CZECH METROLOGY INSTITUTE

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Progress report on electrical metrology at CMI between 2017 and 2019

for the 31st meeting of the Consultative Committee for Electricity and Magnetism (CCEM), March 2019

DC & Quantum Metrology

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The national standard of DC voltage was updated by new software for intercomparison and evaluation of standard Zener cells. New connecting cables and arrangement was prepared to minimize errors of wiring. The laboratory is being prepared for the installation of a new programmable Josephson voltage standard that was developed by Supracon and is due to install in next two months.

The new method for calibration of AD converters using JAWS was developed and published. [15]. 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.

In the framework of EMPIR project QuADC, control software was developed for operation of a new quantum voltmeter based on JAWS chip. The software is able to control instruments and process the measured data and is partly based on the Q-Wave ToolBox developed in the EMRP project Q-Wave and TWM developed in the EMPIR project TracePQM.

Resistance

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A bilateral comparison of 1 Ω and 10 kΩ standards (BIPM.EM-K13.a and 13.b) proved in 2015 CMCs of CMI. Subsequently, the on-site key comparison BIPM.EM-K12 between BIPM and CMI carried out in April 2017 showed a very good agreement in the measurements of a conventional 100 Ω resistor in terms of the quantized Hall resistance, and in the determination of the resistance ratios 10 kΩ /100 Ω and 100 Ω /1 Ω [1]. Improved CMCs for DC resistance standards and sources under CIPM MRA were accepted and CMC for DC resistance ratio devices was introduced in 2017. Several aspects on calibration of resistance ratio bridges were investigated [2].

Within finished EMRP project SIB51 GraphOhm, a successful realization of QHR demonstrated the possibility of using 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 [3]. Properties of QHE devices operated at higher temperatures were investigated too [4].

Impedance and voltage ratio

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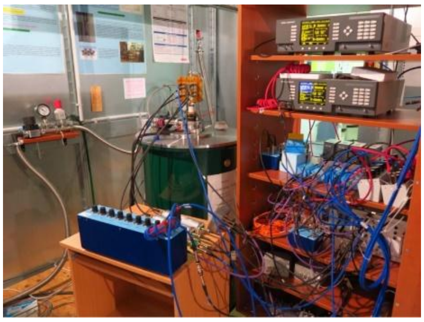
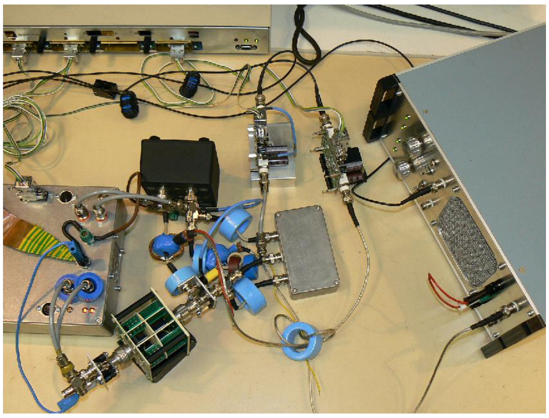


Within finished EMRP project SIB53 AIM QuTE and internal projects, a reconfigurable digitally assisted and fully digital 4-TP bridge was developed. It enables impedance ratio scaling with uncertainty of few parts in 10^8 at 1 kHz or operation in the whole impedance complex plane [5]. In general, the impedance scale is covered with traceability to QHE for frequencies up to 1.5 MHz now. A work on primary traceability of the impedance scale above MHz range is ongoing, especially in the field of verification of calculable impedance standards [6]. Successful quantization of QHR in AC regime for realization of quantum impedance standard was reported [4]. Realization of the capacitance unit from the quantum impedance unit is under development.



Digital sampling bridge [14] for calibration of low impedances up to 1 MHz was codeveloped in scope of TracePQM project. A new bifilar calculable standards of phase angle with expanded uncertainty 110 ps were developed. A comparison at low impedance shunts was held and showed agreement below 30 µΩ/Ω and 55 ps at 1 MHz. The bridge was also successfully used for calibration of resistive voltage dividers with and comparison was performed showing agreement below 100 µV/V and below 500 µrad at 1 MHz. An experimental two-terminal calculable resistor [10] for calibration of RLC meters up to 120 MHz was developed and compared to s-matrix measurements.

State-of-the-art devices for building primary traceability chains based on digital bridges, calculable resistance and capacitance standards and quantum impedance standards were realized (modular precise generators and coaxial multiplexers, calculable standards, thermostats …) in last years. The work is exploited within EMPIR project 17RPT04 VersICaL. A new EMPIR project 18SIB07 GIQS dealing with realization of impedance quantum standard with graphene-based devices will start in 2019.

Precision input buffer for QuADC EMPIR project is being developed. Flatness below 0.2 µV/V up to 10 kHz, below 3 µV/V at 100 kHz and below 120 µV/V at 1 MHz were reached. Buffers are being further developed in order to reach sub-0.1 µV/V flatness and stability up to 10 kHz. Design was made open hardware (https://github.com/smaslan/QuADC-buffer).

Impedance bridge and simulated standard for ultralow impedances and frequencies are being developed in scope of LiBforSecUse EMPIR project (Li-ion batteries for second use).

Several specialized measurement systems were developed. A simplistic digital sampling setup for calibration of strain gauge bridge calibration unit BN100 (or similar) was developed [7]. The method reaches comparable uncertainty to traditional method with IVDs for ratios up to 2 mV/V (uncertainty from 7 to 30 parts in 10^9).

CMI also possesses CMCs for phase shift measurement in wide range of frequencies using sampling systems with multiparameter sine fitting. The setup is capable to measure up to 1 MHz. Extension to 100 MHz is planned in 2019 – 2020.

CMI is also one of the few laboratories with CMCs for THD (Total Harmonic Distortion) outside industrial frequencies. A unique analogue calculable source of THD is in use since 90’.

AC-DC difference, AC Voltage and Current Metrology

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In recent years the traceability of ac-dc current transfer difference was extended up to 1 MHz by development of own primary standard based on a single junction thermal converter [17] and validated by a bilateral comparison with BEV in 2016. New CMCs in AC-DC current transfer difference were established based results of EURAMET.EM.K12 comparison (measured in 2012) and also on results of bilateral comparison with BEV in 2016.

Improved CMCs in AC-DC voltage transfer difference were established based on results of two bilateral comparisons with GUM in 2011 and BEV in 2016.

After improvements of the AC-DC voltage transfer step up/down procedure new CMCs were also established for calibration of AC measurement standards (such as 5790A).

In recent years a new set of current shunts up to 20 A was built based on lumped element modelling [18]. Then, the measurement range of AC current was extended up to 100 A and 100 kHz by development of new high current shunts with an active cooling reducing the level dependence of DCR and AC-DC difference [19].

Power and Energy

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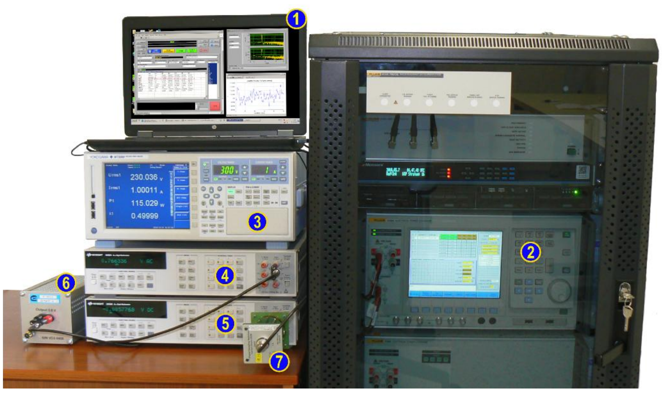
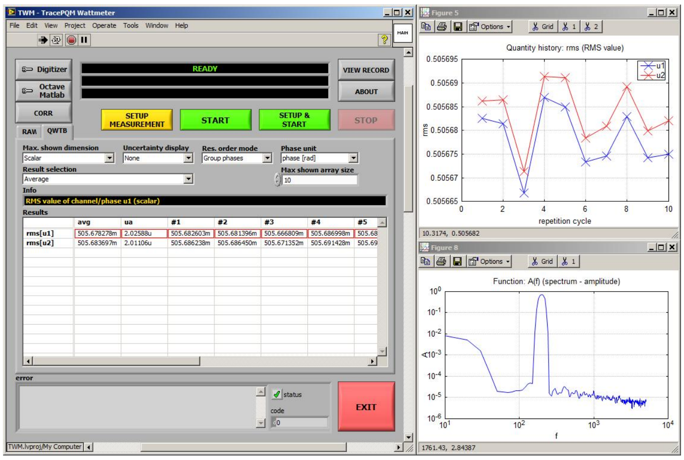
A unique open source tool for digital sampling measurement of power and power quality parameters is being developed in scope of TracePQM EMPIR project (http://tracepqm.cmi.cz). The tool enables easy implementation of support for new digitizers (currently Keysight 3458A and NI5922) and easy integration of new algorithms in Matlab or GNU Octave. The tool is intended for highest accuracy measurements at low frequencies reaching 20 µW/VA expanded uncertainty as well as for wideband operation up to 1 MHz with higher uncertainty (goal is below 5 mW/VA).



Uncertainty of ROCOF Calculated by Means of Monte Carlo Method was evaluated [8] and uncertainty of Phasor Measurement Unit Calculated by Means of Monte Carlo Method was evaluated in scope of EMPIR project ROCOF. The algorithm used for ROCOF calculation was developed by Strathclyde university. The uncertainty simulator implements full measurement path with transducer, digitizer and data processing algorithm. The simulator is able to propagate uncertainty or to calculate sensitivity coefficients [16].



The department purchased a three-phase calibrator for measuring and calibrating the PMU. This assembly is compatible with all three IEEE Standard for Synchrophasor Measurements for Power

A 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. A new edition of standard IEC 62586-2: 2017 has introduced new test categories for measuring power quality meters. The testing system was supplemented by current amplitudes, current harmonics, current inter-harmonics, current unbalances and rapid voltage changes.

High voltage and current measurements

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In recent years (in the field of High Voltage and Current measurements), CMI has developed and realized 3 inductive dividers for input voltages of (10, 100 and 1 000) V, a resistive DC/AC voltage divider up to 20 kV, a procedure for clamp ammeters calibration in the frequency band up to 5 kHz and current range up to 300 A. Also, calibration uncertainties of DC voltage in the range of up to 100 kV were improved. 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 are ensured. Two current loops for AC current meters calibration are available. Both loops up to 30 kA and 50 kA are placed at a CMI detached workplace in Brno. A system for calibration of instrument transformer burdens using 3-voltmeters method was designed and realized.

Laboratory participated in EMPIR project 14IND08 ElPow **-** Metrology for the electrical power industry.

Participation in comparisons:

- **EURAMET 1081**- Comparison of the measurements of current transformers
- **EURAMET 1187** - Comparison of instrument current transformers up to 10 kA (**pilot CMI**)
- **EURAMET 1217** - Comparison of High DC Current Ratio Standard
- **COOMET.EM-S18** - Comparison of electric capacitance and loss dissipation factor

High Frequency and Fields

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Laboratory maintains several national standards:

National standard of RF power

frequency range up to 40 GHz (up to 50 GHz under preparation)

- calibration factor of power sensors CMC 0.004 to 0.02
- absolute power level (-100 to 55) dB(mW) CMC (0.05 to 0.12) dB
- RF attenuation (primary standard) (0 to 110) dB CMC (0.02 to 0.57) dB

National standard of RF reflection and transmission coefficient (scattering parameters) (primary standard)

frequency range up to 26.5 GHz (up to 50 GHz under preparation)

- N-type connector CMC (refl. coef) 0.004 to 0.038
- PC-7 connector CMC (refl. coef) 0.002 to 0.004
- 3.5 mm connector CMC (refl. coef) 0.004 to 0.008

National standard of RF electromagnetic field (primary standard)

- E-field in anechoic chamber up to 100 V/m, 18 GHz CMC 0.8 dB
- E-field in TEM cells up to 300 V/m, up to 3 GHz CMC (0.5 to 1) dB
- E-field in waveguide (1 to 2.5) GHz, up to 200 V/m CMC 0.4 dB
- H-field up to 30 MHz CMC (0.14 to 0.8) dB
- Antenna gain (horn antenna) up to 18 GHz CMC 0.25 dB
- Antenna factor (loop antenna) up to 30 MHz CMC (0.14 to 1) dB

Laboratory participated in following international comparisons:

- Supplementary comparison EUROMET.EM.RF-S25, Comparison of Electrical Field Strength Measurements above 1 GHz (**pilot CMI**)
- BIPM Key Comparison CCEM.RF-K23.F, On-axis Gain in Ku Band at 12.4, 15 and 18 GHz
- BIPM Key Comparison CCEM.RF-K24.F, E-field measurement at frequencies of 1 GHz, 2.45 GHz, 10 GHz and 18 GHz and at indicated field levels of 10 V/m, 30V/m and 100 V/m
- Supplementary comparison EURAMET.EM.RF-S27, Antenna Factor for Loop Antennas
- BIPM Key Comparison CCEM.RF-K5c.CL, Scattering Coefficients by Broad-Band Methods 100 MHz - 33 GHz - 3.5 mm connector
- EURAMET comparison 1426, Comparison of S-parameter Measurements in N-type connector devices, in the frame of EMPIR 15RPT01 project
- CIPM Key Comparison CCEM.RF-K26, Attenuation at 18 GHz, 26.5 GHz and 40 GHz using a step attenuator

Laboratory has been involved in following European EMPIR projects:

- **EMPIR 14IND10 (2015-2018)**, http://empir.npl.co.uk/met5g/

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 analyser.

- **EMPIR 15RPT01 (2016-2019)**, http://rfmw.cmi.cz/

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 work package which aims to maximise the impact of this project within the European community of national metrology institutes and industrial end-users

Magnetic measurements

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In the field of magnetic measurements CMI developed a programmable capacitor array that enables an AC amplitude magnetic flux density (MFD) value up to 150 µT up to 150 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 used for calibration of devices with 3-axis coil probe. 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 with expanded uncertainty of 20 to 60 ppm. We also developed a system with AC electromagnet and PCB search coil for transversal Hall probe calibration up to 1 T at low frequencies (30 Hz up to 70 Hz) with expanded uncertainty of 0.2%. Development of amorphous AC electromagnet for extending the frequency range of Hall probe calibration up to 1 kHz is now in progress.

Laboratory participate in EMPIR project 15SIB06 NanoMag - Nano-scale traceable magnetic field measurements.

Participation in comparison:

- **EURAMET 446 -** International comparison of magnetic flux density by means of field coil transfer standards
- **EURAMET 597 -** Intercomparison of magnetic flux by means of coil transfer standard (**pilot CMI**)
- **CCEM.M-K1 -** Magnetic flux density by means of transfer standard coil
- **COOMET 516** - Measurements of magnetic loss power in electrical steel at the frequency of 50 Hz and 60 Hz
- **EURAMET.EM.RF-S27** - Antenna factor for loop antennas, 10 Hz to 10 MHz
- **P1-APMP.EM-S14** - Comparison of Earth-Level DC Magnetic Flux Density
- **EURAMET.EM.M-S2** - Polarization and specific total power loss in soft magnetic materials

EMC , radio parameters, electrical safety

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TESTING & CALIBRATION, CERTIFICATION

- Testing in Accredited laboratory (EMC , radio parameters, electrical safety)
  According to generic, product (EN), OIML, ETSI and international Standards

  Of broad range of products : legal metrology, multimedia, IT, alarm, automotive, railroad applications, Med, House

- Calibration of Antennas (loop, biconical, log-periodic, hybrid, horn, special)
  According to ANSI, SAE ARP standards
  Frequency range 9 kHz – 18 GHz

- Certification (RED 2014/53/EU) – Notified Body No.1383

INTERNATIONAL ACTIVITIES

- EMRP project IND 60 EMC Industry (2013-2016)
  Improved EMC test methods in industrial environment

- EMPIR project 17NRM02 MeterEMI (2018-2021)
  Electromagnetic Interference on Static Electricity Meters

- Interlaboratory comparisons (EMC)
  2015 – Interlaboratory comparison on EN 61000-4-6 with TUBITAK, INTA, LNE, METAS SIQ, SP, VSL
  2016 – Interlaboratory comparison on EN 61000-3-2 with TUBITAK, INTA, LNE, METAS SIQ, SP, VSL
- EMC Measurement of railway applications in Europe
- International projects and training of experts
  Project consultation and training for EMC Center Uzbekistan

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