State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (SE “Ukrmetrteststandard”)

Approved by the chairman of TC 1.3 COOMET
Chairman of TC 1.3 COOMET
_________________ T. Kolomiets

Final Report on
COOMET Key Comparison of Capacitance at 10 pF (COOMET.EM-K4)

Oleh Velychko, Olexander Akhmadov

October 2014

Pilot laboratory: SE “Ukrmeterteststandard”
4 Metrologichna str., 03680, Kyiv, Ukraine
E-mail: Velychko@ukrcsm.kiev.ua

Coordinator of comparison:

_________________ O. Velychko

Participants of comparisons:
SE “Ukrmetrteststandard”, Ukraine
PTB, Germany
VNIIM, Russia
NMIJ/AIST, Japan
BIM, Bulgaria
KazInMetr, Kazakhstan
BelGIM, Republic of Belarus

Kyiv, Ukraine

Table of contents

1 Introduction

Key of acronyms used:
NMIs is national metrology institutes;
KC is Key Comparison;
CRV is key comparison reference values for COOMET comparison;
KCRV is key comparison reference values for CCEM comparison.

The COOMET Key Comparison (KC) of Capacitance at 10 pF (comparison identifier – COOMET.EM-K4) was conducted in the framework of COOMET 345/UA/05 project [1] from 2006 to 2009.

This project for comparing of national standards of electrical capacitance was conducted between countries which are member laboratories of regional metrology organization COOMET, and also EURAMET, APMP. In this comparison take part seven national metrology institutes (NMI): SE "Ukrmetrteststandard" – UMTS (Ukraine); PTB (Germany); VNIIM (Russia); NMIJ/AIST (Japan); BIM (Bulgaria); BelGIM (Belarus); KazInMetr (Kazakhstan).

Proposed to link the results from COOMET.EM-K4 to the CCEM-K4 [2] carried out between 1994 and 1996. PTB (Germany) and VNIIM (Russia) are linking NMIs as far as they participated in CCEM-K4.

The State Enterprise "All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer" (SE "Ukrmeterteststandard"), Ukraine was the pilot laboratory.

2 Participants

List of participating NMIs, countries and regional organizations is show in Table 1.

Table 1 List of participating NMIs, countries and regional organizations

NMI	Country	Regional organization
UMTS – State Enterprise "All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer" (SE "Ukrmeterteststandard") **– pilot**	Ukraine	COOMET
PTB – Physikalisch-Technische Bundesanstalt	Germany	COOMET/EURAMET
VNIIM – D. I. Mendeleyev Institute for Metrology	Russia	COOMET/APMP
NMIJ/AIST – National Metrology Institute of Japan	Japan	APMP
BIM – Bulgarian Institute of Metrology	Bulgaria	COOMET/EURAMET
KazInMetr – Republic State Enterprise "Kazakhstan Institute of Metrology"	Kazakhstan	COOMET/APMP
BelGIM – Belarusian State Institute of Metrology	Belarus	COOMET

3 Travelling standard and measurement instructions

3.1 Description of travelling standard

The travelling standard is 10 pF (S/N 01327) Andeen-Hagerling model AH11A fused silica capacitance standard, mounted in a frame model AH1100 (S/N 00108).

The AH 1100 frame provides monitoring of critical temperature control parameters such as the differences within the dual temperature sensors in standard and internal power voltages. AH11A capacitance standard contains built-in precision oven with dual temperature sensor system which provides increased reliability and confidence. The manufacturer's specification for the temperature coefficient with respect to changes in ambient temperature is 0.01 μF/F $^{o}C^{-1}$. Pilot laboratory measurements confirm that the temperature coefficient for the travelling standard is no greater than this value.

The manufacturer's specification for the sensitivity of the AH11A standard to AC measurement voltage is 0.003 μF/F V^{-1} at 1 kHz. Pilot laboratory measurements of the travelling standard at 1592 Hz could not detect a sensitivity to measurement voltage.

The travelling standard was circulated within a container, which is well furnished for the safety of the travelling standard.

3.2 Measurement

After power up of travelling standard in participating NMIs it stabilized for three days.

Measurements were performed under the following conditions:
temperature: 23 °C ± 3 °C;
relative humidity: between 30% and 70%;
measurement frequency: 1000 Hz and 1592 Hz (depending on laboratory's capability);
measuring voltage for capacitor: from 15 V to 100 V.

If measurement voltage differs from 100 V, the actual voltage was recorded and its effect was included in uncertainty budget of NMI measurement.

The temperature coefficient of capacitance with respect to changes in ambient laboratory temperature is less than 0.01 ppm/°C for capacitor. No corrections were made for ambient laboratory temperature.

If measurements were made during several days, then the mean capacitance value for each day should be provided with indication of the exact dates of measurements.

4 Uncertainty of measurement

The uncertainty was calculated following the ISO/IEC Guide 98-3:2008 "Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement" (GUM): standard uncertainties, degrees of freedom, correlations, scheme for the uncertainty evaluation.

All contributions to the uncertainty of measurement were listed separately in the report and identified as either Type A or Type B uncertainties. Uncertainties were evaluated at the level of one standard uncertainty and the number of effective degrees of freedom is to be reported.

5 Traceability to the SI

The traceability to the SI of standards was provided to pilot NMI. The participating NMIs made measurements of this travelling capacitor in terms of either their own calculable capacitor or a quantum Hall standard, or have traceability to other laboratories. This meant that there were a number of independent measurements of capacitor which enabled the representation of the farad in those countries were compared.

The traceability route for the primary standard of capacitance for each NMI is given in Table 2.

Table 2 Traceability route for each participating NMI

NMI	Country	Traceability Route
PTB	Germany	Calculable Capacitor
VNIIM	Russia	Calculable Capacitor
UMTS	Ukraine	PTB (Quantized Hall Resistance, QHR)
NMIJ/AIST	Japan	NMIJ/AIST (Quantized Hall Resistance, QHR)
BIM	Bulgaria	PTB (Calculable Capacitor)*
KazInMetr	Kazakhstan	VNIIM (Calculable Capacitor)*
BelGIM	Belarus	VNIIM (Calculable Capacitor)
* only for 1000 Hz		

6 Behaviour of the travelling standard

The UMTS as pilot laboratory has performed repeated measurements on the travelling standard (S/N 01327) during the course of this comparison. From these measurements, the behaviour of the travelling standard can be seen in Figures 1.

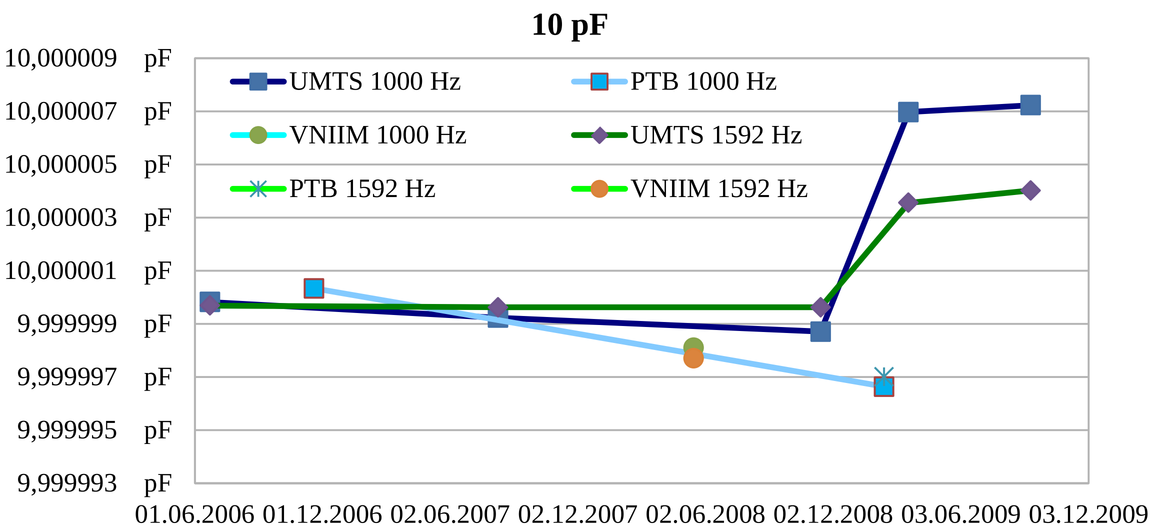


Figure 1 Behaviour of the travelling standard for 10 pF

For capacitor of travelling standard, the result of the measurement, in 2009, are significantly more than the other values. This deviation is most probably caused by a shock that the travelling standard for 10 pF have experienced during transport from PTB to UMTS. The cause of the non-steady behaviour of the artefact and the frequency dependence is not clear. Ambient conditions were not monitored during transportation of the artefacts, so temperature cycling effects cannot be ruled out. Note that the accompanying 100 pF artefact used for the supplementary comparison (separately reported) did not show any significant deviations from a steady linear drift rate during the whole of the comparison.

7 Reported results

7.1 General information and data

A full measurement report containing all relevant data and uncertainty estimates was forwarded to the coordinator within six weeks of completing measurement of the capacitors. The report included a description of the measurements method, the traceability to the SI, and the results, associated uncertainty and number of degrees of freedom.

List of measurement dates of the NMI participants is show in Table 3.

Table 3 List of measurement dates of the NMI participants

NMI	Measurement dates	Frequency	
		1000 Hz	1592 Hz
UMTS1, Ukraine	19.06–23.06.2006	yes	yes
PTB1, Germany	15.11–21.11.2006	yes	no
BIM, Bulgaria	19.06–03.07.2007	yes	no
UMTS2, Ukraine	06.08–10.08.2007	yes	yes
VNIIM, Russia	07.05–01.06.2008	yes	yes
NMIJ/AIST, Japan	15.07–17.07.2008	no	yes
KazInMetr, Kazakhstan	11.09–17.09.2008	yes	no
UMTS3, Ukraine	10.11–14.11.2008	yes	yes
PTB2, Germany	22.01–04.03.2009	yes	yes
UMTS4, Ukraine	16.03–20.03.2009	yes	yes
BelGIM, Belarus	10.08–24.08.2009	yes	yes
UMTS5, Ukraine	07.09–11.09.2009	yes	yes

Additional parameters for measurement of the NMI participants (Appendix 1) are show in Table 4. The capacitance values with its combine standard uncertainties (u_c) and description of the measurements methods reported by the NMI participants for 10 pF at frequencies of 1000 Hz and 1592 Hz (Appendixes 1 and 2) shown on Table 5. In Technical protocol of comparison (Appendix 3) INM (Romania) and SMU (Slovakia) is marked in KCDB, but those NMIs did not take part in comparison in the sequel. NMIJ/AIST (Japan) and KazInMetr (Kazakhstan) joined to comparison in 2008.

Corrected values for PTB at 1000 Hz and 1592 Hz were justified by a bilateral comparison between VNIIM and PTB in December 2011 for frequency dependence. The correction for value for PTB is –1.07 μF/F for 10 pF at 1000 Hz.

Table 4 Parameters for measurement of the NMI participants

Parameter	Value	Absolute expanded uncertainty
BIM, Bulgaria		
Frequency, Hz	1000.0	0.06
Voltage, V	100.0	0.4
Ambient temperature, °C	22.5…22.9	0.5
Relative humidity, %	48…62	6
PTB, Germany		
Frequency, Hz	1005.0 1592.0	0.1
Voltage, V	50.0	0.1
Ambient temperature, °C	23.0	0.5
Relative humidity, %	23…35	10
VNIIM, Russia		
Frequency, Hz	1000.0 1592.0	0.05
Voltage, V	98.5	0.1
Ambient temperature, °C	19.8…20.6	0.5
Relative humidity, %	42…56	8
NMIJ/AIST, Japan		
Frequency, Hz	$10^4/2\pi$	0.01
Voltage, V	100.0	0.2
Ambient temperature, °C	22.80	0.08
Relative humidity, %	46	6
KazInMetr, Kazakhstan		
Frequency, Hz	1000	0.05
Voltage, V	15	0.17
Ambient temperature, °C	20.5	0.06

Parameter	Value	Absolute expanded uncertainty
Relative humidity, %	45…50	3
UMTS, Ukraine		
Frequency, Hz	999.9 1591.99	0.01
Voltage, V	100.0	0.5
Ambient temperature, °C	20.0…21.0	0.5
Relative humidity, %	40…50	10
BelGIM, Belarus		
Frequency, Hz	1000 1600	0.06
Voltage, V	15.0	0.01
Ambient temperature, °C	23.0	0.05
Relative humidity, %	51.8…59.3	0.48

Table 5 Measured results for NMI participants for 1000 Hz and 1592 Hz

NMI	1000 Hz		1592 Hz	
	δC_i (μF/F)	u_{ci} (μF/F)	δC_i (μF/F)	u_{ci} (μF/F)
BIM	0.300	1.160	–	–
PTB*	0.033***	0.208***	–0.300	0.060
VNIIM	–0.190	0.182	–0.230	0.190
NMIJ/AIST	–	–	0.100	0.122
KazInMetr	–0.540	0.352	–	–
UMTS**	–0.080	0.220	–0.025	0.350
BelGIM	–0.230	1.100	–0.280	1.100

* The value for PTB is two measurement results calculated as simple mean value.

** The value for UMTS is first tree measurement results calculated as simple mean value.

*** The corrected value for PTB results from a bilateral comparison between VNIIM and PTB in December 2011 for determination of frequency dependence (1000 Hz and 1592 Hz).

7.2 Calculation of the key comparison reference values and their uncertainties

The key comparison reference values (CRV) x_{ref} are calculated as the mean of participant results with COOMET.EM-K4 data are given by

$$x_{ref} = \sum_{i=1}^{N} \frac{x_i}{u_c^2(x_i)} \bigg/ \sum_{i=1}^{N} \frac{1}{u_c^2(x_i)} \quad (1)$$

with combine standard uncertainties

$$u_c^2(x_{ref}) = 1 \bigg/ \sum_{i=1}^{N} \frac{1}{u_c^2(x_i)} \, . \quad (2)$$

In cases the calculated simple weighted mean of all results was x_{ref} = –0.131 μF/F with an expanded uncertainties U_{ref} = 0.219 μF/F (k = 2) at 1000 Hz and x_{ref} = –0.219 μF/F with an expanded uncertainties U_{ref} = 0.102 μF/F (k = 2) at 1592 Hz.

7.3 Degrees of equivalence of NMI participants

The principal results of this comparison are the pair-wise degrees of equivalence and the degrees of equivalence with respect to the key CRV (KCRV) of CCEM-K4.

Only one value is reported for NMI participants. Degrees of equivalence of the NMI participants are reported with respect to the measurement at 1592 Hz and 1000 Hz.

The degrees of equivalence of i-th NMI and its combined standard uncertainties with respect to the KCRV is estimated as

$$D_i = x_i - x_{ref} \, , \quad (3)$$

$$u_c^2(D_i) = u_c^2(x_i) - u_c^2(x_{ref}) \, . \quad (4)$$

The degrees of equivalence of the NMI participants and its expanded uncertainties $U(D_i)$ (k = 2) with respect to the CRV at 1000 Hz and 1592 Hz are also presented in Tables 6 and the graphs in Figures 2 and 3.

Table 6 Degrees of equivalence of the NMI participants

NMI	1000 Hz		1592 Hz	
	D_i (μF/F)	$U(D_i)$ (μF/F)	D_i (μF/F)	$U(D_i)$ (μF/F)
BIM	0.430	2.310	–	–
PTB	0.164	0.354	–0.081	0.063
VNIIM	–0.059	0.291	–0.011	0.366
NMIJ/AIST	–	–	0.318	0.221
KazInMetr	–0.409	0.669	–	–
UMTS	0.051	0.382	0.194	0.692
BelGIM	–0.099	2.189	–0.061	2.198

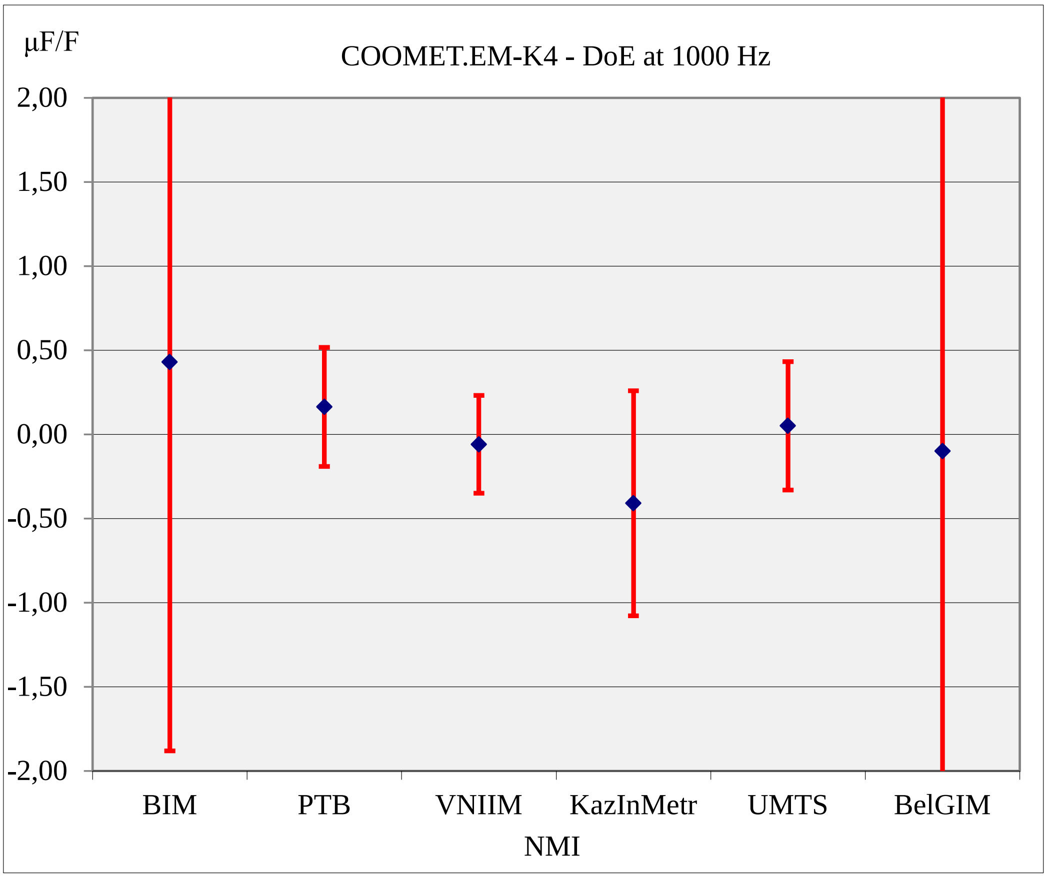


Figure 2 Degree of equivalence for NMI participants at 1000 Hz

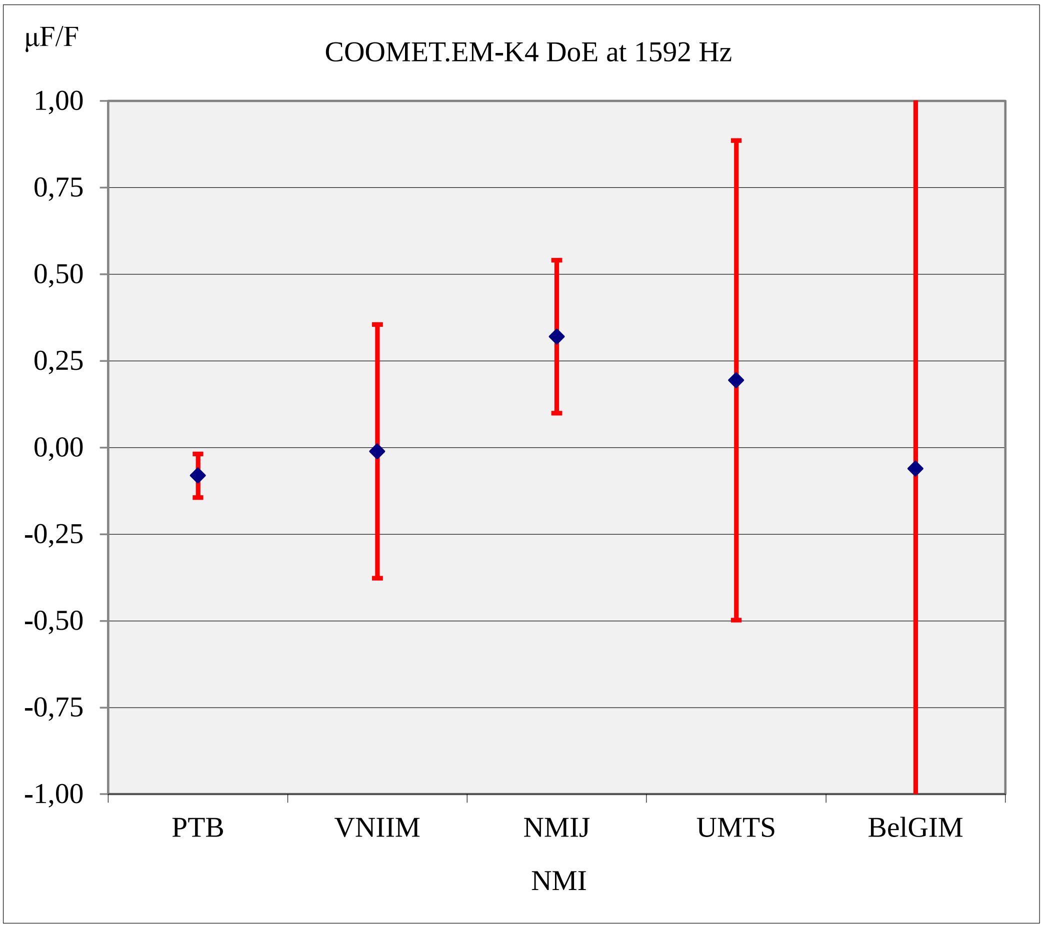


Figure 3 Degree of equivalence for NMI participants at 1592 Hz

The pair degrees of equivalence of *i*-th NMI and *j*-th NMI participants D_{ij} and its expanded uncertainties $U(D_{ij})$ (k = 2) with respect to the CRV at 1000 Hz and 1592 Hz are shown in Tables 7 and 8.

Pair degree of equivalence of *i*-th NMI and *j*-th NMI participants D_{ij} with combined standard uncertainty $u_{\mathrm{c}}(D_{ij})$ are estimated by

$$D_{ij} = x_i - x_j \,, \tag{5}$$

$$u_{\mathrm{c}}^2(D_{ij}) = u_{\mathrm{c}}^2(x_i) + u_{\mathrm{c}}^2(x_j) \,. \tag{6}$$

On the basis of the measurement results of COOMET.EM-K4 and corresponding uncertainties $\{x_i,\ u(x_i)\},\ i = 1,...N$ claimed by comparisons NMI participants, the χ^2 criterion value is calculated

$$\chi^2 = \sum_{i=1}^{N} \frac{(x_i - x_{ref})^2}{u_c^2(x_i)} \quad . \tag{3}$$

If the criterion value calculated in accordance with the data provided by NMIs doesn't exceed the critical value χ^2 with the coverage level 0.95 and the degrees of freedom N – 1

$$\chi^2 = \sum_{i=1}^{N} \frac{(x_i - x_{ref})^2}{u_c^2(x_i)} \prec \chi^2_{0.95(N-1)} \,, \tag{4}$$

then the data provided by different NMIs can be acknowledged as consistent, that is the objective confirmation of the announced uncertainties: $\chi^2 = 2.74 \prec \chi^2_{0.95(5)} = 11.07$ (N = 6) at 1000 Hz and $\chi^2 = 7.09 \prec \chi^2_{0.95(3)} = 7.81$ (N = 4 – without result of NMIJ) at 1592 Hz.

Table 7 Pair degrees of equivalence for NMI participants at 1000 Hz (µF/F)

NMI	BIM		PTB		VNIIM		KazInMetr		UMTS		BelGIM	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BIM			–0.266	2.336	–0.489	2.328	–0.839	2.404	–0.379	2.341	–0.529	3.182
PTB	0.266	2.337			–0.223	0.455	–0.573	0.755	–0.113	0.518	–0.263	2.217
VNIIM	0.489	2.328	0.223	0.455			–0.350	0.728	0.110	0.478	–0.040	2.208
KazInMetr	0.839	2.404	0.573	0.755	0.350	0.728			0.460	0.769	0.310	2.288
UMTS	0.379	2.341	0.113	0.518	–0.110	0.478	–0.460	0.769			–0.150	2.221
BelGIM	0.529	3.182	0.263	2.217	0.040	2.208	–0.310	2.288	0.150	2.221		

Table 8 Pair degrees of equivalence for NMI participants at 1592 Hz (µF/F)

NMI	PTB		VNIIM		NMIJ/AIST		UMTS		BelGIM	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
PTB			0.070	0.368	0.399	0.224	0.275	0.693	0.020	2.198
VNIIM	–0.070	0.368			0.329	0.425	0.205	0.781	–0.050	2.228
NMIJ/AIST	–0.399	0.224	–0.329	0.425			–0.124	0.725	–0.379	2.208
UMTS	–0.275	0.693	–0.205	0.781	0.124	0.725			0.020	2.198
BelGIM	–0.020	2.198	0.050	2.228	0.379	2.208	0.255	2.304		

7.4 Proposal for linking to CCEM-K4 key comparison and degrees of equivalence of NMI participants

We propose that the results COOMET.EM-K4 be linked to CCEM-K4 at 1592 Hz with using a method similar to that used to linking EUROMET.EM-K4 to CCEM-K4 and APMP.EM-K4.1 to CCEM-K4 [3].

The degrees of equivalence of *i*-th NMI with respect to linking to CCEM-K4 is estimated as

$$d_i = D_i + \Delta , \tag{7}$$

where:

D_i – result from COOMET.EM-K4 for a NMI participant in COOMET.EM-K4 only;

d_i – best estimate of result from NMI *i* to linking to CCEM-K4.

Measurements from the linking NMIs provide estimates

$$\Delta_{iLINK} = d_{iLINK} - D_{iLINK} \tag{8}$$

for the correction Δ.

The correction Δ is then calculated as the weighted mean of the linking NMIs estimates, that is:

$$\Delta = \sum_{iLINK} w_{iLINK} \Delta_{iLINK} , \tag{9}$$

where:

d_{iLINK} – result from CCEM-K4 for a linking NMI;

D_{iLINK} – result from COOMET.EM-K4 for a linking NMI;

$$w_{iLINK} = \frac{s^2(\Delta)}{s^2(\Delta_{iLINK})} ; \tag{10}$$

$$s^2(\Delta) = \frac{1}{\left(\sum\limits_{iLINK} \frac{1}{s^2(\Delta_{iLINK})} \right)} . \tag{11}$$

The uncertainty, $s(\Delta_{iLINK})$, associated with Δ_{iLINK} is calculated as in [3] by the root-sum-square of the transfer uncertainty in the CCEM-K4 comparison, u_T = 0.02 μF/F, the transfer uncertainty in the COOMET.EM-K4 comparison, $u(p_i) \approx 0.076$, and the uncertainty associated with the imperfect reproducibility of the results of NMI_{iLINK} in the time period spanning its two measurements (counted twice), r_{iLINK} estimation is driven to the Table 9 for data PTB and VNIIM [3, 4].

The linking NMIs are PTB and VNIIM. No significant changes to the method of measurement used in CCEM-K4 and COOMET.EM-K4 were made by PTB. Note that D_{iLINK} for VNIIM is taken as the CCEM-K4 result adjusted by the 2003 VNIIM Capacitance Unit correction.

The calculated linking correction is Δ = 0.107 μF/F, with a standard deviation $s(\Delta)$ = 0.112 μF/F. Table 9 lists the values of the quantities used in the calculation.

Table 9 CCEM-K4 and COOMET.EM-K4 comparison results
and expanded uncertainties for linking NMIs

Linking NMI	d_{iLINK} (μF/F)	D_{iLINK} (μF/F)	Δ_{iLINK} (μF/F)	u_T (μF/F)	$u(p_i)$ (μF/F)	r_{iLINK} (μF/F)	$s(\Delta_{iLINK})$ (μF/F)	w_{iLINK} (μF/F)
VNIIM	–0.118	–0.099	–0.019	0.020	0.076	0.071	0.162	0.687
PTB	–0.004	–0.169	0.165	0.020	0.076	0.066	0.154	0.726

The best estimate of the result from NMI *i* had it participated in CCEM-K4 is calculated using (7). The standard uncertainty is calculated as:

$$u^2(d_i) = u^2(D_i) + u^2(\Delta) = u^2(D_i) + s^2(\Delta) + u^2(m_{ref}), \quad (12)$$

where: $u(m_{ref})$ = 0.017 μF/F is the uncertainty in $u(m_{ref})$, the CCEM-K4 KCRV. The expanded uncertainty is $U(d_i) = k_{d_i} u(d_i)$, where is chosen k_{d_i} = 2 to give 95 % coverage.

The frequency coefficient of capacitance (1592 Hz/1000 Hz) at a frequency of 1592 Hz for BIM and KazInMetr, which measurements made only at a frequency of 1000 Hz, is $\Delta_{f,1592}$ = –0.088 μF/F with an expanded uncertainty $U(\Delta_{f,1592})$ = 0.244 μF/F with used equations:

$$\Delta_{f,1592} = x_{ref,1592} - x_{ref,1000}, \quad (13)$$

$$u^2(\Delta_{f,1592}) = u^2(x_{ref,1592}) + u^2(x_{ref,1000}). \quad (14)$$

The degrees of equivalence $d_{i,1592}$ with its uncertainties for BIM and KazInMetr are calculated (Table 9) with used equations:

$$d_{i,1592} = D_{i,1000} + \Delta_{f,1592} + \Delta, \quad (15)$$

$$u^2(d_{i,1592}) = u^2(D_{i,1000}) + u^2(\Delta_{f,1592}) + s^2(\Delta). \quad (16)$$

The calculated degrees of equivalence with respect to CCEM-K4 KCRV are tabulated in d_i Table 10.

The declared uncertainties are judged as confirmed if the following equation is satisfied

$$|d_i| < 2u_c(d_i). \quad (17)$$

Degrees of equivalence D_i, with respect to the CCEM-K4 KCRV, for CCEM-K4 (red diamonds), EUROMET.EM-K4 (green triangles), APMP.EM-K4.1 (blue circles) and COOMET.EM-K4 (brown squares) are shown on Figure 4.

Where NMI *i* participated only in COOMET.EM-K4 and NMI *j* participated in COOMET.EM-K4, the pair-wise degrees of equivalence d_{ij} with its uncertainties are those calculated in Section 7.3, that is

$$d_{ij} = D_{ij} \text{ and } U(d_{ij}) = U(D_{ij}). \quad (18)$$

Note that NMI *j* may also have participated in CCEM-K4 and/or EUROMET.EM-K4.

Table 10 Proposed degrees of equivalence for NMI participants relative to the CCEM-K4 KCRV at 1592 Hz

NMI	d_i (µF/F)	$U(d_i)$ (µF/F)
BIM*	0.449	3.369
VNIIM	–	–
PTB	–	–
NMIJ/AIST	0.425	0.250
KazInMetr*	–0.390	0.747
UMTS	0.301	0.727
BelGIM	0.046	2.212

*Measurements made at 1000 Hz.

Where NMI *i* participated only in COOMET.EM-K4 and NMI *j* participated in CCEM-K4 or EUROMET.EM-K4 or APMP.EM-K4.1 but not in COOMET.EM-K4, then

$$d_{ij} = d_i - d_j \,, \tag{19}$$

$$u^2\left(d_{ij}\right) = u^2\left(d_i\right) + u^2\left(d_j\right) - 2u^2\left(m_{ref}\right) - 2u_r^2 \,, \tag{20}$$

where u_r is the standard uncertainty associated with a common reference standard (relevant only if laboratory *i* derives its traceability from NMI *j*, or if NMI *i* and NMI *j* both derive.

Proposed degrees of equivalence for participants of COOMET.EM-K4 with participants in CCEM-K4 (red), EUROMET.EM-K4 (blue), APMP.EM-K4.1 (green) and COOMET.EM-K4 (brow) are shown on Table 11.

8 Summary

A key comparison of capacitance at 10 pF has been conducted between participating COOMET member NMIs and NMIs from other regional metrological organizations. In general there is good agreement between NMI participants for this quantity. It is expected that this comparison will be able to provide support for participants’ entries in Appendix C of the Mutual Recognition Arrangement. Proposal for linking to CCEM-K4 key comparison and degrees of equivalence of NMI participants was made.

References

[1] S. Akhmadov, O. Akhmadov, O. Velychko. International comparison of 10 pF and 100 pF capacitance standards: degrees of equivalence determination in the COOMET project 345/UA/05. Digest of 2006 Conference on Precision Electromagnetic Measurement (*CPEM 2006*). – Torino, Italy, 2006. – P. 185.

[2] A.-M. Jeffery. CCEM Comparison of 10 pF Capacitance Standards. *Final Report,* March 2002.

[3] F. Delahaye and T. J. Witt. Linking the results of key comparisons CCEM-K4 with the 10 pF results of EUROMET.EM-K4. *Metrologia* Tech. Suppl., 01005, Vol. 39, 2002.

[4] H. L. Johnson. APMP.EM-K4.1. APMP Key Comparison of Capacitance at 10 pF. Final Report. *Metrologia* Tech. Suppl., 01003, Vol. 46, 2009.

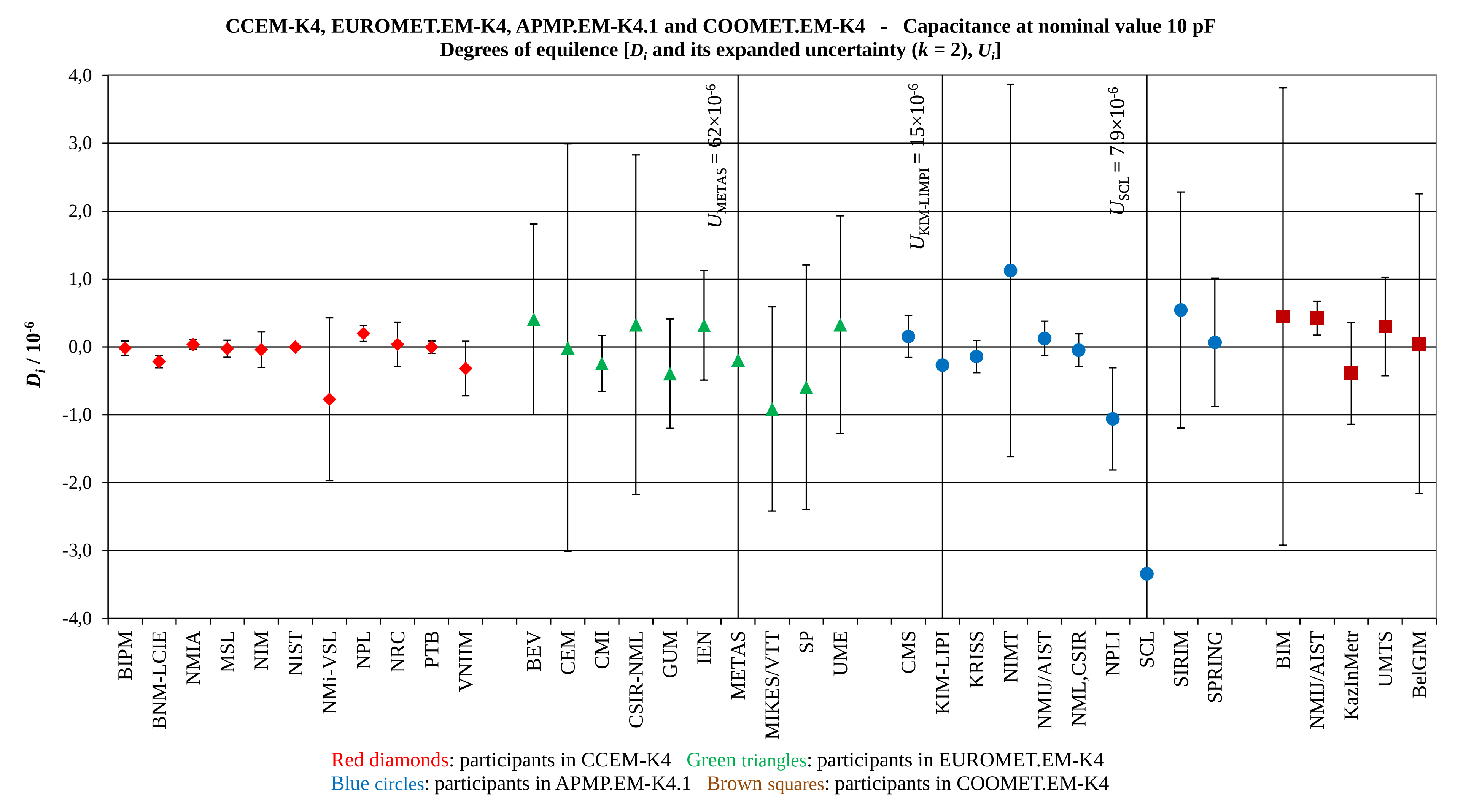


Figure 4 Degrees of equivalence D_i with respect to the CCEM-K4 key comparison reference value

Table 11 Proposed degrees of equivalence for participants of COOMET.EM-K4 with participants in CCEM-K4 (red), EUROMET.EM-K4 (blue), APMP.EM-K4.1 (green) and COOMET.EM-K4 (brow) (μF/F)

NMI	D_i	$U(D_i)$	NMI									
			BIM		NMIJ/AIST		KazInMetr		UMTS		BelGIM	
			D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BIPM	-0.018	0.105	0.467	3.370	0.443	0.266	-0.372	0.753	0.319	0.733	0.064	2.211
BNM-LCIE	-0.216	0.092	0.665	3.370	0.641	0.261	-0.174	0.751	0.517	0.731	0.262	2.210
NMIA	0.035	0.069	0.414	3.369	0.390	0.254	-0.425	0.748	0.266	0.728	0.011	2.209
MSL	-0.026	0.124	0.475	3.371	0.451	0.274	-0.364	0.756	0.327	0.736	0.072	2.212
NIM	-0.040	0.261	0.489	3.379	0.465	0.358	-0.350	0.790	0.341	0.771	0.086	2.224
NIST	-0.003	0.029	0.452	3.369	0.428	0.246	-0.387	0.746	0.304	0.726	0.049	2.209
NMi-VSL	-0.772	1.200	1.221	3.576	1.197	1.225	0.382	1.413	1.073	1.402	0.818	2.513
NPL	0.198	0.116	0.251	3.371	0.227	0.271	-0.588	0.754	0.103	0.734	-0.152	2.211
NRC	0.037	0.324	0.412	3.384	0.388	0.406	-0.427	0.813	0.264	0.794	0.009	2.232
PTB	-0.004	0.092	0.453	3.370	0.429	0.261	-0.386	0.751	0.305	0.731	0.050	2.210
VNIIM	-0.318	0.401	0.767	3.392	0.743	0.470	-0.072	0.846	0.619	0.586	0.364	2.245
BEV	0.407	1.404	0.042	3.649	0.018	1.425	-0.797	1.590	-0.106	1.580	-0.361	2.617
CEM	-0.013	3.002	0.462	4.512	0.438	3.012	-0.377	3.093	0.314	3.088	0.059	3.727
CMI	-0.243	0.412	0.692	3.394	0.668	0.479	-0.147	0.852	0.544	0.834	0.289	2.247
CSIR-NML	0.327	2.502	0.122	4.196	0.098	2.514	-0.717	2.501	-0.026	2.605	-0.281	3.337
GUM	-0.393	0.806	0.842	3.464	0.818	0.842	0.003	1.098	0.694	1.084	0.439	2.351
IEN	0.317	0.806	0.132	3.464	0.108	0.842	-0.707	1.098	-0.016	1.084	-0.271	2.351
METAS	-0.193	62.000	0.642	62.091	0.618	62.000	-0.197	62.004	0.494	62.004	0.239	62.039

NMI	D_i	$U(D_i)$	NMI									
			BIM		NMIJ/AIST		KazInMetr		UMTS		BelGIM	
			D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
MIKES/VTT	-0.913	1.504	1.362	3.689	1.338	1.524	0.523	1.679	1.214	1.670	0.959	2.672
SP	-0.593	1.802	1.042	3.820	1.018	1.819	0.203	1.950	0.894	1.942	0.639	2.850
UME	0.327	1.602	0.122	3.730	0.098	1.621	-0.717	1.767	-0.026	1.759	-0.281	2.728
CMS	0.154	0.309	0.295	3.383	0.271	0.394	-0.544	0.807	0.147	0.788	-0.108	2.230
KIM-LIPI	-0.268	15.072	0.717	15.444	0.693	15.074	-0.122	15.090	0.569	15.089	0.314	15.233
KRISS	-0.142	0.237	0.591	3.377	0.567	0.341	-0.248	0.782	0.443	0.763	0.188	2.221
NIMT	1.125	2.745	-0.676	4.345	-0.700	2.756	-1.515	2.844	-0.824	2.839	-1.079	3.523
NMIJ/AIST	0.124	0.254	0.325	3.378	0.301	0.353	-0.514	0.787	0.177	0.768	-0.078	2.223
NML,CSIR	-0.048	0.240	0.497	3.377	0.473	0.343	-0.342	0.783	0.349	0.764	0.094	2.221
NPLI	-1.060	0.752	1.509	3.452	1.485	0.791	0.670	1.059	1.361	1.045	1.106	2.333
SCL	-3.342	7.860	3.791	8.551	3.767	7.864	2.952	7.895	3.643	7.893	3.388	8.164
SIRIM	0.543	1.740	-0.094	3.791	-0.118	1.757	-0.933	1.893	-0.242	1.885	-0.497	2.812
SPRING	0.066	0.945	0.383	3.499	0.359	0.976	-0.456	1.204	0.235	1.191	-0.020	2.402
BIM	0.449	3.369			-0.024	3.378	-0.839	3.450	-0.148	3.446	-0.403	4.028
NMIJ/AIST	0.425	0.250	0.024	3.378			-0.815	0.786	-0.124	0.767	-0.379	2.223
KazInMetr	-0.390	0.747	0.839	3.450	0.815	0.786			0.691	1.041	0.436	2.331
UMTS	0.301	0.727	0.148	3.446	0.124	0.767	-0.691	1.041			-0.255	2.325
BelGIM	0.046	2.209	0.403	4.028	0.379	2.223	-0.436	2.331	0.255	2.325		

Appendix 1

Reported measurement results for NMI participants

BIM (Bulgaria)

<table>
<tr><th colspan="2">Measurement number</th><th>1</th><th>2</th><th>3…</th><th>…19</th><th>20</th></tr>
<tr><td colspan="2">Measurement date</td><td>19.06.2007</td><td>19.06.2007</td><td>19.06.2007</td><td>29.06.2007</td><td>03.07.2007</td></tr>
<tr><td colspan="2">Measured capacitance, pF</td><td>10.000002</td><td>10.000002</td><td>10.000003</td><td>10.000003</td><td>10.000002</td></tr>
<tr><td colspan="2">Measurement frequency, Hz</td><td colspan="5">1000</td></tr>
<tr><td colspan="2">Chassis temperature, ºC</td><td>28.2</td><td>28.3</td><td>28.0</td><td>28.2</td><td>28.1</td></tr>
<tr><td colspan="2">Drift reading, ppm</td><td colspan="5">+0.014</td></tr>
<tr><td rowspan="3">Measurement result</td><td>Mean measurement date</td><td colspan="5">27.06.2007</td></tr>
<tr><td>Mean capacitance, pF</td><td colspan="5">10.000003</td></tr>
<tr><td>Combined relative standard uncertainty, μF/F</td><td colspan="5">1.16</td></tr>
</table>

The 1:1 substitution method with capacitance bridge type GR 1621 is used. The travelling and the reference standards are measured in turn in three-wire connection. The adapters GR 874 to BNC are used to connect the standards type AH11A to the original cables of the bridge.

UMTS (Ukraine)

<table>
<tr><th colspan="2">Measurement number</th><th>1</th><th>…</th><th>10</th></tr>
<tr><td colspan="2">Measurement date</td><td>06.10.2008</td><td>…</td><td>10.10.2008</td></tr>
<tr><td colspan="2">Measured capacitance, pF</td><td colspan="3">9.9999992</td></tr>
<tr><td colspan="2">Measurement frequency, Hz</td><td colspan="3">999.9</td></tr>
<tr><td colspan="2">Ambient temperature, °C</td><td colspan="3">28.5</td></tr>
<tr><td colspan="2">Drift reading, ppm</td><td colspan="3">+0.005</td></tr>
<tr><td rowspan="4">Measurement result</td><td>Mean measurement date</td><td colspan="3">08.10.2008</td></tr>
<tr><td>Mean capacitance, pF</td><td colspan="3">9.9999992 (for first tree measurement results)</td></tr>
<tr><td>Combined relative standard uncertainty, μF/F</td><td colspan="3">0.22</td></tr>
<tr><td>Degrees of freedom</td><td colspan="3">more than 100</td></tr>
<tr><td colspan="2">Measurement date</td><td>06.10.2008</td><td>…</td><td>10.10.2008</td></tr>
<tr><td colspan="2">Measured capacitance, pF</td><td colspan="3">9.9999975</td></tr>
<tr><td colspan="2">Measurement frequency, Hz</td><td colspan="3">1591.99</td></tr>
<tr><td colspan="2">Ambient temperature, °C</td><td colspan="3">28.6</td></tr>
</table>

Drift reading, ppm		+0.005
Measurement result	Mean measurement date	08.10.2008
	Mean capacitance, pF	9.9999975 (for first tree measurement results)
	Combined relative standard uncertainty, µF/F	0.35
	Degrees of freedom	more than 100

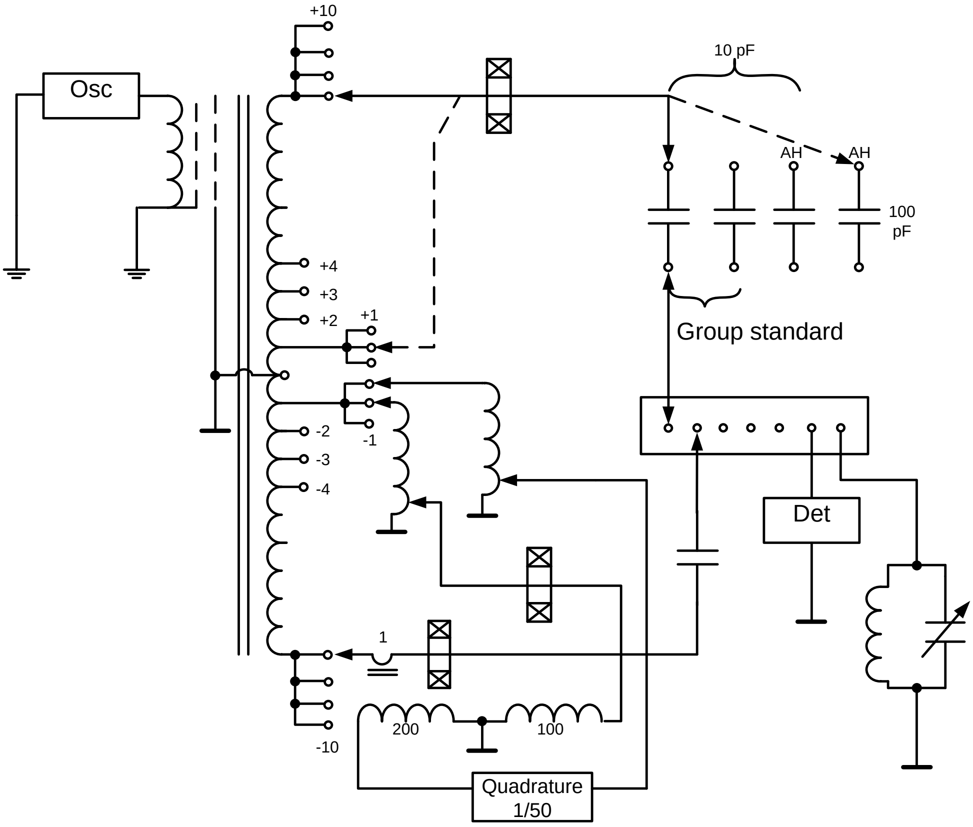
The substitution method with quadrature bridge of National Standards of Capacitance Unit is used. The 10 pF AH capacitor is measured by means of substitution method with use of the group active resistance standard which traceable to the QHR.

VNIIM (Russia)

Measurement number		1	2	3	4	5	6	7
Measurement date		07.05.08	08.05.08	12.05.08	20.05.08	21.05.08	22.05.08	23.05.08
Measured capacitance, pF		9.9999983	9.9999980	9.9999986	9.9999980	9.9999983	9.9999982	9.9999984
Chassis temperature, °C		27.1	27.4	27.3	27.5	27.3	27.2	27.8
Drift reading, ppm		0.015	0.018	0.018	0.018	0.018	0.018	0.018
Mean measurement date		16.05.2008						
Optional	Mean dissipation factor	$5.0 \cdot 10^{-7}$						
	Standard uncertainty	$2.0 \cdot 10^{-7}$						
	Degrees of freedom	6						
Measurement result	Measurement frequency, Hz	1000.0						
	Mean capacitance, pF	9.9999981						
	Combined standard uncertainty, pF	$18.2 \cdot 10^{-7}$						
	Degrees of freedom	34						
	Measurement frequency, Hz	1592.0						
	Mean capacitance, pF	9.9999977						
	Combined standard uncertainty, pF	$19.0 \cdot 10^{-7}$						

The TO-1 transformer bridge which is a part of the secondary standard of capacitance was used to measure 10 pF capacitor. Ratio windings of this bridge are executed as copper straps located side by side so that the output impedance does not exceed 0.030 Ohm at 1 kHz. The bridge can be balanced by adjustment of two six-decade IVDs which outputs are connected in-series with the quadrature circuit and the injection transformer.

The 10 pF AH capacitor is measured by means of substitution method with use of 10 pF capacitors from the group standard that maintains the national unit of capacitance.



NMIJ/AIST (Japan)

Measurement number		1	2	3
Measurement date		2008-07-15	2008-07-16	2008-07-17
Measured capacitance, pF		10.00000110	10.00000093	10.00000097
Measurement frequency, Hz		$10^4/2\pi$		
Chassis temperature, ºC		29.5		
Drift reading, ppm		0.017		
Measurement result	Mean measurement date	2008-07-16		
	Mean capacitance, pF	10.000001		
	Combined relative standard uncertainty, µF/F	0.122		
	Degrees of freedom	135496		

The reference standards of capacitance are traceable to the QHR at NMIJ, the value of which is $R_{K\text{-}90}/2$ with a relative standard uncertainty of 1×10^{-7} to the SI.

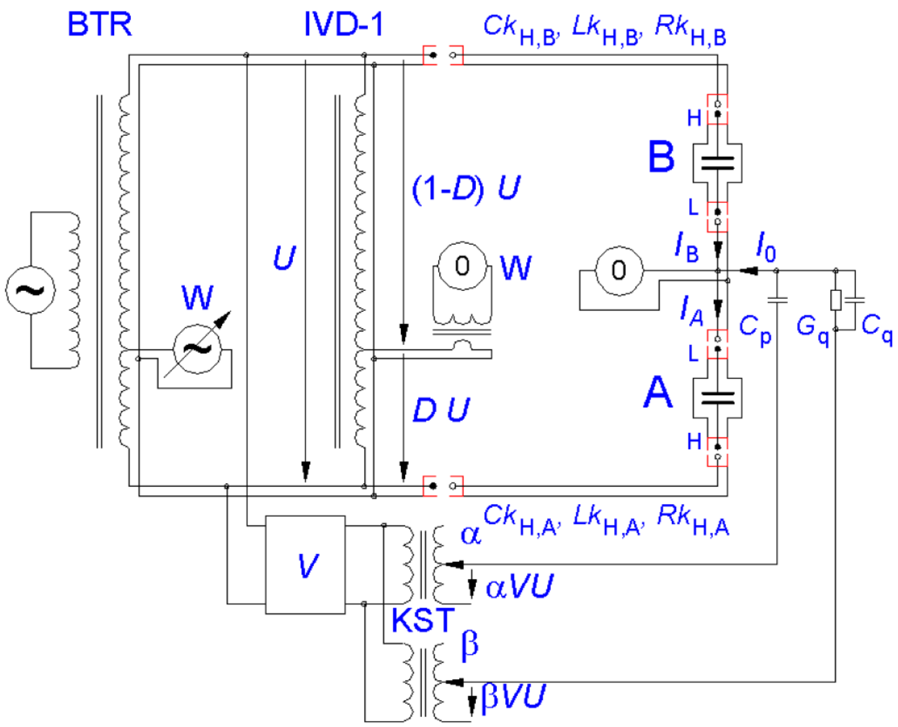
By using the four terminal-pair resistance bridge, the two terminal-pair quadrature bridge, the two terminal-pair capacitance bridge and the AC/DC calculable resistor, the capacitance was derived from the QHR.

PTB (Germany)

	Measurement number	1	…	10
Measurement date		2006-11-15	…	2006-11-21
Measured capacitance, pF		10.0000073		
Measurement frequency, Hz		1005.0		
Chassis temperature, °C		29.6		
Drift reading, ppm		+0.018		
Measurement result	Mean measurement date	2006-11-19		
	Mean capacitance, pF	10.0000073		
	Combined expanded relative standard uncertainty, µF/F	0.41		
	Degrees of freedom	9		
Measurement date		2009-01-22	…	2009-03-04
Measured capacitance, pF		10.0000073		
Chassis temperature, °C		30.3		
Drift reading, ppm		+0,018		
Measurement frequency, Hz		1005.0		
Measurement result	Mean measurement date	2009-02-13		
	Mean capacitance, pF	10.0000073		
	Combined expanded relative standard uncertainty, µF/F	0.42		
	Degrees of freedom	11		
Measurement date		2009-01-22	…	2009-03-04
Measured capacitance, pF		9.999997		
Chassis temperature, °C		30.3		
Drift reading, ppm		+0.017		
Measurement frequency, Hz		1592.0		
Measurement result	Mean measurement date	2009-02-13		
	Mean capacitance, pF	9.999997		
	Combined relative standard uncertainty, µF/F	0.12		
	Degrees of freedom	∞		

The travelling standards AH11A have been compared with appropriate reference standards of capacitance by an 1:1-measurement procedure in the two terminal pair bridge. The reference standards of capacitance are traceable to the Calculable Cross Capacitor and the QHR at PTB.

Uncertainty contributions due to the inductive voltage divider ratio and the leads are cancelled by commutation of reference standard and comparison artefact. The results stated are the mean values of 10 independent bridge readings each.



KazInMetr (Kazakhstan)

Measurement number		1	2	… 5	…9
Measurement date		17.09.2008	12.09.2008	17.09.2008	23.09.2008
Measured capacitance, pF		9.9999943	9.9999934	9.9999955	9.9999947
Measurement frequency, Hz		1000.0			
Chassis temperature, ºC		27.0	28.2	26.6	27.4
Drift reading, ppm		0.015	0.016	0.015	0.015
Measurement result	Mean measurement date	17.09.2008			
	Mean capacitance, pF	9.9999946			
	Combined relative standard uncertainty, µF/F	0.352			
	Degrees of freedom	24			

The substitution method with capacitance bridge type AH2700A is used. 10 measurements readings of the capacitance value of the travelling standard AH11A and reference standard at a frequency of 1 kHz were taken alternately.

BelGIM (Belarus)

Measurement number		1	2	…49	50
Measurement frequency, Hz		1000.0			
Measurement date		17.08.2009	17.08.2009	17.08.2009	17.08.2009
Chassis temperature, ºC		31.0	31.0	31.1	31.1
Drift reading, ppm		0.015			
Measurement result	Mean measurement date	17.08.2009			
	Mean capacitance, pF	9.9999977			
	Combined relative standard uncertainty, μF/F	1.10			
	Degrees of freedom	more 100			
Measurement number		1	2	…49	50
Measurement frequency, Hz		1600.0			
Measurement date		17.08.2009	17.08.2009	17.08.2009	17.08.2009
Chassis temperature, ºC		31.0	31.0	31.1	31.1
Drift reading, ppm		0.015			
Measurement result	Mean measurement date	17.08.2009			
	Mean capacitance, pF	9.9999972			
	Combined relative standard uncertainty, μF/F	1.10			
	Degrees of freedom	more 100			

Method of determination of the actual value is the substitution method. Ultra precision 50 Hz – 20 kHz capacitance bridge AH2700A and ultra-stable capacitance standard AH11A with nominal values of 10 pF and 100 pF were used. 100 measurements readings of the capacitance value of the travelling standard and reference standard at a frequency of 1 kHz and 1.6 kHz were taken alternately.

Appendix 2

Reported measurement uncertainty components for NMI participants

BIM (Bulgaria)

Quantity	Distribution	x_i	Standard uncertainty	ν_i	c_i	Uncertainty contribution
Reference standard, *Cs*, pF	normal	9.999988	9.00E-06	∞	1	9.00E-06
Drift of reference standard, δC_D, pF	rectangular	0.0000006	1.73E-07	∞	1	1.73E-07
Correction of temperature of *Cs*, δC_{TS}, pF	rectangular	-0.000012	6.64E-06	∞	1	6.64E-06
Correction factor for parasitic voltages, temperature dependence of the bridge, errors of reading analog bridge's meters, c_k (relative)	triangular	1	8.16E-08	∞	10 pF	8.16E-07
Ratio of *C* to *Cs*, $\bar{c}$ (relative)	normal	1.0000026	7.73E-08	19	10 pF	7.73E-07
Correction from adapter, δC_{AD}, pF	rectangular	0	2.89E-06	∞	-1	-2.89E-06
Travelling standard, *C*, pF	normal	10000003	1.16E-05	∞		
Final values:						1.16E-06
Mathematical model: $C = (Cs+\delta C_D+\delta C_{TS}).c_k.\bar{c} - \delta C_{AD}$						

UMTS (Ukraine)

Quantity	Source of uncertainty	Relative standard uncertainty, μF/F
1000 Hz		
Ω	Frequency measurement uncertainty	0.06
R_0	Uncertainty of R_0 calibration on resistive primary standard on DC	0.04
	Uncertainty of R_0 AC (1000 Hz) correction coefficient	0.05
	R_0 resistance long term instability	0.04
	Uncertainty, caused by R_0 temperature instability (TCR·Δ*T*)	0.05
	Uncertainty of R_0 temperature measurements	0.03
	Uncertainty of the R_0 calibration by phase angle	0.08

Quantity	Source of uncertainty	Relative standard uncertainty, μF/F
K_c	Quadrature bridge standard deviation during its calibration by R_0	0.04
	Quadrature bridge standard deviation during capacitance unit reproduction	0.04
	Quadrature bridge standard deviation during measurement of dissipation factor	0.10
	Quadrature bridge uncertainty in *R*-*C* transfer mode	0.09
	Quadrature bridge dissipation factor uncertainty during the capacitance unit reproduction	0.04
C_s	Capacitance transfer standard uncertainty, caused by its temperature instability ($TCC \cdot \Delta T$)	0.08
	Final values:	0.22
	1592 Hz	
Ω	Frequency measurement uncertainty	0.06
R_0	Uncertainty of R_0 calibration on resistive primary standard on DC	0.04
	Uncertainty of R_0 AC (1592 Hz) correction coefficient	0.10
	R_0 resistance long term instability	0.04
	Uncertainty, caused by R_0 temperature instability ($TCR \cdot \Delta T$)	0.05
	Uncertainty of R_0 temperature measurements	0.03
	Uncertainty of the R_0 calibration by phase angle	0.20
K_c	Quadrature bridge standard deviation during its calibration by R_0	0.04
	Quadrature bridge standard deviation during capacitance unit reproduction	0.04
	Quadrature bridge standard deviation during measurement of dissipation factor	0.10
	Quadrature bridge uncertainty in *R*-*C* transfer mode	0.20
	Quadrature bridge dissipation factor uncertainty during the capacitance unit reproduction	0.04
C_s	Capacitance transfer standard uncertainty, caused by its temperature instability ($TCC \cdot \Delta T$)	0.08
	Final values:	0.35

Mathematical model: $C_s = \frac{1}{\omega R_0} K_c$,

where:_Ω – operating frequency; K_c – quadrature bridge transfer coefficient; R_0 – active resistance standard; C_s – transfer capacitance is used for unit reproducing.

VNIIM (Russia)

Quantity	Esti-mate	Unit	Standard uncertainty	Unit	Effective degrees of freedom	Sensitivity coefficient	Unit	Contribution to the relative standard uncertainty, μF/F
Realisation of SI farad:								
VNIIM calculable capacitor	0.2	pF						
Geometrical imperfections	0	μF/F	0.08	μF/F	13	1		0.08
Laser interferometer	0	μF/F	0.03	μF/F	8	1		0.03
Transformer bridge	0	μF/F	0.06	μF/F	13	1		0.06
Insufficient sensitivity	0	μF/F	0.09	μF/F	6	1		0.09
Repeatability	0	μF/F	0.10	μF/F	6	1		0.10
Working standard (the group standard for maintenance the national unit of capacitance)	10	pF						
Build-up from calculable capacitor	0	μF/F	0.04	μF/F	8	1		0.04
Extrapolation to mean measurement date	0	μF/F	0.02	μF/F	50	1		0.02
Bridge calibration	0	μF/F	0.02	μF/F	13	1		0.02
Temperature correction	0	μF/F	0.03	μF/F	20	1		0.03
Measurement of comparison artefact								
Mean of *7* independent measurements	- 0.19	μF/F	0.02	μF/F	6	1		0.02
Bridge resolution	0	μF/F	0.02	μF/F	13	1		0.02
Lead correction	-0.017	μF/F	0.005	μF/F	20	1		0.005
Temperature correction	-0.004	μF/F	0.1	°C	13	0.01	μF/F/K	0.001
Final values:	-0.21	μF/F			34			0.182

NMIJ/AIST (Japan)

Quantity	Estimate	Unit	Standard uncertainty	Unit	Type	Effective degrees of freedom	Sensitivity coefficient	Unit	Contribution to the relative standard uncertainty (μF/F)
Realization of SI farad: reference standard									
10 pF capacitance standard based on a quantized Hall resistance (QHR) (1, 2)	1.665	μF/F	0.120	μF/F	B	156796	1		0.120
Measurement of comparison artifact									
Mean of 3 independent measurements	-1.523	μF/F	0.005	μF/F	A	2	1		0.005
Lead correction (3)	-0.042	μF/F	0.017	μF/F	B	∞	1		0.017
Laboratory temperature correction (22.81 ºC → 20 ºC) (4)	0.000	μF/F	0.016	μF/F	B	∞	1		0.016
Measurement voltage: 100 V (5)			0.1	V	B	∞	0.003	(μF/F)/V	0.0003
Measurement frequency: $10^4/2\pi$ Hz (5)			0.005	Hz	B	∞	0.0002	(μF/F)/Hz	0.000001
Final values:	0.100	μF/F				135496			0.122

Notes:

1. The value of the QHR was determined based on the R_{K-90} =25 812.807 Ω with a relative standard uncertainty of 1×10^{-7}.
2. Details of uncertainties are described in IEEE Trans. Instrum. Meas., vol. 50, pp. 290–293, 2001.
3. Leads effect was estimated by measuring the relative change of capacitance with changing the length of leads.
4. No corrections were made for ambient laboratory temperature.
5. Type B uncertainty only.

PTB (Germany)

Page 5 of 9

Laboratory:	PTB
UNCERTAINTY STATEMENT: COOMET.EM-K4 (10 pF) **Serial Number 01327**	

Coomet-K4, AH11A-01327, 10 pF, f = 1 kHz

Uncertainty Budget:

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
V	1.14181240 1	$208\cdot10^{-6}$ %	9	$28\cdot10^{-15}$	$67\cdot10^{-21}$ F	0.00	0.001
T_X	29.6100 °C	0.146 %	9	$-100\cdot10^{-21}$	$-4.3\cdot10^{-21}$ F	-0.01	0.000
a1p	$-3.16120\cdot10^{-3}$ 1	0.115 %	9	$10\cdot10^{-15}$	$37\cdot10^{-21}$ F	0.00	0.000
b1p	$2.9900\cdot10^{-3}$ 1	1.53 %	9	$790\cdot10^{-21}$	$36\cdot10^{-24}$ F	0.01	0.000
a2p	$3.12710\cdot10^{-3}$ 1	0.104 %	9	$-10\cdot10^{-15}$	$-33\cdot10^{-21}$ F	0.00	0.000
b2p	$-1.7100\cdot10^{-3}$ 1	4.31 %	9	$-790\cdot10^{-21}$	$-58\cdot10^{-24}$ F	0.01	0.000
C_{NB}	$10.00006387\cdot10^{-12}$ F	$2.80\cdot10^{-6}$ %	700	1.0	$280\cdot10^{-21}$ F	0.16	0.025
T_{NB}	29.791 °C						
k_{TN}	$11.40\cdot10^{-6}$ K^{-1}	17.5 %	9	$-17\cdot10^{-15}$	$-34\cdot10^{-21}$ F	-0.02	0.000
k_{IN}	$-1.810\cdot10^{-9}$ s	16.6 %	9	$-5.9\cdot10^{-9}$	$-1.8\cdot10^{-18}$ F	-0.99	0.971
f	1005.000 Hz	0.0574 %	infinity	$-18\cdot10^{-21}$	$-10\cdot10^{-21}$ F	-0.01	0.000
DR_N	$-75.0\cdot10^{-9}$ a^{-1}	15.4 %	infinity	$5.0\cdot10^{-12}$	$58\cdot10^{-21}$ F	0.03	0.001
Δt	0.50000 a	1.15 %	infinity	$-750\cdot10^{-21}$	$-4.3\cdot10^{-21}$ F	0.00	0.000
C_N	$10.00007392\cdot10^{-12}$ F	$17.9\cdot10^{-6}$ %					
Cp	$1000.0000\cdot10^{-15}$ F	$500\cdot10^{-6}$ %	4	$-63\cdot10^{-6}$	$-310\cdot10^{-24}$ F	0.00	0.000
Gq	$100.000\cdot10^{-12}$ S	0.100 %	4	0.0	0.0 F	0.0	0.0
Cq	$78.800\cdot10^{-18}$ F	0.152 %	4	$47\cdot10^{-6}$	$5.6\cdot10^{-24}$ F	0.00	0.000
Vp	0.01	$5.80\cdot10^{-3}$ %	infinity	$-6.3\cdot10^{-15}$	$-3.6\cdot10^{-21}$ F	0.00	0.000
Vq	0.0	$5.80\cdot10^{-6}$	infinity	$74\cdot10^{-18}$	$430\cdot10^{-24}$ F	0.00	0.000
b1q	0.0 1	$57.7\cdot10^{-6}$ 1	infinity	$160\cdot10^{-18}$	$9.1\cdot10^{-21}$ F	0.01	0.000
b2q	0.0 1	$57.7\cdot10^{-6}$ 1	infinity	$-160\cdot10^{-18}$	$-9.1\cdot10^{-21}$ F	-0.01	0.000
k_{TX}	$10.00\cdot10^{-9}$ K^{-1}	57.7 %	infinity	0.0	0.0 F	0.0	0.0
T_{XB}	29.61 °C						
C_X	$10.00001105\cdot10^{-12}$ F	$17.9\cdot10^{-6}$ %					
π	3.1415926535898						
ω	6314.60 s^{-1}	0.0574 %					
T_N	29.789286 °C	$2.62\cdot10^{-3}$ %					
D_0	439.932854 1						
D_1	472.41802 1						

Date: 10/21/2009 | File: Coomet-K4_01327_C_TXB | Page 10 of 11

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

Page 6 of 9

Coomet-K4, AH11A-01327, 10 pF, f = 1 kHz

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
D_2	37.684494 1						
D_3	7.472018 1						
D_4	2.920828 1						
D_5	$5.184 \cdot 10^{-3}$ 1						
D_6	-0.963864 1						
D_7	-0.188732 1						
D_8	0.191203 1						
D_9	0.049025 1						
HHC_{Ga}	1.000001122 1						
R_{GaAbl}	28.54292700 Ω	$20.2 \cdot 10^{-6}$ %	infinity	$-1.1 \cdot 10^{-15}$	$-6.5 \cdot 10^{-21}$ F	0.00	0.000
R_{Ga}	28.54295903 Ω	$20.2 \cdot 10^{-6}$ %					
W_{rt90}	1.11823621 1	$276 \cdot 10^{-6}$ %					
W_r	-0.92790475 1	$203 \cdot 10^{-6}$ %					
a	$-178.9 \cdot 10^{-6}$ 1						
W_{Ga}	1.11811800 1	$179 \cdot 10^{-6}$ %	10000	$29 \cdot 10^{-15}$	$58 \cdot 10^{-21}$ F	0.03	0.001
R_{t90}	28.5454367 Ω	$209 \cdot 10^{-6}$ %					
R_S	25.00011100 Ω	$20.0 \cdot 10^{-6}$ %	50	$1.3 \cdot 10^{-15}$	$6.5 \cdot 10^{-21}$ F	0.00	0.000
C_{XB}	$10.0000110 \cdot 10^{-12}$ F	$17.9 \cdot 10^{-6}$ %	9				

Result: Quantity: C_{XB}
Value: $10.0000110 \cdot 10^{-12}$ F
Relative Expanded Uncertainty: $\pm 410 \cdot 10^{-9}$
Coverage Factor: 2.3
Coverage: t-table 95%

Date: 10/21/2009 | File: Coomet-K4_01327_C_TXB | Page 11 of 11

Notes:

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

Page 5 of 15

Laboratory:	PTB

UNCERTAINTY STATEMENT: COOMET.EM-K4 (10 pF)
Serial Number 01327

Coomet-K4, AH11A-01327, 10 pF, f = 1 kHz

Uncertainty Budget:

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
V	1.14179036 1	$126\cdot10^{-6}$ %	10	$28\cdot10^{-15}$	$41\cdot10^{-21}$ F	-0.02	0.000
T_X	30.0364 °C	0.230 %	10	$-100\cdot10^{-21}$	$-6.9\cdot10^{-21}$ F	0.00	0.000
a1p	$-3.29400\cdot10^{-3}$ 1	0.0611 %	10	$10\cdot10^{-15}$	$20\cdot10^{-21}$ F	0.02	0.000
b1p	$2.9818\cdot10^{-3}$ 1	2.25 %	10	$790\cdot10^{-21}$	$53\cdot10^{-24}$ F	-0.09	0.000
a2p	$3.2839\cdot10^{-3}$ 1	0.840 %	10	$-10\cdot10^{-15}$	$-280\cdot10^{-21}$ F	-0.14	0.022
b2p	$-1.8909\cdot10^{-3}$ 1	3.15 %	10	$-790\cdot10^{-21}$	$-47\cdot10^{-24}$ F	0.01	0.000
C_{NB}	$10.00006217\cdot10^{-12}$ F	$5.90\cdot10^{-6}$ %	infinity	1.0	$590\cdot10^{-21}$ F	0.31	0.099
T_{NB}	29.783 °C						
k_{TN}	$11.40\cdot10^{-6}$ K^{-1}	17.5 %	9	$22\cdot10^{-15}$	$44\cdot10^{-21}$ F	0.02	0.001
k_{fN}	$-1.810\cdot10^{-9}$ s	16.6 %	9	$-5.9\cdot10^{-9}$	$-1.8\cdot10^{-18}$ F	-0.94	0.878
f	1005.000 Hz	0.0574 %	infinity	$-18\cdot10^{-21}$	$-10\cdot10^{-21}$ F	-0.01	0.000
DR_N	$-75.0\cdot10^{-9}$ a^{-1}	15.4 %	infinity	0.0	0.0 F	0.0	0.0
Δt	0.0 a	$5.77\cdot10^{-3}$ a	infinity	$-750\cdot10^{-21}$	$-4.3\cdot10^{-21}$ F	0.00	0.000
C_N	$10.00007305\cdot10^{-12}$ F	$18.6\cdot10^{-6}$ %					
Cp	$999.97900\cdot10^{-15}$ F	$500\cdot10^{-6}$ %	4	$-66\cdot10^{-6}$	$-330\cdot10^{-24}$ F	0.00	0.000
Gq	$99.200\cdot10^{-12}$ S	0.101 %	4	0.0	0.0 F	0.0	0.0
Cq	$78.800\cdot10^{-18}$ F	0.152 %	4	$49\cdot10^{-6}$	$5.8\cdot10^{-24}$ F	0.00	0.000
Vp	0.01	$5.80\cdot10^{-3}$ %	infinity	$-6.6\cdot10^{-15}$	$-3.8\cdot10^{-21}$ F	0.00	0.000
Vq	0.0	$5.80\cdot10^{-6}$	infinity	$77\cdot10^{-18}$	$440\cdot10^{-24}$ F	0.00	0.000
b1q	0.0 1	$57.7\cdot10^{-6}$ 1	infinity	$160\cdot10^{-18}$	$9.1\cdot10^{-21}$ F	0.00	0.000
b2q	0.0 1	$57.7\cdot10^{-6}$ 1	infinity	$-160\cdot10^{-18}$	$-9.1\cdot10^{-21}$ F	0.00	0.000
k_{TX}	$10.00\cdot10^{-9}$ K^{-1}	57.7 %	infinity	$36\cdot10^{-15}$	$210\cdot10^{-24}$ F	0.00	0.000
T_{XB}	30.04 °C						
C_X	$10.00000727\cdot10^{-12}$ F	$18.8\cdot10^{-6}$ %					
π	3.1415926535898						
ω	6314.60 s^{-1}	0.0574 %					
T_N	29.785204 °C	$2.09\cdot10^{-3}$ %					
D_0	439.932854 1						
D_1	472.41802 1						

Date: 10/21/2009 | File: Coomet-K4_01327_C_1k | Page 10 of 11

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

Page 6 of 15

	Coomet-K4, AH11A-01327, 10 pF, f = 1 kHz	

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
D_2	37.684494 1						
D_3	7.472018 1						
D_4	2.920828 1						
D_5	$5.184\cdot10^{-3}$ 1						
D_6	-0.963864 1						
D_7	-0.188732 1						
D_8	0.191203 1						
D_9	0.049025 1						
HHC_{Ga}	1.000001122 1						
R_{GaAbl}	28.54281300 Ω	$20.2\cdot10^{-6}$ %	infinity	$-1.1\cdot10^{-15}$	$-6.5\cdot10^{-21}$ F	0.00	0.000
R_{Ga}	28.54284503 Ω	$20.2\cdot10^{-6}$ %					
W_{rt90}	1.11822007 1	$220\cdot10^{-6}$ %					
W_r	-0.92791459 1	$161\cdot10^{-6}$ %					
a	$-178.9\cdot10^{-6}$ 1						
W_{Ga}	1.11811800 1	$179\cdot10^{-6}$ %	10000	$29\cdot10^{-15}$	$58\cdot10^{-21}$ F	0.03	0.001
R_{t90}	28.5449109 Ω	$126\cdot10^{-6}$ %					
R_S	25.000133000 Ω	$1.00\cdot10^{-6}$ %	50	$1.3\cdot10^{-15}$	$320\cdot10^{-24}$ F	0.00	0.000
C_{XB}	$10.0000073\cdot10^{-12}$ F	$18.8\cdot10^{-6}$ %	11				

Result: Quantity: C_{XB}
Value: $10.0000073\cdot10^{-12}$ F
Relative Expanded Uncertainty: $\pm420\cdot10^{-9}$
Coverage Factor: 2.3
Coverage: t-table 95%

Date: 10/21/2009	File: Coomet-K4_01327_C_1k	Page 11 of 11

Notes:

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

Laboratory:	PTB
UNCERTAINTY STATEMENT: COOMET.EM-K4 (10 pF) **Serial Number 01327**	

Coomet-K4, AH11A-01327, 10 pF, f = 1592 Hz

Uncertainty Budget:

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
V	1.14178891 1	$127\cdot10^{-6}$ %	10	$28\cdot10^{-15}$	$41\cdot10^{-21}$ F	0.00	0.005
T_X	30.0455 °C	0.207 %	10	$-100\cdot10^{-21}$	$-6.2\cdot10^{-21}$ F	0.00	0.000
a1p	$-3.27691\cdot10^{-3}$ 1	0.0917 %	10	$10\cdot10^{-15}$	$30\cdot10^{-21}$ F	0.01	0.003
b1p	$7.464\cdot10^{-3}$ 1	1.89 %	10	$500\cdot10^{-21}$	$70\cdot10^{-24}$ F	-0.01	0.000
a2p	$3.26073\cdot10^{-3}$ 1	0.0860 %	10	$-10\cdot10^{-15}$	$-28\cdot10^{-21}$ F	-0.02	0.002
b2p	$-5.182\cdot10^{-3}$ 1	3.03 %	10	$-490\cdot10^{-21}$	$-78\cdot10^{-24}$ F	0.00	0.000
C_{NB}	$10.00006217\cdot10^{-12}$ F	$5.90\cdot10^{-6}$ %	infinity	1.0	$590\cdot10^{-21}$ F	0.99	0.977
T_{NB}	29.783 °C						
k_{TN}	$11.40\cdot10^{-6}$ K^{-1}	17.5 %	9	$18\cdot10^{-15}$	$37\cdot10^{-21}$ F	0.06	0.004
k_{IN}	$-1.810\cdot10^{-9}$ s	16.6 %	9	0.0	0.0 F	0.0	0.0
f	1592.000 Hz	0.0363 %	infinity	$-18\cdot10^{-21}$	$-10\cdot10^{-21}$ F	-0.02	0.000
DR_N	$-75.0\cdot10^{-9}$ a^{-1}	15.4 %	infinity	0.0	0.0 F	0.0	0.0
Δt	0.0 a	$5.77\cdot10^{-3}$ a	infinity	$-750\cdot10^{-21}$	$-4.3\cdot10^{-21}$ F	-0.01	0.000
C_N	$10.000062380\cdot10^{-12}$ F	$5.96\cdot10^{-6}$ %					
Cp	$999.97900\cdot10^{-15}$ F	$500\cdot10^{-6}$ %	4	$-65\cdot10^{-6}$	$-330\cdot10^{-24}$ F	0.00	0.000
Gq	$99.200\cdot10^{-12}$ S	0.101 %	4	0.0	0.0 F	0.0	0.0
Cq	$49.500\cdot10^{-18}$ F	0.242 %	4	$130\cdot10^{-6}$	$15\cdot10^{-24}$ F	0.00	0.000
Vp	0.01	$5.80\cdot10^{-3}$ %	infinity	$-6.5\cdot10^{-15}$	$-3.8\cdot10^{-21}$ F	-0.01	0.000
Vq	0.0	$5.80\cdot10^{-6}$	infinity	$130\cdot10^{-18}$	$730\cdot10^{-24}$ F	0.00	0.000
b1q	0.0 1	$57.7\cdot10^{-6}$ 1	infinity	$99\cdot10^{-18}$	$5.7\cdot10^{-21}$ F	0.01	0.000
b2q	0.0 1	$57.7\cdot10^{-6}$ 1	infinity	$-99\cdot10^{-18}$	$-5.7\cdot10^{-21}$ F	-0.01	0.000
k_{TX}	$10.00\cdot10^{-9}$ K^{-1}	57.7 %	infinity	$45\cdot10^{-15}$	$260\cdot10^{-24}$ F	0.00	0.000
T_{XB}	30.05 °C						
C_X	$9.999997011\cdot10^{-12}$ F	$5.97\cdot10^{-6}$ %					
π	3.1415926535898						
ω	10002.83 s^{-1}	0.0363 %					
T_N	29.784843 °C	$2.09\cdot10^{-3}$ %					
D_0	439.932854 1						
D_1	472.41802 1						

Date: 10/21/2009 | File: Coomet-K4_01327_C_1592 | Page 10 of 11

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

Page 9 of 15

Coomet-K4, AH11A-01327, 10 pF, f = 1592 Hz

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
D_2	37.684494 1						
D_3	7.472018 1						
D_4	2.920828 1						
D_5	$5.184 \cdot 10^{-3}$ 1						
D_6	-0.963864 1						
D_7	-0.188732 1						
D_8	0.191203 1						
D_9	0.049025 1						
HHC_{Ga}	1.000001122 1						
R_{GaAbl}	28.54281300 Ω	$20.2 \cdot 10^{-6}$ %	infinity	$-1.1 \cdot 10^{-15}$	$-6.5 \cdot 10^{-21}$ F	-0.01	0.000
R_{Ga}	28.54284503 Ω	$20.2 \cdot 10^{-6}$ %					
W_{rt90}	1.11821865 1	$220 \cdot 10^{-6}$ %					
W_r	-0.92791546 1	$162 \cdot 10^{-6}$ %					
a	$-178.9 \cdot 10^{-6}$ 1						
W_{Ga}	1.11811800 1	$179 \cdot 10^{-6}$ %	10000	$29 \cdot 10^{-15}$	$58 \cdot 10^{-21}$ F	0.10	0.009
R_{t90}	28.5448746 Ω	$127 \cdot 10^{-6}$ %					
R_S	25.000133000 Ω	$1.00 \cdot 10^{-6}$ %	50	$1.3 \cdot 10^{-15}$	$320 \cdot 10^{-24}$ F	0.00	0.000
C_{XB}	$9.99999701 \cdot 10^{-12}$ F	$5.95 \cdot 10^{-6}$ %	infinity				

Result: Quantity: C_{XB}
Value: $9.9999970 \cdot 10^{-12}$ F
Relative Expanded Uncertainty: $\pm 120 \cdot 10^{-9}$
Coverage Factor: 2.0
Coverage: t-table 95%

Date: 10/21/2009 | File: Coomet-K4_01327_C_1592 | Page 11 of 11

Notes:

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

KazInMetr (Kazakhstan)

Quantity	Estimate, μF/F	Standard uncertainty, μF/F	Effective degrees of freedom, distribution	Sensitivity coefficient	Contribution to the relative standard uncertainty, μF/F
Measurement uncertainty of the built-in bridge in the standard	0.6	0.3	3 normal	1	0.300
Instability of the built-in bridge built in the standard	0.4	0.173	∞ rectangular	1	0.173
The amendment on an of connecting cables impedance	0.01	0.006	∞ rectangular	1	0.006
Resolution of the bridge	0.01	0.005	∞ rectangular	1	0.005
Environment influence on measurement results, including a hysteresis caused by temperature drift	0.05	0.03	∞ rectangular	1	0.030
Statistical processing of 9 independent measurements	0.075	0.025	8 normal	1	0.025
Final values:			24		0.352

BelGIM (Belarus)

Quantity	x_i, pF	+/- r pF	Distri-bution	Type	Standard uncertainty, pF	c_i	Uncertainty contribution, pF
1000 Hz							
Measurement of transfer standard, C_x	9.9999908		normal	A	0.00000087	1	0.00000087
Measurement of reference standard, C_{xEt}	9.9999421		normal	A	0.00000093	1	0.00000093
Error of set up of reference standard value, δC_H	0.0	0.000021	square	B	0.00001050	-1	-0.00001050
Drift of reference standard, δC_H	0.0	0.000004	square	B	0.00000231	-1	-0.00000231
Resolution of the bridge, δC_{KB}	0.0	0.00000005	square	B	0.00000003	-1	-0.00000003
Final values:	9.9999977						0.0000217

Quantity	x_i, pF	+/- r pF	Distri-bution	Type	Standard uncertainty, pF	c_i	Uncertainty contribution, pF
1600 Hz							
Measurement of transfer standard, C_x	9.9999894		normal	A	0.00000090	1	0.00000090
Measurement of reference standard, C_{xEt}	9.9999413		normal	A	0.00000083	1	0.00000083
Error of set up of reference standard value, δC_H	0.0	0.000021	square	B	0.00001050	-1	-0.00001050
Drift of reference standard, δC_H	0.0	0.000004	square	B	0.00000231	-1	-0.00000231
Resolution of the bridge, δC_{KB}	0.0	0.00000005	square	B	0.00000003	-1	-0.00000003
Final values:	9.9999972						0.0000216

Appendix 3

Technical protocol of comparison

TECHNICAL PROTOCOL
for project COOMET 345/UA/05

COOMET Key Comparison of Capacitance at 10 pF
(COOMET.EM-K4)

and

COOMET Supplementary Comparison of Capacitance at 100 pF (COOMET.EM-S4)

O. AKHMADOV, S. AKHMADOV, O. VELYCHKO
State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (Ukrmeterteststandard), Kyiv, Ukraine

May 2008
(Rev_3)

1. Introduction

The COOMET Key Comparison of Capacitance at 10 pF (comparison identifier: COOMET.EM-K4) and the COOMET Supplementary Comparison of Capacitance at 100 pF (comparison identifier: COOMET.EM-S4) are conducted in the framework of COOMET project 345/UA/05.
This project for comparing of National standards of electrical capacitance is to be conducted between counties which are member laboratories of regional metrology organization COOMET. In this comparison take part nine national metrology institutes: Ukrmetrteststandard (Ukraine); PTB (Germany); VNIIM (Russian Federation); BelGIM (Belarus); NMIJ-AIST (Japan); NCM (Bulgaria); INM (Romania); SMU (Slovakia); “KazInMetr” (Kazakhstan).
It is planned to link the results from COOMET.EM-K4 key comparison to the international key comparison CCEM-K4 carried out between 1994 and 1996. PTB (Germany) and VNIIM (Russian Federation) will act as linking laboratories as far as they participated in CCEM-K4.
The State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (Ukrmeterteststandard), Ukraine was selected as the pilot laboratory. Dr. Olexander Akhmadov will act as the coordinator. The pilot laboratory is responsible for providing the travelling standard, coordinating the schedule, collecting and analyzing the comparison data, preparing the draft report, etc.
It is planned to complete this comparison at the end of 2008.

2. Description of travelling standard

The selected travelling standards are 10 pF (S/N 01327) and 100 pF (S/N 01328) Andeen-Hagerling model AH11A fused silica capacitance standards, mounted in a frame model AH1100 (S/N 00108) – Figure 1.

Comparison identifier	COOMET.EM-K4	COOMET.EM-S4
Comparison type	Key	Supplementary
Nominal value of capacitance	10 pF	100 pF
Serial number of capacitor	01327	01328

Figure 1. Front view of travelling standard

The AH 1100 frame provides monitoring of critical temperature control parameters such as the differences within the dual temperature sensors in each standard and internal power voltages. Each AH11A capacitance standard contains built-in precision oven with dual temperature sensor system which provides increased reliability and confidence.

The main manufacturer specifications for AH11A capacitors and AH1100 frame:
- stability is better than 0.3 ppm/year;
- temperature coefficient of the capacitance with respect to changes in ambient temperature is less than 0.01 ppm/°C;
- hysteresis resulting from temperature cycling is less than 0.05 ppm;
- hysteresis resulting from mechanical shock is less than 0.05 ppm;
- AC voltage coefficient is less than 0.003 ppm/volt;
- DC voltage coefficient is less than 0.0001 ppm/volt;
- power line sensitivity is less than 0.0003 ppm per 1% change in power line voltage;
- dissipation factor is less than 0.000 003 tan delta;
- power voltage ranges: 85 to 115, 102 to 138, 187 to 253 and 204 to 276 volts rms;
- power frequency: 48 to 440 Hz;
- operating temperature range: 10° to 40° C;
- storage temperature range: -40° to +75° C;
- maximum allowable applied voltage: 250 volts peak;
- operating humidity range: 0 to 85% relative humidity, non-condensing;
- AH 1100 frame size: 89 mm high and 381 mm deep behind the front panel;
- total weight of AH1100 frame and two AH11A capacitors: 8.4 kg.

Shipping is simple since continuous temperature control of the ovens is not needed to maintain the stability specification.
The fused-silica element is hermetically sealed in dry nitrogen.

The AH 1100/11A Operation and Maintenance Manual will be included with the shipment. Participants should familiarize themselves with the operation of the standards before proceeding.
The HIGH and LOW terminals of the capacitors have different properties. Refer to Chapter 2 of the AH 1100/11A Operation and Maintenance Manual for more information.

<u>NOTE</u>: THE CORRECT LINE VOLTAGE MUST BE SELECTED AND A CORRESPONDING FUSE FITTED BEFORE APPLYING POWER TO THE UNIT.

3. Handling of travelling standard

The travelling standard will be circulated within a container, which is well furnished for the safety of the travelling standard. Upon receipt, participants shall check the container to determine if all parts on the list are present. At the end of the test, the travelling standard shall be carefully re-packed in the container in which it arrived. The dimensions of the transport container are 700 mm x 520 mm x 220 mm. The container weight (including contents) is 20 kg. If this container was damaged, the travelling standard shall be re-packed in a new container that will provide adequate protection during shipment.

On receipt of the travelling standard inspect the outside of the transport container for any signs of physical damage. Open the transport container and check that the contents are complete (refer to Packing List for list of contents).
A copy of the AH 1100/11A Operation and Maintenance Manual will be included in the shipment. Also will be included the cable for connecting to AH11A terminals. If you have not used this type of standard before, please familiarize yourself with the operation of the standards before proceeding.

The AH1100 frame containing the two capacitance standards should be removed from the transport case. Please do not open the AH1100 frame. Please do not remove the AH11A capacitance standards from the frame. Before applying power to the unit, select the correct line

voltage and fit an appropriate fuse, referring to pages 1–5 and 1–6 of the AH 1100/11A Operation and Maintenance Manual.
If any failure of the travelling standard is noted, then the pilot laboratory should be informed immediately by e-mail or fax. If the travelling standard requires repair, then the participant will send it to pilot laboratory.

Participants should inform the pilot laboratory by e-mail or fax when the travelling standard has arrived by filling the following form given in Figure 2.

Confirmation note for receipt		
Date of arrival		
NMI		
Name of responsible person		
Travelling standard	□ Damaged	□ Not Damaged
Notes:		

Figure 2. Sample form for the information of receipt of the travelling standard

Participants should inform the pilot laboratory and the recipient laboratory by e-mail or fax when the travelling standard is dispatched by filling the following form given in Figure 3.

Confirmation note for dispatch	
Date of shipment	
NMI	
Name of responsible person	
Shipment information	
Notes:	

Figure 3. Sample form for the information of dispatch of the travelling standard

On completion of measurements each participant is requested to ship the travelling standard to the next scheduled laboratory. Participating laboratories are responsible for arranging transportation to the next participant. Addresses for dispatching the travelling standard are given in the Participant List.

4. Measurement Instructions

After power up of travelling standard it should be left to stabilize for three days.

Measurements should be performed under the following conditions:
- temperature: 23°C ± 1°C;
- relative humidity: between 30% and 70%;
- measurement frequency: 1000 Hz and 1592 Hz (depending on laboratory’s capability);
- measuring voltage for both capacitor: 100 V (RMS).

Participants shall inform the pilot laboratory if these conditions cannot be met.

If measurement voltage differs from 100 V (RMS), the actual voltage should be recorded and its effect should be included in uncertainty budget. In any case the voltage applied to AH11A capacitors must not exceed a peak value of 250 V.
To make connections to the capacitors, participants may use any of the leads and adapters, but participants are responsible for determining any necessary corrections for leads or adapters to obtain the capacitance at the terminals on the AH1100 frame.
The temperature coefficient of capacitance with respect to changes in ambient laboratory temperature is less than 0.01 ppm/°C for both capacitors. No corrections should be made for ambient laboratory temperature. Participants may choose to include a component for ambient laboratory temperature in their uncertainty budget if the ambient laboratory temperature significantly differs from 20 °C.

For each measurement, the following quantities should be recorded:
- measurement date;
- measurement frequency;
- applied voltage;
- measured capacitance;
- measured tangent of losses (if this quantity realized in NMI);
- air temperature in the vicinity of the AH1100 frame and the measuring apparatus;
- AH1100 frame temperature and the oven drift reading.

If measurements will be made during several days, than the mean capacitance value for each day should be provided with indication of the exact dates of measurements.

5. Reporting of results

A full measurement report in English containing all relevant data and uncertainty estimates is to be forwarded to the coordinator within six weeks of completing measurement of the capacitors. Prompt reporting is encouraged to allow rapid identification of problems with the travelling standard. The report should include a description of the measurement method (facilities and methodology), the traceability to the SI, and the results, associated uncertainty and number of degrees of freedom.
<u>Note</u>: the capacitance at the terminals on the AH1100 frame is to be reported for each capacitor.

The measurement period, the measurement frequency and the applied voltage must also be reported for each capacitor. Details of any corrections that have been applied (for example, bridge corrections or leads corrections) must be given.
All results should be identified with the capacitor’s serial number and nominal value.

6. Uncertainty of measurement

The uncertainty must be calculated following the ISO “Guide to the expression of uncertainty in measurement”: standard uncertainties, degrees of freedom, correlations, scheme for the evaluation of uncertainty.
All contributions to the uncertainty of measurement should be listed separately in the report and identified as either Type A or Type B uncertainties. The overall uncertainty, as calculated from the individual uncertainties, should be stated. Uncertainties are to be evaluated at the level of one standard uncertainty and the number of effective degrees of freedom is to be reported. The main uncertainty components are expected to be:
- experimental standard uncertainty of the mean of N independent measurements;
- uncertainty in the primary standard or working standard against which the travelling standard is measured;

- uncertainty due to leads correction.
Participants may include additional sources of uncertainty.

7. Traceability to the SI

The traceability to the SI of each standard participating in the comparison should be provided to pilot laboratory.

8. Financial aspects and insurance

Each Participating laboratory is responsible for meeting the costs of its own measurements and the costs of shipment to the next recipient (transportation and customs).
In addition, each participating laboratory is responsible for meeting all costs, and making all arrangements, relating to the transport of the travelling standard from the time it arrives in their country to the time it arrives in the country of the next participating laboratory. Costs may include (but are not limited to) costs associated with the arrival in the country (customs charges, quarantine fees, broker fees, carrier charges from the port of arrival to the participants laboratory) and costs associated with transporting the travelling standard from the participant's laboratory to the international port in the next country closest to the next participant's laboratory.

9. Notes

If any laboratory feels that it would have difficulty meeting any of the above requirements, rather than withdraw from the comparison, it should discuss the problem with the coordinator so that satisfactory arrangements can be made. It is expected that amongst participating laboratories, uncertainties will cover a wide range (according to local requirements). This should not be seen as a deterrent to participating in the comparison.

10. Participants

List of participants and contact information is show in Table 1.

11. Schedule

List of the participants and measurement dates is show in Table 2.

Table 1. List of participants and contact information

Laboratory address	Contact name, e-mail, tel. and fax number
State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (Ukrmetertestandard) 4, Metrologichna St. Kyiv-143, 03143, UKRAINE	Olexander Akhmadov ermatec@ukrcsm.kiev.ua Tel./fax: +38 044 526 55 68
Physikalisch-Technische Bundesanstalt (PTB) Department 2.1 Bundesallee 100 38116 Braunschweig, GERMANY	Jürgen Melcher juergen.melcher@ptb.de Tel.: +49 531 592 2100 Fax: +49 531 592 2105
D.I. Mendeleyev Institute of Metrology (VNIIM) 19, Moskovsky pr. 190005 St. Petersburg, RUSSIA	Yuri Semenov y.p.semenov@vniim.ru Tel.: +7 812 323 96 21
Belarussian State Institute of Metrology (BelGIM) 93, Starovilensky trakt Minsk, 220053, BELARUS	Elena Kazakova kazakova@belgim.by Tel.: +375 17 233 52 55
National Centre of Metrology (NCM) 52-B G. M. Dimitrov Str. 1797 Sofia, BULGARIA	Petya Aladzhem ncm@sasm.orbitel.bg Tel.: +359 2 710 237 Fax: +359 2 717 050
National Institute of Metrology (INM) sos. Vitan Barzesti 11 sector 4 042122 Bucuresti, ROMANIA	Armine Caranfilian armine.caranfilian@inm.ro Tel.: +40 21 334 50 60, ext 153 Telefax: +40 21 334 55 33
Slovak Institute of Metrology (SMU) Karloveská 63 842 55 Bratislava, SLOVAKIA	Stefan Gasparík gasparik@smu.gov.sk Tel.: +421 2 60294385(360) Fax: +421 2 65429592
National Metrology Institute of Japan (NMIJ-AIST) Electricity and Magnetism Division AIST Central 3, 1-1-1 Umezono Tsukuba Ibaraki 305-8563, JAPAN	Atsushi Domae domae-atsushi@aist.go.jp Tel.: +81 29 861 5464 Fax: +81 29 861 3469
Republic State Enterprise “Kazakhstan Institute of Metrology” (RSE “KazInMetr”) Orynbor Str.,11, Left riverside Astana, 010000, KAZAKHSTAN REPUBLIC	Tuymekulova Nagima nagimakaz@mail.ru Tel.: + 7172 79-32-73, Tel/fax: + 7172 24-32-97, Cell: + 7 701 483 77 74

Table 2. List of the participants and measurement dates

Laboratory	Measurement Dates (Results)	Report Date
Ukrmeterteststandard, Ukraine	19 – 23 June 2006	–
PTB, Germany	15 – 21 November 2006	–
NCM, Bulgaria	19 June – 03 July 2007	July 2007
Ukrmeterteststandard, Ukraine	06 – 10 August 2007	–
VNIIM, Russia	07 May – 01 June 2008	June 2008
NMIJ-AIST, Japan	15 – 17 July 2008	August 2008
RSE “KazInMetr”, R. Kazakhstan	1–12 September 2008	October 2008
Ukrmeterteststandard, Ukraine	15–22 September 2008	–
INM, Romania	29 September – 10 October 2008	November 2008
Ukrmeterteststandard, Ukraine	15–25 October 2008	–
SMU, Slovakia	27 October – 7 November 2008	November 2008
Ukrmeterteststandard, Ukraine	12–21 November 2008	–
PTB, Germany	24 November – 5 December 2008	December 2008
Ukrmeterteststandard, Ukraine	15–25 December 2008	–
BelGIM, Belarus	February 2009	March 2009
Ukrmeterteststandard, Ukraine	March 2009	April 2009

12. Summary of results

Comparisons COOMET.EM-K4 and COOMET.EM-S4

Capacitance measurements of 10 pF and 100 pF at 1 kHz

Acronym of institute: Country:

Average date of measurements:

Remarks:

Measurement result:

Capacitance 10 pF (sn. 01327), pF	Capacitance 100 pF (sn. 01328), pF

Uncertainty:

Capacitance 10 pF (sn. 01327), ppm	Capacitance 100 pF (sn. 01328), ppm

Additional parameters:

Parameter	Capacitance 10 pF	sn. 01327	Capacitance 100 pF	sn. 01328
	Value	Exp. unc.	Value	Exp. unc.
Tangent of loss (*tgδ*)				
Frequency (*f*), Hz				
Voltage (*U*), rms V				
Ambient temperature, °C				
Relative humidity, %				