12. Uncertainty budget for 100 mV, 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	99,9944	1,92E-04	normal	1	1,92E-04
W_O	99,9999	4,19E-04	normal	-1	-4,19E-04
$\delta_1 W_Z$	0,0000	2,89E-05	rectangular	1	2,89E-05
$\delta_2 W_O$	0,0000	9,24E-04	rectangular	-1	-9,24E-04
Error (E_x)	-0,0055	Combined Uncertainty, $u(E_x)$			0,00103
		Effective Degrees of Freedom, ν_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,00207

Table 13. Uncertainty budget for 100 mV, 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	99,9984	1,66E-04	normal	1	1,66E-04
W_O	99,9992	4,18E-04	normal	-1	-4,18E-04
$\delta_1 W_Z$	0,0000	2,89E-05	rectangular	1	2,89E-05
$\delta_2 W_O$	0,0000	9,24E-04	rectangular	-1	-9,24E-04
Error (E_x)	-0,0008	Combined Uncertainty, $u(E_x)$			0,00103
		Effective Degrees of Freedom, ν_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,00206

Table 14. Uncertainty budget for 10 V, 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	10,00056	7,28E-06	normal	1	7,28E-06
W_O	10,00005	3,71E-05	normal	-1	-3,71E-05
$\delta_1 W_Z$	0,00000	2,89E-06	rectangular	1	2,89E-06
$\delta_2 W_O$	0,00000	3,70E-05	rectangular	-1	-3,70E-05
Error (E_x)	0,00051	**Combined Uncertainty, $u(E_x)$**			0,000053
		Effective Degrees of Freedom, ν_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,000106

Table 15. Uncertainty budget for 10 V, 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	10,00096	8,19E-06	normal	1	8,19E-06
W_O	10,00003	3,71E-05	normal	-1	-3,71E-05
$\delta_1 W_Z$	0,00000	2,89E-06	rectangular	1	2,89E-06
$\delta_2 W_O$	0,00000	3,70E-05	rectangular	-1	-3,70E-05
Error (E_x)	0,00093	**Combined Uncertainty, $u(E_x)$**			0,000053
		Effective Degrees of Freedom, ν_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,000106

Table 16. Uncertainty budget for 10 V, 100 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	10,00106	5,07E-05	normal	1	5,07E-05
W_O	9,99989	4,18E-05	normal	-1	-4,18E-05
$\delta_1 W_Z$	0,00000	2,89E-06	rectangular	1	2,89E-06
$\delta_2 W_O$	0,00000	9,09E-05	rectangular	-1	-9,09E-05
Error (E_x)	0,00117	**Combined Uncertainty, $u(E_x)$**			0,000112
		Effective Degrees of Freedom, ν_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,000224

Table 17. Uncertainty budget for 100 V, 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	99,9985	7,53E-05	normal	1	7,53E-05
W_O	99,9993	4,44E-04	normal	-1	-4,44E-04
$\delta_1 W_Z$	0,0000	2,89E-05	rectangular	1	2,89E-05
$\delta_2 W_O$	0,0000	3,70E-04	rectangular	-1	-3,70E-04
Error (E_x)	-0,0008	**Combined Uncertainty, $u(E_x)$**			0,00058
		Effective Degrees of Freedom, ν_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,00117

Table 18. Uncertainty budget for 100 V, 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	100,0021	4,47E-05	normal	1	4,47E-05
W_O	99,9990	4,44E-04	normal	-1	-4,44E-04
$\delta_1 W_Z$	0,0000	2,89E-05	rectangular	1	2,89E-05
$\delta_2 W_O$	0,0000	3,70E-04	rectangular	-1	-3,70E-04
Error (E_x)	0,0031	**Combined Uncertainty, $u(E_x)$**			0,00058
		Effective Degrees of Freedom, ν_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,00116

7.5. AC Current

Table 19. Uncertainty budget for 10 mA, 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	10,00051	9,85E-06	normal	1	9,85E-06
W_O	10,00010	3,98E-05	normal	-1	-3,98E-05
$\delta_1 W_Z$	0,00000	2,89E-06	rectangular	1	2,89E-06
$\delta_2 W_O$	0,00000	9,53E-05	rectangular	-1	-9,53E-05
Error (E_x)	0,00041			**Combined Uncertainty, $u(E_x)$**	0,000104
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,000208

Table 20. Uncertainty budget for 10 mA, 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	10,00064	9,59E-06	normal	1	9,59E-06
W_O	10,00003	3,97E-05	normal	-1	-3,97E-05
$\delta_1 W_Z$	0,00000	2,89E-06	rectangular	1	2,89E-06
$\delta_2 W_O$	0,00000	9,53E-05	rectangular	-1	-9,53E-05
Error (E_x)	0,00061			**Combined Uncertainty, $u(E_x)$**	0,000104
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,000207

Table 21. Uncertainty budget for 1 A, 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	0,999916	1,46E-06	normal	1	1,46E-06
W_O	1,000026	4,22E-06	normal	-1	-4,22E-06
$\delta_1 W_Z$	0,000000	2,89E-07	rectangular	1	2,89E-07
$\delta_2 W_O$	0,000000	1,59E-05	rectangular	-1	-1,59E-05
Error (E_x)	-0,000110			**Combined Uncertainty, $u(E_x)$**	0,000017
				Effective Degrees of Freedom, ν_{eff}	∞
				Coverage Factor, k	2
				Expanded Uncertainty, $U(E_x)$	0,0000330

Table 22. Uncertainty budget for 1 A, 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$
W_Z	1,000004	1,07E-06	normal	1	1,07E-06
W_O	1,000051	4,18E-06	normal	-1	-4,18E-06
$\delta_1 W_Z$	0,000000	2,89E-07	rectangular	1	2,89E-07
$\delta_2 W_O$	0,000000	1,59E-05	rectangular	-1	-1,59E-05
Error (E_x)	-0,000047	**Combined Uncertainty, $u(E_x)$**			0,000016
		Effective Degrees of Freedom, v_{eff}			∞
		Coverage Factor, k			2
		Expanded Uncertainty, $U(E_x)$			0,0000330

1. PARTICIPANT INSTITUTE

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2. PERIOD OF MEASUREMENTS

3. AMBIENT CONDITIONS

Temperature : (20 ± 1) °C

Relative Humidity : (45 ± 10) % rh

4. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Digital Multimeter	Fluke	8508A	976156885	EIM
Calibrator	Fluke	5720A	9216214	SIQ

5. MEASUREMENT METHOD

Direct measurement method is used for the calibration of UUT for the quantities DCV, DCI, ACV, ACI, DC resistance.
The multifunctional calibrator has powered in the same time the Reference and UUT Multimeter for all the required quantities.
The applied value is considered the reading of the reference multimeter corrected from the last calibration certificate.

MEASUREMENT RESULTS

DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 mV	+ 100 mV	100.00028 mV	99.99992 mV	- 3.6 µV/V	11 µV/V
20 V	+ 10 V	9.999969 V	10.000006 V	3.8 µV/V	4.1 µV/V
200 V	+ 100 V	99.99987 V	99.99981 V	- 0.55 µV/V	6.5 µV/V
1000 V	+ 1000 V	999.9996 V	1000.0006 V	1.0 µV/V	7.1 µV/V

DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 µA	+ 100 µA	99.99924 µA	99.99885 µA	- 3.9 µA/A	99 µA/A
20 mA	+ 10 mA	9.999968 mA	10.000183 mA	22 µA/A	35 µA/A
1 A	+ 1 A	0.9999823 A	0.9998731 A	- 0.11 mA/A	0.17 mA/A

DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
20 Ω	TrueΩ	10 Ω	9.999476 Ω	9.999745 Ω	27 µΩ/Ω	26 µΩ/Ω
20 kΩ	TrueΩ	10 kΩ	9.999990 kΩ	10.000073 kΩ	8.3 µΩ/Ω	10 µΩ/Ω
	TrueΩ LoI	10 kΩ	10.000007 kΩ	10.000135 kΩ	13 µΩ/Ω	11 µΩ/Ω
2 MΩ	Normal Ω	1 MΩ	0.9999667 MΩ	0.9999800 MΩ	13 µΩ/Ω	17 µΩ/Ω

AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99.9934 mV	99.9893 mV	- 41 µV/V	0.18 mV/V
	100 mV	1 kHz	99.9998 mV	99.9937 mV	- 61 µV/V	0.18 mV/V
20 V	10 V	55 Hz	9.99977 V	10.00052 V	75 µV/V	95 µV/V
	10 V	1 kHz	10.00031 V	10.00093 V	62 µV/V	0.10 mV/V
	10 V	100 kHz	10.00245 V	10.00415 V	0.17 mV/V	0.57 mV/V
200 V	100 V	55 Hz	99.9967 V	99.9982 V	15 µV/V	99 µV/V
	100 V	1 kHz	100.0016 V	100.0018 V	2.5 µV/V	84 µV/V

AC CURRENT

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Current	Frequency				
20 mA	10 mA	300 Hz	10.00028 mA	10.00054 mA	26 µA/A	0.35 mA/A
	10 mA	1 kHz	10.00045 mA	10.00068 mA	23 µA/A	0.35 mA/A
1 A	1 A	300 Hz	0.999930 A	0.999893 A	- 37 µA/A	0.68 mA/A
	1 A	1 kHz	1.000068 A	1.000070 A	1.5 µA/A	0.68 mA/A

[1] *Expanded uncertainty corresponding to the coverage probability of approximately 95 %.*

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6. UNCERTAINTY BUDGET

6.1. DC Voltage

Table 1. Uncertainty budget for 100 mV

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	Voltage indicated by DMM (UUT)	99.99992 mV	0.003 µV	Normal	1	0.003 µV	19
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	100.00028 mV	0.008 µV	Normal	1	0.008 µV	19
$\delta V_{s.cal}$	Uncertainty from the calibration certificate of the reference DMM	0.00000 mV	0.5 µV	Normal	1	0.50 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.00000 mV	0.14 µV	Normal	1	0.14 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.00000 mV	0.05 µV	Normal	1	0.05 µV	∞
$\delta U_{s.drift}$	Drift Time	0.00000 mV	0.01 µV	Rectangular	1	0.01 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.00000 mV	0.07 µV	Rectangular	1	0.07 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.00000 mV	0.0029 µV	Rectangular	1	0.00 µV	∞
δV_{ftem}	Wiring therm EMF	0.00000 mV	0.12 µV	Rectangular	1	0.12 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.00000 mV	0.07 µV	Rectangular	1	0.07 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (7 dig)	0.00000 mV	0.0029 µV	Rectangular	1	0.00 µV	∞
Error (E_x) $Ex=V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} + \delta V_{ftem} - \delta V_{s.temp} - \delta V_{s.resol}$		-3.6 µV/V	**Combined Uncertainty, $u(E_x)$**				**0.54 µV**
			Effective Degrees of Freedom, ν_{eff}				393624559.4
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**11 µV/V**

Table 2. Uncertainty budget for 10 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_{ix}	Voltage indicated by DMM (UUT)	10.000006 V	0.07 µV	Normal	1	0.075 µV	19
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	9.999969 V	0.24 µV	Normal	1	0.240 µV	19
$\delta V_{s.cal}$	Uncertainty from the calibration certificate of the reference DMM	0.0000 V	14.0 µV	Normal	1	14.00 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.0000 V	13.50 µV	Normal	1	13.50 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.0000 V	2.00 µV	Normal	1	2.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.0000 V	1.49 µV	Rectangular	1	1.49 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.0000 V	5.20 µV	Rectangular	1	5.20 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.0000 V	0.29 µV	Rectangular	1	0.29 µV	∞
δV_{ftem}	Wiring therm EMF	0.0000 V	0.12 µV	Rectangular	1	0.12 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.0000 V	5.20 µV	Rectangular	1	5.20 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (7 dig)	0.0000 V	0.29 µV	Rectangular	1	0.29 µV	∞
Error (E_x) $Ex=V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} + \delta V_{ftem} - \delta V_{s.temp} - \delta V_{s.resol}$		3.8 µV/V	**Combined Uncertainty, $u(E_x)$**				**20.95 µV**
			Effective Degrees of Freedom, ν_{eff}				1098183717.7
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**4.1 µV/V**

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Table 3. Uncertainty budget for 100 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	99.99981 V	0.96 µV	Normal	1	0.956 µV	19
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	99.99987 V	11.24 µV	Normal	1	11.240 µV	19
$\delta V_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.0000 V	195.0 µV	Normal	1	195.00 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.0000 V	200.00 µV	Normal	1	200.00 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.0000 V	20.00 µV	Normal	1	20.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.0000 V	22.57 µV	Rectangular	1	22.57 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.0000 V	121.24 µV	Rectangular	1	121.24 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.0000 V	2.89 µV	Rectangular	1	2.89 µV	∞
δV_{ftem}	Wiring therm EMF	0.0000 V	0.12 µV	Rectangular	1	0.12 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.0000 V	121.24 µV	Rectangular	1	121.24 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (7 dig)	0.0000 V	2.89 µV	Rectangular	1	2.89 µV	∞
Error (E_x) $E_x = V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} + \delta V_{ftem} - \delta V_{s.temp} - \delta V_{s.resol}$		-0.55 µV/V	**Combined Uncertainty, $u(E_x)$**				**329.35 µV**
			Effective Degrees of Freedom, v_{eff}				14003363.4
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**6.5 µV/V**

Table 4. Uncertainty budget for 1000 V

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	1000.0006 V	7.79 µV	Normal	1	7.8 µV	19
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	999.9996 V	23.55 µV	Normal	1	23.5 µV	19
$\delta V_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.0000 V	2450.0 µV	Normal	1	2450.0 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.0000 V	2000.00 µV	Normal	1	2000.0 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.0000 V	250.00 µV	Normal	1	250.0 µV	∞
$\delta U_{s.drift}$	Drift Time	0.0000 V	225.73 µV	Rectangular	1	225.7 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.0000 V	1212.44 µV	Rectangular	1	1212.4 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.0000 V	28.87 µV	Rectangular	1	28.9 µV	∞
δV_{ftem}	Wiring therm EMF	0.0000 V	0.12 µV	Rectangular	1	0.1 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.0000 V	1212.44 µV	Rectangular	1	1212.4 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (7 dig)	0.0000 V	28.87 µV	Rectangular	1	28.9 µV	∞
Error (E_x) $E_x = V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} + \delta V_{ftem} - \delta V_{s.temp} - \delta V_{s.resol}$		1.0 µV/V	**Combined Uncertainty, $u(E_x)$**				**3613.51 µV**
			Effective Degrees of Freedom, v_{eff}				10413263709.7
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**7.1 µV/V**

6.2. DC Current

Table 5. Uncertainty budget for 100 µA

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current indicated by DMM (UUT)	99.99885 µA	0.00001 µA	Normal	1	0.00001 µA	19
$I_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	99.99924 µA	0.00001 µA	Normal	1	0.00001 µA	19
$\delta I_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.00000 µA	0.00475 µA	Normal	1	0.00475 µA	∞
$\delta I_{s.spec1}$	Reading (Specs) of the reference DMM	0.00000 µA	0.00032 µA	Normal	1	0.00032 µA	∞
$\delta I_{s.spec2}$	Range (Specs) of the reference DMM	0.00000 µA	0.00020 µA	Normal	1	0.00020 µA	∞
$\delta I_{s.drift}$	Drift Time	0.00000 µA	0.00005 µA	Rectangular	1	0.00005 µA	∞
$\delta I_{s.temp}$	Temp of the reference DMM	0.00000 µA	0.00007 µA	Rectangular	1	0.00007 µA	∞
$\delta I_{s.resol}$	The finite resolution of the reference DMM	0.00000 µA	0.000003 µA	Rectangular	1	0.000003 µA	∞
δI_{leak}	Wiring leakage current	0.00000 µA	0.00001 µA	Rectangular	1	0.00001 µA	∞
$\delta I_{ix.temp}$	Temp of the DMM (UUT)	0.00000 µA	0.00007 µA	Rectangular	1	0.00007 µA	∞
$\delta I_{ix.resol}$	The finite resolution of UUT, DMM (7 dig)	0.00000 µA	0.000003 µA	Rectangular	1	0.000003 µA	∞
Error (E_x) $E_x=I_{ix} - I_{s.corr} + \delta I_{ix.temp} + \delta I_{ix.resol} - \delta I_{s.cal} - \delta I_{s.spec1} - \delta I_{s.spec2} + \delta I_{s.drift} + \delta I_{leak} - \delta I_{s.temp} - \delta I_{s.resol}$		-3.9 µA/A				**Combined Uncertainty, $u(E_x)$**	**0.01 µA**
						Effective Degrees of Freedom, v_{eff}	1576292368053.53
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**99 µA/A**

Table 6. Uncertainty budget for 10 mA

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current indicated by DMM (UUT)	10.000183 mA	0.00032 µA	Normal	1	0.00032 µA	19
$I_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	9.999968 mA	0.00382 µA	Normal	1	0.00382 µA	19
$\delta I_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.00000 mA	0.17 µA	Normal	1	0.17 µA	∞
$\delta I_{s.spec1}$	Reading (Specs) of the reference DMM	0.00000 mA	0.04 µA	Normal	1	0.04 µA	∞
$\delta I_{s.spec2}$	Range (Specs) of the reference DMM	0.00000 mA	0.02 µA	Normal	1	0.02 µA	∞
$\delta I_{s.drift}$	Drift Time	0.00000 mA	0.0058 µA	Rectangular	1	0.00577 µA	∞
$\delta I_{s.temp}$	Temp of the reference DMM	0.00000 mA	0.0225 µA	Rectangular	1	0.02252 µA	∞
$\delta I_{s.resol}$	The finite resolution of the reference DMM	0.00000 mA	0.00029 µA	Rectangular	1	0.00029 µA	∞
δI_{leak}	Wiring leakage current	0.00000 mA	0.00001 µA	Rectangular	1	0.00001 µA	∞
$\delta I_{ix.temp}$	Temp of the DMM (UUT)	0.00000 mA	0.0225 µA	Rectangular	1	0.02252 µA	∞
$\delta I_{ix.resol}$	The finite resolution of UUT, DMM (7 dig)	0.00000 mA	0.00029 µA	Rectangular	1	0.000289 µA	∞
Error (E_x) $E_x=I_{ix} - I_{s.corr} + \delta I_{ix.temp} + \delta I_{ix.resol} - \delta I_{s.cal} - \delta I_{s.spec1} - \delta I_{s.spec2} + \delta I_{s.drift} + \delta I_{leak} - \delta I_{s.temp} - \delta I_{s.resol}$		22 µA/A				**Combined Uncertainty, $u(E_x)$**	**0.18 µA**
						Effective Degrees of Freedom, v_{eff}	92662452.80
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**35 µA/A**

Table 7. Uncertainty budget for 1 A

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current indicated by DMM (UUT)	0.9998731 A	0.036 µA	Normal	1	0.03622 µA	19
$I_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	0.9999823 A	4.45 µA	Normal	1	4.45 µA	19
$\delta I_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.000000 A	0.04 µA	Normal	1	0.04 µA	∞
$\delta I_{s.spec1}$	Reading (Specs) of the reference DMM	0.000000 A	85.0 µA	Normal	1	85 µA	∞
$\delta I_{s.spec2}$	Range (Specs) of the reference DMM	0.000000 A	8.0 µA	Normal	1	8.00 µA	∞
$\delta I_{s.drift}$	Drift Time	0.000000 A	16.44 µA	Rectangular	1	16.4 µA	∞
$\delta I_{s.temp}$	Temp of the reference DMM	0.000000 A	13.9 µA	Rectangular	1	13.9 µA	∞
$\delta I_{s.resol}$	The finite resolution of the reference DMM	0.000000 A	0.029 µA	Rectangular	1	0.029 µA	∞
δI_{leak}	Wiring leakage current	0.000000 A	0.00001 µA	Rectangular	1	0.00001 µA	∞
$\delta I_{ix.temp}$	Temp of the DMM (UUT)	0.000000 A	13.9 µA	Rectangular	1	13.85 µA	∞
$\delta I_{ix.resol}$	The finite resolution of UUT, DMM (7 dig)	0.000000 A	0.029 µA	Rectangular	1	0.029 µA	∞
Error (E_x) $Ex=I_{ix} - I_{s.corr} + \delta I_{ix.temp} + \delta I_{ix.resol} - \delta I_{s.cal} - \delta I_{s.spec1} - \delta I_{s.spec2} + \delta I_{s.drift} + \delta I_{leak} - \delta I_{s.temp} - \delta I_{s.resol}$		-0.11 mA/A				**Combined Uncertainty, $u(E_x)$**	**89.23 µA**
						Effective Degrees of Freedom, v_{eff}	3075931.10
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**0.17 mA/A**

6.3. DC Resistance

Table 8. Uncertainty budget for 10 Ω TrueΩ

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
R_{ix}	Current indicated by DMM (UUT)	9.999745 Ω	0.59 µΩ	Normal	1	0.6 µΩ	9
$R_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	9.999476 Ω	67.7 µΩ	Normal	1	67.7 µΩ	9
$\delta R_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.000000 Ω	105 µΩ	Normal	1	105.0 µΩ	∞
$\delta R_{s.spec}$	Reading (Specs) of the reference DMM	0.000000 Ω	35 µΩ	Normal	1	35.0 µΩ	∞
$\delta R_{s.spec}$	Range (Specs) of the reference DMM	0.000000 Ω	7 µΩ	Normal	1	7.0 µΩ	∞
$\delta R_{s.drift}$	Drift Time	0.000000 Ω	0.01 µΩ	Rectangular	1	0.0 µΩ	∞
$\delta R_{s.temp}$	Temp of the reference DMM	0.000000 Ω	10 µΩ	Rectangular	1	10.4 µΩ	∞
$\delta R_{s.resol}$	The finite resolution of the reference DMM	0.000000 Ω	0.29 µΩ	Rectangular	1	0.3 µΩ	∞
$\delta R_{ix.tem}$	Temp of the DMM (UUT)	0.000000 Ω	10 µΩ	Rectangular	1	10.4 µΩ	∞
$\delta R_{ix.reso}$	The finite resolution of UUT, DMM (7 dig)	0.000000 Ω	0.29 µΩ	Rectangular	1	0.3 µΩ	∞
Error (E_x) $Ex=R_{ix} - R_{s.corr} + \delta R_{ix.temp} + \delta R_{ix.resol} - \delta R_{s.cal} - \delta R_{s.spec1} - \delta R_{s.spec2} + \delta R_{s.drift} - \delta R_{s.temp} - \delta R_{s.resol}$		27 µΩ/Ω	**Combined Uncertainty, $u(E_x)$**				**131 µΩ**
			Effective Degrees of Freedom, ν_{eff}				264.72
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**26 µΩ/Ω**

Table 9. Uncertainty budget for 10 kΩ TrueΩ

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
R_{ix}	Current indicated by DMM (UUT)	10.000073 kΩ	615.06 µΩ	Normal	1	615.1 µΩ	9
$R_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	9.999990 kΩ	2270.6 µΩ	Normal	1	2270.6 µΩ	9
$\delta R_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.000000 kΩ	37500 µΩ	Normal	1	37500.0 µΩ	∞
$\delta R_{s.spec}$	Reading (Specs) of the reference DMM	0.000000 kΩ	35000 µΩ	Normal	1	35000.0 µΩ	∞
$\delta R_{s.spec}$	Range (Specs) of the reference DMM	0.000000 kΩ	2500 µΩ	Normal	1	2500.0 µΩ	∞
$\delta R_{s.drift}$	Drift Time	0.000000 kΩ	697.44 µΩ	Rectangular	1	697.4 µΩ	∞
$\delta R_{s.temp}$	Temp of the reference DMM	0.000000 kΩ	8660 µΩ	Rectangular	1	8660.2 µΩ	∞
$\delta R_{s.resol}$	The finite resolution of the reference DMM	0.000000 kΩ	288.7 µΩ	Rectangular	1	288.7 µΩ	∞
$\delta R_{ix.tem}$	Temp of the DMM (UUT)	0.000000 kΩ	8660 µΩ	Rectangular	1	8660.3 µΩ	∞
$\delta R_{ix.reso}$	The finite resolution of UUT, DMM (7 dig)	0.000000 kΩ	288.7 µΩ	Rectangular	1	288.7 µΩ	∞
Error (E_x) $Ex=R_{ix} - R_{s.corr} + \delta R_{ix.temp} + \delta R_{ix.resol} - \delta R_{s.cal} - \delta R_{s.spec1} - \delta R_{s.spec2} + \delta R_{s.drift} - \delta R_{s.temp} - \delta R_{s.resol}$		8.3 µΩ/Ω	**Combined Uncertainty, $u(E_x)$**				**52855 µΩ**
			Effective Degrees of Freedom, ν_{eff}				5548954.65
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**10 µΩ/Ω**

Table 10. Uncertainty budget for 10 kΩ TrueΩ LoI

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	Current indicated by DMM (UUT)	10.000135 kΩ	6356.18 µΩ	Normal	1	6356.2 µΩ	9
$R_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	10.000007 kΩ	6761.9 µΩ	Normal	1	6761.9 µΩ	9
$\delta R_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.000000 kΩ	37500 µΩ	Normal	1	37500.0 µΩ	∞
$\delta R_{s.spec}$	Reading (Specs) of the reference DMM	0.000000 kΩ	35000 µΩ	Normal	1	35000.0 µΩ	∞
$\delta R_{s.spec}$	Range (Specs) of the reference DMM	0.000000 kΩ	7000 µΩ	Normal	1	7000.0 µΩ	∞
$\delta R_{s.drift}$	Drift Time	0.000000 kΩ	697.44 µΩ	Rectangular	1	697.4 µΩ	∞
$\delta R_{s.temp}$	Temp of the reference DMM	0.000000 kΩ	10392 µΩ	Rectangular	1	10392.3 µΩ	∞
$\delta R_{s.resol}$	The finite resolution of the reference DMM	0.000000 kΩ	288.7 µΩ	Rectangular	1	288.7 µΩ	∞
$\delta R_{ix.tem}$	Temp of the DMM (UUT)	0.000000 kΩ	10392 µΩ	Rectangular	1	10392.4 µΩ	∞
$\delta R_{ix.reso}$	The finite resolution of UUT, DMM (7 dig)	0.000000 kΩ	288.7 µΩ	Rectangular	1	288.7 µΩ	∞
Error (E_x) $E_x = R_{ix} - R_{s.corr} + \delta R_{ix.temp} + \delta R_{ix.resol} - \delta R_{s.cal} - \delta R_{s.spec1} - \delta R_{s.spec2} + \delta R_{s.drift} - \delta R_{s.temp} - \delta R_{s.resol}$		13 µΩ/Ω				**Combined Uncertainty, $u(E_x)$**	**54616 µΩ**
						Effective Degrees of Freedom, v_{eff}	45411.24
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**11 µΩ/Ω**

Table 11. Uncertainty budget for 1 MΩ Normal

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
R_{ix}	Current indicated by DMM (UUT)	0.9999800 MΩ	659651.12 µΩ	Normal	1	659651 µΩ	9
$R_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	0.9999667 MΩ	255928.0 µΩ	Normal	1	255928 µΩ	9
$\delta R_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.0000000 MΩ	7500000 µΩ	Normal	1	7500000 µΩ	∞
$\delta R_{s.spec}$	Reading (Specs) of the reference DMM	0.0000000 MΩ	3499883 µΩ	Normal	1	3499883 µΩ	∞
$\delta R_{s.spec}$	Range (Specs) of the reference DMM	0.0000000 MΩ	500000 µΩ	Normal	1	500000 µΩ	∞
$\delta R_{s.drift}$	Drift Time	0.0000000 MΩ	318072.66 µΩ	Rectangular	1	318073 µΩ	∞
$\delta R_{s.temp}$	Temp of the reference DMM	0.0000000 MΩ	1039196 µΩ	Rectangular	1	1039196 µΩ	∞
$\delta R_{s.resol}$	The finite resolution of the reference DMM	0.0000000 MΩ	28867.5 µΩ	Rectangular	1	28868 µΩ	∞
$\delta R_{ix.tem}$	Temp of the DMM (UUT)	0.0000000 MΩ	1039210 µΩ	Rectangular	1	1039210 µΩ	∞
$\delta R_{ix.reso}$	The finite resolution of UUT, DMM (7 dig)	0.0000000 MΩ	28867.5 µΩ	Rectangular	1	28868 µΩ	∞
Error (E_x) $E_x = R_{ix} - R_{s.corr} + \delta R_{ix.temp} + \delta R_{ix.resol} - \delta R_{s.cal} - \delta R_{s.spec1} - \delta R_{s.spec2} + \delta R_{s.drift} - \delta R_{s.temp} - \delta R_{s.resol}$		13 µΩ/Ω				**Combined Uncertainty, $u(E_x)$**	**8456460 µΩ**
						Effective Degrees of Freedom, v_{eff}	501788.24
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**17 µΩ/Ω**

6.4. AC Voltage

Table 12. Uncertainty budget for 100 mV @ 55 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	99.9893 mV	0.173 µV	Normal	1	0.173 µV	49
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	99.9934 mV	0.255 µV	Normal	1	0.255 µV	49
$\delta V_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.00000 mV	7.5 µV	Normal	1	7.5 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.00000 mV	5.00 µV	Normal	1	5.00 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.00000 mV	2.00 µV	Normal	1	2.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.00000 mV	1.00 µV	Rectangular	1	1.00 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.00000 mV	0.87 µV	Rectangular	1	0.87 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.00000 mV	0.03 µV	Rectangular	1	0.03 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.00000 mV	0.87 µV	Rectangular	1	0.87 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.00000 mV	0.03 µV	Rectangular	1	0.03 µV	∞
Error (E_x) $Ex=V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} - \delta V_{s.temp} - \delta V_{s.resol}$		-41 µV/V				**Combined Uncertainty, $u(E_x)$**	**9.4 µV**
						Effective Degrees of Freedom, v_{eff}	28855393.41
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**0.18 mV/V**

Table 13. Uncertainty budget for 100 mV @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	99.9937 mV	0.156 µV	Normal	1	0.156 µV	49
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	99.9998 mV	0.226 µV	Normal	1	0.226 µV	49
$\delta V_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.00000 mV	7.5 µV	Normal	1	7.5 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.00000 mV	5.00 µV	Normal	1	5.00 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.00000 mV	1.00 µV	Normal	1	1.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.00000 mV	0.32 µV	Rectangular	1	0.32 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.00000 mV	0.87 µV	Rectangular	1	0.87 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.00000 mV	0.03 µV	Rectangular	1	0.03 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.00000 mV	0.87 µV	Rectangular	1	0.87 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.00000 mV	0.03 µV	Rectangular	1	0.03 µV	∞
Error (E_x) $Ex=V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} - \delta V_{s.temp} - \delta V_{s.resol}$		-61 µV/V				**Combined Uncertainty, $u(E_x)$**	**9.2 µV**
						Effective Degrees of Freedom, v_{eff}	41758468.36
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**0.18 mV/V**

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Table 14. Uncertainty budget for 10 V @ 55 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	10.00052 V	12.1 µV	Normal	1	12.1 µV	49
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	9.99977 V	14.9 µV	Normal	1	14.9 µV	49
$\delta V_{s.cal}$	Uncertainty from the calibration certificate of the reference DMM	0.0000 V	225.0 µV	Normal	1	225.0 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.0000 V	400.0 µV	Normal	1	399.99 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.0000 V	100.00 µV	Normal	1	100.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.0000 V	11.80 µV	Rectangular	1	11.80 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.0000 V	86.6 µV	Rectangular	1	86.60 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.0000 V	2.89 µV	Rectangular	1	2.89 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.0000 V	86.6 µV	Rectangular	1	86.61 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.0000 V	2.89 µV	Rectangular	1	2.89 µV	∞
Error (E_x) $E_x = V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} - \delta V_{s.temp} - \delta V_{s.resol}$		75 µV/V				**Combined Uncertainty, $u(E_x)$**	**485.9 µV**
						Effective Degrees of Freedom, v_{eff}	15109189.81
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**95 µV/V**

Table 15. Uncertainty budget for 10 V @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	10.00093 V	2.1 µV	Normal	1	2.1 µV	49
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	10.00031 V	2.0 µV	Normal	1	2.0 µV	49
$\delta V_{s.cal}$	Uncertainty from the calibration certificate of the reference DMM	0.0000 V	405 µV	Normal	1	405.0 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.0000 V	300 µV	Normal	1	300.01 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.0000 V	100 µV	Normal	1	100.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.0000 V	23.09 µV	Rectangular	1	23.09 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.0000 V	86.6 µV	Rectangular	1	86.61 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.0000 V	2.89 µV	Rectangular	1	2.89 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.0000 V	86.6 µV	Rectangular	1	86.61 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.0000 V	2.89 µV	Rectangular	1	2.89 µV	∞
Error (E_x) $E_x = V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} - \delta V_{s.temp} - \delta V_{s.resol}$		62 µV/V				**Combined Uncertainty, $u(E_x)$**	**528.8 µV**
						Effective Degrees of Freedom, v_{eff}	39864835654
						Coverage Factor, k	1.96
						Expanded Uncertainty, $U(E_x)$	**0.10 mV/V**

Table 16. Uncertainty budget for 10 V @ 100 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	10.00415 V	1.8 µV	Normal	1	1.8 µV	49
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	10.00245 V	128.7 µV	Normal	1	128.7 µV	49
$\delta V_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.0000 V	600 µV	Normal	1	600.0 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.0000 V	2501 µV	Normal	1	2500.61 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.0000 V	1000 µV	Normal	1	1000.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.0000 V	117.78 µV	Rectangular	1	117.78 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.0000 V	693 µV	Rectangular	1	692.99 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.0000 V	2.89 µV	Rectangular	1	2.89 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.0000 V	693 µV	Rectangular	1	693.11 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.0000 V	2.89 µV	Rectangular	1	2.89 µV	∞
Error (E_x) $Ex=V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} - \delta V_{s.temp} - \delta V_{s.resol}$		0.17 mV/V	**Combined Uncertainty, $u(E_x)$**				**2933.3 µV**
			Effective Degrees of Freedom, v_{eff}				5127946.353
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**0.57 mV/V**

Table 17. Uncertainty budget for 100 V @ 55 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	99.9982 V	119.1 µV	Normal	1	119.1 µV	49
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	99.9967 V	162.6 µV	Normal	1	162.6 µV	49
$\delta V_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.0000 V	2650 µV	Normal	1	2650.0 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.0000 V	4000 µV	Normal	1	3999.87 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.0000 V	1000 µV	Normal	1	1000.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.0000 V	35.91 µV	Rectangular	1	35.91 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.0000 V	866 µV	Rectangular	1	866.00 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.0000 V	28.87 µV	Rectangular	1	28.87 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.0000 V	866 µV	Rectangular	1	866.01 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.0000 V	28.87 µV	Rectangular	1	28.87 µV	∞
Error (E_x) $Ex=V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} - \delta V_{s.temp} - \delta V_{s.resol}$		15 µV/V	**Combined Uncertainty, $u(E_x)$**				**5056.1 µV**
			Effective Degrees of Freedom, v_{eff}				13786627.89
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**99 µV/V**

Table 18. Uncertainty budget for 100 V @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{ix}	Voltage indicated by DMM (UUT)	100.0018 V	19.4 µV	Normal	1	19.4 µV	49
$V_{s.corr}$	Voltage indicated by reference DMM corrected by calibration certificate	100.0016 V	46.4 µV	Normal	1	46.4 µV	49
$\delta V_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.0000 V	2650 µV	Normal	1	2650.0 µV	∞
$\delta V_{s.spec1}$	Reading (Specs) of the reference DMM	0.0000 V	3000 µV	Normal	1	3000.05 µV	∞
$\delta V_{s.spec2}$	Range (Specs) of the reference DMM	0.0000 V	1000 µV	Normal	1	1000.00 µV	∞
$\delta U_{s.drift}$	Drift Time	0.0000 V	112.9 µV	Rectangular	1	112.87 µV	∞
$\delta U_{s.temp}$	Temp of the reference DMM	0.0000 V	866 µV	Rectangular	1	866.04 µV	∞
$\delta U_{s.resol}$	The finite resolution of the reference DMM	0.0000 V	28.87 µV	Rectangular	1	28.87 µV	∞
$\delta V_{ix.temp}$	Temp of the DMM (UUT)	0.0000 V	866 µV	Rectangular	1	866.04 µV	∞
$\delta V_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.0000 V	28.87 µV	Rectangular	1	28.87 µV	∞
Error (E_x) $Ex = V_{ix} - V_{s.corr} + \delta V_{ix.temp} + \delta V_{ix.resol} - \delta V_{s.cal} - \delta V_{s.spec1} - \delta V_{s.spec2} + \delta U_{s.drift} - \delta V_{s.temp} - \delta V_{s.resol}$		2.5 µV/V	**Combined Uncertainty, $u(E_x)$**				**4305.7 µV**
			Effective Degrees of Freedom, v_{eff}				1368824915
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**84 µV/V**

6.5. AC Current

Table 19. Uncertainty budget for 10 mA @ 300 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current indicated by DMM (UUT)	10.00054 mA	0.00428 µA	Normal	1	0.00428 µA	49
$I_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	10.00028 mA	0.00762 µA	Normal	1	0.00762 µA	49
$\delta I_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.00000 mA	0.75 µA	Normal	1	0.75 µA	∞
$\delta I_{s.spec1}$	Reading (Specs) of the reference DMM	0.00000 mA	1.25 µA	Normal	1	1.25 µA	∞
$\delta I_{s.spec2}$	Range (Specs) of the reference DMM	0.00000 mA	1.00 µA	Normal	1	1.00 µA	∞
$\delta I_{s.drift}$	Drift Time	0.00000 mA	0.0693 µA	Rectangular	1	0.06928 µA	∞
$\delta I_{s.temp}$	Temp of the reference DMM	0.00000 mA	0.1732 µA	Rectangular	1	0.17321 µA	∞
$\delta I_{s.resol}$	The finite resolution of the reference DMM	0.00000 mA	0.00289 µA	Rectangular	1	0.00289 µA	∞
$\delta I_{ix.temp}$	Temp of the DMM (UUT)	0.00000 mA	0.1732 µA	Rectangular	1	0.17321 µA	∞
$\delta I_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.00000 mA	0.00289 µA	Rectangular	1	0.002887 µA	∞
Error (E_x) $Ex=I_{ix} - I_{s.corr} + \delta I_{ix.temp} + \delta I_{ix.resol} - \delta I_{s.cal} - \delta I_{s.spec1} - \delta I_{s.spec2} + \delta I_{s.drift} - \delta I_{s.temp} - \delta I_{s.resol}$		26 µA/A	**Combined Uncertainty, $u(E_x)$**				**1.79 µA**
			Effective Degrees of Freedom, v_{eff}				52299708557.82
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**0.35 mA/A**

Table 20. Uncertainty budget for 10 mA @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current indicated by DMM (UUT)	10.00068 mA	0.00246 µA	Normal	1	0.00246 µA	49
$I_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	10.00045 mA	0.01847 µA	Normal	1	0.01847 µA	49
$\delta I_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.00000 mA	0.75 µA	Normal	1	0.75 µA	∞
$\delta I_{s.spec1}$	Reading (Specs) of the reference DMM	0.00000 mA	1.25 µA	Normal	1	1.25 µA	∞
$\delta I_{s.spec2}$	Range (Specs) of the reference DMM	0.00000 mA	1.00 µA	Normal	1	1.00 µA	∞
$\delta I_{s.drift}$	Drift Time	0.00000 mA	0.0231 µA	Rectangular	1	0.02309 µA	∞
$\delta I_{s.temp}$	Temp of the reference DMM	0.00000 mA	0.1732 µA	Rectangular	1	0.17321 µA	∞
$\delta I_{s.resol}$	The finite resolution of the reference DMM	0.00000 mA	0.00289 µA	Rectangular	1	0.00289 µA	∞
$\delta I_{ix.temp}$	Temp of the DMM (UUT)	0.00000 mA	0.1732 µA	Rectangular	1	0.17322 µA	∞
$\delta I_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.00000 mA	0.00289 µA	Rectangular	1	0.002887 µA	∞
Error (E_x) $Ex=I_{ix} - I_{s.corr} + \delta I_{ix.temp} + \delta I_{ix.resol} - \delta I_{s.cal} - \delta I_{s.spec1} - \delta I_{s.spec2} + \delta I_{s.drift} - \delta I_{s.temp} - \delta I_{s.resol}$		23 µA/A	**Combined Uncertainty, $u(E_x)$**				**1.79 µA**
			Effective Degrees of Freedom, v_{eff}				1658336638.55
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**0.35 mA/A**

Table 21. Uncertainty budget for 1 A @ 300 Hz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current indicated by DMM (UUT)	0.999893 A	1.01 µA	Normal	1	1.00621 µA	49
$I_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	0.999930 A	12.51 µA	Normal	1	12.511 µA	49
$\delta I_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.000000 A	140 µA	Normal	1	140.00 µA	∞
$\delta I_{s.spec1}$	Reading (Specs) of the reference DMM	0.000000 A	300.0 µA	Normal	1	299.98 µA	∞
$\delta I_{s.spec2}$	Range (Specs) of the reference DMM	0.000000 A	100.0 µA	Normal	1	100.00 µA	∞
$\delta I_{s.drift}$	Drift Time	0.000000 A	19.8 µA	Rectangular	1	19.75115 µA	∞
$\delta I_{s.temp}$	Temp of the reference DMM	0.000000 A	17.3 µA	Rectangular	1	17.31930 µA	∞
$\delta I_{s.resol}$	The finite resolution of the reference DMM	0.000000 A	0.29 µA	Rectangular	1	0.28868 µA	∞
$\delta I_{ix.temp}$	Temp of the DMM (UUT)	0.000000 A	17.3 µA	Rectangular	1	17.31865 µA	∞
$\delta I_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.000000 A	0.29 µA	Rectangular	1	0.288675 µA	∞
Error (E_x) $Ex=I_{ix} - I_{s.corr} + \delta I_{ix.temp} + \delta I_{ix.resol} - \delta I_{s.cal} - \delta I_{s.spec1} - \delta I_{s.spec2} + \delta I_{s.drift} - \delta I_{s.temp} - \delta I_{s.resol}$		-37 µA/A	**Combined Uncertainty, $u(E_x)$**				**347.47 µA**
			Effective Degrees of Freedom, v_{eff}				11303538.86
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**0.68 mA/A**

Table 21. Uncertainty budget for 1 A @ 1 kHz

Quantity X_i		Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
I_{ix}	Current indicated by DMM (UUT)	1.000070 A	0.98 µA	Normal	1	0.98005 µA	49
$I_{s.corr.}$	Current indicated by reference DMM corrected by calibration certificate	1.000068 A	23.35 µA	Normal	1	23.346 µA	49
$\delta I_{s.cal}$	Uncertainity from the calibration certificate of the reference DMM	0.000000 A	140 µA	Normal	1	140.00 µA	∞
$\delta I_{s.spec1}$	Reading (Specs) of the reference DMM	0.000000 A	300.0 µA	Normal	1	300.02 µA	∞
$\delta I_{s.spec2}$	Range (Specs) of the reference DMM	0.000000 A	100.0 µA	Normal	1	100.00 µA	∞
$\delta I_{s.drift}$	Drift Time	0.000000 A	12.5 µA	Rectangular	1	12.46499 µA	∞
$\delta I_{s.temp}$	Temp of the reference DMM	0.000000 A	17.3 µA	Rectangular	1	17.32169 µA	∞
$\delta I_{s.resol}$	The finite resolution of the reference DMM	0.000000 A	0.29 µA	Rectangular	1	0.28868 µA	∞
$\delta I_{ix.temp}$	Temp of the DMM (UUT)	0.000000 A	17.3 µA	Rectangular	1	17.32172 µA	∞
$\delta I_{ix.resol}$	The finite resolution of UUT, DMM (6 dig)	0.000000 A	0.29 µA	Rectangular	1	0.288675 µA	∞
Error (E_x) $Ex=I_{ix} - I_{s.corr} + \delta I_{ix.temp} + \delta I_{ix.resol} - \delta I_{s.cal} - \delta I_{s.spec1} - \delta I_{s.spec2} + \delta I_{s.drift} - \delta I_{s.temp} - \delta I_{s.resol}$		1.5 µA/A	**Combined Uncertainty, $u(E_x)$**				**347.73 µA**
			Effective Degrees of Freedom, v_{eff}				935107.79
			Coverage Factor, k				1.96
			Expanded Uncertainty, $U(E_x)$				**0.68 mA/A**

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Customer:	UME/ Interlaboratory Comparison EURAMET 1341- Calibration of Digital Multimeter
Description:	Digital Multimeter
Manufacturer:	FLUKE
Type:	8508A
Serial Number:	969656608
Date of receipt:	*23/05/2016*
Period of Calibration:	24/05/2016 – 10/06/2016

Date of issue:	Measurements Performed by :	Report Approved By:
07.07.2016	*Ermira Mahmutaj*	*Agron Shurdhani*
07.07.2016	*Gentrit Rexha*	

Ambient Conditions	
Temperature [ºC] :	23,0±1
Relative Humidity [%]:	43±12

Reference Standards Used	
Reference Standard	**Serial Number**
Fluke DMM 8508A/01	967456392
Fluke Calibrator 5520A	966001
DC Resistor 10Ω	728570/BZ3
DC Resistor 100Ω	738457/BZ3
DC Resistor 1 kΩ	738395/BZ3
DC Resistor 10 kΩ	720843/BZ3

Measurements Performed

1. DC and AC Voltage:

1.1. Method Used

The method used for the calibration of DC and AC Voltage is the **substitution method.**

KMA's reference multimeter DMM Fluke 8508A/01 has been used as reference standard and multifunctional calibrator Fluke 5720A as source of DC or AC Voltage voltage. The reference multimeter is traceable to the Turkish National Institute of Metrology (UME).

The calibration of the digital multimeter which was used as transfer standard (UUT) was carried out at the points indicated by intercomparison protocol during 5 days in period from the 24th of May to the 10th of June 2016.

Twenty (20) repeated observations of DC and AC voltage were taken on each one of the 5 days for both the Reference DMM, as well as the UUT. The mean values (Eq. 1), as well as the relevant experimental standard deviations (Eq. 2), of each of the sets of the 20 measurements were calculated.

$$\overline{X}_j = \frac{\sum_{i=1}^{20} x_i}{n} \quad j\text{=1 to 5} \qquad \text{(Eq. 1)}$$

$$s_j = \sqrt{\frac{\sum_{i=1}^{n} \left(x_i - \overline{X}_j\right)^2}{n(n-1)}} \quad j\text{=1 to 5} \qquad \text{(Eq. 2)}$$

After performing a consistency F-test, in order to prove that all measurements belong in the same population, the overall mean value, as the weighted mean of all 5 sets of measurements taken on each of the 5 days, was calculated for each of the measuring points (Eq. 3), as well as the weighted standard uncertainty (Eq. 4). The reciprocal of the variance of each one of the five sets was used as weight for each day.

$$\overline{X} = \frac{\sum_{j=1}^{5} \frac{\overline{X_j}}{s_j^2}}{\sum_{j=1}^{5} \frac{1}{s_j^2}} \qquad \text{(Eq. 3)}$$

$$\sigma_{\overline{X}} = \sqrt{\frac{1}{\sum_{j=1}^{5} \frac{1}{s_j^2}}} \qquad \text{(Eq. 4)}$$

1.2. Measurement Equation

Mathematical model used for the evaluation of the error and the uncertainty of DC and AC voltage calibration :

$$E_X = V_X - V_S + \delta V_{Xres} - \delta V_S - \delta V_{Sres} + \delta V_C \qquad \text{(Eq. 5)}$$

Where:

E_X **:** The measurement error of the DMM-UUT

V_X**:** The Voltage indicated by the UUT-DMM

V_S **:**The Voltage indicated by the Ref-DMM 8508A

δV_{Xres} :The correction of the indicated voltage V_X due to the finite resolution of the DMM-UUT

δV_S **:** The correction of the indicated voltage V_S due to the 1 year specification of the Ref-DMM

δV_{Xres} **:**The correction of the indicated voltage V_S due to the finite resolution of the Ref-DMM

δV_C **:** The correction due to Short term stability of the voltage source (multifunctional calibrator's 6 h specification)

1.3. Uncertainty calculation

The uncertainty estimation has been carried out according to the principles set in GUM, taking into account all uncertainty sources that affect the measurement result. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k, which corresponds to a coverage probability of approximately 95 %.

According to the law of propagation of uncertainties $\left(u_c^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) \right)$ and Eq. 4, the uncertainty of the error ***Ex*** will given by the following formula:

$$u_c^2(E_x) = u^2(V_x) - u^2(V_S) + u^2(\delta V_{xres}) - u^2(\delta V_S) - u^2(\delta V_{Sres}) + u^2(\delta V_C) \quad \text{(Eq.6)}$$

Where:

u(V_x) is the weighted standard uncertainty of the weighted mean of the measurements taken by the UUT DMM (Normal distribution, 1σ, type A)

u(V_S) is the weighted standard uncertainty of the weighted mean of the measurements taken by the Ref. DMM (Normal distribution, 1σ, type A)

u(V_{xres}) is the standard uncertainty due to the finite resolution of the UUT DMM (Rectangular distribution, 1σ, type B)

u(δV_S) is the standard uncertainty of the correction to the indication of the Ref. DMM. The correction is taken as zero and the st. uncert. is taken from the 1 year specifications of the Ref. DMM (Normal distribution, 1σ, type B)

u(V_{Sres}) is the standard uncertainty due to the finite resolution of the Ref. DMM (Rectangular distribution, 1σ, type B)

u(V_C) is the standard uncertainty due to the finite stability of the Voltage source (calibrator). The 6h stability is taken into account. (Rectangular distribution, 1σ, type B)

The uncertainty budgets for DC and AC Voltage are presented in tables 1 and 2.

2. Resistance

2.1. Method Used

The method used for the calibration of Resistance is the **substitution** one.

KMA's reference multimeter DMM Fluke 8508A/01 has been used as reference standard and two resistors of nominal value 10 Ω and 10 kΩ as source of Resistance. The reference multimeter is traceable to the Turkish National Institute of Metrology (UME). The standard resistors are periodically calibrated internally, by using the Reference DMM. Their traceability is also to UME.

The calibration of the digital multimeter which was used as transfer standard (UUT) was carried out at the points indicated by intercomparison protocol during 5 days in period from the 24th of May to the 10th of June 2016.

Twenty (20) repeated observations of Resistance were taken on each one of the 5 days for both the Reference DMM, as well as the UUT. The mean values (Eq. 1), as well as the relevant experimental standard deviations (Eq. 2), of each of the sets of the 20 measurements were calculated.

Finally, the weighted mean and its standard uncertainty were calculated according to the equations 3 and 4.

2.2. Measurement Equation

Mathematical model used for the evaluation of the error and the uncertainty of Resistance calibration :

$$E_X = R_X - R_S + \delta R_{Xres} - \delta R_S - \delta R_{Sres} + \delta R_{Dr} + \delta R_T \qquad \text{(Eq. 7)}$$

Where:
E_X **:** The measurement error of the DMM-UUT

R_X**:** The Resistance indicated by the UUT-DMM

R_S **:**The Resistance indicated by the Ref-DMM 8508A

δR_{Xres} :The correction of the indicated resistance R_X due to the finite resolution of the DMM-UUT

δR_S **:** The correction of the indicated resistance R_S due to the 1 year specification of the Ref-DMM

δR_{Xres} **:**The correction of the indicated resistance R_S due to the finite resolution of the Ref-DMM

δR_{Dr} **:** The correction due to the drift of the value of the standard resistor (6 h)

δR_T **:** The correction due to the influence of the temperature variation on the standard resistor's value (multifunctional calibrator's 6 h specification)

2.3. Uncertainty calculation

The uncertainty estimation has been carried out according to the principles set in GUM, taking into account all uncertainty sources that affect the measurement result. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k, which corresponds to a coverage probability of approximately 95 %.

According to the law of propagation of uncertainties $\left(u_c^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) \right)$ and Eq. 7, the uncertainty of the error Ex will given by the following formula:

$$u_c^2(E_x) = u^2(R_x) - u^2(R_S) + u^2(\delta R_{xres}) - u^2(\delta R_S) - u^2(\delta R_{Sres}) + u^2(\delta R_{Dr}) + u^2(\delta R_T) \qquad \text{(Eq.8)}$$

Where:

$u(R_x)$ is the weighted standard uncertainty of the weighted mean of the measurements taken by the UUT DMM (Normal distribution, 1σ, type A)

$u(R_S)$ is the weighted standard uncertainty of the weighted mean of the measurements taken by the Ref. DMM (Normal distribution, 1σ, type A)

$u(R_{xres})$ is the standard uncertainty due to the finite resolution of the UUT DMM (Rectangular distribution, 1σ, type B)

$u(\delta R_S)$ is the standard uncertainty of the correction to the indication of the Ref. DMM. The correction is taken as zero and the st. uncert. is taken from the 1 year specifications of the Ref. DMM (Normal distribution, 1σ, type B)

$u(R_{Sres})$ is the standard uncertainty due to the finite resolution of the Ref. DMM (Rectangular distribution, 1σ, type B)

$u(R_{Dr})$ is the standard uncertainty due to the drift of the value of the standard resistor (calibrator). The 6h stability is taken into account. (Rectangular distribution, 1σ, type B)

$u(R_T)$ is the standard uncertainty due to the influence of the temperature variation on the value of the standard resistor. The temperature coefficient is 4 ppm/°C. (Rectangular distribution, 1σ, type B)

The uncertainty budgets for the Resistance are presented in tables 3 .

3. DC Current

3.1. Method Used

The method used for the calibration of Resistance is the **indirect method using Ohm's law**.

The Calibrator Fluke 5520A was used as the source of DC voltage and was connected in series to the standard resistor and the UUT DMM, which was used in its DC current function. The DC voltage drop on the standard resistor was measured by the Reference DMM, which was used in its DC voltage function. The reference multimeter is traceable to the Turkish National Institute of Metrology (UME). The standard resistors are periodically calibrated internally, by using the Reference DMM. Their traceability is also to UME.

The calibration of the digital multimeter which was used as transfer standard (UUT) was carried out at the points of 100 μA and 10 mA, as it was not possible to perform measurements at 1 A. The measurements were performed during 5 days in period from the 24th of May to the 10th of June 2016.

Twenty (20) repeated observations of DC Current (UUT DMM) and DC Current (Ref. DMM) were taken on each one of the 5 days. The mean values (Eq. 1), as well as the relevant experimental standard deviations (Eq. 2), of each of the sets of the 20 measurements were calculated.

Finally, the weighted mean and its standard uncertainty were calculated according to the equations 3 and 4.

3.2. Measurement Equation

Mathematical model used for the evaluation of the error and the uncertainty of DC Current calibration :

$$E_X = I_X + \delta I_X - \frac{V_{DVM} + \delta V_{DVM} + \delta V_{DVMres} + \delta V_{DVMload}}{R_S + \delta R_D + \delta R_T + \delta R_P}$$

(Eq.9)

I_X: The current indicated by the UUT-DMM

δI_X :The correction of indicated current due to finite resolution of the UUT-DMM

V_{DVM} : The voltage indicated by the reference DMM

δV_{DVM} : The correction of indicated voltage due to specification (1 year absolute specification)

δV_{DVMres} : The correction due to finite resolution of the reference DMM

$\delta V_{DVMload}$: The correction of voltage due to finite input impedance of the reference DMM

R_S -: The resistance value of the standard resistors stated in the calibration certificate

δR_D : The correction due to drift of standard resistors since their last calibration

δR_P : The correction of the resistance value of the standard resistors due to power dissipation

δR_T : The correction of resistance of the standard resistor due to the temperature variation

3.3. Uncertainty calculation

The uncertainty estimation has been carried out according to the principles set in GUM, taking into account all uncertainty sources that affect the measurement result. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor k, which corresponds to a coverage probability of approximately 95 %.

According to the law of propagation of uncertainties $\left(u_c^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) \right)$ and Eq. 9, the uncertainty of the error Ex will given by the following formula:

$$u_c^2(E_x) = u^2(I_x) + u^2(\delta I_x) + \left(-\frac{1}{R_S} \right)^2 \left[u^2(V_{DVM}) + u^2(\delta V_{DVM}) + u^2(\delta V_{DVMres}) + u^2(\delta V_{DVMload}) \right] + \left(\frac{V_{DVM}}{R_S^2} \right)^2 \left[u^2(R_S) + u^2(\delta R_D) + u^2(\delta R_T) + u^2(\delta R_P) \right]$$

(Eq.10)

Where:

$u(I_x)$ is the weighted standard uncertainty of the weighted mean of the measurements taken by the UUT DMM (Normal distribution, 1σ, type A)

$u(\delta I_x)$ is the standard uncertainty due to the finite resolution of the UUT DMM (Rectangular distribution, 1σ, type B)

$u(V_{DVM})$ is the weighted standard uncertainty of the weighted mean of the measurements taken by the UUT DMM (Normal distribution, 1σ, type A)

$u(\delta V_{DVM})$ is the standard uncertainty correction of indicated voltage of the voltage measurements taken by the reference DMM due to its specification (Normal distribution, 1σ, type B)

$u(\delta V_{DVMres})$ is the standard uncertainty due to the finite resolution of the reference DMM (Rectangular distribution, 1σ, type B)

$u(\delta V_{DVMload})$ is the standard uncertainty due to the correction of voltage due to finite input impedance of the reference DMM (Rectangular distribution, 1σ, type B)

$u(R_S)$ is the standard uncertainty of the calibrated value of the standard resistor (Normal distribution, 1σ, type B)

$u(R_D)$ is the standard uncertainty due to the drift of the value of the standard resistor (calibrator). The 6h stability is taken into account. (Rectangular distribution, 1σ, type B)

$u(R_T)$ is the standard uncertainty due to the influence of the temperature variation on the value of the standard resistor. The temperature coefficient is 4 ppm/°C. (Rectangular distribution, 1σ, type B)

$u(R_P)$ is the standard uncertainty due to the influence of the power dissipation on the standard resistor. The power coefficient is 0.2 ppm/mW. (Rectangular distribution, 1σ, type B)

The uncertainty budgets for the Resistance are presented in tables 4 .

4. AC Current

Unfortunately, the AC current could not be calibrated due to a malfunction of the calibrator.

5. Effective Degrees of Freedom

All effective degrees of freedom were calculated using the Welch-Satterthwaite formula:

$$\nu_{eff} = \frac{u_c^4(y)}{\sum_{i=1}^{N} \frac{u_i^4(y)}{\nu_i}}$$

Measurements Results

1. DC Voltage

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A[2]	Uncertainty
200 mV	100 mV	100.013 68 mV	100.013 46 mV	-0.000 22 mV	0.000 61 mV
20 V	10 V	10.000 027 V	10.000 035 V	0.000 008 V	0.000 039 V
200 V	100 V	100.000 10 V	99.999 62 V	-0.000 48 V	0.000 59 V
1000 V	1000 V	999.994 6 V	999.988 5 V	-0.006 1 V	0.006 0 V

2. AC Voltage

Range of 8508A	Nominal Value		Applied Value	Reading of 8508A	Error of 8508A[2]	Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99.998 56 mV	100.001 19 mV	0.002 63 mV	0.015 52 mV
	100 mV	1 kHz	99.999 57 mV	100.002 48 mV	0.002 91 mV	0.013 04 mV
20 V	10 V	55 Hz	9.999 181 V	10.000 292 V	0.001 110 V	0.001 1 V
	10 V	1 kHz	9.999 259 V	10.000 311 V	0.001 051 V	0.000 95 V
	10 V	100 kHz	9.997 582 V	9.997 642 V	0.000 060 V	0.007 7 V
200 V	100 V	55 Hz	99.990 5 V	99.995 0 V	0.004 5 V	0.011 V
	100 V	1 kHz	99.988 9 V	99.993 1 V	0.004 2 V	0.009 5 V

3. *Resistance*

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A[2]	Uncertainty
20 Ω	TrueΩ	100 Ω	10.000 320 Ω	10.000 214 Ω	-0.000 106 Ω	0.000 112 Ω
20 kΩ	TrueΩ	10 kΩ	10.000 153 kΩ	10.000 169 kΩ	0.000 016 kΩ	0.000 089 kΩ
	TrueΩ LoI	100 kΩ	10.000 190 kΩ	10.000 275 kΩ	0.000 085 kΩ	0.000 097 kΩ

4. *DC Current*

Range of 8508A	Nominal Value	Current	Reading of 8508A	Error of 8508A[2]	Uncertainty
100 µA	100 µA	99.991 50 µA	99.991 09 µA	-0.000 408 µA	1.33 nA
10 mA	10 mA	10.000 117 mA	10.000 242 mA	0.000 125 mA	0.12 µA

1 DC Voltage

100 mV

Quantity X_i		Estimate Xi	Standard Uncertainty $u(X_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom (DoF) v_i
V_S	DC Voltage indicated by Ref DMM	100.013 68 mV	0.09 µV/V	Normal	-1	0.09 µV/V	99
δV_{Sres}	Resolution of Ref DMM	0 mV	0.03 µV/V	Rectangular	-1	0.03 µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0 mV	3.00 µV/V	Normal	-1	3.00 µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	100.013 46 mV	0.08 µV/V	Normal	1	0.08 µV/V	99
δV_{Xres}	Resolution of UUT DMM	0 mV	0.03 µV/V	Rectangular	1	0.03 µV/V	inf.
δV_C	Short Term stability of Calibrator	0 mV	0.46 µV/V	Rectangular	-1	0.46 µV/V	inf.
Error (E_X) $E_X=(V_X-V_S+\delta V_X-\delta V_S)$		-0.000 22 mV	**Combined Uncertainty, $u(E_X)$**				3.04 µV/V
			Effective Degrees of Freedom, v_{eff}				7.91E+07
		-2.2 µV/V	**Coverage Factor, k**				2
			Expanded Uncertainty, $U(E_X)$				6.08 µV/V

10 V

Quantity X_i		Estimate Xi		Standard Uncertainty $u(X_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) v_i
V_S	DC Voltage indicated by Ref DMM	10.000 027	V	0.04	µV/V	Normal	-1	0.04	µV/V	99
δV_{Sres}	Resolution of Ref DMM	0	V	0.03	µV/V	Rectangular	-1	0.03	µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0	V	1.95	µV/V	Normal	-1	1.95	µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	10.000 035	V	0.03	µV/V	Normal	1	0.03	µV/V	99
δV_{Xres}	Resolution of UUT DMM	0	V	0.03	µV/V	Rectangular	1	0.03	µV/V	inf.
δV_C	Short Term stability of Calibrator	0	V	0.13	µV/V	Rectangular	-1	0.13	µV/V	inf.
Error (E_X)		0.000 008	V	**Combined Uncertainty, $u(E_X)$**						1.96 µV/V
$E_X=(V_X-V_S+\delta V_X-\delta V_S)$				**Effective Degrees of Freedom, v_{eff}**						4.30E+08
		0.8	**µV/V**	**Coverage Factor, k**						2
				Expanded Uncertainty, $U(E_X)$						3.91 µV/V

100 V

Quantity X_i		Estimate X_i		Standard Uncertainty $u(x_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) v_i
V_S	DC Voltage indicated by Ref DMM	100.000 10	V	0.04	µV/V	Normal	-1	0.04	µV/V	99
δV_{Sres}	Resolution of Ref DMM	0	V	0.03	µV/V	Rectangular	-1	0.03	µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0	V	2.95	µV/V	Normal	-1	2.95	µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	99.999 62	V	0.04	µV/V	Normal	1	0.04	µV/V	99
δV_{Xres}	Resolution of UUT DMM	0	V	0.03	µV/V	Rectangular	1	0.03	µV/V	inf.
δV_C	Short Term stability of Calibrator	0	V	0.13	µV/V	Rectangular	-1	0.13	µV/V	inf.
Error (E_X) $E_X=(V_X-V_S+\delta V_X-\delta V_S)$		-0.000 48	V	**Combined Uncertainty, $u(E_X)$**						2.95 µV/V
				Effective Degrees of Freedom, v_{eff}						1.47E+09
		-4.8	**µV/V**	**Coverage Factor, k**						2
				Expanded Uncertainty, $U(E_X)$						5.91 µV/V

1000 V

Quantity X_i		Estimate X_i		Standard Uncertainty $u(x_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) v_i
V_S	DC Voltage indicated by Ref DMM	999.994 6	V	0.05	µV/V	Normal	-1	0.05	µV/V	99
δV_{Sres}	Resolution of Ref DMM	0	V	0.03	µV/V	Rectangular	-1	0.03	µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0	V	3.00	µV/V	Normal	-1	3.00	µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	999.988 5	V	0.01	µV/V	Normal	1	0.01	µV/V	99
δV_{Xres}	Resolution of UUT DMM	0	V	0.03	µV/V	Rectangular	1	0.03	µV/V	inf.
δV_C	Short Term stability of Calibrator	0	V	0.12	µV/V	Rectangular	-1	0.12	µV/V	inf.
Error (E_X)		-0.006 1	V	**Combined Uncertainty, u(E_X)**						3.00 µV/V
$E_X=(V_X-V_S+\delta V_X-\delta V_S)$				**Effective Degrees of Freedom, v_{eff}**						1.29E+09
		-6.1	**µV/V**	**Coverage Factor, k**						2
				Expanded Uncertainty, U(E_X)						6.01 µV/V

100mV 55Hz

	Quantity X_i	Estimate X_i		Standard Uncertainty $u(x_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) ν_i
V_S	DC Voltage indicated by Ref DMM	99.998 56	mV	2.89	µV/V	Normal	-1	2.89	µV/V	99
δV_{Sres}	Resolution of Ref DMM	0	mV	0.03	µV/V	Rectangular	-1	0.03	µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0	mV	77.50	µV/V	Normal	-1	77.50	µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	100.001 19	mV	2.44	µV/V	Normal	1	2.44	µV/V	99
δV_{Xres}	Resolution of UUT DMM	0	mV	0.03	µV/V	Rectangular	1	0.03	µV/V	inf.
δV_{Dr}	Correction due to drift of ACV DMM	0	mV	0.00	µV/V	Rectangular	-1	0.00	µV/V	inf.
Error (E_X) $E_X=V_X-V_S+\delta V_X-\delta V_S$		0.002 63	mV	**Combined Uncertainty, $u(E_X)$**						77.59 µV/V
				Effective Degrees of Freedom, ν_{eff}						3.41E+07
		26.3	**µV/V**	**Coverage Factor, k**						2
				Expanded Uncertainty, $U(E_X)$						155.18 µV/V

100mV 1kHz

Quantity X_i		Estimate X_i		Standard Uncertainty $u(x_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) v_i
V_S	DC Voltage indicated by Ref DMM	99.999 57	mV	3.74	µV/V	Normal	-1	3.74	µV/V	99
δV_{Sres}	Resolution of Ref DMM	0	mV	0.10	µV/V	Rectangular	-1	0.10	µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0	mV	65.00	µV/V	Normal	-1	65.00	µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	100.002 48	mV	3.76	µV/V	Normal	1	3.76	µV/V	99
δV_{Xres}	Resolution of UUT DMM	0	mV	0.03	µV/V	Rectangular	1	0.03	µV/V	inf.
δV_{Dr}	Correction due to drift of ACV DMM	0	mV	0.16	µV/V	Rectangular	-1	0.16	µV/V	inf.
Error (E_X) $E_X=V_X-V_S+\delta V_X-\delta V_S$		0.002 91	mV	**Combined Uncertainty, u(E_X)**						65.22 µV/V
				Effective Degrees of Freedom, v_{eff}						4.53E+06
		29.1	**µV/V**	**Coverage Factor, k**						2
				Expanded Uncertainty, U(E_X)						130.43 µV/V

10V 55Hz

Quantity X_i		Estimate X_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) ν_i
V_S	DC Voltage indicated by Ref DMM	9.999 181 V	1.74 µV/V	Normal	-1	1.74 µV/V	99
δV_{Sres}	Resolution of Ref DMM	0 V	1.00 µV/V	Rectangular	-1	1.00 µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0 V	55.00 µV/V	Normal	-1	55.00 µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	10.000 292 V	2.06 µV/V	Normal	1	2.06 µV/V	99
δV_{Xres}	Resolution of UUT DMM	0 V	0.29 µV/V	Rectangular	1	0.29 µV/V	inf.
δV_{Dr}	Correction due to drift of ACV DMM	0 V	0.93 µV/V	Rectangular	-1	0.93 µV/V	inf.
Error (E_x) $E_X=V_X-V_S+\delta V_X-\delta V_S$		0.001 11 V	Combined Uncertainty, $u(E_x)$				55.08 µV/V
			Effective Degrees of Freedom, ν_{eff}				3.35E+07
		111.1 µV/V	Coverage Factor, k				2
			Expanded Uncertainty, $U(E_x)$				110.17 µV/V

10V 1kHz

Quantity X_i		Estimate X_i		Standard Uncertainty $u(x_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) ν_i
V_S	DC Voltage indicated by Ref DMM	9.999 259	V	1.48	µV/V	Normal	-1	1.48	µV/V	99
δV_{Sres}	Resolution of Ref DMM	0	V	1.00	µV/V	Rectangular	-1	1.00	µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0	V	47.50	µV/V	Normal	-1	47.50	µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	10.000 311	V	1.47	µV/V	Normal	1	1.47	µV/V	99
δV_{Xres}	Resolution of UUT DMM	0	V	0.29	µV/V	Rectangular	1	0.29	µV/V	inf.
δV_{Dr}	Correction due to drift of ACV DMM	0	V	0.93	µV/V	Rectangular	-1	0.93	µV/V	inf.
Error (E_X) $E_X = V_X - V_S + \delta V_X - \delta V_S$		0.001 05	V				**Combined Uncertainty, u(E_X)**			47.57 µV/V
							Effective Degrees of Freedom, ν_{eff}			5.35E+07
		105.2	**µV/V**				**Coverage Factor, k**			2
							Expanded Uncertainty, U(E_X)			95.13 µV/V

10V 100kHz

Quantity X_i		Estimate X_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom (DoF) ν_i
V_S	DC Voltage indicated by Ref DMM	9.997 582 V	3.36 µV/V	Normal	-1	3.36 µV/V	99
δV_{Sres}	Resolution of Ref DMM	0 V	1.00 µV/V	Rectangular	-1	1.00 µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0 V	385.09 µV/V	Normal	-1	385.09 µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	9.997 642 V	2.77 µV/V	Normal	1	2.77 µV/V	99
δV_{Xres}	Resolution of UUT DMM	0 V	0.29 µV/V	Rectangular	1	0.29 µV/V	inf.
δV_{Dr}	Correction due to drift of ACV DMM	0 V	5.56 µV/V	Rectangular	-1	5.56 µV/V	inf.
Error (E_X)		0.000 06 V				Combined Uncertainty, $u(E_X)$	385.16 µV/V
						Effective Degrees of Freedom, ν_{eff}	1.17E+10
$E_X=V_X-V_S+\delta V_X-\delta V_S$		**6.0 µV/V**				Coverage Factor, k	2
						Expanded Uncertainty, $U(E_X)$	770.31 µV/V

100V 55Hz

Quantity X_i		Estimate Xi	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom (DoF) v_i
V_S	DC Voltage indicated by Ref DMM	99.990 514 V	2.07 µV/V	Normal	-1	2.07 µV/V	99
δV_{Sres}	Resolution of Ref DMM	0 V	1.00 µV/V	Rectangular	-1	1.00 µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0 V	55.01 µV/V	Normal	-1	55.01 µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	99.995 022 V	1.79 µV/V	Normal	1	1.79 µV/V	99
δV_{Xres}	Resolution of UUT DMM	0 V	0.29 µV/V	Rectangular	1	0.29 µV/V	inf.
δV_{Dr}	Correction due to drift of ACV DMM	0 V	1.48 µV/V	Rectangular	-1	1.48 µV/V	inf.
Error (E_X) $E_X=V_X-V_S+\delta V_X-\delta V_S$		0.004 51 V	**Combined Uncertainty, $u(E_X)$**				55.11 µV/V
			Effective Degrees of Freedom, v_{eff}				3.19E+07
		45.1 µV/V	**Coverage Factor, k**				2
			Expanded Uncertainty, $U(E_X)$				110.22 µV/V

100V 1kHz

Quantity X_i		Estimate X_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom (DoF) v_i
V_S	DC Voltage indicated by Ref DMM	99.990 514 V	1.73 µV/V	Normal	-1	1.73 µV/V	99
δV_{Sres}	Resolution of Ref DMM	0 V	1.00 µV/V	Rectangular	-1	1.00 µV/V	inf.
δV_S	Absolute (1 year) specification of Ref DMM	0 V	47.50 µV/V	Normal	-1	47.50 µV/V	inf.
V_X	DC Voltage indicated by UUT DMM	99.993 086 V	1.65 µV/V	Normal	1	1.65 µV/V	99
δV_{Xres}	Resolution of UUT DMM	0 V	0.29 µV/V	Rectangular	1	0.29 µV/V	inf.
δV_{Dr}	Correction due to drift of ACV DMM	0 V	1.48 µV/V	Rectangular	-1	1.48 µV/V	inf.
Error (E_X) $E_X=V_X-V_S+\delta V_X-\delta V_S$		0.002 57 V	**Combined Uncertainty, $u(E_X)$**				47.59 µV/V
			Effective Degrees of Freedom, v_{eff}				1.68E+05
		25.7 µV/V	**Coverage Factor, k**				2
			Expanded Uncertainty, $U(E_X)$				95.19 µV/V

10 Ω

Quantity X_i		Estimate X_i		Standard Uncertainty $u(X_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) v_i
R_S	Resistance indicated by Ref DMM	10.000 320	Ω	0.09	μΩ/Ω	Normal	-1	0.09	μΩ/Ω	99
δR_{Sres}	Resolution of Ref DMM	0	Ω	0.03	μΩ/Ω	Rectangular	-1	0.03	μΩ/Ω	inf.
δR_S	Absolute (1 year) specification of Ref DMM	0	Ω	5.45	μΩ/Ω	Normal	-1	5.45	μΩ/Ω	inf.
R_X	Resitance indicated by UUT DMM	10.000 214	Ω	0.12	μΩ/Ω	Normal	1	0.12	μΩ/Ω	99
δR_{Xres}	Resolution of UUT DMM	0	Ω	0.03	μΩ/Ω	Rectangular	1	0.03	μΩ/Ω	inf.
δR_{Dr}	Correction due to drift of standard resistor	0	Ω	0.29	μΩ/Ω	Rectangular	1	0.29	μΩ/Ω	inf.
δR_T	Correction due to temperature change of resistance	0	Ω	1.15	μΩ/Ω	Rectangular	-1	1.15	μΩ/Ω	inf.
Error (E_X)		-0.000 106	Ω	**Combined Uncertainty, $u(E_X)$**						5.58 μΩ/Ω
$E_X=R_X-R_S+\delta R_{Xres}-\delta R_S-\delta R_{Sres}+\delta R_{Dr}+\delta R_{RT}$				**Effective Degrees of Freedom, v_{eff}**						3.51E+08
		-10.60	**μΩ/Ω**	**Coverage Factor, k**						2
				Expanded Uncertainty, $U(E_X)$						11.16 μΩ/Ω

10 000 Ω

Quantity X_i		Estimate Xi		Standard Uncertainty $u(X_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) v_i
R_S	Resistance indicated by Ref DMM	10 000.153 459	Ω	0.32	µΩ/Ω	Normal	-1	0.32	µΩ/Ω	99
δR_{Sres}	Resolution of Ref DMM	0	Ω	0.03	µΩ/Ω	Rectangular	-1	0.03	µΩ/Ω	inf.
δR_S	Absolute (1 year) specification of Ref DMM	0	Ω	4.25	µΩ/Ω	Normal	-1	4.25	µΩ/Ω	inf.
R_X	Resitance indicated by UUT DMM	10 000.169 045	Ω	0.22	µΩ/Ω	Normal	1	0.22	µΩ/Ω	99
δR_{Xres}	Resolution of UUT DMM	0	Ω	0.03	µΩ/Ω	Rectangular	1	0.03	µΩ/Ω	inf.
δR_{Dr}	Correction due to drift of standard resistor	0	Ω	0.29	µΩ/Ω	Rectangular	1	0.29	µΩ/Ω	inf.
δR_T	Correction due to temperature change of resistance	0	Ω	1.15	µΩ/Ω	Rectangular	-1	1.15	µΩ/Ω	inf.
Error (E_X)		0.015 585	Ω	**Combined Uncertainty, $u(E_X)$**						4.43 µΩ/Ω
				Effective Degrees of Freedom, v_{eff}						2.97E+06
$E_X = R_X - R_S + \delta R_{Xres} - \delta R_S - \delta R_{Sres} + \delta R_{Dr} + \delta RRT$		**1.56**	**µΩ/Ω**	**Coverage Factor, k**						2
				Expanded Uncertainty, $U(E_X)$						8.86 µΩ/Ω

10 000 Ω (LoI)

Quantity X_i		Estimate Xi		Standard Uncertainty $u(X_i)$		Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$		Degrees of Freedom (DoF) v_i
R_S	Resistance indicated by Ref DMM	10 000.190 090	Ω	0.33	μΩ/Ω	Normal	-1	0.33	μΩ/Ω	99
δR_{Sres}	Resolution of Ref DMM	0	Ω	0.03	μΩ/Ω	Rectangular	-1	0.03	μΩ/Ω	inf.
δR_S	Absolute (1 year) specification of Ref DMM	0	Ω	4.70	μΩ/Ω	Normal	-1	4.70	μΩ/Ω	inf.
R_X	Resitance indicated by UUT DMM	10 000.274 747	Ω	0.34	μΩ/Ω	Normal	1	0.34	μΩ/Ω	99
δR_{Xres}	Resolution of UUT DMM	0	Ω	0.03	μΩ/Ω	Rectangular	1	0.03	μΩ/Ω	inf.
δR_{Dr}	Correction due to drift of standard resistor	0	Ω	0.29	μΩ/Ω	Rectangular	1	0.29	μΩ/Ω	inf.
δR_T	Correction due to temperature change of resistance	0	Ω	1.15	μΩ/Ω	Rectangular	-1	1.15	μΩ/Ω	inf.
Error (E_x)		0.084 658	Ω	**Combined Uncertainty, $u(E_x)$**						4.87 μΩ/Ω
				Effective Degrees of Freedom, v_{eff}						2.21E+06
$E_X = R_X - R_S + \delta R_{Xres} - \delta R_S - \delta R_{Sres} + \delta R_{Dr} + \delta R_T$		**8.47**	**μΩ/Ω**	**Coverage Factor, k**						2
				Expanded Uncertainty, $U(E_x)$						9.74 μΩ/Ω

100 µA

Quantity X_i		Estimate x_i	Standart Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
V_{DVM}	Voltage indicated by Ref DMM	99.996 29 mV	0.000 020 mV	Normal	-1.00 $k\Omega^{-1}$	-0.020 nA	99
V_{DVMres}	Correction for the indicated voltage due to the finite resolution of Ref DMM	0 mV	0.000 003 mV	Rectangular	-1.00 $k\Omega^{-1}$	-0.003 nA	inf.
δV_{DVM}	Voltage correction of the Ref DMM	0 mV	0.000 300 mV	Normal	-1.00 $k\Omega^{-1}$	-0.300 nA	inf.
$\delta V_{DVMload}$	Correction due to loading voltage	0 mV	0.000 006 mV	Rectangular	-1.00 $k\Omega^{-1}$	0.006 nA	inf.
R_S	Resistance standard	1.000 048 kΩ	0.000 004 kΩ	Normal	-99.99 $mV.k\Omega^{-2}$	-0.425 nA	inf.
δR_D	Correction due to drift of standard resistor	0 kΩ	0.000 001 kΩ	Rectangular	-99.99 $mV.k\Omega^{-2}$	-0.100 nA	inf.
δR_T	Correction due to temperature change of resistance	0 kΩ	0.000 004 kΩ	Rectangular	-99.99 $mV.k\Omega^{-2}$	-0.400 nA	inf.
δR_P	Correction due to power coefficient of the resistance	0 kΩ	0.000 000 kΩ	Rectangular	-99.99 $mV.k\Omega^{-2}$	0.000 nA	inf.
I_X	Current indicated by UUT DMM	99.991 09 µA	0.000 019 µA	Normal	1 µA	0.019 nA	99
δI_X	Correction of the indicated current due to the finite resolution of the UUT DMM	0 µA	0.000 003 µA	Rectangular	1 µA	0.003 nA	inf.
Error (E_x)		-0.000 41 µA				**Combined Uncertainty, $u(E_x)$**	0.66 nA
$E_X = I_X + \delta I_X - \frac{V_{DVM} + \delta V_{DVMres} + \delta V_{DVM}}{R_S + \delta R_D + \delta R_T + \delta R_P}$		-4.1 µA/A				**Effective Degrees of Freedom, v_{eff}**	6.60E+07
						Coverage Factor, k	2
						Expanded Uncertainty, $U(E_x)$	1.33 nA
							13.3 µA/A

10 mA

Quantity X_i		Estimate X_i		Standart Uncertainty $u(X_i)$		Probability Distribution	Sensitivity Coefficient c_i		Uncertainty Contribution $u_i(E_X)$		Degrees of Freedom (DoF) v_i
V_{DVM}	Voltage indicated by Ref DMM	1.000 013 8	V	0.26	µV	Normal	-0.01	Ω^{-1}	-0.003	µA	99
V_{DVMres}	Correction for the indicated voltage due to the finite resolution of Ref DMM	0	V	0.03	µV	Rectangular	-0.01	Ω^{-1}	0.000	µA	inf.
δV_{DVM}	Voltage correction of the Ref DMM	0	V	1.95	µV	Normal	-0.01	Ω^{-1}	-0.020	µA	inf.
$\delta V_{DVMload}$	Correction due to loading voltage	0	mV	0.01	µV	Rectangular	-0.01	Ω^{-1}	0.000	µA	inf.
R_S	Resistance standard	100.000 217	Ω	0.43	mΩ	Normal	-0.1	$mV.\Omega^{-2}$	-0.043	µA	inf.
δR_D	Correction due to drift of standard resistor	0	Ω	0.10	mΩ	Rectangular	-0.1	$mV.\Omega^{-2}$	-0.010	µA	inf.
δR_T	Correction due to temperature change of resistance	0	Ω	0.40	mΩ	Rectangular	-0.1	$mV.\Omega^{-2}$	-0.040	µA	inf.
δR_P	Correction due to power coefficient of the resistance	0	Ω	0.00	mΩ	Rectangular	-0.1	$mV.\Omega^{-2}$	0.000	µA	inf.
I_X	Current indicated by UUT DMM	10.000 24	mA	0.002 36	µA	Normal	1		0.002	µA	99
δI_X	Correction of the indicated current due to the finite resolution of the UUT DMM	0	mA	0.000 29	µA	Rectangular	1		0.000	µA	inf.
Error (E_X)		0.000 12	mA	**Combined Uncertainty, u(E_X)**							0.06 µA
$E_X = I_X + \delta I_X - \frac{V_{DVM} + \delta V_{DVMres} + \delta V_{DVM}}{R_S + \delta R_D + \delta R_T + \delta R_P}$		1.25	µA/A	**Effective Degrees of Freedom, v_{eff}**							2.03E+07
				Coverage Factor, k							2
				Expanded Uncertainty, U(E_X)							0.12 µA 12 µA/A

NSAI National Metrology Laboratory

EURAMET Project N0. 1341

Comparison on Calibration of Multimeter

Results of NSAI-NML (Ireland)

Mean Date of Measurements: 29 Jun 2016

Report Date: 05 Aug 2016

Report by: Oliver Power

Approved by: Paul Hetherington

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Introduction

This report presents the results of the participation of the NSAI National Metrology Laboratory, which is the national metrology institute for Ireland, in EURAMET project 1341 (Comparison of Calibration of Multimeter).

A short description of the measurement methods used is given, and the metrological traceability of the of the measurement results is described. The results are presented in the format specified in the technical protocol. Detailed uncertainty budgets for the measurement results are given.

Measurement Timetable

Receipt of travelling standard:	20 Jun 2016
Start of Measurements:	23 Jun 2016
End of Measurements:	01 Jul 2016
Return of travelling standard to pilot laboratory:	08 Jul 2016
Mean Date of Measurements:	29 Jun 2016

Ambient Conditions during the measurements

The ambient temperature and relative humidity were monitored throughout the measurement period and were maintained within the following limits:

Temperature:	(22 ± 1) °C
Relative Humidity:	(45 ± 10) %rh

Measurement Standards

Fluke 732A DC Reference Standard, No. 0189

Measurements International 8000A Automated Potentiometer, No. 0120

Fluke 752A Reference Divider, No. 0190

Tinsley 1695 1 Ω Standard Resistor, No. 0297

Tinsley 5685A 10 Ω Standard Resistor, No. 0597

Tinsley 5685A 100 Ω Standard Resistor, No. 0598

Tinsley 5685A 10 kΩ Standard Resistor, No. 0356

ESI SR104 10 kΩ Standard Resistor, No. 0355

Guildline 9334 1 MΩ Standard Resistor, No. 0541

Fluke 5790A AC Measurement Standard, No. 0165

SIQ 10 mA AC Current Shunt, No. 0 960

JV 3A AC Current Shunt, No. 0771

Fluke 8508A Multimeter, No. 0645

Measurement Traceability

Parameter	Source of Traceability	Note
DC Voltage	BIPM	BIPM.EM-K11b
DC Voltage Ratio	METAS	METAS Certificate 212-03992
Resistance	BIPM	BIPM.EM-K13a,b
Resistance Ratio	METAS	METAS Certificate 212-05729
AC Voltage	METAS	METAS Certificate 212-05345
AC Current	JV, SIQ	JV Certificate 08/491-1, SIQ Certificate 15C00095

Measuring Methods

Brief descriptions of the measuring methods are given below. The multimeter settings were set as per the instructions given in the technical protocol and the settling times set out in the protocol were used. Several repeat measurements were performed for each parameter during the measuring period and the mean measured values are reported.

100 mV DC Measurement

A multifunction calibrator was used as a source of stable DC voltage. The voltage at the input terminals of the multimeter was monitored using an automated potentiometer (MIL 8000A), which had been standardized against a 10 V reference standard. Measurements were made with the calibrator set to 0 mV and 100 mV.

10 V DC Measurement

A 10 V electronic voltage standard was used as a standard. The measuring leads were connected together at the low output terminal of the voltage standard and the multimeter zero reading was recorded. The leads were then connected to the voltage standard output terminals and, after the specified settling time, the multimeter reading was recorded.

100 V and 1 000 V DC Measurements

A multifunction calibrator was used as a source of stable DC voltage. The voltage at the input terminals of the multimeter was monitored using a reference divider (Fluke 752A) and 10 V reference standard.

DC Current Measurements

A multifunction calibrator was used as A source of stable DC current. The output of the calibrator was measured using a current shunt , connected in series with the current input terminals of the multimeter. The voltage drop across the shunt was measured using a long-scale voltmeter (FLuke 8508A).

DC Resistance Measurements

Standard resistors, which had been measured immediately prior to use, were connected to the multimeter. Note that the manufacturer's recommended zeroing procedure, given on page 3-18 of the User's Manual (Fluke PN 1673798, Jul 2002), was used to zero the 4-wire ohms function of the multimeter.

AC Voltage Measurements

A multifunction calibrator was used as a source of stable AC Voltage. The output of the calibrator was connected to a coaxial tee. One output of the tee was connected directly to the input of an AC measurement standard (Fluke 5790A) and the other output of the tee was connected, via an adapter, to the input terminals of the multimeter. In this way the voltage appearing at the input terminals of the multimeter was measured using the AC reference standard.

AC Current Measurements

A multifunction calibrator was used as a source of stable AC current. Immediately prior to its use, the output current of the calibrator was measured using an AC-DC transfer method by means of an AC shunt and an AC-DC transfer standard.

Results

DC VOLTAGE

8508A Range	Nominal Value	Applied Value	8508A Reading	8508A Error of Indication	Measurement Uncertainty(1)
200 mV	100 mV	100.000 04 mV	100.000 13 mV	+0.09 µV	0.40 µV
20 V	10 V	10.000 005 V	10.000 045 V	+ 40 µV	11 µV
200 V	100 V	100.000 05 V	99.999 84 V	-210 µV	180 µV
1000 V	1000 V	1000.000 5 V	999.998 7 V	-1.8 mV	3.0 mV

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DC CURRENT

8508A Range	Nominal Value	Applied Value	8508A Reading	8508A Error of Indication	Measurement Uncertainty
200 µA	100 µA	100.000 2 µA	99.999 1 µA	-1.1 nA	1.5 nA
20 mA	10 mA	9.999 95 mA	10.000 19 mA	+240 nA	100 nA
2 A	1 A	0.999 869 A	0.999 998 A	-129 µA	25 µA

DC RESISTANCE

8508A Range	Nominal Value	Applied Value	8508A Reading(2)	8508A Error of Indication	Measurement Uncertainty
20 Ω	10 Ω	9.999 998 Ω	10.000 143 Ω	145 µΩ	36 µΩ
20 kΩ	10 kΩ	10.000 014 kΩ	10.000107 kΩ	93 mΩ	25 mΩ
20 kΩ (LoI)	10 kΩ	10.000 014 kΩ	10.000 119 kΩ	105 mΩ	28 mΩ
1 MΩ	1 MΩ	0.999 999 1 MΩ	1.000 007 8 MΩ	8.7 Ω	11 Ω

AC VOLTAGE

8508A Range	Nominal Value		Applied Value	8508A Reading(3)	8508A Error of Indication	Measurement Uncertainty
	Level	Frequency				
200 mV	100 mV	55 Hz	100.001 8 mV	99.999 7 mV	-2.1 µV	13 µV
	100 mV	55 Hz	99.994 0 mV	99.997 1 mV	+3.1 µV	12 µV
20 V	10 V	55 Hz	9.999 69 V	10.000 32 V	+0.63 mV	0.50 mV
	10 V	1 kHz	9.999 46 V	10.000 52 V	+1.06 mV	0.42 mV
	10 V	100 kHz	10.001 52 V	10.002 38 V	+0.86 mV	1.66 mV
200 V	100 V	55 Hz	99.995 2 V	99.995 0 V	-0.2 mV	7.9 mV
	100 V	1 kHz	99.992 4 V	99.997 4 V	+5.0 mV	7.0 mV

AC CURRENT

8508A Range	Nominal Value		Applied Value	8508A Reading	8508A Error of Indication	Measurement Uncertainty
	Level	Frequency				
20 mA	10 mA	300 Hz	9.999 84 mA	10.000 52 mA	+0.68 µA	1.3 µA
	10 mA	1 kHz	9.999 98 mA	10.000 75 mA	+0.77 µA	1.5 µA
2 A	1 A	300 Hz	1.000 007 A	0.999 909 A	-98 µA	260 µA
	1 A	1 kHz	0.999 872 A	0.999 852 A	-20 µA	320 µA

Notes: (1) Expanded uncertainty with a coverage probability of approximately 95%.

(2) For the 4-wire ohms function, the multimeter was zeroed using the manufacturer's recommended method.

(3) The multimeter was set to AC coupling for all AC measurements. At a frequency of 55 Hz, the difference between readings for AC and DC coupling is significant (approximately 40 µV/V).

Uncertainty Evaluation

The uncertainty analyses and associated uncertainty budgets for the measurements are shown below. In all cases, the magnitudes of the uncertainty components which had low degrees of freedom associated with them were significantly smaller than the combined uncertainty. Consequently a coverage factor *k*=2 was used to arrive at an expanded uncertainty (coverage probability of 95%) for all the measurements.

100 mV DC Measurement

The measurement equation, which relates the measured quantity (the error of indication of the test DMM) to the input quantities, is :

$$E_X = (X - X_0) - [(K_X + \delta K_{X1} + \delta K_{X2}) \cdot -(K_0 + \delta K_{01} + \delta K_{02})] \cdot (U_S + \delta U_1) + \delta_T + \delta_R$$

Where E_X is the error of indication of the DMM under test,
X and X_0 are the DMM readings corresponding to calibrator settings of 100 mV and 0 mV respectively,
K_X and K_0 are the potentiometer ratio readings corresponding to the DMM readings X and X_0,
δK_{X1} is the linearity correction of the potentiometer at the reading K_X,
δK_{X2} is the offset correction of the potentiometer,
δK_{01} and δK_{02} are the corresponding potentiometer corrections for reading K_0,
U_S is the value of the potentiometer's source voltage as determined during standardization,
δU_1 is a correction due to changes in the source voltage due to drift and temperature,
δ_T is the correction due to uncorrected thermoelectric voltage, and
δ_R is a correction, with nominal value of zero, which accounts for the non-repeatability of the measurement.
We note that the potentiometer offset corrections, δK_{X2} and δK_{02}, are highly correlated, so the quantity $(\delta K_{X2} - \delta K_{o2})$ is referred to in the uncertainty budget and its associated uncertainty takes account of the correlation.
The uncertainty budget is shown in Table 1.

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Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	100.000 15 mV	0.02 µV	Uniform	1	0.02 µV	∞
X_0	0.000 02 mV	0.02 µV	Uniform	1	0.02 µV	∞
K_X	0.010 000 024	-	-	-	-	-
δK_{X1}	0.000 000 020	1.0e-08	Normal	10 V	0.10 µV	∞
K_0	0	-	-	-	-	-
δK_{01}	0	1.0e-08	Normal	10 V	0.10 µV	∞
$(\delta K_{X2} - \delta K_{o2})$	0	0.5e-08	Normal	10 V	0.05 µV	∞
U_S	10.000 000 V	5.0 µV	Normal	0.01	0.05 µV	∞
δU_1	0 V	2.0 µV	Normal	0.01	0.02 µV	∞
δ_T	0 V	0.1 µv	Uniform	1	0.10 µV	
δ_R	0 V	0.07 µV	Student-t	1	0.07 µV	8
Ex	+0.09 µV		Combined Uncertainty $u(E_X)$			0.20 µV
			Effective Degrees of Freedom ν_{eff}			560
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			0.40 µV

Table 1 **Uncertainty budget for 100 mV DC measurement**

10 V DC Measurement

The measurement equation, which relates the measured quantity (the error of indication of the test DMM) to the input quantities, is as follows:

$$E_X = (X - X_0) - (U_S + \delta U_1 + \delta U_2 - U_0) + \delta_T + \delta_R$$

where E_X is the error of indication of the DMM under test,

X and X_0 are the DMM readings when the DMM input terminals are connected to the reference voltage standard and to a low thermal short circuit respectively,

U_S is the value of the reference voltage standard on the date of its last calibration,

δU_1 is a correction due to change in the reference voltage standard due to drift since calibration,

δU_2 is a correction due to the effects of ambient temperature and pressure changes on the reference voltage standard output,

U_0 is the voltage produced by the low thermal short circuit,

δ_T is the correction due to uncorrected thermoelectric voltages,

δ_R is a correction, with nominal value of zero, which accounts for the non-repeatability of the measurement.

The uncertainty budget is shown in Table 2.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	10.000 046 V	0.6 µV	Uniform	1	0.6 µV	∞
X_0	0.000 001 V	0.6 µV	Uniform	1	0.6 µV	∞
U_S	10.000 005 V	5.0 µV	Normal	1	5.0 µV	∞
δU_1	0 V	2.0 µV	Normal	1	2.0 µV	∞
δU_2	0 V	2.0 µV	Normal	1	2.0 µV	∞
U_0	0.000 000 V	-	-	-	-	-
δ_T	0 V	0.2 µv	Uniform	1	0.2 µV	
δ_R	0 V	1.0 µV	Student-t	1	1.0 µV	5
E_X	40 µV		Combined Uncertainty $u(E_X)$			5.5 µV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			11 µV

Table 2 **Uncertainty budget for 10 V DC measurement**

100 V DC Measurement

The measurement equation, which relates the measured quantity (the error of indication of the test DMM) to the input quantities, is as follows:

$$E_X = (X - X_0) - [(K_X + \delta K_{X1} + \delta K_{X2}) \cdot (U_S + \delta U_1) - U_0] + \delta_T + \delta_R$$

where E_X is the error of indication of the DMM under test,

X and X_0 are the DMM readings corresponding to calibrator settings of 100 V and 0 V respectively,

K_X is the calibrated ratio of the reference divider,

δK_{X1} is the correction to the reference divider's ratio due to drift,

δK_{X2} is the correction to the reference divider's ratio due to temperature changes and self-heating, ,

U_0 is the output EMF of the calibrator, when set to zero.

δ_R is a correction, with nominal value of zero, which accounts for the non-repeatability of the measurement.

The uncertainty budget is shown in Table 3.

Quantity ***X_i***	***Estimate*** ***x_i***	***Standard Uncertainty*** ***$u(x_i)$***	***Probability Density Function***	***Sensitivity Coefficient*** ***$\|c_i\|$***	***Uncertainty Contribution*** ***$u_i(E_x)$***	***Degrees of Freedom***
X	99.999 84 V	10 µV	Uniform	1	10 µV	∞
X_0	0.000 00 V	10 µV	Uniform	1	10 µV	∞
K_X	10.000 000	2.5e-6	Normal	10 V	25 µV	∞
δK_{X1}	0	2.5e-6	Normal	10 V	25 µV	∞
δK_{X2}	0	5.0e-6	Normal	10 V	50 µV	∞
U_S	10.000 005 V	5.0 µV	Normal	10	50 µV	∞
δU_1	0 V	3.0 µV	Normal	10	30 µV	∞
U_0	0.000 00 V	20 µv	Uniform	1	20 µV	
δ_R	0 V	10 µV	Student-t	1	10 µV	4
Ex	-210 µV		Combined Uncertainty *$u(E_X)$*			89 µV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor *k*			2
			Expanded Uncertainty *$U(E_X)$*			180 µV

Table 3 Uncertainty budget for 100 V DC measurement

1000 V DC Measurement

The measurement equation for the 1 000 V measurement is identical to that for the 100 V measurement, shown above.
The uncertainty budget is shown in Table 4.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom
X	999.998 6 V	0.1 mV	Uniform	1	0.1 mV	∞
X_0	-0.000 1 V	0.1 mV	Uniform	1	0.1 mV	∞
K_X	100.000 00	5.0e-5	Normal	10 V	0.50 mV	∞
δK_{X1}	0	2.5e-5	Normal	10 V	0.25 mV	∞
δK_{X2}	0	1.25e-4	Normal	10 V	1.25 mV	∞
U_S	10.000 005 V	5.0 µV	Normal	100	0.50 mV	∞
δU_1	0 V	3.0 µV	Normal	100	0.30 mV	∞
U_0	0.000 0 V	0.2 mV	Uniform	1	0.20 mV	
δ_R	0 V	0.2 mV	Student-t	1	0.20 mV	4
E_X	-1.8 mV		Combined Uncertainty $u(E_X)$			1.5 mV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			3.0 mV

Table 4 **Uncertainty budget for 1 000 V DC measurement**

100 μA DC Measurement

The measurement equation, which relates the measured quantity (the error of indication of the test DMM) to the input quantities, is as follows:

$$E_X = (X - X_0) - [\frac{(D_X + \delta D_{X1} + \delta D_{X2} + \delta D_{X3}) - (D_0 + \delta D_{01} + \delta D_{02})}{(R_S + \delta R_{S1} + \delta R_{S2} + \delta R_{S3})}] + \delta_L + \delta_R$$

where E_X is the error of indication of the DMM under test,

X and X_0 are the DMM readings corresponding to calibrator settings of 100 μA and 0 μA respectively,

D_X and D_0 are the readings of the reference voltmeter (connected across the current shunt) when the calibrator is set to 100 μA and 0 μA respectively.

δD_{X1} is the correction to the voltmeter reading D_X determined at its last calibration,

δD_{X2} is the correction to the voltmeter reading D_X due to drift, and other influence factors ,

δD_{X3} is the correction to the reference voltmeter reading D_X due to common mode effects.

δD_{01} and δD_{02} are the corresponding corrections to the reference voltmeter reading D_0 .

R_S is the calibrated value of the shunt resistance,

δR_{S1} is the correction to the shunt resistance due to drift,

δR_{S2} is the correction to the shunt resistance due to temperature changes (including self-heating effects),

δR_{S3} is the correction to the shunt resistance due to the loading effect of the voltmeter.

δ_L is a correction due to leakage effects.

δ_R is a correction, with nominal value of zero, which accounts for the non-repeatability of the measurement.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	99.999 1 µA	0.012 nA	Uniform	1	0.12 nA	∞
X_0	0.000 0 µA	0.012 nA	Uniform	1	0.12 nA	∞
D_X	1.000 001 V	-	-	-	-	-
δD_{X1}	0 V	2.0 µV	Normal	$10^{-4}\ \Omega^{-1}$	0.20 nA	∞
δD_{X2}	0 V	2.5 µV	Normal	$10^{-4}\ \Omega^{-1}$	0.25 nA	∞
δD_{X3}	0 V	2.5 µV	Normal	$10^{-4}\ \Omega^{-1}$	0.25 nA	∞
D_0	0 V	-	-	-	-	-
δD_{01}	0 V	1.0 µV	Normal	$10^{-4}\ \Omega^{-1}$	0.10 nA	∞
δD_{02}	0 V	1.0 µV	Normal	$10^{-4}\ \Omega^{-1}$	0.10 nA	∞
R_S	9999.989 Ω	0.01 Ω	Normal	$10^{-8}\ V\ \Omega^{-2}$	0.10 nA	∞
δR_{S1}	0 Ω	0.01 Ω	Normal	$10^{-8}\ V\ \Omega^{-2}$	0.10 nA	∞
δR_{S2}	0 Ω	0.01 Ω	Normal	$10^{-8}\ V\ \Omega^{-2}$	0.10 nA	∞
δR_{S3}	0 Ω	0.05 Ω	Normal	$10^{-8}\ V\ \Omega^{-2}$	0.50 nA	∞
δ_L	0 nA	0.10 nA	Uniform	1	0.10 nA	∞
δ_R	0 nA	0.20 nA	Student-t	1	0.20 nA	2
E_X	-1.1 nA		Combined Uncertainty $u(E_X)$			0.74 nA
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			1.5 nA

Table 5 **Uncertainty budget for 100 µA DC measurement**

10 mA DC Measurement

The measurement equation for the 10 mA measurement is identical to that for the 100 µA measurement, shown above.
The uncertainty budget is shown in Table 6.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	10.000 20 mA	0.012 nA	Uniform	1	6 nA	∞
X_0	-0.000 01 mA	0.012 nA	Uniform	1	6 nA	∞
D_X	0.999 995 V	-	-	-	-	-
δD_{X1}	0 V	2.0 µV	Normal	$10^{-2}\ \Omega^{-1}$	20 nA	∞
δD_{X2}	0 V	2.5 µV	Normal	$10^{-2}\ \Omega^{-1}$	25 nA	∞
δD_{X3}	0 V	2.5 µV	Normal	$10^{-2}\ \Omega^{-1}$	25 nA	∞
D_0	0.000 002 V	-	-	-	-	-
δD_{01}	0 V	1.0 µV	Normal	$10^{-2}\ \Omega^{-1}$	10 nA	∞
δD_{02}	0 V	1.0 µV	Normal	$10^{-2}\ \Omega^{-1}$	10 nA	∞
R_S	99.999 57 Ω	0.05 mΩ	Normal	10^{-2} V Ω^{-2}	5 nA	∞
δR_{S1}	0 Ω	0.05 mΩ	Normal	10^{-4} V Ω^{-2}	5 nA	∞
δR_{S2}	0 Ω	0.05 mΩ	Normal	10^{-4} V Ω^{-2}	5 nA	∞
δR_{S3}	0 Ω	0.00 mΩ	Normal	10^{-4} V Ω^{-2}	0 nA	∞
δ_L	0 nA	0 nA	Uniform	1	0 nA	∞
δ_R	0 nA	20 nA	Student-t	1	20 nA	3
E_X	240 nA		Combined Uncertainty $u(E_X)$			48 nA
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			100 nA

Table 6 Uncertainty budget for 10 mA DC measurement

1 A DC Measurement

The measurement equation for the 1 A measurement is identical to that for the 100 µA measurement, shown above.
The uncertainty budget is shown in Table 7.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom
X	0.999 874 A	1.2 µA	Uniform	1	1.2 µA	∞
X_0	0.000 005 A	1.2 µA	Uniform	1	1.2 µA	∞
D_X	1.000 029 V	-	-	-	-	-
δD_{X1}	0 V	2.5 µV	Normal	1 Ω^{-1}	2.5 µA	∞
δD_{X2}	0 V	2.5 µV	Normal	1 Ω^{-1}	2.5 µA	∞
δD_{X3}	0 V	2.5 µV	Normal	1 Ω^{-1}	2.5 µA	∞
D_0	0.000 000 V	-	-	-	-	-
δD_{01}	0 V	1.0 µV	Normal	1 Ω^{-1}	1.0 µA	∞
δD_{02}	0 V	1.0 µV	Normal	1 Ω^{-1}	1.0 µA	∞
R_S	1.000 031 Ω	5 µΩ	Normal	1 V Ω^{-2}	2.5 µA	∞
δR_{S1}	0 Ω	5 µΩ	Normal	1 V Ω^{-2}	5.0 µA	∞
δR_{S2}	0 Ω	10 µΩ	Normal	1 V Ω^{-2}	10.0 µA	∞
δR_{S3}	0 Ω	0.0 µΩ	Normal	1 V Ω^{-2}	0.0 µA	∞
δ_L	0 µA	0.0µA	Uniform	1	0.0 µA	∞
δ_R	0 µA	1 µA	Student-t	1	1.0 nA	1
E_X	-129 µA		Combined Uncertainty $u(E_X)$			12.5 µA
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			25 µA

Table 7 Uncertainty budget for 1 A DC measurement

10 ohm Measurement

The measurement equation, which relates the measured quantity (the error of indication of the test DMM) to the input quantities, is as follows:

$$E_X = (X - X_0) - (R_S + \delta R_{S1} + \delta R_{S2}) + \delta_L + \delta_R$$

where E_X is the error of indication of the DMM under test,

X and X_0 are the DMM readings when the 10 Ω reference standard and the 0 Ω source are connected to the DMM input terminals, respectively,

R_S is the calibrated value of the reference resistance,

δR_{S1} is the correction to the value of the reference resistance standard due to drift since calibration,

δR_{S2} is the correction to the value of the reference resistance standard due to temperature,

δ_L is a correction for leakage resistance effects,

δ_R is a correction, with nominal value of zero, which accounts for the non-repeatability of the measurement.

The uncertainty budget is shown in Table 8.

Quantity X_i	**Estimate** x_i	**Standard Uncertainty** $u(x_i)$	**Probability Density Function**	**Sensitivity Coefficient** $\lvert c_i \rvert$	**Uncertainty Contribution** $u_i(E_x)$	**Degrees of Freedom**
X	10.000 143 Ω	1.2 µΩ	Uniform	1	1.2 µΩ	∞
X_0	0.000 000 Ω	1.2 µΩ	Uniform	1	1.2 µΩ	∞
R_S	9.999 998 Ω	10 µΩ	Normal	1	10 µΩ	∞
δR_{S1}	0 Ω	10 µΩ	Normal	1	10 µΩ	∞
δR_{S2}	0 Ω	10 µΩ	Normal	1	10 µΩ	∞
δ_L	0 Ω	0 µΩ	Uniform	1	0 µΩ	∞
δ_R	0 Ω	10 µΩ	Student-t	1	10 µΩ	3
E_X	145 µΩ		Combined Uncertainty $u(E_X)$			18 µΩ
			Effective Degrees of Freedom ν_{eff}			515
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			36 µΩ

Table 8 Uncertainty budget for 10 Ω measurement

10 kΩ Measurement

The measurement equation for the 10 kΩ (100 µA test current) measurement is identical to that for the 10 Ω measurement, shown above. The uncertainty budgets for the 100 µA and 10 µA Test currents are shown in Tables 9a and 9b, respectively.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	10.000 108 kΩ	0.6 mΩ	Uniform	1	0.6 mΩ	∞
X_0	0.000 001 kΩ	0.6 mΩ	Uniform	1	0.6 mΩ	∞
R_S	10.000 014 kΩ	1.0 mΩ	Normal	1	1.0 mΩ	∞
δR_{S1}	0 Ω	0.5 mΩ	Normal	1	0.5 mΩ	∞
δR_{S2}	0 Ω	0.5 mΩ	Normal	1	0.5 mΩ	∞
δ_L	0 Ω	1.0 mΩ	Uniform	1	1.0 mΩ	∞
δ_R	0 Ω	1.0 mΩ	Student-t	1	1.0 mΩ	2
E_X	93 mΩ		Combined Uncertainty $u(E_X)$			12.4 mΩ
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			25 mΩ

Table 9 Uncertainty budget for 10 kΩ measurement (100 µA test current)

10 kΩ Measurement (10 μA test current)

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	10.000 117 kΩ	2.9 mΩ	Uniform	1	0.6 mΩ	∞
X_0	-0.000 002 kΩ	2.9 mΩ	Uniform	1	0.6 mΩ	∞
R_S	10.000 014 kΩ	1.0 mΩ	Normal	1	1.0 mΩ	∞
δR_{S1}	0 Ω	0.5 mΩ	Normal	1	0.5 mΩ	∞
δR_{S2}	0 Ω	0.5 mΩ	Normal	1	0.5 mΩ	∞
δ_L	0 Ω	1.0 mΩ	Uniform	1	1.0 mΩ	∞
δ_R	0 Ω	5.0 mΩ	Student-t	1	1.0 mΩ	2
E_X	105 mΩ		Combined Uncertainty $u(E_X)$			13.9 mΩ
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			28 mΩ

Table 9b **Uncertainty budget for 10 kΩ measurement (10 μA test current)**

1 MΩ Measurement

The measurement equation for the 1 MΩ measurement is identical to that for the 10 Ω measurement, shown above. The uncertainty budget is shown in Table 10.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	1.0000078 MΩ	1.2 Ω	Uniform	1	1.2 Ω	∞
X_0	0.0000000 Ω	1.2 Ω	Uniform	1	1.2 Ω	∞
R_S	0.999999 1 MΩ	4.0 Ω	Normal	1	4.0 Ω	∞
δR_{S1}	0 Ω	2.5 Ω	Normal	1	2.5 Ω	∞
δR_{S2}	0 Ω	1.5 Ω	Normal	1	1.5 Ω	∞
δ_L	0 Ω	1.0 Ω	Uniform	1	1.0 Ω	∞
δ_R	0 Ω	1.0 Ω	Student-t	1	1.0 Ω	7
E_X	8.7 Ω		Combined Uncertainty $u(E_X)$			5.4 Ω
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			11 Ω

Table 10 **Uncertainty budget for 1 MΩ measurement**

100 mV AC Measurement

The measurement equation, which relates the measured quantity (the error of indication of the test DMM) to the input quantities, is as follows:

$$E_X = X - (D_X + \delta D_{X1} + \delta D_{X2}) + \delta_{CM} + \delta_{TM} + \delta_R$$

where E_X is the error of indication of the DMM under test,
X is the DMM reading when the calibrator is set to 100 mV,
D_X is the corresponding reading of the AC measurement standard,
δD_{X1} is the correction to the AC measurement standard reading determined at its most recent calibration,
δD_{X2} is the correction to the AC measurement standard reading due to non-linearity, drift, and temperature effects,
δ_{CM} is a correction due to effects,
δ_{TM} is a correction due to transmission line effects,
δ_R is a correction, with nominal value of zero, which accounts for the non-repeatability of the measurement.
The uncertainty budgets for the measurements at 55 Hz and 1 kHz are shown in Tables 11a and 11b, respectively.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	99.999 7 mV	0.6 µV	Uniform	1	0.6 µV	∞
D_X	100.000 8 mV	-	-	-	-	-
δR_{X1}	0.001 0 mV	6.0 µV	Normal	1	6.0 µV	∞
δD_{X2}	0 mV	2.3 µV	Normal	1	2.3 µV	∞
δ_{CM}	0 mV	0.5 µV	Uniform	1	0.5 µV	∞
δ_{TM}	0 mV	0.0 µV	Uniform	1	0.0 µV	∞
δ_R	0 mV	0.4 µV	Student-t	1	0.9 µV	3
E_X	-2.1 µV		Combined Uncertainty $u(E_X)$			6.5 µV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			13 µV

Table 11a **Uncertainty budget for 100 mV, 55 Hz measurement**

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	99.997 1 mV	0.6 µV	Uniform	1	0.6 µV	∞
D_X	99.993 6 mV	-	-	-	-	-
δR_{X1}	0.000 4 mV	5.5 µV	Normal	1	6.0 µV	∞
δD_{X2}	0 mV	2.3 µV	Normal	1	2.3 µV	∞
δ_{CM}	0 mV	0.5 µV	Uniform	1	0.5 µV	∞
δ_{TM}	0 mV	0.0 µV	Uniform	1	0.0 µV	∞
δ_R	0 mV	0.3 µV	Student-t	1	0.9 µV	2
E_X	3.1 µV		Combined Uncertainty $u(E_X)$			6.1 µV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			12 µV

Table 11b **Uncertainty budget for 100 mV, 1 kHz measurement**

10 V AC Measurement

The measurement equation for the 10 V AC measurement is identical to that for the 100 mV AC measurement, shown above. The uncertainty budgets for the 55 Hz, 1 kHz and 100 kHz measurements are shown in Tables 12a, 12b, and 12c, respectively.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom
X	10.000 32 V	0.012 mV	Uniform	1	0.012 mV	∞
D_X	9.999 71 V	-	-	-	-	-
δR_{X1}	-0.000 02 V	0.15 mV	Normal	1	0.15 mV	∞
δD_{X2}	0 V	0.13 mV	Normal	1	0.13 mV	∞
δ_{CM}	0 V	0.15 mV	Uniform	1	0.15 mV	∞
δ_{TM}	0 V	0.00 mV	Uniform	1	0.00 mV	∞
δ_R	0 V	0.02 mV	Student-t	1	0.02 mV	3
E_X	0.63 mV		Combined Uncertainty $u(E_X)$			0.25 mV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			0.50 mV

Table 12a **Uncertainty budget for 10 V, 55 Hz measurement**

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom
X	10.000 52 V	0.012 mV	Uniform	1	0.012 mV	∞
D_X	9.999 48 V	-	-	-	-	-
δR_{X1}	-0.000 02 V	0.15 mV	Normal	1	0.15 mV	∞
δD_{X2}	0 V	0.13 mV	Normal	1	0.13 mV	∞
δ_{CM}	0 V	0.05 mV	Uniform	1	0.05 mV	∞
δ_{TM}	0 V	0.00 mV	Uniform	1	0.00 mV	∞
δ_R	0 V	0.02 mV	Student-t	1	0.02 mV	2
E_X	+1.06 mV		Combined Uncertainty $u(E_X)$			0.21 mV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			0.42 mV

Table 12b **Uncertainty budget for 10 V, 1 kHz measurement**

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom
X	10.002 38 V	0.01 mV	Uniform	1	0.01 mV	∞
D_X	10.001 77 V	-	-	-	-	-
δR_{X1}	-0.000 25 V	0.35 mV	Normal	1	0.35 mV	∞
δD_{X2}	0 V	0.50 mV	Normal	1	0.50 mV	∞
δ_{CM}	0 V	0.25 mV	Uniform	1	0.25 mV	∞
δ_{TM}	0 V	0.50 mV	Uniform	1	0.50 mV	∞
δ_R	0 V	0.02 mV	Student-t	1	0.02 mV	2
E_X	0.86 mV		Combined Uncertainty $u(E_X)$			0.83 mV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			1.66 mV

Table 12c **Uncertainty budget for 10 V, 100 kHz measurement**

100 V AC Measurement

The measurement equation for the 100 V AC measurement is identical to that for the 100 mV AC measurement, shown above. The uncertainty budgets for the 55 Hz, 1 kHz measurements are shown in Tables 13a and 13b, respectively.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	99.995 0 V	0.12 mV	Uniform	1	0.12 mV	∞
D_X	99.995 1 V	-	-	-	-	-
δR_{X1}	0.000 1 V	3.0 mV	Normal	1	3.0 mV	∞
δD_{X2}	0 V	2.5 mV	Normal	1	2.5 mV	∞
δ_{CM}	0 V	0.5 mV	Uniform	1	0.5 mV	∞
δ_{TM}	0 V	0.0 mV	Uniform	1	0.0 mV	∞
δ_R	0 V	0.2 mV	Student-t	1	0.2 mV	3
E_X	-0.2 mV		Combined Uncertainty $u(E_X)$			3.9 mV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			7.9 mV

Table 13a **Uncertainty budget for 100 V, 55 Hz measurement**

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	99.997 4 V	0.12 mV	Uniform	1	0.12 mV	∞
D_X	99.993 7 V	-	-	-	-	-
δR_{X1}	-0.001 3 V	3.0 mV	Normal	1	3.0 mV	∞
δD_{X2}	0 V	1.7 mV	Normal	1	1.7 mV	∞
δ_{CM}	0 V	0.5 mV	Uniform	1	0.5 mV	∞
δ_{TM}	0 V	0.0 mV	Uniform	1	0.0 mV	∞
δ_R	0 V	0.2 mV	Student-t	1	0.2 mV	2
E_X	5.0 mV		Combined Uncertainty $u(E_X)$			3.5 mV
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			7.0 mV

Table 13b **Uncertainty budget for 100 V, 1 kHz measurement**

10 mA AC Measurement

The measurement equation, which relates the measured quantity (the error of indication of the test DMM) to the input quantities, is as follows:

$$E_X = X - (I_X + \delta I_{X1} + \delta I_{X2} + \delta I_{X3}) + \delta_R$$

where E_X is the error of indication of the DMM under test,
X is the DMM reading when the calibrator is set to 10 mA,
I_X is the calibrator setting,
δI_{X1} is the correction to the calibrator output determined at its most recent calibration,
δI_{X2} is the correction to the calibrator output due to drift, and temperature effects,
δI_{X3} is the correction to the calibrator output due to change in the loading,
δ_R is a correction, with nominal value of zero, which accounts for the non-repeatability of the measurement.
The uncertainty budgets for the measurements at 55 Hz and 1 kHz are shown in Tables 14a and 14b, respectively.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\|c_i\|$	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom
X	10.000 52 mA	0.12 µA	Uniform	1	0.12 µA	∞
I_X	9.999 84 mA	-	-	-	-	-
δI_{X1}	0 mA	0.50 µA	Normal	1	0.50 µA	∞
δI_{X2}	0 mA	0.25 µA	Normal	1	0.25 µA	∞
δI_{X3}	0 mA	0.25 µA	Uniform	1	0.25 µA	∞
δ_R	0 mA	0.10 µA	Student-t	1	0.10 µA	3
E_X	+0.68 µA		Combined Uncertainty $u(E_X)$			0.63 µA
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			1.3 µA

Table 14a **Uncertainty budget for 10 mA, 300 Hz measurement**

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	10.000 75 mA	0.12 µA	Uniform	1	0.12 µA	∞
I_X	9.999 98 mA	-	-	-	-	-
δI_{X1}	0 mA	0.50 µA	Normal	1	0.50 µA	∞
δI_{X2}	0 mA	0.25 µA	Normal	1	0.25 µA	∞
δI_{X3}	0 mA	0.50 µA	Uniform	1	0.50 µA	∞
δ_R	0 mA	0.10 µA	Student-t	1	0.10 µA	3
E_X	0.77 µA		Combined Uncertainty $u(E_X)$			0.77 µA
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			1.5 µA

Table 14b **Uncertainty budget for 10 mA, 1 kHz measurement**

1 A AC Measurement

The measurement equation for the 1 A AC measurement is identical to that for the 10 mA AC measurement, shown above. The uncertainty budgets for the 55 Hz, 1 kHz measurements are shown in Tables 15a and 15b, respectively.

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	0.999 909 A	3 µA	Uniform	1	3 µA	∞
I_X	1.000 007 A	-	-	-	-	-
δI_{X1}	0 A	115 µA	Normal	1	115 µA	∞
δI_{X2}	0 A	25 µA	Normal	1	25 µA	∞
δI_{X3}	0 A	50 µA	Uniform	1	50 µA	∞
δ_R	0 A	5 µA	Student-t	1	5 µA	1
E_X	-98 µA		Combined Uncertainty $u(E_X)$			128 µA
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			260 µA

Table 15a **Uncertainty budget for 1 A, 300 Hz measurement**

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Density Function	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom
X	0.999 852 A	3 µA	Uniform	1	3 µA	∞
I_X	0.999 872 A	-	-	-	-	-
δI_{X1}	0 A	115 µA	Normal	1	115 µA	∞
δI_{X2}	0 A	25 µA	Normal	1	25 µA	∞
δI_{X3}	0 A	100 µA	Uniform	1	50 µA	∞
δ_R	0 A	5 µA	Student-t	1	5 µA	1
E_X	-20 µA		Combined Uncertainty $u(E_X)$			160 µA
			Effective Degrees of Freedom ν_{eff}			> 1000
			Coverage Factor k			2
			Expanded Uncertainty $U(E_X)$			320 µA

Table 15b **Uncertainty budget for 1 A, 1 kHz measurement**

NSAI National Metrology Laboratory

Measurement Report for Comparison on Calibration of Multimeter for EURAMET Project No 1341

Jon Bartholomew, Shamsa Al Kayyoomi and Hamad Deiban

Electrical, Time and Frequency Laboratory

Emirates Metrology Institute

Abu Dhabi Quality and Conformity Council

Rev. 0

27 September 2016

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1. Participant Institute

Institute	Emirates Metrology Institute Abu Dhabi Quality and Conformity Council
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2. Period of Measurements

14 August 2016 to 22 August 2016

3. Ambient Conditions

Temperature : (23 ± 1) °C

Relative Humidity : (45 ± 10) % rh

4. Measurement Standards Used

Name	Manufacturer	Model No	Serial No	Traceability
Multi-Function Calibrator	Fluke	5720A	2217201	EMI, UAE
DC Voltage Standard	Fluke	732B	2169033	NPL, UK
Automatic Potentiometer	Measurements International	8000A	1040805	EMI, UAE
1200V Range Extender	Measurements International	8001A	1040806	EMI, UAE
10 Ω Standard Resistor	Measurements International	9331	1102536	EMI, UAE
10 kΩ Standard Resistor	IET	SR104	J2-1529650	EMI, UAE
1 MΩ Standard Resistor	Measurements International	9331	1101330	EMI, UAE

5. Measurement Method

5.1. The Travelling Standard

The instrument measured was Fluke 8508A Reference Multimeter Serial Number 969656608.

5.2. Preparation

The Multimeter was received on 9 August 2016 and was allowed to stabilize in the laboratory overnight before turning on. The Multimeter was allowed to warm up under power for 10 minutes and then reset to the power up default configuration. A self-test of the "Circuits" was run and the result was "Self-Test Passed". The Multimeter was left powered in the laboratory until 14 August 2016 when measurements commenced. The Multimeter was powered continuously throughout the measurement period.

5.3. DC Voltage

Before each DC Voltage measurement the Multimeter was zeroed using the 4-wire shorting device supplied.

5.3.1. Nominal Value of 100 mV

The Multimeter was used to measure the output of the Fluke 5720A calibrator. At the same time the output of the Fluke 5720A calibrator was measured using the Measurements International 8000A Automatic Potentiometer referenced to the 10V output of the Fluke 732B DC Voltage Standard.

The Automatic Potentiometer is known to have a zero offset which can be significant for measurements at low voltages. The Automatic Potentiometer cannot measure at 0 V so EMI measure the zero offset by making measurements at ±1 mV. The mean value of these measurements is the zero offset of the Automatic Potentiometer. This offset is subtracted from the value measured by the Automatic Potentiometer at the nominal value of 100mV. The reported value is the mean of 50 measurements.

5.3.2. Nominal Value of 10 V

The 10V output of the Fluke 732B DC Voltage Standard was directly measured using the Multimeter.

5.3.3. Nominal Values of 100 V and 1000 V

The Multimeter was used to measure the output of the Fluke 5720A calibrator. At the same time the output of the Fluke 5720A calibrator was measured using the Measurements International 8000A Automatic Potentiometer with the 8001A Range Extender set to an appropriate range. The zero offset of the Automatic Potentiometer is not significant for these measurements so no correction is made. The reported value is the mean of 50 measurements.

5.4. DC Current

The Multimeter was used to measure the output of the Fluke 5720A calibrator. Before each DC Current measurement the Multimeter was zeroed with the input terminals open circuit.

5.5. DC Resistance

The Multimeter was used to measure the resistance of calibrated standard resistors. Before each DC Resistance measurement the Multimeter was zeroed using the 4-wire shorting device supplied.

5.6. AC Voltage

The Multimeter was used to measure the output of the Fluke 5720A calibrator.

5.7. AC Current

The Multimeter was used to measure the output of the Fluke 5720A calibrator.

6. Calculation of Multimeter Error

The Multimeter Error was calculated using the following formula

$$Error\ of\ 8508A = \frac{Reading\ of\ 8508A - Appled\ Value}{Applied\ Value}$$

7. Measurement Results

7.1. DC Voltage

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 mV	+ 100 mV	100.000 12	100.000 12	2.0×10^{-8}	7.3×10^{-6}
20 V	+10 V	10.000 011	10.000 052	4.0×10^{-6}	1.2×10^{-6}
200 V	+100 V	99.999 92	99.999 49	-4.3×10^{-6}	4.0×10^{-6}
1000 V	+1000 V	999.997 4	999.996 8	-5.6×10^{-7}	1.3×10^{-5}

7.2. DC Current

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 µA	+ 100 µA	100.003 41	100.000 81	-2.6×10^{-5}	5.4×10^{-5}
20 mA	+10 mA	10.000 150	10.000 226	7.6×10^{-6}	3.7×10^{-5}
1 A	+1 A	1.000 030 7	0.999 885 1	-1.5×10^{-4}	6.1×10^{-5}

7.3. DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
20 Ω	TrueΩ	10 Ω	10.000 046	10.000 241	1.9×10^{-5}	6.9×10^{-7}
20 kΩ	TrueΩ	10 kΩ	10.000 007	10.000 096	8.9×10^{-6}	1.1×10^{-6}
	TrueΩ LoI	10 kΩ	10.000 007	10.000 110	1.0×10^{-5}	2.2×10^{-6}
2 MΩ	Normal Ω	1 MΩ	0.999 995 9	1.000 004 4	8.5×10^{-6}	4.4×10^{-6}

7.4. AC Voltage

Range of 8508A	Nominal Value		Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99.999 9	99.994 5	-5.4×10^{-5}	2.5×10^{-4}
	100 mV	1 kHz	100.001 6	99.998 7	-2.9×10^{-5}	2.5×10^{-4}
20 V	10 V	55 Hz	10.000 06	10.000 58	5.2×10^{-5}	6.0×10^{-5}
	10 V	1 kHz	10.000 06	10.000 98	9.2×10^{-5}	5.7×10^{-5}
	10 V	100 kHz	9.999 86	10.000 52	6.6×10^{-5}	1.6×10^{-4}
200 V	100 V	55 Hz	99.999 4	99.998 5	-9.3×10^{-6}	7.6×10^{-5}
	100 V	1 kHz	99.998 9	100.001 9	3.0×10^{-5}	7.1×10^{-5}

7.5. AC Current

Range of 8508A	Nominal Value		Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
20 mA	10 mA	300 Hz	10.000 15	10.000 61	4.6×10^{-5}	1.9×10^{-4}
	10 mA	1 kHz	10.000 12	10.000 70	5.8×10^{-5}	1.9×10^{-4}
1 A	1 A	300 Hz	1.000 031	0.999 919	-1.1×10^{-4}	4.7×10^{-4}
	1 A	1 kHz	1.000 028	0.999 986	-4.2×10^{-5}	4.7×10^{-4}

8. Uncertainty Budget

8.1. DC Voltage

8.1.1. Nominal Value of 100 mV

Model Function:

$$E_x = \frac{(I_{MM} + V_E + V_D + V_S + V_T + V_{TC} + V_N + V_T + I_R)}{I_{AP}} - 1$$

I_{MM} = *Indication of multimeter*
I_{AP} = *Indication of automatic potentiometer*
V_E = *Error of automatic potentiometer from last calibration*
V_D = *Drift in error of automatic potentiometer since last calibration*
V_S = *Calibration of Voltage Standard*
V_C = *Uncorrected drift since last calibration*
V_{TC} = *Temperature effects on Voltage Standard*
V_N = *Noise of Voltage Standard*
V_T = *Thermoelectric voltages generated at junctions of leads and terminals*
I_R = *Repeatability of indication*

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	0.1 V	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_{AP}	0.1 V	0.005	ppm	Rectangular	1.7321	1	0.003	∞
I_R	0	0.840	ppm	Normal k=1	1.0000	1	0.840	49
V_E	0	0.440	ppm	Normal k=2	2.0000	1	0.220	∞
V_C	0	0.100	ppm	Rectangular	1.7321	1	0.058	∞
V_S	10 V	0.030	ppm	Normal k=2	2.0000	1	0.015	∞
V_D	0	0.960	ppm	Rectangular	1.7321	1	0.554	∞
V_{TC}	0	0.120	ppm	Rectangular	1.7321	1	0.069	∞
V_N	0	0.060	ppm	Rectangular	1.7321	1	0.035	∞
V_T	0	0.600	µV	Rectangular	1.7321	10	3.464	∞
							Combined Uncertainty, $u(E_x)$	3.615
							Effective Degrees of Freedom, v_{eff}	1.68E+04
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	7.3

8.1.2. Nominal Value of 10 V

Model Function:

$$E_x = \frac{(I_{MM} + V_D + V_T + V_{TC} + V_N + I_R)}{V_S} - 1$$

I_{MM} = Indication of multimeter
I_R = Repeatability of indication
V_S = Calibration of Voltage Standard
V_D = Uncorrected drift since last calibration
V_{TC} = Temperature effects on Voltage Standard
V_N = Noise of Voltage Standard
V_T = Thermoelectric voltages generated at junctions of leads and terminals

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	10 V	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_R	0	0.100	ppm	Normal k=1	1.0000	1	0.100	9
V_S	10 V	0.030	ppm	Normal k=2	2.0000	1	0.015	∞
V_D	0	0.960	ppm	Rectangular	1.7321	1	0.554	∞
V_{TC}	0	0.120	ppm	Rectangular	1.7321	1	0.069	∞
V_N	0	0.060	ppm	Rectangular	1.7321	1	0.035	∞
V_T	0	0.600	µV	Rectangular	1.7321	0.1	0.035	∞
Combined Uncertainty, $u(E_x)$								0.570
Effective Degrees of Freedom, v_{eff}								9.53E+03
Coverage Factor, k								2.000
Expanded Uncertainty, $U(E_x)$								1.2

8.1.3. Nominal Values of 100 and 1000 V

Model Function:

$$E_x = \frac{(I_{MM} + V_E + V_X + V_D + V_S + V_T + V_{TC} + V_N + I_R)}{I_{AP}} - 1$$

I_{MM} = Indication of multimeter
I_{AP} = Indication of automatic potentiometer
V_E = Error of automatic potentiometer from last calibration
V_X = Error of range extender from last calibration
V_D = Drift in error of automatic potentiometer since last calibration
V_S = Calibration of Voltage Standard
V_C = Uncorrected drift since last calibration
V_{TC} = Temperature effects on Voltage Standard
V_N = Noise of Voltage Standard
I_R = Repeatability of indication

100 V

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	100 V	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_{AP}	100 V	0.005	ppm	Rectangular	1.7321	1	0.003	∞
I_R	0	0.040	ppm	Normal k=1	1.0000	1	0.040	49
V_E	0	0.044	ppm	Normal k=2	2.0000	1	0.022	∞
V_X	0	3.800	ppm	Normal k=2	2.0000	1	1.900	∞
V_D	0	0.100	ppm	Rectangular	1.7321	1	0.058	∞
V_S	10 V	0.030	ppm	Normal k=2	2.0000	1	0.015	∞
V_C	0	0.960	ppm	Rectangular	1.7321	1	0.554	∞
V_{TC}	0	0.120	ppm	Rectangular	1.7321	1	0.069	∞
V_N	0	0.060	ppm	Rectangular	1.7321	1	0.035	∞
							Combined Uncertainty, $u(E_x)$	1.982
							Effective Degrees of Freedom, v_{eff}	2.96E+08
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	4.0

1000 V

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	1000 V	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_{AP}	1000 V	0.005	ppm	Rectangular	1.7321	1	0.003	∞
I_R	0	0.085	ppm	Normal k=1	1.0000	1	0.085	49
V_E	0	0.044	ppm	Normal k=2	2.0000	1	0.022	∞
V_X	0	12.000	ppm	Normal k=2	2.0000	1	6.000	∞
V_D	0	0.100	ppm	Rectangular	1.7321	1	0.058	∞
V_S	10 V	0.030	ppm	Normal k=2	2.0000	1	0.015	∞
V_D	0	0.960	ppm	Rectangular	1.7321	1	0.554	∞
V_{TC}	0	0.120	ppm	Rectangular	1.7321	1	0.069	∞
V_N	0	0.060	ppm	Rectangular	1.7321	1	0.035	∞
							Combined Uncertainty, $u(E_x)$	6.027
							Effective Degrees of Freedom, v_{eff}	1.24E+09
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	13

8.2. DC Current

Model Function:

$$E_x = \frac{(I_{MM} + I_R + C_D)}{C_S} - 1$$

I_{MM} = Indication of multimeter
I_R = Repeatability of indication
C_S = Calibration of Multifunction Calibrator
C_D = Stability of Multifunction Calibrator since calibration

100 µA

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	100 µA	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_R	0	0.300	ppm	Normal k=1	1.0000	1	0.300	9
C_S	100 µA	8.700	ppm	Normal k=2	2.0000	1	4.350	∞
C_D	0	46.000	ppm	Rectangular	1.7321	1	26.558	∞
							Combined Uncertainty, $u(E_x)$	26.914
							Effective Degrees of Freedom, v_{eff}	5.83E+08
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	54

10 mA

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	10 mA	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_R	0	0.100	ppm	Normal k=1	1.0000	1	0.100	9
C_S	10 mA	8.700	ppm	Normal k=2	2.0000	1	4.350	∞
C_D	0	31.000	ppm	Rectangular	1.7321	1	17.898	∞
							Combined Uncertainty, $u(E_x)$	18.419
							Effective Degrees of Freedom, v_{eff}	1.04E+10
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	37

1 A

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	1 A	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_R	0	0.200	ppm	Normal k=1	1.0000	1	0.200	9
C_S	1 A	9.300	ppm	Normal k=2	2.0000	1	4.650	∞
C_D	0	52.000	ppm	Rectangular	1.7321	1	30.022	∞
							Combined Uncertainty, $u(E_x)$	30.381
							Effective Degrees of Freedom, v_{eff}	4.79E+09
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	61

8.3. DC Resistance

Model Function:

$$E_x = \frac{(I_{MM} + R_D + R_{TC} + R_P + I_R)}{R_S} - 1$$

I_{MM} = Indication of multimeter
I_R = Repeatability of indication
R_S = Calibration of Standard Resistor
R_D = Uncorrected drift since last calibration
RP = Power effects on Standard Resistor
R_{TC} = Temperature effects on Standard Resistor

10 Ω

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	10	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_R	0	0.200	ppm	Normal k=1	1.0000	1	0.200	9
R_S	10	0.470	ppm	Normal k=2	2.0000	1	0.235	∞
R_D	0	0.100	ppm	Rectangular	1.7321	1	0.058	∞
R_P	0	0.000	ppm	Rectangular	1.7321	1	0.000	∞
R_{TC}	0	0.200	ppm	Rectangular	1.7321	1	0.115	∞
							Combined Uncertainty, $u(E_x)$	0.336
							Effective Degrees of Freedom, v_{eff}	7.15E+01
							Coverage Factor, k	2.036
							Expanded Uncertainty, $U(E_x)$	0.69

10 kΩ

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) ν_i
I_{MM}	10 k	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_R	0	0.400	ppm	Normal k=1	1.0000	1	0.400	9
R_S	10 k	0.570	ppm	Normal k=2	2.0000	1	0.285	∞
R_D	0	0.100	ppm	Rectangular	1.7321	1	0.058	∞
R_P	0	0.000	ppm	Rectangular	1.7321	1	0.000	∞
R_{TC}	0	0.080	ppm	Rectangular	1.7321	1	0.046	∞
							Combined Uncertainty, $u(E_x)$	0.498
							Effective Degrees of Freedom, ν_{eff}	2.15E+01
							Coverage Factor, k	2.126
							Expanded Uncertainty, $U(E_x)$	1.1

10 kΩ Lo I

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) ν_i
I_{MM}	10 k	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_R	0	0.800	ppm	Normal k=1	1.0000	1	0.800	9
R_S	10 k	0.570	ppm	Normal k=2	2.0000	1	0.285	∞
R_D	0	0.100	ppm	Rectangular	1.7321	1	0.058	∞
R_P	0	1.000	ppm	Rectangular	1.7321	1	0.577	∞
R_{TC}	0	0.080	ppm	Rectangular	1.7321	1	0.046	∞
							Combined Uncertainty, $u(E_x)$	1.030
							Effective Degrees of Freedom, ν_{eff}	2.47E+01
							Coverage Factor, k	2.110
							Expanded Uncertainty, $U(E_x)$	2.2

1 MΩ

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) ν_i
I_{MM}	1 M	0.050	ppm	Rectangular	1.7321	1	0.029	∞
I_R	0	1.000	ppm	Normal k=1	1.0000	1	1.000	9
R_S	1 M	3.600	ppm	Normal k=2	2.0000	1	1.800	∞
R_D	0	0.900	ppm	Rectangular	1.7321	1	0.520	∞
R_P	0	0.500	ppm	Rectangular	1.7321	1	0.289	∞
R_{TC}	0	0.220	ppm	Rectangular	1.7321	1	0.127	∞
							Combined Uncertainty, $u(E_x)$	2.147
							Effective Degrees of Freedom, ν_{eff}	1.91E+02
							Coverage Factor, k	2.013
							Expanded Uncertainty, $U(E_x)$	4.4

8.4. AC Voltage

Model Function:

$$E_x = \frac{(I_{MM} + I_R + I_N + V_D)}{V_S} - 1$$

I_{MM} = *Indication of multimeter*
I_R = *Repeatability of indication*
V_S = *Calibration of Multifunction Calibrator*
V_D = *Stability of Multifunction Calibrator since calibration*
I_N = *Zero indication of multimeter*

100 mV at 55 Hz and 1 kHz

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	100 mV	0.500	ppm	Rectangular	1.7321	1	0.289	∞
I_R	0	8.000	ppm	Normal k=1	1.0000	1	8.000	9
V_S	100 mV	37.900	ppm	Normal k=2	2.0000	1	18.950	∞
V_D	0	145.000	ppm	Rectangular	1.7321	1	83.716	∞
I_N	0	15.000	µV	Rectangular	1.7321	10	86.603	∞
							Combined Uncertainty, $u(E_x)$	122.195
							Effective Degrees of Freedom, v_{eff}	4.90E+05
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	245.00

10 V at 55 Hz

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	10 V	0.500	ppm	Rectangular	1.7321	1	0.289	∞
I_R	0	9.000	ppm	Normal k=1	1.0000	1	9.000	9
V_S	10 V	17.600	ppm	Normal k=2	2.0000	1	8.800	∞
V_D	0	47.000	ppm	Rectangular	1.7321	1	27.135	∞
I_N	0	15.000	µV	Rectangular	1.7321	0.1	0.866	∞
							Combined Uncertainty, $u(E_x)$	29.927
							Effective Degrees of Freedom, v_{eff}	1.10E+03
							Coverage Factor, k	2.002
							Expanded Uncertainty, $U(E_x)$	60

10 V at 1 kHz

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	10 V	0.500	ppm	Rectangular	1.7321	1	0.289	∞
I_R	0	1.000	ppm	Normal k=1	1.0000	1	1.000	9
V_S	10 V	16.100	ppm	Normal k=2	2.0000	1	8.050	∞
V_D	0	47.000	ppm	Rectangular	1.7321	1	27.135	∞
I_N	0	15.000	µV	Rectangular	1.7321	0.1	0.866	∞
Combined Uncertainty, $u(E_x)$								28.337
Effective Degrees of Freedom, v_{eff}								5.80E+06
Coverage Factor, k								2.000
Expanded Uncertainty, $U(E_x)$								57

10 V at 100 kHz

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	10 V	0.500	ppm	Rectangular	1.7321	1	0.289	∞
I_R	0	1.000	ppm	Normal k=1	1.0000	1	1.000	9
V_S	10 V	19.600	ppm	Normal k=2	2.0000	1	9.800	∞
V_D	0	130.000	ppm	Rectangular	1.7321	1	75.056	∞
I_N	0	15.000	µV	Rectangular	1.7321	0.1	0.866	∞
Combined Uncertainty, $u(E_x)$								75.705
Effective Degrees of Freedom, v_{eff}								2.96E+08
Coverage Factor, k								2.000
Expanded Uncertainty, $U(E_x)$								152

100 V at 55 Hz

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	100 V	0.500	ppm	Rectangular	1.7321	1	0.289	∞
I_R	0	9.000	ppm	Normal k=1	1.0000	1	9.000	9
V_S	100 V	32.600	ppm	Normal k=2	2.0000	1	16.300	∞
V_D	0	57.000	ppm	Rectangular	1.7321	1	32.909	∞
I_N	0	15.000	µV	Rectangular	1.7321	0.1	0.866	∞
Combined Uncertainty, $u(E_x)$								37.822
Effective Degrees of Freedom, v_{eff}								2.81E+03
Coverage Factor, k								2.001
Expanded Uncertainty, $U(E_x)$								76

100 V at 1 kHz

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	100 V	0.500	ppm	Rectangular	1.7321	1	0.289	∞
I_R	0	2.000	ppm	Normal k=1	1.0000	1	2.000	9
V_S	100 V	24.300	ppm	Normal k=2	2.0000	1	12.150	∞
V_D	0	57.000	ppm	Rectangular	1.7321	1	32.909	∞
I_N	0	15.000	µV	Rectangular	1.7321	0.1	0.866	∞
							Combined Uncertainty, $u(E_x)$	35.149
							Effective Degrees of Freedom, v_{eff}	8.59E+05
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	71

8.5. AC Current

Model Function:

$$E_x = \frac{(I_{MM} + I_R + C_D)}{C_S} - 1$$

I_{MM} = Indication of multimeter
I_R = Repeatability of indication
C_S = Calibration of Multifunction Calibrator
C_D = Stability of Multifunction Calibrator since calibration

10 mA at 300 Hz and 1 kHz

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	10 mA	0.500	ppm	Rectangular	1.7321	1	0.289	∞
I_R	0	3.000	ppm	Normal k=1	1.0000	1	3.000	9
C_S	10 mA	67.300	ppm	Normal k=2	2.0000	1	33.650	∞
C_D	0	150.000	ppm	Rectangular	1.7321	1	86.603	∞
							Combined Uncertainty, $u(E_x)$	92.959
							Effective Degrees of Freedom, v_{eff}	8.30E+06
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	186

1 A at 300 Hz and 1 kHz

Quantity X_i	Estimate x_i	Uncertainty $u(x_i)$, ppm		Probability Distribution	Divisor	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$, ppm	Degrees of Freedom (DoF) v_i
I_{MM}	1 A	0.500	ppm	Rectangular	1.7321	1	0.289	∞
I_R	0	3.000	ppm	Normal k=1	1.0000	1	3.000	9
C_S	1 A	101.600	ppm	Normal k=2	2.0000	1	50.800	∞
C_D	0	390.000	ppm	Rectangular	1.7321	1	225.167	∞
							Combined Uncertainty, $u(E_x)$	230.846
							Effective Degrees of Freedom, v_{eff}	3.16E+08
							Coverage Factor, k	2.000
							Expanded Uncertainty, $U(E_x)$	462

9. EMI Laboratory Personnel

Travelling Standard Calibrated by	Mr Jon Bartholomew Eng Shamsa Saleh Al Kayyoomi
EMI Standards Calibrated by	Eng Shamsa Saleh Al Kayyoomi Eng Hamad Ali Deiban
Report Prepared by	Mr Jon Bartholomew
Report Checked by	Eng Shamsa Saleh Al Kayyoomi Eng Hamad Ali Deiban

Signed:

Jon Bartholomew
Head of Electrical, Time and Frequency Laboratory
Emirates Metrology Institute
Abu Dhabi Quality and Conformity Council

<END OF REPORT>

الهيئة السعودية للمواصفات والمقاييس والجودة - المركز الوطني للقياس والمعايرة

Saudi Standards, Metrology and Quality Organization - National Measurement and Calibration Center

Technical Report
For
Comparison on Calibration of Multimeter

EURAMET Project No 1341

Contact Persons:

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Riyadh, November 2016

1. Introduction

During the 6th Meeting of the EURAMET FG FNMID, held in Istanbul (Turkey) in November 2013, it was decided to organize an intercomparison on multimeter calibration, in order to support the CMCs of NMIs in the CIPM KCDB. This comparison was already proposed by UME and was registered as EURAMET Project No 1341. UME is acting as the pilot institute and is responsible for providing the travelling standard, monitoring its performance during circulation, and the evaluation and reporting of the measurement results. National Measurement and Calibration Center (Saudi Standards, Metrology and Quality Organization, KSA) has been participated in this compaison, as the last participant, to support the accreditation needs for the electrical department in the field of electrical quantities.

The topic of that comparison is “Calibration of 8½ digits Multimeter” for the following quantities:

- ✓ DC Voltage
- ✓ AC Voltage
- ✓ DC Current
- ✓ AC Current
- ✓ DC Resistance

The travelling standard was the 8½ digit Multimeter, Fluke 8508A Reference Multimeter (Figure 1), that already provided by TÜBİTAK UME. This DMM was chosen for its high accuracy and excellent short-term stability on DC Voltage, AC voltage, DC current, AC current and resistance measurement functions.

Figure 1. Travelling standard: Fluke 8508 Reference Multimeter

Front Panel

Rear Panel

NMCC
المركز الوطني للقياس والمعايرة
National Measurement & Calibration Center

2. Information about the Participant Institute

Institute	National Measurement and Calibration Center, NMCC (Saudi Standards, Metrology and Quality Organization, KSA)
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Address	Saudi Standards, Metrology and Quality Organization (SASO) PO. B 3437 Riyadh- Al Muhammadiyah in front of King Saud University (Bldg. # 4, NMCC), 11471 Riyadh Kingdom of Saudi Arabia

3. PERIOD OF MEASUREMENTS

All measurements had performed during the period of: Sunday, 2 October 2016 to Thursday 13 October 2016.

4. AMBIENT TEMPERATURE

- Temperature: (23 ± 1) ^{O}C
- Relative Humidity: (45 ± 5) %

5. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability
Current Shunt	Guildline	9211A	71338	GUILDLINE 2906.01 19/02/2015
Calibrator	Fluke	5730A	2843503	UME, G1LV-0190 06/06/2016

Digital Multimeter	Agilent	3458A	MY45050871	UME,G1LV0005
Standard Resistance	Guildline	9334A-1M	71176	UME,G1LR-0017 01/12/2015
Standard Resistance	Tinsley	5685B	248738, 246844	SASO 2016/51/ EL-IM 7 C
Standard Resistance	Tinsley	5685B	246844	SASO 2016/51/ EL-IM 5 C
DC Standard	Fluke	732B	1978030	SASO 2016/26/EL-VO 11 C
Multi-junction Thermal Converter	Holt	11	322/2+80B	SASO 2016/03/EL-VO 02 C
Multi-junction Thermal Converter	Holt	11	322/2+80D	SASO 2016/03/EL-VO 04 C
Thermal Current Converter	UME	CS10mA/MJ-1V	CS-0001/TC 15 006	UME, G1LV-0263
Thermal Current Converter	UME	CS1A/MJ-1V	CS-0017/TC 15 006	UME, G1LV-0263

6. MEASUREMENT METHOD

6.1 For DC Voltage

- **Range of 20 V**

NMCC performed the calibration of the range of DC-20 V (*for applied value = 10 V*) through the direct method using a traceable Fluke 732B, Reference Standard (as shown in Fig. 2). FLUKE 5730A is already traceable to SI unit through calibration certificate UME (as described in sec. 5). The calibration results of DC Voltage (from 100 mV to 1000 V) are listed in Table 1.

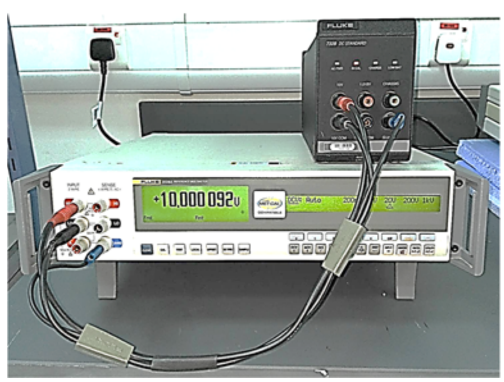

Fig. 2: Direct Measurement of 10V DC using Fluke-732B Ref. St.

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- **Range of 200 mV, 200 V and 1000 V**

NMCC performed the calibration of these ranges (*for applied values = 100 mV, 100 V and 1000 V respectively*) through the direct method using Fluke 5730A, High Performance Multifunction Calibrator (Fig. 3). FLUKE 5730A is already traceable to SI unit through UME (as described in section 5). The calibration results of DC Voltage are listed in Table 1.

Fig. 3: Direct Method for calibration of 100 mV DC

Table 1: Measurement Results of DC Voltage

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 mV	100 mV	99.99994 mV	99.99981 mV	- 0.00013 mV (-1.26 µV/V)	9.7 µV/V
20 V	10 V	10.000038 V	10.000085 V	+ 0.000047 V (+ 4.75 µV/V)	2.3 µV/V
200 V	100 V	99.99987 V	99.99978 V	- 0.00009 V (- 0.89 µV/V)	4.5 µV/V
1000 V	1000 V	999.9999 V	1000.0007 V	+ 0.0008 V (+ 0.77 µV/V)	5.8 µV/V

6.2 For DC Current

NMCC performed the calibration of the ranges of 200 µA, 20 mA and 1 A (*for injected values = 100 µA, 10 mA and 1 A respectively*) through the in-direct method using: Current Shunt (Guildline-9211A) and Digital Multimeter (Agilent-3458A), as shown in Fig. 4. All devices used in this method are already traceable to SI unit through UME and GUILDLINE Co. (as described in section 5). The calibration results of DC Current are listed in Table 2.

Table 2: Measurement Results of DC Current

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 µA	100 µA	100.00360 µA	100.00109 µA	- 0.00251 µA (- 25.1 µA/A)	18 µA/A
20 mA	10 mA	10.000196 mA	10.000299 mA	+ 0.000102 mA (+ 10.2 µA/A)	16 µA/A
1 A	1 A	1.0000237 A	0.9998463 A	- 0.0001774 A (- 177.37 µA/A)	21 µA/A

Fig. 4: In-Direct Method for calibration of DC Currents

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6.3 For Resistance

NMCC performed the calibration of the ranges of: 20 Ω, 20 kΩ and 2 MΩ (for injected values = 10 Ω and 10 kΩ respectively) through the direct method using: Standard Resistors immersed inside controlled oil bath, (as shown in Fig. 5) and 1 MΩ Standard Resistors immersed inside controlled air bath .All devices used in this method are already traceable to SI unit through UME, (as described in section 5). The calibration results of DC resistance are listed in Table 3.

Fig. 5: Direct Method for calibration of DC Resistance

Table 3: Measurement Results of DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
20 Ω	True Ω	10 Ω	9.999729 Ω	9.999859 Ω	+ 0.000130 Ω (+ 13.02 μΩ/Ω)	2.5 μΩ/Ω
20 kΩ	True Ω	10 kΩ	10.000183 kΩ	10.000270 kΩ	+ 0.000087 kΩ (+ 8.68 μΩ/Ω)	2.5 μΩ/Ω
	True Ω Lo I	10 kΩ	10.000183 kΩ	10.000283 kΩ	+ 0.000100 kΩ (+ 10.04 μΩ/Ω)	2.5 μΩ/Ω
2 MΩ	Normal Ω	1 MΩ	1.0000005 MΩ	1.0000101 MΩ	+ 0.0000096 MΩ (+ 9.6 μΩ/Ω)	7.0 μΩ/Ω

6.4 For AC Voltage

6.4.1 Range of 200 mV, 20 V and 200 (55 Hz and 1 kHz)

NMCC performed the calibration of the range of AC voltage: 200 mV (*for applied value = 100 mV @ 55 Hz and 1 kHz*) through the direct method using Fluke 5730A, High Performance Multifunction Calibrator (Fig. 6). FLUKE 5730A is already traceable to SI unit through UME, (as described in section 5). The calibration results of AC Voltage are listed in Table 4.

Fig. 6: Direct Measurement of 100 mV @ 55 Hz and 1 kHz using Calibrator Fluke-5730A

Table 4: Measurement Results of AC Voltage

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequenc				
200 mV	100 mV	55 Hz	100.0000 mV	99.9951 mV	- 0.0050 mV (- 49.50 µV/V)	131 µV/V
	100 mV	1 kHz	100.0000 mV	99.9989 mV	- 0.0011 mV (- 11.0 µV/V)	150 µV/V

20 V	**10 V**	**55 Hz**	**10.00018 V**	**10.00057 V**	**0.00039 V (39.1 µV/V)**	**49 µV/V**
	10 V	**1 kHz**	**10.00012 V**	**10.00097 V**	**0.00085 V (84.6 µV/V)**	**48 µV/V**
	10 V	**100 kHz**	**9.99994 V**	**9.99980 V**	**- 0.00014 V (- 13.8 µV/V)**	**105 µV/V**
200 V	**100 V**	**55 Hz**	**99.9980 V**	**99.9985 V**	**0.0005 V (4.6 µV/V)**	**62 µV/V**
	100 V	**1 kHz**	**99.9964 V**	**100.0017 V**	**0.0053 V (52.7 µV/V)**	**50 µV/V**

6.5 For AC Current

NMCC performed the calibration of the ranges of 20 mA and 2 A (*for injected values = 10 mA and 1 A @ 300 Hz and 1 kHz respectively*) through the in-direct method using: Current Shunt combined in parallel with Multi-junction thermal converter, as shown in Fig. 7. All devices used in this method are already traceable to SI unit through UME, (as described in section 5). The calibration results of DC Current are listed in Table 5.

Fig. 7: In-Direct Method for calibration of AC Currents

Table 5: Measurement Results of AC Current

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty
	Current	Frequency				
20 mA	10 mA	300 Hz	10.00000 mA	10.00064 mA	+ 0.00064 mA (+ 64 µA/A)	43 µA/A
	10 mA	1 kHz	10.00000 mA	10.00067 mA	+ 0.00067 mA (+ 67 µA/A)	43 µA/A
1 A	1 A	300 Hz	1.000000 A	0.999914 A	- 0.000086 A (- 86 µA/A)	94 µA/A
	1 A	1 kHz	1.000000 A	0.999956 A	- 0.000044 A (- 44 µA/A)	96 µA/A

7. SUMMARY OF MEASUREMENT RESULTS

7.1 DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 mV	100 mV	99.99994 mV	99.99981 mV	- 0.00013 mV (-1.26 µV/V)	9.7 µV/V
20 V	10 V	10.000038 V	+ 10.000085 V	+ 0.000047 V (+ 4.75 µV/V)	2.3 µV/V
200 V	100 V	99.99987 V	+ 99.99978 V	- 0.00009 V (- 0.89 µV/V)	4.5 µV/V
1000 V	1000 V	999.9999 V	+ 1000.0007 V	+ 0.0008 V (+ 0.77 µV/V)	5.8 µV/V

7.2 DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 µA	100 µA	100.00360 µA	+ 100.00109 µA	- 0.00251 µA (- 25.07 µA/A)	18 µA/A
20 mA	10 mA	10.000196 mA	+ 10.000299 mA	+ 0.000102 mA (+ 10.2 µA/A)	16 µA/A
1 A	1 A	1.0000237 A	+ 0.9998463 A	- 0.0001774 A (- 177.4 µA/A)	21 µA/A

7.3 DC RESISTANCE

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
20 Ω	True Ω	10 Ω	9.999729 Ω	9.999859 Ω	+ 0.000130 Ω (+ 13.02 µΩ/Ω)	2.5 µΩ/Ω
20 kΩ	True Ω	10 kΩ	10.000183 kΩ	10.000270 kΩ	+ 0.000087 kΩ (+ 8.68 µΩ/Ω)	2.5 µΩ/Ω
	True Ω LoI	10 kΩ	10.000183 kΩ	10.000283 kΩ	+ 0.000100 kΩ (+ 10.04 µΩ/Ω)	2.5 µΩ/Ω
2 MΩ	Normal Ω	1 MΩ	1.0000005 MΩ	1.0000101 MΩ	+ 0.0000096 MΩ (+ 9.6 µΩ/Ω)	7.0 µΩ/Ω

7.4 AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	100.0000 mV	99.9951 mV	- 0.0050 mV (- 49.50 µV/V)	131 µV/V
	100 mV	1 kHz	100.0000 mV	99.9989 mV	- 0.0011 mV (- 11.0 µV/V)	150 µV/V
20 V	10 V	55 Hz	10.00018 V	10.00057 V	0.00039 V (39.1 µV/V)	49 µV/V
	10 V	1 kHz	10.00012 V	10.00097 V	0.00085 V (84.6 µV/V)	48 µV/V
	10 V	100 kHz	9.99994 V	9.99980 V	- 0.00014 V (- 13.8 µV/V)	105 µV/V
200 V	100 V	55 Hz	99.9980 V	99.9985 V	0.0005 V (4.6 µV/V)	62 µV/V
	100 V	1 kHz	99.9964 V	100.0017 V	0.0053 V (52.7 µV/V)	50 µV/V

7.5 AC CURRENT

Range of 8508A	Nominal Value		Applied Current	Reading of 8508A	Error of 8508A	Uncertainty
	Current	Frequency				
20 mA	10 mA	300 Hz	10.00000 mA	10.00064 mA	+ 0.00064 mA (+ 64 µA/A)	43 µA/A
	10 mA	1 kHz	10.00000 mA	10.00067 mA	+ 0.00067 mA (+ 67 µA/A)	43 µA/A
2 A	1 A	300 Hz	1.000000 A	0.999914 A	- 0.000086 A (- 86 µA/A)	94 µA/A
	1 A	1 kHz	1.000000 A	0.999956 A	- 0.000044 A (- 44 µA/A)	96 µA/A

8. UNCERTAINTY BUDGET

Table 6: Uncertainty budget for 100 mV

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	3.4×10^{-9} V	Normal	1.0	3.4×10^{-9} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	1×10^{-7} V	Normal	1.0	1×10^{-7} V	∞
Resolution of UUT	0 V	2.9×10^{-9} V	Rectangular	1.0	2.9×10^{-9} V	∞
Specs of Ref. (5730A)	0 V	4.7×10^{-7} V	Normal	1.0	4.7×10^{-7} V	∞
Thermal emf of the Cable Used	0 V	6.6×10^{-8} V	Rectangular	1.0	6.6×10^{-8} V	∞
Error (E_X)	- 0.00013 mV (-1.26 µV/V)	Combined Uncertainty, $u(E_X)$				4.8×10^{-7} V
		Effective Degrees of Freedom, *veff*				1.5×10^{7} (≈ ∞)
		Coverage Factor, *k*				2
		Expanded Uncertainty, $U(E_X)$				9.7×10^{-7} V (9.7 µV/V)

Table 7: Uncertainty budget for 10 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	1.33 x 10^{-7} V	Normal	1.0	1.33 x 10^{-7} V	9
Calibration Certificate of Ref. St. (732B)	0 V	2.5 x 10^{-7} V	Normal	1.0	2.5 x 10^{-7} V	∞
Resolution of UUT	0 V	2.9 X 10^{-7} V	Rectangular	1.0	2.9 X 10^{-7} V	∞
One-year of Ref. (732B)	0 V	1.15 X 10^{-5} V	Rectangular	1.0	1.15 X 10^{-5} V	∞
Thermal emf of the Cable Used	0 V	6.6 X 10^{-8} V	Rectangular	1.0	6.6 X 10^{-8} V	∞
Error (E_x)	0.000047 V (4.75 µV/V)	Combined Uncertainty, $u(E_x)$				1.16 x 10^{-5} V
		Effective Degrees of Freedom, v_{eff}				1.7 x 10^{5} (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				2.3 X 10^{-5} V (2.3 µV/V)

Table 8: Uncertainty budget for 100 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	2.77 x 10^{-6} V	Normal	1.0	2.77 x 10^{-6} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	5.5 x 10^{-5} V	Normal	1.0	5.5 x 10^{-5} V	∞
Resolution of UUT	0 V	2.9 X 10^{-6} V	Rectangular	1.0	2.9 X 10^{-} V	∞
One-year Specs of Ref. (5730A)	0 V	2.2 X 10^{-4} V	Normal	1.0	2.2 X 10^{-4} V	∞
Thermal emf of the Cable Used	0 V	6.6 X 10^{-8} V	Rectangular	1.0	6.6 X 10^{-8} V	∞
Error (E_x)	-0.00009 V (-0.89 µV/V)	Combined Uncertainty, $u(E_x)$				2.2 x 10^{-4} V
		Effective Degrees of Freedom, v_{eff}				1.6 x 10^{6} (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				4.5 X 10^{-4} V (4.5 µV/V)

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Table 9: Uncertainty budget for 1000 V

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	1.53 x 10^{-7} V	Normal	1.0	1.53 x 10^{-5} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	5.5 x 10^{-4} V	Normal	1.0	5.5 x 10^{-4} V	∞
Resolution of UUT	0 V	2.9 X 10^{-5} V	Rectangular	1.0	2.9 X 10^{-5} V	∞
One-year Specs of Ref. (5730A)	0 V	2.8 X 10^{-3} V	Normal	1.0	2.8 X 10^{-3} V	∞
Thermal emf of the Cable Used	0 V	6.6 X 10^{-8} V	Rectangular	1.0	6.6 X 10^{-8} V	∞
Error (E_x)	0.0008 V (0.77 µV/V)	Combined Uncertainty, $u(E_x)$				2.9 x 10^{-3} V
		Effective Degrees of Freedom, v_{eff}				1.6 x 10^7 (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_x)$				5.8 X 10^{-3} V (5.8 µV/V)

Table 10: Uncertainty budget for 100 µA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0	0.15 ppm	Normal	1.0	0.15 ppm	9
Calibration Certificate of Current Shunt	0	1.35 ppm	Normal	1.0	1.35 ppm	∞
Resolution of UUT	0	0.029 ppm	Rectangular	1.0	0.029 ppm	∞
Drift of Current Shunt	0	5.06 ppm	Rectangular	1.0	5.06 ppm	∞
Calibration Certificate of Digital Voltmeter	0	2.5 ppm	Normal	1.0	2.5 ppm	∞
Thermal emf of cable used in measuring V	0	0.26 ppm	Rectangular	1.0	0.26 ppm	∞
Impedance of DVM	0	0.06 ppm	Rectangular	1.0	0.06 ppm	∞
One-year Specs of Digital Voltmeter	0	6.93 ppm	Rectangular	1.0	6.93 ppm	∞

Error (E_X)	**- 0.00251 µA (-25.1 µA/A)**	**Combined Uncertainty, $u(E_X)$**	**9.04 ppm**
		Effective Degrees of Freedom, *veff*	**2 x 10^7 (≈ ∞)**
		Coverage Factor, *k*	**2**
		Expanded Uncertainty, $U(E_X)$	**(1.8 nA) (18 µA/A)**

Table 11: Uncertainty budget for 10 mA

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	**0**	**0.022 ppm**	**Normal**	**1.0**	**0.022 ppm**	**9**
Calibration Certificate of Current Shunt	**0**	**1.3 ppm**	**Normal**	**1.0**	**1.3 ppm**	∞
Resolution of UUT	**0**	**0.029 ppm**	**Rectangular**	**1.0**	**0.029 ppm**	∞
Drift of Current Shunt	**0**	**1.68 ppm**	**Rectangular**	**1.0**	**1.68 ppm**	∞
Calibration Certificate of Digital Voltmeter	**0**	**2.5 ppm**	**Normal**	**1.0**	**2.5 ppm**	∞
Thermal emf of cable used in measuring V	**0**	**0.26 ppm**	**Rectangular**	**1.0**	**0.26 ppm**	∞
Impedance of DVM	**0**	**0.06 ppm**	**Rectangular**	**1.0**	**0.06 ppm**	∞
One-year Specs of Digital Voltmeter	**0**	**6.93 ppm**	**Rectangular**	**1.0**	**6.93 ppm**	∞
Error (E_X)	**0.000102 µA (10.2 µA/A)**	**Combined Uncertainty, $u(E_X)$**				**7.7 ppm**
		Effective Degrees of Freedom, *veff*				**4.4 x 10^9 (≈ ∞)**
		Coverage Factor, *k*				**2**
		Expanded Uncertainty, $U(E_X)$				**(160 nA) (16 µA/A)**

Table 12: Uncertainty budget for 1 A

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	**0.0 ppm**	**0.0 ppm**	**Normal**	**1.0**	**0.0 ppm**	**9**
Calibration Certificate of Current Shunt	**0.0 ppm**	**1.35 ppm**	**Normal**	**1.0**	**1.35 ppm**	∞
Resolution of UUT	**0.0 ppm**	**0.029 ppm**	**Rectangular**	**1.0**	**0.029 ppm**	∞
Drift of Current Shunt	**0.0 ppm**	**7.16 ppm**	**Rectangular**	**1.0**	**7.16 ppm**	∞
Calibration Certificate of Digital Voltmeter	**0.0 ppm**	**2.5 ppm**	**Normal**	**1.0**	**2.5 ppm**	∞
Thermal emf of cable used in measuring V	**0.0 ppm**	**0.26 ppm**	**Rectangular**	**1.0**	**0.26 ppm**	∞
Impedance of DVM	**0.0 ppm**	**0.06 ppm**	**Rectangular**	**1.0**	**0.06 ppm**	∞
One-year Specs of Digital Voltmeter	**0.0 ppm**	**6.93 ppm**	**Rectangular**	**1.0**	**6.93 ppm**	∞

Error (E_X)	**- 0.0001774 µA (-177.4 µA/A)**	**Combined Uncertainty, *u(Ex)***	**10.4 ppm**
		Effective Degrees of Freedom, *veff*	∞
		Coverage Factor, *k*	**2**
		Expanded Uncertainty, *U(Ex)*	**(21 µA) (21 µA/A)**

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Table 13: Uncertainty budget for 10 Ω (True Ω)

Quantity *Xi*	Estimate *xi*	Standard Uncertainty *u(xi)*	Probability Distribution	Sens. Coeff. *ci*	Uncertainty Contribution *ui(Ex)*	Degrees of Freedom (DoF), *vi*
Repeatability of UUT	0 Ω	1.33×10^{-7} Ω	Normal	1.0	1.33×10^{-7} Ω	9
Calibration Certificate of Standard Resistor	0 Ω	1.5×10^{-6} Ω	Normal	1.0	1.5×10^{-6} Ω	∞
Resolution of UUT	0 Ω	0.29×10^{-6} Ω	Rectangular	1.0	0.29×10^{-6} Ω	∞
Drift of Standard Resistor	0 Ω	1.8×10^{-7} Ω	Rectangular	1.0	1.8×10^{-7} Ω	∞
One-year spec of Resistor	0 Ω	1.15×10^{-5} Ω	Rectangular	1.0	1.15×10^{-5} Ω	∞
Error (Ex)	0.000130 Ω (13.02 μΩ/Ω)	Combined Uncertainty, *u(Ex)*				1.2×10^{-5} Ω
		Effective Degrees of Freedom, *veff*				2.5×10^{7} (≈ ∞)
		Coverage Factor, *k*				2
		Expanded Uncertainty, *U(Ex)*				2.5×10^{-5} Ω (2.5 μΩ/Ω)

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Table 14: Uncertainty budget for 10 kΩ (True Ω)

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 Ω	1.33×10^{-4} Ω	Normal	1.0	1.33×10^{-4} Ω	9
Calibration Certificate of Standard Resistor	0 Ω	2×10^{-3} Ω	Normal	1.0	2×10^{-3} Ω	∞
Resolution of UUT	0 Ω	0.29×10^{-3} Ω	Rectangular	1.0	0.29×10^{-3} Ω	∞
Drift of Standard Resistor	0 Ω	6.02×10^{-4} Ω	Rectangular	1.0	6.02×10^{-4} Ω	∞
One-year spec of Resistor	0 Ω	1.15×10^{-2} Ω	Rectangular	1.0	1.15×10^{-2} Ω	∞
Error (E_X)	0.000087 kΩ (8.68 µΩ/Ω)	Combined Uncertainty, $u(E_X)$				1.2×10^{-2} Ω
		Effective Degrees of Freedom, $veff$				5.7×10^{5} (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_X)$				2.5×10^{-2} Ω (2.5 µΩ/Ω)

Table 15: Uncertainty budget for 10 kΩ (Low I)

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 Ω	3.06×10^{-4} Ω	Normal	1.0	3.06×10^{-4} Ω	9
Calibration Certificate of Standard Resistor	0 Ω	2×10^{-3} Ω	Normal	1.0	2×10^{-3} Ω	∞
Resolution of UUT	0 Ω	0.29×10^{-3} Ω	Rectangular	1.0	0.29×10^{-3} Ω	∞
Drift of Standard Resistor	0 Ω	6.02×10^{-4} Ω	Rectangular	1.0	6.02×10^{-4} Ω	∞
One-year spec of Resistor	0 Ω	1.15×10^{-2} Ω	Rectangular	1.0	1.15×10^{-2} Ω	∞
Error (E_X)	0.000100 kΩ (10.04 µΩ/Ω)	Combined Uncertainty, $u(E_X)$				1.2×10^{-2} Ω
		Effective Degrees of Freedom, v_{eff}				2.2×10^{4} (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_X)$				2.5×10^{-2} Ω (2.5 µΩ/Ω)

Table 16: Uncertainty budget for 1 MΩ (High I)

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 Ω	7.4×10^{-17} MΩ	Normal	1.0	7.4×10^{-17} MΩ	9
Calibration Certificate of Standard Resistor	0 Ω	2×10^{-6} MΩ	Normal	1.0	2×10^{-6} MΩ	∞
Resolution of UUT	0 Ω	0.29×10^{-7} MΩ	Rectangular	1.0	0.29×10^{-7} MΩ	∞
Drift of Standard Resistor	0 Ω	6.6×10^{-9} MΩ	Rectangular	1.0	6.6×10^{-9} MΩ	∞
One-year spec of Resistor	0 Ω	2.9×10^{-6} MΩ	Rectangular	1.0	2.9×10^{-6} MΩ	∞
Error (E_X)	0.0000096 MΩ (9.6 µΩ/Ω)	Combined Uncertainty, $u(E_X)$				3.5×10^{-6} MΩ
Error (E_X)	0.0000096 MΩ (9.6 µΩ/Ω)	Effective Degrees of Freedom, $veff$				4.8×10^{43} (≈ ∞)
Error (E_X)	0.0000096 MΩ (9.6 µΩ/Ω)	Coverage Factor, k				2
Error (E_X)	0.0000096 MΩ (9.6 µΩ/Ω)	Expanded Uncertainty, $U(E_X)$				7×10^{-6} MΩ (7.0 µΩ/Ω)

Table 17: Uncertainty budget for 100 mV @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	7.03 x 10^{-8} V	Normal	1.0	7.03 x 10^{-8} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	1.5 x 10^{-6} V	Normal	1.0	1.5 x 10^{-6} V	∞
Resolution of UUT	0 V	0.29 X 10^{-7} V	Rectangular	1.0	0.29 X 10^{-7} V	∞
Drift of Ref. (5730A)	0 V	1.92 X 10^{-8} V	Rectangular	1.0	1.92 X 10^{-8} V	∞
One-year spec of Ref. (Fluke-5730A)	0 V	6.35 x 10^{-6} V	Normal	1.0	6.35 x 10^{-6} V	∞
Error (E_X)	- 0.0050 mV (- 49.5 µV/V)	Combined Uncertainty, $u(E_X)$				6.6 x 10^{-6} V
		Effective Degrees of Freedom, *veff*				1.9 x 10^{6} (≈ ∞)
		Coverage Factor, *k*				2
		Expanded Uncertainty, $U(E_X)$				1.3 X 10^{-5} V (131 µV/V)

Table 18: Uncertainty budget for 100 mV @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	7.45 x 10^{-8} V	Normal	1.0	7.45 x 10^{-8} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	1.5 x 10^{-6} V	Normal	1.0	1.5 x 10^{-6} V	∞
Resolution of UUT	0 V	0.29 X 10^{-7} V	Rectangular	1.0	0.29 X 10^{-7} V	∞
Drift of Ref. (5730A)	0 V	5.77 X 10^{-8} V	Rectangular	1.0	5.77 X 10^{-8} V	∞
One-year spec of Ref. (Fluke-5730A)	0 V	7.5 x 10^{-6} V	Normal	1.0	7.5 x 10^{-6} V	∞
Error (E_X)	- 0.0011 mV (- 11.0 µV/V)	Combined Uncertainty, $u(E_X)$				7.5 x 10^{-6} V
		Effective Degrees of Freedom, *veff*				1.5 x 10^{6} (≈ ∞)
		Coverage Factor, *k*				2
		Expanded Uncertainty, $U(E_X)$				15 X 10^{-6} V (150 µV/V)

Table 19: Uncertainty budget for 10 V @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	5.5×10^{-6} V	Normal	1.0	5.5×10^{-6} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	6×10^{-5} V	Normal	1.0	6×10^{-5} V	∞
Resolution of UUT	0 V	2.9×10^{-6} V	Rectangular	1.0	2.9×10^{-6} V	∞
Drift of Ref. (5730A)	0 V	6.3×10^{-6} V	Rectangular	1.0	6.3×10^{-6} V	∞
One-year spec of Ref. (Fluke-5730A)	0 V	2.4×10^{-4} V	Normal	1.0	2.4×10^{-4} V	∞
Error (E_X)	0.00039 V (39.1 µV/V)	Combined Uncertainty, $u(E_X)$				2.43×10^{-4} V
		Effective Degrees of Freedom, *veff*				2×10^{43}
		Coverage Factor, *k*				2
		Expanded Uncertainty, $U(E_X)$				4.9×10^{-4} V (49 µV/V)

Table 20: Uncertainty budget for 10 V @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	1.63×10^{-6} V	Normal	1.0	1.63×10^{-6} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	5.5×10^{-5} V	Normal	1.0	5.5×10^{-5} V	∞
Resolution of UUT	0 V	2.9×10^{-6} V	Rectangular	1.0	2.9×10^{-6} V	∞
Drift of Ref. (5730A)	0 V	2.9×10^{-6} V	Rectangular	1.0	2.9×10^{-6} V	∞
One-year spec of Ref. (Fluke-5730A)	0 V	2.3×10^{-4} V	Normal	1.0	2.3×10^{-4} V	∞
Error (E_X)	0.00085 V (84.6 µV/V)	Combined Uncertainty, $u(E_X)$				2.4×10^{-4} V
		Effective Degrees of Freedom, *veff*				4.2×10^{3} (≈ ∞)
		Coverage Factor, *k*				2
		Expanded Uncertainty, $U(E_X)$				4.8×10^{-4} V (48 µV/V)

Table 21: Uncertainty budget for 10 V @ 100 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	**0 V**	**3.9×10^{-6} V**	**Normal**	**1.0**	**3.9×10^{-6} V**	**9**
Calibration Certificate of Ref. (Fluke-5730A)	**0 V**	**1×10^{-4} V**	**Normal**	**1.0**	**1×10^{-4} V**	∞
Resolution of UUT	**0 V**	**2.9×10^{-6} V**	**Rectangular**	**1.0**	**2.9×10^{-6} V**	∞
Drift of Ref. (5730A)	**0 V**	**1.2×10^{-5} V**	**Rectangular**	**1.0**	**1.2×10^{-5} V**	∞
One-year spec of Ref. (Fluke-5730A)	**0 V**	**5.1×10^{-4} V**	**Normal**	**1.0**	**5.1×10^{-4} V**	∞
Error (E_X)	**- 0.00014 V (-13.8 µV/V)**				**Combined Uncertainty, $u(E_X)$**	**5.25×10^{-4} V**
					Effective Degrees of Freedom, v_{eff}	**1641 (≈ ∞)**
					Coverage Factor, k	**2**
					Expanded Uncertainty, $U(E_X)$	**1.05×10^{-3} V (105 µV/V)**

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Table 22: Uncertainty budget for 100 V @ 55 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	3.1×10^{-5} V	Normal	1.0	3.1×10^{-5} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	1×10^{-3} V	Normal	1.0	1×10^{-3} V	∞
Resolution of UUT	0 V	2.9×10^{-5} V	Rectangular	1.0	2.9×10^{-5} V	∞
Drift of Ref. (5730A)	0 V	4.8×10^{-5} V	Rectangular	1.0	4.8×10^{-5} V	∞
One-year spec of Ref. (Fluke-5730A)	0 V	2.9×10^{-3} V	Normal	1.0	2.9×10^{-3} V	∞
Error (E_X)	0.0005 V (4.6 µV/V)	Combined Uncertainty, $u(E_X)$				3.1×10^{-3} V
		Effective Degrees of Freedom, v_{eff}				2×10^{6} (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_X)$				6.1×10^{-3} V (62 µV/V)

Table 23: Uncertainty budget for 100 V @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0 V	2.6×10^{-5} V	Normal	1.0	2.6×10^{-5} V	9
Calibration Certificate of Ref. (Fluke-5730A)	0 V	7.5×10^{-4} V	Normal	1.0	7.5×10^{-4} V	∞
Resolution of UUT	0 V	2.9×10^{-5} V	Rectangular	1.0	2.9×10^{-5} V	∞
Drift of Ref. (5730A)	0 V	9.6×10^{-6} V	Rectangular	1.0	9.6×10^{-6} V	∞
One-year spec of Ref. (Fluke-5730A)	0 V	2.4×10^{-3} V	Normal	1.0	2.4×10^{-3} V	∞
Error (E_X)	0.0053 V (52.7 µV/V)	Combined Uncertainty, $u(E_X)$				2.5×10^{-3} V
		Effective Degrees of Freedom, $veff$				6×10^4 (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_X)$				5×10^{-3} V (50 µV/V)

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Table 24: Uncertainty budget for 10 mA @ 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0	6 x 10^{-11} ppm	Normal	1.0	6 x 10^{-11} ppm	9
Calibration Certificate of DC Current Source (5730A)	0	6.5 ppm	Normal	1.0	6.5 ppm	∞
Resolution of UUT	0	0.29 ppm	Rectangular	1.0	0.0029 ppm	∞
Drift of DC Current Source (5730A)	0	0.39 ppm	Rectangular	1.0	0.39 ppm	∞
Calibration Certificate of Thermal Current Converter (TCC)	0	2 ppm	Normal	1.0	2 ppm	∞
Setup of AC-DC System	0	5 ppm	Rectangular	1.0	5 ppm	∞
One-year spec of DC Current sources as a Ref. (5730)	0	19.5 ppm	Normal	1.0	19.5 ppm	∞
Drift of Thermal Current Converter (TCC)	0	2 ppm	Rectangular	1.0	2 ppm	∞
Error (E_X)	0.00064 mA (64 µA/A)	Combined Uncertainty, $u(E_X)$				21.4 ppm
		Effective Degrees of Freedom, *veff*				1.7 x 10^{45} (≈ ∞)
		Coverage Factor, *k*				2
		Expanded Uncertainty, $U(E_X)$				(0.43 µA) (43 µA/A)

Table 25: Uncertainty budget for 10 mA @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0	5.8×10^{-11} ppm	Normal	1	5.8×10^{-11} ppm	9
Calibration Certificate of DC Current Source (5730A)	0	6.5 ppm	Normal	1	6.5 ppm	∞
Resolution of UUT	0	0.29 ppm	Rectangular	1	0.29 ppm	∞
Drift of DC Current Source (5730A)	0	0.39 ppm	Rectangular	1	0.39 ppm	∞
Calibration Certificate of Thermal Current Converter (TCC)	0	2 ppm	Normal	1	2 ppm	∞
Setup of AC-DC System	0	5 ppm	Rectangular	1	5 ppm	∞
One-year spec of DC Current sources as a Ref.	0	19.5 ppm	Normal	1	19.5 ppm	∞
Drift of Thermal Current Converter (TCC)	0	2 ppm	Rectangular	1	2 ppm	∞
Error (E_X)	0.00067 mA (67 µA/A)	Combined Uncertainty, $u(E_X)$				21.4 ppm
		Effective Degrees of Freedom, *veff*				1.7×10^{45} (≈ ∞)
		Coverage Factor, *k*				2
		Expanded Uncertainty, $U(E_X)$				(0.43 µA) (43 µA/A)

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Table 26: Uncertainty budget for 1 A @ 300 Hz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_X)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0	0.42 ppm	Normal	1.0	0.42 ppm	9
Calibration Certificate of DC Current Source (5730A)	0	7.5 ppm	Normal	1.0	7.5 ppm	∞
Resolution of UUT	0	0.3 ppm	Rectangular	1.0	0.3 ppm	∞
Drift of DC Current Source (5730A)	0	0.15 ppm	Rectangular	1.0	0.15 ppm	∞
Calibration Certificate of Thermal Current Converter (TCC)	0	4 ppm	Normal	1.0	4 ppm	∞
Setup of AC-DC System	0	10 ppm	Rectangular	1	10 ppm	∞
One-year spec of DC Current sources as a Ref. (5730)	0	45 ppm	Normal	1	45 ppm	∞
Drift of Thermal Current Converter (TCC)	0	2 ppm	Rectangular	1	2 ppm	∞
Error (E_X)	- 0.000086 A (- 86 µA/A)	Combined Uncertainty, $u(E_X)$				47 ppm
		Effective Degrees of Freedom, $veff$				1.5×10^9 (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_X)$				(94 µA) (94 µA/A)

Table 27: Uncertainty budget for 1 A @ 1 kHz

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sens. Coeff. c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF), v_i
Repeatability of UUT	0	8.7 ppm	Normal	1.0	8.7 ppm	9
Calibration Certificate of DC Current Source (5730A)	0	7.5 ppm	Normal	1.0	7.5 ppm	∞
Resolution of UUT	0	0.29 ppm	Rectangular	1.0	0.29 ppm	∞
Drift of DC Current Source (5730A)	0	0.15 ppm	Rectangular	1.0	0.15 ppm	∞
Calibration Certificate of Thermal Current Converter (TCC)	0	4 ppm	Normal	1.0	4 ppm	∞
Setup of AC-DC System	0	10 ppm	Rectangular	1	10 ppm	∞
One-year spec of DC Current sources as a Ref. (5730)	0	45 ppm	Normal	1	45 ppm	∞
Drift of Thermal Current Converter (TCC)	0	2 ppm	Rectangular	1	2 ppm	∞
Error (E_X)	- 0.000044 A (- 44 µA/A)	Combined Uncertainty, $u(E_X)$				48 ppm
		Effective Degrees of Freedom, v_{eff}				8200 (≈ ∞)
		Coverage Factor, k				2
		Expanded Uncertainty, $U(E_X)$				(96 µA) (96 µA/A)

End of Report