EURAMET Project 1341

"Comparison on the Calibration of Multimeter"

Draft B Report

Saliha TURHAN

TÜBİTAK Ulusal Metroloji Enstitüsü (UME)

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1. Introduction

During the 6th Meeting of the EURAMET Focus Group Metrology Infrastructure Development (FG FNMID), held in Istanbul (Turkey) in November 2013, it was decided to organize an intercomparison on multimeter calibration, in order to support the CMCs of NMIs in the CIPM KCDB.

During the EURAMET TC-EM meeting, which was held in MIRS, Ljubljana (Slovenia) on October 16-17, 2014, it was decided to announce the comparison to all TC-EM members asking for further participants. The comparison was proposed by TÜBİTAK UME and was registered as EURAMET Project No 1341.

The comparison was planned for 5 participants in the EURAMET FG FNMID meeting. After the announcement in EURAMET TC-EM, sixteen participants have applied to participate in the EURAMET Project 1341. Out of sixteen applicants, fourteen institutes are members of EURAMET, two institutes are the member of GULFMET. TÜBİTAK UME agreed to be the pilot laboratory in this comparison.

The comparison was conducted in accordance with the Technical Protocol, given in Appendix IV, which was prepared by TÜBİTAK UME and approved by the participants.

2. Participants of the Comparison

2.1. Participants

List of participating laboratories is given in Table 1.

Table 1. List of participating laboratories

Acronym of Institute	Country	Contact Person	Shipping Address
MBM	Montenegro	Rabina Šabotić rabina.sabotic@metrologija.gov.me Tel: +382 20 601 360	Montenegrin Bureau of Metrology (MBM) Kralja Nikole 2 XM-81000 Podgorica, Montenegro
IMBiH	Bosnia and Herzegovina	Vladimir Milojevic vladimir.milojevic@met.gov.ba Tel: +387 33 568 901	Institute of Metrology of Bosnia and Herzegovina Augusta Brauna 2 BA-71000 Sarajevo, Bosnia and Herzegovina
HMI/FER-PEL*	Croatia	Damir Ilic damir.ilic@fer.hr Tel: +385 1 612 9753	University of Zagreb, Faculty of Electrical Engineering and Computing Primary Electromagnetic Laboratory Unska 3, HR-10000 Zagreb, Croatia
INM	Romania	Liliana Cirneanu liliana.cirneanu@inm.ro Tel: +4021 334 50 60 (ext. 153)	National Institute of Metrology (INM) Sos. Vitan-Bârzesti 11 RO-042122 Bucuresti, Romania
CMI*	Czech Republic	Jiri Streit jstreit@cmi.cz Tel: +420 545 555 208	Czech Metrology Institute Laboratory of DC/LF Electrical Quantities Okruzni 31 638 00 BRNO, Czech Republic

Acronym of Institute	Country	Contact Person	Shipping Address
FTMC	Lithuania	Andrius Bartasiunas andrius.bartasiunas@ftmc.lt Tel: +370 5 261 80 65	Centre for Physical Sciences and Technology, A. Gostauto str. 11 LT-01108 Vilnius, Lithuania
IPQ	Portugal	Luis Ribeiro LRibeiro@ipq.pt Tel: +351 212 948 161	Instituto Português da Qualidade Laboratório Nacional de Metrologia Rua António Gião 2 PT-2829-513 Caparica, Portugal
BoM	FYR Macedonia	Stanislava Kroneva Petrovska stanislava.kroneva@bom.gov.mk Tel: +389 2 2403 676	Bureau of Metrology Bull. Jane Sandanski 109 a MK-1000 Skopje R., FYR Macedonia
AS METROSERT	Estonia	Andrei Pokatilov andrei.pokatilov@metrosert.ee Tel: +372 529 7095	Central Office of Metrology National Standards Laboratory for Electrical Quantities R&D division Metrosert AS Teaduspargi 8, 12618 Tallinn, Estonia
GUM	Poland	Paweł Zawadzki p.zawadzki@gum.gov.pl Tel: +48 22 581 9241	Central Office of Measures Glówny Urzad Miar ul. Elektoralna 2 PL-00 950 Warszawa, Poland
DPM	Albania	Yljon Seferi yljon.seferi@dpm.gov.al Tel: +355 4 2233 174	General Directorate of Metrology Autostrada Tiranë - Durrës, km 8 (Rruga dytësore) Tiranë Albania
KMA	Kosovo	Musa Misini Musa.Misini@rks-gov.net Tel: +381 38 512 100	Kosovo Metrology Agency Str."Smajl Hajdaraj" p.n. Lagja Universitetit 10000 Prishtinë, Republika e Kosovës
NSAI NML	Ireland	Oliver POWER oliver.power@nsai.ie T: + 353 1 808 2610	NSAI National Metrology Laboratory Griffith Avenue Extension, Glasnevin,Dublin 11, D11 E527 Ireland.
EMI	United Arab Emirates (UAE)	Jon Bartholomew jon.bartholomew@qcc.abudhabi.ae Tel: +971 503862676	Emirates Metrology Institute Sultan Bin Zayed the First Street Abu Dhabi, UAE
SASO	Kingdom of Saudi Arabia	Eng. Abdullah Alrobaish a.robaish@saso.gov.sa Tel: +966 504104070 Dr. Mamdouh Halawa mamdouh_halawa@yahoo.com Tel: +966 508796538	The Saudi Standards, Metrology and Quality Organization (SASO) PO. B 3437 Riyadh- Al Muhammadiyah – in front of King Saud University (Bldg. # 4, NMCC) 11471 Riyadh Kingdom of Saudi Arabia
TÜBİTAK UME	Turkey	Saliha Turhan saliha.turhan@tubitak.gov.tr Tel: +90 262 679 50 00 (Ext. 4201)	TÜBİTAK Ulusal Metroloji Enstitüsü TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY

* HMI/FER-PEL and CMI did not send their comparison reports and they withdrew from the comparison.

2.2. Pilot Institute

This comparison was piloted by TÜBİTAK UME. The pilot institute is responsible for preparing the measurement instructions, controlling the stability of the transfer standard, calculating the results and preparing the comparison report.

3. Organisation of the Comparison

3.1. The time schedule

The time schedule for the comparison is given in the Table 2. Circulation of the travelling standard started in March 2015 and comparison measurements were completed in September 2016. The circulation of travelling standard was organized in loops of not more than 3 institutes in order to monitor the performance of the travelling standard. Each participating institute covered the costs of customs clearance, and shipment to the next institute.

Table 2. Circulation Time Schedule

Acronym of Institute	Country	Starting Date	Time for Measurement and Transportation
TÜBİTAK UME	Turkey	02.03.2015	14 days
MBM	Montenegro	16.03.2015	14 days
IMBiH	Bosnia and Herzegovina	30.03.2015	14 days
TÜBİTAK UME	Turkey	13.04.2015	14 days
HMI/FER-PEL*	Croatia	27.04.2015	14 days
INM	Romania	11.05.2015	14 days
CMI*	Czech Republic	25.05.2015	14 days
TÜBİTAK UME	Turkey	08.06.2015	35 days
FTMC	Lithuania	13.07.2015	14 days
TÜBİTAK UME	Turkey	27.07.2015	35 days
IPQ	Portugal	31.08.2015	14 days
BoM	FYR Macedonia	14.09.2015	14 days
TÜBİTAK UME	Turkey	28.09.2015	28 days
AS METROSERT	Estonia	26.10.2015	14 days
GUM	Poland	09.11.2015	14 days
DPM	Albania	19.01.2016	27 days

Acronym of Institute	Country	Starting Date	Time for Measurement and Transportation
TÜBİTAK UME	Turkey	15.02.2016	91 days
KMA	Kosovo	16.05.2016	14 days
NSAI NML	Ireland	20.06.2016	14 days
TÜBİTAK UME	Turkey	01.08.2016	14 days
EMI	United Arab Emirates (UAE)	15.08.2016	14 days
SASO	Kingdom of Saudi Arabia	29.08.2016	14 days
TÜBİTAK UME	Turkey	12.09.2016	14 days

* HMI/FER-PEL and CMI did not send their comparison reports and they withdrew from the comparison.

3.2. Unexpected events

During the course of the comparison, some delays occurred in the planed schedule due to severe customs and transport delays. Also, during the comparison, two GULFMET institutes, EMI (United Arab Emirates (UAE)) and SASO (Kingdom of Saudi Arabia) have been included as additional participants. No damages were reported on the travelling standards during the comparison.

4. Travelling Standard

The travelling standard, supplied by TÜBİTAK UME, was an 8½ digit multimeter, Fluke 8508A Reference Multimeter, serial number 969656608 (Figure 1). 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. The general specifications of 8508A are given in Table 3.

The travelling standard was shipped in a ruggedized transit case with dimensions (80 × 62 × 45) cm, and the package weighed approximately 26 kg.

Front Panel

Rear Panel

Figure 1. Travelling standard is Fluke 8508A Reference Multimeter with serial number 969656608

Table 3. The general specifications of 8508A Reference Multimeter

Power	Power supply 200 V to 240 V rms ±10 % @ 47 Hz to 63 Hz Consumption < 80 VA
Dimensions	Height 88 mm (3.5 inches) Width 427 mm (16.8 inches) Depth 487 mm (19.2 inches)
Weight	11.5 kg (25.5 lbs)
Environment Temperature	Operating 0 °C to 50 °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

5. Measurement Instructions

The measurement instructions, describing the preliminary operations to be performed on the travelling standard and its configuration required for each measurement function and range, were given in the Technical Protocol given in “Appendix IV”. 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 V.

6. Quantities Measured

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

Table 4. Measurement quantities & points and the configuration of Fluke 8508A

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 @ 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 (‡ Normal Ω for 1 MΩ) Resolution 7 4-Wire Low Current OFF (‡ Low Current ON) Filter ON Fast OFF Front Input
	10 kΩ	20 kΩ	5 min	
	10 kΩ‡		5 min	
	1 MΩ‡	2 MΩ	5 min	

7. Temperature and humidity during the comparison measurements

Acronym of Institute	Country	Temperature ºC	Relative Humidity %rh
TÜBİTAK UME	Turkey	23 ± 1	45 ± 10
MBM	Montenegro	23 ± 1	45 ± 10
IMBiH	Bosnia and Herzegovina	23 ± 1	50 ± 10
INM	Romania	23 ± 1	50 ± 10
FTMC	Lithuania	23 ± 1	45 ± 10
IPQ	Portugal	23 ± 1	61 ± 9
BoM	FYR Macedonia	23 ± 1	46 ± 5
AS METROSERT	Estonia	23 ± 1.5	45 ± 10
GUM	Poland	23 ± 1	40 ± 20
DPM	Albania	20 ± 1	45 ± 10
KMA	Kosovo	23 ± 1	43 ± 12
NSAI NML	Ireland	22 ± 1	45 ± 10
EMI	United Arab Emirates (UAE)	23 ± 1	45 ± 10
SASO	Kingdom of Saudi Arabia	23 ± 1	45 ± 5

8. Drift of the Travelling Standard

The drift of travelling standard was determined using eight individual measurements of TÜBİTAK UME, performed at different times during the comparison starting in March 2015 until September 2016. The measurements results TÜBİTAK UME used to analyse the drift of the travelling standard are given in Appendix III for each measurement function.

The drift of the standard was modelled using a linear fit, given as in Equation (1):

$$y = y_0 + m \times (x - x_0) \tag{1}$$

Where,

y	(10^{-6})	The measurement result given by linear fit on date x
y_0	(10^{-6})	The average measurement result of the TÜBİTAK UME measurements
x	(days)	A given measurement date
x_0	(days)	The average measurement date of the TÜBİTAK UME measurements
m	(10^{-6} /day)	The drift of the travelling standard per day

The fit parameters of the drift of the travelling standard and the corresponding standard uncertainties (k = 1) are given in Table 5.

Table 5. Fit parameters of the drift of the travelling standard and the corresponding uncertainties

Quantity	Measurement Point	x_0	y_0 (10^{-6})	$u(y_0)$ (10^{-6})	m (10^{-6}/day)	$u(m)$ (10^{-6}/day)
DC Voltage	100 mV	15.11.2015	2.09	0.17	0.000759	0.000845
	10 V	15.11.2015	4.22	0.10	0.000277	0.000483
	100 V	15.11.2015	-2.19	0.12	-0.001938	0.000592
	1000 V	15.11.2015	-1.47	0.14	-0.002353	0.000673
DC Current	100 µA	15.11.2015	-8.45	0.52	-0.00273	0.00254
	10 mA	15.11.2015	22.87	0.41	0.00329	0.00198
	1 A	15.11.2015	-124.14	1.24	-0.03609	0.00599
AC Voltage	100 mV, 55 Hz	18.11.2015	-0.22	1.58	-0.01005	0.00758
	100 mV, 1 kHz	18.11.2015	43.60	1.53	-0.00648	0.00734
	10 V, 55 Hz	18.11.2015	50.48	0.41	0.00009	0.00198
	10 V, 1 kHz	18.11.2015	94.54	0.51	0.00129	0.00243
	10 V, 100 kHz	18.11.2015	64.60	4.38	-0.03399	0.02109
	100 V, 55 Hz	18.11.2015	-11.72	0.78	-0.00278	0.00377
	100 V, 1 kHz	18.11.2015	28.35	0.82	-0.00179	0.00396
AC Current	10 mA, 300 Hz	18.11.2015	57.39	1.23	0.01317	0.00591
	10 mA, 1 kHz	18.11.2015	74.48	0.99	0.01273	0.00478
	1 A, 300 Hz	18.11.2015	-97.74	1.65	-0.02973	0.00794
	1 A, 1 kHz	18.11.2015	-32.62	2.64	-0.03034	0.01273
DC Resistance	10 Ω	16.11.2015	14.52	0.19	0.003143	0.000909
	10 kΩ	16.11.2015	8.99	0.21	0.002281	0.001036
	10 kΩ (LOI)	16.11.2015	9.86	0.21	0.002708	0.001030
	1 MΩ	16.11.2015	9.19	0.12	0.005075	0.000605

9. Measurement Results of Participants

The measurement results were required to be reported as the relative error of the travelling standard, calculated with;

$$x_i = \frac{\text{Measured Value (reading of Travelling Standard)} - \text{Applied Value}}{\text{Applied Value}} \quad (2)$$

Each participant results (x_i) were corrected according to the drift of the standard (δx_{drf}) to the average measurement date of TÜBİTAK UME by using Equation (3);

$$x_i' = x_i + \delta x_{drf} \quad (3)$$

where,

$$\delta x_{drf} = m \times (t_i - t_0)$$

m	(10^{-6} /day)	The drift of the travelling standard per day
t_i	(days)	The average measurement date of the i^{th} participant
t_0	(days)	The average measurement date of the TÜBİTAK UME

The uncertainty of the corrected results $U(x_i')$ was calculated using Equation (4).

$$U(x_i') = \sqrt{U(x_i)^2 + U(\delta x_{drf})^2} \quad (4)$$

$U(x_i)$	The expanded uncertainty of the measurements of the participant (x_i)
$U(\delta x_{drf})$	The uncertainty of the correction values (δx_{drf})

The result of TÜBİTAK UME in this comparison was calculated as the average value of the individual results of TÜBİTAK UME which are given in Appendix III. The averaged TÜBİTAK UME results are given in on the last lines of Table 6 to Table 10 for each measurement point.

The uncertainty of the averaged TÜBİTAK UME result ($U(x_{UME})$) was calculated as a combined uncertainty of the individual results. It has been assumed that the contributions determined by a type B evaluation [1] are fully correlated between the individual results, whereas the contributions from the type A evaluation [1] are expected to be uncorrelated.

The errors reported by the participants (x_i), the correction values (δx_{drf}), the corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) are presented in Table 6 to Table 10.

Table 6. The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for DC Voltage

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (μV/V)	$U(x_i)$ (μV/V)	δx_{drf} (μV/V)	$U(\delta x_{drf})$ (μV/V)	x_i' (μV/V)	$U(x_i')$ (μV/V)
200 mV	100 mV	MBM	20.03.2015	-6.4	5.9	-0.18	0.60	-6.6	5.9
		IMBIH	02.04.2015	-11.0	5.6	-0.17	0.60	-11.2	5.6
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	-0.2	5.1	-0.08	0.60	-0.3	5.1
		IPQ	06.09.2015	-1.2	1.3	-0.05	0.60	-1.3	1.4
		BOM	24.09.2015	-16	21	-0.04	0.60	-16	21
		METROSERT	31.10.2015	4.3	5.9	-0.01	0.60	4.3	5.9
		GUM	13.11.2015	1.7	4.5	0.00	0.60	1.7	4.5
		DPM	29.01.2016	-4	11	0.06	0.60	-4	11
		KMA	01.06.2016	-2.2	6.1	0.15	0.60	-2.0	6.1
		NSAI NML	29.06.2016	0.9	4.0	0.17	0.60	1.1	4.0
		EMI	18.08.2016	0.0	7.3	0.21	0.60	0.2	7.3
		SASO	07.10.2016	-1.3	9.7	0.25	0.60	-1.0	9.7
		UME	15.11.2015	2.1	2.9	0.00	0.60	2.1	3.0
20 V	10 V	MBM	20.03.2015	6.7	1.1	-0.07	0.34	6.6	1.2
		IMBIH	02.04.2015	5.3	2.4	-0.06	0.34	5.2	2.4
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	4.4	1.0	-0.03	0.34	4.4	1.1
		IPQ	06.09.2015	3.96	0.22	-0.02	0.34	3.94	0.41
		BOM	24.09.2015	-1	13	-0.01	0.34	-1	13
		METROSERT	31.10.2015	4.1	1.0	0.00	0.34	4.1	1.1
		GUM	13.11.2015	3.7	1.4	0.00	0.34	3.7	1.4
		DPM	29.01.2016	3.8	4.1	0.02	0.34	3.8	4.1
		KMA	01.06.2016	0.8	3.9	0.06	0.34	0.9	3.9
		NSAI NML	29.06.2016	4.0	1.1	0.06	0.34	4.1	1.2
		EMI	18.08.2016	4.0	1.2	0.08	0.34	4.1	1.2
		SASO	07.10.2016	4.8	2.3	0.09	0.34	4.8	2.3
		UME	15.11.2015	4.2	0.8	0.00	0.34	4.2	0.9

Table 6. The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for DC Voltage (Continue)

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (µV/V)	$U(x_i)$ (µV/V)	δx_{drf} (µV/V)	$U(\delta x_{drf})$ (µV/V)	x_i' (µV/V)	$U(x_i')$ (µV/V)
200 V	100 V	MBM	20.03.2015	-1.4	5.3	0.47	0.42	-0.9	5.3
		IMBIH	02.04.2015	-1.6	4.1	0.44	0.42	-1.2	4.1
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	-1.1	1.5	0.21	0.42	-0.9	1.6
		IPQ	06.09.2015	-1.3	1.8	0.14	0.42	-1.2	1.8
		BOM	24.09.2015	-7	14	0.10	0.42	-7	14
		METROSERT	31.10.2015	-2.2	2.1	0.03	0.42	-2.2	2.1
		GUM	13.11.2015	-2.3	2.1	0.00	0.42	-2.3	2.1
		DPM	29.01.2016	-0.6	6.5	-0.14	0.42	-0.7	6.5
		KMA	01.06.2016	-4.8	5.9	-0.39	0.42	-5.2	5.9
		NSAI NML	29.06.2016	-2.1	1.8	-0.44	0.42	-2.5	1.8
		EMI	18.08.2016	-4.3	4.0	-0.54	0.42	-4.8	4.0
		SASO	07.10.2016	-0.9	4.5	-0.63	0.42	-1.5	4.5
		UME	15.11.2015	-2.2	1.1	0.00	0.42	-2.2	1.2
1000 V	1000 V	MBM	20.03.2015	1.5	5.9	0.57	0.48	2.1	5.9
		IMBIH	02.04.2015	-3.3	4.5	0.53	0.48	-2.8	4.5
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	-0.6	1.4	0.26	0.48	-0.3	1.5
		IPQ	06.09.2015	2.4	2.4	0.16	0.48	2.5	2.4
		BOM	24.09.2015	-4	15	0.12	0.48	-4	15
		METROSERT	31.10.2015	-2.4	2.1	0.04	0.48	-2.4	2.2
		GUM	13.11.2015	-1.9	2.5	0.00	0.48	-1.9	2.5
		DPM	29.01.2016	1.0	7.1	-0.18	0.48	0.8	7.1
		KMA	01.06.2016	-6.1	6.0	-0.47	0.48	-6.6	6.0
		NSAI NML	29.06.2016	-1.8	3.0	-0.53	0.48	-2.3	3.0
		EMI	18.08.2016	-1	13	-0.65	0.48	-1	13
		SASO	07.10.2016	0.8	5.8	-0.77	0.48	0.0	5.8
		UME	15.11.2015	-1.5	1.4	0.00	0.48	-1.5	1.5

Table 7. The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for DC Current

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (µA/A)	$U(x_i)$ (µA/A)	δx_{drf} (µA/A)	$U(\delta x_{drf})$ (µA/A)	x_i' (µA/A)	$U(x_i')$ (µA/A)
200 µA	100 µA	MBM	20.03.2015	-16	18	0.7	1.8	-15	18
		IMBIH	02.04.2015	-20.8	5.5	0.6	1.8	-20.2	5.8
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	-8	34	0.3	1.8	-8	34
		IPQ	06.09.2015	-10.92	0.73	0.2	1.8	-10.7	1.9
		BOM	24.09.2015	-1	146	0.1	1.8	-1	146
		METROSERT	31.10.2015	-11.3	9.6	0.0	1.8	-11.3	9.8
		GUM	13.11.2015	-10.0	4.0	0.0	1.8	-10.0	4.4
		DPM	29.01.2016	-4	99	-0.2	1.8	-4	99
		KMA	01.06.2016	-4	13	-0.5	1.8	-5	13
		NSAI NML	29.06.2016	-11	15	-0.6	1.8	-12	15
		EMI	18.08.2016	-26	54	-0.8	1.8	-27	54
		SASO	07.10.2016	-25	18	-0.9	1.8	-26	18
		UME	15.11.2015	-8	10	0.0	1.8	-8	10
20 mA	10 mA	MBM	20.03.2015	31.0	5.0	-0.8	1.4	30.2	5.2
		IMBIH	02.04.2015	20.0	3.4	-0.7	1.4	19.3	3.7
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	24	28	-0.4	1.4	23	28
		IPQ	06.09.2015	21.4	0.7	-0.2	1.4	21.2	1.6
		BOM	24.09.2015	0	72	-0.2	1.4	0	72
		METROSERT	31.10.2015	26.8	9.5	0.0	1.4	26.8	9.6
		GUM	13.11.2015	22.0	4.0	0.0	1.4	22.0	4.2
		DPM	29.01.2016	22	35	0.2	1.4	22	35
		KMA	01.06.2016	13	12	0.7	1.4	13	12
		NSAI NML	29.06.2016	24	10	0.7	1.4	25	10
		EMI	18.08.2016	8	37	0.9	1.4	9	37
		SASO	07.10.2016	10	16	1.1	1.4	11	16
		UME	15.11.2015	23	10	0.0	1.4	23	10

Table 7. The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for DC Current (Continue)

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (μA/A)	$U(x_i)$ (μA/A)	δx_{drf} (μA/A)	$U(\delta x_{drf})$ (μA/A)	x_i' (μA/A)	$U(x_i')$ (μA/A)
2 A	1 A	MBM	20.03.2015	-250	90	8.7	4.3	-241	90
		IMBIH	02.04.2015	-139	172	8.2	4.3	-131	172
		INM	-						
		FTMC	29.07.2015	-88	120	4.0	4.3	-84	120
		IPQ	06.09.2015	-115.6	1.3	2.5	4.3	-113.1	4.4
		BOM	24.09.2015	-141	204	1.9	4.3	-139	204
		METROSERT	31.10.2015	-120	12	0.5	4.3	-120	12
		GUM	13.11.2015	-119	24	0.1	4.3	-119	24
		DPM	29.01.2016	-110	170	-2.7	4.3	-113	170
		KMA	-	-	-	-	-	-	-
		NSAI NML	29.06.2016	-129	25	-8.2	4.3	-137	25
		EMI	18.08.2016	-146	61	-10.0	4.3	-156	61
		SASO	07.10.2016	-177	21	-11.8	4.3	-189	21
		UME	15.11.2015	-124	12	0.0	4.3	-124	13

Table 8. The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for Resistance

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (μΩ/Ω)	$U(x_i)$ (μΩ/Ω)	δx_{drf} (μΩ/Ω)	$U(\delta x_{drf})$ (μΩ/Ω)	x_i' (μΩ/Ω)	$U(x_i')$ (μΩ/Ω)
20 Ω	10 Ω	MBM	20.03.2015	20	10	-0.76	0.64	19	10
		IMBIH	02.04.2015	14.0	1.2	-0.72	0.64	13.3	1.4
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	14.0	1.1	-0.35	0.64	13.7	1.3
		IPQ	06.09.2015	13.49	0.69	-0.22	0.64	13.27	0.94
		BOM	24.09.2015	3	45	-0.17	0.64	3	45
		METROSERT	31.10.2015	14.0	1.0	-0.05	0.64	14.0	1.2
		GUM	13.11.2015	11.4	2.1	-0.01	0.64	11.4	2.2
		DPM	29.01.2016	27	26	0.23	0.64	27	26
		KMA	01.06.2016	-11	11	0.62	0.64	-10	11
		NSAI NML	29.06.2016	14.5	3.6	0.71	0.64	15.2	3.7
		EMI	18.08.2016	19.00	0.69	0.87	0.64	19.87	0.94
		SASO	07.10.2016	13.0	2.5	1.03	0.64	14.0	2.6
		UME	16.11.2015	14.5	1.3	0.00	0.64	14.5	1.5
20 kΩ	10 kΩ	MBM	20.03.2015	19.0	8.0	-0.55	0.73	18.4	8.0
		IMBIH	02.04.2015	8.7	1.2	-0.52	0.73	8.2	1.4
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	8.9	1.1	-0.25	0.73	8.6	1.3
		IPQ	06.09.2015	9.21	0.63	-0.16	0.73	9.05	0.97
		BOM	24.09.2015	-3	23	-0.12	0.73	-3	23
		METROSERT	31.10.2015	8.8	1.0	-0.04	0.73	8.8	1.2
		GUM	13.11.2015	10.9	1.9	-0.01	0.73	10.9	2.0
		DPM	29.01.2016	8	10	0.17	0.73	8	10
		KMA	01.06.2016	1.6	8.9	0.45	0.73	2.1	8.9
		NSAI NML	29.06.2016	9.3	2.5	0.52	0.73	9.8	2.6
		EMI	18.08.2016	8.9	1.1	0.63	0.73	9.5	1.3
		SASO	07.10.2016	8.7	2.5	0.74	0.73	9.4	2.6
		UME	16.11.2015	9.0	3.0	0.00	0.73	9.0	3.1

Table 8. The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for Resistance (Continue)

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (µΩ/Ω)	$U(x_i)$ (µΩ/Ω)	δx_{drf} (µΩ/Ω)	$U(\delta x_{drf})$ (µΩ/Ω)	x_i' (µΩ/Ω)	$U(x_i')$ (µΩ/Ω)
20 kΩ LoI	10 kΩ	MBM	20.03.2015	11.0	9.0	-0.65	0.73	10.3	9.0
		IMBIH	02.04.2015	9.8	1.2	-0.62	0.73	9.2	1.4
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	10.0	1.3	-0.30	0.73	9.7	1.5
		IPQ	06.09.2015	9.37	0.63	-0.19	0.73	9.18	0.96
		BOM	24.09.2015	-1	23	-0.14	0.73	-1	23
		METROSERT	31.10.2015	10.0	1.0	-0.04	0.73	10.0	1.2
		GUM	13.11.2015	11.5	1.9	-0.01	0.73	11.5	2.0
		DPM	29.01.2016	13	11	0.20	0.73	13	11
		KMA	01.06.2016	8.5	9.7	0.54	0.73	9.0	9.7
		NSAI NML	29.06.2016	10.5	2.8	0.61	0.73	11.1	2.9
		EMI	18.08.2016	10.0	2.2	0.75	0.73	10.7	2.3
		SASO	07.10.2016	10.0	2.5	0.88	0.73	10.9	2.6
		UME	16.11.2015	9.9	3.0	0.00	0.73	9.9	3.1
2 MΩ	1 MΩ	MBM	20.03.2015	6	86	-1.22	0.43	5	86
		IMBIH	02.04.2015	7.7	5.2	-1.16	0.43	6.5	5.2
		INM	-	-	-	-	-	-	-
		FTMC	29.07.2015	9.1	1.7	-0.56	0.43	8.5	1.8
		IPQ	06.09.2015	15.9	1.6	-0.36	0.43	15.5	1.7
		BOM	24.09.2015	-4	42	-0.27	0.43	-4	42
		METROSERT	31.10.2015	10.5	9.3	-0.08	0.43	10.4	9.3
		GUM	13.11.2015	9.8	1.5	-0.01	0.43	9.8	1.6
		DPM	29.01.2016	13	17	0.37	0.43	13	17
		KMA	-	-	-	-	-	-	-
		NSAI NML	29.06.2016	9	11	1.15	0.43	10	11
		EMI	18.08.2016	8.5	4.4	1.40	0.43	9.9	4.4
		SASO	07.10.2016	9.6	7.0	1.66	0.43	11.3	7.0
		UME	16.11.2015	9.2	6.0	0.00	0.43	9.2	6.0

Table 9. The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for AC Voltage

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (mV/V)	$U(x_i)$ (mV/V)	δx_{drf} (mV/V)	$U(\delta x_{drf})$ (mV/V)	x_i' (mV/V)	$U(x_i')$ (mV/V)
200 mV	100 mV 55 Hz	MBM	20.03.2015	0.00	0.16	0.0024	0.0054	0.00	0.16
		IMBIH	02.04.2015	0.05	0.19	0.0023	0.0054	0.05	0.19
		INM	22.05.2015	-0.06	0.13	0.0018	0.0054	-0.06	0.13
		FTMC	29.07.2015	-0.06	0.14	0.0011	0.0054	-0.05	0.14
		IPQ	06.09.2015	-0.011	0.018	0.0007	0.0054	-0.010	0.019
		BOM	24.09.2015	-0.01	0.23	0.0006	0.0054	-0.01	0.23
		METROSERT	31.10.2015	-0.050	0.059	0.0002	0.0054	-0.050	0.059
		GUM	13.11.2015	-0.055	0.021	0.0001	0.0054	-0.055	0.022
		DPM	29.01.2016	-0.04	0.18	-0.0007	0.0054	-0.04	0.18
		KMA	01.06.2016	0.03	0.16	-0.0020	0.0054	0.02	0.16
		NSAI NML	29.06.2016	-0.02	0.13	-0.0022	0.0054	-0.02	0.13
		EMI	18.08.2016	-0.05	0.25	-0.0027	0.0054	-0.06	0.25
		SASO	07.10.2016	-0.05	0.13	-0.0033	0.0054	-0.05	0.13
		UME	18.11.2015	0.000	0.040	0.0000	0.0054	0.000	0.040
200 mV	100 mV 1 kHz	MBM	20.03.2015	0.05	0.14	0.0016	0.0052	0.05	0.14
		IMBIH	02.04.2015	0.04	0.18	0.0015	0.0052	0.04	0.18
		INM	22.05.2015	-0.02	0.13	0.0012	0.0052	-0.01	0.13
		FTMC	29.07.2015	-0.01	0.13	0.0007	0.0052	-0.01	0.13
		IPQ	06.09.2015	0.020	0.018	0.0005	0.0052	0.021	0.019
		BOM	24.09.2015	0.11	0.22	0.0004	0.0052	0.11	0.22
		METROSERT	31.10.2015	-0.004	0.059	0.0001	0.0052	-0.004	0.059
		GUM	13.11.2015	-0.008	0.021	0.0000	0.0052	-0.008	0.022
		DPM	29.01.2016	-0.06	0.18	-0.0005	0.0052	-0.06	0.18
		KMA	01.06.2016	0.03	0.13	-0.0013	0.0052	0.03	0.13
		NSAI NML	29.06.2016	0.03	0.12	-0.0014	0.0052	0.03	0.12
		EMI	18.08.2016	-0.03	0.25	-0.0018	0.0052	-0.03	0.25
		SASO	07.10.2016	-0.01	0.15	-0.0021	0.0052	-0.01	0.15
		UME	18.11.2015	0.044	0.040	0.0000	0.0052	0.044	0.040

Table 9 The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for AC Voltage (Continue)

Measurement Range	**Measurement Point**	**NMI**	**Average Date**	**Participant Result**		**Drift Correction**		**Corrected Result**	
			t dd.mm.yyyy	x_i (mV/V)	$U(x_i)$ (mV/V)	δx_{drf} (mV/V)	$U(\delta x_{drf})$ (mV/V)	x_i' (mV/V)	$U(x_i')$ (mV/V)
20 V	10 V 55 Hz	MBM	20.03.2015	0.02	0.11	-0.00002	0.0014	0.02	0.11
		IMBIH	02.04.2015	0.03	0.11	-0.00002	0.0014	0.03	0.11
		INM	22.05.2015	0.048	0.042	-0.00002	0.0014	0.048	0.042
		FTMC	29.07.2015	0.062	0.044	-0.00001	0.0014	0.062	0.044
		IPQ	06.09.2015	0.056	0.012	-0.00001	0.0014	0.056	0.012
		BOM	24.09.2015	-0.01	0.14	0.00000	0.0014	-0.01	0.14
		METROSERT	31.10.2015	0.052	0.058	0.00000	0.0014	0.052	0.058
		GUM	13.11.2015	0.051	0.011	0.00000	0.0014	0.051	0.011
		DPM	29.01.2016	0.08	0.10	0.00001	0.0014	0.08	0.10
		KMA	01.06.2016	0.11	0.11	0.00002	0.0014	0.11	0.11
		NSAI NML	29.06.2016	0.063	0.050	0.00002	0.0014	0.063	0.050
		EMI	18.08.2016	0.052	0.060	0.00002	0.0014	0.052	0.060
		SASO	07.10.2016	0.039	0.049	0.00003	0.0014	0.039	0.049
		UME	18.11.2015	0.050	0.011	0.00000	0.0014	0.050	0.011
20 V	10 V 1 kHz	MBM	20.03.2015	0.010	0.120	-0.0003	0.0017	0.01	0.12
		IMBIH	02.04.2015	0.090	0.091	-0.0003	0.0017	0.090	0.091
		INM	22.05.2015	0.092	0.042	-0.0002	0.0017	0.092	0.042
		FTMC	29.07.2015	0.106	0.043	-0.0001	0.0017	0.106	0.043
		IPQ	06.09.2015	0.0993	0.0088	-0.0001	0.0017	0.0992	0.0090
		BOM	24.09.2015	0.03	0.14	-0.0001	0.0017	0.03	0.14
		METROSERT	31.10.2015	0.098	0.058	0.0000	0.0017	0.098	0.058
		GUM	13.11.2015	0.093	0.011	0.0000	0.0017	0.093	0.011
		DPM	29.01.2016	0.06	0.10	0.0001	0.0017	0.06	0.10
		KMA	01.06.2016	0.105	0.095	0.0003	0.0017	0.105	0.095
		NSAI NML	29.06.2016	0.106	0.042	0.0003	0.0017	0.106	0.042
		EMI	18.08.2016	0.092	0.057	0.0004	0.0017	0.092	0.057
		SASO	07.10.2016	0.085	0.048	0.0004	0.0017	0.085	0.048
		UME	18.11.2015	0.095	0.010	0.0000	0.0017	0.095	0.010

Table 9 The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for AC Voltage (Continue)

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (mV/V)	$U(x_i)$ (mV/V)	δx_{drf} (mV/V)	$U(\delta x_{drf})$ (mV/V)	x_i' (mV/V)	$U(x_i')$ (mV/V)
20 V	10 V 100 kHz	MBM	20.03.2015	-0.03	0.72	0.008	0.015	-0.02	0.72
		IMBIH	02.04.2015	0.00	0.71	0.008	0.015	0.01	0.71
		INM	22.05.2015	0.05	0.11	0.006	0.015	0.05	0.11
		FTMC	29.07.2015	0.08	0.33	0.004	0.015	0.08	0.33
		IPQ	06.09.2015	0.074	0.014	0.002	0.015	0.076	0.021
		BOM	24.09.2015	-0.04	0.96	0.002	0.015	-0.04	0.96
		METROSERT	31.10.2015	0.11	0.12	0.001	0.015	0.11	0.12
		GUM	13.11.2015	0.117	0.022	0.000	0.015	0.117	0.027
		DPM	29.01.2016	0.17	0.57	-0.002	0.015	0.17	0.57
		KMA	01.06.2016	0.01	0.77	-0.007	0.015	0.00	0.77
		NSAI NML	29.06.2016	0.09	0.17	-0.008	0.015	0.08	0.17
		EMI	18.08.2016	0.07	0.16	-0.009	0.015	0.06	0.16
		SASO	07.10.2016	-0.01	0.11	-0.011	0.015	-0.02	0.11
		UME	18.11.2015	0.065	0.016	0.000	0.015	0.065	0.022
200 V	100 V 55 Hz	MBM	20.03.2015	-0.04	0.11	0.0007	0.0027	-0.04	0.11
		IMBIH	02.04.2015	-0.03	0.12	0.0006	0.0027	-0.03	0.12
		INM	22.05.2015	-0.011	0.051	0.0005	0.0027	-0.010	0.051
		FTMC	29.07.2015	-0.010	0.057	0.0003	0.0027	-0.010	0.057
		IPQ	06.09.2015	-0.021	0.023	0.0002	0.0027	-0.021	0.023
		BOM	24.09.2015	-0.05	0.28	0.0002	0.0027	-0.05	0.28
		METROSERT	31.10.2015	-0.015	0.059	0.0001	0.0027	-0.015	0.059
		GUM	13.11.2015	-0.008	0.012	0.0000	0.0027	-0.008	0.012
		DPM	29.01.2016	0.02	0.10	-0.0002	0.0027	0.01	0.10
		KMA	01.06.2016	0.05	0.11	-0.0005	0.0027	0.04	0.11
		NSAI NML	29.06.2016	-0.002	0.079	-0.0006	0.0027	-0.003	0.079
		EMI	18.08.2016	-0.009	0.076	-0.0008	0.0027	-0.010	0.076
		SASO	07.10.2016	0.005	0.062	-0.0009	0.0027	0.004	0.062
		UME	18.11.2015	-0.012	0.015	0.0000	0.0027	-0.012	0.015

Table 9 The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for AC Voltage (Continue)

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (mV/V)	$U(x_i)$ (mV/V)	δx_{drf} (mV/V)	$U(\delta x_{drf})$ (mV/V)	x_i' (mV/V)	$U(x_i')$ (mV/V)
200 V	100 V 1 kHz	MBM	20.03.2015	-0.010	0.090	0.0004	0.0028	-0.010	0.090
		IMBIH	02.04.2015	0.025	0.098	0.0004	0.0028	0.025	0.098
		INM	22.05.2015	0.027	0.051	0.0003	0.0028	0.027	0.051
		FTMC	29.07.2015	0.033	0.052	0.0002	0.0028	0.033	0.052
		IPQ	06.09.2015	0.018	0.019	0.0001	0.0028	0.018	0.019
		BOM	24.09.2015	-0.01	0.27	0.0001	0.0028	-0.01	0.27
		METROSERT	31.10.2015	0.026	0.059	0.0000	0.0028	0.026	0.059
		GUM	13.11.2015	0.031	0.012	0.0000	0.0028	0.031	0.012
		DPM	29.01.2016	0.003	0.084	-0.0001	0.0028	0.002	0.084
		KMA	01.06.2016	0.042	0.095	-0.0003	0.0028	0.042	0.095
		NSAI NML	29.06.2016	0.050	0.070	-0.0004	0.0028	0.050	0.070
		EMI	18.08.2016	0.030	0.071	-0.0005	0.0028	0.030	0.071
		SASO	07.10.2016	0.053	0.050	-0.0006	0.0028	0.052	0.050
		UME	18.11.2015	0.028	0.018	0.0000	0.0028	0.028	0.018

Table 10 The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for AC Current

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (mA/A)	$U(x_i)$ (mA/A)	δx_{drf} (mA/A)	$U(\delta x_{drf})$ (mA/A)	x_i' (mA/A)	$U(x_i')$ (mA/A)
20 mA	10 mA 300 Hz	MBM	20.03.2015	0.14	0.49	-0.0032	0.0042	0.14	0.49
		IMBIH	02.04.2015	0.049	0.086	-0.0030	0.0042	0.046	0.086
		INM	22.05.2015	0.05	0.13	-0.0024	0.0042	0.05	0.13
		FTMC	29.07.2015	-0.01	0.57	-0.0015	0.0042	-0.01	0.57
		IPQ	06.09.2015	0.057	0.052	-0.0010	0.0042	0.056	0.052
		BOM	24.09.2015	-0.13	0.65	-0.0007	0.0042	-0.13	0.65
		METROSERT	31.10.2015	0.057	0.017	-0.0002	0.0042	0.057	0.018
		GUM	13.11.2015	0.041	0.021	-0.0001	0.0042	0.041	0.021
		DPM	29.01.2016	0.03	0.35	0.0009	0.0042	0.03	0.35
		KMA	-	-	-	-	-	-	-
		NSAI NML	29.06.2016	0.07	0.13	0.0029	0.0042	0.07	0.13
		EMI	18.08.2016	0.05	0.19	0.0036	0.0042	0.05	0.19
		SASO	07.10.2016	0.064	0.043	0.0043	0.0042	0.068	0.043
		UME	18.11.2015	0.057	0.020	0.0000	0.0042	0.057	0.020
20 mA	10 mA 1 kHz	MBM	20.03.2015	0.09	0.49	-0.0031	0.0034	0.09	0.49
		IMBIH	02.04.2015	0.093	0.086	-0.0029	0.0034	0.090	0.086
		INM	22.05.2015	0.07	0.13	-0.0023	0.0034	0.07	0.13
		FTMC	29.07.2015	0.02	0.55	-0.0014	0.0034	0.01	0.55
		IPQ	06.09.2015	0.070	0.052	-0.0009	0.0034	0.069	0.052
		BOM	24.09.2015	-0.11	0.65	-0.0007	0.0034	-0.11	0.65
		METROSERT	31.10.2015	0.072	0.017	-0.0002	0.0034	0.072	0.017
		GUM	13.11.2015	0.061	0.021	-0.0001	0.0034	0.061	0.021
		DPM	29.01.2016	0.02	0.35	0.0009	0.0034	0.02	0.35
		KMA	-	-	-	-	-	-	-
		NSAI NML	29.06.2016	0.08	0.15	0.0028	0.0034	0.08	0.15
		EMI	18.08.2016	0.06	0.19	0.0035	0.0034	0.06	0.19
		SASO	07.10.2016	0.067	0.043	0.0041	0.0034	0.071	0.043
		UME	18.11.2015	0.074	0.020	0.0000	0.0034	0.074	0.020

Table 10 The participant results (x_i), drift corrections (δx_{drf}), corrected results (x_i') and their corresponding uncertainties ($U(x_i)$, $U(\delta x_{drf})$ and $U(x_i')$) for AC Current (Continue)

Measurement Range	Measurement Point	NMI	Average Date	Participant Result		Drift Correction		Corrected Result	
			t dd.mm.yyyy	x_i (mA/A)	$U(x_i)$ (mA/A)	δx_{drf} (mA/A)	$U(\delta x_{drf})$ (mA/A)	x_i' (mA/A)	$U(x_i')$ (mA/A)
2 A	1 A 300 Hz	MBM	20.03.2015	-0.10	0.82	0.0072	0.0057	-0.09	0.82
		IMBIH	02.04.2015	-0.10	0.84	0.0068	0.0057	-0.09	0.84
		INM	22.05.2015	-0.06	0.29	0.0054	0.0057	-0.05	0.29
		FTMC	29.07.2015	-0.2	1.2	0.0034	0.0057	-0.2	1.2
		IPQ	06.09.2015	-0.08	0.12	0.0022	0.0057	-0.07	0.12
		BOM	24.09.2015	-0.2	1.5	0.0016	0.0057	-0.2	1.5
		METROSERT	31.10.2015	-0.091	0.024	0.0005	0.0057	-0.090	0.025
		GUM	13.11.2015	-0.110	0.033	0.0002	0.0057	-0.110	0.033
		DPM	29.01.2016	-0.04	0.68	-0.0021	0.0057	-0.04	0.68
		KMA	-	-	-	-	-	-	-
		NSAI NML	29.06.2016	-0.10	0.26	-0.0066	0.0057	-0.10	0.26
		EMI	18.08.2016	-0.11	0.47	-0.0081	0.0057	-0.12	0.47
		SASO	07.10.2016	-0.086	0.094	-0.0096	0.0057	-0.096	0.094
		UME	18.11.2015	-0.098	0.035	0.0000	0.0057	-0.098	0.035
2 A	1 A 1 kHz	MBM	20.03.2015	-0.2	1.1	0.0074	0.0091	-0.2	1.1
		IMBIH	02.04.2015	-0.04	0.84	0.0070	0.0091	-0.03	0.84
		INM	22.05.2015	0.02	0.27	0.0055	0.0091	0.02	0.27
		FTMC	29.07.2015	-0.1	1.2	0.0034	0.0091	-0.1	1.2
		IPQ	06.09.2015	0.01	0.12	0.0022	0.0091	0.02	0.12
		BOM	24.09.2015	-0.3	1.5	0.0017	0.0091	-0.3	1.5
		METROSERT	31.10.2015	-0.010	0.024	0.0006	0.0091	-0.009	0.026
		GUM	13.11.2015	-0.047	0.033	0.0002	0.0091	-0.047	0.034
		DPM	29.01.2016	0.00	0.68	-0.0022	0.0091	0.00	0.68
		KMA	-	-	-	-	-	-	-
		NSAI NML	29.06.2016	-0.02	0.32	-0.0068	0.0091	-0.03	0.32
		EMI	18.08.2016	-0.04	0.47	-0.0083	0.0091	-0.05	0.47
		SASO	07.10.2016	-0.044	0.096	-0.0098	0.0091	-0.054	0.096
		UME	18.11.2015	-0.033	0.035	0.0000	0.0091	-0.033	0.036

10. The Comparison Reference Value (CRV)

The Comparison Reference Values (x_{CRV}) were calculated for each measurement point using the weighted mean with the normalized weight. To reach corrected result x_i' a normalised weight w_i was attributed, given by;

$$w_i = C \times \frac{f_{pi}}{u(x_i')^2}$$

f_{pi} is the flag indicating if the result of participant is taken into account in the calculation of x_{CRV} or not. It takes the values 1 or 0. For the first attempt, f_{pi} is set to 1 for all participants.

The normalising factor, C, is given by:

$$C = \frac{1}{\sum_1^N \frac{f_{pi}}{u(x_i')^2}}$$

The x_{CRV} is given by:

$$x_{CRV} = \sum_{i=1}^{N} w_i \times x_i' = \frac{\sum_1^N f_{pi} \frac{x_i'}{u(x_i')^2}}{\sum_1^N \frac{f_{pi}}{u(x_i')^2}} \quad (5)$$

and the uncertainty of the Comparison Reference Values (x_{CRV}) was calculated by:

$$u(x_{CRV}) = \sqrt{C} = \sqrt{\frac{1}{\sum_1^N \frac{f_{pi}}{u(x_i')^2}}} \quad (6)$$

The expanded uncertainty of the Comparison Reference Values (x_{CRV}) was calculated by:

$$U(x_{CRV}) = 2 \times u(x_{CRV}) \quad (7)$$

A chi-square test was applied to carry out a consistency check of the results [2]. The test consists in comparing the values of $F_N(x_i')$ calculated by Equation (8) with the value of the chi-square distribution calculated for $\upsilon = N - 1$ degrees of freedom at probability 0.05.

$$F_N(x_i') = \sum_1^N f_{pi} \times \frac{(x_i' - x_{CRV})^2}{u(x_i')^2} \quad (8)$$

x_{CRV} and N measurement results x_i' were regarded as consistent if;

$$F_N\,(x_i') \leq \chi^2_{(N-1;\,0.05)}$$

N : The number of participants

$F_N\,(x_i')$: The sum of squares function constitutes the sum of N contributions

$\chi^2_{(N-1;\,0.05)}$: Chi-squared distribution for $\upsilon = N - 1$ degrees of freedom at probability 0.05

Where the chi-square test failed for the full set (N contributions), the Comparison Reference Value (x_{CRV}) was calculated as the weighted mean of a largest consistent subset (r contributions), contains as many as possible of those results of participants that are consistent with the weighted mean of the that subset by using Equation (9). The result of the participant with the largest E_n was excluded from the Comparison Reference Value by setting f_p to 0 and then the chi-square test was again applied. This process of excluding the result with the largest E_n from contributing to the weighted mean was iterated until statistical consistency was reached.

$$F_r\,(x_i') = \sum_{1}^{r} f_{pi} \times \frac{(x_i' - x_{CRV})^2}{u(x_i')^2} \qquad (9)$$

x_{CRV} and r measurement results x_i' were regarded as consistent if;

$$F_r\,(x_i') \leq \chi^2_{(r-1;\,0.05)}$$

r : The number of participants for the largest consistent subset

$F_r\,(x_i')$: The observed Chi-squared value, the sum of squares function constitutes the sum of r contributions, χ^2_{obs}

$\chi^2_{(r-1;\,0.05)}$: Chi-squared distribution for $\upsilon = r - 1$ degrees of freedom at probability 0.05

The results presented in Table 11 show the chi-squared distributions ($F_N\,(x_i')$ & $F_r\,(x_i')$), the observed Chi-square values ($\chi^2_{(N-1;\,0.05)}$ & $\chi^2_{(r-1;\,0.05)}$), the result of the consistency test, the outlier(s) which were excluded from the Comparison Reference Value and the Comparison Reference Values (x_{CRV}) and the corresponding uncertainties ($U(x_{CRV})$).

Table 11. Results of chi-square test and the Comparison Reference Values

Range	Test Point	N	$F_N\,(x_i')$	$\chi^2_{(N-1;\,0.05)}$	Consistency/ Outlier(s)	r	$F_r\,(x_i')$	$\chi^2_{(r-1;\,0.05)}$	Consistency	x_{CRV} (10^{-6})	$U(x_{CRV})$ (10^{-6})
DC Voltage											
200 mV	100 mV	13	29.8	21	No Outlier :IMBIH	12	16.0	20	**Yes**	-0.54	1.02
20 V	10 V	13	26.4	21	No Outlier: MBM	12	5.8	20	**Yes**	4.03	0.27
200 V	100 V	13	7.7	21	**Yes**	N/A	N/A	N/A	N/A	-1.92	0.64
100 V	100 V	13	18.2	21	**Yes**	N/A	N/A	N/A	N/A	-0.99	0.75
DC Current											
200 µA	100 µA	13	15.1	21	**Yes**	N/A	N/A	N/A	N/A	-11.4	1.1
20 mA	10 mA	13	19.6	21	**Yes**	N/A	N/A	N/A	N/A	21.5	1.1
2 A	1 A	12	65.1	20	No Outlier: SASO	11	17.2	18	**Yes**	-115.3	3.3
Resistance											
20 Ω	10 Ω	13	197.3	21	No Outliers: KMA & EMI	11	8.8	18	**Yes**	13.45	0.50
20 kΩ	10 kΩ	13	16.4	21	**Yes**	N/A	N/A	N/A	N/A	9.04	0.44
20 kΩ	10 kΩ LoI	13	10.2	21	**Yes**	N/A	N/A	N/A	N/A	9.71	0.47
2 MΩ	1 MΩ	12	50.4	20	No Outlier: IPQ	11	3.4	18	**Yes**	9.22	1.04
AC Voltage											
200 mV	100 mV 55 Hz	14	14.4	22	**Yes**	N/A	N/A	N/A	N/A	-27.4	12.5
200 mV	100 mV 1 kHz	14	9.7	22	**Yes**	N/A	N/A	N/A	N/A	11.7	12.5
20 V	10 V 55 Hz	14	3.7	22	**Yes**	N/A	N/A	N/A	N/A	52.4	6.2
20 V	10 V 1 kHz	14	5.1	22	**Yes**	N/A	N/A	N/A	N/A	95.8	5.4
20 V	10 V 100 kHz	14	16.1	22	**Yes**	N/A	N/A	N/A	N/A	79.8	11.8
200 V	100 V 55 Hz	14	3.0	22	**Yes**	N/A	N/A	N/A	N/A	-10.6	8.2
200 V	100 V 1 kHz	14	3.9	22	**Yes**	N/A	N/A	N/A	N/A	28.1	8.2
AC Current											
20 mA	10 mA 300 Hz	13	2.9	21	**Yes**	N/A	N/A	N/A	N/A	54	10
20 mA	10 mA 1 kHz	13	1.7	21	**Yes**	N/A	N/A	N/A	N/A	70	10
2 A	1 A 300 Hz	13	1.2	21	**Yes**	N/A	N/A	N/A	N/A	-97	16
2 A	1 A 1 kHz	13	4.7	21	**Yes**	N/A	N/A	N/A	N/A	-25	17

11. Degree of Equivalences (D_i) and Normalised Errors (E_n)

The results of the comparison are reported as the degrees of equivalence and the normalised error between a participant's result and the Comparison Reference Values (x_{CRV}).

The degree of equivalence of each participant (D_i), was calculated as:

$$D_i = x'_i - x_{CRV}$$

where x'_i is the corrected result of the participants corrected for the drift of the travelling standard with time, and x_{CRV} is the Comparison Reference Value.

The expanded uncertainty of the degree of equivalence for a participant's result ($U(D_i)$), was calculated as:

$$U(D_i) = \sqrt{U(x'_i)^2 + U(x_{CRV})^2} \quad (5)$$

$$U(D_i) = \sqrt{U(x'_i)^2 - U(x_{CRV})^2} \quad (6)$$

where $U(x'_i)$ is the expanded uncertainty of the corrected results of each participant and $U(x_{CRV})$ is the expanded uncertainty of the Comparison Reference Value. Equation (5) was used where the participant result does not contribute to the Comparison Reference Value. Due to the correlation with the Comparison Reference Value, Equation (6) was used where the participant result contributes to the Comparison Reference Value.

For each participant's result, the normalised errors (E_n) were calculated as.

$$E_n = \frac{x'_i - x_{CRV}}{\sqrt{U(x'_i)^2 - U(x_{CRV})^2}} = \frac{D_i}{U(D_i)} \quad (7)$$

$$E_n = \frac{x'_i - x_{CRV}}{\sqrt{U(x'_i)^2 + U(x_{CRV})^2}} = \frac{D_i}{U(D_i)} \quad (8)$$

Equation (7) was used for the results which contribute to the Comparison Reference Value. Equation (8) was used for the participant results which are excluded from the Comparison Reference Value.

The participant results were regarded as satisfactory if $|E_n| \leq 1$.

The degree of equivalences and the normalised errors for each comparison points are presented in Appendix 1 and Appendix 2 in tables and in graphs respectively.

12. Summary and Conclusions

The EURAMET Project 1341 which is the comparison project attracted a lot of interest within the EURAMET and GULFMET community with 16 participants.

The transfer standard was an 8½ digit multimeter, Fluke 8508A Reference Multimeter, and it was circulated without a major problem from March 2015 to September 2016. Due to the large number of participants, unexpected problems with customs and delays in receipt of participants reports, the comparison took longer than anticipated.

The comparison reference value has been determined based on the weighted mean of the largest statistically consistent data set.

As seen from Table 12, most of the results show a good agreement with the comparison reference values. Out of 291 measurement results, 16 measurement results of participants (%5.5) have $|E_n| > 1$. The related statistics are given in Table 12.

Table 12. Statistics on Normalised Error Values

Measurand	Test Point	Number of Results	Number of Results for $|E_n| > 1$	Measurand	Test Point	Number of Results	Number of Results for $|E_n| > 1$
DC Voltage	100 mV	13	2	AC Voltage	100 mV 55 Hz	14	2
	10 V	13	1		100 mV 1 kHz	14	1
	100 V	13	0		10 V 55 Hz	14	0
	100 V	13	1		10 V 1 kHz	14	0
DC Current	100 µA	13	1		10 V 100 kHz	14	1
	10 mA	13	1		100 V 55 Hz	14	0
	1 A	12	2		100 V 1 kHz	14	0
Resistance	10 Ω	13	2	AC Current	10 mA 300 Hz	13	0
	10 kΩ	13	1		10 mA 1 kHz	13	0
	10 kΩ LoI	13	0		1 A 300 Hz	13	0
	1 MΩ	12	1		1 A 1 kHz	13	0

13. References

[1] JCGM 100, "Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM)", 2008.

[2] Cox M. G., "The evaluation of key comparison data", 2002 Metrologia **39**, 589-595.

Appendix I: Degrees of Equivalence and Normalised Errors

Table 13. The degree of equivalences (D_i), its expanded uncertainties ($U(D_i)$) and the normalised errors (E_n) for DC voltage

NMI	100 mV			10 V			100 V			1000 V		
	D_i (µV/V)	$U(D_i)$ (µV/V)	E_n	D_i (µV/V)	$U(D_i)$ (µV/V)	E_n	D_i (µV/V)	$U(D_i)$ (µV/V)	E_n	D_i (µV/V)	$U(D_i)$ (µV/V)	E_n
MBM	-6.0	5.8	**-1.03**	2.6	1.2	**2.20**	1.0	5.3	0.19	3.1	5.9	0.52
IMBIH	-10.6	5.7	**-1.86**	1.2	2.4	0.50	0.8	4.1	0.19	-1.8	4.5	-0.40
INM	-	-	-	-	-	-	-	-	-	-	-	-
FTMC	0.3	5.0	0.05	0.3	1.0	0.34	1.0	1.4	0.73	0.6	1.3	0.50
IPQ	-0.7	1.0	-0.73	-0.09	0.30	-0.28	0.7	1.7	0.43	3.5	2.3	**1.51**
BOM	-15	21	-0.74	-5	13	-0.37	-5	14	-0.33	-3	15	-0.22
METROSERT	4.8	5.8	0.83	0.1	1.0	0.07	-0.2	2.0	-0.12	-1.4	2.0	-0.68
GUM	2.2	4.4	0.51	-0.3	1.4	-0.23	-0.4	2.0	-0.18	-0.9	2.4	-0.37
DPM	-3	11	-0.27	-0.2	4.1	-0.05	1.2	6.5	0.19	1.8	7.1	0.26
KMA	-1.5	6.0	-0.25	-3.2	3.9	-0.81	-3.3	5.9	-0.55	-5.6	6.0	-0.93
NSAI NML	1.6	3.9	0.41	0.0	1.1	0.03	-0.6	1.7	-0.35	-1.3	2.9	-0.46
EMI	0.8	7.3	0.11	0.0	1.2	0.04	-2.9	4.0	-0.73	0	13	-0.02
SASO	-0.5	9.7	-0.05	0.8	2.3	0.35	0.4	4.5	0.09	1.0	5.8	0.17
UME	2.6	2.8	0.94	0.2	0.8	0.24	-0.3	1.0	-0.26	-0.5	1.3	-0.38

Table 14. The degree of equivalences (D_i), its expanded uncertainties ($U(D_i)$) and the normalised errors (E_n) for DC current

NMI	100 µA			10 mA			1 A		
	D_i (µA/A)	$U(D_i)$ (µA/A)	E_n	D_i (µA/A)	$U(D_i)$ (µA/A)	E_n	D_i (µA/A)	$U(D_i)$ (µA/A)	E_n
MBM	-4	18	-0.22	8.7	5.1	**1.72**	-126	90	**-1.40**
IMBIH	-8.8	5.7	**-1.54**	-2.3	3.5	-0.64	-15	172	-0.09
INM	-	-	-	-	-	-	-	-	-
FTMC	4	34	0.12	2	28	0.07	32	120	0.26
IPQ	0.7	1.6	0.43	-0.3	1.1	-0.30	2.2	2.9	0.74
BOM	11	146	0.07	-22	72	-0.31	-24	204	-0.12
METROSERT	0.2	9.7	0.02	5.2	9.5	0.55	-5	12	-0.38
GUM	1.4	4.3	0.33	0.5	4.1	0.12	-4	24	-0.16
DPM	7	99	0.07	1	35	0.02	3	170	0.02
KMA	7	13	0.51	-8	12	-0.69	-	-	-
NSAI NML	0	15	-0.01	3	10	0.32	-22	25	-0.87
EMI	-15	54	-0.28	-13	37	-0.35	-40	61	-0.66
SASO	-15	18	-0.81	-10	16	-0.64	-74	22	**-3.41**
UME	3	10	0.29	1	10	0.14	-9	12	-0.72

Table 15. The degree of equivalences (D_i), its expanded uncertainties ($U(D_i)$) and the normalised errors (E_n) for Resistance

NMI	10 Ω			10 kΩ			10 kΩ LoI			1 MΩ		
	D_i (μΩ/Ω)	$U(D_i)$ (μΩ/Ω)	E_n	D_i (μΩ/Ω)	$U(D_i)$ (μΩ/Ω)	E_n	D_i (μΩ/Ω)	$U(D_i)$ (μΩ/Ω)	E_n	D_i (μΩ/Ω)	$U(D_i)$ (μΩ/Ω)	E_n
MBM	6	10	0.58	9.4	8.0	**1.17**	0.6	9.0	0.07	-4	86	-0.05
IMBIH	-0.2	1.3	-0.13	-0.9	1.3	-0.64	-0.5	1.3	-0.40	-2.7	5.1	-0.52
INM	-	-	-	-	-	-	-	-	-	-	-	-
FTMC	0.2	1.2	0.18	-0.4	1.2	-0.31	0.0	1.4	-0.01	-0.7	1.4	-0.48
IPQ	-0.18	0.80	-0.22	0.01	0.86	0.01	-0.53	0.84	-0.63	6.3	2.0	**3.23**
BOM	-11	45	-0.24	-12	23	-0.53	-11	23	-0.47	-13	42	-0.32
METROSERT	0.5	1.1	0.47	-0.3	1.2	-0.24	0.2	1.1	0.22	1.2	9.3	0.13
GUM	-2.1	2.1	-0.96	1.9	2.0	0.93	1.8	2.0	0.90	0.6	1.2	0.49
DPM	14	26	0.53	-1	10	-0.06	3	11	0.32	4	17	0.24
KMA	-23	11	**-2.09**	-7.0	8.9	-0.78	-0.7	9.7	-0.07	-	-	-
NSAI NML	1.8	3.6	0.49	0.8	2.6	0.30	1.4	2.9	0.49	1	11	0.06
EMI	6.42	1.07	**6.02**	0.5	1.2	0.39	1.0	2.3	0.46	0.7	4.3	0.16
SASO	0.6	2.5	0.24	0.4	2.6	0.15	1.2	2.6	0.47	2.0	6.9	0.29
UME	1.1	1.4	0.78	0.0	3.1	-0.02	0.1	3.1	0.05	0.0	5.9	0.00

Table 16. The degree of equivalences (D_i), its expanded uncertainties ($U(D_i)$) and the normalised errors (E_n) for AC Voltage

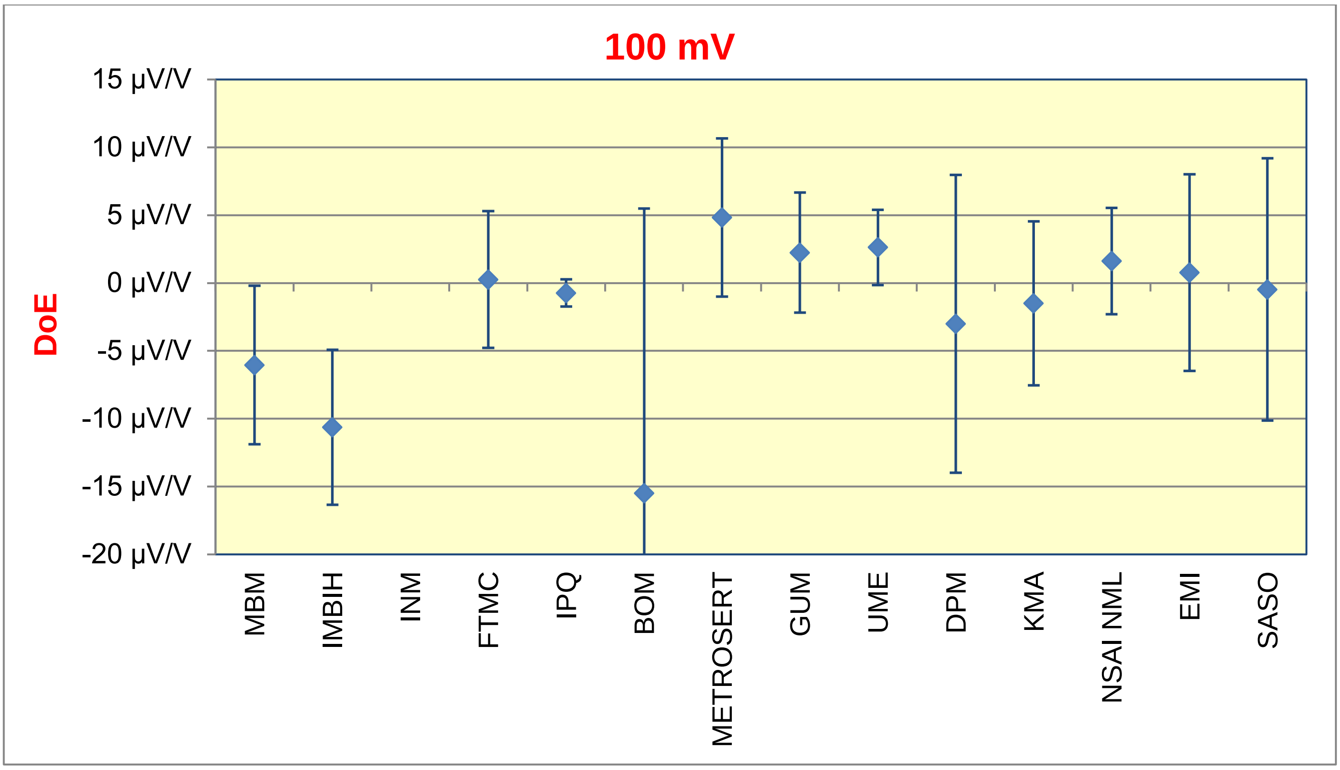
NMI	100 mV, 55 Hz			100 mV, 1 kHz			10 V, 55 Hz			10 V, 1 kHz		
	D_i (mV/V)	$U(D_i)$ (mV/V)	E_n	D_i (mV/V)	$U(D_i)$ (mV/V)	E_n	D_i (mV/V)	$U(D_i)$ (mV/V)	E_n	D_i (mV/V)	$U(D_i)$ (mV/V)	E_n
MBM	0.03	0.16	0.19	0.04	0.14	0.29	-0.03	0.11	-0.29	-0.09	0.12	-0.72
IMBIH	0.07	0.19	0.39	0.03	0.18	0.18	-0.02	0.11	-0.18	-0.006	0.091	-0.07
INM	-0.03	0.13	-0.23	-0.03	0.13	-0.20	-0.004	0.042	-0.11	-0.004	0.042	-0.10
FTMC	-0.03	0.14	-0.19	-0.02	0.13	-0.15	0.010	0.044	0.22	0.010	0.043	0.24
IPQ	0.017	0.014	1.22	0.009	0.014	0.67	0.004	0.010	0.35	0.0034	0.0071	0.48
BOM	0.02	0.23	0.09	0.10	0.22	0.43	-0.06	0.14	-0.40	-0.06	0.14	-0.47
METROSERT	-0.022	0.058	-0.39	-0.016	0.058	-0.27	0.000	0.058	-0.01	0.002	0.058	0.04
GUM	-0.028	0.018	-1.58	-0.020	0.018	-1.11	-0.0014	0.0092	-0.15	-0.003	0.010	-0.29
DPM	-0.01	0.18	-0.08	-0.07	0.18	-0.41	0.023	0.095	0.24	-0.03	0.10	-0.34
KMA	0.05	0.15	0.33	0.02	0.13	0.12	0.06	0.11	0.53	0.010	0.095	0.10
NSAI NML	0.00	0.13	0.03	0.02	0.12	0.15	0.011	0.050	0.21	0.011	0.042	0.25
EMI	-0.03	0.25	-0.12	-0.04	0.25	-0.17	0.000	0.060	-0.01	-0.003	0.057	-0.06
SASO	-0.03	0.13	-0.19	-0.02	0.15	-0.17	-0.013	0.049	-0.27	-0.011	0.048	-0.23
UME	0.027	0.038	0.71	0.032	0.038	0.83	-0.0019	0.0092	-0.20	-0.0012	0.0086	-0.14

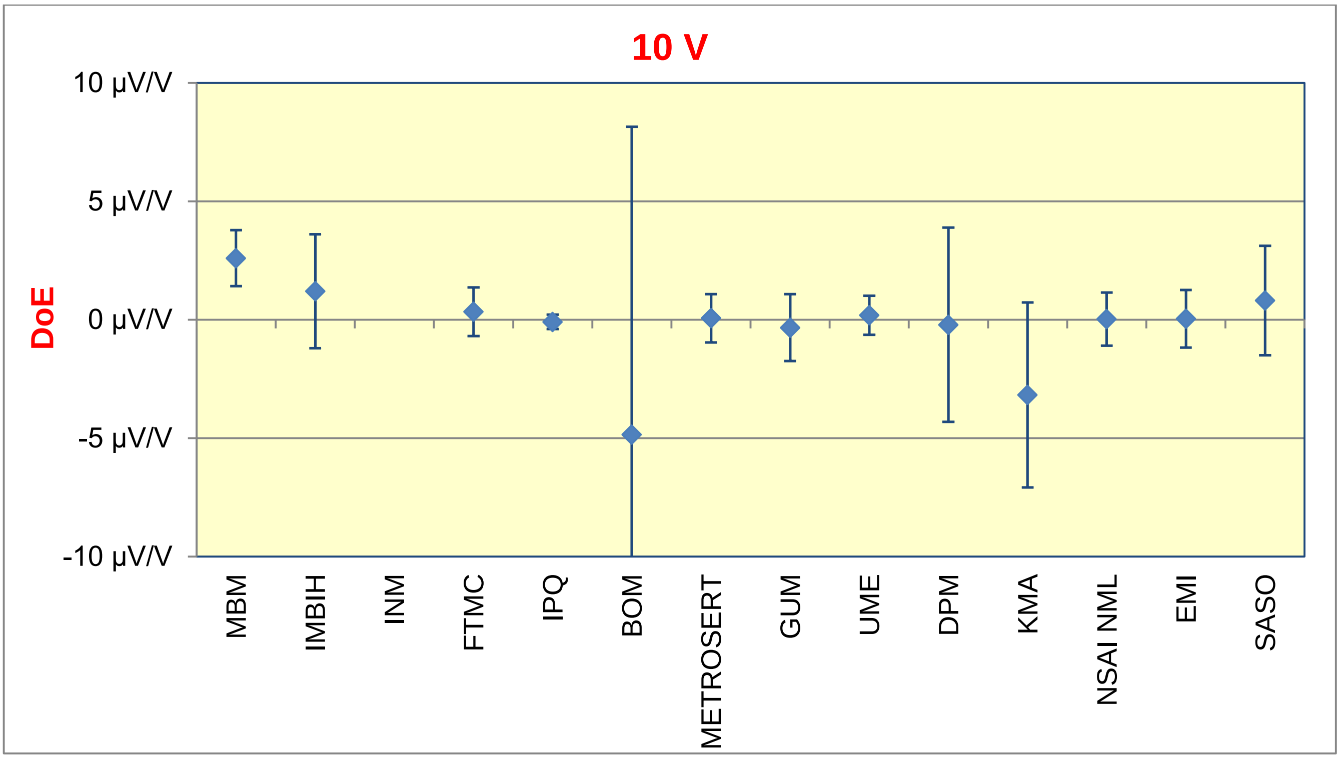
NMI	10 V, 100 kHz			100 V, 55 Hz			100 V, 1 kHz		
	D_i (mV/V)	$U(D_i)$ (mV/V)	E_n	D_i (mV/V)	$U(D_i)$ (mV/V)	E_n	D_i (mV/V)	$U(D_i)$ (mV/V)	E_n
MBM	-0.10	0.72	-0.14	-0.03	0.11	-0.26	-0.038	0.090	-0.42
IMBIH	-0.07	0.71	-0.10	-0.02	0.11	-0.19	-0.003	0.098	-0.03
INM	-0.03	0.11	-0.27	0.000	0.050	0.00	-0.001	0.050	-0.02
FTMC	0.01	0.33	0.02	0.001	0.056	0.02	0.005	0.051	0.10
IPQ	-0.004	0.017	-0.23	-0.010	0.022	-0.47	-0.010	0.017	-0.58
BOM	-0.12	0.96	-0.12	-0.04	0.28	-0.15	-0.04	0.27	-0.15
METROSERT	0.03	0.12	0.29	-0.004	0.058	-0.07	-0.002	0.058	-0.04
GUM	0.037	0.024	1.56	0.003	0.009	0.28	0.003	0.009	0.31
DPM	0.09	0.57	0.15	0.025	0.099	0.26	-0.026	0.084	-0.31
KMA	-0.08	0.77	-0.10	0.06	0.11	0.50	0.014	0.095	0.14
NSAI NML	0.00	0.17	-0.01	0.008	0.079	0.10	0.021	0.070	0.31
EMI	-0.02	0.16	-0.14	0.001	0.076	0.01	0.001	0.071	0.02
SASO	-0.10	0.11	-0.99	0.014	0.062	0.23	0.024	0.049	0.49
UME	-0.015	0.019	-0.82	-0.001	0.013	-0.09	0.000	0.016	0.01

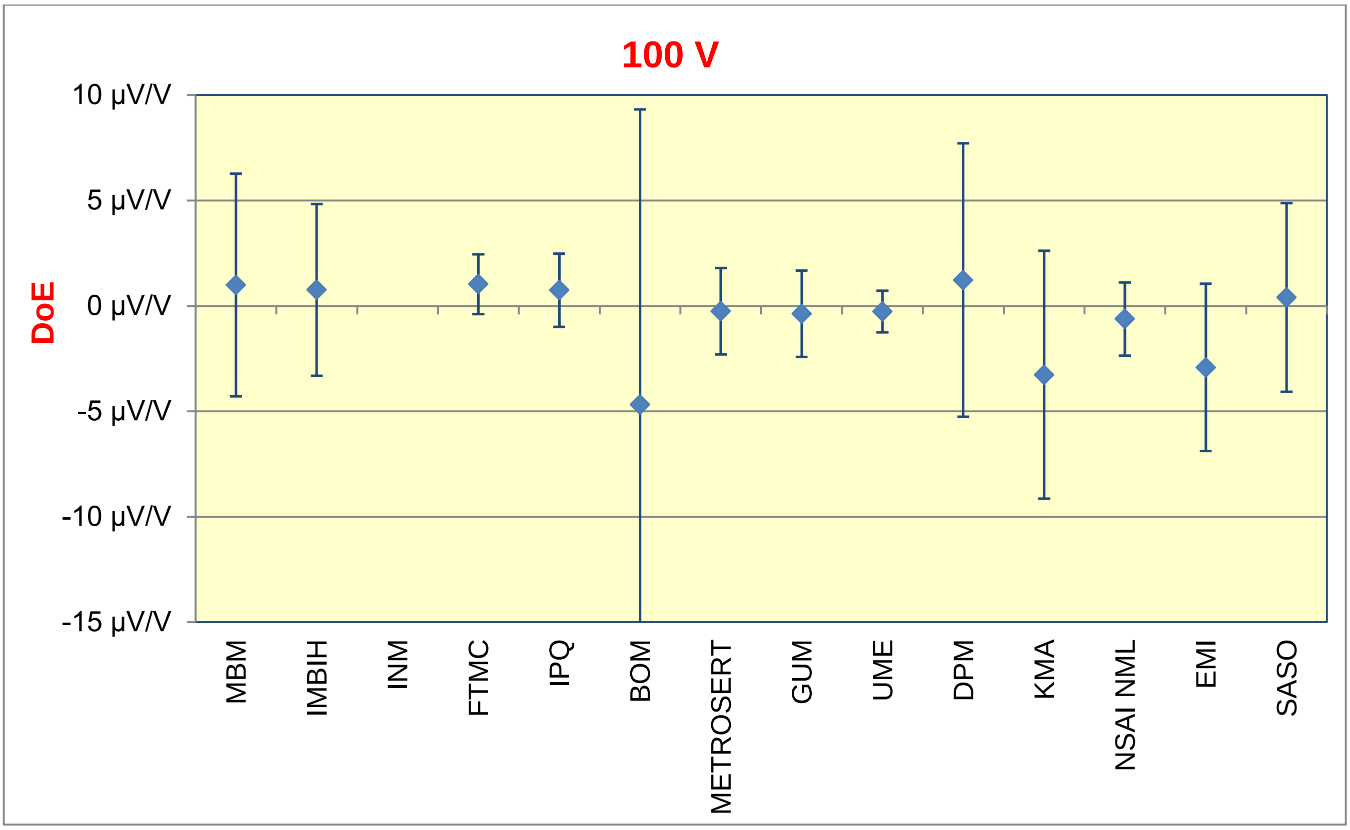
Table 17. The degree of equivalences (D_i), its expanded uncertainties ($U(D_i)$) and the normalised errors (E_n) for AC Current

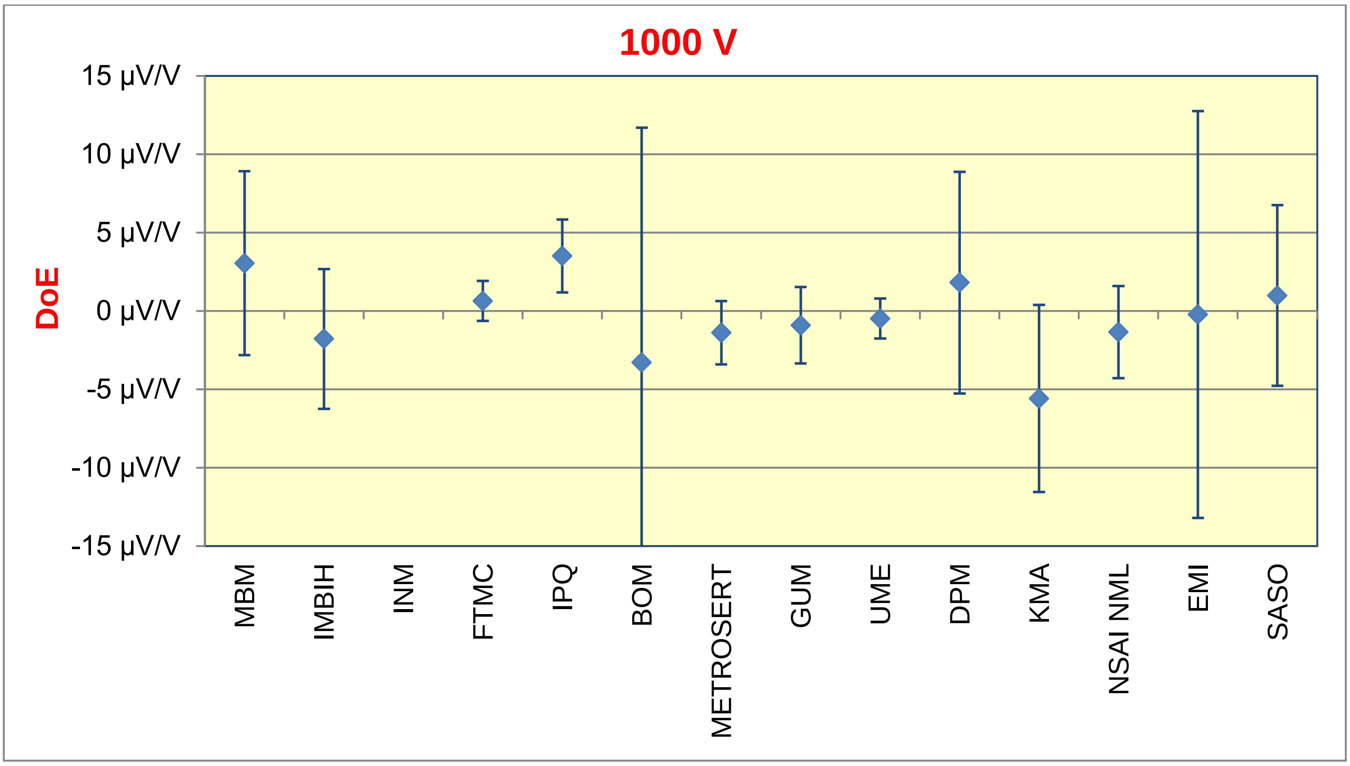
NMI	10 mA, 300 Hz			10 mA, 1 kHz			1 A, 300 Hz			1 A, 1 kHz		
	D_i (mA/A)	$U(D_i)$ (mA/A)	E_n	D_i (mA/A)	$U(D_i)$ (mA/A)	E_n	D_i (mA/A)	$U(D_i)$ (mA/A)	E_n	D_i (mA/A)	$U(D_i)$ (mA/A)	E_n
MBM	0.08	0.49	0.17	0.02	0.49	0.03	0.00	0.82	0.00	-0.2	1.1	-0.15
IMBIH	-0.008	0.086	-0.09	0.020	0.085	0.23	0.01	0.84	0.01	0.00	0.84	0.00
INM	0.00	0.13	-0.02	0.00	0.13	-0.02	0.04	0.29	0.15	0.05	0.27	0.18
FTMC	-0.07	0.57	-0.11	-0.06	0.55	-0.10	-0.1	1.2	-0.06	-0.1	1.2	-0.09
IPQ	0.002	0.051	0.04	-0.001	0.051	-0.02	0.02	0.12	0.19	0.04	0.12	0.36
BOM	-0.19	0.65	-0.29	-0.18	0.65	-0.28	-0.1	1.5	-0.07	-0.2	1.5	-0.15
METROSERT	0.003	0.014	0.21	0.002	0.014	0.12	0.006	0.019	0.33	0.016	0.020	0.80
GUM	-0.013	0.019	-0.68	-0.009	0.019	-0.49	-0.013	0.029	-0.45	-0.022	0.030	-0.72
DPM	-0.03	0.35	-0.08	-0.05	0.35	-0.13	0.06	0.68	0.08	0.02	0.68	0.04
KMA	-	-	-	-	-	-	-	-	-	-	-	-
NSAI NML	0.02	0.13	0.13	0.01	0.15	0.07	-0.01	0.26	-0.03	0.00	0.32	-0.01
EMI	0.00	0.19	-0.02	-0.01	0.19	-0.05	-0.02	0.47	-0.05	-0.03	0.47	-0.05
SASO	0.015	0.042	0.35	0.001	0.042	0.03	0.001	0.093	0.01	-0.029	0.095	-0.30
UME	0.004	0.018	0.21	0.004	0.018	0.25	-0.001	0.032	-0.03	-0.007	0.032	-0.23

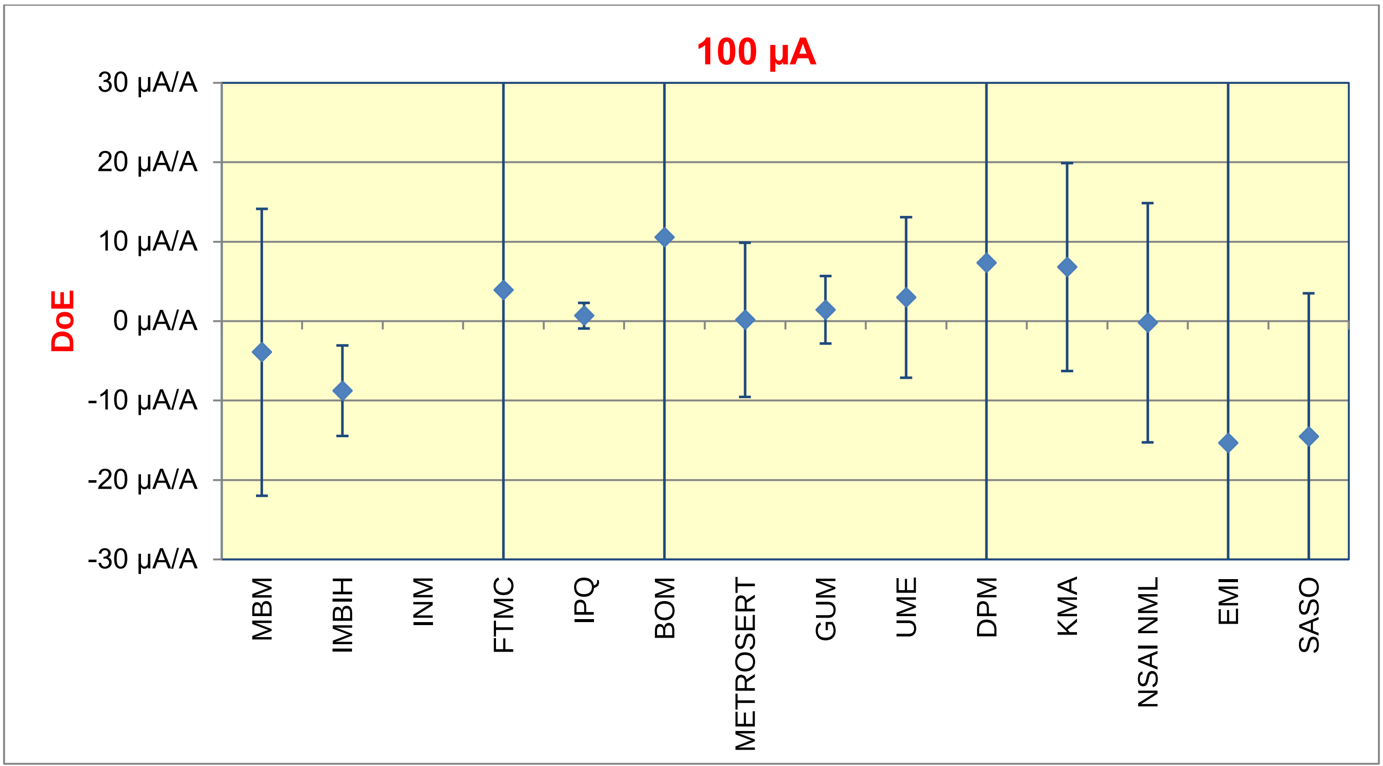
Appendix II: Graphs of Degrees of Equivalence (DoE)






100 V
10 µV/V
5 µV/V
0 µV/V
-5 µV/V
-10 µV/V
-15 µV/V
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


1000 V
15 µV/V
10 µV/V
5 µV/V
0 µV/V
-5 µV/V
-10 µV/V
-15 µV/V
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO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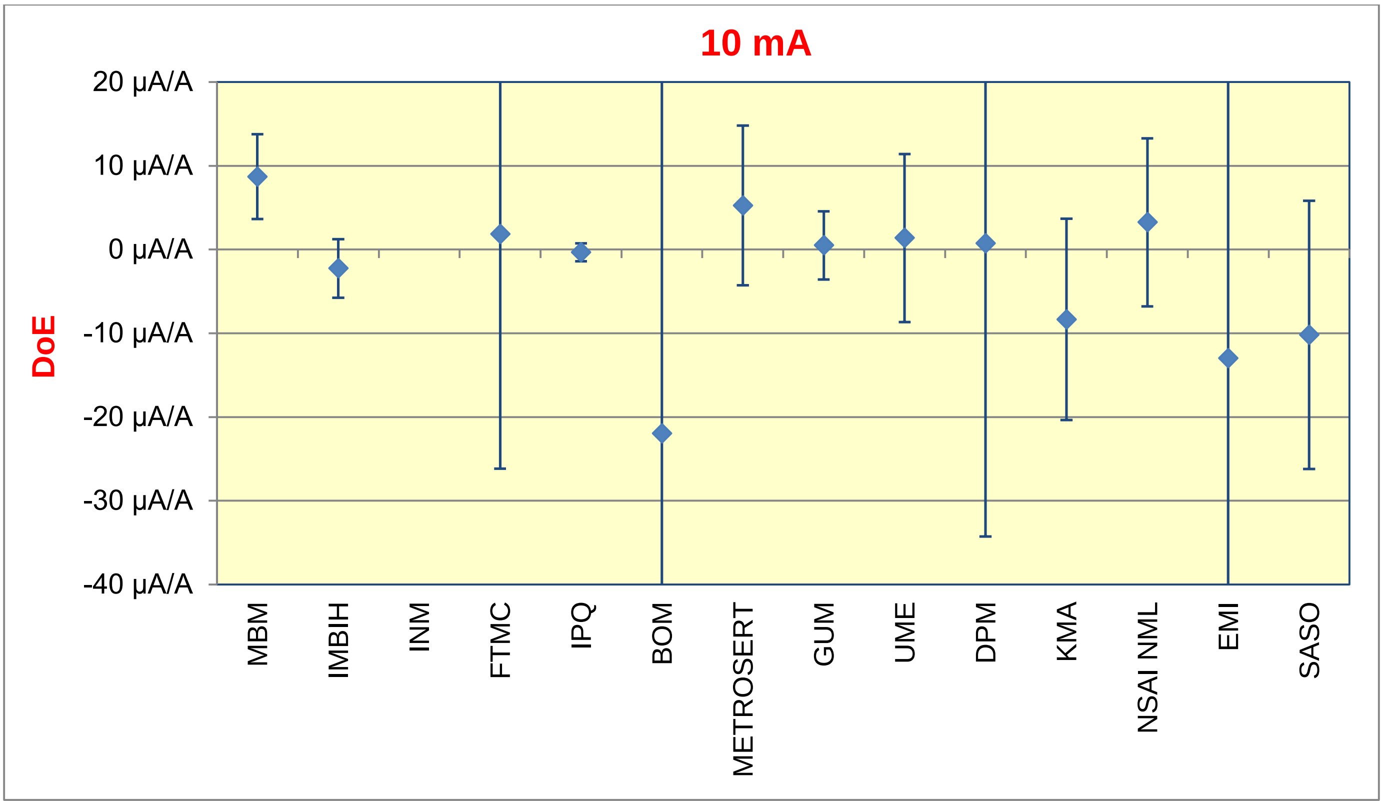
30 µA/A
20 µA/A
10 µA/A
0 µA/A
-10 µA/A
-20 µA/A
-30 µA/A
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO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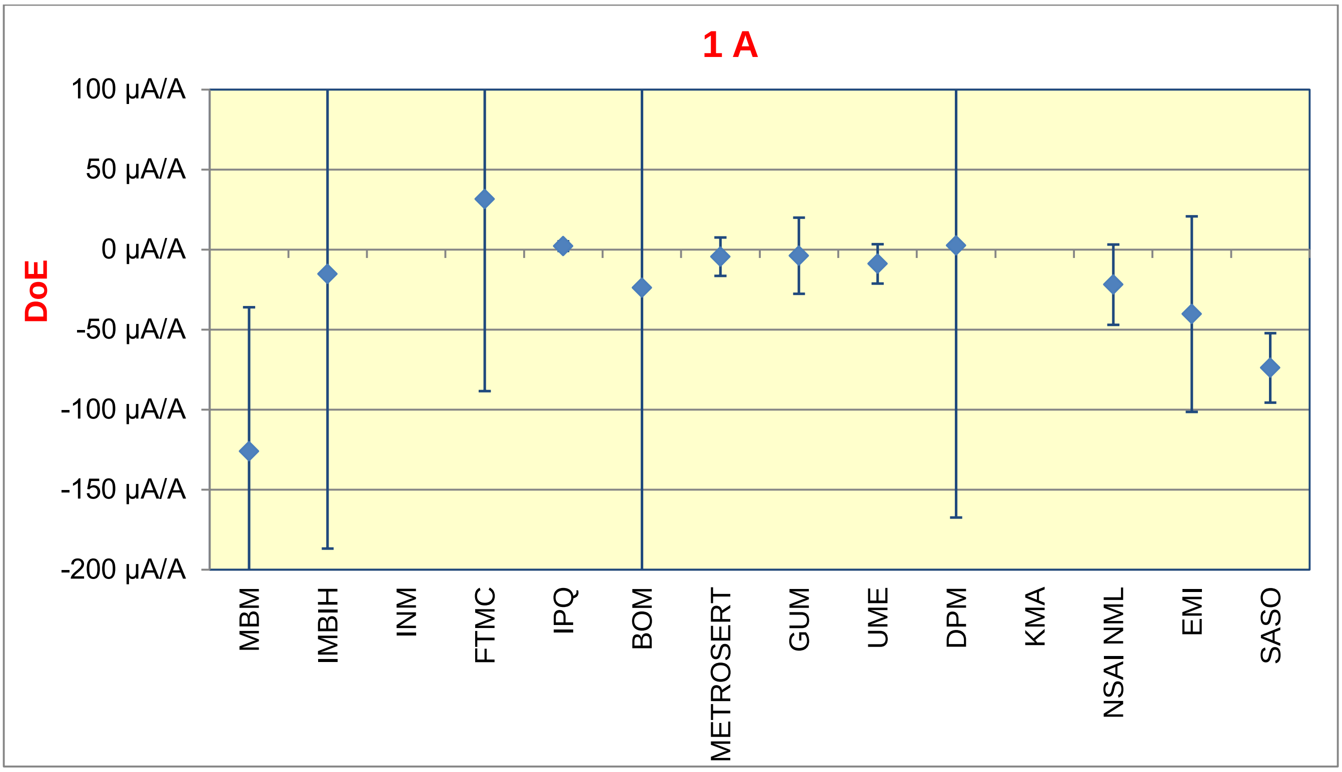
20 µA/A
10 µA/A
0 µA/A
-10 µA/A
-20 µA/A
-30 µA/A
-40 µA/A
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO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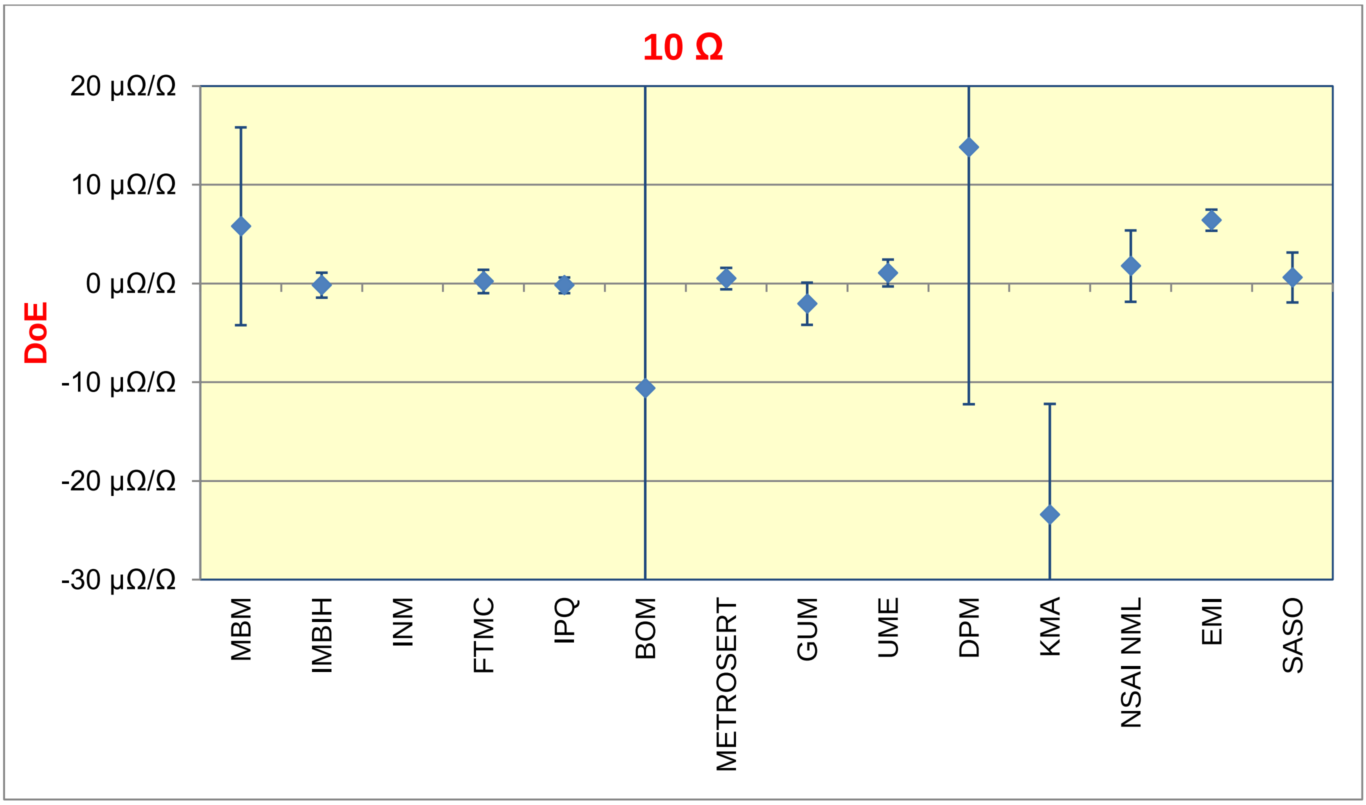
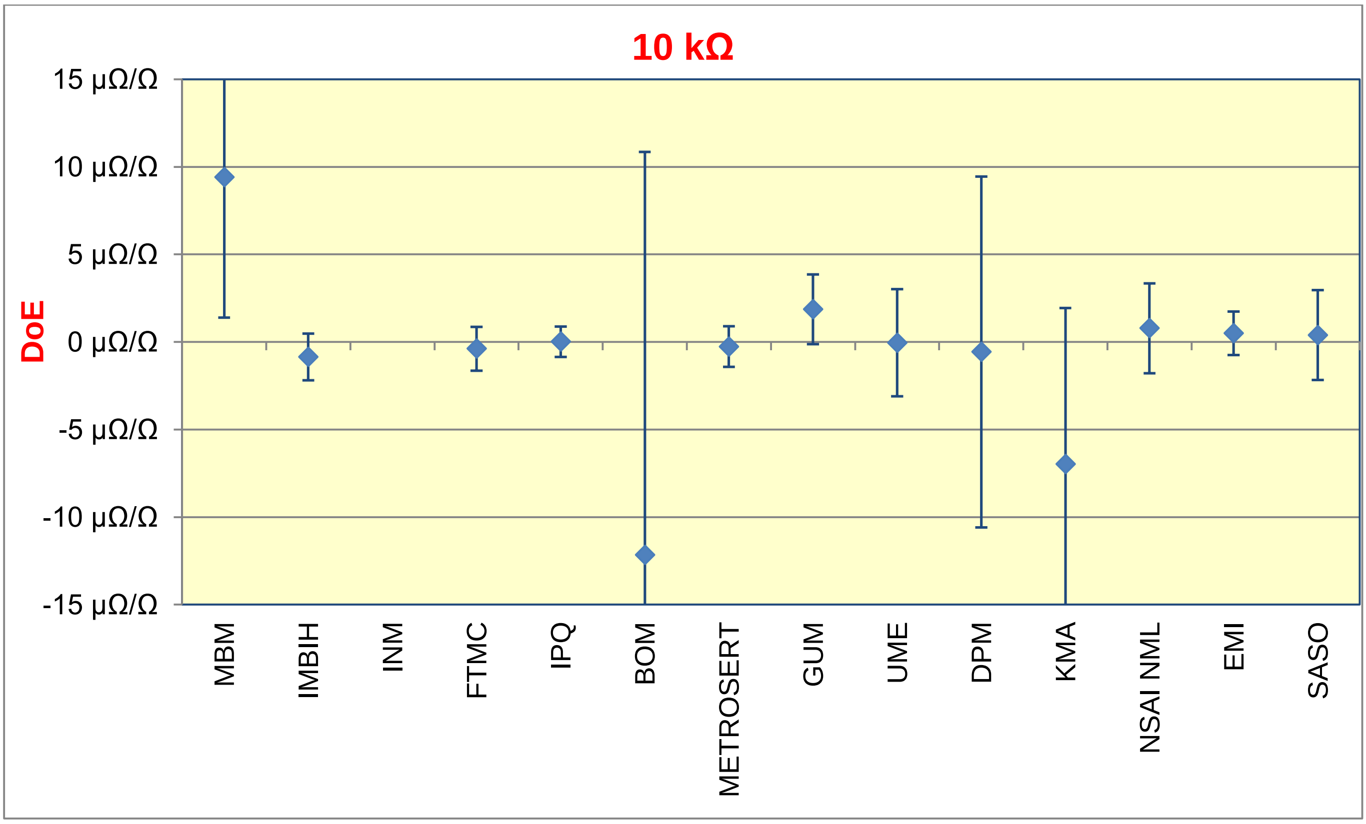
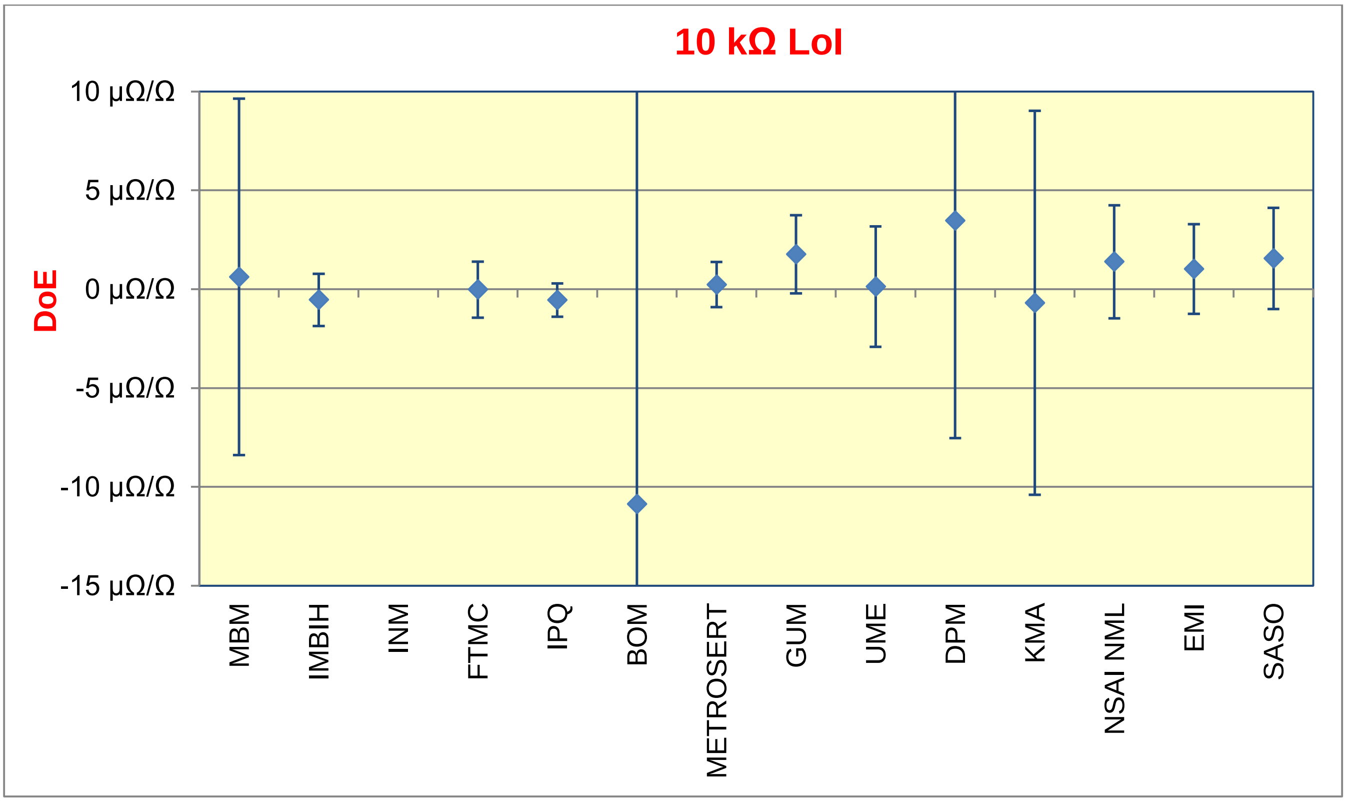
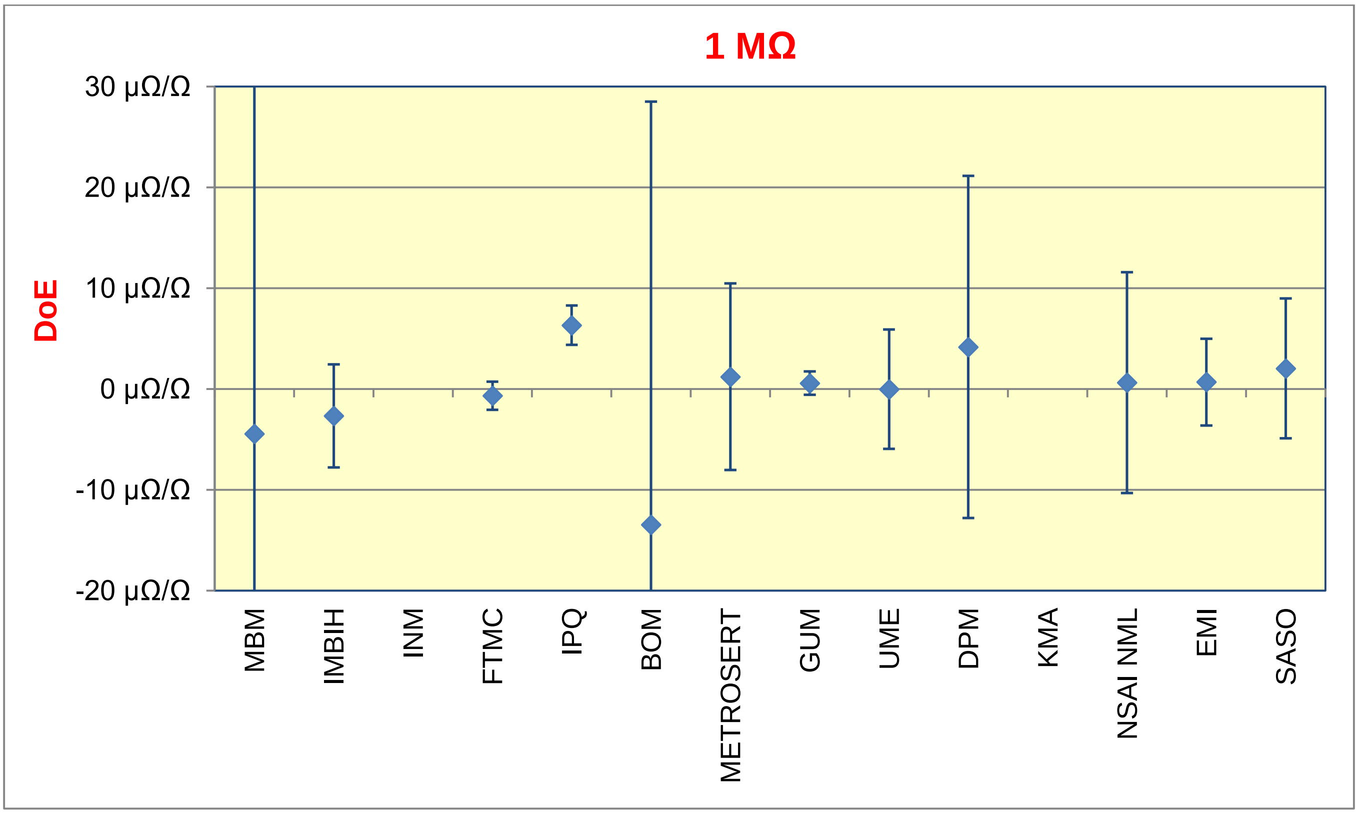
100 µA/A
50 µA/A
0 µA/A
-50 µA/A
-100 µA/A
-150 µA/A
-200 µA/A
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


10 Ω
20 µΩ/Ω
10 µΩ/Ω
0 µΩ/Ω
-10 µΩ/Ω
-20 µΩ/Ω
-30 µΩ/Ω
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


10 kΩ
15 µΩ/Ω
10 µΩ/Ω
5 µΩ/Ω
0 µΩ/Ω
-5 µΩ/Ω
-10 µΩ/Ω
-15 µΩ/Ω
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


10 kΩ LoI
10 µΩ/Ω
5 µΩ/Ω
0 µΩ/Ω
-5 µΩ/Ω
-10 µΩ/Ω
-15 µΩ/Ω
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO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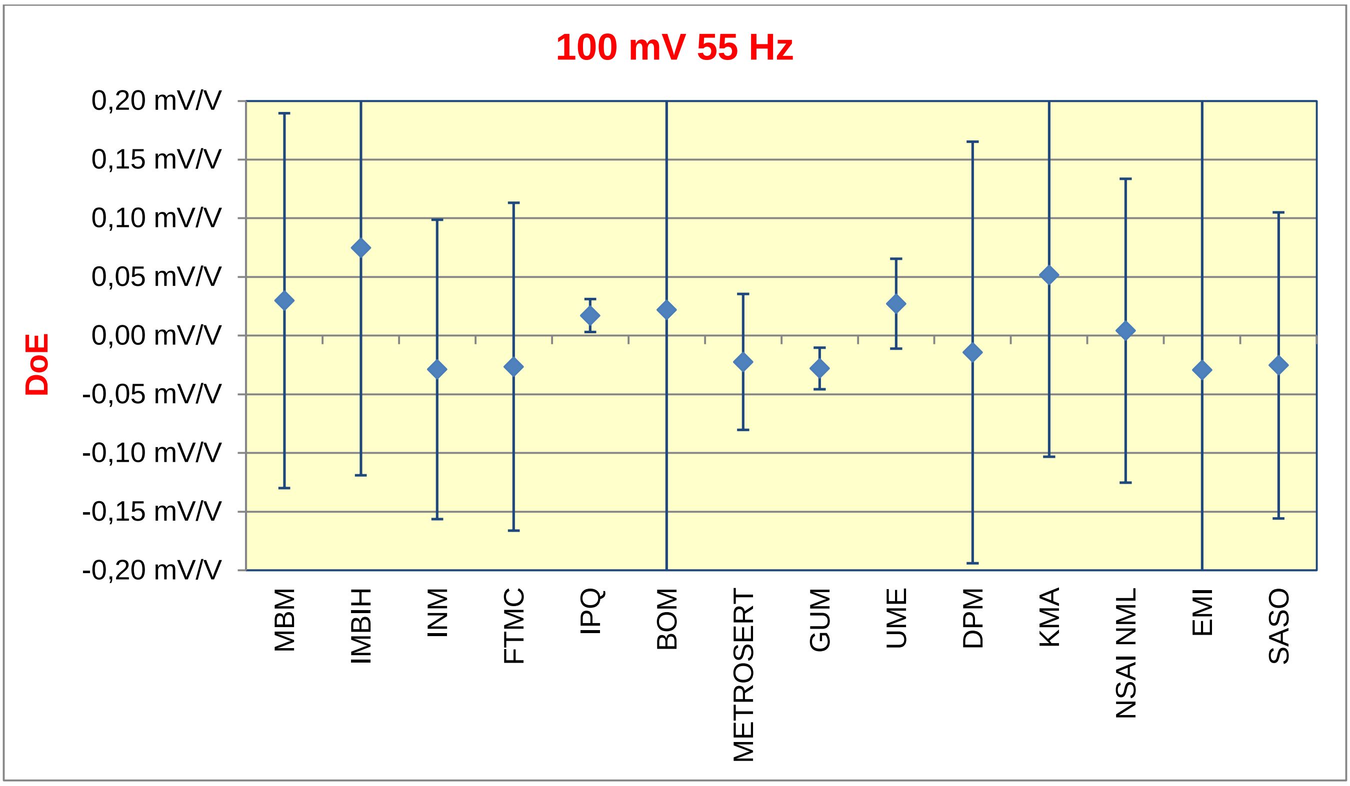
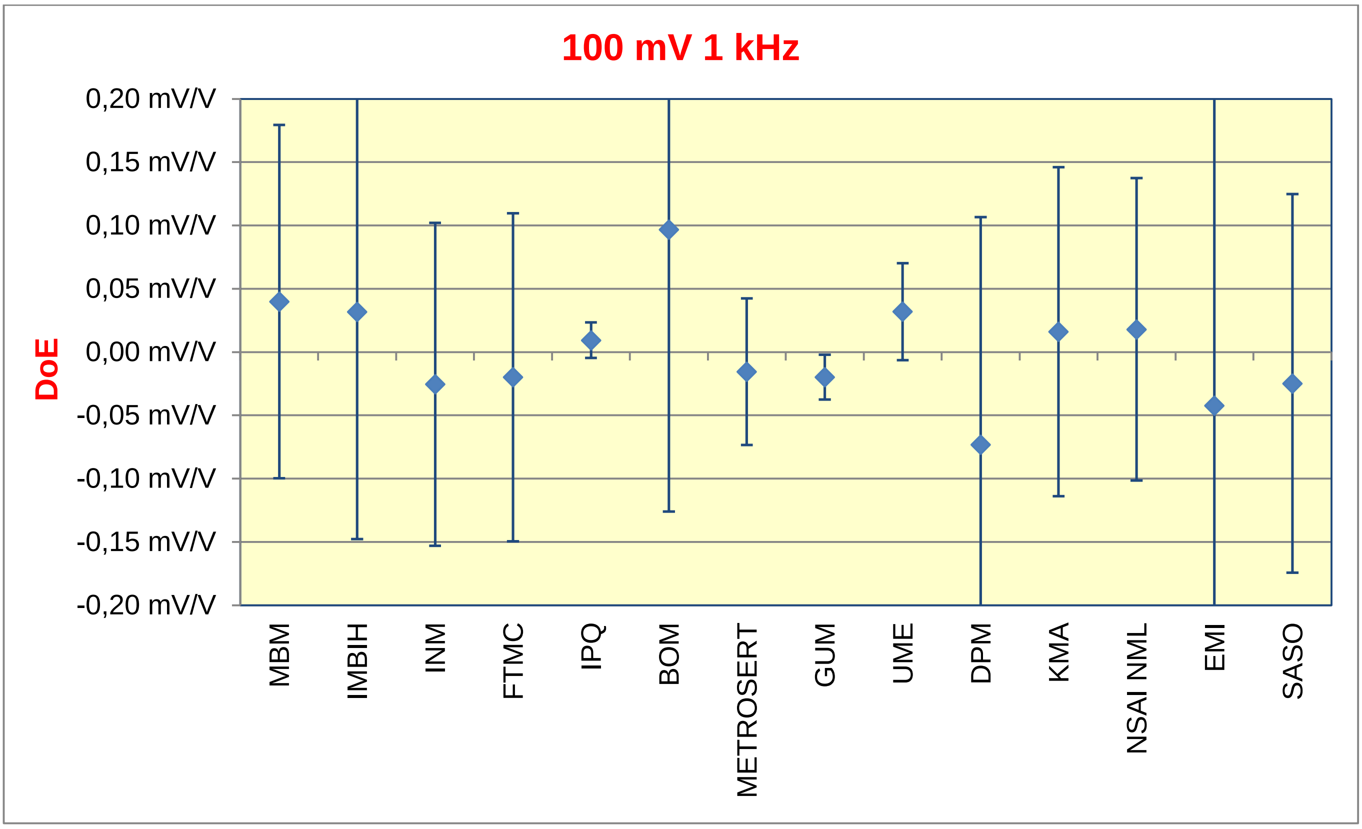
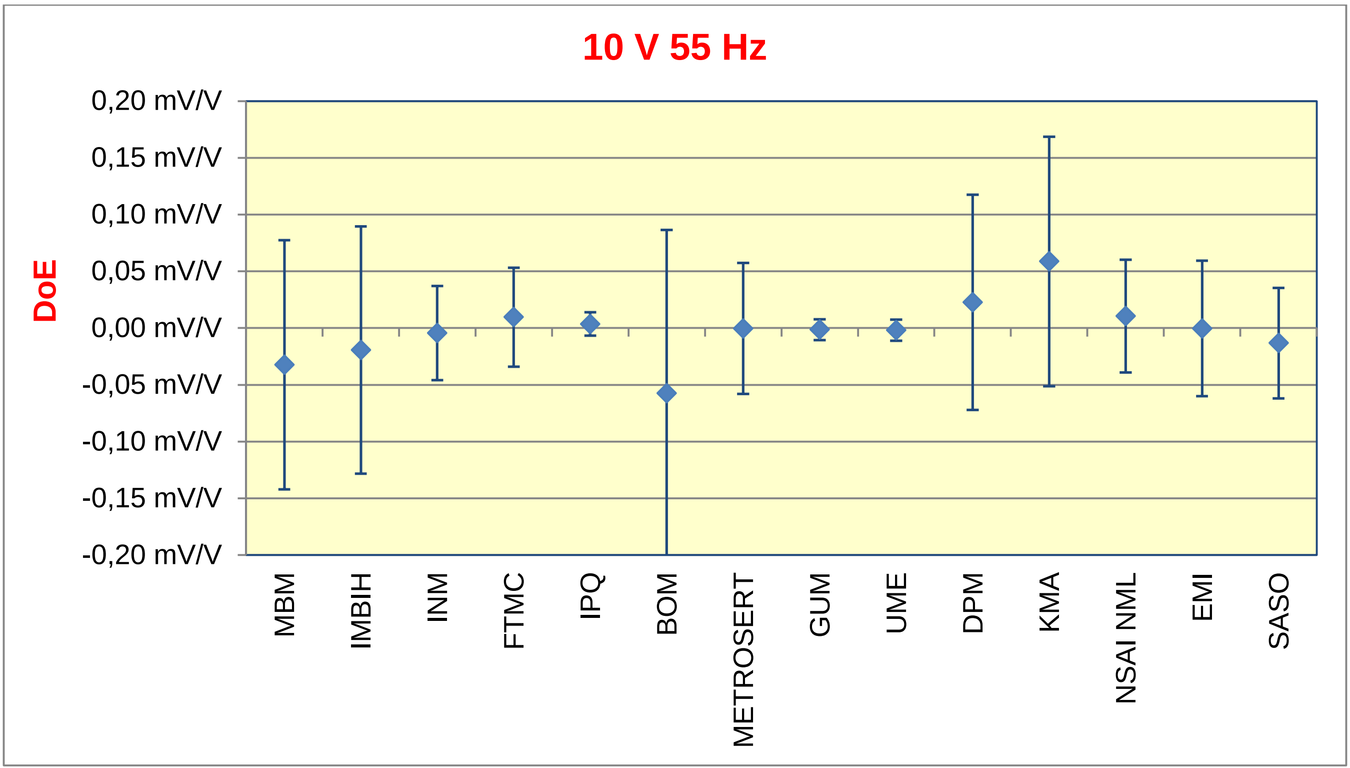
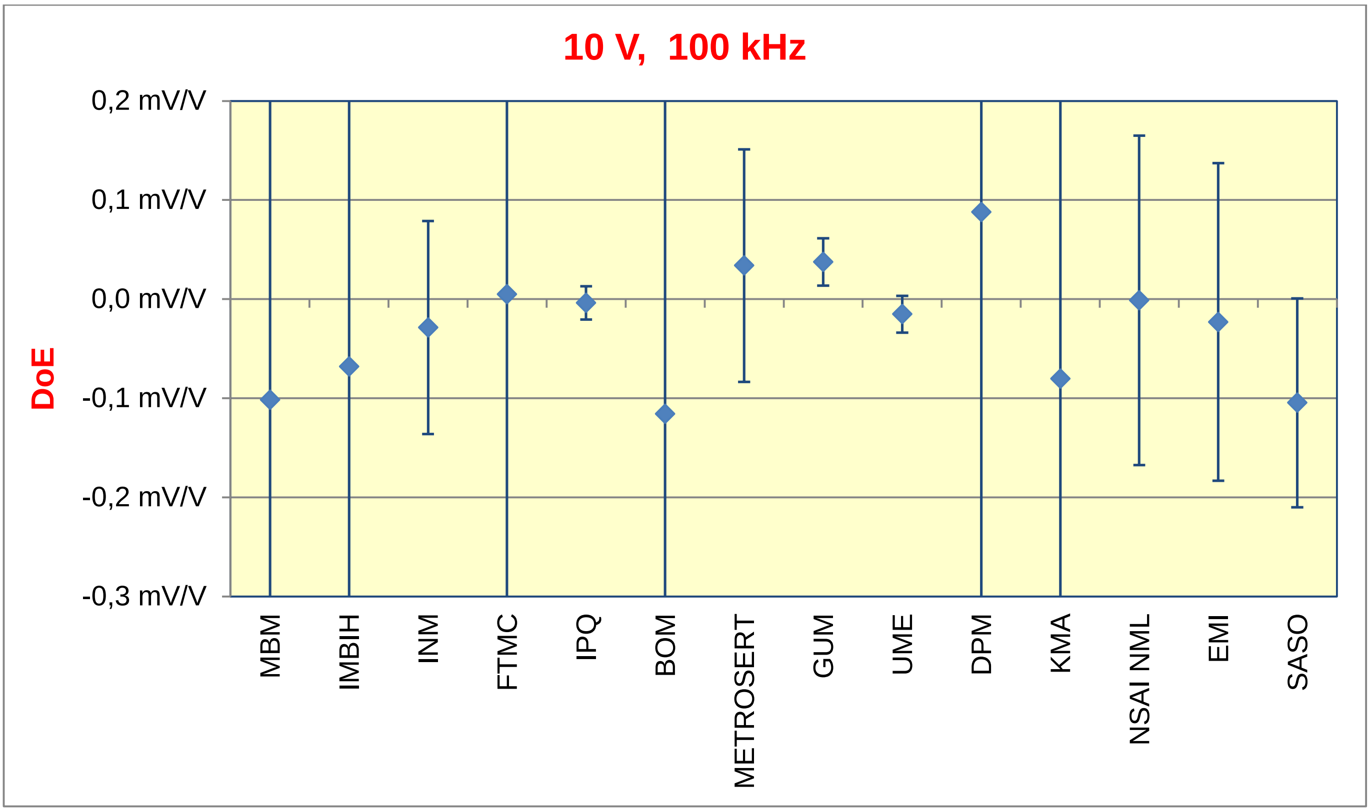
30 µΩ/Ω
20 µΩ/Ω
10 µΩ/Ω
0 µΩ/Ω
-10 µΩ/Ω
-20 µΩ/Ω
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO

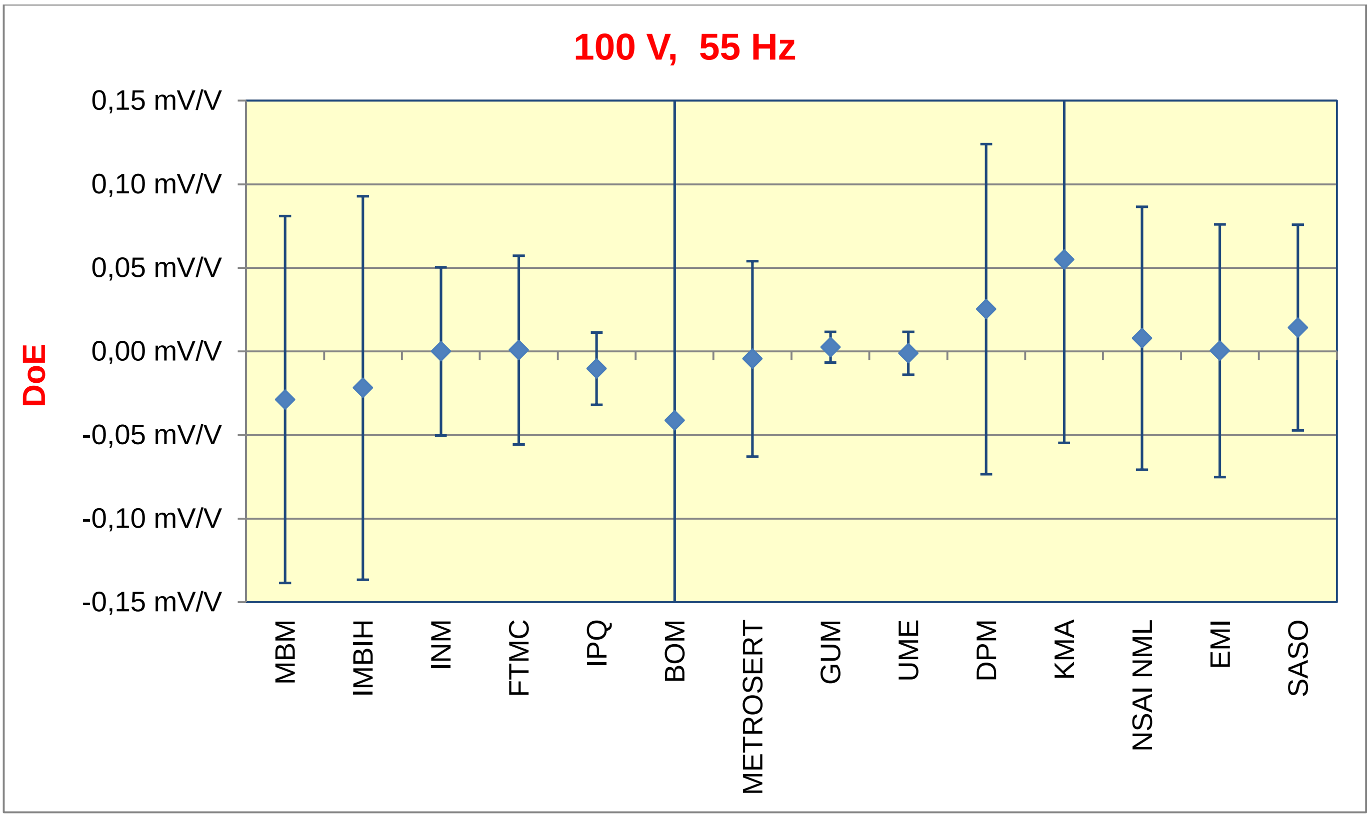

100 mV 55 Hz
DoE
0,20 mV/V
0,15 mV/V
0,10 mV/V
0,05 mV/V
0,00 mV/V
-0,05 mV/V
-0,10 mV/V
-0,15 mV/V
-0,20 mV/V
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO

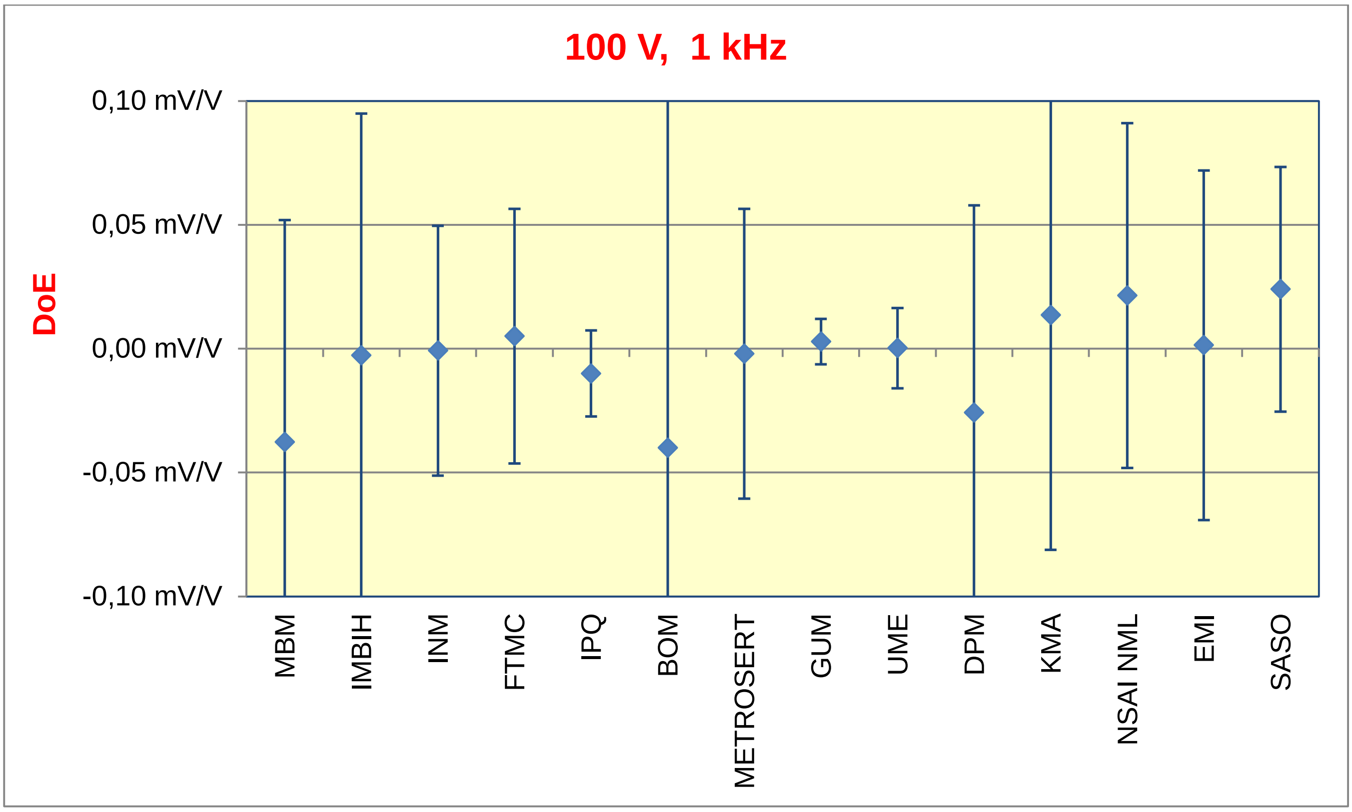

100 mV 1 kHz
DoE
0,20 mV/V
0,15 mV/V
0,10 mV/V
0,05 mV/V
0,00 mV/V
-0,05 mV/V
-0,10 mV/V
-0,15 mV/V
-0,20 mV/V
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


10 V 55 Hz
DoE
0,20 mV/V
0,15 mV/V
0,10 mV/V
0,05 mV/V
0,00 mV/V
-0,05 mV/V
-0,10 mV/V
-0,15 mV/V
-0,20 mV/V
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


10 V, 1 kHz
DoE
0,15 mV/V
0,10 mV/V
0,05 mV/V
0,00 mV/V
-0,05 mV/V
-0,10 mV/V
-0,15 mV/V
-0,20 mV/V
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


10 V, 100 kHz
DoE
0,2 mV/V
0,1 mV/V
0,0 mV/V
-0,1 mV/V
-0,2 mV/V
-0,3 mV/V
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


100 V, 55 Hz
DoE
0,15 mV/V
0,10 mV/V
0,05 mV/V
0,00 mV/V
-0,05 mV/V
-0,10 mV/V
-0,15 mV/V
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO


100 V, 1 kHz
DoE
0,10 mV/V
0,05 mV/V
0,00 mV/V
-0,05 mV/V
-0,10 mV/V
MBM
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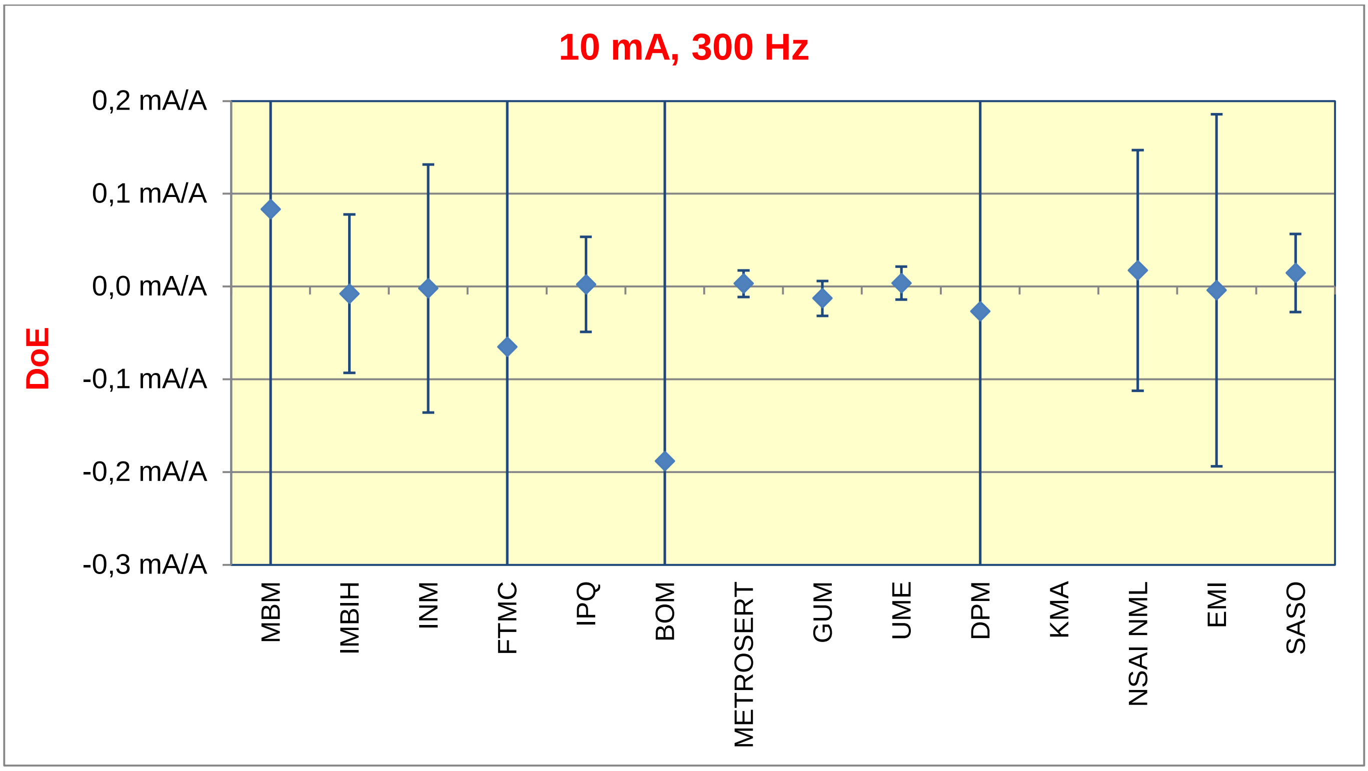
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO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0,2 mA/A
0,1 mA/A
0,0 mA/A
-0,1 mA/A
-0,2 mA/A
-0,3 mA/A
DoE
MBM
IMBIH
INM
FTMC
IPQ
BOM
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GUM
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DPM
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NSAI NML
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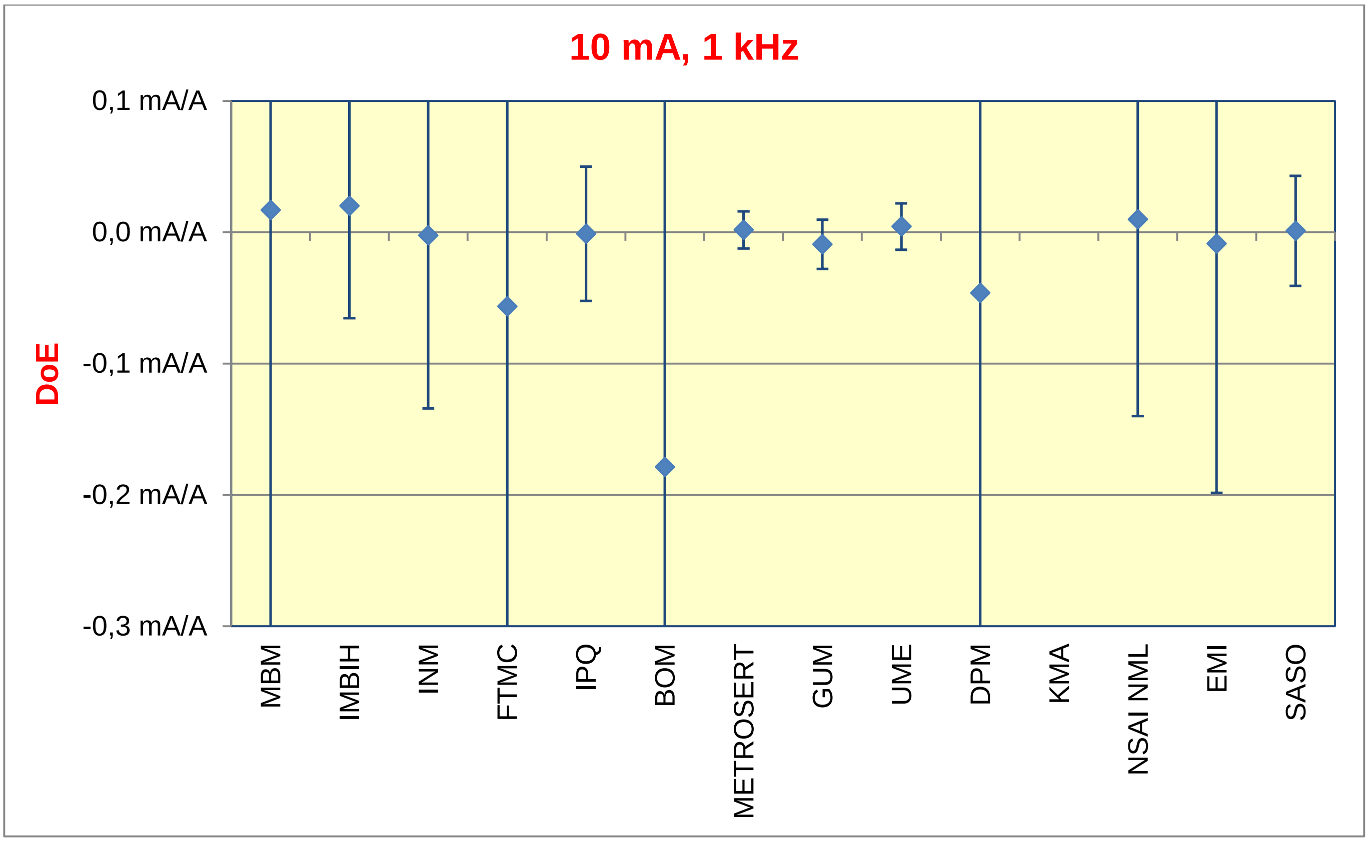
SASO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0,1 mA/A
0,0 mA/A
-0,1 mA/A
-0,2 mA/A
-0,3 mA/A
DoE
MBM
IMBIH
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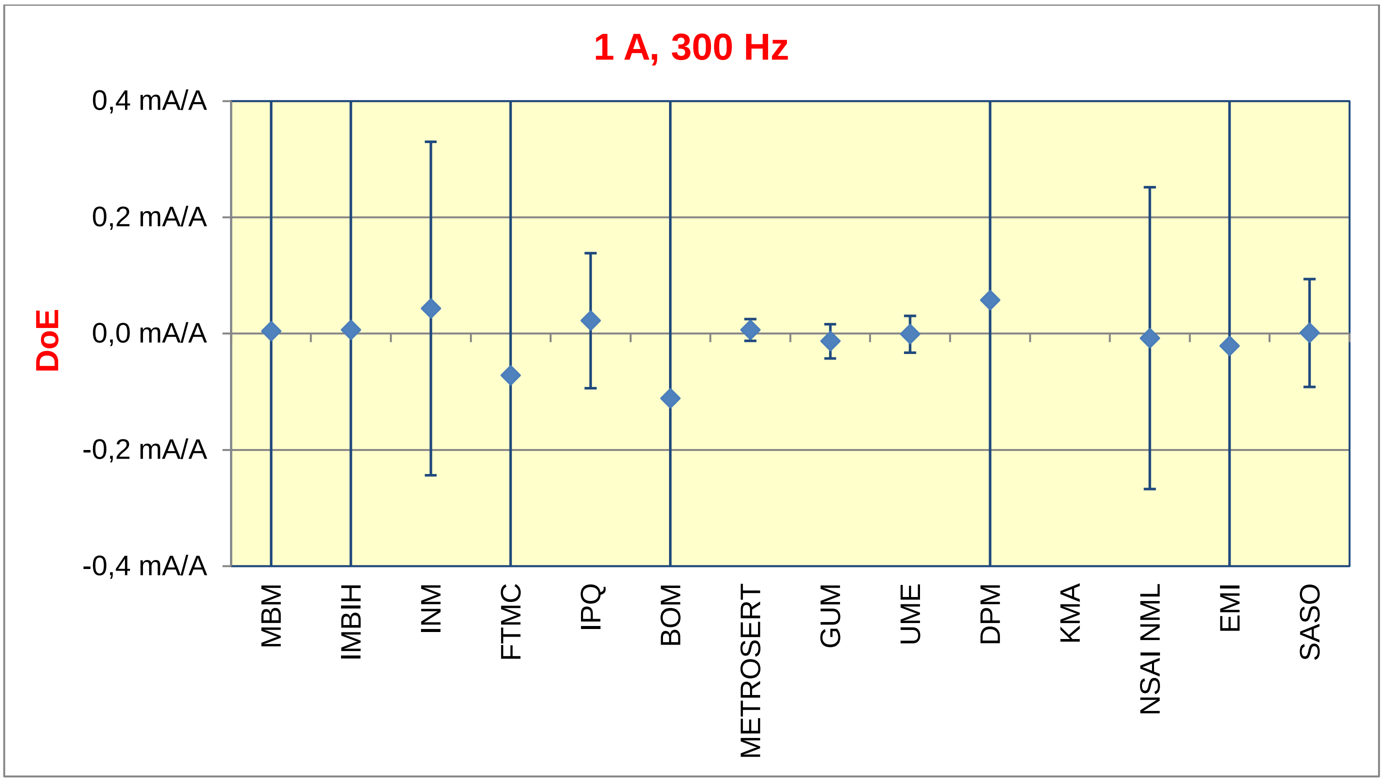
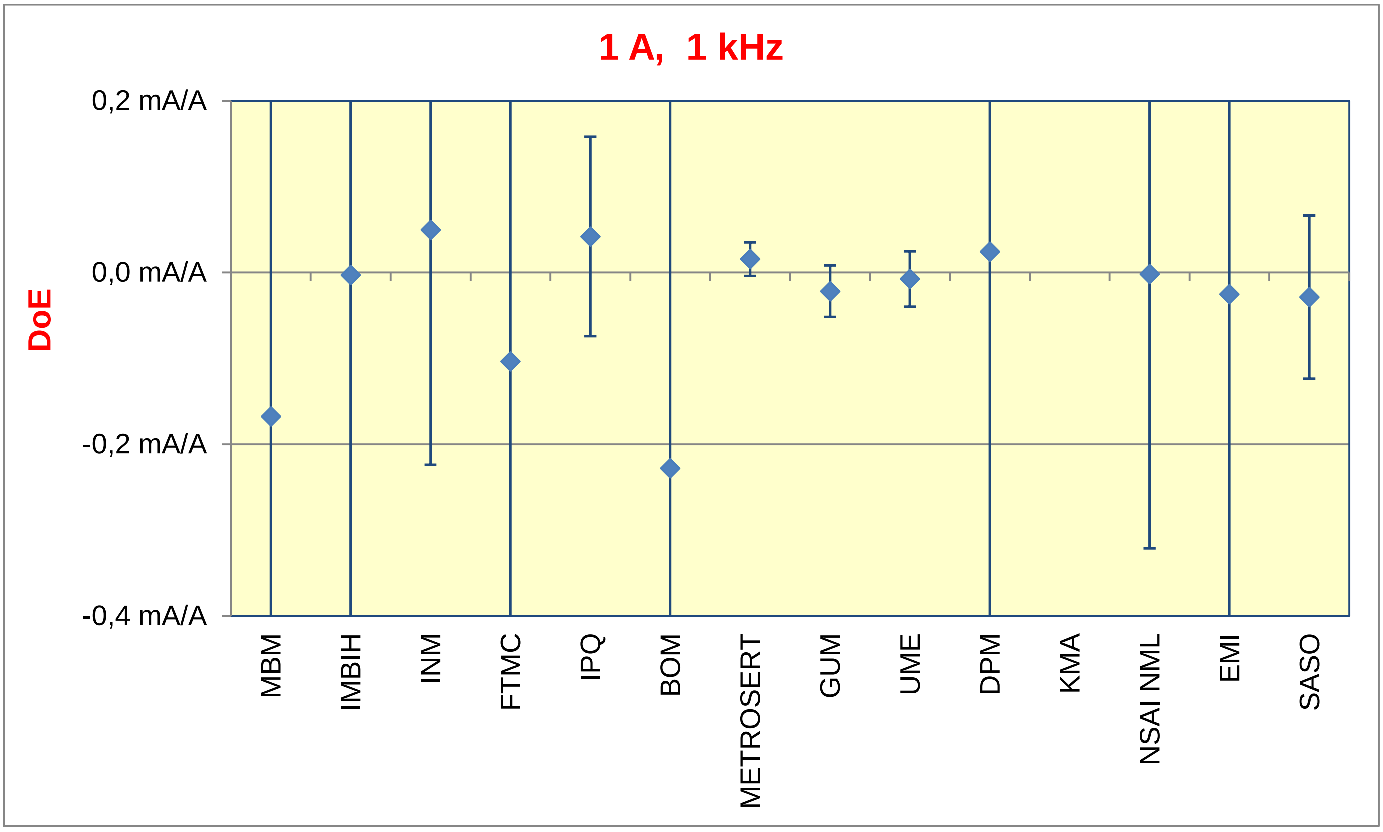
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO



1 A, 300 Hz
DoE
0,4 mA/A
0,2 mA/A
0,0 mA/A
-0,2 mA/A
-0,4 mA/A
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO



1 A, 1 kHz
DoE
0,2 mA/A
0,0 mA/A
-0,2 mA/A
-0,4 mA/A
MBM
IMBIH
INM
FTMC
IPQ
BOM
METROSERT
GUM
UME
DPM
KMA
NSAI NML
EMI
SASO

Appendix III: Measurement Results of UME, Used to Determine Drift of the Travelling Standard

DC VOLTAGE

Range	Measurement Point	Index i	Date x_i	Measured Error E_i	Uncertainty $U(E_i)$
200 mV	100 mV	UME1	12.03.2015	1.3 µV/V	2.9 µV/V
		UME2	20.04.2015	2.1 µV/V	2.9 µV/V
		UME3	24.06.2015	2.5 µV/V	2.9 µV/V
		UME4	20.08.2015	2.3 µV/V	2.9 µV/V
		UME5	19.10.2015	2.0 µV/V	2.9 µV/V
		UME6	25.02.2016	2.1 µV/V	2.9 µV/V
		UME7	29.07.2016	1.6 µV/V	2.9 µV/V
		UME8	07.11.2016	2.8 µV/V	2.9 µV/V
20 V	10 V	UME1	12.03.2015	4.1 µV/V	0.8 µV/V
		UME2	20.04.2015	4.7 µV/V	0.8 µV/V
		UME3	24.06.2015	3.9 µV/V	0.8 µV/V
		UME4	20.08.2015	4.2 µV/V	0.8 µV/V
		UME5	19.10.2015	4.1 µV/V	0.8 µV/V
		UME6	25.02.2016	3.9 µV/V	0.8 µV/V
		UME7	29.07.2016	4.4 µV/V	0.8 µV/V
		UME8	07.11.2016	4.5 µV/V	0.8 µV/V
200 V	100 V	UME1	12.03.2015	-1.8 µV/V	1.1 µV/V
		UME2	20.04.2015	-1.3 µV/V	1.1 µV/V
		UME3	24.06.2015	-1.8 µV/V	1.1 µV/V
		UME4	20.08.2015	-2.2 µV/V	1.1 µV/V
		UME5	19.10.2015	-2.6 µV/V	1.1 µV/V
		UME6	25.02.2016	-2.6 µV/V	1.1 µV/V
		UME7	29.07.2016	-2.4 µV/V	1.1 µV/V
		UME8	07.11.2016	-2.9 µV/V	1.1 µV/V
1000 V	1000 V	UME1	12.03.2015	-1.2 µV/V	1.4 µV/V
		UME2	20.04.2015	-0.5 µV/V	1.4 µV/V
		UME3	24.06.2015	-0.9 µV/V	1.4 µV/V
		UME4	20.08.2015	-1.5 µV/V	1.4 µV/V
		UME5	19.10.2015	-1.8 µV/V	1.4 µV/V
		UME6	25.02.2016	-1.7 µV/V	1.4 µV/V
		UME7	29.07.2016	-1.6 µV/V	1.4 µV/V
		UME8	07.11.2016	-2.5 µV/V	1.4 µV/V

DC CURRENT

Range	Measurement Point	Index i	Date x_i	Measured Error E_i	Uncertainty $U(E_i)$
200 µA	100 µA	UME1	12.03.2015	-6 µA/A	10 µA/A
		UME2	22.04.2015	-8 µA/A	10 µA/A
		UME3	16.06.2015	-10 µA/A	10 µA/A
		UME4	24.08.2015	-9 µA/A	10 µA/A
		UME5	19.10.2015	-7 µA/A	10 µA/A
		UME6	26.02.2016	-9 µA/A	10 µA/A
		UME7	01.08.2016	-8 µA/A	10 µA/A
		UME8	07.11.2016	-10 µA/A	10 µA/A
20 mA	10 mA	UME1	12.03.2015	21 µA/A	10 µA/A
		UME2	22.04.2015	22 µA/A	10 µA/A
		UME3	16.06.2015	21 µA/A	10 µA/A
		UME4	24.08.2015	23 µA/A	10 µA/A
		UME5	19.10.2015	25 µA/A	10 µA/A
		UME6	26.02.2016	23 µA/A	10 µA/A
		UME7	01.08.2016	24 µA/A	10 µA/A
		UME8	07.11.2016	23 µA/A	10 µA/A
2 A	1 A	UME1	12.03.2015	-118 µA/A	12 µA/A
		UME2	22.04.2015	-112 µA/A	12 µA/A
		UME3	16.06.2015	-115 µA/A	12 µA/A
		UME4	24.08.2015	-124 µA/A	12 µA/A
		UME5	19.10.2015	-127 µA/A	12 µA/A
		UME6	26.02.2016	-125 µA/A	12 µA/A
		UME7	01.08.2016	-134 µA/A	12 µA/A
		UME8	07.11.2016	-137 µA/A	12 µA/A

AC VOLTAGE

Range	Measurement Point	Index i	Date x_i	Measured Error E_i	Uncertainty $U(E_i)$
200 mV	100 mV @ 55 Hz	UME1	09.03.2015	-2 µV/V	40 µV/V
		UME2	20.04.2015	6 µV/V	40 µV/V
		UME3	29.06.2015	-4 µV/V	40 µV/V
		UME4	25.08.2015	6 µV/V	40 µV/V
		UME5	20.10.2015	3 µV/V	40 µV/V
		UME6	07.03.2016	-2 µV/V	40 µV/V
		UME7	03.08.2016	-7 µV/V	40 µV/V
		UME8	10.11.2016	-2 µV/V	40 µV/V
	100 mV @ 1 kHz	UME1	09.03.2015	41 µV/V	40 µV/V
		UME2	20.04.2015	48 µV/V	40 µV/V
		UME3	29.06.2015	40 µV/V	40 µV/V
		UME4	25.08.2015	48 µV/V	40 µV/V
		UME5	20.10.2015	45 µV/V	40 µV/V
		UME6	07.03.2016	49 µV/V	40 µV/V
		UME7	03.08.2016	38 µV/V	40 µV/V
		UME8	10.11.2016	40 µV/V	40 µV/V
20 V	10 V @ 55 Hz	UME1	09.03.2015	52 µV/V	11 µV/V
		UME2	20.04.2015	50 µV/V	11 µV/V
		UME3	29.06.2015	50 µV/V	11 µV/V
		UME4	25.08.2015	50 µV/V	11 µV/V
		UME5	20.10.2015	50 µV/V	11 µV/V
		UME6	07.03.2016	53 µV/V	11 µV/V
		UME7	03.08.2016	51 µV/V	11 µV/V
		UME8	10.11.2016	50 µV/V	11 µV/V

Range	Measurement Point	Index i	Date x_i	Measured Error E_i	Uncertainty $U(E_i)$
20 V	10 V @ 1 kHz	UME1	09.03.2015	96 µV/V	10 µV/V
		UME2	20.04.2015	94 µV/V	10 µV/V
		UME3	29.06.2015	93 µV/V	10 µV/V
		UME4	25.08.2015	93 µV/V	10 µV/V
		UME5	20.10.2015	95 µV/V	10 µV/V
		UME6	07.03.2016	97 µV/V	10 µV/V
		UME7	03.08.2016	96 µV/V	10 µV/V
		UME8	10.11.2016	94 µV/V	10 µV/V
	10 V @ 100 kHz	UME1	09.03.2015	72 µV/V	16 µV/V
		UME2	20.04.2015	67 µV/V	16 µV/V
		UME3	29.06.2015	91 µV/V	16 µV/V
		UME4	25.08.2015	56 µV/V	16 µV/V
		UME5	20.10.2015	54 µV/V	16 µV/V
		UME6	07.03.2016	74 µV/V	16 µV/V
		UME7	03.08.2016	54 µV/V	16 µV/V
		UME8	10.11.2016	51 µV/V	16 µV/V
200 V	100 V @ 55 Hz	UME1	09.03.2015	-12 µV/V	15 µV/V
		UME2	20.04.2015	-7 µV/V	15 µV/V
		UME3	29.06.2015	-14 µV/V	15 µV/V
		UME4	25.08.2015	-13 µV/V	15 µV/V
		UME5	20.10.2015	-11 µV/V	15 µV/V
		UME6	07.03.2016	-12 µV/V	15 µV/V
		UME7	03.08.2016	-10 µV/V	15 µV/V
		UME8	10.11.2016	-14 µV/V	15 µV/V
	100 V @ 1 kHz	UME1	09.03.2015	27 µV/V	18 µV/V
		UME2	20.04.2015	33 µV/V	18 µV/V
		UME3	29.06.2015	26 µV/V	18 µV/V
		UME4	25.08.2015	27 µV/V	18 µV/V
		UME5	20.10.2015	29 µV/V	18 µV/V
		UME6	07.03.2016	30 µV/V	18 µV/V
		UME7	03.08.2016	29 µV/V	18 µV/V
		UME8	10.11.2016	26 µV/V	18 µV/V

AC CURRENT

Range	Measurement Point	Index i	Date x_i	Measured Error E_i	Uncertainty $U(E_i)$
20 mA	10 mA @ 300 Hz	UME1	09.03.2015	54 µA/A	20 µA/A
		UME2	21.04.2015	53 µA/A	20 µA/A
		UME3	29.06.2015	52 µA/A	20 µA/A
		UME4	25.08.2015	56 µA/A	20 µA/A
		UME5	20.10.2015	64 µA/A	20 µA/A
		UME6	07.03.2016	60 µA/A	20 µA/A
		UME7	03.08.2016	61 µA/A	20 µA/A
		UME8	10.11.2016	60 µA/A	20 µA/A
	10 mA @ 1 kHz	UME1	09.03.2015	71 µA/A	20 µA/A
		UME2	21.04.2015	70 µA/A	20 µA/A
		UME3	29.06.2015	71 µA/A	20 µA/A
		UME4	25.08.2015	72 µA/A	20 µA/A
		UME5	20.10.2015	79 µA/A	20 µA/A
		UME6	07.03.2016	77 µA/A	20 µA/A
		UME7	03.08.2016	80 µA/A	20 µA/A
		UME8	10.11.2016	76 µA/A	20 µA/A
2 A	1 A @ 300 Hz	UME1	09.03.2015	-91 µA/A	35 µA/A
		UME2	21.04.2015	-88 µA/A	35 µA/A
		UME3	29.06.2015	-93 µA/A	35 µA/A
		UME4	25.08.2015	-99 µA/A	35 µA/A
		UME5	20.10.2015	-101 µA/A	35 µA/A
		UME6	07.03.2016	-93 µA/A	35 µA/A
		UME7	03.08.2016	-110 µA/A	35 µA/A
		UME8	10.11.2016	-107 µA/A	35 µA/A
	1 A @ 1 kHz	UME1	09.03.2015	-29 µA/A	35 µA/A
		UME2	21.04.2015	-21 µA/A	35 µA/A
		UME3	29.06.2015	-27 µA/A	35 µA/A
		UME4	25.08.2015	-37 µA/A	35 µA/A
		UME5	20.10.2015	-35 µA/A	35 µA/A
		UME6	07.03.2016	-22 µA/A	35 µA/A
		UME7	03.08.2016	-45 µA/A	35 µA/A
		UME8	10.11.2016	-45 µA/A	35 µA/A

RESISTANCE

Range	Measurement Point	Index i	Date x_i	Measured Error E_i	Uncertainty $U(E_i)$
20 Ω (TrueΩ)	10 Ω	UME1	12.03.2015	14.2 µΩ/Ω	1.3 µΩ/Ω
		UME2	22.04.2015	13.9 µΩ/Ω	1.3 µΩ/Ω
		UME3	24.06.2015	13.7 µΩ/Ω	1.3 µΩ/Ω
		UME4	21.08.2015	13.9 µΩ/Ω	1.3 µΩ/Ω
		UME5	19.10.2015	14.0 µΩ/Ω	1.3 µΩ/Ω
		UME6	25.02.2016	15.1 µΩ/Ω	1.3 µΩ/Ω
		UME7	01.08.2016	16.1 µΩ/Ω	1.3 µΩ/Ω
		UME8	08.11.2016	15.1 µΩ/Ω	1.3 µΩ/Ω
20 kΩ (TrueΩ)	10 kΩ	UME1	12.03.2015	9.3 µΩ/Ω	3.0 µΩ/Ω
		UME2	22.04.2015	8.6 µΩ/Ω	3.0 µΩ/Ω
		UME3	24.06.2015	8.4 µΩ/Ω	3.0 µΩ/Ω
		UME4	21.08.2015	8.9 µΩ/Ω	3.0 µΩ/Ω
		UME5	19.10.2015	8.0 µΩ/Ω	3.0 µΩ/Ω
		UME6	25.02.2016	8.7 µΩ/Ω	3.0 µΩ/Ω
		UME7	01.08.2016	9.7 µΩ/Ω	3.0 µΩ/Ω
		UME8	08.11.2016	10.3 µΩ/Ω	3.0 µΩ/Ω
	10 kΩ (LOI)	UME1	12.03.2015	8.9 µΩ/Ω	3.0 µΩ/Ω
		UME2	22.04.2015	10.2 µΩ/Ω	3.0 µΩ/Ω
		UME3	24.06.2015	9.4 µΩ/Ω	3.0 µΩ/Ω
		UME4	21.08.2015	10.0 µΩ/Ω	3.0 µΩ/Ω
		UME5	19.10.2015	8.8 µΩ/Ω	3.0 µΩ/Ω
		UME6	25.02.2016	10.0 µΩ/Ω	3.0 µΩ/Ω
		UME7	01.08.2016	10.5 µΩ/Ω	3.0 µΩ/Ω
		UME8	08.11.2016	11.2 µΩ/Ω	3.0 µΩ/Ω
2 MΩ (Normal)	1 MΩ	UME1	12.03.2015	8.3 µΩ/Ω	6.0 µΩ/Ω
		UME2	22.04.2015	8.1 µΩ/Ω	6.0 µΩ/Ω
		UME3	24.06.2015	7.9 µΩ/Ω	6.0 µΩ/Ω
		UME4	21.08.2015	8.6 µΩ/Ω	6.0 µΩ/Ω
		UME5	19.10.2015	9.3 µΩ/Ω	6.0 µΩ/Ω
		UME6	25.02.2016	10.1 µΩ/Ω	6.0 µΩ/Ω
		UME7	01.08.2016	10.3 µΩ/Ω	6.0 µΩ/Ω
		UME8	08.11.2016	11.0 µΩ/Ω	6.0 µΩ/Ω

Appendix IV: Technical Protocol

TECHNICAL PROTOCOL

Comparison on Calibration of Multimeter

EURAMET Project No 1341

TÜBİTAK UME

(Rev. 6)
August 02, 2016

ULUSAL METROLOJİ ENSTİTÜSÜ
Gebze Yerleşkesi P.K. 54 41470 Gebze Kocaeli T 262 679 50 00 F 0626 679 50 01 www.ume.tubitak.gov.tr

Contents

1. Introduction

During the 6th Meeting of the EURAMET FG FNMID, held in Istanbul (Turkey) in November 2013, it was decided to organize an intercomparison on multimeter calibration, in order to support the CMCs of NMIs in the CIPM KCDB.

During the EURAMET TC-EM meeting, which was held in MIRS, Ljubljana (Slovenia) on October 16-17, 2014, it was decided to announce the comparison to all TC-EM members asking for further participants. The comparison was proposed by UME and was registered as EURAMET Project No 1341.

UME is acting as the pilot institute. Thus, UME is responsible for providing the travelling standard, monitoring its performance during circulation, and the evaluation and reporting of the measurement results.

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

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

The comparison will be carried out in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [1].

2. Travelling Standard

The travelling standard is an 8½ digit multimeter, Fluke 8508A Reference Multimeter (Figure 1), supplied by TÜBİTAK UME. 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. The general specifications of 8508A are given in Table 1.

Front Panel | Rear Panel

Figure 1. Travelling standard is a Fluke 8508 Reference Multimeter

Table 1. The general specifications of 8508A Reference Multimeter

Power	Power supply 200 V to 240 V rms ±10 % @ 47 Hz to 63 Hz Consumption < 80 VA
Dimensions	Height 88 mm (3.5 inches) Width 427 mm (16.8 inches) Depth 487 mm (19.2 inches)
Weight	11.5 kg (25.5 lbs)
Environment Temperature	Operating 0 °C to 50 °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

3. Participant Laboratories

The pilot institute for this comparison is TÜBİTAK UME (Turkey). The contact details of the coordinator are given below:

Pilot Institute	:	TÜBİTAK Ulusal Metroloji Enstitüsü (UME)
Coordinator	:	Saliha TURHAN Tel: +90 262 679 50 00 Fax: +90 262 679 50 01 E-mail: saliha.turhan@tubitak.gov.tr

A list of all participating institutes and contact persons with their addresses is given in Annex 1.

4. Time Schedule

The time schedule for the supplementary comparison is given in the Table 2. The comparison will begin in March 2015 and is scheduled to be completed within 1 year. The circulation of travelling standard will be organized in loops of not more than 3 institutes in order to monitor the performance of the travelling standard. Each laboratory will have 2 weeks to carry out the measurements and transportation. Any deviation in the agreed plan should be approved by the pilot institute.

Table 2. Circulation Time Schedule

Acronym of Institute	Country	Starting Date	Time for measurement and transportation
UME	Turkey	02.03.2015	14 days
MBM	Montenegro	16.03.2015	14 days
IMBiH	Bosnia and Herzegovina	30.03.2015	14 days
UME	Turkey	13.04.2015	14 days
HMI/FER-PEL	Croatia	27.04.2015	14 days
INM	Romania	11.05.2015	14 days
CMI	Czech Republic	25.05.2015	14 days
UME	Turkey	08.06.2015	35 days
FTMC	Lithuania	13.07.2015	14 days
UME	Turkey	27.07.2015	35 days
IPQ	Portugal	31.08.2015	14 days
BoM	FYR Macedonia	14.09.2015	14 days
UME	Turkey	28.09.2015	28 days
AS METROSERT	Estonia	26.10.2015	14 days
GUM	Poland	09.11.2015	14 days
DPM	Albania	19.01.2016	27 days
UME	Turkey	15.02.2016	91 days
KMA	Kosovo	16.05.2016	14 days
NSAI NML	Ireland	20.06.2016	14 days
UME	Turkey	01.08.2016	14 days
EMI	United Arab Emirates (UAE)	15.08.2016	14 days
SASO	Kingdom of Saudi Arabia	29.08.2016	14 days
UME	Turkey	12.09.2016	14 days

5. Measurement Quantities and Points

The quantities to be measured are DC voltage, DC current, AC voltage, AC current and DC resistance. The measurement points for each quantities and the configuration of the travelling standard, Fluke 8508A, during the comparison measurements are given in Table 3.

Table 3. Measurement quantities & points and the configuration of Fluke 8508A

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 @ 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 (‡ Normal Ω for 1 MΩ) Resolution 7 4-Wire Low Current OFF (‡ Low Current ON) Filter ON Fast OFF Front Input
	10 kΩ	20 kΩ	5 min	
	10 kΩ‡		5 min	
	1 MΩ‡	2 MΩ	5 min	

6. Calculation of the Comparison Reference Value

The Comparison Reference Value (CRV) for each measurement point will be calculated as the weighted mean of the corrected results of the institutes due to the time dependence of the travelling standard, which will be calculated using the results of the pilot institute. Any result identified as inconsistent will be excluded from the determination of the CRV.

7. Transportation of Travelling Standard

The travelling standard will be transported using an ATA Carnet for custom clearance where possible.

It is the responsibility of each laboratory that the ATA carnet is used properly. At each transport the carnet must be presented to the customs on leaving the country and upon the arrival in the country of destination.

The travelling standard is packed in a transport case of size (79.4 x 61.5 x 44.4) cm and a total weight of 26 kg. The transport case can easily be opened for customs inspection.

7.1. Transport Case

The pilot institute must be informed of receipt of the standard and its dispatch to the next laboratory using the forms provided. The checklist (Annex 2), the receipt form (Annex 3) and dispatch form (Annex 4) will be sent to participants by e-mail.

On receipt of the case, the device should be unpacked carefully and checked for any damage. The functioning of the 8508A shall be controlled by initiating the “Self Test” (See details in page 3.36 of 8508A Users Manual [2])

1. Allow the Multimeter to warm-up under power at least 10 minutes.
2. Press the CLEAR key, select “Pwr Up Dflt” to restore the power up default configuration and display the DCV menu.
3. Press the “Test” key and select “Std” to initiate a selftest.

The contents of the transport case also should be checked. The receipt form (Annex 3) should be completed and sent to the pilot institute by e-mail.

Before sending the case out, the checklist form should be carefully followed in order to include all the material for the next laboratory. The dispatch form (Annex 4) should be completed and sent to the pilot institute by e-mail.

The content of the transport case is given below:

1. Fluke 8508A Reference Multimeter (Serial No: 969656608)*
2. Power cord
3. 4 wire shorting device
4. ATA Carnet

* The multimeter will be supplied without input leads.

7.2. Failure of Travelling Standard

In case of any damage or malfunction of the travelling standard, the pilot institute shall be informed immediately. The comparison will be carried out after the travelling standard is repaired.

7.3. Financial aspects

Each participant institute is responsible for its own costs for the measurements, transportation to the next participant, insurance of the shipment to the next participant and any customs charges as well as 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.

8. Measurement Instructions

8.1. Before the Measurements

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

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

8.2. Measurement Conditions

1. The standard ambient conditions for measurement are ;

   Temperature : (23 ± 1) °C

   Relative humidity : (45 ± 10) %rh

2. The non-volatile adjustment of Reference Multimeter is not allowed during the comparison measurements. Therefore the rear panel calibration keyswitch is set to DISABLE position and the CAL legend is not shown on the main display.
3. The reference multimeter should be allowed to warm-up under power at least 4 hours.
4. The reference multimeter should be used in the configurations given in Table 3.
5. The front input terminals of Reference Multimeter must be used for all measurements.
6. The settling time of the reference multimeter must be considered.
7. A single earth connection must be used in the measurement setup to avoid ground loops.
8. Before making DC measurements, for each point, a “zero” should be applied and “Null Zero” should be executed.
9. Any standard method may be used for calibrating the reference multimeter.
10. The measurement points required by the comparison protocol are given in Table 3.
11. The measurement result shall be reported as the relative error of the Reference Multimeter and calculated by;

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

9. Measurement Uncertainty

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

All contributions to the measurement uncertainty should be listed in the report submitted by each participant. In uncertainty evaluations, the effective degrees of freedom and the coverage factor should be reported.

Even though the contributions to the uncertainty are specific to the measurement method used, it may be useful to consider the list of 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)
3. Drift of the reference standard (drift due to time, temperature, loading etc.)
4. Finite resolution of the travelling standard (DMM)
5. Repeatability

10. Reporting of Results

The results should be communicated to the pilot institute within 30 days of completing the measurements.

The measurement results should be reported in the format given in Annex 5 and should contain (for each measurement) at least:

- Details of participating institute,
- The date of the measurements,
- A detailed description of the method used,
- The measurement standards used in the comparison measurements,
- The environmental conditions during the measurements,
- Results of measurement (the relative error of the travelling standard and associated expanded uncertainty),
- A detailed uncertainty budget.

11. Final Report of the Comparison

The pilot institute is responsible for the preparation of a report on the comparison.

After the results have been received from the participants, a first draft (Draft A) of the report will be prepared by the pilot institute within 4 months and will be sent to the participants. This draft will be confidential to the participants.

The participants will have one month to send their comments on Draft A. On the basis of the comments received, the pilot institute will prepare the second draft (Draft B), where the withdrawn results will not appear or, in case of correction, the original and the corrected results, with the given explanation, are reported.

Draft B will be submitted to the EURAMET TC-EM and, after approval, will become the Final Report. The Final Report will form the basis for the publication of results.

12. References

[1] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons, 2007

[2] Users Manual of Fluke 8508A, Rev. 6, 3/13, July 2002 (available on the Fluke website: http://download.flukecal.com/secure/8508A___umeng0600.pdf?nvb=20141106132929&nva=20141106134429&token=020b92b6195b5e710f30d)

[3] Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement (GUM), JCGM 100, First edition, September 2008 (available on the BIPM website: http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf)

Annex 1: Participating Institutes

No	Country	Acronym of Institute	Name of Institute	Shipping Address	Contact Person	ATA Carnet
1.	Albania	DPM	General Directorate of Metrology	Autostrada Tiranë - Durrës, km 8 (Rruga dytësore) Tiranë Albania	Yljon Seferi yljon.seferi@dpm.gov.al Tel: +355 4 2233 174	Yes
2.	Bosnia and Herzegovina	IMBiH	Institute of Metrology of Bosnia and Herzegovina	Institute of Metrology of Bosnia and Herzegovina Augusta Brauna 2 BA-71000 Sarajevo, Bosnia and Herzegovina	Vladimir Milojevic vladimir.milojevic@met.gov.ba Tel: +387 33 568 901	Yes
3.	Czech Republic	CMI	Czech Metrology Institute	Czech Metrology Institute Laboratory of DC/LF Electrical Quantities Okruzni 31 638 00 BRNO, Czech Republic	Jiri Streit jstreit@cmi.cz Tel: +420 545 555 208	Yes
4.	Croatia	HMI/FER-PEL	Faculty of Electrical Engineering and Computing - Primary Electromagnetic Laboratory	University of Zagreb, Faculty of Electrical Engineering and Computing Unska 3, HR-10000 Zagreb, Croatia	Damir Ilic damir.ilic@fer.hr Tel: +385 1 612 9753	Yes
5.	Estonia	AS METROSERT	Central Office of Metrology	National Standards Laboratory for Electrical Quantities R&D division Metrosert AS Teaduspargi 8, 12618 Tallinn, Estonia	Andrei Pokatilov andrei.pokatilov@metrosert.ee Tel: +372 529 7095	Yes
6.	FYR Macedonia	BoM	Bureau of Metrology	Bureau of Metrology (BoM) Bull. Jane Sandanski 109 a MK-1000 Skopje R., FYR Macedonia	Stanislava Kroneva Petrovska stanislava.kroneva@bom.gov.mk Tel: +389 2 2403 676	Yes
7.	Ireland	NSAI NML	NSAI National Metrology Laboratory	NSAI National Metrology Laboratory Griffith Avenue Extension, Glasnevin, Dublin 11, D11 E527 Ireland.	Oliver POWER Oliver.Power@nsai.ie T: + 353 1 808 2610	No
8.	Kosovo	KMA	Kosovo Metrology Agency	KMA (Kosovo Metrology Agency) Str."Smajl Hajdaraj" p.n. Lagja Universitetit 10000 Prishtinë, Republika e Kosovës	Musa Misini Musa.Misini@rks-gov.net Tel: +381 38 512 100	No
9.	Lithuania	FTMC	Centre for Physical Sciences and Technology	Centre for Physical Sciences and Technology A. Gostauto str. 11 LT-01108 Vilnius, Lithuania	Andrius Bartasiunas andrius.bartasiunas@ftmc.lt Tel: +370 5 261 80 65	Yes

No	Country	Acronym of Institute	Name of Institute	Shipping Address	Contact Person	ATA Carnet
10.	Montenegro	MBM	Montenegrin Bureau of Metrology	Montenegrin Bureau of Metrology (MBM) Kralja Nikole 2 XM-81000 Podgorica, Montenegro	Rabina Šabotić rabina.sabotic@metrologija.gov.me Tel: +382 20 601 360	Yes
11.	Poland	GUM	Central Office of Measures	Central Office of Measures Glówny Urzad Miar ul. Elektoralna 2 PL-00 950 Warszawa, Poland	Paweł Zawadzki p.zawadzki@gum.gov.pl Tel: +48 22 581 9241	Yes
12.	Portugal	IPQ	Instituto Português da Qualidade	Instituto Português da Qualidade Laboratório Nacional de Metrologia Rua António Gião 2 PT-2829-513 Caparica, Portugal	Luis Ribeiro LRibeiro@ipq.pt Tel: +351 212 948 161	Yes
13.	Romania	INM	National Institute of Metrology	National Institute of Metrology (INM) Sos. Vitan-Bârzesti 11 RO-042122 Bucuresti, Romania	Liliana Cirneanu liliana.cirneanu@inm.ro Tel: +4021 334 50 60 (ext. 153)	Yes
14.	Saudi Arabia	SASO	The Saudi Standards, Metrology and Quality Organization (SASO)	**الهيئة السعودية للمواصفات والمقاييس والجودة** **أمام جامعة الملك سعود -حي المحمدية -الرياض** **ص.ب 3437 الرياض 11471 المملكة العربية السعودية** **(مبنى رقم 4 - المركز الوطني للمعايرة)** The Saudi Standards, Metrology and Quality Organization (SASO) PO. B 3437 Riyadh- Al Muhammadiyah – in front of King Saud University (Bldg. # 4, NMCC) 11471 Riyadh Kingdom of Saudi Arabia	Eng. Abdullah Alrobaish a.robaish@saso.gov.sa Tel: +966 504104070 Dr. Mamdouh Halawa mamdouh_halawa@yahoo.com Tel: +966 508796538	No
15.	United Arab Emirates (UAE)	EMI	Emirates Metrology Institute (EMI)	Emirates Metrology Institute Sultan Bin Zayed the First Street Abu Dhabi, UAE	Jon Bartholomew Jon.Bartholomew@qcc.abudhabi.ae Tel: +971 503862676	No
16.	Turkey	UME	TÜBİTAK Ulusal Metroloji Enstitüsü (UME)	TÜBİTAK Ulusal Metroloji Enstitüsü (UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY	Saliha Turhan saliha.turhan@tubitak.gov.tr Tel: +90 262 679 50 00 (Ext. 4201)	Yes

Annex 2: The Checklist Form

Comparison on Calibration of Multimeter

EURAMET Project 1341

- ☐ Fluke 8508A Reference Multimeter (Serial No: 969656608)
- ☐ Power cord
- ☐ 4 wire shorting device
- ☐ ATA Carnet

Annex 3: The Receipt Form

Comparison on Calibration of Multimeter

EURAMET Project 1341

The received date of transport case	
Was there any serious damage on the transport case?	Yes ☐ No ☐
Was the contents of the transport case (given in Annex 2) completed?	Yes ☐ No ☐ If No, please list missing items:
After inspection, the travelling standard is in working condition?	Yes ☐ No ☐
The travelling standard passed the selftest?	Yes ☐ No ☐
Remarks	

The transport case was received by:

Institute	
Contact Person	
E-mail Address	
Telephone No	

Please send the form to the coordinator of the comparison!

saliha.turhan@tubitak.gov.tr

Annex 4: The Dispatch Form

Comparison on Calibration of Multimeter

EURAMET Project 1341

The travelling standard is in working condition?	Yes ☐ No ☐
The travelling standard passed the selftest?	Yes ☐ No ☐
Is the contents of the transport case (given in Annex 2) completed?	Yes ☐ No ☐
The dispatch date of transport case	
Shipping way (Courier, in hand etc.)	 Courier Name: Tracking No: Airline: Flight No: Dated:
Shipping to (Participant Name & Address)	
Remarks	

The transport case was dispatch by:

Institute	
Contact Person	
E-mail Address	
Telephone No	

Please send the form to the next participant and the coordinator of the comparison!

saliha.turhan@tubitak.gov.tr

Annex 5: The Format for Reporting the Results

1. PARTICIPANT INSTITUTE

Institute	
Contact Person	
E-mail	
Address	

2. PERIOD OF MEASUREMENTS

3. AMBIENT CONDITIONS

Temperature : (±) °C

Relative Humidity : (±) % rh

4. THE MEAUREMENT STANDARDS USED

Name	Manufacturer	Model No	Serial No	Traceability

5. MEASUREMENT METHOD

6. MEASUREMENT RESULTS

DC VOLTAGE

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 mV	+ 100 mV				
20 V	+ 10 V				
200 V	+ 100 V				
1000 V	+ 1000 V				

DC CURRENT

Range of 8508A	Nominal Value	Applied Value	Reading of 8508A	Error of 8508A	Uncertainty[1]
200 μA	+ 100 μA				
20 mA	+ 10 mA				
2 A	+ 1 A				

DC RESISTANCE

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

AC VOLTAGE

Range of 8508A	Nominal Value		Applied Voltage	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Voltage	Frequency				
200 mV	100 mV	55 Hz				
	100 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 Current	Reading of 8508A	Error of 8508A	Uncertainty[1]
	Current	Frequency				
20 mA	10 mA	300 Hz				
	10 mA	1 kHz				
2 A	1 A	300 Hz				
	1 A	1 kHz				

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

7. UNCERTAINTY BUDGET

7.1. DC Voltage

Model Function:

$E_x = f\ (x_1, x_2,, \ldots, x_N)$

Table 1. Uncertainty budget for 100 mV

Quantity X_i	Estimate x_i	Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(E_x)$	Degrees of Freedom (DoF) v_i
Error (E_x)		**Combined Uncertainty, $u(E_x)$**				
		Effective Degrees of Freedom, v_{eff}				
		Coverage Factor, k				
		Expanded Uncertainty, $U(E_x)$				

7.2. DC Current

7.3. DC Resistance

7.4. AC Voltage

7.5. AC Current