Advances in NPL's Internet Calibration and Measurement Services for High-Frequency Electrical Quantities†

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Abstract

In February 2001 the UK's National Physical Laboratory (NPL) launched a revolutionary type of measurement service. The service makes extensive use of the Internet to fully control a vector network analyser, situated at a location remote to NPL, to perform high frequency electrical measurements. This paper will review the principles of this Internet measurement service and outline the capabilities offered at the launch, subsequent extensions, improvements and steps taken to achieve third party (i.e. UKAS) accreditation.

1. Introduction

Regular instrument calibration is an essential part of today's quality driven measurement environment and a link to a national or international standard should be present. Achieving traceability requires a laboratory 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 that is difficult to assess.

The downtime experienced by laboratories fulfilling calibration schedules can be extremely disruptive and costly while the equipment is away from the laboratory for calibration. On the equipment's return, system checks, paperwork and the update of soft or hard calibration figures compound the delays. A calibration laboratory or NMI that provides a highly efficient service, minimising clients' downtime and re-commissioning time, will have a clear advantage and this has created the search for calibration services, which can be executed remotely.

The implementation of 'remote calibrations' using the Internet as a data transmission medium has emerged 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.

2. Traceability over the Internet

In the field of Vector Network Analyser (VNA) measurements, traceability has been established traditionally through the physical transfer of a series of reference artefacts. 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 VNA using a conventional calibration kit, which is assumed to be perfect, and measures the electrical reference artefacts returned from the NMI. The results achieved by the laboratory are verified by comparison with the values supplied by the NMI on the certificate of calibration. The agreement between the laboratory and NMI 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 VNAs can provide measurements over a wide range of frequencies and dynamic range, 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. Such certificates are issued for typically four to six devices. 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 re-calibration of each device is recommended at intervals of typically 12 months.

A system termed the Primary IMpedance Measurement System [1] (PIMMS) has been developed at NPL to address the calibration of VNAs. PIMMS utilises a commercial VNA controlled by an external computer over a

† www.internetcalibrations.com

GPIB connection, overriding the firmware calibration procedure. Algorithms for calibration, measurement and uncertainty evaluation are implemented within PIMMS using NPL constructed code.

PIMMS takes advantage of a calibration scheme reliant on lengths of precision coaxial or waveguide transmission line, which only require measurement of dimensional variations to assess the overall quality of the standard. Measurement uncertainty is thus 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 and reducing the size of the traceability chain to a single link. The reference transmission lines are inherently stable items with a calibration period that can be extended to two or three years. This compares favourably with the recommended annual requirement for re-calibrations of electrical standards.

Reflection and transmission measurements are further affected by random errors in the measurement process. The causes of these errors include: the connection repeatability of both the calibration and measurement artefacts; electrical noise present on the signals detected by the VNA; any cable flexing whilst making the measurements; and, fluctuations in the laboratory environmental conditions. The effects of all the random errors on the measurement process are evaluated in-situ by repeating, a number of times, the connection of both calibration and measurement artefacts. Under normal circumstances, the process is repeated between 6 and 8 times to achieve a realistic determination of the size of the random errors affecting the measurements.

The PIMMS software takes all the above factors into account during the VNA calibration, device measurement and uncertainty calculations. Therefore, it can be seen that, if an external laboratory has access to the NPL PIMMS routines, an NPL verified reference transmission line and a VNA, it is possible to perform a measurement with a level of accuracy comparable to that of NPL. Reducing the measurement chain in this way also prevents the usual broadening of uncertainty intervals from national standard to end-user. The final outcome is that the level of measurement uncertainties achieved by the client laboratory is the same as those achieved at NPL.

Neglecting the intricacies, PIMMS can be simplified to three basic components: the reference lines, instrumentation and instrument firmware (as shown in Figure 1a). Therefore, the move to an Internet system can be achieved by allowing the NPL PIMMS software to control secondary laboratorys' VNAs, with knowledge of the VNA performance and the reference lines used in the process (as shown in Figure 1b). We have termed this new Internet version of PIMMS as *i*PIMMS.

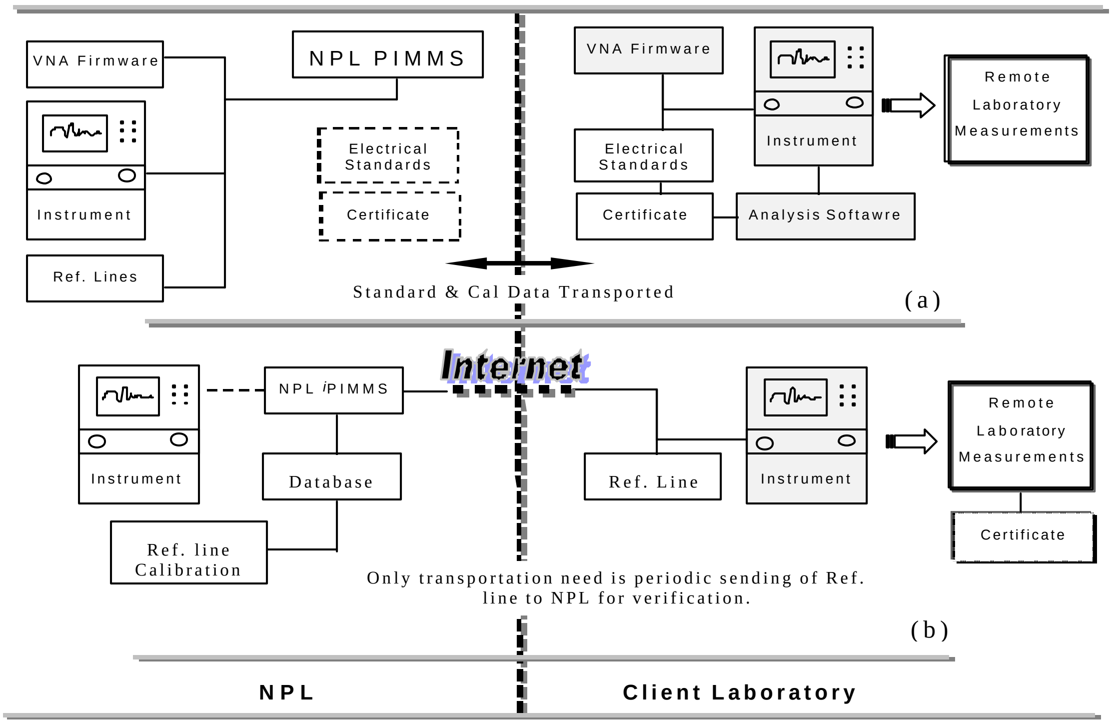

Figure 1: (a) basic components of NPL VNA calibration system: artefacts, instrument and control firmware, producing a certificate for the remote laboratory's artefacts; (b) the Internet system removes the need for travelling verification artefacts by allowing direct access to PIMMS.

*i*PIMMS provides direct access to NPL's PIMMS software, reference transmission line database and technical procedures. Characterisation of the VNA linearity and isolation can also be performed remotely using a travelling step attenuator and low reflecting loads. The client laboratory thus establishes a remote, fully traceable, highest level of measurement capability across the Internet with a minimal commissioning time and reduced level of downtime through artefact transportation and calibration.

3. *i*PIMMS Calibration

The Internet approach effectively extends the GPIB connection between the local control computer of PIMMS and the VNA, across the Internet, to a client's control computer and VNA. 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 the laboratory through the measurement process while initialising and controlling the measurement system. NPL firmware controls the measurement hardware, interprets the data, corrects measurements 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.

Whilst 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.

The data for each customer line and VNA Test Set are stored in a database within *i*PIMMS, so that when a given client logs-on to the service, the appropriate data for their equipment 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 and VNA Test Set data stored in the database. This enables very efficient uncertainty intervals to be established based on the client's own primary reference standards and equipment. The *i*PIMMS calculation routines evaluate the uncertainty in the client's measurements using internationally accepted methods [2].

4. *i*PIMMS Technology

Selecting the appropriate software to allow two-way communication between an NPL server and a remote laboratory, overcoming company firewalls and running at an acceptable speed, while maintaining data security presents significant challenges. Several options are available of which JavaScript, 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 VNA, 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, and so on. The data is stored on the NPL server, which is backed up on a regular basis, but can optionally be downloaded to the client's local PC for use in records or calibration certificates.

5. *i*PIMMS Measurement Service

Following extensive field trials with a remote laboratory, BAE SYSTEMS, the UK's first commercial Internet calibration and measurement service has been established for VNAs operating in coaxial line from 45 MHz to 26.5 GHz. The *i*PIMMS calibration and measurement service received its official launch in February 2001 at BAE SYSTEMS headquarters in London, and was attended by members of the laboratory community, accreditation bodies and UK government representatives responsible for science policy. In future, BAE SYSTEMS will be using *i*PIMMS to enhance their measurement capabilities for materials characterisation in projects such as the Eurofighter Typhoon aircraft.

[†] Details can be found at www.internetcalibrations.com

In the period since the launch of *i*PIMMS, it has remained reliable, has suffered no malicious attacks or loss of service due to hardware or software failure. The number of registered users continues to grow and NPL's commitment to the service continues with recent upgrades, enabling multi-line calibration for coaxial measurements over a broad bandwidth and accreditation of the service in compliance with ISO 17025 [3] is currently being addressed.

6. *i*PIMMS Developments

Subsequent to the launch of *i*PIMMS, development has continued with the extension from a single VNA to the support of the three leading manufacturers of these instruments. Initial *i*PIMMS calibrations used a single line for the TRL scheme, limiting the operational frequency range. In coaxial geometries, such as Type-N, GPC-7 and GPC-3.5, two or three lines are recommended to enable full coverage of the line's bandwidth. Upgrading to a 'multi-line' scheme in September has allowed the service to extend the calibration frequency to the full range of the connectors used. Support for waveguide is provided in the software; however, this service will not be available until Jan 2002 while final verifications are completed.

Planned upgrades to the system include an Internet system to allow the measurement of the linearity and isolation of the analyser at the start of an *i*PIMMS registration. A recent discussion has also highlighted the need for frequency verification on some systems and an Internet controlled check for this is currently under investigation.

7. Conclusion

NPL's Internet calibration of VNAs is unique and in February 2001 became the UK's first calibration and measurement service to offer traceability to national standards 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. A full system demonstration along with the hardware and software requirements can be found at www.internetcalibrations.com.

8. Acknowledgments

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9. References

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[3] ISO, "Guide to the expression of uncertainty in measurement", International Organization for Standardization, 1st edition, 1995.