CCEM/17-Report-MSL

Report on Electromagnetic Metrology Activities at MSL, New Zealand Prepared for the 30th Meeting of the CCEM, 22 and 24 March 2017

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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 29th meeting of the CCEM (2015).

Staff

(i) DC/LF

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

(ii) RF

- Dr Blair Hall, MSL Quality Manager

Dr Early took on the role as chair of the APMP Technical Committee for Electricity and Magnetism at the APMP General Assembly in Beijing, November 2015. His term will conclude at the end of 2018.

MSL Management

Dr Fleur Francois took over as the director of MSL in May 2016, replacing Dr Tim Armstrong who retired in September 2016. Dr Francois was previously responsible for the relationship between Callaghan Innovation (the parent organisation of MSL) and the NZ government.

Ms Eleanor Howick, team leader of MSL Length Standards, was also appointed as the Chief Metrologist of MSL in August 2016, a role previously held by Dr Armstrong. The Chief Metrologist for MSL has a legal standing in the NZ Measurement Standards Act as a verifying authority for measurement standards.

Dr Blair Hall took over from Dr Murray Early as MSL Quality Manager in January 2016.

CPEM

In early 2016 MSL submitted a joint bid with NMI Australia to host the 2022 Conference on Precision Electromagnetic Measurements. Following bid presentations at the CPEM Executive Meeting during CPEM 2016 in Ottawa it was announced that the MSL-NMI bid had been successful. CPEM 2022 is tentatively scheduled for early May 2022.

Electrical Standards Laboratories

The McKay building housing the MSL Electrical, Temperature, and Time Standards laboratories employs asbestos in the external cladding and some interior walls. A positive finding of asbestos in a routine test of an office space in June 2016 lead to the immediate evacuation of the building and relocation of our office space to a separate building. Some remedial work was carried out to limit dust entering laboratory space. In addition, a series of medium earthquakes in late 2016 lead to additional asbestos findings. This resulted in very limited access to our laboratories for the last half of 2016. Further remedial work has been carried out in January and we now have more routine access.

Plans to relocate these laboratories have been accelerated and we are waiting on a high-level decision on this matter. It is anticipated that in early 2018 the Electrical, Temperature, and Time Standards laboratories will be housed in refurbished laboratory space in the same building as the rest of MSL (Mass, Length and Light Standards).This has been a difficult time to maintain our metrology work and has unfortunately led to the need to withdraw from several comparisons and defer some development work while the building issues are resolved.

17025 Accreditation and Peer Review

Our 1725 accreditation has been maintained with the New Zealand accreditation body, IANZ, carrying out annual surveillance assessments of MSL and the technical groups. These routine assessments are primarily intended to verify compliance with the quality system requirements of ISO 17025. We are due for full reassessment in the DC and LF area later this year or in early 2018 and in the RF area the following year.

Revision to the GUM

Blair Hall attended the *BIPM Workshop on Measurement Uncertainty* in June 2015 and presented a paper there about the evaluation and expression of uncertainty in complex quantities. Following the meeting, an article was published in a special focus issue of Metrologia [1]. The article reviews the methods now available for handling measurement uncertainty in complex quantities in RF metrology. It shows that there is now essentially a complete set of extensions of the familiar methods used in the conventional GUM approach available for complex quantities. These methods are not based on the Bayesian approach to uncertainty, which has been controversial in the context of proposed changes to the GUM.

[1] B. D. Hall *Expanded uncertainty regions for complex quantities in polar coordinates,* Metrologia **52** (2015) 486-495 (doi:10.1088/0026-1394/52/4/486)

Kibble Balance

In support of the MSL Kibble balance development, a 2 V PJVS system has been assembled (using a chip kindly provided by NIST) and successfully operated. Separate visits by Dr Alain Rüfenacht and Dr Sam Benz of NIST have been extremely helpful in tuning the performance of the system and providing guidance on using the PJVS for the proposed Kibble balance. The MSL system is based on a liquid helium volume sustained in a cryocooled zero-loss dewar [2].

While in NZ, Dr Alain Rüfenacht gave a plenary address to the MSA Conference in Queenstown on the impact of Josephson Voltage Standards in the proposed redefinition of the SI units, which was appreciated by the attendees.

[2] T. J. Stewart, T. B. Lawson, and L. A. Christian, *Implementation of a programmable Josephson voltage standard in a zero boil-off dewar*, Conference on Precision Electromagnetic Measurements (CPEM) Digest, July 2016, Ottawa (also an oral presentation at the conference with C. M. Sutton contributing).

SET Devices

We are associated with the Dodd-Walls Centre for Photonic and Quantum Technologies, which is one of ten New Zealand Centres of Research Excellence. Our work in this collaboration is concentrated on quantum measurement and manipulation. Our contribution includes developing a scheme for teleportation and entanglement swapping of electron spins in hybrid superconductor—normal-metal devices [3].

Another recent study resulted in the development of a quantum field theoretical formalism to describe generation and measurement of entangled electrons in hybrid superconductor—normal-metal devices. Our approach is based on unification of Nambu-Gorkov formalism of superconductivity and nonequilibrium Green's function Schwinger-Keldysh formalism. Previous theoretical work, performed by Levy Yeyati et al (Nature Physics 3 (2007) 455), concluded that the nonzero nonlocal differential conductance in the lowest order of perturbation in tunnel Hamiltonian results from cross-correlations of the charges at different tunnel junctions of the device. Our results in this limit show that nonzero nonlocal conductance emerges due to dissipative circuit impedance, even when charge fluctuation cross-correlations are absent. Our method enables the inclusion of tunnel Hamiltonian to all orders of perturbation, which is necessary in the limit of high barrier transmission, and we show that in this case elastic cotunneling dominates crossed Andreev reflection processes. Our results agree with the experimental results of Wei and Chandrasekhar (Nature Physics 6 (2010) 494) [4].

In collaboration with a NZ high-tech company we consider fabrication and electronic properties of two-dimensional materials. This project involves a research internship for university students. Last year we hosted a student from the University of Waikato in Hamilton, who worked on Chemical Vapour Deposition-based methods of fabricating boron nitride films. This year, we hosted a student from the Victoria University of Wellington, who worked on Density Functional Theory calculations of doped graphene.

Publications

[3] V. Bubanja, *Quantum teleportation and entanglement swapping of electron spins in superconducting hybrid structures*, Annals of Physics **357**, 40 (2015).

[4] V. Bubanja, M. Yamamoto, and S. Iwabuchi, *Nonequilibrium electron transport in a hybrid superconductor—normal-metal entangler in a dissipative environment*, Physical Review B **94**, 184515 (2016).

Mains Frequency Transformer Calibration

There has been strong industry interest in trying to replace traditional methods of high-accuracy field calibration of metering transformers. Commercially available transformer testers can make reasonable estimates of ratio errors based on separate measurements of core and winding impedances, and turns ratio. The testers simplify the logistics of accessing sites and significantly reduce calibration time. However, there are some challenges relating to calibrating the testers, such as accounting for the differences between testing and operating conditions, and calculating the overall uncertainty of the measurement. These challenges are yet to be satisfactorily resolved for calibrations on the national distribution network.

[5] K. Jones and T. J. Stewart, *Indirect transformer calibration*, oral presentation, Metrology Society of Australasia, Queenstown, October 2015.

[6] T. J. Stewart and K. Jones, *Maintaining Traceability of a National Standard – Mains Power Improvements*, oral presentation, Metrology Society of Australasia, Queenstown, October 2015.

DC Voltage

The Reference Step Method developed at MSL is now routinely used to propagate traceability from our 10 V Josephson voltage standard. Work has begun on developing Python software to enable use of the method with a wider range of commonly available instruments. It is intended that this software will make the method more widely accessible. An APMP-supported training course on using the method is planned for later this year.

[7] L. A. Christian and M. D. Early, oral presentation, *Applications of the Reference Step Method in DC Voltage Traceability*, oral presentation, Metrology Society of Australasia, Queenstown, October 2015.

[8] M. D. Early and L. A. Christian, *Digital Multimeter Calibrations from 3.5 to 8.5 Digits*, oral presentation, Metrology Society of Australasia, Queenstown, October 2015.

RF and Microwave

Standards Development

A capability for RF generator source match measurement has been developed. The implementation covers frequencies from 10 MHz up to 2500 MHz (but could be extended with additional hardware). This measurement capability has been added to our scope of accreditation.

A capability in impedance measurement up to 26.5 GHz in 3.5 mm connector technology is being developed. We will seek the addition of this to our scope during the next peer review, in 2018.

Publications

[9] B. D. Hall, *Evaluating the measurement uncertainty of complex quantities: a selective review*, Metrologia **53** S25 (2015) (Focus issue on the 2015 BIPM GUM Revision workshop) (doi: 10.1088/0026-1394/53/1/S25).

[10] Djamel Allal, B. D. Hall, Patricia Vincent, Alexis Litwin et François Ziadé, *Propagation automatique des incertitudes : application aux techniques d'auto-étalonnage des analyseurs de réseau vectoriels,* 17th International Congress of Metrology, Sept 21-24, Paris, France. 12006 (2015) (DOI : 10.1051/metrology/201512006) (4 pages)

Presentations

Djamel Allal and B. D. Hall, Propagation of calibration standards uncertainties through TRL procedure, EMRP HF-Circuits ANAMET Seminar, 3 June 2015, Bern, Switzerland.

B. D. Hall, The measurement uncertainty of complex quantities, BIPM workshop on measurement uncertainty, 15-16 June 2015, BIPM, Sèvres, France.

Status of Comparisons

1/ APMP.EM-K2: High resistance at 10 MΩ and 1 GΩ, draft A (support group).

2/ APMP.EM.RF-S6.CL: Scattering parameters for Type-N, 50 ohms connectors: technical protocol approved, comparison did not start in 2015, as planned. New start date unknown.

3/ APMP.EM.RF.K8.CL: RF power in 50-Ohm coaxial lines, report submitted, waiting on draft A.

4/ APMP.EM-K5.1: AC power at 50 Hz, waiting on draft A.

5/ APMP.EM-K12: AC-DC current, likely to withdraw.

6/ APMP.EM-S12: Voltage, Current and Resistance Meters, participated in 2016 but withdrew owing to laboratory difficulties.