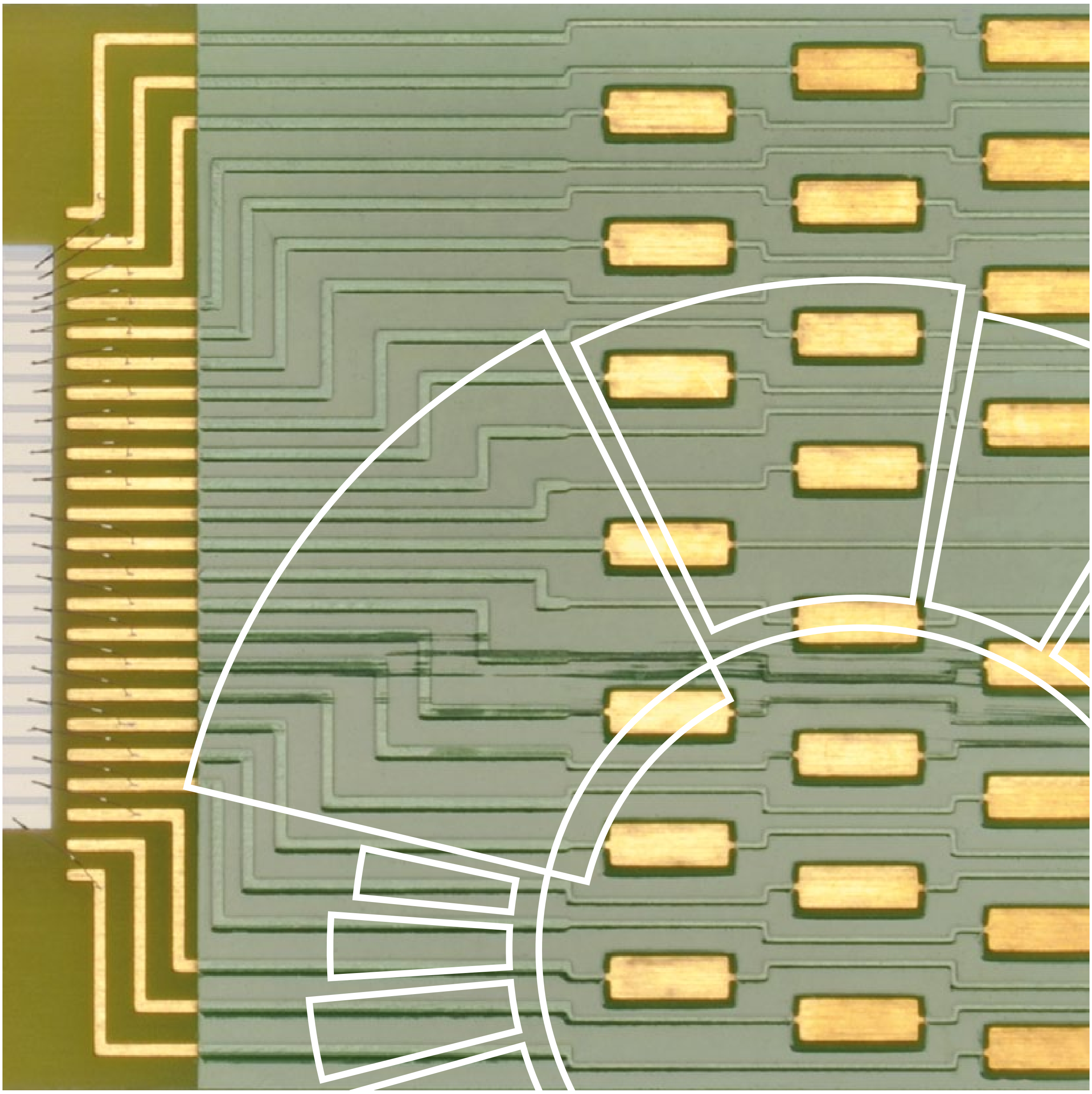
INFO SHEET

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT

DIVISION 2

Electricity



Electricity

Electric measurements are of a multidisciplinary nature. In almost all industrial, technical and scientific fields, in medicine as well as in environmental and climate observation, non-electric measurands are transformed into electric quantities. This is the reason why electric measurements play a key role in metrology.

PTB's primary standard for electrical power.

Electric Energy

In Germany, approx. 50 billion euros are billed for electric energy every year; this corresponds to the consumption of approx. 480 billion kWh. For correct billing, 42 million electricity meters measure the consumption of electricity in private households, and another 650 000 meters connected via instrument transformers are used to measure the energy consumption in industry. All these meters are traced back to PTB's standard for electrical power via a calibration chain. This standard is based on the synchronous sampling method, which was developed at PTB, and has the lowest measurement uncertainty worldwide. This ensures that the electric energy is measured at the customer's with the required accuracy.

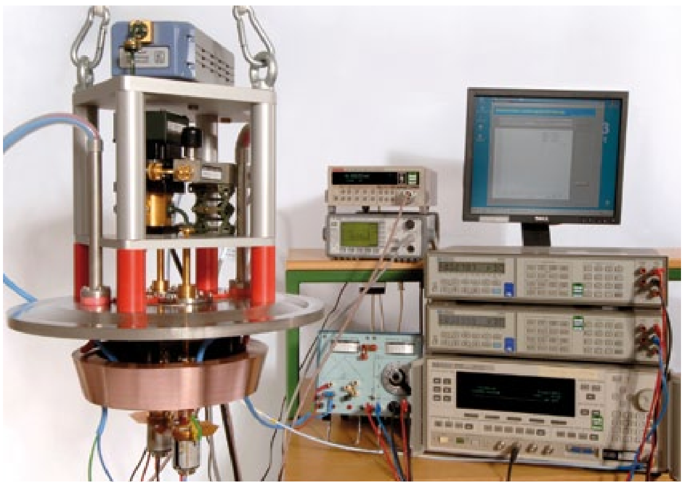
For electricity meters or instrument transformers which are used for billing purposes, conformity assessment is required. To this end, PTB performs national or European type examinations and issues – on average – 70 certificates for electricity meters and instrument transformers every year. A precondition for this is that the instruments have successfully passed all those metrological tests which simulate their future conditions of use as realistically as possible.

In order to promote the increasing use of regenerative energy sources and to ensure the security of energy supply, PTB is undertaking research on smart electrical grids, the quality of the electric energy supplies, and the low-loss transport of electric energy over long distances using high-voltage direct current transmission. ■

Information and Communications Technology

Information and communications technology is playing a key role in the development of today's society. This technology is to ensure that everybody has access to the required information – anytime, anywhere. To this end, mobile broadband communication facilities have to be developed which are used in all kinds of fields – from traffic control to environmental and climate observation and from medical technologies to safety engineering. To develop these information and communications technologies, it is necessary to constantly make new frequency ranges accessible, since the bandwidth required by new applications is constantly increasing.

PTB is supporting this development by extending the high-frequency, the field and the antenna measuring techniques to higher frequencies, by providing standards to industry and by investigating new communications technologies, such as wireless communication using terahertz waves.



Microcalorimeter for the traceable measurement of the calibration factors of a W-band power sensor in the frequency range 75 GHz–110 GHz.

The increasing use of electromagnetic fields for wireless communication raises the question as to whether such fields have an impact on human health. To monitor compliance with the existing regulations, PTB is establishing traceability of the relevant measurands, such as, e. g., the specific absorption rate (SAR). In order to establish a reliable metrological basis to investigate the impact of electromagnetic fields on biological tissue, research is done in the field of dosimetry of non-ionizing radiation.

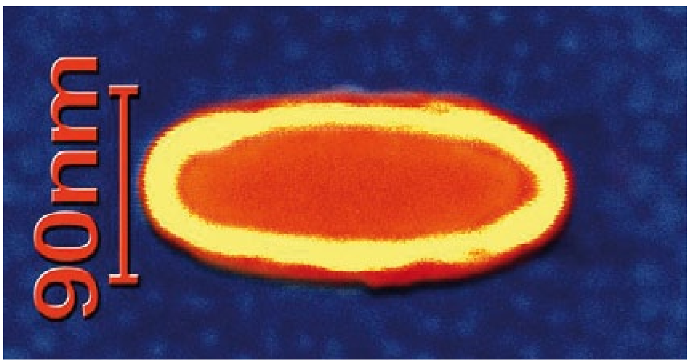
Electrical Measurands for Industry

More than 100 industrial laboratories are currently accredited by the German accreditation body (DAkkS) for the calibration of electrical and magnetic measurands. These laboratories trace their measurements back to the standards of the Electricity Division of PTB. In general, PTB's customers need calibrations over a wide range of values, covering several decades of the measurand, and at different measuring frequencies. The number of measurands for which the Division has to supply standards is correspondingly large. The primary realization of the electric units is, however, done for a few values only and at a fixed frequency (usually at the frequency 0, i. e., using direct current (DC) measuring techniques).

Therefore, the realization of unit scales over wide ranges of values and frequencies is an essential field of work of the Division. To this end, various techniques of electrical precision metrology are used such as, e. g., comparator techniques to trace DC resistors back to a known reference resistance or bridge measuring techniques to disseminate the unit of capacitance and the unit of inductance. The reference standards used are the quantum standards which have been developed by the Electricity Division. Alternating currents (AC) and voltages with frequencies up to 1 MHz are traced back to the corresponding DC quantities by means of thermal conversion techniques. For the AC/DC transfer at technical frequencies, sampling procedures have been developed which are also used for the calibration of the electrical part of the measuring chain when tracing back non-electric measurands such as force, pressure, torque, acceleration and temperature.

All procedures are permanently improved in order to fulfil our customers' latest requirements.

Cryogenic current comparator set-up used to compare different DC resistors in order to establish the ohm scale.



Electron microscope image of a nanoscale magnetic storage cell of an MRAM (Magnetic Random Access Memory).

Magnetism

Magnetic effects and magnetic materials are the basis of key technologies such as, e. g., power engineering, data storage or sensor technologies. Therefore, PTB offers the calibration of magnetic field quantities and of important parameters of magnetic materials. These calibrations are traced back to PTB's primary standard for the unit of magnetic flux density which is realized on the basis of the gyromagnetic ratio of the proton in water. As a knowledge transfer activity, PTB supports manufacturers of magnetic measuring instruments, e. g., in developing magnetic coils which generate specific field distributions.

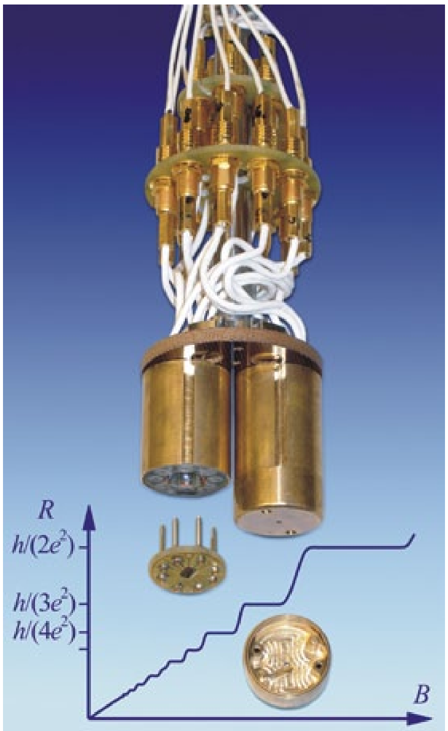
Metrology for nanomagnetic structures and systems, which are used in data storage and sensor technology, is an active research area. Reliable and comparable measurements underpin innovation and product development involving the use of nanomagnetic structures. For the time-resolved measurement of magnetization switching in nanosystems, magneto-resistance-based and inductive measuring techniques have been realized, which provide picoseconds time resolution. With these methods, switching times as well as important parameters of metallic and semiconducting ferromagnetic nanosystems can be determined. An example of such a parameter is the critical current of nanomagnetic storage cells whose magnetization is switched by spin-polarized currents. The present work aims at the standardization of the measuring techniques and at a better understanding of the underlying microscopic phenomena.

Electrical Quantum Standards

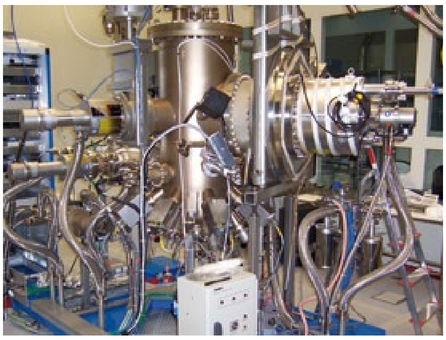
Quantum standards utilize macroscopic quantum effects such as the Josephson effect and the quantum Hall effect, which link the units of voltage and of resistance to fundamental constants. Using quantum effects electric units can be reproduced with an accuracy that cannot be achieved with common procedures. At PTB's clean room facility, the Electricity Division develops and manufactures quantum standards for voltage and resistance for applications in DC and AC metrology. This work is aimed at making quantum standards increasingly applicable to the representation and dissemination of the electric units over extended ranges of values and frequencies.

For the measurand "voltage", the work is focused on the development of programmable binary and pulse-driven Josephson junction arrays to generate arbitrary waveforms with fundamental accuracy. PTB has successfully developed a technology for the fabrication of programmable binary Josephson junction arrays with 10 V output voltage. Using this so-called "SNS technology" a high fabrication yield is achieved. Current work using the Josephson voltage standards aims at the realization of the impedance scales and at the dissemination of the unit of voltage at technical frequencies. The latter is being dealt with together with partners from industry within the scope of a technology transfer project.

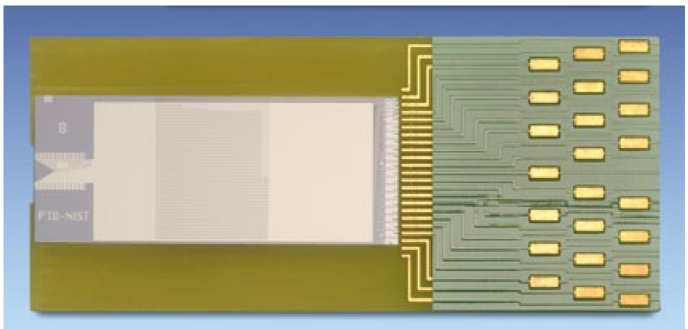
The quantum Hall effect is established for reproducing the DC resistance linked to the elementary charge and Planck's constant. For precise AC applications of the quantum Hall effect, PTB has developed a special shielding technique for quantum Hall resistors in order to suppress disturbing effects which would preclude precise measurements. Using a special measuring bridge, the capacitance can now be traced back to the AC quantum Hall effect with an uncertainty which is better than that of the conventional capacitance realization. For this reason, PTB's capacitance scale will, in future, be derived from this quantum capacitance.



Support holder for two shielded quantum Hall resistors which represent the core of a quantum standard for capacitance. The diagram shows the quantum steps of the quantum Hall resistor.



Molecular beam epitaxy machine used to manufacture semiconductor quantum standards such as quantum Hall resistors.



Programmable Josephson voltage standard in SNS technology with 70 000 Josephson junctions and an output voltage of 10 V.

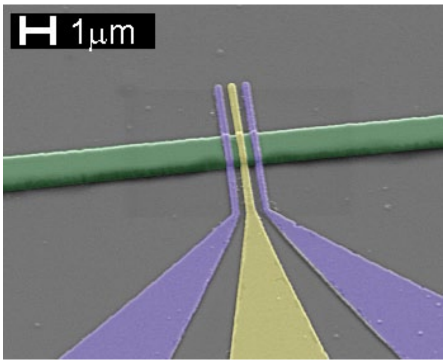
Implementing the New Definition of the Ampere

The Metre Convention envisages re-defining the SI base unit ampere on the basis of the elementary charge. PTB is developing quantum current standards to enable the implementation of the re-definition. For practical reasons, their currents must lie in the nA range.

In quantum current standards, single elementary charges are transported through mesoscopic circuits at frequencies in the GHz range. Semiconducting single-electron pumps have turned out to be a very promising approach with regard to the operating frequency, to their error rate predicted by theory and to the requirements placed on the operating conditions. PTB is currently optimizing the transport of electrons through a single transport channel. Moreover, other efforts aim at parallelizing several channels in order to increase the current.

In order to independently determine the error rate for the transport of single elementary charges with low uncertainties (better than 10^{-7}), highly sensitive, quantum-limited electrometers are being developed to detect single elementary charges. These single-charge detectors are designed to be combined with the quantum current standards. Such a combination represents a "self-referenced" quantum current standard with integrated error detection and is therefore a direct "source-based" implementation of the new definition of the ampere.

A quantum amperemeter is currently being developed as a measuring instrument for the practical implementation of the new definition. With this instrument, measurements of the current are traced back to the measurement of Josephson voltages over quantum Hall resistors. ■

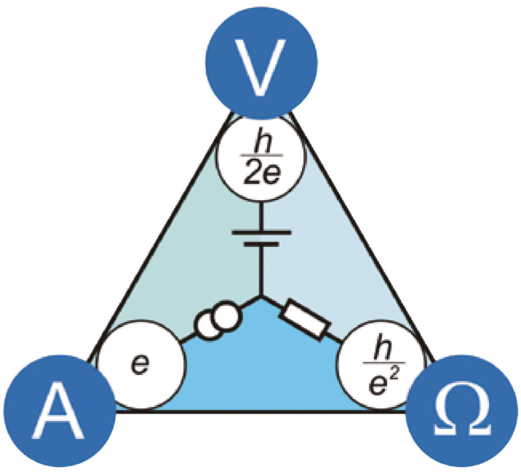


Electron microscope image of a semiconductor single-electron pump: transport channel (green), gate electrodes (violet, yellow).

Fundamental Quantum Experiments

Fundamental quantum experiments have to be carried out to validate the future system of units which will be based on fundamental constants, such as the elementary charge and Planck's constant.

In the field of electrical metrology, PTB's work aims at scrutinising whether the description of the Josephson effect, of the quantum Hall effect and of the single-charge transport by the elementary charge and Planck's constant is consistent. For this purpose, a Josephson voltage, a quantum Hall resistance and a single-electron current are compared in the so-called "quantum metrology triangle". In this experiment, the voltage drop which is caused by a single-electron current when passing through a quantum Hall resistor is compared with the Josephson voltage which is expected if the currently used description of the quantum effects is absolutely correct. From this comparison, upper limits of any discrepancies can be determined. An uncertainty of better than 10^{-7} is aimed at in this experiment. To reach this ambitious goal, all components of the quantum metrology triangle have to be characterized with high accuracy prior to the experiment – which represents a great experimental challenge, especially for the single-electron current source. ■



Quantum metrology triangle illustrating the links between electric units and fundamental constants (*e* is the elementary charge, *h* is Planck's constant).

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The Electricity Division is responsible for realizing and disseminating the electric and the magnetic units. To this end, the Division carries out research and development work in the field of precision electromagnetic measurements. This work is based on nanotechnology, which is adapted to the requirements of electric quantum metrology to allow the in-house manufacturing of superconducting and semiconducting quantum standards. The Division carries out fundamental investigations of quantum phenomena in solids to provide the basis for tomorrow's electric metrology.

The electric and the magnetic units are disseminated to calibration laboratories of the German accreditation body (DAkkS), to industry, to verification authorities of the German federal states, to state-approved test centres for measuring instruments for electricity, and to universities and research institutes. The Division renders consultation to political stakeholders, to society and to the economy with regard to electricity-measuring techniques. Furthermore, industry is supported in solving metrological problems within the scope of technology transfer projects. ■

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