Report on Electromagnetic Metrology Activities at MSL, New Zealand
Prepared for the 33rd Meeting of the CCEM, 8 and 9 March 2023

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Introduction

This report covers activities of the Electrical Standards section of the Measurement Standards Laboratory of New Zealand (MSL) carried out since the 32nd meeting of the CCEM (2021).

MSL is New Zealand's NMI and is embedded in the Innovation Expertise division of Callaghan Innovation, a Crown (government) Agency. With some 450 researchers, scientists, engineers, technologists, investment managers and account managers, Callaghan Innovation connects businesses with research organisations across the innovation system and administers the R&D tax credit system in NZ.

Staff

Manager: Dr Matthias Vest

(i) DC/LF

- Dr Vladimir Bubanja – SET modelling and AC/DC voltage
- Dr Guy Dubuis – cryogenic standards, dc high current
- Dr Murray Early – AC voltage and current, DC voltage, quantum Hall/CCC
- Mr Keith Jones – impedance, current transformers, on-site metering accuracy
- Mr Adam Knight: mains energy, high DC current and low resistance
- Dr Tim Lawson - Josephson voltage standards, quantum Hall/CCC, dc high resistance
- Mr Tom Stewart - mains energy, impedance
- Mr Cheng Yang - digital instruments and time standards
- Mr Minyu Zhang – mains energy and impedance

(ii) RF

- There is no RF activity at present.

MSL Management

MSL Director: Dr Annette Koo. The previous director, Mr Cliff Hastings, now has responsibility for all the science groups in Callaghan Innovation as head of the Innovation Expertise division.

Chief Metrologist: Dr Annette Koo. The Chief Metrologist for MSL has legal standing in the NZ Measurement Standards Act as a verifying authority for measurement standards.

Quality Manager: Mr Neil Swift

Manager Electricity, Time and Frequency, Temperature and Humidity: Dr Matthias Vest
Manager Light, Mass and Length: Mr Mesh Pillay

Dr Laurie Christian was farewelled in December 2022 (at the conclusion of CPEM 2022) after 44 years' service.

Electrical Standards Laboratories

Following detailed analysis of the environmental performance of the Electrical Standards area of the new MSL building, substantial modifications of the air conditioning system were designed and constructed to achieve the desired performance (e.g. temperature stability between 0.1 K and 0.5 K depending on the zone). Following these modifications, a careful move from the old building to the new was carried out over a period of several months mid-2022. Particular attention was paid to ensure continuity of performance (traceability) through measurements before and after the move. Because of this approach, no major loss of traceability occurred because of the move.

Two new screened rooms have been installed and commissioned by the manufacturer's installation engineer over from Australia (during COVID restrictions that required one week quarantine).

There is now quite a considerable effort required to have all systems running efficiently and also to commission several new major CAPEX items (see following sections).

Carefully transporting the delicate MSL Calculable Capacitor to the new laboratory. Jacks on the trolley are used to keep the capacitor level at all times. Loading and offloading the capacitor together with the move took around three days.

The construction of a new laboratory space in an existing building to house Time and Frequency Standards has also been completed. A similar careful approach was taken, and the lab (and clocks) are now fully operational.

17025 Accreditation and Peer Review

Our next full assessment of the capabilities of the Electrical Standards Team is planned for April 2023. Dr Nobu-Hisa Kaneko (NMIJ) and Dr Hyung-Kew Lee (KRISS) have been invited to provide the technical peer review. The New Zealand accreditation body, IANZ, is an independent organisation that will lead the assessment process.

In March 2022 IANZ carried out an annual surveillance assessment of all MSL, including the Electrical Standards section. There were no corrective action findings from these assessments for this section.

CMCs for RF power remain suspended ('greyed out'). At present there are no specific plans to reinstate RF standards.

International/CPEM

CPEM 2022, jointly hosted by MSL and NMI Australia, was held in Wellington from 12th to 16th December. A decision was made earlier in the year to delay the conference originally planned for May, owing to strong COVID-19 restrictions on entry to NZ. Fortunately, by December most people were able to travel to NZ. Around 180 attended the conference with a further 50 accessing the sessions online. Authors of oral and poster presentations were required to make their presentations in-person, but exceptions were made for authors from China and Ukraine.

The program was remarkably full program. Around 280 papers were accepted for presentation, and most will be published in the CPEM Digest. 55 papers have been submitted to the special section of the IEEE Transactions on Instrumentation and Measurement.

The opening plenary session was used to make a presentation of the 2023 IEEE Joseph Keithley award to the NRC Kibble Balance researchers (Dr Barry Wood, Dr Carlos Sanchez and Dr Richard Green), and also to celebrate what had been achieved by our electrical colleagues that enabled the 2019 redefinition to take place.

Keith Jones is now engaged with the PTB-funded MEDEA project and working closely with the APMP Developing Economies Committee (DEC). His previous activity in providing strategic assistance to the Myanmar Government for the establishment of their national metrology system is presently on hold.

Murray Early was appointed as chair of the CCEM working Group on Low Frequency Quantities (WGLF) at the CCEM meetings in 2019 and chaired the online meetings of the WGLF in 2021 (minutes of this will be available at the upcoming meeting website). A summary of the WGLF meeting was presented to the CCEM [document CCEM/2021-05_b, may require login]. Further short presentations have been made to EURAMET SCLF meeting (14 Jun 21) and the APMP TCEM (24 Nov 22). A new method of getting individual members of the WGLF to carry out comparisons reviews has been initiated and seems to work well, although there is still a backlog to clear.

Kibble Balance

The MSL Kibble balance development continues with a few key components being constructed and evaluated separately by the MSL Mass and Pressure team. The magnetic

field at the coil position is currently being mapped out. A test coil with an interferometer has been installed and the interferometer system now includes a time interval analyser for high-speed data acquisition. We are modelling the moving mode and its uncertainties with focus on the synchronicity of the induced AC voltage and velocity measurements for an oscillatory coil moment. The frequency dependence of the coil impedance is also being investigated concurrently. For mechanical components, we have developed a method to use a syringe pump for position control of the coil. There is progress in converting the two pressure balances into a rotating cylinder configuration. A vacuum chamber to house the instrument has been manufactured and has passed acceptance tests carried out in our laboratory.

A new 100 Ω high-precision resistor together with a rack mounted air bath have been obtained by the Electrical team and will be used to transfer electrical traceability to the Kibble lab. The CCC developments (below) are critical to maintain the accuracy of this important component of the Kibble system.

DC Voltage and Resistance

A new 10 V PJVS has been supplied by NIST (Boulder) and has been established in the new building. It is operational thanks to some online assistance from Dr Alain Rufenacht, and will be more fully commissioned once an onsite comparison with a travelling NIST system takes place later this year. We have yet to carry out a cross check with our aging SIS array that was used in two BIPM comparison visits. Importantly the PJVS comes with a low acoustic noise cryocooler so that it can be used in our main laboratory without disturbing other activities.

A Magnicon CCC bridge was ordered in May 2020, but we delayed delivery until we were operating in the new building. The bridge and CCC have arrived, but initial commissioning of the system has been severely affected by the present liquid helium (LHe) crisis. At this stage we have yet to establish a reliable source of LHe and are considering the use of the recondensing system used with the 2 V PJVS.

Once we have a reliable way of cooling the system, a PTB expert will come to provide commissioning and training. This bridge should then allow resistance ratio measurements to be carried out with an accuracy of better than 10^{-8} and will support an improved traceability link to our QHR standard. Meanwhile we are relying on BIPM calibrations of a 1 Ω and a 10 kΩ standard resistor to maintain traceability.

Mains Frequency Power and Transformer Calibration

A new power standard from NMIA employing sampling techniques was exhibited at CPEM 2022 and is in the process of being commissioned. A technician visited from NMIA to assist with its installation in February 2023 and a NMIA scientist is visiting in March 2023 for further training. This will become our new mains power standard and in addition enable traceable measurements of harmonic content hopefully leading to new and improved CMC claims.

The existing CT calibration system was successfully transferred to the new building and is fully operational. New electronic CT comparator systems are now being evaluated and a stable electronic high-current supply has been installed. Commissioning of these systems will continue with the expectation they will replace the aging manual system. Ratio values will continue to be derived from the set of two-stage transformers with calculable parallel to series connection corrections.

Secondary injection methods for CT calibration are being used by industry, but only under restrictions that retain confidence in traceability to primary methods.

Impedance

Our calculable capacitor was successfully relocated to the new building thanks to extraordinary care to minimise mechanical stress. It will take some time before the performance of the capacitor can be thoroughly evaluated.

Theoretical Modelling

1. ***The expanding role of NMIs in the quantum era***
   Vladimir Bubanja is a member of the IMEKO TC25 (Technical Committee on Quantum Information and Quantum Measurement). The Committee published a paper exploring the critical role of National Metrology Institutes in the quantum revolution [1].

2. ***Solotronics***
   The electronic, magnetic, and optical properties of semiconductors are sensitively dependent on doping, i.e. the introduction of foreign atoms into the crystal lattice of a semiconductor. Recently it became possible to identify the effects of a solitary dopant on the fundamental properties of semiconductors and device performance. Novel applications that require a single dopant include single-spin devices in the area of quantum information and on-demand photon sources. We use non-equilibrium Green's Function formalism to describe electron transport in boron and nitrogen doped C_{60}-dimers and discover a region of parameters where such devices can be used as molecular rectifiers [2].

3. ***Quantum capacitance***
   Miniaturization of electronic components leads to increasing usage of 2D electronic materials. When devices include capacitor plates with such materials (e.g. FinFET), at plate separation of the order of effective Bohr radius, the contribution of quantum capacitance dominates over the electrostatic capacitance. By employing the density functional theory, we have investigated the enhancement of quantum capacitance of graphene by phosphorous doping [3].

4. ***Electrode modelling for Li ion batteries***
   Some of the most commonly used materials for LIBs have fairly low electronic conductivity values. Existing studies show that pure graphene cannot be a substitute for current commercial electrode materials due to its low coulombic efficiency and poor cycle stability. However, when used as a matrix for use as a cathode material it has been found that it can significantly improve cathode electrochemical performance. Its superior electron transfer capabilities can improve the transmission and diffusion abilities of electron and ion in cathode materials. We have employed the density functional theory to provide atomistic insights into lithium adsorption and migration on phosphorous-doped graphene [4].

5. ***Atomic structure of 2D materials***

We have investigated the atomic structure and rippling of amorphous two-dimensional silicon carbide nanoribbons by employing the molecular dynamics simulations [5].

6. ***AC-DC difference metrology***
   We have obtained a very good agreement between the analytical, numerical, and experimental results for the ac-dc difference of single-junction thermal converters in the frequency range from 10 Hz to 1 kHz [6].

Publications [2-5] are continuation of our collaboration with NZ companies in the area of semiconductor doping and fabrication of low-dimensional material. The numerical calculations for this work was performed at the supercomputing facilities of the New Zealand eScience Infrastructure (NeSI).

Vladimir has been working on an assignment with NZ government agencies and international partners in the area of quantum communications.

Publications

[1] A. Tzalenchuk, N. Spethmann, T. Prior, J. H. Hendricks, Y. Pan, V. Bubanja, G. P. Temporão, D.-H. Yu, D. Ilić, B. L. Goldstein: *The Expanding Role of National Metrology Institutes in the Quantum Era*, Nature Physics **18**, 724 (2022).

[2] S. Kaur, H. Sharma, V. K. Jindal, V. Bubanja and I. Mudahar: *Ab initio study of nitrogen and boron doped C60 dimers,* Molecular Physics **120**, 2100294 (2022).

[3] B. Rani, V. Bubanja and V. K. Jindal: *Density functional theory study of the enhancement of quantum capacitance of graphene by phosphorous doping,* International Journal of Quantum Chemistry **123**, 27052 (2023).

[4] B. Rani, V. Bubanja and V. K. Jindal: *Atomistic insights into lithium adsorption and migration on phosphorus-doped graphene,* International Journal of Quantum Chemistry **121**, 26659 (2021).

[5] V. V. Hoang, N. H. Giang, T. Q. Dong, V. Bubanja: *Atomic structure and rippling of amorphous two-dimensional SiC nanoribbons – MD simulations,* Computational Materials Science **203**, 111123 (2022).

[6] V. Bubanja, Y. Amagai, K. Okawa, and N-H. Kaneko: *Mathematical Modeling and Measurement of Low Frequency Characteristics of Single-Junction Thermal Converters,* IEEE Transactions on Instrumentation & Measurement **71**, 1500704 (2022).

Presentations

[7] V. Bubanja: *Effect of quantum fluctuations on the critical supercurrent through a mesoscopic normal-metal island,* XXIII IMEKO World Congress, August 30 − September 3, 2021, Yokohama, Japan (Online).

[8] V. Bubanja: *Quantum metrology and quantum technologies,* World Metrology Day 20 May 2022, Measurement Standards Laboratory of New Zealand, (https://youtu.be/AXwRjR4hRBk)

[9] V. Bubanja: *Effect of quantum fluctuations on the critical supercurrent through a mesoscopic normal-metal island*, The International Symposium on Applied Science 2022, 14-16 October 2022, HCMC University of Technology, Ho Chi Minh City, Vietnam, Invited Talk (Online).

Data Metrology/Digital Transformation

Blair Hall of MSL chairs the APMP Focus Group on Digital Transformation and is a member of the CIPM Task Group on the Digital SI (CIPM-TG-DSI), with personal interests in the digital representation of SI units and the propagation of uncertainty components. This approach to the rigorous calculation of uncertainties (sometimes named as GUM Tree or GTC) is widely used in MSL [10] and has been proposed to help with the analysis of comparisons.

The topic of Digital Transformation was covered at the MSL World Metrology Day events in 2021 and 2022. Recordings of relevant presentations can be found at the MSL YouTube channel (https://www.youtube.com/@measurementstandardslabora6920/videos).

While MSL has an interest in the application of digital transformation to metrology, there is yet to be any significant uptake. In part this reflects the present lack of demand from second tier laboratories for these developments.

[10] B.D. Hall, *The GUM Tree Calculator: A Python Package for Measurement Modelling and Data Processing with Automatic Evaluation of Uncertainty*. Metrology 2022, 2, 128-149. https://doi.org/10.3390/metrology2010009

Status of Comparisons

- APMP.EM-K2: High resistance at 10 MΩ and 1 GΩ, draft B (support group).
- APMP.EM-K5.1: AC power at 50 Hz, draft B.
- APMP.EM-K1.1: dc resistance, planned to participate in 2023.

A DMM proficiency test (PT) for NZ calibration laboratories is being prepared. The protocol for this PT is based on RMO comparisons such as APMP.EM-S8. Owing to delays in accessing our laboratories this year it is expected the PT will commence mid-2023.

Prepared by Murray Early and the ETF Team
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