NISTIR 4466

CALIBRATION PROCEDURES FOR INDUCTANCE STANDARDS USING A COMMERCIAL IMPEDANCE METER AS A COMPARATOR

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ABSTRACT

Procedures for calibrating customers' inductance standards using a commercial impedance meter to compare them with NIST inductance standards by a substitution method are reported. These procedures are based on a six-month evaluation of the meter by measuring a group of six NIST inductance standards of different values at a frequency of 1 kHz. For each inductance standard, the results of measurements with the meter and the Maxwell-Wien bridge, which is used to realize the henry at NIST, are analyzed to determine the stabilities of the standards and the impedance meter as well as to estimate the random transfer uncertainty of the meter measurements. Values of inductance obtained using the Maxwell-Wien bridge are compared with corresponding values of inductance obtained with the meter by substituting customers' inductance standards with the six NIST standards over a period of six months. The statistical analyses used to assure that measurements made using such procedures are in control are described, as well as future plans to expand the substitution technique to include other values of inductance standards at various frequencies.

Keywords: calibration; impedance calibration procedures; impedance data analysis; impedance meter; inductance measurements; inductance standard; Maxwell-Wien bridge; prediction.

1. Introduction

The system for calibrating inductance standards at NIST is a typical Maxwell-Wien bridge with complete shielding and a Wagner ground circuit [1]. It is mainly used to determine the inductance of air-core standards of 50 μH to 10 H over the frequency range of 100 Hz to 10 kHz in terms of capacitance. The total uncertainty of a measurement made using this bridge is in the range from 0.02% to 0.20%, depending on the measured value and the measurement frequency. Occasionally, standards with values smaller than 50 μH or larger than 10 H are sent in by customers, but the number of those calibrations is very small.

The NIST Maxwell-Wien bridge was originally constructed at NBS approximately 35 years ago using commercial components. The latest modification, addition of the Wagner ground circuit, was carried out in 1965. Calibration procedures, which are documented in laboratory notes for this particular bridge, are based on the analysis and methods of ref. [2]. Due to the wear and tear of daily operation of the bridge, some of its components have become difficult or impossible to adjust to obtain a balance. Replacement of such aged components is almost impossible because most have been discontinued by the manufacturers.

An investigation was made of the possibility of using a commercial impedance meter in a comparison, or transfer, technique for the calibration of inductance standards. The principle of the methodology is to measure a customer's standard and an NIST standard of like value with the meter, and to assign a value for the customer's standard based on the difference in meter readings and a value of the NIST standard extrapolated from periodic measurements made using the Maxwell-Wien bridge. In this report, this technique is referred as the "substitution method". The reasons for using such a method are to reduce the workload on the Maxwell-Wien bridge to prolong its life, and to reduce the time required to perform calibrations. A GenRad 1689M RLC Digibridge[1] has been used as the comparison instrument in establishing the measurement procedures for calibrating customers' inductance standards by the substitution method.

2. Approach

In general, there are 20 types (values) of customers' inductance standards. Each is capable of being calibrated at up to four frequencies at NIST. It is necessary to evaluate each type of standard at each frequency to determine the feasibility of using the substitution method for calibration. Since the main purpose of adopting this measurement procedure is to reduce the workload requiring use of the Maxwell-Wien bridge, the most common types of customers'

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[1] Such commercial instrument is identified in this report 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 the instrument is necessarily the best available for the purpose.

standards have priority for evaluations. Records dating back over the last ten years of NIST calibration of inductance standards owned by varies customers were analyzed to determine the distribution of the values of the inductors and the calibration frequencies used. The results are shown in table 1, with the 20 general types of standards equivalent to GenRad Model 1482 type BB through SI. The NIST calibration laboratory has two sets of 17 inductance standards (type A through T), a primary set used for calibrations and a secondary set used for backup. The other three types of inductors (BB, CC, and SI) are seldom sent in by customers to be calibrated, as indicated by the past ten years' results in table 1.

According to the past ten years' calibration history of customers' inductance standards, 70% of the population are of six particular values (100 μH, 1 mH, 10 mH, 100 mH, 1 H, and 10 H), as shown in table 1. Table 1 also indicates the percentage of calibrations at a frequency of 1 kHz and gives the percentage of the total number of customers' inductance standards calibrated at these six values and at a frequency of 1 kHz to be 49%. Therefore, it was decided that initially a group having those six values at a frequency of 1 kHz would be evaluated.

3. Evaluations and Results

The evaluation of the new calibration method consisted of a two step process; first, the reproducibility of the impedance meter was determined, and second, customer standards sent in for calibration were calibrated by both methods, i.e., directly with the Maxwell-Wien bridge and also with the substitution method. For the initial reproducibility evaluation, six inductance standards from the NIST impedance calibration laboratory were selected to be monitored by both the Maxwell-Wien bridge and the impedance meter at a frequency of 1 kHz. Their model types, serial numbers, and nominal values are shown in table 2.

The first step was to observe the reproducibility of the meter by measuring these six inductors several times a day for a few days. The initial results indicated that the standard deviations of the within-day measurements for types E, H, L, P, and T inductance standards were less than 10 ppm, with typical values of 1 to 6 ppm. The within-day standard deviations of the type B inductance standard were in the range between 20 to 25 ppm. Additional information concerning the characteristics of the meter, as compared with those of the Maxwell-Wien bridge, were also obtained by monitoring the behavior of these six inductors with both instruments. After three months (September 1988 to December 1988) of measurements with the meter, ranging from once a week to twice a week, data for these six inductors were analyzed by fitting a regression line to obtain the average rate of change (slope) of each standard. Simultaneously, the slopes of the regression lines from the Maxwell-Wien bridge measurement results for six months (June 1988 to December 1988) were also obtained for each inductor. Using the method described in Handbook 91 [3], the slopes of these two regression lines were tested statistically at a significance level of 0.05 for a statistically significant difference between them. Results from these data indicate that, for each standard, the slopes of regression lines from measurements by both techniques are statistically identical. Although the equality of the slopes has no bearing on the within-day reproducibility of the impedance meter it discloses the quality of the meter's internal reference for measuring these six types of inductors at a frequency of 1 kHz.

The second step in the evaluation was to determine the values of a number of customers' inductors using the substitution method and to compare these values with the corresponding values obtained from measurements using the Maxwell-Wien bridge. In the substitution method the customer's standard and a NIST standard of the same type are measured sequentially with the meter. The difference in the values obtained is added to (or subtracted from) the value of the NIST standard predicted from the history of its Maxwell-Wien bridge measurements. Meanwhile, data from both the Maxwell-Wien bridge (every three months) and the impedance meter (at least once a month), for each standard, are updated to obtain new regression lines.

The difference between the calculated value for a customer's standard and the measured value from the Maxwell-Wien bridge, DL, can be obtained from the following equations :

$$\mathrm{DL} = \hat{\mathrm{L}} - \mathrm{L}_M \qquad (1)$$

$$\hat{\mathrm{L}} = \hat{L}(t) - L + \mathrm{L} \qquad (2)$$

$$\hat{L}(t) = m*(\mathrm{DATE}) + b \qquad (3)$$

where DL is the difference between calculated and measured values,
- L_M is the measured value of customer's standard by Maxwell-Wien bridge,
- $\hat{\mathrm{L}}$ is the calculated value of customer's standard,
- L is the measured value of customer's standard by impedance meter,
- *L* is the measured value of NIST standard of the same type by impedance meter,
- $\hat{L}(t)$ is the predicted value of NIST standard on the same day (DATE) when all measurements are performed,
- m and b are regression coefficients (slope and intercept) of the measurement history of the NIST standards when using the Maxwell-Wien bridge.

After eight months (December 1988 to August 1989) evaluation of over 80 customers' inductors at six values, the differences (DL) between the calculated and the Maxwell-Wien bridge measured values were found to range from 1 to 73 ppm; these differences are small compared to the calibration uncertainties for the Maxwell-Wien bridge (from 200 to 1000 ppm). The mean difference between calculated and measured values should be zero for all six standards. The t-statistics for testing this premise are shown on the last line of table 3. Except for Type-H inductors, the t-statistics are all non-significant at the 95% probability level, confirming that the comparator method of calibration produces results which are unbiased relative to the Maxwell-Wien bridge. Table 3 gives the uncertainties and a detailed breakdown for each type of the customers' standards being evaluated during this eight month period. The quoted uncertainties for Maxwell-Wien bridge measurements in table 3 are based on the analysis and method for estimation of the bridge [2], and documented in laboratory notes. Note that the existence of the non-randomness of the differences (DL) between the calculated and measured values in table 3 is due to the seasonal variations of the standards which are not modeled by the prediction equation.

The random transfer uncertainty due to impedance meter measurements using the substitution method is estimated from the scattering of data obtained by both the meter and the Maxwell-Wien bridge measurements. According to eq. (2), the standard deviation of the calculated value of a customer's standard ($L\hat{}$) due to the random error, S_r, is given as :

$$S_r = (S_p{}^2 + S_n{}^2 + S_c{}^2)^{(1/2)} \quad (4)$$

where S_r is the random error of $L\hat{}$ in eq. (2) using the substitution method,
S_p is the standard deviation of the predicted value of NIST standard, $\hat{L}(t)$ in eq. (2), on the same day of measurement,
S_n is the within-day standard deviation of L in eq. (2),
S_c is the within-day standard deviation of L in eq. (2).

The random transfer uncertainties, $3S_r$, resulting from using the substitution method to calibrate customers' standards were found to be less than 50 ppm in all cases. The increment in total calibration uncertainty, which includes both the systematic error and the random error, when using the meter with the substitution method was found to be within 10 ppm for all types of inductors, as compared with the uncertainty when using only the Maxwell-Wien bridge. Therefore, the evaluation of the meter as a transfer standard to calibrate customers' standards of the six designated values at a frequency of 1 kHz shows it to be successful, and the calibrated values are equivalent to the calculated values, $L\hat{}$, given in eq. (2). Accordingly, the substitution method will be used to calibrate customers' standards of those types without using the Maxwell-Wien bridge unless the process shows an anomaly. Both the Maxwell-Wien bridge and the impedance meter will be used to monitor the appropriate NIST standards at least every three months to observe any unexpected changes of the standards or the equipment.

Figures 1 to 6 illustrate the data resulting from the measurements of the six NIST standards using the Maxwell-Wien bridge and the impedance meter through December 1989, with the quoted calibration uncertainty as the range of the vertical axis in each case. The regression lines, which will be updated every time a new measurement is made, are also shown on these figures, and the analytical results concerning the precision of measurements, such as standard deviations of the fits of these regression lines, are given in table 4. Note that these data were used simply to evaluate the stability and precision of the working standards and the impedance meter. In a calibration, the difference between meter readings for standard and unknown is used to calculate a final value; the fact that the illustrated regression lines are not coincident does not contribute to a calibration offset.

4. Calibration Procedures

4.1 Laboratory Measurement

Measurements of inductance standards by the impedance meter are made automatically under control of a desktop computer system, via the instrumentation[2] bus. A NIST-constructed test fixture is also used. The only manual action required is to connect the inductor being measured to the fixture and start the program. The software is "menu-driven", with explanations of parameters to be entered throughout the program. Data are printed out with an option to write them on a floppy disk. The measurement time for each inductor is extremely short, about one minute. Also, all calculations are done by the computer to save time as well as reduce human errors.

The main software program, DIGIDFL, controls the meter to make inductance measurements and stores data to a file, MMDDYY-#.DFL, which identifies the month (MM), the day (DD), and the year (YY) of measurement; and the order of measurements (#) of the day. A detailed description of DIGIFL is in Appendix A. Each MMDDYY-#.DFL file contains data on NIST and/or customers' standards for measurements at the same frequency. After all measurements are completed, a program, APP-FILE, is used to append data from .DFL files to the existing files, TP-xxxx.LDB and TP-FILE.CDB. TP-xxxx.LDB are files specific to NIST standards at all frequencies; their titles identify the type (TP) and the serial number (xxxx) of the subject standard. TP-FILE.CDB contains data of customers' standards of the same type (TP), at all frequencies. Measurements made on NIST standards immediately after those on customers' standards of the same type (TP) are also included in the TP-FILE.CDB files for convenience in obtaining calculated values of customers' standards. Both .LDB and .CDB files are archived and backed up each day after APP-FILE is used; while .DFL files are deleted after the backup process. A flow chart of the above process is given in Fig. 7.

During the evaluation period, we built the data base of .LDB files and added data to .CDB files whenever customers' standards were available. Meanwhile, both NIST and customers' inductors were being measured on the Maxwell-Wien bridge. The measured results of NIST standards are stored in data files as .LMW; and those of customers' standards, L_M, are used to make comparisons with the calculated values, as given in eq. (1). After the evaluation was completed, there were no more values of L_M, because customers' inductors were no longer measured on the Maxwell-Wien bridge for those six types given in table 2 at 1 kHz. The other three data files (.LDB, .CDB, and .LMW) are still needed for calculation and data analysis. After each measurement of NIST standards with the Maxwell-Wien bridge (every three months), the file containing regression coefficients (m and b), TBLMW.TXT, is updated by adding the new parameters.

The final program to obtain calculated values of customers' standards is CALCTMDB. It predicts the value of $\hat{L}(t)$ in eq.(3) from TBLMW.TXT, and

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[2] Standard Digital Interface for Programmable Instrumentation ANSI/IEEE 488.1-1987.

calculates the value $L^{\wedge}$ in eq.(2) from .CDB files. The result, $L^{\wedge}$, which is equivalent to the calibrated value is printed out for NIST documentation as well as reported to the customer. Figure 7 is a block diagram of the complete calibration procedure for customers' standards.

4.2 Statistical Analysis

During the evaluation period, measurement data were analyzed to observe the reproducibility of the impedance meter and to compare the calculated and measured values of customers' inductors to validate the substitution method, as discussed in Sec. 3. After the substitution method is adopted, NIST standards will still be monitored by both the Maxwell-Wien bridge and the meter in order to avoid measurement errors caused by any unexpected changes of the meter or the standards.

For each NIST inductance standard, a regression line, with slope m and intercept b, is fitted to the results of Maxwell-Wien bridge measurements. When a new measurement by the Maxwell-Wien bridge is obtained on day DD, the value of the new data point, L_M is compared with the predicted value, $\hat{L}(t)$, for that date from a previous fit to determine whether L_M is within the 95% confidence interval of $\hat{L}(t)$. The method and equations used are discussed in detail in Chapter 5, Handbook 91 [4]. If the difference between L_M and $\hat{L}(t)$ falls within the confidence interval, we can conclude that the most recent datum agrees with the regression line model. In order to minimize extrapolation, the new data point, L_M is added to the original data set to obtain a new regression line with a new set of parameters, slope m_1 and intercept, b_1. Meanwhile, data from the impedance meter measurements are also tested by fitting them to a regression line to obtain slope, m_d and intercept, b_d. The graphical interpretations of the data and the regression lines from both impedance meter and Maxwell-Wien bridge measurements are also produced to observe the characteristics of the impedance meter and to avoid measurement errors. (Additional characteristics concerning the stability of the impedance meter, using the Maxwell-Wien bridge as a reference, can be obtained by testing the slopes of these two regression lines, m_1 and m_d, for statistical identity with a significant level of 0.05, but this is not a necessary procedure). After the above two tests are completed, the file TBLMW.TXT is updated with new parameters, m_1 and b_1, and used for future calculations of the values of customers' standards.

5. Discussion and Future Plans

All customers' standards of the six types shown in table 2 have been calibrated at a frequency of 1 kHz using the procedures in Section 4 since August 1989, and the statistical analysis indicates our model for prediction is valid and our measurements are in statistical control. If the workload for inductance standard calibration continues to be similar to that of the past ten years, we will have reduced the time taken for inductance calibrations by one half by using this method.

The next step is to expand these procedures to calibrate inductors other than the above mentioned types and at other frequencies. Using table 1 as a guideline, it has been decided to divide the other 11 types of standards at a frequency of 1 kHz into two arbitrary groups, and the six types shown in table 2 at a frequency of 100 Hz, as a third group, and include them in an evaluation for the next 12 to 18 months to determine if the substitution method can be applied to any of these inductors. Thus, we have a total of four groups of standards to be monitored, as shown in table 5.

Besides those in Group I, we have monitored since September 1988, at least once a month for preliminary evaluations, standards in both Groups II and III of table 5 using the impedance meter. In addition, standards in Group II have been measured on the Maxwell-Wien bridge since June 1988. Therefore, the order of evaluation will be Groups II, III, and IV. This will be done by monitoring each group of standards using both the Maxwell-Wien bridge and the meter every three months, and, after we have enough data points, by comparing the calculated and measured values of customers' standards sent in for calibration. If we do not have customer's standards of a certain type for a period of three months, we will used a standard from our secondary set in lieu of a customer's standard for the evaluation.

6. Conclusions

An impedance meter has been evaluated for over a year in use as a transfer standard to calibrate inductance standards of six values (100 μH, 1 mH, 10 mH, 100 mH, 1 H, and 10 H) at a frequency of 1 kHz. Results indicate that it is sufficiently reproducible for measuring these inductors, as compared with the Maxwell-Wien bridge used at NIST to realize the henry; and the models for obtaining predicted values for NIST standards from Maxwell-Wien bridge measurements are valid.

The differences between the calculated values using the substitution method and the actual measured values using the Maxwell-Wien bridge for the above six standards are found to range from 1 to 73 ppm. These differences are relatively small compared with the stated calibration uncertainties of these standards when measured with the Maxwell-Wien bridge (from 200 to 1000 ppm). The random transfer uncertainties due to the substitution method are estimated to be within 50 ppm, and the increment in total calibration uncertainty using the impedance meter as a comparator is found to be less than 10 ppm. Therefore, the calibration procedures described in this report will be applied to those six types of customers' standards at a frequency of 1 kHz, as long as the NIST standards and the impedance meter exhibit predictable behavior. Using the impedance meter as a transfer standard instead of using the Maxwell-Wien bridge for customer measurements, substantially reduces the workload and will prolong the life of the Maxwell-Wien bridge until a new technique for realizing the henry can be perfected. Preliminary evaluation results also suggest that similar procedures should be applied to other values of standard inductors at various frequencies. Plans have been made to evaluate three more groups of inductance standards.

7. Acknowledgements

The authors would like to gratefully acknowledge Dr. Bruce Field and Mr. Norman Belecki for their valuable suggestions and contributions to the evaluation of the procedures. Special thanks to Mr. Lai Lee for his technical support in the design of the measurement fixture.

8. References

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3. Natrella, M. G., Experimental Statistics, NBS Handbook 91; 1963. Chapter 3.

4. Natrella, M. G., Experimental Statistics, NBS Handbook 91; 1963. Chapter 5.

Table 1. Distribution of Customers' Inductance Standards Calibrated by NIST- from 1978 to 1988

Model - Type	Nominal Value	At Frequency of				Total Number at all Frequencies	Percentage of Total at 1 kHz
		100 Hz	400 Hz	1 kHz	10 kHz		
GR 1482-BB	10 μH	2	0	3	2	7	43%
GR 1482-CC	20 μH	2	0	2	2	6	33%
GR 1482-A	50 μH	10	2	31	8	51	61%
GR 1482-B	100 μH	38	20	175	24	257	68%
GR 1482-C	200 μH	13	7	38	9	67	57%
GR 1482-D	500 μH	13	3	43	11	70	61%
GR 1482-E	1 mH	55	20	211	22	308	69%
GR 1482-F	2 mH	18	0	33	13	64	52%
GR 1482-G	5 mH	19	9	51	10	89	57%
GR 1482-H	10 mH	43	19	184	22	268	69%
GR 1482-J	20 mH	17	1	30	11	59	51%
GR 1482-K	50 mH	18	4	39	12	73	53%
GR 1482-L	100 mH	69	31	310	15	425	73%
GR 1482-M	200 mH	17	2	35	0	54	65%
GR 1482-N	500 mH	16	0	44	0	60	73%
GR 1482-P	1 H	65	13	169	0	247	68%
GR 1482-Q	2 H	19	0	26	0	45	58%
GR 1482-R	5 H	23	3	39	0	65	60%
GR 1482-T	10 H	57	14	123	0	194	63%
GR 1482-SI	253 mH	0	0	3	0	3	100%
Total Number of All Values		514	148	1589	161	2412	66%
Total Number of Types B, E, H, L, P, and T		327	117	1172	83	1699	69%
Percentage of Total (of the Six Types)		64%	79%	74%	52%	70%	49%

Table 2. NIST Inductance Standards Used for Initial Test

Model - Type	Serial Number	Nominal Value
GR 1482 - B	2085	100 μH
GR 1482 - E	1182	1 mH
GR 1482 - H	1204	10 mH
GR 1482 - L	1813	100 mH
GR 1482 - P	1382	1 H
GR 1482 - T	2477	10 H

Table 3. Comparisons of Calculated and Measured Values of Customers' Inductance Standards

Standard's Type (Value)	B(100 μH)	E (1 mH)	H (10 mH)	L (100 mH)	P (1 H)	T (10 H)
Uncertainty Stated in Maxwell-Wien Bridge Measurements (ppm)	1000	200	200	200	500	1000
Differences between Calculated & Measured Values DL (ppm)	16	-9	-14	-26	2	11
	-9	-13	-5	-24	-6	-25
	-20	-17	16	-20	1	-11
	-53	-8	1	-16	-8	15
	-73	-11	8	-4	1	34
	-28	-28	1	7	34	-39
	-43	-35	8	14	41	9
	21	-6	32	8	24	22
		2	23	8	-3	-28
		-50	24	7	6	6
		-9	15	11		-20
		6	2	8		-59
		7		10		
		22		18		
		11		8		
		14		14		
		23		24		
		34		4		
		38		-4		
		30		-4		
				3		
				-4		
SUMMARY						
Mean	-23.63	0.05	9.25	1.91	9.20	-7.08
Std. Dev. of Data	32.70	23.25	13.27	13.42	17.38	27.69
No. of Measurements	8	20	12	22	10	12
Std. Dev. of Mean	11.56	5.20	3.83	2.86	5.50	7.99
t-statistic for Testing Mean = 0	-2.04	0.01	2.41	0.67	1.67	-0.89

Table 4. Analytical Results of NIST Inductance Standards Measured by the Maxwell-Wien Bridge and the Impedance Meter

NIST Standards Type - Serial Number (Nominal Values)		Standard Deviation of Fit (ppm)	Slope of Regression Line (ppm/day)
B-2085	by Maxwell-Wien Bridge	14	-0.003
(100 μH)	by Impedance Meter	29	-0.025
E-1182	by Maxwell-Wien Bridge	12	-0.029
(1 mH)	by Impedance Meter	10	0.002
H-1204	by Maxwell-Wien Bridge	11	-0.019
(10 mH)	by Impedance Meter	9	-0.01
L-1813	by Maxwell-Wien Bridge	9	0.001
(100 mH)	by Impedance Meter	11	0.088
P-1382	by Maxwell-Wien Bridge	11	0.004
(1 H)	by Impedance Meter	9	0.029
T-2477	by Maxwell-Wien Bridge	32	-0.192
(10 H)	by Impedance Meter	37	-0.238

Table 5. Four Groups of NIST Inductance Standards Being Monitored

Group I at 1 kHz	Group II at 1 kHz	Group III at 1 kHz	Group IV at 100 Hz
B-2085	A-6776	G-2226	B-2085
E-1182	C-1894	J-1616	E-1182
H-1204	D-2197	K-1763	H-1204
L-1813	F-2240	M-1843	L-1813
P-1382		N-1826	P-1382
T-2477		Q-1421	T-2477
		R-2071	

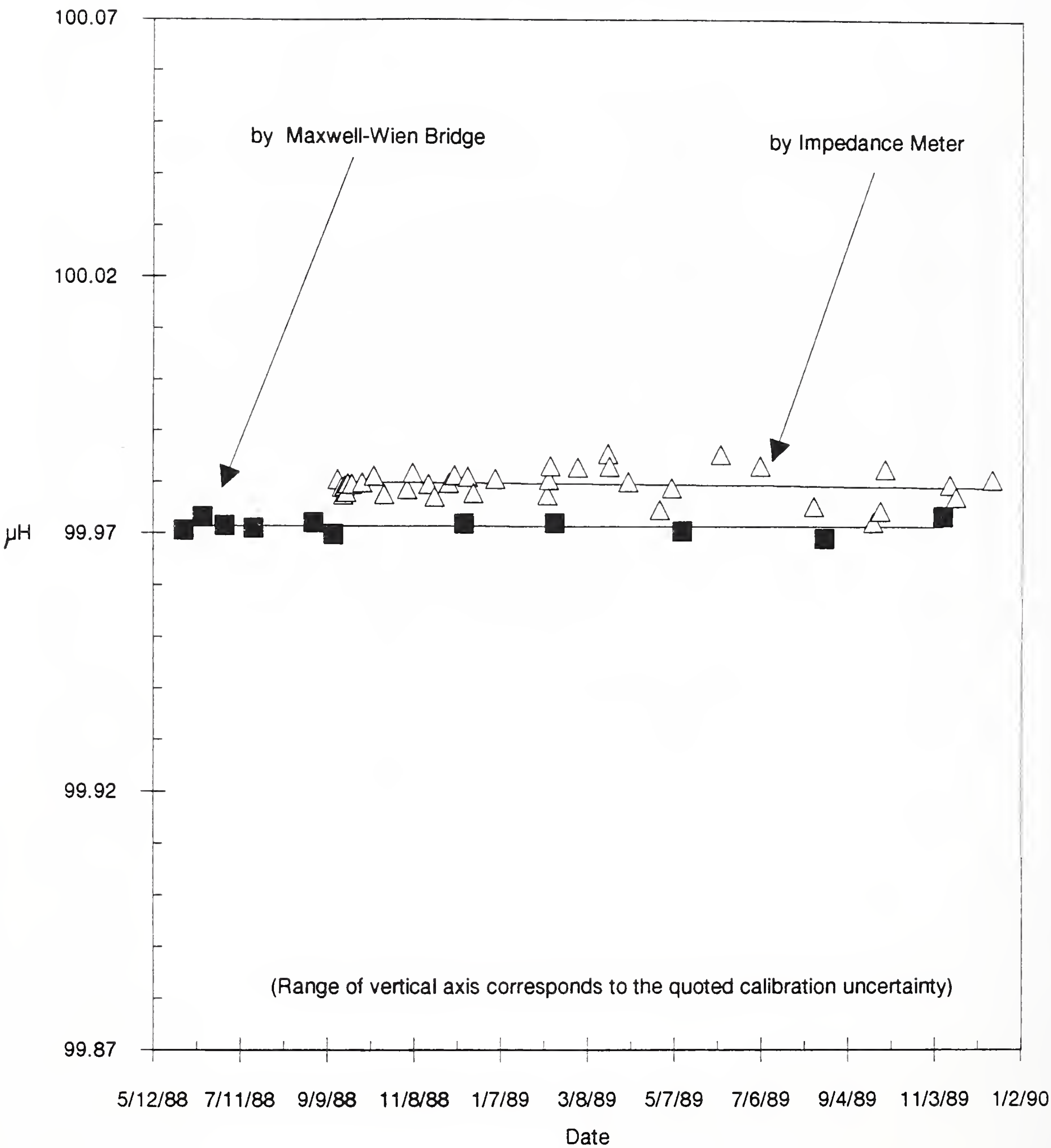

Figure 1. Measurements of NIST Standard B-2085 at 1 kHz

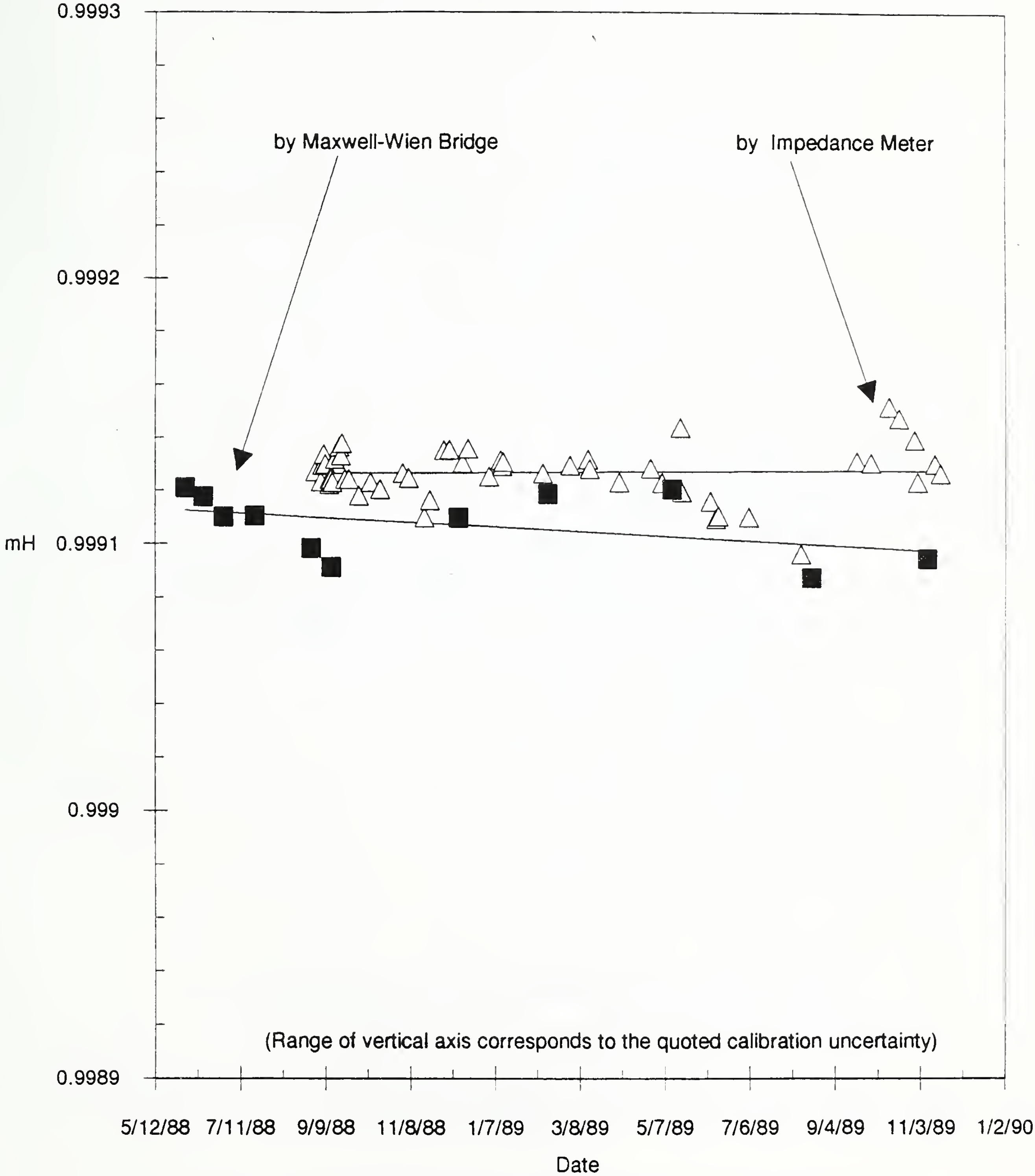

Figure 2. Measurements of NIST Standard E-1182 at 1 kHz

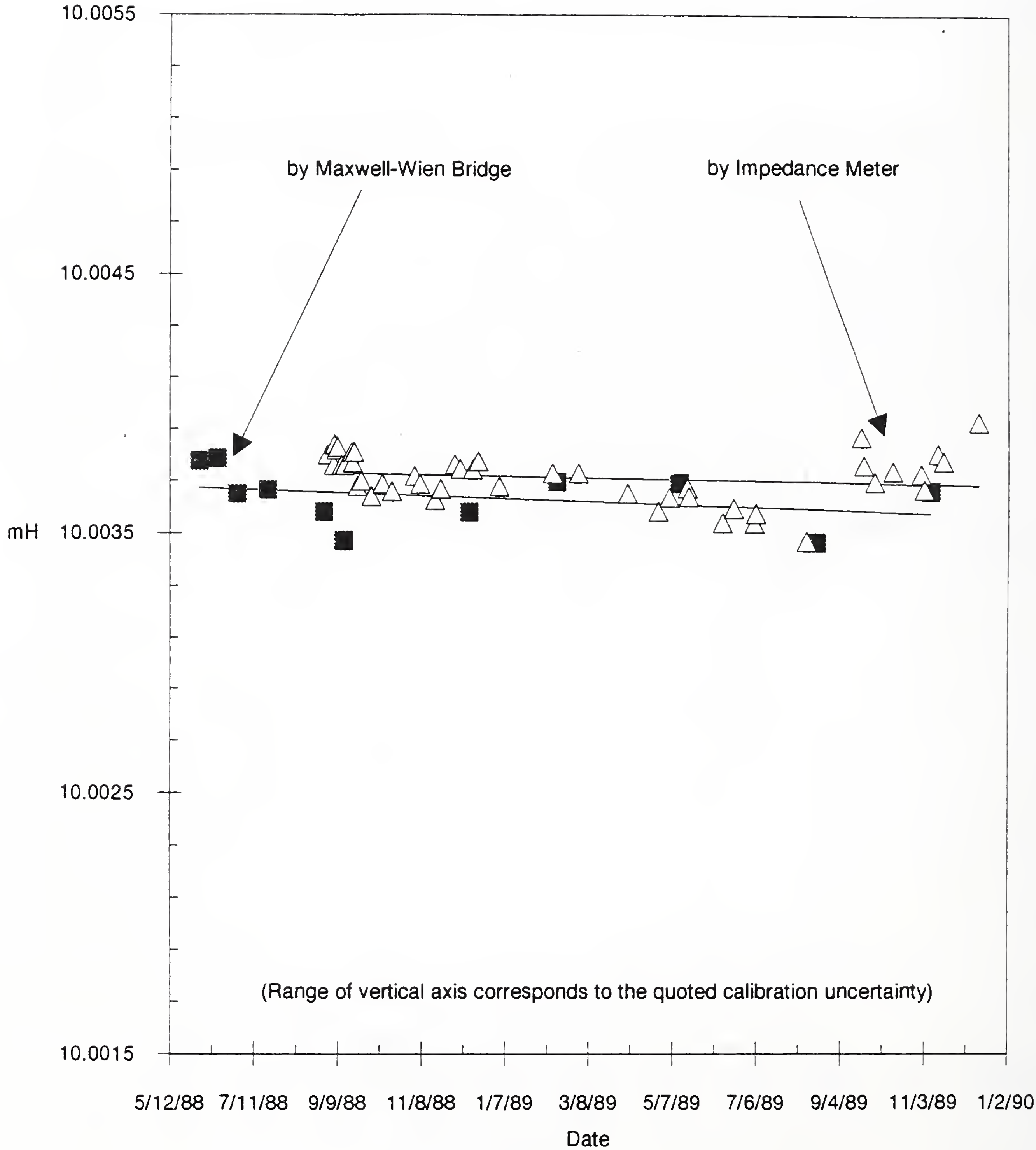

Figure 3. Measurements of NIST Standard H-1204 at 1 kHz

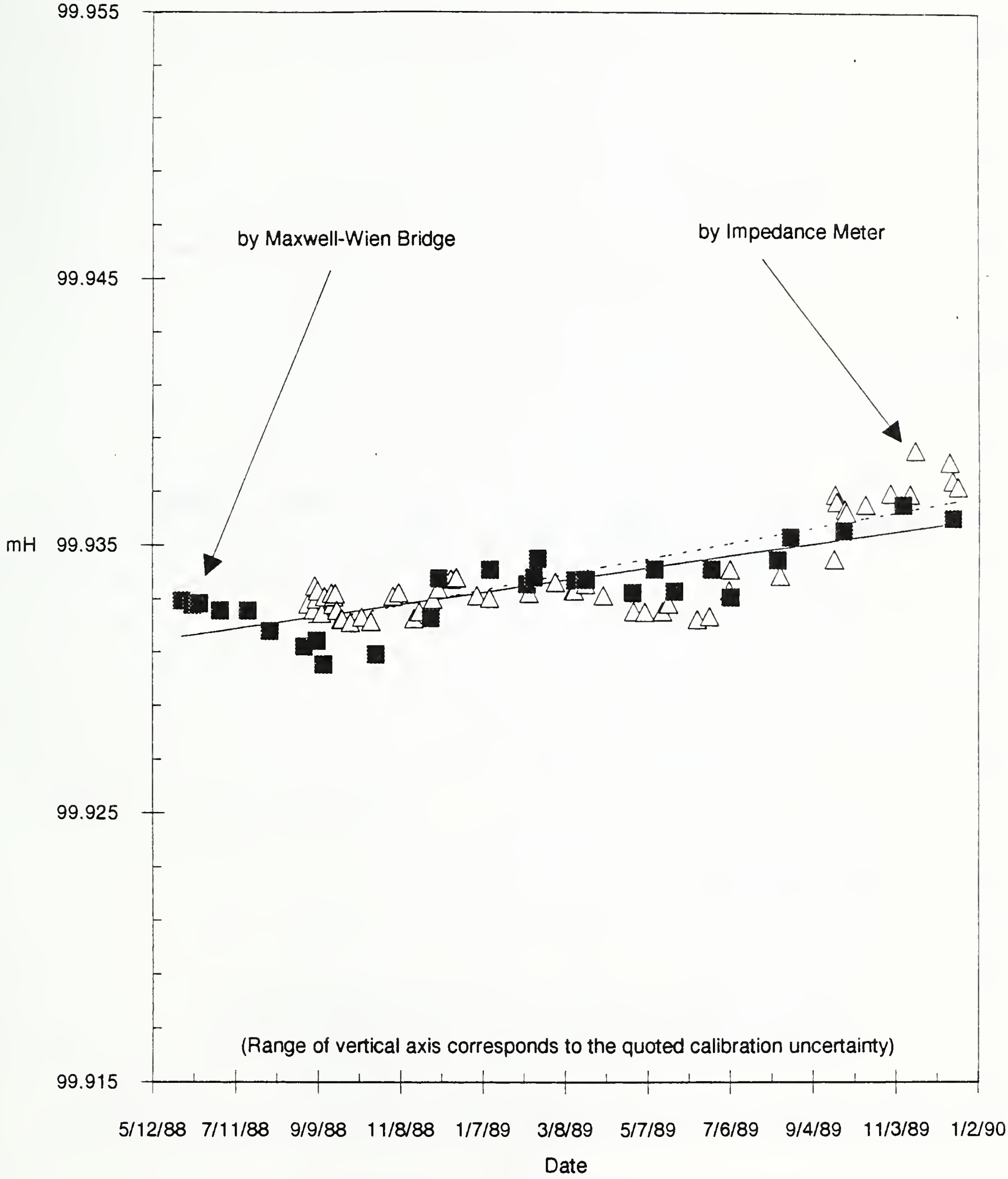

Figure 4. Measurements of NIST Standard L-1813 at 1 kHz

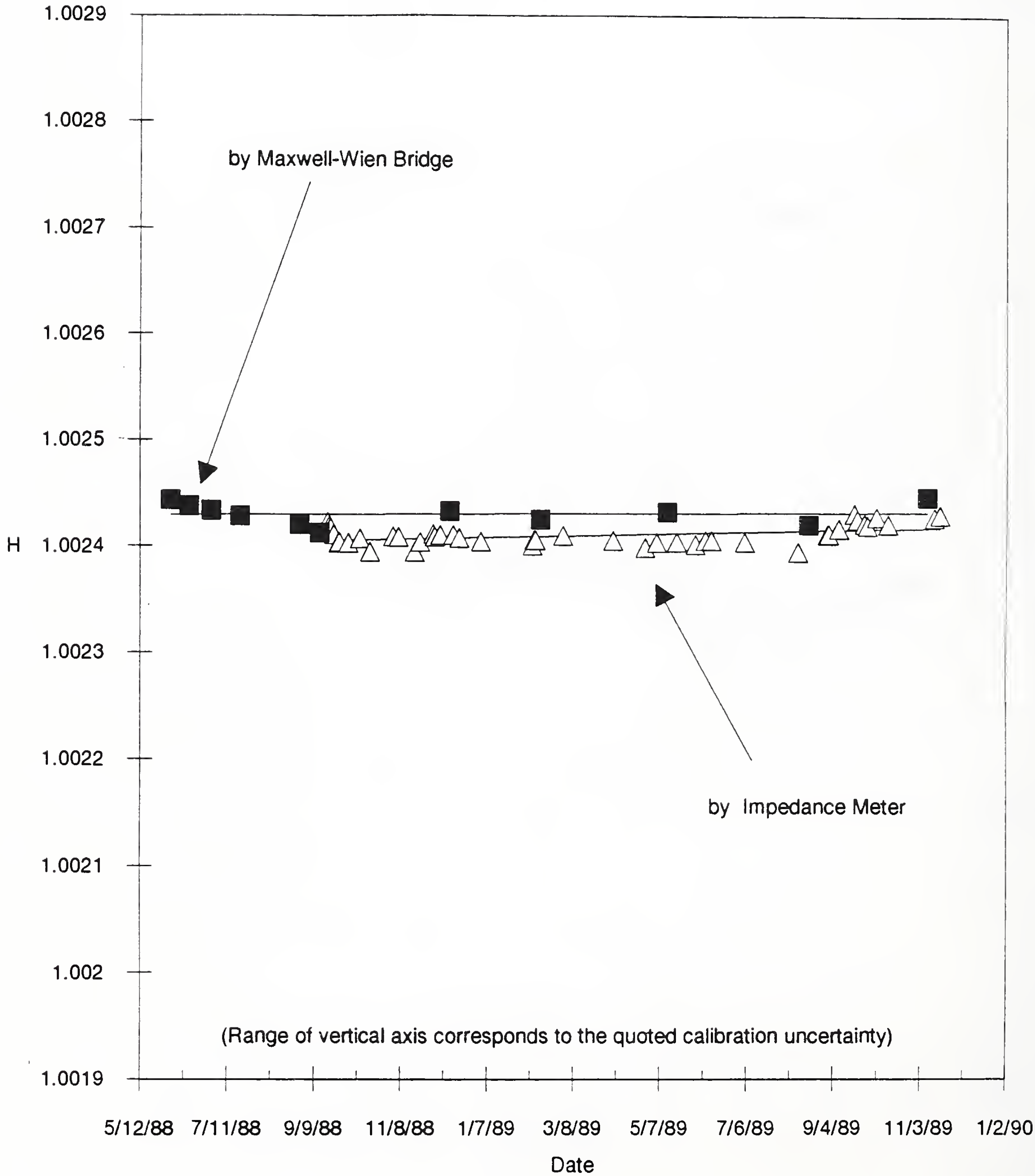

Figure 5. Measurements of NIST Standard P-1382 at 1 kHz

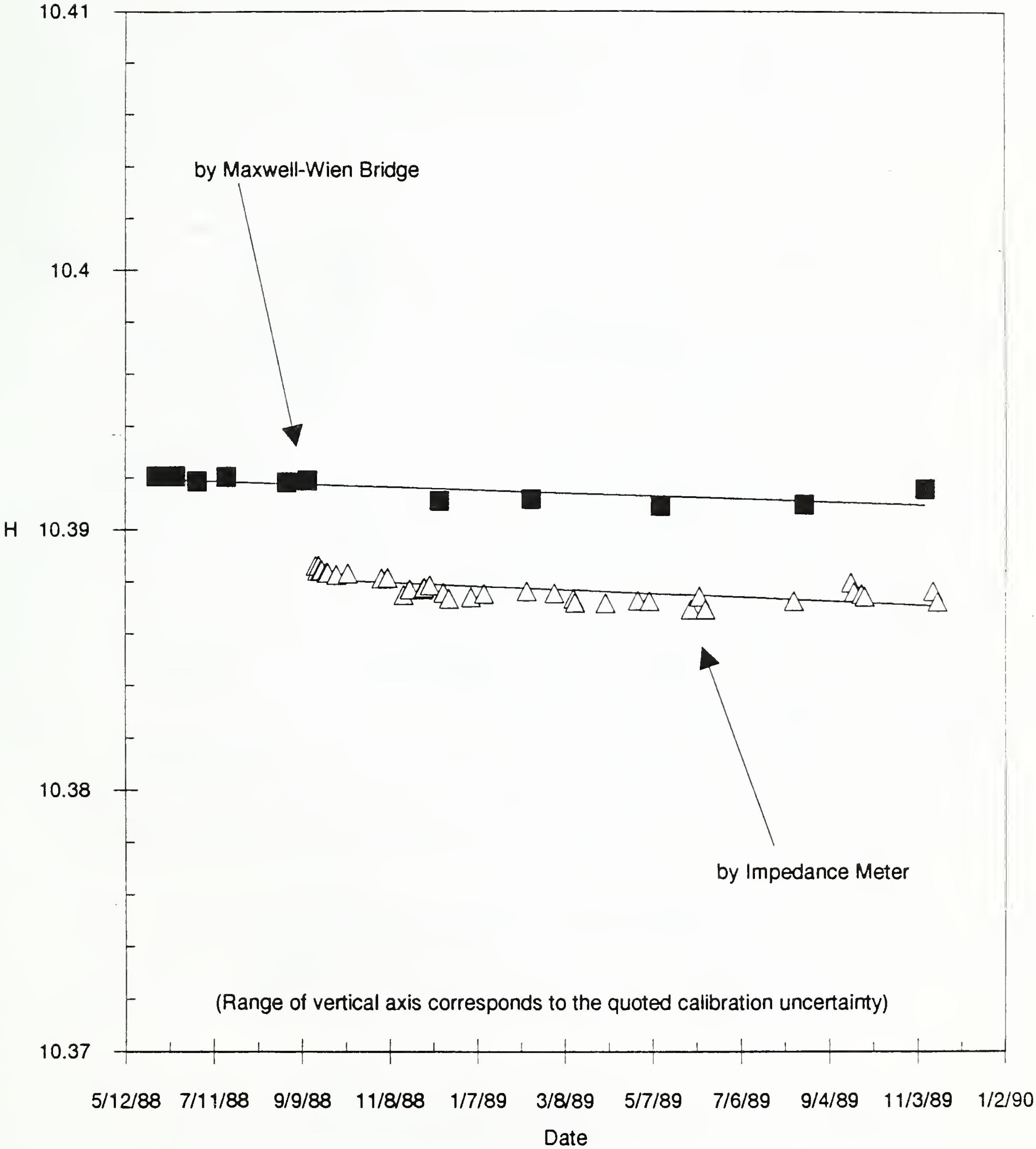

Figure 6. Measurements of NIST Standard T-2477 at 1 kHz

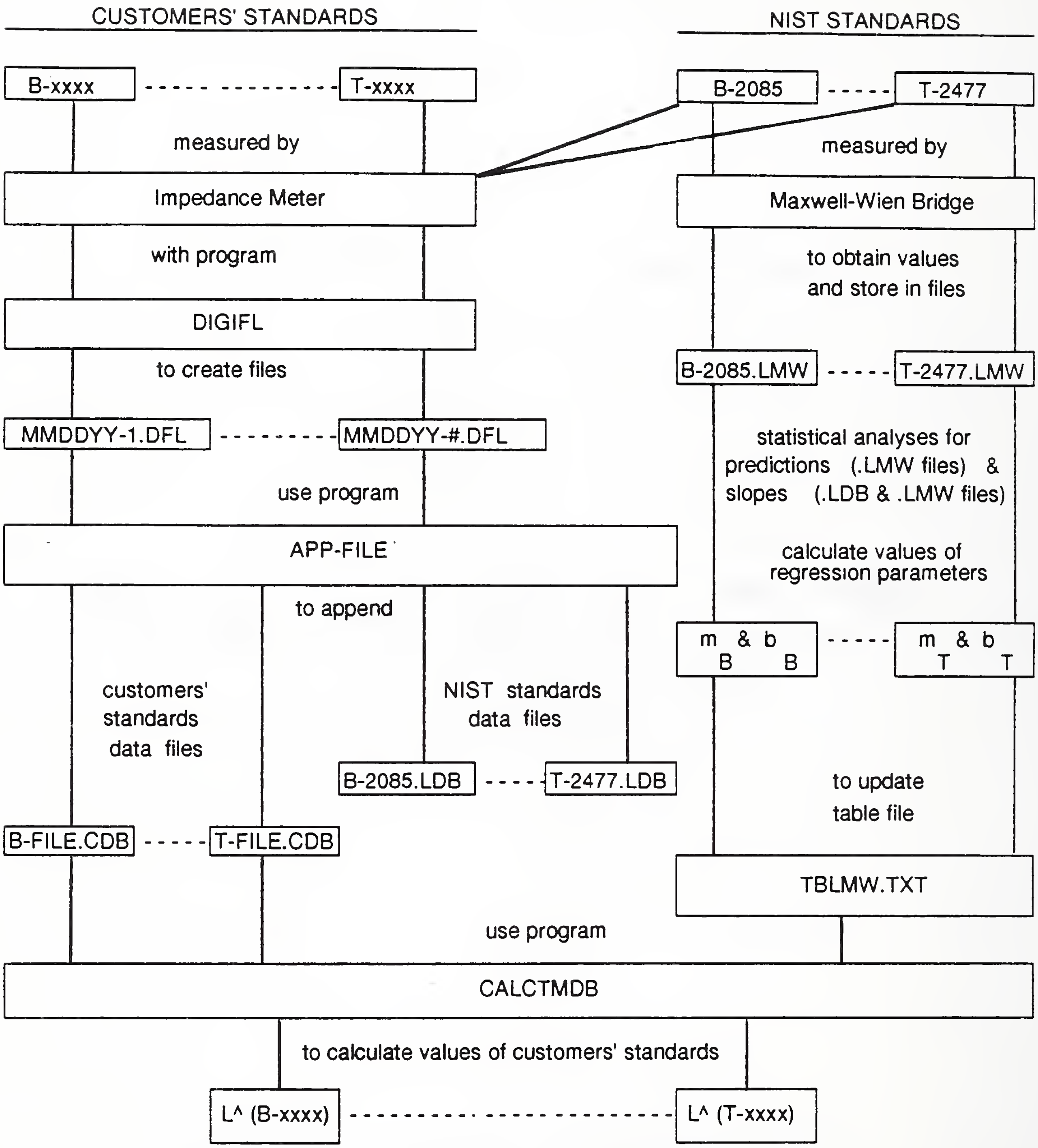

Figure 7. Block Diagram of Calibration Procedures for Inductance Standards

APPENDIX A. Description of Program DIGIDFL

The program DIGIDFL is written in the BASIC language to be run in a desktop computer system with HPBASIC[3] or HTBASIC[3] software and IEEE-488 instrumentation interface capability to measure inductance standards. When the program is started the parameters that need to be entered and measurement procedures required to be performed will be shown on the screen. The order is given in the following steps :

1. Enter frequency (in kHz) and room temperature (in °C).

2. Enter standard's group number (I, II, or III), or customer's (CTM).

3. Zeroing for the digibridge ? (YES/NO)
   If a YES is answered, OPEN and SHORT circuits zeroing for the meter are required to be performed following instructions given on the screen.
   If a NO is answered, the digibridge is ready to make measurements.

4. Enter standard's type and serial number.

Measurements will begin after parameters for step 4. are entered. Detailed information and results will be displayed on the screen with the option to print them on the line printer. A short form of only the measured data, with option for the line printer, will be displayed next on the screen.

5. More measurements needed for standards of same group at same frequency ?
   If a YES is answered, the program will go to step 3. above.
   If a NO is answered, an option to write data on the disk is displayed.
   A NO will end the program.
   A YES will initiate the following steps:

6. Enter the number of measurements for that date. (1, or 2, or any number)

After data are saved on the disk, there is an option to read the data back to the screen or to the line printer. At the conclusion of the program the screen will display END OF MEASUREMENTS.

When a customer's standard is being measured (Group CTM), after step 4., an option to measure a NIST standard of the same type will be displayed instead. This option enables a group of customer's standards of the same type to be measured prior to the measurement of the NIST standard. Afterwards, steps 5. and 6. will follow.

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[3] Such commercial software packages are identified in this report only to specify the measurement procedures adequately. It is not to be taken as a recommandation or endorsement by NIST, nor does it imply that such softwares are necessarily the best available for the purpose.

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☐ DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

Procedures for calibrating customers' inductance standards using a commercial impedance meter to compare them with NIST inductance standards by a substitution method are reported. These procedures are based on a six-month evaluation of the meter by measuring a group of six NIST inductance standards of different values at a frequency of 1 kHz. For each inductance standard, the results of measurements with the meter and the Maxwell-Wien bridge, which is used to realize the henry at NIST, are analyzed to determine the stabilities of the standards and the impedance meter as well as to estimate the random transfer uncertainty of the meter measurements. Values of inductance obtained using the Maxwell-Wien bridge are compared with corresponding values of inductance obtained with the meter by substituting customers' inductance standards with the six NIST standards over a period of six months. The statistical analyses used to assure that measurements made using such procedures are in control are described, as well as future plans to expand the substitution technique to include other values of inductance standards at various frequencies.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

calibration; impedance calibration procedures; impedance data analysis; impedance meter; inductance measurements; inductance standard; Maxwell-Wien bridge; prediction.

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