Report on Electromagnetic Metrology Activities at MSL, New Zealand
Prepared for the 32nd Meeting of the CCEM, 14 and 15 April 2021

Prepared by Murray Early, Electrical Standards,
Measurement Standards Laboratory of New Zealand,
PO Box 31310, Lower Hutt 5040, New Zealand

Introduction

This report covers activities of the Electrical Standards section of the Measurement Standards Laboratory of New Zealand (MSL) carried out since the 31st meeting of the CCEM (2019).

MSL is New Zealand's NMI and is embedded in the R&D Solutions 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.

Staff

Acting Manager: Mr Kevin Gudmundsson

(i) DC/LF

- Dr Vladimir Bubanja – SET modelling and AC/DC voltage
- Dr Laurie Christian - Josephson voltage standards, dc high resistance, dc high current
- 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 - 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

Acting MSL Director: Mr Cliff Hastings. The previous director, Dr Fleur Francois, left in October 2020 to take up a new role elsewhere.

Chief Metrologist: Ms Eleanor Howick. The Chief Metrologist for MSL has legal standing in the NZ Measurement Standards Act as a verifying authority for measurement standards.

Quality Manager: Dr Blair Hall

Acting Manager Electricity, Time and Frequency: Mr Kevin Gudmundsson

Acting Manager Temperature and Light: Ms Cynthia Lendrum
Acting Manager Mass and Length: Mr Mesh Pillay

Dr Christian retired in December 2020 after 42 years' service and has been replaced by Dr Dubuis who has extensive experience in cryogenic systems. Fortunately, Laurie will continue to work on a part-time basis for another year.
Mr Bruce McLennan also retired in September 2019 and has been replaced by Mr Minyu Zhang who had previously worked in the NZ Police calibration laboratory.

SI Redefinition

Amongst a number of activities, MSL hosted a special mini symposium to promote the SI redefinition at the 2019 I2MTC conference held in Auckland, NZ. This conference, coincidentally held the same week as World Metrology Day, is the flagship event for the IEEE Instrumentation and Measurement Society and was attended by over 300 international participants.

The symposium featured four presentations covering each of the new SI constant definitions - for the elementary charge see [1]. MSL also sponsored a plenary talk by Dr Michael de Podesta of NPL. This was an outstanding presentation of the thinking behind the SI redefinition and was accorded a standing ovation.

In March Murray Early gave an invited presentation to the Metrology Society of Australasia conference in Melbourne on the future development of the SI following the redefinition [2].

World Metrology Day, 20 May 2020, was marked by an MSL online event. Murray gave a presentation on a similar topic [3] and Blair Hall discussed developments in Data Metrology [4]. About 100 people attended the virtual meeting.

[1] M. D. Early, "The Elementary Charge and the Ampere", oral presentation to the I2MTC conference, Auckland, 20-23 May 2019.

[2] M. D. Early, "*The 2019 SI Redefinition: Now What?*", Invited presentation, Metrology Society of Australia, Melbourne, Australia, 3-5 March 2020.

[3] M. D. Early, "*The 2019 SI Redefinition: Now What?*", MSL World Metrology Day Webinar, 20 May 2020, also on YouTube: https://youtu.be/PaStGpEIQOs (starts 20:30 ends 43:30).

[4] B. D. Hall, "Data metrology", MSL World Metrology Day Webinar, 20 May 2020, also on YouTube: https://youtu.be/KsyCNil7rGA.

Electrical Standards Laboratories

The new building to house MSL's Electrical and Temperature Standards groups was practically completed in 2020 and the Temperature Standards group has moved into their new laboratory spaces. The temperature control in the Electrical Standards Laboratory still requires further development and we have been working with a mechanical engineer from Callaghan Innovation to understand the environmental performance. This involves modelling the air flow and validating the results against temperature measurements throughout the lab, with a view to proposing modifications to ensure that the required control (between 0.1 K and 0.5 K depending on the zone) can be achieved.

We expect to be transferring to this new laboratory space sometime in July-August 2021 (see photo). Two new screened rooms have arrived but have their installation has been delayed owing to the COVID-19 complications to bring the installation engineer over from Australia. However, it is now expected these will be able to be installed within a few months.

New MSL Laboratories for Electrical and Temperature Standards

[5] C. D. Hastings, "*Update on the New MSL Building Commissioning Project*", MSL World Metrology Day Webinar, 20 May 2020, also in YouTube: https://youtu.be/PaStGpEIQOs (starts 7:30 ends 20:20).

Work is also progressing in constructing a new laboratory space in an existing building to house Time and Frequency Standards. This renovation work should be completed mid-2021.

17025 Accreditation and Peer Review

A full assessment of the capabilities of the Electrical Standards Team was last carried out in April 2018 involving peer technical assessment by Dr Wey Chua (NMC) and Mr Lucas di Lillo (INTI) working with two assessors from the New Zealand accreditation body, IANZ. In March 2020 and March 2021 IANZ has 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.

International/CPEM

CPEM 2022 was scheduled to be held in Wellington New Zealand on the first week of May 2022. Owing to the effects of COVID-19 we are presently investigating options to delay this conference towards the end of 2022. The conference will be jointly hosted by MSL and NMI Australia. Please consult the website (http://www.cpem2022.nz/) for the latest information. A

presentation inviting participants to CPEM 2022 was made available on the CPEM 2020 website [6].

[6] M. D. Early and I Budovsky, “An Invitation to CPEM 2022”, CPEM 2020 Virtual Conference, Colorado, 24 August 2020

Keith Jones has (until recently) been providing strategic assistance to the Myanmar Government for the establishment of their national metrology system. His work is funded by the German Government as part of their international aid to the Asia-Pacific Region. The future of this consultancy work is now unclear.

Murray Early was appointed as chair of the CCEM working Group on Low Frequency Quantities (WGLF) at the CCEM meetings in 2019.

Blair Hall has joined a group of metrologists providing support and advice to the CIPM Task Group on the Digital SI. This group organised a successful workshop about "The International System of Units (SI) in FAIR digital data", in February 2021 (https://www.bipm.org/en/conference-centre/bipm-workshops/digital-si/).

Kibble Balance

Construction of the MSL Kibble balance is progressing with the magnet system now assembled. Various rigs have been developed to evaluate key components of this novel twin pressure balance design. A current source design, kindly provided by METAS, has been constructed and initial characterization looks very promising. Design work on the mass exchangers and vacuum enclosure is well advanced. Our 2 V cryocooled PJVS system has been installed in the Kibble lab, and a highly stable resistor and air bath have been purchased to enable high accuracy coil current measurements. While the main developments are presently associated with the mechanical construction, it is expected that the electrical measurement system, initially using a sampling 3458A to measure the difference of the coil output voltage and the PJVS voltage, will require careful implementation in the next few years.

DC Voltage

Two major investments to support DC primary standards have been approved and we hope to take delivery of these in 2021. A Magnicon CCC bridge was ordered in May 2020. This bridge should 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. This system employs a conventional storage dewar of liquid He. It is hoped that such a system can be eventually operated using a condensing cryocooler.

A 10 V PJVS was ordered in October 2020 from the NIST Boulder group and will provide a much-needed operational system replacing our SIS array of almost 30 years. This standard comes with a low acoustic noise cryocooler so that it can be used in our main laboratory without disturbing other activities.

Our RefStep method has been extended down to 1 mV to support the calibration of nanovoltmeters and has been verified using a resistance voltage divider.

Mains Frequency Transformer Calibration

MSL has purchased a sampling system from NMIA to become our new mains power standard and enable traceable measurements of harmonic content. It is intended that this standard will be commissioned in the new MSL building in 2021.

Some initial evaluation work is taking place with our new CT calibration (including repair of one new instrument by the manufacturer) but the whole system will not be commissioned until it is setup in the new building.

We have an ongoing interest in the validity of transformer calibration through secondary injection as this technique is attractive to the local calibration industry. We have concerns regarding the traceability of this method and our accreditation body is keen to clarify the status of this method for second-tier calibration laboratories. A short presentation regarding this issue was made at a workshop on 'Model based testing' at MSA 2020 [7] and has provided a useful connection with Australian colleagues who also have concerns regarding this matter.

[7] K. Jones and T. J. Stewart, "*Indirect Transformer Calibration*", presented by M. D. Early to the workshop on "*Model Based Testing"*, Metrology Society of Australia, Melbourne, Australia, 3-5 March 2020.

2D Materials

Two-dimensional materials (2D) are currently the focus of intense research efforts. On the one hand, their ultimate thinness makes them very attractive for electronic applications, while on the other, the physical properties of monolayers often drastically differ from those of their parent 3D materials, thereby unveiling new physical phenomena.

Silicene, a monatomic sheet of silicon atoms, shares many of the outstanding properties of graphene, and has the great potential for applications due to the compatibility with current silicon-based nanoelectronics. Given the similarity with graphene, many of the same fundamental properties and potential applications of graphene are been considered for silicene (e.g. quantum spin Hall effect, quantum anomalous Hall effect, valleytronics, band gap engineering, field effect transistor etc.). Recent density functional theory calculations, in addition to hexa-silicene, revealed the existence of a new topological phase of silicene, tetra-silicene. Due to the different structures, hexa- and tetra-silicene are expected to have different properties (such as topologically protected metallic states, spin-orbit effects etc.), opening new avenues for applications.

Vladimir Bubanja and colleagues have investigated the atomic mechanism underlying the formation of crystalline tetra-silicene from hexa-silicene via compression, and the reverse transition from obtained tetra-silicene to hexa-silicene via heating [8]. For this work we employed the New Zealand eScience Infrastructure (NeSI) supercomputing facilities. The work is in part supported by the Dodd-Walls Centre for Photonic and Quantum Technologies, which is one of ten New Zealand Centres of Research Excellence.

Vladimir has also performed a consultancy project for a New Zealand Government Agency in the field of quantum communication and quantum computation. Subsequently he gave an invited talk to international partners [9]. Additional talks about the quantum Josephson effects have been made [10,11].

[8] V. V. Hoang, N. H. Giang and V. Bubanja: "*Hexa ↔ tetra silicene crystal–crystal phase transition*", Philosophical Magazine 100 (2019) 551-570.

[9] V. Bubanja: "*Quantum Metrology and Quantum Technologies*", 7 May 2020.

[10] V. Bubanja: "*Effect of quantum fluctuations on the critical supercurrent through a mesoscopic normal metal island*", Quantum 2020 Institute of Physics virtual conference 19-22 October 2020.

[11] V. Bubanja: "*Effect of quantum fluctuations on the critical supercurrent through a mesoscopic normal metal island*", Dodd-Walls Centre for Photonic and Quantum Technologies, Symposium, 20-22 October 2020.

Data Metrology

Blair Hall has continued to look at opportunities presented to metrology by digital transformation. A very successful special session on this topic was organized jointly by MSL and PTB at the 2020 IEEE International workshop on metrology for industry 4.0 and IoT (Metroind40iot) conference [12]. As a result, another session on "Metrology for data interoperability in industry 4.0" is being organised at the 2021 conference (https://www.bipm.org/en/conference-centre/bipm-workshops/digital-si/), and a paper submitted [13].

Although the AMCTM conference planned for September 2020 was cancelled due to the pandemic, two chapters have been accepted for the monograph that accompanies the conference, which will still be published [14,15].

The metrology organisation IMEKO has formed a new technical committee (TC6) with a focus on digitalisation. Blair Hall is a member of TC6 and has submitted three papers to the IMEKO World Congress, which will be held in September [16,17,18].

Blair has also collaborated with Annette Koo and her team, looking at some questions relating to the interpretation of measurement comparison data [19,20]. Blair and Robin Willink also released a detailed report on the statistical treatment of small samples of observations of complex quantities, with examples taken from the field of vector network (VNA) analyser measurements [21].

[12] B. D. Hall, *"Software for calculation with physical quantities"*, IEEE International Workshop on Metrology for Industry 4.0 and IoT, 3 – 5 June 2020, Rome, Italy. [online]

[13] B. D. Hall, "*Considerations about quantities, units, and dimensions for interoperability*", 2021 IEEE International Workshop on Metrology for Industry 4.0 & IoT, Roma, Italy, 2021 submitted

[14] B. D. Hall, *Software representation of measured physical quantities*, in Advanced Mathematical and Computational Techniques in Metrology XII, World Scientific, Series on Advances in Mathematics for Applied Sciences, in press.

[15] B. D. Hall and D. R. White, *Digital representation of metrological traceability*, in Advanced Mathematical and Computational Techniques in Metrology XII, World Scientific, Series on Advances in Mathematics for Applied Sciences, in press.

[16] B. D. Hall and D. R. White, "*Digital representation of measurement uncertainty*", XXIII IMEKO World Congress (August 30 – September 3, 2021, Yokohama, Japan) submitted

[17] B. D. Hall and M. Kuster, "*Metrological support for quantities and units in digital systems*", XXIII IMEKO World Congress (August 30 – September 3, 2021, Yokohama, Japan) submitted

[18] S. J. Chalk, D. N. Coppa, F. Flamenco, A. Forbes, B. D. Hall, R. J. Hanisch, K. Hosaka, D. Hutzschenreuter, J. S. Park, "*International development of the SI in FAIR digital data*", XXIII IMEKO World Congress (August 30 – September 3, 2021, Yokohama, Japan) submitted

[19] A. Koo and B. D. Hall, *"Linking an RMO or bilateral comparison to a primary CCPR comparison"*, Callaghan Innovation Report 776, July 2020 (23 pages)
doi: 10.5281/zenodo.3958381

[20] E. Molloy, A. Koo, B. D. Hall and R. Harding, "*The statistical power of some key comparison analysis methods to correctly identify participant bias*", Metrologia, submitted.

[21] R. Willink and B. D. Hall, *"An extension to GUM methodology: degrees-of-freedom calculations for correlated multidimensional estimates"*,
Callaghan Innovation Report 838, August 2020 (29 pages)
doi: 10.5281/zenodo.3996686

[22] Sharifi, M., Meenken, E.D, Hall, B.D., Espig, M., Finlay-Smits, S., and Wheeler, D.M., *Importance of Measurement and Data Uncertainty in a Digitally Enabled Agriculture System*. In: Nutrient Management in Farmed Landscapes. (Eds. C.L. Christensen, D.J. Horne and R. Singh). http://flrc.massey.ac.nz/publications.html, Occasional Report No. 33. Farmed Landscapes Research Centre, Massey University, Palmerston North, New Zealand. (9 pages).

[23] B. D. Hall, *"Making metrological traceability traceable"*, NCLSI Webinar series: Metrology in motion – A global effort to digitalize metrology, 23 Sept. 2020 [online].

[24] B. D Hall, *Metrology 4 Digital Transformation: The relevance and potential of digitalization for developing NMIs* (online workshop), 5 – 8 Oct. 2020, [online].

[25] B. D. Hall, "*Preparing for Digital Transformation*", APMP-TCQS Workshop, 9 Nov. 2020 [online].

[26] B. D. Hall, "*Why SI notation is not quite enough*", NCLSI Webinar series: Metrology in motion – A global effort to digitalize metrology, 28 April 2021 [online].

Status of Comparisons

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

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

3/ APMP.EM-K5.1: AC power at 50 Hz, draft B.

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-2021.