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INRIM Progress Report: Mar 2017 - Mar 2019

The progress report is arranged according to the branches of the CCEM Classification.

Branch 1-3: DC voltage, current and resistance

QHARSmachine, a software for modeling quantum Hall effect resistance standards (QHARS), is available online. A 10 Mohm QHARS chip from NMIJ/AIST Japan has been simulated, and results compared with measurements. Contact: Martina Marzano, m.marzano@inrim.it

M. Marzano, T. Oe, M. Ortolano, L. Callegaro, N-H. Kaneko, “Error modelling of quantum Hall array resistance standards”, Metrologia 55(2), 2018.

A new setup for the calibration of ultralow-current transresistance amplfiiers based on the capacitance-charging method has been developed. Contact: Luca Callegaro, l.callegaro@inrim.it

I. Finardi, L. Callegaro, "Calibration Setup for Ultralow-Current Transresistance Amplifiers," IEEE Trans. Instr. Meas 67(11), 2676 (2018).

INRiM has demonstrated how simple thermal control of dc low-current amplifier improves its gain and offset stability. A case study has been performed on a commercial transresistance amplifier (FEMTO mod. DDPCA-300), popular in nanoscience experiments and other experimental fields involving low-current measurements. Contact: Emanuele Enrico, e.enrico@inrim.it

E. Enrico, L. Cannataro, V. D’Elia, I. Finardi and L. Callegaro, “Simple thermal control of dc low-current amplifiers improves stability”, Meas. Sci. Tech. 1361-650 (2018)

INRiM proposed and realized a new kind of hybrid device with potential application in single charge manipulation and quantized current generation. INRiM has shown that by tuning superconductivity on two proximized nanowires, coupled via a Coulombic normal-metal island, one can be able to control its charge state configuration. This device supports a one-control-parameter cycle being actuated by the sole magnetic flux. In a voltage biased regime, the phase-tunable superconducting gaps can act as energy barriers for charge quanta leading to an additional degree of freedom in single electronics. The resulting configuration is fully electrostatic and the current across the device is governed by the quasiparticle populations in the source and drain leads. Notably, the proposed device can be realized using standard nanotechniques opening the possibility to a straightforward coupling with the nowadays well developed superconducting electronics. Contact: Emanuele Enrico, e.enrico@inrim.it

E. Enrico, E. Strambini, and F. Giazotto, “Phase-driven charge manipulation in Hybrid Single-Electron Transistor”, Scientific Reports 7, 13492 (2017)

Branch 4: Impedance up to the MHz range

INRIM participates to the EMPIR Project 17RPT04 VersICaL, “A versatile electrical impedance calibration laboratory based on digital impedance bridges.” International stakeholders and collaborators are welcome.

The results of an international intercomparison on impure phase standards between INRIM, METAS and CMI with digital bridges, carried out in the context of EMRP AimQuTE project, have been published. Contact: Luca Callegaro, l.callegaro@inrim.it

M. Ortolano, L. Palafox, J. Kučera, L. Callegaro, V. D'Elia, M. Marzano, F. Overney, G. Gülmez, "An international comparison of phase angle standards between the novel impedance bridges of CMI, INRIM and METAS", Metrologia 55(4), 2018.

Branch 5-7: AC voltage, current and power

INRIM coordinates and participates to the EMPIR Project 16ENG08 MICEV “ Metrology for inductive charging of electric vehicles.” The project aims to improve the traceability of the measurements related to the inductive charging of electric vehicles, both from the point of view of electrical quantities, in particular voltage, current and power, and from the point of view of magnetic quantities. The reference frequency bandwidth is up to 150 kHz..

A new reference resistive-capacitive voltage divider has been realized, operating in DC and AC up to 1 kV from 10 kHz up to 200 kHz. The phase error is lower than 400 microrad at 100 kHz. The device relative measurement uncertainty is lower than 500E-6 up to 200 kHz. A voltage comparator and a step-up procedure for the calibration of voltage dividers, including the phase measurement, have been setup making use of the reference divider. More information at www.micev.eu website. Contact: Mauro Zucca, m.zucca@inrim.it

In the field of primary AC voltage metrology, INRIM realized of a new measuring setup for the extension of AC voltage traceability beyond 1 MHz using an automatic ac-dc difference comparator. Its validation was performed by an inter-laboratory comparison at 3 V in the frequency range 1 kHz to 30 MHz.

In the framework of TracePQM project, INRIM participated in intercomparisons to compare traceable calibration methods for current shunts, resistive voltage dividers and wideband digitizers in terms of amplitude and phase up to 1 MHz. The development of new LF and WB modular measurement setup for the measurement of power and PQ quantities has been completed. The validation of both macro setups and open source software project TWM and TPQA is nearing completion.

Contact: Bruno Trinchera, b.trinchera@inrim.it

Branch 8: High voltage and current

Innovative techniques for accurate characterisation of the non-linear behaviour of inductive measurement instrument transformers and for the improvement of their performances in the first

harmonic range have been developed and laboratory validated. They involve: a) measurement of the transformer non-linearities under high voltage/current power frequency waveform and use of the measured phasors for the compensation of the transformer errors under distorted operating conditions; b) use of an approach based on simplified frequency-domain polynomial models, which are identified and validated with a large set of realistic primary waveforms injected by a reference set-up. Contact: GarielaCrotti, g.crotti@inrim.it

A. Cataliotti ; V. Cosentino ; G. Crotti ; A. Delle Femine ; D. Di Cara ;D. Gallo ; D. Giordano ; C. Landi ; M. Luiso ; M. Modarres ;G. Tinè Modarres " Compensation of Nonlinearity of Voltage and Current Instrument Transformers", IEEE Trans. Instrum. Meas, DOI: 10.1109/TIM.2017.2652638.

M. Faifer ; C. Laurano ; R. Ottoboni ; S. Toscani ; M. Zanoni ; G. Crotti ; D. Giordano ; L. Barbieri ; M. Gondola ; P-Mazza" Overcoming Frequency Response Measurements of Voltage Transformers: An Approach Based on Quasi-Sinusoidal Volterra Models", IEEE Trans. Instrum. Meas, DOI: 10.1109/TIM.2018.2871229

INRIM coordinates and participates to the EMPIR project 16ENG04 MyRailS “Metrology for smart energy management in electric railway systems”. The project aims to develop the metrological framework and measurement infrastructure that underpin the adoption of energy efficient technologies in the European railway systems. In particular, INRIM is developing a new reference system able to generate a DC voltage up to 6 kV with superimposed arbitrary ripple up to 10 kHz and DC current up to 300 A with arbitrary ripple up to some kilohertz. The system is able to generate voltage and current with time-coherence, thus a *phantom power* for the calibration of power/energy measurement chain for on-board train applications. The target uncertainty associated with the *phantom power* is 0.1%.

A. Delle Femine and D. Gallo and D. Giordano and C. Landi and M. Luiso and R. Visconte, “A Set-up for Static and Dynamic Characterization of Voltage and Current Transducers used in Railway Application”, 2018 Journal of Physics: Conference Series IOP Conf. Series: Journal of Physics: Conf. Series 1065 (2018) 052019 doi:10.1088/1742-6596/1065/5/052019

A new setup for the calibration of high short circuit current measuring system, based on high precision multimeter digitizer, has been developed and validated. The short-circuit tests are essential for the validation of safety and reliability of electrical equipment. These activities must be performed in accordance with the product standards, which refer to the IEC 62475 standard, related to high current test techniques. The current sensors, normally Rogowski coils or shunt, must be traceable to national standards and comply with the requirements of the standard, in particular for their operation under dynamic conditions. In order to guarantee the traceability of the measurement system used in testing laboratories, INRIM has developed over the years a reference system able to calibrate the devices directly in dynamic conditions comparable to those present during short-circuit tests. The improvement in the measurement capability, compared to the methods currently used, is considerable, from 1.5% to 0.6% for the scale factor and up to 3.2% for the evaluation of the Joule Integral. Contact: Paolo Roccato, p.roccato@inrim.it

Roccato P.E., Capra P.P., “Using high precision multimeter digitizer for high short circuit current calibration”,IEEE Trans. Instr. Meas, in press

Branch 9: Other DC and low frequency measurements

A setup for the low-frequency (1/f) noise based on cross-correlation measurements has been developed. With this setup 1/f noise measurements were performed on CVD graphene samples

exposed to plasma-etching treatments.

Cultrera, Alessandro, et al. "Role of plasma-induced defects in the generation of 1/f noise in graphene." *Applied Physics Letters* 112.9 (2018): 093504.

Branch 10: Electric and magnetic fields

INRIM participates in the EMPIR project 17IND01 “MIMAS”, *Procedures allowing medical implant manufacturers to demonstrate compliance with MRI safety regulations*, with the specific aim of evaluating the thermal effect of the gradient fields used in Magnetic Resonance Imaging (MRI) on prostheses implanted in the body. A new reference set-up for generating such fields is under development and, in the next future, might be used for testing and calibration services.

Arduino A., Bottauscio O., Chiampi M., Zilberti L., “Douglas–Gunn Method Applied to Dosimetric Assessment in Magnetic Resonance Imaging”, IEEE Transactions on Magnetics 53(6), 2017.

Alotto P., Bettini P., Bottauscio O., Chiampi M., Zilberti L., “H-matrix Sparsification Applied to Bioelectromagnetic Analysis of Large Scale Human Models”, IEEE Transactions on Magnetics 53(6), 2017.

INRIM coordinates the EMPIR project 18HLT05 “QUIERO”, *Quantitative MR-based imaging of physical biomarkers*, whose kick-off is planned for the next June. The project wants to underpin the transformation of MRI into a quantitative diagnostic tool, exploring the clinical application of Electric Properties Tomography and MR fingerprinting.

Arduino A., Chiampi M., Pennecchi F., Zilberti L., Bottauscio O., “Monte Carlo Method for Uncertainty Propagation in Magnetic Resonance-based Electric Properties Tomography”, IEEE Transactions on Magnetics 53(11), 2017.

Arduino A., Bottauscio O., Chiampi M., Zilberti L., “Magnetic resonance-based imaging of human electric properties with phaseless contrast source inversion”, Inverse Problems 34, 2018.

The results of the theoretical investigation of magnetic cloaking for reducing artifacts in MRI have been published.

Zanovello U., Matekovits L., Zilberti L., “An ideal dielectric coat to avoid prosthesis RF-artifacts in magnetic resonance imaging”, Scientific Reports 7, 2017.

Contact: Luca Zilberti, l.zilberti@inrim.it .

Branch 11: Radio Frequency measurements

Concerning power standard, INRIM operates from dc to 40 GHz with a microcalorimeter in coaxial line, by using thermoelectric sensors in 7, 3.5 and 2.92 mm coaxial lines as transfer standards. The present measurement method and model is superior respect to a more traditional one in terms of measurement uncertainty from dc to 40 GHz. A comparison among two different kind of thermoelectric sensors has been undertaken. It turned out that, by using sensors equipped with a separate DC/LF heater, the primary RF/MW power standard can be realized independently of the assumption of unitary efficiency ad DC/LF, which involves complex measurements to be verified.

INRiM participates in the EMPIR 17FUN10 project “ParaWave”, *Josephson traveling wave parametric amplifier and its application for metrology*, started in June 2018. The project involves a group of three European national metrology institutes (PTB, NPL, INRiM) and two universities (RHUL and LanU) which carry out a program of research and development of an entirely new

type of advanced quantum limited microwave amplifier for the amplification of extremely small electric and photonic microwave signals with sufficiently large gain, wide bandwidth and with the lowest possible added noise. Contact: Emanuele Enrico, e.enrico@inrim.it

https://sites.google.com/inrim.it/parawave

Branch 12: Measurements on materials

INRIM continued the theoretical and experimental analysis of giant magnetostrictive materials using the new facility built over the past few years. In particular, the work done on direct force transducers based on Fe-Ga rods has highlighted that the output power and voltage depend on the magnetic bias according to an exponentially modified Gaussian distribution. Keeping constant the other parameters and varying the mechanical bias, a family of modified Gaussian distributions is obtained. Moreover, fixing the electric load, the amplitude and frequency of the vibration, the couple of values "magnetic bias – mechanical preload" corresponding to the maximum output power of the device depicts a linear behavior.

S Palumbo, P Rasilo, M Zucca (2019), *Experimental investigation on a Fe-Ga close yoke vibrational harvester by matching magnetic and mechanical biases*, Journal of Magnetism and Magnetic Materials 469, 354-363

In the frame of the EMPIR project TOPS and italian project QUANTUMET, INRIM is doing research on spitrionic and spin-caloritronic effects. In particular INRIM conducted research on the measurement of DMI constant (for skyrmions), on the measurement of the spin Seebeck and spin Peltier effects and on the quantum effects on magnon transport. Several scientific papers have been published on these topics in 2018. Furthermore at CPEM 2018, M. Pasquale and V.Basso (Tecnical Program Committee Members CPEM 2018) have proposed and organized a special invited session on "Nanomagnetism and spintronics" with the following contributions:

1. -Sibylle Sievers PTB "Quantitative Magnetic Force Microscopy"
2. -Alessandro Sola INRIM "Spincaloritronics measurements"
3. -Pavel Ripka Czech technical university in Prague "Demagnetization coefficient and effective permeability of nanowire arrays"
4. -Mark Bieler PTB "Coherent control of phonon-induced magnetization dynamics in magnetic tunnel junctions"

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