

**Bilateral Comparison of 10 pF Capacitance Standards**  
**(ongoing BIPM key comparison BIPM.EM-K14.a)**  
**between the CMI, Czech Republic and the BIPM, January-July 2009**

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### **Introduction**

This bilateral comparison between the CMI (Czech Republic) and the BIPM was carried out from January to July 2009. One 10 pF travelling standard belonging to the CMI was used. The comparison was carried out with an 'A-B-A' pattern of measurements; the standard was measured first at the CMI for a period of about one month, then for a similar period at the BIPM, and finally again at the CMI. The measurand was the two terminal-pair capacitance at a frequency of 1000 Hz and for a measuring voltage of 15 V. The BIPM was the pilot laboratory, and the comparison forms part of the ongoing BIPM key comparison BIPM.EM-K14.a.

### **Travelling standard**

The travelling standard was an Andeen-Hagerling model AH11A capacitance module having a nominal value of 10 pF, serial number 01181. The module was hand carried between the two laboratories without an AH1100 frame. During the measurements at the CMI, it was mounted in a custom made enclosure (which provides the same power supply and monitoring connections as an AH1100 frame); at the BIPM, the module was mounted in an AH1100 frame belonging to the BIPM (serial number 00104).

Previous studies and experience at the BIPM show that AH11A capacitance modules can be moved between different AH1100 frames and reproduce the same capacitance value (after temperature stabilisation) to within at worst a few parts in  $10^8$  (relative value change). The effect of ambient temperature on standards mounted in an AH1100 frame has also been tested between 20 °C to 25 °C, and no change in the capacitance values greater than 1 part in  $10^8$  was detected over this range. Both laboratories measured the travelling standard at an ambient temperature of  $23.0 \pm 0.5$  °C. In these conditions, the temperature corrections are negligible. The effects of normal variations in atmospheric pressure and humidity are also negligible. No corrections have therefore been applied for changes in ambient conditions or the change in mounting environment between the two laboratories. The 'drift' and temperature indications of the AH1100 frame (or equivalent) were recorded for completeness during all measurement periods, but these are not reported here. A conservative relative standard uncertainty component of  $0.058 \times 10^{-6}$  (estimated by a rectangular probability distribution covering the range  $\pm 0.1$  ppm) has been included in the uncertainty of the transfer to cover any differences of the mounting environment in the two laboratories.

## **Measurement principle**

### *CMI capacitance standard and measurement method*

Czech Metrology Institute (CMI) use following standards to maintain the value of capacitance and to provide high precision measurements:

- Set of four fused silica capacitors AH11 of nominal value 100 pF (s. n. 1323, 1324, 1325 and 1326), accommodated in frame AH1100, s. n. 00055.
- One AH11 of nominal value 10 pF (s. n. 1181), accommodated in a transport box (the power supply circuits are identical with original frame AH1100).

The reference standard (AH11, 100 pF, s.n. 1323) was calibrated by BIPM in years 2002, 2003, 2005, and the last calibration was provided 17. 4. 2007.

Standards are periodically compared by means of 1 kHz ultra-precision capacitance bridge AH2500A, option E, s. n. 000549. The period of measurements is approximately 30 days. The measuring voltage was set to 15 V. The frequency was set to 1 kHz. First, the predicted value of reference standard and value measured by AH2500A were compared. Next, the value of the unknown standard was measured by AH2500A and actual value calculated. These measurements were repeated as mentioned above.

### *BIPM capacitance standard and measurement method*

The BIPM maintains a reference group of four fused silica 10 pF capacitors (one of the NBS type and three of the GR 1408-A type). Since 1999, the mean value of the group has been measured twice a year using a measurement chain linking the 10 pF capacitances to the recommended value of the von Klitzing constant,  $R_{K-90} = 25\,812.807\ \Omega$ . The chain includes a capacitance bridge with ratio 10/1, a multi-frequency quadrature bridge, an ac-dc coaxial resistor with calculable frequency dependence of resistance, and a quantum Hall device operated at 1 Hz. The relative drift rate of the mean value of the reference group is about  $-3.5$  parts in  $10^8$  per year.

The travelling standard was measured in terms of the BIPM 10 pF reference group by substitution on a coaxial bridge for two terminal-pairs capacitances with 10/1 ratio. The measurements were made using the standard BIPM conditions: nominal frequency of 1592 Hz and nominal voltage of 100 V. The frequency and voltage coefficients of the travelling standard were separately measured against the known properties of a 100 pF reference.

## **Results**

Table 1 gives the values assigned to the capacitance of standard 01181 on 29/03/2009 by BIPM and CMI, along with the resulting relative difference,  $\Delta$ , and the corresponding uncertainties. All the uncertainties are given as relative standard uncertainties ( $1\sigma$  estimates). 29/03/2009 is the mean date of the BIPM measurements. The uncertainty on  $\Delta$  is the combination of the CMI and BIPM uncertainties with the uncertainty of the transfer. Details of all three uncertainty budgets are in the annex.

The BIPM value is calculated as the simple mean of 6 measurements over the period 17/03/2009 to 14/04/2009. A linear fit has been made to the CMI ‘before’ and ‘after’ measurements, and the CMI value is the value predicted by this fit for the date 29/03/2009.

**Table 1:** Final values for standard 01181

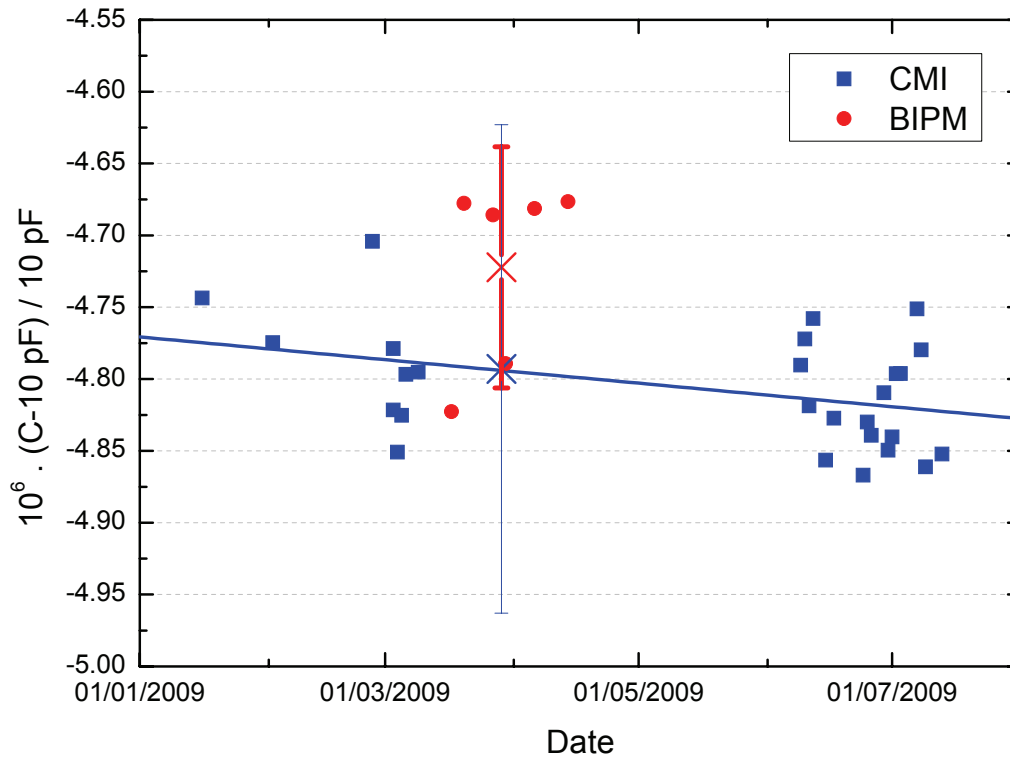
	CMI	BIPM
$C_{01181}$ on 29/03/2009	9.999 952 1 pF	9.999 952 8 pF
Relative total uncertainty ( $1\sigma$ est)	$0.18 \times 10^{-6}$	$0.083 \times 10^{-6}$
Transfer uncertainty (relative)	0.058	
$\Delta = (C_{CMI} - C_{BIPM}) / C_{BIPM}$	$-0.07 \times 10^{-6}$	
Combined uncertainty on $\Delta$ ( $1\sigma$ est)	$0.21 \times 10^{-6}$	

Figure 1 shows all the individual measurements of both the BIPM and the CMI. The mean value of the BIPM measurements is shown, along with its uncertainty bar ( $1\sigma$ ). The linear fit to the CMI before and after measurements is also shown, along with the  $1\sigma$  uncertainty bar for the predicted value at the time of the BIPM measurements.

The result can be summarised in the form of a degree of equivalence,  $D_{CMI}$ , between CMI and BIPM for measurements of 10 pF standards at 1 kHz and 15 V, with its associated expanded uncertainty,  $U_{CMI}$  ( $k=2$ , 95% confidence):

$$D_{CMI} = (C_{CMI} - C_{BIPM}) / 10 \text{ pF} = -0.07 \times 10^{-6}$$

$$U_{CMI} = 0.42 \times 10^{-6}$$



**Figure 1:** all results for standard 01181, showing CMI measurements and linear fit, plus BIPM measurements with mean and  $1\sigma$  uncertainty bars.

## Comments

The CMI takes its capacitance traceability from the BIPM, via regular calibrations of a 100 pF standard (another AH11a type, serial number 01323). The purpose and interpretation of this bilateral comparison may therefore not be clear. It is true that there is no independent realisation of the farad at the CMI which is being tested. What is being tested however is the ability of the CMI to use the periodic calibrations at the BIPM to provide a continuous calibration service to clients. The last calibration provided by the BIPM was in April 2007, so this comparison is a good test of the ability of the CMI to extrapolate the value of the reference, and of the uncertainty budgets that cover this and the use of the equipment required for capacitance scaling.

During the same period as the BIPM measurements for this comparison, a regular calibration of the standard 01323 was carried out; obviously, the results of this calibration were not released to the CMI until after the completion of the present comparison report. The travelling standard here, 01181, has also been previously measured at the BIPM on two occasions (in 2005 and 2007), but any extrapolation of its behaviour based on only two points was not considered reliable enough to compromise the blind nature of the comparison. (The usual procedure of using travelling standards belonging to the BIPM was not used in this case, as the standards were not available at a time that coincided with the possibility for hand transport between the CMI and the BIPM).

The 'before' and 'after' measurements at CMI demonstrate an excellent behaviour of the transport standard during this comparison (no doubt due to it being transported by hand between the two laboratories). During the measurement period at BIPM, the stability was not as good as would be expected from this type of standard ideally, but this has not been a limiting factor in the comparison.

The different measurement frequencies and voltages in the two laboratories are significant, but the frequency and voltage coefficients of the travelling standard were measured at the BIPM, so the required corrections could be applied with confidence. A conservative uncertainty component has also been included to account for the different mounting environment of the capacitance module at CMI and BIPM, but again this has not been a limiting factor in the overall uncertainty.

An identical comparison of 100 pF standards was carried out at the same time as this comparison; the corresponding report is being published simultaneously, and shows very similar results to those presented here.

## Annex: Uncertainty budgets

### *BIPM Uncertainty Budget*

<b>Component</b>	<b>Relative uncertainty/10<sup>-9</sup></b>
Values at 1 Hz of 51.6 kΩ resistors used in quadrature bridge, with respect to $R_{K-90}$	14
1 Hz – 1541 Hz difference of 51.6 kΩ resistors	22
Operation of quadrature bridge at 1541 Hz	13
Scaling from 2000 pF capacitors of quadrature bridge to 10 pF reference	15
Extrapolation of the value of the 10 pF reference group	14
Link between unknown and 10 pF reference group	15
Uncertainty on voltage correction (change from 100 V to 15 V)	20
Uncertainty on frequency correction (change from 1592 Hz to 1000 Hz)	26
Stability of standard at BIPM	66
<b>Total</b>	<b>83</b>

All values are standard uncertainties ( $1\sigma$  estimates).

### *CMI Uncertainty Budget*

<b>Source of Uncertainty</b>	<b>Contribution to combined relative standard uncertainty in parts in 10<sup>6</sup></b>	<b>Degrees of Freedom</b>
Prediction of reference standard	0.062	14
Repeatability	0.009	8
Noise and Ripples of reference standard	0.050	861
Noise and Ripples of unknown	0.058	869
Temperature stability of reference standard	0.005	50
Temperature stability of unknown	0.005	50
Temp. stability of bridge at value 100 pF	0.001	50
Temp. stability of bridge at value 10 pF	0.001	50
Linearity of AH bridge	0.150	10
<b>Combined relative standard uncertainty</b>	<b>0.180</b>	<b>14</b>

### *Uncertainty of the Transfer*

<b>Component</b>	<b>Relative uncertainty /10<sup>-8</sup></b>
Uncertainty due to mounting and ambient conditions	58
Possible step change of standard during transport	negligible
<b>Total</b>	<b>58</b>

All values are standard uncertainties ( $1\sigma$  estimates).