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Network-Assisted Procedure for Impedance Dissemination

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Abstract *– A new technique for disseminating impedance measurement units from National Metrology Institutes to secondary laboratories is proposed in this paper. Such a technique takes advantage of a client-server application over the Internet and employs a commercially available impedance calibrator with computer-interfacing capabilities. The calibrator, which is employed as a traveling standard, is sent to the secondary laboratory, where the traceability transfer process toward a digital impedance meter is performed. Such a process is remotely managed through the Internet by the National Metrology Institute, which acquires the measurement results and issues the calibration certificate of the impedance meter. The proposed solution allows the impedance dissemination process to be largely simplified with respect to the traditional calibration technique, so that the traceability-maintenance cost a secondary laboratory has to sustain is drastically reduced. The architecture of the developed client-server application over the Internet is described in the paper and preliminary results that are related to the characterization of the employed traveling standard are reported.*

Keywords *– standard, calibration, impedance measurement, internetworking, interconnected system*

I. INTRODUCTION

The measurement of electrical impedance is frequently required both in electrical applications, such as in the characterization of electrical machines and AC current shunts, and in the measurement of non-electrical quantities, since a lot of sensors convert physical and chemical quantities into impedance changes. However, the traceability of instruments that carry out impedance measurements is often hard to achieve, due to the low number of laboratories that offer impedance calibration services. As an example, within the Italian National Calibration System only three secondary laboratories out of 173 provide capacitance calibration, two inductance calibration and only one AC resistance calibration.

This situation is due to high cost and complexity of the dedicated systems that allows impedance measurement to be performed. Such systems are commonly based on manually-adjusted or auto-balancing bridges, which require the availability of a large set of variable standards, or employ costly vector-voltmeters. In addition to the initial investment for such instruments, another reason often prevents secondary laboratories from activating an impedance-calibration service, that is the cost of the traceability maintenance. National Metrology Institutes (NMI) usually disseminate impedance measurement units by means of artifact standards, therefore secondary laboratories have to own a great number of artifact standards that have to be periodically sent to the NMI for calibration. Such a calibration is costly not only for the calibration cost itself, but also for the cost of transferring these large and heavy artifacts to and from the NMI.

In this paper, an alternative solution is proposed for the dissemination of impedance measurement units, which is based on a traveling standard and on a client-server application over the Internet that allows the calibration of the secondary-laboratory instruments to be remotely exercised. Main goal of the proposed solution is a strong reduction of the traceability-maintenance cost, that would encourage secondary laboratories to extend their capabilities to the impedance.

II. NETWORK-ASSISTED DISSEMINATION PROCEDURE

The dissemination of impedance measurement units is commonly performed by means of the traceability chain shown in Fig. 1.(a). A large set of primary standards is maintained at the NMI, which is used in international comparison programs and assures the compatibility of the realized measurement units with the units of other NMIs. The secondary laboratories own a set of artifact standards, such as resistors, inductors and capacitors, which act as the secondary standards and that are periodically sent to the NMI for the verification against the primary standards. When a secondary laboratory receives its standards from the NMI, a series of procedures is activated for the traceability transfer towards the working standards, which are employed to calibrate instruments and standards of external clients. Besides the calibration of the working standards, the traceability transfer procedures also deal with other activities that are related to the laboratory quality-assurance. Examples of these activities are the estimation of the transport effects on

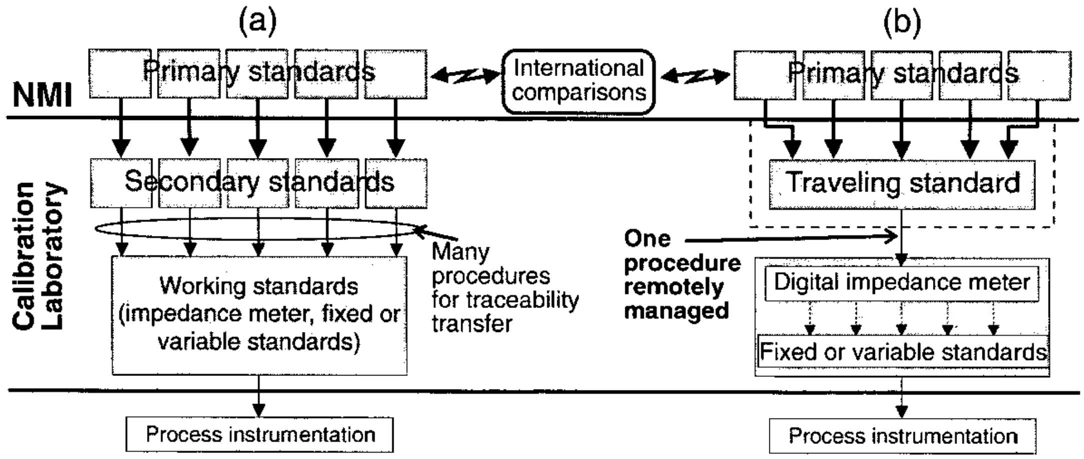

Fig. 1. Dissemination of impedance measurement units: the conventional (a) and the proposed traceability chains (b).

the secondary standards and the mutual periodical verification between the laboratory standards.

The described dissemination process suffers from three main problems:

- the high cost of the artifact standards that the laboratory employs for the traceability transfer;
- the high cost that is connected with the periodical calibration of the artifact standards and their movement;
- the complexity of the traceability-transfer process from secondary towards working standards.

These problems often arise in the dissemination of other electrical quantities and some solutions have been already proposed in order to tackle them. Such solutions are based on traveling standards that are sent to the secondary laboratories and that are remotely managed. In such a way, a full control of the calibration process can be performed by employing digital cameras and microphones at both NMI and secondary laboratory [1] or by means of commercial [2] or specifically-designed software [3].

In this paper a similar solution is proposed that allows the calibration procedure to be remotely exercised in a fully automated way. The traceability chain the authors propose has the architecture that is shown in Fig. 1.(b). The bulky set of secondary standards, owned by the secondary laboratory and used in the conventional procedure, is replaced by a single traveling standard, equipped with a computer interface card (RS-232, USB, IEEE-488, ...)., which is provided by the NMI. Such a traveling standard is calibrated against the primary standards at the NMI and then is sent to the secondary laboratories, where a traceability-transfer process is performed towards a digital impedance meter.

In order to perform the proposed calibration procedure, the digital impedance meter needs to be equipped with a computer interface, but this does not represent a real limitation, since all modern devices are computer controllable.

This way the calibration process is remotely managed by the NMI that is able to operate on both the traveling standard and impedance meter through the Internet. Other laboratory working-standards can be eventually be calibrated against the impedance meter.

This solution allows four main advantages to be obtained:

- the laboratory is not required to invest in the secondary standards, since the digital impedance meter is calibrated against the traveling standard;
- the traceability transfer procedures the laboratory has to activate are drastically reduced, since only fixed or variable standards have to be calibrated against the impedance meter;
- it is not required a skilled technician to attend the impedance meter calibration, since it is remotely exercised;
- the quality management of the traveling standard is responsibility of the NMI.

The proposed procedure therefore transfers most of the calibration problems from the secondary laboratory to the NMI, that has to acquire one or more traveling standards. However, the cost of such standards usually does not have a significant impact on the budget of an NMI. Furthermore, it seems the NMI has to spend more time in the quality management of these devices than in the conventional procedure, but this operation can be performed in a fully automated way, thus minimizing the time effort of the NMI.

A. *Implemented procedure*

Thanks to the recent commercial availability of an impedance calibrator (Orbit Controls AG - model OCM 500B) that can be employed as the traveling standard, the traceability chain described in the previous section has been implemented by arranging the interconnected system that is shown in Fig.

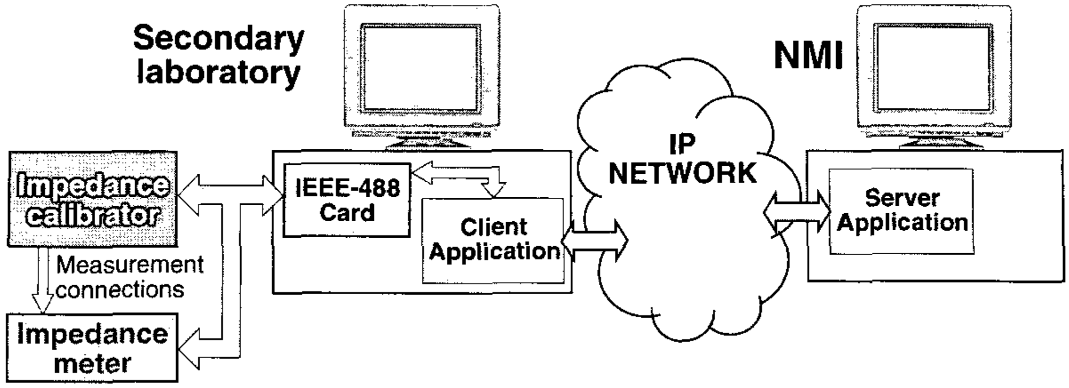

Fig. 2. Architecture of the proposed network-assisted dissemination process.

2. The calibrator and the impedance meter under calibration are connected through an IEEE-488 card to a Personal Computer at the secondary LABoratory (LAB-PC). A specifically-designed software program runs on the LAB-PC and acts as the client application that connects through the Internet to a server application, which runs on a Personal Computer at the NMI (NMI-PC). Once the connection between LAB-PC and NMI-PC has been established, the server application sends messages to the client application in order to remotely exercise the calibration procedure. The client application routes these messages to the local operator, through visual instructions, to the impedance calibrator and to the meter, through an IEEE-488 card. Messages for the operator are basically connection instructions, while the other messages are intended for the configuration of traveling standard and meter under calibration. The client application also acquires the measurements the meter carries out, which are sent to the server-application at the NMI-PC. There the calibration results are real-time processed in order to highlight non-conformity situations or procedure malfunctions.

The client-server application over the Internet has the architecture that is shown in Fig. 3. The application, which is a modified version of a previous authors' work [3], [4], has been developed in the Java language for portability purposes. Client and server applications embed the Java class SSLSocket that allows the Secure Sockets Layer (SSL) protocol [5] to be employed in the communication between LAB-PC and NMI-PC. The SSL protocol provides data encryption that assures confidentiality and integrity of the information exchanged through the Internet. The system has already been tested in the Windows^{TM} environment and is now under test in a Linux platform. Due to the portable nature of Java, the client application is not able to directly access to the hardware devices, therefore the Java Native Interface (JNI) tool has been employed to develop a Dynamic Link Library (DLL) that acts as an intermediate layer between the Java application and the manufacturer driver of the IEEE-488 card.

The calibration procedure, which is required for the specific impedance meter to be calibrated, is coded into a textual Command File, which is a sequence of instructions that configure impedance calibrator and meter under calibration, require the operator at the secondary laboratory to perform the measurement connections, set the calibrator output and acquire the meter readings. In many cases, the operator is required to connect the calibrator to the meter only once at the beginning of the procedure.

The Management Module at the NMI-PC loads the Command File in order to start the calibration procedure and save the calibration results into a Data File, which the NMI employs to issue the calibration certificate.

More details about the client-server application and the data flow between LAB-PC and NMI-PC can be found in [3], [4].

B. Uncertainty of the working traceability-chain vs the network-assisted chain

The working chain the Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN) maintains in Italy for the electrical impedance is based on discrete standards of AC resistance, inductance and capacitance. Such a chain ensures the calibration uncertainties that are declared in IEN Common Measurement Capabilities (CMC) [6]. The table that is shown in Fig. 4 summarizes the calibration uncertainty for some of these standards, which correspond to the values the impedance calibrator can provide.

The calibration uncertainty of the proposed traceability chain mainly depends on the metrology specifications of the impedance calibrator. Such a device allows four terminal-pair connection to be performed and contains 9 resistance standards in the range of 100 mΩ to 10 MΩ in decade series, 7 capacitance standards in the range of 10 pF to 10 μF in decade series and 5 inductance standards in the range of 1 mH to 10 H in decade series. Values of all resistance and capacitance standards are provided at 9 different frequencies (100 Hz, 120 Hz,

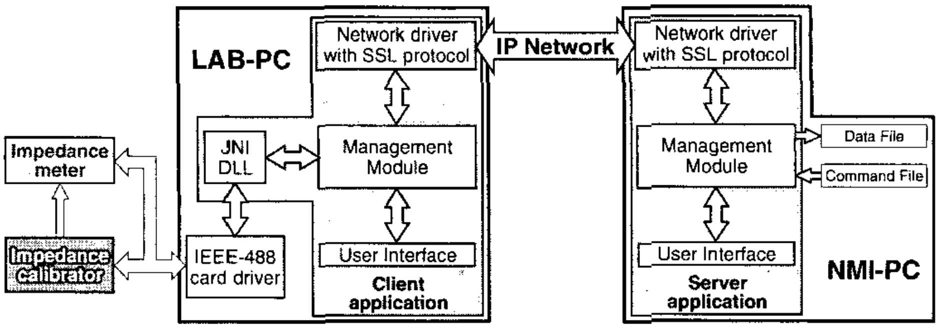

Fig. 3. Architecture of the client-server application.

200 Hz, 400 Hz, 1 kHz, 2 kHz, 4 kHz, 10 kHz and 20 kHz). The value of 1 mH and 10 mH inductance standards are provided at the same frequencies, while the other inductance standards are stated only for certain frequency values. The uncertainty of these standards, which are stated only @ 1 kHz and in the temperature range of 22 °C to 24 °C, spans from 0.05% for medium resistance and capacitance values to 0.5% for inductance values, as shown in the fig. 4.

One should note that the calibration uncertainties of the working chain can not be directly compared with the impedance-calibrator uncertainties, since in the working chain the contribution of the secondary standards has also to be taken into account (see fig. 1). Such a contribution can degrade the uncertainty at the laboratory site up to an order of magnitude.

The twelve months stability and the maximum temperature coefficient in the temperature range of 20 °C to 30 °C of the impedance calibrator are also declared, whose values indicate the possibility to obtain a lower uncertainty if the calibrator is suitably adjusted. Therefore, if the traveling standard is calibrated against the IEN primary standards, the expected calibration uncertainties of the proposed chain at the laboratory site are those shown in the last column of the table. The adjustment process takes advantage of an automatic substitution procedure that employs an RLC bridge as a comparator [7].

III. EXPERIMENTAL RESULTS

A. *Characterization of the impedance calibrator*

The reliability of the impedance calibrator that is employed as the traveling standard is not well known, because of its recent commercial availability. For this reason, a preliminary check of its metrology specification is mandatory before starting the network-assisted dissemination process. In addition, the calibrator uncertainty is stated only at 1 kHz, therefore an uncertainty estimation at the other frequencies is advisable. A set of experimental tests has been planned in order to estimate time and thermal drifts of the calibrator and to characterize its frequency behaviour.

The impedance calibrator has been inserted into a climatic chamber and the impedance values it provides have been measured at different frequencies by means of a traceable impedance meter (QuadTech - model 7600). The uncertainty the meter provides is better than the calibrator uncertainty, except for low resistance and capacitance values, where the uncertainty is similar. The measurements have been performed at the nominal temperature of 23 °C and with a nominal relative humidity of 50 %RH. The same measurements have been also carried out at 20 °C and 30 °C to estimate the thermal drift of the different impedance standards.

The obtained results at 23 °C show the conformity of the calibrator to its stated uncertainty @ 1 kHz (@ 10 kHz for 100 mH inductance and @ 100 Hz for 10 H inductance). Inductance values at other frequencies are within the stated limit of 0.5 %, while low (100 mΩ and 1 Ω) and high (1 MΩ and 10 MΩ) resistance values at every frequency and low capacitance values (10 pF and 100 pF) at frequency lower than 1 kHz seem not meet the 1 kHz specification.

The temperature coefficients of the standards that are housed into the impedance calibrator have been also estimated. The obtained results do not seem to fully conform to the manufacturer temperature coefficients for the two lower resistance and capacitance standards. Other tests are in progress in order to validate these preliminary results.

Authors are now planning specific tests in order to estimate long-term stability and transport effect of the impedance calibrator.

B. *Network-assisted tests*

The interconnected system shown in Fig. 2 has been arranged by installing server and client applications on Windows^{TM} based PCs. The system has firstly been tested over a LAN and then over the Internet, with the server at the Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN) and the client, which access to the network through an internet provider, at the Politecnico di Torino. The client PC

Impedance value	Working chain with discrete standards	Network-assisted chain (calibrator as is)	Network-assisted chain (calibrator adjusted)
Resistance	U_r (ppm)	U_r (ppm) (expected)	U_r (ppm) (expected)
0.1 Ω		1000	1000
1 Ω	10	1000	50
10 Ω	10	500	50
100 Ω	10	500	50
1 kΩ	10	500	50
10 kΩ	10	500	50
100 kΩ		500	500
1 MΩ		1000	1000
10 MΩ		2000	2000
Capacitance	U_r (ppm)	U_r (ppm) (expected)	U_r (ppm) (expected)
10 pF	5	20000	130
100 pF	5	2000	130
1 nF	5	500	130
10 nF	20	500	150
100 nF	30	500	160
1 μF	50	1000	400
10 μF		1000	1000
Inductance	U_r (ppm)	U_r (ppm) (expected)	U_r (ppm) (expected)
1 mH	30	500	350
10 mH	30	500	350
100 mH	30	500 (@ 10 kHz)	150
1 H	30	500	250
10 H	100	500 (@ 100 Hz)	300

Fig. 4. Comparison between metrology capabilities of working and network-assisted traceability chains @ 1 kHz.

is equipped with an IEEE-488 card that allows the communication with the impedance calibrator and with a digital impedance meter to be performed.

Different tests have been performed in order to verify the effectiveness of the network-assisted procedure by employing two different digital impedance meters: the RLC meter HIOKI - model LCR HiTESTER 3532-50 and the impedance meter QuadTech - model 7600. For both such instruments a specific command file has been developed that allows the measurements of all the standard values of the calibrator to be carried out. This process is performed in a fully automated way and the technician assistance is required only for the initial connection between calibrator and meter under verification.

IV. CONCLUSIONS

An innovative solution has been proposed for the dissemination of impedance measurement units, whose main advantage is a drastic reduction of the traceability maintenance cost for the secondary laboratories. This should increase the number of laboratories that offer an impedance calibration service, which is nowadays hard to be achieved. The proposed solution employs an impedance calibrator as a traveling standard and a client-server application over the Internet, that allows the traceability-transfer process to be remotely exercised. The client-server application is based on a mature technology and has been already tested in another internet-based calibration service. The employed traveling standard is instead a new instrument, whose specifications are not completely stated and, in addition, some questions arise regarding the actual instrument performance. For this reason, it has been decided to perform a complete metrology characterization of the standard before starting the network-assisted dissemination process.

Authors are now performing a series of experimental tests in order to obtain a good level of confidence about the metrology behaviour of the calibrator before starting the new calibration service.

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