

Quantum Leap in Metrology: Memristors as a New Standard for Electrical Resistance

Researchers at the Italian National Institute of Metrological Research (INRiM), together with international collaborators, have demonstrated for the first time that memristors—novel nanoscale switching devices—can provide stable resistance values directly linked to fundamental constants of nature. This paves the way for electrical units such as electrical resistance to be traced back far more simply and directly than it has been possible to date. By contrast, conventional, quantum-based measurement technology is so demanding that it can only be carried out in a few specialized laboratories worldwide.

Since 2019, all base units of the International System of Units (SI) – including the meter, second, and kilogram – have been based on fundamental natural constants. For example, the kilogram, which was once based on the “prototype kilogram,” is now linked to Planck's constant h . A meter is defined by the speed of light, and a second by the oscillation of the cesium atom.

Thanks to laser interferometers and atomic clocks, units of length and time can be verified relatively easily worldwide. The situation is quite different for physical quantities such as mass and electrical units. Their metrological traceability is so complex that the measurements are feasible only in a handful of national metrology institutes.

Until now, the quantum Hall effect has served as the standard for electrical resistance. While it provides precise, reproducible values, it requires extreme laboratory conditions—temperatures close to absolute zero and magnetic fields stronger than those in clinical MRI systems. The measurements require sophisticated cryogenic systems and strictly controlled facilities.

Memristors offer a radically different approach. Originally developed as building blocks for novel computing architectures, they exhibit switching behaviour that directly follows universal constants. Functionally, they act as programmable resistors—essentially transistors with memory. Conductive nanofilaments of individual silver atoms form inside them. By applying electrical bias, these filaments can be adjusted with atomic precision so that their conductance changes not continuously, but in discrete quantum steps.

“For the first time, we have demonstrated that memristors can reliably generate discrete resistance states that are directly related to universal constants of nature—without the need for elaborate cooling systems or high magnetic fields,” says Gianluca Milano, coordinator of the european [MEMQuD project](#) that joined efforts from 15 institutes and universities across all Europe to achieve this result.

The foundation of this work is the quantized electrical conductance G_0 , derived from Planck's constant h and the elementary charge e . In the experiments, memristors were reproducibly programmed in air at room temperature into stable conductance states of $1 \cdot G_0$ and $2 \cdot G_0$, maintained over extended periods. The key lies in a process analogous to fine grinding: so-called “electrochemical polishing” here discussed for the first time. In this process, unstable atoms are removed from the conducting filament until only a stable quantized conduction channel remains.

This approach brings into reach a concept known as “NMI-on-a-chip”—the service of a national metrology institute condensed into a microchip. In the future, this could allow a measuring device to have its reference built directly into the chip. Lengthy calibration chains—from measurements in metrology institutes, through reference resistors and precision calibrators, down to the calibration of end-user devices—would no longer be necessary. Instead of repeatedly sending a multimeter to the calibration laboratory, it could check itself internally against the unchanging natural constant – a built-in calibration standard.

Applications range from simplified calibration procedures in industry to mobile measuring systems and portable standards for research in the field or in space. “We are at the beginning of a paradigm shift—moving away from complex large-scale facilities towards intrinsic, quantum-accurate standards that can be integrated into any chip,” Milano summarizes.