IEE Measurement Prize 2005 - nomination

"Internet-enabled traceability for high precision measurements using microwave network analysers"

N M Ridler[1], A G Morgan[1], I Instone[2], S Wylie[3] and R A Dudley[1]

[1] National Physical Laboratory, Teddington
[2] Agilent Technologies, South Queensferry
[3] BAE SYSTEMS, Warton

Summary

Traceable, high precision, measurements play an essential role in many areas of science and technology. Such measurements enable a quantitative assessment to be made about the quality and reliability of other measurements and their subsequent application (e.g. in research and development, product manufacturing and testing).

Traditionally, measurement traceability is established through an unbroken chain of comparisons (i.e. a traceability chain) linking an end-user's measurement result to 'known' references provided by primary national standards maintained by National Metrology Institutes (NMIs). The comparisons involve laboratories performing calibrations of transfer devices that are transported between the laboratories. Each laboratory forms a link in the traceability chain and must have a stated uncertainty for their measurements. The size of the uncertainty for the end-user is dependent on three factors:

i) The number of links in the traceability chain between the end-user and the NMI (the more links, the larger the uncertainty);
ii) The type and health of the equipment (including the standards used to calibrate the equipment and the operator of the equipment) used by the end-user;
iii) The measurement methods used by the end-user.

A drawback with the traditional traceability method is that there can often be many links in the traceability chain between end-user and NMI and this can cause the end-user's uncertainties to be unacceptably large. For example, the end-user might be a commercial company manufacturing products to a given specification. Under these circumstances, the testing of a product can be adversely affected by large uncertainties since these uncertainties need to be taken into consideration when assessing compliance of the product to its specification. With increasing commercial demands to produce tighter specifications for products, it can be of great advantage to make the lowest possible uncertainties accessible to the end-user (e.g. on the production lines of manufacturing facilities). This is indeed the case for numerous manufactured components, sub-systems and systems that require testing at RF and microwave frequencies (e.g. in the communications, computing and defence industries).

The programme of work comprising this nomination has successfully solved this traceability 'problem' for measurements at RF and microwave frequencies. In particular, a facility has been implemented that provides the primary national standard level of accuracy for vector network analyser (VNA) measurements at any suitable end-user location (including industrial production lines). The facility utilises the Internet to achieve this traceability by enabling the end-user to implement national standard measurement methods using their own equipment (including standards) at their own chosen location.

The primary reference standards are owned by the end-user and are of a similar type and quality as used by the NMI. These standards are available commercially from suppliers of such components.[1] The standards (lengths of precision air-filled coaxial or waveguide transmission lines) are characterised solely in terms of mechanical (length) measurements. These measurements have traceability directly to SI Base Units (in this case, the metre) and hence the number of links in the traceability chain between end-user and NMI is reduced to the minimum (i.e. to a chain with only one link). This is how the primary standard level of accuracy is achieved wherever and whenever it is required by the end-user.

---

[1] Examples of suitable suppliers include: Agilent Technologies, Maury Microwave Corp, Rosenberger and Flann Microwave.

The mechanical measurements providing the traceability are much less expensive than the electrical measurements that were required previously to establish traceability using the traditional method. In addition, the mechanical characterisations of the standards are inherently more stable, so the intervals for these re-calibrations are typically between three to five years (compared with the annual electrical re-calibrations required previously for the traditional traceability method). This provides a further cost saving for the end-user, resulting in an overall cost reduction of typically an order of magnitude compared with the traditional traceability method.

Workers at NPL (Nick Ridler, Andrew Morgan and Richard Dudley) developed and implemented the measurement processes that interact directly with the end-user's VNA firmware to perform calibrations and measurements. The system is called "Internet-enabled Primary IMpedance Measurement System" (or *i*PIMMS, for short) since it is essentially an Internet version of NPL's primary national standard impedance measurement facility.[2] *i*PIMMS enables end-users to achieve levels of accuracy previously only attainable at NPL – these being equal to the best available in the world.

The development of a commercial version of *i*PIMMS was greatly facilitated by off-site testing performed by staff at BAE SYSTEMS, Warton, led by Stewart Wylie. This facility was launched in 2001 and became the UK's (and probably the world's) first commercial measurement service to offer traceability to national standards by connecting to the Internet.[3] The facility has since been taken up by other organisations in the UK and elsewhere in Europe (with much interest also shown by organisations from outside Europe).[4]

A recent success of this service has been to get a client using the facility assessed against the international accreditation standard, ISO 17025. Much of this work has been undertaken by staff at Agilent Technologies, South Queensferry, under the leadership of Ian Instone. In 2004, an assessment to ISO 17025 was undertaken by UKAS (the United Kingdom Accreditation Service, www.ukas.org) resulting in the accreditation of *i*PIMMS as operated by staff at Agilent Technologies' South Queensferry site.

The staff at Agilent have since used *i*PIMMS to provide traceability for production line testing. A key product manufactured at the South Queensferry site is test equipment used for measuring the performance of mobile telephones. This enormous commercial market is therefore now benefiting from direct access to national standard levels of accuracy for production line testing. Another key commercial feature is that Agilent Technologies is now offering an accredited calibration service for external third-party customers using *i*PIMMS. This is providing access to the benefits of Internet-enabled traceability for all such customers and hence to the industry as a whole.

To demonstrate the technical performance of the *i*PIMMS service, the following table shows an extract from the UKAS Scope of Accreditation now being offered by Agilent Technologies at their South Queensferry site. It should be noted that the quoted uncertainties are comparable with the leading NMIs in this area – i.e. NPL in the UK, NIST in the USA and PTB in Germany.

Extract from *i*PIMMS UKAS Scope of Accreditation for Agilent Technologies, South Queensferry (UKAS accreditation number 0813)

Measured quantity	**Range**	**Best Measurement Capability** [5]	**Remarks**
Linear complex voltage reflection coefficient (VRC) in 50 Ω coaxial line	45 MHz to 18 GHz 0 ≤ |VRC| ≤ 1	0.002 to 0.007	For devices fitted with 7 mm or Type-N connectors
	45 MHz to 26.5 GHz 0 ≤ |VRC| ≤ 1	0.006 to 0.012	For devices fitted with 3.5 mm connectors
Linear complex voltage transmission reflection coefficient in 50 Ω coaxial line[6]	0 dB to 40 dB	0.013 dB to 0.043 dB 0.09 º to 0.29 º	For devices fitted with 7 mm or Type-N connectors
	60 dB	0.043 dB to 0.42 dB 0.29 º to 2.9 º	
	0 dB to 30 dB	0.013 dB to 0.043 dB 0.09 º to 0.29 º	For devices fitted with 3.5 mm connectors
	60 dB	0.043 dB to 0.83 dB 0.29 º to 5.7 º	

[2] N M Ridler, "A review of existing national measurement standards for RF and microwave impedance parameters in the UK", *IEE Colloquium Digest No 99/008*, pp 6/1-6/6, February 1999.
[3] The service was launched in 2001 by Lord Sainsbury, the government minister for Science and Innovation, at the London head office of BAE SYSTEMS.
[4] The system has been operated successfully by organisations throughout Europe, the Americas and the Asia-Pacific region.
[5] Expressed as an expanded uncertainty at an estimated level of confidence of 95 %.
[6] Values are expressed in terms of attenuation and transmission phase.

Publications

*(Those marked ** are considered to be the four most important/significant publications.)*

1 ** J Hurll[7], I Instone and N M Ridler, “First accreditation of Internet-enabled calibration”, *Quality Today magazine*, p 14, March 2005. (Also published in *UKAS Update magazine*, number 36, Winter 2004/5 edition.)

2 A G Morgan, I Instone and N M Ridler, “VNA measurements via the internet”, *ARMMS (RF & Microwave Society) Conference*, Hotel Elizabeth, Corby, Northamptonshire, 1st/2nd November 2004.

3 ** A G Morgan, I Instone, N M Ridler and R P Thompson[8], “Comparing Internet-enabled VNA measurements with primary national standards”, *63rd Automatic RF Techniques Group (ARFTG) conference*, pp 29-34, Fort Worth, Texas, USA, 11 June 2004.

4 ** R A Dudley and N M Ridler, “Traceability via the Internet for microwave measurements using vector network analysers”, *IEEE Trans*, **IM-52**(1):130-134, February 2003.

5 N M Ridler, R A Dudley and A G Morgan, “Using the Internet to facilitate high precision microwave impedance measurements at any geographical location”, *Proceedings of the Joint BIPM-NPL workshop on the impact of information technology in metrology*, National Physical Laboratory, 16th/19th September 2002.

6 N M Ridler, “Calibrate VNAs over the Internet”, *Test & Measurement Europe*, pp 21-23, April/May 2002. (Also published in *Test & Measurement World,* **22**(7): pp 39-43, 2002.)

7 R A Dudley, A G Morgan and N M Ridler, “*i*PIMMS – An internet-based calibration and measurement service for vector network analysers”, *ARMMS (RF & Microwave Society) Conference*, Hotel Elizabeth, Corby, Northamptonshire, 22nd/23rd April 2002.

8 R A Dudley, A G Morgan and N M Ridler, “Advances in NPL’s Internet calibration and measurement services for high-frequency electrical quantities”, *BEMC'2001 conference*, November 2001.

9 N M Ridler, R A Dudley, A G Morgan, S Wylie et al[9], “Maintaining an Internet calibration facility: experiences gained from the first six months of operation”, *NCSL International Workshop and Symposium 2001 (National Conference of Standards Laboratories)*, Washington Hilton and Towers, Washington DC, USA, 29 July to 2 August 2001.

10 R A Dudley and N M Ridler, “Internet calibration direct to national measurement standards for automatic network analysers”, *IMTC'2001 Proceedings of the 18th IEEE Instrumentation and Measurement Technology Conference*, pp 255-258, Budapest, Hungary, 21-23 May 2001.

11 R A Dudley, N M Ridler and J M Williams[8], “Internet-based calibrations of electrical quantities at the United Kingdom’s National Physical Laboratory”, *Cal Lab – the international journal of metrology*, **7**(6):22-25, November/December 2000.

12 ** R A Dudley, N M Ridler and J M Williams[8], “Internet-based calibrations of electrical quantities at the UK’s National Physical Laboratory”, *NCSL Workshop and Symposium 2000 (National Conference of Standards Laboratories)*, Westin Harbour Castle, Toronto, Ontario, Canada, 16-20 July 2000. (**AWARDED CONFERENCE BEST PAPER**.)

13 R A Dudley and N M Ridler, “Calibration over the Internet”, *Quality Today*, pp s12-s14, May 2000.

14 G French[8] and N M Ridler, “Calibrations over the internet – myth or reality?”, *ANAMET News*, Issue 13, p 6, Autumn 1999.

---

[7] UKAS (United Kingdom Accreditation Service).
[8] NPL.
[9] BAE SYSTEMS.