

XXXIV Consultative Committee for Electricity and Magnetism

6-7 Mar 2025, BIPM, Paris-Sèvres, France



Progress Report April 2023 to February 2025

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

The boxes are national, European or international projects in collaboration with other institutions.

Branch 1-3: DC voltage, current and resistance

A 10 V Programmable Josephson Voltage Standard (PJVS) from Supracon AG, operating in liquid helium, has been set up as Italian volt realization. The PJVS system successfully participated in the BIPM international comparison BIPM.EM-K11. Contact: p.durandetto@inrim.it

Solve, S., Chayramy, R., Stock, M., Durandetto, P., & Enrico, E. (2024). Bilateral comparison of 1.018 V and 10 V standards between INRIM (Italy) and the BIPM, November to December 2023 (part of the ongoing BIPM key comparison BIPM. EM-K11. a and b). Metrologia, 61(1A). doi: 10.1088/0026-1394/61/1A/01004

INRIM performed a series of experiments devoted to characterise commercial direct-current comparator resistance bridge, also by comparison with the cryogenic current comparator. Contact: m.marzano@inrim.it

M. Marzano, P. P. Capra, C. Cassiago, V. D'Elia, E. Gasparotto, L. Callegaro, "Metrological assessment of DC current comparator resistance bridges," Measurement, vol. 215, pp. 112858, 2023, doi: 10.1016/j.measurement.2023.112858

M. Marzano, C. Cassiago, V. D'Elia, E. Gasparotto, L. Callegaro, "On the calibration of DC current comparator resistance ratio bridges", Measurement, vol. 223, 113664 (2023), <https://doi.org/10.1016/j.measurement.2023.113664>

	EPM 23FUN07 QuAHMET Quantum Anomalous Hall Effect materials and devices for metrology is a project focusing on the traceable measurement and characterisation of quantum anomalous Hall effect (QAHE) materials as devices and primary resistance standard candidates. INRIM is the leader of the Impact Workpackage. Website: https://sites.google.com/inrim.it/quahmet LinkedIn: https://www.linkedin.com/groups/8824119/ YouTube: https://www.youtube.com/@quahmet_gigs Contact: m.marzano@inrim.it
	EPM 23FUN05 AQuanteC Advanced quantum technology for metrology of electrical currents is a project focusing on advanced methods to close the impending nA-gap in direct quantum current generation, examine the fundamental uncertainties of single-electron pumps, and explore novel device concepts exploiting technological advances driven by solid-state quantum technology research. INRiM is leader of the Workpackage focusing on the Exploration of Novel Quantum Device Concepts for Electrical Current Metrology. Website: https://ptb.de/epm2023/aquantec LinkedIn: https://linkedin.com/company/aquantec Zenodo: https://zenodo.org/communities/aquantec Contact: e.enrico@inrim.it

INRIM is involved in the EURAMET.EM-S45 comparison. The calibration uncertainty in the range from 100 pA to 5 μ A have been strongly improved by introducing a Ultrastable Low-noise Current Amplifier (Magnicon ULCA), having a nominal transresistance of 1 G Ω , calibrated with a cryogenic current comparator. Contact: m.marzano@inrim.it

L. Callegaro, "Fundamentals of Measurement: Small Electric Currents," in IEEE I&M Mag., vol. 27, no. 9, pp. 7-11, December 2024, doi: 10.1109/MIM.2024.10772030.

Branch 4: Impedance up to the MHz range

	EMPIR 18SIB07 GIQS - Graphene Impedance Quantum Standard. General info: https://www.ptb.de/empir2019/giqs/home/ . The project produced a set of videos available in a dedicated YouTube channel. The project has produced a Good Practice Guide for the graphene-based AC-QHE realisation of the farad which is open access. The associated EURAMET Project #1501 "Technical assessment of novel digital impedance bridges" is publishing "Trilateral Comparison Among Digital and Josephson Impedance Bridges" on IEEE Trans. Instr. Meas.
	23IND04 MetSuperCap: Metrology for static and dynamic characterisation of supercapacitors is an Industry Joint Research Project of the European Partnership on Metrology (EPM) research funding programme. The project consortium involves twelve partners from seven European countries, including European National Metrology Institutes (NMIs), industrial companies, and academia. It will run from 2024 to 2027. Contact: m.zucca@inrim.it M. Zucca, M. Hassanzadeh, O. Conti and U. Pogliano, "Accurate Parameters Identification of a Supercapacitor Three-Branch Model," in IEEE Access, vol. 11, pp. 122387-122398, 2023, doi: 10.1109/ACCESS.2023.3328803.

In preparation for the forthcoming CCEM-K3 comparison, a study of the stability of temperature hysteresis of artifact inductance standards has been performed. Results are in press on IEEE Trans. Instr. Meas.

Branch 5-7: AC voltage, current and power

The primary AC voltage and current of INRIM is presently based on the use of thermal AC-DC transfer standards and EMF comparators for automatic AC-DC transfer measurements. In the framework of CCEM-K12.2025, INRIM is one of the pilot laboratories and conducted the characterization of the 10 mA travelling standard.

The primary power and energy standard of INRIM is based on simultaneous sampling of voltage and current waveforms by synchronized digital multimeters or wideband ADCs. A new modular digital sampling power standard has been developed and validated in the framework of the EURAMET-EM-K5.2018 international comparison at power line frequency, allowing both traceable power and energy measurements in the kHz range as well as traceable measurements of power quality parameters. The overall traceability is ensured through the calibration of its main components starting from DC and AC current and voltage standards. Contact: b.trinchera@inrim.it

	The goal of INRIM participation was the development and internal verification of a novel quantum power standard based on an alternating programmable Josephson voltage standard (AC-PJVS). The integration of the AC-PJVS into the existing sampling power setup was possible by using a coaxial multiplexer appositely developed during the project. Contact: b.trinchera@inrim.it B. Trinchera, D. Serazio, P. Durandetto, L. Oberto, L. Fasolo, "Development of a PJVS system for quantum-based sampled power measurements.", <i>Measurement</i>, vol. 219, 2023, 113275, ISSN 0263-2241, B. Trinchera, P. Durandetto, D. Serazio, "Quantum sampling AC standard for electrical power metrology based on programmable Josephson junction series array.", <i>Measurement</i>, vol. 233, 2024, 114747, ISSN 0263-2241,
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	INRIM is the WP leader of the EPM project 23RPT01 WAC Wideband AC quantum traceability https://www.cem.es/es/WAC. In this project INRIM will further exploit programmable Josephson voltage standards (PJVS) by developing novel working implementations of Wideband Quantum Voltage (WBQV) standards based on sub-sampling methods. The development will focus on permanent integration and an optimised combination of PJVS with high-precision and high-bandwidth waveform digitizers. This will provide a robust reference metrological framework, laying the foundation for the step change from thermal converter techniques to quantum standards, as expected in the ongoing implementation stage of the new quantum SI. The quantum sub-sampling method provides substantial advantages for enhancing the traceability of LF-AC quantities, such as voltage, current, power, and energy, compared to the conventional and time-consuming AC-DC transfer method. INRIM, will improve and adapt the method to provide quantum traceability for multitone signals. Contact: b.trinchera@inrim.it
	INRIM is WP leader of the EPM project 22RPT02 Towards a true 8-digit digitiser https://true8digit.eu/ The project aims to identify at least 2 novel metrology grade ADC architectures for the DC to 100 kHz frequency band and develop comprehensive digital models covering integrating ADC (IADC), Sigma-Delta ($\Delta\Sigma$) and at least 1 mixed design. INRIM is carrying out research activities in the framework of WP2 - with particular emphasis on the meteorological assessment of novel ICOPA and charge injection phenomena in CMOS switches - and WP4, concerning the development of precision (< 50 ps jitter) timing solution for the ADC architectures identified in other WPs , with a galvanically isolated external trigger, lock-in and internal clock frequency output, and to develop the metrological tools such as jitter and synchronisation measurement to evaluate ADC architectures' timing performance. Contact: b.trinchera@inrim.it
	The agreement between the Ministero dello Sviluppo Economico (Ministry of Economic Development, MISE) and INRIM entitled "Collaboration for the development of validation methods for electrical energy meters under realistic conditions, towards market surveillance and consumer protection" was completed. The new setup based on a ZERA MTS310 phantom power generator and a COM5003 reference wattmeter allows for the automation of many calibration procedures. A final report to the MISE has been issued including inputs for the update of national regulation in legal metrology for the active energy meters. Contact: l.callegaro@inrim.it A. Cultrera, G. Germito, D. Serazio, F. Galliana, B. Trinchera, G. Aprile, M. Chirulli, L. Callegaro, "Active Energy Meters Tested in Realistic Non-Sinusoidal Conditions Recorded on the Field and Reproduced in Laboratory", <i>Energies</i> vol. 17, n. 6, p. 1403 (2024).

Branch 8: High voltage and current

	20NRM03 DC grids started in June 2021 and concluded in May 2024. This project's goal was the traceable measurement and characterisation of PQ parameters to support standardisation in the further development and future use of low-voltage DC grids and to ensure future customer confidence. INRIM is developing and testing algorithms for the detection of DC power quality events. Moreover, INRIM is setting up a procedure to generate PQ events in order to investigate on the reliability of the developed algorithm. Contact: Domenico Giordano D. Giordano, A. D. Femine, D. Gallo and D. Signorino, "Traceability for AC Ripple Over DC Current," in <i>IEEE Transactions on Instrumentation and Measurement</i>, vol. 73, pp. 1-9, 2024, Art no. 1004509, G. Frigo <i>et al.</i>, "Inter-Laboratory Comparison of Reference Systems for DC Power Quality Measurements," 2024 <i>IEEE 14th Int. Workshop on Applied Measurements for Power Systems (AMPS)</i>, Caserta, Italy, 2024, pp. 1-6.
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	INRIM coordinates the EPM project 22NRM04 e-TRENY “Metrology support for enhanced energy efficiency in DC transportation systems” - Start date: 01 June 2023, duration: 36 months. The aim is to provide the metrological infrastructure to accurately determine the efficiency of power converters supplying DC railway metro and tramway systems. Two measurement campaigns are scheduled, one on line 10B of Metro de Madrid and one in a substation supplying the tramway system of Hannover. Standardization committees of reference are IEC TC9, CENLEC TC9x and IEC TC14. Contact: Domenico Giordano (d.giordano@inrim.it) D. Giordano et al., "Metrology support for enhanced energy efficiency in DC transportation systems," 2024 Conference on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 2024, pp. 1-2.
	INRIM coordinates the EPM project 22NRM06 ADMIT “Characterisation of AC and DC MV instrument transformers in an extended frequency range up to 150 kHz” - Start date: 01 June 2023, duration: 36 months. The aim is to provide the metrological infrastructure for the characterization of instrument transformers upto 250 kHz. Standardization committees of reference are IEC TC38 and CENELEC TC38. Contact: Domenico Giordano (d.giordano@inrim.it) G. Crotti et al., "A Novel Generation and Measurement Setup for the Characterization of MV Voltage Transformers From 9 kHz up to 150 kHz," in IEEE Trans. Instr. Meas. vol. 73, pp. 1-11, 2024, Art no. 9004711
	The EPM 23IND01 project ENSURE, “Electrical energy and Supply Reliability” is developing new HV metrology tools for monitoring the increased level of grid harmonic disturbances and their impact on the efficiency of power grid components as well as new methods to evaluate the reliability of HVDC cables (https://www.epm-ensure.eu). INRIM is leading WP1, which deals with the non-invasive traceable calibration of current transformers in substations by reference instrumentation based on optical current sensors. In this framework, it is contributing to the implementation of sensor characterisation procedures. INRIM also contributes to WP3, as regards the development of new traceable methods for the determination of harmonic losses in HVAC cables. Contact: Gabriella Crotti (g.crotti@inrim.it)

Branch 10: Electric and magnetic fields

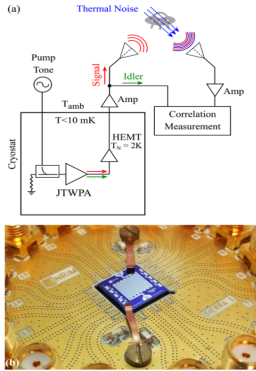
	EMPIR 21NRM05 STASIS, Standardisation for safe implant scanning in MRI. https://www.ptb.de/stasis/home. The overall objective of the project, which started on October, 1st 2022, is to support standardisation for safety assessment of medical implants in MRI scanners. Approaching the end of the project, a standard on a test method for measurement of gradient magnetic field induced heating on or near non-active implants during magnetic resonance imaging” has been drafted and it will be submitted to ASTM F04.15 MR. This proposal will complement the present available standards ISO 10974, ASTM F2182 and IEC 60601-2-33. Parallel activities have been focused on: (a) stochastic approaches to the evaluation of factors influencing SAR prediction in vivo, (b) role of orthopedic implants in affecting the electric field induced by switching gradients in MR and (c) gradient-induced vibrations and motion-induced Lenz effects on conductive nonmagnetic orthopedic implants in MR. L. Zilberti, A. Arduino, R. Torchio, U. Zanovello, F. Baruffaldi, H. Sanchez-Lopez, P. Bettini, P. Alotto, M. Chiampi, O. Bottauscio "Orthopedic implants affect the electric field induced by switching gradients in MRI", Magn Reson Med. 91, 398-412, 2024, doi: 10.1002/mrm.29861 O. Bottauscio, U. Zanovello, A. Arduino, L. Zilberti, "Polynomial Chaos Expansion of SAR and temperature increase variability in 3 T MRI due to stochastic input data", Phys. Med. Biol. 69 (2024) 125005. L. Zilberti, C. Curreli, A. Arduino, U. Zanovello, F. Baruffaldi, O. Bottauscio, "Gradient-induced vibrations and motion-induced Lenz effects on conductive nonmagnetic orthopedic implants in MRI", Magn Reson Med. 2025;93:341–352. DOI: 10.1002/mrm.30263.
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	EMPIR 22HLT02 A4IM, Affordable low-field MRI reference system. https://www.a4im.ptb.de/home. The overall goal of this project, which started on September, 1st 2023, is to establish affordable open-source low-field MRI systems covering hardware components, data acquisition and image reconstruction within the EURAMET network, which are reproducible, fully documented and metrologically characterised. In particular, three low field MRI scanners, fully characterized, will be available at the end of the projects in three NMIs (PTB, INRiM and TUBITAK).
	INRIM coordinated the proposal “Trustworthy and quality-assured quantitative magnetic resonance imaging”, selected for EPM digital transformation call 24DIT01 APULEIO. The project (follow up of the 18HLT05 QUIERO project) aims at producing general principles for the evaluation of the pixel-wise uncertainty in quantitative maps obtained from magnetic resonance imaging (MRI). The framework will be developed on two case studies (Electric Properties Tomography and EPT and Magnetic Resonance Fingerprinting - MRF) and validated in vivo, covering both model-based and data-driven approaches. Attention will be paid to embedding the pixel-wise uncertainty evaluation into the reconstruction algorithms, which will produce their own self-evaluation. As a side result of the research, datasets of interoperable reference data and digital twins will be produced and made available. In the project, INRIM will focus on uncertainty evaluation for model-based EPT approaches. Contact: Luca Zilberti, l.zilberti@inrim.it A. Arduino and L. Zilberti, "Metrological contributions to magnetic resonance-based electric properties tomography," 2023 17th European Conference on Antennas and Propagation (EuCAP), Florence, Italy, 2023, pp. 1-5, doi: 10.23919/EuCAP57121.2023.10132952.
	INRIM was involved in the EMPIR Project 20NMR05 iMet-MRI “Improved metrology for quantitative MRI”, (Jun 2021 - May 2024). The aim of the project was to provide test objects, analysis tools and best practice guidance for various quantitative Magnetic Resonance Imaging (MRI) techniques and demonstrate them in an international multi-site trial. The need of metrological harmonization arises for MRI routine clinical practice, which produces images designed for single use, to be looked at by individual human experts, and lacks consistency when comparing images acquired on different scanners or at different times. In particular, INRIM was involved in the development of an MRI simulator and digital twins for calibration of MRI scanners. The MRI simulator is able to replicate the full image acquisition pipeline, for different types of pulse sequences, and was applied to an extensive sensitivity analysis on a calibration phantom. R. Ferrero, M. Vicentini, E. Cooke, C. McGrath, A. McCann, A. McDowell, N. Zafeiropoulos, P. Tofts, M. G. Hall, and A. Manzin, “GAMS: A GPU-Accelerated MRI Simulator for synthetic image generation”, <i>Computer Methods and Programs in Biomedicine</i>, submitted. E. A. Cooke, R. Ferrero, et al., “Analysis of the sensitivity of MRI T2 relaxation time estimates to scanner set up and fitting model parameters using an MRI simulator”, <i>PlosOne</i>, submitted. Contacts: Alessandra Manzin, a.manzin@inrim.it; Riccardo Ferrero, r.ferrero@inrim.it

INRIM successfully took part in the EURAMET.EM.RF-S46 Comparison of Magnetic Field Strength Measurements for Frequencies up to 30 MHz. Capabilities in the measurement of low frequency magnetic field strengths were extended up to 5 μ T at 300 kHz by the INRIM reference Helmholtz coil based system and validated by the comparison results. They are now included in the BIPM KCDB. Contact: g.crotti@inrim.it

Branch 11: Radio Frequency measurements

	INFN DARTWARS, “Detector Array Readout with Traveling Wave AmplifierS” https://dartwars.unimib.it The aim of the project is to boost the sensitivity of INFN experiments based on low-noise superconducting detectors. This goal will be reached through the development of wideband
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	superconducting amplifiers at microwaves with noise at the quantum limit and the implementation of a quantum-limited readout in different types of superconducting detectors. Contact: Emanuele Enrico (e.enrico@inrim.it) L. Fasolo, et. al., Experimental Characterization of RF-SQUIDS Based Josephson Traveling Wave Parametric Amplifier Exploiting Resonant Phase Matching Scheme, IEEE Trans. on Applied Superconductivity, (2024) C. Guarcello, et. al., Nonlinear Behavior of Josephson Traveling Wave Parametric Amplifiers, IEEE Trans. on Applied Superconductivity, (2024)
	HORIZON2020 Project - Call H2020-FETOPEN-2018-2019-2020-01. https://supergalax.eu/. Detection of single photons in the microwave range has a number of applications ranging from galactic dark matter axions search to quantum computing and metrology. A novel approach to the acquisition of extremely low energy microwave signals (~1 GHz), based on passive quantum detection is proposed. The key novel concept that is intended to be used is the coherent quantum network composed of a large amount of strongly interacting superconducting qubits embedded in a low dissipative superconducting resonator. INRiM is involved in the development of a Parametric Down Conversion (PDC) microwave photon source based on the Traveling Wave Josephson Parametric Amplifier (TW-JPA) with a clock frequency of a few kHz. Contact: Giorgio Brida (g.brida@inrim.it) E. Enrico, et. al., Superconducting qubit network as a single microwave photon detector for Galactic Axion search, IEEE Trans. on Applied Superconductivity, (2023) C. Gatti, et. al., Coherent quantum network of superconducting qubits as a highly sensitive detector of microwave photons for searching of galactic axions, IEEE Trans. on Applied Superconductivity, 33 (5) 1-5 (2023)
	QUANTUM RADAR. The project aims to investigate new quantum techniques based on quantum states of microwave radiation (1-10 GHz band), in particular of "twin" "entangled" beams, for the creation of a prototype of "Quantum Radar" with increased precision (increase of signal-to-noise ratio (SNR)) of interferometric measurements, indispensable in the detection of location of non-cooperating targets, and reduction of destructive effects due to noise environmental. Indeed, quantum states of radiation make it possible to detect objects and carry them out sensing and communication protocols with a performance not achievable if limited to using traditional "classical" sources, i.e. without quantum correlations such as squeezing and entanglement. INRiM is involved in the characterization of the non-classical source of microwave radiation based on the parametric downconversion effect in hundreds of Josephson-junctions embedding devices. Contact: Emanuele Enrico (e.enrico@inrim.it) P. Livreri, et. al., Josephson Traveling Wave Parametric Amplifier as Quantum Source of Entangled Photons for Microwave Quantum Radar Applications, Electromagnetic Waves, 179, 113-124, (2024).
	The project EMPIR 20FUN07 SuperQuant - Microwave metrology for superconducting quantum circuits - led the way to fundamental microwave metrology at cryogenic temperatures to support the quantum technology industry. The project enabled, e.g., a quantum standard of microwave power and a quantum-traceable cryogenic sampling oscilloscope with 1 THz bandwidth. INRiM developed a platform for traceable measurements of scattering parameters in cryogenic environments in the mK range and was involved in the metrological characterization of superconducting quantum power sensors. Contact: Luca Oberto (l.oberto@inrim.it) L. Oberto, et. al., "Measurement and Calibration Approaches for Two-Ports Scattering Parameters at mK Temperatures", submitted to IEEE Trans. Instr. Meas.
	The Project EMP 23FUN08 MetSuperQ - Metrology for superconducting qubits will develop a new generation of metrological methods and tools for superconducting qubits and apply them to state-of-the-art one- and two-qubit circuits. These new tools will underpin further engineering advances and allow for accurate characterization of qubits and materials and manipulation and read-out. INRiM is the leader of the Impact Workpackage. Website: www.metsuperq.eu Contact: e.enrico@inrim.it

Branch 12: Measurements on materials

INRIM is active in the development of accurate methods for the electrical characterisation of thin-film and 2D materials (graphene) using traceable contact methods. The corresponding research outcome is functional to the participation in normative bodies (IEC).

A. Cultrera, D. Serazio, N. Fabricius, L. Callegaro, New IEC standards for the measurement of sheet resistance on large-area graphene using the van der Pauw and the in-line four-point probe methods, *Measurement*, Volume 236, 2024, 114980.

INRIM continued the activity of numerical modeling of nano/microstructured magnetic materials and devices providing support to experimental analysis and design. Advances were achieved in the modeling of new magnetic field sensors, for possible integration in lab-on-chip devices, and for the measurement of magnetic biosignals. In parallel, both experimental and modelling activities are continuing on the study of magnetic nanoparticles for hyperthermia and drug delivery applications. The potentiality of magnetic nanoparticles in releasing heat when excited by AC magnetic fields was also explored for promoting radical polymerization processes.

In the framework of magnetic material modeling at the nanoscale, INRIM is also involved in the national project IT-SPIN “*The Italian factory of micromagnetic modeling and spintronics*”, funded by the Ministry of University and Research. Contact: Alessandra Manzin, a.manzin@inrim.it.

M. Vicentini, R. Ferrero, and A. Manzin, “Influence of coil geometry, supply conditions and nanoparticle heating properties on magnetic hyperthermia in mouse models”, *International Journal of Thermal Sciences*, vol. 203, 109151, 2024.

R. Ferrero, M. Vicentini, and A. Manzin, “Influence of size, volume concentration and aggregation state on magnetic nanoparticle hyperthermia properties versus excitation conditions”, *Nanoscale Adv.*, vol. 6, pp. 1739-1749, 2024.

M. Vassallo, M. Vicentini, M. Salzano De Luna, G. Barrera, P. Tiberto, A. Manzin, and D. Martella, “Magnetic Hyperthermia to Promote Acrylamide Radical Polymerizations”, *ACS Appl. Polym. Mater.*, vol. 6, pp. 4696–4707, 2024.

INRIM is active on the study of thermomagnetic effects and on the spintronic effects in magnetic materials. s. Specifically on: i) The study of the magnetocaloric effects and on the Nernst effect of ferromagnets ii) The effects related to the presence of spin currents associated to the spin waves in ferromagnets in relation to the electric field effects and to the presence of boundaries with other media, as for examples spin Hall metals. Contact: v.basso@inrim.it

A. Sola, E. S. Olivetti, L. Martino, V. Basso, Polycrystalline MnBi as a transverse thermoelectric material, *AIP Advances* 13, 035231 (2023) <https://doi.org/10.1063/5.0135578>

V Basso, P Ansalone, A Di Pietro, Disentangling electric field effect on spin waves in ferromagnetic insulators, *Physica B: Condensed Matter* 671, 415422 (2023) (HMM 2023) doi: 10.1016/j.physb.2023.415422

Vittorio Basso, Alessandro Magni, Alessandro Sola, Michaela Kuepferling, Boundary conditions for micromagnetism with spin currents, *Physica B* 682, 415887 (2024) (HMM 2023) doi: 10.1016/j.physb.2024.415887

INRIM is active in the development of accurate methods for the electrical characterisation of thin-film and 2D materials (graphene) using traceable contact methods. The corresponding research outcome is functional to the participation in normative bodies (IEC).

A. Cultrera, D. Serazio, N. Fabricius, L. Callegaro, New IEC standards for the measurement of sheet resistance on large-area graphene using the van der Pauw and the in-line four-point probe methods, *Measurement*, Volume 236, 2024, 114980.



HEFMAG

INRIM coordinated the EMPIR project 19ENG06 HEFMAG, “Metrology of magnetic losses in electrical steel sheets for high-efficiency energy conversion”. <https://hefmag.inrim.it/>. Novel products based on magnetic steel sheets require accurate magnetic loss measurements and modelling under high temperature, 2D excitation, distorted flux with high harmonic content, skin effects and dc currents.

Round robins have been carried out among the partners to verify/improve the metrology of magnetic losses worldwide. The INRIM activity focused on the measurement and modeling of magnetic losses in a very wide range of excitation conditions.

Novel developments of the HEFMAG activities are directed to the analysis of magnetic permeability and losses from DC to several MHz, with specific reference to current sensing and power electronics devices Contact: Massimo Pasquale, m.pasquale@inrim.it

O.de la Barrière, E.Ferrara, A.Magni, A.Sola, C.Ragusa, C.Appino, F.Fiorillo, Wideband magnetic losses and their interpretation in HGO steel sheets, *J. Mag. Magn. Mater.* 565, 170214 (2023)

Temperature and frequency dependence of magnetic losses in Fe-Co

N Banu, E Ferrara, M Pasquale, F Fiorillo... - IEEE Access, 2023 [10.1109/ACCESS.2023.3322941](https://doi.org/10.1109/ACCESS.2023.3322941)



EMPIR 20FUN03 COMET - “Two dimensional lattices of covalent- and metal-organic frameworks for the Quantum Hall resistance standard” (2021 - 2024, [website](#)). The project investigated based on covalent/metallic organic frameworks (COF/MOF), as an alternative to graphene for an improved industrial quantum standard. The research activity at INRIM is focused on the implementation of electrical conductivity mapping by means of electrical resistance tomography (ERT) and low frequency noise measurements on samples to be provided by the consortium partners. A new socket for the INRIM’s ERT and noise setups is being developed to fit packaged devices. Dedicated large area ERT samples with no contact patterns were produced by the consortium for performing direct ERT conductivity mapping. A new low noise, voltage regulated bias source for 1/f noise measurements has been implemented and used with a new probestation fitted with micromanipulators to acquire noise spectra on bare and geometrised samples. INRIM is also in contact with IEC TC 113 WG8 “graphene and related materials”, to which regular updates are made.



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**EUROPEAN
PARTNERSHIP**



**Co-funded by
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**METROLOGY
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