A high-precision view of the sun

On board the International Space Station ISS, the solar-spectroradiometer SOLSPEC has been measuring the spectral irradiance of the sun since February of this year. Its high accuracy has been guaranteed by the calibration at a high-temperature cavity radiator at PTB.

In February 2008 the space shuttle Atlantis transported the European space module Columbus to the International Space Station ISS where it was installed. The external platform SOLAR with different facilities for solar observation was also on board. Here, the solar-spectroradiometer SOLSPEC is the central measurement station, with which the spectral irradiance of the sun from the UV spectral range to the near infrared will be observed continuously over a long period of time. Before take-off, this instrument stopped by at PTB for its absolute calibration.

The international SOLSPEC team used the calculable spectral irradiance of a PTB high-temperature cavity radiator for its measurements. At radiator temperatures around 3100 K with high temperature stability (drift < 0.2 K/h) and an expanded temperature measurement uncertainty of only 1 K, the team could precisely determine the spectral irradiance and calibrate SOLSPEC with the highest accuracy.

The achieved uncertainties of this second version of the SOLSPEC experiment are therefore clearly lower than those of its predecessor, which provided reliable and precise measurement results during space missions in the 1990s. In the meantime SOLSPEC has started its work which is planned for 15 months and is observing the sun.

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Measuring forces in the mN range

Very small forces are measured and generated ever more frequently in various technical areas of application. Examples of this are tactile measuring probes in precision engineering and actuators in micro-assembly as well as applications in medical products, such as in insulin pumps and functional catheters. PTB has developed and put into operation a new standard measuring device based on electromagnetically compensated load cells for the force range from 1 mN to 2 N.

The essential components of the new measuring device are an electromagnetically compensated load cell as well as a piezoelectric actuator, which simultaneously applies the test loads to the load cell assembled above it as well as to the force transducer to be calibrated which is assembled below it. The test piece is thus operated in its normal position. To avoid additional transverse forces the action of forces on the test piece takes place via a horizontal decoupling; furthermore the transducer is positioned so it can be adjusted according to the piezo actuator. To be able to generate the test loads in a defined way, the adjustment travel of the piezo actuator has to be regulated with a resolution of better than 1 nm to the load cell signal, because of the high mechanical stiffness of the sensor. Very high demands on the thermal and mechanical stability of the components necessary for the measuring device result from this, in particular of the mounting frame which is variable and adjustable in height.

Up to now, an electromagnetically compensated load cell with a maximum range of 2 N and a resolution of 0.1 µN has been used in the new measuring device. An extension to load cells with a maximum range of 12 N or 0.2 N is planned. With the load cell used, force steps from 2 N down to 1 mN seem possible, as a measurement uncertainty below 1 µN has been achieved. The uncertainty is thereby in part itself influenced by the characteristics of the transducer, such as for example its long-term stability, its temperature dependence and its sensitivity to the mounting conditions.

Through the new standard measuring device, the force scale of PTB has been extended to small forces of up to 1 mN. Suitable force sensors can now be calibrated with uncertainties in the µN range. For

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The quantum Hall effect in a twin pack

The technological basis for quantum circuits to realise decade resistance values is expanded through the vertical integration of two conducting layers positioned one over the other in a novel semiconductor structure.

Like the volt, the resistance unit ohm is reproduced by a macroscopic quantum effect which is only dependent on the fundamental constants \( h \) and \( e \). For the ohm, this is the quantum Hall effect (QHE) which occurs in ultra-thin conductive layers, so-called two-dimensional electron gases (2DEG) at high magnetic fields. The quantum standards developed to date made of gallium arsenide semiconductors now furnish the precise resistance value of \( \frac{h}{2e^2} \) (at 12 906 ohm), but this has to be transferred with difficulty to the decade resistance scale necessary for practical applications by means of measuring bridges. Work is therefore being undertaken throughout the world to establish a direct decade quantum ohm scale made of parallel and series circuits of quantum Hall elements on one chip.

In the Clean Room Centre of PTB, a double 2DEG structure has now been developed, with which the integration of parallel circuits is now simpler. A novel crystal contains, instead of the usual single conductive layer, two layers positioned one over the other. In order to get a certain resistance value, only half the number of parallel Hall elements have to be integrated. The challenge during development was controlling the growth of the crystal in layers in such a way that both layers have almost the same electrical characteristics. Only then do they have the same working point, and the necessary accuracy of the quantised resistance value is also achieved for the parallel circuit.

Precision measurements at the new double 2DEG structures have impressively shown that this goal has been reached. The measured resistance value agreed to the theoretical value within an accuracy of \( 10^{-9} \). A double quantum Hall circuit is, as such, just as precise as a conventional quantum standard with only one layer.

In future, integrated parallel circuits are to be made from the double layers, which will expand the quantum resistance scale below 12 906 ohm. Through the double 2DEG, the number of individual elements will be halved, the size of the chips will fall to the same extent, and the frequency of errors in producing circuits will be reduced.

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EMC testing on measuring systems on site

Complex measuring systems, for example vehicle scales, can occasionally be disturbed by radio receivers or even mobile telephones, even though the standard requirements for electromagnetic compatibility (EMC) of the systems have been complied with in the laboratory. In order to be able to assess the interference resistance of such systems under the actual operating conditions, an on-site testing device has been developed.

The legal requirements for measuring devices subject to legal control also include the EMC, which is tested within the scope of the type examination by PTB. Hereby, the single components of the measuring system are exposed to defined electromagnetic fields in the laboratory. Although the components have passed an EMC test conforming to standards, the measuring systems installed on site are occasionally disturbed by radio receivers or mobile telephones such that false measurement values are shown. For this reason, the responsible authorities have in several cases rejected the verification of vehicle scales.

The awareness that the interference resistance of measuring systems is very decisively dependent on the configuration and the installation on site has not been sufficiently taken into account in the normative requirements. This discrepancy is based on the
EMC testing on measuring systems on site
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fact that the European testing requirements worked out several years ago do not sufficiently take into account the actual present-day disturbance source situation due to the spread of radio receivers and mobile telephones. Due to this technical requirement and also the possible political consequences, a revision of the respective standards was initiated in which the PTB is participating. For the determination of new normative limiting values and for the assessment of the interference resistance of measuring devices on site by the verification authorities, metrologically traceable EMC tests on site are necessary, for which there has not been a measuring device available up to now.

For this reason, a transportable testing device was developed at the PTB, which enables testing at discrete frequencies between 27 MHz and 5.8 GHz.

The frequencies were selected such that, on the one hand, the real disturbance sources are displayed and, on the other hand, the disturbance of radio services is avoided, so that as a result, the Federal Network Agency could grant a special permit for the restricted test operation. The frequencies of the testing device lie in the vicinity of the frequency bands of classical means of communication such as company radio and amateur radio, but also in the vicinity of the frequency ranges of modern communications systems such as GSM, DECT, UMTS, Bluetooth and WLAN. In the test operation on site, the critical parts of the measuring system can at a distance of 1 m from the transmitting antenna be charged with the electromagnetic field successively for 1 min in each case for each single frequency and thereby the correct function of the measuring system.

THz radiation measured absolutely for the first time

Longwave terahertz radiation enables new, harmless methods of security check in tourist travel. Essential for this is the quantitative measurement of the radiation. With cavity radiators developed at PTB, which provide the calculable THz radiation for absolute measurements, it was possible for the first time to absolutely determine the spectral responsivity of THz receivers.

Radiation in the THz range (with wavelengths from 30 µm to 3000 µm and frequencies from 0.1 THz to 10 THz) penetrates clothing and many other organic materials and furthermore offers spectroscopic information on safety-relevant materials such as explosives and pharmacological substances. The broad spectrum of the possible applications extends from security check to the investigation of the spatial and/or time structure of the electron packages in the storage rings for synchrotron radiation production and in free-electron lasers, for which the receivers of the German Electron Synchrotron DESY characterized here are used.

The complete information on the THz spectra can only be determined with detectors of known spectral responsivity. Up to now, the integral responsivity of the respective detectors and their spectral distribution are still largely unknown. The PTB has now for the first time determined the spectral responsivities of two THz detectors in the wavelength range from 50 µm to 600 µm with the aid of cavity radiators.

In order to make available spectral radiation fluxes in the THz range, calculable according to Planck’s radiation law, the PTB uses two THz cavity radiators at different temperatures in connection with THz band and longwave-pass filters. The interior surfaces of the radiators are provided with a special coating which possesses a known and high emissivity also in the THz range and thus enables the calculability of the radiation incident on the detector. In order to obtain a sufficiently spectral purity of the THz radiation, a suppression of the infrared radiation of more than nine orders of magnitude is necessary.

By using an FT-IR spectrometer, the transmittance for all filter combinations used was accurately determined in the wavelength range from 0.8 µm to 1700 µm. Due to the calculable radiation of the cavity radiators and the known transmittance of the filters, it is possible to accurately determine the spectral radiation fluxes and thus determine the spectral absolute responsivities of THz receivers for the first time. Such absolutely characterized receivers will in future be utilized, e.g., both at the Metrology Light Source of the PTB to investigate the THz radiation produced there and in the investigation of the effect of THz radiation on the biological cell cycle.

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The THz filters consist of layers of copper webbing with a defined spacing and defined structuring.
**Fighting tumour with the correct dose**

With three new electron accelerators, the PTB is expanding its measuring capabilities for dosimetry in radiation therapy. The Richard Glocker Building, which was dedicated on 11th July and which houses the new accelerators, offers unique conditions both for practical measurements as well as for fundamental experimental questions. With two therapy accelerators, the type of which is used also in clinics, and an 11 meter-long linear accelerator, photons and electrons can be produced in the energy range from 0.5 MeV to 50 MeV. With it, dosimeters and measuring methods can be investigated under any conceivable, practical irradiation conditions. This was one of the essential conditions for the design of the facility, because in view of the continually growing progress of the medical irradiation methods, the demands made on dosimetry are growing at the same time.

**Metrological Research in a joint European cooperation**

The starting signal has been given for a joint research programme of the national metrology institutes in Europe. The European Commission is initially funding 21 joint research projects with durations of between three and four years. Of the total volume amounting to 64 million Euros for all research projects, the EMU is covering approximately one third. The remaining funds are carried by the national research partners from a total of 20 European states. The PTB is participating in a total of 20 of the 21 research projects and is assuming the role of coordinator in seven of these projects. These 21 projects form the “vanguard” for a large-scale European metrological research programme (European Metrology Research Programme, EMRP) which is to be presented yet this year by the European Commission as a measure within the scope of Article 169 of the EC Treaty. The research volume estimated for this EMRP amounts to approximately 400 million Euros and 50 % would – in the case of success – be financed from EU funds. A decision, which in the end will be made by the European Parliament and the Council of Ministers, is expected in the coming year.

**Synchrotron storage ring put into operation**

It is intensive, of high brilliance and its spectrum can be calculated exactly: the synchrotron radiation of the “Metrology Light Source” (MLS) of the PTB. These and a number of further characteristics make it exceptionally interesting for broad application in science and technology. On 23 June, the PTB put its own low-energy storage ring for the production of synchrotron radiation, the MLS, in Berlin-Adlershof, into operation. It is optimized for the spectral range between the extreme ultraviolet (EUV) and terahertz radiation which is continuously available at only a few sites worldwide. This spectrum is suited, for example, to applied research in the field of EUV lithography for the production of computer chips of the next generations and in the field of terahertz technology which will in future play an important role in safety engineering and materials testing.

**Successful start for International Graduate School of Metrology**

The PTB and the Technical University of Braunschweig have together within the past year launched the Internationale Graduiertenschule für Metrologie (International Graduate School of Metrology), IGSM – with the aim of concentrating the diverse activities of TU and PTB for the education of candidates for a doctor’s degree in the broad field of metrology. Now after two semesters, the project shows an impressive result. What is offered extends from research work in the laboratory, to join courses in English, and beyond to internships in industry. And also the travel funds for attending conferences, made available by the State of Niedersachsen (Lower Saxony), as well as the full-time scholarships for students from all over the world has met with great interest. In case of successful evaluation of the previous work of the IGSM, the State of Niedersachsen (Lower Saxony) will extend the funding so that TU and PTB will be able to continue their joint activities within the scope of the IGSM in the next few years.