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# Report from RISE Research Institutes of Sweden within the field of Electrical Metrology

## Organisation

RISE Research Institutes of Sweden was established in Jan 2017. After RISE acquirement in 2018 of a major part of Swerea, a research group specialising in applied scientific research in materials development, production and product development, the restructuring of the research institute sector in Sweden has now been finalized. A number of research institutes and more than hundred test beds and demonstration environments are now gathered under the umbrella of a single innovation partner. RISE operates from some 35 sites all over Sweden plus a few abroad. The new headquarter is located in Gothenburg. RISE has now a staff of about 2800 and a turnover of 350 M€. The Swedish state is the sole owner of RISE.

The activities as a NMI is coordinated by the Department for Measurement Science and Technology which is part of the Safety and Transport Division. This Department also holds most of the staff working in the field of metrology or quality assured measurements, about 140 employees. Professor Jan Johansson is the NMI director.

## Technical news since CCEM meeting in 2017

## Subfield DC, LF and Quantum metrology

RISE participated in the EMPIR project QuADC which finished 2019. In this project we developed new wideband (DC-100 kHz) voltage dividers for 100 V – 1 kV suitable for integration in a Josephson based sampling system. After the end of the project we continued the development by integrating a buffer amplifier with the divider. Work is ongoing to improve the performance at the highest frequencies and voltages. We planned to present this work at the CPEM 2020 conference, but when the in-person conference was cancelled we decided to wait until we could improve the design further.

We are participating in another EMPIR project, LibForSecUse, aimed at developing methods to characterize the performance of second life Li-ion batteries. RISE is focusing on calibration methods and traceability for impedance measurements in ranges typical of vehicle Li-ion battery cells (~1 mΩ, ~1 F, 10 mHz – 5 kHz).

A cryo-free (dry) cryostat from Oxford Instruments with a base temperature of 1.6 K has been installed. The cryostat is equipped with a 12 Tesla magnet and an additional inset with a closed He-3 system that allows for cooling to 0.3 K. The new cryostat will enable measurements run over longer timespans and at lower temperatures than before, and will be a key factor for future research projects. Over time it will replace the present (wet) system for standard QHR measurements.

We are also participating in a third EMPIR project, GIQS. In this project we are constructing a Josephson voltage standard to be integrated in our new cryostat for quantum Hall measurements. The aim is to demonstrate simultaneous operation of a Josephson voltage standard (JVS) and a quantum Hall resistance standard (QHR) in the same cryostat. This is a step towards realising a universal quantum electrical standard (UNIQUE standard) for all electrical quantities.

We are continuing our strong collaboration with Chalmers university on graphene development. Thanks to our new dry cryostat we have further reduced our resistance uncertainty and we are evaluating the long term stability of graphene based QHR standards using the electrochemical doping method developed at Chalmers. [D1, D2] We are also planning to fabricate arrays of graphene Hall bars to realize resistance levels other than the usual 12.9 kΩ.

In collaboration with the NMIs of United Kingdom and South Africa, RISE has started the development of a new Kibble balance for realization of the new kilogram. The electricity group is working with the JVS part of the setup for the measurement of the electrical signals. A fully working prototype balance is planned for early 2022.

A new method has been developed for realizing absolute phase displacement of wideband current shunts. The method requires only relative phase measurements and a set of three geometrically identical shunts. The new method will improve our calibration uncertainties for power analysers and current transducers. [D3, D4] A similar method has been developed for realisation of inductance and quality factor to improve our capability at high frequencies, up to 1 MHz. [D5]

RISE is building an automated system for Zener reference calibrations and voltmeter linearity calibrations based on a 10 V programmable Josephson array.

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## Subfield Power and Energy

RISE is coordinating an EMPIR project 19ENG02 FutureEnergy. The project will extend the traceable calibration of Ultra-High Voltage Direct Current (UHVDC) up to at least 1600 kV possibly 2000 kV, developing a new modular voltage divider with an expanded measurement uncertainty better than 200 µV/V at 1600 kV, and extending the 1000 kV modular divider from EMRP ENG07 HVDC to 1200 kV with expanded measurement uncertainty better than 40 µV/V at 1200 kV. It will extend and research linear extension methods for lightning impulse voltage calibration for testing of UHV equipment. The target is to provide new input to IEC 60060-2 for time parameters and voltage measurement on ultra-high voltages above 2.5 MV with an uncertainty for peak voltage better than 1 %. It will further develop new method(s) for linearity determination of HV capacitors with a target calibration uncertainty for HVAC of 80 µV/V at 800 kV. The project will also develop and demonstrate implementation of partial discharge (PD) measurement techniques for testing of equipment under d.c. stress, with specific emphasis on detection and prevention of insulation failures in HVDC cables, GIS and convertors.

RISE is participating in the EMPIR 19NRM07 HVcom$^2$ where traceability for composite and combined waves will be developed. The aim of this research is to realize the necessary metrology required for the standardization of high voltage testing with composite and combined wave shapes. In order to address the current lack of traceability, traceable measurement systems and calibration services will be developed for composite and combined wave shapes, and the relationship between impulse voltages with High Voltage Alternating Current (HVAC) or High Voltage Direct Current (HVDC) measurements will be determined. RISE aim to realize metrology for composite wave up to 800 kV and combined wave up to 400 kV.

In the EMPIR 17NRM01 TrafoLoss project (2018-2021) RISE published a review paper on best achievable traceability of loss factor of high voltage capacitors [1]. For this project RISE has refurbished a 40 kV reference capacitor for transformer loss factor determination at power frequency, targeting a loss factor determination of $2 \cdot 10^{-6}$. A Guildline 9910 capacitance bridge has also for this purpose been rebuilt with a target expanded uncertainty of $2 \cdot 10^{-6}$ and a resolution in the $10^{-7}$ range.

RISE coordinated the EMPIR project 15NRM02 UHV May 2016 – April 2019. In this project RISE provided traceability for Very Fast Transients (VFT) in GIS, Very Fast Transient Overvoltages (VFTO) in instrument transformers and traceability for ultralow PD levels and metrology for PD under d.c. stress. Traceability for VFT has been obtained by taking part in the development of the 14-bit PXIe-5164 transient recorder built by National Instruments. This state-of-the-art recorder was characterized and has a settling time of 4.5 ns [14], operates with 1 GS/s, has a bandwidth of 400 MHz. This digitizer and puncture testing divider, developed in 14IND08 ElPow, was used to establish calibration services at FFII-LCOE for GIS for wideband sensors up to 100 kV, with rise times down to 6 ns, with an expanded uncertainty of 1.1 % for the peak value [15]. As a follow up RISE redesigned the puncture testing divider by VTT developed in 14IND08 ElPow to achieve traceability to 200 kV with a settling time of 25 ns. A new calibration service was established for Very Fast Transient Overvoltages (VFTO) up to 400 kV with lightning impulse time parameters 0.4-0.8/50 µs [17].

The expanded measurement uncertainties are $U_p$ < 10 mV/V, T1 < 20 ms/s (0.4 – 0.6 µs), T2 < 10 ms/s (40 – 60 µs). Methods for improved accuracy for calibrating PD-calibrators was developed and a comparison between four NMIs have been performed [16], leading to a new CMC claim for RISE for PD-calibrators down to 0.1 pC with an expanded measurement uncertainty of 0.001 pC.

RISE coordinated the EMPIR project 14IND08 Elpow from June 2015 to May 2018. This project has provided valuable insight in impulse testing where methods to characterize such measurements have been refined with focus on linear extension methods with a measurement uncertainty of 1% up to 3200 kV. Appreciable distortion of lightning impulse waveshape was found to be owing to effects of coaxial cable between the voltage divider and transient recorder [2-9]. An intercomparison of LI measurement systems were performed between RISE, VTT and PTB [8] and between further HV class dividers between RISE and STRI testing lab in Ludvika, Sweden. All collected data from these two campaigns is now evaluated in the above described EMPIR 19ENG02 FutureEnergy for a good practice guide in LI measurements. An impulse divider for puncture testing with front times down to 200 ns was also developed in 14IND08 ElPow. The performance is discussed in a master’s thesis and also published in [10]. The project developed theory for accurate determination of losses in an HVDC converter station for the case of voltage source converters [11], which can be operated in back-to-back (regenerative) mode. The stratagem was adopted by Svenska Kraftnät for verification of guaranteed losses in the new South-West link in Sweden. The task is ongoing, with RISE performing the measurements,

RISE piloted the Supplementary Comparison EURAMET.EM-S42 Lightning Impulse intercomparison together with VTT and LCOE. The comparison started in Nov 2016 and was completed in April 2019. The system was circulated within EURAMET for measurements by 7 NMI:s (SP, VTT, PTB, INRIM, FFII-LCOE, LNE, TUBITAK-UME) and around the world via IATTE (Argentina), NMIA (Australia), VNIIMS (Russia), NIM (China), JHILL (Japan) and NRC (Canada). The final report was released in Dec 2020 and published in Metrologia [13]. New improved CMCs will be claimed for Lightning Impulse for RISE.

Final reporting of international comparison of current transformers has been published [12], and the analysis of RISE results has led to ameliorations in our procedures for high currents that are expected to reduce uncertainties at high current ratios.

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## Subfield RF and MW

The high frequency laboratory at RISE participated in the project 14IND10 MET5G Metrology for 5G Communications in the EMPIR program 2015-2018. The main task was to establish traceability for non-linear vector network analyzer measurements.

Since several years we are partners in the GHz Centre, which is a microwave research Centre of excellence financed by VINNOVA and operated by Chalmers in collaboration with industry and RISE. Within the GHz Centre at Chalmers we are working on S-parameter measurements on membrane circuits suitable for THz frequencies, cryogenic S-parameters measurements on HEMTs as well as measurements of broadband S-parameters [G1].

In December 2018 we were awarded funding for a PhD student to work on THz Metrology. The project will focus on measurement of S-parameters at frequencies from 0,3 – 3 THz and will be executed in close collaboration with Chalmers.The aim of the research project is to develop terahertz mixers for future space missions (ESA, DLR, PDI, VDI) and to demonstrate precise and traceable terahertz characterization methods for next generation of wireless systems (SSF, TEMMT).

Goals in the project is to design and development of 3.5 THz x6 harmonic mixer for QCL frequency stabilization, design and development of 4.7 THz x8 harmonic mixer and fundamental mixer and inter-laboratory comparison of waveguide S-parameter measurements at 500-750 GHz and 1.1-1.5 THz.

RISE participated in the EMPIR project 15RPT01 RF Microwave aiming for traceable calibration of S-parameters in test environments such as EMC chambers. One of the project tasks is to investigate the possibilities for traceable calibration methods of loop antennas, using VNA techniques.

In 2018-2019 we had a project for calibration of field probes in a Reverberation Chamber. This included calibration method development with measurement uncertainty analysis and comparison with other relevant calibration methods.

We have an ongoing project for a comparison of the methods from HF theory and the ones employed by traditional DC-LF theories in the frequency range 9 kHz-45 MHz. This project also includes implementations of knowledge developed within the 2018 closed EMPIR project 15RPT01 RF Microwave.

RISE have participated in the soon-to-be ended EMPIR project 16ENG08 MICEV working on simulations and metrology concerning low-frequency magnetic fields connected with charging of electrical vehicles.

Since 2007 we were active in the Chase centre which ended 2016. This work is now continued within the ChaseOn centre, which also is an antenna centre of excellence financed by Vinnova, and operated by Chalmers in collaboration with industry and research institutes. Within the centre RISE participates in development of characterization methods of vehicular 5G systems [F1-F4]. Together with telecom industry we work on evaluation methods of 5G systems, both in-band properties and EMC characteristics.

RISE has invested in a new communication test chamber for the automotive industry (AWITAR). In parallel the research and measurement group develops over-the-air test methods (OTA test methods) needed for future vehicle models and investigates the possibilities to use the AWITAR test chamber as an indoor antenna calibration facility [F5].

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