Foundations for a redefinition of the SI base unit ampere

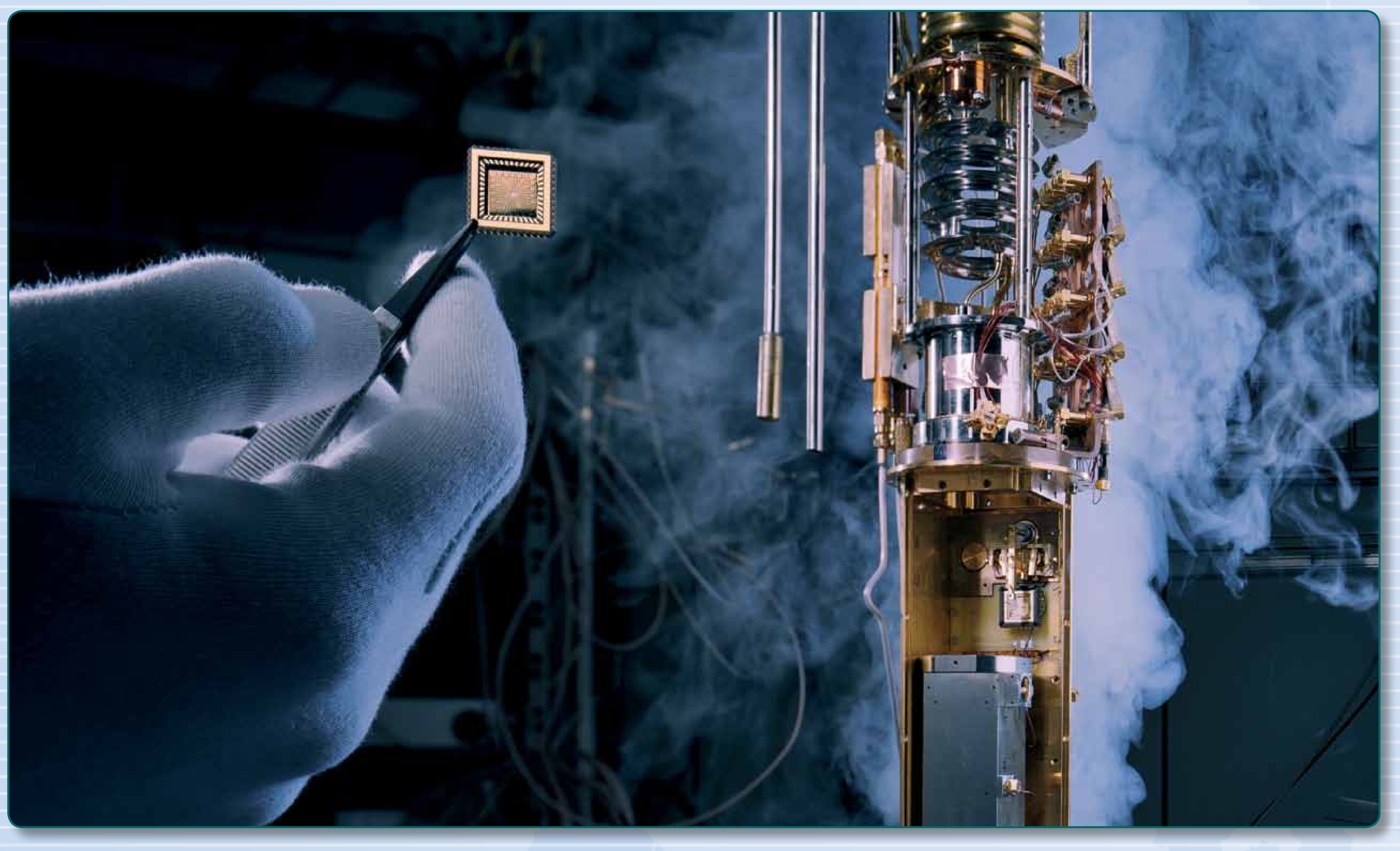
EURAMET
European Association of National Metrology Institutes

The need for the project

In a proposed redefinition of the international system of units, the ampere and kilogram would be based on fixing values for *e* (elementary charge) and *h* (Planck constant). This would replace the 'conventional values' assigned to the Josephson constant (K_J) and the von-Klitzing constant (R_K) in the current system for defining the volt and ohm. In theory there are simple relationships between these four constants ($K_J = 2e/h$ and $R_K = h/e^2$) but these have not been experimentally verified with sufficient accuracy.

The work by metrologists to prove that these simple relationships can be relied upon to define the volt and ohm is an experiment commonly referred to as the Quantum Metrological Triangle (QMT). It requires devices, which generate a known current by counting single electrons.

This project aimed to close the QMT and improve the uncertainty associated with *e* and *h* values.



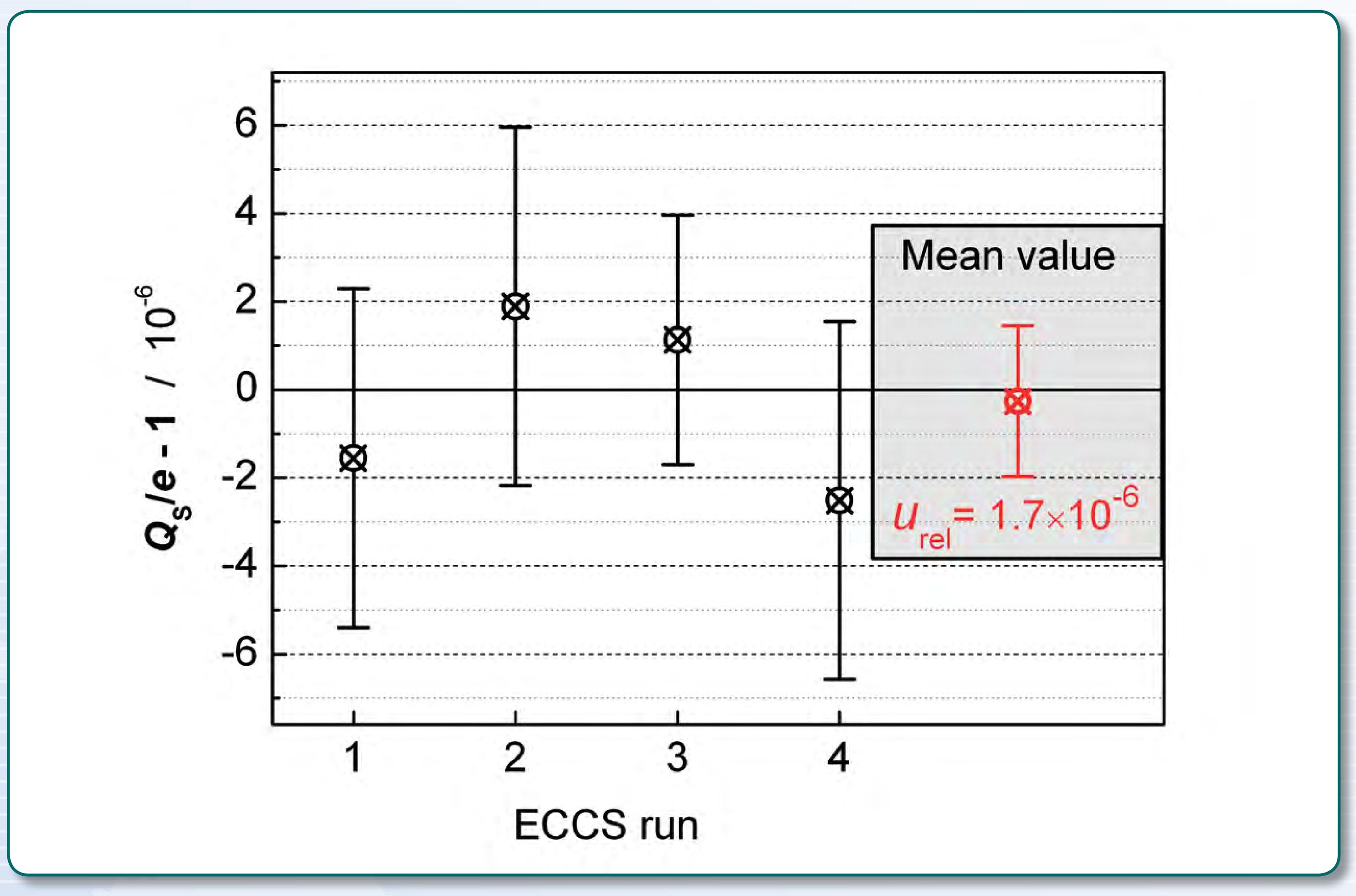
A chip carrier with a single electron pumping nano-circuit before being mounted into the milli-kelvin cryostat. The grey metal box in the lower part of the cryo-system houses the precision 1 pF capacitor which is charged with up to 63 million electrons.

Technical achievements

Two QMT setups were implemented, based on current and charge comparison. With the charge comparison QMT, a Single Electron Transport (SET) device was operated at an error rate sufficiently low to close the QMT. A precision linkage of the involved 1 pF capacitor to the von-Klitzing constant was performed. This QMT variant was closed with an uncertainty of 1.7 parts per million (ppm).

For the QMT based on current comparison, a cryogenic current comparator was developed which amplifies currents by a factor of 20,000. Using the traditional SET devices, evidence was collected that, even in seemingly perfect devices, peculiarities of the transport features may prevent reliable results. This finding has important consequences for the next generation QMT experiments employing high current devices.

Progress was made with high current SET devices; hybrid turnstiles featuring a combination of superconducting and normal conducting elements were made and operated in parallel to produce currents of 100 pA and above. The project also developed tunable semiconductor single electron pumps that allow similar or higher currents by higher frequency operation. Finally, an error detection concept was developed which will allow a precise determination of current even when the current generating device operates at error rates as large as 1 in 10^4.



Results from the Electron Counting Capacitance Standard (ECCS) QMT experiment. In this first complete test run an uncertainty of 1.7 ppm was obtained after only 2 h of measurement time.

Supporting a redefinition of the SI units

The results of this project will improve the threshold uncertainty (7 parts in 10^7) associated with SI units based on *h* and *e* values, through the QMT experiment.

The unit of mass, and units derived from it, will also be affected, via the redefinition of the kilogram with the watt balance experiment.

The Committee on Data for Science and Technology has confirmed that it will consider the project's results in a new report.

New high current SET devices

Developed three high current SET devices; hybrid turnstiles, tunable semiconductor single electron pumps and an error detection concept to enable the precise determination of current. The high current SET devices are able to calibrate current meters with an uncertainty 20 times better than currently available.

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