PTBnews
Metrology
Technology
Services
Cooperation
05.1

10 million electrons for a capacitance standard

PTB has developed a highly precise quantum standard based on the fundamental constant *e* (electric charge of one electron). It will be deployed in practical applications as a quantum capacitance standard. However, the new device will also play an important role in a new definition of basic units in the future. Heart of the standard device is a counter circuit for single electrons. The counter utilizes a new method to minimize counting errors. The method was developed by PTB and successfully tested for the first time.

The electrical repulsion of electrons in circuits with tunnel junctions of size in the nanometre range can be exploited to detect and count single electrons at low temperatures. However, in controlled tunneling of single electrons through a chain of small metal islands, errors occur because, for instance, some electrons will "slide" through the entire chain quasi in one step – even at temperatures as low as 50 mK.

Unlike the American NIST which is attempting to use a long chain to create a new charge standard, the novel PTB electron counter rather uses specifically developed microscopic metal film resistors at the end of the chains to minimize the counter errors. The counter works with a clock frequency of 2 MHz and delivers a mean electrical current of 0.32 pA.

Applying controlled single electron transfer to create a current standard is not feasible because of the very low current. However, it can be used to create a capacitance standard. For that purpose the electrons are accumulated, i.e. collected in a capacitor. This under great expenditures recently developed low temperature capacitor with a capacitance of 1 pF is the second important component of the new standard. Charging the capacitor with exactly one million electrons yields a voltage of over 1 Volt which can be readily compared with a quantum standard for voltage at extremely high accuracy.

With a given number of electrons and the corresponding charge $Q = n \cdot e$ the capacitance C is determined with high accuracy. So, in practice, one has an applicable quantum standard for electrical capacitance, based on its fundamental definition $C = Q/U$. The relevance of the standard for a new definition of basic units lies in the fact that in an alternating current of frequency ω the capacitance C appears in the resistance $1/(\omega \cdot C)$, which can be compared with a resistance, R, based on a quantum standard. By this means a possible new definition can be covered by internal consistency tests with three different quantum standards.

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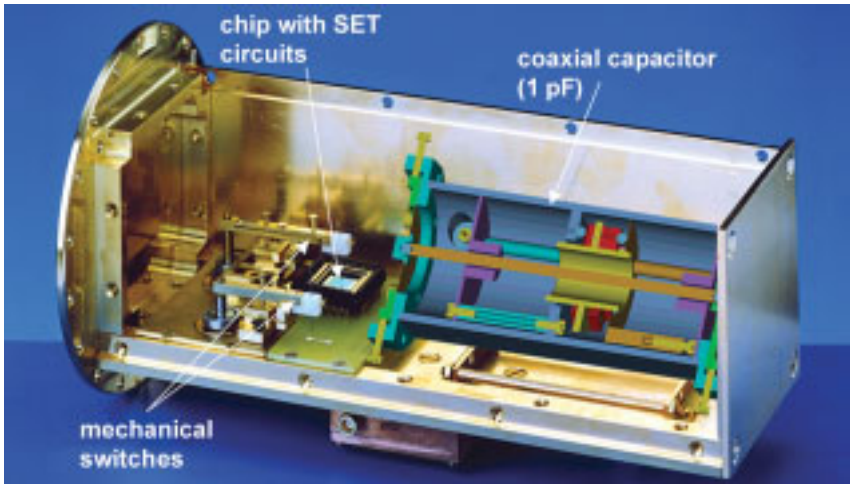

Sample box for the quantum capacitance standard with single electron (SET) circuits and low temperature capacitor for operation in a dilution refrigerator.

High-resolution sampling of ultrafast optical data signals

In future optical telecommunication systems bit rates of up to 640 Gbit/s will be achieved. For timely provision of the measurement technology needed to characterize the employed system components PTB has developed an ultra fast optical sampling oscilloscope with a temporal resolution below 100 fs.

As a consequence of the steadily increasing bandwidth requirements for world-wide telecommunications systems, not only the transmission via glass fibres, but also the data distribution in routers and switches will be all-optical. Laboratory applications in optical time division multiplexing today already achieve transmission rates of up to 320 Gbit/s. New ultra fast optical measuring techniques will become necessary.

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High–resolution sampling of ultra fast optical data signals (Continued fom page 1)

Hitherto deployed electronic sampling oscilloscopes with a maximal bandwidth of 80 GHz are no longer suitable for future highest-bit-rate systems. Optical sampling oscilloscopes, on the other hand, are suited. In these the light signal is not directly transformed into an electrical signal by a photodetector but first probed with very short light pulses at a low repetition rate. By means of a nonlinear optical process the product of the momentary data signal and the sampling pulse is formed. Repetitive scanning of the data signal at different points in time subsequently yields a highly-resolved image of the time dependent course of the signal.

Precondition is that the sampling pulse is synchronized with the data stream. The PTB optical sampling oscilloscope exploits techniques developed by PTB for high-precision time and frequency measurements. It utilizes a novel synchronisation method with unique properties. In result a temporal resolution below 70 fs is achieved. The timing instability amounts to a few femtoseconds.

Need for such optical sampling oscilloscopes is also found in the diagnosis of ultra short pulses, for instance, in femtochemistry.

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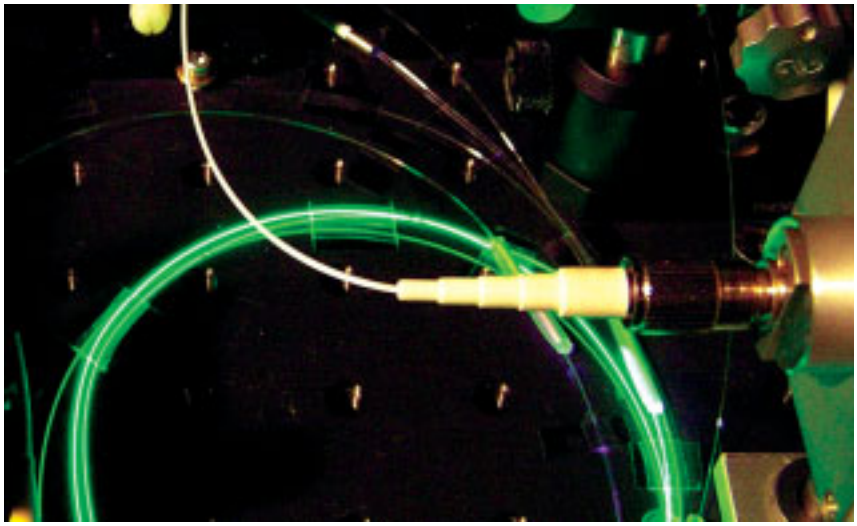


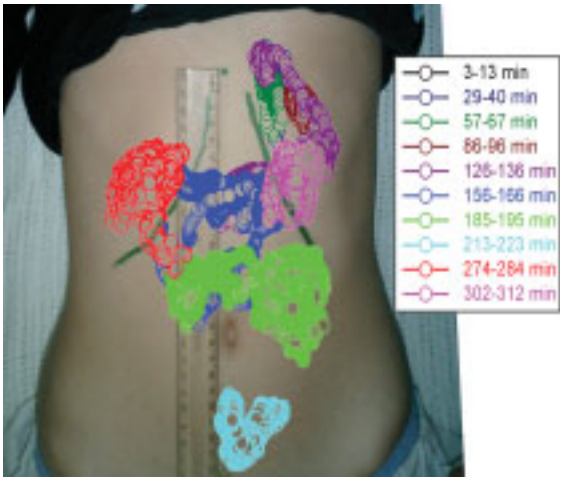
The probe laser: an Erbium-doted fibre laser that delivers 70 fs probe pulses.

Dissolution of tablets in the gastrointestinal tract made visible

In order to optimize the delivery of the active substances of a tablet you should know where and when the tablet dissolves. At PTB a new method has been developed to monitor the path of a tablet during dissolution in the gastrointestinal tract without subjecting the patient to additional stress. In cooperation with the international pharmaceutical company AstraZenecea various types of medication have now been tested for the first time.

The basic concept of the procedure is to mix magnetic powder particles in the tablet. These particles are readily used as colour pigments in foods. The tablet is subjected to a strong magnetic field to create a permanent magnetization of the particles in the pill. After the tablet is taken the state of dissolution of the pill is given by the strength of the permanent magnetic moment.

This process is monitored by the 63-channel SQUID-array that PTB operates for medical diagnostics in its laboratory at the Charité medical clinic in Berlin. The two-dimensional flat array is held at –269 °C in a helium Dewar in close distance above the abdomen of the volunteer. Position and strength of the magnetic moments are calculated from the measurement data with high precision and good time resolution. The method is contactless and without any health hazard. It is therefore suitable for mass surveys to obtain statistical statements on the dissolution behaviour of drugs in the human body.



Path of a tablet from the stomach through the duodenum, small intestine and colon, presented in distinguished colours for different time stages. The entire transport time until final dissolution displayed here was approximately 5 hours.
The investigation was carried out in cooperation with the enterprise AstraZenica, the Institute for Pharmaceutics of Ernst-Moritz-Arndt-University Greifswald, and Charité campus Rudolf Virchow.

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Robust optical profiler

The fabrication of high-precision optics and mechanical precision stages requires a demanding metrology. For this purpose, an optical profiler based on angle measurement has been developed at PTB with the aid of which a measurement uncertainty of the topographic measurement of 1.5 milli arc seconds has been achieved.

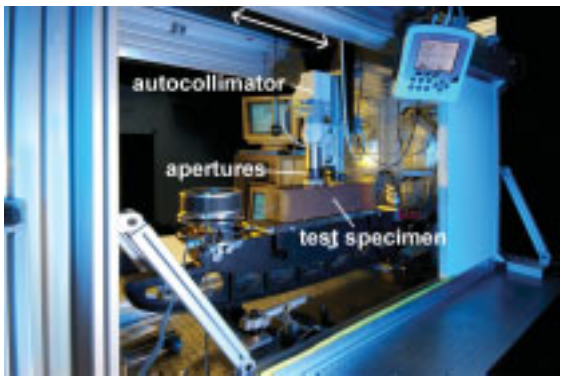
Today, the fabrication and subsequent form correction of optically polished surfaces with dimensions larger than 300 mm is possible by advanced local processing methods. The resolution of the respective procedures is better than 1 nm in the removal; laterally, it amounts to up to 1 mm. The accuracy achievable is limited by the accuracy of the correction data which must be metrologically acquired.

At PTB, a procedure and a measurement device have been developed which are in a position to work steadily in a manufacturing environment. In the measuring system, a commercial electronic autocollimator determines the angle between its optical measuring beam and a back-reflecting surface. The autocollimator was modified by the manufacturer in a way that the angle difference between elements of a reflecting surface, when segmented by apertures, can be read out. The sensor head equipped with a threefold diaphragm allows two angle differences to be simultaneously measured.

For the measurement, the sensor head is guided at a short distance along the surface to be measured by a conventional stage in a way that disturbances of the ambient air cannot occur. With the aid of a procedure patented for PTB, the complete angular information can be reconstructed from the two angle differences measured along the specimen. This allows reproducible results to be achieved even under unfavourable ambient conditions such as building vibrations or air circulation which are limited only by the long-term stability of the autocollimator. This stability lies clearly below the measurement limit of single milli arc seconds as measurements performed on the angle comparator of PTB (cf. PTBnews 03.3) have shown.

Even for the measurement of free-form surfaces, this procedure does not require any form reference, but only calibration of the zero point of the angle differences which is, for example, performed by means of a flat reference plate. The topographic height profile results from the integration of the angle over the length.

The device was used to measure the central track of flat test specimens made of Zerodur with lengths up to 620 mm. Determination of the height topography in comparison with the result of an alternative instrument (cf. PTBnews 02.3) showed a maximum systematic difference of $1 \cdot 10^{-9}$ m after subtraction of the mean curvature. Here, the measurement uncertainty amounts to 1.5 milli arc seconds ($7.3 \cdot 10^{-9}$ rad).



The new profiler allows test specimens up to one metre in length to be measured within 20 minutes per individual measurement.

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Universal calibration device for simple length measuring tools

Now, a universal calibration device is available for the control of inspection equipment in production measurement technology. Special merit is the low measurement uncertainty, even under shop floor conditions and a continuous range of nominal values from 0 mm to 300 mm.

Inspection equipment monitoring is an indispensable part of quality control in production. Hand-held measuring equipment for length measurements (micrometer gauges, callipers and dial gauges) are regularly tested by comparison with solid measures like slip gages and ring gages. Therefore multiple solid measures must be held which are associated with high costs. In addition, the testing measures often do not cover the measurement range for which the particular hand-held measuring device is used in sufficient manner.

A universal calibration device with a linear slide unit, on the other hand, offers a continuous application scale and can substitute various solid measures. Such a calibration device was developed in a new international project lead by PTB and funded by the EU. Heart piece of the calibration device is a diode laser interferometer. A measurement slide is integrated to accommodate the measuring device to be tested. The slide has a three-speed manual drive with 0.1 µm step size. It is positioned along a 300 mm guide way. The device is particularly robust and easy to transport.

A particular challenge was to construct a special laser interferometer. In general, the uncertainty of a

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Universal calibration device for simple length measuring tools (Continued from page 3)

practical interferometric length measurement is essentially determined by influences of the temperature of the measurement object, and the refractive index of the air. These influences were to be compensated. This was achieved by applying a diode laser tuneable over an extended wave length range. The wavelength of the laser was dynamically adjusted to the environmental conditions. This was achieved by stabilizing the laser frequency on to the transmission maximum of an open Fabry-Perot-interferometer. The hitherto required sensors to determine the environmental conditions are thus superfluous.

With one single calibration device a wide spectrum of hand-held measuring devices can be precisely calibrated with ease on a length scale up to 300 mm. Depending on the particular measurement device an uncertainty of at most $1\ \mu m + 10^{-5} \cdot L$ (L: length) has been achieved even under shop floor conditions. Presently, the measuring system is undergoing further development to become an interferometer for absolute measurements. This will facilitate practical applications even further.

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New routes for technology transfer

In October 2004 ETALON AG was founded – a spin-off enterprise that will initially reside on the PTB site. In roughly three years the company will move to a new location outside PTB. The goal of ETALON is to enable and foster optimal technology transfer of two developments of the department "Coordinate Metrology": an internet-based system to control measurement instruments in industry and a novel procedure to collect and correct deviations of measuring and manufacturing machines. Besides two PTB employees two regional medium-sized-enterprises joined the founding of the enterprise. So far, two new full-time jobs have been created.

Further information see www.etalon-ag.com

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ECG process control via internet

Based on a signal pattern databank developed by PTB a procedure has now been created for evaluation and process control of ECGs (electrocardiograms) via the internet.

In between October 2002 to October 2004 PTB and the company "getemed-Medizintechnik" in Teltow developed a "demonstrator solution" to monitor and evaluate ECGs via the internet within the framework of a BMBF project. The new solution was tested with three clinical partners in Berlin (Charité, Jewish Hospital, Cardio logical practice Rankestraße).

Basis for this demonstrator solution was a method developed at PTB to evaluate and control the course of ECGs by means of signal pattern recognition. The method relies on a large signal pattern data bank with approximately 24000 ECGs. An ECG to be examined is compared with all ECGs in the databank with respect to its signal pattern. An updated diagnostic finding is derived from the diagnostics and other information stored under the most similar ECGs in the databank. In particular, this method can calculate a quantitative diagnostic progression on the base of earlier stored ECGs of the same person in the databank. The calculated progression can make a prognosis of the course of an illness.

Special client-server-infrastructure was set up for this project. At the project partner getemed an ECG evaluation server was set up. That server contained the signal pattern database and the evaluation algorithm. The server was connected to the internet via a firewall.

The participating medical doctors evaluated functionality and practicability of the solution achieved in the project in a concluding discussion. They assessed the cardio logical ECG evaluation as excellent. The procedure was patented internationally.

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