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NIST
CAPACITANCE MEASUREMENT ASSURANCE PROGRAM (MAP)

Y. May Chang
Electronics Engineer
Electricity Division
National Institute of Standards and Technology

ABSTRACT

This paper describes the recently developed capacitance Measurement Assurance Program (MAP) service at the National Institute of Standards and Technology (NIST). Using a commercial digital capacitance meter as the transport standard, two separate pilot programs for the capacitance MAP have been carried out for standards at both the 1000 pF and 100 pF levels. The first was carried out as a single transfer with a government standards laboratory, and the second was designed for round-robin measurements as a multiple transfer by three industrial standards laboratories. In contrast to the normal MAP, where the transport standards are measured by the client laboratory, the capacitance MAP involves measurements performed on "dummy" standards by both the meter (transport standard) and the laboratory capacitance measuring systems. Results from these two pilot programs are presented. Also included are requirements and procedures for laboratories interested in participating in the capacitance MAP service.

INTRODUCTION

Background

The NIST Measurement Assurance Program services have been in existence for many years. The purpose of a MAP service is the evaluation of the customer's measurement system, and the determination of values of their standards. Presently, NIST provides MAP services in several areas, such as resistance, dc voltage, power, mass [1], and ac-dc difference [2]. Pilot MAP transfers have taken place in ac voltage [3] as well. An initial capacitance MAP (C-MAP) at NIST (which was then NBS) was started in 1973 [4]. Four 1000 pF, nitrogen-dielectric capacitors were used as transport standards. They were placed in a box specially designed and constructed to have minimal variations in temperature and mechanical shock during transportation. The program was discontinued in 1983.

In 1989, an evaluation was performed on a commercial 1 kHz digital capacitance meter (hereafter referred to as the Meter) with temperature controlled, fused silica dielectric reference capacitors, and having a resolution as high as a part in 10^8. The results of measurements over a few months indicated that the short term stability of the Meter is better than 0.05 ppm while the long term stability is estimated to be within 0.5 ppm/year. Experimentation involving local transportation of the Meter under adverse shipment and environmental conditions did not cause any significant changes in measurement results. This indicated the feasibility of using the Meter as a transport standard for a C-MAP.

Results from the Pilot Capacitance MAP Transfer

Two pilot capacitance MAPs have been performed to evaluate the Meter as a transport standard at the 1000 pF and 100 pF capacitance levels.

The first pilot program was carried out as a single transfer with a government standards laboratory (Lab A) from March to September 1990. At Lab A, the reference standards are 100 pF GR-1408[1] fused silica capacitors, and the check standards are 100 pF and 1000 pF GR-1404[1] gas-dielectric capacitors. Measurements were performed at Lab A using two systems; a GR-1615[1] bridge and a capacitance meter, CM 1 (same model as the transport standard). The results of the first pilot MAP are summarized in table 1. In November 1990, the primary reference standard of Lab A was sent to NIST for recalibration. The difference between the value assigned by the MAP transfer and the calibrated value was 0.11 ppm (negligible compared to the uncertainties). As indicated in table 1, the differences between the Lab A unit and NIST unit of capacitance for the 100 pF standards were 0.43 ppm and 0.42 ppm for the GR-1615 bridge and the CM 1, respectively. The total uncertainty of the MAP transfer for the 100 pF reference standards at the 3σ level was estimated to be 1.75 ppm. (During the course of measurements, an error of 0.49 ppm was discovered in the 1:1 ratio of the GR-1615 bridge. This error could have been eliminated by making reversal measurements. However, since such procedures were not performed at Lab A, the differences between the Lab A unit and the NIST unit of capacitance for the 100 pF standards were corrected for this error.)

Since the Lab A did not have any 1000 pF reference standards, bridge corrections for the 1:10 ratio were estimated for measurements of 1000 pF against the 100 pF standards. Results from the MAP transfer indicated the corrections for the GR-1615 bridge and the CM 1 for measuring the 1000 pF standards were 0.75 ppm and 0.13 ppm, respectively, with a total uncertainty of 2 ppm at the 3σ level.

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[1] Such commercial products and instrument are identified in this paper only to specify the measurement procedures adequately. It is not to be taken as a recommendation or endorsement by NIST, nor does it imply that such products and instrument are necessarily the best available for the purpose.

Table 1. Results of NIST Capacitance MAP Transfer with Lab A (March, 1990 to September, 1990)

Temperature = 23.3 (oC)	100 pF standards	1000 pF standards
Difference Corrected for Bridge Ratio Error* Fc(Lab A) - F(NIST)	(ppm)	(ppm)
GR-1615 Bridge	0.43	0.75
CM 1	0.42	0.13
Total Uncertainty	(ppm)	(ppm)
GR-1615 Bridge	1.75	2.00
CM 1	1.75	2.00

* See text

The second pilot program was designed as a multiple transfer to three standard laboratories of private industry (Lab X, Lab Y, and Lab Z) during the period between September 1991, and April 1992. All laboratories were using GR-1404 capacitors as reference standards, (both 100 pF and 1000 pF), and they measured the capacitors using the GR-1615 bridges with or without a redundant set of measurements for their calibration scheme. Data from all three laboratories, as well as those from the before and after MAP measurements from NIST are shown in figures 1 and 2 for the 100 pF and the 1000 pF standards, respectively. The results of the analysis are summarized in table 2. As shown in table 2, the differences between the individual laboratory's unit and the NIST unit of capacitance for the 1000 pF standards were between -0.68 ppm and 1.76 ppm, each with a total uncertainty of 2 ppm. For the 100 pF standards, such differences were between -9.67 ppm to 3.72 ppm, with total uncertainties between 1.75 ppm and 2.5 ppm.

DESCRIPTION OF SERVICE

Capacitance Standards

The present C-MAP involves 1 kHz measurements of "dummy" capacitance standards with nominal values of 100 pF and 1000 pF. After the completion of measurements at the customer laboratory (hereafter referred to as the Lab) and at NIST, and after data analysis, assigned values of the reference standards at the Lab will be given, together with the total uncertainty for the value of each standard.

Items for Shipping and Receiving

The Lab will receive two cases. One contains four gas-dielectric standards (two 100 pF and

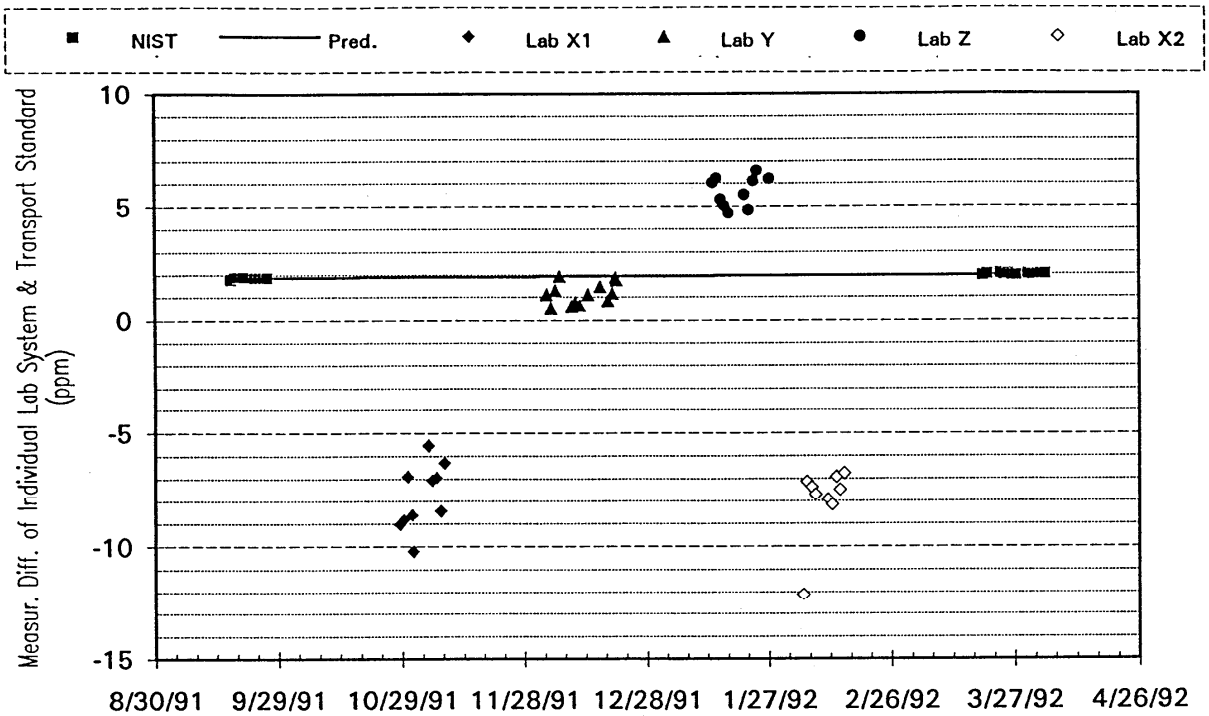

Figure 1. Results of NIST Capacitance MAP Transfer of 100 pF Standards.

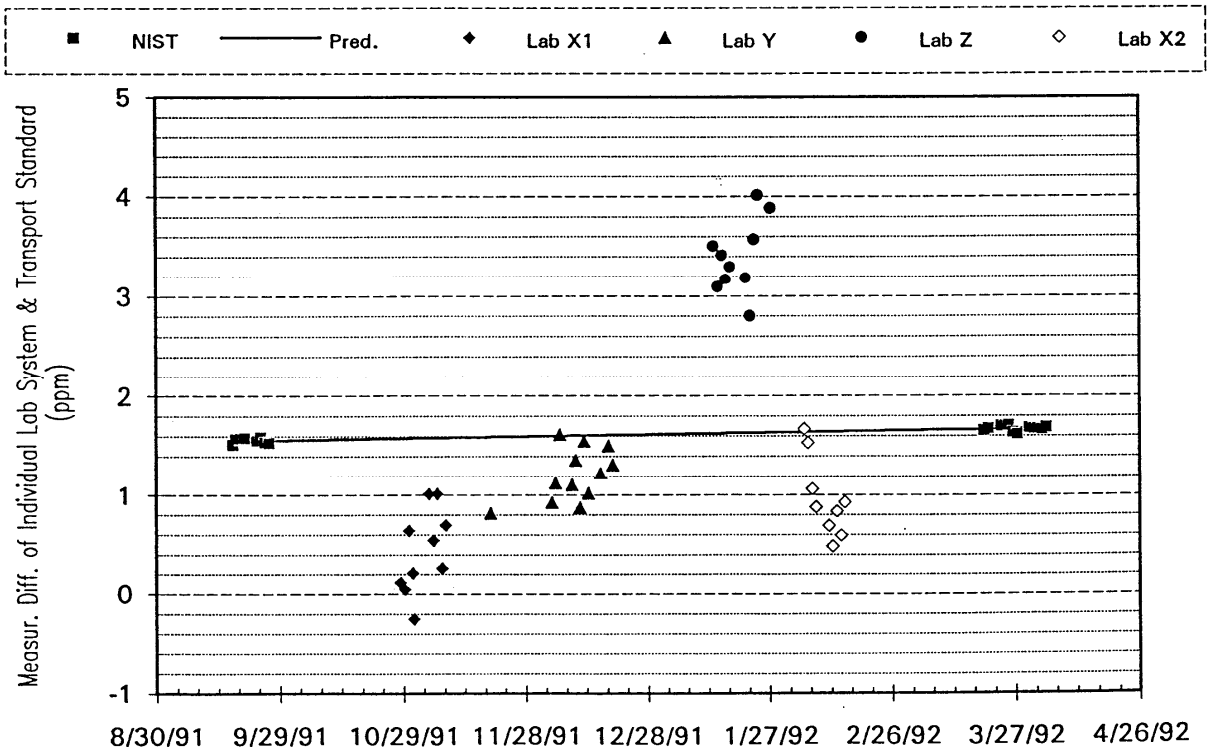

Figure 2. Results of NIST Capacitance MAP Transfer of 1000 pF Standards.

two 1000 pF), and the other contains the transport standard, the Meter. The capacitors must remain inside the case during measurements. It is necessary to unpack the Meter to make measurements because of potential problems from temperature rise from heat developed by the electronic components and power supplies. The Meter must be packed in the original case after measurements are completed. Test data should be returned with the instruments.

Table 2. Results of NIST Capacitance MAP for a Multiple Transfer (September, 1991 to April, 1992)

Customer Laboratory	Date (average)	Temp (oC) (average)	100 pF Standards		1000 pF Standards	
			F(LAB) - F(NIST) (ppm)	Uncertainty (ppm)	F(LAB) - F(NIST) (ppm)	Uncertainty (ppm)
Lab X1*	11/2/91	23.6	-9.67	2.50	-1.15	2.00
Lab Y	12/9/91	24.0	-0.75	1.75	-0.40	2.00
Lab Z	1/19/91	22.2	3.72	1.75	1.76	2.00
Lab X2*	2/9/92	23.2	-9.40	1.75	-0.68	2.00

* Different laboratory locations

CUSTOMER LABORATORY REQUIREMENTS

Prior to the initiation of the C-MAP, the Lab is asked to complete a CAPACITANCE MAP INFORMATION SHEET provided by NIST, as shown in table 3. In addition, the following information is also requested from the Lab :

* A description of the measurement system(s) used for routine calibration of capacitance standards.

* Description of techniques used to transfer the farad from reference standard(s) to check standard(s), and to determine the values of standards being calibrated.

Table 3. Information Sheet to be Completed by Customer Laboratory

CAPACITANCE MAP INFORMATION SHEET

TEST NO. : _____ (by NIST)

LABORATORY : _____ Telephone No. : _____

Address : _____

_____ Contact Person : _____

_____ Lab Temperature : _____

_____ Lab R. Humidity : _____

CAPACITANCE MEASUREMENT SYSTEM(S) : _____

LIST OF STANDARDS (as Ref., Check, and Working STD, or others)

	TYPE	SER. NO.	NOM. VAL.(pF)	USED AS	CAL. BY	CAL. INTVL.
Examples :	Model ABC	12345	100	Ref	NIST	2 years
	Model DEF	45678	1000	Check	Ref	1 month

COMPUTING SYSTEM(S) : _____

Disk Drive(s) : _____ Disk Size(s) : _____ Printer(s) : _____

Software Language(s) : (check all) _____ HPBASIC

_____ HTBASIC

_____ IBMBASIC(A)

_____ Others (please state) : _____

Interface : (check all) _____ IEEE-488.1

_____ IEEE-488.2

_____ Others (please state) : _____

After the above materials are received, the Lab will be notified of a tentative schedule.

MEASUREMENT PROCEDURES

Measurement Approach

The transport standard used in the C-MAP is a digital capacitance meter that operates at a frequency of 1 kHz. Since the Meter cannot readily be calibrated through direct measurement of its ratio transformer or reference capacitors, it must be evaluated by utilizing check standards or "dummy" capacitors that are measured using the Meter and by some other means. At NIST, this "other means" is the "Type-2 Capacitance Bridge" [5,6] used to calibrate three-terminal capacitors. The standard capacitors used at NIST are two reference standards - 100 pF fused silica commercial capacitors and two check standards - 1000 pF gas-dielectric parallel-plate commercial capacitors (with modifications). Two pairs of dummy capacitors of the same nominal values are also sent along to the client lab with the Meter.

In a traditional MAP, the measurement capability of the Lab is quantified by evaluating the results of a set of measurements of precision transport standards whose performance is characterized by extensive measurements at NIST before and after the transport standard's stay in the customer laboratory. In the C-MAP, the Meter is the transport standard, and the dummy standards simply provide the opportunity for the redundant measurements needed to evaluate the laboratory's measurement system. The measurement approach is :

* The dummy capacitors and the NIST reference and check standards are measured at NIST using the Type-2 Capacitance Bridge and the Meter before and after the MAP transfer.

* The laboratory measures the dummy capacitors relative to its own reference and check standards using its own calibration system. Thus, the transport standard is used to measure the customer's reference and check standards, and the "dummy" standards for redundancy.

Instruction for Measurements

At the time the transport standard and the dummy standards are ready to be shipped to the Lab for a C-MAP, the Lab will be provided with a computer program and a copy of "INSTRUCTIONS FOR THE CAPACITANCE MAP", which includes instructions for unpacking and packing items, preparation of the standards, procedures for performing measurements, execution of the program, and data collection . The program used to make measurements with the Meter is written in BASIC and is provided on a floppy disk with listing. Also provided are the step by step instructions which describe how to perform measurements and to record data properly.

Table 4. Data Report Format by the Customer Laboratory

CAPACITANCE MAP DATA SHEET

TEST NO. :

Page No. :

COMPANY :

STD SERIAL NO. :

STD TYPE (GR1404 or SC1000) :

NOMINAL VALUE :

USED AS (REF or CHECK STD) :

FINAL RESULTS (by Laboratory Measurement System)

DATE	TIME	FINAL VALUE (pF)	TEMP (oC)	RH (%)	REMARK

DATA SUBMITTED BY THE LABORATORY

All measurements will be performed by two systems, the Lab's calibration system and the transport standard. Data obtained from the Lab's system should be reduced by the Lab personnel and the final results of each standard should be reported on the CAPACITANCE MAP DATA SHEET, as shown in table 4. Measurements using the transport standard will be made automatically under computer control and the data will be written on a floppy disk and printed out.

The Lab should send the data from the first couple of days to NIST to ensure that the procedure is being followed correctly, to identify any significant changes in the standards, and to determine when a sufficient quantity of data have been taken. After the completion of all measurements, the Lab will contact NIST to arrange for the shipment, either back to NIST or to some other location. Data sheets and floppy disk(s) are sent to NIST directly, including copies of the original data sheets. The Lab should make duplicates of all data sheet(s) and data disk(s) before sending them to NIST.

REPORT OF CALIBRATION

After the completion of measurements and data analysis, a REPORT OF CALIBRATION from NIST will be issued to the Lab. This gives the assigned value(s) for the lab reference standard(s) with total uncertainties. Also included are equations for calculations of assigned values and for error analysis to obtain random uncertainties.

REFERENCES

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