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Internet calibration direct to national measurement standards for automatic network analysers

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Abstract.

At the UK's National Physical Laboratory, the Internet has been utilised to provide highly efficient and cost-effective calibration services for Automatic Network Analysers (ANA). Remote calibration of ANAs from two of the leading instrument manufacturers has been achieved with direct access to primary national measurement standards and procedures, via the Internet for microwave frequencies in the range 45MHz-110 GHz.

***Keywords* – Internet, Calibration, Standards, Measurement & Testing**

I. INTRODUCTION

Laboratories requiring traceable measurements are required to periodically send 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 service downtime introduced by calibration schedules can be extremely disruptive to a measurement laboratory while equipment and calibration artefacts are off-site. On the equipment's return additional delays are introduced while the system is reinstated, performance checks made, paperwork completed and new calibration figures incorporated.

The implementation of 'remote calibrations' using the Internet as a transmission medium is rapidly emerging as a solution to all of the transportation, environmental, downtime and cost issues with current calibration schemes. Additional benefits emerge in the dissemination of measurement techniques and good practice equally to all laboratories.

The use of the Internet to assist the calibration procedure is a recent topic and was primarily launched at IMTC 1999, where systems offering video conferencing and remote monitoring [1, 2] to assist the interaction between NMIs and secondary laboratories were presented. The interactive control of instrumentation via the Internet has been addressed by O'Dowd et al [3] and is now becoming features of software packages such as Labview 6i.

At the National Physical Laboratory (NPL), UK, we have combined the technology of remote monitoring, remote control and NMI calibration techniques for Automatic Network Analysers (ANAs) to provide a service allowing calibration and device measurement, with traceability to Primary National Standards [4]. Within this paper the details of the new service will be discussed beginning with issues of traceability, followed by a discussion of the service implementation and testing for the Internet calibration of ANAs.

II. TRACEABILITY OVER THE INTERNET

Traceability of measurements is a requirement for both existing international accreditation standards [5] and quality management standards [6]. Traceability is defined [**7**] as the "property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties". The unbroken chain of comparisons is called a "traceability

In the field of ANA measurements, traceability has been established traditionally through the physical transfer of a series of reference artefacts. Typically, a laboratory requiring traceability sends electrical reference artefacts (attenuators, matched and mismatched transmission lines) to an NMI where the devices are evaluated electrically, in terms of reflection and transmission coefficient measurements, and a certificate of calibration is issued. The laboratory then calibrates their own ANA (using standards assumed to be perfect) and measures the electrical reference artefacts. The results achieved by the laboratory are verified by comparison with the values supplied by the NMI on the certificate of calibration. The closeness of agreement between the two data sets indicates the validity of the uncertainty of measurement quoted by the laboratory – the laboratory having previously evaluated the uncertainty of measurement for their own system.

Since ANAs can provide measurements over a wide range of frequencies and a wide range of nominal values, the laboratory is required to verify the system's performance under these wide-ranging conditions. To do this, the certificate of calibration supplied by the NMI often contains results at several hundred different frequencies for each of typically between four to six devices with different characteristics. The electrical behaviour of these devices at RF and microwave frequencies is subject to drift with time, due to changes such as environmental conditions, so that re-calibration of each device is recommended at intervals of typically 12 months.

A system termed the Primary Impedance Microwave Measurement System [4] (PIMMS) has been developed at NPL to address the calibration of ANAs. PIMMS utilises a commercial ANA controlled by an external computer over a GPIB connection, overriding the firmware calibration procedure. Algorithms for calibration, measurement and uncertainty evaluation are implemented within PIMMS using NPL constructed code.

Neglecting the intricacies, the PIMMS measurement system can be simplified to three basic components, the calibration artefacts, instrumentation and instrument firmware, see Figure 1a. Therefore, the move to an Internet system can be achieved by allowing the NPL PIMMS software to control secondary laboratories ANAs, with a knowledge of the calibration artefacts and ANA performance, figure 1b. We have termed this new version of PIMMS as *i*PIMMS.

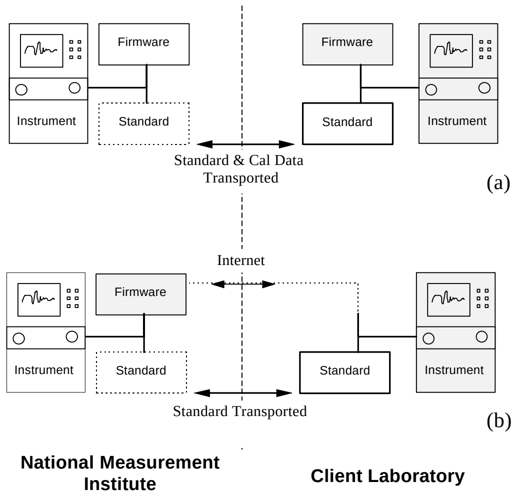

Figure 1:Basic components of a measurement system, calibration artefacts, instrument and control firmware. Conventional traceability situation is shown in (a) while the differences of an Internet calibration are shown in (b).

NPL's *i*PIMMS facility removes the need for the electrical reference artefacts to be sent periodically to NPL for calibration. Instead, the *standards* used by a client laboratory to calibrate their ANA (previously assumed to be perfect) are measured directly by NPL. These standards are lengths of precision transmission line, such as coaxial line, waveguide, etc. The measurements made by NPL on these standards are the dimensions of the standards leading to a direct assessment of the overall quality of the standard. This enables the uncertainty of measurement to be traced directly back to dimensional measurements (i.e. the SI base unit, the metre), avoiding the need for the electrical calibrations of the verification artefacts. This reduces the traceability chain between the electrical measurements made by the client laboratory and the SI base units to the minimum, i.e. a chain with one link! This, then, prevents the usual broadening of uncertainty intervals due to moving through a traceability chain, from national standard to end-user – the size of the uncertainties achieved by the client laboratory being the same as those achieved at NPL.

In the case of standards in coaxial line, the dimensional measurements made by NPL are of the diameters of the inner and outer conductors of the line. These measurements are made, for example, using an Air-Gauging Measurement System [8]. These values are used to establish the characteristic impedance, Z_0, of the line using the following expression:

$$Z_0 = \frac{1}{2p}\sqrt{\frac{m}{e}}\ln\left(\frac{b}{a}\right) = 59.93904 \times \ln\left(\frac{b}{a}\right) \qquad [1]$$

where:

b = diameter of outer conductor
a = diameter of inner conductor
$å = å_0 å_r$
$å_r$ = 1.000649 (for 'standard' air at 23C, 50% RH and 1013.25 mb) [9]
$ì = ì_0 ì_r$
$ì_r$ = 1.000000

In the case of rectangular waveguide transmission lines, the dimensions of the waveguide apertures are used to establish the quality of the line using expressions given in [10].

The data for each customer line is stored in a database within *i*PIMMS, so that when a given client logs-on to the service, the appropriate data is up-loaded from the database. Measurements are then corrected directly at the client's premises, by sending commands and controls over the Internet, using the dimensional data stored in the database. This enables very efficient uncertainty intervals to be established based on the client's own primary reference standards. The *i*PIMMS calculation routines evaluate the uncertainty in the client's measurements using internationally accepted methods [11].

III. *i*PIMMS APPROACH TO CALIBRATION

The Internet approach effectively extends the GPIB connection between the local control computer of PIMMS and the ANA, across the Internet to a client's control computer and ANA. When a secondary laboratory now requires a measurement at the highest level of accuracy, it logs-on to the appropriate NPL web page†, which then guides them through the measurement process while initialising and controlling the measurement system. NPL firmware controls the measurement hardware, interprets the data, corrects it using the database of calibration data and evaluates the uncertainty of measurement. This method not only reduces the amount of work required by the secondary laboratory but also ensures the latest procedures are followed and has the ability to shrink the hierarchy of a measurement laboratory's traceability chain to a single link with the national or international standards available.

While on-line the client enters the required measurement parameters and is offered options based on the knowledge NPL has about the client's equipment. From this point the entire measurement process is controlled automatically by the NPL web-server and the need for clients to provide their own uncertainty budget is removed.

Following extensive field trials with a remote laboratory, BAE SYSTEMS, the first commercial Internet Calibration service was launched in February 2001 for ANAs from two of the leading manufacturers.

IV. *i*PIMMS TECHNOLOGY

Selecting the appropriate software to allow two-way communication between an NPL server and a remote laboratory, while maintaining data security, overcoming company firewalls and running at an acceptable speed, presented significant challenges. Several options are available of which Java, ActiveX and VB script are three technologies used by NPL to implement the *i*PIMMS system.

Data flow between server and client, which includes both measurement data and GPIB controls to the ANA, are performed in a secure manner using a Secure Sockets Layer (SSL) ensuring that data integrity is maintained in both directions. The route taken by the data is also constrained to standard web browser communication ports, reducing a client's liaison with service providers and computer services. If a client can currently browse the Internet and complete web-forms then the NPL *i*PIMMS service will be easily accessible.

The *i*PIMMS system contains features one would associate with any standard data acquisition software, allowing data files to be catalogued and viewed, re-calculated, measurement runs to be suspended or added to. The data is stored on the NPL server, backed up on a regular basis, but can optionally be downloaded to the client's local PC for use in records or calibration certificates.

A series of screen shots from the current version of *i*PIMMS is shown in figure 2, highlighting a standard measurement of an audit device with full traceability. Two post processing screens called *i*DataScan and *i*Rho allow an assessment of the measurement data quality and that of the reference air-line. At this stage the client may wish to select the addition of measurements if a problem is spotted, before proceeding to the uncertainty calculations.

V. CONCLUSION

NPL's Internet calibration of ANAs is unique and in February 2001 became the first ever calibration service to offer measurement traceability to a National Standards laboratory simply by connecting to the Internet. NPL regards the system as a pioneer to a series of future services to be offered in other areas of metrology.

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† http://www.internetcalibration.com

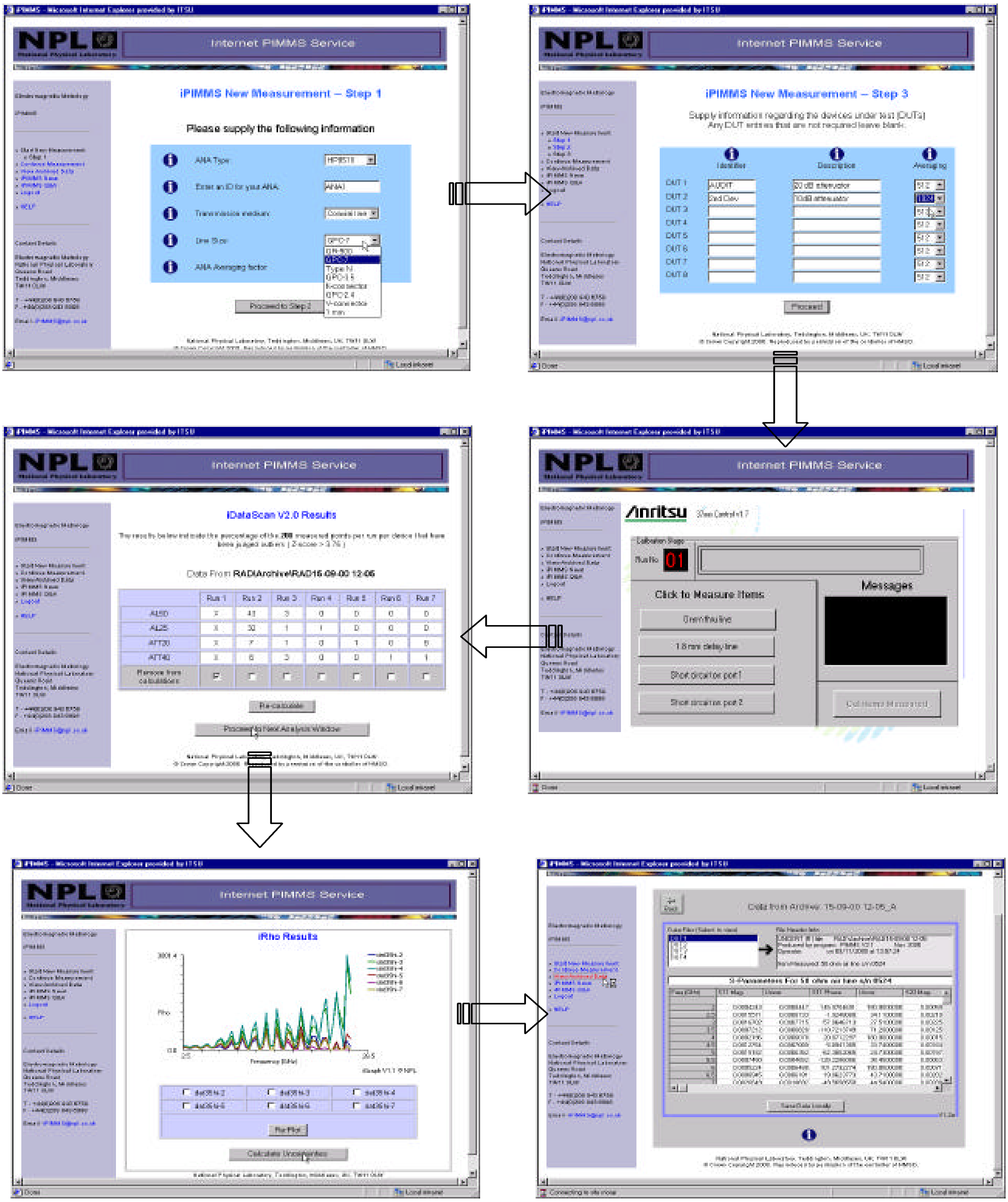

Figure 2: Screen shots from *i*PIMMS Internet calibration software. The screens show some of the processes staring with: selecting the waveguide/coax type, entering details of the devices to be measured, the control screen which interacts with the ANA to control calibration and measurement, *i*DataScan and *i*Rho screens to inform the user of any anomalies in the data, finally the display screen where the user gets S-parameters and uncertainties for all the devices measured.