Report on Electromagnetic Metrology Activities at MSL, New Zealand
Prepared for the 29th Meeting of the CCEM, 12-13 March 2015

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Introduction

This report covers activities of the Electrical Standards and RF Standards teams of the Measurement Standards Laboratory of New Zealand (MSL) carried out since the 28th meeting of the CCEM (2013).

Staff

(i) DC/LF

- Dr Laurie Christian - Josephson array, mains energy
- Mr Keith Jones – impedance, current transformers, on-site metering accuracy
- Dr Murray Early – (Team Leader) AC voltage and current, DC voltage, quantum Hall/CCC, MSL Quality Manager
- Dr Vladimir Bubanja – SET modelling and AC/DC voltage
- Dr Tim Lawson - quantum Hall/CCC
- Mr Tom Stewart - mains energy, impedance
- Mr Bruce McLennan – mains energy and dc resistance

(ii) RF

- Dr Blair Hall

17025 Accreditation and Peer Review

A full assessment of the capabilities of the Electrical Standards Team was carried out in April 2013 involving peer technical assessment by Drs Barry Wood (NRC) and Ilya Budvosky (NMIA) working with two IANZ assessors. Corrective actions related to this assessment have been cleared.

An assessment of the RF capabilities was carried out in March 2014 involving peer technical assessment Dr Tieren Zhang of NMIA also with an IANZ assessor. There were no corrective actions required.

The New Zealand accreditation body, IANZ, continues to carry out annual surveillance assessments of MSL. These routine assessments are primarily intended to verify compliance with the quality system requirements of ISO 17025.

Revision to the GUM

There has been much discussion of the proposed revision to the *Guide to the Expression of Uncertainty in Measurement* (GUM) at MSL in recent years. A working document by Blair Hall summarizing a number of concerns is being tabled at this CCEM [1]. The main point is that while the proposed revision to the GUM may appear to be a modest change, it represents a very significant shift in the concepts around probability and coverage that may be at odds with the present understanding of many metrologists. In view of the upcoming proposed *BIPM Workshop on Measurement Uncertainty* in June 2015, it would seem timely for working metrologists to consider the concerns that Blair has highlighted.

We also are concerned that the changes being proposed will require a massive effort in modifying the existing implementation of the GUM in technical procedures, spreadsheets, validated software, training materials etc. Unless the advantages are overwhelming such a change would be hard to justify in terms of the cost to undertake such wide-scale revision both at the NMI level and at the level of second tier laboratories.

[1] B. Hall, "The new GUM and measurement uncertainty: some thoughts", document submitted to the 29th Meeting of the CCEM, 2015 (CCEM 15/07)

Watt Balance

MSL is continuing to develop a watt balance based on coupled pressure balances and utilising low frequency sinusoidal motion of the coil in the dynamic mode [2]. This method requires the precise measurement of an approximately 1 V, 1 Hz alternating coil voltage and for this we are using the NIST PJVS technology. The PJVS has been assembled with tremendous support from the team at NIST Boulder and this is greatly appreciated. The PJVS chip has recently been cooled down for the first time and we are about to generate the first voltages.

We have also installed timing boards supplied by NIST Gaithersburg in two 3458As achieving considerable reduction in the sample timing uncertainty of these DVMs. This is a critical improvement for the successful use of these DVMs with our watt balance.

[2] C M Sutton, "An oscillatory dynamic mode for a watt balance", Metrologia, 46, 2009, 467-472.

SET Devices

We are considering electron transport in hybrid superconductor--normal-metal systems. We have developed a quantum field theoretical approach for evaluation of tunnelling rates of electron tunnelling to all orders of the tunnel Hamiltonian. This has enabled us to derive the error rates of Andreev and Cooper-pair-electron processes, which are the dominant errors in the SINIS turnstile. This device is one of the candidates for the realization of the current standard in the new SI. We are also developing a theory that will enable accurate determination of noise in these hybrid systems.

In addition we are collaborating with a New Zealand advanced materials company in an effort to produce a new generation of sensors based on two-dimensional active surfaces. Currently we are attempting to manufacture transistors based on a doped boron nitride one-atom thick hexagonal lattice. We plan to measure the current-voltage characteristics and perform computer simulations using a microscopic approach.

[3] V Bubanja, “Tunneling rates of electron pumping in the R-SINIS transistor”, Journal of Low Temperature Physics, Volume 175, Number 3-4, p.564-579, (2014).

[4] V Bubanja and S Iwabuchi: “Transport and noise properties of hybrid superconductor—normal-metal devices”, 27th International Conference on Low Temperature Physics, August, 2014, Buenos Aires, Argentina (poster presentation).

Mains Frequency Power

Software developed at MSL (the MIE calculator) that rigorously evaluates the error and uncertainty of an electricity metering site is beginning to be adopted by the New Zealand industry as the tool of choice for this purpose. In practice most users require significant training to make best use of the tool.

Improvements to the MSL primary standard of mains power have been made with a best uncertainty around 20 µW/VA, reported at CPEM 2014 [5]. Areas of improvement include the traceability of the phase angle and the ac-dc difference of the current shunts. This standard was used in our participation in APMP.EM-K5.1 and the Draft A report for this comparison is expected soon. Further improvements guided by the detailed uncertainty budget in [5] are expected to be carried out in the next few years.

[5] T J Stewart and K Jones, Improvements to the MSL Mains-Frequency Power Standard, Conference on Precision Electromagnetic Measurements (CPEM) Digest, pp. 724-725, August 2014, Brazil (also an oral presentation at the conference).

Impedance

A second set of AH capacitors (10 pF and 100 pF) has been purchased to support a future bilateral comparison, now that the calculable capacitor and capacitance scale build-up bridges are operational. A local industry presentation was made [6] to encourage improved sensor measurement practice and also assistance was given to a local medical research project [7].

[6] K Jones, Coaxial Networks for Impedance Sensing, IEEE Instrumentation and Measurement Society, Auckland, November 2014 (oral presentation).

[7] M T Wilson, M Elbohouty, O D Lin, L J Voss, K Jones, and D A Steyn-Ross, Measuring the Electrical Impedance of Mouse Brain Cortex, International Biophysics Conference, August 2014, Brisbane, Australia (poster presentation).

Resistance

We participated in the APMP.EM-K2 high resistance comparison and are presently waiting on the Draft A report. At the WGLF meeting at CPEM 2014 a request was made for an additional APMP participant in the CCEM-K2 comparison by the comparison organiser and we have volunteered to do this. The artefacts have just arrived in New Zealand and measurements will begin in March.

AC and DC Voltage

The Reference Step Method developed at MSL proves to be a versatile way of maintaining the dc voltage scale. Originally developed for voltage dividers then sources (or calibrators), we have implemented an extension to the method to simultaneously calibrate the gains of a meter [8]. Also colleagues at SP (Sweden) have extended the range of the method down to 1 mV where it performs sufficiently well to provide a way to calibrate commercial nanovoltmeters [9]. These developments were both presented at CPEM 2014.

Several ac-dc current shunts that we obtained from JV (Norway) some time ago have been recently calibrated at PTB (Germany) with excellent results. These will be used to support our participation in the upcoming APMP ac-dc current comparison.

[8] M D Early, L A Christian and T J Lawson, Building up the DC Voltage Scale for Sources and Meters, Conference on Precision Electromagnetic Measurements (CPEM) Digest, pp. 138-139, August 2014, Brazil (a poster presentation at the conference).

[9] B-O Andersson, M D Early, G Eklund, O Gunnarsson and K-E Rydler, The Reference Step Method for DC Voltage at 1 mV and 10 mV, Conference on Precision Electromagnetic Measurements (CPEM) Digest, pp. 520-521, August 2014, Brazil (a poster presentation at the conference).

RF and Microwave

Standards Development

Following peer-assessment of our laboratory by Dr T. Zhang (NMIA) in March 2014, our IANZ scope for Calibration Factor measurements has been extended in frequency range up to 18 GHz and we have added a new capability to our IANZ scope for S-parameter measurements in type-N from 30 kHz up to 18 GHz.

A capability for RF generator source match measurement has been developed. The implementation covers frequencies from 10 MHz up to 2000 MHz (but could be extended with additional hardware). A paper on the setup has been presented to the Asia Pacific Microwave Conference in Sendai, Japan, in November 2014 [13].

Research

1) We have been looking at the propagation of measurement uncertainties in the TRL calibration procedure. There is a difficulty because the TRL calibration equations are not directly differentiable with respect to the standards' values (the TRL is sometimes characterised as a `self-calibrating procedure` for this reason). We have found an indirect method of obtaining the required partial derivatives that uses derivatives of the network analyser's error-model. Our method is easily implemented with automatic uncertainty propagation software. We are currently working on a demonstration of the technique with LNE.

2) The uncertainty of a complex quantity is often expressed in polar (as opposed to rectangular) coordinates, but the level of confidence of such uncertainty statements is not well understood. We have developed a method of calculating uncertainty regions for complex quantities that can be expressed in polar coordinates and that guarantees a nominal level of confidence (or greater). Unfortunately, these regions are larger, on average, than suitable regions expressed in rectangular coordinates. A publication has been submitted to Metrologia [14] (NB, [12] publication noted below deals only with rectangular coordinates).

3) We have continued to provide extensions to the existing GUM methodology suitable complex quantities. Publication [10], below, extends the conventional method of uncertainty calculation for complex quantities when dealing with a small number of observations. (By conventional, we mean the bivariate extensions to the original GUM method for complex quantities, rather than the propagation of distributions approach -- implemented by a Monte Carlo method -- recommended in the second GUM Supplement.)

Our paper unifies earlier results and extends them. It presents an earlier method for propagating degrees of freedom when there is correlation between the real and imaginary components of individual complex quantities. This method is then extended, so that degrees of freedom information about a set of quantities (e.g. the 4 S-parameters of a two-port device) may be propagated when there is correlation between the different complex-quantity estimates (as would occur, for example, when a number of repeat measurements of S-parameters are collected).

4) A new version of the GUM Tree Calculator (GTC) software has been released (http://mst.irl.cri.nz). There continues to be steady interest in this software.

Publications

[10] R. Willink and B. D. Hall, "An extension to GUM methodology: degrees-of-freedom calculations for correlated multidimensional estimates" http://arxiv.org/abs/1311.0343

[11] B. D. Hall "Object-oriented software for evaluating measurement uncertainty", Meas. Sci. Tech. 24 (2013) 055004 (doi:10.1088/0957-0233/24/5/055004)

[12] B. D. Hall "Expanded uncertainty regions for complex quantities" Metrologia 50 (2013) 490-498 (doi:10.1088/0026-1394/50/5/490)

[13] B. D. Hall, 'Measuring Signal Generator Source Match', Conference Digest, Asia-Pacific Microwave Conference, (4-7 Nov, 2014, Sendai, Japan).

[14] B. D. Hall "Expanded uncertainty regions for complex quantities in polar coordinates", Metrologia, submitted

Presentations

B. D. Hall, "Uncertain-Number Software", at the 10th Biennial Conference of the Metrology Society of Australia (Oct 15-17, 2013, Sydney Australia).

B. D. Hall, “Changes to the `Guide to the Expression of Uncertainty in Measurement’ (GUM)”, at the 10th Biennial Conference of the Metrology Society of Australia (Oct 15-17, 2013, Sydney Australia).

B. D. Hall, “On evaluating the uncertainty of VNA self-calibrating procedures”, to the Laboratoire national de métrologie et d'essais (LNE), (December 3, 2013, Trappes, France)

B. D. Hall, “On evaluating the uncertainty of VNA self-calibrating procedures”, Presented to the EMRP Project HF-Circuits, First workshop “Electronic Calibration Units” (December 5, 2013, SP Technical Research Institute, Boras, Sweden).

B. D. Hall, Measurement Uncertainty and Vector Network Analysis, Asia-Pacific Microwave Conference Workshop: “Introduction to: Theory of operation and reliability in Vector Network Analyzer measurement at RF, microwave and millimeter-wave frequencies”, (4 Nov, 2014, Sendai, Japan) [invited].

Status of Comparisons

1/ APMP.EM-K2: High resistance at 10 MΩ and 1 GΩ, waiting on draft A.
2/ CCEM-K2: High resistance at 10 MΩ and 1 GΩ; starting measurements in March 2015.
3/ APMP.EM.RF-S6.CL: Scattering parameters for Type-N, 50 ohms connectors: technical protocol approved, measurements will be made in 2015.
4/ APMP.EM.RF.K8.CL: RF power in 50-Ohm coaxial lines, report submitted, comparison in progress.
5/ APMP.EM-K5.1: AC power at 50 Hz, waiting on draft A.
6/ APMP.EM-K12: AC-DC current, scheduled for March-April 2015.
7/ APMP.EM-S12: Voltage, Current and Resistance Meters, scheduled to participate late 2015/early 2016.

MSL has agreed to participate in the following comparisons when they are available:

8/ APMP.EM.BIPM-K1.1: DC resistance; 1 Ω and 10 kΩ.
9/ APMP.EM-K3: Inductance at 10 mH with supplementary at 100 mH.

We are also on the Support Groups for APMP.EM-K2, APMP.EM-K3, APMP.EM-K12, and APMP.EM-S12.

In addition we have agreed to participate in a CCEM Pilot Study on High Capacitance.