Internet-based Calibrations of Electrical Quantities at the UK's National Physical Laboratory

Speaker : R A Dudley
Centre for Electromagnetic and Time Metrology
National Physical Laboratory, Teddington, Middlesex, TW11 0LW, UK.
E-mail: richard.dudley@npl.co.uk, **Tel:** +44 208 943 6770

Paper Co-Authors: N M Ridler, J M Williams
Centre for Electromagnetic National Physical Laboratory, UK.

Abstract
This paper will present work undertaken at the UK's National Physical Laboratory to utilise the Internet to provide highly efficient and cost-effective calibration services for some electrical quantities. The Internet has been used to facilitate remote calibrations of instruments and artefacts with direct access (via the Internet) to primary national measurement standards and procedures. Methods based on both comparison techniques and fully characterised in-situ standards will be presented. Work will also be presented showing applications of such facilities and techniques operating at DC, low frequency, radio-frequency and microwave frequencies (DC-110 GHz).

Introduction

Internet applications have opened up a wealth of new technologies including electronic mail, video conferencing [(1)], remote monitoring [(2)], virtual instrument control [(3)], on-line shopping and now the possibility of Internet calibrations. Clearly, Internet calibration is not applicable to all metrology areas, as physical constraints or human interaction is sometimes essential. However, measurements which rely on a standard issue instrument, or artefact, or are distinctive in the software developed by the standard laboratory, are open to Internet implementation.

The National Physical Laboratory (NPL) has undertaken a period of research to develop the technology for the creation of Internet Calibration Applications (ICAs) initially in the field of electromagnetic metrology. In this paper the benefits of internet calibration will be discussed, followed by details of the technology used to implement such services. The concluding sections deal with the two systems developed at NPL for Automatic Network Analyser (ANA) remote calibration and uncertainty determination and a travelling calibration system for use at remote laboratories for resistance and voltage calibration.

Why use the Internet for Calibrations ?

Neglecting the intricacies, most calibrated measurement systems can be simplified to three basic components, the calibration artefacts, instrument and control firmware, Figure 1. Under most instances a laboratory requiring traceable measurements sends their standards to be calibrated at a National Measurement Institute (NMI), acquiring a certificate and correction values. The standards are measured under carefully controlled conditions at the NMI but there is no guarantee that these conditions will be reproduced when the standards are used at the remote laboratory. Furthermore, in some cases, the value of the standards can be affected by transport leading to an uncertainty component which is difficult to assess. The implementation of remote calibration via the Internet to help with these problems varies considerably with each measurement example. This will be illustrated by the two cases studies described in this paper.

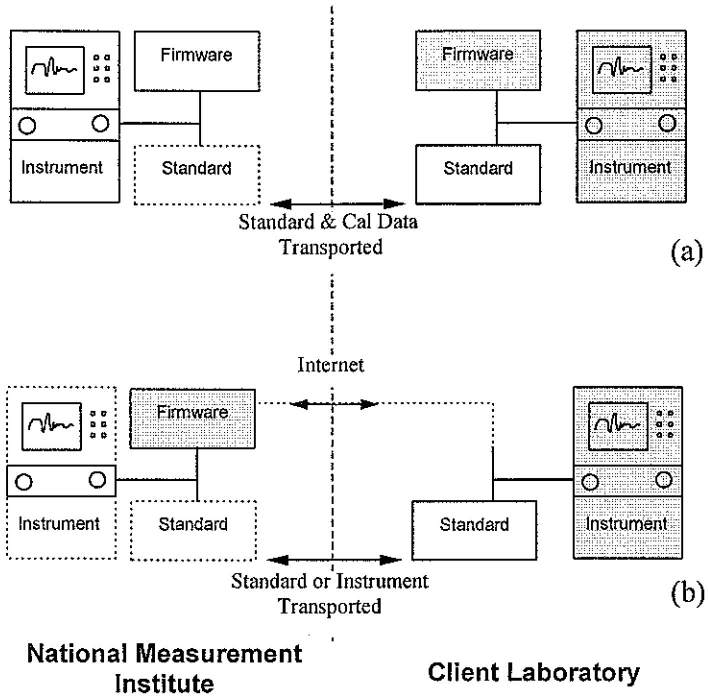

Figure 1:Basic components of a measurement system, calibration artefacts, instrument and control firmware. Conventional traceability situation is shown in (a) while the differences of an Internet calibration are shown in (b).

In the case of the ANA, a precision transfer standard, largely unaffected by transport, travels between the NMI and the remote laboratory. The measurements performed by the secondary laboratory introduce further uncertainties into any measurement and require additional work to include the NMI calibration data. An alternative system is for the NMI to retain full details of a customers calibration artefact on a database accessible over the Internet. When the secondary laboratory now requires a measurement to be made with NMI traceability, they log-on to the NMI web page, which then takes control of the measurement system. NMI firmware informs the client of any procedures, operates the measurement hardware over the internet, interprets the data, corrects it using the database of calibration data and provides a measure of uncertainties. In this way ICAs have the ability to shrink the hierarchy of a measurement laboratories traceability chain to a single link with the National or International standards available and follow the latest guidelines and procedure for their measurements. The benefit of the Internet in this example is that the calibration using the transfer at the remote laboratory can be done using sophisticated software developed at the NMI to process results taken using the ANA at the remote laboratory.

In the case of resistance and voltage calibrations, a complete measurement system with internal standards travels between the two laboratories and is used to calibrate working standards at the remote laboratory. This has the advantage that the working standards do not have to travel and are calibrated under their normal conditions of use. The Internet is used to control the travelling measurement system when it is at the remote laboratory and to record other data such as ambient temperature. Photographic records of connection configurations used during the calibration can also be recorded using a digital camera.

The reduction in cost, development time and delays to measurement services to the secondary laboratory is a further attraction. Client access to the ICA service can be through several routes. It can either be offered as a subscription service for clients or a pay per use option, depending on the clients demands for the service. It would be backed up with regular calibration of any artefacts required to maintain the service.

Implementation

The requirement of an ICA is simply the extension of a GPIB, or RS232, connection across the Internet between the NMI and the client's equipment. Although feasible, direct connection of an instrument to the Internet is not currently practical. However, many commercial instruments now use personal computer mainframes and future plans to include direct connection to the Internet would make this option practical. At this time the communication link to the instrument is provided through two PCs, one at the NMI and another at the client, Figure 2.

Parsing of commands between the two PCs requires more than a standard Internet connection, although some applications could use e-mail transfer if timing and real-time data acquisition is not an issue. The type of connection actually requires a data socket to be established, which acts much like a file handle for listening to incoming connections or receiving/sending data. Two types exist, a TCP socket which specifies where data is being sent and thus allows data sum checking and error parsing. The second type is a UDP socket, which is analogous to a transmit only channel, not allowing two way communication resulting in data prone to loss and error. Obviously, with such critical instrument control and data analysis algorithms TCP type transfers must be adhered.

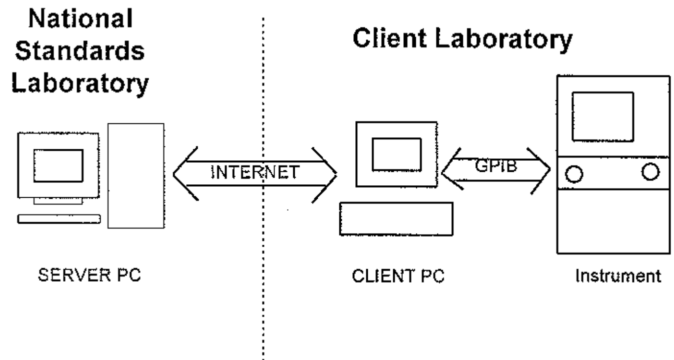

Figure 2: Client / NMI structure for Internet based GPIB / RS control

Software at the client end can be based on many different Internet supported languages such as Java, VRML, DHTML and Active-X components. These languages are supported by the two main Internet browser, Internet Explorer and Netscape Communicator, and load with standard page data to add functionality such as active image maps, comment sheets and data base searching. NPL has selected Active-X based user-control objects written using Visual Basic, which although currently restricts use to Windows based systems running Internet Explorer 3 and above, does add a huge range of functionality. Additionally, the Active-X route allows for the inclusion of many other windows based software components such as C and LabView control. Active-X objects however, do have the potential to damage a client's PC's file system and to overcome such security issues the objects must be licensed and digitally signed by an external body.

The server software is currently implemented on a standard PC running Windows 98 with Microsoft Personal Web Server installed. The server is connected to the Internet through the NPL standard firewall and is thus secure from attack. The server hosts a Common Gateway Interface program in the `cgi-bin`, and is the backbone of the entire system containing Visual Basic source code for GPIB communication and data analysis. The majority of CGI programs are normally written in a language call Perl, but since a large proportion of existing software at NPL is written using Visual Basic, it was the logical choice.

The client makes various choices in forms that are contained on the HTML page displayed on their browser. On clicking on the Proceed button on these pages, the client's browser packages all the selections and data, sending it to the CGI program via a socket. Upon receipt of this data the server software executes the CGI script, analyses the information and responds accordingly. Ultimately, the CGI script sends data, usually HTML code representing a new web page, back to the server. The server sends this back to the client's browser for displays.

The first stage of establishing an Internet instrument control follows the following route,

- Launch Internet Explorer and open URL of NMI site
- Identify user though password and IP address, rejected if not a subscriber to service
- Client completes series of Internet forms to define measurement

Once the NMI server has received all the above information the client is sent a web page containing an active component and if it is a first time calibration will be promoted that several active components are being downloaded and installed on their machine. The active software now provides a series of instructions to the client, specifying what is the next step in the procedure. Behind these instructions the active component communicates with the client's `Gpib-32.dll` windows file to allow GPIB commands to be sent to the control instrument. Data retrieved from the instrument through the same route can be either returned to the NMI server via a data socket or processed on the client's PC. Finally, a new web page containing the measurement results and uncertainty data is displayed. The client now has several options, the data can be stored locally, printed or if measurements are for a third party, automatically incorporated into a calibration certificate, printed or e-mailed straight to the third party.

Internet ANA Calibrations

ANAs provide a swept frequency measurement of the transmission and reflection coefficients for an electrical network. Calibration is performed using instrument firmware and a set of standard devices, all of which are assumed to be ideal and are available as standard items from the ANA manufacture. Correction of the measurement data to that of NMI comes via precision verification artefacts, air spaced transmission lines, attenuators and terminations, whose properties change little over time.

At NPL the Primary IMpedance Measurement System [(4)] (PIMMS) utilises a commercial ANA driven by an external computer overriding the firmware calibration procedure. Algorithms for calibration, measurement and uncertainty evaluation are determined by the external computer under NPL constructed code. The extension of control across the Internet is ideal for this particular system and has been realised between NPL and UK industrial partners.

The calibration procedure under non-Internet conditions, requires the client to send the NMI their precision verification artefacts for periodic calibration. The NMI returns the verification device plus certificate and correction data. The client must then implement their measurements using the verification information and introduce their own uncertainty budget. It should be noted that typically a 1 - 18 GHz calibration can result in several thousand correction values being generated. The majority of ANA firmware does not allow inclusion of these correction values and a client will usually have to resort to creation of proprietary control software or use a spreadsheet to correct measured data using the calibration information.

The Internet version, while not removing the need for physical movement between sites of the instrument's standard reference, does simplify the process. When NPL receives the client standard all correction factors are stored in a NPL on-line database. The standard is returned, but now all a client needs to do to measure a device with traceability is connect their control PC to the NPL PIMMS web pages. While on-line the client enters the required measurement parameters and is offered options based on the knowledge NPL has about the clients equipment, Figure 3. From this point the entire measurement process is controlled by NPL and the need for a client to assess their own uncertainty budget is removed.

A quality issue does arise however. What if the client is inexperienced, or does not follow the PIMMS instructions correctly? Checks are be built into the software to identify incorrect device connection with relative ease. An additional system of video monitoring, taking snapshots of the measurement area each time a device is connected, will provide a further level of quality assurance. Operator experience can also be verified in the traditional way by measurement facility accreditation from an external body.

It is hoped a 'live' or 'virtual' demonstration of the Internet PIMMS system will be given during the conference paper or at a separate session during the conference.

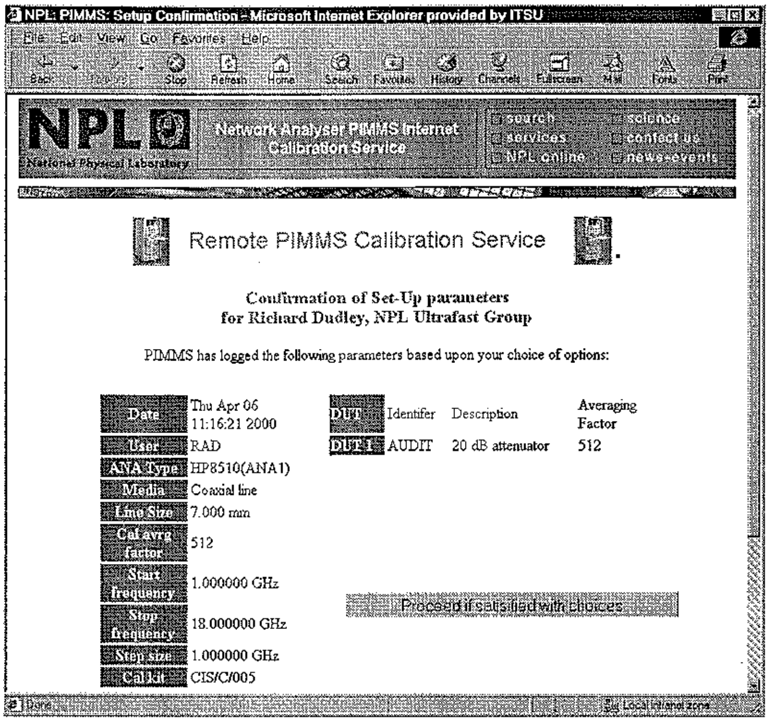

Figure 3: Screen shot from current NPL Internet PIMMS Calibration Facility. This screen is displayed once client has entered all measurement parameters, when 'proceed if satisfied...' is clicked a new window appears with the Visual Basic ANA controls.

ICA for Resistance and Voltage Standards using a Travelling Measurement System

Traceability of dc measurement quantities relies heavily on the use of Zener or standard cell voltage references and standard resistors. The majority of top level calibration laboratories maintain their traceability by sending one or more such standards away to a NMI for calibration. Work is being done at NPL to establish the principle of using a travelling measurement system, controlled over the Internet, to maintain this traceability link. The travelling system is a Wavetek Datron 4950 multi-function transfer standard which contains both internal standards and precision measurement electronics capable of operating with a relative uncertainty of a few parts in 10^6 or better. The procedure will be to first calibrate the 4950 at NPL against local working standards, transport the 4950 to the remote laboratory where it will measure local standards using the Internet as a control medium then finally re-calibrate the 4950 at NPL to check for loop closure and the effect of transport. The advantage of using the Internet in this process is that the results can be reviewed at NPL before the 4950 is returned and repeats made as necessary. Also, the configurations used in the calibration can be recorded using a digital camera and the results of the calibration can be archived at NPL and historical data analysed to calculate the drift characteristics of the standards belonging to the remote laboratory.

Conclusion

NPL has developed the technology and demonstrated the use of Internet for the calibration of two distinctly different measurement situations. The collapsing of the traceability chain and the simplification of calibration transfer between sites has huge benefits for many organisations. NPL is currently looking to expand this technique to other fields of metrology and redefine the way some measurements are made.

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