Final report of comparison

Project EURAMET.EM-S33

Supplementary comparison

"Traceability of AC High Voltage Reference Measuring Systems up to 200 kV"

Report by: **Dr. Anders Bergman (SP – Sweden)**
Dr. Jari Hällstrom (MIKES – Finland)
Mr. Pascual Simón (L.C.O.E. – Spain)

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This report is made up of 26 pages and three attachments of 19, 9 and 39 pages.

1 Introduction

AC high voltage (power frequency) is an important quantity in testing of high voltage equipment. It is important to ensure the accuracy of measurement. One of the methods to check the metrological capabilities of the National Metrology Institutes (NMI) and Designated Institutes (DI) is by performing international comparisons, including supplementary comparisons.

This comparison was proposed in order to check the capabilities of the participating institutes in the area of high AC voltage. The relevant quantities are the peak and RMS values of high AC voltage. Measurement capabilities of AC peak and RMS values of the voltage were compared.

Ten national metrology institutes and/or designated institutes took part in this comparison project, nine of them from EURAMET and the other one from a different regional metrological organization (COOMET). Coordination of the comparison was carried out by the "*Laboratorio Central Oficial de Electrotecnia*" (LCOE) of the "*Fundación para el Fomento de la Innovación Industrial*" (FFII) from Spain as pilot laboratory and owner of the Travelling Reference Measuring System (TRMS).

The TRMS circulated among the participants and they compared the high AC (50 Hz) voltages obtained by their own measuring system with those obtained by the TRMS. All the participants were asked to follow their usual measurement procedures corresponding to their best measurement capabilities. The measurement period of this comparison started in March 2 010 and ended in May 2 013. Some draft reports were discussed before issuing this final report. First draft report was presented in May 2015, next one in January 2016. After receiving some remarks from the WGLF of CCEM in august 2017, thechnical protocol of the intercomparison is added to the report and final report is improved.

2 Participants

The participants and their affiliation, the ten institutes involved, are listed in Table 1 in order of the TRMS circulation:

R. Martín / T. García	FFII - LCOE, *Laboratorio Central Oficial de Electrotecnia*, Madrid, Spain.
E. Dimitrov	BIM, Bulgarian Institute of Metrology, Sofia, Bulgaria
I. Blanc / M. Agazar	LNE, *Laboratoire National de métrologie et d'Essais*, Trappes, France
J. Hällström / E. Suomalainen	MIKES, Centre for Metrology and Accreditation, Helsinki, Finland
A. Sardi	INRIM, *Instituto Nazionale di Ricerca Metrologica*, Torino, Italy
E. Houtzager	VSL, *Nederlands Meetinstituut*, Delft, The Netherlands
A. Bergman	SP, Technical Research Institute of Sweden, Borås, Sweden
A. Merev	TÜBITAK UME, *TÜBITAK Ulusal Metroloji Enstitüsü*, Gebze/Kocaeli, Turkey
V. Kiselev / N. Boyarin	VNIIMS, All-Russian Research Institute of Metrological Service, Moscow, Russia
H. Seifert	PTB, *Physikalisch-Technische Bundesanstalt*, Braunschweig, Germany

Table 1. List of comparison participants.

3 Equipment

3.1 Travelling standards

<u>General requirements</u>

The TRMS consisted of a capacitive divider with fixed input and grounding leads, a coaxial cable, a digital multimeter and a computer with a printer. The TRMS had two ranges, 20 kV and 200 kV, depending on the low voltage arm connected to the high voltage capacitor. Besides, an arbitrary waveform generator was included among the travelling devices to carry out the low voltage measurements of this comparison.

Description of the TRMS:

Note: Annex I, "*TRMS's Photos*", of the comparison's technical protocol included pictures of the elements the TRMS was made up of and some set up details. Technical protocol is included in the Annex III of this report.

<u>Low voltage measurements:</u>

Voltmeter:	Manufacturer:	Hewlett-Packard.	
	Type:	3458A.	
	Serial Nº :	2823 A 18964.	
Software:	Manufacturer:	LCOE.	
	LCOE reference:	III-1-SOFT-018.	

<u>TRMS up to 20 kV:</u>

H.V lead:	Description:	Copper tube (length = 2 m; Ǿ = 28 mm).	
Divider:	Description:	Capacitive divider.	
	Manufacturer:	H.V. arm:	TETTEX
		L.V. arm:	SP
	Type:	H.V. arm:	3370/100/200
		L.V. arm:	s/m
	LCOE reference:	H.V. arm:	III-2-DT09-001
		L.V. arm:	III-2-DT09-009
	Nom. capacitance:	H.V. arm:	100 pF
		L.V. arm:	500 nF
	Nominal voltage:	H.V. arm:	20 kV
		L.V. arm:	4 V
	Nominal ratio:	5 000	
Measuring cable 1:	Description:	Coaxial cable.	
	Type:	RG-59 B/U.	
	Characteristic Z:	75 Ω.	
	Length:	0,5 m.	
	LCOE reference:	H.V. arm:	III-2-DT09-011
Measuring cable 2:	Description:	Coaxial cable.	
	Type:	RG-59 B/U.	
	Characteristic Z:	75 Ω.	

	Length:	10 m.	
	LCOE reference:	H.V. arm:	III-2-DT09-012
Voltmeter:	Manufacturer:	Hewlett-Packard.	
	Type:	3458A.	
	Serial Nº :	2823 A 18964.	
Software:	Manufacturer:	LCOE.	
	LCOE reference:	III-1-SOFT-018.	

<u>TRMS up to 200 kV:</u>

H.V lead:	Description:	Copper tube (length = 2 m; Ǿ = 28 mm).	
Divider:	Description:	Capacitive divider.	
	Manufacturer:	H.V. arm:	TETTEX
		L.V. arm:	SP
	Type:	H.V. arm:	3370/100/200
		L.V. arm:	s/m
	LCOE reference:	H.V. arm:	III-2-DT09-001
		L.V. arm:	III-2-DT09-010
	Nom. capacitance:	H.V. arm:	100 pF
		L.V. arm:	5000 nF
	Nominal voltage:	H.V. arm:	200 kV
		L.V. arm:	4 V
	Nominal ratio:	50 000	
Measuring cable 1:	Description:	Coaxial cable.	
	Type:	RG-59 B/U.	
	Characteristic Z:	75 Ω.	
	Length:	0,5 m.	
	LCOE reference:	H.V. arm:	III-2-DT09-011
Measuring cable 2:	Description:	Coaxial cable.	
	Type:	RG-59 B/U.	
	Characteristic Z:	75 Ω.	
	Length:	10 m.	
	LCOE reference:	H.V. arm:	III-2-DT09-012
Voltmeter:	Manufacturer:	Hewlett-Packard.	
	Type:	3458A.	
	Serial Nº :	2823 A 18964.	
Software:	Manufacturer:	LCOE.	
	LCOE reference:	III-1-SOFT-018.	

<u>Arbitrary waveform generator:</u>

Generator:	Manufacturer:	Agilent Technologies.
	Type:	33220A.
	Serial Nº:	MY44045377.

3.2 Reference measuring systems of participants

According to the reports provided each participating institute carried out the comparison measurements using the following devices:

BIM – Bulgaria

Electronic standard voltage divider, Tettex Instruments, type 4861, s/n: 153132.
H.V. arm: compressed gas capacitor, Haefely Trench, type NK/100-100, s/n: P3-05045-5.
L.V. arm: air capacitor, Tettex Instruments, type 3330/10 000 AD, s/n: 153210.
Identification required (serial number, internal code).
Multimeter Hewlett-Packard, type P3458A, sn 2823A22007.

FFII-LCOE – Spain

- Reference transformer TETTEX, type 4829a, nº 138 119.
- Reference transformer TETTEX, type 4825, nº 103 679.
- Reference calibrator FLUKE, type 5720A, nº 7825210
- Sampling voltmeter: Hewlett Packard, 3458A, III-1-MD-005.
- Software LCOE, ref. III-1-SOFT-018.

INRIM – Italy

- Compressed gas capacitor: Hartman & Braun, 103.59 pF, 250 kV, nº 50959.
- Low voltage arm 1 (ratio 200 000/4 V): 50 class 1 (0 – 30 ppm/ºC Tc), 100 nF/100V ceramic capacitors connected in parallel on a double layer PCB. This PCB is placed in a steel case with coaxial I/O and ground connections.
- Low voltage arm 2 (ratio 20 000/4 V): 5 capacitors of the same type are connected in parallel and placed in a silver plate coaxial brass box
- Measuring cable: coaxial cable with H&B connector on one end and UHF PL on the other, to join the low voltage arm with the high voltage arm.
- Measuring cable: triaxial cable with BNC connector for the core and the first shield and 4 mm banana plug for the outer shield. This cable joins the LV output to the measuring/recording instruments.
- Measuring/recording instrument: Agilent, type 3458A.
- LabVIEW® software.

LNE – France

- High voltage measurement transformer: Walter, nº 92817. Ratio: 150 kV / 150 V. For voltages up to 150 kV.
- High voltage capacitor (100 pF) connected to a low voltage capacitor (5 µF): High Volt, type MCP 300, nº 881757.
- Digital voltmeter Agilent, type 3458A (for RMS value measurements).
- Peak detector Tektronix, type 7A13 (for peak value measurements).

MIKES – Finland

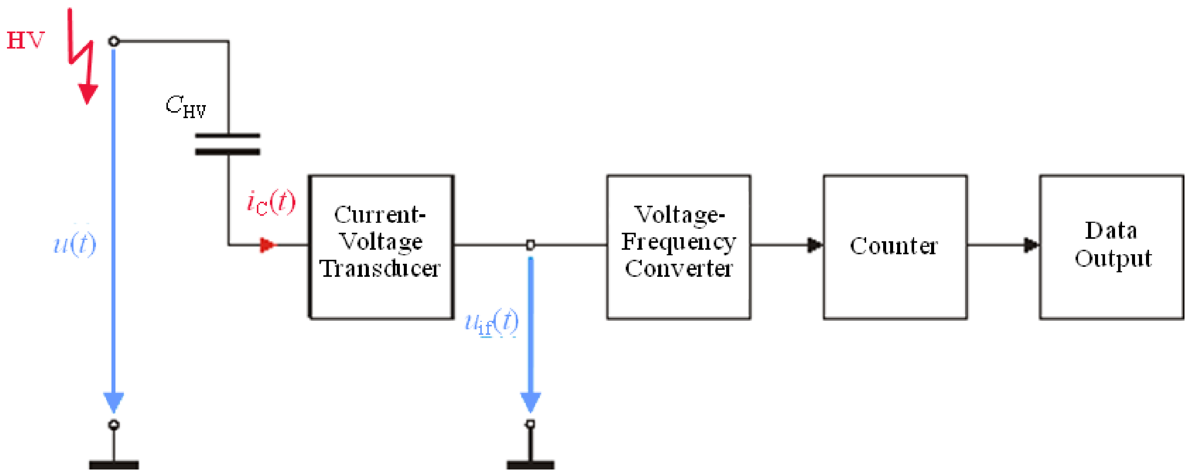
- Compressed gas capacitor: Micafil, 100 pF, 200 kV, type PG1, MIKES004850.
- Low voltage arm: NP0 ceramic capacitor, 1 µF, MIKES004853.
- Measuring cable: 10 metres.

- Sampling voltmeter: Agilent, type 3458A, MIKES003643.
- Software "acmeac_2010.vee".

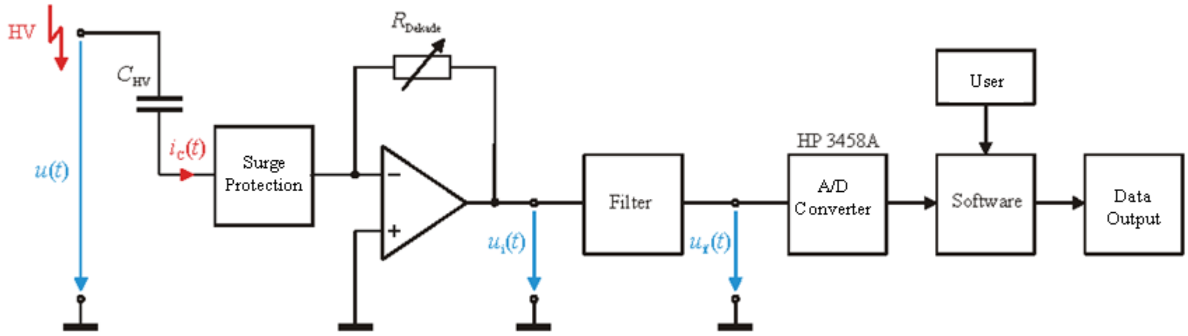
Low voltage peak measurement: performed with sampling voltmeter Agilent, type 3458A, MIKES003643. Set up according to comparison report from the participating laboratory.

PTB – Germany

- Peak voltage measurement: PTB's system MAZI 9301 with resistor decade Burster, Type 1423, S. No. 83199.



- RMS voltage measurement: PTB's system UMAS ID 20000 2219, Software TestPoint UMAS.TST, dated 30.06.2006.



H.V. capacitor (C_{HV}):

Range 750 V to 20 kV: MWB, type SC 100, 100 pF, nº: HL8720550.
Range 20 kV to 200 kV: Hartman & Braun, type CLP 250, 45 pF, nº: 40570.

Automatic capacitance bridge Andeen-Hagerling, type AH 2500A, nº (C_{HV}):

SP – Sweden

Capacitive divider consisting of: Haefely NK300 (SP 501990) compressed gas capacitor, two different low voltage arms (SP 6027998 and SP 602797) of the same type as that of the TRMS, a 7 m long RG213 cable (SP 602896) for connecting the low voltage arm to the high voltage arm, 2x2m of RG58 cables for connection between the low voltage capacitor and the DMM and a wall feedthrough between the high voltage lab and the control room. The DMM used was a HP 3458A (SP 502401).

TÜBITAK UME – Turkey

Capacitive divider:

- Compressed gas capacitor: HighVolt, 100 pF, 200 kV, type MCP200, nº 884675.
- Low voltage arm (range 1 kV - 20 kV): capacitor TÜBITAK UME, type LVC, 500 nF / 700 Vac, nº UMEG1YG201202.
- Low voltage arm (range 20 kV - 200 kV): capacitor TÜBITAK UME, type LVC, 5 µF / 700 Vac, nº UMEG1YG201201.
- Measuring cable: RG214/U, length 15 m.
- Sampling voltmeter: Agilent, type 3458A, nº MY45040360.
- Software ACMpeak.vee and ACMrms.vee.

VNIIMS – Russia

Capacitive divider:

- Manufacturer/brand: VNIIMS, type ДНО-230-01-50, serial number: 01; rated capacitance of high voltage arm: 44.5 pF, rated capacitance of low voltage arm: 712 nF; used scale factor: 17 156.
- Digital voltmeter manufactured by VNIIMS, type LQV-1020, serial number: 01; AC voltage range (peak): 0.06 V – 16 V; input impedance: 1GΩ.

VSL – The Netherlands

- Reference transformer with multiple taps (10 kV, 25 kV, 50 kV and 100 kV), PFIFFNER, type EOF 100 PI, s/n: 2003.1045.01/1.
- Measuring cable: length: 5 m.
- Sampling voltmeter: Agilent Technologies, type 3458A, s/n: 2823A21638.
- AC meter (measurements at 1 kV): Fluke, type 5790A, s/n: 7065031.
- Software: High Voltage Measurement suite v1.0.

3.3 Traceability

Each national metrology institute carried out the comparison measurements using their own national standards.

Information provided about traceability for high voltage measurements is the following:

- BIM: internal (l.v. measurements), external (PTB) (h.v. measurements).
- LCOE: internal.

- LNE: internal.
- MIKES: internal.
- PTB: internal.
- SP: internal.
- TÜBITAK UME: internal.
- VNIIMS: internal
- VSL: internal (l.v. measurements), external (PTB) (h.v. measurements).

Concerning low voltage measurements all institutes claimed self traceability.

4 Organization of the comparison

The TRMS was transported during the comparison inside robust containers made of metal, wood and Styrofoam. As a result no damage of the TRMS occurred during the comparison measurements and it was not necessary to transport the standards personally.

The final time schedule of the comparison is shown in Table 2.

Laboratory / Place of measurement	**Measurement month**
FFII-LCOE I / Madrid, Spain	March, 2 010
BIM / Sofia, Bulgaria	May, 2 010
LNE / Trappes, France	July, 2 010
MIKES / Helsinki, Finland	August, 2 010
INRIM / Torino, Italy	October, 2 010 - January, 2 011
VSL / Delft, The Netherlands	March – May, 2 011
SP / Boras, Sweden	July - August, 2 011
LNE / Trappes, France	October, 2 011
TÜBITAK UME / Gebze/Kocaeli, Turkey	November, 2 011 - May, 2 012
VNIIMS / Madrid, Spain	July, 2 012
LCOE / Madrid, Spain (TRMS Check)	July, 2 012
PTB / Braunschweig, Germany	October 2 012 - April, 2 013
LCOE / Madrid, Spain (TRMS Check)	May, 2 013

Table 2. Final comparison schedule.

The initial comparison schedule suffered several delays on account of different issues over the measurement stage.

INRIM in Italy had problems to finish the comparison measurements because of shifting of the laboratories to new premises.

The French institute, LNE, asked to have the TRMS back to their facilities to check some of the comparison measurements because they have some doubts about the way they had been done. That is the reason why the system was shipped from SP (Sweden) to LNE (France), in September 2 011, after SP's measurements.

During the EURAMET's high voltage experts meeting held in September 2 011, the German institute PTB requested to take part in this comparison project so that this institute was included among the participants. Apparently PTB was ready to do the comparison measurements and that is why the TRMS was shipped from France to Germany. However the German institute was eventually not able to do the measurements because of problems related to other scheduled works and the calibration of their standards. That is the reason why the TRMS ended up in Turkey in order TÜBITAK UME could do the comparison measurements. PTB managed the ATA carnet required to get the system into Turkey.

Even though TÜBITAK UME were supposed to be able to do the comparison measurements they had problems related to lack of qualified personnel due to unexpected on-site works plus the fact that the head of the high voltage service was in Finland to participate in work related to the development of the ultra-high voltage DC divider in the frame of the EMRP ENG07. Several attempts were made in order to bring forward some remaining measurements but it was not possible in the end.

The TRMS was shipped from Turkey to Spain where FFII-LCOE checked it. Besides, technicians from VNIIMS went to FFII-LCOE's facilities to perform their measurements using VNIIMS reference system. When PTB was ready to do the comparison measurements the TRMS was shipped again to Germany, where measurements were finally carried out.

At the end of April 2 013 the TRMS arrived at LCOE in Madrid where a new set of checking measurements was performed in May.

5 Comparison measurements

Low voltage and high voltage measurements were scheduled in this comparison program. The former in order to check the capabilities of low voltage part (multimeter and analysis software) of the participating laboratories' measurement systems when measuring distorted waveshapes, and the latter to check the whole reference measurement chains of the participants.

5.1 Measured quantity

In low voltage measurements, the reading of the TRMS was compared with the local reference measuring system.The difference between both readings was calculated according to this formula:

$$E_m[\%] = \frac{U_{TRMS} - U_{REF}}{U_{REF}} \cdot 100 \ , \qquad (1)$$

where: E_m: Measurement error of the TRMS.

U_{TRMS}: AC voltage value obtained by means of the TRMS.

U_{REF}: AC voltage value obtained by means of the reference measuring system of the laboratory (LRMS).

Low voltage measurements were performed considering 1 (direct reading) as rated scale factor of the TRMS (see clause 3.1 above).

In high voltage measurements, the reported result was the scale factor of the TRMS, F_i, obtained by each participant in comparison with its local reference measuring system. Rated scale factors of the TRMS were as follows:

- 5 000 when using TRMS up to 20 kV (see clause 3.1 above).
- 50 000 when using TRMS up to 200 kV (see clause 3.1 above).

5.2 Low voltage measurements

5.2.1. Conditioning of the travelling generator

An arbitrary waveform generator Agilent Technologies, type 33220A, was provided to carry on these measurements. Control of this generator was accomplished with the commercial Agilent´s software "Agilent IntuiLink Waveform Editor".

Annex 6, "*Arbitrary Waveform Generator – User´s Guide*", of the comparison's technical protocol explained control and setting of the arbitrary generator to carry on these measurements.

Measurements using the travelling arbitrary waveform generator had to be done inside the ambient temperature range 18 ºC - 28 ºC. The generator and the measurement systems had to be placed on the measurements room at least 24 hours before comparison measurements.

The TRMS consisted on the HP 3458A connected to the PC with the analysis measuring software (see clause 3.1 of this document). Its rated scale factor was 1.

5.2.2. Scheduled measurements

All the comparison measurements were done with AC low voltage (50 Hz). Measurements were carried out measuring AC peak voltage.

Seven different signals were considered in order to simulate conditions that can be encountered in the field. These signals had amplitude of 10 V peak to peak and the following characteristics:

1) Pure sine wave.
2) Third harmonic distortion (30 %).
3) Forth harmonic distortion (5 %).
4) High frequency interference on the high voltage signal (5 % of the 20^{th} harmonic).
5) DC offset:
    5.1) 5 % of DC offset.
    5.2) 100 % of DC offset.
6) Triangular wave.

The signals had to be applied to the input of both, TRMS and laboratory's measuring system connected in parallel, and the AC peak voltage had to be measured. At least 10 readings had to be taken in every case.

5.2.3. Method of measurement

The participating laboratories were asked to follow their usual measurement procedures in order to reach their best measurement capabilities.

5.3 High voltage measurements

5.3.1. Conditioning of the TRMS

The TRMS had to be kept in the laboratory before the measurements for at least 24 hours so that it reached stable temperature. It was recommended to keep the ambient temperature on the value 23°C ± 2°C. The rest of instrumentation had to be placed on the control room next to the high voltage hall, and the measuring instrument of the TRMS had to be powered and switched on at least 2 hours before the measurements.

It was recommended to read Annex 5, *"A.C. Comparison Software – User's* Guide", of the comparison's technical protocol before doing the scheduled measurements.

The data of the ambient conditions during the measurements had to be included in the measurement report (part B, Annex 7 of the technical protocol of the comparison).

5.3.2. Scheduled measurements

All the comparison measurements had to be done with AC voltage (50 Hz) measuring AC peak and RMS values.

The rated scale factor of the TRMS was:

- 5 000 (up to 20 kV).
- 50 000 (voltage levels higher than 20 kV).

Determination of the measurement error should be made at the following voltage levels:

TRMS range	Voltage levels (kV)					
20 kV	0.75	1	5	10	15	20
200 kV	20	50	75	100	150	200

Table 3. Scheduled high voltage comparison measurements.

Measurements had to be done from the lowest to the highest voltage level. At least ten (10) readings had to be taken at each voltage level and then the voltage had to be increased immediately to the next level.

5.3.3. Method of measurement

The participating laboratories were asked to follow their usual measurement procedures in order to reach their best measurement capabilities.

6 Procedure of analysis of comparison results

6.1 General

Analysis of comparison results has been performed using the weighted mean together with a consistency test based on classical statistics.

6.2 Estimation of the Comparison Reference Values (CRV)

6.2.1 Low voltage measurements

The followed procedure has been applied considering that the next three conditions are satisfied:

1. Each participant gives one result of the TRMS which has good short term stability in comparison with its expanded uncertainty. Also a good stability during transportation has been observed taking into account participant results, even if a quantitative figure can not be given.
2. Measurements of different institutes are independent from each other. According to the information provided by the participating institutes, they all get their traceability by applying internal procedures and their own national standards so it is considered that there is no mutual dependence among the measurements of the comparison participants.
3. A Gaussian distribution can be assigned to the measurements by each laboratory (mean value equals the laboratory measurement and standard deviation equals the corresponding standard uncertainty).

On each type of measurement (waveshape), the comparison reference value, CRV, is considered as estimation, y, of the measurand according to the measurements provided by the participating laboratories.

This estimation, y, is determined as a weighted mean of the results provided where the weights are the inverse values of the squares of the associated standard uncertainties. However, this procedure cannot be applied in case of some of the measurements are not consistent with the others.

The number of participating laboratories, *N*, depends on the case considered (measurement waveshape). It ranges from 3 to 7.

The input magnitudes to evaluate are the measurement errors of the TRMS, ε_i, i = 1, 2, …, *N*, and the corresponding standard uncertainties, $u(\varepsilon_i)$, i = 1, 2, …, N, as provided by the participants.

The procedure is developed in the following steps:

a) Estimation of the CRV, y, as weighted means according to the following expression:

$$y = \frac{\sum_{i=1}^{N} \varepsilon_i \, u^{-2}(\varepsilon_i)}{\sum_{i=1}^{N} u^{-2}(\varepsilon_i)} \qquad (2)$$

b) Calculation of standard uncertainty of CRV, $u(y)$, according to the following expression:

$$u(y) = \frac{1}{\sqrt{\sum_{i=1}^{N} u^{-2}(\varepsilon_i)}} \qquad (3)$$

6.2.2 <u>High voltage measurements</u>

<u>Case 1: Measurement of RMS value</u>

The followed procedure is proposed considering that the next three conditions are satisfied on a first approach:

1. Each participant gives one result of the TRMS which has good short term stability in comparison with its expanded uncertainty. Also a good stability during transportation has been observed taking into account participant results, even if a quantitative figure can not be given.
2. Measurements of all different institutes are <u>not</u> independent among them. According to the information provided by the participating institutes BIM and VSL had their reference measurement systems calibrated in PTB, so that it is considered that there is mutual dependence among the measurements of these comparison participants. Then it is estimated that coherent correlation coefficients of BIM and VSL with PTB is 0.50, and between laboratories BIM and VSL is 0.25. Influence of uncertainty of estimated correlation factors is deemed negligible.
3. A Gaussian distribution can be assigned to the measurements by each laboratory (mean value equals the laboratory measurement and standard deviation equals the corresponding standard uncertainty).

On each voltage level, the comparison reference value, CRV, is considered as estimation, y, of the measurand according to the measurements provided by the participating laboratories.

This estimation, y, is determined as a weighted mean of the results provided, where the weights are the inverse values of the squares of the associated standard uncertainties. However, this procedure cannot be applied in case of some of the measurements are not consistent with the others.

The number of participating laboratories, N, depends on the voltage level considered. It ranges from 7 to 10.

The input magnitudes to evaluate are the scale factors of the TRMS, F_i, and their standard uncertainties $u(F_i)$, as provided by the participants, i = 1, 2, …, N. Correlation factors, r_{ij} , estimated as 0.50 (between BIM and PTB, and VSL and PTB), 0.25 (between BIM and VSL) and 0 in the remaining cases.

The procedure is developed in the following steps:

a) Estimation of the CRV, y, as weighted means according to the following expression:

$$y = \frac{\sum_{i=1}^{N} u^T(F_i)\cdot C^{-1}\cdot u(F_i)\cdot F_i}{\sum_{i=1}^{N} u^T(F_i)\cdot C^{-1}\cdot u(F_i)} \quad (4)$$

Where C^{-1} is the covariance matrix.

b) The standard uncertainty of CRV, $u(y)$, is calculated according to the following expression:

$$u(y) = \frac{1}{\sqrt{\sum_{i=1}^{N} u^T(F_i)\cdot C^{-1}\cdot u(F_i)}} \quad (5)$$

<u>Case 2: Measurement of Peak value / √2</u>

Same procedure as to low voltage measurements is applied (see 6.2.1), but using the scale factors, F_i, instead of the measurement errors, ε_i.

6.3 Analysis of consistency of results

<u>Compatibility with CRV</u>

A chi-squared test has been applied to carry out an overall consistency check of the results obtained (i.e. if all results can be regarded as belonging to the same statistical ensemble). For each measurement point the observed chi-squared value χ^2_{obs} has been determined as:

$$\chi^2_{obs,LV} = \sum_{i=1}^{N} \frac{(\varepsilon_i - y)^2}{u^2(\Delta\varepsilon_i)} \qquad \chi^2_{obs,HV} = \sum_{i=1}^{N} \frac{(F_i - y)^2}{u^2(\Delta F_i)} \quad (6)$$

The degrees of freedom are $\nu = N - 1$, for N results.

The consistency check is considered failed if Pr{ $\chi^2(\nu) > \chi^2_{obs}$ }< 5%

where Pr denotes "probability of".

If the chi-squared does not fail the determined CRV is deemed valid. When the chi-squared test fails, then the compatibility indexes $|d_i|$ are considered:

Degrees of equivalence of laboratory i, i = 1, 2, …, N, with the corresponding estimated CRV is determined as the pair of values for the deviation from the estimation y and the uncertainty of this deviation [$\Delta\varepsilon_i$, $U(\Delta\varepsilon_i)$] for LV, and [ΔF_i, $U(\Delta F_i)$] for HV measurements, according to the expressions:

$$\Delta\varepsilon_i = \varepsilon_i - y \quad ; \qquad \Delta F_i = F_i - y \quad (7)$$

$$U(\Delta\varepsilon_i) = 2\cdot u(\Delta\varepsilon_i) \quad ; \quad U(\Delta F_i) = 2\cdot u(\Delta F_i) \quad (8)$$

Where $u(\Delta\varepsilon_i)$ or $u(\Delta F_i)$ are obtained applying the following expression: $u^2(\Delta\varepsilon_i) = u^2(\varepsilon_i) - u^2(y)$; $u^2(\Delta F_i) = u^2(F_i) - u^2(y)$ (9)

Note 1: The factor 2 in expression (8) above indicates a coverage factor of 95 % corresponding to a Gaussian distribution function.

Note 2: Expression (9) establishes a difference of two variances as consequence of the mutual dependence (or correlation) between ε_i and CRV or between F_i and CRV.

Compatibility index, d_i, is defined as the ratio between the difference from the reference value and the standard uncertainty:

$$d_i = \frac{\Delta\varepsilon_i}{u(\Delta\varepsilon_i)} = \frac{\varepsilon_i - y}{\sqrt{u^2(\varepsilon_i) - u^2(y)}} \; ; \qquad d_i = \frac{\Delta F_i}{u(\Delta F_i)} = \frac{F_i - y}{\sqrt{u^2(F_i) - u^2(y)}} \qquad (10)$$

The compatibility index $|d_i|$ describes the deviation from the estimated CRV in relation to the calculated standard uncertainty of the deviation.

Assuming results ε_i or F_i , follow a normal distribution and their standard uncertainty $u(\varepsilon_i)$ or $u(F_i)$ are properly estimated, indexes d_i would follow a normal distribution with zero mean value and variance one. Then the probability that $|d_i|$ (absolute value) is higher than 2 is approximately 5 % and so comparison results with $|d_i|$ higher than 2 (confidence level of 95 %) could be deemed non-compatible with the CRV.

Then, in each measurement point, where the corresponding chi-squared test fails the laboratory with larger compatibility index $|d_i|$ is excluded from the determination of the CRV and the whole process is repeated again (estimation of CRV and their uncertainties, chi-squared test and calculation of compatibility indexes). This procedure is followed as many times as needed until the chi-square test is successful.

The standard uncertainties of the differences corresponding to those laboratories whose results are not considered in the reference value calculation are obtained applying the following expression:

$$u^2(\Delta\varepsilon_i) = u^2(\varepsilon_i) + u^2(y) \; ; \quad u^2(\Delta F_i) = u^2(F_i) + u^2(y) \qquad (11)$$

since now the values are not correlated.

7 Comparison results

7.1 Measurement environmental conditions

Tables 4 and 5 show ambient conditions as reported by each participating laboratory during their measurements.

Laboratory	Temperature (ºC)	Humidity (%)
LCOE	23 ± 2	< 60
LNE	23 ± 1	NR
MIKES	21.0 ± 0.5	NR
SP	24.5 ± 1.0	NR
TÜBITAK-UME	23 ± 1	NR
VNIIMS	28 ± 1	22

Table 4. Reported ambient conditions. Low voltage measurements.

Laboratory	Temperature (ºC)	Humidity (%)
BIM	23 ± 2	40 - 60
LCOE	25 ± 2	40 ± 3
LNE	23 ± 1	NR
INRIM	23.2	50
MIKES	21 ± 0.5	NR
PTB	22	NR
SP	23.5 ± 1	NR
TÜBITAK-UME	23 ± 1	NR
VNIIMS	25 ± 2	< 50
VSL	23 ± 0.5	45 ± 5

Table 5. Reported ambient conditions. High voltage measurements.

7.2 Results of low voltage measurements

Tables 6 and 7 summarize the results obtained by every laboratory. The first one contains the error of the TRMS as given by the participating laboratories and the second one shows the corresponding expanded uncertainty (k = 2). The nominal scale factor of the TRMS was 1 (direct reading).

Waveshape description	**Reported Error of TRMS, ε_i (ppm)**						
	Lab.						
	LCOE	**LNE**	**MIKES**	**INRIM**	**SP**	**TÜBITAK**	**VNIIMS**
Pure sine wave	-15	57	-3	-1 969	14	18	94
30 % of 3rd harmonic	-10	-57	-10	-2 222	-14	-16	73
5 % of 4th harmonic	-15	-177	-9	-378	-35	14	27
5 % of 20th harmonic	-	-	-153	-	-694	-	-15
5 % of DC offset	-20	-212	-7	-223	-35	-60	40
100 % of DC offset	-	-57	-6	-608	28	8	125
Triangular wave (*)	-28	-4 353	-385	-2 766	-3 573	-51	-2 950

Table 6. Low voltage comparison results. Error of TRMS. Low voltage Peak/√2 value measurement.

(*) Due to a misunderstanding, triangular wave with very sharp corners was utilized in the comparison instead of the proposed one, which was limited to the 11th harmonic. The test was intended as a proof of the capability of measuring waveforms that are distorted, but still possible to encounter on high voltage alternating sources. Therefore, this part of the comparison is of little interest in relation to high alternating voltages measuring capability under the conditions set out in Standards IEC 60060-1 and IEC 60060-2.

Waveshape description	Expanded uncertainty of Error of TRMS, $U(\varepsilon_i)$(ppm)						
	Lab.						
	LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS
Pure sine wave	300	300	22	2 350	234	102	210
30 % of 3rd harmonic	300	300	22	2 174	234	122	210
5 % of 4th harmonic	300	300	30	2 306	234	102	210
5 % of 20th harmonic	-	-	40	-	236	-	210
5 % of DC offset	300	300	22	2 002	234	102	210
100 % of DC offset	-	300	22	2 782	234	102	210
Triangular wave	300	300	600	2 372	368	768	210

Table 7. Low voltage comparison results. Expanded uncertainty. Low voltage Peak/√2 value measurement.

7.3 Results of high voltage measurements

7.3.1 Measurement of RMS value

Tables 8 and 9 summarize the results obtained by every laboratory when measuring RMS value of the applied high voltage. The former contains the scale factor of the TRMS as reported by the participating laboratories and the latter shows the corresponding expanded uncertainty (k = 2). The nominal scale factors of the TRMS were 5 000 for 20 kV range and 50 000 for 200 kV range.

Range (kV)	Voltage level (kV)	Reported Scale Factor of TRMS, F_i. RMS value									
		Lab.									
		LCOE	BIM	LNE	MIKES	INRIM	VSL	SP	TÜBITAK	VNIIMS	PTB
20	0.75	4 988	-	4 980.6	4 982.2	4 978	4 980	4 979	4 981	5 001	4 977
	1	4 988	-	4 980.6	4 982.1	4 981	4 981	4 980	4 981	5 001	4 976.9
	5	4 982	4 978	4 981.3	4 982.4	4 979	4 979,6	4 979	4 982	4 998	4 979.3
	10	4 983	4 979	4 980.9	4 982.1	4 980	4 980,90	4 981	4 982	5 001	4 978.9
	15	4 982	4 980	4 980.8	4 981.6	-	4 981,3	4 981	4 981	5 000	4 978.8
	20	4 981	4 980	4 980.8	4 981.4	4 981	4 981,1	4 979	4 982	-	4 978.4
200	20	50 005	49 976	49 981	50 003	50 069	50 004	49 992	50 003	49 990	49 977
	50	49 995	49 978	49 982	50 009	50 111	49 987	49 981	49 999	49 995	49 993
	75	49 982	50 001	49 986	50 010	50 119	49 996	49 987	50 001	49 997	49 992
	100	49 998	50 006	49 995	50 010	50 125	50 000	50 009	49 999	50 005	49 988
	150	49 998	-	49 985	50 008	50 144	-	50 004	50 002	50 012	49 981
	200	49 998	-	49 984	50 002	50 156	-	49 975	49 999	-	49 979

Table 8. High voltage comparison results. Scale Factor of TRMS. RMS value measurement.

Range (kV)	Voltage level (kV)	Expanded uncertainty of reported TRMS' scale factor, $U(F_i)$ (ppm)									
		Lab.									
		LCOE	BIM	LNE	MIKES	INRIM	VSL	SP	TÜBITAK	VNIIMS	PTB
20	0.75	500	-	164	84	5160	302	462	600	380	260
	1	500	-	162	72	4584	502	434	600	380	194
	5	500	812	154	88	4008	122	406	614	380	160
	10	500	744	138	79	4000	104	400	612	380	160
	15	500	596	138	57	-	106	994	612	380	160
	20	500	616	136	57	4000	102	448	608	-	160
200	20	500	568	148	283	4000	102	416	662	380	162
	50	500	634	134	119	4000	138	368	632	380	162
	75	500	476	424	107	4000	174	442	630	380	160
	100	500	330	420	112	4000	130	434	642	380	160
	150	500	-	448	54	4000	-	638	646	380	190
	200	500	-	844	62	5160	-	508	630	-	240

Table 9. High voltage comparison results. Expanded uncertainty (k = 2). RMS value measurement.

7.3.2 Measurement of Vpeak / √2 value

Tables 10 and 11 summarize the results obtained by every laboratory when measuring peak value / √2 of the applied high voltage sine wave. The former contains the scale factor of the TRMS as reported by the participating laboratories and the latter shows the corresponding expanded uncertainty (k = 2). The nominal scale factors of the TRMS were 5 000 for 20 kV range and 50 000 for 200 kV range.

Range (kV)	Voltage level (kV)	Reported Scale Factor of TRMS, F_i . Peak/√2 value							
		Lab.							
		LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS	PTB
20	0.75	4980	4981	4980,4	4 985	4 978	4 981	4 999	4 978.7
	1	-	4981	4980,4	4 985	4 978	4 981	4 999	4 978.7
	5	4982	4981	4980,2	4 986	4 981	4 981	5 000	4 979.0
	10	4981	4981	4980,2	4 984	4 979	4 981	5 000	4 978.9
	15	4981	4981	4980,2	-	4 981	4 981	5 000	4 979.0
	20	4981	4981	4980,2	4 983	4 982	4 981	-	4 979.0
200	20	49 995	50 005	49 985	50 061	49 985	49 982	49 988	49 980
	50	49 993	49 990	49 988	50 153	49 983	49 989	49 982	49 983
	75	49 991	49 991	49 987	50 151	49 972	49 982	49 974	49 984
	100	49 991	49 985	49 989	50 140	49 994	49 983	49 967	49 982
	150	49 991	50 004	49 988	49 979	49 994	49 986	49 981	49 981
	200	49 989	49 994	49 982	49 723	49 990	49 984	-	49 982

Table 10. High voltage comparison results. Scale Factor of TRMS. Peak/√2 value measurement.

Range (kV)	Voltage level (kV)	Expanded uncertainty of reported TRMS' scale factor, $U(F_i)$ (ppm)							
		Lab.							
		LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS	PTB
20	0.75	500	558	79	6 002	512	602	450	82
	1	-	568	68	6 020	408	602	450	84
	5	500	538	52	6 034	530	618	450	80
	10	500	568	42	6 004	470	614	450	80
	15	500	568	40	-	564	610	450	80
	20	500	556	38	6 014	602	610	-	82
200	20	500	1106	155	6 006	408	680	450	82
	50	500	1026	109	6 004	498	640	450	82
	75	500	1284	77	6 004	328	626	450	90
	100	500	3340	52	6 002	336	648	450	82
	150	500	2100	50	6 002	312	656	450	82
	200	500	3570	60	7 560	460	644	-	82

Table 11. High voltage comparison results. Expanded uncertainty. Peak/√2 value measurement.

8 Analysis of comparison results

8.1 General

Analysis of comparison results has been performed following the procedures described in clause 6 above.

8.2 Estimation of the Comparison Reference Values (CRV)

8.2.1 *CRV for low voltage measurements*

Table 12 shows the comparison reference values, *CRV*, corresponding to the low voltage measurements with several waveshapes, as well as their expanded uncertainty, *U(CRV)*. Furthermore, Annex I, part 1, shows the result of applying the procedure described in the previous clause 6.2, so that it is possible to check wich laboratories' results have been considered for *CRV* calculation.

Waveshape description	*CRV* (ppm)	*U(CRV)* (k = 2) (ppm)
Pure sine wave	-1	21
30 % of 3rd harmonic	-10	21
5 % of 4th harmonic	-8	28
5 % of 20th harmonic	-148	39
5 % of DC offset	-10	21
100 % of DC offset	-4	21
Triangular wave	-2949	209

Table 12. Comparison reference values (*CRV*) and their uncertainties for **low voltage measurements**.

8.2.2 *CRV for high voltage measurements. Measurement of RMS value*

When applying the analysis procedure described in 6.2.2 above (case 1) for RMS measurements, the consistency chi-squared test according to clause 6.3 fails and the CRV is not valid. Then, a large compatibility index for some of the participants with lower uncertainties was obtained, so that they had to be ruled out of CRV calculation. Then the CRV obtained were no representative of the comparison measurements.

Further investigation was carried out in order to figure out that incompatibility. The technical protocol of the comparison and the way measurements were done by the participants were checked in order to find out differences. No mistakes or measurement errors were pinpointed by the participants with lowest uncertainties. Furthermore, the pilot laboratory performed additional measurements in order to determine possible influence of the temperature dependence of the capacitors that make up the TRMS, taking into account that the participants performed their measurements in a range of 23 ºC ± 2 ºC.

It was realized that stability of the TRMS in the long term was affected by the lack of stability of the measurement instrument (Hewlett-Packard, 3458A) of the travelling system due to the measurement mode (ACD ANA) used to carry out the comparison measurements. According to manufacturer's specifications of the 3458A when mode ACD ANA is used, a drifting up to 600 ppm of the reading + 100 ppm of the measurement range should be considered. This error source is significant enough to account for the scattered results and the lack of compatibility between the institutes with the lowest uncertainties.

Estimating a standard contribution of a quarter of the device specification, the drifting of the TRMS due to the setup of its measuring instrument 3458A is named u_{inst} and calculated as shown in the following table.

H.V. Level (kV)	**TRMS ratio**	**L.V. Level (V)**	***3458A range (V)***	***3458A Specification (ppm)***	**u_{inst} (ppm)**
0.75	5 000	0.15	1	1 267	317
1	5 000	0.2	1	1 100	275
5	5 000	1.0	1	700	176
10	5 000	2.0	10	1 100	275
15	5 000	3.0	10	933	234
20	5 000	4.0	10	850	213
20	50 000	0.4	1	850	213
50	50 000	1.0	1	700	176
75	50 000	1.5	10	1 267	317
100	50 000	2.0	10	1 100	275
150	50 000	3.0	10	933	234
200	50 000	4.0	10	850	213

Table 13. Estimation of instability of TRMS due to measurement setup of 3458A.

As a result, and in order to calculate *CRV*, an enlarged standard uncertainty for each participant can be calculated taking into account not only the uncertainty reported by each Institute, but also the estimated drifting of the measuring instrument 3458 A:

$$u(x_i) = u^2_{Institute_i} + u^2_{inst.}$$

where:

$u(x_i)$ standard uncertainty assigned to participant, *i*, taking into account possible drif of 3458 A digital multimeter.

$u^2_{Institute_i}$ standard uncertainty reported by NMI, *i*, (expanded uncertainty of table 9 divided by 2).

$u^2_{inst.}$ standard uncertainty due to the possible drift between participants of 3458 A digital multimeter.

Table 14 shows the comparison reference values, *CRV*, and its expanded uncertainty, *U(CRV)*, at each voltage level. Furthermore, Annex I, part 3, of this report shows the result of applying the procedure described in the previous paragraph 6.2.2 (case 2), and it is possible to check which laboratories were considered to obtain these *CRV*.

Range (kV)	**Voltage level (kV)**	***CRV***	***U(CRV)* (k = 2) (ppm)**
20	0.75	4 980.0	289
	1	4 980.2	261
	5	4 980.1	182
	10	4 981.0	227
	15	4 980.8	206
	20	4 980.4	186
200	20	49 992	181
	50	49 992	154
	75	49 996	244
	100	50 001	216
	150	49 999	230
	200	49 991	242

Table 14. Comparison reference values and their uncertainties. H.V. measurements, rms value.

8.2.3 *CRV for high voltage measurements. Measurement of Peak value / √2*

Table 15 shows the comparison reference values, *CRV*, and its expanded uncertainty, *U(CRV)*, at each voltage level. Furthermore, Annex I, part 2, of this report shows the result of applying the procedure described in the previous paragraph 6.2.2 (case 2), and it is possible to check which laboratories were considered to obtain these *CRV*.

Range (kV)	Voltage level (kV)	*CRV*	*U(CRV)* (k = 2) (ppm)
20	0.75	4 980.4	76
	1	4 978.8	81
	5	4 980.2	51
	10	4 980.2	41
	15	4 980.2	40
	20	4 980.2	38
200	20	49 982	69
	50	49 985	63
	75	49 985	56
	100	49 987	43
	150	49 986	42
	200	49 982	48

Table 15. Comparison reference values and their uncertainties. H.V. measurements, Peak/√2 value.

Note: CRV are obtained by statistical treatment of participants results. The CRV obtained for 1 kV level clearly shows a lack of linearity in comparison with the rest of scale factors of the same range. Taking into account that the measuring system is composed of linear behaviour elements (standard capacitors and the analogue to digital converter of the DMM) an intermediate scale factor value between the scale factor values of 0,75 kV and 5 kV seems more likely. Anywhere all adopted CRV are obtained by the procedure described in 8.2. and summarized in table 15.

8.3 Compatibility of results

8.3.1 Compatibility of low voltage results

According to clause 6.3.1 above, table 16 summarizes the differences between each laboratory's results and the corresponding comparison reference value, and in table 17 the corresponding expanded uncertainties of those differences are included.

Waveshape description	Difference from CRV (ppm): $\Delta\varepsilon_i = \varepsilon_i - CRV$						
	Lab.						
	LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS
Pure sine wave	-14	58	-2	-1968	15	19	95
30 % of 3rd harmonic	0	-47	0	-2212	-4	-6	83
5 % of 4th harmonic	-7	-169	0	-370	-27	22	35
5 % of 20th harmonic	-	-	-5	-	-546	-	133
5 % of DC offset	-10	-202	3	-213	-25	-50	50
100 % of DC offset	-	-53	-2	-604	32	12	129
Triangular	2921	-1404	2564	183	-624	2898	-1

Table 16. **Low voltage comparison results**. Differences from the comparison reference value.

Waveshape description	Expanded uncertainty of the difference from CRV (ppm): $U(\Delta\varepsilon_i)$						
	Lab.						
	LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS
Pure sine wave	299	299	6	2350	233	100	209
30 % of 3rd harmonic	299	299	5	2174	233	120	209
5 % of 4th harmonic	299	299	11	2306	232	98	208
5 % of 20th harmonic	-	-	7	-	239	-	206
5 % of DC offset	299	299	6	2002	233	100	209
100 % of DC offset	-	299	6	2782	233	100	209
Triangle	366	366	635	2363	423	796	19

Table 17. **Low voltage comparison results**. Expanded uncertainties of the differences from the CRV.

Annex II, part 1 of this report summarizes graphically the results of this part of the comparison.

8.3.2 Compatibility of high voltage results, rms value.

Table 18 summarizes the differences between each laboratory and the comparison reference value for these measurements, and in table 19 the corresponding expanded uncertainties of those differences are included.

Range (kV)	Voltage level (kV)	Difference from CRV (ppm): $\Delta F_i = F_i - CRV$. rms value									
		Lab.									
		LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS	BIM	VSL	PTB
20	0.75	1606	120	442	-402	-201	201	4217	-	0	-602
	1	1567	81	382	161	-40	161	4177	-	161	-662
	5	372	231	452	-231	-231	372	3584	-432	-110	-171
	10	410	-12	229	-193	8	209	4023	-393	-12	-414
	15	247	6	167	-	46	46	3861	-154	107	-395
	20	111	71	191	111	-290	312	-	-90	131	-411
200	20	265	-216	225	1545	5	225	-35	-316	245	-296
	50	62	-198	342	2383	-218	142	62	-278	-98	22
	75	-273	-193	287	2467	-173	107	27	107	7	-73
	100	-69	-129	171	2471	151	-49	71	91	-29	-269
	150	-11	-271	189	2909	109	69	269	-	-	-351
	200	139	-141	219	3299	-321	159	-	-	-	-241

Table 18. **High voltage measurements, rms value**. Difference from CRV.

Range (kV)	Voltage level (kV)	Expanded uncertainty of the difference from CRV (ppm): *U(*ΔF$_i$)									
		Lab.									
		LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS	BIM	VSL	PTB
20	0.75	857	586	569	5191	728	823	793	-	639	620
	1	787	509	488	4609	649	770	717	-	697	520
	5	583	337	405	4019	505	683	548	866	324	340
	10	707	518	506	4027	640	790	705	896	510	525
	15	653	442	424	-	1079	742	637	729	433	450
	20	630	407	388	4018	590	719	-	726	397	416
200	20	632	413	478	4019	567	766	542	687	399	418
	50	591	343	337	4005	485	706	494	708	344	355
	75	769	722	594	4039	732	859	697	753	609	606
	100	711	657	517	4027	666	817	632	603	521	530
	150	645	606	411	4017	757	764	557	-	-	450
	200	611	914	356	5169	617	721	-	-	-	425

Table 19. **High voltage measurements, rms value**. Expanded uncertainties of the differences from the CRV.

8.3.3 Compatibility of high voltage results. Peak/√2 value

Table 20 summarizes the differences between each laboratory and the comparison reference value for these measurements, and in table 21 the corresponding expanded uncertainties of those differences are included.

Range (kV)	Voltage level (kV)	Difference from *CRV* (ppm): $\Delta F_i = F_i - CRV$. Peak/√2 value							
		Lab.							
		LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS	PTB
20	0.75	-72	129	8	932	-474	129	3743	-333
	1	-	450	329	1253	-153	450	4065	-12
	5	354	153	-8	1157	153	153	3968	-249
	10	160	160	-1	762	-242	160	3975	-262
	15	157	157	-3	-	157	157	3972	-244
	20	157	157	-4	559	358	157	-	-245
200	20	265	465	65	1586	65	5	125	-35
	50	161	101	61	3362	-39	81	-59	-39
	75	116	116	36	3317	-264	-64	-224	-24
	100	81	-39	41	3062	141	-79	-399	-99
	150	97	355	35	-145	155	-5	-105	-105
	200	135	237	-3	-5185	157	37	-	-3

Table 20. **High voltage measurements. Peak/√2 value**. Difference from CRV.

Range (kV)	Voltage level (kV)	Expanded uncertainty of the difference from CRV (ppm): $U(\Delta\varepsilon_i)$							
		Lab.							
		LCOE	LNE	MIKES	INRIM	SP	TÜBITAK	VNIIMS	PTB
20	0.75	494	553	22	6002	506	597	456	112
	1	-	562	106	6019	400	597	457	23
	5	497	536	10	6034	528	616	453	95
	10	498	566	7	6004	468	613	452	90
	15	498	567	6	-	563	609	452	89
	20	499	555	5	6014	601	609	-	90
200	20	495	1104	139	6006	402	676	445	44
	50	496	1024	89	6004	494	637	446	52
	75	497	1283	52	6004	323	623	446	70
	100	498	3340	29	6002	333	647	448	70
	150	498	2100	27	6002	309	655	448	71
	200	498	3570	36	7560	458	642	-	67

Table 21. **High voltage measurements. Peak/√2 value**. Expanded uncertainties of the differences from the CRV.

Annex II, part 2 of this report summarizes graphically the results of this part of the comparison.

9 Final remarks

Nine EURAMET institutes and one COOMET institute participated in this international supplementary comparison of AC high voltage measurement up to 200 kV. The same measurement method was used by all the participants: comparison with reference measuring system.

The comparison reference values, *CRV*, and their uncertainties were calculated as weighted means according to the above mentioned formulae. In each voltage level, the consistency of the *CRV* was checked studying the difference of each provided result and the estimation of the comparison reference value (weighted mean), together with the standard uncertainties of those differences. Those results non consistent were not included in the calculation of the comparison *CRV*.

It can be noticed that the expanded relative uncertainty (k=2) of the *CRV* varies a lot depending on the measurement group: for low voltage measurements between 21.10^{-6} and 39.10^{-6} depending on the waveshape, for Peak/√2 hv measurements between 38.10^{-6} and 81.10^{-6} depending on the voltage level and for *RMS* hv measurements between 154.10^{-6} and 289.10^{-6} depending also on the voltage.

Therefore, CRV expanded relative uncertainty is lower for low voltage measurments, around double for peak hv measurments and much grater for RMS hv measurements. The reason is that for RMS hv measurements, long term stability of the *TRMS* was affected by the lack of stability of the multimeter (Hewlett-Packard, 3458A) of the *TRMS* due to the measurement mode (ACD ANA) used to carry out the comparison measurements. Therefore in order to estimate the CRV and their uncertainties together with the compatibility index, d_i, of each laboratory an enlarged uncertainty associated with the measuring result of each participant has been calculated using an estimation of the long term stability of 3458A. For that reason uncertainties associated with *RMS* CRV are greater than for peak values.

The differences from the CRV and their uncertainties together with the compatibility index, d_i, of each laboratory result are presented. There are significant differences among the uncertainties given by the participants and as a result of that the CRV are biased towards the institutes with lowest uncertainties. Not all the participants used equivalent reference measuring systems, most of them used capacitive dividers for hv, but others used standard voltage transformers, low voltage branch is also different, most of them used digital multimeter 3458 A, but others used special designed RMS o peak voltage measuring systems. Also software is different. All this explains the differences among the uncertainties given by the participants.

Some of the measurements performed in low voltage were not useful or valid for comparison purposes due to the different reasons explained in this report. Specifically, triangular wave used for some of the low voltage comparisons had very high order harmonics, therefore conclusions for this waveshape have no interest in relation to high alternating voltages measuring capability.

Results of the comparison offer the chance to check the calibration and measurement capabilities of the participants in the field of high voltage AC measurement, specially when performing peak hv measurements up to 200 kV with expanded uncertainties in the range of 40 ppm to 80 ppm.

ANNEX I

Determination of comparison reference values, *CRV*, and compatibility index, d_i .

ANNEX I. Part 1

Determination of comparison reference values, *CRV*, and compatibility index, d_i, for

Low voltage measurements

Waveshape: “Pure sine wave”

Laboratory	x_i (ppm)	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0 (ppm)	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	χ^2 test	Exclude
LCOE	-15	150	0,0000	0,5%	-1	-14	150	-0,10	0,01	
LNE	57	150	0,0000	0,5%		58	150	0,39	0,15	
MIKES	-3	11	0,0083	92,8%	$u(x_0)$ (ppm)	-2	3	-0,71	0,04	
INRIM	-1969	1175	0,0000	0,0%	11	-1968	1175	-1,68	2,81	
SP	14	117	0,0001	0,8%		15	117	0,13	0,02	
TÜBITAK	18	51	0,0004	4,3%		19	50	0,38	0,13	
VNIIMS	94	105	0,0001	1,0%		95	104	0,91	0,81	

χ^2_{obs}	3,96
N-1	6
Probability	68,2%

Accepted

Waveshape: “30 % of 3rd harmonic”

Laboratory	x_i (ppm)	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0 (ppm)	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	-10	150	0,0000	0,5%	-10	0	150	0,00	0,00	
LNE	-57	150	0,0000	0,5%		-47	150	-0,32	0,10	
MIKES	-10	11	0,0083	94,1%	$u(x_0)$ (ppm)	0	3	-0,07	0,00	
INRIM	-2222	1087	0,0000	0,0%	11	-2212	1087	-2,04	4,14	
SP	-14	117	0,0001	0,8%		-4	117	-0,04	0,00	
TÜBITAK	-16	61	0,0003	3,1%		-6	60	-0,10	0,01	
VNIIMS	73	105	0,0001	1,0%		83	104	0,79	0,62	

χ^2_{obs}	4,87
N-1	6
Probability	56,0%

Accepted

Waveshape: "5 % of 4th harmonic"

Laboratory	x_i (ppm)	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0 (ppm)	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	-15	150	0,0000	0,9%	-8	-7	149	-0,04	0,00	
LNE	-177	150	0,0000	0,9%		-169	149	-1,13	1,26	
MIKES	-9	15	0,0044	87,4%	$u(x_0)$ (ppm)	0	5	-0,08	0,00	
INRIM	-378	1153	0,0000	0,0%	14	-370	1153	-0,32	0,10	
SP	-35	117	0,0001	1,4%		-27	116	-0,23	0,05	
TÜBITAK	14	51	0,0004	7,6%		22	49	0,46	0,19	
VNIIMS	27	105	0,0001	1,8%		35	104	0,34	0,11	

χ^2_{obs}	1,73
N-1	6
Probability	94,3%

Accepted

Waveshape: "5 % of 20th harmonic"

Laboratory	x_i (ppm)	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0 (ppm)	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE					-148					
LNE										
MIKES	-153	20	0,0025	96,5%	$u(x_0)$ (ppm)	-5	4	-1,29	0,06	
INRIM					20					
SP	-694	118				-546	120	-4,56		x
TÜBITAK										
VNIIMS	-15	105	0,0001	3,5%		133	103	1,29	1,61	

χ^2_{obs}	1,67
N-1	1
Probability	19,7%

Accepted

Waveshape: "5 % of DC offset"

Laboratory	x_i (ppm)	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0 (ppm)	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	-20	150	0,0000	0,5%	-10	-10	150	-0,07	0,00	
LNE	-212	150	0,0000	0,5%		-202	150	-1,35	1,81	
MIKES	-7	11	0,0083	92,8%	$u(x_0)$ (ppm)	3	3	1,07	0,08	
INRIM	-223	1001	0,0000	0,0%	11	-213	1001	-0,21	0,05	
SP	-35	117	0,0001	0,8%		-25	117	-0,21	0,04	
TÜBITAK	-60	51	0,0004	4,3%		-50	50	-1,00	0,95	
VNIIMS	40	105	0,0001	1,0%		50	104	0,48	0,23	

χ^2_{obs}	3,17
N-1	6
Probability	78,8%

Accepted

Waveshape: "100 % of DC offset"

Laboratory	x_i (ppm)	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0 (ppm)	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE					-4					
LNE	-57	150	0,0000	0,5%		-53	150	-0,36	0,13	
MIKES	-6	11	0,0083	93,3%	$u(x_0)$ (ppm)	-2	3	-0,67	0,03	
INRIM	-608	1391	0,0000	0,0%	11	-604	1391	-0,43	0,19	
SP	28	117	0,0001	0,8%		32	117	0,27	0,07	
TÜBITAK	8	51	0,0004	4,3%		12	50	0,24	0,05	
VNIIMS	125	105	0,0001	1,0%		129	104	1,23	1,50	

χ^2_{obs}	1,98
N-1	5
Probability	85,3%

Accepted

Waveshape: “Triangular”

Laboratory	x_i (ppm)	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0 (ppm)	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	-28	150			-2949	2921	183	15,97		x
LNE	-4353	150				-1404	183	-7,68		x
MIKES	-385	300			$u(x_0)$ (ppm)	2564	318	8,07		x
INRIM	-2766	1186	0,0000	0,8%	105	183	1181	0,15	0,02	
SP	-3573	184				-624	212	-2,95		x
TÜBITAK	-51	384				2898	398	7,28		x
VNIIMS	-2950	105	0,0001	99,2%		-1	9	-0,15	0,00	

χ^2_{obs}	0,02
N-1	1
Probability	87,7%

Accepted

ANNEX I. Part 2

Determination of comparison reference values, *CRV*, and compatibility index, d_i, for H.V. measurements (Peak/√2 value)

Range: 20 kV. Level: 0.75 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	4980	250	0,00001600	2,3%	4980,4	-72	247	-0,29	0,08	
LNE	4981	279	0,00001285	1,8%	$u(x_0)$ (ppm)	129	276	0,47	0,21	
MIKES	4980,4	39,5	0,00064092	92,1%	38	8	11	0,73	0,04	
INRIM	4985	3001	0,00000011	0,0%		932	3001	0,31	0,10	
SP	4978	256	0,00001526	2,2%		-474	253	-1,87	3,42	
TÜBITAK	4981	301	0,00001104	1,6%		129	299	0,43	0,18	
VNIIMS	4999	225				3743	228	16,40		x
PTB	4978,7	41				-333	56	-5,97		x
								χ^2_{obs}	4,04	
								N-1	5	
Accepted								Probability	54,3%	

Range: 20 kV. Level: 1 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE					4978,8					
LNE	4981	284	0,00001240	2,0%	$u(x_0)$ (ppm)	450	281	1,60	2,51	
MIKES	4980,4	34			40	329	53	6,24		x
INRIM	4985	3010	0,00000011	0,0%		1253	3010	0,42	0,17	
SP	4978	204	0,00002403	3,9%		-153	200	-0,76	0,56	
TÜBITAK	4981	301	0,00001104	1,8%		450	298	1,51	2,23	
VNIIMS	4999	225				4065	229	17,78		x
PTB	4978,7	42	0,00056689	92,3%		-12	12	-1,06	0,09	
								χ^2_{obs}	5,56	
								N-1	4	
Accepted								Probability	23,5%	

Range: 20 kV. Level: 5 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	4982	250	0,00001600	1,0%	4980,2	354	249	1,42	2,00	
LNE	4981	269	0,00001382	0,9%	$u(x_0)$ (ppm)	153	268	0,57	0,32	
MIKES	4980,2	26	0,00147929	96,4%	26	-8	5	-1,61	0,09	
INRIM	4986	3017	0,00000011	0,0%		1157	3017	0,38	0,15	
SP	4981	265	0,00001424	0,9%		153	264	0,58	0,33	
TÜBITAK	4981	309	0,00001047	0,7%		153	308	0,50	0,24	
VNIIMS	5000	225				3968	226	17,52		x
PTB	4979,0	40				-249	47	-5,24		x
								χ^2_{obs}	3,14	
								N-1	5	
								Probability	67,9%	

Accepted

Range: 20 kV. Level: 10 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	4981	250	0,00001600	0,7%	4980,2	160	249	0,64	0,41	
LNE	4981	284	0,00001240	0,5%	$u(x_0)$ (ppm)	160	283	0,56	0,32	
MIKES	4980,2	21	0,00226757	97,5%	21	-1	3	-0,26	0,00	
INRIM	4984	3002	0,00000011	0,0%		762	3002	0,25	0,06	
SP	4979	235	0,00001811	0,8%		-242	234	-1,03	1,06	
TÜBITAK	4981	307	0,00001061	0,5%		160	306	0,52	0,27	
VNIIMS	5000	225				3975	226	17,59		x
PTB	4978,9	40				-262	45	-5,81		x
								χ^2_{obs}	2,12	
								N-1	5	
								Probability	83,2%	

Accepted

Range: 20 kV. Level: 15 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	4981	250	0,00001600	0,6%	4980,2	157	249	0,63	0,40	
LNE	4981	284	0,00001240	0,5%	$u(x_0)$ (ppm)	157	283	0,56	0,31	
MIKES	4980,2	20	0,00250000	98,0%	20	-3	3	-1,14	0,03	
INRIM										
SP	4981	282	0,00001257	0,5%		157	281	0,56	0,31	
TÜBITAK	4981	305	0,00001075	0,4%		157	304	0,52	0,27	
VNIIMS	5000	225				3972	226	17,59		x
PTB	4979,0	40				-244	45	-5,47		x
								χ^2_{obs}	1,31	
								N-1	4	
Accepted								Probability	86,0%	

Range: 20 kV. Level: 20 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	4981	250	0,00001600	0,6%	4980,2	157	249	0,63	0,39	
LNE	4981	278	0,00001294	0,5%	$u(x_0)$ (ppm)	157	277	0,57	0,32	
MIKES	4980,2	19	0,00277008	98,2%	19	-4	3	-1,45	0,04	
INRIM	4983	3007	0,00000011	0,0%		559	3007	0,19	0,03	
SP	4982	301	0,00001104	0,4%		358	300	1,19	1,41	
TÜBITAK	4981	305	0,00001075	0,4%		157	304	0,52	0,26	
VNIIMS										
PTB	4979,0	41				-245	45	-5,42		x
								χ^2_{obs}	2,46	
								N-1	5	
Accepted								Probability	78,2%	

Range: 200 kV. Level: 20 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	49995	250	0,00001600	1,9%	49982	265	248	1,07	1,12	
LNE	50005	553	0,00000327	0,4%	$u(x_0)$ (ppm)	465	552	0,84	0,71	
MIKES	49985	77,5	0,00016649	20,0%	35	65	69	0,94	0,70	
INRIM	50061	3003	0,00000011	0,0%		1586	3003	0,53	0,28	
SP	49985	204	0,00002403	2,9%		65	201	0,32	0,10	
TÜBITAK	49982	340	0,00000865	1,0%		5	338	0,01	0,00	
VNIIMS	49988	225	0,00001975	2,4%		125	222	0,56	0,31	
PTB	49980	41	0,00059488	71,4%		-35	22	-1,60	0,73	
								χ^2_{obs}	3,95	
								N-1	7	
								Probability	78,5%	

Accepted

Range: 200 kV. Level: 50 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	49993	250	0,00001600	1,6%	49985	161	248	0,65	0,42	
LNE	49990	513	0,00000380	0,4%	$u(x_0)$ (ppm)	101	512	0,20	0,04	
MIKES	49988	54,5	0,00033667	33,8%	32	61	44	1,38	1,27	
INRIM	50153	3002	0,00000011	0,0%		3362	3002	1,12	1,25	
SP	49983	249	0,00001613	1,6%		-39	247	-0,16	0,02	
TÜBITAK	49989	320	0,00000977	1,0%		81	318	0,26	0,06	
VNIIMS	49982	225	0,00001975	2,0%		-59	223	-0,26	0,07	
PTB	49983	41	0,00059488	59,7%		-39	26	-1,49	0,89	
								χ^2_{obs}	4,02	
								N-1	7	
								Probability	77,7%	

Accepted

Range: 200 kV. Level: 75 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	49991	250	0,00001600	1,3%	49985	116	248	0,47	0,22	
LNE	49991	642	0,00000243	0,2%	$u(x_0)$ (ppm)	116	641	0,18	0,03	
MIKES	49987	38,5	0,00067465	53,8%	28	36	26	1,37	0,87	
INRIM	50151	3002	0,00000011	0,0%		3317	3002	1,10	1,22	
SP	49972	164	0,00003718	3,0%		-264	162	-1,63	2,59	
TÜBITAK	49982	313	0,00001021	0,8%		-64	312	-0,21	0,04	
VNIIMS	49974	225	0,00001975	1,6%		-224	223	-1,00	0,99	
PTB	49984	45	0,00049383	39,4%		-24	35	-0,69	0,29	
								χ^2_{obs}	6,25	
								N-1	7	
Accepted								Probability	51,0%	

Range: 200 kV. Level: 100 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	49991	250	0,00001600	0,7%	49987	81	249	0,33	0,11	
LNE	49985	1670	0,00000036	0,0%	$u(x_0)$ (ppm)	-39	1670	-0,02	0,00	
MIKES	49989	26	0,00147929	68,6%	22	41	15	2,82	2,50	
INRIM	50140	3001	0,00000011	0,0%		3062	3001	1,02	1,04	
SP	49994	168	0,00003543	1,6%		141	167	0,85	0,71	
TÜBITAK	49983	324	0,00000953	0,4%		-79	323	-0,24	0,06	
VNIIMS	49967	225	0,00001975	0,9%		-399	224	-1,78	3,14	
PTB	49982	41	0,00059488	27,6%		-99	35	-2,84	5,82	
								χ^2_{obs}	13,38	
								N-1	7	
Accepted								Probability	6,3%	

Range: 200 kV. Level: 150 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	49991	250	0,00001600	0,7%	49986	97	249	0,39	0,15	
LNE	50004	1050	0,00000091	0,0%	$u(x_0)$ (ppm)	355	1050	0,34	0,11	
MIKES	49988	25	0,00160000	70,1%	21	35	14	2,57	1,98	
INRIM	49979	3001	0,00000011	0,0%		-145	3001	-0,05	0,00	
SP	49994	156	0,00004109	1,8%		155	155	1,00	0,99	
TÜBITAK	49986	328	0,00000930	0,4%		-5	327	-0,01	0,00	
VNIIMS	49981	225	0,00001975	0,9%		-105	224	-0,47	0,22	
PTB	49981	41	0,00059488	26,1%		-105	35	-2,97	6,54	

χ^2_{obs}	10,00
N-1	7
Probability	18,9%

Accepted

Range: 200 kV. Level: 200 kV (Peak/√2 value)

Laboratory	x_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i (ppm)	$u(\Delta x_i)$ (ppm)	d_i	chi^2 test	Exclude
LCOE	49989	250	0,00001600	0,9%	49982	135	249	0,54	0,29	
LNE	49994	1785	0,00000031	0,0%	$u(x_0)$ (ppm)	237	1785	0,13	0,02	
MIKES	49982	30	0,00111111	63,5%	24	-3	18	-0,17	0,01	
INRIM	49723	3780	0,00000007	0,0%		-5185	3780	-1,37	1,88	
SP	49990	230	0,00001890	1,1%		157	229	0,69	0,47	
TÜBITAK	49984	322	0,00000964	0,6%		37	321	0,12	0,01	
VNIIMS										
PTB	49982	41	0,00059488	34,0%		-3	33	-0,09	0,01	

χ^2_{obs}	2,69
N-1	6
Probability	84,7%

Accepted

ANNEX I. Part 3

Determination of comparison reference values, *CRV*, and compatibility index, d_i, for H.V. measurements (rms value)

Range: 20 kV. Level: 0.75 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	4988	403			4980,0	1606	428	3,75		X
LNE	4980,6	327	0,00000935	19,6%	$u(x_0)$ (ppm)	120	293	0,41	0,17	
MIKES	4982,2	319	0,00000981	20,5%	145	442	285	1,55	2,41	
INRIM	4978	2599	0,00000015	0,3%		-402	2595	-0,15	0,02	
SP	4979	392	0,00000651	13,6%		-201	364	-0,55	0,30	
TÜBITAK	4981	436	0,00000526	11,0%		201	411	0,49	0,24	
VNIIMS	5001	369				4217	396	10,64		X
BIM										
VSL	4980	351	0,00000813	17,0%		0	319	0,00	0,00	
PTB	4977	342	0,00000854	17,9%		-602	310	-1,94	3,78	
				100,0%				χ^2_{obs}	6,92	
								N-1	6	
Accepted								Probability	32,8%	

Range: 20 kV. Level: 1 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	4988	371			4980,2	1567	394	3,98		X
LNE	4980,6	286	0,00001221	20,8%	$u(x_0)$ (ppm)	81	255	0,32	0,10	
MIKES	4982,1	277	0,00001305	22,2%	131	382	244	1,56	2,45	
INRIM	4981	2308	0,00000019	0,3%		161	2305	0,07	0,00	
SP	4980	350	0,00000817	13,9%		-40	325	-0,12	0,01	
TÜBITAK	4981	407	0,00000605	10,3%		161	385	0,42	0,17	
VNIIMS	5001	334				4177	358	11,65		X
BIM										
VSL	4981	372	0,00000723	12,3%		161	348	0,46	0,21	
PTB	4976,9	291	0,00001180	20,1%		-662	260	-2,54	6,48	
				100,0%				χ^2_{obs}	9,43	
								N-1	6	
Accepted								Probability	15,1%	

Range: 20 kV. Level: 5 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	4982	305	0,00001072	8,9%	4980,1	372	292	1,27	1,62	
LNE	4981,3	192	0,00002723	22,5%	$u(x_0)$ (ppm)	231	169	1,37	1,88	
MIKES	4982,4	181			91	452	202	2,23		X
INRIM	4979	2012	0,00000025	0,2%		-231	2010	-0,11	0,01	
SP	4979	268	0,00001389	11,5%		-231	252	-0,91	0,84	
TÜBITAK	4982	354	0,00000800	6,6%		372	342	1,09	1,18	
VNIIMS	4998	259				3584	274	13,07		X
BIM	4978	442	0,00000511	4,2%		-432	433	-1,00	0,99	
VSL	4979,6	186	0,00002897	23,9%		-110	162	-0,68	0,46	
PTB	4979,3	193	0,00002688	22,2%		-171	170	-1,00	1,00	
				100,0%				χ^2_{obs}	7,99	
								N-1	7	
Accepted								Probability	33,3%	

Range: 20 kV. Level: 10 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	4983	371	0,00000725	9,4%	4981,0	410	353	1,16	1,34	
LNE	4980,9	283	0,00001248	16,1%	$u(x_0)$ (ppm)	-12	259	-0,05	0,00	
MIKES	4982,1	277	0,00001300	16,8%	114	229	253	0,90	0,82	
INRIM	4980	2019	0,00000025	0,3%		-193	2014	-0,10	0,01	
SP	4981	340	0,00000867	11,2%		8	320	0,03	0,00	
TÜBITAK	4982	411	0,00000592	7,7%		209	395	0,53	0,28	
VNIIMS	5001	334				4023	353	11,41		X
BIM	4979	462	0,00000468	6,1%		-393	448	-0,88	0,77	
VSL	4980,9	279	0,00001281	16,6%		-12	255	-0,05	0,00	
PTB	4978,9	286	0,00001223	15,8%		-414	262	-1,58	2,49	
				100,0%				χ^2_{obs}	5,71	
								N-1	8	
Accepted								Probability	67,9%	

Range: 20 kV. Level: 15 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	4982	342	0,00000853	9,1%	4980,8	247	327	0,76	0,57	
LNE	4980,8	244	0,00001680	17,9%	$u(x_0)$ (ppm)	6	221	0,03	0,00	
MIKES	4981,6	236	0,00001800	19,1%	103	167	212	0,79	0,62	
INRIM										
SP	4981	549	0,00000331	3,5%		46	540	0,09	0,01	
TÜBITAK	4981	385	0,00000674	7,2%		46	371	0,13	0,02	
VNIIMS	5000	301				3861	319	12,12		X
BIM	4980	379	0,00000697	7,4%		-154	365	-0,42	0,18	
VSL	4981,3	240	0,00001737	18,5%		107	217	0,49	0,24	
PTB	4978,8	247	0,00001635	17,4%		-395	225	-1,76	3,09	
				100,0%				χ^2_{obs}	4,73	
								N-1	7	
Accepted								Probability	69,3%	

Range: 20 kV. Level: 20 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	4981	328	0,00000927	8,0%	4980,4	111	315	0,35	0,12	
LNE	4980,8	224	0,00002000	17,2%	$u(x_0)$ (ppm)	71	203	0,35	0,12	
MIKES	4981,4	215	0,00002165	18,6%	93	191	194	0,99	0,97	
INRIM	4981	2011	0,00000025	0,2%		111	2009	0,06	0,00	
SP	4979	309	0,00001047	9,0%		-290	295	-0,99	0,97	
TÜBITAK	4982	371	0,00000726	6,2%		312	359	0,87	0,75	
VNIIMS										
BIM	4980	374	0,00000713	6,1%		-90	363	-0,25	0,06	
VSL	4981,1	219	0,00002085	17,9%		131	198	0,66	0,44	
PTB	4978,4	228	0,00001932	16,6%		-411	208	-1,98	3,91	
				100,0%				χ^2_{obs}	7,36	
								N-1	8	
Accepted								Probability	49,9%	

Range: 200 kV. Level: 20 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	50005	328	0,00000927	7,6%	49991,8	265	316	0,84	0,70	
LNE	49981	225	0,00001967	16,1%	$u(x_0)$ (ppm)	-216	207	-1,04	1,09	
MIKES	50003	256	0,00001529	12,5%	90	225	239	0,94	0,88	
INRIM	50069	2011	0,00000025	0,2%		1545	2009	0,77	0,59	
SP	49992	298	0,00001128	9,2%		5	284	0,02	0,00	
TÜBITAK	50003	394	0,00000645	5,3%		225	383	0,59	0,34	
VNIIMS	49990	285	0,00001227	10,0%		-35	271	-0,13	0,02	
BIM	49976	355	0,00000793	6,5%		-316	343	-0,92	0,84	
VSL	50004	219	0,00002085	17,0%		245	200	1,23	1,50	
PTB	49977	228	0,00001926	15,7%		-296	209	-1,41	2,00	
				100,0%				χ^2_{obs}	7,97	
								N-1	9	
Accepted								Probability	53,8%	

Range: 200 kV. Level: 50 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	49995	305	0,00001072	6,3%	49991,9	62	296	0,21	0,04	
LNE	49982	188	0,00002834	16,8%	$u(x_0)$ (ppm)	-198	171	-1,15	1,33	
MIKES	50009	185	0,00002912	17,2%	77	342	169	2,03	4,12	
INRIM	50111	2008	0,00000025	0,1%		2383	2002	1,19	1,42	
SP	49981	254	0,00001547	9,2%		-218	242	-0,90	0,81	
TÜBITAK	49999	361	0,00000765	4,5%		142	353	0,40	0,16	
VNIIMS	49995	259	0,00001495	8,8%		62	247	0,25	0,06	
BIM	49978	362	0,00000762	4,5%		-278	354	-0,78	0,62	
VSL	49987	189	0,00002812	16,6%		-98	172	-0,57	0,32	
PTB	49993	193	0,00002677	15,8%		22	177	0,13	0,02	
				100,0%				χ^2_{obs}	8,90	
								N-1	9	
Accepted								Probability	44,6%	

Range: 200 kV. Level: 75 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	49982	403	0,00000615	9,2%	49995,7	-273	384	-0,71	0,51	
LNE	49986	381	0,00000689	10,3%	$u(x_0)$ (ppm)	-193	361	-0,54	0,29	
MIKES	50010	321	0,00000971	14,5%	122	287	297	0,97	0,93	
INRIM	50119	2025	0,00000024	0,4%		2467	2020	1,22	1,49	
SP	49987	386	0,00000671	10,0%		-173	366	-0,47	0,22	
TÜBITAK	50001	447	0,00000502	7,5%		107	430	0,25	0,06	
VNIIMS	49997	369	0,00000734	10,9%		27	348	0,08	0,01	
BIM	50001	396	0,00000638	9,5%		107	377	0,28	0,08	
VSL	49996	328	0,00000928	13,8%		7	305	0,02	0,00	
PTB	49992	326	0,00000938	14,0%		-73	303	-0,24	0,06	
				100,0%				χ^2_{obs}	3,65	
								N-1	9	
Accepted								Probability	93,3%	

Range: 200 kV. Level: 100 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	49998	371	0,00000725	8,4%	50001,5	-69	355	-0,20	0,04	
LNE	49995	346	0,00000837	9,7%	$u(x_0)$ (ppm)	-129	328	-0,39	0,16	
MIKES	50010	280	0,00001274	14,8%	108	171	259	0,66	0,44	
INRIM	50125	2019	0,00000025	0,3%		2471	2014	1,23	1,51	
SP	50009	350	0,00000817	9,5%		151	333	0,45	0,20	
TÜBITAK	49999	422	0,00000561	6,5%		-49	408	-0,12	0,01	
VNIIMS	50005	334	0,00000897	10,4%		71	316	0,22	0,05	
BIM	50006	320	0,00000975	11,3%		91	302	0,30	0,09	
VSL	50000	282	0,00001257	14,6%		-29	261	-0,11	0,01	
PTB	49988	286	0,00001223	14,2%		-269	265	-1,02	1,03	
				100,0%				χ^2_{obs}	3,54	
								N-1	9	
Accepted								Probability	93,9%	

Range: 200 kV. Level: 150 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
LCOE	49998	342	0,00000853	11,3%	49998,6	-11	323	-0,04	0,00	
LNE	49985	324	0,00000953	12,6%	$u(x_0)$ (ppm)	-271	303	-0,90	0,80	
MIKES	50008	236	0,00001802	23,8%	115	189	206	0,92	0,84	
INRIM	50144	2014	0,00000025	0,3%		2909	2008	1,45	2,10	
SP	50004	396	0,00000639	8,4%		109	379	0,29	0,08	
TÜBITAK	50002	399	0,00000629	8,3%		69	382	0,18	0,03	
VNIIMS	50012	301	0,00001101	14,5%		269	279	0,96	0,93	
BIM										
VSL										
PTB	49981	253	0,00001568	20,7%		-351	225	-1,56	2,44	
				100,0%				χ^2_{obs}	7,23	
								N-1	7	
Accepted								Probability	40,5%	

Range: 200 kV. Level: 200 kV (rms value)

Laboratory	X_i	$u(x_i)$ (ppm)	$1/u^2(x_i)$ (ppm^{-2})	Weight (%)	x_0	Δx_i(ppm)	$u(\Delta x_i)$ (ppm)	di	chi^2 test	Exclude
A	49998	328	0,00000927	13,6%	49991,1	139	305	0,45	0,21	
B	49984	473	0,00000448	6,6%	$u(x_0)$ (ppm)	-141	457	-0,31	0,10	
C	50002	215	0,00002158	31,6%	121	219	178	1,23	1,51	
D	50156	2589	0,00000015	0,2%		3299	2585	1,28	1,63	
E	49975	331	0,00000910	13,3%		-321	309	-1,04	1,08	
F	49999	380	0,00000692	10,1%		159	360	0,44	0,19	
G										
H										
I										
J	49979	244	0,00001673	24,5%		-241	212	-1,14	1,29	
				100,0%				χ^2_{obs}	6,01	
								N-1	6	
Accepted								Probability	42,2%	

ANNEX II

Graphs of differences to the reference values and their uncertainties.

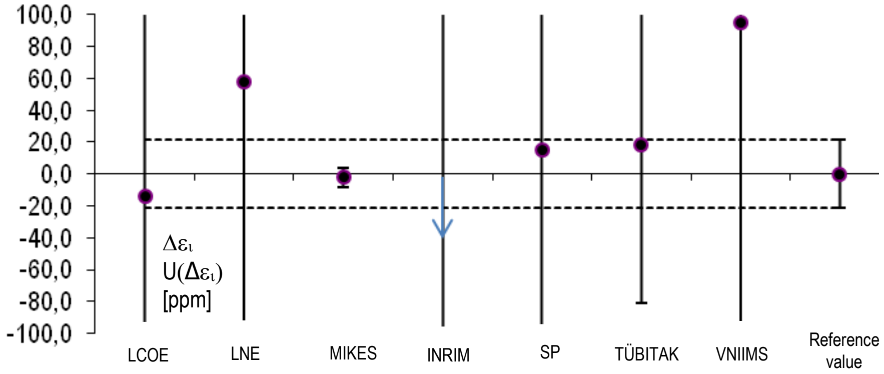
ANNEX II. Part 1

Graphs of differences to the reference values and their uncertainties: Low Voltage Measurements

LOW VOLTAGE MEASUREMENTS

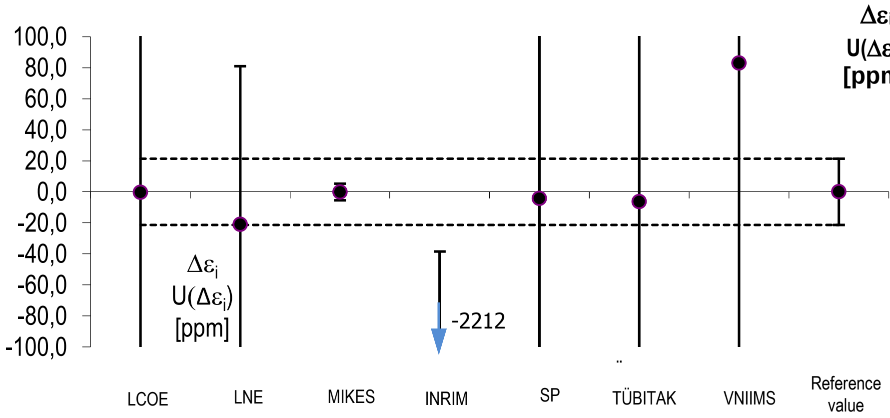
Δεi
U(Δεi)
[ppm]

Pure sine wave	Δεi [ppm]	U (Δεi) [ppm]
LCOE	-14	299
LNE	58	299
MIKES	-2	6
INRIM	-1968	2350
SP	15	233
TÜBITAK	19	100
VNIIMS	95	209
Ref. value	0	21



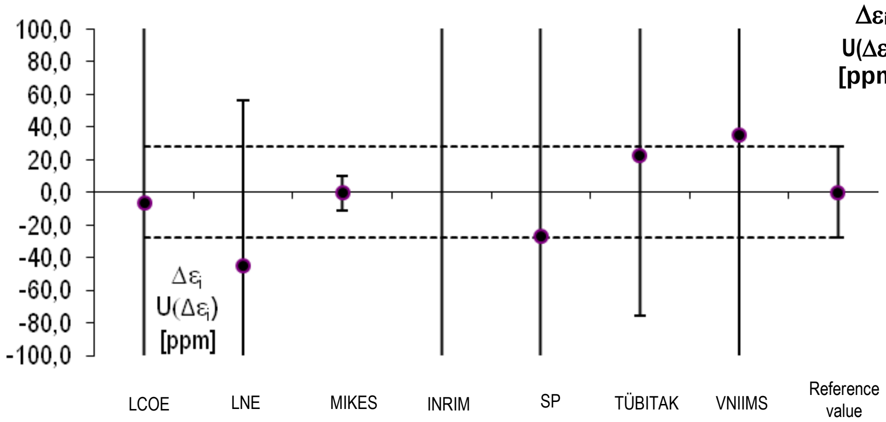
Δεi
U(Δεi)
[ppm]

30%, 3rd Harmonic	Δεi [ppm]	U (Δεi) [ppm]
LCOE	0	299
LNE	-21	102
MIKES	0	5
INRIM	-2212	2174
SP	-4	233
TÜBITAK	-6	120
VNIIMS	83	209
Ref. value	0	21



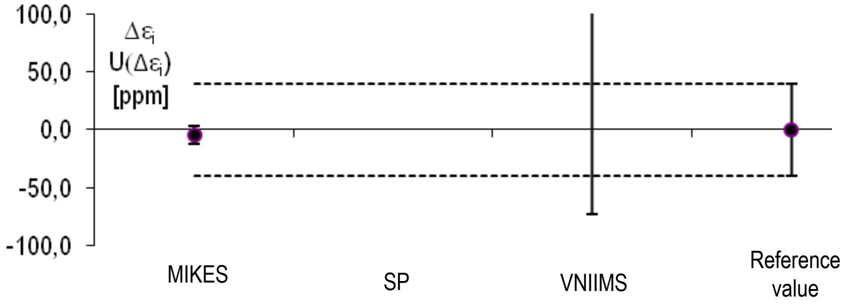
Δεi
U(Δεi)
[ppm]

5%, 4th Harmonic	Δεi [ppm]	U (Δεi) [ppm]
LCOE	-7	299
LNE	-45	101
MIKES	0	11
INRIM	-370	2306
SP	-27	232
TÜBITAK	22	98
VNIIMS	35	208
Ref. value	0	28

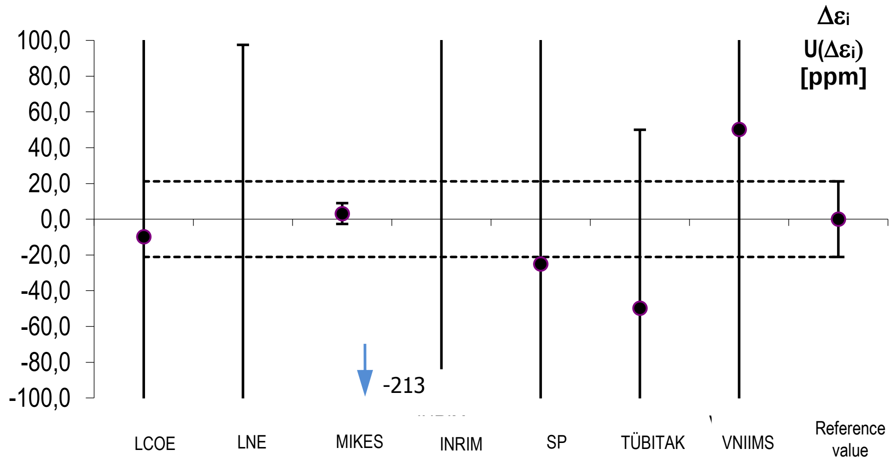


Δεi
U(Δεi)
[ppm]

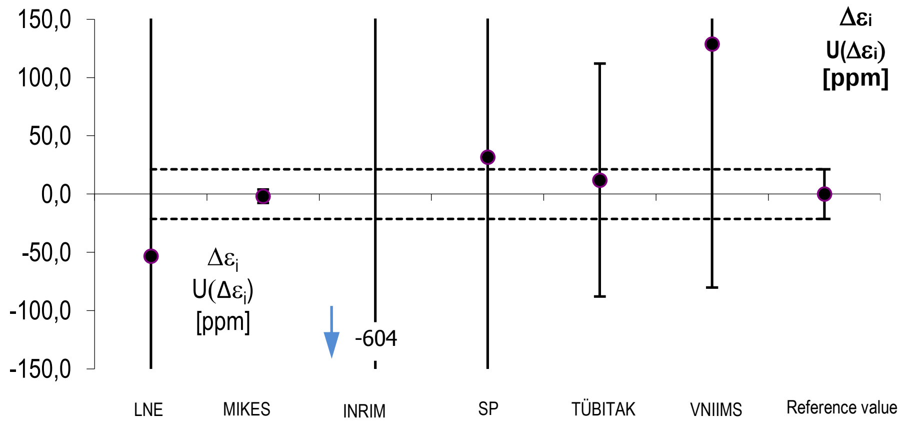
5%, 20th Harmonic	Δεi [ppm]	U (Δεi) [ppm]
MIKES	-5	7
SP	-546	239
VNIIMS	133	206
Ref. value	0	39



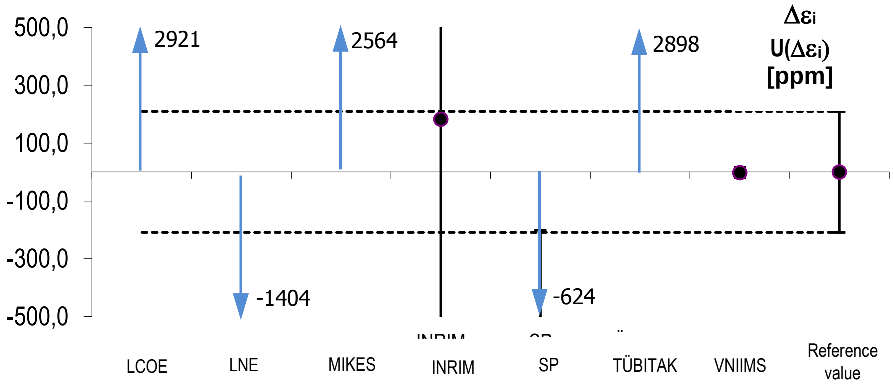
5%, DC Offset	Δεi [ppm]	U (Δεi) [ppm]
LCOE	-10	299
LNE	-202	299
MIKES	3	6
INRIM	-213	2002
SP	-25	233
TÜBITAK	-50	100
VNIIMS	50	209
Ref. value	0	21



100%, DC Offset	Δεi [ppm]	U (Δεi) [ppm]
LNE	-53	299
MIKES	-2	6
INRIM	-604	2782
SP	32	233
TÜBITAK	12	100
VNIIMS	129	209
Ref. value	0	21



Triangle	Δεi [ppm]	U (Δεi) [ppm]
LCOE	2921	366
LNE	-1404	366
MIKES	2564	635
INRIM	183	2363
SP	-624	423
TÜBITAK	2898	796
VNIIMS	-1	19
Ref. value	0	209

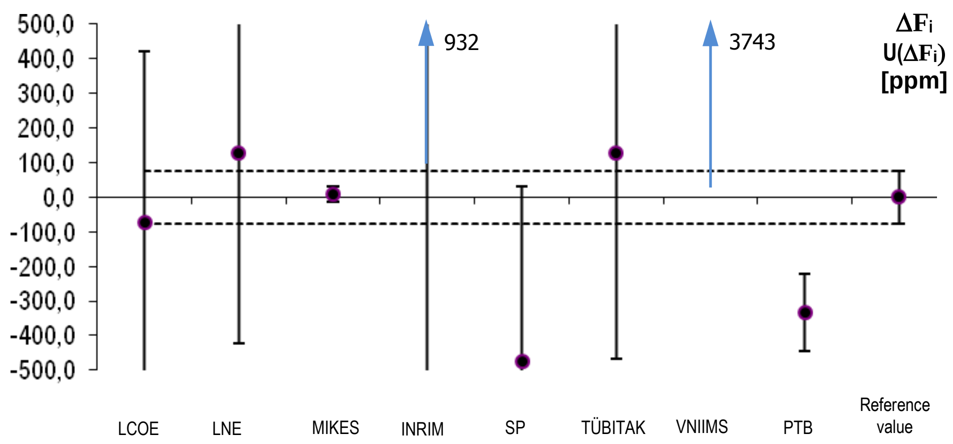


ANNEX II. Part 2

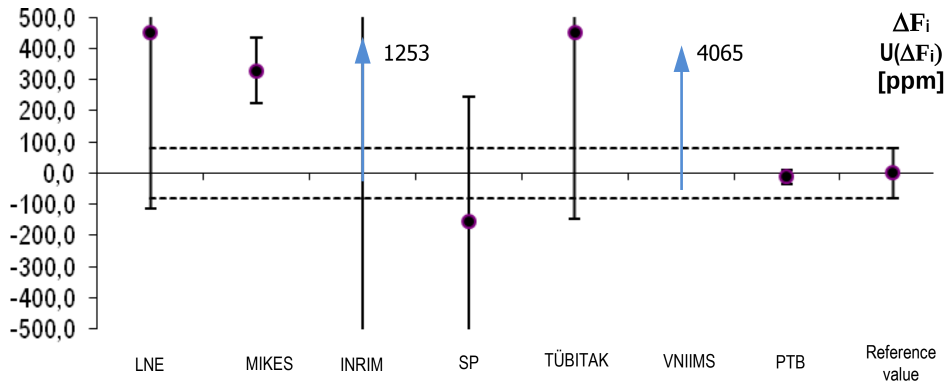
Graphs of differences to the reference values and their uncertainties: H.V. Measurements (Peak/√2 value)

PEAK VOLTAGE /√2 MEASUREMENTS: Range 20 kV

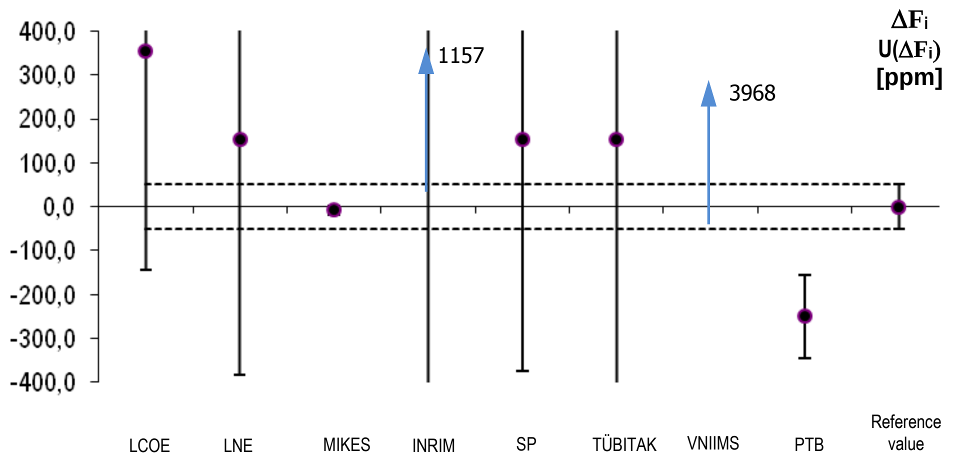
0.75 kV	ΔF_i [ppm]	U (ΔF_i) [ppm]
LCOE	-72	494
LNE	129	553
MIKES	8	22
INRIM	932	6002
SP	-474	506
TÜBITAK	129	597
VNIIMS	3743	456
PTB	-333	112
Ref. value	0	76



1 kV	ΔF_i [ppm]	U(ΔF_i) [ppm]
LNE	450	562
MIKES	329	106
INRIM	1253	6019
SP	-153	400
TÜBITAK	450	597
VNIIMS	4065	457
PTB	-12	23
Ref. value	0	81

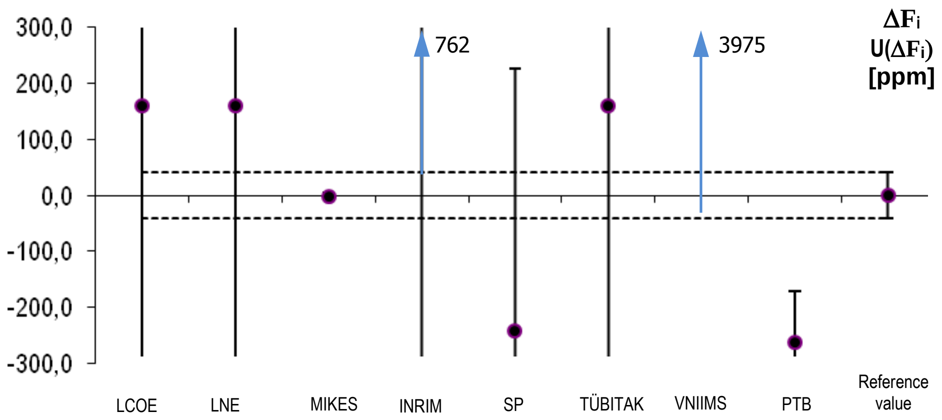


5 kV	ΔF_i [ppm]	U (ΔF_i) [ppm]
LCOE	354	497
LNE	153	536
MIKES	-8	10
INRIM	1157	6034
SP	153	528
TÜBITAK	153	616
VNIIMS	3968	453
PTB	-249	95
Ref. value	0	51

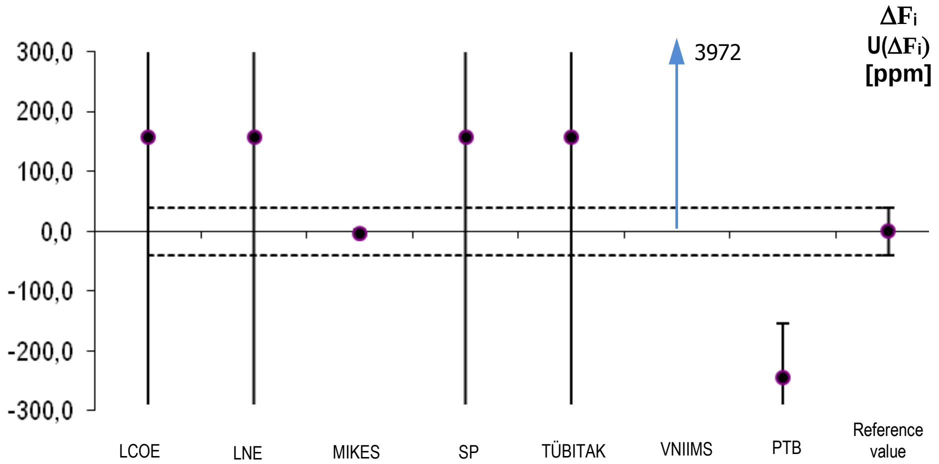


PEAK VOLTAGE /√2 MEASUREMENTS: Range 20 kV (cont.)

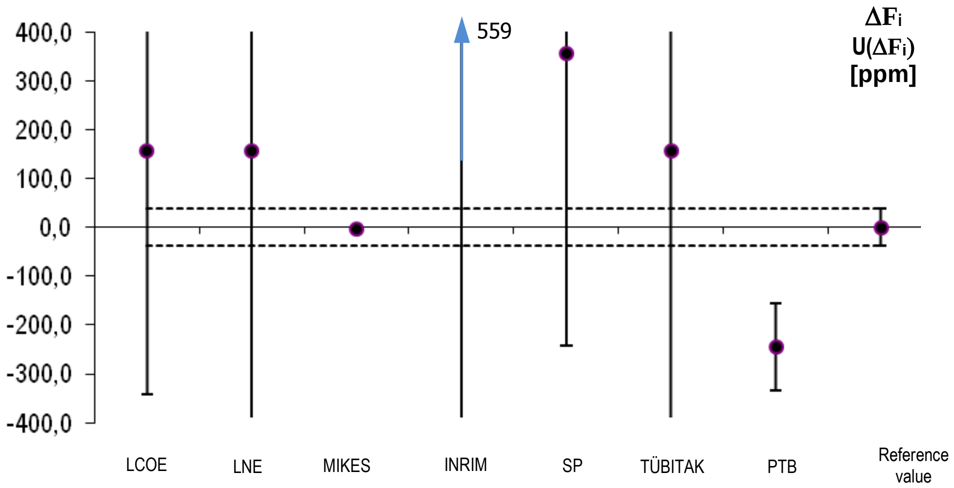
10 kV	ΔF_i [ppm]	U (ΔF_i) [ppm]
LCOE	160	498
LNE	160	566
MIKES	-1	7
INRIM	762	6004
SP	-242	468
TÜBITAK	160	613
VNIIMS	3975	452
PTB	-262	90
Ref. value	0	41



15 kV	ΔF_i [ppm]	U (ΔF_i) [ppm]
LCOE	157	498
LNE	157	567
MIKES	-3	6
SP	157	563
TÜBITAK	157	609
VNIIMS	3972	452
PTB	-244	89
Ref. value	0	40

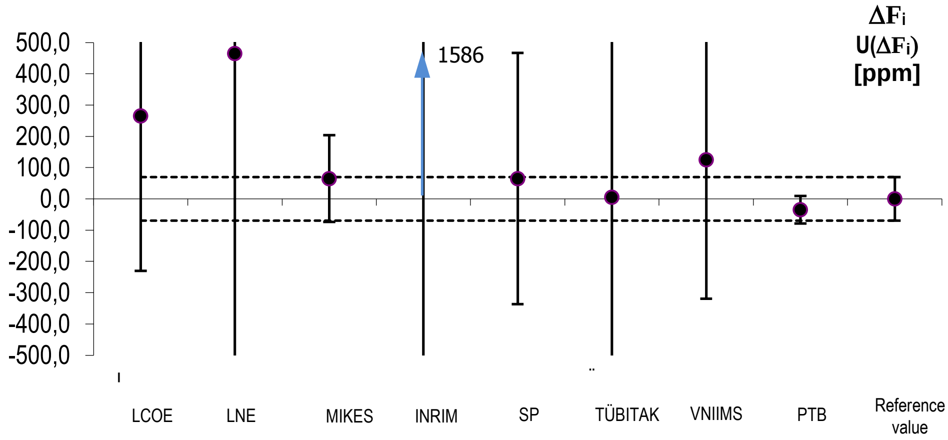


20 kV	ΔF_i [ppm]	U(ΔF_i) [ppm]
LCOE	157	499
LNE	157	555
MIKES	-4	5
INRIM	559	6014
SP	358	601
TÜBITAK	157	609
PTB	-245	90
Ref. value	0	38

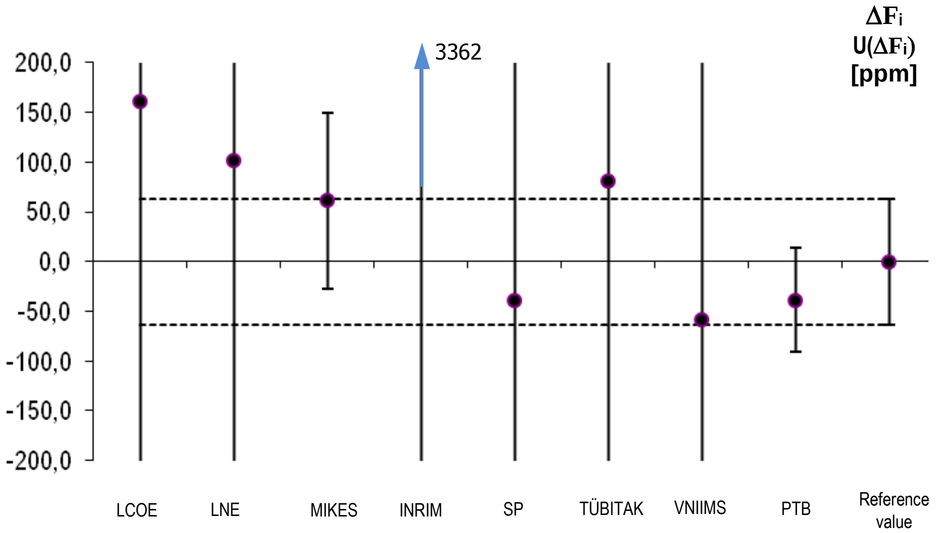


PEAK VOLTAGE /√2 MEASUREMENTS: Range 200 kV

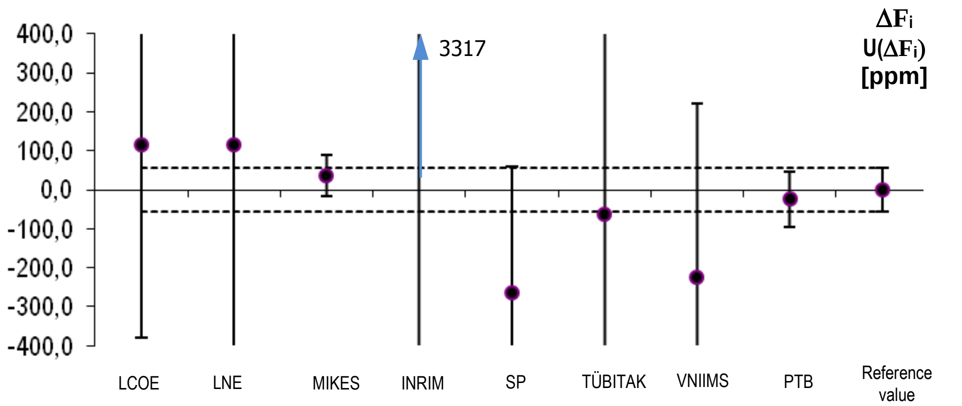
20 kV	ΔFi [ppm]	U (ΔFi) [ppm]
LCOE	265	495
LNE	465	1104
MIKES	65	139
INRIM	1586	6006
SP	65	402
TÜBITAK	5	676
VNIIMS	125	445
PTB	-35	44
Ref. value	0	69



50 kV	ΔFi [ppm]	U (ΔFi) [ppm]
LCOE	161	496
LNE	101	1024
MIKES	61	89
INRIM	3362	6004
SP	-39	494
TÜBITAK	81	637
VNIIMS	-59	446
PTB	-39	52
Ref. value	0	63

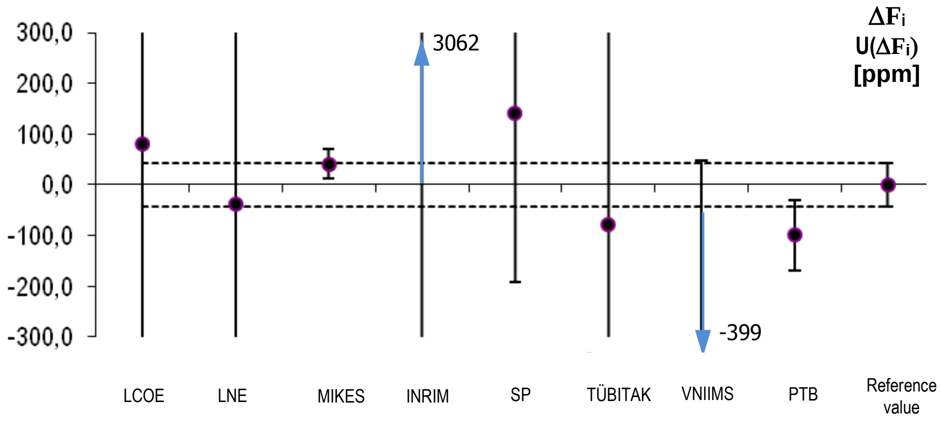


75 kV	ΔFi [ppm]	U (ΔFi) [ppm]
LCOE	116	497
LNE	116	1283
MIKES	36	52
INRIM	3317	6004
SP	-264	323
TÜBITAK	-64	623
VNIIMS	-224	446
PTB	-24	70
Ref. value	0	56

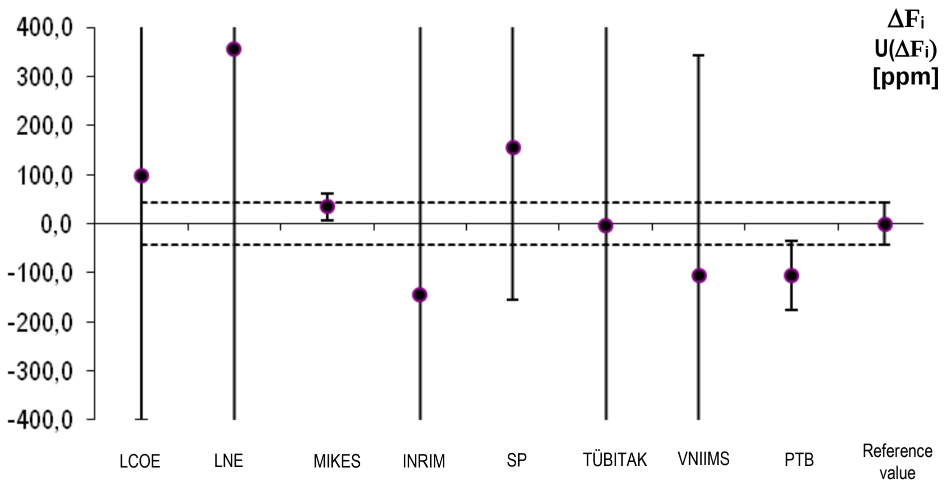


PEAK VOLTAGE /√2 MEASUREMENTS: Range 200 kV (cont.)

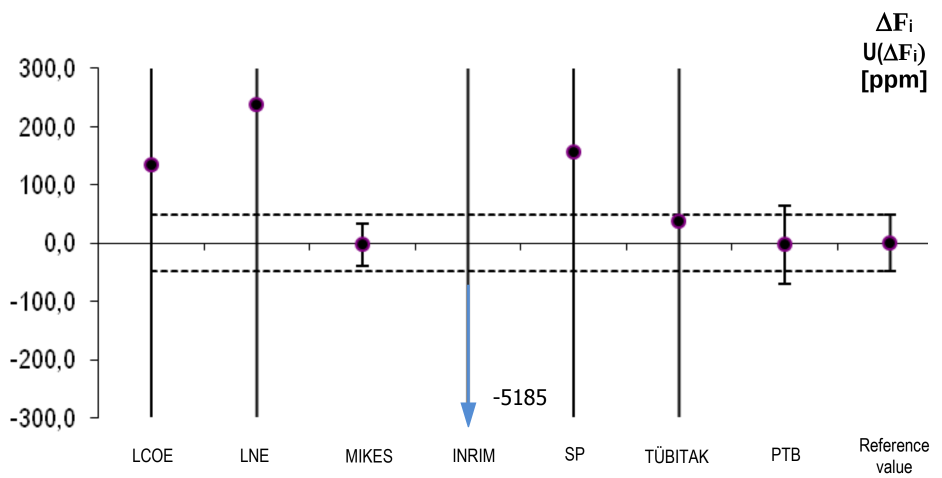
100 kV	ΔF_i [ppm]	U (ΔF_i) [ppm]
LCOE	81	498
LNE	-39	3340
MIKES	41	29
INRIM	3062	6002
SP	141	333
TÜBITAK	-79	647
VNIIMS	-399	448
PTB	-99	70
Ref. value	0	43



150 kV	ΔF_i [ppm]	U (ΔF_i) [ppm]
LCOE	97	498
LNE	355	2100
MIKES	35	27
INRIM	-145	6002
SP	155	309
TÜBITAK	-5	655
VNIIMS	-105	448
PTB	-105	71
Ref. value	0	42



200 kV	ΔF_i [ppm]	U (ΔF_i) [ppm]
LCOE	135	498
LNE	237	3570
MIKES	-3	36
INRIM	-5185	7560
SP	157	458
TÜBITAK	37	642
PTB	-3	67
Ref. value	0	48



ANNEX III.

Final technical protocol of the intercomparison (march 2011)

(39 pages)

COMPARISON

EURAMET.EM-S33

"Traceability of AC High Voltage Reference Measuring Systems up to 200 kV"

Technical Protocol (draft)

1. Introduction

AC high voltage (power frequency) is an important quantity in metrology for testing of high voltage equipment. It is important to ensure the accuracy of measurement. So it is necessary to compare national standards of European states.

The relevant quantities are the peak and RMS values of high AC voltage. This comparison is proposed in order to check the capabilities of the participating NMIs in the area of high AC voltage (50 Hz). Measurement capabilities of AC peak and RMS values of the voltage will be compared.

A Travelling Reference Measuring System (TRMS) will circulate among the participants and they will compare the high AC (50 Hz) voltages measured by their own measuring system with those obtained by the TRMS.

2. Travelling standards

2.1. General requirements

The TRMS consists of a capacitive divider with fixed input and grounding leads, a coaxial cable, a digital multimeter and a computer with a printer. The TRMS has two ranges, 20 kV and 200 kV, depending on the low voltage arm connected to the high voltage capacitor. Besides, an arbitrary waveform generator is included among the travelling devices to carry on the low voltage measurements of this comparison.

During the comparison measurements the divider will be placed in the high voltage hall at least 24 hours before the measurements performance. The rest of instrumentation will be placed on the control room next to the high voltage hall, and the measuring instrument of the TRMS will be powered and switched on at least 2 hours before the measurements.

2.2. Description of the TRMS

Measuring system up to 20 kV:

H.V lead:	Description:	Cupper tube (length = 2 m; Ǿ = 28 mm).	
Divider:	Description:	Capacitive divider.	
	Manufacturer:	H.V. arm:	TETTEX
		L.V. arm:	SP
	Type:	H.V. arm:	3370/100/200

		L.V. arm:	s/m
	LCOE reference:	H.V. arm:	III-2-DT09-001
		L.V. arm:	III-2-DT09-009
	Nominal capacity:	H.V. arm:	100 pF
		L.V. arm:	500 nF
	Nominal voltage:	H.V. arm:	20 kV
		L.V. arm:	4 V
	Nominal ratio:	5 000	
Measuring cable 1:	Description:	Coaxial cable.	
	Type:	RG-59 B/U.	
	Characteristic Z:	75 Ω.	
	Lenght:	0,5 m.	
	LCOE reference:	H.V. arm:	III-2-DT09-011
Measuring cable 2:	Description:	Coaxial cable.	
	Type:	RG-59 B/U.	
	Characteristic Z:	75 Ω.	
	Lenght:	10 m.	
	LCOE reference:	H.V. arm:	III-2-DT09-012
Voltmeter:	Manufacturer:	Hewlett-Packard.	
	Type:	3458A.	
	Serial Nº :	2823 A 18964.	
Software:	Manufacturer:	LCOE.	
	LCOE reference:	III-1-SOFT-018.	

<u>Measuring system up to 200 kV:</u>

H.V lead:	Description:	Cupper tube (length = 2 m; Ǿ = 28 mm).	
Divider:	Description:	Capacitive divider.	
	Manufacturer:	H.V. arm:	TETTEX
		L.V. arm:	SP
	Type:	H.V. arm:	3370/100/200
		L.V. arm:	s/m
	LCOE reference:	H.V. arm:	III-2-DT09-001
		L.V. arm:	III-2-DT09-010
	Nominal capacity:	H.V. arm:	100 pF
		L.V. arm:	5000 nF
	Nominal voltage:	H.V. arm:	200 kV
		L.V. arm:	4 V
	Nominal ratio:	50 000	
Measuring cable 1:	Description:	Coaxial cable.	
	Type:	RG-59 B/U.	
	Characteristic Z:	75 Ω.	
	Lenght:	0,5 m.	
	LCOE reference:	H.V. arm:	III-2-DT09-011

Measuring cable 2:	Description:	Coaxial cable.	
	Type:	RG-59 B/U.	
	Characteristic Z:	75 Ω.	
	Lenght:	10 m.	
	LCOE reference:	H.V. arm:	III-2-DT09-012
Voltmeter:	Manufacturer:	Hewlett-Packard.	
	Type:	3458A.	
	Serial Nº :	2823 A 18964.	
Software:	Manufacturer:	LCOE.	
	LCOE reference:	III-1-SOFT-018.	

Arbitrary waveform generator:

Generator:	Manufacturer:	Agilent Technologies.
	Type:	33220A.
	Serial Nº:	MY44045377.

Annex 1 shows pictures of the different elements of the TRMS.

2.3. Quantities to be measured

In both, high voltage and low voltage measurements, the reading of the TRMS is compared with the local reference measuring system. Coordinator will set the scale factor to be used for the TRMS.

The difference between the readings will be calculated as:

$$E_m[\%]=\frac{U_{TRMS}-U_{REF}}{U_{REF}}\cdot 100 \ ,$$

where:

- E_m: Measurement error of the TRMS.
- U_{TRMS}: AC peak voltage / RMS value obtained by means of the TRMS.
- U_{REF}: AC peak voltage / RMS value obtained by means of the reference measuring system of the laboratory.

Expanded uncertainty in the whole range of measurements is expected to be better than ± 500 ppm.

NO TEXT UNDER THIS LINE

3. Organization

3.1. Co-ordinator and members of the support group

The address of the co-ordinator and of the pilot laboratory is:

Mr. Ricardo Martín
Laboratorio Central Oficial de Electrotecnia (LCOE)
High Voltage Department
C/ José Gutiérrez Abascal, 2
28006 Madrid
SPAIN
E-mail: rmartin@lcoe.etsii.upm.es
Phone: +34 91 562 51 16
Fax: +34 91 561 88 18

The members of the supporting group are:

Dr. Fernando Garnacho
Laboratorio Central Oficial de Electrotecnia (LCOE)
High Voltage and Current
C/ José Gutiérrez Abascal, 2
28006 Madrid
SPAIN

Dr. Anders Bergman
SP Technical Research Institute of Sweden
Department Electrical Metrology
Brinellgatan 4, P.O. Box 857
SE-501 15. Boras
SWEDEN

Dr. Jari Hällstrom
Centre for Metrology and Accreditation
Tekniikantie 1, P.O. Box 9
FIN 02151 Espoo
FINLAND

NO TEXT UNDER THIS LINE

3.2. Participants

The following National Metrology Institutes take part in this comparison:

- Bulgarian Institute of Metrology (BIM) (Bulgaria).
- Czech Metrology Institute (CMI) (Czech Republic).
- Istituto Nazionale di Ricerca Metrologica (INRIM) (Italy).
- Laboratorio Central Oficial de Electrotecnia (LCOE) (Spain).
- Laboratoire National de Métrologie et d'essais (LNE) (France).
- Centre for Metrology and Accreditation (MIKES) (Finland).
- Physikalisch-Technische Bundesanstalt (PTB) (Germany).
- Technical Research Institute of Sweden (SP) (Sweden).
- TUBITAK Ulusal Metroloji Enstitüsü (UME) (Turkey).
- Russian Research Institute of Metrological Service (VNIIMS) (Russia).
- Dutch Metrology Institute (VSL) (The Netherlands).

Persons responsible of every Institute are indicated in Annex 2.

3.3. Time schedule

Four weeks are allowed for each participant and includes transportation time to the next participant.

Timetable

LCOE Madrid, Spain	February – March, 2010
VNIIMS Madrid, Russia	March, 2010
BIM Sofia, Bulgaria	May, 2010
LNE París, France	June - July, 2010
MIKES Espoo, Finland	August, 2010
INRIM Torino, Italy	September 2010
PTB Braunschweig, Germany	October, 2010
VSL Delft, The Netherlands	November, 2010
CMI Prague, Czech Republic	December, 2010
SP Boras, Sweden	January, 2011
LCOE Madrid, Spain	February, 2011
UME Kokaeli, Turkey	March , 2011
LCOE Madrid, Spain	April, 2011

3.4. Transportation

Participants will be responsible for arranging transportation to the next participant. Transportation is each laboratory's own responsibility and cost.

The transfer standards are packed in two containers with dimensions (length x width x height):

- Metallic container: 940 x 940 x 1 780. Weight: 250 Kg.
- Plastic container: 620 x 520 x 275. Weight: 20 Kg
- Containers need not be transported personally.

Annex 1 shows pictures of both containers.

Please, inform the pilot laboratory of the arrival of the package by completing and returning the form provided (confirmation note of receipt Annex 3) by e-mail or fax.

After having completed the measurements, the package is to be transported to the next participant. It is advisable to prepare and organize this transportation beforehand. Participants should inform the next recipient by e-mail or fax. Please, when the standards are sent on to the next laboratory, inform also the pilot laboratory by completing and returning the form provided (Annex 4) by e-mail or fax.

3.5. Failure of the travelling standard

In case of failure of the traveling standard it should be sent back to the pilot laboratory. After the problem has been solved the comparison will start again.

3.6. Financial aspects, insurance

Each participating laboratory covers the costs of its measurements, transportation and possible customs charges as well as of any damage that may have occurred within its country. The pilot laboratory covers overall costs for the organization of the comparison. The value of the TRMS was declared 65 000 €. The pilot laboratory has an insurance for any loss or damage of the standard during transportation. The cost of this insurance will be divided among all participants.

NO TEXT UNDER THIS LINE

4. Measurement instructions

4.1. High voltage measurements

4.1.1. Conditioning of the TRMS

The TRMS must be kept in the laboratory before the measurements for at least 24 hours so that it reaches stable temperature. It is recommended to keep the ambient temperature on the value 23°C ± 2°C.

Read Annex 5 before measurements performing.

The data of the ambient conditions during the measurements must be given in the measurement report, part B Annex 7.

4.1.2. Measurement performance

All the comparison measurements should be made with AC voltage (50 Hz). Measurements will be carried out measuring AC peak and RMS values.

The rated scale factor of the TRMS is:

- 5 000 (up to 20 kV).
- 50 000 (voltage levels bigger than 20 kV)

Determination of the measurement error should be made at the following voltage levels:

TRMS range	Voltage levels (kV)					
20 kV	0.75	1	5	10	15	20
200 kV	20	50	75	100	150	200

Measurements will be made from the lowest to the highest voltage level. At least ten (10) readings will be made at each voltage level and then the voltage will be increased immediately to the next level.

4.1.3. Method of measurement

The participating laboratories are asked to follow their usual measurement procedure to their best measurement capabilities with respect to the allowed time frame for the comparison.

4.2. Low voltage measurements

4.2.1. Conditioning of the travelling generator

An arbitrary waveform generator Agilent Technologies, type 33220A, is provided to carry on these measurements. Control of this generator is accomplished with the commercial Agilent´s software “Agilent IntuiLink Waveform Editor”.

Annex 6, "*Arbitrary Waveform Generator – User´s Guide*", explain control and setting of the arbitrary generator to carry on these measurements.

Measurements using the travelling arbitrary waveform generator should be done inside the range 18 ºC to 28 ºC. The generator and the measurement systems will be placed on the measurements room at least 24 hours before comparison measurements.

The TRMS consists on the HP 3458A connected to the PC with the measuring software. Its scale factor is 1.

4.2.2. <u>Measurements</u>

All the comparison measurements will be made with AC low voltage (50 Hz). Measurements will be carried out measuring AC peak voltage.

Seven signals are considered trying to simulate conditions that can be encountered in the field. These signals have amplitude of 10 Vpp and have the following characteristics:

1) Pure sine wave.
2) Third harmonic distortion (30 %).
3) Forth harmonic distortion (5 %).
4) High frequency interference on the high voltage signal (5 % of the 20th harmonic).
5) DC offset:
   5.1) 5 % of DC offset.
   5.2) 100 % of DC offset.
6) Triangle.

The signals are applied to the input of both, TRMS and laboratory's measuring system connected in parallel, and the AC peak voltage will be measured. At least 10 readings will be taken in every case.

5. Uncertainty of measurement

All participants should provide their results with the associated uncertainty of measurement and a complete uncertainty budget. The uncertainty must be evaluated at a level of one standard uncertainty and information must be given on the number of effective degrees of freedom.

The uncertainty of the measurement must be estimated according to the ISO Guide to the Expression of Uncertainty in Measurement (GUM).

A list of the principal components of the uncertainty budget to be evaluated by each participant cannot be included in this technical protocol. It is supposed that each participating laboratory applies a different method depending on its facilities.

Therefore a list of the principal components, relevant for all participants, cannot be presented.

6. Measurement report

A short description of the measuring set/up used (Annex 7, part A), the measurement results (Annex 7, part B) and a detailed evaluation of the uncertainty of measurement for the AC peak and RMS values should be reported. The measurement report forms in the Annex 7 of this document will be sent by e-mail to all participants. Please use these forms for your report. Hand written notes are sufficient for Annex 7 part A, but the measurement results given in Annex 7 part B should also be completed in electronic form (MS-Office) and send back electronically to the pilot laboratory. A signed report of the results (Annex 7) must also be sent. In case of any differences, the signed forms are considered to be the valid version.

The report should be sent to the pilot laboratory no later than six weeks after the measurements have been completed. No information about differences of the reported results with respect to others will be communicated before the completion of the comparison, unless large deviations of a laboratory's result, with respect to the preliminary reference results obtained by the pilot laboratory, are observed. In this case the laboratory in question will be asked to check its results for numerical errors.

7. Report of the comparison

Within 3 months after completion of all measurements the coordinator will prepare a first draft report and send it to the participants for comments. In this report an overview about the different measuring systems and used standards will be included.

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Annexes

Annex 1

“TRMS´s Photos”

1. Travelling Reference Measuring System:

1.1 High Voltage Divider

Photo 1.1 – High Voltage Capacitor (III-2-DT09-001)

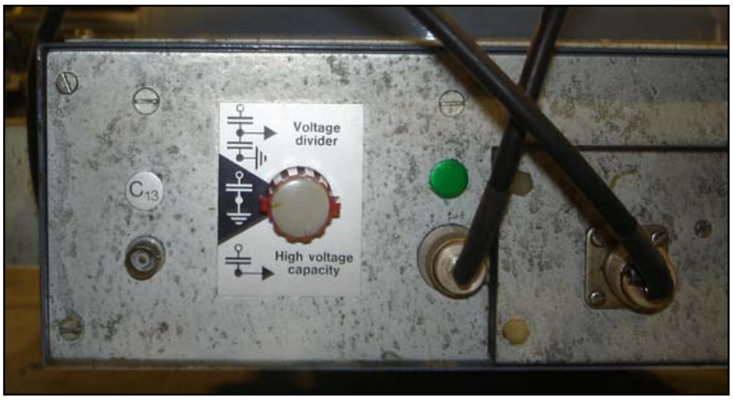
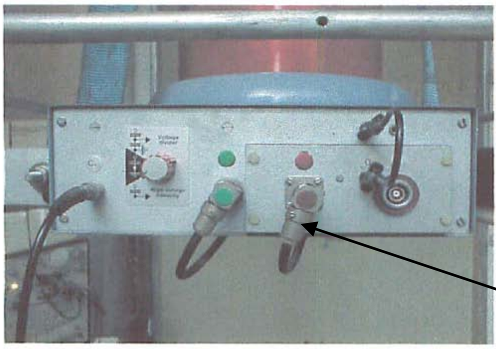


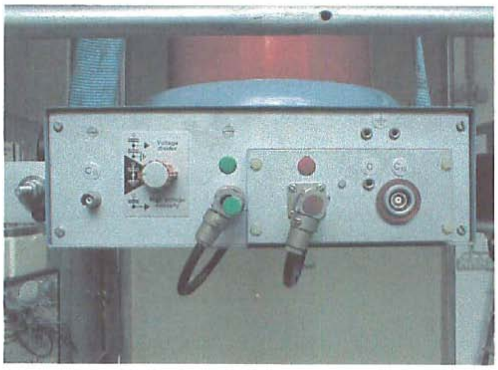
Photo 1.2 – HV Capacitor – Switch position for AC voltage measurements.
Grounding of low voltage terminal of the C_{13} capacitor.

Connection of the HV capacitor for AC Voltage measurement:
The cable with the red mark must be disconnected and the cable III-2-DT09-011 (LEMO FFA.2E.250.CTAC60) must be connected in the low part of the capacitor.



Messungen C_{13}

This cable (red mark) must be disconnected



Messungen C_{12}

Anschlußkabel

Measuring Cable 1 III-2-DT09-011
LEMO Connector FFA.2E.250.CTAC60

Photo 1.3 – Low Voltage Capacitor (III-2-DT09-009)

Photo 1.4 – Low Voltage Capacitor (III-2-DT09-010)

1.2 Measuring Cable 1

Photo 1.5 – Measuring Cable 1 (III-2-DT09-011)

Photo 1.6 – Measuring Cable 1 – LEMO Connector FFA.3S.140.CTAC62 (to connect to the LV capacitor)

Photo 1.7 – Measuring Cable 1 – LEMO Connector FFA.2E.250.CTAC60 (to connect to the HV capacitor) Main capacitance C_{12} -

1.1 Measuring Cable 2

Photo 1.8 – Measuring Cable 2 (III-2-DT09-012)
BNC Connectors

1.2 Voltmeter

Photo 1.9 – Voltmeter (III-1-MD-013)

1.3 Arbitrary waveform generator

Photo 1.10 – Waveform Generator (III-1-GEN-010)

2. Laptop and GPIB/USB Card:

Photo 2.1 – Laptop

Photo 2.2 – Agilent USB/GPIB Card

Photo 2.3 – Laptop´s briefcase

3. Metallic Containers:

Photo 3.1 – Container 1 and metallic box.

Photo 3.2 – Case of the Multimeter 3458A

Photo 3.3 – Suitcase of the Laptop

Photo 3.4 – Container 4

- Metallic Container 1 includes:
  - High Voltage Capacitor III-1-DT09-001
  - Low Voltage Capacitor III-1-DT09-009
  - Low Voltage Capacitor III-1-DT09-010
  - Measuring Cable 1 III-2-DT09-011
  - Measuring Cable 2 III-2-DT09-012 + Pomona 1269
  - Waveform Generator 33220A III-1-GEN-010
  - Power – Cord
  - External Trigger BNC (× 4)
  - Suitcase 3:
    - Laptop.
    - Mouse and AC/DC adapter of the computer.
    - Agilent USB/GPIB Card.
    - Agilent Product Reference CD and Automation – Ready CD.
    - Quick Start Guide of Agilent USB/GPIB Interface.

- Case 2 includes:
  - Multimeter 3458A III-1-MD-013
  - Power - Cord

- Container 4 includes:
  - Low Voltage Capacitor SP 1404-B.

4. Dimensions.

Container	Weight (kg)	External Dimensions (mm)		
		Length	Width	Heigth
1 – AC Measuring System	230	940	940	1780
2 – Multimeter 3458A	20	620	520	275
3 – Laptop	15	500	390	140
4 – Low Voltage Capacitor SP	8	460	460	260

Annex 2

Detailed list of participants

Laboratory address	Contact name, e-mail, fax number
Bulgarian Institute of Metrology (BIM) Section "Electric Energy Measurements" 52-B G. M. Dimitrov Blvd. 1040 Sofia Bulgaria	Mr. Emil Dimitrov e.dimitrov@bim.government.bg Fax: +359 2 9702 735 Phone: +359 2 9702 792
Czech Metrology Institute (CMI) V Botanice 4 CZ-150 72 Prague 5 Cezh Republic www.cmi.cz	Mrs. Renata Styblikoyá rstyblikova@cmi.cz Fax: +420 257 328 077 Phone: +420 257 288 335 / +420 602 196 072
Istituto Nazionale di Ricerca Metrologica (I.N.R.I.M.) High Voltage Laboratory – Elettromagnetism Div. Str. Delle Cacce, 91 10135 Torino Italy http://www.inrim.it	Mr. Angelo Sardi sardi@inrim.it Fax: +39 011 3919 849 Phone: +39 011 3919 832
Laboratorio Central Oficial De Electrotecnia (L.C.O.E) High Voltage Department José Gutiérrez Abascal, 2 ES-28006 Madrid Spain http://www.ffii.es	Mr. Ricardo Martin Berjano rmartin@lcoe.etsii.upm.es Fax: +34 91 561 88 18 Phone: +34 91 562 51 16
Laboratoire National de Métrologie et d'essais (LNE) ZA de Trappes-Élancourt 29, avenue Roger Hennequin 78197 Trappes Cedex France www.lne.fr	Mrs. Isabelle Blanc Isabelle.blanc@lne.fr Fax: 01 30 16 24 52 Phone: 01 30 69 21 08
MIKES Centre for Metrology and Accreditation P.O. Box 9 Tekniikantie 1 FIN 02151 ESPOO. Finland http://www.mikes.fi	Mr. Esa-Pekka Suomalainen esa-pekka.suomalainen@mikes.fi Fax: +358 10 6054 498 Phone: +358 10 6054 442
Dutch Metrology Institute (VSL) Thijsseweg 11 2629 JA Delft P.O. Box 654 2600 AR Delft The Netherlands www.vsl.nl	Mr. Ernest Houtzager / Mr. Gert Rietveld ehoutzager@vsl.nl / grietveld@nmi.nl Fax: + 31 15 269 1645 / 638 Phone: + 31 15 269 1500 / 91
Russian Research Institute of Metrological Service (VNIIMS)	Mrs. Tatiana Dubrovskaja tatiana_d@vniims.ru Fax: + Phone: +

SP Technical Research Institute of Sweden Electrical Metrology Department Brinellgatan 4, P.O. Box 857 SE-501 15. Boras Sweden http://www-v2.sp.se/eng/	Mr. Anders Bergman anders.bergman@sp.se Fax: +463 31 65 78 Phone: +463 31 25 038
TUBITAK Ulusal Metroloji Enstitüsü (UME) PK.54 41470 Gebze/Kocaeli - TR Turkey ume@ume.tubitak.gov.tr	Mr. Ahmet Merev ahmet.merev@ume.tubitak.gov.tr Fax: + 90 262 6795001 Phone: +90 262 6795000 (4350)

Annex 3

T e l e f a x   T e l e f a x   T e l e f a x

(Please pass on immediately!)

To: Laboratorio Central Oficial de Electrotecnia (LCOE)
High Voltage Department att.: D. Ricardo Martín Berjano
C/ José Gutiérrez Abascal, 2 – 28006 Madrid (Spain).
FAX No. : + 34 91 561 88 18
e-mail: rmartin@lcoe.etsii.upm.es

From: (participating laboratory):

Fax: International ++

Pages (total): 1

In the case of faulty reproduction, please call:

Re: Euramet No. - Receipt of transfer standard

Date:

We confirm having received the TRMS of the

Euramet No. comparison on...................................

After visual inspection:

□ **No damage** of the suitcase and the TRMS **has been noticed**.

□ The following **damage(s) must be reported** (if possible add a picture):

....

....

Date: **Signature**

Annex 4

T e l e f a x   T e l e f a x   T e l e f a x

(Please pass on immediately!)

To: Laboratorio Central Oficial de Electrotecnia (LCOE)
High Voltage Department att.: D. Ricardo Martín Berjano
C/ José Gutiérrez Abascal, 2 – 28006 Madrid (Spain).
FAX No. : + 34 91 561 88 18
e-mail: rmartin@lcoe.etsii.upm.es

From: (participating laboratory):

Fax: International ++

Pages (total): 1

In the case of faulty reproduction, please call:

Re: Euromet No. -Sending of TRMS

Date:

We have informed the next participant on .... that we will send the TRMS to them next time.

We confirm having sent TRMS of the Euromet No. comparison on .... to the next participant.

Additional information:
....
....

Date:.......................... **Signature:....………………..**

Annex 5

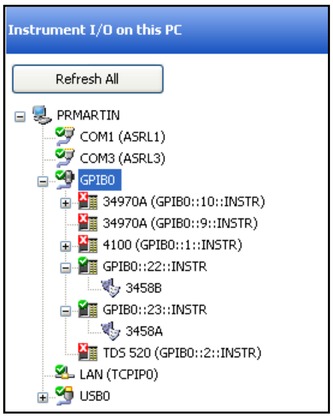
“AC Comparison Software – User´s Guide”

1. Configuring For Measurements:

- Prior to configuring for measurements, you should warm up the multimeter for 2 hours and then run the Autocalibration of the 3458A for DCV and ACV mode to ensure the maximum accuracy. Always disconnect any input cables before performing **AutoCal**.

- Connect the Agilent GPIB Card to the GPIB connector of the instrument 3458A, and the 82357B USB cable into an available USB port on the computer. The green **READY LED** of the card should remain ON.

- Make double-click on *“Agilent Connection Expert”* icon in the Desktop. When this program has loaded, click on the *“Refresh All”* button.



- The address of the Agilent GPIB Card (GPIB0) must be equal to **21**.

- Multimeter´s GPIB address of the TRMS must be equal to **23** and the VISA alias of the multimeter must be “**3458A**”.

- Notice the display's **REM** annunciator of the multimeter is illuminated. This means the multimeter is in the remote mode and has been addressed to listen (receive a command).

2. Making Measurements:

- There are five versions of the program in Labview 8.5 for making the measurements:

  - Version RMS 1.0 ⇒ Use this software for measuring RMS voltage.

  - Version RMS 1.1 ⇒ Use this version for measuring RMS voltage if the Laboratory Reference Measuring System uses a 3458A. The instruments will be simultaneously triggered.

- Version RMS 1.2 ⇒ Use this version for measuring RMS voltage, if the multimeters of both Measuring Systems are synchronized by using an External Trigger.

- Version Peak Voltage 1.0 ⇒ Use this software for measuring Peak value of high voltage AC voltage.

- Version Peak Voltage 1.1 ⇒ Uses this version for measuring Peak voltage, if the multimeters of both Measuring Systems are synchronized by using an External Trigger.

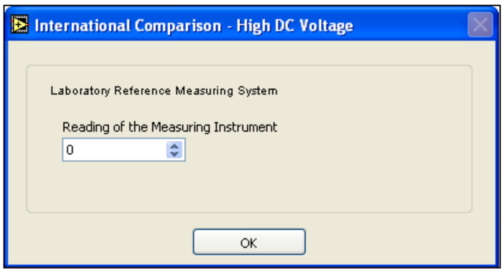
- Version Peak Waveform Generator 1.0 ⇒ Use this software for measuring the peak value of distorted waveforms (pure sinewave 50 Hz, 30 % 3rd harmonic, 5 % 4th harmonic, 5 % 20th harmonic, DC offset 5 % and 100 %, triangle).

a) Version RMS 1.0

- Double-click on "*AC RMS 1.0*" desktop icon to execute the VI (Virtual Instrument).

- All data introduced in the program (Laboratory name, Scale Factors, Voltage Level, Temperature, Humidity, etc.) will be automatically transferred to the Excel workbook *"AC Comparison.xls"*.

- After the voltage level is adjusted, for making measurements click on the *"First Measurement"* (*"Next Measurement"* or *"Repeat Measurement"*) button. When this button is clicked, the multimeter of the TRMS takes a reading which is transferred to the Excel Sheet. After that, it is possible introduce in the software the reading of the LRMS´s voltmeter, and also it will be transferred to the sheet.



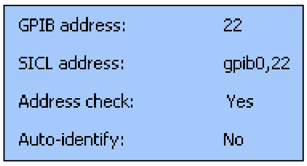
- Finally, when the measurements of the comparison have been completed, it is possible rename the Excel workbook and save the file in the *"Results AC Comparison"* folder.

b) Version RMS 1.1

- Connect the two 3458A of the Reference Measuring Sytems, to the GPIB connector on the 82357B (Agilent GPIB Card) with a GPIB cable.

- Click on the *“Refresh All”* button of the *“Agilent Connection Expert”* window.

- Multimeter´s GPIB address of the LRMS must be equal to **22**. The VISA alias of the multimeter must be “**3458B**”. Notice the display's **REM** annunciator of the multimeter is illuminated.

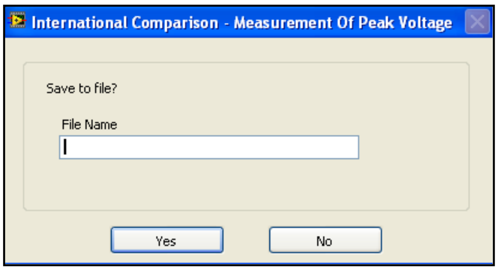


- Double-click on “*AC RMS 1.1*” desktop icon to execute the VI (Virtual Instrument).

- All data introduced in the program (Laboratory name, Scale Factors, Voltage Level, Temperature, Humidity, etc.) will be automatically transferred to the Excel workbook *“AC Comparison.xls”*.

- After the voltage level is adjusted, for making measurements click on the *“First Measurement”* (*“Next Measurement”* or *“Repeat Measurement”*) button and the instruments will be simultaneously triggered. The readings of the multimeters are transferred to the Excel Sheet.

- When the measurements of the comparison have been completed, it is possible rename the Excel workbook and the file will be saved in the *“Results AC Comparison”* folder in the Desktop.



c) Version RMS 1.2

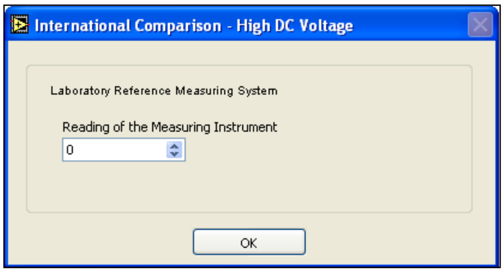
- Connect an external DC source (up to 5 V and with negative edge) to the "*Ext Trig*" terminal of the 3458A (TRMS) for triggering the multimeter. Use the same source for triggering the voltmeter of the LRMS.

- Double-click on "*AC RMS 1.2*" desktop icon to execute the VI (Virtual Instrument).

- All data introduced in the program (Laboratory name, Scale Factors, Voltage Level, Temperature, Humidity, etc.) will be automatically transferred to the Excel workbook *"AC Comparison.xls"*.

- After the voltage level is adjusted, for making measurements click on the *"First Measurement"* (*"Next Measurement"* or *"Repeat Measurement"*) button and the instrument will be configured for waiting external trigger. Notice the message ***"Waiting For External Trigger"*** in the front panel of the software.

- When a negative edge occurs, the multimeter of the TRMS takes a reading which is transferred to the Excel Sheet. After that, it is possible introduce in the software the reading of the LRMS´s voltmeter, and also it will be transferred to the sheet.



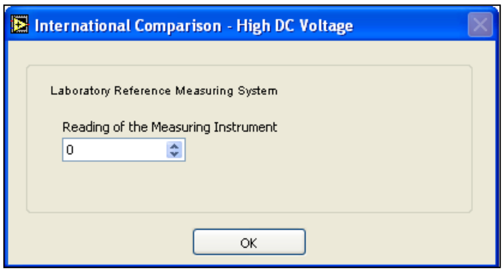
- Finally, when the measurements of the comparison have been completed, it is possible rename the Excel workbook and save the file in the *"Results AC Comparison"* folder.

d) Version Peak Voltage 1.0

- Double-click on "*AC Peak Voltage 1.0*" desktop icon to execute the VI (Virtual Instrument).

- All data introduced in the program (Laboratory name, Scale Factors, Voltage Level, Temperature, Humidity, etc.) will be automatically transferred to the Excel workbook *"AC Comparison.xls"*.

- After the voltage level is adjusted, for making measurements click on the *"First Measurement"* (*"Next Measurement"* or *"Repeat Measurement"*) button. When this button is clicked, the multimeter of the TRMS takes a reading which is transferred to the Excel Sheet. After that, it is possible introduce in the software the reading of the LRMS´s voltmeter, and also it will be transferred to the sheet.



- Finally, when the measurements of the comparison have been completed, it is possible rename the Excel workbook and save the file in the *"Results AC Comparison"* folder.

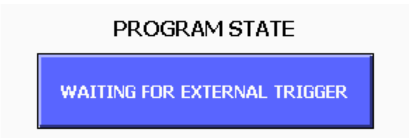
e) Version Peak Voltage 1.1

- Connect an external DC source (up to 5 V and with negative edge) to the "*Ext Trig*" terminal of the 3458A (TRMS) for triggering the multimeter. Use the same source for triggering the voltmeter of the LRMS.

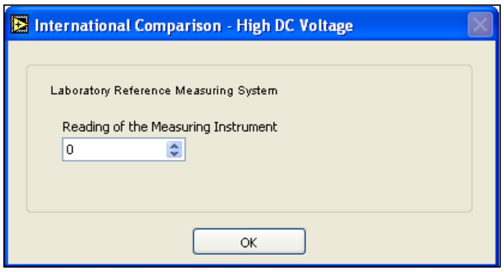
- Double-click on "*AC Peak Voltage 1.1*" desktop icon to execute the VI (Virtual Instrument).

- All data introduced in the program (Laboratory name, Scale Factors, Voltage Level, Temperature, Humidity, etc.) will be automatically transferred to the Excel workbook *"AC Comparison.xls"*.

- After the voltage level is adjusted, for making measurements click on the *"First Measurement"* (*"Next Measurement"* or *"Repeat Measurement"*) button and the instrument will be configured for waiting external trigger. Notice the message ***"Waiting For External Trigger"*** in the front panel of the software.



- When a negative edge occurs, the multimeter of the TRMS takes a reading which is transferred to the Excel Sheet. After that, it is possible introduce in the software the reading of the LRMS´s voltmeter, and also it will be transferred to the sheet.



- Finally, when the measurements of the comparison have been completed, it is possible rename the Excel workbook and save the file in the *"Results AC Comparison"* folder.

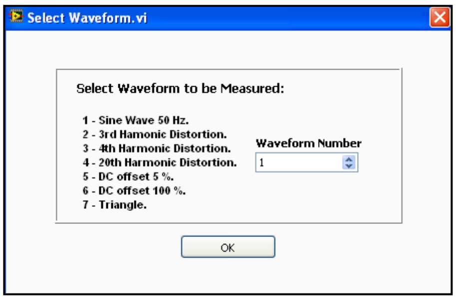
f) Version Peak Waveform Generator 1.0

- Connect the output of the Arbitrary Waveform Generator 33220A, to the input of the instrument 3458A (front input HI – LO and III-2-DT09-002 cable).

- Double-click on "*AC Peak Waveform Generator 1.0*" desktop icon to execute the VI (Virtual Instrument).

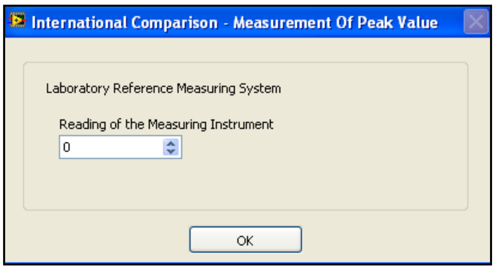
- All data introduced in the program (Laboratory name, Scale Factors, Voltage Level, Temperature, Humidity, etc.) will be automatically transferred to the Excel workbook *"AC Comparison.xls"*.

- Select the waveform to be measured and the amplitude (peak to peak) of the waveform.

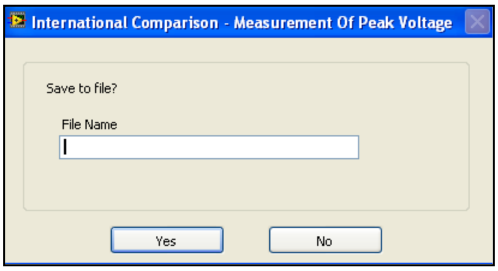


- Then, load the waveform to the Arbitrary Waveform Generator (See *Arbitrary Waveform Generator - Users´Guide*) by using the waveform editor software (icon on the desktop).

- After the waveform is loaded, for making measurements click on the *"First Measurement"* (*"Next Measurement"* or *"Repeat Measurement"*) button. When this button is clicked, the multimeter of the TRMS takes a reading which is transferred to the Excel Sheet. After that, it is possible introduce in the software the reading of the LRMS´s voltmeter, and also it will be transferred to the sheet.



- Finally, when the measurements of the comparison have been completed, it is possible rename the Excel workbook and save the file in the *"Results AC Comparison"* folder.



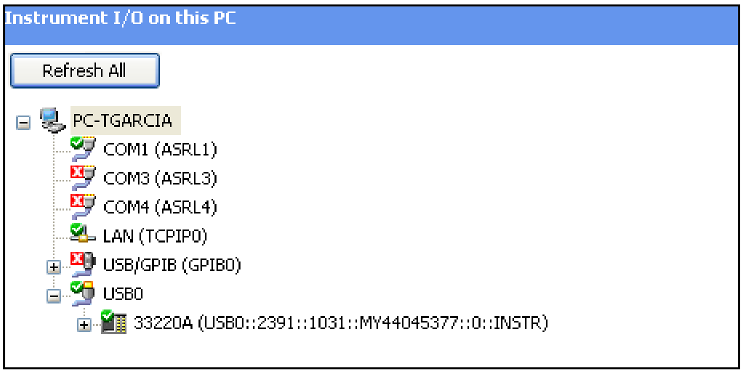
Annex 6

"Arbitrary Waveform Generator – User´s Guide"

1. Establishing a connection to the Arbitrary Generator:

- Connect the Agilent 33220A to the PC by means of a USB 2.0 cable.

- Make double-click on *"Agilent Connection Expert"* icon in the Desktop. When this program has loaded, click on the *"Refresh All"* button.



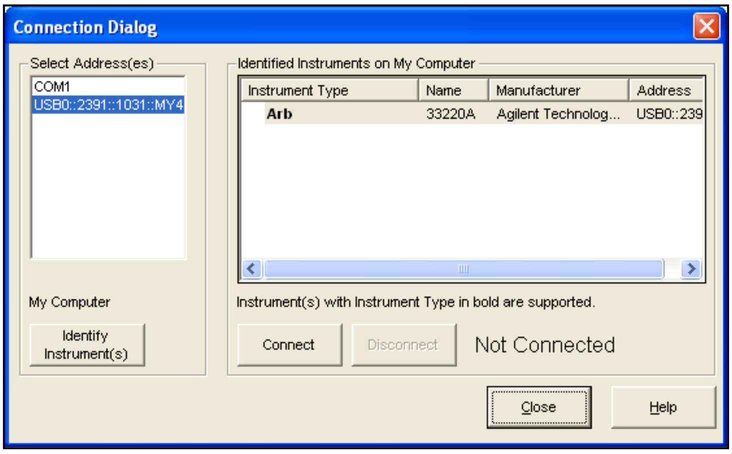
- Notice a **REMOTE** message appears in the display of the waveform generator. This means the generator is in the remote mode and has been addressed to listen (receive a command).

2. Using the Waveform Editor Software:

- Make double-click on *"Waveform Editor"* icon in the Desktop.

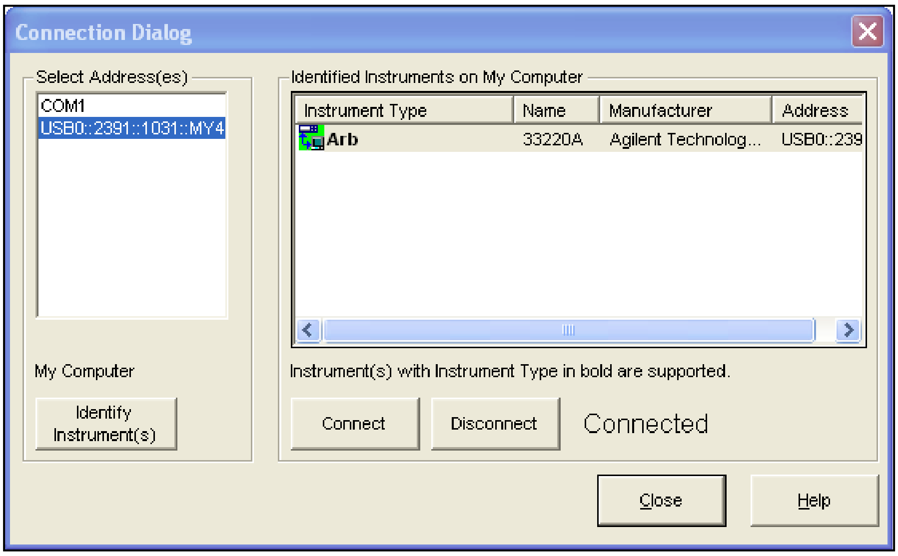
- From the **Communications** menu, select **Connection**. The Connection dialog box appears.

- Click on address **USB0::2391::1031** under "*Select Address(es)*" on the left side of this form. Then click on the "*Identify Instrument(s)"* button. The instrument is identified on the right side of the form under "*Identified Instruments on My Computer*" as shown below.



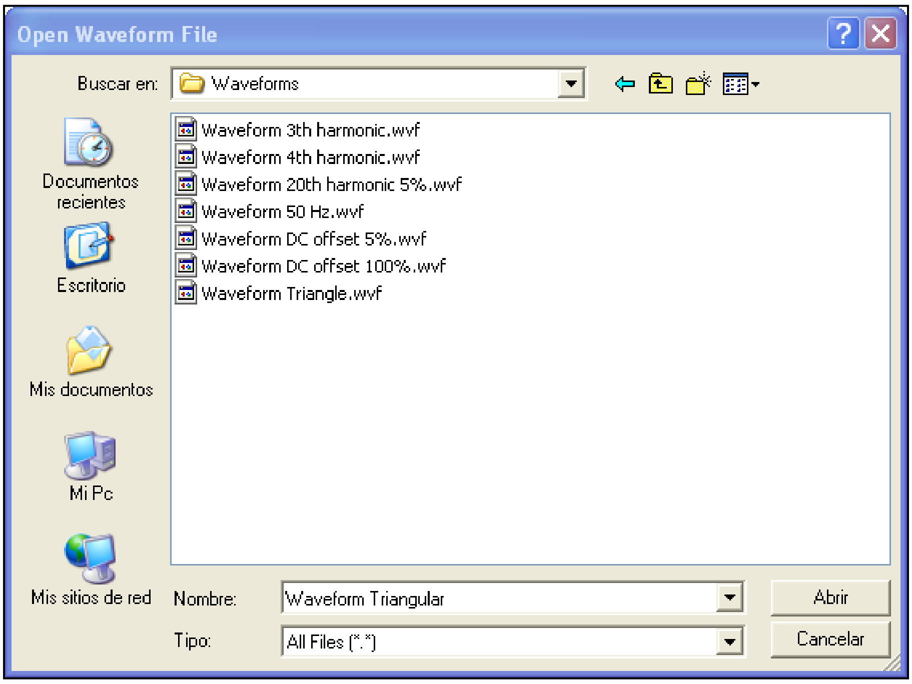
- Click on the "*Connect*" button to connect the instrument.

- Once an arbitrary function generator has been connected, the *"Connected"* message appears. Click on Close to close the dialog box.

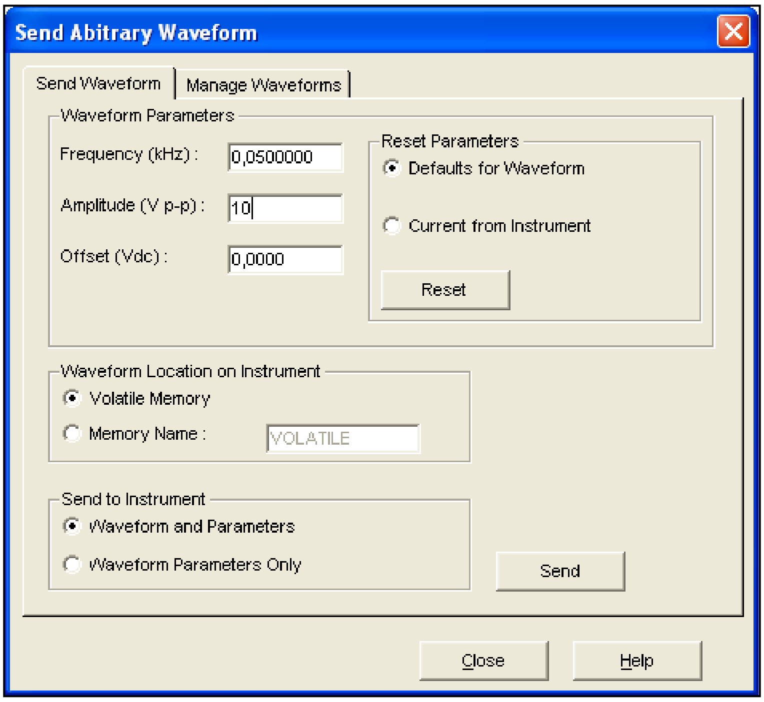


3. Sending Waveforms to the Arbitrary Generator:

- From the file menu, select open to load one of the waveforms.



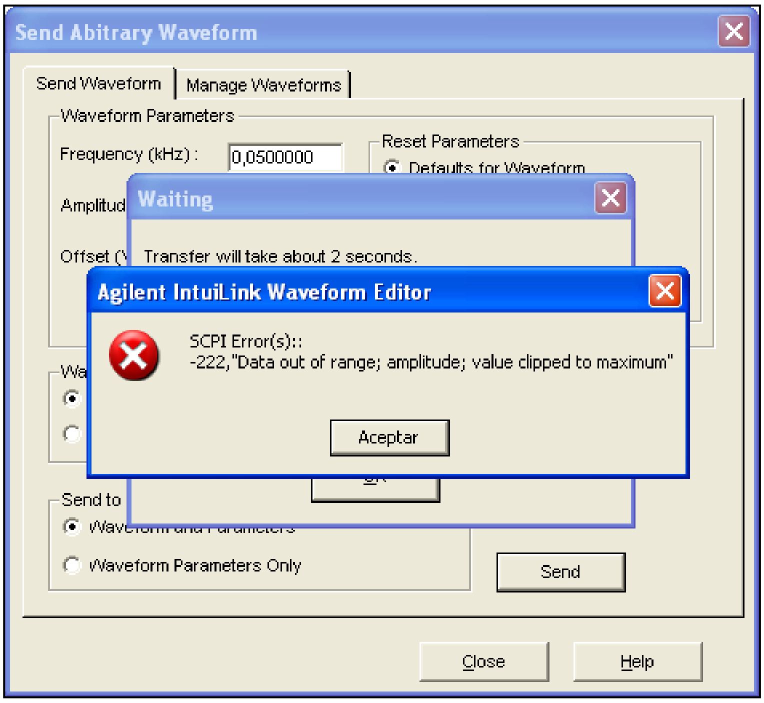
- Then, from the "*Connections*" menu, select "*Send Waveform*" (or click on the icon in the waveform toolbar). The "*Send Arbitrary Waveform"* dialog box appears.



a. Select the following parameters to send the waveform.

- Frequency ⇒ **0.050 kHz**
- Amplitude ⇒ **10 Vp-p (***)**
- Offset (Vdc) ⇒ **0**
- Waveform Location On Instrument ⇒ **Volatile Memory**
- Send to Instrument ⇒ **Waveform and Parameters**

******* In some waveforms the value peak to peak must be lower than 10 V to avoid the following error:



b. Click on the "*Send*" button to send the waveform.

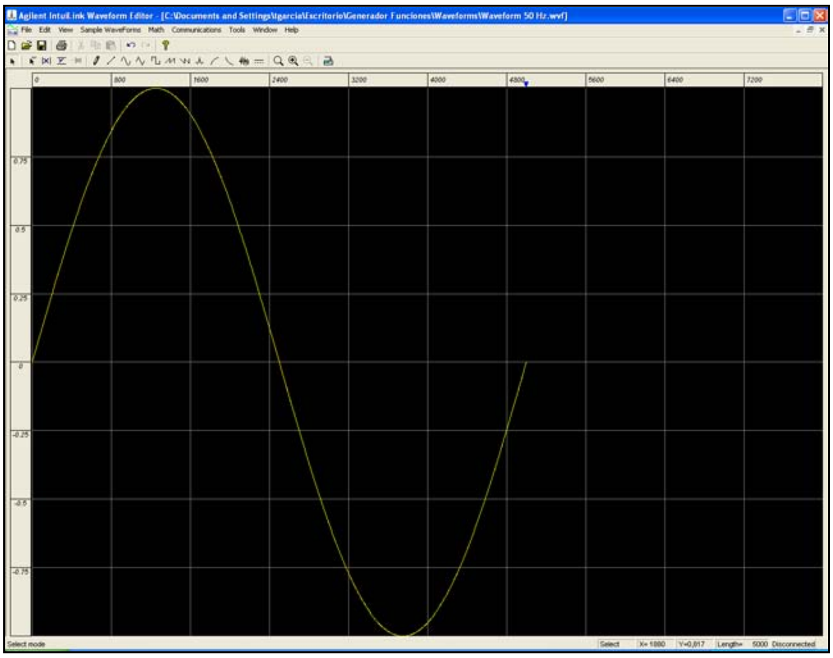
c. The estimated time to send the waveform is displayed. Click on "*OK*" to continue.

d. Once the waveform is completely sent, you are returned to the "*Send Arbitrary Waveform*" dialog box. Click on "*Close*" to exit this dialog box.

4. Parameters of the Waveforms to analyzing.

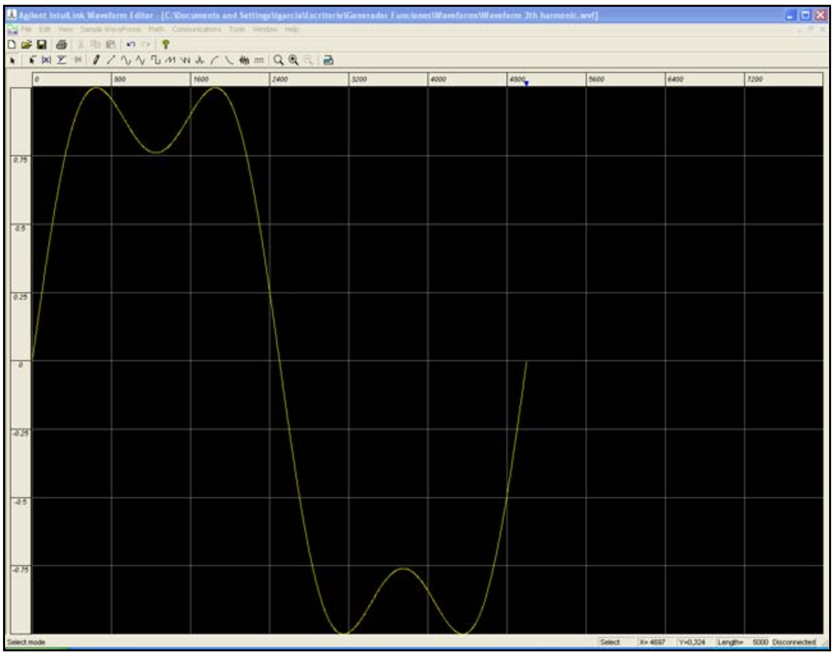
a. Pure sine wave.

- Frequency ⇒ **0.050 kHz**
- Amplitude ⇒ **10 Vp-p**
- Offset (Vdc) ⇒ **0**



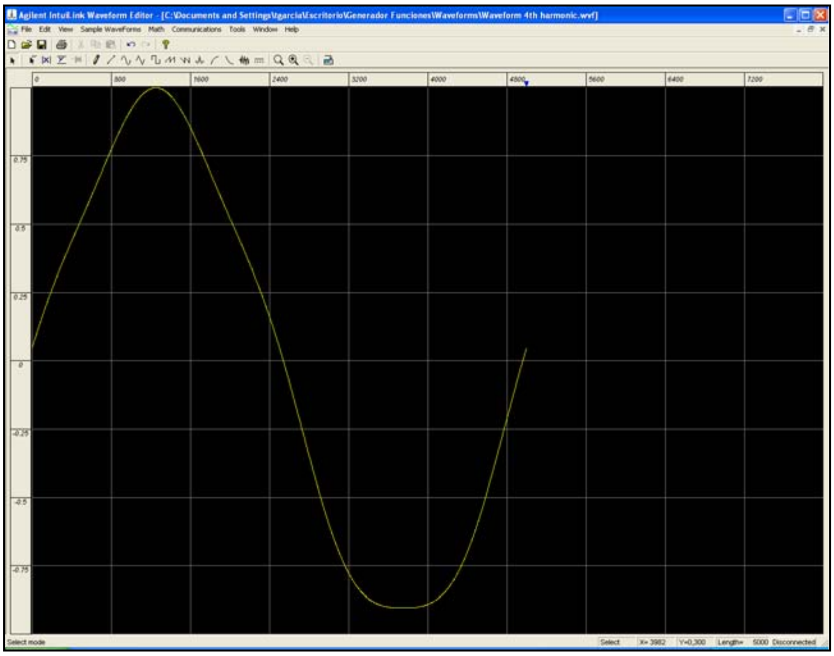
b. Third harmonic distortion 30 %.

- Frequency ⇒ **0.050 kHz**
- Amplitude ⇒ **10 Vp-p**
- Offset (Vdc) ⇒ **0**



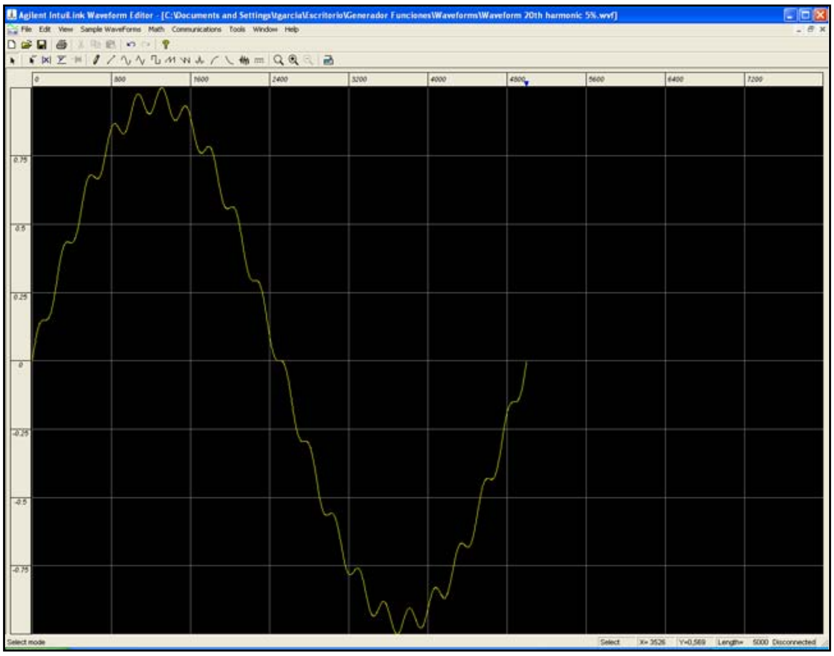
c. Forth harmonic distortion 5 %.

- Frequency ⇒ **0.050 kHz**
- Amplitude ⇒ **8 Vp-p to avoid SCPI Error**
- Offset (Vdc) ⇒ **0**



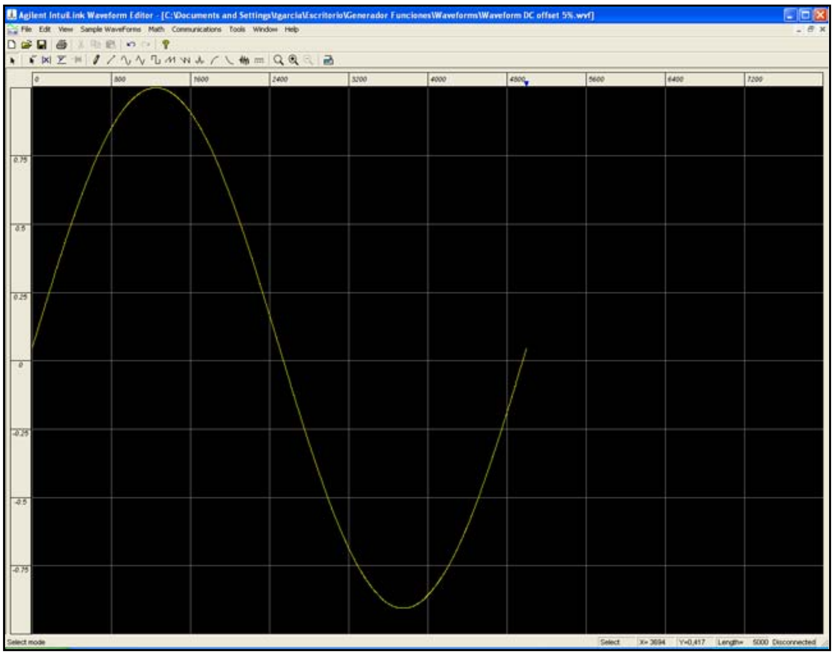
d. High frequency interference on the high voltage signal (5 % of the 20th harmonic).

- Frequency ⇒ **0.050 kHz**
- Amplitude ⇒ **10 Vp-p**
- Offset (Vdc) ⇒ **0**



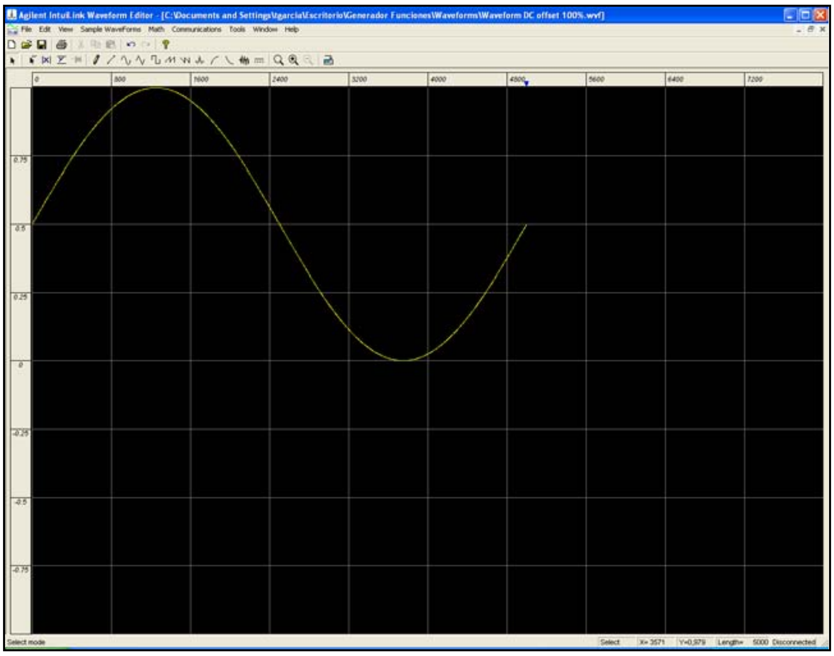
e. DC offset 5 %.

- Frequency ⇒ **0.050 kHz**
- Amplitude ⇒ **8 Vp-p to avoid SCPI Error**
- Offset (Vdc) ⇒ **0**



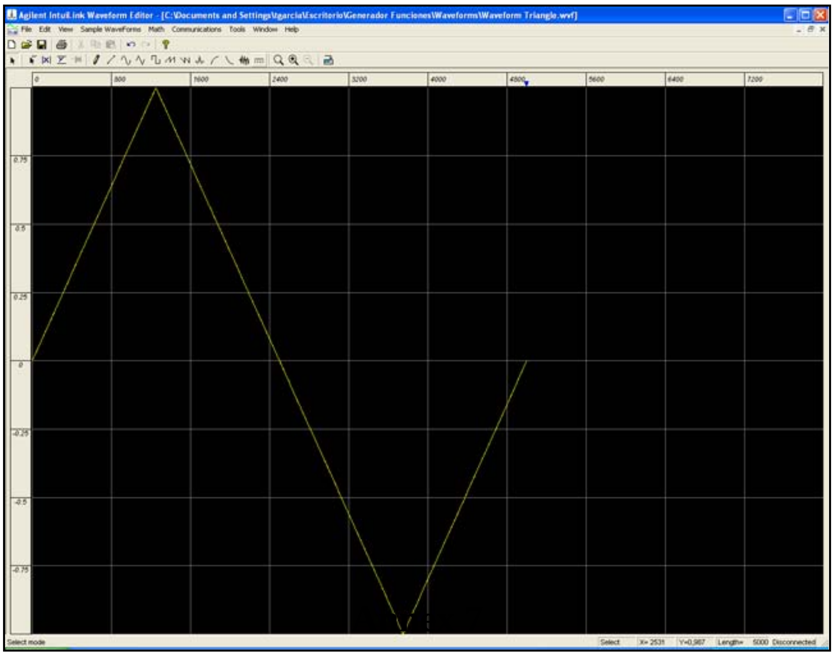
f. DC offset 100 %.

- Frequency ⇒ **0.050 kHz**
- Amplitude ⇒ **5 Vp-p to avoid SCPI Error**
- Offset (Vdc) ⇒ **0**



g. Triangle.

- Frequency ⇒ **0.050 kHz**
- Amplitude ⇒ **10 Vp-p**
- Offset (Vdc) ⇒ **0**



Annex 7

Measurement report, part A

In this part A of the report a free description should be given including drawings and references, whereas in part B a tabular form has to be filled out. This information will be used in the final report to be prepared by the pilot laboratory.

A) Description of the measurement method(s), measurement scheme and relevant instruments:

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Participating laboratory: ....

Date: .... Signature …......……....………..

Annex 7

Measurement report, part B

Measurement results and uncertainty budget

Measurand: **Assigned Scale Factor. Measurement of Upp / √2 (according to new 60060-1)**

Voltage level [kV]	Measured Scale Factor ot the TRMS	standard uncertainty type A U_A [ppm]	standard uncertainty type B U_B [ppm]	combined standard uncertainty U [ppm]
0.75				
1				
5				
10				
15				
20				
20				
50				
75				
100				
150				
200				

Record of the voltage waveform should be taken for each voltage level. This could be e.g. an oscilloscope record. In that way we can afterward try to understand the influence of the waveform.

Temperature:
Frequency:
Effective degrees of freedom ν_{eff} :

Annex 7

Measurement report, part B

Measurement results and uncertainty budget

Measurand: **Assigned Scale Factor. Measurement of RMS value**

Voltage level [kV]	Measured Scale Factor ot the TRMS	standard uncertainty type A U_A [ppm]	standard uncertainty type B U_B [ppm]	combined standard uncertainty U [ppm]
0.75				
1				
5				
10				
15				
20				
20				
50				
75				
100				
150				
200				

Temperature:
Frequency:
Effective degrees of freedom ν_{eff} :

Annex 7

Measurement report, part B

Measurement results and uncertainty budget

Measurand: **Low voltage measurements. Measurement of Upp / √2 (according to new 60600-1)**

Type of signal	Local Upp / √2 [V]	TRMS Upp / √2 [V]	standard uncertainty type A U_A [ppm]	standard uncertainty type B U_B [ppm]	combined standard uncertainty U [ppm]
Pure sine					
3rd harmonic					
4th harmonic					
5 % DC offset					
100 % DC offset					
Triangle					

Temperature:
Frequency:
Effective degrees of freedom ν_{eff} :