

Progress report on electrical metrology at CMI between 2015 and 2017
for the 30th meeting of the Consultative Committee for Electricity and Magnetism (CCEM),
March 2017

DC & Quantum Metrology

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Work on modernization of national standard of DC voltage is underway. New software for intercomparison and evaluation of standard Zener cells has been creating and testing, to allow to connect an arbitrary number of cells. New arrangement will be applied to minimize errors of wiring and allow further automation of JVS to standard cells measurement.

In cooperation with PTB a method for calibration of multiple parameters of AD converters at once have been tested on JAWS. Method is based on generating a specially constructed waveform enabling simultaneous calibration of ADC at multiple frequency/amplitude points and calibration of other several parameters of ADC such as THD, SINAD, ENOB, time stability of these coefficients and correlations between coefficients.

AC-DC difference, AC Voltage and Current Metrology

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Traceability of ac-dc current difference was extended up to 1 MHz by development of own primary standard based on a single junction thermal converter. Setup for measurement of ac-dc current difference was modified to measure in potential driven circuit. A bilateral comparison with BEV was organized to provide validation of the new established traceability.

Two of the special range resistors used in CMI's ac-dc voltage transfer difference step up procedure for 500 V and 1 kV had to be rebuild because of their increasing instability. A bilateral comparison with BEV was organized to confirm the uncertainty budget and to support the correct traceability after the new build-up at high voltages.

Resistance

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Bilateral comparison of 1 Ω and 10 k Ω standards (ongoing BIPM key comparisons BIPM.EM-K13.a and 13.b) from 2015 was successfully finished [7]. Proposal of improvements and new CMCs in the KCDB database for dc resistance were submitted. Realization of QHE with new cryoprobe operating at temperatures above 2 K instead of older one at 0.3 K was implemented. Several aspects on calibration of resistance ratio bridges were investigated [8].

Within finished EMRP GraphOhm project, a successful realization of QHR demonstrated the possibility of using the QHE to reproduce the unit of electrical resistance with an uncertainty below a few parts in 10^8 without an external supply of liquid helium [9].

Impedance and signal analysis

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Within finished EMRP AIMQute project, fully digital 4-TP bridge designed for operation in the whole impedance complex plane was built. A bridge version reconfigured to digitally assisted form with uncertainty a few parts in 10^8 at 1 kHz was investigated [4]. A work on primary traceability of impedance scale above MHz range is ongoing, especially in the field of verification of calculable impedance standards [11].

Digital sampling bridge for low impedances (0 to 100) k Ω and frequency band 20 Hz up to 100 kHz was developed and validated with expanded magnitude uncertainties from few $\mu\Omega/\Omega$ up to 35 $\mu\Omega/\Omega$ and phase angle uncertainty from sub- μ rad up to 50 μ rad (100 kHz) [1,3].

New digital sampling bridge for low impedances covering frequency range up to MHz band is being finalized (replacement of 100 kHz version). Expected uncertainties are less than 70 $\mu\Omega/\Omega$ at 1 MHz for modulus and less than 200 μ rad/MHz for phase angle. The bridge will be also used in scope of TracePQM project for characterization of coaxial current shunts in MHz range.

Primary calculable resistance standards of time constant (phase angle) were developed with expanded uncertainty down to 0.2 ns (1.4 μ rad/kHz) [4]. The standards were compared with CMI HF coaxial standards with time constant deviations below 60 ps. The standards are being further developed towards 0.1 ns uncertainty.

Precision input buffer for QuADC EMPIR project is being developed. Flatness below 0.2 μ V/V up to 10 kHz, below 3 μ V/V at 100 kHz and below 120 μ V/V at 1 MHz were reached. Buffers are being further developed in order to reach sub-0.1 μ V/V flatness and stability up to 10 kHz.

A unique software toolbox QWTB has been developed. It is written in M-code and is running in MATLAB or GNU Octave. It aims for aggregation of high-quality algorithms required for data processing of sampled measurements.

The toolbox gives the possibility to use different data processing algorithms with one set of data and removes the need to reformat data for every particular algorithm. The toolbox can also variate input data and calculate uncertainties by means of Monte Carlo Method (MCM).

QWTB can help with searching of useful algorithms, learning how to use algorithms and application of algorithms to a user data. QWTB has standardized format of (input/output) quantities independent on the used algorithm, standardized use of algorithms, examples for every implemented algorithm, full documentation with examples, integration into LabVIEW, simple QWTB GUI. QWTB is easy to use, open source and extensible.

Power and Energy

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A simulator of Phasor Measurement Unit has been prepared to analyse uncertainties by means of Monte Carlo method.

Simulator implements full measurement path with transducer, digitizer and data processing algorithm for TVE, ROCOF and THD parameters. The simulator is able to propagate uncertainty or to calculate

sensitivity coefficients. With cooperation of INRIM and Università degli Studi di Napoli Federico II an effect of transducer compensation on the uncertainty of TVE is studied.

A new standard IEC 62586-2 requires new tests of quality meters. Several of them has been implemented into a new testing system consisting of generators, amplifiers, digitizers and special control software. The system can generate three phase arbitrary voltage waveforms related to the absolute time.

CMI is a coordinator of EMPIR joint research project 15RPT04 TracePQM. The project is referred to a category of Research Potential (RPOT) projects and addresses the increasing demands on traceable measurement of electrical power and power quality measurements. The overall goal of this project is to develop and validate a modular and well documented metrology grade system for the measurement of power and PQ parameters accompanied by open SW tool. The project runtime is from 1.6.2016 to 31.5.2019. More information can be found on project website: <http://tracepqm.cmi.cz>

Magnetic measurements

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A programmable capacitor array that enables an AC amplitude magnetic flux density (MFD) value up to 150 μT up to 140 kHz and an AC amplitude MFD value up to 220 μT up to 120 kHz to be generated in a single-layer Helmholtz-type solenoid has been realized. An AC amplitude MFD value of 110 μT at maximum can be generated at a frequency of 150 kHz for a short time. CMI also improved the NMR method with flowing water (the nutation method) for DC calibration of magnetic flux density coil standard with the nominal constant below 20 mT/A. We also developed an AC electromagnet for MFD generation up to 1 T at low frequencies for transversal Hall probe calibration.

High voltage and current measurements

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Calibration uncertainties of DC voltage in the range of up to 100 kV were improved. The Vitrek 4700 kilovoltmeter including three HV probes up to 100 kV was calibrated in the PTB Braunschweig.

The calibration capability in the area of high DC currents was extended. A DC current source with output current of 1,2 kA with a commutator was bought and so calibrations of DC meters is ensured.

Three current loops for AC current meters calibration is available. The first one for 10 kA is located at the CMI laboratory in Prague and the other two loops up to 30 kA and 50 kA are placed at the detached workplace in Brno.

A system for calibration of instrument transformer burdens using 3-voltmeters method was designed. Its hardware part is now constructed.

Participation in comparisons:

- Euramet 1187 - "Comparison of Instrument Current Transformers up to 10 kA" (pilot CMI)
- EURAMET EM.S35 – "Comparison on DC High-Current Ratio Standard" (pilot INRIM)
- "Traceability of AC High Voltage Ratio and Phase displacement Measuring Systems up to 500 kV" (pilot (LCOE))

Participation in EMRP and EMPIR projects:

NanoMag - Nano-scale traceable magnetic field measurements

CMI is involved in WP4 and WP 5 in MFM measurements and in alternate MFM tip characterization by coil standard of magnetic flux density

ENG52 Smart Grids II - Measurement Tools for Smart Grid Stability and Quality

CMI is involved in Task 4.1: Optimisation and Application of Non-Invasive Current Transducers. CMI is focused on design and realization of a split instrument current transformer for non-invasive current measurement.

ENG61 Future Grids - Non-conventional voltage and current sensors for future power gridsProject in progress.

CMI is involved in WP 2 and it is focused on design improving of Rogowski coils with regard to their resistance against outer spurious influences.

14IND08 EIpow - Metrology for the electrical power industry.

CMI is involved in WP 2 and it will together with MIKES and Aalto collaboratively find an optimal solution for the test setup for puncture testing of disc insulators.

High Frequency and Fields

Ongoing and planned comparisons

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In 2015, CMI will prepare for the key comparison CCEM GT-RF/13-18 (attenuation 20 dB to 90 dB, 18 GHz to 40 GHz).

EMRP/EMPIR projects

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In the period 2015-2017, the Department of primary metrology of RF electrical quantities has been involved in three EMRP programme projects and two EMPIR programme projects. Each project is described separately.

EMRP SIB62 (Metrology for new electrical measurement quantities in high-frequency circuits, 2013-2016) – further information about this project can be found at the webpage <http://www.hfcircuits.org>. The project finished in June 2016. CMI has been mainly involved in development of calibration standards for balanced vector network analyzer (VNA) measurements and development of calibration and verification standards for measurement of extreme impedances using VNA (i.e., impedances significantly different from 50 Ω).

EMRP IND51 (Metrology for optical and RF communication systems, 2013-2016) – further information about this project can be found at the webpage. The project finished in June 2016. CMI has been involved in characterization of coherent optical communications systems using optical signal analyzers and development of traceable error vector magnitude measurements in the optical domain.

EMPIR 14IND10 (Metrology for 5G Communications, 2015-2018) – further information about this project can be found at the webpage <http://empir.npl.co.uk/met5g/>. The project started in May 2015. The role of CMI has been mainly in developing methods for a traceable measurement of Signal to Noise and Interference (SINR), cooperation on the characterization of a wideband sampling systems and measurement uncertainty analysis of novel methods for characterization of nonlinear devices using a vector network analyzer.

EMPIR 15RPT01 (Development of RF and microwave metrology capability, 2016-2019) – further information about this project can be found at the webpage <http://rfmw.cmi.cz/>. The project started in June 2016. This project aims to increase and develop research and measurement capacities and expertise of emerging EURAMET countries on microwave metrology by transferring the theoretical and practical know-how between the partners and combining their skills to focus on microwave and electromagnetic compatibility (EMC) measurements. CMI participates on VNA measurements, calibration methods for diode power sensors, large power measurements, pulse measurements and leads the workpackage which aims to maximise the impact of this project within the European community of national metrology institutes and industrial end-users

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