# Stability Evaluation of High-Precision Multifunction Instruments for Traceability Transfer

Cristina Cassiago, Giuseppe La Paglia, and Umberto Pogliano

***Abstract*—In the traceability transfer process from the national standards of the Istituto Elettrotecnico Nazionale "Galileo Ferraris" (IEN) to standards of calibration laboratories accredited by Servizio di Taratura in Italia (SIT), the use of high-precision multifunction instruments, in particular digital multimeters (DMMs), as reference standards turned out to be a good transfer method. In fact, their use provides swift and less expensive transfer at an uncertainty level comparable to that one obtained using high-precision individual standards, such as 10 V dc voltage standards, standard resistors, or ac/dc transfer standards.**

**In this paper, it is described how this transfer process is performed and what results are obtained.**

***Index Terms*—Calibration, electric measurements, instrument specifications, instrument stability, reference and transfer standards.**

## I. Introduction

In the last ten years, the introduction of high-precision electronic instruments, like digital multimeters (DMMs) and multifunction calibrators (MFCs), has significantly changed the traceability transfer process from metrological laboratories to calibration centers (CalLabs) and industrial laboratories, where these instruments are widely used as reference standards.

This work describes the investigations and systems developed by IEN, in order to check the metrological characteristics of the multifunction instruments intended to be used both as reference and working standards. Investigations have been especially focused on the evaluation of the medium- and the short-term stability of DMMs and MFCs, usually not specified by manufacturers, which enables the use of these instruments in more refined procedures with accuracy higher than that possible on the basis of their one-year specifications.

## II. IEN Laboratory for Calibration of High-Precision Multifunction Instruments

High-precision multifunction instruments are a result of the development of digital and analog electronics. The new remarkable features of these instruments are: high accuracy (in many measurement fields it is close to that of the best commercial standards), given by components such as DCV references, resistance networks, ac/dc converters, and analog-to-digital (A/D) converters [1]; several measurement fields, usually ac and dc voltage and current and dc resistance; microprocessor-based control for internal settings and the execution of internal self-calibration procedures, with the possibility of storing the correction factors; remote control (usually by IEEE488 interface). The block diagram in Fig. 1 shows, as an example, the key components of a DMM.

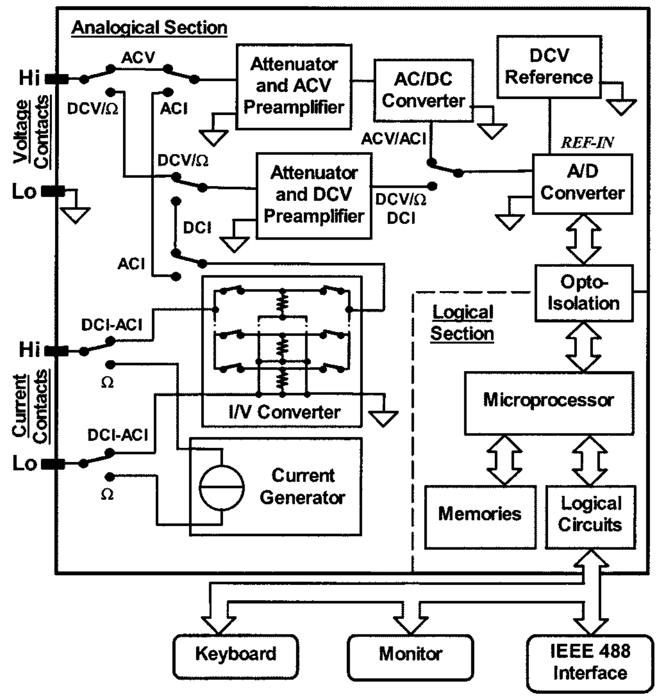


Fig. 1. Block diagram of a DMM. It gives an example of the key components employed in high-precision multifunction instruments.

The use of this kind of instrument by CalLabs as reference and working standards some years ago induced IEN to set up a dedicated laboratory (IENLab) for transferring the traceability from the national standards to the CalLab standards [2], [3], and for analyzing and developing more accurate calibration procedures.

The calibration system of the IENLab consists of a group of reference standards (shown in detail in Fig. 2), such as 10 V Zener voltage reference standard, two resistive voltage dividers, a set of standard resistors and shunts, and a programmable ac/dc voltage transfer standard, which are periodically calibrated versus the national standards. The system also includes three MFCs, used as working instruments, and some other auxiliary instruments used to extend the traceability.

The calibration of the MFCs is periodically performed and consists of an adjustment and a verification process, which consist of comparison measurements with IENLab reference standards.

Manuscript received May 26, 1999; revised July 7, 2000.

The authors are with the Department of Electrical Metrology of Istituto Elettrotecnico Nazionale "Galileo Ferraris," 91-10135 Turin, Italy.

Publisher Item Identifier S 0018-9456(00)09169-5.

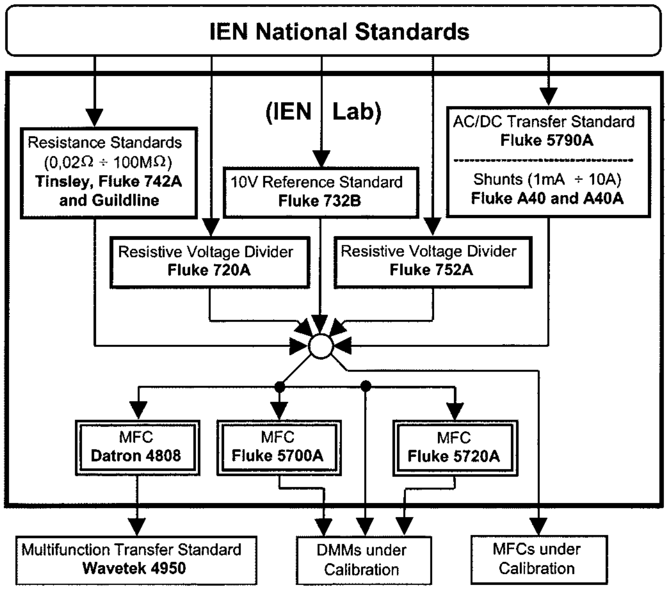


Fig. 2. IEN traceability chain for calibration of multifunction instrument calibration. Reference and working standards of the dedicated IEN laboratory are shown in detail.

The verification is performed immediately after the adjustment, and it covers a wide set of measurement points (usually larger than the adjustment point set). This MFC characterization allows the determination of MFC errors for each verification point and the calculation of correction factors. These factors are stored in the personal computer that controls the automatic calibration of other instruments, and the use of these factors reduces considerably their calibration uncertainty. Moreover, when possible, the MFC verification is obtained by means of a set of procedures for automatic adjustment and verification of MFCs from the associated standards.

The IENLab systems typically calibrate high-stability DMMs, which are used both for transferring the traceability and for testing the metrological capabilities of CalLabs by means of interlaboratory comparisons (ILCs).

## III. Metrological Characteristics of the High-Precision Multifunction Instruments

The results of the IEN periodic calibrations and verifications, in addition to other more specific measurements, have been used [4] to acquire knowledge about the metrological characteristics of the multifunction instruments, such as their medium- and short-term stability (i.e., the one-month and the 24-h stability), and to improve their capability for the transfer and the maintenance of the traceability. In fact, the medium-term stability can be exploited for more refined calibration processes that permit a simpler, easier and less expensive traceability transfer with a given accuracy, and for a more reliable ILC, in a fast way and over a wide measurement field. The short-term stability is considered in the comparison with dc, resistance and ac standards to simplify and improve the measurement processes.

### *A. Medium-Term Stability*

The medium-term stability of a MFC and of a DMM is considered in the case of the traceability transfer to a high-precision MFC used as a working standard. The high level of MFC accuracy requires a calibration uncertainty lower than that which would be possible on the basis of the DMM specifications. Usually, as advised by the manufacturer, the calibration can be obtained using high-precision individual standards (voltage reference standards, standard resistors, ac/dc transfer standards, etc.) periodically calibrated, but this way is expensive and complex. A simpler way is given by using a DMM as reference standard, but in this case, there is an increase in the MFC uncertainty, caused by DMM accuracy specifications (one-year specifications).

Some CalLabs chose the second method, exploiting the DMM as transfer standard. In this case, its medium-term stability, instead of one-year specifications, intervenes in the transfer process uncertainty that became comparable to that one obtained by mean individual standards. That traceability transfer process is described in Fig. 3, and essentially consists of:

- 1° step: characterization of the IEN laboratory MFC in a well-defined set of measurement points, as it is described in Section II;
- 2° step: automatic calibration of the DMM (the CalLab transfer instrument), by means of the IENLab MFC and performing the calibration procedures suggested in the instrument handbook, within one month from the characterization of the MFC on the same set of measurement points or a subset of them; the results are automatically corrected by a program that uses the MFC correction factors stored in a personal computer;
- 3° step: calibration of the MFC (the CalLab working instrument), by means of the CalLab DMM and performing the calibration procedures suggested in the instrument handbook, at the same measurement points of the DMM calibration, correcting the results by data of the DMM calibration certificate.

The most significant uncertainty components of the traceability transfer process are represented by the uncertainty of the IENLab reference standards, the medium-term stability of the characterized MFC and the medium-term stability of the DMM (related to the transfer from the DMM to the CalLab MFC).

At the present time the market offers only two types of DMM, which can operate on all electrical function with the sufficient level of accuracy. Table I gives an example of the results of the traceability transfer by means of these DMMs. These data are obtained from several ILCs, where some travelling instruments of the two different types (DMM A is a Datron 1281 and B a Hewlett-Packard 3458) are directly compared with the IENLab MFC before and after the transportation, in a period of time of about one month. The repeatability of the results is given by the average and by the maximum difference between the comparison results versus the IENLab MFC. These data contain the medium-term stability of both the MFC and the DMM and the contribution of transportation, and they are clearly better (about half order) than the one-year instrument specifications.

The validity of this transfer method is also deduced from data of Table II, where the uncertainty levels of MFC calibration using the DMM (type A), as reference and transfer stan-

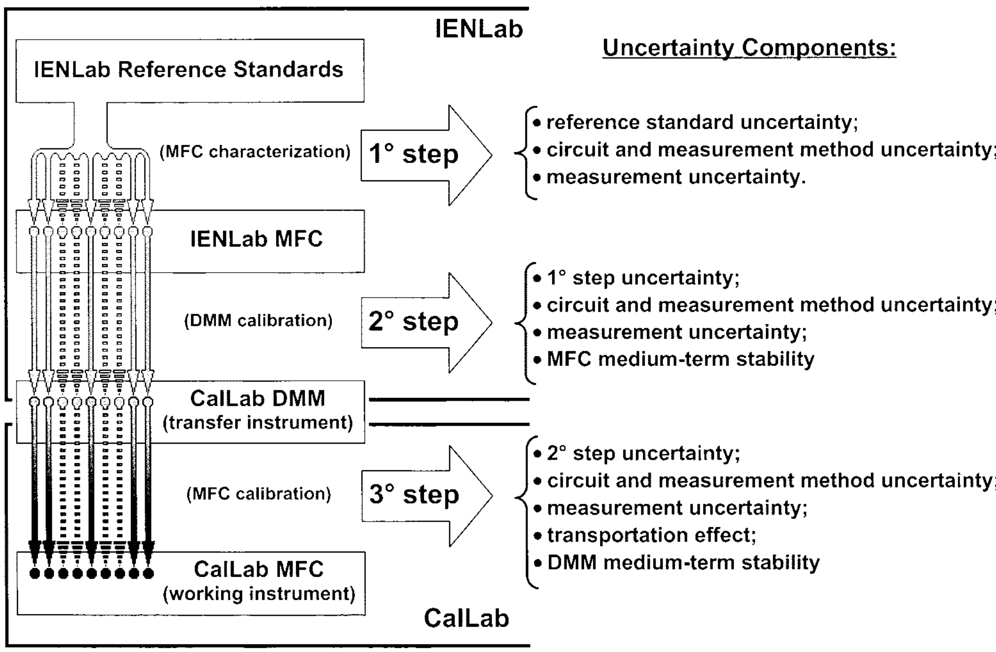


Fig. 3. Representation of the traceability transfer by means of high-precision DMMs, with the uncertainty components of the transfer process.

TABLE I
DATA OBTAINED FROM SEVERAL INTERLABORATORY COMPARISONS, WHERE SOME TRAVELLING INSTRUMENTS OF DIFFERENT MODELS (DMM A = DATRON 1281 AND DMM B = HP 3458) ARE COMPARED AGAINST THE IEN MFC BEFORE AND AFTER THE TRANSPORTATION, IN A PERIOD OF TIME OF ABOUT A MONTH. ((*) MEASUREMENT PERFORMED AT 600 V)

| Function | Calibration Point | 1-year Specifications | | DMM Verification Relative Differences | | | |
|---|---|---|---|---|---|---|---|
| | | | | DMM A | | DMM B | |
| | | DMM A ($10^{-6}$) | DMM B ($10^{-6}$) | average ($10^{-6}$) | max ($10^{-6}$) | average ($10^{-6}$) | max ($10^{-6}$) |
| VDC | 100mV | 7 | 15 | 1.7 | 4.2 | 1.5 | 2.5 |
| | 1V | 3.4 | 5 | 0.4 | 0.8 | 0.7 | 1.1 |
| | 10V | 3.2 | 4.2 | 0.3 | 0.4 | 0.6 | 1.3 |
| | 100V | 6.4 | 6.3 | 1.2 | 2.0 | 0.7 | 1.1 |
| | 1000V | 6.4 | 16.1 | 1.2 | 1.7 | 0.6 | 0.8 |
| VAC | 100mV 1kHz | 120 | 90 | 1.9 | 3.0 | 7.4 | 15 |
| | 1V 1kHz | 80 | 90 | 2.7 | 6.0 | 12 | 20 |
| | 10V 1kHz | 80 | 90 | 2.9 | 8.0 | 11 | 20 |
| | 10V 100kHz | 700 | 820 | 38 | 82 | 18 | 35 |
| | 100V 1kHz | 80 | 220 | 3.2 | 9 | 21 | 29 |
| | 1000V 1kHz | 1276 | | 7.2 | 13 | 22* | 38* |
| IDC | 1mA | 29 | 25 | 7.4 | 12 | 4.5 | 8.3 |
| | 10mA | 29 | 25 | 7.7 | 19 | 3.4 | 6.8 |
| | 100mA | 60 | 40 | 2.2 | 3.9 | 13 | 18 |
| | 1A | 170 | 120 | 10 | 21 | 13 | 23 |
| IAC | 10mA 1kHz | 400 | 320 | 29 | 60 | 23 | 41 |
| | 100mA 1kHz | 400 | 320 | 34 | 90 | 18 | 28 |
| | 1A 1kHz | 900 | 1020 | 36 | 110 | 31 | 49 |
| OHM | 10Ω | 14 | 20 | 4.0 | 8.0 | 1.1 | 1.7 |
| | 100Ω | 8.6 | 17 | 0.7 | 1.0 | 1.0 | 1.1 |
| | 1kΩ | 6.6 | 10.5 | 0.5 | 0.9 | 0.6 | 0.9 |
| | 10kΩ | 6.6 | 10.5 | 0.3 | 0.6 | 0.4 | 0.7 |
| | 100kΩ | 6.6 | 10.5 | 1.6 | 4.6 | 0.6 | 1.0 |

TABLE II
THE UNCERTAINTY LEVELS OF MFC CALIBRATION USING THE DMM (AS REFERENCE AND TRANSFER STANDARD) AND HIGH-PRECISION INDIVIDUAL STANDARDS ARE COMPARED. DATA OF CASE 2 AND 3 ARE OBTAINED CONSIDERING THE DMM ONE-YEAR SPECIFICATIONS AND ITS SHORT-TERM STABILITY; DATA OF CASE 1 ARE TYPICAL ACCREDITATION LEVELS OF A CalLab, WITH HIGH PRECISION INDIVIDUAL STANDARDS

| Function | Calibration Point | MFC 1-year Specifications ($10^{-6}$) | MFC Calibration Accuracy | | |
|---|---|---|---|---|---|
| | | | Case 1 ($10^{-6}$) | Case 2 ($10^{-6}$) | Case 3 ($10^{-6}$) |
| VDC | 100mV | 17 | 7 | 9,2 | 7,1 |
| | 1V | 9,2 | 1,3 | 4,6 | 2,9 |
| | 10V | 8,4 | 1,3 | 4,5 | 2,9 |
| | 100V | 10 | 2,1 | 7 | 3,4 |
| | 1000V | 11,6 | 4 | 7,7 | 4,6 |
| VAC | 100mV 1kHz | 210 | 81 | 134 | 66 |
| | 1V 1kHz | 92 | 38 | 87 | 36 |
| | 10V 1 kHz | 92 | 38 | 87 | 36 |
| | 10V 100 kHz | 320 | 100 | 716 | 138 |
| | 100V 1kHz | 100 | 40 | 96 | 56 |
| | 1000V 1kHz | 94 | 57 | 1277 | 62 |
| IDC | 1mA | 70 | 11 | 33 | 22 |
| | 10mA | 70 | 11 | 33 | 22 |
| | 100mA | 80 | 14 | 63 | 23 |
| | 1A | 125 | 41 | 174 | 44 |
| IAC | 10mA 1kHz | 200 | 85 | 406 | 93 |
| | 100mA 1kHz | 400 | 95 | 406 | 123 |
| | 1A 1kHz | 790 | 95 | 907 | 150 |
| OHM | 10Ω | 33 | 8 | 17,3 | 13 |
| | 100Ω | 20 | 3 | 10,1 | 3,5 |
| | 1kΩ | 15 | 3 | 8,5 | 3,5 |
| | 10kΩ | 14 | 2 | 8,5 | 3,5 |
| | 100kΩ | 16 | 6,5 | 8,5 | 7,2 |

dard (Cases 2 and 3), and high-precision individual standards (Case 1) are compared. The data of the Case 3 are evaluated as showed in Fig. 3, where the medium-term stability is the max value of Table I. In the Case 2, the DMM one-year specification is considered, instead of the DMM medium-term stability. The data of the Case1 represent typical uncertainty levels of a CalLab that uses individual reference standards. For all the five electrical functions, a significant improvement can be observed, in particular for the ac functions, and the Cases 1 and 3 show how the MFC calibration accuracy using the DMM as transfer standard is comparable to that one obtained using a set of high-precision individual standards.

## *B. Short-Term Stability*

The short-term stability of multifunction instruments, together with their high linearity, can remarkably simplify some calibration processes in the CalLabs, reducing the number of

TABLE III
DISPERSION OF A SERIES OF TEN MEASUREMENTS, ABOUT ONCE AN HOUR, PERFORMED WITH TWO DIFFERENT MODELS OF DMMs, WITH AND WITHOUT THE ACTIVATION OF THE AUTO-CALIBRATION PROCESS (DMM A = DATRON 1281 AND DMM B = HP 3458)

| Function | Measurement Point | Dispersion (1σ) DMM A Autocalibration without ($10^{-6}$) | DMM A Autocalibration with ($10^{-6}$) | DMM B Autocalibration without ($10^{-6}$) | DMM B Autocalibration with ($10^{-6}$) |
|---|---|---|---|---|---|
| DCV | 100mV | 0.6 | 1.4 | 0.6 | 0.8 |
| | 1V | 0.1 | 0.2 | 0.1 | 0.2 |
| | 10V | 0.0 | 0.2 | 0.1 | 0.1 |
| | 100V | 0.4 | 1.0 | 0.3 | 0.1 |
| | 1000V | 0.3 | 1.2 | 0.2 | 0.2 |
| ACV | 100mV 1kHz | 2.5 | 2.1 | 4.2 | 4.4 |
| | 1V 1kHz | 0.6 | 0.8 | 5.6 | 4.3 |
| | 10V 1kHz | 0.5 | 1.0 | 4.3 | 3.4 |
| | 1MHz | 130 | 60 | 21 | 29 |
| | 100V 1kHz | 0.8 | 0.7 | 5.5 | 12.2 |
| DCI | 1mA | 1.9 | 1.0 | 2.7 | 0.2 |
| | 100mA | 0.4 | 3.5 | 6.5 | 1.9 |
| | 1A | 1.3 | 1.5 | 2.8 | 17.7 |
| ACI | 1mA 1kHz | 7.9 | 6.3 | 9.6 | 16.4 |
| | 100mA 1kHz | 7.0 | 4.5 | 5.8 | 15.5 |
| | 1A 1kHz | 8.3 | 4.7 | 16.2 | 19.3 |
| | 5kHz | 6.3 | 7.1 | 57.2 | 63.0 |
| OHM | 100Ω | 0.1 | 0.2 | 0.7 | 1.1 |
| | 10kΩ | 0.1 | 0.2 | 0.7 | 0.3 |
| | 1MΩ | 0.1 | 0.3 | 0.5 | 0.4 |

instruments involved (such as Kelvin–Varley dividers, null detectors and dedicated bridges) and the performing time. In this way, it is possible to increase the number of measurements with a consequent increase of information about the metrological capability of this kind of instrument.

To evaluate the short-term stability of DMMs a series of ten measurements, about once an hour, was performed with the two different types of high-precision DMMs, also evaluating the influence of the auto-calibration process (SELFCAL and ACAL function). It can be deduced, from Table III, that the effect of the auto-calibration does not influence the DMM short-term stability. This is useful when it needs compensation of drift effects caused by temperature. As a general consideration, the high stability of these multifunction instruments allows comparisons between high-precision individual standards [5], [6], since the comparison uncertainty is essentially the DMM short-term stability.

A typical example is given by the comparison of 10 V DCV standards. In this case, the comparison uncertainty is reduced in comparison with the one-year instrument stability and the DCV standard uncertainty that is used as reference.

The same happens with the resistance standard comparisons, in particular in the range from 100 Ω to 1 MΩ. Instead, for lower resistance values there is a worsening due to the reduced DMM resolution and stability. Then an indirect method can be applied, supplying the series of two resistors by the measurement current and reading the voltage drop on them separately. For higher resistance values, the effects of measurement cables and the environmental conditions have to be considered.

Another application, where the consideration of the short-term stability may be used, is in the ac standard comparisons. Here the instrument used as comparison device is

TABLE IV
DISPERSION OF A SERIES OF FOUR CALIBRATION PROCESSES IN ACV BY MEANS OF ac/dc TRANSFER PERFORMED IN A TIME FROM 1 TO 24 h

| Function | Frequency | Measurement Point | AC Standard 1-year Absolute Specifications ($10^{-6}$) | Dispersion (1σ) ($10^{-6}$) |
|---|---|---|---|---|
| ACV | 40Hz | 0.1V | 53 | 2.9 |
| | | 1V | 24 | 0.9 |
| | | 10V | 27 | 1.1 |
| | | 100V | 31 | 1.9 |
| | | 1000V | 38 | 1.3 |
| | 1kHz | 0.1V | 53 | 2.7 |
| | | 1V | 24 | 1.4 |
| | | 10V | 27 | 1.1 |
| | | 100V | 31 | 2.3 |
| | | 1000V | 38 | 2.3 |
| | 20kHz | 0.1V | 53 | 2.3 |
| | | 1V | 24 | 0.7 |
| | | 10V | 27 | 0.9 |
| | | 100V | 31 | 0.8 |
| | | 1000V | 38 | 9.7 |
| | 100kHz | 1V | 71 | 1.4 |
| | | 10V | 81 | 2.5 |
| | | 100V | 98 | 7.3 |
| | 500kHz | 1V | 260 | 49 |
| | | 10V | 400 | 36 |
| | 1MHz | 1V | 900 | 109 |
| | | 10V | 1200 | 95 |

a MFC. The validity of this comparison method is shown by data presented in Table IV, where, with the high-precision ac standard specifications, the results of four MFC calibration processes in ACV, performed in a time from 1 to 24 h, are reported. From them the MFC short-term stability can be deduced. It can be observed that only on the higher frequency range (500 kHz and 1MHz) the instrument stability is worse, but in general it can be used as a good comparison device for ac standards. It has to take into account of the possible loading effects caused by different input impedance of the ac standards compared, that can introduce systematic errors [7].

## IV. CONCLUSION

The IEN analysis about the metrological characteristics performed in these years of a significant number of high-precision multifunction instruments showed their stability characteristics, such as medium- and short-term stability, can be considered intrinsic of the instrument models. This kind of information is not so easily achievable, because it can be obtained only by CalLabs with a very high traceability level and with a long calibration activity on a large number of these instruments, like the manufacturers or a national laboratory. So, because of the very large number of tested and calibrated instruments, the obtained results may be extended to the whole instrument class, contributing to the definition of better uncertainty levels in the use of these instruments. Then the CalLabs can be confident in employing MFCs and DMMs, in more refined calibration procedures without special characterizations, as standards to transfer and maintain the traceability at an accuracy level sufficient even for the calibration of other instruments of the same level. Moreover, the DMMs can be used as good travelling standards for improving the control of the CalLab metrological capabilities.

## References

[1] P. B. Crisp, “A generic DMM test and calibration strategy,” *Int. J. Petrol.*, pp. 24–34, July/Aug. 1997.

[2] G. C. Bosco, G. La Paglia, U. Pogliano, and G. Zago, “A system for traceability maintenance and verification based on high stability multimeters,” in *Proc. XIII IMEKO World Congr.* , Torino, Italy, 1994, pp. 517–522.

[3] U. Pogliano, G. C. Bosco, R. Cerri, and G. La Paglia, “An alternative approach to ensure traceability utilizing high stability multimeters,” in *Proc. Métrologie’97*, Nimes, France, 1995, pp. 346–351.

[4] G. C. Bosco, R. Cerri, C. Cassiago, G. La Paglia, and U. Pogliano, “Investigation on the use of multifunction programmable instruments,” in *Proc. X IMEKO TC4 Symp.*, 1998, pp. 489–492.

[5] P. B. Crisp, “Getting the best out of long scale DMMs in metrology application,” in *MCSL Workshop and Symp.*, 1997, pp. 151–160.

[6] ——, “DMMs high linearity eases resistance calibration,” in *Test and Measurement Europe*, Feb./Mar. 1998, pp. 26–28.

[7] N. Faulkner and B. Stott, “Loading effects of AC/DC transfer standards,” in *NCSL Workshop and Symp.*, 1997.

**Cristina Cassiago** was born in 1966 in Turin, Italy. She received the M.S. degree in physics in 1994 from Università degli Studi di Turin, were she worked on electron spectroscopy analysis of diamond thin films.

She joined the Electrical Metrology Department of the Istituto Elettrotecnico Nazionale “Galileo Ferraris” (IEN), Turin, in 1996. At present, she is working on Quantum Hall Effect and in the field of precision measurement and and traceability transfer processes by means of high precision multifunction instruments.

**Giuseppe La Paglia** was born in 1953 in Turin, Italy. He received the high school degree in nuclear energy.

Since 1972, he has been at the Electrical Metrology Department of Istituto Elettrotecnico Nazionale “Galileo Ferraris” (IEN), Turin, working on measurements in the field of high voltages and strong currents, measurement transformers, electrical power and energy, and on high-precision multifunction instruments. He is also Technical Secretary of SIT (Italian Calibration Service).

**Umberto Pogliano** was born in 1950 in Leinì, Turin, Italy. He received the Dr. Ing. degree in electronic engineering in 1975 and the doctorate degree in metrology in 1987, both from the Politecnico of Turin.

In 1997, he joined the Electrical Metrology Department of the Istituto Elettrotecnico Nazionale “Galileo Ferraris” (IEN), Turin. His research activity has been focused on the modeling of standards, and on the development of systems and procedures in the field of precision dc and ac low-frequency measurements. At present, his main interests are in the ac-dc transfer standard, in the ac voltage, current, and power measurements, and in the generation, acquisition, and reconstruction of electrical signals.