REPORT ON THE CCEM COMPARISON OF 10 pF CAPACITANCE STANDARDS

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Abstract

This paper describes the recent Comité Consultatif d'Électricité et Magnétisme (CCEM) comparison of 10 pF capacitors. This comparison of electrical standards between the regional metrology organization (RMOs) will establish the relationship of the capacitance unit, the farad, for national metrology institutes (NMIs) from several metrology regions.

Introduction

This key comparison of 10 pF capacitors began in 1996 and lasted 3 years with the National Institute of Standards and Technology (NIST) acting as the pilot laboratory. So that the comparison could be completed in a reasonable time, only a few laboratories were selected from each metrology region. Each region will then perform their own comparison to establish links with a much larger number of NMIs. The key comparisons are expected to test the principal techniques in each field of metrology and check the uncertainties of independent primary realizations of the units of the SI. With this in mind, preference was given to laboratories with an independent estimate of the farad. Participants are listed in Table 1.

Table 1. Participant list.

Laboratory	Country	Region
NIST- National Institute of Standards and Technology - Pilot	USA	NORAMET
BIPM- Bureau International des Poids et Mesures	International	-
BNM-LCIE – Bureau National de Métrologie, Laboratoire Central des Industries Électriques	France	EUROMET
CSIRO-NML –Commonwealth Scientific and Industrial Research Organization – National Measurement Laboratory	Australia	APMP
IRL - Industrial Research Laboratory	New Zealand	APMP
NIM – National Institute of Metrology	China	APMP
NMi - Nederlands Meetinstituut	Netherlands	EUROMET
NPL – National Physical Laboratory	UK	EUROMET
NRC – National Research Council	Canada	NORAMET
PTB – Physikalisch-Technische Bundesanstalt	Germany	EUROMET/ COOMET
VNIIM – D. I. Mendeleyev Institute for Metrolgy	Russia	COOMET

Capacitance Standards

The standards used in the comparison are 10 pF fused silica dielectric capacitors in hermetically sealed dry nitrogen filled metal containers with British Post Office (BPO) connectors. The capacitors were made at NIST and are described in [1]. The capacitors have a large temperature coefficient of approximately 10 μF/F per K and require immersion in a temperature controlled bath stable to about 1 mK if the capacitance value is to be measured to within 0.01 μF/F.

This type of capacitor has been successfully used in several comparisons. However, during the comparison prior to this one, large shifts in the capacitance value after travel were seen. These shifts were determined to be due to temperature hysteresis and a prescription of temperature cycling was therefore developed to remove this effect. The temperature cycling comprises of three cycles, each cycle being from 25 °C to 50 °C and back to 25 °C. The cycling causes the capacitor values to drift and the capacitors should be allowed at least three weeks to settle down to a stable and sufficiently small drift rate. How this drift rate is dealt with is discussed below.

Two sets of two capacitance standards were used for the comparison. Capacitors S/N 108 and S/N 185 were sent to 8 of the 10 participants. Capacitors S/N 190 and S/N 193 were introduced half way through the comparison to ease the tight schedule of the comparison and were sent to 2 out of the 10 participants. All capacitors were subjected to several sets of cycling and monitoring before they were sent out.

Measurement

The capacitors were measured at an applied voltage of 100 V and at a frequency of 1592 Hz. The capacitors were to be placed in a stable temperature bath at ≈ 25 °C for measurement and the 25 Ω resistance thermometer inside each capacitor was to be measured to within 0.01 mΩ (0.1 mK) at a current of 1 mA. The capacitance measurement is corrected to a defined reference temperature to ensure that there are no differences in value due to differences in the measurement temperatures.

Since the time restriction of a measurement did not allow the capacitors to fully settle after the temperature cycling, only data from a specified time period after the cycling was used. It was shown that selection of such a time period after cycling gives consistent measurements after each temperature cycle. This behavior is illustrated in Fig. 1 where the circled points are data taken in a

[1] Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce. Official contribution of the National Institute of Standards and Technology, not subject to copyright in the United States.

specified time period, which was usually a two-week period 3 or 4 weeks after the end of the temperature cycling. A linear fit made to the circled points is then used to predict the NIST value of the capacitors at the mean measurement date of each laboratory.

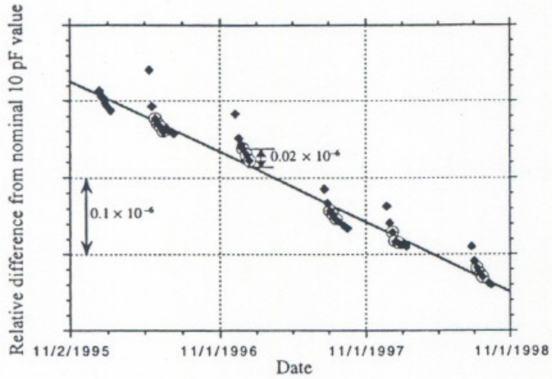

Figure 1. Behavior of Capacitor S/N 185 after cycling. Circled points are those in the specified time period.

Results

The results of the comparison are obtained as differences from the NIST measurements of the capacitors. This is necessary as all the capacitors drift with time and it is only by assuming by assuming consistency of the values measured by the NIST throughout the comparison that that the effect of the drift can be eliminated. At NIST, the capacitors are compared against a bank of four 10 pF capacitors that have a linear drift rate of 2×10^{-7} pF per year. The bank is measured against the NIST calculable capacitor [2] two to three times per year. The total relative combined standard uncertainty of the measurement of capacitors from the NIST calculable capacitor is 0.02×10^{-6}.

Each laboratory reports a value for each capacitor measured on a mean measurement date along with a measurement uncertainty, u_L. These values are an average of the measurements taken in a specific time period after cycling. The NIST predicted value for that date is found from a linear fit to the before and after NIST data in a similar time window after cycling as used by the laboratory. The final result for each laboratory is the average of the two differences from the NIST predicted values for the two capacitors.

A linear fit to all the NIST measurements throughout the comparison was not used to predict the NIST value corresponding to each laboratory's measurement date since laboratories selected different time periods after cycling. However, a linear fit to all the NIST measurements from a selected time period after cycling was used to estimate the relative standard transport uncertainty, u_T, which is 0.02×10^{-6}.

The differences from the NIST value for each laboratory are applied to the average of the NIST measurements of the four capacitors on the mean date of the comparison. These results are shown in Fig. 2. The weighted average of the measurements from laboratories whose value is derived from a calculable capacitor is then used to find a reference value. This is also shown in Fig. 2.

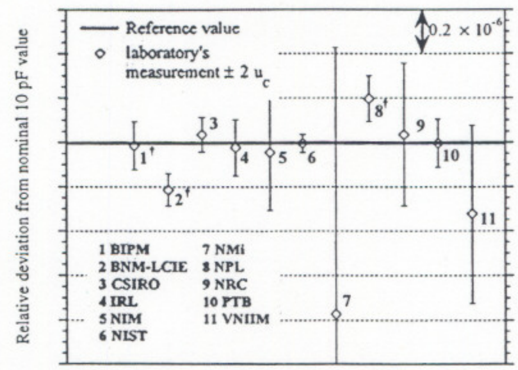

Figure 2. Measurements of each participant in terms of the NIST mean comparison value. †Measurements derived from R_{K-90} that have an associated relative uncertainty of 0.2×10^{-6}. $u_C^2 = u_L^2 + u_T^2$

Details of the data analysis, the determination of transport uncertainty, and the reference value calculation will be discussed. A reference value will be reported along with various methods of presenting the data.

Conclusion

This comparison establishes the relationships among the capacitance standards of laboratories in four regional metrology organizations and of the BIPM. There appear to be some differences between capacitance units, but for the majority of participants, there is agreement at the 95% level of confidence.

References

[1] R. D. Cutkosky and L. H. Lee, "Improved ten-picofarad fused silica dielectric capacitor", NBS J. Res. 69C, pp. 173-179, 1965.

[2] A. Jeffery, R. E. Elmquist, J. Q.Shields, L. H. Lee, M. E. Cage, and R. F. Dziuba, "Determination of the von Klitzing constant and the fine-structure constant through a comparison of the quantized Hall resistance and the ohm derived from the NIST calculable capacitor", Metrologia, 35, pp. 83-96, 1998.