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INRIM Progress Report: March 2015 - Feb 2017

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

1-3 DC voltage, current and resistance

A high performance Selectable value High DC Voltage transportable Standard operating from 10 V to 100 V in 10 V steps and a 1 Ω and 10 kΩ high precision transportable standard setup to be employed as Laboratory Standards or travelling Standards for high-level interlaboratory comparisons and to calibrate multifunction electrical instruments were developed. Contacts: Flavio Galliana (f.galliana@inrim.it), Pier Paolo Capra (p.capra@inrim.it)

F. Galliana, R. Cerri, L. Roncaglione Tet, "High performance selectable-value transportable high dc voltage standard" Measurement, vol. 102; p. 131-137, 2017.

P. P. Capra and F. Galliana: "1 Ω and 10 kΩ high precision transportable setup to calibrate multifunction electrical instruments", Measurement 82, 367-374, March 2016.

INRiM have shown how the flux dependence of the proximity gap induced in the weak link of a SQUIPT (Superconducting Quantum Interference Proximity Transistor) can be exploited as a phase-tunable energy barrier which enables charge pumping configurations with enhanced functionalities. Coupling two SQUIPTs with a metallic Coulomb island INRiM has implemented a novel single-electron superconducting transistor (called SQUISET) in which the charging landscape is coherently driven by an external magnetic field. This device adds new perspectives to single electronics being an alternative building block in fields such as quantum metrology, coherent caloritronics, or quantum information technology. Contact: E. Enrico, e.enrico@inrim.it

E. Enrico and F. Giazotto, Superconducting Quantum Interference Single-Electron Transistor , Physical Review Applied, Vol. 5, Issue 6, no. 064020, 2016.

The modeling of circuits including quantum Hall effect devices is progressing with a collaboration with NMIJ/AIST Japan, which realized a 10 kohm GaAs quantum Hall array resistance standard of INRIM design. INRIM is simulating the device including all contact and wire resistance, to estimate its error respect to the quantized value. Contact: L. Callegaro, l.callegaro@inrim.it

Single or multiple devices based on nanofabrication have been studied and realized for applications to the voltage standard and sensing applications. Optimization of their structure and thermal stability has been exploited for the employ in cryocooler setup. Contact: N. De Leo, M. Fretto n.deleo@inrim.it m.fretto@inrim.it

N. De Leo, M. Fretto, V. Lacquaniti, C. Granata, A. Vettoliere, “Fabrication of high sensitivity 3D nanoSQUIDs based on a focused ion beam sculpting technique”, *Supercond. Sci. Technol*., vol 29, no 9, p 094007, (2016)

V. Lacquaniti, C. Cassiago, N. De Leo, M. Fretto, P. Durandetto,E. Zhitlukhina, and M. Belogolovskii, “Superconducting and dissipative characteristics of overdamped SNIS Josephson junctions for sensing applications” *IEEE Trans. Appl. Supercond*., vol. 27, no. 4, pp. 1–5, (2016).

V. Lacquaniti, N. De Leo, M. Fretto, C. Cassiago, R. Rocci, A. Sosso, and M. Belogolovskii, “Controlling the interface properties of submicrometric Nb/Al-AlOx-Nb Josephson junctions,” IEEE Trans. Appl. Supercond., vol. 25, no. 3, pp. 1–4, (2015).

C. Granata, D. Massarotti, A. Vettoliere, M. Fretto, L. D'Ortenzi, N. De Leo, D. Stornaiulo, P. Silvestrini, B. Ruggiero, F. Tafuri, V. Lacquaniti,” Niobium nanoSQUIDs based on submicron Josephon tunnel junctions: performance as a function of the temperature” IEEE Trans. App. Supercond., vol 26, no 3, p 1-3, (2016)

4 Impedance up to the MHz range

The EMRP 2012 SIB 53 AimQuTE project workpackage "Digital bridges" finished in 2016 with an international intercomparison of impure phase standards (realized for purpose by UME) between INRIM, METAS and CMI. The comparison involved the new digitally-assisted, three-arm current comparator impedance bridge. The results have shown that the new digital bridges developed can calibrate impedance standards of arbitrary magnitude and phase with relative uncertainties in the 10^{-5} - 10^{-6} range and will be published in literature in the course of 2017. Contact: Luca Callegaro, l.callegaro@inrim.it

M. Ortolano, V. D'Elia, L. Callegaro, "A three-arm current comparator digitally-assisted bridge for the comparison of arbitrary four terminal-pair impedances", IEEE Trans. Instr. Meas, in press.

L. Callegaro, "Traceable measurements of electrical impedance," IEEE Instr. & Meas. Magazine, 18(6), 42-46

L Callegaro, V D’Elia, J Kučera, M Ortolano, F Pourdanesh, B Trinchera, "Self-Compensating Networks for Four-Terminal-Pair Impedance Definition in Current Comparator Bridges," IEEE Trans. Instr. Meas. 65 (5), 1149-1155.

5-7 AC voltage, current and power

Research is being conducted towards the frequency extension of the AC current standards up to 1 MHz. The activities undertaken will have reflections on the new EMPIR 15RPT04 TracePQM project, where INRIM is developing methods for precise measurement of ac-dc

transfer error of current shunts coupled in parallel with thermal converters for frequencies up to 1 MHz.
Moreover, a trilateral comparison of planar thin-film thermal AC voltage standard up to 1 MHz between INRIM, Trescal and SUT was concluded and the most relevant results will be published in literature. Contact: Bruno Trinchera, b.trinchera@inrim.it

M. Kampik, M. Grzenik, T. Lippert, B. Trinchera, “Comparison of a Planar Thin-Film Thermal AC Converter Standard up to 1 MHz,” IEEE Trans. Instr. Meas, in press

In the framework of EMRP ENG52 SmartGrid II project, INRIM developed and tested a new wideband asynchronous digital phase comparator suitable for operation up to 1 MHz. In particular the comparator has been used for the characterization of passive and active devices, e.g. compensated resistive voltage dividers, current shunts, voltage and current amplifiers, employed in the construction of a PMU calibrator. The phase error of the proposed digital comparator is below 300 nrad at 50 Hz and grows up to 100 μrad at 100 kHz with applied voltages ranging between 500 mV and 3 V. Contacts: B. Trinchera b.trinchera@inrim.it

B. Trinchera, D. Serazio, U. Pogliano, “Asynchronous phase comparator for characterization of devices for PMUs calibrator,” IEEE Trans. Instr. Meas, in press

In the field of the AC quantum voltage metrology, a new experimental setup has been successfully employed and tested for the synthesis of stepwise quantum waves using a binary divided 1 V array, consisting of 8192 intrinsically shunted superconductor-normal-insulator-superconductor (SNIS) overdamped Josephson junctions (JJs). Stepwise sine waves with rms amplitude ranging from 1 to 2 V using the first ($n = 1$) and second ($n = 2$) Shapiro steps, different temperatures and bias-current set points have been synthesized up to the kHz range. Moreover, INRIM is developing synchronous and asynchronous methods for direct calibration of state-of-the-art high speed DACs and ADCs in terms of fundamental constants using AC quantum voltage synthesizer. Contacts: Bruno Trinchera, Andrea Sosso b.trinchera@inrim.it, a.sosso@inrim.it

B. Trinchera, V. Lacquaniti, A. Sosso, M. Fretto, P. Durandetto, E. Monticone, “On the synthesis of stepwise quantum waves using a SNIS programmable Josephson array in a cryocooler ,” IEEE Trans. on Appl. Supercond., vol. 27, n. 4, pp. June 2017, Art. no. 1500805.

8 High voltage and current

A measuring system of stationary heavy currents up to 10 kA for characterization of the temperature rise of the electrical equipment and a reference system "Lightning impulse voltage measurement systems" with its related software for metrological activities up to 700 kV and for the participation to the international comparison EURAMET.EM-S42 were developed. Contact: Paolo Roccato, p.roccato@inrim.it.

A set-up for the frequency characterisation of voltage measurement transformers under actual medium voltage (MV) waveforms has been developed within the EMRP ENG52 “Smart Grid II” project. It is based on a two-steps procedure that makes use of high voltage gas insulated capacitors and a digital bridge and allows calibrations under distorted waveforms with MV fundamental tone and superimposed harmonics up 20 kHz, with amplitudes from 20% to 0.1% of the fundamental one. Combined standard uncertainty is within a few hundred microvolts/volt and microradians for the ratio and phase error respectively up to 10 kHz.

An effective computational tool for the simulation and design of high and medium voltage dividers has been realized, which takes advantage of a detailed 3D finite element procedure for the accurate computation of the divider stray capacitances. These latter are input to a circuit solver procedure based on the modified node potential technique, which provides the divider complex frequency response.
As to the calibration chain measuring instruments, methods based on the black-box or input impedance measurement approach have been developed for the frequency characterisation of of the input stage of high resolution digital voltmeters up to a hundred of kilohertz. Correction filters are then implemented, which allows reduction up to two orders of magnitude of the ratio and phase errors introduced by the digitisers in the direct comparisons of signals with significant amplitude difference. Contact: Gabriella Crotti g.crotti@inrim.it.

G. Crotti, D. Gallo, D. Giordano, C. Landi, M. Luiso, M. Modarres "Frequency Response of MV Voltage Transformer under Actual Waveform", IEEE Trans. Instrum. Meas, DOI: 10.1109/TIM.2017.2652638.

M. Zucca, M. Modarres, D. Giordano, and G. Crotti, "Numerical Tool for the Design of MV/HV Resistive Dividers Including the Role of the Resistor Body", IEEE Trans. Power Delivery, 2015, DOI: 10.1109/TPWRD.2015.2498705.

Crotti, D. Giordano, M. Luiso, P. Pescetto, "Improvement of Agilent 3458A Performances in Wideband Complex Transfer Function Measurement", IEEE Trans. Instrum. Measur., in press.

9 Other DC and low frequency measurements

A setup for electrical resistance tomography, which images the local resistivity of thin film from four-terminal resistance measurements on the outer contour of the sample, has been developed. Contact: Alessandro Cultrera, a.cultrera@inrim.it

A. Cultrera, L. Callegaro, "Electrical Resistance Tomography on conductive thin films", IEEE Trans. Instr. Meas., Vol. 65, Issue 9, pp. 2101-2106, 2016. DOI: 10.1109/TIM.2016.2570127

10 Electric and magnetic fields

In the field of electromagnetic dosimetry, INRIM has carried on activities related to Magnetic Resonance Imaging (MRI) safety, with specific reference to the evaluation of exposure of both patients and operators to the fields produced by MRI scanners. In particular, the original

numerical tools developed at INRIM have been used to perform, according to the new ICNIRP Guidelines, the first wide exposure assessment of the medical staff to the “motion-induced” electric fields which arise due to the movement through the static magnetic field of MRI. Moreover, the possible heating of metallic prostheses implanted inside the patient's body has been further investigated thanks to advanced computational tools conceived for this purpose.
A theoretical activity aimed at evaluating the possible use of metamaterials for the cloaking of metallic prostheses with respect to the RF field of MRI, thus reducing the onset of image artifacts and hot-spots of energy deposited in tissues, has been carried out.
An analysis of the electric field induced in patient's body by the gradient fields of MRI has been also started, to underpin the design of new coils able to reduce the undesired effect of peripheral nerve stimulation (PNS). An experimental setup for the characterization of RF MRI antennas has been realized. The setup has been used in the validation of numerical tools simulating the antennas and in the characterization of a “dual-tuned” RF coil for 7 T MRI scanner. A special attention has been finally paid to the development of accurate and efficient MRI-based EPT (Electric Properties Tomography) techniques, able to exploit the measurements of magnetic field performed during an MRI exam to get a mapping of the body in terms of electric conductivity and dielectric permittivity. Contact: Luca Zilberti, l.zilberti@inrim.it.

Methods for the identification and correction of artifacts in the measurement of pulsed magnetic fields close to medical and industrial devices have been studied to reduce unacceptable errors in dosimetric or electromagnetic compatibility magnetic field evaluations. Starting from the experimental identification of the AC meter input high pass filter, correction algorithms have been worked out and implemented, to reconstruct the true field waveform starting from the measured distorted one. Contact: Domenico Giordano, d.giordano@inrim.it

As regards the measurement of electromagnetic fields in the electromagnetic compatibility (EMC) area, the University of Florence and INRIM organized and piloted two proficiency tests (PT) of radiated emission measurements by using traveling samples with “preassigned” reference values: the first one in the frequency range between 30 MHz and 1 GHz and the second one in the range between 30 MHz and 6 GHz. What is new is that two different test environments (fully anechoic rooms and semianechoic rooms) and test distances (3 m and 10 m) are involved in each PT. Nonetheless, the measurement results are, after appropriate transformation, mixed together and reliable reference values are determined by using the standard statistical processing described in ISO 13528. A new CMC was proposed and approved: the extension from 1 GHz to 18 GHz of the standard electromagnetic field generated in the INRIM anechoic room. Contacts: Michele Borsero, Giuseppe Vizio m.borsero@inrim.it ; g.vizio@inrim.it .

O. Bottauscio, M. Chiampi, J. Hand, L. Zilberti, "A GPU Computational Code for Eddy-Current Problems in Voxel-Based Anatomy", IEEE Trans. Magn., Vol. 51, No. 3, 2015, 5100904.

L. Zilberti, O. Bottauscio, M. Chiampi, J. Hand, H. S. Lopez, Rudiger Bruhl and S. Crozier, "Numerical Prediction of Temperature Elevation Induced around Metallic Hip Prostheses by Traditional, Split,and Uniplanar Gradient Coils", Magnetic Resonance in Medicine, 74, 272–279 (2015).

L. Zilberti, O. Bottauscio, M. Chiampi, "Motion-induced fields in MRI: are the dielectric currents really negligible?", IEEE Magnetics Letters, Vol. 6, 2015, 1500104.

O. Bottauscio, A.M. Cassarà, J.W. Hand, D. Giordano, L. Zilberti, M. Borsero, M. Chiampi, G. Weidemann, "Assessment of computational tools for MRI RF dosimetry by comparison with measurements on a laboratory phantom", Phys. Med. Biol., Vol. 60, 2015, pp. 5655–5680.

L. Zilberti, O. Bottauscio and M. Chiampi, "Assessment of Exposure to MRI Motion-Induced Fields Based on the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines", Magnetic Resonance in Medicine Vol. 76, pp. 1291–1300, 2016.

O. Bottauscio, M. Zucca, M. Chiampi, L. Zilberti, "Evaluation of the Electric Field Induced in Transcranial Magnetic Stimulation Operators", IEEE Trans. Magn., Vol. 52, No. 3, 2016, 5000204.

L. Zilberti, O. Bottauscio, M. Chiampi, "A Potential-based Formulation for Motion-Induced Electric Fields in MRI", IEEE Trans. Magn., Vol. 52, No. 3, 2016, 5000304.

L. Zilberti, “Charge relaxation in biological tissues with extremely high permittivity”, IEEE Magnetics Letters, Vol. 7, 2016, 1504105.

A. Arduino, M. Chiampi, L. Zilberti and O. Bottauscio, "Alternative Approaches to Magnetic Resonance-based Electric Properties Tomography and Local Specific Absorption Rate Estimation", IEEE Trans. Magn., Vol. 53, No. 2, 2017, 5100108.

L. Zilberti, A. Arduino, O. Bottauscio, and M. Chiampi, "The Underestimated Role of Gradient Coils in MRI Safety", Magnetic Resonance in Medicine, Vol. 77, pp. 13-15, 2017.

G. Crotti, L. Giaccone, D. Giordano: Identification and correction of artefact in the measurement of pulsed magnetic fields, IEEE Trans. Instrum. Meas.: DOI: 10.1109/TIM.2017.2652739.

C. Carobbi, A. Bonci, M. Cati, C. Panconi, M. Borsero, G. Vizio, “Proficiency Testing by Using Traveling Samples with Preassigned reference Values”, IEEE Trans. on EMC, Vol 58, No.4, pp. 1339-1348, 2016.

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 is currently ongoing.
In the field of S-parameter measurements, INRIM covers the frequency range from 30 kHz to 110 GHz in coaxial and waveguide transmission lines, but the related CMCs remain limited to coaxial line measurements from 50 MHz to 50 GHz.

INRIM recently acquired a probe station that will allow to perform microstrip measurement from 50 MHz to 50 GHz for research purposes. At the moment no CMCs will be related to this activity.
Another research activity concerns development of a TDS in the THz gap finalized to dielectric material characterization. In this framework, a THz Time Domain Spectrometer able to perform measurements in the band 0.3-3 THz has been set-up and a detailed investigation on measurement uncertainty sources has been conducted. INRIM acted also as the pilot of a Round Robin Test with two PTB laboratories among different kind of THz spectrometers: TDS, FTIR and VNA-based on the measurement of the complex refractive index of selected dielectric materials. Contact: Luca Oberto, l.oberto@inrim.it

L. Oberto, M. Bisi, A. Kazemipour, A. Steiger, T. Kleine-Ostmann, T. Schrader: Measurement comparison among Time-Domain, FTIR and VNA-based spectrometers in the THz frequency range. Metrologia, Vol. 54, no. 1, pp. 77-84, January 2017.

N. Shoaib, M. Sellone, L. Brunetti, L. Oberto: Uncertainty evaluation for material characterization using Vector Network Analyser. Microwave and Optical Technology Letters, Vol. 50, no. 8, pp.1841-1844, August 2016.

D. Jahn, S. Lippert, M. Bisi, L. Oberto, J.C. Balzer, M.Koch: On the influence of delay line uncertainty in THz Time-Domain Spectroscopy. Journal of Infrared, Millimeter, and Terahertz Waves, Vol. 37, no 6, pp. 605-613, June 2016.

L. Brunetti, L. Oberto, M. Sellone, N. Shoaib, E. Vremera: *Improvements on INRIM Coaxial Microcalorimeter and Outcome of a Model Comparison*. IEEE Trans. Instr. Meas., Vol. 64, no. 6, pp. 1472-1476, June 2015.

As regards the BIPM CMC database, twelve new calibration and measurement capabilities were proposed and approved. They deal with the parameters (scattering parameters, signal and pulse characteristics, RF voltage and current) involved in the calibration of burst/electrical fast transient (EFT) generators, coupling/decoupling networks (CDN) and electrostatic discharge (ESD) targets and generators employed in the electromagnetic compatibility (EMC) tests.
Contacts: Giuseppe Vizio, Michele Borsero g.vizio@inrim.it ; m.borsero@inrim.it .

12 Measurements on materials

Growth of graphene onto Cobalt substrates has been approached. Strain in graphene has been observed when grown onto holey Co substrates. Strain can be fruitfully employed to open a gap in the electronic density of states of graphene. Contact: Giampiero Amato g.amato@inrim.it

In the field of magnetostrictive materials and application INRIM has set up a new facility for the static and dynamic characterization of magneto-elastic samples under magnetic and mechanical excitation. Frequencies are up to 100 Hz and forces up to 10 kN. Linear, torsional and combined mechanical excitations are possible. Magnetostrictive materials like Terfenol-D can be fully characterized through the facility, including electrical steels. The facility can also produce full controlled vibrations for energy harvesting purposes. Concerning this latter topic, a modular cantilever harvester based on magnetostrictive Fe-Co (Vacoflux) laminations has been studied highlighting the importance of the magnetic field bias in the performance of such a device.

M. Zucca., Callegaro L. (2015). A Setup for the Performance Characterization and Traceable Efficiency Measurement of Magnetostrictive Harvesters. IEEE Trans. Instr. Meas., vol. 64; p. 1431-1437

M. Zucca, Arash Hadadian, Oriano Bottauscio (2015). Quantities affecting the behavior of vibrational magnetostrictive transducers . IEEE Trans. Magn., vol. 51; p. 8000104-1-8000104-4

Regarding the topic of nanostructured devices for magnetic field detection, INRIM has developed complex numerical models, oriented to the analysis of:
- nanostructured systems for single particle detection (e.g. miniaturized Hall devices made of graphene and magnetoresistive sensing elements exploiting anisotropic magnetoresistance or planar Hall effect);
- magnetic nanoconveyors for possible applications in magnetic bio-sensing, targeted drug delivery and bio-particle manipulation;
- magnetic nanopatterned films based on antidot arrays for potential use as frequency-based magnetic field detectors operating in the Gigahertz range.

In the field of magnetic nanostructure fabrication and characterization, important results have been reached on the study of magnetic nanoparticles for hyperthermia applications as well as on the analysis of nanostructured films based on self-assembled dot arrays. Moreover, a novel field-dependent magnetic force microscopy technique enabling the measurement of local hysteresis loops has been applied to study vortex chirality in magnetic dots. Contacts: Alessandra Manzin a.manzin@inrim.it, Paola Tiberto p.tiberto@inrim.it.

A. Manzin, G. Barrera, F. Celegato, M. Coïsson and P. Tiberto, Influence of lattice defects on the ferromagnetic resonance behaviour of 2D magnonic crystals, Scientific Reports 6, 22004 (2016).

M. Monticelli, A. Torti, M. Cantoni, D. Petti, E. Albisetti, A. Manzin, E. Guerriero, R. Sordan, G. Gervasoni, M. Carminati, G. Ferrari, M. Sampietro and R. Bertacco, On-Chip Magnetic Platform for Single-Particle Manipulation with Integrated Electrical Feedback, Small 12, 921-929 (2016).

H. Corte-León, P. Krzysteczko, F. Marchi, J.-F. Motte, A. Manzin, H. W. Schumacher, V. Antonov and O. Kazakova, Detection of a magnetic bead by hybrid nanodevices using scanning gate microscopy, AIP Advances 6, 056502 (2016).

A. Manzin, E. Simonetto, G. Amato, V. Panchal and O. Kazakova, Modeling of graphene Hall effect sensors for microbead detection. J. Appl. Phys. 117, 17B732 (2015).

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P. Tiberto, F. Celegato, G. Barrera, M. Coisson, F. Vinai and P. Rizzi, Magnetization reversal and microstructure in polycrystalline $Fe_{50}Pd_{50}$ dot arrays by self-assembling of polystyrene nanospheres, Sci. Technol. Adv Mat 17 (2016) 462

M. Coïsson, G. Barrera, F. Celegato, A. Manzin, F. Vinai, P. Tiberto, "Magnetic vortex chirality determination via local hysteresis loops measurements with magnetic force microscopy", Sci. Rep. 6 (2016) 29904

M. Coïsson, G. Barrera, F. Celegato, L. Martino, F. Vinai, P. Martino, G. Ferraro, P. Tiberto, "Specific absorption rate determination of magnetic nanoparticles through hyperthermia measurements in non-adiabatic conditions", J. Magn. Magn. Mater. 415 (2016) 2-7

M. Coïsson, G. Barrera, F. Celegato, L. Martino, S.N. Kane, S. Raghuvanashi, F. Vinai, P. Tiberto, "Hysteresis losses and specific absorption rate measurements in magnetic nanoparticles for hyperthermia applications", BBA Gen. Sub. (in press) http://dx.doi.org/10.1016/j.bbagen.2016.12.006

The magnetics laboratory of INRIM concluded in 2015 an international comparison on the magnetic properties of grain-oriented steel sheets. The exercise was promoted by the Working Group2 of the Technical Committee 68 of the International Electrotechnical Committee (IEC Project TR68-7).Four metrological labs (INRIM, PTB, NPL, NIM) and seven industrial labs took part in the comparison. INRIM played the role of pilot laboratory. In 2016 the IEC Technical Report 68-62981-Ed1 on the comparison was prepared. A second project 1337 EURAMET.EM.M.S2 was concluded in 2016 on measurement of the power losses in grain-oriented and non-oriented steel sheets.

C. Appino, E. Ferrara, F. Fiorillo, L. Rocchino, C. Ragusa, J. Sievert, T. Belgrand, C. Wang, P. Denke, S. Siebert, Y. Norgren, K. Gramm, S. Norman, R. Lyke, M. Albrecht, X. Zhou, W. Fan, X. Guo, M. Hall, “International comparison on SST and Epstein measurements in grain-oriented Fe-Si sheet steel” , Int. J. Appl. Electromagnetics Mech. vol. 48 (2015), pp. 123-133.

In the frame of the EMRP Project EXL01 SpinCal “Spintronics and spin-caloritronics in magnetic nanosystems” INRIM conducted a theoretical study “Nonequilibrium thermodynamics of the spin Seebeck and spin Peltier effects” and together with Bielefeld University obtained accurate measurements of the longitudinal Spin Seebeck effect, validated in different laboratories, by using different setups and employing both the temperature difference method and the heat flux method. The lack of reproducibility in other experiments can be mainly attributed to the thermal contact resistance between the sample and the thermal baths which generate the temperature gradient. Due to the variation of the thermal resistance, we found that the scaling of the LSSE voltage to the heat flux through the sample rather than to the temperature difference across the sample greatly reduces the uncertainty. The systematic errors that can affect the temperature difference method can be considerably reduced with the heat flux method.

A. Sola, P. Bougiatioti, M. Kuepferling, D. Meier, G. Reiss, M. Pasquale, T. Kuschel, V. Basso, Longitudinal spin Seebeck coefficient: heat flux vs. temperature difference method. ArXiv:1701.03285 (2017).

Nonequilibrium thermodynamics of the spin Seebeck and spin Peltier effects V Basso, E Ferraro, A Magni, A Sola, M Kuepferling, M Pasquale Physical Review B 93 (18), 184421 (2016).

In the same SpinCal project we conducted experiments for the characterization of magnetic vortices, topologically stable structures which can be thought as an example of novel magnetic storage systems. A study on “Vortex dynamics in Co-Fe-B magnetic tunnel junctions in presence of defects” and then the work was extended in a collaboration with INL Braga, as it was recently shown that the presence of thermal gradients in magnetic nano-devices influences the magnetization state and dynamics in several ways, as for example by the generation of spin currents, spin waves, spin transfer torque. The generation of spin waves or spin currents was investigated widely due to phenomena as the Spin Seebeck effect, the starting point of the research field called spincaloritronics. We studied the influence of thermal gradients on the magnetization dynamics of a vortex structure. The possible influence of thermal gradients on a gyrating vortex present in a magnetic tunnel junction (MTJ) pillar we and interpret the results by performing numerical simulations was shown.

M Kuepferling, S Zullino, A Sola, B Van de Wiele, G Durin, M Pasquale, “Vortex dynamics in Co-Fe-B magnetic tunnel junctions in presence of defects,” J. Appl. Phys. 117 (17), 17E107 (2015).

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