Progress Towards Internet-based Calibration of Electrical Quantities

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Abstract

The UK's National Physical Laboratory, in collaboration with Fluke, recently completed a feasibility study on internet-based calibration of electrical quantities (results of which were presented at the NCSL 2000 conference). We report here a study on the performance of the 4950 multifunction transfer standard (MTS), which is central to facilitating this new route for transferring accurate traceable measurements of DC resistance and voltage. The corresponding measurement functions of the MTS have been evaluated at different environmental applied conditions, such as temperature, humidity, mains supply and warm-up times, to determine its suitability in terms of drift, stability and accuracy for providing calibration of electrical quantities via the internet.

1.0 Introduction

The advent of the World Wide Web or internet has led to a flurry of new applications in consumer and business commerce, video conferencing, electronic mail, remote monitoring, instrument control and at the NCSL 2000 conference, to this list was added internet-based calibration (*i*Cal) [1]. This fast evolving and powerful medium has created new opportunities for National Metrology Institutes (NMIs) to consider its relevance to their activities. Internet-based calibration of certain electrical quantities, such as DC resistance and voltage as discussed in this paper, is one area of application where this technology can have immediate impact in disseminating traceable[*] measurements to their client organisations.

Two key questions arise; what are the benefits of *i*Cal and how would this new application be implemented in practice? The benefits of *i*Cal have already been discussed extensively in [1,2]. Therefore, briefly, they can be summarised as direct traceability to national standards, reduction in down-time, elimination of transportation (consequently any cause of uncertainty), calibration under operating environment, a likely reduction in cost and an increased efficiency from multi-parameter calibration. Indeed, the latter two aspects are the main driving forces behind this new concept of *i*Cal. Since *i*Cal is based mostly on automation of measurements, it is possible to make continuous measurement of the client's standards which can be used to determine, in addition to their traceable values to a given accuracy, a whole array of other parameters such as drift, stability and environmental effects. Other future applications are the possible use of *i*Cal in international key comparisons and the provision of services to clients irrespective of their location. Finally, a less discussed aspect in the literature is on the importance of knowledge transfer or 'best practice' to client laboratories. Clients will be able to access latest procedures and measurement guides on-line, which could lead to wider application of metrological philosophy in industry.

In practice, the only requirement on the part of the client laboratories is to have access to the internet, assuming for the moment adequate hardware, software and appropriate web browser facilities. There are essentially two main elements to a DC resistance and voltage *i*Cal system currently being developed at NPL; a multi-function transfer standard (MTS), and 'interfacing' software. Interfacing software here implies not only the software necessary for interfacing the MTS with NPL *i*Cal web-server via HTML based web-pages, but also software needed for the instrument firmware control, measurement data transmission and security, on-line exchange via video/voice/text and authentication. The MTS is a precision measurement instrument, which is capable of storing multi-parameter reference values, and permits firmware control over the internet via a PC connected to its GPIB/RS232 interface bus. Characterisation of the MTS, which in our case is a Wavetek-Datron 4950 MTS, is the subject of this paper. We report progress on the evaluation of the 4950 measurement functions at different applied environmental conditions, and assess its suitability for providing more accurate (than the 3 ppm transfer stability specified by the manufacturer) traceable measurements of DC resistance and voltage via the internet. A similar evaluation has been carried out by Rietveld *et al*. [3], except on a 5700 A series II

[*] New issues regarding accreditation of *iCal* services is a major area of discussion which is yet to be considered by the relevant bodies such as UKAS or DKD.

calibrator. A brief outline of the actual implementation of an *i*Cal system is discussed next, followed by characterisation measurements on the 4950 MTS.

2.0 *i*Cal Implementation

Although the concept of *i*Cal is essentially an extension of a GPIB connection from a NMI to a client laboratory which has received the *i*Cal measurement system, the complexity arises from the requirement to transfer traceability. The new proposed *i*Cal system implementation is graphically illustrated in Figure 1 [4]. The 4950 MTS is fully characterised at NPL, facilitating traceability transfer, before being dispatched to a client laboratory, steps one and two in Figure 1. At the client laboratory the 4950 MTS is connected to the working standards to be measured, interfaced to a PC running an appropriate operating system (UNIX or Windows NT) and the client logs-on (establishing a TCP data socket connection) to NPL *i*Cal web-server, preferably using one of the main internet browsers – Microsoft Internet Explorer or Netscape Navigator/Communicator. The web-server transmits source code for user interactive web-pages, written in internet supported languages such as (D)HTML, Java(ps) or Active-X, via a common gateway interface programme to the client's web browser for display. After security clearance, the client selects relevant options on the displayed pages, and provides

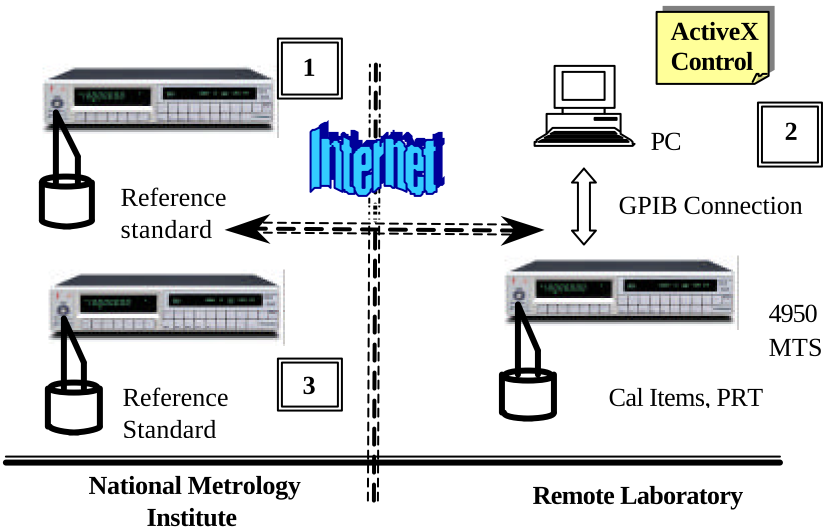

Figure 1. *The iCal system under development at NPL for transferring traceable measurements to a remote laboratory via the internet.*

information defining the types of measurements to be carried out. Progress of the measurements can be viewed graphically, and repeat measurements performed if necessary. When NPL and the client are satisfied with the measurements, the data (which may also consists of digital photographs showing measurement connections and environmental information) is transmitted to NPL where measurement uncertainties are evaluated, data stored on NPL database, and an authenticated electronic certificate issued to the client. Issuing of the certificate may await the 'loop closure' tests, step three in Figure 1. These are carried out when the 4950 MTS is returned to NPL for operational verification of its selected measurement functions to a predefined level.

It is interesting to note that the *i*Cal system for DC electrical quantities is distinct from that based on Automatic Network Analysers [1]. The only commonality between the two systems is control of the two-way information via the internet. The actual implementation of traceability transfer, in the latter case, is achieved by comparing results from the calibration of a client's standard at NPL and when the same standard is measured on the client's network analyser by NPL via the internet, removing uncertainty contributions due to client laboratory measurements.

3.0 Experimental set-up for characterising the 4950 MTS

For temperature and humidity dependence of the DC resistance and voltage measurement functions the 4950 MTS is situated in a chamber with a working range of 10°C - 40 °C and 20% - 80% RH. The DC resistance and voltage standards are located outside the chamber and as such this enables the measurement functions of the 4950 MTS alone to be investigated. The temperature of the chamber was measured using a PRT and a reference standard connected to an ASL (Automatic Systems Laboratory) bridge. The 4950 MTS is interfaced to a desktop PC for measurement control and data storage. National Instruments Labview™ was used to control the 4950 MTS and the ASL instrument.

3.1 Resistance Measurement Performance of the 4950 MTS

Figures 2 shows the performance of the 4950 MTS when measuring 1 Ω, 10 Ω and 100 Ω reference standards at 20 °C and 45% RH (typical laboratory environment) for three days. The 4950 MTS was set to high accuracy, four-wire and band limit on. Since the reference standards used in these measurements typically have drift less than a few parts in 10^9/day and stability better than 0.01 ppm, the results demonstrate the effective resolution of the 4950 MTS. From Figure 1, the 1 Ω results show an approximately 20 ppm scatter, this is because the 4950 MTS can only measure low value resistances on its 10% setting on the 10 Ω range. In contrast, the scatter on the 10 Ω measurements is approximately 1 ppm whereas for the 100 Ω it is less than 0.4 ppm. The resolution of the 4950 MTS (with its 7.5 digit display in the high accuracy mode) is 0.1 ppm, as demonstrated by the 100 Ω measurements in Figure 2. Since the scatter of the measurements is much larger than the effective resolution of the 4950 MTS, improved results could be achieved with averaging the measured data.

3.2 Temperature Cycling

The effect of temperature cycling on the same 1 Ω, 10 Ω and 100 Ω measurement functions of the 4950 MTS over a day is shown in Figure 3. The relative humidity during these measurements was kept constant at 45%. Generally the influence of relative humidity on all measurement functions was found to be negligible. The temperature of the environment chamber was varied from 20 °C to 10 °C over the first four hours, and kept constant at 10 °C for the next eight hours, followed by an increase to 25 °C. Also shown in Figure 3 is the internal temperature of the 4950 MTS. The 10 Ω and the 100 Ω measurement functions show a -0.16 ppm/°C and –0.3 ppm/°C temperature dependence, respectively, whereas the 1 Ω temperature dependence is indistinguishable. These measurements also demonstrate the lack of temperature hysteresis in the 4950 MTS resistance measurement functions.

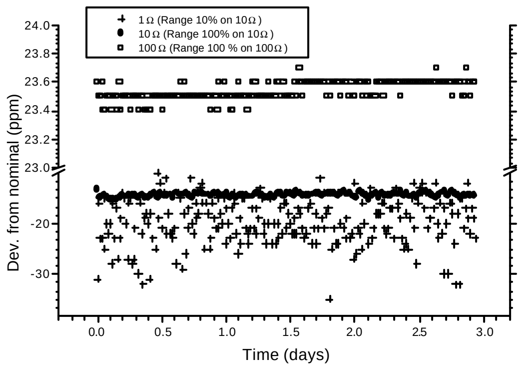

Figure 2. *Performance of the 4950 MTS low resistance measurement functions.*

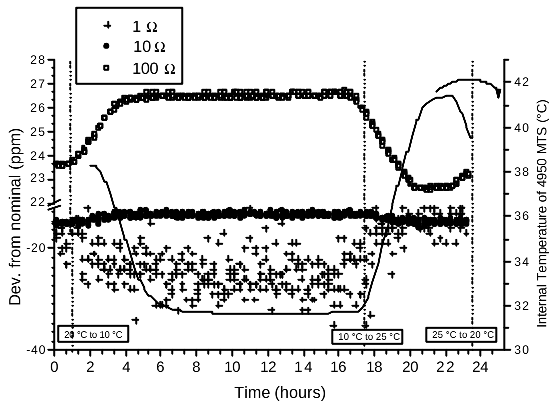

Figure 3*. Effect of temperature cycling on the measurement functions.*

3.3 Effect of warm-up time and mains supply

The effect of warm-up time of the 4950 MTS on its resistance measurement functions in the range 1 Ω to 100 Ω is shown in Figure 4. There is direct correlation between the warm-up time and the measured values whilst the 4950 MTS reaches a stable temperature for the higher value resistances except for the1 Ω measurement function. The difference between the initial and the final (i.e. after warm-up) values is between 3 - 5 ppm for the 10 Ω and 100 Ω measurement functions. The mains supply to the 4950 MTS was kept constant at 205 volts for a day and changed to 255 V (±1 V), in one step, for a further day, whilst monitoring the 1 Ω to 100 Ω measurement functions. No appreciable influence of the mains supply voltage was observed on the measured values. Similarly recent observations confirm negligible influence of the mains supply voltage on the 1 V, 1.018 V and 10 V measurement functions.

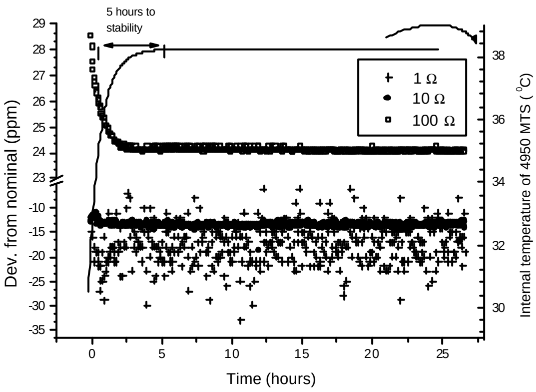

Figure 4. *Influence of warm-up time on the measured parameters.*

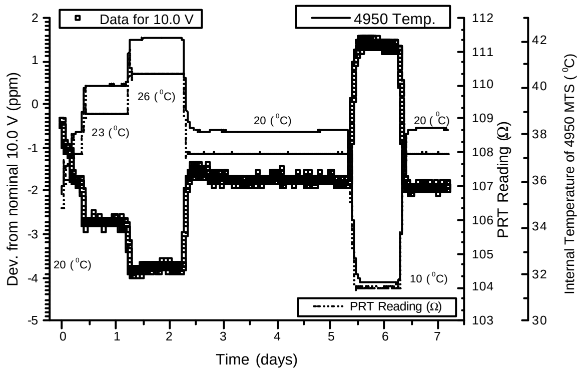

Figure 5*. Temperature cycling dependence of the 4950 MTS 10 V function.*

3.5 Voltage Measurement Performance of the 4950 MTS

The corresponding results for the 10 V measurement function of the 4950 MTS at varying temperatures is shown in Figure 5. The temperature of the chamber was cycled between 10 °C and 26 °C whilst the 10 V standard located externally was measured using the 4950 MTS. Notice that the 16 °C chamber temperature variation corresponds to approximately 11 °C internal temperature variation of the 4950 MTS. The corresponding temperature dependence of the 10 V measurement function is found to be –0.35 ppm /°C, with negligible hysteresis.

4.0 Conclusions

A new route for transferring traceable measurements of DC resistance and voltage via the internet using a 4950 multifunction transfer standard, currently under development at NPL, has been discussed. Both the resistance and voltage measurement functions have been found to have a temperature dependence which must be applied as corrections for more accurate measurements. In contrast, humidity, mains supply and warm-up time (providing requisite time after instrument activation) were found to have negligible effect on the measurement functions. However, it should be noted that the influence of such parameters will vary for different instruments of the same type. Further measurements on higher decade resistance and the remaining 1 V and 1.018 V measurement functions will be presented at the conference. Evaluation of the effects of EM interference on DC resistance and voltage measurement functions of the 4950 MTS are currently in progress.

5.0 Acknowledgements

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6.0 References

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