Czech Metrology Institute

Okruzni 31, 638 00 Brno
Czech Republik

Progress report on electrical metrology at CMI between 2013 and 2015

for the 29th meeting of the Consultative Committee for Electricity and Magnetism (CCEM), March 2015

DC & Quantum Metrology

Contact person: Martin Šíra msira@cmi.cz Jiří Streit jstreit@cmi.cz

The Josephson Voltage System was recently improved by increased amount of automation. Automatic calibration of nanovoltmeters was finalised. Preparations for acquirement of the programmable Josephson Voltage System started.

AC-DC difference, AC voltage and current Metrology

Contact person: Věra Nováková Zachovalová vnovakovazachovalova@cmi.cz

A calculable model of the CMI AC/DC cage shunts (designed in 2007) was developed using lumped circuit elements. A new improved generation of the AC/DC cage shunts from 30 mA up to 100 A was built based on the model calculation. The shunts are suitable for use with digital sampling wattmeter or with planar multijunction thermal converters.

Resistance

Contact person: Jan Kučera, jkucera@cmi.cz

DC resistance lab was equipped with new CCC system. First evaluation of properties of the new CCC setup was successful. In 2015 is planned bilateral comparison with BIPM. Results of successful supplementary comparison EURAMET.EM-S32 of resistance standards 1 TΩ and 100 TΩ were published [1] with details about method used for realization of ultrahighohmic scale in [2] .

Impedance and signal analysis

Contact person: Jan Kučera jkucera@cmi.cz , Stanislav Mašláň smaslan@cmi.cz

Laboratory works on using of coaxial bridges developed at CTU for calibration of resistance and capacitance standards in frequency range up to 1 MHz with traceability to national resistance and capacitance standards by means of resistance a capacitance [3] standards with calculable frequency dependence.

Laboratory developed precision fast programmable generators with high resolution and stability together with coaxial switches with high isolation between channels for various measurement purposes in kHz frequency range. Within EMRP AIMQute project, work on impedance calibration in the whole impedance complex plane is ongoing and first fully digital bridge was built. Within EMRP

GraphOhm project, cryogen-free system is under development and first tests of functionality of cryogen-free vacuum vessel at 5 K were performed.

New 4TP sampling bridge for low impedances based on National Instruments PXI-5922 digitizer and synthesizer PXI-6733 has been developed. Current frequency range is 40 Hz up to 20 kHz with possible extension at least up to 50 kHz. Expected uncertainty for in phase component ratio is several parts per million. Full uncertainty evaluation is planned to year 2015.

International comparison of inductor Q factor COOMET.EM-S8 was successfully finished. Reached uncertainties were from 0.6 % for Q 75 at 50 kHz up to 4 % at Q 250 at 20 MHz. The Q factors up to 150 and 1 MHz were measured on RLC bridges. The Q 250 standards were measured by means of fitting the resonant curve of series resonance circuit by a multiparameter model.

Recently developed non-coherent sampling phase meter was extended by a dual voltage divider to increase input voltage range up to 120 Vrms. Stability of the digitizer and new voltage divider have been extensively investigated.

A new non-coherent sampling harmonic distortion meter based on the NI PXI-5922 digitizer has been developed and uncertainty of the measurement analyzed. Its measurement capabilities were verified by means of classical THD measurement methods. Calculable source of THD has been used to verify high distortion levels and low distortion source with selective voltmeter has been used to verify low distortion levels in order of 0.0001 %.

Power and Energy

Contact person: Martin Šíra msira@cmi.cz Jiří Streit jstreit@cmi.cz

A digital sampling wattmeter has been developed in CMI. The wattmeter was based on three stock sampling cards (National Instruments), thus measurement of three-phase electric power is possible. Measurement system is being evaluated.

In addition to NEW04, GraphOhm and QWave, CMI will be active participant in new EMRP projects SmartGrids II (calculating transfer of uncertainties in power measurement systems).

Magnetic measurements

Contact person: Michal Ulvr mulvr@cmi.cz

CMI developed a single-layer Helmholtz type solenoid with a glass epoxy frame for calibration of AC magnetometers (e.g. ELT 400, EFA 300, C.A. 42) in the range of frequencies from 3 kHz up to 50 kHz in the last years. Now we expand the frequency range for calibration up to 100 µT up to 100 kHz (new CMC's in the KCDB database) and we are working on extending the frequency range up to 150 kHz.

Also we can measure now the NdFeB magnets on a detached workplace.

High voltage and current measurements

Contact person: Renata Styblíková rstyblikova@cmi.cz

CMI has developed and made an inductive divider for the input voltage 1 kV.

CMI has developed and made a resistive DC/AC voltage divider up to 20 kV.
CMI has developed a procedure for clamp ammeters calibration in the frequency band up to 5 kHz and current range up to 500 A.

Participation in comparisons:

- 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
- EURAMET.EM-S37 Comparison of Instrument Current Transformers up to 10 kA
- EURAMET.EM-S35 High DC current ratio
- COOMET.EM-S18 Comparison of electric capacitance and loss dissipation factor

Participation in EMRP and EMPIR projects:

IND08 MetMags (in collaboration with the Czech Technical University in Prague (CTU). This project finished in 2014 with very good results.

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 ElPow - Metrology for the electrical power industryProject in preparation, planned start May 2015.

High Frequency and Fields

Ongoing and planned comparisons

Contact person: Karel Dražil (kdrazil@cmi.cz)

In 2013, CMI participated in the CCEM.RF-K5c.CL comparison (Scattering Coefficients by Broad-Band Methods, 100 MHz - 33 GHz - 3.5 mm connector).

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

Contact person: Martin Hudlička (mhudlicka@cmi.cz)

Currently Department of primary metrology of RF electrical quentities has been involved in four EMRP programme projects and one EMPIR programme project which is scheduled to start in April 2015. Each project is described separately.

EMRP IND16 (Metrology for ultrafast electronics and high-speed communications, 2011-2014) **–** further information about this project can be found at the webpage http://www.ptb.de/emrp/ultrafast.html. Project finished in May 2014. The main outputs from this project are following

- development of laser-based techniques for the measurement of pulsed and cw high-frequency signals
- provision of a software tool for uncertainty propagation that can be applied to long data sets and is available free of charge
- investigation of antenna and channel properties in the mm- and sub-mm wave range
- establishing methods for traceable calibration of vector signal generators and analysers and developing tools for a better understanding of the measurement uncertainty of digital signals

EMRP NEW07 (Microwave and terahertz metrology for homeland security, 2012-2015) **–** further information about this project can be found at the webpage http://www.ptb.de/emrp/thz_security.html. The project will finish in May 2015. CMI has been actively involved in development of traceable methods for material parameters measurement in the millimneter and sub-millimeter frequency bands.

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. CMI has been mainly involved in development of calibration standards for balanced vector network analyzer (VNA) measurements, calibration and verification standards for measurement of extreme impedances using VNA.

EMRP IND51 (Metrology for optical and RF communication systems, 2013-2016) **–** further information about this project can be found at the webpage http://www.emrp-ind51-morse.org/. CMI has been involved in characterization of coherent optical communications systems using optical signal analyzers and development of traceable error vector magnitude measurements.

EMPIR 14IND10 (Metrology for 5G Communications, 2015-2018). The project will start in April 2015. The role of CMI is mainly in developing methods for a traceable measurement of Signal to Noise and Interference (SINR) and novel methods for characterization of nonlinear devices using vector network analyzer.

PUBLICATIONS:

[1] Jeckelmann, B. & col. 2013, "Final report on supplementary comparison EURAMET.EM-S32: Comparison of resistance standards at 1 TΩ and 100 TΩ", *Metrologia*, 50(1A), 0100

[2] Kučera, J. & Zikán, J. 2014, "Realization of the Ultrahigh-Ohmic Resistance Scale at CMI", Precision *Electromagnetic Measurements (CPEM 2014), 2014 Conference on. IEEE*, p. 298-299

[3] Kučera, J., Sedláček, R., Boháček, J. 2014, “Improved Calculable 4TP Coaxial Capacitance Standards", *Precision Electromagnetic Measurements (CPEM 2014), 2014 Conference on. IEEE*, p. 288-289

[4] S. Maslan, J. Horska, and J. Streit, ‘Measurement of the Q factor by means of fitting the resonance curve by a model of the resonance circuit’, in 2014 Conference on Precision Electromagnetic Measurements (CPEM 2014), 2014, pp. 568–569.

[5] V. N. Zachovalova, ‘On the Current Shunts Modeling’, IEEE Transactions on Instrumentation and Measurement, vol. 63, no. 6, pp. 1620–1627, Jun. 2014.

[6] J. Horska, S. Maslan, J. Streit, and M. Sira, ‘A validation of a THD measurement equipment with a 24-bit digitizer’, in 2014 Conference on Precision Electromagnetic Measurements (CPEM 2014), 2014, pp. 502–503.

[7] S. Maslan and M. Sira, ‘Automated non-coherent sampling THD meter with spectrum analyser’, in 2014 Conference on Precision Electromagnetic Measurements (CPEM 2014), 2014, pp. 488–489.

[8] V. Nováková Zachovalová, M. Šíra and P. Bednář, ‘New generation of cage-type current shunts at CMI’, in Proceedings of the 20 th IMEKO TC4 International Symposium ‘Research on Electrical and Electronic Measurement for the Economic Upturn’ and 18th IMEKO TC-4 International Workshop on ADC and DAC Modelling and Testing, Benevento, Italy, 2014, pp. 942–946.

[9] D. Pražák, M. Šíra, and M. Vičar, ‘On the future of the SI prefixes’, Technological Forecasting and Social Change, 2014.

[10] M. Sira and S. Maslan, ‘Uncertainty analysis of non-coherent sampling phase meter with four parameter sine wave fitting by means of Monte Carlo’, in 2014 Conference on Precision Electromagnetic Measurements (CPEM 2014), 2014, pp. 334–335.

[11] M. Sira and V. N. Zachovalova, ‘System for calibration of non-intrusive load meters with load identification ability’, in 2014 Conference on Precision Electromagnetic Measurements (CPEM 2014), 2014, pp. 676–677.

[12] M. Šíra, S. Mašláň, and V. Nováková Zachovalová, ‘Design, stability analysis and uncertainty contribution of a voltage divider designed for a phase meter’, in Proceedings of the 20 th IMEKO TC4 International Symposium ‘Research on Electrical and Electronic Measurement for the Economic Upturn’ and 18th IMEKO TC-4 International Workshop on ADC and DAC Modelling and Testing, Benevento, Italy, 2014, pp. 942–946.

[13] Ripka, P; Draxler, K; Styblíková, R.: Measurement of DC Currents in the Power Grid by Current Transformer. IEEE Transaction on Magnetics, vol.49, No. 1, January 2013.

[14] Draxler, K; Styblíková, R.: Use of an Inductive Divider for AC Voltage Ratio Calibration. Proc. of I2MTC 13 Conference, pp 142-145.

[15] Draxler, K; Styblíková, R.: Precise Measurement of High DC Currents up to 1 kA. Proc. of Applied Electronics – 2013, pp 63-64

[16]Draxler, K; Styblíková, R; Rada, V; Kučera, J; Odehnal; M : Using a Current Loop and Homogeneous Primary Winding for Calibrating a Current Transformer. IEEE Transaction on Instrumentation and measurement, vol. 62, June 2013, pp1658-1663

[17] M. Ulvr: „Calibration of Measuring Device for Determining of the Specific Saturation Magnetization by a Special Coil“, Journal of Electrical Engineering, vol. 65, No. 4, 2014.

[18] M. Ulvr: „Setup for generating an AC magnetic field from 3 kHz up to 100 kHz“, IEEE Transaction on Magnetics, vol.51, No. 1, January 2015.

[19] Ripka, P; Draxler, K; Styblíková, R.: „DC compensated Current Transformer“, Proc. of I2MTC 14 Conference, pp 212-216.

[20] Draxler, K; Styblíková, R.: „Use of Lock-in Amplifier for Calibrating an Instrument Current Transformer“, Proc. of I2MTC 14 Conference, pp 732-736.

[21] Ripka, P; Draxler, K; Styblíková, R.: „AC/DC Current Transformer with Single Winding“, IEEE Trans. on Magnetics, Vol. 50, No 4, April 2014.

[22] Ripka, P; Draxler, K; Bauer, J; Styblíková, R.: „Demagnetization of Current Transformers“, Proc. of EMSA 2014, pp. 184, Vienna, 2014.

[23] M. Ulvr: „Calibration of magnetic field meters up to 50 kHz at CMI“, Proc. of IMEKO TC-4 Symposium, 18th – 19th July 2013, Barcelona, Spain.

[24] Draxler, K; Styblíková, R.: “Calibration of AC Clamp Meters”. Accepted paper for the I2MTC 2015 Conference in Pisa, Italy

[25] K. Dražil, C. Eio, D. Gentle, A. Fernandez, Y. Le Sage, T. Kleine-Ostmann, D. Camell, M. Borsero, G. Vizio, F. Pythoud, B. Mühlemann, D. Zhao, Y. Ji, N.-W. Kang, L. Dabo, X. Ming, T. Morioka, M. Hirose, S. Neustroev, M. Cetintas, O. Sen: Final report on key comparison CCEM.RF-K24.F: E-field measurements at frequencies of 1 GHz, 2.45 GHz, 10 GHz and 18 GHz and at indicated field levels of 10 V/m, 30 V/m and 100 V/m. *Metrologia*. 2013, 50 (1A), pp. 1-358. ISSN 0026-1394.

[26] A. Kazemipour, M. Hudlicka, R. Dickhoff, M. Salhi, T. Kleine-Ostmann, T. Schrader: The Horn Antenna as Gaussian Source in the mm-Wave Domain: Analytical Study and Measurement Results, *Journal of Infrared, Millimeter and Terahertz Waves*, Vol. 35, No. 9, Sept. 2014, pp. 720-731

[27] A. Kazemipour, M. Hudlicka, S.-K. Yee, M. Salhi, D. Allal, T. Kleine-Ostmann, T. Schrader: Design and Calibration of a Compact Quasi-Optical System for Material Characterization in Millimeter/Submillimeter Wave Domain, *IEEE Trans. Instrumentation Meas.*, accepted for publication, 2015

[28] D. A. Humphreys, M. Hudlička, I. Fatadin: Calibration of Wideband Digital Real-time Oscilloscopes, *IEEE Trans. Instrumentation Meas.*, accepted for publication, 2015

[29] A. Kazemipour, M. Hudlička and T. Kleine-Ostmann: Quasi-optical System for Material Characterization in Millimeter and Sub-millimeter Wave Domain, In *Proc. of 6th International Workshop on Terahertz Technology and Applications*, Kaiserslautern, Germany, March 2014

[30] A. Kazemipour, S.-K. Yee, M. Hudlicka, M. Salhi, T. Kleine-Ostmann, T. Schrader: Design and Calibration of a Compact Quasi-Optical System for Material Characterization in Millimeter/Sub-millimeter Wave Domain, In *Proc. of Conference on Precision Electromagnetic Measurements 2014*, Rio de Janeiro, Brazil, August 2014, pp. 482-483.

[31] A. Kazemipour, M. Hudlicka, T. Kleine-Ostmann, T. Schrader: A Reliable Simple Method to Extract the Intrinsic Material Properties in Millimeter/Sub-millimeter Wave Domain, In *Proc. of Conference on Precision Electromagnetic Measurements 2014*, Rio de Janeiro, Brazil, August 2014, pp. 576-577.

[32] David A. Humphreys, Martin Hudlicka, and Irshaad Fatadin: Calibration of Wideband Digital Real-time Oscilloscopes, *In Proc. of Conference on Precision Electromagnetic Measurements 2014*, Rio de Janeiro, Brazil, August 2014, pp. 698-699.

[33] K. Ojasalo, M. Hudlicka, D. A. Humphreys: Uncertainty of communication signals measurement, In *Proc. of Conference on Precision Electromagnetic Measurements 2014*, Rio de Janeiro, Brazil, August 2014, pp. 338-339.

[34] A. Kazemipour, M. Salhi, M. Hudlicka, T. Kleine-Ostmann, T. Schrader: Probe Correction for Near-Field Scanning with a Dielectric Fiber, In *Proc. of 39th International Conference on Infrared, Millimeter, and Terahertz Waves*, Tucson, Arizona, September 2014, pp. 1-2.

[35] A. Kazemipour, M. Hudlicka, S.-K. Yee, M. Salhi, T. Kleine-Ostmann, T. Schrader: Wideband Frequency-Domain Material Characterization Up To 500 GHz, In *Proc. of 39th International Conference on Infrared, Millimeter, and Terahertz Waves,* Tucson, Arizona, September 2014, pp. 1-2, DOI: 10.1109/IRMMW-THz.2014.6956130

[36] A. Kazemipour, M. Hudlicka, M. Salhi, T. Kleine-Ostmann, T. Schrader: Free-space Quasi-optical Spectrometer for Material Characterization in the 50-500 GHz Frequency Range, In *Proc. of European Microwave Conference*, Rome, Italy, October 2014, pp. 636-639