Measurement Standards Laboratory of New Zealand

Report on Electromagnetic Metrology Activities at MSL, New Zealand Prepared for the 34th Meeting of the CCEM, 6 and 7 March 2025

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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 33rd meeting of the CCEM (2023).

MSL is New Zealand's NMI. Since 2013 MSL has been embedded in the Innovation Expertise division of Callaghan Innovation, a Crown (government) Agency. Following a national review of the NZ science sector a decision was made in January 2025 by the NZ government to shut down Callaghan Innovation by June 2025 while retaining MSL. Some of the Callaghan Innovation activities connecting businesses with research organisations across the innovation system (including the administration of the NZ R&D tax credit system) will be moved to a government ministry. The remaining scientific and commercialisation activities will cease. It is intended that MSL will eventually be placed in a restructured Crown Research entity. Until then the nature of the supporting structure is unclear, but it is intended that it should be 'business as usual' for MSL. We hope that eventually MSL will be able to return to a more active international role after several years of restrictions.

Staff

Manager: Mr Tom Stewart

(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.

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: Mr Tom Stewart
Manager Mass and Pressure, Temperature and Humidity: Dr Peter McDowall
Manager Light, Length and Digital: Mr Chris Young

A highlight for us in 2024 was the award of the New Zealand Order of Merit to Keith Jones for services to metrology by the Governor General of New Zealand (representing King Charles). It was gratifying to see metrology acknowledged through Keith's more than 40 years of service. His support for the metrology activities in Myanmar, Malaysia, Philippines, and Chile was noted.

Keith with the Governor General of New Zealand, Dame Cindy Kiro.

Electrical Standards Laboratories

The new MSL building that houses the Electrical Standards laboratory has performed well in the last two years, although there have been several surprising failures of relatively new components of the air conditioning system.

The remarkable low noise performance of the new CCC system (see below) has highlighted the effectiveness of the electrical environment in the laboratory. The ideas employed include the use of overhead neutral screened mains power cable with fewer high current (15 A)

outlets. We had three levels of power quality all going back to a dedicated power transformer outside the building. DC LED lighting is also beneficial compared with mains powered fluorescents that we had in the previous building.

17025 Accreditation and Peer Review

A full assessment of the capabilities of the Electrical Standards team was carried out in April 2023. Dr Nobu-Hisa Kaneko (NMIJ) and Dr Hyung-Kew Lee (KRISS) provided the technical peer review. The New Zealand accreditation body, IANZ, is an independent organization that led the assessment process. Three corrective actions were required, and all have now been cleared. The team is particularly grateful for the technical knowledge and insights of the peer-reviewers.

In March 2024 IANZ carried out an annual surveillance assessment of all MSL, including the Electrical Standards section. There was just one corrective action finding for Electrical Standards regarding the interpretation of CMCs when there are only a few degrees of freedom in the measurement results.

While at present there are no specific plans to reinstate RF standards, Cheng Yang attended the 'VNA Tools training course'" at METAS from 7th to 9th November 2023 to maintain some competence in this important area.

International/CPEM

We submitted three papers to CPEM 2024, all accepted for oral presentation. However, these had to be withdrawn owing to organisational restrictions on travel.

Keith Jones' significant engagement with the PTB-funded MEDEA project (also with the APMP Developing Economies Committee) will conclude with the ending of the project in April 2025.

Murray Early will complete his term as chair of the CCEM working Group on Low Frequency Quantities (WGLF) in 2025. He was first appointed at the CCEM meetings in 2019 and has overseen the review and approval of almost 60 comparison reports.

The minutes of the CCEM-WGLF meeting 2023 are available at the BIPM CCEM website. A summary of the WGLF meeting was presented to the 33rd meeting of the CCEM (document CCEM/2023-09). Further short online presentations on the activities of the WGLF have been made to the EURAMET SCLF meeting (25th May 23) and the APMP TCEM (29th Nov 23 and 2nd Nov 24).

Kibble Balance

The MSL Kibble balance team are progressing with a few key components being developed and, concurrently, being experimentally evaluated. We have started the moving mode experiments in measuring the initial BL value of the magnet-coil system while identifying frequency dependent effects. These include the coil impedance error and the heterodyne

interferometry non-linearity error. We have also determined the magnetic field uniformity and the thermal coefficient of the magnet. We are designing a new coil with thinner wire and a more rigid former. Moving-mode data acquisition and analysis methods for an oscillatory motion, with the induced AC voltage measured by a 3458A, are currently under investigation. For the weighing mode, we are conducting experiments on the twin pressure balance with rotating cylinders, which includes methods to oppose the drag force on the piston and determining the stability of the twin pressure balance as a force comparator under this configuration. The ADC/DAC board for current source and coil position servo control is currently under development.

Electrical standards is assisting with a preliminary study of the coil impedance when the coil is in its operating position in the magnet. Also, the CCC developments (below) are critical to establish the accuracy of the resistors needed for the measurement of the weighing current in the Kibble system.

DC Voltage and Resistance

In November 2024 Dr Raegan Johnson of NIST (Boulder) spent a week at MSL commissioning our new NIST 10 V PJVS. A travelling PJVS system installed in our own storage dewar was sent prior to Raegan's arrival and operated without problem. Comparison between the systems helped identify a couple of minor issues (excess current leakage via a redundant temperature sensor connector; intermittent short on one of the bias cables; a minor bug in the software which caused some results to be overwritten) that were easily resolved. Agreement at the level of 5 nV (comparing 10 V outputs) was consistently achieved. Note that the new PJVS operates with a low acoustic noise cryocooler so it can be used continuously in our main laboratory without disturbing other activities.

We are now able to operate our new CCC in a condensing cryocooled cryostat, which is a great help in overcoming major difficulties (and cost) for us in the supply of liquid helium. It is working surprisingly well thanks to the vibration isolation and temperature stability of employing a small volume of condensed liquid.

We have collaborated with an expert from KRISS, Dr Dong-Hun Chae, who has extensive experience with the Magnicon CCC system and has visited MSL twice, once to help commission the system and more recently (Feb 2025) to perform measurements of noise resulting from mechanical disturbance from the cryocooler and other nearby lab equipment. It has been found that the CCC is largely insensitive to external noise sources in the 1-5 Hz frequency range which includes the typical ~1-2 Hz from the cryocooler rotary valve.

Resistance ratio measurements have been carried out with an accuracy of better than 10^{-8} and will support an improved traceability link to our QHR standard. Future access to a dry 16 T magnet in a neighbouring building will allow us to operate our QHR samples (including a recently purchased graphene device). We are currently working on a low noise screened link between our CCC and the magnet. Meanwhile we are relying on BIPM calibrations of a 1 Ω and two 100 Ω standard resistors to maintain traceability.

Mains Frequency Power and Transformer Calibration

The precision power standard purchased from NMIA was commissioned in 2023 and has since been used regularly as MSL's primary standard for power dissemination. Work has commenced on calibrating its component parts here at MSL to ensure ongoing traceability. Supporting this also, a project has commenced to link our recently commissioned 10 V PJVS to the AC voltage measurements made for power.

Impedance

Design work has commenced on incorporating digital sources (DualDAC3) in bridges to realise the audio impedance scales. Similarly, work has commenced on supporting LCR meter calibration up to 2 MHz.

Theoretical Modelling

2D materials

Single-atom-layer materials show superlative electrical, optical, mechanical, and thermal properties that enable their applications in a range of fields, such as quantum resistance standards, photodetection, flexible electronics, energy conversion and storage. We have considered the effects of substitutional doping by nitrogen and phosphorus of graphene with mono- and di-vacancies on its structural and electronic properties. The appearance of localized states near the Fermi level of modified graphene leads to significant enhancement of quantum capacitance and stored charges, which is expected to be useful for design considerations of graphene-based supercapacitors [1], [2]. We also considered bandgap engineering of 2D Sic by hydrogenation, which can have useful applications in optoelectronics [3].

High-entropy materials

Most materials used today are based on a couple of principal elements with further elements used only in low fractions. In recent years a new approach based on mixing multiple principal elements in relatively high concentrations has attracted much attention. This approach stands in sharp contrast to the traditional practice and requires novel computational tools for exploration of its vast compositional space. The ability to create materials with designed quantum properties, accurately measure, and improve their properties will empower quantum industry to reliably develop targeted applications. We considered electronic, magnetic and mechanical properties of five novel Fe-based high-entropy alloys [4].

Publications

[1] B. Rani, V. K. Jindal, and V. Bubanja:
Quantum capacitance of N/P coordinated Si-doped graphene: A DFT study,
Physica B **684** (2024) 415985.

[2] B. Rani, V. Bubanja and V. K. Jindal:
Enhanced quantum capacitance of MX4 (M = Fe, Co, Ni, Cu, and Zn; X = N, P) moieties embedded graphene: a DFT study,
Journal of Physics: Condensed Matter **35**, 415503 (2023).

[3] H. T. T. Tran, P. M. Nguyen, H. V. Nguyen, T. V. Chong, V. Bubanja, and V. V. Hoang:
Atomistic Study of the Bandgap Engineering of Two-Dimensional Silicon Carbide by Hydrogenation,
ACS Omega **8**, 25424 (2023).

[4] P. Sharma, N. K. Sharma, H. Sharma, V. K. Jindal, I. Mudahar, and V. Bubanja:
First-principles study of five Fe-based high entropy alloys,
Computational Materials Science **244**, 113221 (2024).

Presentations

[5] V. Bubanja: Atomic electronics,
NZ Institute of Physics Conference, Auckland, New Zealand, 3-5 July 2023.

[6] V. Bubanja: Atomic electronics,
IMEKO XXIV World Congress, 26-29 August 2024, Hamburg, Germany.

The numerical calculations for the above work were performed at the supercomputing facilities of the New Zealand eScience Infrastructure (NeSI).

Funding to attend the IMEKO Congress was provided by Quantum Technologies Aotearoa, which is a national multi-institution research program.

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

Data Metrology/Digital Transformation

Blair Hall of MSL was the past chair of the APMP Focus Group on Digital Transformation and plays a leading role as a member of the CIPM Task Group on the Digital SI (CIPM-TG-DSI). His interests include the digital representation of SI units and the propagation of uncertainty components. His approach to the rigorous calculation of uncertainties (sometimes named as GUM Tree or GTC) is widely used in MSL [7] and has been proposed to help with the analysis of comparisons.

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.

[7] 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, published.
- APMP.EM-K5.1: AC power at 50 Hz, draft B in need of revision by pilot

- APMP.EM-K1.1: dc resistance, measurements made in 2023.

A DMM proficiency test (PT) for NZ calibration laboratories is being carried out. The protocol for this PT is based on RMO comparisons such as APMP.EM-S8. Owing to equipment problems the PT has been significantly interrupted. It is expected the PT will re-commence mid-2025.

Prepared by Murray Early and the Electrical Standards Team
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