GULFMET.EM.S8

Comparison of Calibration of Multimeter

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Issue 1

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1. Introduction

GULFMET is the regional metrology organisation (RMO) for national metrology institutes (NMIs) of the Gulf region. The members and associate members within this RMO agreed to organize a supplementary comparison (SC) on the calibration of 8½ digit multimeter The Emirates Metrology Institute (EMI) agreed to act as pilot laborator and characterise the travelling standards. Standards and Calibration Laboratory (SCL), as an associate member of GULFMET agreed to support the comparison, particularly by carrying out the analysis of results..

This comparison was approved by GULFMET Technical Committee Electricity, Magnetism, Time and Frequency (TC EMTF) at its June 2020 meeting and declared as supplementary comparison GULFMET.EM-S8.

The travelling standard was an 8½ digit Fluke 8508A Reference Multimeter. The measurement points were chosen to be the same as used in EURAMET Project No 1341.

2. Participants and organization for the comparison

2.1 Coordinator and support group

The Emirates Metrology Institute (EMI) will coordinate the comparison, monitor the stability of the standard and report the measurement results.

Standards and Calibration Laboratory (SCL) supported the comparison, particularly by reviewing the protocol and report and carrying out the analysis of results.

2.2 List of Participants

Table 1 List of Participants

No	Country / Economy	Acronym of Institute	Name of Institute
1.	United Arab Emirates	EMI	Abu Dhabi Quality and Conformity Council, Emirates Metrology Institute
2.	Hong Kong, China	SCL	Standards and Calibration Laboratory
3.	Saudi Arabia	SASO-NMCC	Saudi Standards, Metrology and Quality Organization National Measurement and Calibration Center
4.	Qatar	QGOSM	Qatar General Organization for Standards and Metrology
5.	Bosnia and Herzegovina	IMBIH	Institute of Metrology of Bosnia and Herzegovina
6.	Uzbekistan	UzNIM	Uzbek National Institute of Metrology of Uzstandard Agency

2.3 Comparison Schedule

Table 2 Comparison Schedule

Measurement Dates	Country / Economy	Acronym of Institute
3 October to 15 October 2021	United Arab Emirates	EMI
9 December to 15 December 2021	Saudi Arabia	SASO-NMCC
23 December to 24 February 2022	United Arab Emirates	EMI
24 April to 17 May 2022*	Qatar	QGOSM
13 June to 24 June 2022	United Arab Emirates	EMI
25 July to 5 August 2022	Bosnia and Herzegovina	IMBIH
5 September to 16 September 2022	Hong Kong, China	SCL
17 October to 28 October 2022	Uzbekistan	UzNIM
28 November to 16 December 2022*	United Arab Emirates	EMI
***Period extended to allow for public holiday**		

3. Travelling Standard

The travelling standard was an 8½ digit Fluke 8508A Reference Multimeter Serial Number 218865629 (Figure 1), supplied by EMI. This DMM was chosen for its high accuracy and stability in time on DC Voltage, AC voltage, DC current, AC current and resistance measurement functions. It can be remotely operated by means of an IEEE 488 interface. The general specifications of Fluke 8508A are given in Table 3.

Full descriptions, manuals and specifications for the transfer standard can be found at:
https://us.flukecal.com/products/obsolete-products/8508a-85-digit-reference-multimeter?quicktabs_product_details=2

The travelling standard was packed in a transport case of size (80.5 x 53.0 x 32.5) cm and a total weight of 20 kg.

Front Panel

Rear Panel

Figure 1 The travelling standard.

Table 3 The general specifications of the travelling standard

Power	Power supply Consumption	100 v to 120V or 200 V to 240 V rms ±10 % @ 47 Hz to 63 Hz < 80 VA
Dimensions	Height Width	88 mm 427 mm

	Depth 487 mm
Weight	11.5 kg
Environment Temperature	Specified Operation 5 °C to 40 °C Storage -20 °C to 70 °C
Relative Humidity	Operating 5 °C to 40 °C < 90 %rh Storage 0 °C to 70 °C < 95 %rh
Warm Up Time	4 hours to full uncertainty specification
Measurement Ranges	DC Voltage: 200 mV, 2 V, 20 V, 200 V, 1000 V AC Voltage: 200 mV, 2 V, 20 V, 200 V, 1000 V (1 Hz to 1 MHz) DC Current: 200 µA, 2 mA, 20 mA, 200 mA, 2 A, 20 A AC Current: 200 µA, 2 mA, 20 mA, 200 mA, 2 A, 20 A (1 Hz to 100 kHz) Resistance: 2 Ω, 20 Ω, 200 Ω, 2 kΩ, 20 kΩ, 200 kΩ, 2 MΩ, 20 MΩ, 200 MΩ, 2 GΩ, 20 GΩ

4. Measurement Instructions

The measurement instructions, describing the preliminary operations to be performed on the travelling standard and the configuration required for each measurement function and range, were given in the Technical Protocol given in Appendix A. The measurements were performed according to participants' normal calibration procedure. Measurement methods used by the participants were given in the comparison reports of participants in Appendix B

5. Quantities to be measured.

The quantities to be measured are DC voltage, DC current, AC voltage, AC current and DC resistance. The measurement points for each quantity, the settling time and the configuration of the Fluke 8508A, during the comparison measurements are given in Table 4

The measurement results were reported as the relative error of the reference multimeter and calculated by:

$$Relative\ Error = \frac{Indicated\ Value - Applied\ Value}{Applied\ Value}$$

Table 4 Measurement quantities, points and conditions

Quantity	Measurement Point	Range of 8508A	Settling Time of 8508A	Configuration of 8508A
DC Voltage	100 mV	200 mV	5 min	Resolution 7 Filter ON Fast OFF Front Input
	10 V	20 V	5 min	
	100 V	200 V	5 min	
	1000 V	1000 V	10 min	
DC Current	100 µA	200 µA	5 min	Resolution 7 Filter ON Fast OFF Front Input
	10 mA	20 mA	5 min	
	1 A	2 A	30 min	
AC Voltage	100 mV @ 55 Hz┼	200 mV	5 min	Resolution 6 Transfer ON AC Coupled RMS Filter 100 Hz (┼RMS Filter 40 Hz at 55 Hz) Front Input
	100 mV @ 1 kHz		5 min	
	10 V @ 55 Hz┼	20 V	5 min	
	10 V @ 1 kHz		5 min	
	10 V @ 100 kHz		5 min	
	100 V @ 55 Hz┼	200 V	5 min	
	100 V @ 1 kHz		5 min	
AC Current	10 mA @ 300 Hz	20 mA	5 min	Resolution 6 AC Coupled RMS Filter 100 Hz Front Input
	10 mA @ 1 kHz		5 min	
	1 A @ 300 Hz	2 A	30 min	
	1 A @ 1 kHz		30 min	
DC Resistance	10 Ω	20 Ω	5 min	TrueΩ Resolution 7 4-Wire Low Current OFF Fast OFF Front Input
	10 kΩ	20 kΩ	5 min	
	10 kΩ	20 kΩ	5 min	TrueΩ Resolution 7 4-Wire Low Current ON Fast OFF Front Input
	1 MΩ	2 MΩ	5 min	Normal Ω Resolution 7 4-Wire Low Current OFF Filter ON Fast OFF Front Input

6. Behaviour of the Travelling Standards

6.1 Stability of the travelling standards

Drift trends were estimated from the measurements made by EMI at the beginning, middle and end of the comparison. The measurements results used to analyse the drift of the travelling standard are given in the EMI results in Appendix B

Drift trends were assumed to be a linear model as:

$$y_{ref} = \alpha + \beta t$$

Model parameters (α, β) were found by linear regression.

The standard error of the estimate (se) is used as the standard uncertainty:

$$u(y_{ref}) = se$$

All 3 data points were included for regression of the trend line.

Drift trends at all test points were found to be within specification.

The travelling standard is therefore considered as having good stability.

The fit parameters of the drift of the travelling standard are given in Table 5

Table 5 Fit parameters of the drift of the travelling standard

Function	Test Point				Spec 95%	Measured drift trend		In-spec
	Value	**Unit**	**Frequency**		**10^{-6}/365 days**	**10^{-6}/day**	**10^{-6}/365 days**	
DCV	100	mV			7.4	0.00039	0.14235	Y
	10	V			7.4	0.00096	0.3504	Y
	100	V			7.4	0.0005	0.1825	Y
	1000	V			6.7	-0.0032	-1.168	Y
DCI	100	µA			16.2	0.0032	1.168	Y
	10	mA			17.2	0.0021	0.7665	Y
	1	A			186.2	0.097	35.405	Y
DCR	10	Ω			10.6	-0.00072	-0.2628	Y
	10	kΩ			8.2	-0.00052	-0.1898	Y
	10	kΩ	LoI		8.9	-0.00064	-0.2336	Y
	1	MΩ			9.7	0.0056	2.044	Y
ACV	100	mV	55	Hz	150	-0.0016	-0.584	Y
	100	mV	1	kHz	125	-0.021	-7.665	Y
	10	V	55	Hz	105	0.008	2.92	Y
	10	V	1	kHz	85	0.0045	1.6425	Y
	10	V	100	kHz	705	0.56	204.4	Y
	100	V	55	Hz	105	0.00025	0.09125	Y
	100	V	1	kHz	85	0.0026	0.949	Y
ACI	10	mA	300	Hz	480	0.019	6.935	Y
	10	mA	1	kHz	480	0.16	58.4	Y
	1	A	300	Hz	800	-0.035	-12.775	Y
	1	A	1	kHz	800	-0.028	-10.22	Y

7. Reference Values

7.1 Correction for Drift

Daily drift is given by:

$$drift = \beta(t - t0)$$

Where:

$t0$ is as the mean date of the first measurement performed by the pilot lab,

t is the mean date of individual measurements.

All measurement results are then corrected for the drift:

$$x_i^{'} := x_i - drift$$

Measurement uncertainties are then updated as:

$$u(x_i') := \sqrt{u^2(x_i) + u^2(y_{ref})}$$

7.2 Calculation of Reference Values

The weighted mean of participants' results is calculated as the comparison reference value (CRV):

$$y = \sum w_i \cdot x_i^{'}$$

Where the weights are computed from the standard uncertainties of individual measurements:

$$w_i = \frac{1}{u^2(x_i^{'})}$$

The standard uncertainty of weighted mean is given by:

$$u(y) = \sqrt{\frac{1}{\sum w_i}}$$

For EMI which has performed multiple measurements, the result of the measurements made in the middle of the comparison is used for the calculation of the deviation and weighted mean.

Deviations from the weighed mean are calculated for each measurement results:

$$d_i = x_i^{'} - y$$

Standard uncertainty of deviation is given by:

$$u(d_i) = \sqrt{u^2\left(x_i^{'}\right) - u^2(y)}$$

As a consistency check the observed chi-squared value is calculated as:

$$\chi^2_{obs} = \sum \frac{(x_i^{'} - y)^2}{u^2(x_i^{'})}$$

The consistency check does not fail if:

$$P(\chi^2(\nu) > \chi^2_{obs}) \geq 0.05$$

The degrees of freedom, ν, is assigned as the number of observations n-1.

If the consistency check fails, discrepant results are identified as outliers:

$$|d_i| > 2u(d_i)$$

The outliers are then removed from the calculation of the weighted mean. If multiple outliers have been identified outliers are removed one-by-one with the largest normalized error (En) first.

For results included in weighted mean

$$E_n = \frac{d_i}{\sqrt{U^2(x_i') - U^2(y)}}$$

For results excluded from weighted mean

$$E_n = \frac{d_i}{\sqrt{U^2(x_i') + U^2(y)}}$$

The weighted mean is re-calculated until the consistency check does not fail. When the consistency check does not fail, the value y is taken as the comparison reference value (CRV), or x_{ref}

Degree of equivalence for each measurement result is calculated as:

$$d_i = x_i' - x_{ref}$$

$$U(d_i) = 2u(d_i)$$

Where the uncertainties are given by:

For results included in CRV:

$$u(d_i) = \sqrt{u^2(x_i') - u^2(x_{ref})}$$

For results excluded from CRV:

$$u(d_i) = \sqrt{u^2(x_i') + u^2(x_{ref})}$$

7.3 Results of the Participating Institutes

The participant's reported results and detailed uncertainty budgets from all participants are given in Appendix B.

7.4 Traceability Information for the Participating Institutes

Traceability information provided by the laboratories showed no common sources of traceability.

7.5 Differences from Reference Values

Table 6 shows the degrees of equivalence for the DC voltage measurements. Figure 2 to Figure 5 show the corrected relative measured error of the participating institutes and the deviation with respect to the comparison reference value. Uncertainty bars represent the expanded uncertainty.

Table 6 DC Voltage Results

Degree of Equivalence (DoE)		100 mV		10 V		100 V		1000 V	
Participant		Deviation	Expanded uncertainty	Deviation	Expanded uncertainty	Deviation	Expanded uncertainty	Deviation	Expanded uncertainty
n		D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
		(µV/V)	(µV/V)	(µV/V)	(µV/V)	(µV/V)	(µV/V)	(µV/V)	(µV/V)
1	SASO	1.25	7.59	0.11	3.99	0.28	5.17	0.74	6.94
2	QGOSM	1.49	5.13	0.97	1.06	1.60	1.84	0.71	5.04
3	EMI	-1.40	3.40	-0.19	1.16	-0.72	4.30	0.21	6.94
4	IMBIH	1.76	3.09	-0.62	0.63	-0.45	1.49	-0.87	4.90
5	SCL	-1.06	3.62	0.11	0.28	-0.37	1.70	0.54	4.96
6	UzNIM	-9.31	13.82	-5.31	4.32	-4.32	6.43	-2.63	9.34

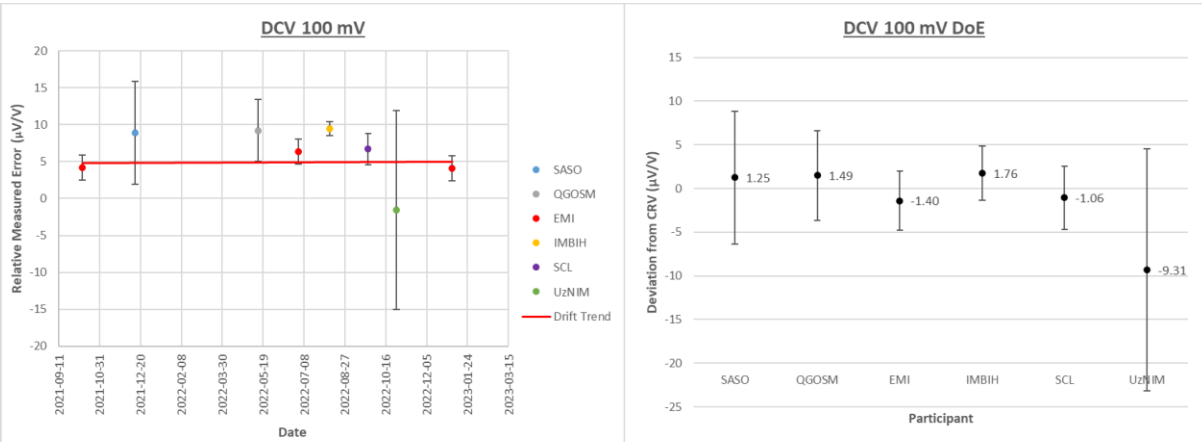


Figure 2

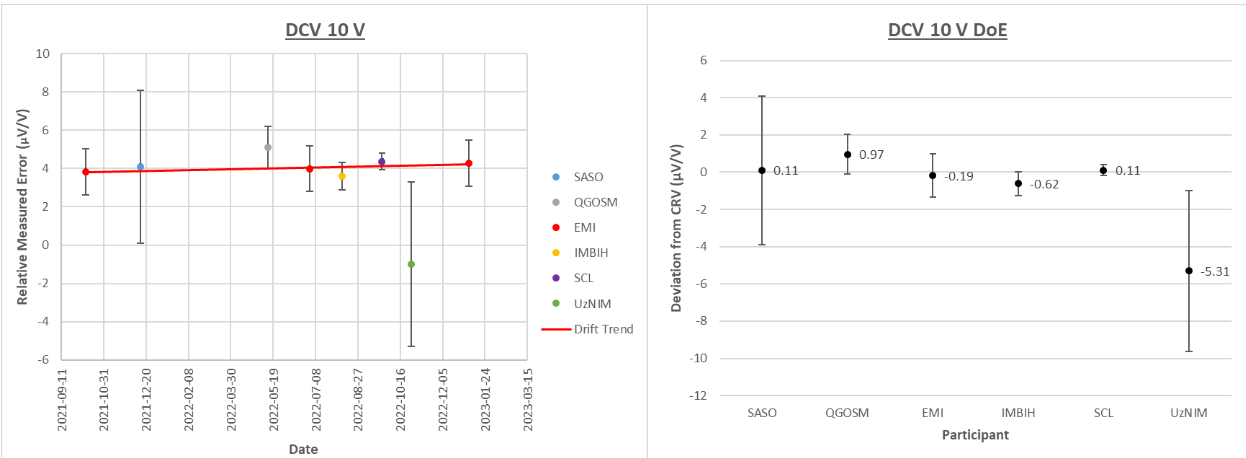


Figure 3

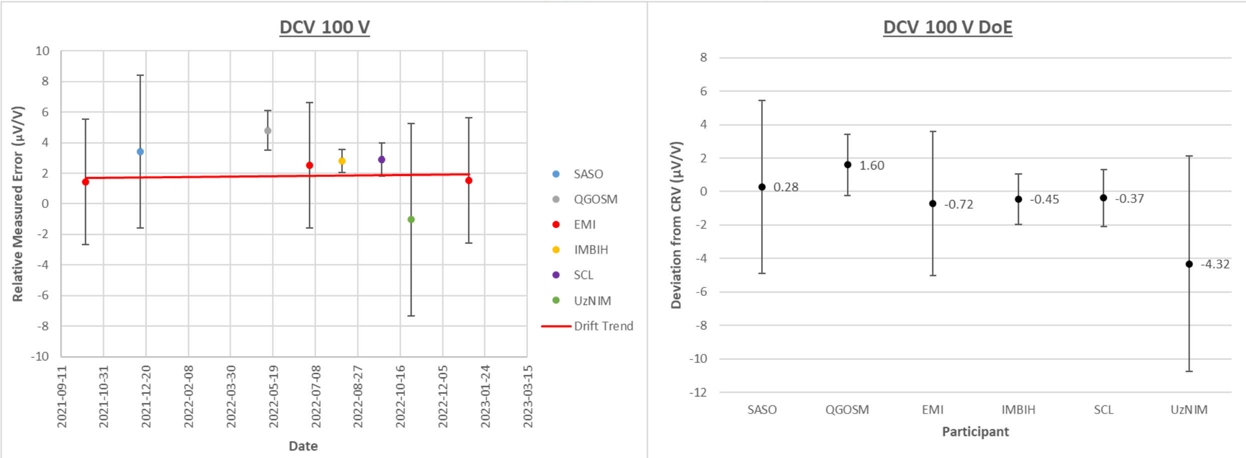


Figure 4

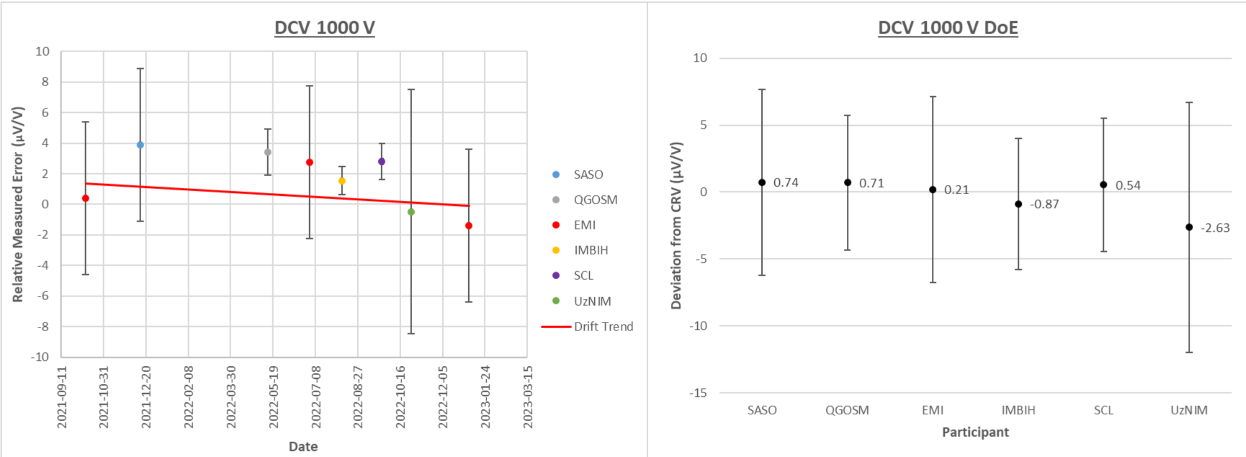


Figure 5

Table 7 shows the degrees of equivalence for the DC current measurements. Figure 6 to Figure 8 show the corrected relative measured error of the participating institutes and the deviation with respect to the comparison reference value. Uncertainty bars represent the expanded uncertainty.

Table 7 DC Current Results

Degree of Equivalence (DoE)		100 µA		10 mA		1 A	
Participant		**Deviation**	**Expanded uncertainty**	**Deviation**	**Expanded uncertainty**	**Deviation**	**Expanded uncertainty**
n		D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
		(µA/A)	**(µA/A)**	**(µA/A)**	**(µA/A)**	**(µA/A)**	**(µA/A)**
1	SASO	-28.98	37.99	-20.08	39.99	-21.54	73.38
2	QGOSM	-0.68	6.83	-3.26	4.64	2.36	60.43
3	EMI	-3.39	4.91	-5.86	6.45	39.97	82.70
4	IMBIH	3.74	6.33	0.12	3.92	-15.01	58.38
5	SCL	0.08	0.30	0.20	0.23	5.11	58.49
6	UzNIM	-16.93	117.20	-9.01	46.89	189.84	130.30

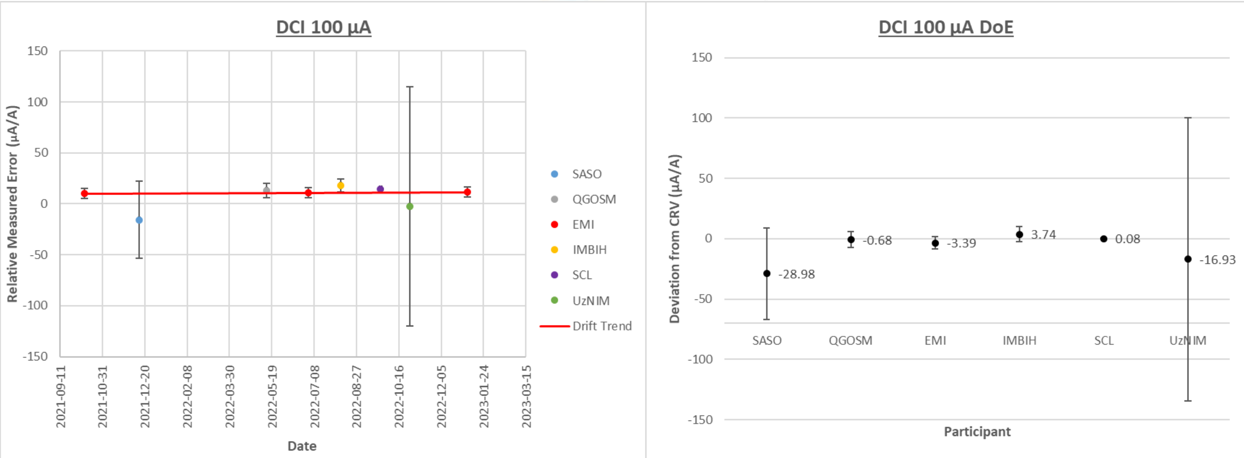


Figure 6

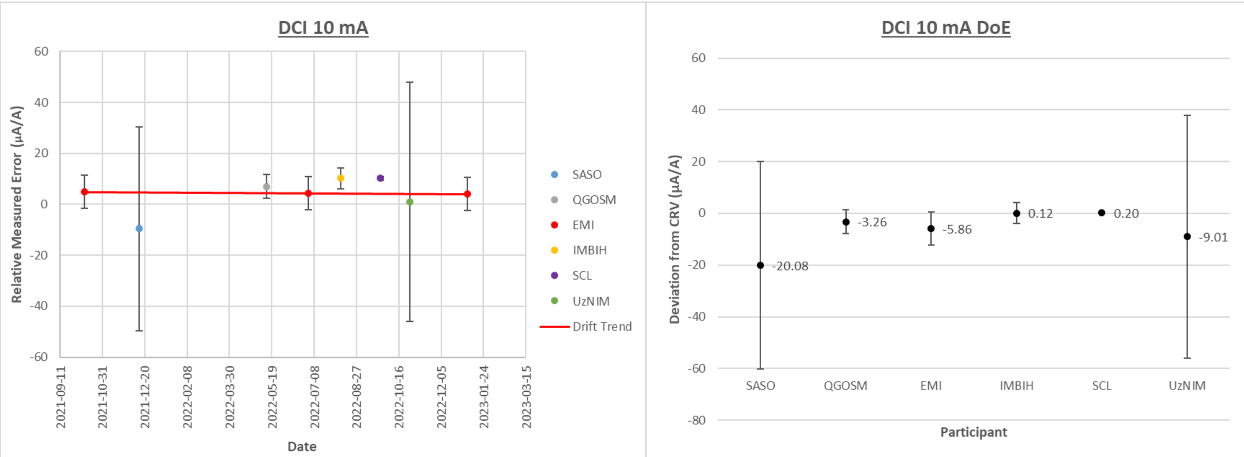


Figure 7

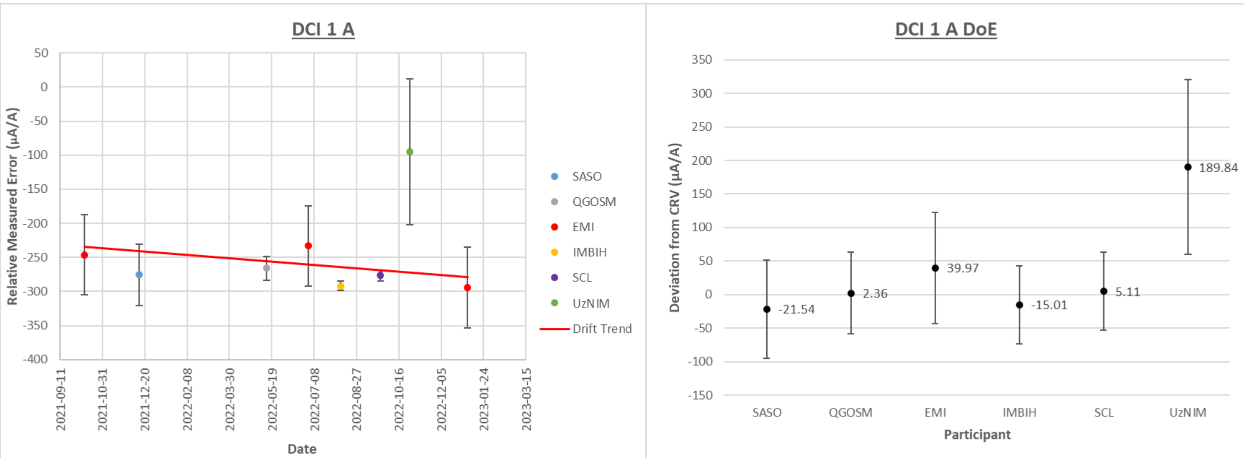


Figure 8

Table 8 shows the degrees of equivalence for the DC resistance measurements. Figure 9 to Figure 12 show the corrected relative measured error of the participating institutes and the deviation with respect to the comparison reference value. Uncertainty bars represent the expanded uncertainty.

Table 8 DC Resistance Results

Degree of Equivalence (DoE)		**10 Ω**		**10 kΩ**		**10 kΩ LoI**		**1 MΩ**	
Participant		**Deviation**	**Expanded uncertainty**	**Deviation**	**Expanded uncertainty**	**Deviation**	**Expanded uncertainty**	**Deviation**	**Expanded uncertainty**
n		***D*i**	***U*(*D*i)**	***D*i**	***U*(*D*i)**	***D*i**	***U*(*D*i)**	***D*i**	***U*(*D*i)**
		(µΩ/Ω)	**(µΩ/Ω)**	**(µΩ/Ω)**	**(µΩ/Ω)**	**(µΩ/Ω)**	**(µΩ/Ω)**	**(µΩ/Ω)**	**(µΩ/Ω)**
1	SASO	-14.66	15.01	2.21	10.99	-7.14	10.99	-1.85	18.18
2	QGOSM	-3.71	7.12	1.48	2.96	3.66	3.66		
3	EMI	-0.53	3.14	-1.78	3.56	-1.74	3.56	-3.32	4.90
4	IMBIH	0.56	0.95	1.73	1.05	2.61	1.11	0.33	2.94
5	SCL	-0.23	0.86	-0.02	0.16	-0.03	0.15	1.87	2.94
6	UzNIM	-11.03	5.36	-3.46	1.38	-1.64	1.46	-9.03	15.41

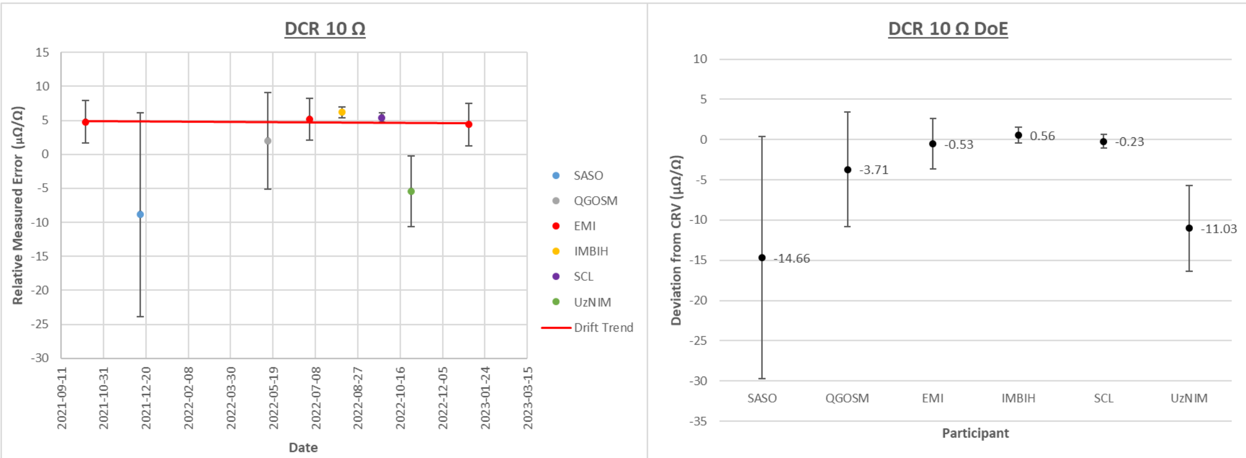


Figure 9

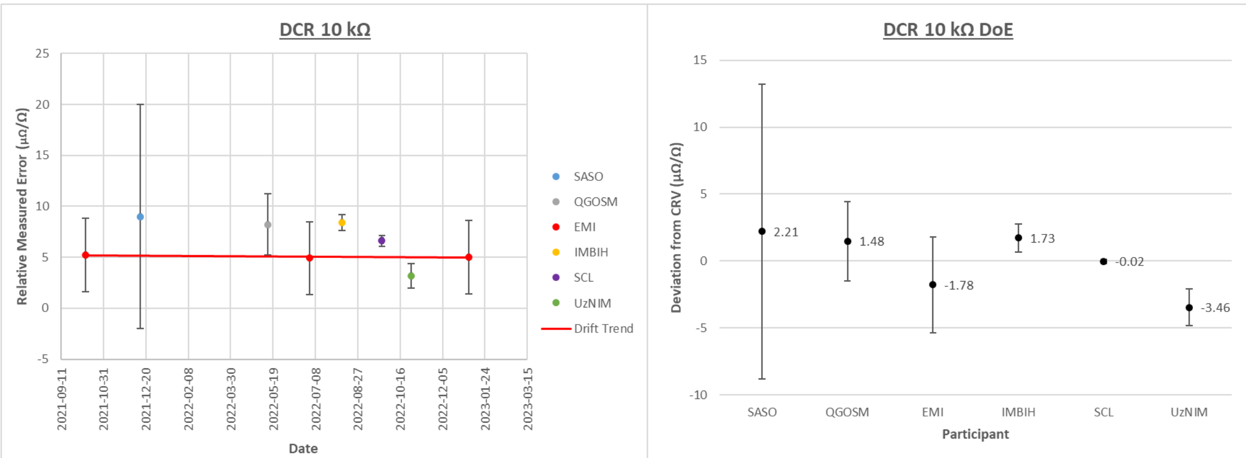


Figure 10

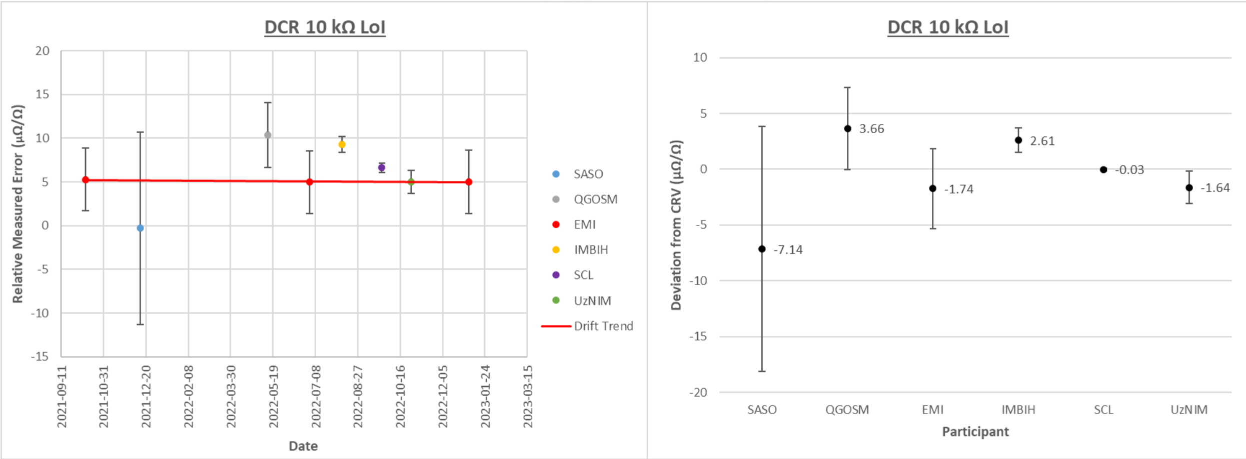


Figure 11

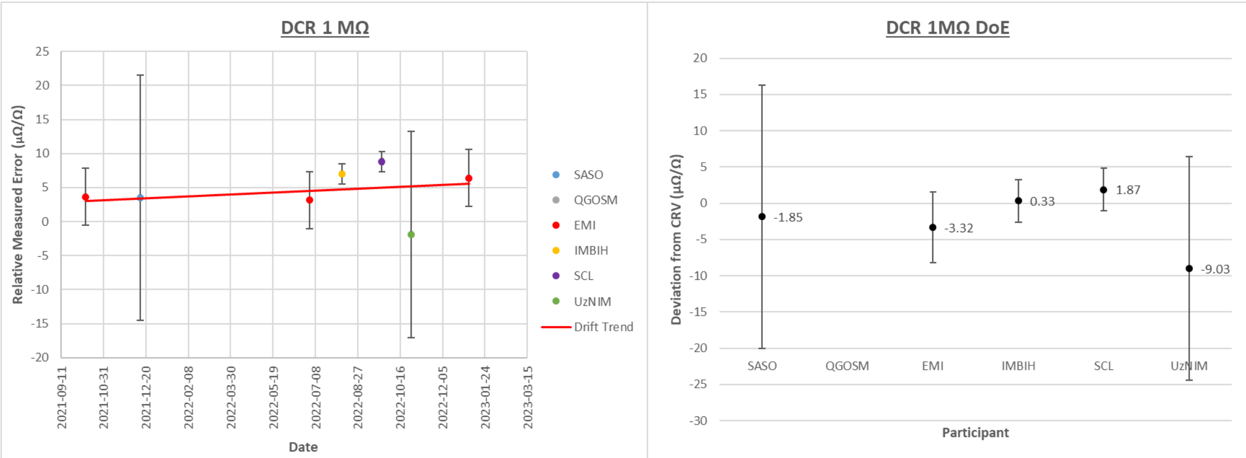


Figure 12

Table 9 to Table 11 show the degrees of equivalence for the AC voltage measurements. Figure 13 to Figure 19 show the corrected relative measured error of the participating institutes and the deviation with respect to the comparison reference value. Uncertainty bars represent the expanded uncertainty.

Table 9 AC Voltage 100 mV

Degree of Equivalence (DoE)		100 mV@55 Hz		100 mV@1 kHz	
Participant		Deviation	Expanded uncertainty	Deviation	Expanded uncertainty
n		D_i	$U(D_i)$	D_i	$U(D_i)$
		(µV/V)	(µV/V)	(µV/V)	(µV/V)
1	SASO	-62.11	115.53	-46.05	116.24
2	QGOSM	51.33	56.42	18.08	54.88
3	EMI	-43.89	71.35	-26.91	64.15
4	IMBIH	-7.27	81.99	7.90	83.00
5	SCL	-1.51	47.65	12.87	49.35
6	UzNIM	22.04	167.17	-22.51	167.66

Table 10 AC Voltage 10 V

Degree of Equivalence (DoE)		10 V@55 Hz		10 V@1 kHz		10 V@100 kHz	
Participant		Deviation	Expanded uncertainty	Deviation	Expanded uncertainty	Deviation	Expanded uncertainty
n		D_i	$U(D_i)$	D_i	$U(D_i)$	D_i	$U(D_i)$
		(µV/V)	(µV/V)	(µV/V)	(µV/V)	(µV/V)	(µV/V)
1	SASO	-6.65	66.09	-3.96	69.34	145.54	199.24
2	QGOSM	48.16	29.33	4.37	16.41	-123.00	297.41
3	EMI	-5.03	36.30	-1.05	28.43	72.61	152.07
4	IMBIH	-0.54	23.61	-1.02	31.58	-34.68	164.31
5	SCL	-60.91	27.59	-1.23	10.20	-95.79	131.77
6	UzNIM	21.51	64.61	-13.88	67.93	40.95	219.64

Table 11 AC Voltage 100 V

Degree of Equivalence (DoE)		100 V@55 Hz		100 V@1 kHz	
Participant		Deviation	Expanded uncertainty	Deviation	Expanded uncertainty
n		D_i	$U(D_i)$	D_i	$U(D_i)$
		(µV/V)	(µV/V)	(µV/V)	(µV/V)
1	SASO	-13.02	81.94	-8.67	74.49
2	QGOSM	19.93	29.30	12.95	24.50
3	EMI	-20.98	38.92	-8.58	35.96
4	IMBIH	-18.09	41.21	2.73	46.19
5	SCL	-80.10	27.13	-4.39	14.59
6	UzNIM	40.49	80.49	4.02	81.94

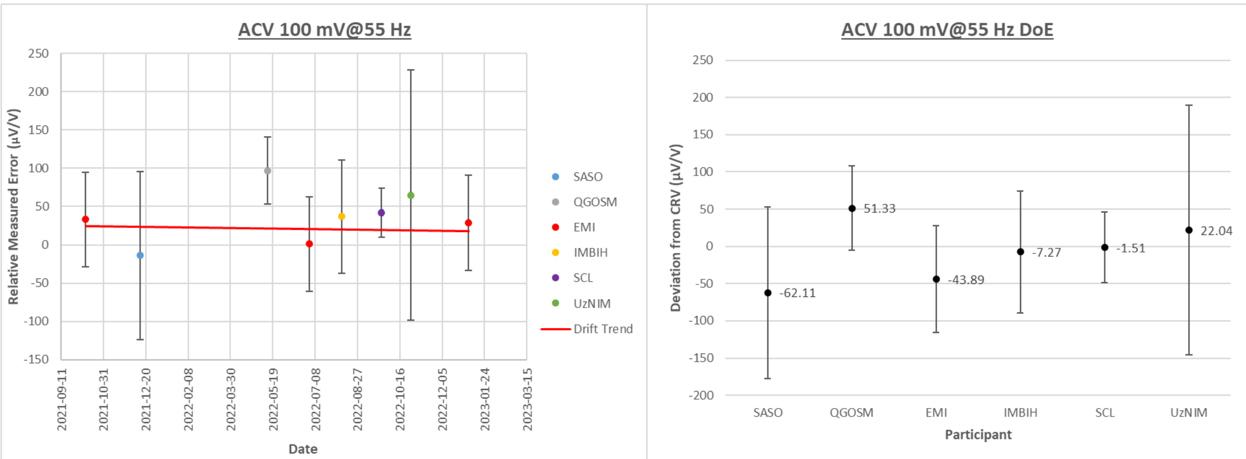


Figure 13

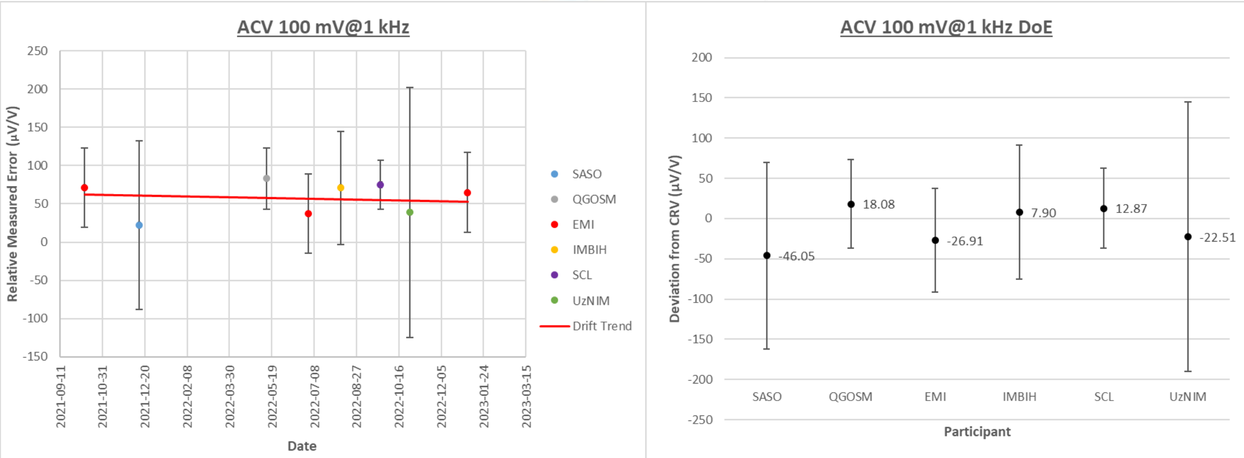
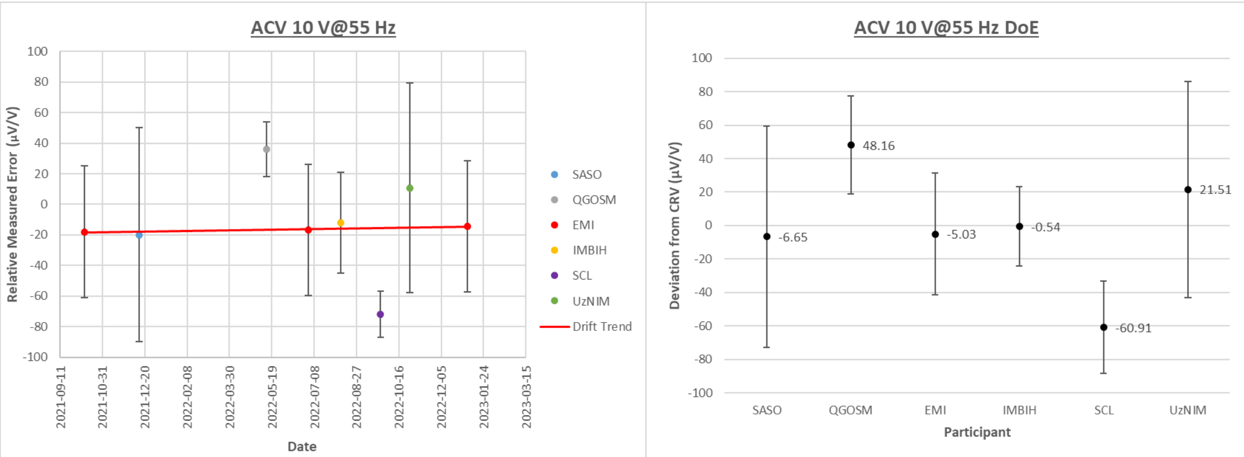


Figure 14



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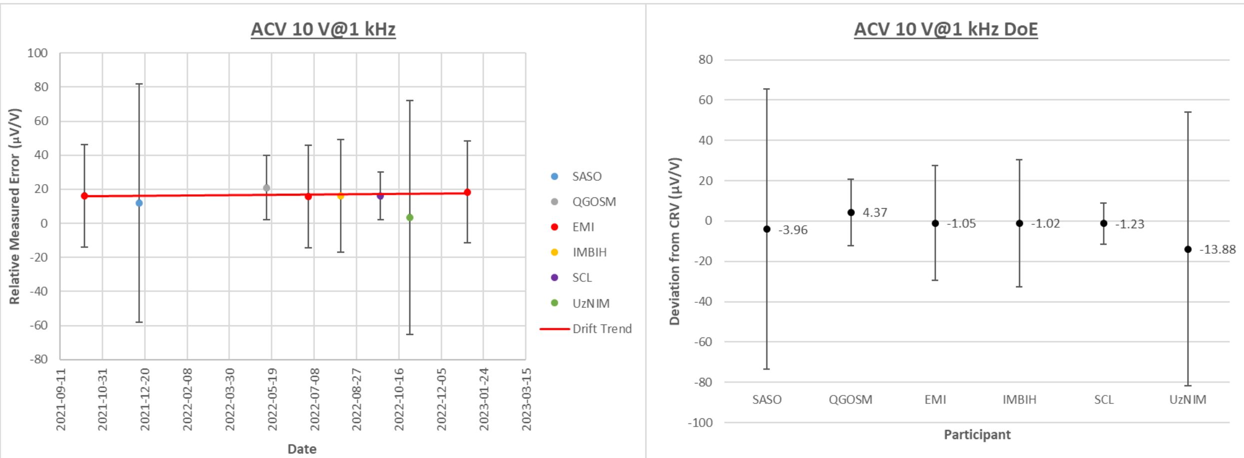


Figure 16

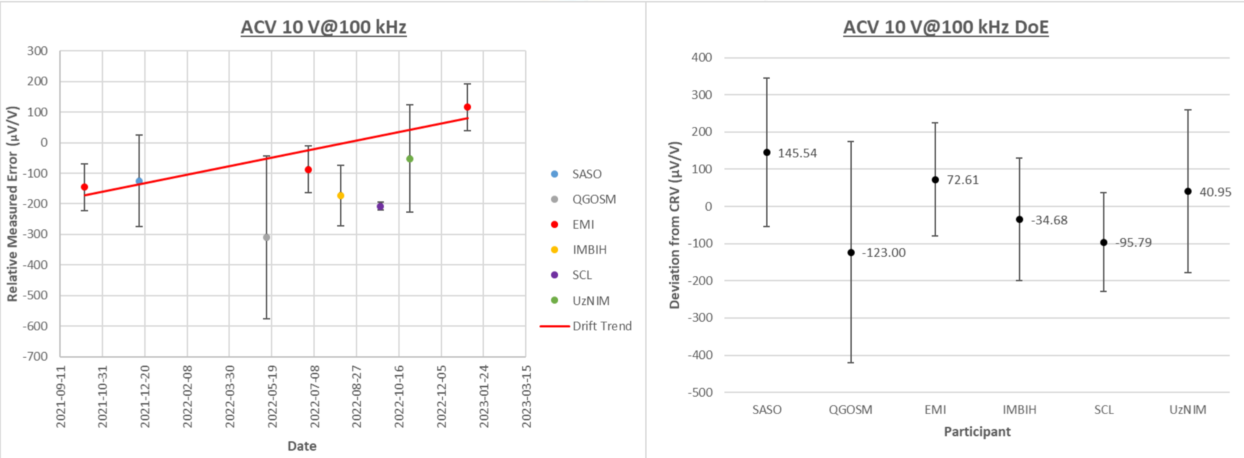


Figure 17

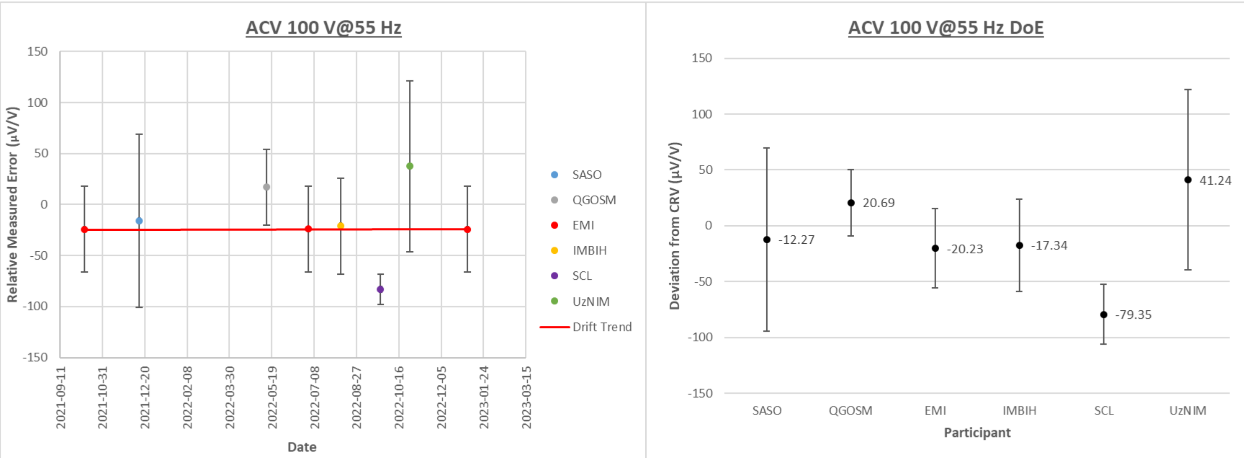


Figure 18

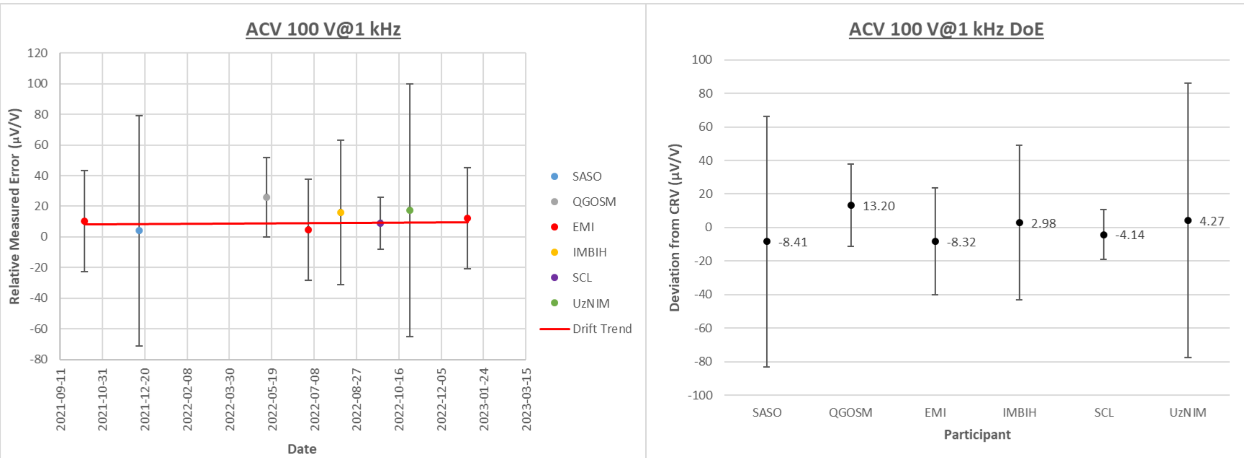


Figure 19

Table 12 to Table 13 show the degrees of equivalence for the AC current measurements. Figure 20 to Figure 23 show the corrected relative measured error of the participating institutes and the deviation with respect to the comparison reference value. Uncertainty bars represent the expanded uncertainty.

Table 12 AC Current 10 mA

Degree of Equivalence (DoE)		10 mA@300 Hz		10 mA@1 kHz	
Participant		Deviation	Expanded uncertainty	Deviation	Expanded uncertainty
n		D_i	$U(D_i)$	D_i	$U(D_i)$
		(µA/A)	(µA/A)	(µA/A)	(µA/A)
1	SASO	-14.82	118.87	-9.05	98.72
2	QGOSM	7.37	28.63	-0.44	28.90
3	EMI	-30.35	94.59	-27.91	94.67
4	IMBIH	-9.26	38.66	-5.83	38.87
5	SCL	3.87	27.48	7.42	25.42
6	UzNIM	-4.97	179.25	5.37	179.29

Table 13 AC Current 1 A

Degree of Equivalence (DoE)		1 A@300 Hz		1 A@1 kHz	
Participant		Deviation	Expanded uncertainty	Deviation	Expanded uncertainty
n		D_i	$U(D_i)$	D_i	$U(D_i)$
		(µA/A)	(µA/A)	(µA/A)	(µA/A)
1	SASO	-12.43	229.77	0.96	230.26
2	QGOSM	8.88	44.81	4.27	47.29
3	EMI	28.48	95.44	19.59	96.63
4	IMBIH	-17.19	42.76	-21.34	45.35
5	SCL	1.43	30.27	7.98	33.83
6	UzNIM	585.82	411.45	610.05	411.96

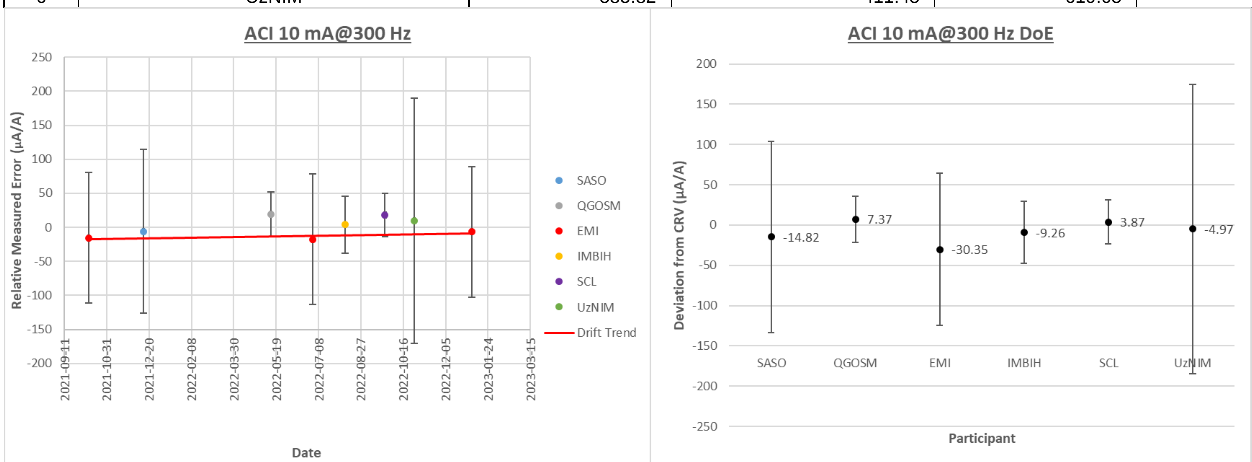


Figure 20

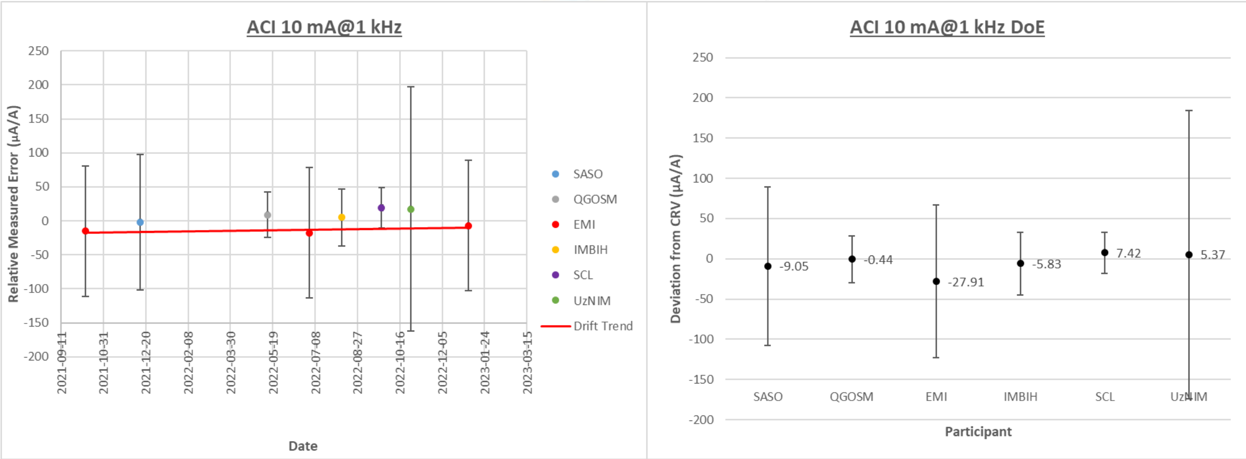


Figure 21

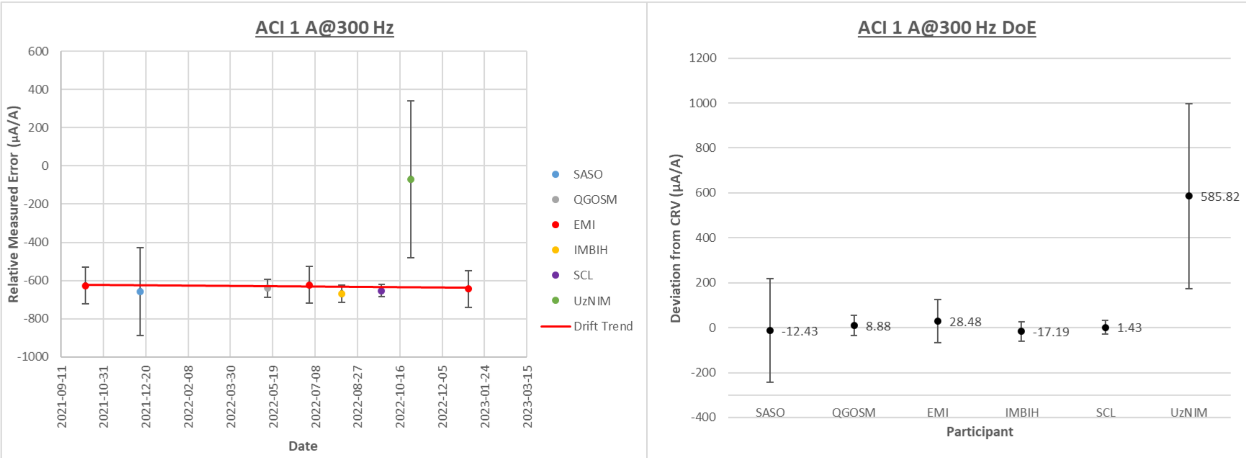


Figure 22

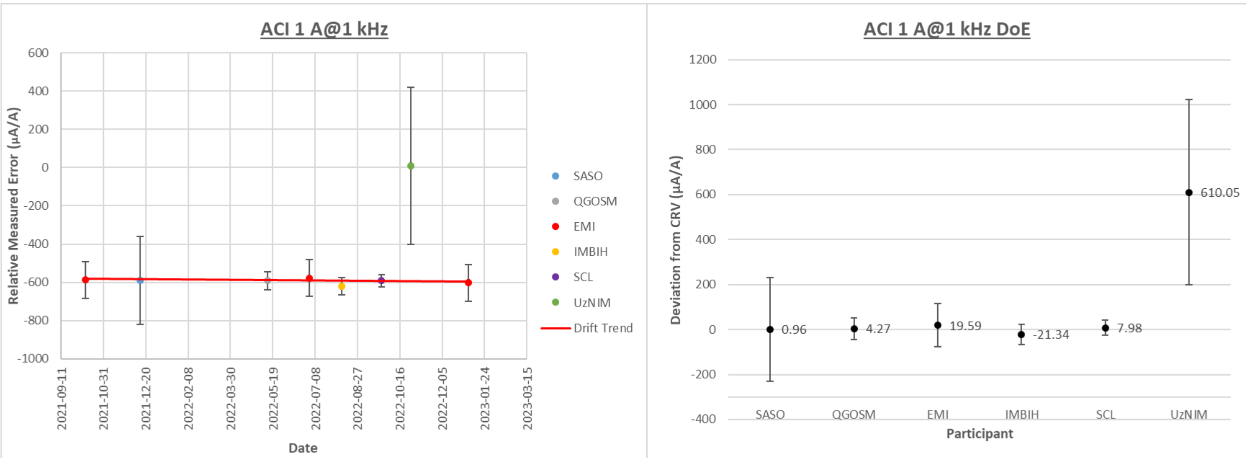


Figure 23

8. Summary

The supplementary comparison GULFMET.EM-S8 on the calibration of 8½ digit multimeter has been conducted for GULFMET member laboratories, with the support associate member SCL, from the APMP.

The DOE with respect to CRV were tabulated in Table 6 to Table 13 and illustrated graphically in Figure 2 to Figure 23. The agreement between participating laboratories is good. A total of 131 results were received, of which 12 were not in good agreement with the CRV.

It is expected that this comparison could provide support for GULFMET member laboratories to submit new measurement capability entries to the BIPM KCDB.

9. References

[1] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons, 2007 (available on the BIPM website: http://www.bipm.org/utils/common/pdf/CC/CCEM/ccem_guidelines.pdf)

[2] M G Cox, The evaluation of key comparison data, 2002 Metrologia 39 589.

[3] EURAMET Project 1341, "Comparison on the Calibration of Multimeter", Draft B (Final) Report.

[4] C M Sutton, Analysis and linking of international measurement comparisons, 2004 Metrologia 41 272.

Appendix A: Measurement Protocol

The measurement protocol is given on the following pages.

GULFMET.EM.S8

Comparison of Calibration of Multimeter

Technical Protocol

Version 5
(Last update: 12/07/2022)

Jon Bartholomew
Emirates Metrology Institute
PO Box 853, Abu Dhabi
UAE

معهد الإمارات للمترولوجيا
Emirates Metrology Institute

CONTENTS

1. INTRODUCTION

The technical basis of the Mutual Recognition Arrangement (MRA) is a set of results obtained in a course of time through key and supplementary comparisons carried out by the Consultative Committees (CCs) of the CIPM, the BIPM and the Regional Metrology Organizations (RMOs). As part of this process, the GULFMET Technical Committee for Electricity and Magnetism decided at its June 2020 meeting to carry out the RMO supplementary comparison GULFMET.EM-S8. The Emirates Metrology Institute (EMI) agreed to act as pilot laboratory with support from Standards and Calibration Laboratory (SCL).

The scope of the comparison is calibration of 8½ digit multimeter for the following quantities:

- DC Voltage
- AC Voltage
- DC Current
- AC Current
- DC Resistance

The measurement points were chosen to be the same as used in EURAMET Project No 1341.

The comparison will be carried out according to the requirement of Measurement comparisons in the CIPM MRA Guidelines for organizing, participating and reporting CIPM MRA-G-11 [1] and Gulf Association for Metrology (GULFMET) Guidelines on Conducting Comparisons. GULFMET 02 [2].

2. TRAVELING STANDARD

3. Travelling Standard Description

The travelling standard is an 8½ digit Fluke 8508A Reference Multimeter (Figure 1), supplied by EMI. This DMM was chosen for its high accuracy and stability in time on DC Voltage, AC voltage, DC current, AC current and resistance measurement functions. It can be remotely operated by means of an IEEE 488 interface. The general specifications of 8508A are given in Table 3.
Full descriptions, manuals and specifications for the transfer standard can be found at:
https://us.flukecal.com/products/obsolete-products/8508a-85-digit-reference-multimeter?quicktabs_product_details=2

Front Panel

Rear Panel

Figure 24 The travelling standard

Table 14 The general specifications of the travelling standard

Power	Power supply	100 v to 120V or 200 V to 240 V rms ±10 % @ 47 Hz to 63 Hz
	Consumption	< 80 VA

Dimensions	Height Width Depth	88 mm 427 mm 487 mm
Weight	11.5 kg	
Environment Temperature	Specified Operation Storage	5 °C to 40 °C -20 °C to 70 °C
Relative Humidity	Operating Storage	5 °C to 40 °C < 90 %rh 0 °C to 70 °C < 95 %rh
Warm Up Time	4 hours to full uncertainty specification	
Measurement Ranges	DC Voltage: 200 mV, 2 V, 20 V, 200 V, 1000 V AC Voltage: 200 mV, 2 V, 20 V, 200 V, 1000 V (1 Hz to 1 MHz) DC Current: 200 µA, 2 mA, 20 mA, 200 mA, 2 A, 20 A AC Current: 200 µA, 2 mA, 20 mA, 200 mA, 2 A, 20 A (1 Hz to 100 kHz) Resistance: 2 Ω, 20 Ω, 200 Ω, 2 kΩ, 20 kΩ, 200 kΩ, 2 MΩ, 20 MΩ, 200 MΩ, 2 GΩ, 20 GΩ	

4. Quantities to be measured

The quantities to be measured are DC voltage, DC current, AC voltage, AC current and DC resistance. The measurement points for each quantity, the settling time and the configuration of the Fluke 8508A, during the comparison measurements are given in Table 4

Table 15 Measurement quantities, points and conditions

Quantity	Measurement Point	Range of 8508A	Settling Time of 8508A	Configuration of 8508A
DC Voltage	100 mV	200 mV	5 min	Resolution 7 Filter ON Fast OFF Front Input
	10 V	20 V	5 min	
	100 V	200 V	5 min	
	1000 V	1000 V	10 min	
DC Current	100 µA	200 µA	5 min	Resolution 7 Filter ON Fast OFF Front Input
	10 mA	20 mA	5 min	
	1 A	2 A	30 min	
AC Voltage	100 mV @ 55 Hz┼	200 mV	5 min	Resolution 6 Transfer ON AC Coupled RMS Filter 100 Hz (┼RMS Filter 40 Hz at 55 Hz) Front Input
	100 mV @ 1 kHz		5 min	
	10 V @ 55 Hz┼	20 V	5 min	
	10 V @ 1 kHz		5 min	
	10 V @ 100 kHz		5 min	
	100 V @ 55 Hz┼	200 V	5 min	
	100 V @ 1 kHz		5 min	
AC Current	10 mA @ 300 Hz	20 mA	5 min	Resolution 6 AC Coupled RMS Filter 100 Hz Front Input
	10 mA @ 1 kHz		5 min	
	1 A @ 300 Hz	2 A	30 min	
	1 A @ 1 kHz		30 min	
DC Resistance	10 Ω	20 Ω	5 min	TrueΩ Resolution 7 4-Wire Low Current OFF Fast OFF Front Input
	10 kΩ	20 kΩ	5 min	
	10 kΩ	20 kΩ	5 min	TrueΩ Resolution 7 4-Wire Low Current ON Fast OFF Front Input
	1 MΩ	2 MΩ	5 min	Normal Ω Resolution 7 4-Wire Low Current OFF Filter ON Fast OFF Front Input

5. Calculation of the Comparison Reference Value (CRV)

The Comparison Reference Value (CRV) for each measurement point will be calculated as the weighted mean of the results of the institutes corrected for the time dependence of the travelling standard. The time dependence of the travelling standards during the comparison period will be characterized using the results from the Pilot Laboratory. Any result identified as inconsistent will be excluded from the determination of the CRV.

6. ORGANIZATION

7. Coordinator and members of the support group

The Emirates Metrology Institute (EMI) will coordinate the comparison, monitor the stability of the standard and report the measurement results.

Pilot Institute:	**Emirates Metrology Institute (EMI)**
Coordinator:	Mr Jon Bartholomew Tel: +971 50 386 2676 E-mail: jon.bartholomew@qcc.gov.ae

Support group:

Institute:	**Standards and Calibration Laboratory (SCL)**
Coordinator:	Dr Steven Yang Tel: +852 2829 4833 Fax: +852 2829 4865 E-mail: steven.yang@itc.gov.hk

8. Participants

A list of participating institutes with contacts of responsible person and shipping address is listed in Appendix A.

9. Time schedule

The comparison schedule is given in Appendix B. The comparison will begin in October 2021 and is scheduled to be completed within less than 2 years. Because of customs practices in the UAE the circulation of the travelling standard will be organized as a series of loops between the pilot laboratory and one participant. The pilot laboratory will monitor the performance of the travelling standard after each loop. The period between measurements by each participant is six weeks. This allows two weeks for measurements, and 4 weeks for shipping to the pilot laboratory. Should a participant require more time for shipping to the next participant, the measurement time must be shortened.

If unforeseen circumstances prevent a laboratory from carrying out the measurements within the allocated time, the original schedule should be followed by sending the standards to the pilot

laboratory without delay. The laboratory may be allowed to carry out additional measurements after the completion of the original schedule and before the end of this comparison.

10. TRANSPORTATION

11. Transportation

Each participant is responsible for arranging transport and insurance from their institute to the pilot laboratory. **Arrangements and documentation with their local customs and the pilot laboratory's customs must be prepared in advance.**

Arrival and departure of the standards must be communicated with the pilot laboratory by E-mail using the forms available in Appendix D of this protocol

- When the package arrives at your laboratory, fill in the "Receiving form" in Appendix D and send the form to the pilot laboratory by E-mail.

- When preparing the package for shipment, fill in the "Shipping checklist" in Appendix D and send the checklist to the pilot laboratory by E-mail.

- When the package is shipped, fill in the "Dispatch form" in Appendix D and send the checklist to the pilot laboratory by E-mail.

Please resend any forms that are not acknowledged. If any delay due to transportation is expected, the sender and/or the receiver should promptly contact the pilot laboratory.

12. Transport Case

The travelling standard is packed in a transport case of size (80.5 x 53.0 x 32.5) cm and a total weight of 20 kg. The transport case can easily be opened for customs inspection. HS Code is 903031. Insurance Value 7000 USD

On receipt of the case, the device should be unpacked carefully and checked for any damage.
The content of the transport case is given below:

1. Fluke 8508A Reference Multimeter (Serial No: 218865629)*
2. 4 wire shorting device

* The multimeter will be supplied without input leads.

Please refer to Appendix E for illustration of the shipping package.

13. Self-Test on Receipt

On receipt of the case, the device should be unpacked carefully and checked for any damage. The correct functioning of the 8508A shall be confirmed by initiating the "Self-Test" (See details in 8508A Reference Multimeter Users Manual [3]):

1. Ensure that the mains voltage setting is applicable to the local supply
2. Allow the Multimeter to warm-up under power at least 10 minutes.
3. Press the CLEAR key, select "Pwr Up Dflt" to restore the power up default configuration and display the DCV menu.
4. Press the "Test" key and select "Std" to initiate a self-test.

14. Failure of Travelling Standard

In case of any damage or malfunction of the standards, the participating laboratory must report to the pilot laboratory immediately

15. Financial aspects

Each participant institute is responsible for its own costs for the measurements, transportation to the pilot laboratory and insurance of the shipment to the pilot laboratory.

Each participant institute is responsible for paying any customs charges, duties, deposits or surcharges within its country.

Each participant institute is responsible for any damage that may occur within its country.

The overall costs for the organisation of the comparison are covered by the pilot institute. The pilot institute has no insurance for any loss or damage of the travelling standard.

16. MEASUREMENT INSTRUCTIONS

17. Before the measurements

Ensure that the mains voltage setting is applicable to the local supply, and check that the instrument is functioning correctly.

The instrument should be allowed to stabilize in a temperature and humidity-controlled environment for at least 24 hours before commencing measurements.

18. Measurement Conditions

1. The standard ambient conditions for measurement are:

   Temperature: (23 ± 1) °C

   Relative humidity: (50 ± 10) %rh
2. The ambient temperature and humidity conditions during the measurements must be measured and reported.
3. The reference multimeter shall not be adjusted during the comparison measurements.
4. The reference multimeter shall be allowed to warm-up under power at least 4 hours.
5. The reference multimeter should be used in the configurations given in Table 4.
6. The measurement points required are given in Table 2.
7. The front input terminals of the reference multimeter shall be used for all measurements.
8. A single “earth” connection should be used in the measurement setup to avoid “earth” loops.
9. Before each DC measurement point (i.e., DC voltage, DC Current and Resistance), a “zero” input shall be applied and the instrument “Input Zero” shall be executed.
10. Sufficient settling time shall be allowed for each measurement.
11. Any standard method may be used for calibrating the reference multimeter.
12. The measurement result shall be reported as the relative error of the reference multimeter and calculated by:

$$Relative\ Error = \frac{Indicated\ Value - Applied\ Value}{Applied\ Value}$$

19. MEASUREMENT UNCERTAINTY

The measurement uncertainty shall be evaluated in accordance with the JCGM 100:2008 – Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement [1][4] for a 95% level of confidence.

In uncertainty evaluations, all uncertainty components taken into account should be included. The coverage factor and the effective degrees of freedom should be reported.

The contributions to the uncertainty are specific to the participant's measurement system and the measurement method used, however it may be useful to consider some of the possible uncertainty sources given below.

1. The measurement standard used e.g.:
    a Multifunction calibrator for all or some of the measurements
    b Reference voltage standard for DC voltage measurements
    c Standard resistor for resistance measurements
    d DC current shunt for DC current measurements
    e AC/DC transfer standard for AC voltage measurements
    f AC/DC current shunt for AC current measurements
2. Thermal electromotive force (emf) for low DC voltage measurements
3. Drift of the measurement standard used e.g. due to time, temperature, loading etc.
4. Finite resolution of the reference multimeter
5. Repeatability of the measurement

20. MEASUREMENT REPORT

21. File Format

The participant's report must be submitted electronically to the pilot laboratory within **one month** from the completion of the measurements, using the following file format:

-Word 2003 or later version for the report including the participant's results
-Excel 2003 or later version for the raw data and detailed uncertainty budget

22. Contents of report

The report must contain:

- **Details of participating institute,**
- **The date of the measurements**
- **Detailed description of the method of measurement**
- **The measurement standards used in the comparison measurements,**
- **A statement of traceability for the measurements**
- **Temperature and humidity in the laboratory during the measurement**
- **The results of the measurement**
  For each reported value the information must be provided in Excel using the template attached in Appendix C.
- **Uncertainty budget and calculation**
  The uncertainty analysis should include a list of all sources of Type B uncertainty, together with the associated standard uncertainties as well as their evaluation method. For clarity, it is recommended to present the uncertainty budget in the form of a table. For each reported value, the expanded uncertainty and the coverage factor k must be given for confidence level of approximate 95 %.

23. FINAL REPORT OF THE COMPARISON

At the conclusion of circulation of the standards, the pilot laboratory will prepare the draft A report within 4 months. In the case of any outliers, the results will not be communicated until the participants concerned have been contacted to ensure that no arithmetic, typographical or transcription errors are present. The draft A report is confidential and will be sent to all participants for review and discussion.

The participants will have two months for comments on the draft A report. In the case of results that are discrepant with the reference value or are not consistent with their published CMCs, the rules given in [1] will be followed.

On the basis of the comments received, the pilot laboratory will prepare the second draft (draft B), where the withdrawn results will be removed. The draft B report will be submitted to the GULFMET TC-EMTF for approval.

Once approved by the GULFMET TC-EMTF the report will be sent to the CCEM WGLF for editorial review. On the basis of the comments received the pilot laboratory will prepare the Final Report. The Final Report will form the basis for the publication of results.

24. REFERENCES

[1] Measurement comparisons in the CIPM MRA. Guidelines for organizing, participating and reporting. CIPM MRA-G-11.
https://www.bipm.org/documents/20126/43742162/CIPM-MRA-G-11.pdf/9fe6fb9a-500c-9995-2911-342f8126226c

[2] Gulf Association for Metrology (GULFMET) Guidelines on Conducting Comparisons. GULFMET 02, Issue 1, 20/ 02 /2012
https://www.gulfmet.org/document-and-guidelines

[3] 8508A Reference Multimeter Users Manual. PN 1673798, July 2002. Rev. 6, 3/13
https://us.flukecal.com/literature/product-manuals/8508a-reference-multimeter-users-manual

[4] JCGM 100:2008 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement, September 2008
https://www.bipm.org/en/publications/guides

APPENDIX A: List of Participants

No	Country / Economy	Acronym of Institute	Name of Institute	Shipping Address	Contact Person
7.	United Arab Emirates	EMI	Emirates Metrology Institute	Emirates Metrology Institute Abu Dhabi Quality and Conformity Council (QCC) Kryptolabs Building, Masdar City Abu Dhabi, UAE	Mr Waleed Al Kalbani w.alkalbani@qcc.gov.ae Tel: +971 50 889 0080
8.	Hong Kong, China	SCL	Standards and Calibration Laboratory	Standards and Calibration Laboratory 36/F Immigration Tower, 7 Gloucester Road, Wan Chai, Hong Kong	Dr Steven Yang steven.yang@itc.gov.hk Tel.: +852 2829 4833
9.	Saudi Arabia	SASO-NMCC	Saudi Standards, Metrology and Quality Organization National Measurement and Calibration Center	Saudi Standards, Metrology and Quality Organization (SASO)-National Measurements & Calibration Center PO. B 3437 Riyadh- Al Muhammadiyah – in front of King Saud University (Bldg. # 4, NMCC) 11471 Riyadh Kingdom of Saudi Arabia	Mr. Ahmed AlAyali a.ayli@saso.gov.sa
10.	Qatar	QGOSM	Qatar General Organization for Standards and Metrology	Qatar General Organization for Standards and Metrology P.O. Box: 23277, Doha - Qatar	Ms Nany S. Al-Kuwari nsalkwary@mme.gov.qa
11.	Bosnia and Herzegovina	IMBIH	Institute of Metrology of Bosnia and Herzegovina	Laboratory for electrical quantities and time and frequency Institute of metrology of Bosnia and Herzegovina Branilaca Sarajeva 25 71 000 Sarajevo Bosnia and Herzegovina	Mr Srdjan Calija srdjan.calija@met.gov.ba Tel: +387 (0)33 568 924
12.	Uzbekistan	UzNIM	Uzbek National Institute of Metrology of Uzstandard Agency	Department of Electr and magnetic measurements 1000049, Farobiy street, 333A, Tashkent city,	Mr Kamoliddin Makhamatov k.makhamatov@nim.uz Tel: +99878 150 26 03

No	Country / Economy	Acronym of Institute	Name of Institute	Shipping Address	Contact Person
				Uzbekistan	+99897 773 37 22 Or Sardor Ikramov, s.ikramov@nim.uz Tel: +99878 150 26 03 +99897 704 44 21

APPENDIX B: Measurement Schedule

Measurement Dates	Country / Economy	Acronym of Institute
3 October to 15 October 2021	United Arab Emirates	EMI
9 December to 15 December 2021	Saudi Arabia	SASO-NMCC
23 December to 24 February 2022	United Arab Emirates	EMI
24 April to 17 May 2022*	Qatar	QGOSM
13 June to 24 June 2022	United Arab Emirates	EMI
25 July to 5 August 2022	Bosnia and Herzegovina	IMBIH
5 September to 16 September 2022	Hong Kong	SCL
17 October to 28 October 2022	Uzbekistan	UzNIM
28 November to 16 December 2022*	United Arab Emirates	EMI

*Period extended to allow for public holiday

APPENDIX C: Measurement Results

DC Voltage

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
200 mV	+ 100 mV				
20 V	+ 10 V				
200 V	+ 100 V				
1000 V	+ 1000 V				

DC Current

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
200 µA	+ 100 µA				
20 mA	+ 10 mA				
2 A	+ 1 A				

DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
20 Ω	TrueΩ	10 Ω				
20 kΩ	TrueΩ	10 kΩ				
	TrueΩ LoI	10 kΩ				
2 MΩ	Normal	1 MΩ				

AC Voltage

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz				
	100 mV	1 kHz				
20 V	10 V	55 Hz				
	10 V	1 kHz				
	10 V	100 kHz				
200 V	100 V	55 Hz				
	100 V	1 kHz				

AC Current

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
	Voltage	Frequency				
20 mA	10 mA	300 Hz				
	10 mA	1 kHz				
2 A	1 A	300 Hz				
	1 A	1 kHz				

APPENDIX D: Forms for Transportation

GULFMET.EM.S8 COMPARISON
Receiving Form

(Send this form to the pilot laboratory as soon as you have received the standard)

Arrival Date & Time	Date:__________ Time:____________	
Is the package damaged?	Yes ☐	No ☐
	Comments:	
Is the standard damaged?	Yes ☐	No ☐
	Comments:	
Are all materials listed in the packing list available in the package?	Yes ☐	No ☐
	Comments:	

The transport case was received by:

(Please fill in your contact information)

Institute	
Contact Person	
E-mail Address	
Telephone No	

GULFMET.EM.S8 COMPARISON
Dispatch Form

(Send this form to the pilot as soon as the standard is shipped.)

The dispatch date of transport case	Date:_________ Time:______________
The travelling standards are in working condition?	Yes ☐ No ☐
Comments on the behaviour of the standards:	
Method of Shipment	Courier Name: Tracking No: *Airline (if available):* *Flight No (if available):*
Informed courier about documentation requirement of ATA carnet. (if applicable)	Yes ☐ No ☐
Shipping to **(Participant Name & Address)**	

The transport case was dispatch by:

(Please fill in your contact information)

Institute	
Contact Person	
E-mail Address	
Telephone No	

APPENDIX E: Shipping package

Appendix B: Reports of Measurement

Details of measurement method, results uncertainty estimates and metrological traceability to SI units by individual participants are given on the following pages

Report on

Measurements performed for

GULFMET.EM-S8

Comparison of Calibration of Multimeter

Measurements performed on

Fluke 8508A
(Serial number: 218865629)

From 14 September to 5 October 2022

Performed by

創新科技署
Innovation and Technology Commission

標準及校正實驗所
Standards and Calibration Laboratory

Standards and Calibration Laboratory (SCL)
36/F, Immigration Tower,
7 Gloucester Road, Wan Chai,
Hong Kong, China

Introduction

The GULFMET.EM-S8 comparison protocol requires that the travelling standard, a Fluke 8508A serial number 218865629 (the Unit under Test – UUT), be measured at a number of points for each of its measurement functions. These are direct voltage, direct current, alternating voltage, alternating current and resistance. The measurement points are detailed in the comparison protocol.

The instrument was received on 9 September 2022. The fuse and mains voltage selection switch was checked before applying power. The UUT was allowed to stabilise for 24 hours with the power turned on before any measurements were made. The instrument's self-test was performed and completed without any errors.

The measurements were performed from 14 September to 5 October 2022. The instrument was sent to the National Institute of Metrology of Uzbekistan on 10 October 2022.

Direct Voltage

Test methods:

Direct voltage was measured using two methods:

1. For 100 mV and 10 V, the correction of the UUT was determined by direct connection of the UUT to a Fluke 732C zener voltage reference standard calibrated in-prior against a programmable Josephson voltage standard.
2. For 100 V and 1000 V, test voltages were applied in parallel to the input of the Guildline 9700PL Voltage Ratio Box (VRB) and the UUT. The scaled down test voltages were measured by a Guildline 9930 DCC Potentiometer used in conjunction with a Fluke 732B zener voltage reference standard. The test voltage was calculated as the product of the measured scaled down voltage and the voltage ratio of the VRB. The error of the UUT was determined by comparing the UUT reading to the calculated test voltage.

See figure 1.1 for the direct voltage measurement setups.

The 'External Guard' function was turned off for measurements using method 1, where the guard terminal and low voltage terminal were connected to a common ground point internally by the UUT. The 'External Guard' function was turned on for measurements using method 2, where the guard terminal and low voltage terminal were connected to a common ground point at the VRB. The low current terminal was always connected to the low voltage terminal and the high current terminal was always connected to the high voltage terminal for all measurements.

Traceability:

All the test methods described for direct voltage was metrological traceable to the Standards and Calibration Laboratory's (SCL) programmable Josephson voltage standard. See figure 2.1 for the direct voltage traceability chart.

Conditions of measurement:

During the direct voltage measurements, the following conditions of measurement prevailed:

Ambient temperature: 23 °C ± 1 °C
Relative humidity: 45 %RH ± 8 %RH

Measurement results:

Range	Nominal Voltage	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
200 mV	100 mV	100.004 982 mV	100.005 7 mV	6.7 μV/V	2.1 μV/V
20 V	10 V	10.000 016 347 V	10.000 06 V	4.37 μV/V	0.42 μV/V
200 V	100 V	99.999 807 V	100.000 1 V	2.9 μV/V	1.1 μV/V
1000 V	1000 V	999.996 72 V	999.999 5 V	2.8 μV/V	1.2 μV/V

Detailed uncertainty budgets for the direct voltage measurements are shown in appendix 3.1.

Direct Current

Test methods:

Direct current was measured by the following method:

The error of the UUT was determined by comparing its readings to the calculated value of the applied current. A calibrated current shunt was connected in series with the UUT. The voltage drop across the current shunt was measured with a calibrated voltmeter. The applied current was calculated from the resistance of the shunts and the measured voltage.

See figure 1.2 for the direct current measurement setup.

Traceability:

The resistance of the current shunt was traceable to the 100 Ω standard resistor maintained by the SCL. The 100 Ω standard resistor was directly traceable to an overseas NMI. See figure 2.2 for the resistance traceability chart.

The direct voltage was metrological traceable to the SCL's programmable Josephson voltage standard. See figure 2.1 for the direct voltage traceability chart.

Conditions of measurement:

During the direct current measurements, the following conditions of measurement prevailed:

Ambient temperature: 23 °C ± 1 °C
Relative humidity: 45 %RH ± 8 %RH

Measurement results:

Range	Nominal Current	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
200 µA	100 µA	100.000 783 9 µA	100.002 2 µA	14.4 µA/A	1.0 µA/A
20 mA	10 mA	10.000 028 24 mA	10.000 13 mA	10.18 µA/A	0.81 µA/A
2 A	1 A	0.999 982 433 A	0.999 706 A	-276.4 µA/A	7.9 µA/A

Detailed uncertainty budgets for the direct current measurements are shown in appendix 3.2.

Alternating Voltage

Test methods:

Alternating voltage was measured using two methods:

1. For 100 mV, the correction of the UUT was determined by comparing the UUT reading to the voltage generated by an NL-1A inductive voltage divider with the 10 V AC input voltage measured by a Fluke 5790A precision AC voltmeter.
2. For 10 V to 100 V, the correction of the UUT was determined by comparing the UUT reading to the voltage obtained from an ac-dc difference measurement with a Fluke 792A thermal transfer standard. The applied alternating voltage was calculated from the applied DC voltage and the ac-dc difference.

See figure 1.4 for the alternating voltage measurement setups.

Traceability:

For 100 mV, the AC voltage was traceable to the following quantities: the voltage ratios of the SCL's NL-1A inductive voltage divider which were calibrated by NPL (UK), the ac-dc difference of Fluke 792A were calibrated by SCL's thermal voltage converters which were calibrated by NPL (UK), and the DC voltage quantity was traceable to SCL's JAVS system.
For 10 V & 100 V, the AC voltage was traceable to the following quantities: the ac-dc difference of Fluke 792A were calibrated by SCL's thermal voltage converters which were calibrated by NPL (UK), the DC voltage quantity were traceable to SCL's JAVS system.

See figure 2.3 for the ac-dc difference traceability chart.

Conditions of measurement:

During the alternating voltage measurements, the following conditions of measurement prevailed:

Ambient temperature: 23 °C ± 1 °C
Relative humidity: 45 %RH ± 8 %RH

Measurement results:

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	100.000 024 mV	100.004 mV	42 μV/V	32 μV/V
		1 kHz	100.000 063 mV	100.008 mV	75 μV/V	32 μV/V
20 V	10 V	55 Hz	10.000 046 95 V	9.999 33 mV	-72 μV/V	15 μV/V
		1 kHz	10.000 024 66 V	10.000 2 mV	16 μV/V	14 μV/V
		100 kHz	9.999 486 98 V	9.997 40 V	-208 μV/V	13 μV/V
200 V	100 V	55 Hz	99.999 278 44 V	99.991 0 V	-83 μV/V	15 μV/V
		1 kHz	99.998 905 99 V	99.999 8 V	9 μV/V	17 μV/V

Detailed uncertainty budgets for the alternating voltage measurements are shown in appendix 3.3.

Alternating Current

Test methods:

Alternating current was measured by the following method:

The correction of the UUT was determined by comparing its readings to the calculated value of the applied current. A calibrated current shunt was connected in series with the UUT. The voltage drop across the current shunt was measured with a calibrated alternating voltage measurement standard. The applied current was calculated from the DC resistance and the ac-dc differences of the shunt, and the measured voltage across the shunt.

See figure 1.5 for the alternating current measurement setup.

Traceability:

The DC resistance of the current shunt was traceable to the 100 Ω standard resistor maintained by the SCL. The 100 Ω standard resistor was directly traceable to the National Physical Laboratory (NPL, UK). The ac-dc resistance difference of the current shunts was traceable to the standard resistors of SCL which were calibrated by the National Physical Laboratory (UK).

The DC voltage quantities were traceable to SCL's JAVS system. The ac-dc difference of Fluke 792A was calibrated by SCL's thermal voltage converters which were calibrated by NPL (UK).

See figure 2.3 for the resistance traceability chart and figure 2.3 for the ac-dc difference traceability chart.

Conditions of measurement:

During the alternating current measurements, the following conditions of measurement prevailed:

Ambient temperature: 23 °C ± 1 °C
Relative humidity: 45 %RH ± 8 %RH

Measurement results:

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
	Current	Frequency				
20 mA	10 mA	300 Hz	9.999 877 00 mA	10.000 1 mA	18 µA/A	32 µA/A
		1 kHz	9.999 855 65 mA	10.000 1 mA	19 µA/A	30 µA/A
2 A	1 A	300 Hz	1.000 656 65 A	1.000 00 A	-653 µA/A	32 µA/A
		1 kHz	0.999 978 81 A	0.999 39 A	-592 µA/A	32 µA/A

Detailed uncertainty budgets for the alternating current measurements are shown in appendix 3.4.

Resistance

Test methods:

The error of the UUT was determined by comparing its readings to a set of standard resistors.

See figure 1.3 for the resistance measurement setup.

Traceability:

The DC resistance of the standard resistors was traceable to the 100 Ω standard resistor maintained by the SCL. The 100 Ω standard resistor was directly traceable to Physikalisch-Technische Bundesanstalt (PTB).

See figure 2.2 for the resistance traceability chart.

Conditions of measurement:

During the resistance measurements, the following conditions of measurement prevailed:

Ambient temperature: 23 °C ± 1 °C
Relative humidity: 45 %RH ± 8 %RH

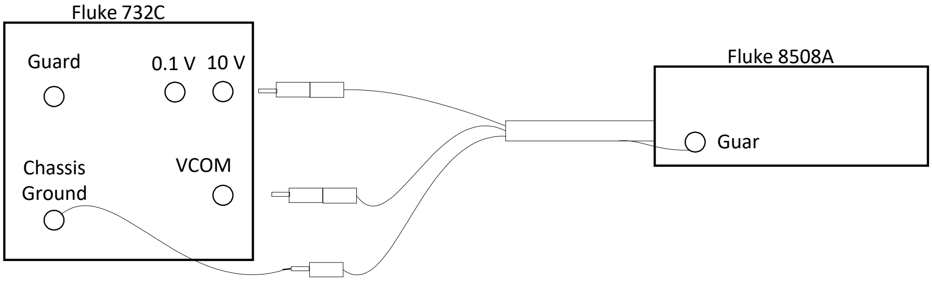
Measurement results:

Range	Nominal Resistance	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
20 Ω	10 Ω	9.999 911 2 Ω	9.999 965 Ω	5.38 μΩ/Ω	0.69 μΩ/Ω
20 kΩ	10 kΩ	10.000 063 7 kΩ	10.000 13 kΩ	6.63 μΩ/Ω	0.53 μΩ/Ω
20 kΩ (LoI)	10 kΩ	10.000 063 7 kΩ	10.000 13 kΩ	6.63 μΩ/Ω	0.56 μΩ/Ω
2 MΩ	1 MΩ	1.000 032 2 MΩ	1.000 041 MΩ	8.8 μΩ/Ω	1.5 μΩ/Ω

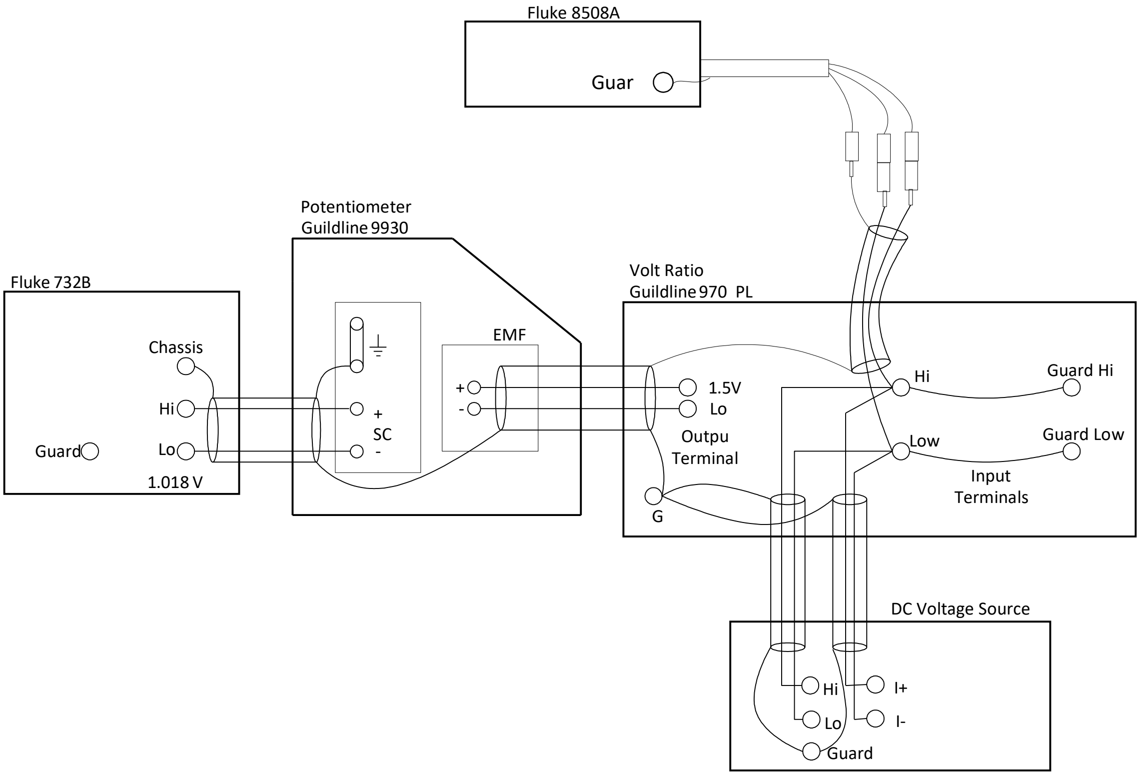
Detailed uncertainty budgets for the resistance measurements are shown in appendix 3.5.

Appendix 1: Measurement setups

Direct Voltage



(b) 100 mV and 10 V measurements



(b) 100 V and 1000 V measurements

Figure 1.1: Direct voltage measurement setup

Direct Current

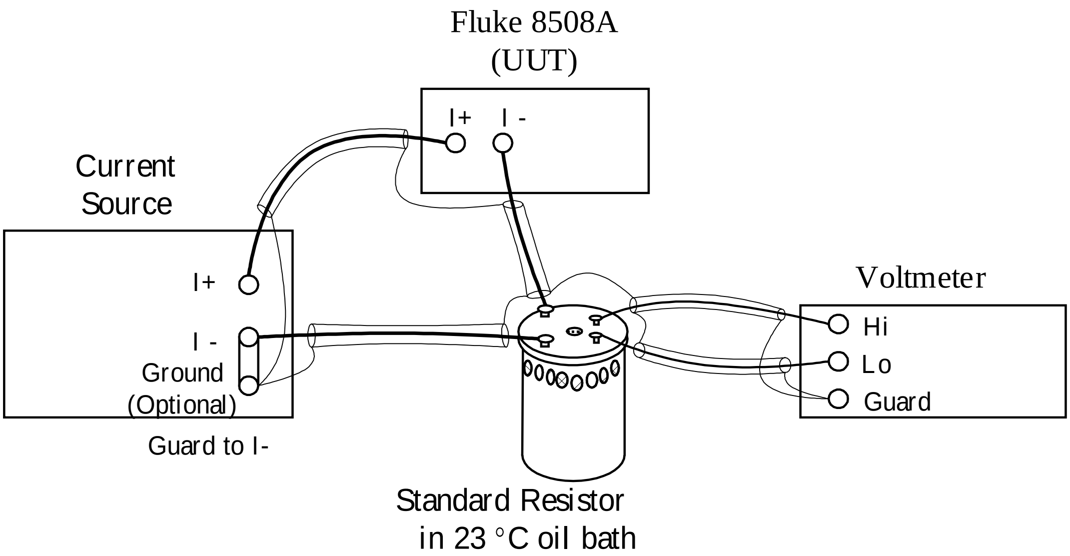
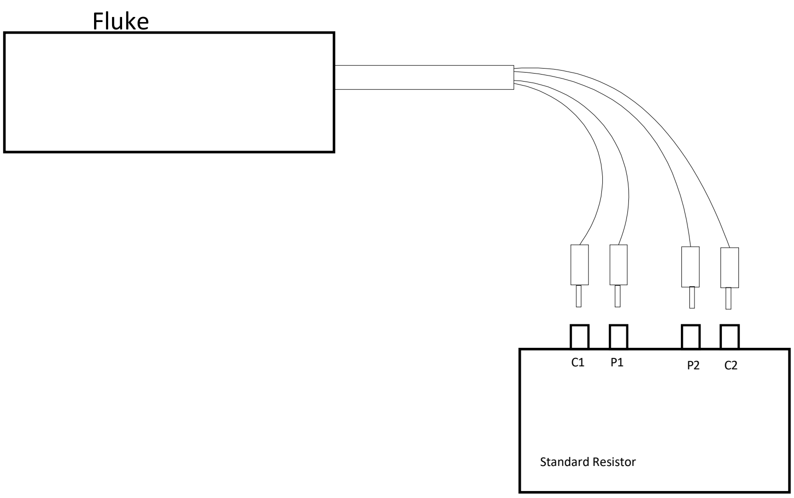


Figure 1.2: Direct current measurement setup

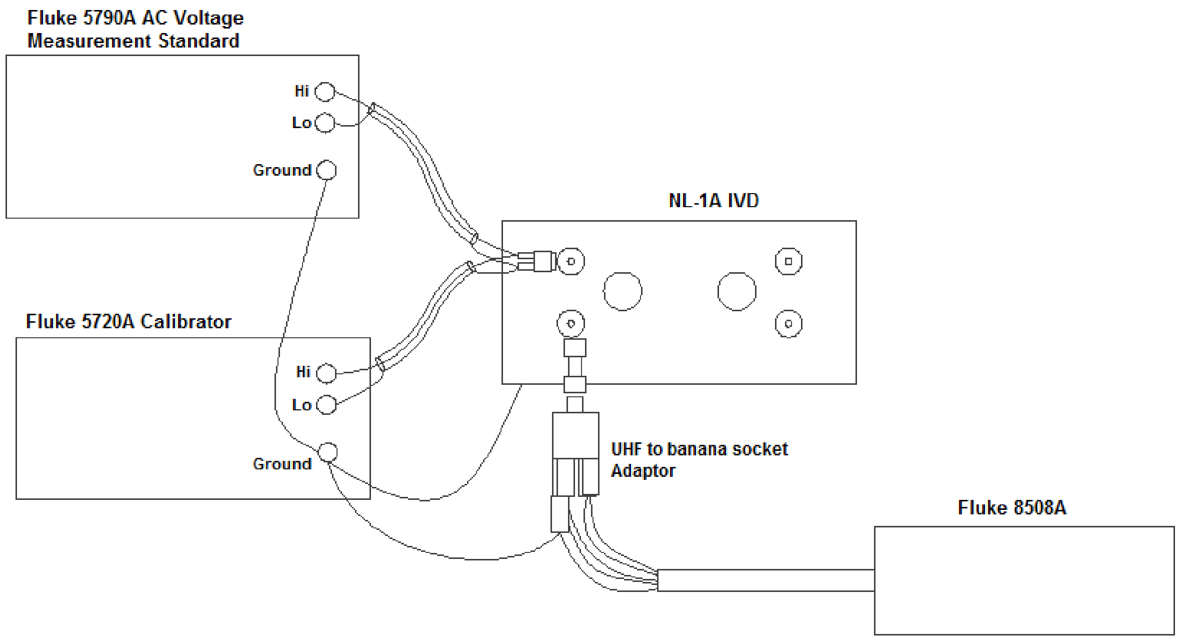
Resistance



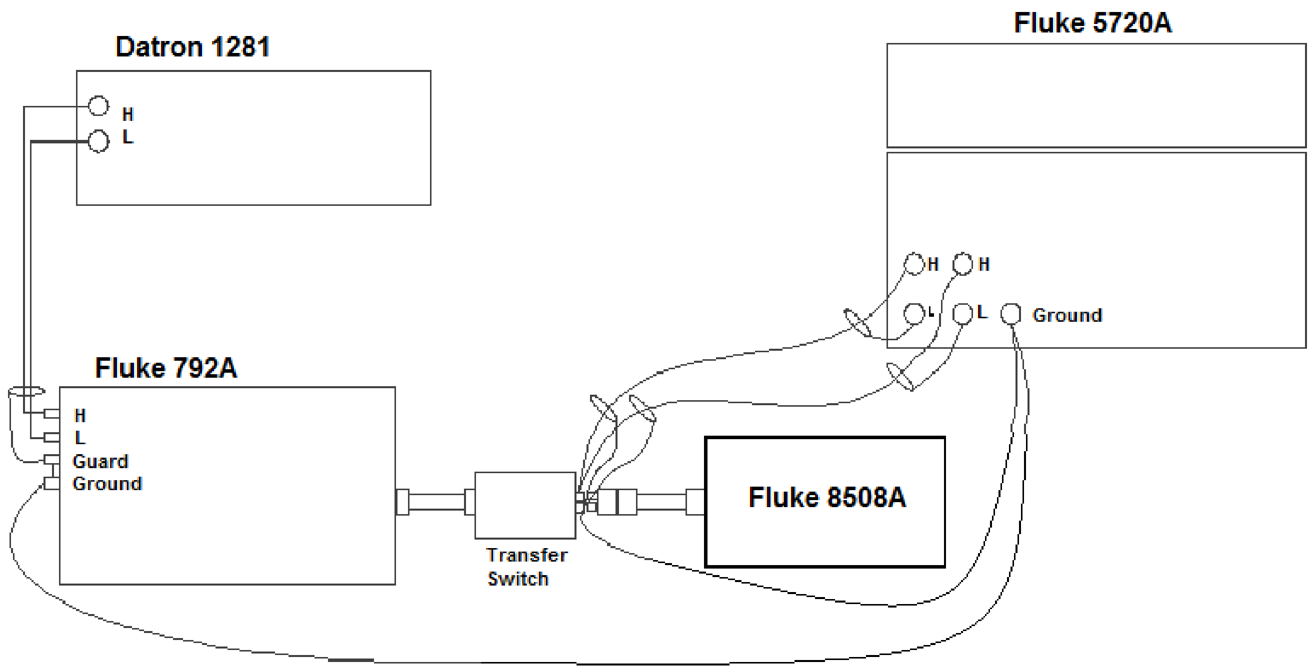
Four wire resistance for 10 Ω, 10 kΩ and 1 MΩ

Figure 1.3: Resistance measurement setup

Alternating Voltage



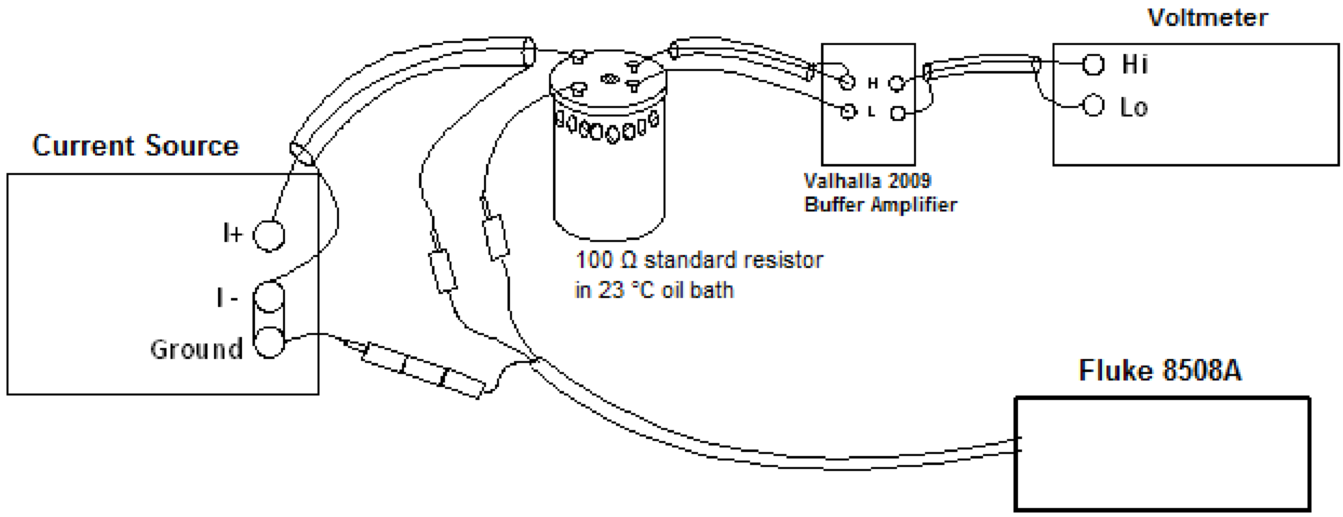
(a) 100 mV



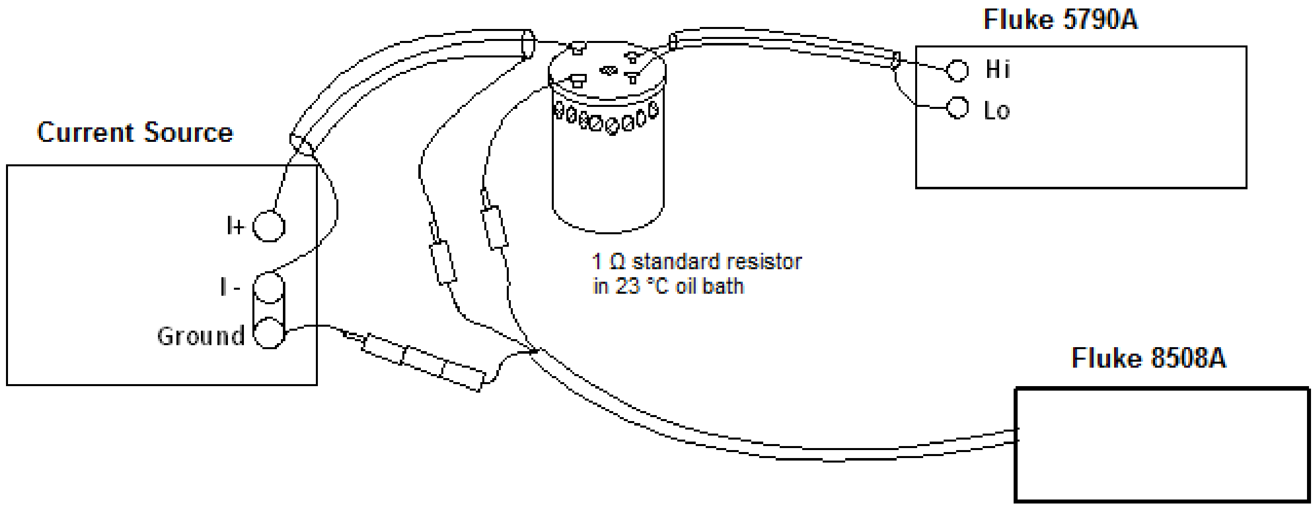
(b) 10 V and 100 V

Figure 1.4: Alternating voltage measurement setups

Alternating Current



(a) AC 10 mA



(b) AC 1 A

Figure 1.5: Alternating current measurement setup

Appendix 2: Traceability charts

Direct Voltage

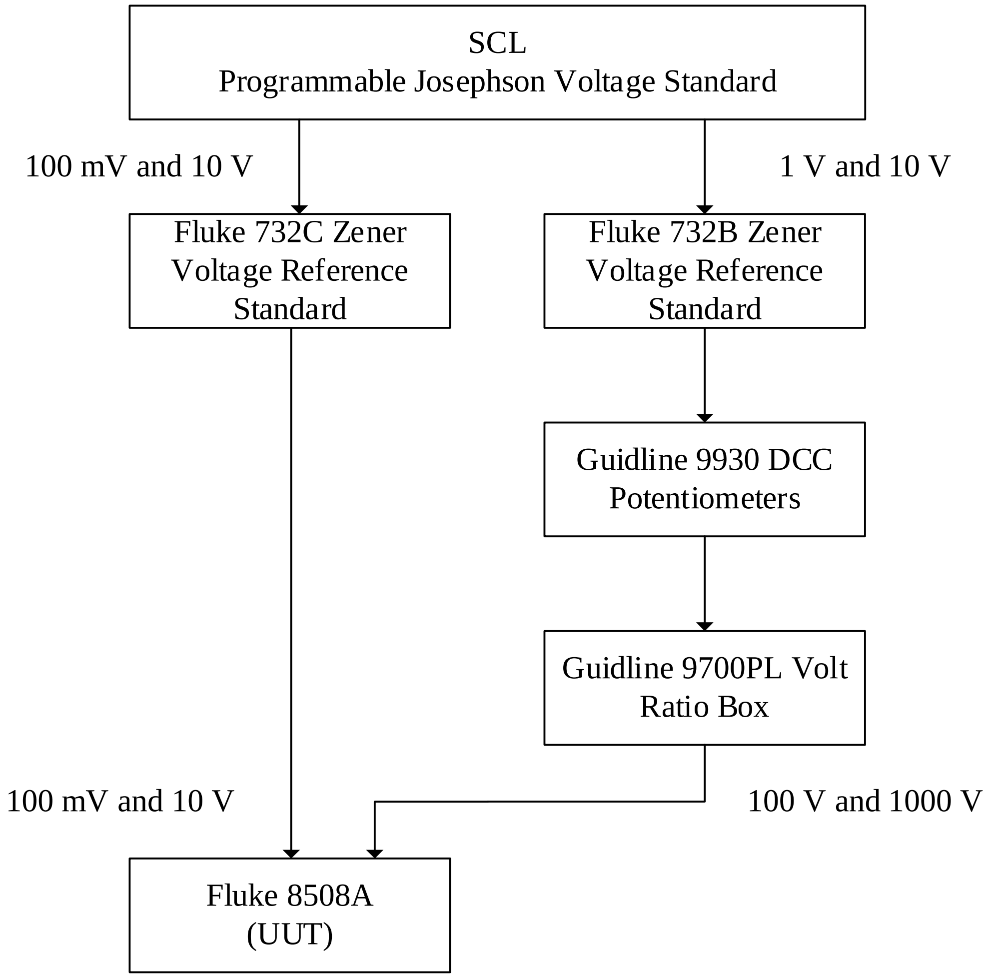


Figure 2.1: Direct voltage traceability

Resistance

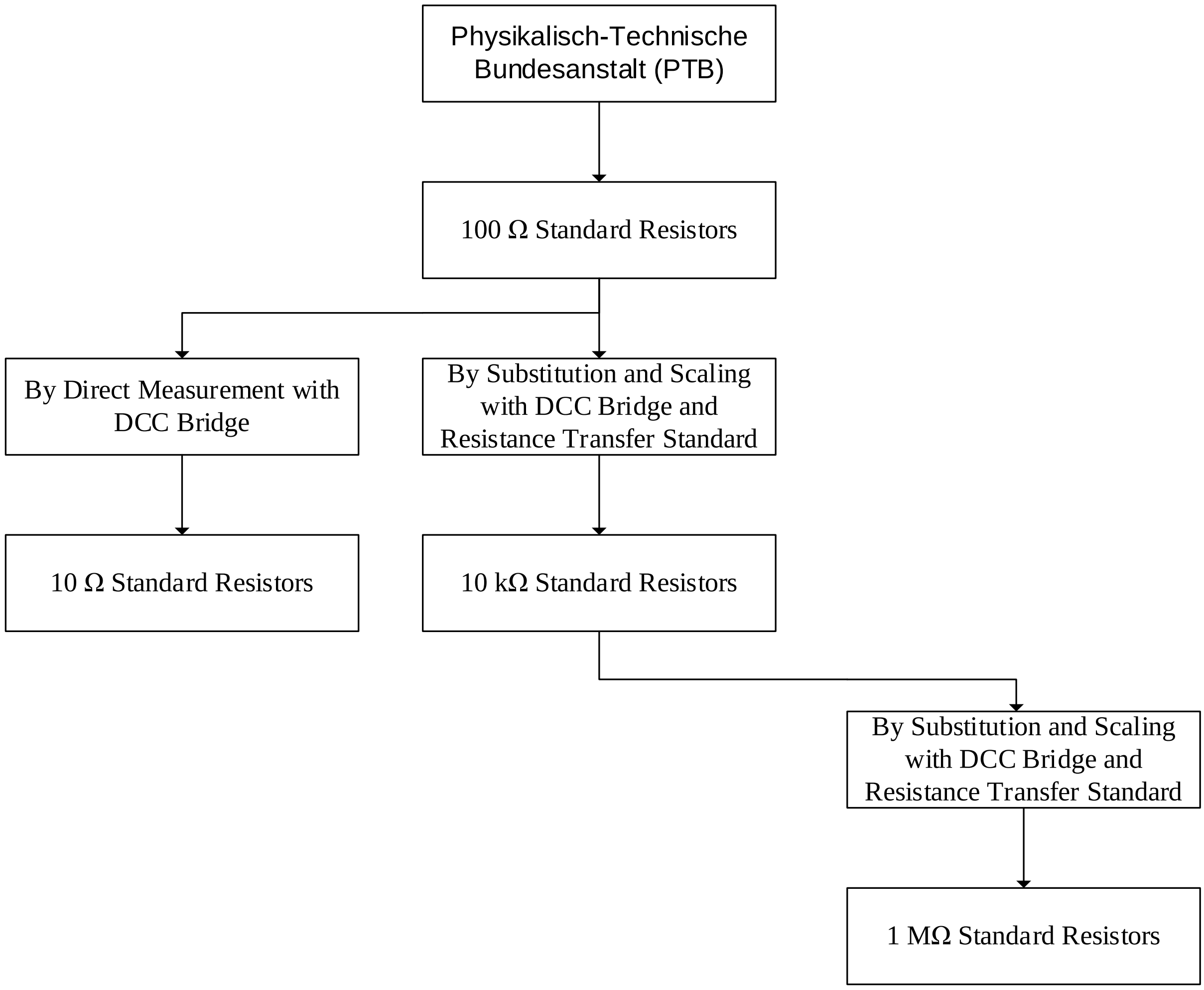


Figure 2.2: Resistance traceability

Ac-dc difference

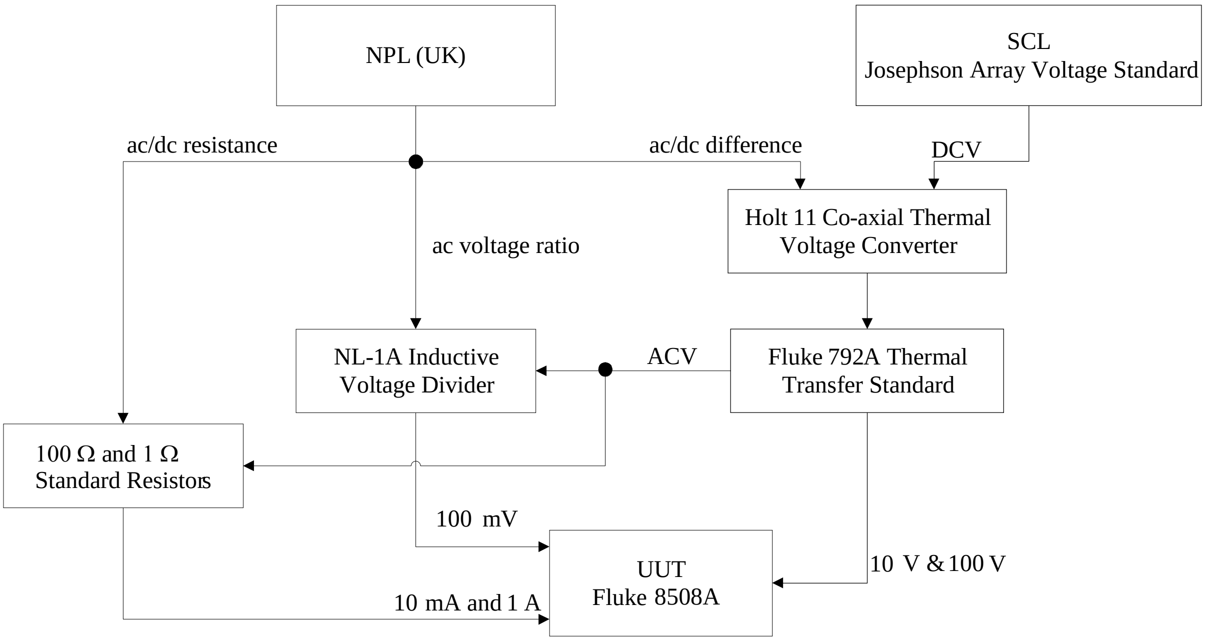


Figure 2.3: AC-DC difference traceability

Appendix 3: Uncertainty budgets

3.1 Direct Voltage

For direct voltage at 100 mV and 10 V the following components contribute to the uncertainty of measurement:

- DC voltage standard: Service uncertainty from the last calibration report
- UUT repeatability: Random variations from the observed data
- UUT resolution: From the unit under test specifications
- UUT stability: From repeated tests during the measurement period at the SCL

Uncertainty budget for DC 100 mV and 10 V measurement:

Component	Type	Value		Unit	Divisor	Standard uncertainty		Sensitivity coefficient	Uncertainty contribution		Degrees of Freedom	
		100 mV	10 V			100 mV	10 V		100 mV	10 V	100 mV	10 V
DC voltage standard	B	2.000	0.3018	µV/V	2	0.99995	0.1509	1	0.99995	0.1509	1970	2994
UUT repeatability	A	0.03	0.0167	µV/V	1	0.03	0.017	1	0.03	0.017	9	9
UUT resolution	B	0.05	0.05	µV/V	√3	0.029	0.0289	1	0.029	0.0289	∞	∞
UUT stability	B	0.665	0.2473	µV/V	√3	0.384	0.1427	1	0.384	0.1427	∞	∞
Combined standard uncertainty									1.072	0.210	µV/V	
Effective degrees of freedom									2601	10774		
Coverage factor									2.0	2.0		
Expanded uncertainty									2.1	0.42	µV/V	
Expanded uncertainty									0.21	4.2	µV	

For direct voltage at 100 V and 1000 V the following components contribute to the uncertainty of measurement:

- DC voltage standard: Service uncertainty from the last calibration report
- Measurement uncertainty of the Potentiometer
- Measurement uncertainty of the voltage ratio box
- UUT repeatability: Random variations from the observed data
- UUT resolution: From the UUT specification
- UUT stability: From repeated tests during the measurement period at the SCL

Uncertainty budget for DC 100 V and 1000 V measurement:

Uncertainty component	**Type**	**Value**		**Unit**	**Divisor**	**Standard uncertainty**		**Sensitivity coefficient**	**Uncertainty contribution**		**Degrees of Freedom**	
		100 V	**1 kV**			**100 V**	**1 kV**		**100 V**	**1 kV**	**100 V**	**1 kV**
DC voltage standard	B	0.8	0.8	µV/V	2	0.4	0.4	1	0.4	0.4	2496	2496
Potentiometer	B	0.231	0.23	µV/V	2	0.1155	0.1155	1	0.1155	0.1155	∞	∞
Voltage ratio box	B	0.57	0.87	µV/V	2	0.285	0.435	1	0.285	0.435	500	500
UUT repeatability	A	0.016	0.045	µV/V	1	0.016	0.045	1	0.016	0.045	9	9
UUT resolution	B	0.05	0.05	µV/V	√3	0.0289	0.0289	1	0.0289	0.0289	∞	∞
UUT stability	B	0.345	0.21	µV/V	√3	0.1992	0.1212	1	0.1992	0.1212	∞	∞
Combined standard uncertainty									0.543	0.616	µV/V	
Effective degrees of freedom									3717	1752		
Coverage factor									2.0	2.0		
Expanded uncertainty									1.1	1.2	µV/V	
Expanded uncertainty									0.11	1.2	mV	

3.2 Direct Current

For direct current the following components contribute to the uncertainty of measurement:

- Voltmeter repeatability: Random variations from the observed data
- Measurement uncertainty of voltmeter for voltage drop
- Shunt resistance: Service uncertainty from the last calibration report
- UUT repeatability: Random variations from the observed data
- UUT resolution: From the UUT specifications
- UUT stability: From repeated tests during the measurement period at the SCL

Uncertainty budget for DC 100 µA, 10 mA and 1 A measurement:

Uncertainty component	Type	Value			Unit	Divisor	Standard uncertainty			Sensitivity coefficient	Uncertainty contribution			Degrees of Freedom		
		100 µA	10 mA	1 A			100 µA	10 mA	1 A		100 µA	10 mA	1 A	100 µA	10 mA	1 A
Voltmeter repeatability	A	0.12	0.05	0.07	µV/V	1	0.12	0.05	0.07	1	0.12	0.05	0.07	9	9	9
Voltmeter for volt drop	B	0.352	0.352	0.733	µV/V	1	0.352	0.352	0.733	1	0.352	0.352	0.733	2053	2053	1182
Shunt resistance	B	0.42	0.18	3.7	µΩ/Ω	2	0.21	0.09	1.85	1	0.21	0.09	1.85	500	500	500
UUT repeatability	A	0.13	0.07	0.07	µA/A	1	0.13	0.07	0.07	1	0.13	0.07	0.07	9	9	19
UUT resolution	B	0.05	0.05	0.05	µA/A	√3	0.029	0.029	0.029	1	0.029	0.029	0.029	∞	∞	∞
UUT stability	B	0.308	0.255	5.957	µA/A	√3	0.178	0.148	3.439	1	0.178	0.148	3.439	∞	∞	∞
Combined standard uncertainty											0.482	0.403	3.97	µA/A		
Effective degrees of freedom											813	2392	10542			
Coverage factor											2.0	2.0	2.0			
Expanded uncertainty											1.0	0.81	7.9	µA/A		
Expanded uncertainty											0.10 nA	8.1 nA	7.9 µA			

3.3 Alternating Voltage

For alternating voltage at 100 mV the following components contribute to the uncertainty of measurement:

- Uncertainty of input voltage to inductive voltage divider: From the specification of the AC Volt measurement standard
- AC voltmeter standard repeatability: From the observed data
- AC voltmeter standard resolution: From the unit under test specifications
- Uncertainty of voltage ratio of the inductive voltage divider:
- UUT repeatability: From the observed data
- UUT resolution: From the unit under test specifications
- UUT stability: From repeated tests during the measurement period at the SCL

Uncertainty budget for AC 100 mV measurement:

Uncertainty Component	Type	Value		Unit	Divisor	Standard uncertainty		Sensitivity coefficient	Uncertainty contribution		Degrees of Freedom	
		55 Hz	1 kHz			55 Hz	1 kHz		55 Hz	1 kHz	55 Hz	1 kHz
AC Voltmeter	B	27.00	27.00	µV/V	√3	15.59	15.59	1	15.59	15.59	∞	∞
Voltmeter repeatability	A	0.38	0.33	µV/V	1	0.38	0.33	1	0.38	0.33	19	19
Voltmeter resolution	B	0.05	0.05	µV/V	√3	0.03	0.03	1	0.03	0.03	∞	∞
Voltage ratio of IVD	B	1.20	0.60	µV/V	2.0	0.30	0.60	1	0.60	0.30	71	7361
UUT repeatability	A	0.65	0.72	µV/V	1	0.65	0.72	1	0.65	0.72	19	19
UUT resolution	B	0.50	0.50	µV/V	√3	0.29	0.29	1	0.29	0.29	∞	∞
UUT stability	B	1.71	1.92	µV/V	√3	0.99	1.11	1	0.99	1.11	∞	∞
Combined standard uncertainty									15.65	15.65	µV/V	
Effective degrees of freedom									4974458	407195		
Coverage factor									2	2		
Expanded uncertainty									32	32	µV/V	
Expanded uncertainty									3.2	3.2	µV	

For alternating voltage at 10 V & 100 V the following components contribute to the uncertainty of measurement:

- Uncertainty of applied DC voltage: From the specification of the DC Voltage calibrator
- Reference ac-dc difference: From the last calibration report of the Fluke 792A
- Unit under test ac-dc difference repeatability: From the observed data
- Uncertainty of DMM for Fluke 792A output measurement: From the DMM (Datron 1281) specifications
- UUT repeatability: From the observed data
- UUT resolution: From the UUT specifications
- UUT stability: From repeated tests during the measurement period at the SCL

Uncertainty budget for AC 10 V measurement:

Uncertainty Component	**Type**	**Value**			**Unit**	**Divisor**	**Standard uncertainty**			**Sensitivity coefficient**	**Uncertainty contribution**			**Degrees of Freedom**		
		55 Hz	**1.000 kHz**	**100 kHz**			**55 Hz**	**1.000 kHz**	**100 kHz**		**55 Hz**	**1.000 kHz**	**100 kHz**	**55 Hz**	**1.000 kHz**	**100 kHz**
DC Volt calibrator	B	4.30	4.30	4.30	µV/V	√3	2.48	2.48	2.48	1	2.48	2.48	2.48	∞	∞	∞
ac-dc difference 792A	B	14.00	13.00	9.00	µV/V	2.0	7.00	6.50	4.50	1	7.00	6.50	4.50	200	200	200
792A repeatability	A	0.37	0.53	0.33	µV/V	1	0.37	0.53	0.33	1	0.37	0.53	0.33	3	3	3
DMM for 792A	B	0.55	0.55	0.55	µV/V	√3	0.32	0.32	0.32	1	0.32	0.32	0.32	∞	∞	∞
UUT repeatability	A	0.70	0.42	2.75	µV/V	1	0.70	0.42	2.75	1	0.70	0.42	2.75	3	3	3
UUT resolution	B	0.50	0.50	0.50	µV/V	√3	0.29	0.29	0.29	1	0.29	0.29	0.29	∞	∞	∞
UUT stability	B	0.78	0.73	3.80	µV/V	√3	0.45	0.42	2.19	1	0.45	0.42	2.19	∞	∞	∞
Combined standard uncertainty											7.50	7.02	6.25	µV/V		
Effective degrees of freedom											260	270	72			
Coverage factor											2	2	2			
Expanded uncertainty											15	14	13	µV/V		
Expanded uncertainty											0.15	0.14	0.13	mV		

Uncertainty budget for AC 100 V measurement: (Cont'd)

Uncertainty Component	Type	Value		Unit	Divisor	Standard uncertainty		Sensitivity coefficient	Uncertainty contribution		Degrees of Freedom	
		55 Hz	1 kHz			55 Hz	1 kHz		55 Hz	1 kHz	55 Hz	1 kHz
DC Volt calibrator	B	6.50	6.50	µV/V	√3	3.75	3.75	1	3.75	3.75	∞	∞
ac-dc difference 792A	B	12.00	15.00	µV/V	2.0	6.00	7.50	1	6.00	7.50	200	200
792A repeatability	A	0.61	0.46	µV/V	1	0.61	0.46	1	0.61	0.46	3	3
DMM for 792A	B	0.55	0.55	µV/V	√3	0.32	0.32	1	0.32	0.32	∞	∞
UUT repeatability	A	2.15	0.32	µV/V	1	2.15	0.32	1	2.15	0.32	3	3
UUT resolution	B	0.50	0.50	µV/V	√3	0.29	0.29	1	0.29	0.29	∞	∞
UUT stability	B	1.78	0.45	µV/V	√3	1.03	0.26	1	1.03	0.26	∞	∞
Combined standard uncertainty									7.50	8.43	µV/V	
Effective degrees of freedom									233	217		
Coverage factor									2	2		
Expanded uncertainty									15	17	µV/V	
Expanded uncertainty									1.5	1.7	mV	

3.4 Alternating Current

For alternating current the following components contribute to the uncertainty of measurement:

- ACV measurement uncertainty: A Fluke 5790A AC voltage measurement standard is used to determine the voltage drop across the shunt. From the specification of the Fluke 5790A
- ACV reference repeatability: From the observed data
- ACV reference resolution: From the specification of the Fluke 5790A
- Uncertainty of AC voltage drop measurement between measurement and verification: From the specification of the Wavetek 1281 (For 10 mA test only)
- Current shunt impedance: From the latest calibration report
- UUT repeatability: From the observed data
- UUT resolution: From the specifications of the UUT
- UUT stability: From repeated tests during the measurement period at the SCL

Uncertainty budget for AC 10 mA measurement:

Uncertainty Component	**Type**	**Value**		**Unit**	**Divisor**	**Standard uncertainty**		**Sensitivity coefficient**	**Uncertainty contribution**		**Degrees of Freedom**	
		300 Hz	**1 kHz**			**300 Hz**	**1 kHz**		**300 Hz**	**1 kHz**	**300 Hz**	**1 kHz**
AC Voltmeter	B	24	24	µV/V	√3	13.86	13.86	1	13.86	13.86	∞	∞
Voltmeter repeatability	A	0.51	0.03	µV/V	1	0.51	0.03	1	0.51	0.03	19	19
Voltmeter resolution	B	0.05	0.05	µV/V	√3	0.03	0.03	1	0.03	0.03	∞	∞
Voltmeter for AC volt drop (Wavetek 1281)	B	5	5	µV/V	√3	2.89	2.89	1	2.89	2.89	∞	∞
Shunt resistance	B	11.2	7.8	µΩ/Ω	2.0	5.60	3.90	1	5.60	3.90	200	200
UUT repeatability	A	0.43	0.22	µA/A	1	0.43	0.22	1	0.43	0.22	19	19
UUT resolution	B	0.5	0.5	µA/A	√3	0.29	0.29	1	0.29	0.29	∞	∞
UUT stability	B	6.33	4.02	µA/A	√3	3.66	2.32	1	3.66	2.32	∞	∞
Combined standard uncertainty									15.67	14.87	µA/A	
Effective degrees of freedom									12252	42242		
Coverage factor									2	2		
Expanded uncertainty									32	30	µA/A	
Expanded uncertainty									0.32	0.30	µA	

Uncertainty budget for AC 1 A measurement:

Uncertainty Component	Type	Value		Unit	Divisor	Standard uncertainty		Sensitivity coefficient	Uncertainty contribution		Degrees of Freedom	
		300 Hz	1 kHz			300 Hz	1 kHz		300 Hz	1 kHz	300 Hz	1 kHz
AC Voltmeter	B	24	24	µV/V	√3	13.86	13.86	1	13.86	13.86	∞	∞
Voltmeter repeatability	A	0.15	0.09	µV/V	1	0.15	0.09	1	0.15	0.09	19	9
Voltmeter resolution	B	0.05	0.05	µV/V	√3	0.03	0.03	1	0.03	0.03	∞	∞
Shunt resistance	B	9.90	8.70	µΩ/Ω	2.0	4.95	4.35	1	4.95	4.35	200	200
UUT repeatability	A	0.99	1.49	µA/A	1	0.99	1.49	1	0.99	1.49	19	9
UUT resolution	B	0.5	0.5	µA/A	√3	0.29	0.29	1	0.29	0.29	∞	∞
UUT stability	B	10.28	11.27	µA/A	√3	5.93	6.51	1	5.93	6.51	∞	∞
Combined standard uncertainty									15.90	15.99	µA/A	
Effective degrees of freedom									20940	27903		
Coverage factor									2	2		
Expanded uncertainty									32	32	µA/A	
Expanded uncertainty									32	32	µA	

3.5 Resistance

For resistance the following components contribute to the uncertainty of measurement:

- Reference resistor: Service uncertainty from the latest calibration report
- UUT repeatability: From the observed data
- UUT resolution: From the specifications of the UUT
- UUT stability: From repeated tests during the measurement period at the SCL

Uncertainty budget for Resistance measurement:

Uncertainty component	**Type**	**Value**		**Unit**	**Divisor**	**Standard uncertainty**		**Sensitivity coefficient**	**Uncertainty contribution**		**Degrees of Freedom**	
		10 Ω	**10 kΩ**			**10 Ω**	**10 kΩ**		**10 Ω**	**10 kΩ**	**10 Ω**	**10 kΩ**
Reference resistance	B	0.38	0.46	μΩ/Ω	2	0.19	0.23	1	0.19	0.23	500	500
UUT repeatability	A	0.10	0.03	μΩ/Ω	1	0.10	0.03	1	0.10	0.03	9	9
UUT resolution	B	0.05	0.05	μΩ/Ω	√3	0.029	0.029	1	0.0029	0.0029	∞	∞
UUT stability	B	0.47	0.22	μΩ/Ω	√3	0.271	0.127	1	0.271	0.127	∞	∞
Combined standard uncertainty									0.346	0.266	μΩ/Ω	
Effective degrees of freedom									1226	881		
Coverage factor									2.0	2.0		
Expanded uncertainty									0.69	0.53	μΩ/Ω	
Expanded uncertainty									6.9 μΩ	5.3 mΩ		

Uncertainty component	**Type**	**Value**		**Unit**	**Divisor**	**Standard uncertainty**		**Sensitivity coefficient**	**Uncertainty contribution**		**Degrees of Freedom**	
		10 kΩ (LoI)	**1 MΩ**			**10 kΩ (LoI)**	**1 MΩ**		**10 kΩ (LoI)**	**1 MΩ**	**10 kΩ (LoI)**	**1 MΩ**
Reference resistance	B	0.46	1.2	μΩ/Ω	2	0.23	0.60	1	0.23	0.60	500	500
UUT repeatability	A	0.08	0.18	μΩ/Ω	1	0.08	0.18	1	0.08	0.18	19	19
UUT resolution	B	0.05	0.05	μΩ/Ω	√3	0.029	0.029	1	0.0029	0.0029	∞	∞
UUT stability	B	0.24	0.695	μΩ/Ω	√3	0.139	0.401	1	0.139	0.401	∞	∞
Combined standard uncertainty									0.282	0.744	μΩ/Ω	
Effective degrees of freedom									433747	1583		
Coverage factor									2.0	2.0		
Expanded uncertainty									0.56	1.5	μΩ/Ω	
Expanded uncertainty									5.6 mΩ	1.5 Ω		

-END-

Measurement Report for Comparison on Calibration of Multimeter

GULFMET.EM.S8

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Unite Arab Emirates

17 April 2024

1. Participant Institute

Institute	Emirates Metrology Institute (EMI) Abu Dhabi Quality and Conformity Council (ADQCC)
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2. Period of Measurements

EMI measured the transfer standard three times during the comparison. These periods were

Measurement Period 1: 5 October to 10 October 2021

Measurement Period 2: 20 June to 1 July 2022

Measurement Period 3: 19 December 2022 to 5 January 2023

3. Ambient Conditions

Temperature : (23 ± 1) °C

Relative Humidity : (45 ± 10) % rh

4. Measurement Standards Used

Name	Manufacturer	Model No	Serial No	Calibrated by
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
Reference Multimeter	Fluke	8508A	218865636	EMI, UAE
AC Measurement Standard	Fluke	5790A	2030032	CMI, CZ
AC-DC Current Shunt 10 mA	Fluke	A40B	194564261	UME, TR / EMI, UAE
AC-DC Current Shunt 1 A	Fluke	A40B	194565348	UME, TR / EMI, UAE

5. Traceability

Quantity	Reference standards	Traceability
DCV	DC Voltage Standard	Calibration by NPL, UK
DCI	DC Voltage Standard	Calibration by NPL, UK
	Standard Resistors	Calibration by NPL, UK
ACV	AC Measurement Standard	Calibration by CMI, CZ
ACI	AC Measurement Standard	Calibration by CMI, CZ
	AC-DC transfer	Calibration by UME, TR
	Standard Resistors	Calibration by NPL, UK
Resistance	Standard Resistors	Calibration by NPL, UK

6. Measurement Method

6.1. The Travelling Standard

The instrument measured was Fluke 8508A Reference Multimeter Serial Number 218865629.

6.2. Preparation

The Multimeter 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 for at least 24 hours before measurements commenced. The Multimeter was powered continuously throughout the measurement period.

6.3. DC Voltage

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

6.3.1. 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 taken as the zero offset of the Automatic Potentiometer. This offset is subtracted from the value measured by the Automatic Potentiometer at the nominal value of 100 mV. The reported value is the mean of 50 measurements.

6.3.2. Nominal Value of 10 V

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

6.3.3. 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.

6.4. DC Current

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 a shunt and Fluke 8508A Reference Multimeter. The shunts used were Fluke A40B shunts for 10 mA and 1 A and the 10 kΩ standard resistor at 100 µA. Before each DC Current measurement, the Multimeter was zeroed with the input terminals open circuit.

6.5. 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.

6.6. AC Voltage

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 5790A AC Measurement Standard.

6.7. AC Current

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 Fluke A40B shunts and Fluke 8508A Reference Multimeter.

7. Calculation of Multimeter Error

The Multimeter Error was calculated using the following formula:

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

8. Measurement Results

8.1. Measurement Period 1

8.1.1. DC Voltage

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
200 mV	+ 100 mV	99.9998542	100.000272	4.18E-06	1.7E-06
20 V	+10 V	9.99999773	10.00003598	3.83E-06	1.2E-06
200 V	+100 V	99.9999498	100.0000913	1.42E-06	4.1E-06
1000 V	+1000 V	1000.001012	1000.001424	4.12E-07	5.0E-06

8.1.2. DC Current

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
200 µA	+ 100 µA	100.0009743	100.001968	9.94E-06	5.0E-06
20 mA	+10 mA	9.999998668	10.0000478	4.91E-06	6.5E-06
1 A	+1 A	1.000009124	0.999763	-2.46E-04	5.9E-05

8.1.3. DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
20 Ω	TrueΩ	10 Ω	10.0003353	10.000383	4.77E-06	3.1E-06
20 kΩ	TrueΩ	10 kΩ	9.9999309	9.9999832	5.23E-06	3.6E-06
	TrueΩ LoI	10 kΩ	9.9999309	9.9999838	5.29E-06	3.6E-06
2 MΩ	Normal Ω	1 MΩ	0.9999943	0.99999796	3.66E-06	4.2E-06

8.1.4. AC Voltage

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99.9949	99.9982	3.30E-05	6.2E-05
	100 mV	1 kHz	99.9947	100.0018	7.10E-05	5.2E-05
20 V	10 V	55 Hz	10.00002	9.99984	-1.80E-05	4.3E-05
	10 V	1 kHz	9.999968	10.00013	1.62E-05	3.0E-05
	10 V	100 kHz	10.000574	9.99912	-1.45E-04	7.7E-05
200 V	100 V	55 Hz	99.99912	99.9967	-2.42E-05	4.5E-05
	100 V	1 kHz	99.99878	99.9998	1.02E-05	3.7E-05

8.1.5. AC Current

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
20 mA	10 mA	300 Hz	10.0002969	10.00014	-1.57E-05	9.6E-05
	10 mA	1 kHz	10.00019064	10.00004	-1.51E-05	9.6E-05
1 A	1 A	300 Hz	1.000032244	0.999405	-6.27E-04	9.6E-05
	1 A	1 kHz	1.000021496	0.999434	-5.87E-04	9.6E-05

8.2. Measurement Period 2

8.2.1. DC Voltage

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
200 mV	+ 100 mV	99.9999281	100.0005609	6.33E-06	1.7E-06
20 V	+10 V	9.9999941	10.00003403	3.99E-06	1.2E-06
200 V	+100 V	99.9998014	100.0000527	2.51E-06	4.1E-06
1000 V	+1000 V	999.998917	1000.001657	2.74E-06	5.0E-06

8.2.2. DC Current

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
200 µA	+ 100 µA	100.001415	100.00248	1.06E-05	5.0E-06
20 mA	+10 mA	9.999999	10.000042	4.30E-06	6.5E-06
1 A	+1 A	0.9999751	0.9997418	-2.33E-04	5.9E-05

8.2.3. DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
20 Ω	TrueΩ	10 Ω	10.00038234	10.0004338	5.15E-06	3.1E-06
20 kΩ	TrueΩ	10 kΩ	9.9999309	9.9999800	4.91E-06	3.6E-06
	TrueΩ LoI	10 kΩ	9.9999309	9.9999806	4.97E-06	3.6E-06
2 MΩ	Normal Ω	1 MΩ	0.9999941	0.99999724	3.14E-06	4.2E-06

8.2.4. AC Voltage

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99.9991	99.9992	1.00E-06	6.2E-05
	100 mV	1 kHz	99.999	100.0027	3.70E-05	5.2E-05
20 V	10 V	55 Hz	10.000058	9.99989	-1.68E-05	4.3E-05
	10 V	1 kHz	10.000022	10.00018	1.58E-05	3.0E-05
	10 V	100 kHz	10.000481	9.99961	-8.71E-05	7.7E-05
200 V	100 V	55 Hz	99.99959	99.9972	-2.39E-05	4.5E-05
	100 V	1 kHz	99.99934	99.9998	4.60E-06	3.7E-05

8.2.5. AC Current

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
20 mA	10 mA	300 Hz	10.00027815	10.0001	-1.78E-05	9.6E-05
	10 mA	1 kHz	10.00019689	10.00002	-1.77E-05	9.6E-05
1 A	1 A	300 Hz	1.000021996	0.999399	-6.23E-04	9.6E-05
	1 A	1 kHz	1.000026995	0.999449	-5.78E-04	9.6E-05

8.3. Measurement Period 3

8.3.1. DC Voltage

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
200 mV	+ 100 mV	99.99994	100.0003511	4.11E-06	1.7E-06
20 V	+10 V	10.00000453	10.0000472	4.27E-06	1.2E-06
200 V	+100 V	100.0001111	100.0002638	1.53E-06	4.1E-06
1000 V	+1000 V	1000.004735	1000.003342	-1.39E-06	5.0E-06

8.3.2. DC Current

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
200 μA	+ 100 μA	100.002507	100.00365	1.14E-05	5.0E-06
20 mA	+10 mA	10.0000132	10.000053	3.98E-06	6.5E-06
1 A	+1 A	1.00003374	0.9997395	-2.94E-04	5.9E-05

8.3.3. DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
20 Ω	TrueΩ	10 Ω	9.9999386	9.9999824	4.38E-06	3.1E-06
20 kΩ	TrueΩ	10 kΩ	9.9999264	9.9999766	5.02E-06	3.6E-06
	TrueΩ LoI	10 kΩ	9.9999264	9.9999766	5.02E-06	3.6E-06
2 MΩ	Normal Ω	1 MΩ	0.9999941	1.0000005	6.40E-06	4.2E-06

8.3.4. AC Voltage

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	99.997	99.9999	2.90E-05	6.2E-05
	100 mV	1 kHz	99.9965	100.003	6.50E-05	5.2E-05
20 V	10 V	55 Hz	10.000063	9.99992	-1.43E-05	4.3E-05
	10 V	1 kHz	10.000026	10.00021	1.84E-05	3.0E-05
	10 V	100 kHz	10.000478	10.00164	1.16E-04	7.7E-05
200 V	100 V	55 Hz	100.00021	99.9978	-2.41E-05	4.5E-05
	100 V	1 kHz	99.99889	100.0001	1.21E-05	3.7E-05

8.3.5. AC Current

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Uncertainty
	Voltage	Frequency				
20 mA	10 mA	300 Hz	10.00018439	10.00012	-6.44E-06	9.6E-05
	10 mA	1 kHz	10.00009063	10.00002	-7.06E-06	9.6E-05
1 A	1 A	300 Hz	1.000018497	0.999374	-6.44E-04	9.6E-05
	1 A	1 kHz	1.000008249	0.999406	-6.02E-04	9.6E-05

9. Uncertainty Budget

9.1. DC Voltage

9.1.1. 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}	0.001	0.050	Rectangular	1.7321	1	0.029	∞
I_{AP}	0.001	0.005	Rectangular	1.7321	1	0.003	∞
I_R	0	0.434	Normal k=1	1.0000	1	0.434	5
V_E	0	0.440	Normal k=2	2.0000	1	0.220	∞
V_C	0	0.100	Rectangular	1.7321	1	0.058	∞
V_S	10	0.030	Normal k=2	2.0000	1	0.015	∞
V_D	0	0.960	Rectangular	1.7321	1	0.554	∞
V_{TC}	0	0.120	Rectangular	1.7321	1	0.069	∞
V_N	0	0.060	Rectangular	1.7321	1	0.035	∞
V_T	0	0.600	Rectangular	1.7321	1	0.346	∞
Combined Uncertainty, $u(E_x)$							0.821
Effective Degrees of Freedom, v_{eff}							6.43E+01
Coverage Factor, k							2.040
Expanded Uncertainty, $U(E_x)$, ppm							1.7

9.1.2. 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	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	0.008	Normal k=1	1.0000	1	0.008	5
V_S	10	0.030	Normal k=2	2.0000	1	0.015	∞
V_D	0	0.960	Rectangular	1.7321	1	0.554	∞
V_{TC}	0	0.120	Rectangular	1.7321	1	0.069	∞
V_N	0	0.060	Rectangular	1.7321	1	0.035	∞
V_T	0	0.600	Rectangular	1.7321	0.1	0.035	∞
					Combined Uncertainty, $u(E_x)$		0.562
					Effective Degrees of Freedom, v_{eff}		1.16E+08
					Coverage Factor, k		2.000
					Expanded Uncertainty, $U(E_x)$, ppm		1.2

9.1.3. 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 = Stability 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	0.050	Rectangular	1.7321	1	0.029	∞
I_{AP}	100	0.005	Rectangular	1.7321	1	0.003	∞
I_R	0	0.313	Normal k=1	1.0000	1	0.313	5
V_E	0	0.044	Normal k=2	2.0000	1	0.022	∞
V_X	0	3.800	Normal k=2	2.0000	1	1.900	∞
V_D	0	0.100	Rectangular	1.7321	1	0.058	∞
V_S	10	0.030	Normal k=2	2.0000	1	0.015	∞
V_C	0	0.960	Rectangular	1.7321	1	0.554	∞
V_{TC}	0	0.120	Rectangular	1.7321	1	0.069	∞
V_N	0	0.060	Rectangular	1.7321	1	0.035	∞
						Combined Uncertainty, $u(E_x)$	2.007
						Effective Degrees of Freedom, v_{eff}	8.39E+03
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	4.1

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	0.050	Rectangular	1.7321	1	0.029	∞
I_{AP}	1000	0.005	Rectangular	1.7321	1	0.003	∞
I_R	0	1.264	Normal k=1	1.0000	1	1.264	5
V_E	0	0.044	Normal k=2	2.0000	1	0.022	∞
V_X	0	3.800	Normal k=2	2.0000	1	1.900	∞
V_D	0	0.100	Rectangular	1.7321	1	0.058	∞
V_S	10	0.030	Normal k=2	2.0000	1	0.015	∞
V_D	0	0.960	Rectangular	1.7321	1	0.554	∞
V_{TC}	0	0.120	Rectangular	1.7321	1	0.069	∞
V_N	0	0.060	Rectangular	1.7321	1	0.035	∞
						Combined Uncertainty, $u(E_x)$	2.351
						Effective Degrees of Freedom, v_{eff}	5.98E+01
						Coverage Factor, k	2.043
						Expanded Uncertainty, $U(E_x)$, ppm	5.0

9.2. DC Current

Model Function:

$$E_x = \left(\frac{I_{MM}\,(R_{CL} + R_{DR} + R_{TC} + R_{PW}) + I_R}{V_{CM} - V_{CL} - V_{DR} - V_{TH}}\right) - 1$$

Where:

I_{MM} = Indication of multimeter
V_{CM} =Indication of the calibrated measuring instrument
V_{CL} = Correction for the calibrated value of the measuring instrument
V_{DR} = Stability of the measuring instrument since the last calibration
V_{TH} = Thermoelectric voltage
R_{CL} = Calibrated value of the reference resistor
R_{DR} = Drift of the reference resistor since the last calibration
R_{TC} = Change of the reference resistor due to temperature
R_{PW} = Change of the reference resistor due to power
I_R = Repeatability of indication

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	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	0.500	Normal k=1	1.0000	1	0.500	9
V_{CM}	1	0.050	Rectangular	1.7321	1	0.029	∞
I_{CL}	0	2.200	Normal k=2	2.0000	1	1.100	∞
I_{DR}	0	3.700	Rectangular	1.7321	1	2.136	∞
V_{TH}	0	0.500	Rectangular	1.7321	1	0.289	∞
R_{CL}	10000	0.190	Normal k=2	2.0000	1	0.095	∞
R_{DR}	0	0.077	Rectangular	1.7321	1	0.044	∞
R_{TC}	0	0.170	Rectangular	1.7321	1	0.098	∞
R_{PW}	0	0.000	Rectangular	1.7321	1	0.000	∞
						Combined Uncertainty, $u(E_x)$	2.476
						Effective Degrees of Freedom, v_{eff}	5.41E+03
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	5.0

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	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	0.300	Normal k=1	1.0000	1	0.300	9
V_{CM}	800	0.063	Rectangular	1.7321	1	0.036	∞
I_{CL}	0	2.200	Normal k=2	2.0000	1	1.100	∞
I_{DR}	0	3.950	Rectangular	1.7321	1	2.281	∞
V_{TH}	0	0.625	Rectangular	1.7321	1	0.361	∞
R_{CL}	80	0.430	Normal k=2	2.0000	1	0.215	∞
R_{DR}	0	3.400	Rectangular	1.7321	1	1.963	∞
R_{TC}	0	0.044	Rectangular	1.7321	1	0.025	∞
R_{PW}	0	0.000	Rectangular	1.7321	1	0.000	∞
						Combined Uncertainty, $u(E_x)$	3.246
						Effective Degrees of Freedom, v_{eff}	1.23E+05
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	6.5

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	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	0.400	Normal k=1	1.0000	1	0.400	9
V_{CM}	800	0.063	Rectangular	1.7321	1	0.036	∞
I_{CL}	0	2.200	Normal k=2	2.0000	1	1.100	∞
I_{DR}	0	3.950	Rectangular	1.7321	1	2.281	∞
V_{TH}	0	0.625	Rectangular	1.7321	1	0.361	∞
R_{CL}	800	0.400	Normal k=2	2.0000	1	0.200	∞
R_{DR}	0	3.400	Rectangular	1.7321	1	1.963	∞
R_{TC}	0	50.000	Rectangular	1.7321	1	28.868	∞
R_{PW}	0	0.000	Rectangular	1.7321	1	0.000	∞
Combined Uncertainty, $u(E_x)$							29.050
Effective Degrees of Freedom, v_{eff}							2.50E+08
Coverage Factor, k							2.000
Expanded Uncertainty, $U(E_x)$, ppm							59

9.3. 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
R_P = 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	Rectangular	1.7321	1	0.029	∞
I_R	0	0.300	Normal k=1	1.0000	1	0.300	9
R_S	10	0.430	Normal k=2	2.0000	1	0.215	∞
R_D	0	2.000	Rectangular	1.7321	1	1.155	∞
R_P	0	0.000	Rectangular	1.7321	1	0.000	∞
R_{TC}	0	1.600	Rectangular	1.7321	1	0.924	∞
Combined Uncertainty, $u(E_x)$							1.524
Effective Degrees of Freedom, v_{eff}							6.00E+03
Coverage Factor, k							2.000
Expanded Uncertainty, $U(E_x)$, ppm							3.1

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) v_i
I_{MM}	10	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	0.300	Normal k=1	1.0000	1	0.300	9
R_S	10	0.540	Normal k=2	2.0000	1	0.270	∞
R_D	0	2.200	Rectangular	1.7321	1	1.270	∞
R_P	0	0.000	Rectangular	1.7321	1	0.000	∞
R_{TC}	0	2.000	Rectangular	1.7321	1	1.155	∞
Combined Uncertainty, $u(E_x)$							1.7945
Effective Degrees of Freedom, v_{eff}							1.07E+04
Coverage Factor, k							2.000
Expanded Uncertainty, $U(E_x)$, ppm							3.6

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) v_i
I_{MM}	10	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	0.300	Normal k=1	1.0000	1	0.300	9
R_S	10	0.540	Normal k=2	2.0000	1	0.270	∞
R_D	0	2.200	Rectangular	1.7321	1	1.270	∞
R_P	0	0.000	Rectangular	1.7321	1	0.000	∞
R_{TC}	0	2.000	Rectangular	1.7321	1	1.155	∞
Combined Uncertainty, $u(E_x)$							1.7945
Effective Degrees of Freedom, v_{eff}							1.07E+04
Coverage Factor, k							2.000
Expanded Uncertainty, $U(E_x)$, ppm							3.6

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) v_i
I_{MM}	1	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	0.100	Normal k=1	1.0000	1	0.100	9
R_S	1	3.500	Normal k=2	2.0000	1	1.750	∞
R_D	0	0.000	Rectangular	1.7321	1	0.000	∞
R_P	0	0.000	Rectangular	1.7321	1	0.000	∞
R_{TC}	0	2.000	Rectangular	1.7321	1	1.155	∞
Combined Uncertainty, $u(E_x)$							2.099
Effective Degrees of Freedom, v_{eff}							1.75E+06
Coverage Factor, k							2.000
Expanded Uncertainty, $U(E_x)$, ppm							4.2

9.4. AC Voltage

Model Function:

$$E_x = \frac{(I_{MM} + I_R + V_{CL} + V_D)}{V_{CM}} - 1$$

I_{MM} = Indication of multimeter
I_R = Repeatability of indication
V_{CM} = Indication of the calibrated measuring instrument
V_{CL} = Correction for the calibrated value of the measuring instrument
V_D = Stability of the measuring instrument since the last calibration

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	0.500	Rectangular	1.7321	1	0.289	∞
I_R	0	15.000	Normal k=1	1.0000	1	15.000	9
V_{CL}	0	29.000	Normal k=2	2.0000	1	14.500	∞
V_D	0	39.000	Rectangular	1.7321	1	22.517	∞
V_{CM}	100	0.500	Rectangular	1.7321	10	0.289	∞
						Combined Uncertainty, $u(E_x)$	30.699
						Effective Degrees of Freedom, v_{eff}	1.58E+02
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	62

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	0.500	Rectangular	1.7321	1	0.289	∞
I_R	0	15.000	Normal k=1	1.0000	1	15.000	9
V_{CL}	0	16.000	Normal k=2	2.0000	1	8.000	∞
V_D	0	22.000	Rectangular	1.7321	1	12.702	∞
V_{CM}	10	0.500	Rectangular	1.7321	10	0.289	∞
						Combined Uncertainty, $u(E_x)$	21.225
						Effective Degrees of Freedom, v_{eff}	3.61E+01
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	43

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	0.500	Rectangular	1.7321	1	0.289	∞
I_R	0	1.000	Normal k=1	1.0000	1	1.000	9
V_{CL}	0	15.000	Normal k=2	2.0000	1	7.500	∞
V_D	0	22.000	Rectangular	1.7321	1	12.702	∞
V_{CM}	10	0.500	Rectangular	1.7321	10	0.289	∞
						Combined Uncertainty, $u(E_x)$	14.790
						Effective Degrees of Freedom, v_{eff}	4.31E+05
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	30

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	0.500	Rectangular	1.7321	1	0.289	∞
I_R	0	1.000	Normal k=1	1.0000	1	1.000	9
V_{CL}	0	21.000	Normal k=2	2.0000	1	10.500	∞
V_D	0	64.000	Rectangular	1.7321	1	36.950	∞
V_{CM}	10	0.500	Rectangular	1.7321	10	0.289	∞
						Combined Uncertainty, $u(E_x)$	38.429
						Effective Degrees of Freedom, v_{eff}	1.96E+07
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	77

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	0.500	Rectangular	1.7321	1	0.289	∞
I_R	0	14.000	Normal k=1	1.0000	1	14.000	9
V_{CL}	0	20.000	Normal k=2	2.0000	1	13.500	∞
V_D	0	25.000	Rectangular	1.7321	1	14.434	∞
V_{CM}	100	0.500	Rectangular	1.7321	10	0.289	∞
						Combined Uncertainty, $u(E_x)$	22.459
						Effective Degrees of Freedom, v_{eff}	60
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	45

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	0.500	Rectangular	1.7321	1	0.289	∞
I_R	0	6.000	Normal k=1	1.0000	1	14.000	9
V_{CL}	0	20.000	Normal k=2	2.0000	1	13.500	∞
V_D	0	25.000	Rectangular	1.7321	1	14.434	∞
V_{CM}	100	0.500	Rectangular	1.7321	10	0.289	∞
						Combined Uncertainty, $u(E_x)$	24.224
						Effective Degrees of Freedom, v_{eff}	81
						Coverage Factor, k	2.000
						Expanded Uncertainty, $U(E_x)$, ppm	45

9.5. AC Current

Model Function:

$$E_x = \left(\frac{I_{MM}\,(R_{CL} + R_{DR} + R_{TC} + R_{FR} + R_{PW}) + I_R}{V_{CM} - V_{CL} - V_{DR}}\right) - 1$$

Where:

I_{MM} = Indication of multimeter
V_{CM} =Indication of the calibrated measuring instrument
V_{CL} = Correction for the calibrated value of the measuring instrument
V_{DR} = Stability of the measuring instrument since the last calibration
R_{CL} = Calibrated value of the reference resistor
R_{DR} = Drift of the reference resistor since the last calibration
R_{TC} = Change of the reference resistor due to temperature
R_{FR} = Change of the reference resistor due to frequency
R_{PW} = Change of the reference resistor due to power
I_R = Repeatability of indication

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	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	3.000	Normal k=1	1.0000	1	3.000	9
V_{CM}	800	0.050	Rectangular	1.7321	1	0.029	∞
I_{CL}	0	24.000	Normal k=2	2.0000	1	12.000	∞
I_{DR}	0	80.000	Rectangular	1.7321	1	46.188	∞
R_{CL}	80	0.463	Normal k=2	2.0000	1	0.231	∞
R_{DR}	0	5.000	Rectangular	1.7321	1	2.887	∞
R_{TC}	0	1.000	Rectangular	1.7321	1	0.577	∞
R_{FR}	0	5.000	Normal k=2	2.0000	1	2.500	∞
R_{PW}	0	0.000	Rectangular	1.7321	1	0.000	∞
					Combined Uncertainty, $u(E_x)$		47.972
					Effective Degrees of Freedom, v_{eff}		5.88E+05
					Coverage Factor, k		2.000
					Expanded Uncertainty, $U(E_x)$, ppm		96

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	0.050	Rectangular	1.7321	1	0.029	∞
I_R	0	0.400	Normal k=1	1.0000	1	0.400	9
V_{CM}	800	0.050	Rectangular	1.7321	1	0.029	∞
I_{CL}	0	24.000	Normal k=2	2.0000	1	12.000	∞
I_{DR}	0	80.000	Rectangular	1.7321	1	46.188	∞
R_{CL}	800	0.375	Normal k=2	2.0000	1	0.188	∞
R_{DR}	0	5.000	Rectangular	1.7321	1	2.887	∞
R_{TC}	0	1.000	Rectangular	1.7321	1	0.577	∞
R_{FR}	0	9.000	Normal k=2	2.0000	1	4.500	∞
R_{PW}	0	0.000	Rectangular	1.7321	1	0.000	∞
					Combined Uncertainty, $u(E_x)$		48.025
					Effective Degrees of Freedom, v_{eff}		1.87E+09
					Coverage Factor, k		2.000
					Expanded Uncertainty, $U(E_x)$, ppm		96

10. EMI Laboratory Personnel

Travelling Standard Calibrated by	Mr Jon Bartholomew Waleed Al Kalbani Alia Al Blooshi
Report Prepared by	Mr Jon Bartholomew
Report Checked by	Waleed Al Kalbani Alia Al Blooshi

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
Saudi Standards, Metrology and Quality Org.

المركز الوطني للقياس والمعايرة
National Measurment & Calibration Center

Report of

GULFMET.EM.S8

Comparison of Calibration of

Multimeter

Ahmed R. AlAyali

Ahmed N. AlJomaie

Mohammed S. AlTkroni

09/01/2022

Contents

1. Participant Institute:

Institute	National Measurements and Calibration Center
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Address	Saudi Standards, Metrology and Quality Organization (SASO)-National Measurements & Calibration Center PO. B 3437 Riyadh- Al Muhammadiyah – in front of King Saud University (Bldg. # 4, NMCC) 11471 Riyadh Kingdom of Saudi Arabia

2. Period of Measurements:

Start Date	End Date
12/12/2021	15/12/2021

3. Measurements Method and Set-up:

Direct Method using reference calibrator Fluke 5730A

4. The Measurement Standards Used:

Name	Manufacturer	Model No	Serial No
Calibrator	Fluke	5730 A	2843503

5. A statement of traceability for the measurements:

The reference device used is traceable to national standard which realize unit of measurement according to the international system of unit (SI).

6. Temperature and humidity in the laboratory during the measurement:

Temperature	Humidity
(23±2) °C	(40±20)% rh

7. The results of the measurement:

DC Voltage

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
200 mV	+ 100 mV	99.99918 mV	100.00007 mV	0.00089 mV	7.0 µV/V
20 V	+ 10 V	9.999995 V	10.000036 V	0.000041 V	4.0 µV/V
200 V	+ 100 V	99.999746 V	100.000087 V	0.000341 V	5.0 µV/V
1000 V	+ 1000 V	999.9994 V	1000.0033 V	0.0039 V	5.0 µV/V

DC Current

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
200 µA	+ 100 µA	100.005 µA	100.00344 µA	-0.00156 µA	38 µA/A
20 mA	+ 10 mA	10.00020 mA	10.000105 mA	-0.000095 mA	40 µA/A
2 A	+ 1 A	1.00004 A	0.9997644 A	-0.0002756 A	45 µA/A

DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
20 Ω	TrueΩ	10 Ω	9.9989990 Ω	9.998999 Ω	9.998911 Ω	15 µΩ/Ω
20 kΩ	TrueΩ	10 kΩ	9.999913 kΩ	9.999913 kΩ	10.000003 kΩ	11 µΩ/Ω
	TrueΩ LoI	10 kΩ	9.999913 kΩ	9.999913 kΩ	9.999910 kΩ	11 µΩ/Ω
2 MΩ	Normal	1 MΩ	0.9999556 MΩ	0.9999556 MΩ	0.9999591 MΩ	18 µΩ/Ω

AC Voltage

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	100.000 mV	99.9986 mV	-0.0014 mV	0.11 mV/V
	100 mV	1 kHz	100.000 mV	100.0022 mV	0.0022 mV	0.11 mV/V
20 V	10 V	55 Hz	10.00003 V	9.99983 V	-0.00020 V	70 µV/V
	10 V	1 kHz	10.00003 V	10.00015 V	0.00012 V	70 µV/V
	10 V	100 kHz	10.00035 V	9.99910 V	-0.00125 V	0.15 mV/V
200 V	100 V	55 Hz	99.9982 V	99.9966 V	-0.0016 V	85 µV/V
	100 V	1 kHz	99.9986 V	99.9990 V	0.0004 V	75 µV/V

AC Current

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
	Voltage	Frequency				
20 mA	10 mA	300 Hz	10.0002 mA	10.00014 mA	-0.00006 mA	0.12 mA/A
	10 mA	1 kHz	10.0001 mA	10.00008 mA	-0.00002 mA	0.10 mA/A
2 A	1 A	300 Hz	1.00004 A	0.999383 A	-0.000657 A	0.23 mA/A
	1 A	1 kHz	1.00003 A	0.999439 A	-0.000591 A	0.23 mA/A

Also Please Refer to attached excel file “Result of Measurements” which contains same tables

8. Uncertainty budget and calculation:

Please Refer to attached excel file “Uncertainty Calculation” which contains uncertainty parameter and its evaluation.

IMBIH

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

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Tel. +387 33 568 924, Fax +387 33 568 909
e-mail: info@met.gov.ba

Description:	ILC on Calibration of Multimeter
Project:	GULFMET.EM.S8
Type:	DMM Fluke 8508A
Serial Number:	218865629
Date of receipt:	July 2022
Date of measurement:	From 02-8-2022 to 15-08-2022

Date of issue:	Measurements Performed by :	Report Approved By:
22. November 2022.	Milojevic Vladimir Srdjan Calija Calibration engineer	Jasmina Loncarevic Head of Laboratory for electrical quantities

Laboratory Condition

Ambient Conditions	
Temperature	23±1°C
Relative Humidity	45±25 %

Reference standards used in intercomparison

Reference standards	Serial No.
Reference DMM 8508A/01	154961897
Multifunctional calibrator 5720A	1560210
Reference Zener cell Fluke 732B	2231035
Nano-voltmeter Keithley 2182A	4007156
Reference voltage divider 752A	1574019
Reference voltmeter 5790A	1551030
Set of reference resistors (Ohms Labs 2001_0.1 Ω, Fluke 742 A:10 Ω , 100Ω, 1kΩ, 1 MΩ)	15354;1481018;1602001;1602002 ;154009
AC Current shunt SIQ -10 mA AC Current shunt SIQ -1 A	SIQ12067 SIQ12073

Calculation mean and standard uncertainty type A:

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

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

Where:
$\bar{X}$ - mean value of *i* the set of measurement
$\sigma_{\bar{X}}$- standard uncertainty of N measurements

1. Calibration of DC voltage

IMBIH reference methods used in this intercomparison for calibration of DC voltage are direct method and voltage comparison methods (Procedure LE-P.111-v1 2018). The reference Zener cell Fluke 732B, reference voltage divider Fluke 752A, multifunctional calibrator Fluke 5720A and null indicator nanovoltmeter Keithley 2182A have been used as reference calibration setup. In case of 100 mV calibration point, the 10 V output of the DC voltage Zener standard divided by ratio 100:1 of reference divider is measured with DMM-UUT, while for the

10 V measurement with DMM-UUT has been performed directly on the 10 V output of reference Zener cell. Calibration points 100 V and 1 kV are calibrated by using voltage comparison methods. The output value from the reference Zener cell Fluke 732B on one side and the voltage values generated by the multifunctional calibrator Fluke 5720A divided by ratio 10:1 and 100:1 of reference voltage divider Fluke 752A have been aligned with null indicator Keithley 2182A, while voltage measurement with DMM-UUT has been measured on the output of calibrator 5720A.Prior the calibration process, the ratio of voltage divider has been calibrated following manufacturer self-calibration procedure. Null indicator (Keithley 2182A) is traceable via IMBIH internal calibration procedure for calibration DCV bellow 100 mV to the values of reference Zener cell and set of standard resistors. Our reference Zener cell is traceable to Josephson Voltage Standard of National metrology institute of Serbia (DMDM).

❖ *Uncertainty evaluation*

The measurement uncertainties reported in the tables 1 have been obtained taking into account all contributing factors 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 errors and uncertainties of DC voltage:

100mV

$$E = V_{dmm} + \delta V_{dmm,a} + \delta V_{dmm,res} - \frac{V_Z + \delta V_{Z,T} + \delta V_{Z,cal} + \delta V_{Z,drift}}{r + \delta r_{spec}}$$

10 V

$$E = V_{dmm} + \delta V_{dmm,a} + \delta V_{dmm,res} - \left(V_Z + \delta V_{Z,T} + \delta V_{Z,cal} + \delta V_{Z,drift}\right)$$

100 V i 1000 V

$$E = V_{dmm} + \delta V_{dmm,a} + \delta V_{dmm,res} - \left(V_N + \delta V_{N,a} + \delta V_{N,res} + \delta V_{N,spec} + V_Z + \delta V_{Z,T} + \delta V_{Z,cal} + \delta V_{Z,drift}\right) \cdot \left(r + \delta r_{spec}\right)$$

E *error indicated by DMM-UUT*
V_{dmm} *voltage indicated by DMM-UUT (mean value of N readings)*
V_Z *output value of referece volatge standard (Zener Cell)*
r *ratio of reference voltage divider*
δr_{spec} *ratio correction due to ref voltage divider accuracy specification*
$\delta V_{dmm,a}$ *correction due to measurement data scattering on DMM-UUT*
$\delta V_{dmm,res}$ *correction due to resolution of DMM-UUT*
$\delta V_{Z,T}$ *correction of reference voltage due to temperature effect*
$\delta V_{Z,cal}$ *correction of reference voltage due to last calibration*
$\delta V_{Z,drift}$ *correction of reference voltage due to drift from last calibration*
V_N *volatge diference measured by nanovoltmeter (mean value of N radings)*
$\delta V_{N,a}$ *correction due to measurement data scattering on nanovoltmeter*
$\delta V_{N,res}$ *correction due to nanovoltmeter resolution*

2. Calibration of AC voltage

IMBIH reference method used in this intercomparison for calibration of AC voltage is comparison method (Procedure LE-P.108v1_2018). The reference voltmeter DVM Fluke 5790A has been used as reference standard and multifunctional calibrator Fluke 5720A as source of AC voltage. Voltage generated from the voltage source is measured in the same time with reference DVM Fluke 5790A and DMM UUT, and results are compared. Our reference voltmeter is traceable to Slovenian Institute for Quality (SIQ). The calibration of the digital multimeter (UUT) was carried out at the points indicated by intercomparison protocol on 4. August 2022.

Twenty (20) repeated observations of AC voltage have been taken in account for evaluation of mean value (1) and experimental standard uncertainty according to formula (2).

❖ Uncertainty evaluation

The measurement uncertainty reported in the table 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 AC voltage:

$$E = V_x + \delta V_{xres} - \left(V_S + \delta V_{S_{res}} + \delta V_{Scal} + \delta V_{S_{spec}}\right)$$

E *–Measurement error of the DMM-UUT*
V_x *–mean of N voltage readings, indicated by the UUT-DMM*
δV_{xres} *-Correction of the indicated voltage due to the finite resolution of the DMM-UUT*
V_S *- mean of N voltage readings, indicated by the Ref-DVM 5790A*
δV_{Sres} *-Correction of the indicated voltage due to the finite resolution of the Ref-DVM 5790A*
δV_{Sspec} *-Correction of the measured voltage by the Ref-DVM due to specification*
δV_{Scal} *–Correction due to last calibration of Ref DVM*

3. Calibration of resistance

Method used in this intecomparison for calibration resistances is direct method (Procedure LE-P.107 v1_2015) using our set of reference resistors Fluke 742A as reference standard. Our reference resistors are traceable to IMBIH’s reference standard and further to Czech Metrology Institute and Slovenian Institute for Quality (SIQ).

The calibration of the digital multimeter (UUT) was carried out at the points indicated by intercomparison protocol in period of 04 -05 August 2022.

Twenty observations for resistance have been take in account for evaluation mean value (1) and experimental standard uncertainty according to formula (2). Standard resistors during measurement have been placed in temperature stabilized air bath with temperature stability ±0.05°C.

❖ ***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 uncertainties of resistance are:

Direct method:

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

E *-Measurement error of the DMM-UUT*
$\boldsymbol{R_x}$ *-Resistance, indicated by the UUT-DMM*
$\boldsymbol{\delta R_{ixres}}$ *-Correction of the indicated resistance due to the finite resolution of the DMM-UUT*
$\boldsymbol{R'_S}$ *–Resistance of standard resistors*
$\boldsymbol{\delta R_{Sdrift}}$ *-Correction of the resistance of standard resistors due to drift*
$\boldsymbol{\delta R'_{Scal}}$ *- Correction due to last calibration of standard resistors*
$\boldsymbol{\delta R_{Stemp}}$ *–Correction of resistance of standard resistors due to temperature change*

4. Calibration of DC current

IMBIH reference methods used for calibration DC current are <u>indirect method using Ohm's low (Procedure LE-P.106 v1_2015) for value 100 µA ; 10 mA and 1 A</u>. Two Fluke 742A (1 kΩ and 100 Ω) and Ohms Labs 2001_0.1 Ω reference resistors and 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 Institute for Quality (SIQ).

Calibration of the digital multimeter (UUT) was carried out at the points indicated by intercomparison protocol in period of 03-15 August 2022.

Twenty observations have been taken in account for evaluation mean value (1) and experimental standard uncertainty according to formula (2).

Standard resistors during measurement have been placed in environment conditions which exist in laboratory (T=23±1°C and H=50±10%). Nominal value of resistors was chosen in such way that dissipated power is less than 10 mW. Calibration of DMM –UUT on 1 A point have been performed with reference resistor immerse in oil bath with temperature stability T=23±0.05°C

❖ *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 indirect method is:

$$E_X = I_X + \delta I_X - \frac{V_S + \delta V_{Sspec} + \delta V_{Sresx} + \delta V_{load}}{R_S + \delta R_{drift} + \delta R_{Power} + \delta R_{temp}}$$

Ex *-Measurement error of the DMM-UUT*
I_x *-Current indicated by the UUT-DMM*
δI_x *-Correction of indicated current due to finite resolution of the UUT-DMM*
V_S *-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*

5. Calibration of AC current

IMBIH reference method used for calibration of AC current is indirect method based on Ohm's low (Procedure LE-P.109 v1_2018) by measuring AC voltage drop on coaxial current shunt with known resistance and AC/DC current difference**.** Reference current shunts SIQ-10 mA, SIQ-1A and Ref DVM Fluke 5790A for indirect method have been used as reference standards. Our reference current shunt and Ref DVM are traceable to Slovenian Institute for Quality (SIQ).

Calibration of the digital multimeter (UUT) was carried out at the points indicated by intercomparison protocol on 03. August 2022.

Twenty eight observations of current have been taken in account for evaluation of mean value (1) and experimental standard uncertainty according to formula (2). Standard current shunt during measurement have been placed on conditions which exists in laboratory (T=23±1°C and H=45±25%).

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 indirect method via the AC current shunt is:

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

Ex *The error of indication of the UUT-DMM*
I_x *mean of N readings of current indicated by the UUT -DMM*
V_S *mean of N readings of 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*
δR_{Power} *Correction of DC resistance of the reference current shunt due to power coefficient*
δI_x *Correction of indicated current due to finite resolution of the UUT-DMM*
δ_{Load} *Correction of circuit loading due to finite input impedance of the reference voltmeter*
δ_{AC-DC} *AC-DC difference of current shunt*
δ_{drift} *Correction due to drift of AC-DC difference of the current shunt since its last calibration*

NOTE:
δR_{Power} Correction of DC resistance of the reference current shunt due to power coefficient is not taken in account in uncertainty budget because resistance of shunt has been determined on nominal current of current shunts.

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	100.000 413 mV	100.001 36 mV	0.000 95 mV	0.000 093 mV
20 V	+ 10 V	10.000 041 V	10.000 077 V	0.000 035 V	0.000 007 V
200 V	+ 100 V	100.000 020 V	100.000 30 V	-0.000 28 V	0.000 074 V
1000 V	+ 1000 V	1000.002 76 V	1000.004 3 V	0,001 54 V	0.000 91 V

Table 2. DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty
200 µA	+ 100 µA	100.000 34 µA	100.002 13 µA	0.001 79 µA	0.000 64 µA
20 mA	+ 10 mA	9.999 974 mA	10.000 076 mA	0.000 102 mA	0.000 040 A
1 A	+ 1 A	1.000 018 A	0.999 726 A	-0.000 292 A	0.000 007 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	99.994 5 mV	99.998 2 mV	0.003 7 mV	0.007 4 mV
	100 mV	1 kHz	99.994 4 mV	100.001 5 mV	0.007 1 mV	0.007 4 mV
20 V	10 V	55 Hz	9.999 98 V	9.999 86 V	-0.000 12 V	0.000 33 V
	10 V	1 kHz	9.999 98 V	10,000 14 V	0.000 16 V	0.000 33 V
	10 V	100 kHz	10.000 09 V	9.998 35 V	-0.001 73 V	0.000 99 V
200 V	100 V	55 Hz	99.998 8 V	99.996 7 V	-0.002 1 V	0.004 7 V
	100 V	1 kHz	99.998 5 V	100.001 2 V	0.001 6 V	0.004 7 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	9.999 97 mA	10.000 01 mA	0.000 04 mA	0.000 42 mA
	10 mA	1 kHz	9.999 31 mA	9.999 36 mA	0.000 05 mA	0.000 42 mA
1 A	1 A	300 Hz	1.000 018 A	0.999 35 A	-0.000 67 A	0.000 044 A
	1 A	1 kHz	1.000 008 A	0.999 39 A	-0.000 62 A	0.000 044 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	10.000 196 Ω	10.000 257 Ω	0.000 062 Ω	0.000 008 Ω
20 kΩ	TrueΩ	10 kΩ	10.000 023 kΩ	10,000 107 kΩ	0.000 084 kΩ	0.000 008 kΩ
	TrueΩ LoI	10 kΩ	10.000 023 kΩ	10,000 116 kΩ	0.000 093 kΩ	0.000 009 kΩ
2 MΩ	Normal Ω	1 MΩ	1.000 017 MΩ	1.000 024 MΩ	0.000 007 MΩ	0.000 001 5 MΩ

2. MEASURMENT UNCERTAINTY BUDGETS

1. Results for DC Voltage

100 mV

Value X_i		Estimation x_i		Uncertainty		divisor	Standard uncertainty $u(x_i)$		Probability distribution	Sensitivity coeficient c_i		Uncertainty contribution $u_i(E_x)$		Degree of freedom vi
Ratio of reference divider	δr_{spec}	100	-	5.00E+01	µV/V	1.73	2.89E+01	µV/V	rectangular	-1.00E-03	V	-2.887E-02	µV	∞
Volatge indicated by DMM UUT	V_{dmm}	100.001 366	mV	-	-	-	-	-	-	-	-	-	-	-
Resolution of DMM-UUT	$\delta V_{dmm,res}$	0		1.00E-03	µV	3.46	2.89E-04	µV	rectangular	1	µV/µV	2.887E-04	µV	∞
Correction due to measurement data scattering on DMM UUT	$\delta V_{dmm,a}$	0		0.010	µV	1	0.010	µV	normal	1	µV/µV	1.031E-02	µV	9
Output value of reference voltage standard	V_Z	10.000 041	V	-	-	-	-	-	-	-	-	-	-	-
Correction of reference voltage due to temperatue effect	$\delta V_{Z,T}$	0		0.4	µV	1.73	0.23	µV	rectagular	-0.01	V/V	-2.309E-03	µV	∞
Correction of reference voltage due to last calibration	$\delta V_{Z,cal}$	0		0.7	µV	2	0.35	µV	normal	-0.01	V/V	-3.500E-03	µV	∞
Correction of reference voltage due to drifft from last calibration	$\delta V_{Z,drift}$	0		6	µV	1.73	3.46	µV	rectangular	-0.01	V/V	-3.464E-02	µV	∞
Reference value	*Vref*	100.000 413	mV				**Combined uncertainty u(Ex)**					0.046	**µV**	
Error and expanded uncertainty of DMM UUT	*E=*	**0.000 952 ±**		**0.000 093 mV**			**Abs. expanded uncertainty (95%)**					0.093	**µV**	
							Rel. expanded uncertainty (95%)					0.929	**µV/V**	
							Effective degree of freedom, veff					3710.12		
							Coverage factor, k					2.00		

10 V

Value X_i		Estimation x_i		Uncertainty		divisor	Standard uncertainty $u(x_i)$		Probability distribution	Sensitivity coeficient c_i		Uncertainty contribution $u_i(E_x)$		Degree of freedom vi
Volatge indicated by DMM UUT	V_{dmm}	10.000 077	V	-	-	-	-	-	-	-	-	-	-	-
Resolution of DMM-UUT	$\delta V_{dmm,res}$	0		1.00E-01	µV	3.46	2.89E-02	µV	rectangular	1	µV/µV	2.887E-02	µV	∞
Correction due to measurement data scattering on DMM UUT	$\delta V_{dmm,a}$	0		0.342	µV	1	0.342	µV	normal	1	µV/µV	3.416E-01	µV	9
Output value of reference voltage standard	V_Z	10.000 041	V	-	-	-	-	-	-	-	-	-	-	-
Correction of reference voltage due to temperatue effect	$\delta V_{Z,T}$	0		0.4	µV	1.73	0.23	µV	rectangular	-1	V/V	-2.309E-01	µV	∞
Correction of reference voltage due to last calibration	$\delta V_{Z,cal}$	0		0.7	µV	2	0.35	µV	normal	-1	V/V	-3.500E-01	µV	∞
Correction of reference voltage due to drifft from last calibration	$\delta V_{Z,drift}$	0		6	µV	1.73	3.46	µV	rectangular	-1	V/V	-3.464E+00	µV	∞
Error and expanded uncertainty of DMM UUT	*E=*	**0.000 035 2**		**± 0.000 007 0 V**			**Combined uncertainty u(Ex)**					3.506	**µV**	
							Abs. expanded uncertainty (95%)					7.012	**µV**	
							Rel. expanded uncertainty (95%)					0.701	**µV/V**	
							Effective degree of freedom, veff					99928.24		
							Coverage factor, k					2.00		

100 V

Value X_i		Estimation x_i		Uncertainty		divisor	Standard uncertainty $u(x_i)$		Probability distribution	Sensitivity coeficient c_i		Uncertainty contribution $u_i(E_x)$		Degree of freedom vi
Ratio of reference divider	δr_{spec}	10	-	2.00E+00	µV/V	1.73	1.15E+00	µV/V	rectangular	-9.961E+00	V	-1.150E+01	µV	∞
Volatge indicated by DMM UUT	V_{dmm}	100.000 299	V	-	-	-	-	-	-	-	-	-	-	-
Resolution of DMM-UUT	$\delta V_{dmm,res}$	0		1.00E+00	µV	3.46	2.89E-01	µV	rectangualr	1	µV/µV	2.887E-01	µV	∞
Correction due to measurement data scattering on DMM UUT	$\delta V_{dmm,a}$	0		1.795	µV	1	1.795	µV	normal	1	µV/µV	1.795E+00	µV	9
Voltage difference measured by nanovoltneter	V_N	-0.039 26	mV	-	-	-	-	-	-	-	-	-	-	-
Correction od nanovoltmeter due to specification	$\delta V_{N,spec}$	0		3.80E-02	µV	1.73	2.20E-02	µV	rectangular	-10	µV/µV	-2.196E-01	µV	∞
Correction due to nanovoltmeter resolution	$\delta V_{N,res}$	0		1.00E-02	µV	3.46	2.89E-03	µV	rectangular	-10	µV/µV	-2.887E-02	µV	∞
Correction due to measurement data scattering on nanovoltmeter	$\delta V_{N,a}$	0		0.132	µV	1	0.132	µV	normal	-10	µV/µV	-1.320E+00	µV	9
Output value of reference voltage standard	V_Z	10.000 041	V	-	-	-	-	-	-	-	-	-	-	-
Correction of reference voltage due to temperatue effect	$\delta V_{Z,T}$	0		0.4	µV	1.73	0.23	µV	rectangular	-10.00	V/V	-2.309E+00	µV	∞
Correction of reference voltage due to last calibration	$\delta V_{Z,cal}$	0		0.7	µV	2	0.35	µV	normal	-10.00	V/V	-3.500E+00	µV	∞
Correction of reference voltage due to drifft from last calibration	$\delta V_{Z,drift}$	0		6	µV	1.73	3.46	µV	rectangular	-10.00	V/V	-3.464E+01	µV	∞
Reference value	*Vref*	100.000 020	V				**Combined uncertainty u(Ex)**					36.8	**µV**	
Error and expanded uncertainty of DMM UUT	*E=*	**0.000 279 ±**		**0.000 074 V**			**Abs. expanded uncertainty (95%)**					73.6	**µV**	
							Rel. expanded uncertainty (95%)					0.736	**µV/V**	
							Effective degree of freedom, v_{eff}					1231362.52		
							Coverage factor, k					2.00		

1000 V

Value X_i		Estimation x_i		Uncertainty		divisor	Standard uncertainty $u(x_i)$		Probability distribution	Sensitivity coeficient c_i		Uncertainty contribution $u_i(E_x)$		Degree of freedom vi
Ratio of reference divider	δr_{spec}	100	-	5.00E+01	µV/V	1.73	2.89E+01	µV/V	rectangular	-9.986E+00	V	-2.883E+02	µV	∞
Volatge indicated by DMM UUT	V_{dmm}	1000.004 30	V	-	-	-	-	-	-	-	-	-	-	-
Resolution of DMM-UUT	$\delta V_{dmm,res}$	0		1.00E+01	µV	3.46	2.89E+00	µV	rectangualr	1	µV/µV	2.887E+00	µV	∞
Correction due to measurement data scattering on DMM UUT	$\delta V_{dmm,a}$	0		21.082	µV	1	21.082	µV	normal	1	µV/µV	2.108E+01	µV	9
Voltage difference measured by nanovoltneter	V_N	-0.013 66	mV	-	-	-	-	-	-	-	-	-	-	-
Correction od nanovoltmeter due to specification	$\delta V_{N,spec}$	0		3.93E-02	µV	1.73	2.27E-02	µV	rectangular	-100	µV/µV	-2.270E+00	µV	∞
Correction due to nanovoltmeter resolution	$\delta V_{N,res}$	0		1.00E-02	µV	3.46	2.89E-03	µV	rectangular	-100	µV/µV	-2.887E-01	µV	∞
Correction due to measurement data scattering on nanovoltmeter	$\delta V_{N,a}$	0		0.034	µV	1	0.034	µV	normal	-100	µV/µV	-3.422E+00	µV	9
Output value of reference voltage standard	V_Z	10.000 041	V	-	-	-	-	-	-	-	-	-	-	-
Correction of reference voltage due to temperatue effect	$\delta V_{Z,T}$	0		0.4	µV	1.73	0.23	µV	rectangular	-100.00	V/V	-2.309E+01	µV	∞
Correction of reference voltage due to last calibration	$\delta V_{Z,cal}$	0		0.7	µV	2	0.35	µV	normal	-100.00	V/V	-3.500E+01	µV	∞
Correction of reference voltage due to drifft from last calibration	$\delta V_{Z,drift}$	0		6	µV	1.73	3.46	µV	rectangular	-100.00	V/V	-3.464E+02	µV	∞
Reference value	*Vref*	1000.002 764	V				**Combined uncertainty u(Ex)**					453.1	**µV**	
Error and expanded uncertainty of DMM UUT	*E=*	**0.001 54 ±**		**0.000 91 V**			**Abs. expanded uncertainty (95%)**					906.3	**µV**	
							Rel. expanded uncertainty (95%)					0.906	**µV/V**	
							Effective degree of freedom, veff					1919686.22		
							Coverage factor, k					2.00		

2. Results for DC Current

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)	100.001 11	1.15E-05	normal	-1	1/kΩ	-1.15E-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	3.18E-04	rectangular	-1	1/kΩ	-3.18E-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)	1.000 007 66	3.25E-07	normal	-100	mV/kΩ^2	-3.25E-05	µA	inf
Correction due to drift of standard resistor (kΩ)	0	5.77E-08	rectagular	-100	mV/kΩ^2	-5.77E-06	µA	inf
Correction due to temperature change of standard resistor (kΩ)	0	1.73E-07	rectagular	-100	mV/kΩ^2	-1.73E-05	µA	inf
Current indicated by UUT-DMM (µA)	100.002 13	5.55E-06	normal	1	µA	5.55E-06	µA	19
Resolution of UUT- DMM (µA)	0	2.89E-06	rectagular	1	µA	2.89E-06	µA	inf
Is(µA)	**100.000 34**	**Combined Uncertainty, u(Ex) (µA)**						**3.20E-04**
Error Ex (µA)	**0.001 79**	**Effective degrees of freedom, veff**						**1.08E+07**
Error Ex (µA/A)	**17.9**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (µA/A)						**6.4**

10 mA

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci		Uncertainty contribution ui(Ex)		Degrees of freedom vi
Voltage indicated by Ref DMM (V)	1.000 003 0	1.55E-08	normal	-0.01	1/Ω	-1.55E-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	1.96E-06	rectangular	-0.01	1/Ω	-1.96E-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)	100.000 557 0	3.25E-05	normal	-0.0001	V/Ω^2	-3.25E-06	mA	inf
Correction due to drift of standard resistor (Ω)	0	5.77E-06	rectagular	-0.0001	V/Ω^2	-5.77E-07	mA	inf
Correction due to temperature change of standard resistor (Ω)	0	1.73E-05	rectagular	-0.0001	V/Ω^2	-1.73E-06	mA	inf
Current indicated by UUT-DMM (mA)	10.000 076	3.65E-07	normal	1	mA	3.65E-07	mA	19
Resolution of UUT- DMM (mA)	0	2.89E-07	rectagular	1	mA	2.89E-07	mA	inf
Is (mA)	**9.999 974**	**Combined Uncertainty, u(Ex) (mA)**						**2.00E-05**
Error Ex (mA)	**0.000 102**	**Effective degrees of freedom, veff**						**1.66E+08**
Error Ex (µA/A)	**10.2**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (µA/A)						**4.0**

1A

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 79	4.88E-06	normal	-10	1/Ω	-4.88E-08	A	19
Resolution of Ref DMM (mV)	0	2.89E-06	rectangular	-10	1/Ω	-2.89E-08	A	inf
Absolute (1 year) specification of Ref DMM (mV)	0	3.18E-04	rectangular	-10	1/Ω	-3.18E-06	A	inf
Loading voltage of Ref DMM (mV)	0	5.77E-10	rectangular	-10	1/Ω	-5.77E-09	A	inf
Standard resistor Rs (kΩ)	0.099 999 98	1.00E-07	normal	-10000	mV/Ω^2	-1.00E-06	A	inf
Correction due to drift of standard resistor (Ω)	0	1.15E-08	rectagular	-10000	mV/Ω^2	-1.15E-07	A	inf
Correction due to temperature change of standard resistor (Ω)	0	2.89E-08	rectagular	-10000	mV/Ω^2	-2.89E-07	A	inf
Current indicated by UUT-DMM (A)	0.999 726	4.64E-08	normal	1	A	4.64E-08	A	19
Resolution of UUT- DMM (A)	0	2.89E-07	rectagular	1	A	2.89E-07	A	inf
Is (A)	**1.000 018**	**Combined Uncertainty, u(Ex) (µA)**						**3.36E-06**
Error Ex (A)	**-0.000 292**	**Effective degrees of freedom, veff**						**2.34E+08**
Error Ex (µA/A)	**-292**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (µA/A)						**6.7**

3. Results for AC Voltage

AC Voltage 100 mV 55Hz

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 5	3.12E-05	normal	-1	-3.12E-05	19
Resolution of Ref DMM (mV)	0	2.89E-05	rectangular	-1	-2.89E-05	inf
2 year specification for Ref DMM (mV)	0	3.35E-03	rectangular	-1	-3.35E-03	inf
Correction due to last calibration of Ref DMM (mV)	0	1.55E-03	normal	-1	-1.55E-03	inf
Voltage idicated by UUT-DMM (mV)	99.998 2	7.24E-05	normal	1	7.24E-05	19
Resolution of UUT- DMM (mV)	0	2.89E-05	rectagular	1	2.89E-05	inf
Error Ex (mV)	**0.0037**	**Combined Uncertainty, u(Ex) (mV)**				**3.69E-03**
		Effective degrees of freedom, veff				**1.24E+08**
Error Ex (µV/V)	**37.5**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**73.8**

AC Voltage 100 mV 1kHz

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 4	2.85E-05	normal	-1	-2.85E-05	19
Resolution of Ref DMM (mV)	0	2.89E-05	rectangular	-1	-2.89E-05	inf
2 year specification for Ref DMM (mV)	0	3.35E-03	rectangular	-1	-3.35E-03	inf
Correction due to last calibration of Ref DMM (mV)	0	1.55E-03	normal	-1	-1.55E-03	inf
Voltage idicated by UUT-DMM (mV)	100.001 5	7.58E-05	normal	1	7.58E-05	19
Resolution of UUT- DMM (mV)	0	2.89E-05	rectagular	1	2.89E-05	inf
Error Ex (mV)	**0.0071**	**Combined Uncertainty, u(Ex) (mV)**				**3.69E-03**
		Effective degrees of freedom, veff				**1.05E+08**
Error Ex (µV/V)	**70.7**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**73.8**

AC Voltage 10 V 55Hz

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 98	3.31E-06	normal	-1	-3.31E-06	19
Resolution of Ref DMM (V)	0	2.89E-06	rectangular	-1	-2.89E-06	inf
2 year specification for Ref DMM (V)	0	1.56E-04	rectangular	-1	-1.56E-04	inf
Correction due to last calibration of Ref DMM (mV)	0	5.15E-05	normal	-1	-5.15E-05	inf
Voltage idicated by UUT-DMM (V)	9.999 86	5.45E-06	normal	1	5.45E-06	19
Resolution of UUT- DMM (V)	0	2.89E-06	rectagular	1	2.89E-06	inf
Error Ex (V)	**-0.000 13**	**Combined Uncertainty, u(Ex) (V)**				**1.64E-04**
		Effective degrees of freedom, veff				**1.38E+07**
Error Ex (µV/V)	**-13**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**33**

AC Voltage 10 V 1kHz

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 98	2.12E-06	normal	-1	-2.12E-06	19
Resolution of Ref DMM (V)	0	2.89E-06	rectangular	-1	-2.89E-06	inf
2 year specification for Ref DMM (V)	0	1.56E-04	rectangular	-1	-1.56E-04	inf
Correction due to last calibration of Ref DMM (V)	0	5.15E-05	normal	-1	-5.15E-05	inf
Voltage idicated by UUT-DMM (V)	10.000 14	2.76E-06	normal	1	2.76E-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)**				**1.64E-04**
		Effective degrees of freedom, veff				**1.77E+08**
Error Ex (µV/V)	**16**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**33**

AC Voltage 10 V 100kHz

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 09	1.96E-06	normal	-1	-1.96E-06	19
Resolution of Ref DMM (V)	0	2.89E-06	rectangular	-1	-2.89E-06	inf
2 year specification for Ref DMM (V)	0	4.91E-04	rectangular	-1	-4.91E-04	inf
Correction due to last calibration of Ref DMM (V)	0	6.05E-05	normal	-1	-6.05E-05	inf
Voltage idicated by UUT-DMM (V)	9.998 35	3.02E-06	normal	1	3.02E-06	19
Resolution of UUT- DMM (V)	0	2.89E-06	rectagular	1	2.89E-06	inf
Error Ex (V)	**-0.001 73**	**Combined Uncertainty, u(Ex) (V)**				**4.94E-04**
		Effective degrees of freedom, veff				**1.17E+10**
Error Ex (µV/V)	**-173**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**99**

AC Voltage 100 V 55Hz

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)	99.998 8	3.60E-05	normal	-1	-3.60E-05	19
Resolution of Ref DMM (V)	0	2.89E-05	rectangular	-1	-2.89E-05	inf
2 year specification for Ref DMM (V)	0	2.19E-03	rectangular	-1	-2.19E-03	inf
Correction due to last calibration of Ref DMM (mV)	0	7.90E-04	normal	-1	-7.90E-04	inf
Voltage idicated by UUT-DMM (V)	99.996 7	4.83E-05	normal	1	4.83E-05	19
Resolution of UUT- DMM (V)	0	2.89E-05	rectagular	1	2.89E-05	inf
Error Ex (V)	**-0.002 1**	**Combined Uncertainty, u(Ex) (V)**				**2.33E-03**
		Effective degrees of freedom, veff				**7.89E+07**
Error Ex (µV/V)	**-21**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**47**

AC Voltage 100 V 1kHz

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)	99.998 6	2.76E-05	normal	-1	-2.76E-05	19
Resolution of Ref DMM (V)	0	2.89E-05	rectangular	-1	-2.89E-05	inf
2 year specification for Ref DMM (V)	0	2.19E-03	rectangular	-1	-2.19E-03	inf
Correction due to last calibration of Ref DMM (V)	0	7.90E-04	normal	-1	-7.90E-04	inf
Voltage idicated by UUT-DMM (V)	100.000 1	3.02E-05	normal	1	3.02E-05	19
Resolution of UUT- DMM (V)	0	2.89E-05	rectagular	1	2.89E-05	inf
Error Ex (V)	**0.001 6**	**Combined Uncertainty, u(Ex) (V)**				**2.33E-03**
		Effective degrees of freedom, veff				**4.00E+08**
Error Ex (µV/V)	**16**	**Coverage Factor, k**				**2**
		Expanded uncertainty U(Ex) (µV/V)				**47**

4. Results for 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 DVM (V)	1.000 004 6	6.65E-08	normal	-0.01	1/Ω	-6.65E-07	mA	27
Resolution of Ref DVM (V)	0	2.89E-08	rectangular	-0.01	1/Ω	-2.89E-07	mA	inf
Calibration Ref DVM (V)	0	1.00E-05	normal	-0.01	1/Ω	-1.00E-04	mA	inf
Absolute (1 year) specification of Ref DVM (V)	0	1.68E-05	rectangular	-0.01	1/Ω	-1.68E-04	mA	inf
Correction due to Loading of Ref DMM (1-δload)	1.000 008 3	2.50E-06	rectangular	-0.01	V/Ω	-2.50E-05	mA	inf
DC resistance of current shunts Rs (Ω)	100.001 6	2.50E-04	normal	-0.0001	V/Ω^2	-2.50E-05	mA	inf
Correction due to drift of shunt resistance (Ω)	0	5.77E-05	rectagular	-0.0001	V/Ω^2	-5.77E-06	mA	inf
Correction due to temperature change of shunt resistance (Ω)	0	5.77E-05	rectagular	-0.0001	V/Ω^2	-5.77E-06	mA	inf
AC-DC difference of current shunt	1.000 000	5.50E-06	normal	-0.01	V/Ω	-5.50E-05	mA	inf
Drift of AC-DC difference of current shunt	0	2.89E-06	rectangular	-0.01	V/Ω	-2.89E-05	mA	inf
Current indicated by UUT-DMM (mA)	10.000 01	5.58E-06	normal	1	mA	5.58E-06	mA	27
Resolution of UUT- DMM (mA)	0	5.77E-06	rectagular	1	mA	5.77E-06	mA	inf
I_S (mA)	**9.999 97**	**Combined Uncertainty, u(Ex) (mA)**						**2.08E-04**
Error Ex (mA)	**0.000 04**	**Effective degrees of freedom, veff**						**5.25E+07**
Error Ex (µA/A)	**4**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (µA/A)						**42**

10 mA 1kHz

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)	0.999 937 6	2.79E-08	normal	-0.01	1/Ω	-2.79E-07	mA	27
Resolution of Ref DMM (V)	0	2.89E-08	rectangular	-0.01	1/Ω	-2.89E-07	mA	inf
Calibration Ref DMM (V)	0	1.00E-05	normal	-0.01	1/Ω	-1.00E-04	mA	inf
Absolute (1 year) specification of Ref DMM (V)	0	1.68E-05	rectangular	-0.01	1/Ω	-1.68E-04	mA	inf
Correction due to Loading of Ref DMM (1-δload)	1.000 008 3	2.50E-06	rectangular	-0.01	V/Ω	-2.50E-05	mA	inf
DC resistance of current shunts Rs (Ω)	100.001 6	2.50E-04	normal	-0.0001	V/Ω^2	-2.50E-05	mA	inf
Correction due to drift of shunt resistance (Ω)	0	5.77E-05	rectagular	-0.0001	V/Ω^2	-5.77E-06	mA	inf
Correction due to temperature change of shunt resistance (Ω)	0	5.77E-05	rectagular	-0.0001	V/Ω^2	-5.77E-06	mA	inf
AC-DC difference of current shunt	1.000 001	5.50E-06	normal	-0.01	V/Ω	-5.50E-05	mA	inf
Drift of AC-DC difference of current shunt	0	2.89E-06	rectangular	-0.01	V/Ω	-2.89E-05	mA	inf
Current indicated by UUT-DMM (mA)	9.999 36	2.94E-06	normal	1	mA	2.94E-06	mA	27
Resolution of UUT- DMM (mA)	0	5.77E-06	rectagular	1	mA	5.77E-06	mA	inf
I_S (mA)	**9.999 31**	**Combined Uncertainty, u(Ex) (mA)**						**2.08E-04**
Error Ex (mA)	**0.000 05**	**Effective degrees of freedom, veff**						**6.80E+08**
Error Ex (μA/A)	**5**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (μA/A)						**42**

1A 300 Hz

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci		Uncertainty contribution ui(Ex)		Degrees of freedom vi
Voltage indicated by Ref DMM (V)	1.000 302 0	7.31E-08	normal	-1	1/Ω	-7.31E-08	A	27
Resolution of Ref DMM (V)	0	2.89E-08	rectangular	-1	1/Ω	-2.89E-08	A	inf
Calibration Ref DMM (V)	0	1.00E-05	normal	-1	1/Ω	-1.00E-05	A	inf
Absolute (1 year) specification of Ref DMM (V)	0	1.68E-05	rectangular	-1	1/Ω	-1.68E-05	A	inf
Correction due to Loading of Ref DMM (1-δload)	1.000 000 1	2.50E-06	rectangular	-1	V/Ω	-2.50E-06	A	inf
DC resistance of current shunts Rs (Ω)	1.000 285	5.00E-06	normal	-1	V/Ω^2	-5.00E-06	A	inf
Correction due to drift of shunt resistance (Ω)	0	1.16E-06	rectagular	-1	V/Ω^2	-1.16E-06	A	inf
Correction due to temperature change of shunt resistance (Ω)	0	2.89E-06	rectagular	-1	V/Ω^2	-2.89E-06	A	inf
AC-DC difference of current shunt	1.000 001	5.50E-06	normal	-1	V/Ω	-5.50E-06	A	inf
Drift of AC-DC difference of current shunt	0	2.89E-06	rectangular	-1	V/Ω	-2.89E-06	A	inf
Current indicated by UUT-DMM (A)	0.999 35	8.77E-07	normal	1	A	8.77E-07	A	27
Resolution of UUT- DMM (A)	0	5.77E-06	rectagular	1	A	5.77E-06	A	inf
I_S (A)	**1.000 02**	**Combined Uncertainty, u(Ex) (A)**						**2.22E-05**
Error Ex (A)	**-0.000 67**	**Effective degrees of freedom, veff**						**1.12E+07**
Error Ex (μA/A)	**-67**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (μA/A)						**44**

1A 1kHz

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)	1.000 294 4	5.58E-08	normal	-1	1/Ω	-5.58E-08	A	27
Resolution of Ref DMM (V)	0	2.89E-08	rectangular	-1	1/Ω	-2.89E-08	A	inf
Calibration Ref DMM (V)	0	1.00E-05	normal	-1	1/Ω	-1.00E-05	A	inf
Absolute (1 year) specification of Ref DMM (V)	0	1.68E-05	rectangular	-1	1/Ω	-1.68E-05	A	inf
Correction due to Loading of Ref DMM (1-δload)	1.000 000 1	2.50E-06	rectangular	-1	V/Ω	-2.50E-06	A	inf
DC resistance of current shunts Rs (Ω)	1.000 285	5.00E-06	normal	-1	V/Ω^2	-5.00E-06	A	inf
Correction due to drift of shunt resistance (Ω)	0	1.16E-06	rectagular	-1	V/Ω^2	-1.16E-06	A	inf
Correction due to temperature change of shunt resistance (Ω)	0	2.89E-06	rectagular	-1	V/Ω^2	-2.89E-06	A	inf
AC-DC difference of current shunt	0.999 999	5.50E-06	normal	-1	V/Ω	-5.50E-06	A	inf
Drift of AC-DC difference of current shunt	0	2.89E-06	rectangular	-1	V/Ω	-2.89E-06	A	inf
Current indicated by UUT-DMM (A)	0.999 39	5.02E-07	normal	1	A	5.02E-07	A	27
Resolution of UUT- DMM (A)	0	5.77E-06	rectagular	1	A	5.77E-06	A	inf
I_s (A)	**1.000 008**	**Combined Uncertainty, u(Ex) (mA)**						**2.22E-05**
Error Ex (A)	**-0.000 62**	**Effective degrees of freedom, veff**						**1.04E+08**
Error Ex (µA/A)	**-62**	**Coverage Factor, k**						**2**
		Expanded uncertainty U(Ex) (µA/A)						**44**

5. Results for 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)	10.000 196	3.25E-06	normal	-1	-3.25E-06	19
Correction of Standard Resistors due to drift from last calibration (Ω)	0	2.02E-06	rectangular	-1	-2.02E-06	inf
Correction of Standard Resistors due to temperature change (Ω)	0	1.16E-06	rectagular	-1	-1.16E-06	inf
Resistance indicated by UUT-DMM (Ω)	10.000 257	5.39E-07	normal	1	5.39E-07	19
Resolution of UUT- DMM (Ω)	0	2.89E-07	rectagular	1	2.89E-07	inf
Error Ex (Ω)	**0.000 062**	**Combined Uncertainty, u(Ex) (Ω)**				**4.05E-06**
		Effective degrees of freedom, veff				**45.58**
Error Ex (µΩ/Ω)	**6.2**	**Coverage Factor, k**				**2.0**
		Expanded uncertainty U(Ex) (µΩ/Ω)				**0.8**

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)	10.000 023	3.25E-06	normal	-1	-3.25E-06	19
Correction of Standard Resistors due to drift from last calibration (kΩ)	0	1.45E-06	rectangular	-1	-1.45E-06	inf
Correction of Standard Resistors due to temperature change (kΩ)	0	1.16E-06	rectagular	-1	-1.16E-06	inf
Resistance indicated by UUT-DMM (kΩ)	10.000 107	9.93E-08	normal	1	9.93E-08	19
Resolution of UUT- DMM (kΩ)	0	2.89E-07	rectagular	1	2.89E-07	inf
Error Ex (kΩ)	**0.000 084**	**Combined Uncertainty, u(Ex) (kΩ)**				**3.75E-06**
		Effective degrees of freedom, veff				**33.76**
Error Ex (µΩ/Ω)	**8.4**	**Coverage Factor, k**				**2.0**
		Expanded uncertainty U(Ex) (µΩ/Ω)				**0.8**

10 kΩ True Ohm LoI

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertainty contribution ui(Ex)	Degrees of freedom vi
Standard Resistors (kΩ)	10.000 023	3.25E-06	normal	-1	-3.25E-06	19
Correction of Standard Resistors due to drift from last calibration (kΩ)	0	1.45E-06	rectangular	-1	-1.45E-06	inf
Correction of Standard Resistors due to temperature change (kΩ)	0	1.16E-06	rectagular	-1	-1.16E-06	inf
Resistance indicated by UUT-DMM (kΩ)	10.000 116	5.69E-07	normal	1	5.69E-07	19
Resolution of UUT- DMM (kΩ)	0	2.89E-07	rectagular	1	2.89E-07	inf
Error Ex (kΩ)	**0.000 093**	**Combined Uncertainty, u(Ex) (kΩ)**				**3.79E-06**
		Effective degrees of freedom, veff				**35.25**
Error Ex (µΩ/Ω)	**9.3**	**Coverage Factor, k**				**2.28**
		Expanded uncertainty U(Ex) (µΩ/Ω)				**0.9**

1 MΩ

Quantity	Estimation	Standard uncertainty u(xi)	Probability Distribution	Sensitivity coefficient ci	Uncertainty contribution ui(Ex)	Degrees of freedom vi
Standard Resistors (MΩ)	1.000 017	5.00E-07	normal	-1	-5.00E-07	19
Correction of Standard Resistors due to drift from last calibration (MΩ)	0	3.47E-07	rectangular	-1	-3.47E-07	inf
Correction of Standard Resistors due to temperature change (MΩ)	0	4.05E-07	rectagular	-1	-4.05E-07	inf
Resistance indicated by UUT-DMM (MΩ)	1.000 024	1.24E-08	normal	1	1.24E-08	19
Resolution of UUT- DMM (MΩ)	0	2.89E-08	rectagular	1	2.89E-08	inf
Error Ex (Ω)	**0.000 007**	**Combined Uncertainty, u(Ex) (kΩ)**				**7.31E-07**
		Effective degrees of freedom, veff				**87.01**
Error Ex (µΩ/Ω)	**0.69**	**Coverage Factor, k**				**2.0**
		Expanded uncertainty U(Ex) (µΩ/Ω)				**1.5**

---------------------------- END OF REPORT -----------------------------

Measurement Results of GULFMET.EM.S8 Comparison

of

Qatar Standards – QGOSM

10 May to 16 May 2022

Amendment 2 using new calibration certificate, March 2023

- **Method:** Comparison method using similar reference standard (Fluke 8508 A)
- **Reference Standard:** Reference Multimeter Fluke 8508 A
- **Serial No.**: 401472824
- **Temperature**: 23 ±1 °C
- **Humidity:** 50 ± 10 %
- **Uncertainty estimation:** The reported expanded uncertainty is based on a standard uncertainty multiplied by coverage factor k=2, providing a level of confidence of approximately 95%

  Note: the thermal emf component is not included in the uncertainty budget as we use the same cables during the comparison.
- **Traceability:** the reference multimeter is calibrated by fluke precision measurement Ltd, UK , (calibration Certificate number: 063378)

Measurement Results

DC Voltage

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Relative Error	Expanded Uncertainty
200 mV	**+ 100 mV**	99.99828	99.99920	0.00092 mV	0.00001	0.00042 mV
20 V	**+ 10 V**	9.999856	9.999907	0.000051 V	0.000005	0.000011 V
200 V	**+ 100 V**	99.99899	99.99947	0.00048 V	0.00000	0.00013 V
1000 V	**+ 1000 V**	999.9880	999.9914	0.0034 V	0.0000	0.0015 V

DC Current

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Relative Error	Expanded Uncertainty
200 µA	**+ 100 µA**	99.99308	99.99440	0.00132 µA	0.00001	0.00069 µA
20 mA	**+ 10 mA**	9.999781	9.999851	0.000070 mA	0.000007	0.000047 mA
2 A	**+ 1 A**	1.0000386	0.9997724	-0.0002662 A	-0.0002662	0.0000171 A

DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Relative Error	Expanded Uncertainty
20 Ω	**TrueΩ**	**10 Ω**	10.000137	10.000158	0.000020 Ω	0.000002	0.000071 Ω
20 kΩ	**TrueΩ**	**10 kΩ**	9.999967	10.000049	0.000082 kΩ	0.000008	0.000030 kΩ
	TrueΩ LoI	**10 kΩ**	9.999955	10.000059	0.000104 kΩ	0.000010	0.000037 kΩ
2 MΩ	**Normal**	**1 MΩ**	**This point can't be measured as it's out of our lab capabilities**				

AC Voltage

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Relative Error	Expanded Uncertainty
	Voltage	Frequency					
200 mV	**100 mV**	**55 Hz**	99.9828	99.9924	0.0097 mV	0.0001	0.0044 mV
	100 mV	**1 kHz**	99.9890	99.9973	0.0083 mV	0.0001	0.0040 mV
20 V	**10 V**	**55 Hz**	9.99915	9.99951	0.00036 V	0.00004	0.00018 V
	10 V	**1 kHz**	9.99903	9.99924	0.00021 V	0.00002	0.00019V
	10 V	**100 kHz**	10.00232	9.99922	-0.00310 V	-0.00031	0.00267 V
200 V	**100 V**	**55 Hz**	99.9945	99.9962	0.0017 V	0.0000	0.0037 V
	100 V	**1 kHz**	99.9945	99.9971	0.0026 V	0.0000	0.0026 V

AC Current

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Relative Error	Expanded Uncertainty
	Voltage	Frequency					
20 mA	**10 mA**	**300 Hz**	10.00001	10.00020	0.00019 mA	0.00002	0.00033 mA
	10 mA	**1 kHz**	10.00012	10.00021	0.00009 mA	0.00001	0.00033 mA
2 A	**1 A**	**300 Hz**	1.000178	0.999537	-0.000641 A	-0.000641	0.000046 A
	1 A	**1 kHz**	1.000144	0.999553	-0.000592 A	-0.000592	0.000046 A

All comparison measurements carried by:

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DC Voltage

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
200 mV	+ 100 mV	100.000029 mV	99.99988 mV	-1.5 µV/V	13.5 µV/V
20 V	+ 10 V	9.999998 V	9.999988 V	-1.0 µV/V	4.3 µV/V
200 V	+ 100 V	100.000084 V	99.99998 V	-1.0 µV/V	6.3 µV/V
1000 V	+ 1000 V	1000.00101 V	1000.0005 V	-0.5 µV/V	8.0 µV/V

DC Current

Range of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
200 µA	+ 100 µA	99.99787 µA	99.99762 µA	-2.5 µA/A	117.2 µA/A
20 mA	+ 10 mA	9.999980 mA	9.999989 mA	0.9 µA/A	46.9 µA/A
2 A	+ 1 A	1.0000174 A	0.9999224 A	-95.0 µA/A	107.2 µA/A

DC Resistance

Range of 8508A	Mode of 8508A	Nominal Value	Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
20 Ω	TrueΩ	10 Ω	10.0000384 Ω	9.999984 Ω	-5.4 µΩ/Ω	5.2 µΩ/Ω
20 kΩ	TrueΩ	10 kΩ	10.0000072 kΩ	10.000039 kΩ	3.2 µΩ/Ω	1.2 µΩ/Ω
	TrueΩ LoI	10 kΩ	10.0000072 kΩ	10.000057 kΩ	5.0 µΩ/Ω	1.3 µΩ/Ω
2 MΩ	Normal	1 MΩ	1.0000042 MΩ	1.0000023 MΩ	-1.9 µΩ/Ω	15.2 µΩ/Ω

AC Voltage

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
	Voltage	Frequency				
200 mV	100 mV	55 Hz	100.00036 mV	100.0069 mV	65.0 µV/V	163.4 µV/V
	100 mV	1 kHz	99.99975 mV	100.0036 mV	38.9 µV/V	163.4 µV/V
20 V	10 V	55 Hz	10.000096 V	10.00020 V	10.7 µV/V	68.6 µV/V
	10 V	1 kHz	10.000082 V	10.00012 V	3.5 µV/V	68.6 µV/V
	10 V	100 kHz	10.000231 V	9.99971 V	-52.1 µV/V	176.2 µV/V
200 V	100 V	55 Hz	99.99984 V	100.0036 V	37.6 µV/V	83.6 µV/V
	100 V	1 kHz	99.99883 V	100.0006 V	17.5 µV/V	82.4 µV/V

AC Current

Range of 8508A	Nominal Value		Applied Value	Indication of 8508A	Error of 8508A	Expanded Uncertainty
	Voltage	Frequency				
20 mA	10 mA	300 Hz	10.00014 mA	10.00024 mA	9.8 µA/A	0.18 mA/A
	10 mA	1 kHz	10.00006 mA	10.00024 mA	17.5 µA/A	0.18 mA/A
2 A	1 A	300 Hz	1.000008 A	0.999938 A	-69.8 µA/A	0.41 mA/A
	1 A	1 kHz	1.000008 A	1.000017 A	9.1 µA/A	0.41 mA/A