European Metrology Programme for Innovation and Research

Delivering Impact

A new standard in the field of small current measurements

Many measurement instruments require on-site calibration. To do this highly accurate 'travelling' standards are used to verify instrument performance and traceability to the SI. However, for measurements of currents at 1 nA or below, required for aerosol counters, radioactive monitors and nano-electronics, no standard existed that had been ratified for both transportation and long-term measurement stability, until now.

Europe's National Measurement Institutes working together

The European Metrology Programme for Innovation and Research (EMPIR) has been developed as part of Horizon 2020, the EU Framework Programme for Research and Innovation. EMPIR funding is drawn from 28 participating EURAMET member states to support collaborative research between Measurement Institutes, academia and industry both within and outside Europe to address key metrology challenges and ensure that measurement science meets future needs.

Challenge

Technological advances, such as low power devices, or micro- and nanoelectronics in the semiconductor industry, have introduced the requirement for measurements of small currents of 1 nA and below. Measurements at this scale utilise instruments such as pico-ammeters which require accurate calibration, often in situ. To do this requires 'travelling standards' but none existed that was sensitive enough to ensure both measuring instrument accuracy and traceability to the SI. The EMRP project Qu-Ampere developed an Ultra-stable Low-noise Current Amplifier (ULCA) at Germany's National Metrology Institute (NMI), PTB. This device was a transimpedance standard capable of measuring and generating a wide range of small currents, from below 100 pA up to 1 µA with a dynamic range of ±5 nA. Operating at room temperature, without the need for cryogenics, it outperformed commercial devices and calibration setups in accuracy by up to two orders of magnitude. The ULCA had the potential to make an ideal travelling standard but questions regarding transportation and long-term measurement stability remained to be addressed.

Solution

During the EMPIR project *e-SI-Amp* four ULCA variants were developed including one with an extended current range of 50 nA compared to the standard 5 nA with a two-fold lower measurement uncertainty. In order to test suitability as a transport standard an ULCA developed in the EMRP project and the improved variant were transported from PTB to five partner NMIs. These were then calibrated for current gain of the input stage and the trans-resistance of the output stage. Results indicated that both ULCA versions gave results that changed by no more than 1-2 parts in 10^7 between Institutes. The long-term stability was evaluated at PTB by monitoring calibration values over long time periods, including assessing 5 standard ULCAs over 4 years and two new-variant 'noise-optimised' ULCAs for around 1 year. All versions showed excellent stabilities indicating a robust travelling standard for future international comparisons in small current metrology.

Impact

Magnicon GmbH, specialising in measurements in the field of electromagnetic technologies at the nanoscale and below, commercialised the original EMRP ULCAs and has now licenced two new variants from PTB. The input currents of the new ULCAs have been 'noise-optimised' resulting in a 30% decrease in measurement time representing a significant saving in on-site calibration times. In addition, one is a 'low current' ULCA with a measurement range 1 fA to 1 nA. Representing the highest measurement accuracy for the lowest current levels, Magnicon considers that the new UCLA variants will open up new markets in photometry, nuclear medicine and metrology. The ULCA have since found uses in a range of applications including high-throughput calibrations of radioactivate sources in the medical sector and in optical calibration measurements for a large lighting manufacturer.

In the long term the new travelling standard will allow for more accurate and precise control in products and services, such as environmental protection, medical care, and commercial production of goods.

Developing single electron sources to realise the ampere

The project fabricated over 10 000 semiconductor-based (GaAs or Si) single-electron sources and more than 100 single-electron devices were characterised at low temperatures (4.2 K and below). 3 new instruments were developed to enhance the capability of small current measurements: an Ultra-Low Current Amplifier (ULCA), a Programmable Quantum Current Generator (PQCG) and an Ultra-Low DC Current Source (ULCS). Together these devices cover a wide measurement range from 1 fA to 10 mA. In addition, 4 new advanced ULCA variants were developed, different in stability, gain, noise, and range. Along with new guidelines for testing the accuracy of single-electron sources project results have improved small-current measurement capability at NMIs, with a resolution of atto-amperes. Up to one order of magnitude measurement improvement in the range 1 pA – 100 pA has been achieved which will benefit the development of nano-device fabrication technology. The new, accurate semiconductor-based single-electron sources will become available as candidates for primary standards for the revised SI ampere.

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EMPIR EURAMET

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