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

Final Report on
GULFMET Supplementary Comparison of Inductance at 10 mH and 100 mH at 1 kHz (GULFMET.EM-S4)

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1 Introduction

The GULFMET Supplementary Comparison (SC) of Inductance at 10 mH and 100 mH at 1 kHz (comparison identifier – GULFMET.EM-S4) was carrying out from June to October 2018.

This project for comparing of national standards of electrical inductance was conducted between counties which are member laboratories of regional metrology organizations GULFMET and COOMET. Four national metrology institutes (NMIs) planned to take part in this comparison: SE "Ukrmetrteststandard" (UMTS, Ukraine); QCC EMI (United Arab Emirates); SASO- NMCC (Saudi Arabia) and NMISA (South Africa). NMISA withdrew in November 2018 as they were not able to meet the comparison timescales.

The State Enterprise "All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer" (SE "Ukrmetrteststandard"), Ukraine was selected as the pilot laboratory. Dr. Oleh Velychko was the comparison coordinators. The pilot laboratory is responsible for providing the travelling standard, coordinating the schedule, collecting and analyzing the comparison data, preparing the draft report, etc.

2 Participants

List of participating NMIs, countries of origin is show in Table 1.

Table 1 List of participating NMIs, countries of origin 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 "Ukrmetrteststandard") – **pilot**	Ukraine	COOMET
QCC EMI – Abu Dhabi Quality and Conformity Council, Emirates Metrology Institute	United Arab Emirates	GULFMET
SASO-NMCC – Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi – National Measurements and Calibration Center	Saudi Arabia	GULFMET

List of participant contact information is show in Table 2.

Table 2 List of participant contact information

NMI 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" (SE "Ukrmetrteststandard" – **UMTS),** 4, Metrologichna Str., 03143, Kyiv-143, **Ukraine**	Oleh Velychko Velychko@ukrcsm.kiev.ua Tel./fax: +38 044 526 0335
Abu Dhabi Quality and Conformity Council, Emirates Metrology Institute (**QCC EMI**), CERT Sultan Bin Zayed the First Str., Abu Dhabi, **United Arab Emirates**	Jon Bartholomew Jon.Bartholomew@qcc.abudhabi.ae Tel: +971 503862676 Fax: +971 24066677

NMI address	Contact name, e-mail, tel. and fax number
Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi – National Measurements and Calibration Center (**SASO-NMCC**), In front of king Saud University Riyadh 11471, P.O. Box 3437, **Saudi Arabia**	Abdullah M. Alrobaish a.robaish@saso.gov.sa Tel: +966 11 2529730

3 Travelling standards and measurement instructions

3.1 Description of travelling standards

The selected travelling standards are “Inductance measure reference thermostatically regulated 10 mH” (“*Міра індуктивності еталонна термостатована 10 мГн*”) type P5109 10 mH (No. 424) and “Inductance measure reference thermostatically regulated 100 mH” (“*Міра індуктивності еталонна термостатована 100 мГн*”) type P5113 100 mH (No. 1003) (Figure 1).

Fugure 1. Travelling standards

Thermostatically regulated standards of inductance types P5109 and P5113 allow the monitoring of critical parameters: the temperature difference of values within each standard thermostat and internal supply voltage. Standards contain inbuilt precision thermostat with dual temperature sensors, which provides increased reliability and accuracy of the measurement results.

Main characteristics of measures of inductance:

Instability: 10 ppm/year;

temperature inside the thermostat: from 29.5 °C to 30.5 °C;

temperature instability: 0.05 °C/hour;

time to thermostat operating mode: not more than 3 hours;

weight: 9 kg;

supply voltage thermostat: 15 V DC;

power consumption: no more than 3.5 W;

temperature coefficient: 37 ppm/°C;

linear dimensions of each enclosure measures (mm): height – 275, length – 380; width – 360.

The description and operating manual for the standard of inductance are attached. Participants of comparisons have to read the documentation before the measurements.

3.2 Measurement instructions

Measurements were performed under the following conditions:

temperature: 23 °C ± 1 °C;

relative humidity: from 30 % to 70 %;

measurement frequency: 1 kHz (depending on laboratory's capability);

The full power (active and reactive) on the travelling standard should not exceed 10 mW.

The temperature coefficient does not exceed 37 ppm/°C, and measurement results are not compensated for temperature changes in the laboratory. If the air temperature of measurements in the laboratory is significantly different from 23 °C, the influence of the ambient temperature can be accounted for in the uncertainty budget.

The data to be recorded at each measurement:

date of measurement;

frequency of measuring signal;

measured inductance;

air temperature and relative humidity in the immediate vicinity of the travelling standards;

temperature inside the thermostat.

3.3 Operations before measurements

The travelling standards are shipped between the participants unpowered. After power up of travelling standards in NMI participant it will be stabilized for three days.

To connect travelling standards NMI participants can use any adapters but participants should take into account all relevant adjustments in order to determine the inductance value directly from the input jack inductance measures.

Before the measurements, it is necessary to familiarize design features and operating principles of travelling standards by using technical description. Connect travelling standards in accordance with connection schemes for 2- and 3-terminal shown on Figure 2.

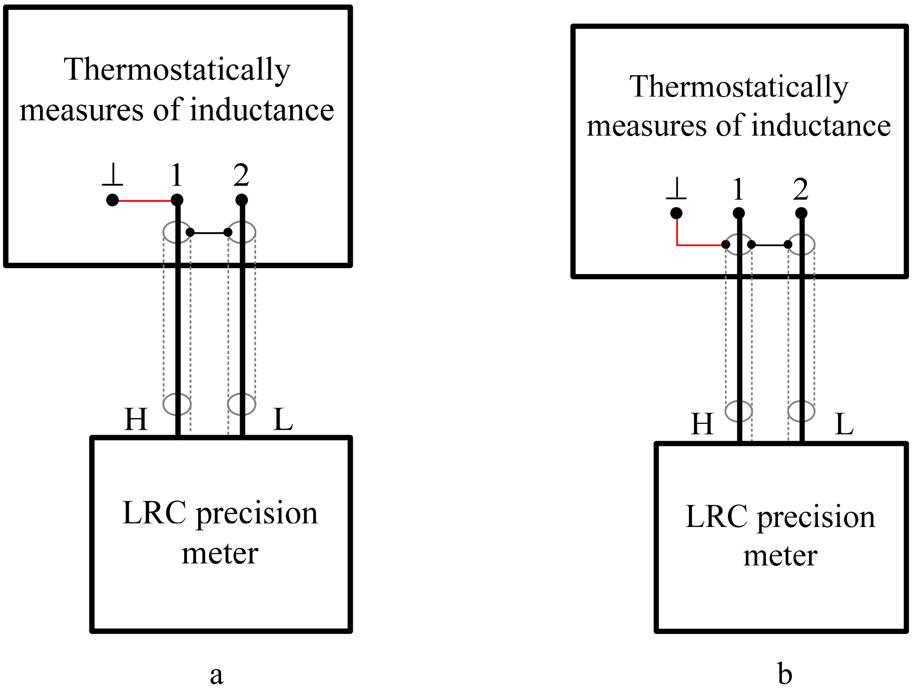

Figure 2 Connection scheme: a) for 2-terminal; b) for 3-terminal

4 Uncertainty of measurement

The uncertainty was calculated following the JCGM 100 [1]: 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. The overall uncertainty, as calculated from the individual uncertainties, was stated. Uncertainties were evaluated at the level of one standard uncertainty and the number of effective degrees of freedom is to be reported.

The main uncertainty components were expected:

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 also included additional sources of uncertainty.

5 Traceability to the SI

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

The traceability route for the primary standard of inductance for each NMI is given in Table 3. Traceability for UMTS, QCC EMI and SASO-NMCC are obtained by comparison of the 10 mH and 100 mH inductance standards using the *RLC* bridges and reference inductors with value traced to NMIs at 1 kHz.

Table 3 Traceability route for each participating NMI

NMI	Country	Traceability Route
UMTS	Ukraine	PTB
QCC EMI	United Arab Emirates	UME
SASO-NMCC	Saudi Arabia	UME

6 Behaviour of the travelling standards

The UMTS as pilot laboratory has performed repeated measurements on the travelling standards types P5109 10 mH (No. 424) and P5113 100 mH (No. 1003) during the course of this comparison as well as COOMET.EM-S14 comparison [2]. From these measurements, the behaviour of the travelling standards can be seen in Figures 3–6.

As the values of the inductance 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. The drift, can be, and was neglected.

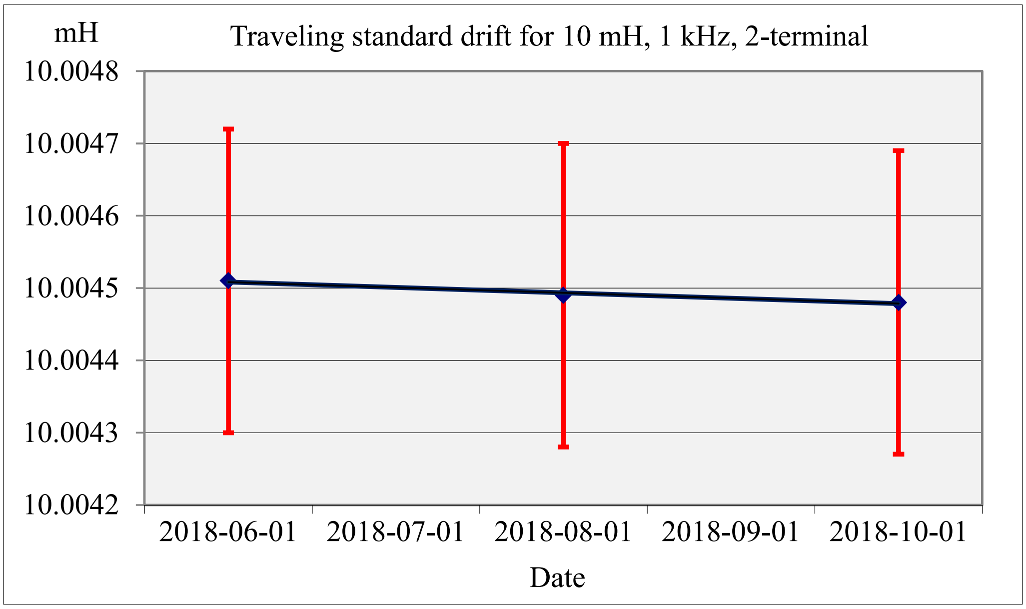

Figure 3 Behaviour of the travelling standard for 10 mH (2-terminal)

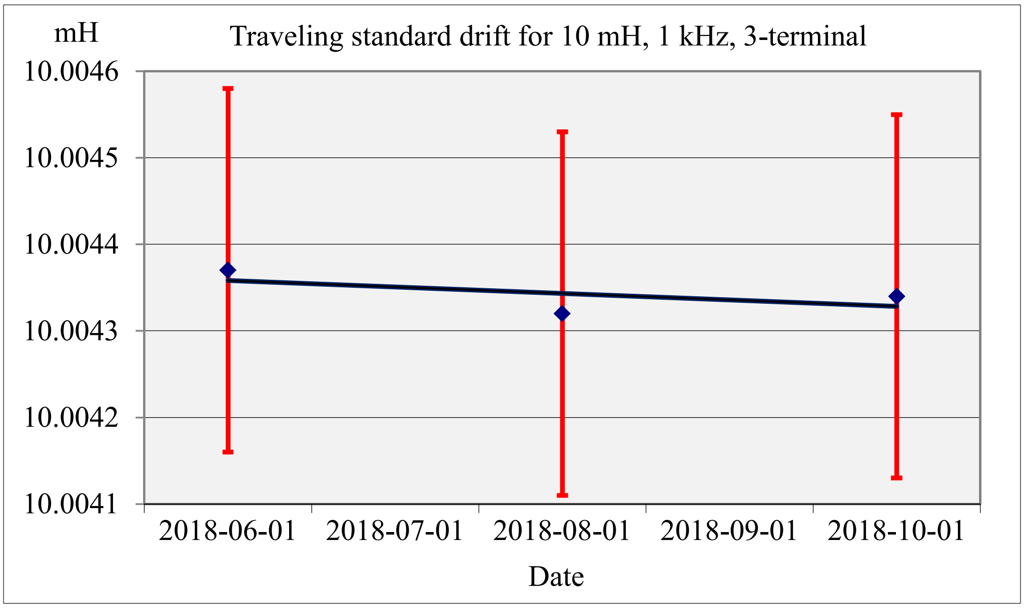

Figure 4 Behaviour of the travelling standard for 10 mH (3-terminal)

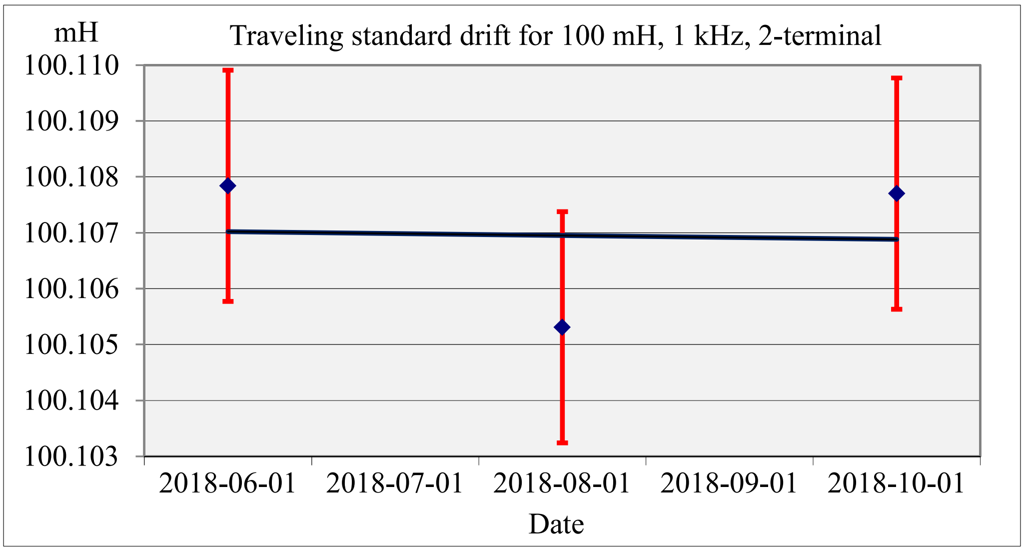

Figure 5 Behaviour of the travelling standard for 100 mH (2-terminal)

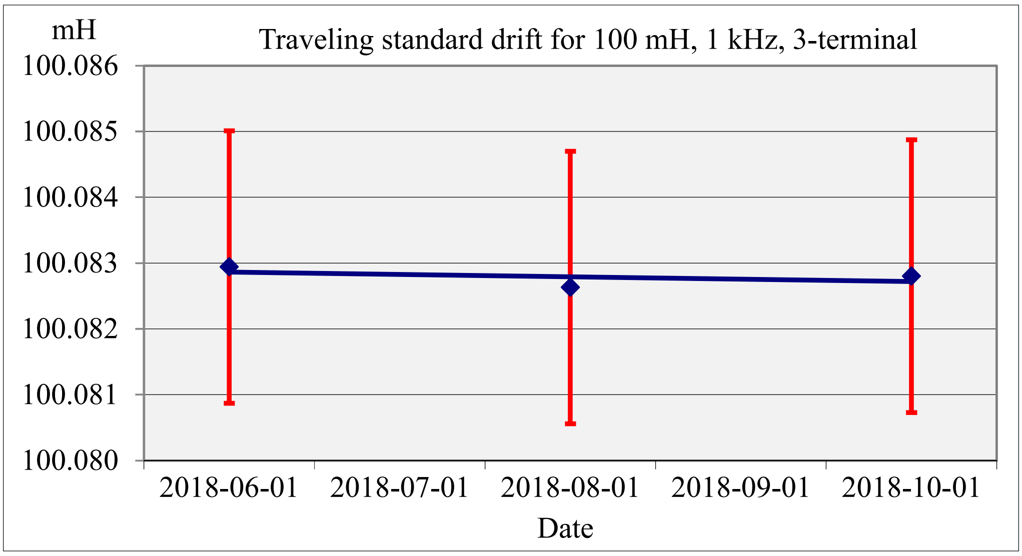

Figure 6 Behaviour of the travelling standard for 10 mH (3-terminal)

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 inductance. The report included 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.

The measurement period, the measurement frequency and the applied voltage were also reported for each inductance. Details of any corrections that have been applied (for example, bridge corrections or leads corrections) were given.

All measurement results and expended uncertainties, and additional parameters for measurement were identified with the serial number of measures inductance and nominal value.

List of measurement dates of the NMI participants is show in Table 4.

Table 4 List of measurement dates of the NMI participants

NMI	Measurement dates
UMTS1, Ukraine	11–15.06.2018
QCC EMI, United Arab Emirates	09–11.07.2018
UMTS2, Ukraine	20–23.08.2018
SASO-NMCC, Saudi Arabia	19–24.10.2018
UMTS3, Ukraine	30.10–02.11.2018

Additional parameters for measurement of the NMI participants are show in Table 5.

Table 5 Additional parameters for measurement of the NMI participants

Parameter	Inductance 10 mH		Inductance 100 mH	
	Value	Expanded uncertainty	Value	Expanded uncertainty
QCC EMI, United Arab Emirates				
Frequency, kHz	1.000003	$5\cdot10^{-6}$	1.000003	$5\cdot10^{-6}$
Measure temperature, °C	29.95…30.01	0.01	29.95…30.01	0.01
Ambient temperature, °C	23 ± 1	0.5	23 ± 1	0.5
Relative humidity, %	50 ± 4	2.5	50 ± 4	2.5
SASO-NMCC, Saudi Arabia				
Frequency, kHz	1.000	$3.5\cdot10^{-5}$	1.000	$3.5\cdot10^{-5}$
Measure temperature, °C	30.05	0.01	29.85	0.01
Ambient temperature, °C	23 ± 1	0.1	23 ± 1	0.1
Relative humidity, %	45	2.0	45	2.0
UMTS, Ukraine				
Frequency, kHz	1.000	$1\cdot10^{-7}$	1.000	$1\cdot10^{-7}$

Parameter	Inductance 10 mH		Inductance 100 mH	
	Value	Expanded uncertainty	Value	Expanded uncertainty
Measure temperature, °C	29.95…29.99	0.01	29.95…29.99	0.01
Ambient temperature, °C	22.5…23.5	0.3	22.5…23.5	0.3
Relative humidity, %	40...50	1.9	40...50	1.9

The inductance values and their expanded uncertainties (U) reported by the NMI participants for 10 mH and 100 mH at frequencies of 1 kHz shown on Table 6. All the uncertainties quoted in this report are expanded uncertainties, having a coverage factor k = 2 which provides a level of confidence of approximately 95%.

Table 6 Deviations for NMI participants

NMI	2-terminal		3-terminal	
	δL_i (mH/H)	U_i (mH/H)	δL_i (mH/H)	U_i (mH/H)
10 mH				
QCC EMI	0.458	0.071	0.442	0.070
SASO-NMCC	0.428	0.080	-	-
UMTS	0.449	0.021	0.434	0.021
100 mH				
QCC EMI	1.050	0.120	0.917	0.087
SASO-NMCC	1.018	0.080	-	-
UMTS	0.971	0.021	0.828	0.021

7.2 Calculation of the reference value and its uncertainty

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

$$x_{ref} = \sum_{i=1}^{N} \frac{x_i}{u^2(x_i)} \Bigg/ \sum_{i=1}^{N} \frac{1}{u^2(x_i)} \qquad (1)$$

with associated standard uncertainty

$$u^2(x_{ref}) = 1 \Bigg/ \sum_{i=1}^{N} \frac{1}{u^2(x_i)} \,. \qquad (2)$$

In cases the calculated simple weighted mean of all results was x_{ref} = 0.448 mH/H for 10 mH (2-terminal) and x_{ref} = 0.435 mH/H for 10 mH (3-terminal) with expanded uncertainty (k = 2) U_{ref} = 0.020 mH/H; x_{ref} = 0.977 mH/H for 100 mH (2-terminal) and x_{ref} = 0.833 mH/H for 100 mH (3-terminal) with expanded uncertainty (k = 2) U_{ref} = 0.020 mH/H.

7.3 Degrees of equivalence

Only one value is reported for each NMI participants. Degrees of equivalence of the NMI participants are reported with respect to the measurement for 10 mH and 100 mH at 1 kHz for 2- and 3-terminals.

The degrees of equivalence of the *i*-th NMI and its expanded uncertainties with respect to the comparison reference value is estimated as [2]

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

$$U^2(D_i) = U^2(x_i) + U^2(x_{ref}) \ . \tag{4}$$

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

$$|D_i| < 2u(D_i) \ . \tag{5}$$

The degrees of equivalence of the NMI participants and its expanded uncertainties (k = 2) with respect to the KCRV for 10 mH and 100 mH at 1 kHz for 2- and 3-terminal are also presented in Table 7 and the graphs in Figures 5–8.

Table 7 Degrees of equivalence of the NMI participants

NMI	**2-terminal**		**3-terminal**	
	D_i (mH/H)	$U(D_i)$ (mH/H)	D_i (mH/H)	$U(D_i)$ (mH/H)
10 mH				
QCC EMI	0.010	0.074	0.007	0.073
SASO-NMCC	-0.020	0.082	-	-
UMTS	0.001	0.029	-0.001	0.029
100 mH				
QCC EMI	0.073	0.122	0.084	0.089
SASO-NMCC	0.041	0.083	-	-
UMTS	-0.006	0.029	-0.005	0.029

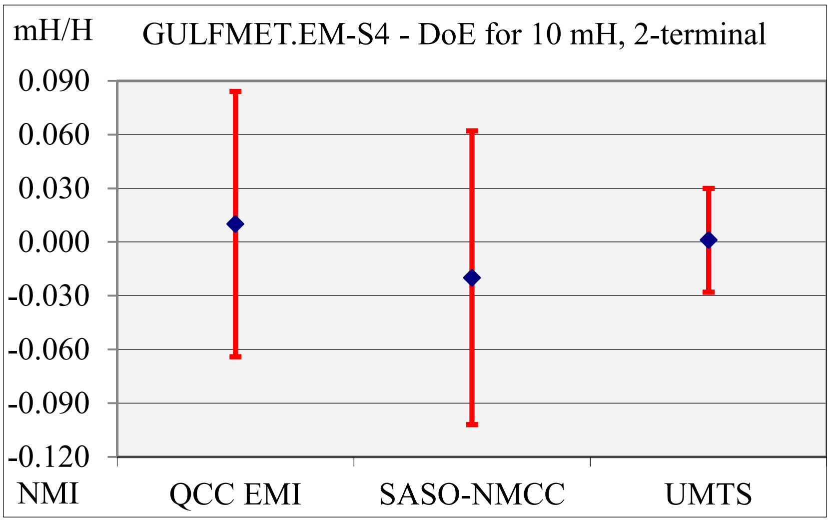

Figure 5 Degree of equivalence of the NMI participants on 10 mH (2-terminal)

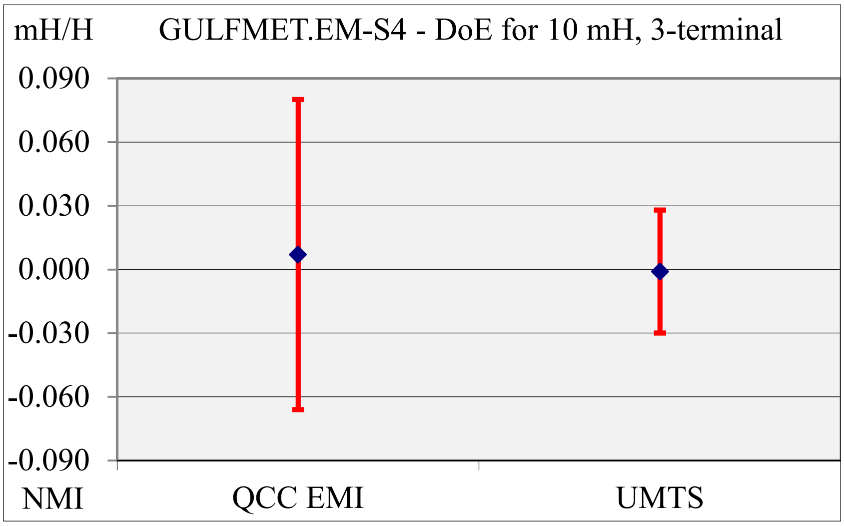

Figure 6 Degree of equivalence of the NMI participants on 10 mH (3-terminal)

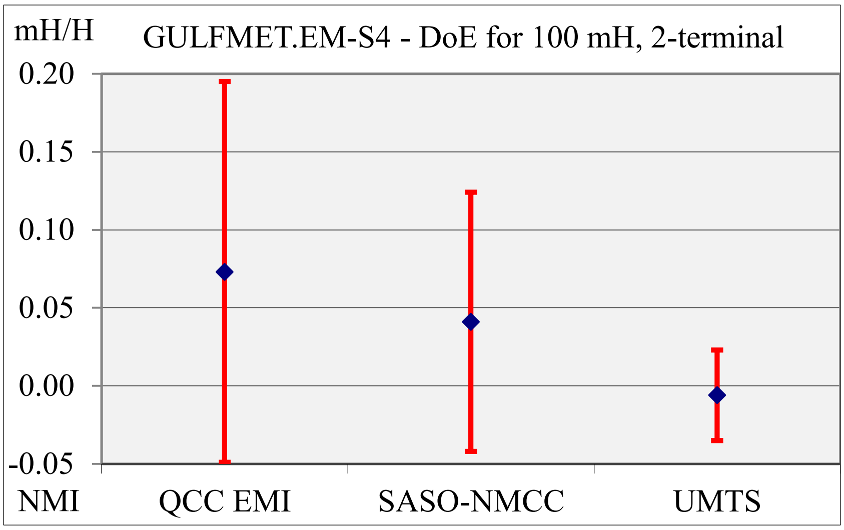

Figure 7 Degree of equivalence of the NMI participants on 100 mH (2-terminal)

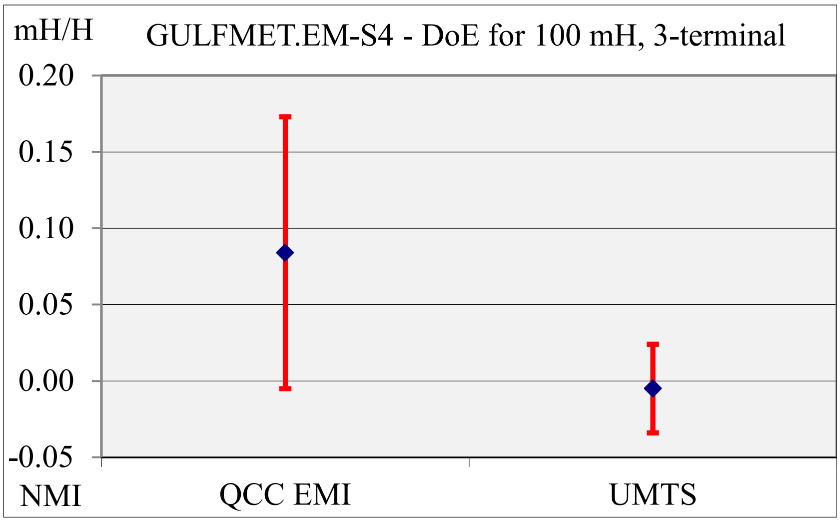

Figure 8 Degree of equivalence of the NMI participants on 100 mH (3-terminal)

7.4 Results of the NMI participants

$$\max_i E_N = \frac{\left| x_i - x_{ref} \right|}{2\sqrt{u^2(x_i) - u^2(x_{ref})}} \le 1.0 . \qquad (6)$$

The maximum E_N criterion and declared uncertainties for degrees of equivalence all NMIs for 10 mH and 100 mH are judged as confirmed by equations (6) (Table 8).

Table 8 Values for E_N criterion

Inductance, mH	**Terminal**	**NMI**	E_N
10	2-terminal	QCC EMI	0.14
		SASO-NMCC	0.26
		UMTS	0.07
	3-terminal	QCC EMI	0.11
		UMTS	0.09
100	2-terminal	QCC EMI	0.62
		SASO-NMCC	0.54
		UMTS	0.66
	3-terminal	QCC EMI	0.99
		UMTS	0.63

8 Summary

A supplementary comparison of inductance at 10 mH and 100 mH at 1 kHz has been conducted between participating GULFMET and COOMET member laboratories. In general there is good agreement between participating laboratories in the region for this quantity at a value of 10 mH and acceptable agreement at a value of 100 mH. It is expected that this comparison will be able to provide support for participants' entries in Appendix C of the CIPM MRA.

References

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

[2] Velychko O., Shevkun S. (2016). Final Report on COOMET Supplementary Comparison of Inductance at 10 mH and 100 mH at 1 kHz (COOMET.EM-S14). Metrologia, Vol. 53, Issue 1A, Tech. Suppl. 01009.

Appendix 1

Reported measurement results for each NMI laboratory

QCC EMI, United Arab Emirates

<table>
<tr><td colspan="2">Measurement frequency, kHz</td><td>1.000003</td></tr>
<tr><td colspan="2">Measure temperature, ºC</td><td>23 ± 1</td></tr>
<tr><td rowspan="3">Measurement result</td><td>Mean measurement date</td><td>09–11.07.2018</td></tr>
<tr><td>Mean inductance (2-terminal), mH</td><td>10.00458</td></tr>
<tr><td>Expanded uncertainty, mH</td><td>0.00071 (k = 2.0)</td></tr>
<tr><td colspan="2">Measurement frequency, kHz</td><td>1.000003</td></tr>
<tr><td colspan="2">Measure temperature, ºC</td><td>23 ± 1</td></tr>
<tr><td rowspan="3">Measurement result</td><td>Mean measurement date</td><td>09–11.07.2018</td></tr>
<tr><td>Mean inductance (3-terminal), mH</td><td>10.00442</td></tr>
<tr><td>Expanded uncertainty, mH</td><td>0.00070 (k = 2.0)</td></tr>
<tr><td colspan="2">Measurement frequency, kHz</td><td>1.000003</td></tr>
<tr><td colspan="2">Measure temperature, ºC</td><td>23 ± 1</td></tr>
<tr><td rowspan="3">Measurement result</td><td>Mean measurement date</td><td>09–11.07.2018</td></tr>
<tr><td>Mean inductance (2-terminal), mH</td><td>100.1050</td></tr>
<tr><td>Expanded uncertainty, mH</td><td>0.0120 (k = 2.0)</td></tr>
<tr><td colspan="2">Measurement frequency, kHz</td><td>1.000003</td></tr>
<tr><td colspan="2">Measure temperature, ºC</td><td>23 ± 1</td></tr>
<tr><td rowspan="3">Measurement result</td><td>Mean measurement date</td><td>09–11.07.2018</td></tr>
<tr><td>Mean inductance (3-terminal), mH</td><td>100.0917</td></tr>
<tr><td>Expanded uncertainty, mH</td><td>0.0087 (k = 2.0)</td></tr>
</table>

SASO-NMCC, Saudi Arabia

Measurement frequency, kHz		1.000
Measure temperature, ºC		29.85
Measurement result	Mean measurement date	19–24.10.2018
	Mean inductance (2-terminal), mH	10.00428
	Expanded uncertainty, mH	0.00080 (k = 2.0)
Measurement frequency, kHz		1.000
Measure temperature, ºC		30.05
Measurement result	Mean measurement date	19–24.10.2018
	Mean inductance (2-terminal), mH	100.1018
	Expanded uncertainty, mH	0.0080 (k = 2.0)

UMTS, Ukraine

Measurement frequency, kHz		1.000
Measure temperature, ºC		29.95…29.99
Measurement result	Mean measurement date	11.06–30.10.2018
	Mean inductance (2-terminal), mH	10.00449
	Expanded uncertainty, mH	0.00021 (k = 2.0)
Measurement frequency, kHz		1.000
Measure temperature, ºC		29.95…29.99
Measurement result	Mean measurement date	11.06–30.10.2018
	Mean inductance (3-terminal), mH	10.00434
	Expanded uncertainty, mH	0.00021 (k = 2.0)
Measurement frequency, kHz		1.000
Measure temperature, ºC		29.95…29.99
Measurement result	Mean measurement date	11.06–30.10.2018
	Mean inductance (2-terminal), mH	100.0971
	Expanded uncertainty, mH	0.00207 (k = 2.0)
Measurement frequency, kHz		1.000
Measure temperature, ºC		29.95…29.99
Measurement result	Mean measurement date	11.06–30.10.2018
	Mean inductance (3-terminal), mH	100.0828
	Expanded uncertainty, mH	0.00207 (k = 2.0)

Appendix 2

Reported measurement results for each NMI laboratory

QCC EMI, United Arab Emirates

Uncertainty budget table 10 mH (2-terminal)

Uncertainty description	Uncertainty, mH	Distribution	Divisor	Standard uncertainty, mH	V_{eff}
UUT Repeatability	0.0000434	Normal *k*=1	1.0000	0.0000434	4
Standard uncertainty	0.0005002	Normal *k*=2	2.0000	0.0002501	inf
Standard drift uncertainty	0.0003000	Rectangular	1.7321	0.0001732	inf
Standard temperature coefficient	0.0003000	Rectangular	1.7321	0.0001732	inf
RLC digibridge resolution	0.0000100	Triangular	2.4495	0.0000041	inf
Combined standard uncertainty				0.0003528	17525
Expanded uncertainty (*k* = 2.0)				0.0007100	

Uncertainty budget table 10 mH (3-terminal)

Uncertainty description	Uncertainty, mH	Distribution	Divisor	Standard uncertainty, mH	V_{eff}
UUT Repeatability	0.0000141	Normal *k*=1	1.0000	0.0000141	4
Standard uncertainty	0.0005002	Normal *k*=2	2.0000	0.0002501	inf
Standard drift uncertainty	0.0003000	Rectangular	1.7321	0.0001732	inf
Standard temperature coefficient	0.0003000	Rectangular	1.7321	0.0001732	inf
RLC digibridge resolution	0.0000100	Triangular	2.4495	0.0000041	inf
Combined standard uncertainty				0.0003504	1506997
Expanded uncertainty (*k* = 2.0)				0.000700	

Uncertainty budget table 100 mH (2-terminal)

Uncertainty description	Uncertainty, mH	Distribution	Divisor	Standard uncertainty, mH	V_{eff}
UUT Repeatability	0.003676	Normal *k*=1	1.0000	0.003676	4
Standard uncertainty	0.007004	Normal *k*=2	2.0000	0.003502	inf
Standard drift uncertainty	0.003200	Rectangular	1.7321	0.001848	inf
Standard temperature coefficient	0.003000	Rectangular	1.7321	0.001732	inf
RLC digibridge resolution	0.000010	Triangular	2.4495	0.000004	inf
Combined standard uncertainty				0.005674	22.7
Expanded uncertainty (k = 2.1)				0.012000	

Uncertainty budget table 100 mH (3-terminal)

Uncertainty description	Uncertainty, mH	Distribution	Divisor	Standard uncertainty, mH	V_{eff}
UUT Repeatability	0.000140	Normal *k*=1	1.0000	0.000140	4
Standard uncertainty	0.007004	Normal *k*=2	2.0000	0.003502	inf
Standard drift uncertainty	0.003200	Rectangular	1.7321	0.001848	inf
Standard temperature coefficient	0.003000	Rectangular	1.7321	0.001732	inf
RLC digibridge resolution	0.000010	Triangular	2.4495	0.000004	inf
Combined standard uncertainty				0.004324	3613580
Expanded uncertainty (k = 2.0)				0.008700	

Model equation that follows from the measurement setup:

$$L_{UUT} = L_{STD} + \delta L_{DR} + \delta L_{TC} + \delta L_{RLC},$$

where:

L_{UUT} is the value of the UUT;

L_{STD} is the calibrated value of the standard inductor;

δL_{DR} is the drift of the standard inductor since the last calibration;

δL_{TC} is the change of the standard inductor with temperature;

δL_{RLC} is the difference in indication of the RLC digibridge.

SASO-NMCC, Saudi Arabia

Uncertainty budget table 10 mH (2-terminal)

Quantity	Distribution	Expected value, mH	Expanded uncertainty, µH/H	Sensitivity coefficient	Uncertainty contribution, $(\mu H/H)^2$	Degrees of freedom
L_{Cer}	G	10	50	1	625	∞
δL_{Drf}	R	0	0	1	0	∞
L_{Ref}	G	10				
$\delta L_{Temp\text{-}R}$	R	0	30	1	303	∞
$\delta L_{Res\text{-}R}$	R	0	1	1	0.34	∞
L_X	G	10				
$\delta L_{Temp\text{-}X}$	R	0	3.6	1	4.4	∞
$\delta L_{Res\text{-}X}$	R	0	1	1	0.34	∞
δL_{Stb}	R	0	20	1	135	10
δL_{Subs}	R	0	30	1	303	20
Repeat.	R		6.2	1		39
$L_{X\text{–}Cal}$	10.00428 mH	Combined standard uncertainty, µH/H			u_c	38
		Effective degrees of freedom			ν_{eff}	> 20
		Expanded uncertainty (95%, k = 2), µH/H			U	80

Uncertainty budget table 100 mH (2-terminal)

Quantity	Distribution	Expected value, mH	Expanded uncertainty, µH/H	Sensitivity coefficient	Uncertainty contribution, $(\mu H/H)^2$	Degrees of freedom
L_{Cer}	G	10	50	1	625	∞
δL_{Drf}	R	0	0	1	0	∞
L_{Ref}	G	10				
$\delta L_{Temp\text{-}R}$	R	0	30	1	303	∞
$\delta L_{Res\text{-}R}$	R	0	1	1	0.34	∞
L_X	G	10				
$\delta L_{Temp\text{-}X}$	R	0	3.6	1	4.4	∞
$\delta L_{Res\text{-}X}$	R	0	1	1	0.34	∞
δL_{Stb}	R	0	20	1	135	10
δL_{Subs}	R	0	30	1	303	20
Repeat.	R		5,8	1		35
$L_{X\text{–}Cal}$	100.1018 mH	Combined standard uncertainty, µH/H			u_c	38
		Effective degrees of freedom			ν_{eff}	> 20
		Expanded uncertainty (95%, k = 2), µH/H			U	80

Model equation that follows from the measurement setup:

$$L_{X-Cal} = (L_{Cer} + \delta L_{Drf}) - (L_{Ref} + \delta L_{Temp-R} + \delta L_{Res-R}) + (L_X + \delta L_{Temp-X} + \delta L_{Res-X}) + \delta L_{Stb} + \delta L_{Subs}$$

where:

L_{Cer} – certificate value of reference inductor;

δL_{Drf} – drift of reference inductor;

L_{Ref} – measurement value of reference inductor;

δL_{Temp-R} – temperature coefficient of reference inductor;

δL_{Res-R} – resolution of RLC meter of reference inductor measurement;

L_X – measurements value of DUT;

δL_{Temp-X} – temperature coefficient of the inductor to be calibrated;

δL_{Res-X} – resolution of RLC meter of the measurement of inductor to be calibrated;

δL_{Stb} – short term stability of RLC meter during two measurements;

δL_{Subs} – systematic errors of subsittution method.

UMTS (Ukraine)

Uncertainty budget table 10 mH (2-terminal)

Quantity, X_i	Estimate, x_i, mH	Standard uncertainty, $u(x_i)$, mH	Probability distribution	Method of evaluation (A, B)	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i \cdot u(x_i)$, mH
L_S	100.04438	9.70E-04	normal	B	1.0	9.70E-04
ΔL_{ST}	0	1.10E-06	rectangular	A	1.0	1.10E-06
ΔL_{Sf}	0	8.30E-06	normal	B	1.0	8.30E-06
$\Delta L_{S\gamma}$	-0.01138	3.40E-04	normal	B	1.0	3.40E-04
L_{SR}	100.03300					
		Combined standard uncertainty			u_c	0.00103
		Effective degrees of freedom			ν_{eff}	> 200, k = 2
		Expanded uncertainty ($p \approx 95\%$)			U	0.00206

Quantity, X_i	Estimate, x_i	Standard uncertainty, $u(x_i)$, mH	Probability distribution	Method of evaluation (A, B)	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i \cdot u(x_i)$, mH
L_{SR}	100.0330 mH	1.03E-03	normal	B	0.10001	1.03E-04
K_{tr}	9.99882	2.00E-05	normal	A	-1.00057 mH	-2.00E-05
ΔL_{QC}	0	5.80E-06	rectangular	B	1	5.80E-06
ΔL_{TX}	0	1.10E-06	rectangular	A	1	1.10E-06
ΔL_{SC}	0	1.07E-06	normal	B	1	1.07E-06
ΔL_{SE}	0	7.90E-06	normal	B	1	7.90E-06
L_X	10.00449 mH					
		Combined standard uncertainty			u_c	0.000105
		Effective degrees of freedom			ν_{eff}	> 200, k = 2
		Expanded uncertainty ($p \approx 95\%$)			U	0.000210

Uncertainty budget table 10 mH (3-terminal)

Quantity, X_i	Estimate, x_i, mH	Standard uncertainty, $u(x_i)$, mH	Probability distribution	Method of evaluation (A, B)	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i \cdot u(x_i)$, mH
L_S	100.0246	9.70E-04	normal	B	1.0	9.70E-04
ΔL_{ST}	0	1.10E-06	rectangular	A	1.0	1.10E-06
ΔL_{Sf}	0	8.30E-06	normal	B	1.0	8.30E-06
$\Delta L_{S\gamma}$	-0.00558	3.40E-04	normal	B	1.0	3.40E-04
L_{SR}	100.01900					
		Combined standard uncertainty			u_c	0.00103
		Effective degrees of freedom			ν_{eff}	> 200, k = 2
		Expanded uncertainty ($p \approx 95\%$)			U	0.00206

Quantity, X_i	Estimate, x_i	Standard uncertainty, $u(x_i)$, mH	Probability distribution	Method of evaluation (A, B)	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i \cdot u(x_i)$, mH
L_{SR}	100.0190 mH	1.03E-03	normal	B	0.10002	1.03E-04
K_{tr}	9.99756	2.00E-05	normal	A	-1.00068 mH	-2.00E-05
ΔL_{QC}	0	5.80E-06	rectangular	B	1	5.80E-06
ΔL_{TX}	0	1.10E-06	rectangular	A	1	1.10E-06
ΔL_{SC}	0	1.07E-06	normal	B	1	1.07E-06
ΔL_{SE}	0	7.90E-06	normal	B	1	7.90E-06
L_X	10.00434 mH					
		Combined standard uncertainty			u_c	0.000105
		Effective degrees of freedom			ν_{eff}	> 200, k = 2
		Expanded uncertainty ($p \approx 95\%$)			U	0.000210

Uncertainty budget table 100 mH (2-terminal)

Quan-tity, X_i	Estimate, x_i	Standard uncertainty, $u(x_i)$, mH	Probability distribution	Method of evaluation (A, B)	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i \cdot u(x_i)$, mH
L_{SR}	100.03300 mH	1.03E-03	normal	B	1.0	1.03E-03
K_{tr}	0.99925	1.20E-06	normal	A	-100.18246 mH	-1.20E-04
ΔL_{QC}	0	5.80E-06	rectangular	B	1.0	5.80E-06
ΔL_{TX}	0	1.10E-06	rectangular	A	1.0	1.10E-06
ΔL_{SC}	0	1.07E-06	normal	B	1.0	1.07E-06
ΔL_{CE}	0	7.90E-06	normal	B	1.0	7.90E-06
L_X	100.10770 mH					
		Combined standard uncertainty			u_c	0.00103
		Effective degrees of freedom			ν_{eff}	> 200, k = 2
		Expanded uncertainty ($p \approx 95\%$)			U	0.00207

Uncertainty budget table 100 mH (3-terminal)

Quan-tity, X_i	Estimate, x_i	Standard uncertainty, $u(x_i)$, mH	Probability distribution	Method of evaluation (A, B)	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i \cdot u(x_i)$, mH
L_{SR}	100.01900 mH	1.03E-03	normal	B	1	1.03E-03
K_{tr}	0.99936	1.20E-06	normal	A	-100.14665 mH	-1.20E-04
ΔL_{QC}	0	5.80E-06	rectangular	B	1	5.80E-06
ΔL_{TX}	0	1.10E-06	rectangular	A	1	1.10E-06
ΔL_{SC}	0	1.07E-06	normal	B	1	1.07E-06
ΔL_{CE}	0	7.90E-06	normal	B	1	7.90E-06
L_X	100.08280 mH					
		Combined standard uncertainty			u_c	0.00103
		Effective degrees of freedom			ν_{eff}	> 200, k = 2
		Expanded uncertainty ($p \approx 95\%$)			U	0.00207

Model equation that follows from the measurement setup:

$$L_X = \frac{L_{SR}}{K_{tr}} + \Delta L_{QC} + \Delta L_{TX} + \Delta L_{SC} + \Delta L_{CE},$$

where:

L_{SR} – real value of reference inductance by nominal 100 mH;

K_{tr} – transfer coefficient of the comparator when calibrating of inductance L_X based on reference inductance L_{SR};

ΔL_{QC} is deviation due to the quantization error of the comparator;

ΔL_{TX} is correction for the temperature drift of the calibrating inductance;

ΔL_{SC} is correction for the comparator's sensitivity;

ΔL_{CE} is comparation error.

Real value of reference inductance L_{SR} is derived from the expression:

$$L_{SR} = L_S + \Delta L_{ST} + \Delta L_{Sf} + \Delta L_{S\gamma},$$

where:

L_S is value of reference inductance by nominal 100 mH from calibration certificate;

ΔL_{ST} is correction for the temperature drift of the reference inductance;

ΔL_{Sf} is correction for the frequency drift of the reference inductance;

$\Delta L_{S\gamma}$ is correction for the drift of reference inductance since the last calibration.

Appendix 3
Technical Protocol of Comparison

State Enterprise "All-Ukrainian state research and production center of standardization, metrology, certification consumers' right protection" (SE "Ukrmeterteststandard")

Technical Protocol on Supplementary Comparison of Inductance at 10 mH and 100 mH at 1 kHz (GULFMET.EM-S4)

Oleh Velychko, Sergii Shevkun

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Coordinator of comparison:

_________________ Oleh Velychko

May 2018
Kyiv, Ukraine

Table of Content

1 Introduction

The GULFMET Supplementary Comparison (SC) of Inductance at 10 mH and 100 mH at 1 kHz (comparison identifier – GULFMET.EM-S4) will be in the framework of GULFMET project from June to September, 2018.

This project for comparing of national standards of inductance will be between counties which are member laboratories of regional metrology organizations GULFMET, COOMET, and AFRIMET. In this comparison take part four national metrology institutes (NMI): SE "Ukrmetrteststandard" (UMTS, Ukraine); QCC EMI (United Arab Emirates); SASO-NMCC (Saudi Arabia), NMIS (South Africa).

The State Enterprise "All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer" (SE "Ukrmetrteststandard"), Ukraine was selected as the pilot laboratory. Dr. Oleh Velychko will be the comparison coordinators. The pilot laboratory is responsible for providing the travelling standard, coordinating the schedule, collecting and analyzing the comparison data, preparing the draft report, etc.

2 Participants and time schedule of the comparison

Each participant is given 2 weeks to perform the measurements of inductive standards and 1 week to transfer standards to the pilot laboratory. The NMI participants and the time schedule of the comparison are given in Table 1 and Table 2. There are 4 NMI participants in this comparison. Participants should have the traveling standard delivered to the address of the participant scheduled to perform measurements after themselves according to the schedule.

Table 1 List of NMI participants of the comparison

№	NMI	Abbreviation of NMI	Address	Contact person	e-mail, phone, fax
1	State Enterprise "All-Ukrainian state research and production center of standardization, metrology, certification consumers' right protecttion" (SE "Ukrmetrteststandard") – **pilot**	**UMTS**	4, Metrologichna Str., 03143, Kyiv, Ukraine	Oleh Velychko	velychko@ukrcsm.kiev.ua Tel./Fax: +38 044 526 0335
2	Abu Dhabi Quality and Conformity Council, Emirates Metrology Institute	**QCC EMI**	CERT Sultan Bin Zayed the First Street, Abu Dhabi, United Arab Emirates	Jon Bartholomew	Jon.Bartholomew@qcc.abudhabi.ae Tel: +971 503862676 Fax: +971 24066677
3	Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi – National Measurements and Calibration Center	**SASO-NMCC**	Front king Saud University Riyadh 11471, P.O. Box 3437 Kingdom of Saudi Arabia	Abdullah M. Alrobaish	a.robaish@saso.gov.sa Tel: +966 11 2529730

№	NMI	Abbreviation of NMI	Address	Contact person	e-mail, phone, fax
4	National Metrology Institute of South Africa	**NMISA**	Buiding 5, CSIR Campus Meiring Naudé Road Brummeria Pretoria, South Africa	Michael Khoza	mkhoza@nmisa.org Tel: +27 12 841 2408 Fax: +27 12 841 4458

Table 2 List of dates of measurements

Abbreviation of NMI	Dates of measurements	Dates of delivery
UMTS	01–15.06.2018	18.06.2018
QCC EMI	25.06–06.07.2018	09.07.2018
UMTS	16-20.07.2018	23.07.2018
SASO-NMCC	30.07–10.08.2018	13.08.2018
UMTS	20–24.08.2018	27.08.2018
NMISA	03–14.09.2018	17.09.2018
UMTS	24–28.09.2018	–

3. Financial aspects and insurance

Each NMI participant of comparison should be at their own expense to perform all the measurements and send travelling standards back to the pilot laboratory (including transportation costs, insurance costs and customs).

In addition, each NMI participant of comparison should be at their own expense to cover all costs from the moment of arrival travelling standard in the country, up to the moment of sending back to the pilot laboratory.

Expenses may include (but are not limited to): charges at check travelling standards (customs fees, brokerage services, transportation within the country) and the costs of returning the standards to the pilot laboratory.

4. Travelling standards and measurement instruction

4.1. Description of the travelling standards

The selected travelling standards are “Inductance measure reference thermostatically 10 mH” (“*Міра індуктивності еталонна термостатована 10 мГн*”) type P5109 (No. 424) and “Inductance measure reference thermostatically 100 mH” (“*Міра індуктивності еталонна термостатована 100 мГн*”) type P5113 (No. 1003) (Figure 1).

Thermostatic inductance measures type P5109 (10 mH, No. 424) and P5113 (100 mH, No. 1003) allow the monitoring of critical parameters: the temperature difference of values within each standard thermostats and internal supply voltage. Thermostatic inductance measures type P5109 and type P5113 contain inbuilt precision thermostat with dual temperature sensors, which provides increased reliability and accuracy of the measurement results.

Figure 1 Travelling standards

Main characteristics of inductance measures:

instability: 10 ppm/year;

the temperature inside the thermostat: from 29.5 °C to 30.5 °C;

temperature instability: 0.05 °C/hour;

time to thermostat operating mode: not more than 3 hours;

weight measures in thermostat: 9 kg;

supply voltage thermostat: 15 V DC;

power consumption: no more than 3.5 W;

temperature coefficient: 37 ppm/°C;

linear dimensions of each enclosure measures (mm): height – 275, length – 380; width – 360.

Transportation of inductance standards is simplified, since for high stability is not necessary to continuously monitor the temperature of the thermostat. Measures are in a sealed oven.

4.2 Handling of travelling standards

Travelling standards will be transported in the transport box which is designed for safe transportation. Upon arrival the participants must check the transport box to make sure that all the parts are present according to the list. After the travelling standards of inductance will be neatly stacked in a transport box in which they arrived (Figure 2).

Linear dimensions of transport box are: 400x600x400 mm. Weight of transport box (together with the content) is about 20 kg. If the damage of transport box is found travelling standards must be packed in new transport box which will provide the necessary protection during transporting.

Casing of travelling standards must be carefully removed from the transport box. Opening the corpus of travelling standards is strictly prohibited. If noticed any malfunction of travelling standards, the NMI participants should immediately notify the pilot laboratory by fax or email. If travelling standards are needed to be repaired the NMI participant must send travelling standards to the pilot laboratory.

NMI participants must inform the pilot laboratory by fax or e-mail about the arrival of travelling standards by using the form shown on Figure 3.

Figure 2 Container for travelling standards

Confirmation note for receipt		
Date of arrival		
NMI		
Name of responsible person		
The travel standard	□ Damaged	□ Not Damaged
Additional notes:		

Figure 3 Sample form for the information of arrival of travelling standards

The NMI participants should inform the pilot laboratory about departure of travelling standards by using the form shown on Figure 4.

Confirmation note for dispatch	
Date of shipment	
NMI	
Name of responsible person	
Shipment information (company name etc.)	
Additional notes:	

Figure 4 Sample form for the information of departure of travelling standards

After the measurements, each NMI participant of comparison must send the travelling standards to the pilot laboratory. NMI participants in the comparison are responsible for arranging shipment of travelling standards to the pilot laboratory.

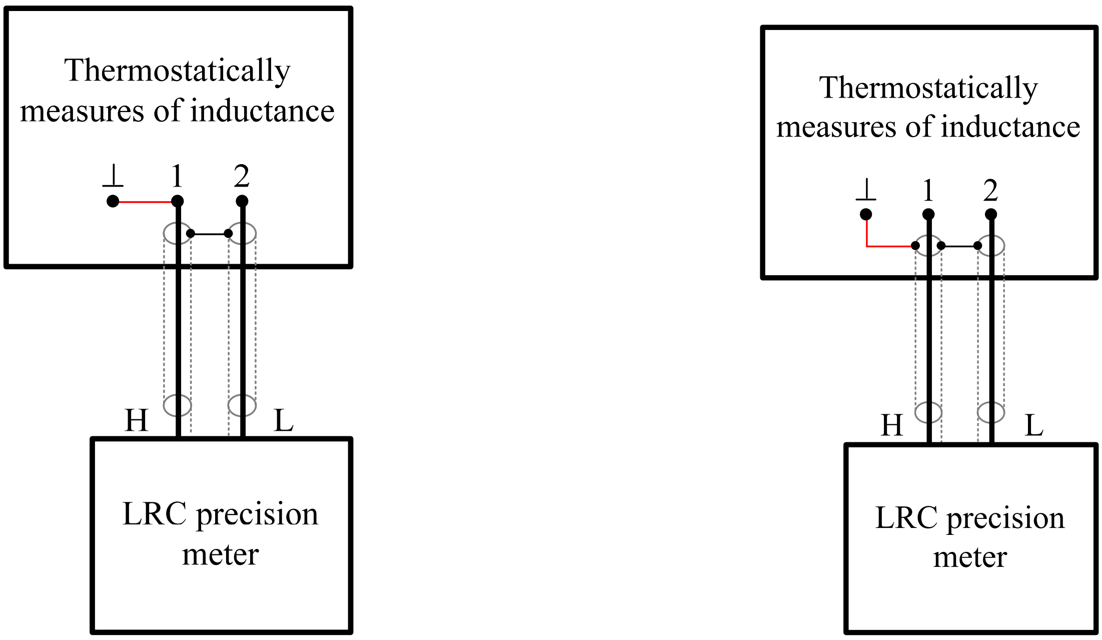
5. Description of the method of measurement

5.1 Operations before measurements

After power up of travelling standards in NMI participant it will be stabilizing for three days.

To connect travelling standards NMI participants can use any adapters but participants should take into account all relevant adjustments in order to determine the inductance value directly from the input jack inductance measures.

Before the measurements, it is necessary to familiarize design features and work principles of travelling standards by using technical description. Connection travelling standards in accordance connection schemes for 2- and 3-terminal are shown on Figure 5.



a b

Figure 5 Connection scheme: a) for 2-terminal; b) for 3-terminal

5.2 Measurements

Measurements were performed under the following conditions:

temperature: 23 °C ± 1 °C;

relative humidity: from 30 % to 70 %;

measurement frequency: 1 kHz (depending on laboratory’s capability);

full power (active and reactive) on the measurement object should not exceed 10 mW.

The participants should inform the pilot laboratory if the above conditions cannot be met.

The temperature coefficient does not exceed 37 ppm/°C, and that’s why doing not be compensated for temperature changes in the laboratory. If the air temperature of measurements in the NMI laboratory is significantly different from 23 °C, the influence of the ambient temperature can be accounted for in the uncertainty budget.

The data to be recorded at each measurement:

date of measurement;

frequency measuring signal;

measured inductance;

air temperature and relative humidity in the immediate vicinity of the casing and measures the measuring apparatus;

measures body temperature and the temperature difference inside the thermostat.

If measurements are carried out within a few days, then measured inductance value together with the measurement date shall be given for each measurement day.

5.3 Measurement uncertainties

Uncertainty of the measurements should be calculated according to the GUM – Guide to the expression of uncertainty in measurement JCGM 100:2008 [1] (GUM 1995 with minor corrections). With the results of measurements should be given a model that describes how the measurement result was obtained considering all influencing quantities.

For each of the influencing quantities should be given the description of the source of uncertainty and an assessment of this uncertainty. All influencing quantities, their uncertainties, influencing coefficients, degrees of freedom and levels of confidence should be given in the budget of the uncertainty.

The budget of the uncertainty (Table 3) should include such number of influencing quantities and their uncertainties, which ensures the highest level measurements of inductance for each of the laboratories.

Table 3 Uncertainty budget L = ____ mH, f = 1 kHz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1							
…							
y	Std uncertainty of measurement						
		Confidential level =		%		k =	
		Expanded uncertainty =					

The components of the uncertainty budget should be expressed as standard uncertainties. The main components of the uncertainty budget are:

standard uncertainty obtained as a result of an experiment from N independent measurements;

uncertainty of the standard of the NMI laboratory, by means of which the inductance of the travelling standard is determined;

uncertainty caused by the corrections.

Participants in the comparisons may include additional sources of uncertainty.

It is expected that among the NMI laboratories participating in the comparison, the uncertainty values of the measurement results will be very different (in accordance with local requirements). This should not be an interfering factor for participation in comparison.

6. The measurement report

6.1 General information

Each NMI participant of the comparisons shall provide a report within six weeks from the date of departure travelling standards to the pilot laboratory. For quick detection of possible problems with the travelling standards a brief report shall be sent immediately after the measurements.

The report shall be sent to the coordinator of comparison by e-mail: velychko@ukrcsm.kiev.ua

The report shall include:

description of measurement method(s);

description of the measurement circuit and used the standard possibilities of electricity;

confirmation of the metrological traceability (if NMI participant has its own inductance units playback system, or must provide proof of traceability from another laboratory).

temperature and humidity in the laboratory during the measurement;

measurement results: certain amendments travelling standards values for frequencies 1 kHz;

values of the respective standard uncertainties, the effective values of the degrees of freedom and expanded uncertainty;

detailed budget of uncertainty, which will be included in a report on the comparisons.

If the corrections (for example: correction of a measuring bridge or connecting wires) affecting the measurement result were applied, then they must be described in the report.

If between the measurements of any NMI participant, provided the pilot laboratory and preliminary comparisons reference value is detected a significant difference, it will be reported to the appropriate party. No other information on the measurement results will not be reported.

If any NMI laboratory has difficulties in fulfilling one or more of the requirements listed in this protocol, instead of not taking part in the comparison, this NMI laboratory is recommended to contact the coordinator of the comparisons and find a way out of this situation.

6.2 Measurement results

GULFMET.EM-S4 comparison.

Measurements of inductance at 10 mH and 100 mH at frequency 1 kHz.

Name of NMI participant: ____________________________________

Country: ____

Dates of measurements: from _________ to _________.

Results of measurements, mH	Expanded uncertainty, mH
10 mH (2-terminal)	
10 mH (3-terminal)	
100 mH (2-terminal)	
100 mH (3-terminal)	

Addition parameter:

Parameter	Value	Expanded uncertainty
Frequency, kHz		
Temperature, °C		
Relative humidity, %		
Measure temperature, °C		

7. The report on comparison

Preliminary and final reports on the results of comparison will be prepared by the pilot laboratory. The report will be prepared by the pilot laboratory within 4 months after the end of the measurement, and sent to the NMI participants. The report is only for the NMI participants of comparisons and is confidential.

Notes. The report should be directed to the pilot laboratory for 2 months from the date of distribution of the Draft A. Comments will be considered in the Draft B. Draft B will be completed within 6 months after the end of the measurement. The final report will be prepared within 1 month from the receipt of the comments on the Draft B.

References

[1] JCGM 100:2008 Evaluation of measurement data – Guide to the expression of uncertainty in measurement.