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

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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

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1 Introduction

The COOMET Supplementary Comparison (SC) of Capacitance at 100 pF (comparison identifier – COOMET.EM-S4) 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" (Ukraine); PTB (Germany); VNIIM (Russia); NMIJ/AIST (Japan); BIM (Bulgaria); BelGIM (Belarus); KazInMetr (Kazakhstan).

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

2 Participants

List of participating NMIs, countries 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 standards is 100 pF (S/N 01328) 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.

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 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 traveling 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. The majority of the laboratories obtain their unit of capacitance from a calculable capacitor either directly or via another laboratory.

6 Behavior of the travelling standards

The UMTS as pilot laboratory has performed repeated measurements on the travelling standard (S/N 01328) during the course of this comparison. From these measurements, the behavior of the travelling standard can be seen in Figures 1.

As the values of the capacitor are time-dependent they were measured before and after each visit so that a drift curve for each one could be established. The drift of the travelling standards by using all results weighted with the variance of the measurements was checked.

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)
NMIJ/AIST	Japan	NMIJ/AIST (Quantized Hall Resistance)
BIM	Bulgaria	PTB (Calculable Capacitor)*
KazInMetr	Kazakhstan	VNIIM (Calculable Capacitor)*
BelGIM	Belarus	VNIIM (Calculable Capacitor)
* only for 1000 Hz		

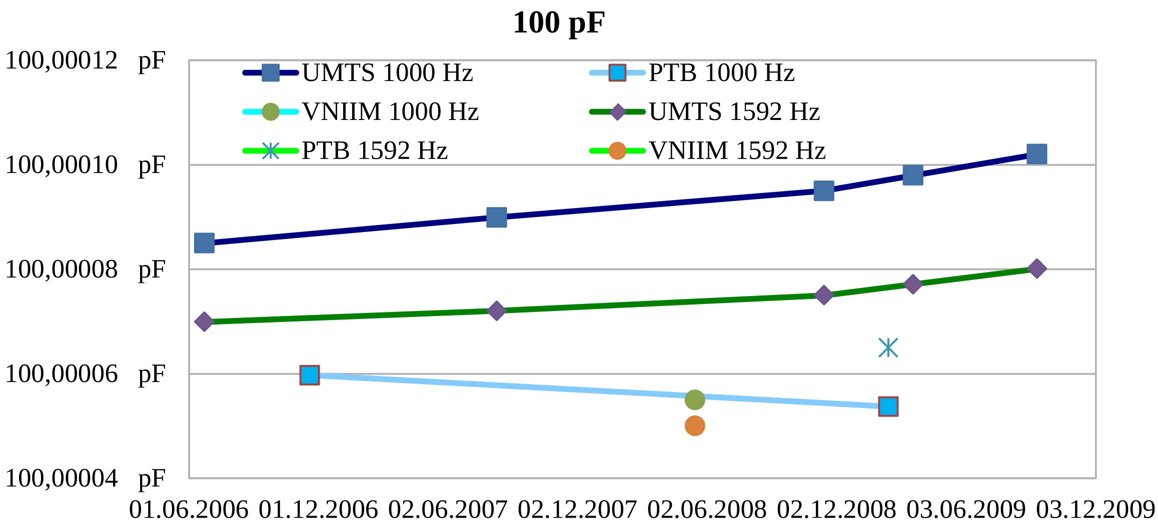

Figure 1 Behavior of the travelling standard for 100 pF

7 Reported of 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.

Additional parameters for measurement of the NMI participants are show in Table 4 (Appendix 1). The capacitance values and its combine standard uncertainties (u_c) reported by the NMI participants for 100 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, but those NMIs did not take part in comparison in the sequel. NMIJ/AIST (Japan) and KazInMetr (Kazakhstan) joined to comparison in 2008.

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

Table 4 Additional parameters for measurement of the NMI participants

Parameter	Value	Absolute expanded uncertainty
BIM, Bulgaria		
Frequency, Hz	997.9	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

Parameter	Value	Absolute expanded uncertainty
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	22.82	0.06
Relative humidity, %	46	6
KazInMetr, Kazakhstan		
Frequency, Hz	1000	0.05
Voltage, V	15	0.17
Ambient temperature, °C	20.5	0.06
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	0.06
Relative humidity, %	51.8…59.3	0.48

Table 5 Measured results for NMI participants on 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	1.000	6.050	–	–
PTB*	0.600**	0.195**	0.650	0.060
VNIIM	0.550	0.204	0.500	0.210
NMIJ/AIST	–	–	0.815	0.106
KazInMetr	0.500	0.420	–	–
UMTS*	0.940	0.230	0.750	0.350
BelGIM	1.034	2.030	1.223	2.030

* The values for PTB and UMTS are all 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 reference values and its uncertainties

The reference values x_{ref} are calculated as the mean of participant results with COOMET.EM-S4 data are given by

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

with combine standard uncertainties

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

In cases the calculated simple weighted mean of all results was x_{ref} = 0.662 μF/F with an expanded uncertainties U_{ref} = 0.231 μF/F (k = 2) at 1000 Hz and x_{ref} = 0.681 μF/F with an expanded uncertainties U_{ref} = 0.100 μF/F (k = 2) at 1592 Hz.

7.3 Degrees of equivalence

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 the *i*-th NMI and its combined standard uncertainties with respect to the comparison reference value as analog estimation for comparison APMP.EM-S7 [2] is estimated as

$$D_i = x_i - x_{ref} \,, \tag{3}$$

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

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

$$\left|D_i\right| < 2u_c(D_i)\,. \tag{5}$$

The degrees of equivalence of the NMI participants and its expanded uncertainties $U(D_i)$ for k =2 with respect to the reference values at 1000 Hz and 1592 Hz are also presented in Tables 6 and on 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	0.338	12.098	–	–
PTB	–0.065	0.314	–0.031	0.066
VNIIM	–0.113	0.337	–0.181	0.408
NMIJ/AIST	–	–	0.134	0.187
KazInMetr	–0.163	0.808	–	–
UMTS	0.278	0.398	0.069	0.693
BelGIM	0.372	4.053	0.542	4.059

On the basis of the measurement results of COOMET.EM-S4 and corresponding uncertainties $\{x_i,\ u(x_i)\},\ i=1,...N$ claimed by comparisons NMI participants, the χ^2 criterion value is calculated

$$\chi^2 = \sum_{i=1}^{N} \frac{(x_i - x_{ref})^2}{u_c^2(x_i)}\ . \tag{6}$$

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

$$\chi^2 = \sum_{i=1}^{N} \frac{(x_i - x_{ref})^2}{u_c^2(x_i)} \prec \chi^2_{0.95(N-1)}\,, \tag{7}$$

then the data provided by different NMIs can be acknowledged as consistent, that is the objective confirmation of the announced uncertainties: $\chi^2 = 2.77 \prec \chi^2_{0.95(5)} = 11.07$ (N = 6) at 1000 Hz and $\chi^2 = 3.83 \prec \chi^2_{0.95(4)} = 9.49$ (N = 5) at 1592 Hz.

8 Summary

A supplementary comparison of capacitance at 100 pF on 1000 Hz and 1592 Hz has been conducted between participating COOMET member laboratories and also EURAMET, APMP. In general there is good agreement between participating NMIs for this value. It is expected that this comparison will be able to provide support for participants' entries in Appendix C of the CIPM MRA.

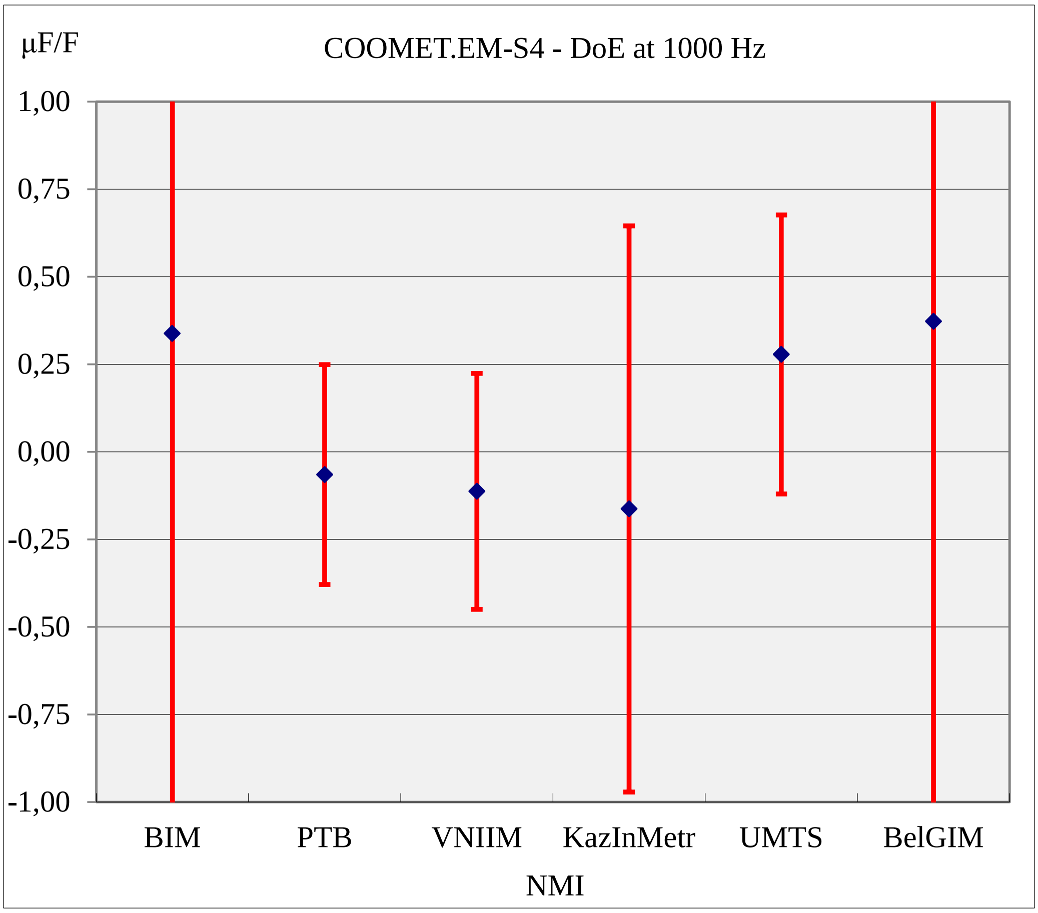

Figure 2 Degree of equivalence for NMI participants at 1000 Hz

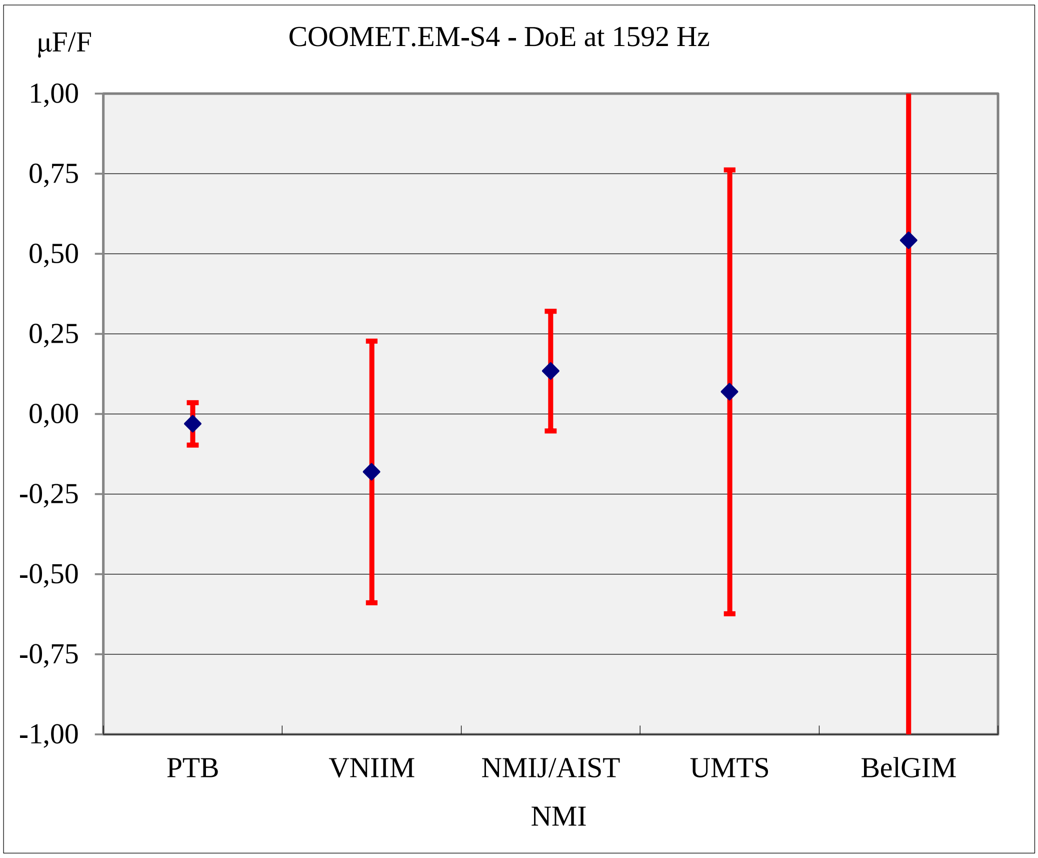

Figure 3 Degree of equivalence for NMI participants at 1592 Hz

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 (9–14 July). – P. 185.

[2] H. L. Johnson. Final report: APMP.EM-S7. APMP Supplementary Comparison of Capacitance at 100 pF. NMIA. February 2008. – 52 p.

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>100.000055</td><td>100.000055</td><td>100.000056</td><td>100.000056</td><td>100.000056</td></tr>
<tr><td colspan="2">Measurement frequency, Hz</td><td colspan="5">997.9</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, µF/F</td><td>–0.011</td><td>–0.011</td><td>–0.011</td><td>–0.012</td><td>–0.011</td></tr>
<tr><td rowspan="3">Measurement result</td><td>Mean measurement date</td><td colspan="5">25.06.2007</td></tr>
<tr><td>Mean capacitance, pF</td><td colspan="5">100.0001</td></tr>
<tr><td>Combined relative standard uncertainty, µF/F</td><td colspan="5">6.05</td></tr>
</table>

PTB (Germany)

<table>
<tr><th colspan="2">Measurement number</th><th>1</th><th>…</th><th>11</th></tr>
<tr><td colspan="2">Measurement date</td><td>2006-11-15</td><td>…</td><td>2006-11-21</td></tr>
<tr><td colspan="2">Measured capacitance, pF</td><td colspan="3">100.000060</td></tr>
<tr><td colspan="2">Measurement frequency, Hz</td><td colspan="3">1005.0</td></tr>
<tr><td colspan="2">Chassis temperature, °C</td><td colspan="3">29.6</td></tr>
<tr><td colspan="2">Drift reading, µF/F</td><td colspan="3">–0.007</td></tr>
<tr><td rowspan="4">Measurement result</td><td>Mean measurement date</td><td colspan="3">2006-11-19</td></tr>
<tr><td>Mean capacitance, pF</td><td colspan="3">100.000060</td></tr>
<tr><td>Combined expanded relative standard uncertainty, µF/F</td><td colspan="3">0.43</td></tr>
<tr><td>Degrees of freedom</td><td colspan="3">13</td></tr>
<tr><td colspan="2">Measurement date</td><td>2009-01-22</td><td>…</td><td>2009-03-04</td></tr>
<tr><td colspan="2">Measured capacitance, pF</td><td colspan="3">100.000060</td></tr>
<tr><td colspan="2">Measurement frequency, Hz</td><td colspan="3">1005.0</td></tr>
<tr><td colspan="2">Chassis temperature, °C</td><td colspan="3">30.3</td></tr>
<tr><td colspan="2">Drift reading, µF/F</td><td colspan="3">+0.018</td></tr>
</table>

Measurement result	Mean measurement date	2009-02-13		
	Mean capacitance, pF	100.000060		
	Combined expanded relative standard uncertainty, µF/F	0.43		
	Degrees of freedom	13		
Measurement date		2009-01-22	…	2009-03-04
Measured capacitance, pF		100.000065		
Measurement frequency, Hz		1592.0		
Chassis temperature, °C		30.3		
Drift reading, µF/F		+0.017		
Measurement result	Mean measurement date	2009-02-13		
	Mean capacitance, pF	100.000065		
	Combined expanded relative standard uncertainty, µF/F	0.12		
	Degrees of freedom	∞		

VNIIM (Russia)

Measurement number		1	2	3	4	5	6	7
Measurement date		12.05.08	20.05.08	21.05.08	23.05.08	26.05.08	29.05.08	01.05.08
Measured capacitance, pF		100.000036	100.000048	100.000045	100.000046	100.000041	100.000035	100.000036
Chassis temperature, ºC		27.1	27.5	27.3	27.8	27.1	27.1	27.2
Drift reading, µF/F		–0.020	–0.021	–0.022	–0.022	–0.023	–0.023	–0.023
Mean measurement date		22.05.2008						
Optional	Mean dissipation factor	$4 \cdot 10^{-7}$						
	Standard uncertainty	$2 \cdot 10^{-7}$						
	Degrees of freedom	6						
Measurement result	Measurement frequency, Hz	1000.0						
	Mean capacitance, pF	100.000055						
	Combined standard uncertainty, pF	$20.4 \cdot 10^{-6}$						
	Degrees of freedom	39						
	Measurement frequency, Hz	1592.0						
	Mean capacitance, pF	100.000050						
	Combined standard uncertainty, pF	$21.0 \cdot 10^{-6}$						

NMIJ/AIST (Japan)

	Measurement number	1	2	3
Measurement date		2008-07-15	2008-07-16	2008-07-17
Measured capacitance, pF		100.0000814	100.0000815	100.0000815
Measurement frequency, Hz		$10^4/2\pi$		
Chassis temperature, ºC		29.6	29.6	29.5
Drift reading, μF/F		–0.019		
Measurement result	Mean measurement date	2008-07-16		
	Mean capacitance, pF	100.0000815		
	Combined relative standard uncertainty, μF/F	0.106		
	Degrees of freedom	115 965		

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		100.00005	100.00004	100.00005	100.00005
Measurement frequency, Hz		1000.0			
Chassis temperature, ºC		27.0	28.2	26.6	27.4
Drift reading, μF/F		–0.024	–0.023	–0.024	–0.023
Measurement result	Mean measurement date	17.09.2008			
	Mean capacitance, pF	100.00005			
	Combined relative standard uncertainty, μF/F	0.42			
	Degrees of freedom	49			

UMTS (Ukraine)

		Measurement number	1	…	10
Measurement date			10.11.2008	…	14.11.2008
Measured capacitance, pF			100.000094		
Measurement frequency, Hz			999.9		
Ambient temperature, ºC			28.5		
Drift reading, µF/F			+0.005		
Measurement result	Mean measurement date		10.11.2008		
	Mean capacitance, pF		100.000094		
	Combined relative standard uncertainty, µF/F		0.23		
	Degrees of freedom		more than 100		
Measurement date			10.11.2008	…	14.11.2008
Measured capacitance, pF			100.000075		
Measurement frequency, Hz			1591.99		
Ambient temperature, ºC			28.5		
Drift reading, µF/F			+0.005		
Measurement result	Mean measurement date		10.11.2008		
	Mean capacitance, pF		100.000075		
	Combined relative standard uncertainty, µF/F		0.35		
	Degrees of freedom		more than 100		

BelGIM (Belarus)

Measurement number		1	2	…	100
Measurement date		17.08.2009	17.08.2009	…	17.08.2009
Measured capacitance, pF		100.0001034	100.0001034	…	100.0001034
Measurement frequency, Hz		1000.0			
Chassis temperature, ºC		31.3	31.3	…	31.3
Drift reading, µF/F		–0.023			
Measurement result	Mean measurement date	17.08.2009			
	Mean capacitance, pF	100.0001034			
	Combined relative standard uncertainty, µF/F	2.0			
	Degrees of freedom	6331755566			

<table>
<tr><th colspan="2">Measurement number</th><th>1</th><th>2</th><th>…</th><th>100</th></tr>
<tr><td colspan="2">Measurement date</td><td>17.08.2009</td><td>17.08.2009</td><td>…</td><td>17.08.2009</td></tr>
<tr><td colspan="2">Measured capacitance, pF</td><td>100.0001223</td><td>100.0001223</td><td>…</td><td>100.0001223</td></tr>
<tr><td colspan="2">Measurement frequency, Hz</td><td colspan="4">1600.0</td></tr>
<tr><td colspan="2">Chassis temperature, ºC</td><td>31.3</td><td>31.3</td><td>…</td><td>31.3</td></tr>
<tr><td colspan="2">Drift reading, µF/F</td><td colspan="4">–0.023</td></tr>
<tr><td rowspan="4">Measurement result</td><td>Mean measurement date</td><td colspan="4">17.08.2009</td></tr>
<tr><td>Mean capacitance, pF</td><td colspan="4">100.0001223</td></tr>
<tr><td>Combined relative standard uncertainty, µF/F</td><td colspan="4">2.0</td></tr>
<tr><td>Degrees of freedom</td><td colspan="4">6331755566</td></tr>
</table>

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	99.99473	6.00E-04	∞	1	6.00E-04
Correction of temperature to Cs, δC_{TS}, pF	rectangular	-0.00019	7.33E-05	∞	1	7.33E-05
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	∞	100 pF	8.16E-06
Ratio between C to Cs, $\bar{c}$ (relative)	normal	1.00006	7.75E-08	19	100 pF	7.75E-06
Correction from adapter, δC_{AD}, pF	rectangular	0	2.89E-06	∞	-1	-2.89E-06
Traveling standard, C, pF	normal	100.0001	6.05E-04	∞		
Final values:						6.05 E-04
Mathematical model: $C = (Cs + \delta C_{TS}) c_k \bar{c} - \delta C_{AD}$						

PTB (Germany)

Laboratory:	PTB
UNCERTAINTY STATEMENT: COOMET.EM-S4 (100 pF) **Serial Number 01328**	

Coomet-K4, AH11A-01328, 100 pF, f = 1 kHz

Uncertainty Budget:

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
V	1.14181220 1	$208 \cdot 10^{-6}$ %	9	$280 \cdot 10^{-15}$	$660 \cdot 10^{-21}$ F	-0.01	0.001
T_X	29.6300 °C	0.151 %	9	$-1.0 \cdot 10^{-18}$	$-45 \cdot 10^{-21}$ F	-0.01	0.000
a1p	-0.0653606 1	0.0656 %	9	$10 \cdot 10^{-15}$	$430 \cdot 10^{-21}$ F	0.01	0.000
b1p	-0.033720 1	0.749 %	9	$790 \cdot 10^{-21}$	$200 \cdot 10^{-24}$ F	0.00	0.000
a2p	0.0649800 1	0.0666 %	9	$-10 \cdot 10^{-15}$	$-430 \cdot 10^{-21}$ F	-0.01	0.000
b2p	0.040570 1	0.529 %	9	$-790 \cdot 10^{-21}$	$-170 \cdot 10^{-24}$ F	0.00	0.000
C_{NB}	$100.0013637 \cdot 10^{-12}$ F	$8.60 \cdot 10^{-6}$ %	infinity	1.0	$8.6 \cdot 10^{-18}$ F	0.44	0.192
T_{NB}	29.791 °C						
k_{TN}	$11.20 \cdot 10^{-6}$ K^{-1}	17.9 %	9	$-180 \cdot 10^{-15}$	$-350 \cdot 10^{-21}$ F	-0.02	0.000
k_{fN}	$-1.110 \cdot 10^{-9}$ s	27.0 %	9	$-59 \cdot 10^{-9}$	$-18 \cdot 10^{-18}$ F	-0.90	0.804
f	1005.000 Hz	0.0574 %	infinity	$-110 \cdot 10^{-21}$	$-64 \cdot 10^{-21}$ F	0.00	0.000
DR_N	$-75.0 \cdot 10^{-9}$ a^{-1}	15.4 %	infinity	$50 \cdot 10^{-12}$	$580 \cdot 10^{-21}$ F	0.03	0.001
Δt	0.50000 a	1.15 %	infinity	$-7.5 \cdot 10^{-18}$	$-43 \cdot 10^{-21}$ F	0.00	0.000
C_N	$100.0014231 \cdot 10^{-12}$ F	$19.6 \cdot 10^{-6}$ %					
Cp	$1000.0000 \cdot 10^{-15}$ F	$500 \cdot 10^{-6}$ %	4	$-1.3 \cdot 10^{-3}$	$-6.5 \cdot 10^{-21}$ F	0.00	0.000
Gq	$100.000 \cdot 10^{-12}$ S	0.100 %	4	0.0	0.0 F	0.0	0.0
Cq	$78.800 \cdot 10^{-18}$ F	0.152 %	4	$-740 \cdot 10^{-6}$	$-89 \cdot 10^{-24}$ F	0.00	0.000
Vp	0.01	$5.80 \cdot 10^{-3}$ %	infinity	$-130 \cdot 10^{-15}$	$-76 \cdot 10^{-21}$ F	0.00	0.000
Vq	0.0	$5.80 \cdot 10^{-6}$	infinity	$-1.2 \cdot 10^{-15}$	$-6.8 \cdot 10^{-21}$ F	0.00	0.000
b1q	0.0 1	$57.7 \cdot 10^{-6}$ 1	infinity	$160 \cdot 10^{-18}$	$9.1 \cdot 10^{-21}$ F	0.00	0.000
b2q	0.0 1	$57.7 \cdot 10^{-6}$ 1	infinity	$-160 \cdot 10^{-18}$	$-9.1 \cdot 10^{-21}$ F	0.00	0.000
k_{TX}	$10.00 \cdot 10^{-9}$ K^{-1}	57.7 %	infinity	0.0	0.0 F	0.0	0.0
T_{XB}	29.63 °C						
C_X	$100.0001197 \cdot 10^{-12}$ F	$19.6 \cdot 10^{-6}$ %					
π	3.1415926535898						
ω	6314.60 s^{-1}	0.0574 %					
T_N	29.789236 °C	$2.62 \cdot 10^{-3}$ %					
D_0	439.932854 1						
D_1	472.41802 1						

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Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

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	Coomet-K4, AH11A-01328, 100 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}	28.54292700 Ω	$20.2\cdot10^{-6}$ %	infinity	$-11\cdot10^{-15}$	$-64\cdot10^{-21}$ F	0.00	0.000
R_{Ga}	28.54295903 Ω	$20.2\cdot10^{-6}$ %					
W_{rt90}	1.11823601 1	$276\cdot10^{-6}$ %					
W_r	-0.92790487 1	$203\cdot10^{-6}$ %					
a	$-178.9\cdot10^{-6}$ 1						
W_{Ga}	1.11811800 1	$179\cdot10^{-6}$ %	10000	$280\cdot10^{-15}$	$570\cdot10^{-21}$ F	0.03	0.001
R_{t90}	28.5454317 Ω	$209\cdot10^{-6}$ %					
R_S	25.00011100 Ω	$20.0\cdot10^{-6}$ %	50	$13\cdot10^{-15}$	$63\cdot10^{-21}$ F	0.00	0.000
C_{XB}	$100.000120\cdot10^{-12}$ F	$19.6\cdot10^{-6}$ %	13				

Result: Quantity: C_{XB}
Value: $100.000120\cdot10^{-12}$ F
Relative Expanded Uncertainty: $\pm430\cdot10^{-9}$
Coverage Factor: 2.2
Coverage: t-table 95%

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Notes:

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

Laboratory:	PTB
UNCERTAINTY STATEMENT: COOMET.EM-S4 (100 pF) **Serial Number 01328**	

Coomet-K4, AH11A-01328, 100 pF, f = 1 kHz

Uncertainty Budget:

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
V	1.14179064 1	$126\cdot10^{-6}$ %	10	$280\cdot10^{-15}$	$400\cdot10^{-21}$ F	0.00	0.000
T_X	30.0636 °C	0.216 %	10	$-1.0\cdot10^{-18}$	$-65\cdot10^{-21}$ F	-0.01	0.000
a1p	-0.0638458 1	0.0374 %	10	$10\cdot10^{-15}$	$240\cdot10^{-21}$ F	0.01	0.000
b1p	-0.03964 1	6.61 %	10	$790\cdot10^{-21}$	$2.1\cdot10^{-21}$ F	-0.01	0.000
a2p	0.0635108 1	0.0410 %	10	$-10\cdot10^{-15}$	$-260\cdot10^{-21}$ F	-0.01	0.000
b2p	0.02290 1	10.5 %	10	$-790\cdot10^{-21}$	$-1.9\cdot10^{-21}$ F	-0.01	0.000
C_{NB}	$100.0013355\cdot10^{-12}$ F	$5.90\cdot10^{-6}$ %	infinity	1.0	$5.9\cdot10^{-18}$ F	0.31	0.099
T_{NB}	29.783 °C						
k_{TN}	$11.20\cdot10^{-6}$ K^{-1}	17.9 %	9	$210\cdot10^{-15}$	$430\cdot10^{-21}$ F	0.02	0.001
k_{IN}	$-1.110\cdot10^{-9}$ s	27.0 %	9	$-59\cdot10^{-9}$	$-18\cdot10^{-18}$ F	-0.94	0.883
f	1005.000 Hz	0.0574 %	infinity	$-110\cdot10^{-21}$	$-64\cdot10^{-21}$ F	0.00	0.000
DR_N	$-75.0\cdot10^{-9}$ a^{-1}	15.4 %	infinity	$200\cdot10^{-12}$	$2.3\cdot10^{-18}$ F	0.12	0.015
Δt	2.00000 a	0.289 %	infinity	$-7.5\cdot10^{-18}$	$-43\cdot10^{-21}$ F	0.00	0.000
C_N	$100.0013880\cdot10^{-12}$ F	$18.7\cdot10^{-6}$ %					
Cp	$1000.0000\cdot10^{-15}$ F	$500\cdot10^{-6}$ %	4	$-1.3\cdot10^{-3}$	$-6.4\cdot10^{-21}$ 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	$-630\cdot10^{-6}$	$-75\cdot10^{-24}$ F	0.00	0.000
Vp	0.01	$5.80\cdot10^{-3}$ %	infinity	$-130\cdot10^{-15}$	$-74\cdot10^{-21}$ F	0.00	0.000
Vq	0.0	$5.80\cdot10^{-6}$	infinity	$-980\cdot10^{-18}$	$-5.7\cdot10^{-21}$ 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	$-360\cdot10^{-15}$	$-2.1\cdot10^{-21}$ F	0.00	0.000
T_{XB}	30.06 °C						
C_X	$100.0001144\cdot10^{-12}$ F	$18.7\cdot10^{-6}$ %					
π	3.1415926535898						
ω	6314.60 s^{-1}	0.0574 %					
T_N	29.785135 °C	$2.09\cdot10^{-3}$ %					
D_0	439.932854 1						
D_1	472.41802 1						

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Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

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Coomet-K4, AH11A-01328, 100 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}	28.54292700 Ω	$20.2\cdot10^{-6}$ %	infinity	$-11\cdot10^{-15}$	$-64\cdot10^{-21}$ F	0.00	0.000
R_{Ga}	28.54295903 Ω	$20.2\cdot10^{-6}$ %					
W_{rt90}	1.11823601 1	$276\cdot10^{-6}$ %					
W_r	-0.92790487 1	$203\cdot10^{-6}$ %					
a	$-178.9\cdot10^{-6}$ 1						
W_{Ga}	1.11811800 1	$179\cdot10^{-6}$ %	10000	$280\cdot10^{-15}$	$570\cdot10^{-21}$ F	0.03	0.001
R_{t90}	28.5454317 Ω	$209\cdot10^{-6}$ %					
R_S	25.00011100 Ω	$20.0\cdot10^{-6}$ %	50	$13\cdot10^{-15}$	$63\cdot10^{-21}$ F	0.00	0.000
C_{XB}	$100.000120\cdot10^{-12}$ F	$19.6\cdot10^{-6}$ %	13				

Result: Quantity: C_{XB}
Value: $100.000120\cdot10^{-12}$ F
Relative Expanded Uncertainty: $\pm430\cdot10^{-9}$
Coverage Factor: 2.2
Coverage: t-table 95%

Date: 10/21/2009 File: Coomet-K4_01328_C_TXB Page 11 of 11

Notes:

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

Laboratory:	PTB
UNCERTAINTY STATEMENT: COOMET.EM-S4 (100 pF) **Serial Number 01328**	

Coomet-K4, AH11A-01328, 100 pF, f = 1592 Hz

Uncertainty Budget:

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Sensitivity Coefficient	Uncertainty Contribution	Corr.-Coeff.	Index
V	1.14179027 1	$157\cdot10^{-6}$ %	10	$280\cdot10^{-15}$	$500\cdot10^{-21}$ F	-0.01	0.007
T_X	30.0636 °C	0.225 %	10	$-1.0\cdot10^{-18}$	$-68\cdot10^{-21}$ F	-0.01	0.000
a1p	-0.0637665 1	0.0599 %	10	$10\cdot10^{-15}$	$380\cdot10^{-21}$ F	0.02	0.004
b1p	-0.052609 1	1.46 %	10	$500\cdot10^{-21}$	$380\cdot10^{-24}$ F	-0.01	0.000
a2p	0.0635385 1	0.0533 %	10	$-10\cdot10^{-15}$	$-340\cdot10^{-21}$ F	-0.03	0.003
b2p	0.06138 1	1.81 %	10	$-490\cdot10^{-21}$	$-550\cdot10^{-24}$ F	-0.02	0.000
C_{NB}	$100.0013355\cdot10^{-12}$ F	$5.90\cdot10^{-6}$ %	infinity	1.0	$5.9\cdot10^{-18}$ F	0.99	0.971
T_{NB}	29.783 °C						
k_{TN}	$11.20\cdot10^{-6}$ K^{-1}	17.9 %	9	$220\cdot10^{-15}$	$440\cdot10^{-21}$ F	0.07	0.005
k_{IN}	$-1.110\cdot10^{-9}$ s	27.0 %	9	0.0	0.0 F	0.0	0.0
f	1592.000 Hz	0.0363 %	infinity	$-110\cdot10^{-21}$	$-64\cdot10^{-21}$ 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	$-7.5\cdot10^{-18}$	$-43\cdot10^{-21}$ F	-0.01	0.000
C_N	$100.00133794\cdot10^{-12}$ F	$5.96\cdot10^{-6}$ %					
Cp	$999.97900\cdot10^{-15}$ F	$500\cdot10^{-6}$ %	4	$-1.3\cdot10^{-3}$	$-6.4\cdot10^{-21}$ 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	$-1.1\cdot10^{-3}$	$-140\cdot10^{-24}$ F	0.00	0.000
Vp	0.01	$5.80\cdot10^{-3}$ %	infinity	$-130\cdot10^{-15}$	$-74\cdot10^{-21}$ F	-0.01	0.000
Vq	0.0	$5.80\cdot10^{-6}$	infinity	$-1.1\cdot10^{-15}$	$-6.6\cdot10^{-21}$ F	0.00	0.000
b1q	0.0 1	$57.7\cdot10^{-6}$ 1	infinity	$99\cdot10^{-18}$	$5.7\cdot10^{-21}$ F	0.00	0.000
b2q	0.0 1	$57.7\cdot10^{-6}$ 1	infinity	$-99\cdot10^{-18}$	$-5.7\cdot10^{-21}$ F	0.00	0.000
k_{TX}	$10.00\cdot10^{-9}$ K^{-1}	57.7 %	infinity	$-360\cdot10^{-15}$	$-2.1\cdot10^{-21}$ F	0.00	0.000
T_{XB}	30.06 °C						
C_X	$100.00006486\cdot10^{-12}$ F	$5.99\cdot10^{-6}$ %					
π	3.14159265358 98						
ω	10002.83 s^{-1}	0.0363 %					
T_N	29.785181 °C	$2.27\cdot10^{-3}$ %					
D_0	439.932854 1						
D_1	472.41802 1						

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Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

Coomet-K4, AH11A-01328, 100 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	$-11 \cdot 10^{-15}$	$-64 \cdot 10^{-21}$ F	-0.01	0.000
R_{Ga}	28.54284503 Ω	$20.2 \cdot 10^{-6}$ %					
W_{rt90}	1.11821999 1	$239 \cdot 10^{-6}$ %					
W_r	-0.92791464 1	$176 \cdot 10^{-6}$ %					
a	$-178.9 \cdot 10^{-6}$ 1						
W_{Ga}	1.11811800 1	$179 \cdot 10^{-6}$ %	10000	$280 \cdot 10^{-15}$	$570 \cdot 10^{-21}$ F	0.10	0.009
R_{t90}	28.5449087 Ω	$157 \cdot 10^{-6}$ %					
R_S	25.000133000 Ω	$1.00 \cdot 10^{-6}$ %	50	$13 \cdot 10^{-15}$	$3.2 \cdot 10^{-21}$ F	0.00	0.000
C_{XB}	$100.0000649 \cdot 10^{-12}$ F	$5.95 \cdot 10^{-6}$ %	infinity				

Result: Quantity: C_{XB}
Value: $100.000065 \cdot 10^{-12}$ F
Relative Expanded Uncertainty: $\pm 120 \cdot 10^{-9}$
Coverage Factor: 2.0
Coverage: t-table 95%

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Notes:

Laboratory: Physikalisch-Technische Bundesanstalt (PTB, Germany)

VNIIM (Russia)

Quantity	Estimate	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	0.41	µF/F	0.016	µF/F	6	1		0.05
Mean of *7* independent measurements	0.16	µF/F	0.08	µF/F	6	1		0.08
Ratio calibration								
Bridge resolution	0	µF/F	0.02	µF/F	13	1		0.02
Lead correction	-0.018	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:	0.55	µF/F			39			0.204

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									
100 pF capacitance standard based on a quantized Hall resistance (QHR) (1)(2)	1.356	µF/F	0.104	µF/F	B	107458	1		0.104
Measurement of comparison artifact									
Mean of 3 independent measurements	-0.5015	µF/F	0.0004	µF/F	A	2	1		0.0004
Lead correction (3)	-0.040	µF/F	0.012	µF/F	B	∞	1		0.012
Laboratory temperature correction (22.82 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:	0.815	µF/F				115965			0.106

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.

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	13 normal	1	0.300
Measurement uncertainty of the ratio 10:1 in bridge shoulder	0.4	0.23	∞ rectangular	1	0.230
Instability of the 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	0.003
Statistical processing of 9 independent measurements	0.063	0.021	8 normal	1	0.021
Final values:			24		0.420

UMTS (Ukraine)

Quantity	Source of uncertainty	Relative standard uncertainty, μF/F
1000 Hz		
Ω	Frequency measurement uncertainty	0.060
R_0	Uncertainty of R_0 calibration on resistive primary standard on DC	0.040
	Uncertainty of R_0 AC (1000 Hz) correction coefficient	0.060
	R_0 resistance long term instability	0.040
	Uncertainty, caused by R_0 temperature instability (TCR·ΔT)	0.050
	Uncertainty of R_0 temperature measurements	0.030
	Uncertainty of the R_0 calibration by phase angle	0.080
K_c	Quadrature bridge standard deviation during its calibration by R_0	0.040
	Quadrature bridge standard deviation during capacitance unit reproduction	0.050
	Quadrature bridge standard deviation during measurement of dissipation factor	0.100
	Quadrature bridge uncertainty in R-C transfer mode	0.090
	Quadrature bridge dissipation factor uncertainty during the capacitance unit reproduction	0.040
C_s	Capacitance transfer standard uncertainty, caused by its temperature instability (TCC·ΔT)	0.080
	Final values:	0.225
1592 Hz		
Ω	Frequency measurement uncertainty	0.060
R_0	Uncertainty of R_0 calibration on resistive primary standard on DC	0.040
	Uncertainty of R_0 AC (1592 Hz) correction coefficient	0.110
	R_0 resistance long term instability	0.040
	Uncertainty, caused by R_0 temperature instability (TCR·ΔT)	0.050
	Uncertainty of R_0 temperature measurements	0.030
	Uncertainty of the R_0 calibration by phase angle	0.200

Quantity	Source of uncertainty	Relative standard uncertainty, μF/F
K_c	Quadrature bridge standard deviation during its calibration by R_0	0.040
	Quadrature bridge standard deviation during capacitance unit reproduction	0.050
	Quadrature bridge standard deviation during measurement of dissipation factor	0.100
	Quadrature bridge uncertainty in *R-C* transfer mode	0.190
	Quadrature bridge dissipation factor uncertainty during the capacitance unit reproduction	0.050
C_s	Capacitance transfer standard uncertainty, caused by its temperature instability (TCC·Δ*T*)	0.080
	Final values:	0.350
	Degrees of freedom:	more than 100
Mathematical model: $C_s = K_c / \omega R_0$		

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

BelGIM (Belarus)

Quantity	Estimate, pF	+/- *r*, pF	Uncer-tainty type, distri-bution	Standard uncertainty, pF	Effective degrees of freedom, distribution	Sensiti vity coeffi-cient	Contribution to the relative standard uncertainty, pF
1000 Hz							
Measured value of capacitance of transfer standard, C_x	100.0000344		A, normal	0.00000100	1719992	1	0.00000100
Measured value of capacitance of lab standard, $C_{xэт}$	99.9994310		A, normal	0.00000078	1518372	1	0.00000078
Correction of standard measure from calibration certificate, $\delta C_{эт}$	0.0	0.0002	B, rectan-gular	0.0001000	∞	-1	-0.0001000
Correction due to the non-stability of standard measure, $\delta C_{н}$	0.0	0.000031	B, rectan-gular	0.0000179	∞	-1	-0.0000179
Correction due to the AC bridge quantizetion process, δC_{KB}	0.0	0.0000005	B, rectan-gular	0.0000003	∞	-1	-0.0000003
Final values:	100.0001034						0.0002032

Quantity	Estimate, pF	+/- r, pF	Uncer-tainty type, distri-bution	Standard uncertainty, pF	Effective degrees of freedom, distribution	Sensitivity coeffi-cient	Contribution to the relative standard uncertainty, pF
1600 Hz							
Measured value of capacitance of transfer standard, C_x	100.0000293		A, normal	0.00000094	1719992	1	0.00000094
Measured value of capacitance of lab standard, $C_{xэт}$	99.9994070		A, normal	0.00000097	1518372	1	0.00000097
Correction of standard measure from calibration certificate, $\delta C_{эт}$	0.0	0.0002	B, rectan-gular	0.0001000	∞	-1	-0.0001000
Correction due to the non-stability of standard measure, $\delta C_{н}$	0.0	0.000031	B, rectan-gular	0.0000179	∞	-1	-0.0000179
Correction due to the AC bridge quantizetion process, $\delta C_{КВ}$	0.0	0.0000005	B, rectan-gular	0.0000003	∞	-1	-0.0000003
Final values:	100.0001223						0.0002032

Mathematical model: $C = C_{д} - \delta C_{эт} - \delta C_{н} - \delta C_{КВ}$

<u>Notes:</u>

$C_{д} = k \cdot \overline{C}_{x} = (C_{эт\,д} / \overline{C}_{x\,эт}) \cdot \overline{C}_{x}$

$C_{этд}$ – value of standard measure from calibration certificate;

$\overline{C}_{x\,эт}$ – average measurand value of standard measure;

$\overline{C}_{x}$ – average measurand value of transfer standard.

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)

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(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 traveling 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 traveling standard

The selected traveling 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 traveling 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 traveling standard

The traveling standard will be circulated within a container, which is well furnished for the safety of the traveling 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 traveling 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 traveling standard shall be re-packed in a new container that will provide adequate protection during shipment.

On receipt of the traveling 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 traveling standard is noted, then the pilot laboratory should be informed immediately by e-mail or fax. If the traveling 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 traveling standard has arrived by filling the following form given in Figure 2.

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

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

Participants should inform the pilot laboratory and the recipient laboratory by e-mail or fax when the traveling 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 traveling standard

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

4. Measurement Instructions

After power up of traveling 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 traveling 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 traveling 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 traveling 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 traveling 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” (Ukrmeterteststandard) 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 ($tg\delta$)				
Frequency (f), Hz				
Voltage (U), rms V				
Ambient temperature, °C				
Relative humidity, %				