Comparison Technical Protocol

Comparison of Four-terminal-pair 1pF, 10 pF, 100 pF and 1000 pF Capacitance Standards at Frequencies of 10 kHz, 100 kHz, 1 MHz and 10 MHz

(updated on 31 May 2018)

1. Introduction

The Mutual Recognition Arrangement (CIPM-MRA) among National Metrology Institutes (NMIs) places particular importance on comparisons to demonstrate an NMI's ability to measure certain quantities. Among the electromagnetic quantities, the CCEM (Consultative Committee for Electricity and Magnetism) has identified capacitance, at a value of 10 pF, as one of those key quantities. As such it is regularly compared within the framework of the CCEM-K4 key comparison [1-4].

The APMP-K4.1 key comparison was carried out and focused on 1592 Hz [4]. In order to calibrate an LCR meter, metrological traceability of capacitance above 10 kHz becomes more and more important. For this reason, NIM (National Institute of Metrology, China) and NPLI (National Physical Laboratory, India) have carried out research on capacitance metrology from 10 kHz to 10 MHz [5, 6], and NIM has recognized calibration capabilities (CMCs) in this area.

According to NPLI's proposal, NPLI and NIM are interested in participating in an APMP bilateral comparison of capacitance from 10 kHz to 10 MHz. The aim of comparison is to provide participating laboratories with the opportunity to compare capacitance in the extended frequency range, and to gain experience and knowledge in this field.

NIMT (National Institute of Metrology, Thailand) joins the comparison in April, 2018.

2. Travelling standards

The travelling standards are a set of the four-terminal-pair standard air capacitors, which are provided by NIM, China.

Details of the Traveling Standards

Name of Instrument: Standard air capacitor

Manufacturer **:** Agilent Technologies

Model **:** 16380A

Serial number **:** 1840J01774

Nominal value **:** 1 pF, 10 pF, 100 pF and 1000 pF

Fig. 1. Front panel of the traveling standard 16380A.

3. Organization

3.1 Contact person

Contact person

Name **:** Dai Dongxue

Organization **:** NIM (National Institute of Metrology, China)

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3.2 Participants

Participants in the comparison are listed in Table 1.

Table 1. Participants of the comparison.

Laboratory address	Contact name, e-mail, tel & fax number
National Physical Laboratory, India (NPLI) LF, HF Impedance and DC Metrology Room No 114, First Floor, Apex Metrology Laboratory New Delhi 110012	Mr. Satish Phone: +91 11 4560 8510, +91 11 4709 1176, +918860564477 (Mobile) Fax: +91 1145609310 E-mail: singhsp3@nplindia.org satish.rfic@gmail.com
National Institute of Metrology, China (NIM) Division of Electricity and Magnetism Room 203, Building 2, No.18, Bei San Huang Dong Lu, Chaoyang District, Beijing, P.R.China, 100029	Dr. Dai Dongxue Phone: +86 10 6452 4508 Fax: +86 10 64218629 Email: daidongxue@nim.ac.cn daidongxue@163.com
National Institute of Metrology, Thailand (NIMT) Electrical Metrology Department 3/4-5 Moo 3, Tambol Klonghar, Amphur Klong Luang, Pathum Thani 12120 Thailand	Dr.-Ing. Monthol Homklintian Phone: + 66(2)577 5100 Fax: + 66(2)577 5093 Email: monthol@nimt.or.th monthol_ton@hotmail.com

3.3 Time Schedule

The travelling standards will be compared among NIM, NPLI and NIMT. The time schedule is listed in Table 2.

Table 2. Time schedule of comparison.

	Beginning date	End date	Duration
Measurement by NIM	1 September 2017	28 September 2017	4 weeks
Transport	29 September 2017	9 November 2017	6 weeks
Standards stabilization	10 November	23 November 2017	2 weeks
Measurement by NPLI	24 November 2017	21 December 2017	4 weeks
Transport	22 December 2017	1 February 2018	6 weeks
Standards stabilization	2 February 2018	15 February 2018	2 weeks
Measurement by NIM	16 February 2018	15 March 2018	4 weeks
Transport	1 June 2018	9 August 2018	10 weeks
Standards stabilization	10 August 2018	23 August 2018	2 weeks
Measurement by NIMT	24 August 2018	20 September 2018	4 weeks
Transport	21 September 2018	29 November 2018	10 weeks
Standards stabilization	30 November 2018	13 December 2018	2 weeks
Measurement by NIM	14 December 2018	10 January 2019	4 weeks
Measurement report	11 January 2019	21 February 2019	6 weeks
Comparison report	22 February 2019	18 April 2019	8 weeks

3.4 Transportation

Each participant will be responsible for both arranging and the cost of transport (including, where necessary, customs clearance) and insurance of the devices from arrival in their laboratory until arrival in the subsequent laboratory.

Participants shall inform each other by e-mail or fax when the traveling standard has arrived by filling the following form given in Fig. 2.

Fig. 2. Sample form for the information of arrival of the traveling standard.

Confirmation Note for Receipt		
Date of Arrival		
NMI		
Name of Responsible Person		
Traveling Standard	☐ Damaged	☐ Not Damaged
Invoice	☐ Received	☐ Not Received
Additional Notes:		

Participants shall also inform the next recipient by e-mail or fax about the shipment of the traveling standard by filling the following form given in Fig. 3.

Fig. 3. Sample form for the information of dispatch of the traveling standard.

Confirmation Note for Dispatch	
Date of Shipment	
NMI	
Name of Responsible Person	
Shipment Information (company name etc.)	

Traveling Standard	☐ Damaged	☐ Not Damaged
Invoice	☐ Enclosed	☐ Not Enclosed
Additional Notes:		

3.5 Unpacking, Handling, Packing

The traveling standard will be circulated in a transportation case, which is well furnished for the safety of the traveling standard. Participants shall check the package, when they receive it, to verify that everything in the parts list is present. Any discrepancies should be reported by e-mail or fax. Participants shall take care when packing the traveling standard to ensure that all parts are enclosed.

3.6 Failure of Traveling Standard

In the event of failure of the standards, the laboratories should be informed. The laboratories will consider whether to continue the comparison with the remaining capacitor, substitute an alternative standard or abandon the comparison.

3.7 Financial Aspects, Insurance

Participants will be responsible for the costs of shipment to the next recipient (transportation and customs formalities).

4. Measurement of capacitors

4.1 Frequency and environmental conditions

The required measurement frequency and environmental conditions are listed in Table 3.

Table 3. Frequency and environmental conditions

Nominal value	Frequency points	Ambient temperature	Relative humidity
1 pF	10 kHz, 100 kHz, 1 MHz and 10 MHz	(23 ± 1)°C	(50 ± 10)%
10 pF			
100 pF			
1000 pF			

4.2 Quantities to be measured

The capacitance and capacitance increment (shown in Formula 1) of the standards are both to be measured. The frequency characteristic of a four-terminal-pair standard capacitor is given by the capacitance increment or deviation from the 1 kHz value. The stability of Model 16380A standard air capacitors at 1 kHz is up to 20 μF/F or worse, but capacitance increment is almost constant. For reasons above, the comparison of capacitance increment is more appropriate from 10 kHz to 10 MHz. The relative capacitance increment can be expressed in the following formula:

$$\frac{\Delta C}{C_{1\mathrm{kHz}}} = \frac{C_{\mathrm{X}} - C_{1\mathrm{kHz}}}{C_{1\mathrm{kHz}}} \tag{1}$$

where, $C_{1\mathrm{kHz}}$ is the capacitance value at 1 kHz, ΔC is the capacitance increment from 1 kHz, and C_{X} is the capacitance value at frequencies of 10 kHz, 100 kHz, 1 MHz and 10 MHz.

4.3 Recorded quantities

For each measurement, the following quantities should be recorded:

- Measurement date.
- Ambient temperature and relative humidity.

- Measurement frequency.

- Measured capacitance.

- Relative capacitance increment from 1 kHz.

5. Measurement report

This report must contain:

- A short description of the measurement method.

- The measurement results.

- An uncertainty budget stating the different sources of uncertainty.

The uncertainty must be calculated following the GUM [7], including standard uncertainties, correlations, and the scheme for the evaluation of uncertainty.

6. Report of the Comparison

The Draft A Report will be prepared after the completion of the measurements and circulated to the participants. Following this, the Draft B Report will be prepared.

References

[1] CCEM-K4.2017 comparison protocol
http://kcdb.bipm.org/appendixB/KCDB_ApB_info.asp?cmp_idy=1597&cmp_cod=CCEM-K4.2017&prov=exalead

[2] Final report: CCEM Comparison of 10 pF Capacitance Standards, A.M. Jeffery, March 2002,
http://kcdb.bipm.org/appendixB/KCDB_ApB_info.asp?cmp_idy=42&cmp_cod=CCEM-K4&prov=exalead

[3] Final Report SIM.EM-K4
http://kcdb.bipm.org/AppendixB/KCDB_ApB_info.asp?cmp_idy=620&cmp_cod=SIM.EM-K4&page=

[4] Final Report APMP.EM-K4.1
http://kcdb.bipm.org/appendixB/KCDB_ApB_info.asp?cmp_idy=607&cmp_cod=APMP.EM-K4.1&prov=exalead

[5] X. Wang, Y. Ruan, D. Dai. Q. Wang, Calibration theory and measurement method of four-terminal-pair standard capacitor frequency characteristic CPEM 2004 Conf. Dig., 2004, pp. 376–377.

[6] Satish, Babita, Bharat Khurana, Sachin Kumar, A.K.Sxaena. Evaluation of four-terminal-pair capacitance standards using electrical equivalent circuit model. Measurement. 2015, pp. 121–126.

[7] Guide to the Expression of Uncertainty in Measurement, JCGM 100:2008,
http://www.bipm.org/fr/publications/guides/gum.html