

**Report to the National
Measurement System
Directorate, Department of
Trade & Industry**

**SURVEY OF INTERNATIONAL
ACTIVITIES IN INTERNET-ENABLED
METROLOGY**

Dr D Rayner

May 2003

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Abstract

Two international meetings have been held during 2002 on the subject of Internet-enabled Metrology, supported by the NMS Software Support for Metrology programme and the MetroNet thematic network. The first was a MetroNet workshop held at NMI in Delft on 15 May 2002 and the second was held at NPL on 18 September 2002, as the third day of the BIPM/NPL workshop on *The Impact of IT in Metrology*.

This report gives an overview of the international activities in this field, as reported at these two meetings. In particular, it covers the activities reported by NIST (USA), PTB (Germany), NMIJ (Japan) and NMI (Netherlands). It also makes reference to the NPL activities reported at these meetings.

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Approved on behalf of the Managing Director, NPL
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SURVEY OF INTERNATIONAL ACTIVITIES IN INTERNET-ENABLED METROLOGY

1 INTRODUCTION

1.1 The Internet-enabled Metrology Promotion and Liaison project

The UK National Measurement System (NMS) Software Support for Metrology (SS/M) programme is managed by NPL and funded by the NMS Directorate of the UK Department of Trade and Industry. Within the SS/M programme for 2001-2004, there is a theme on the NMS Infrastructure. Within that theme there is a cluster of three projects on the use of the Internet to support calibration, what is now being called *Internet-enabled Metrology*. One of those projects is called *Protecting the data*, which is concerned with addressing security and data warehousing issues. The second is called *Demonstration of technology*, which is demonstrating that the generic software developed for NPL's iVR service (for remote calibration of voltage and resistance) can be transferred to a different area of metrology, namely to produce the iOTDR service (for remote calibration of optical time-domain reflectometers). The third project is *Promotion and Liaison*, which is addressing four topics:

- Promotion of the concepts on Internet-enabled metrology, particularly through use of a generic tutorial presentation
- Guidance on accreditation of Internet-enabled Metrology services, developed in liaison with UKAS
- Study of the applicability of Internet-enabled Metrology across the various metrology fields
- Study of international activities in Internet-enabled Metrology

This report is the result of this last study, but also serves as an open report on the applicability of Internet-enabled Metrology resulting from the third study (other results of that study being commercially sensitive).

1.2 The Delft workshop

SofTools_MetroNet (or simply MetroNet for short) is a European Thematic Network started in 2002, which aims at establishing more co-operation in the field of advanced measurement software tools and their mathematical and statistical foundations, by calling upon scientists from the mathematical/computational fields in universities, research centres, industrial organisations and all fields of metrology to meet and share experiences between themselves and with software engineers.

Within MetroNet, NMI (the Dutch National Metrology Institute (NMI)) leads a work package (WP1) on software tools for instrumentation, NPL leads a work package (WP2) on mathematical and statistical software tools, PTB (the German NMI) leads a work package (WP3) on databases and software validation, and BNM-INM (one of the French NMIs) leads a work package (WP4) on training and education. MetroNet's first annual meeting was hosted by NMI on 16-17 May 2002 and associated with that it was decided to hold on 15 May a workshop on *Internet Measurement and Self-calibration*, these being lively topics associated with WP1.

This workshop had only invited speakers. These came from the Technical University of Delft, NMI, Fluke, RvA (a Dutch accreditation body), NPL and PTB. These presentations were followed by a panel discussion.

From this meeting a useful insight was gained into the relevant activities going on at NMI and PTB and useful international exposure was given to the activities at NPL. The discussion revealed various misunderstandings about what was proposed. However, it was clear that there was already much less misunderstanding between those actively engaged in the subject than there had been at various conferences in 2001, including Metrologie in France and the UK's National Measurement Conference. Nevertheless, there was clear unease about using the terms "Internet Calibration" or "Internet Metrology", because we are not calibrating or measuring the Internet itself, and hence the term "Internet-enabled Metrology" was born. There was also concern about accreditation of such services, the discussion of which was helped by the RvA presentation.

1.3 The BIPM/NPL workshop

NPL hosted the first international workshop on *The Impact of Information Technology in Metrology* from 16 to 18 September 2002. There was also a satellite workshop, held on 19 September, on *Key Comparison Data Evaluation*. These workshops were organised as part of both the SS/M programme and the activity of BIPM's Information Technology Group. They were also sponsored by NAG Ltd. and MetroNet. A total of 110 delegates from 22 countries attended.

The third day of the main workshop was devoted to Internet-enabled metrology topics. The day began with an NPL presentation of a tutorial on the concepts of Internet-enabled metrology. The day included more detailed presentations on NPL's three most developed remote calibration services. There were also presentations on relevant activities at NIST (the US NMI), PTB, NMI and NMJJ (the Japanese NMI). UKAS (the UK Accreditation Service) provided further input to the debate about accreditation of such services.

It had been expected that some in the audience would be highly sceptical of Internet-enabled calibration services, especially concerning traceability and quality control, but although there were tough questions the expected scepticism was barely discernable.

The conclusion was that this is a fast-moving development in international metrology. PTB indicated that they planned to host a further workshop on it in 2003 and NIST were hoping to arrange a workshop on it as a satellite event to a major metrology conference in the USA in 2004.

2 INTERNET-ENABLED METROLOGY CONCEPTS AND BENEFITS

2.1 Introduction

Internet-enabled metrology is a term covering the use of the Internet and other means of telecommunication to provide better access to a whole range of measurement services, including:

- Traceable calibration conducted at the user's location but controlled remotely by an NMI or other calibration laboratory (Internet-enabled calibration);
- Remote equipment monitoring;
- Web-based access to libraries of metrology algorithms and software;
- Web-based testing services for numerical software used in metrology;

- Web-based access to calibration history data and other measurement data;
- Web-based access to simulation software, for example to enable virtual experiments and virtual testing to be performed.

2.2 Internet-enabled Calibration concepts

Not all calibration processes can be adapted for use remotely via the Internet. Some basic requirements are necessary before a system can be considered suitable. Any instrument that is to be considered for calibration via the Internet needs the ability to be controlled by a PC.

The measurement process has to rely on either stable artefacts (reference standards) or a rugged instrument that can be transferred between the primary laboratory and the remote (user's) location for Internet-enabled calibration to be feasible.

Two different types of Internet-enabled calibration methods have been identified:

- Type I: Transfer of a stable artefact or set of artefacts
- Type II: Transfer of rugged high-accuracy calibration device

A typical Type I case run by an NMI involves the following:

- The NMI effectively transfers the primary standard, knowledge and expertise to a remote user laboratory – like having a piece of the NMI on the user site
- The user has their own primary standard (artefact or set of artefacts) characterised by the NMI – in some cases they have this on loan from the NMI, in other cases they have to purchase it for themselves and then send it to the NMI for characterisation
- On-line NMI procedures control the calibration process, usually through web-pages accessed from the user site
- Calibration data is stored in the NMI's database, and may be downloaded to produce certificate
- Uncertainties of measurements are calculated by the NMI's software (possibly in real-time)
- System performance (repeatability, stability, etc) is evaluated in-situ by NMI software
- There is the ability to check measurements and repeat/disregard bad measurements
- There is the ability to suspend measurement cycle and resume at another time
- A web-cam may be used to allow critical connections and other aspects of the process to be viewed by staff at the NMI and a video record may be created for inclusion in the audit trail

A typical Type II case run by an NMI is very similar but differs in the following respects:

- A rugged high-accuracy calibration device (transfer standard) is transported - rather than the user's artefact standard(s)
- The calibration device will probably be owned by the NMI, because the NMI will invest a lot of effort in detailed characterisation of the device before it is transported to the user's site
- The calibration device may well be transported together with a laptop PC from the NMI, containing the relevant software for controlling the calibration device as well as

communicating with the NMI – this avoids having to install the software on a user's PC with all the security risks that that would entail

- When the remotely controlled calibrations have been completed, the measurement data is likely to be sent over the Internet to the NMI for analysis, and then provisional results returned in real-time to be issued to the user
- The calibration device should then be sent back to the NMI in order to check that it has not sustained any damage and to check whether its measurements have drifted – only then can the uncertainty evaluations be completed and the final calibration certificate issued

2.3 Benefits of Internet-enabled calibration

The benefits of Internet-enabled calibration can be specific to the type of measurement service to which it is applied, but there are many benefits that are common to almost all such services. These include:

- ***Traceability and accessibility***
 - Internet-enabled calibration has the potential to provide direct traceability to national standards whilst cutting down the calibration chain to one link.
 - Calibrations can be performed at a time of the user's choosing, day or night.
 - Calibrations are performed in the user's environment, ensuring that measurement results accurately reflect the conditions relevant to that user's situation.
 - User equipment stays in the user laboratory, so there is no transport time, and hence there is a much reduced down time for user equipment.
 - Appropriately high levels of accuracy can be transferred to the user's laboratory – in Type I calibrations this can be the very highest levels of accuracy
 - A much better cost to accuracy ratio than for traditional calibrations.
- ***Knowledge transfer and measurement good practice***
 - It is not about de-skilling – calibration skills at the user laboratory are more important than ever – hence the user's calibration staff may need some special training, which is likely to be of real benefit to their normal work.
 - On-line measurement good practice guides can aid the transfer of good measurement practice into the workplace, increasing the confidence in the measurements being made.
 - Ease of use. The remote operator will be guided step by step through the calibration process by the NMI's on-line procedures.
- ***Data-warehousing and other benefits***
 - Calibration results should be stored by the NMI in a database for possible recall by users during subsequent calibrations and audits. Data warehousing can also provide long-term access to calibration history and provide robust, paperless audit trails.

- This process can lead to data being shared in a common file format throughout an organisation.
- On-line visual monitoring of the calibration process can be used for troubleshooting purposes. Manufacturers of instruments connected to the system could be given limited access to the measurement history, allowing them to interpret data to see what parts and servicing are likely to be required during service visits and to improve preventative maintenance.

2.4 Time & Frequency activities

Within the Time & Frequency field of metrology, the concept of Internet-enabled calibration does not apply as described above. However, there are at least four Internet and/or telecommunications-enabled time & frequency services in operation around the world today. These are very briefly introduced in this section. The Japanese activity in the field, detailed in section 7.3 below, should be viewed in this context.

2.4.1 Time Transfer over the Internet

Most NMIs offer a time transfer service over the Internet using the Network Time Protocol (NTP), but NIST are particularly prominent as they serve a whole continent.

2.4.2 Secure Electronic Time Stamps

There are a few of companies seeking to push secure electronic time stamping technology, based on NTP but backed up by a public key infrastructure (PKI), building in traceability to the relevant NMI. These include Datum/Symmetricon (see www.trusted-time.com/). They have worked with NIST, CRL (Japan) and NPL.

2.4.3 Differential GPS

This is where a GPS based frequency standard is used as a transfer standard and compared with NMI data over an telephone link. As far as we are aware, NIST is the only NMI currently offering this service (see www.bldrdoc.gov/timefreq/service/fms.htm).

2.4.4 Common-View GPS

This is where a GPS common-view receiver is used to compare two remote time and frequency standards with the necessary data exchanges over telephone and Internet links. The NMI processes the data for the customer. NIST and NPL offer this service and it is possible that some other NMIs do as well.

3 NPL ACTIVITIES

The Internet-enabled calibration systems that exist or are under development at NPL are as follows:

Existing:

- iPIMMS – Radio frequency (RF) impedance measurement system for calibrating vector network analysers against primary standard artefacts

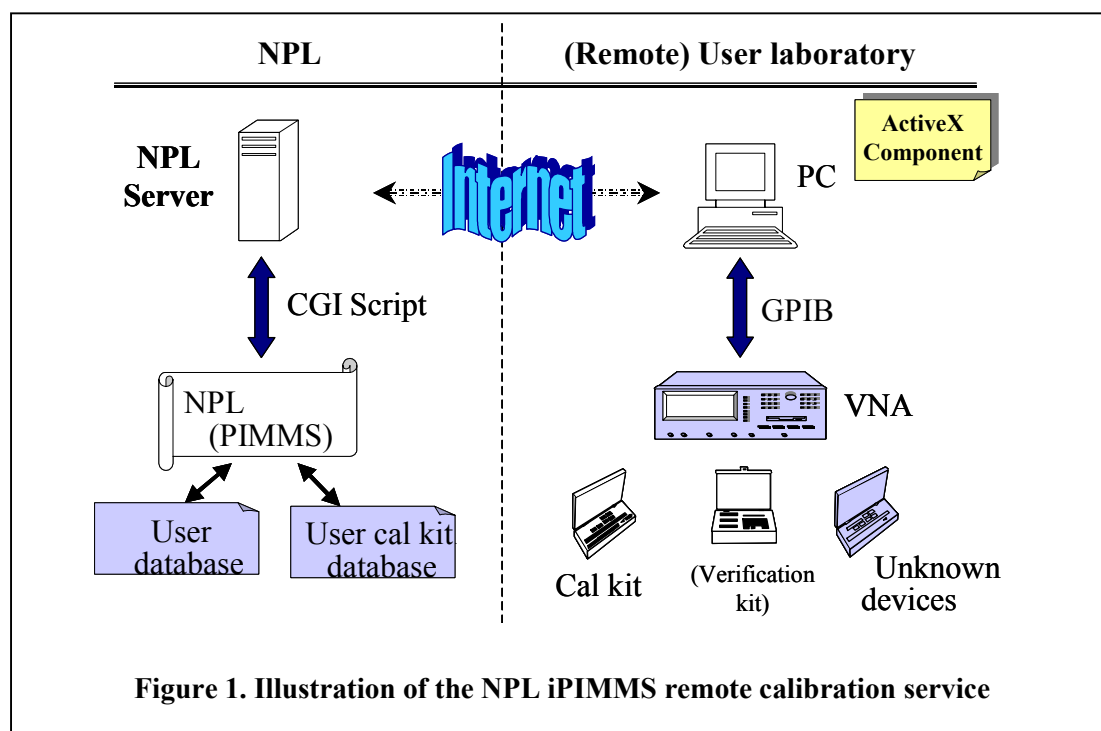
Under development:

- iVR – Voltage and resistance measurement system for calibrating secondary standard voltage sources and resistors against the Fluke 4950 multi-function calibrator, used as a highly characterised transfer standard
- iCOLOUR – Visible spectrum reflectance/colour measurement system for calibrating spectrophotometer colour measuring systems against standard tiles of known reflectance
- iOTDR – Optical time-domain reflectometer (OTDR) measurement system for calibrating OTDR devices against standard optical fibre artefacts

In addition, NPL offers the time transfer over the Internet and common-view GPS services described above. NPL also has established a remotely accessible “virtual testing” capability, particularly with application in materials modelling.

3.1 iPIMMS

The iPIMMS (Internet Primary Impedance Measurement Software) system was launched in February 2001. It allows the user to traceably calibrate RF impedance standards over the Internet. The client owns their own primary standard: a precision transmission line, which is sent to NPL for traceable dimensional characterisation, the data from which is stored in an NPL database. The client also owns a vector network analyser (VNA), which is connected via a PC and the Internet to NPL software. Step by step instructions are given in real time via web pages viewed on the client’s PC. The calibration data stored on the NPL database is used directly during Internet-enabled calibration to correct client measurements. Uncertainties on measurements are calculated by NPL software in real time. The VNA system performance (repeatability, stability, etc.) is evaluated in-situ by NPL software. The resulting data can be downloaded to produce the calibration certificate. This system is illustrated in Figure 1.



3.2 iVR

The prototype iVR (Internet Voltage and Resistance) system was demonstrated to the UK Department of Trade & Industry in July 2002. It allows a secondary laboratory to calibrate its voltage and resistance standards with traceability to NPL through the use of a Fluke 4950 multi-function transfer standard. This is a highly stable device, specifically designed as a transportable transfer standard. NPL owns the particular 4950 used and has spent a lot of effort characterising it in great detail, with changing temperature and pressure, calibrating it against national voltage and resistance standards. It is shipped together with a laptop PC containing the NPL software to the client site, where it is used to calibrate the client's voltage and resistance standards with an uncertainty of 1 ppm at 95% confidence. The process is controlled by step by step instructions sent over the Internet in real time in web pages viewed on the laptop PC. A webcam is integrated into the system to allow the physical connections made at the client site to be checked at NPL. The calibration certificates are not issued until the 4950 has been returned to NPL and re-calibrated to ensure that it has remained stable. Thus, there are three stages of calibration in the iVR system: characterisation of 4950 at NPL, calibration of working standards at client site, and checking of 4950 back at NPL. This is illustrated in Figure 2.

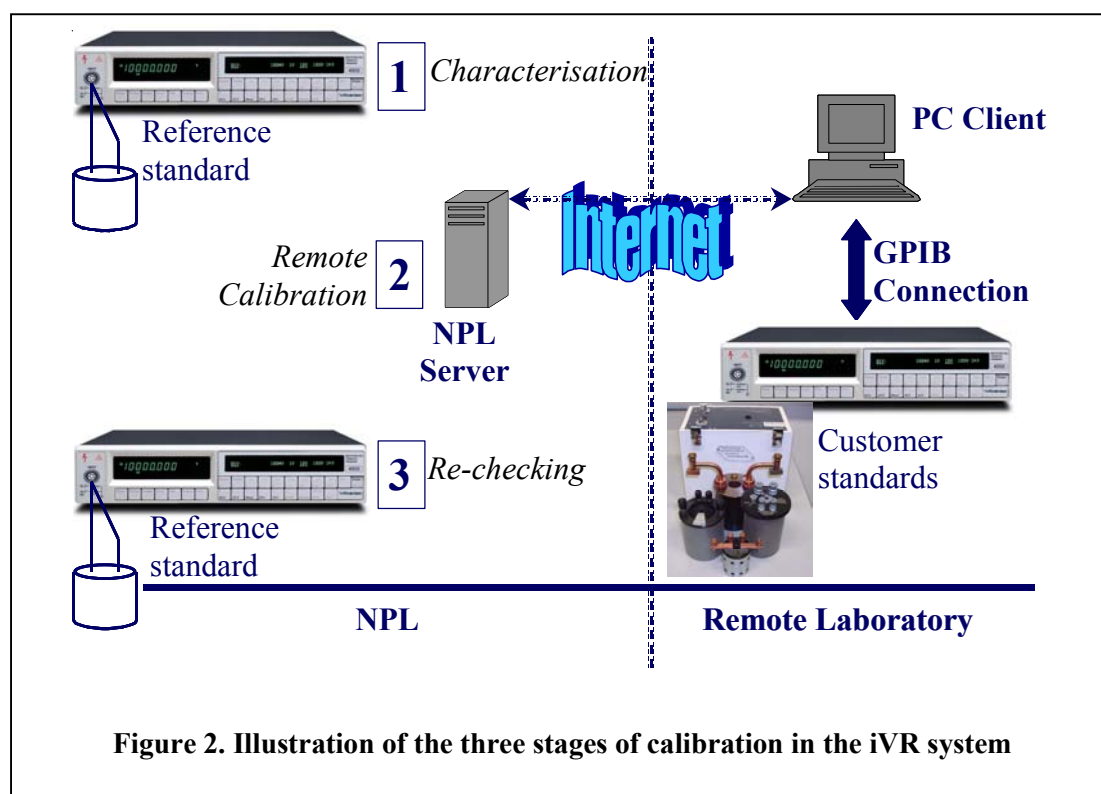


Figure 2. Illustration of the three stages of calibration in the iVR system

The software (called iCAL) used to control the iVR system was developed by Adelard in association with NPL. It was designed to be generic and extensible, so that it could be readily transferred to other Internet-enabled metrology systems in the future. It was developed using a rigorous risk management ("Hazops") approach commonly used for safety-critical software.

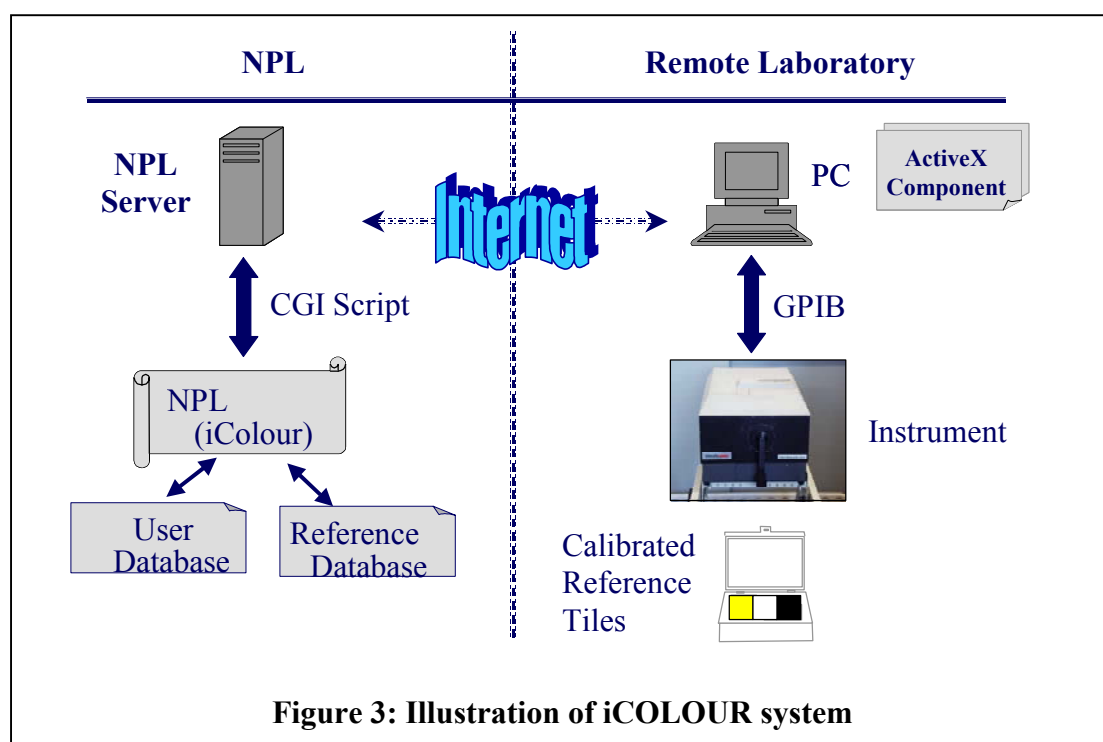
3.3 iCOLOUR

The iColour system is under development as a case study into performance monitoring/calibration of colour-measuring spectrophotometers using the Internet to

communicate between remote sites. It draws heavily on the expertise and code developed as part of the iPIMMS project. It has been developed to determine the feasibility, and to prove the concept, of:

- a remote spectrophotometric calibration system;
- increased traceability and good practice in diffuse reflectance/colour measurements using the Internet;
- an internet-based, fully accredited measurement service.

This is a system in which artefacts are used as transfer standards, sent from NPL to the client site. The artefacts are a set of glossy ceramic tiles of different colours and with known spectral reflectance properties. These will be used to calibrate visible diode array spectrophotometers, which measure visible spectral reflectance data from a sample surface. They are used by industry as reference instruments for colour measurement, for textiles, paint, paper etc. The system is illustrated in Figure 3.



When the system is set up, after system configuration, a short-term stability check is made and then a low-level performance check is needed. Only when these checks are satisfactorily completed can calibration data begin to be collected. The short-term stability check effectively tests for the stability of the xenon lamp. The % change of the measurements with respect to the first data set is checked. The tolerance varies with wavelength but is about 0.2%.

For the low-level performance check:

- A white tile is used for traceability.
- A black tile is used for linearity.
- A yellow tile is used to check the wavelength scale.

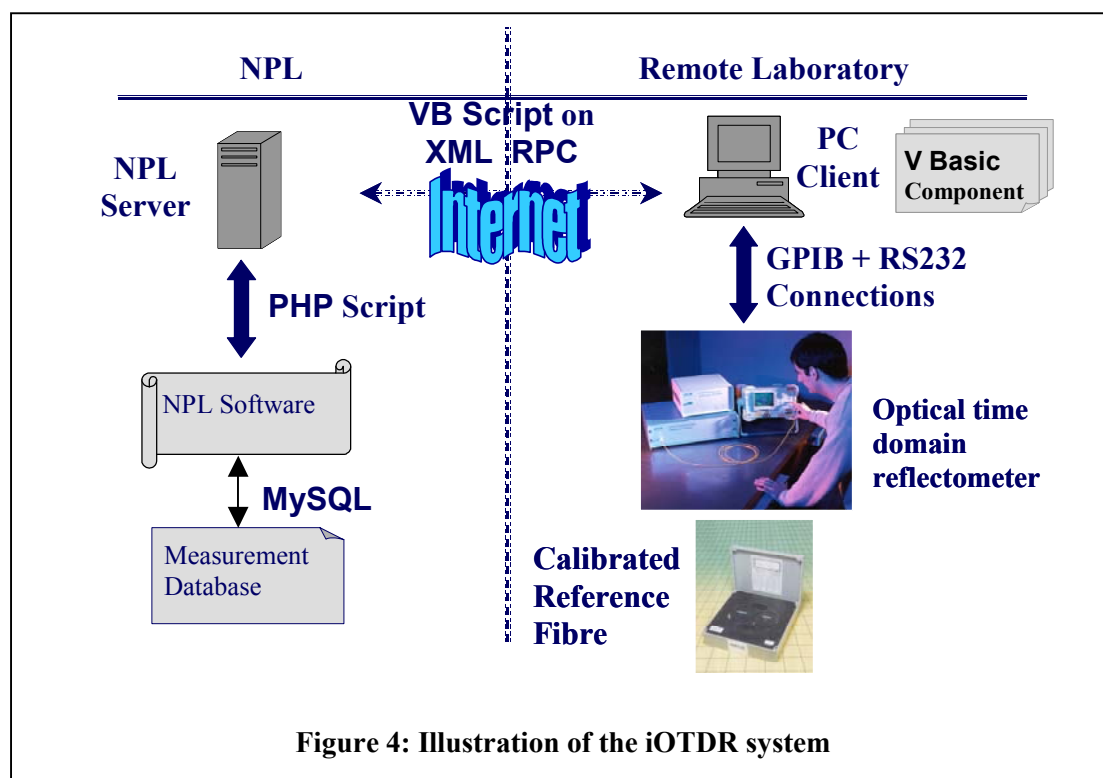
- A trap is used for zero correction.

In these ways the system performance (repeatability, stability, etc) is evaluated in-situ by NPL software. Uncertainties on measurements are also calculated by NPL software in real time.

The system could potentially be extended by broadening the range of artefacts transferred from NPL to the client site. In addition to coloured tile sets, other potential artefact standards include neutral density filters, wavenumber standards, and infrared transmittance standards.

3.4 iOTDR

NPL's fourth Internet-enabled calibration system sees the iCAL software developed for iVR adapted and applied to a new area of metrology, namely photonics. A system is being developed for calibrating optical time-domain reflectometers (OTDRs) using this system. OTDRs are widely used in the telecommunications field for measuring properties of optical fibres. The artefact transferred from NPL to the client site will be an optical fibre standard: a piece of a "golden fibre" of very accurately measured dimensions. The system is illustrated in Figure 4.



4 NIST ACTIVITIES

4.1 Introduction

At the BIPM-NPL workshop, we learned about NIST's focus on using Internet-enabled metrology for regional inter-laboratory comparisons and the difficulties they have faced with tightened security following September 11th 2001. Although many security issues that arise

with Internet-enabled Metrology are readily soluble with current technology, firewalls do pose a special problem. In NIST's case, the tightened firewall restrictions led to the services being unavailable for almost a year.

NIST also has developed a service using digital multi-meters, with similarities to the NPL iVR service, and a dosimetry calibration service; these are described below. NIST has also used the Internet to support training and collaboration, and to provide access to an on-line database.

4.2 SIMnet

Since 1998, NIST has been leading the use of Internet-enabled Metrology in interlaboratory comparisons in the Inter-American Metrology System (SIM) through SIMnet (Figure 5).

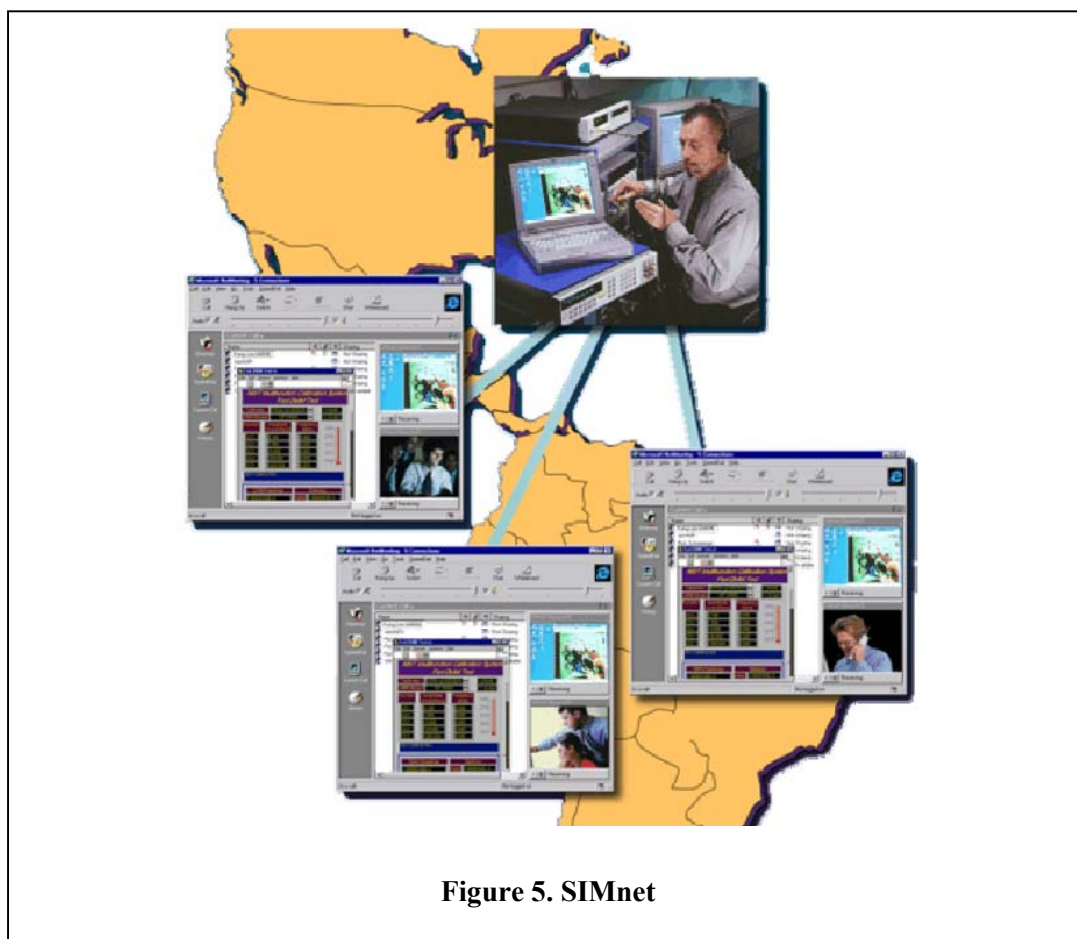


Figure 5. SIMnet

This has involved 24 participants, spanning North, Central and South America. Real-time audio, video and data communication has been used to monitor remote calibrations and comparisons, including access to shared applications and remote control of equipment where appropriate. The audio/video communication is used to hear and see the relevant staff at a remote location, as well as to see how equipment has been connected. In particular, this has been used for the first SIM comparison of five electrical units. In addition, SIMnet has been used to help with training and collaboration.

4.3 MeasureNet

The same technology used in SIMnet has also been used in MeasureNet since 2000 to support training and collaboration between NIST and State weights and measures laboratories.

4.4 Electrical calibration

Also since 2000, the Internet-enabled calibration capability used in SIMnet has been used to provide a remote calibration service to a few of NIST's customers, specifically for on-site calibration of multi-function calibrators using travelling digital multi-meters (DMMs). NIST refer to this as Internet-assisted electrical testing. In this application, test selection and appointment is made on-line. NIST software is sent electronically to the customer. Then a web-conference is initiated. The DMM-calibrator pair is controlled by both NIST and customer software. Once results agree, the DMM is sent to NIST. The DMM is then calibrated and returned to the customer with corrections and uncertainty data for use in a final test. All results gathered throughout the process are sent to NIST for analysis. Finally, the test report for the travelling DMM and the remote calibrator is posted on the NIST website (with access controlled by password). The results have shown that the uncertainty assigned to the remote calibrator was five times lower, using this service, than the calibrator's one-year specification.

Thus, this is a comparable service to NPL's iVR service, but it differs in that the DMM starts and ends with the customer, whereas in iVR the DMM starts and ends with NPL. The NPL approach allows a highly characterized DMM to be used, potentially enabling lower uncertainties to be achieved, but the NIST approach allows multiple customers to be served concurrently. The other difference is that the NIST service covers 5 quantities: DC voltage, DC current, DC resistance, AC voltage and AC current.

4.5 Dosimetry calibration services

Two kinds of conventional dosimetry calibration services are provided by NIST. These are source calibration and dosimeter calibration. In source calibration, reference-class dosimeters are sent from NIST to industry, irradiated by the customer, and returned to NIST for measurement and certification. This is commonly called "transfer dosimetry". In dosimeter calibration, a set of routine-class dosimeters are sent to NIST and irradiated to create a calibration curve for use in in-house dosimetry. In both cases, a certificate of calibration is issued by NIST. The problem is that these services take too long, including postal delays, and are too expensive.

Therefore, a new approach is now under development at NIST. The user will pay an annual subscriber fee and sets up a log-in password. The user purchases a spectrometer to read dosimeters and dosimeters from NIST, which will have been calibrated lots. NIST loads protected software onto the user's computer. Spectrometer performance characteristics are evaluated by NIST (for response normalisation to NIST system). Everything is then ready for calibrations to be controlled over the Internet: what NIST calls an e-calibration service.

In the e-calibration service, the user logs into the NIST-supplied program resident on their PC. This local program sends a request to the NIST server for authorization. The local program gets approval from the server then provides the user with instructions and stores data as acquired. Upon conclusion of the session, an encrypted log of the calibration data is transferred to the NIST server and a provisional certificate is sent to the user. Calibration session spectra and data are evaluated by NIST staff; and a final certificate is prepared, signed and sent electronically to the user. The user charged small fee for the analysis, but the fees are expected to be a factor of 20 lower because the costs to NIST are so much lower.

This has the usual Internet-enabled Metrology benefits of faster turn-around and 24-hour on-demand availability. Subscribers will also have access to dosimeter batch calibrations, which can be used for non-certified, routine dosimetry.

4.6 On-line database

NIST use an online database to support their calibration services in order to

- Reduce effort needed for administration, storing client information and contact addresses
- Improve workflow tracking, with staff being given e-mail alerts of new jobs and due dates, and providing financial and workload status reports
- Improve customer communications, providing customer information, calibration status, instructions and query forms
- Report and analyse the data, using appropriate report templates and accessing device history data as well as current data

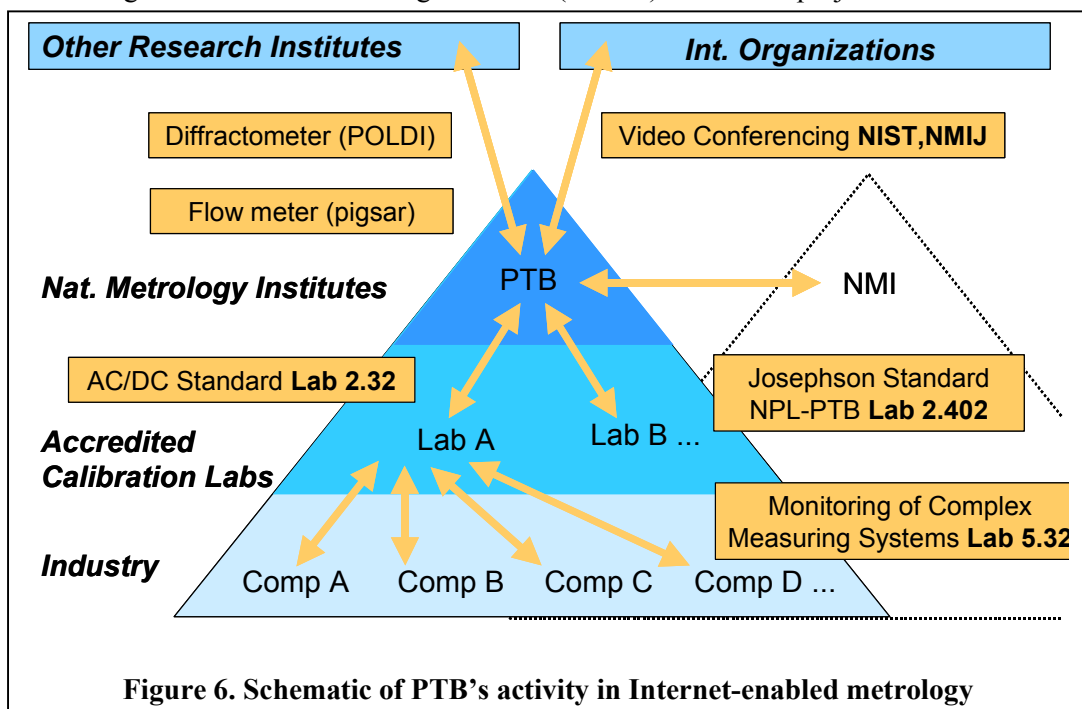
Access is provided to administrative staff, technical staff and customers, enabling each to get an appropriate and consistent view of the calibration service data.

5 PTB ACTIVITIES

5.1 Introduction

Although some PTB experts have been known to express concerns and scepticism about Internet-enabled calibration in response in some of the earlier presentations on the topic at international conferences, PTB is now engaged in a number of projects in what it calls “Internet applications for metrology”, as shown schematically in Figure 6.

It has a major project in collaboration with industry concerned with the calibration and monitoring of coordinate measuring machines (CMMs). It has two projects in the electrical



area, one in collaboration with NPL. It is in discussion with NMIJ about collaboration with them. It has a collaboration with Ruhrgas AG on high-pressure natural gas flow meter “tele-calibration”. It is making use of audio and video communication for supporting contacts between PTB sites, and collaborations both nationally and internationally. It also has supporting activities in Internet security and in databases. All of this is seen in the context of the German initiative on e-government. This latter point contrasts with the UK, where there has been little connection to date between the e-government initiative and Internet-enabled Metrology.

5.2 Coordinate measuring machine calibration and monitoring

Motivated by industry’s need to improve the quality of monitoring of complex measuring systems, in order to improve product quality, PTB has identified the following objectives:

- Increase the significance of interim check procedures
- Increase the frequency of interim checks
- Increase the knowledge of the people responsible for operating such systems
- Satisfy the requirements of traceability

PTB has a project to address these objectives by using an Internet-based infrastructure between highly specialised metrology service providers and metrology users in industry. The idea is to use Internet-enabled remote monitoring of complex measuring systems. PTB illustrates the concept as in Figure 7.

It will be seen in Figure 7 that the measuring system users are thought of typically as SMEs. The SME measures a calibrated artefact at certain intervals. If the artefact is not available at the SME site, it can be ordered from the service provider via the Internet application.

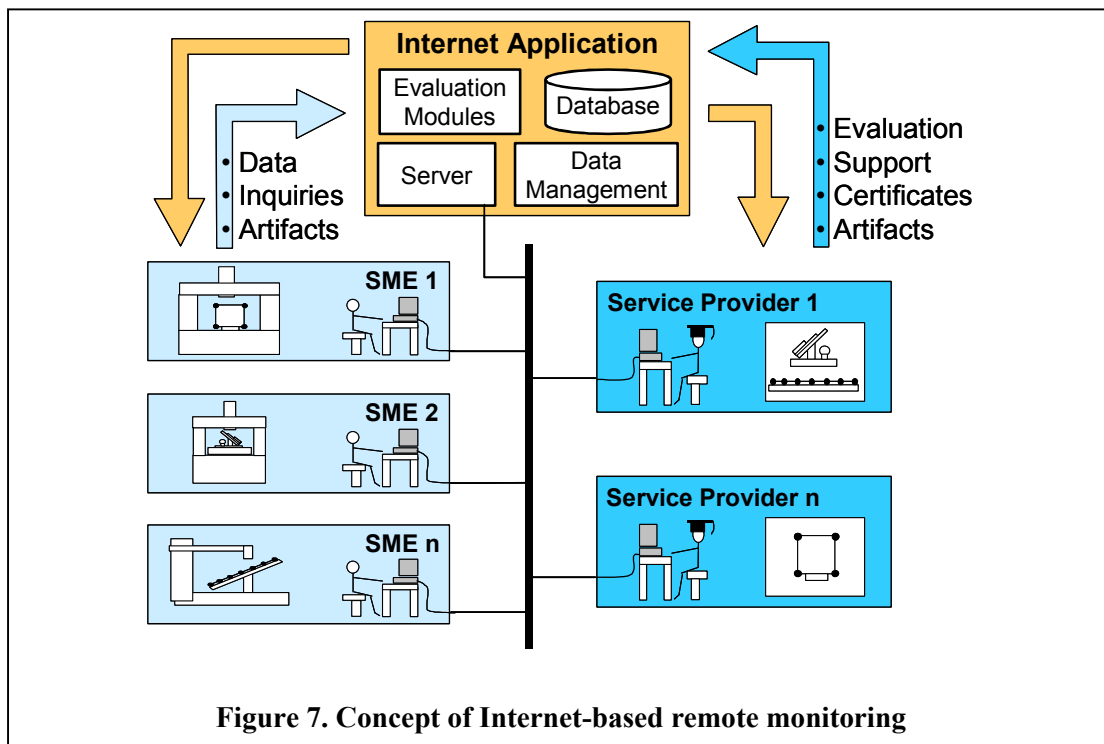


Figure 7. Concept of Internet-based remote monitoring

In order to prove this concept, the first application being made by PTB is to CMMs. The artefact used in this case is a ball cube with data loggers for temperature, humidity and shock

events positioned at the centre of the cube. The struts of the ball cube are made from carbon fibre re-enforced material, giving a light yet stable structure. This is illustrated in Figure 8.

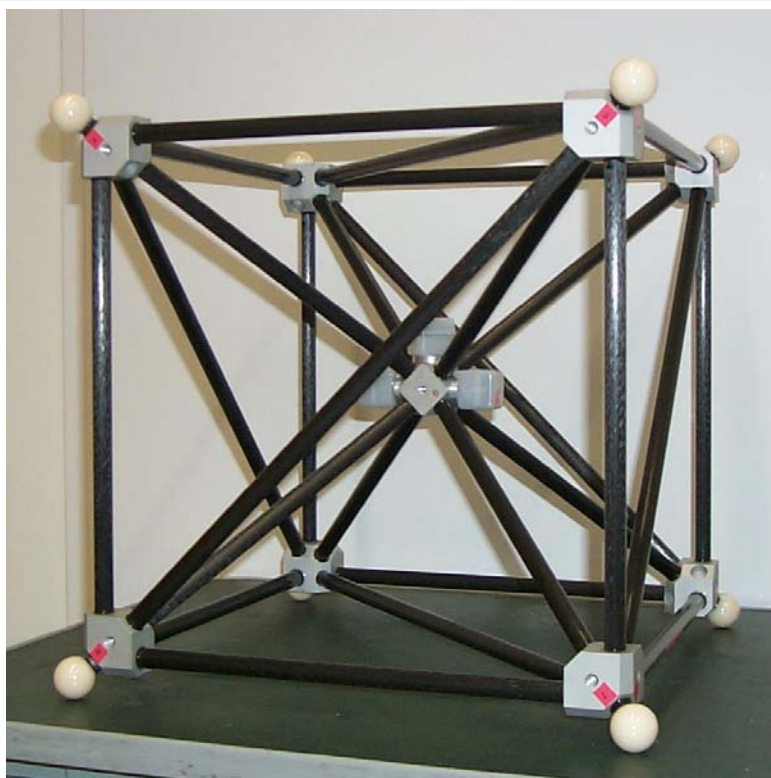


Figure 8. Ball cube – artefact for CMM remote monitoring

PTB has identified that CMMs in industry are subject to three dominant causes of departure from calibration:

- Change in geometry due to thermal influences
- Abrupt changes in probing system and geometry due to defects, thermal shocks or collisions
- Gradual changes due to relaxation effects

Therefore, procedures for interim checks need to be sensitive to these potential sources of error. Cost considerations make it appropriate that the increased cost of interim checks should be offset by the reduced cost of the manpower involved, by using the normal operators to perform the checks instead of external experts. Measuring calibrated 3-dimensional artefacts like ball cubes is an effective method of detecting all at once the typical parametric errors of CMMs, like pitch, yaw, roll, straightness and position errors. Figure 9 shows in close-up the data loggers that record temperature, humidity and shock events during shipping and handling of the artefact.

This work is being carried out as an early stage of a major collaborative project between PTB and German industry, funded by the German Department of Trade and Industry (BMWi). The industry partners are car manufacturers (BMW and Daimler Chrysler), measurement instrument manufacturers (Mahr, Werth and Zeiss) and metrology service providers (Feinmess and MWQ). PTB is developing the architecture and data management for the

application. Some of the metrology service providers and measurement equipment manufacturers are contributing evaluation modules. The car manufacturers will be pilot users during the test period.

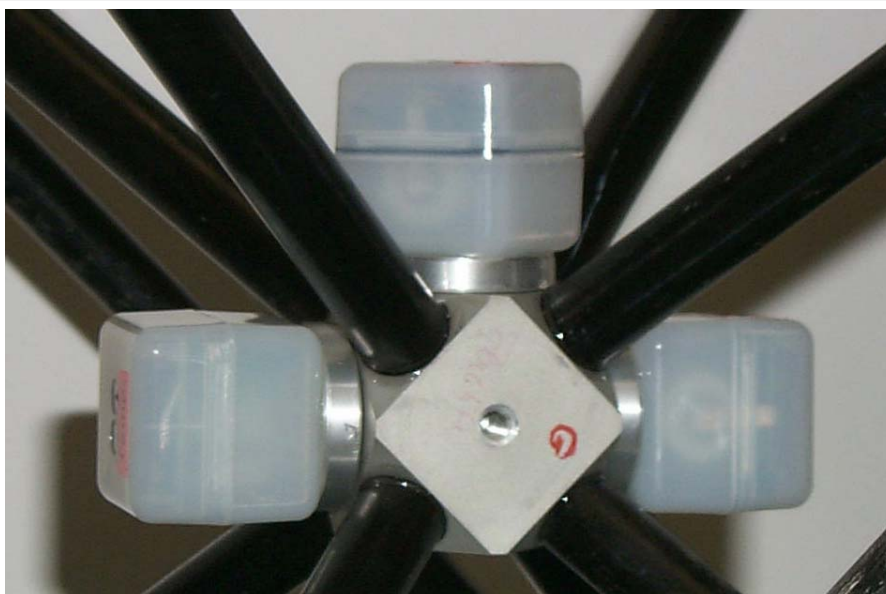


Figure 9. Data loggers for temperature, humidity and shock events

The project started in August 2001, had a test server on-line by autumn 2002, should have pilot customers by May 2003 and is due to end in July 2004. The expectation is that the system will be operated by industry, while traceability and expertise of the service providers will be accredited by the German accreditation service (DKD).

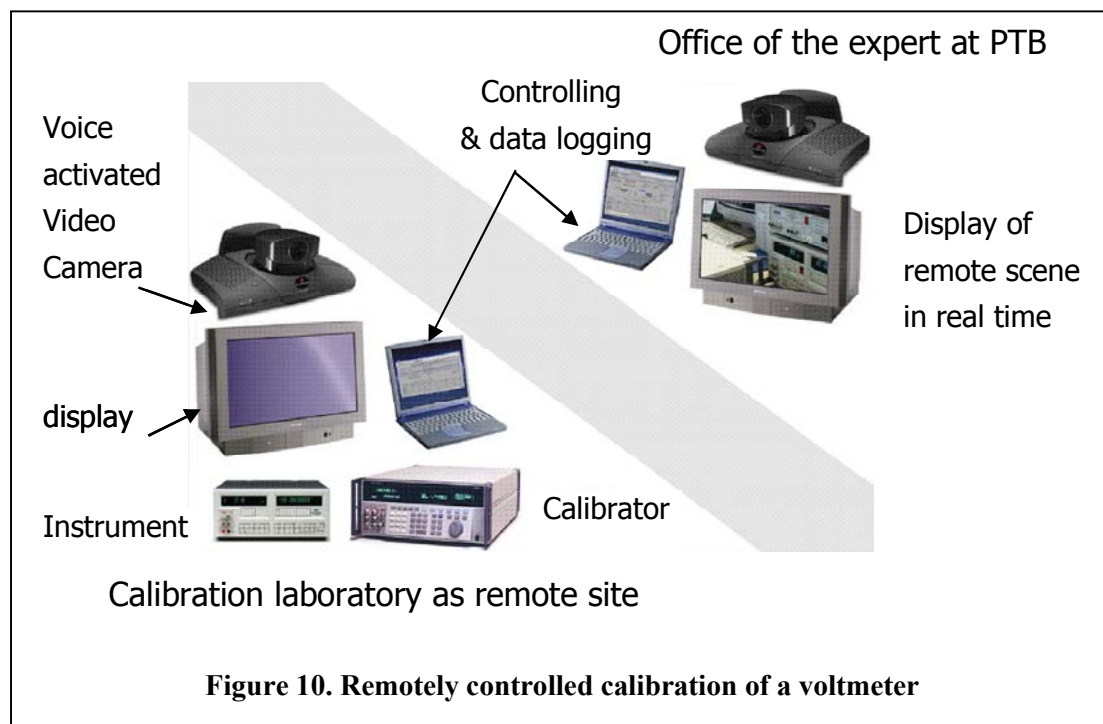


Figure 10. Remotely controlled calibration of a voltmeter

5.3 Electrical calibration

PTB has a project to provide remote calibration of a voltmeter. This is very similar to NPL's iVR service. It is illustrated in Figure 10.

5.4 Collaboration with NPL on AC Josephson voltage standard

PTB is collaborating with NPL on a project involving remote control of a programmable AC-Josephson voltage standard. The electronics is being built at NPL, whilst the array is being designed and fabricated by PTB. It is being brought together at PTB, with remote control from NPL and PTB.

5.5 Tele-calibration for the Primary High-Pressure Natural Gas Standard

The necessary investment to build and operate an appropriate high pressure test facility for high flow rate natural gas meters is enormous and an economic use of such a test facility requires commercial exploitation. Therefore, an agreement between Ruhrgas AG and PTB was concluded to recognize "pigsar" (www.pigsar.de) as a German national standard for natural gas at high pressure, located roughly 300 km away from PTB headquarters.

To run pigsar efficiently, a hardware solution was installed consisting of VXI-data acquisition hardware, a programmable logic controller (PLC) and a computer network of various PCs. The UNIX-based software of pigsar is split into five different modules:

- control (e.g. flow rate, pressure, temperature),
- data acquisition,
- database,
- visualisation and
- tele-calibration.

The connection between the modules is organised by a software layer, known as CORBA middleware, with software tasks running on different computers in parallel. Thus, it is possible to witness and control the measurements from several locations, including locally and at PTB. For security reasons, the tele-calibration task is connected via an ISDN line.

At the 5th International Symposium for Fluid Flow Measurements in Washington in April 2002, the tele-calibration system was demonstrated on-line. The presentation included a direct TV connection to show the calibration activities to the audience. On a second screen, various screenshots were shown to explain the process of calibration and supervision of a gas meter under test.

The system has been in use for routine calibrations and related activities since January 2002. It may be considered as a new metrological tool for maintenance and supervision of the dissemination of the units for volume and mass of natural gas. Furthermore, tele-calibration is seen as a necessary tool for the permanent task to provide PTB-certificates based on the harmonized reference value for high-pressure natural gas as agreed between NMi and PTB.

5.6 Potential collaboration with NMII

PTB is actively considering possible collaboration with NMII on one or more Internet-enabled Metrology projects. See section 6 below for a description of the candidate NMII projects.

5.7 Audio and video communication

PTB is creating an infrastructure to facilitate institutional collaboration, involving audio and video communication using common principles, but multiple realisations. This is being used at three levels:

- Internally with PTB, between the Braunschweig and Berlin sites
- Nationally, between PTB and laboratories in industry and academia
- Internationally, between PTB and other NMIs – NIST and NMIJ already and NPL in the future

5.8 Web-based data acquisition, storage and access

PTB has another project exploring the potential of web-based capture, storage and access of data concerned with particular measurement devices. This should include device description and configuration information, measurement set-up information and calibration data, potentially including calibration history data. This is similar to what has been proposed in a data warehousing study conducted for NPL by Baltimore Professional Services.

The PTB project proposes the use of platform-independent, open source, firewall friendly solutions. These include the use of the standard web protocol HTTP and, for encryption and authorisation, the protocol HTTPS. They propose the storage and transmission of data in XML, organised in an object-oriented web-enabled database system, with appropriate use of SQL for database access and XML RPC for performing remote procedure calls. Access to data and remote control should be through a normal web browser.

Using Frameworks such as Zope, which is an open source application server, for building web applications, LAMP (LINUX, Apache, MySQL, php), and a Content Management System (CMS) there is also the possibility of accessing the database through other programs (e.g. from products of the Microsoft Office family). For data reduction and visualisation, the use of “IDL on the net” (ION) is foreseen.

The absence of a real-time capability of such systems is often seen as a crucial limitation. However, it is argued that this is a moot point because a local PC controls the equipment and it is that PC that is controlled remotely rather than the equipment itself.

PTB feels that the use of open source, platform-independent standards give users and developers freedom of choice and transparency. Using proven business to business technologies makes the applications robust and reliable. However, support for legacy software is crucial and still possible.

5.9 Internet security

Various groups at PTB are collaborating to tackle problems in the rapidly evolving area of Internet security. The topics considered include:

- Digital signatures
- Encryption
- Access validation procedures
- Authentication of documents
- Integrity of documents
- Confidentiality of documents
- Web-forms for use in Internet applications

6 NMI NETHERLANDS ACTIVITIES

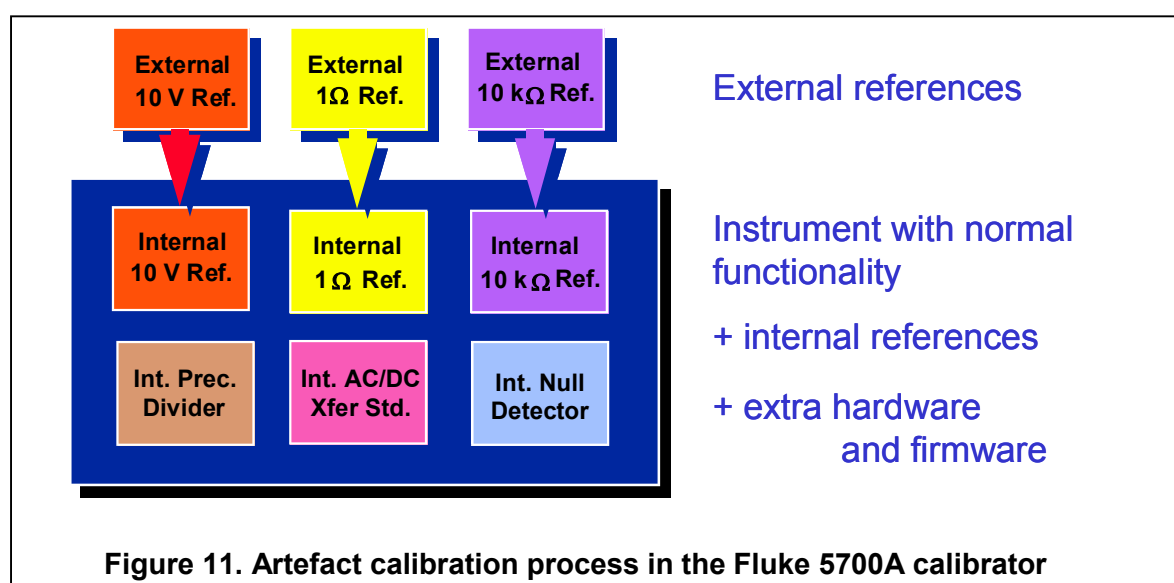
6.1 Introduction

NMi has a collaboration with Fluke on Internet-enabled maintenance of a self-calibrating electrical calibrator, which again uses the Fluke 4950 as a transfer standard. Four levels of checking are involved: internal checks, self-calibration, Internet-enabled calibration, and conventional calibration. This enables the user to get the right balance between cost and uncertainty, with all the data collected going into a single database, to give a complete history of the checks performed on the equipment.

6.2 Internet-enabled maintenance of a self-calibrating electrical calibrator

For its new Internet-enabled maintenance service, NMi has selected as the instrument to be calibrated the Fluke 5700A multifunction electrical calibrator. This instrument can generate many different electrical signals over a wide range of values. It was chosen for several reasons. Firstly, it is widely used in industry. In many electrical calibration laboratories the calibrator is the best reference standard and is the main workhorse. In addition, due to its many functions and ranges, full verification of the instrument requires several hundred different measurements. The analysis of so much data is not trivial. Furthermore, the calibration of the calibrator can be very well automated using a stable, high-resolution, digital multimeter, such as the Fluke 4950.

However, a major reason for selecting the Fluke 5700A is that it has a self-calibration facility – also referred to as artefact calibration. This means that apart from the normal functionality, it contains additional facilities by which it can calibrate itself. Schematically, the self-calibration process is shown in Figure 11.



The self-calibration process is performed in two steps. First, the internal references (10 V, 10 k Ω , and 1 Ω) are calibrated against the external references. Then the external references are disconnected from the instrument, and all other ranges and functions are related to the internal references using additional hardware and software inside the instrument. This extra hardware consists of relays, dividers, a null detector and an internal AC/DC transfer standard.

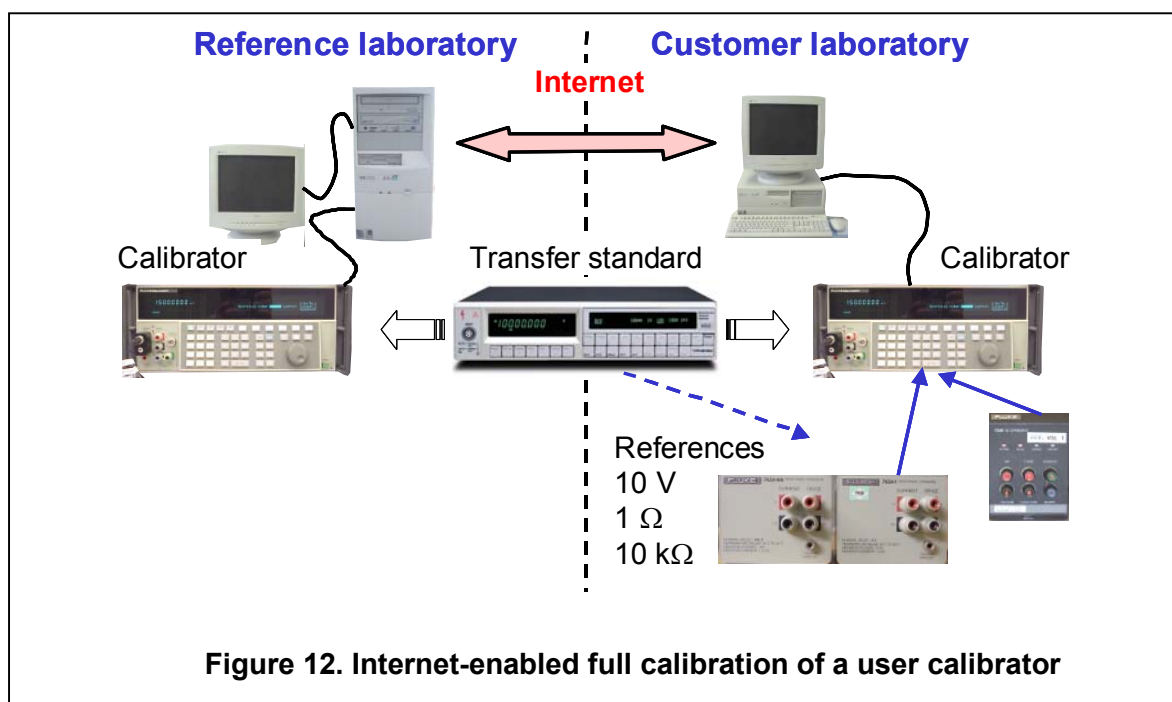
This self-calibrating facility was recently evaluated by an independent group of NMIs. The most important conclusion of that evaluation was that self-calibration in the Fluke 5700A

calibrator performs a traceable calibration of the outputs, under the main provision that the internal AC sensor was sufficiently stable. For NMI's Internet application another conclusion is important as well, namely the fact that the internal reports of the self-calibration results correctly indicate what the shifts are in the outputs.

The Internet maintenance of the calibrator is based on the acquisition of three different sets of calibration data resulting from:

- 'Conventional' full calibration of the calibrator at the binding posts,
- Self-calibration, and
- Internal calibration or Cal-Check. This is the second part of the self-calibration process, omitting the initial step where the internal standards are measured against external references.

The least frequently used calibration in the maintenance will be the most time consuming 'conventional' full calibration. For this, the Fluke Wavetek 4950 will be used, being a very stable, high-resolution, digital multimeter (DMM). This DMM is first calibrated at the reference laboratory and then sent to the users laboratory. There it is connected to the calibrator of the user and the whole combination of calibrator and multimeter is controlled via the Internet. The resulting data are transferred again via Internet to the reference laboratory. The full calibrations are mainly required as an overall check of the calibration of the instrument and of the stability of the internal AC/DC sensor. This whole procedure is shown schematically in Figure 12. It is similar to services set up by NPL, NIST and PTB.



7 NMI JAPAN ACTIVITIES

7.1 Introduction

The National Metrology Institute of Japan (NMIJ) affiliated with the National Institute of Advanced Industrial Science and Technology (AIST), and with Universities and industry in Japan, is working on a very ambitious Internet-enabled Metrology programme (that they prefer to call Internet-enabled traceability), called e-trace, running from 2001 to 2005. This programme covers more areas of metrology than any other NMI's Internet-enabled Metrology programme, but parts of it involve collaboration with other NMIs. At this stage it is in a feasibility study phase and covering the following topics:

- Josephson voltage
- Time and frequency
- Optical frequency
- Length
- AC-DC difference
- Radioactivity
- Coordinate measuring machines
- Temperature
- Pressure
- Flow

A major driver for this programme is the desire to provide a service to Japanese companies that have moved their operations to other countries. The industry needs this service to have a short turn-around time for calibration, world-wide recognised accuracy, consistency of service between Japanese and overseas factories, and low cost. The e-trace programme is supported by the New Energy and Industry technology Development Organisation (NEDO), and the Ministry of Economy, Trade and Industry (METI), with a budget of 150 million yen in 2001, 200 million yen in 2002 and 300 million yen in 2003.

As with NIST, they see a major use being in interlaboratory comparisons. The Japanese programme has the appearance of giving more emphasis to technological innovation than a response to market need and commercial opportunity.

Where relevant, such as for frequency, time, voltage and length measurement, frequency is transmitted via the global positioning system (GPS). In other cases, such as radiation, temperature, pressure and flow, transfer standards need to be transported between the NMI and the client laboratory.

7.2 Josephson voltage

With progress of precision measurement technology, the need for a portable Josephson voltage standard system is increasing. To satisfy these requirements, NMIJ/AIST have been developing a programmable Josephson voltage standard system (DC) which can be operated with a compact refrigerator. This is a desktop-type Josephson voltage standard system which, including the small refrigerator, is only 50 cm in height.

The key technology that has been newly developed and employed is a niobium nitride (NbN) based Josephson junction technology. Since NbN has a high super-conducting critical

temperature ($>15\text{K}$), the voltage standard chips can be operated at a temperature higher than the liquid helium temperature (4.2K).

Recently, they have fabricated a voltage standard chip which contains 32,768 NbN/TiN/NbN junctions. The NbN-based voltage standard chip has the ability to generate a voltage over 1V with metrological accuracy. In order to prove the ability for the chip, they measured current-voltage characteristics for several junction arrays on the chip (see Figure 13). As the goal of this research project, they plan to develop a portable and programmable voltage standard system which has the ability to generate a voltage over 10V with metrological accuracy.

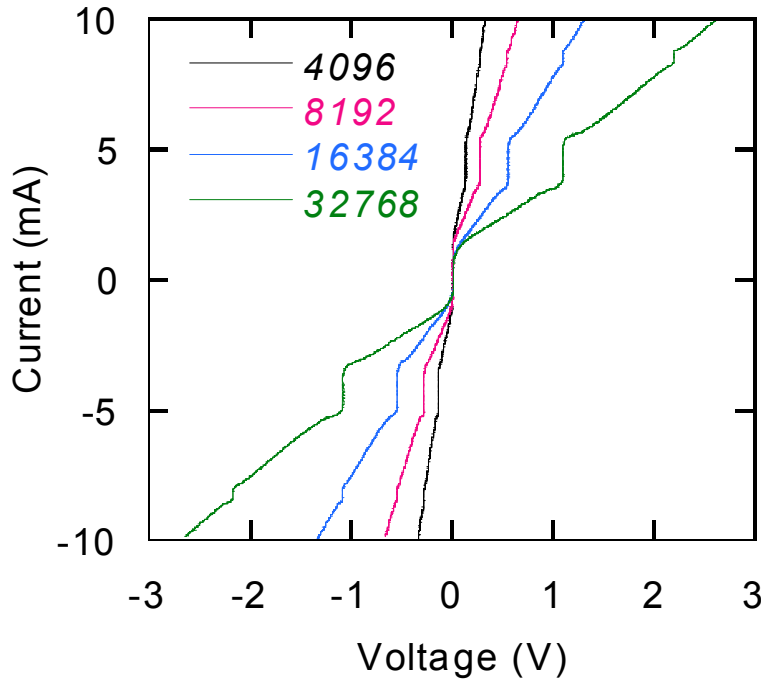


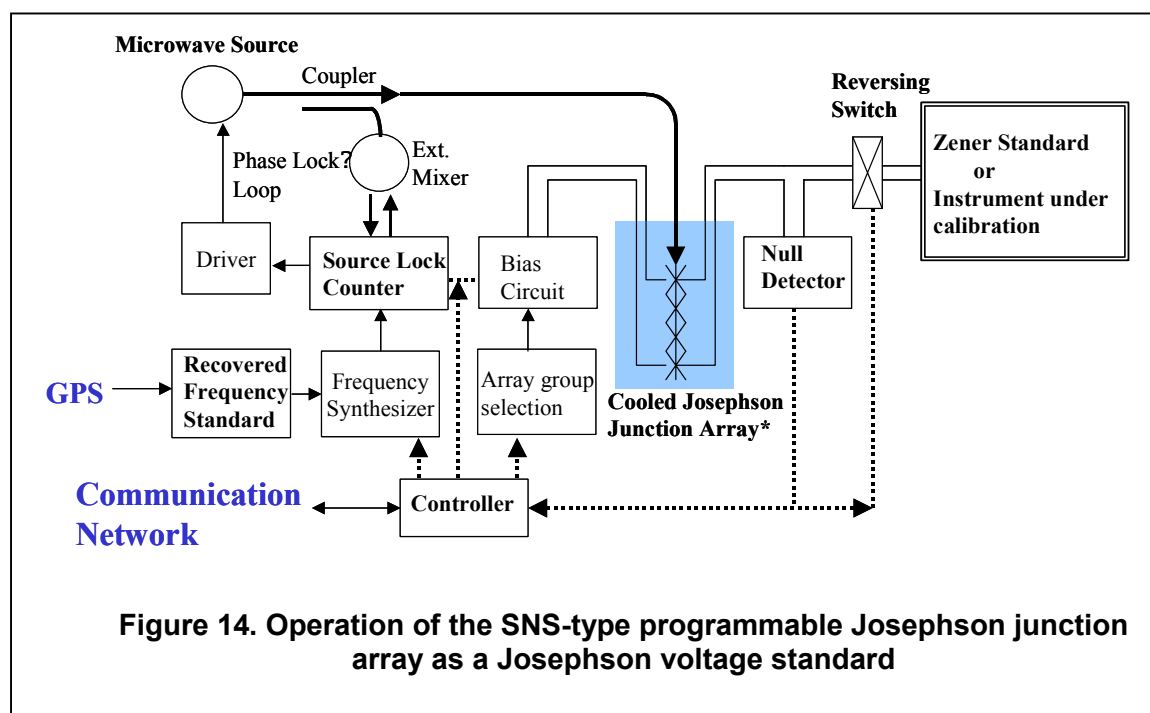
Figure 13. Characteristics of newly developed NbN/TiN/NbN Junction Array

Building on this work, NMIJ is working on the concept of remote calibration and interlaboratory comparison coordinated by the distribution of frequency via GPS. A 10MHz frequency standard can be recovered from a GPS signal frequency of 1.575 GHz, with an uncertainty of less than 1×10^{-11} per day. This frequency f is used for comparisons and calibrations of Josephson voltage V_n through the relationship

$$V_n = nf / K_{J-90}$$

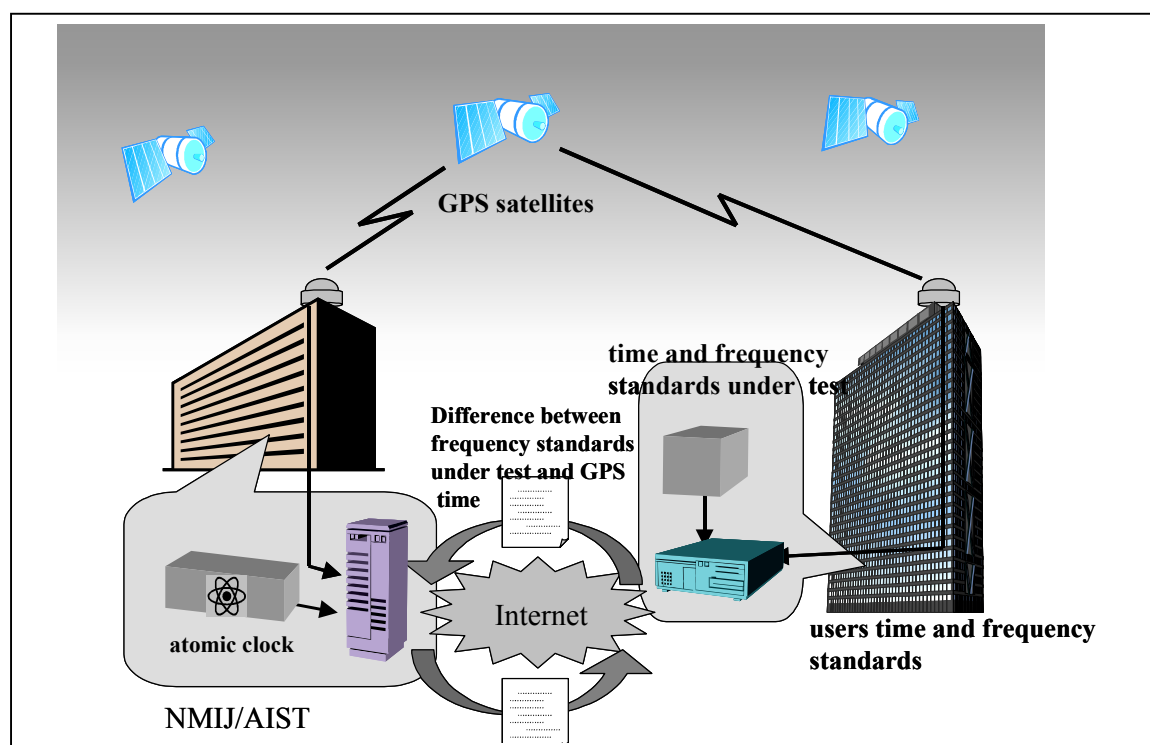
Additional communication among the participating laboratories may be achieved via the Internet. They are using the programmable Josephson junction array held at 10K and irradiated with 16GHz from a microwave source driven from the frequency standard through a phase lock loop. The cooled Josephson junction array is used to calibrate a Zener voltage standard or other instrument, as illustrated in Figure 14.

This work is being done in collaboration with NIST at Boulder.



7.3 Time and frequency

NMIJ and AIST are planning to provide UTC (NMIJ) and to calibrate time and frequency standards via GPS and the Internet. The resulting system will be used to compare different types of time and frequency signal via GPS (as in the Josephson voltage example above).



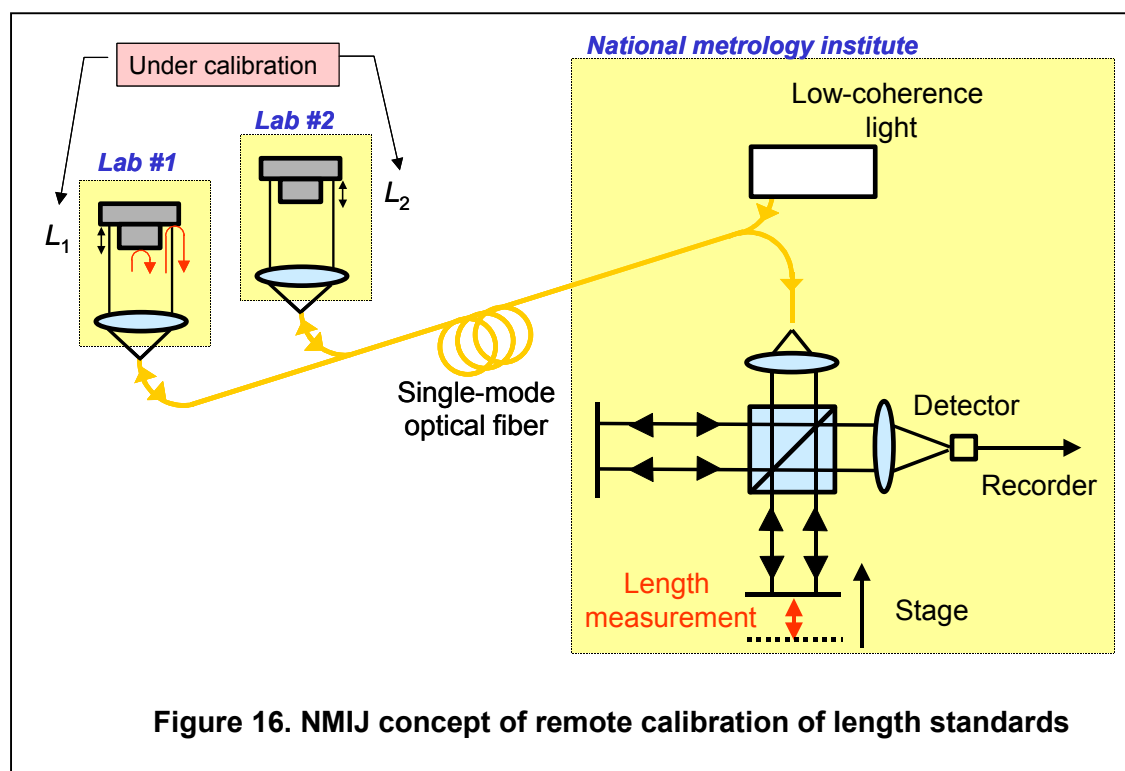
They will transfer securely via the Internet the data concerning the difference between frequency standards under test and the GPS signal from users to NMIJ/AIST. This is illustrated in Figure 15.

7.4 Optical frequency

NMIJ/AIST is collaborating with Tohoku University in planning to provide optical frequency standards in the near-infrared region via optical fibre communication. They are developing an optical comb generator, which is obtained by an ultra-short pulse emitted from a mode-locked fibre laser. The optical comb is converted into the optical region by a non-linear optical device. The University will take charge of narrowing the mode-locked fibre laser spectrum, and stabilisation of the repetition frequency of the mode-locked fibre laser. NMIJ will take charge of extension of the comb spectra, stabilisation of the carrier frequency, and evaluation of the uncertainty of this optical frequency.

7.5 Length

NMIJ is developing a technique for precise and efficient calibration of practical length standards, such as end standards, by transmitting the absolute length based on the definition of the metre in the form of optical phase difference of an optical interferometer.



The idea is that one interferometer would be installed at the NMI and another at an accredited laboratory. These would be connected by a single-mode optical fibre. Low-coherence (wide-spectral bandwidth) light is used as a light source. The output light of the accredited laboratory's interferometer contains the information about the length standards under calibration in the form of optical phase (optical path) difference. Because the absolute length is much longer than the coherence length of the light used, no interference fringe will be observed. The output light is provided to the NMI's interferometer by the optical fibre. When the optical path differences of the two interferometers are balanced within the coherence

length, the interference fringe will be observed on an optical detector; i.e. the length information of one interferometer is precisely transmitted to the other. This is illustrated in Figure 16.

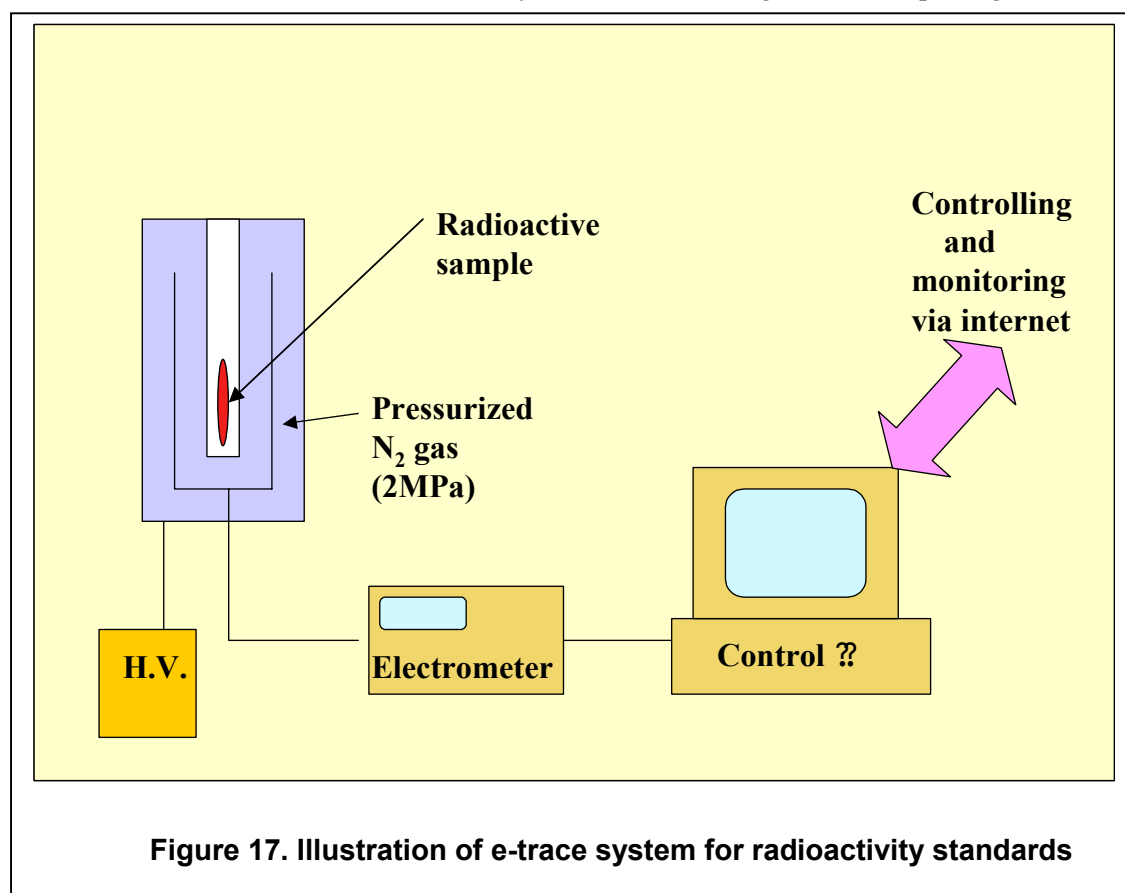
Clearly, this technique has a rather high infrastructure cost, unless the optical fibre link is needed for other purposes as well.

7.6 AC-DC difference

NMIJ is developing a remote calibration system for the AC-DC difference standard using the fast-reversed DC method. The first stage, from 2001 to 2003, involves the development of an AC-DC calibrator based on the fast-reversed DC method. The second stage, from 2004 to 2005, will involve the evaluation of the performance of the remote calibration system using this calibrator. A travelling standard will be calibrated using the calibrator at the customer site, with the calibration being assisted remotely by the NMI.

7.7 Radioactivity

NMIJ will develop a remote calibration and traceability system for standardization of radioactivity. It is expected that in the near future almost all isotopes will be measured by remote control and video communication via the Internet. Usually, gamma-ray emission radio-nuclides are measured by an Ionisation Chamber (IC) and the output electric current is measured and the measurements saved on computer. When the calibration constants of the IC are fixed relative to a long half-life reference source ($^{166\text{m}}\text{Ho}$ has a half-life of 1200 years), then that source can be adapted to work with all ICs of the same type. It is then possible to use a remote calibration service for radioactivity, as illustrated in Figure 17, transporting the

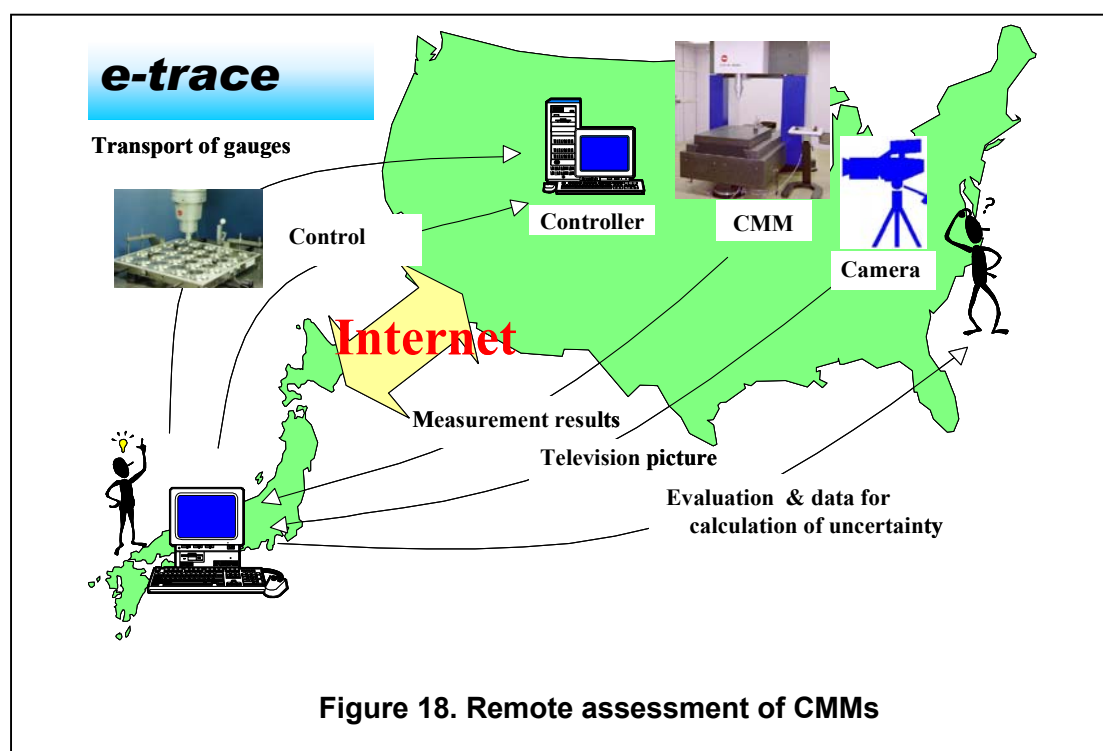


reference source to each laboratory in turn, and controlling and monitoring each IC by video communication via the Internet.

This method can be used not only for calibration but also for interlaboratory comparison. It is expected that the supply area and variety of standard radioactive isotopes of NMIJ will be enlarged by this method.

7.8 Coordinate measuring machines

NMIJ is working on the development of Internet-enabled calibration of CMMs. NMIJ uses a gauge, such as a ball-plate, rather than the ball-cube being developed by PTB. The gauge is transported to the client site, where the client puts it in the CMM. The laboratory (e.g. NMIJ) then controls the CMM through the Internet and measures the gauge. The resulting data are sent back to the laboratory through the Internet. Images of the CMM and gauge are monitored by a video link over the Internet. The laboratory then analyses the data and derives geometrical errors, and sends the results to the client. The clients can estimate the uncertainty in measurements from the geometrical errors. NMIJ picture this being done in association with NMIJ's e-trace network, as shown in Figure 18. In this work, there is some collaboration with the related activities of both NIST and PTB.



7.9 Temperature

NMIJ/AIST is developing remote calibration technology for use in thermometry. Instead of officials from NMIJ visiting accredited calibration laboratories to witness the demonstration of the thermometer calibration for proficiency testing, transfer thermometers and communication equipment will be sent to the accredited calibration laboratory from NMIJ. The resulting data and camera images of the calibration taken during the tests are monitored and sent directly to NMIJ through the Internet.

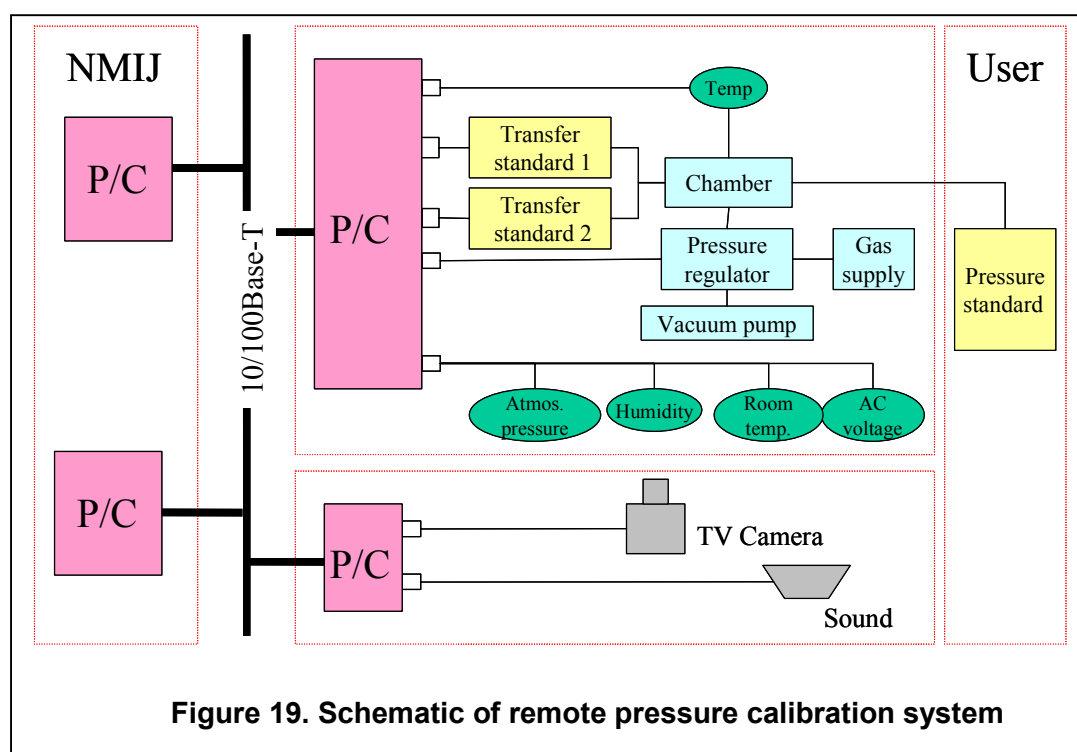
The main tasks of this development are the development of reliable and stable transfer thermometers (thermocouples and platinum resistance thermometers) and the development of a remote monitoring system for calibrations in thermometry.

It is hoped that this technology will also be applicable to other calibration schemes in thermometry.

7.10 Pressure

NMIJ is planning the development of a remote calibration system using a digital pressure gauge. Generally, digital pressure gauges are not used as reference standards or transfer standards, although they are easy to work with. Piston gauges have been widely used as reference standards and transfer standards, because they have higher accuracy and reliability than digital pressure gauges. However, piston gauges require a great deal of skill to operate. On the other hand, there has been remarkable progress recently in the performance of digital pressure gauges. Some gauges show high stability comparable to that of a piston gauge.

NMIJ plans to evaluate precisely the performance of an improved digital pressure gauge. A remote calibration system, as illustrated in Figure 19, using the gauge will be developed and demonstrated, with the expected benefits of low cost, ease of use and traceability. The goal is to achieve an uncertainty (presumably at 95% confidence) of 0.02% for gas pressure in the range 10k to 1Mpa and 0.05% for liquid pressure in the range 1M to 100Mpa.



7.11 Flow

NMIJ is developing a remote monitoring and calibration system for flow measurements based on the national flow standard apparatus located in AIST north centre, Tsukuba. The target uncertainty of 0.1 % ($k=2$) in the flow range 10-300 m³/s is planned to be achieved by the end of 2004. This is expected to be helpful for oil companies.

8 CONCLUSIONS

It is clear that it is now widely accepted that the provision of remote measurement services over the Internet will play an increasingly important role in the field of metrology, sometimes for the provision of primary calibration services, but more often for the provision of secondary calibration or other measurement services, including equipment monitoring. Not all such services will provide traceability to primary standards or the smallest feasible uncertainties, but many will. All should be aimed at providing services that are fit for purpose, meeting the real needs of measurement users more effectively. It would seem that the main limitations to the application of Internet-enabled Metrology to new metrology areas come from our own lack of imagination, provided that there is a market or technical justification for the application and that there can be made available a suitably portable and robust transfer standard or calibration artefact(s).

9 ACKNOWLEDGEMENTS

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