Progress Report on Electrical Metrology at METAS 2017 to 2019

Report prepared for the 31st meeting of the Consultative Committee for Electricity and Magnetism (CCEM)

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This report gives a brief outline of some research and development activities in the field of electricity at the Federal Institute of Metrology METAS.

1. Electrical Quantum Standards & DC/LF Metrology

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1.1 Dual Josephson Impedance Bridge

METAS and NIST have collaborated for several years on the Dual Josephson Impedance Bridge (DJIB) [1,2]. The project consists of putting together the sampling bridge technique and Josephson Arbitrary Waveform Generator Synthesizers (JAWS). Bridges with sources based on voltage ratio transformers can only compare impedance ratios per the predefined voltage ratios corresponding to the of the transformer turn number. Furthermore only impedances of the same nature can be compared, since the phase between the two voltage sources is 0° or 180°. Sampling bridges digitize two independent voltage sources with an accurate amplitude ratio and phase shift, their precision is limited by that of the digitizer. In the DJIB, the voltage sources are two independent pulse-driven JAWS systems, i.e. yielding arbitrary voltage ratios or phase shifts. The stability, linearity, tunability and spectral purity of the JAWS sources are key to the figure of merits of the DJIB. The collaboration between METAS and NIST spans several time zones, and outstanding results have been achieved. An investigation of the systematic effects of the bridge were carried out, a 100 pF capacitor could be calibrated with uncertainties within a few parts in 10^8 at 1233 Hz. A systematic study of the performance over the entire complex plane is under way.

1.2 Impedance simulator

The iSimulator was developed as part of the EMRP AIMQuTE project. It aims at calibrating RLC multimeters over the impedance range 1 Ω – 10 M Ω with any phase angle in the frequency domain 100 Hz – 20 kHz [3]. Measurements International (MI) and METAS signed an agreement for the industrialization of the iSimulator technology, and a prototype to demonstrate the measurement principle was supplied by METAS to MI with an extensive know-how transfer. MI put the demonstrator on display at the Conference on Precision Electromagnetic Measurements held in July 2018 in Paris. MI is now entering the development phase of a production intent unit, which should last an approximate 3 years. In the meantime, a few units will be placed at selected customers in order to gather first-hand return of experience in real life applications. MI customers will now have the ability to calibrate with one single instrument LCR meters over the entire complex plane, to previously unavailable levels of accuracy, uncertainty and automation.

1.3 Computational traceability

Simulations have been used in several collaborations with the industry in order to establish traceability for impedances. The approach has been applied to a broad range of fields, such as contactless measurements using eddy-current techniques, calculations of resistive and capacitive standards for impedance analyzers measuring up to 500 MHz. These new skills are particularly useful for complex geometries and to connect traceable measurements across the RF-LF gap, typically between 100 kHz and 500 MHz, where traceability using classical artefacts is not achievable.

2. Power and Energy

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2.1 Primary power standard for 16.7 Hz

A primary power standard at 16.7 Hz is under development. The main interest for this standard is in the field of railway applications, in particular in the framework of the EMPIR MyRailS project [4]. The standard features uncertainties below 50×10^{-6} for voltages and currents below 700 V and 20 A respectively. The measurement of the voltage and current signals involved in the power computation is by means of type 3458A multimeters in DC mode with an external trigger signal [5]. Different fitting algorithms are used to determine the RMS value and phase of the signal of interest [6]. Comparison with power standards operating at 50 Hz have shown consistent results.

2.2 Calibrator for instrument transformer comparators

Instrument transformer test sets are used to calibrate instrument transformers. Traditionally, commercial and reference transformers were very similar in design. The test sets for the calibration of those transformers were using bridge techniques. While the design of reference transformers has not changed, non-conventional commercial transformers have very different output signals. A calibrator emulating analogue-output instrument transformers with adjustable ratio error and phase displacement has been developed and built using commercial off-the-shelf components as much as possible [7]. It is fully computer controlled and features uncertainties below 10×10^{-6}. CMCs have been published and PTB conducted a successful peer-audit in 2018.

3. RF & Microwave

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3.1 Impedance and Network Analysis

The VNA metrology software *VNA Tools* (www.metas.ch/vnatools) has been further developed [8-10]. Notable additions are a CMC calculator, time domain functionality and a real time interface (RTI). The RTI has been implemented for stable high level access to functionality of the software. The RTI is locked for the general user but can be licensed to interested parties for commercial applications. So far there are close to 800 licensees of *VNA Tools* and almost 200 persons have visited the three-day introductory course, which is provided by METAS.

In the EMPIR RPOT project RFMicrowave (rfmw.cmi.cz/) METAS has been disseminating knowledge in establishing SI traceability for S-parameters and evaluating VNA measurement uncertainties to other NMIs.

A review article [11] to summarize state of the traceability for coaxial S-parameter measurements has been published

3.2 RF power and Noise

The project 110 GHz Power to extend coaxial measurement capabilities in RF power from currently 67 GHz to 110 GHz is nearing completion. An important outcome of this project is the new software *METAS PowerCal*, which can be used to calibrate power sensors on a VNA system. First tests towards a novel primary power standard based on the electro-optical effect have been performed [12].

Because NPL has stopped (as the last lab in Europe) its primary noise service in 2018, METAS has built up its own primary realization of noise for the coaxial systems Type-N and 3.5 mm. The measurement systems are complemented by a new software *METAS NoiseCal*, which is using components of *VNA Tools* and which is based on *METAS UncLib* for proper uncertainty evaluation.

3.3 Scanning Microwave Microscope (SMM)

Within the last two years the METAS SMM has been developed further and has been used in various projects [13]. The EMPIR projects 3D-Stack and PlanarCal were completed in the meantime, and new projects (EMPIR: Hymet, ADVENT; Horizon 2020: MMAMA) have been started. The main objectives of these projects are the fabrication of impedance standards fabricated in a cleanroom using lithographic techniques and the development of a coaxial scanning tip [14]. A first set of impedance standards has been produced and is currently undergoing evaluation. The implementation of the coaxial tip is underway.

3.4 Terahertz

In 2018 the RF&MW laboratory in cooperation with the photonics laboratory started a project (THz-Met) to address Terahertz metrology both from the electronics and the optics perspective. The RF&MW laboratory will establish S-parameter traceability in the 500 GHz to 750 GHz waveguide band. In addition it is planned to establish traceability for power and material measurements. An EMPIR proposal on Terahertz was approved in 2018 and the project TEMMT will start in 2019. Some of the activities of the METAS project THz-Met are also planned in TEMMT.

4. EMC and Antenna

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4.1 Round robin test device for EMC testing

METAS has been continuously expanding its capabilities in proficiency testing [15-17]. A device for surge-immunity testing has recently been developed for testing according to IEC 61000-4-5 [18]. This device is now under evaluation in a national comparison between accredited testing laboratories. A device for testing according to IEC 61000-4-3 is in development and completion is planned for summer 2019. Several devices are now available for proficiency testing: conducted emission, radiated emission (comb generator with antenna), radiated emission (EUT with cabling), conducted immunity according to IEC 61000-4-6, and surge immunity. Radiated immunity will be available shortly.

METAS now provides proficiency testing for accredited labs in Europe (www.metas.ch/emc).

4.2 EA comparison among European accredited calibration labs

METAS has lead one of the most important comparisons among accredited calibration labs in Europe for European Accreditation. The scope of the comparison was the measurement of ESD gun parameters: DC voltage, maximum current, rise time, amplitude and 30 ns and 60 ns. The results of the comparison have shown large disagreement for the amplitude at 30 ns and 60 ns, whence the subject has been raised to the normative committees.

4.3 Traceability for Longitudinal Convertion Loss (LCL) measurements

Traceable measurements of LCL are important for the calibration of coupling-decoupling networks. A concept for traceable calibration of LCL has been established and the first CMC will be published in 2019. The experimental setup will be improved to reduce the uncertainties and increase the range of measurements up to 80 dB.

This calibration capability is now available at METAS and the first certificates for calibration of LCL have been issued.

4.4 Scanning method for measurement of non-ionising radiation

The measurement of non-ionizing radiation is an important issue in Switzerland since it has, based on the precaution principle, stronger limits that the ICNIRP limits. However, the measurement uncertainty of the field measurement is typically 3 dB, which expressed in percent gives about 45 %. This is quite high for the general perception of the public. Therefore, METAS tries to improve the measurement methods and also the measurand in order to decrease the measurement uncertainty. The idea to improve the uncertainty is to scan the field and to identify an averaging method in order to remove the uncertainties due to interference. METAS is currently comparing the actual field scanning method with 3D scanning methods performed by robots.

5. Participation in Comparisons

Comparisons completed since the 2017 CCEM meeting

- European Accreditation: Comparison of ESD pulse measurement; piloted by METAS.
- EURAMET.EM-S31: Comparison of capacitance and capacitance ratio; piloted by PTB.
- BIPM.EM-K12: Comparison of Quantum Hall Effect resistance standards; piloted by BIPM.

6. List of Peer-reviewed Publications

[1] F. Overney and B. Jeanneret, Impedance Bridges: from Wheatstone to Josephson, *Metrologia*, 55-5, pp. S119-S134, 2018

[2] F. Overney, N. E. Flowers-Jacobs, B. Jeanneret, A. Rüfenacht, A. E. Fox, P. D. Dresselhaus and S. P. Benz, Characterization of a Dual Josephson Impedance Bridge, *2018 Conference on Precision electromagnetic Measurements*, 2018

[3] F. Overney and B. Jeanneret, Calibration of a LCR-Meter at Arbitrary Phase Angles using a Fully Automated Impedance Simulator, *IEEE Transactions on Instrumentation and Measurement*, 66-6, pp. 1516-1523, 2017

[4] C. Mester, D. Giordano, P. Clarkson, F. Garnacho, H. E. van den Brom, Accurate Measurements of Energy, Efficiency and Power Quality in the Electric Railway System, *2018 Conference on Precision electromagnetic Measurements*, 2018

[5] C. Mester, Timestamping Type 3458A Multimeter Samples, *2018 Conference on Precision electromagnetic Measurements*, 2018

[6] L. Hentgen and C. Mester, Sampling AC signals: Comparison of Fitting algorithms and FFT, *2018 Conference on Precision Electromagnetic Measurements*, 2018

[7] S. Siegenthaler and C. Mester, A computer-controller calibrator for instrument transformer test sets, *IEEE Transactions on Instrumentation and Measurement*, 66-6, pp. 1184-1190, 2017

[8] M. Wollensack, J. Hoffmann, D. Stalder, J. Ruefenacht, M. Zeier, VNA Tools II: Calibrations Involving Eigenvalue Problems, *89th ARFTG Microwave Measurement Symposium*, 2017

[9] M. Zeier, J. Hoffmann, J. Rüfenacht, M. Wollensack, Contemporary evaluation of measurement un-certainties in vector network analysis, *tm - Technisches Messen*, 84-

5, pp. 348 – 358, 2017

[10] K. Wong and J. Hoffmann, Improve mm-wave measurement repeatability and accuracy by increasing coaxial connector pin gap, *2017 IEEE 26th Conference on Electrical Performance of Electronic Packaging and Systems*, 2017

[11] M. Zeier, J. Hoffmann, P. Hürlimann, J. Rüfenacht, D. Stalder, M. Wollensack, Establishing traceability for the measurement of scattering parameters in coaxial line systems, *Metrologia*, 55-1, S23–S36, 2018

[12] J. Hoffmann, D. Stalder, J. Morel, M. Zeier, Towards High Frequency Power Measurement using the Electro-Optical Effect, *2018 Conference on Precision electromagnetic Measurements*, 2018

[13] A. Buchter, J. Hoffmann, A. Delvallée, E. Brinciotti, D. Hapiuk, C. Licitra, K. Louarn, A. Arnoult, G. Almuneau, F. Piquemal, M. Zeier, F. Kienberger, Scanning microwave microscopy applied to semiconducting GaAs structure, *Review of Scientific Instruments,* 89, 023704 (2018)

[14] T. Le Quang, D. Vasyukov, J. Hoffmann, A, Buchter, M, Zeier, COMSOL Simulations for Scanning Microwave Microscopy, *2018 COMSOL Conference*, 2018

[15] E. Tas, F. Pythoud, Design, Implementation, and Evaluation of Proficiency Testing in EMC Conducted Immunity, *IEEE Transactions on Electromagnetic Compatibility*, 59-5, pp. 1433-1440, 2017

[16] F. Pythoud, E. Tas, Design of a Reference Device for Radiated Immunity, Interlaboratory Comparison, *2017 International Symposium on Electromagnetic Compatibility - EMC EUROPE,* 2017

[17] F. Pythoud, Proficiency Testing in EMC Radiated Immunity, *IEEE Transactions on Electromagnetic compatibility*, 60-5, pp.1249-1253, 2018

[18] E. Tas, F. Pythoud, B. Muehlemann, Design of a Reference Device for Surge Immunity Inter-laboratory Comparison, *2018 International Symposium on Electromagnetic Compatibility - EMC EUROPE*, 2018

[19] E. Mohns, A. Mortara, H. Cayci, E. Houtzager, S. Fricke, M. Agustoni, B. Ayhan, Calibration of Commercial Test Sets for Non-Conventional Instrument Transformers, *2017 IEEE International Workshop on Applied Measurements for Power Systems*, 2017

[20] M. Ortolano, L. Palafox, J. Kučera, L. Callegaro, V. D’Elia, M. Marzano, F. Overney and G. Gülmez, An International Comparison of Phase Angle Standards Between the Novel Impedance Bridges of CMI, INRIM and METAS, *Metrologia*, 55-4, pp. 499-512, 2018

[21] K. Thodkar, Ch. Schönenberger, M. Calame, F. Lüönd, F. Overney and B. Jeanneret, Observation of high accuracy resistance quantization in CVD graphene, *2018 Conference on Precision electromagnetic Measurements*, 2018

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[24] D. Corminboeuf, Calibration of the absolute linearity of lock-in amplifiers, *2018 Conference on Precision electromagnetic Measurements*, 2018

[25] P. Gournay, B. Rolland, A. Mortara and B. Jeanneret, On-site comparison of Quantum Hall Effect Resistance Standards of METAS and the BIPM, *Metrologia*, 55-1A, pp. 01002, 2018

[26] K. Thodkar, D. Thompson, F. Lüönd, L. Moser, F. Overney, L. Marot, Ch. Schönenberger, B. Jeanneret and M. Calame, Restoring the Electrical Properties of CVD Gra-

phene via Physisorption of Molecular Adsorbate, *ACS Applied Materials & Interfaces*, 9, pp. 25014–25022, 2017

[27] M. Agustoni and A. Mortara , A Calibration Setup for IEC 61850-9-2 Devices, *IEEE Transactions on Instrumentation and Measurement*, 66-6, pp. 1124-1130, 2017

[28] F. Lüönd, C.-Ch. Kalmbach, F. Overney, J. Schurr, B. Jeanneret, A. Müller, M. Kruskopf, K. Pierz, and F. Ahlers, AC Quantum Hall Effect in Epitaxial Graphene, *IEEE Transactions on Instrumentation and Measurement*, 66-6, pp. 1459-1466, 2017

[29] D. Corminboeuf, Calibration of the absolute linearity of lock-in amplifiers, *IEEE Transactions on Instrumentation and Measurement*, DOI: 10.1109/TIM.2018.2881808

[30] C. Mester and J.-P. Braun, Power-Quality- und Synchrophasor-Messtechnik, *Handbuch Elektrizitätsmesstechnik*, VDE Verlag GmbH, pp. 631-652, 2017

[31] D. Amaripadath, R. Roche, L. Joseph-Auguste, D. Istrate, D. Fortune, J.P. Braun, F. Gao, 2017 52nd International Universities Power Engineering Conference, 2017

[32] C. Mester, J.-P. Braun, C. Ané, Messunsicherheit bei der Kalibrierung von Power Quality Analysern, *VDI Messunsicherheitstagung Tagungsband*, 2017

[33] J.-P. Braun, Measure of the Absolute Phase Angle of a Power Frequency Sinewave with Respect to UTC, *2018 Conference on Precision Electromagnetic Measurements*, 2018

[34] D. Amaripadath, R. Roche, L. Joseph-Auguste, D. Istrate, D. Fortune, J.P. Braun, F. Gao, Measurement of Supraharmonic Emissions (2 - 150 kHz) in Real Grid Scenarios, *2018 Conference on Precision Electromagnetic Measurements*, 2018

[35] P.S. Wright, G. Rietveld, F. Leferink, H.E. Van den Brom, F.R.I Alonso, J.P. Braun, K. Ellingsberg, M. Pous, M. Svoboda, Evaluation of EMI Effects on Static Electricity Meters, *2018 Conference on Precision Electromagnetic Measurements*, 2018

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[42] S. Dash, F. Pythoud, P. Leuchtmann and J. Leuthold, Method for traceable measurement of LTE signals, *Metrologia*, 55-2, pp. 284-293, 2018