Progress report on electrical metrology at VTT MIKES between 2019 and 2021

for the 32nd meeting of the Consultative Committee for Electricity and Magnetism (CCEM), April 2021

Organization

National Metrology Institute VTT MIKES (about 60 employees) is a part of VTT Technical Research Centre of Finland Ltd (about 2400 employees), which is a fully state-owned not-for-profit-company. VTT MIKES is one of the five Research Areas of Knowledge Intensive Products and Services, which is one of the three Business Areas of VTT. MIKES's Electrical Metrology Team with 15 researchers is responsible for Finland's national metrology activities in fields of electricity, time and frequency, and acoustics.

Applications of Josephson effect in electrical metrology and quantum technologies

VTT MIKES has continued development of a Josephson Arbitrary Waveform Synthesizer (JAWS) driven by a pulsed laser and a photodiode for both DC and AC metrology. Our fairly inexpensive optical pulse pattern generator (PPG) has a superior pulse quality compared to systems based on electrical PPGs operating at tens of GHz. A properly designed mode-locked laser (MLL) produces pulse trains with little jitter and narrow amplitude spread of the pulses. We have built a MLL operating at 1335 nm with pulse repetition rate of 2.3 GHz. An optical time division multiplexer is used to increase the pulse rate to 8-10 GHz. Pulse pattern formation can be done by pulse picking, that is by either passing or blocking pulses at the modest base frequency of 2.3 GHz using optical intensity modulators. We have driven a Josephson Junction Array (JJA) with a low critical current of 360 µA at multiple Shapiro steps, and we have performed experiments with pulse pairs whose time interval can be set freely without distorting the shapes of individual pulses even if they are overlapping [10]. Experimental results are in qualitative agreement with theoretical simulations, but there are quantitative discrepancies which motivate an improved integration of photodiodes and JJAs to improve both the understanding and fidelity of pulse-driven JAWS. In project QuADC of the European Metrology Programme for Innovation and Research (EMPIR), cryogenically operable bipolar photodiode modules suitable for driving the JAWS have been developed [11], [20]. Collaborators of VTT MIKES in this work are PTB, JV and USN (University of South-Eastern Norway).

Considering future quantum technologies in a wider perspective, our optical approach is a potential enabler for fast and energy-efficient pulse drive without an expensive high-bandwidth electrical PPG, and without high-bandwidth electrical cables that yield too high thermal conductance between cryogenic and room temperatures. These aspects are developed in EU FET Open project aCryComm [https://www.acrycomm.eu/] coordinated by VTT. Other partners of the project are PTB, Tampere University, KTH (Stockholm), ETH Zürich, Single Quantum, and Polariton Technologies. The work at VTT is also related to the Finnish Quantum Computer procurement project (20.7 M€), in which Finnish quantum technology company IQM will build Finland's first quantum computer for VTT.

Impedance and graphene

VTT MIKES continues its research activities on graphene-based resistance and impedance metrology in the joint research project GIQS (Graphene Impedance Quantum Standard) [12] of the EMPIR programme. In that project, the main task of VTT MIKES is to develop the technologies needed for the AC operation of both a graphene QHR standard and a Josephson voltage standard in the same cryogen-free cryostat. That would be an important step towards a universal quantum standard for electrical quantities.

Research on coherent quantum phase slips and single-electron effects

VTT coordinates EU FET Open project Quantum e-leaps (2020-2023) [www.e-leaps.eu] that aims at developing a quantum current standard based on coherent quantum phase slips. Other partners of the project are Aalto University, ETH Zürich, Leibniz-IPHT, NPL, Royal Holloway University of London, and University of Regensburg. The project develops superconducting nanowire technology based on both novel 2D superconductors and disordered superconducting films. An important part of the project is the integration of superconducting nanowires with specific electromagnetic environments, which is required for the development of a quantum current standard.

One of the problems of the CQPS element compared to its dual, the Josephson junction, is that its fabrication is less predictable due to the small dimensions. The Quantum e-leaps project aims to solve this problem with unprecedented tuneability: 2D materials allow tuneable superconductivity, and a specially designed CMOS-based platform allows tuneable electromagnetic environments. These properties are expected to allow tuning the devices to the parameter regime that yields the desired inverse Shapiro steps, i.e., quantized current plateaus that are dual to the voltage plateaus of a Josephson voltage standard.

VTT's roles in the project include the development of the CMOS-platform, development of wafer scale processing technology for disordered superconducting nanowires, and the development of the quantum current standard. An important early result of the project is the amorphization and enhanced superconductivity of superconducting nanowires by irradiation with focused ion beam [9].

VTT MIKES has also continued work on quantum current standards based on single-electron tunneling. In the project e-SI-Amp of the EMPIR programme, a silicon nano-MOSFET single-electron pump fabricated by NTT, Japan, was measured by three laboratories – NPL, VTT MIKES, and Aalto University (Finland) – at 4.2 K temperature and zero magnetic field. The results at current level 168 pA agreed within a relative uncertainty of 10^{-6} or less [2].

In addition, VTT MIKES develops thermometry applications of single-electron tunneling in close collaboration with Aalto University. In a joint research project Real-K (Realization of the redefined kelvin) of the EMPIR programme, the main objective of VTT and Aalto is to develop the Coulomb Blockade Thermometer (CBT) for primary thermometry at temperatures between 1 K and 25 K [15]. VTT has also developed cryogenic refrigeration based on tunneling in a structure consisting of a sub-chip of highly doped silicon supported by superconducting thin-film aluminium wires and Al-Si tunnel junctions. Refrigeration of a millimeter-scale Si sub-chip by about 80 mK from a starting temperature of about 240 mK was demonstrated [8].

High voltage and power metrology

The development of the single-phase calibration setup for calibration of voltage, current and power harmonics was completed. The standard is based on a custom digitizer, which is designed for both laboratory and on-site power metrology. Test signals are generated using a dual-channel arbitrary function generator, a voltage amplifier, and a transconductance amplifier. The reference voltage and current measurements are, respectively, based on a capacitive-resistive voltage divider and two different types of resistive shunt designs. For example, the standard has an expanded uncertainty of 32 and 157 μW/VA at 10 kHz for power factors of 1.0 and 0.0, respectively [6].

Other power frequency testing related measurement activities included development of systems for e.g. measurement transmitted overvoltages during instrument voltage transformer testing [1] and measurement of losses of air-core reactors during high-current testing [17].

A new reference system has been set up for calibration of switching impulse (SI) measuring systems. The modular system has a maximum voltage of 400 kV and new software correction techniques have been introduced to reach low uncertainty [4], [19].

Development of lightning impulse (LI) measuring systems has continued, e.g. by simulation propagation and deformation of transient signals in coaxial cable [16]. Also, a joint effort was taken with PTB and RISE to study the feasible uncertainties of LI calibration in megavolt level [21].

New techniques were developed for nanosecond transient measurement, both for high voltage [13] and high current [24], [25].

New low-level partial discharge (PD) calibration system is based on use of charge-sensitive amplifier [3].

Comparisons

VTT MIKES was responsible for analysis and reporting of results of supplementary comparison EURAMET.EM-S42 (Lightning impulse voltage up to 700 kV) coordinated by RISE. The final report of that comparison was published in 2020 [5]. Other comparisons whose final report was approved or draft report appeared during the reporting period are: EURAMET.EM-S33 (AC up to 200 kV), EURAMET.EM-S34 (Capacitance and dissipation factor up to 200 kV), EURAMET.EM-S35 (High DC current ratio) and EURAMET.EM-S37 (Current transformer calibration systems up to 10 kA). The results of VTT MIKES are good and support CMC claims.

In autumn 2019, MIKES participated for the first time the 10 V on-site comparison of Josephson arrays, BIPM.EM-K10.b. The comparison report was submitted for WGLF review in 2020. In addition, MIKES has performed the measurements of the key comparison EURAMET.EM-K5.2018 (50/60 Hz power) during the reporting period.

An informal quadrilateral partial discharge comparison confirmed the new uncertainties of VTT MIKES for low level discharges, e.g. 3% @ 0.01 pC and 1% @ 0.1 pC [18].

Peer reviews

In 2019, a peer review on high voltage measurements was made by Mr Grzegorz Sadkowski from GUM, Poland, with one non-conformity.

Publications 2019 –

Articles

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