PTB news
Metrology
Technology
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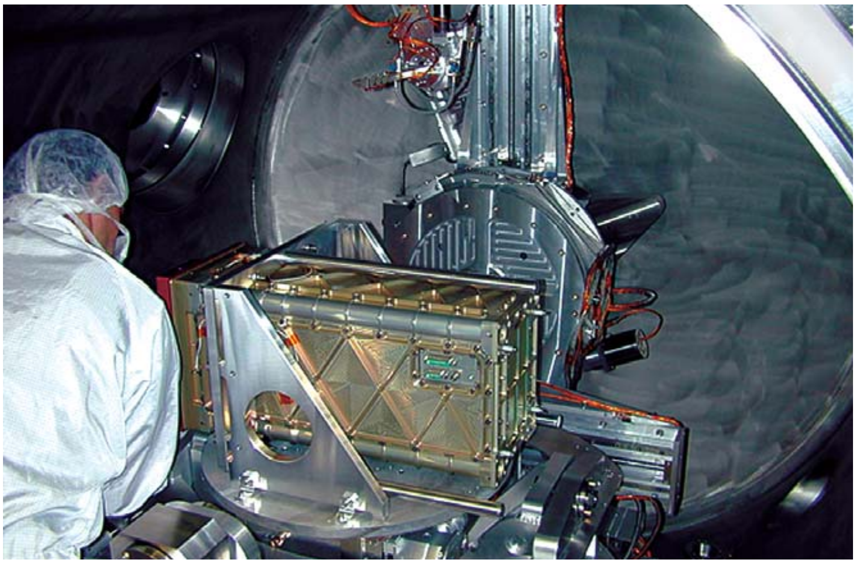
07.1

ISS instrument characterized at BESSY

On the International Space Station ISS, at the end of this year, quantitative measurements of solar radiation with as yet unattained accuracy – above all, in the wavelength range from 17 nm to 220 nm – are to begin. The measuring instrument developed for this purpose has been characterized by the PTB in its radiometry laboratory at the Berlin electron storage ring BESSY II.

The solar observation instrument SolACES (Solar Auto-Calibrating EUV/UV Spectrophotometers) for the short-wave spectral range is a component of the scientific instrument package SOLAR for the ISS. SolACES was developed under the auspices of the *Fraunhofer-Institut für Physikalische Messtechnik* (IPM) in Freiburg and is composed of two double spectrophotometers for the spectrally resolved detection of the incident EUV/UV radiation as well as two ionisation chambers with whose aid auto-calibrations are to be conducted regularly during the flight in order to reliably detect the unavoidable changes in sensitivity of the spectrophotometers. Thus – as the scientific priority objective of SolACES – the measurement of the spectral EUV/UV radiant flux of the sun which constitutes the main energy source of the Earth's upper atmosphere, is to be achieved with an as yet unattained low uncertainty of below 10 %. So far, the uncertainties have been at best between 20 % and more than 400 %. The more accurate measurement results are to also particularly enable the improved prediction of the influence of the so-called space weather on the paths of satellites and space debris as well as on satellite-supported telecommunication and navigation.



Installation of SolACES in the vacuum chamber of the EUV reflectometer system of the PTB at BESSY II

By means of the measurements in the PTB laboratory at BESSY II, which took place at two different beamlines within the scope of a research cooperation with the IPM, the radiometric basis for the aimed at measurement uncertainties was created. For this purpose, correction factors were determined for both of the ionisation chambers. Moreover, the transmission of the – all in all – 43 different thin-film metal and crystal filters and the spectrophotometer sensitivities were measured.

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Extremely rapid SQUID electronics

At PTB, supersensitive SQUIDs are being developed for the most diverse metrological applications. The most recent development, a cooled SQUID electronics, allows the setting up of extremely rapid SQUID measuring systems.

SQUIDs (Superconducting QUantum Interference Devices) are generally used for the sensitive measurement of small magnetic fields, but may very well also be used for the measurement of smallest currents. Thus, they are used, e.g. in medical diagnostic systems for the detection of the magnetic signals of the heart or the brain or as preamplifiers for certain types of radiation detectors such as microcalorimeters, which are operated at low temperatures as are the SQUIDs themselves. In addition to the SQUID chip, the superconductive, integrated sensor circuit, which is normally cooled with liquid helium, one requires readout electronics which amplifies the SQUID output signal at a low noise level and "feeds it back" into the SQUID as magnetic flux, so that the periodic flux voltage characteristic of the SQUIDs is linearised. In this way, the dynamic range of the SQUID which otherwise constitutes only fractions of a magnetic flux quantum, is extended to 10 to 100 flux quanta needed for typical applications. The flux-locked loop (FLL) thus set up determines the bandwidth of the sensor system. By using modern commercial FLL electronics, it has been possible up to now to attain closed-loop bandwidths up to 20 MHz. The bandwidth limitation results thereby from the signal propagation on the connection lines between the SQUID chip – which is located in the helium bath of a cryostat – and the electronic unit which is usually mounted at a distance, on the cryostat cover. Distinctly reduced

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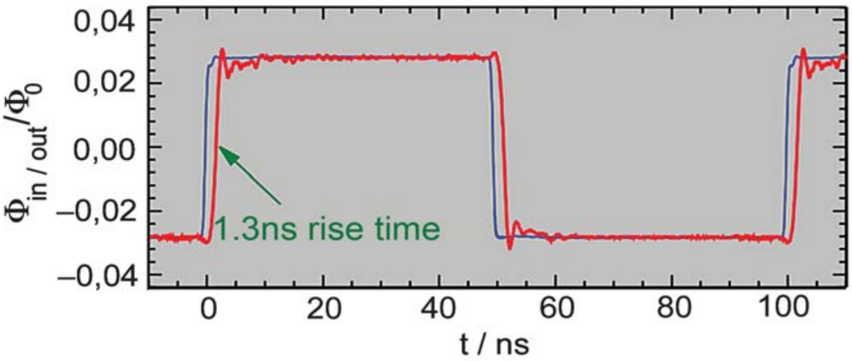
Extremely rapid SQUID electronics *(continued from page 1)*

line lengths and thus higher bandwidths can be obtained if also the FLL electronics is operated in liquid helium in the immediate vicinity of the SQUID chip. That means, however, that the electronics must be rated for a temperature of 4.2 K, which entails considerable effort in the development of the circuit.

At PTB, an FLL circuit cooled with liquid helium has now been developed which has, when operating with a PTB SQUID sensor chip, reached a system bandwidth of 350 MHz and has opened new perspectives for special applications, e.g. in the signal amplification of superconducting hot-spot photon counters. The new electronics, too, is to be made commercially accessible to users.



Averaged small-signal step response of the SQUID electronics operated at 4.2 K. The blue curve indicates the applied magnetic flux which changes practically abruptly; the red curve represents the output signal of the system. With the high small-signal-bandwidth of 350 MHz, the short rise time of the output signal of only 1.3 ns is attained.

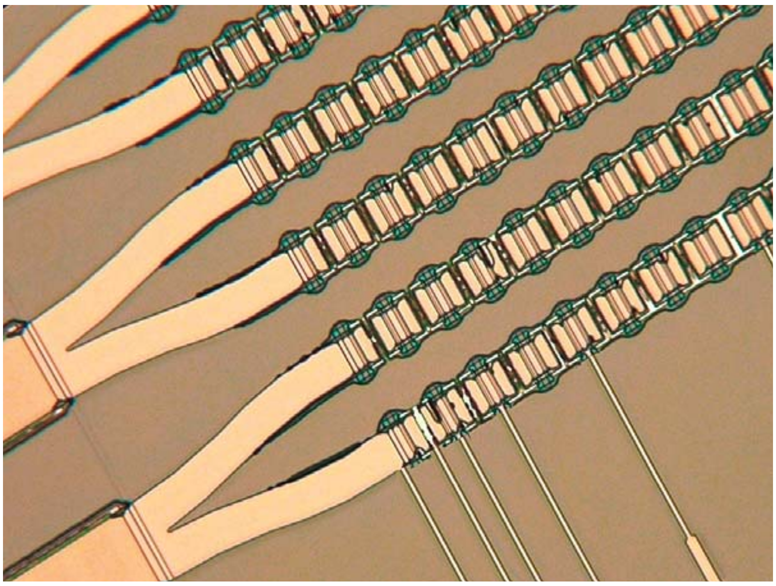
Quantum voltmeter for alternating voltages

The quantum voltmeter for alternating voltages conceived at PTB achieved already in the test phase an uncertainty of $5 \cdot 10^{-8}$ during the measurement of a 400 Hz signal, a value ten times lower than previously. The outstanding performance of superconducting quantum standards used so far for dc voltage calibrations has thus been extended for the measurement of alternating voltages.

In the low frequency range, alternating voltages are measured using sampling methods during which the time-varying voltage is measured repeatedly ("sampled") in rapid succession. The amplification factor and the internal voltage reference of the sampling voltmeter limit, however, the attainable uncertainty. This can in practice be completely avoided if the sampled voltage is directly compared with the voltage of a Josephson quantum standard, known at 1 V to better than 0.1 nV.

This idea is realised in a method developed and patented at PTB. For this purpose, alternating voltages are synthesised with programmable Josephson-series-arrays. A chip cooled down to the temperature of liquid helium contains 8192 superconducting tunnel elements – so-called Josephson junctions – supplied with a microwave frequency of 70 GHz. They are distributed over segments with 1, 2, 4, 8, 16 … junctions. Switchable current sources control the individual segments such that they produce quantised partial voltages which add up to the total voltage. A transition between quantised voltages requires less than 100 ns. Therefore, the slowly changing voltage to be measured can be compensated. If the two time-varying voltages and a sampling voltmeter are synchronized, the differences between the two alternating voltages can be measured with high resolution.

It is nowadays possible – with new programmable Josephson circuits, as yet only produced at PTB – to synthesise alternating voltages with amplitudes of even 10 V, making possible a range of additional applications. In particular, however, the attainable relative measurement uncertainty should, due to the greater signal-to-noise ratio, decrease by an additional order of magnitude.



Part of a Josephson-series-array. From the left, the microwave striplines appear; from below the control leads for the individual segments.

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Robot goniophotometers for measurement of the luminous flux

A worldwide unique goniophotometer with three long-armed robots has now been put into operation. With its newly developed photometer heads, it can detect simultaneously and in a spectrally integrating way photometric, radiometric and colorimetric quantities and at the same time relative spectral distributions by means of a CCD array spectrometer.

It is the task of PTB to distribute the "lumen" unit of the luminous flux, which is fundamentally derived from the SI base unit "candela" for the luminous intensity, on to industry. So far, for calibrations of the transfer standards used for this purpose, a goniophotometer in a fully gimballed suspension construction was developed in the 1970s and used at PTB. Metrological limitations and an outdated computer technology were the reason for a redesign, with which one also expected a reduction in the measurement uncertainties.

The goniophotometer of completely novel design – whose concept is protected by an international patent – was developed at PTB and has now been put into operation. It is composed of three robots, each having 7 controlled axes for moving the slim arms having a length of more than 6.40 m. One robot carries the light source in a freely selectable burning position, aligns it in the instrument center and holds it in position during the measurement. The other two robots each align a photometer head with the light source and divide the room into hemispheres. They can move on any paths at distances of 1 m to 3 m and with measurement periods of typically 10 min to 1 h. The orientation of the robots in the room as well as their kinematic characterisation is determined by means of a laser tracker system. This results in path deviations of the photometer head of < 0.6 mm, and on average only 0.2 mm. The movable photometer heads and a monitor-photometer head are each designed as a tristimulus colorimeter head with 4 channels. In addition, they contain an unfiltered Si-photodiode for radiometric measurements and a CCD array spectrometer. Thus, light, colour and optical radiation are measured through the same light-entry window, all photo currents are measured in parallel and converted to frequencies. This allows the simultaneous measurement of all 18 channels with synchronous triggering and any integration times whatsoever, optimally adapted to the motion sequences of the robots and the modulations of the light.

With the new robot goniophotometers, it is now possible to determine, in addition to the photometric, also chromaticity data of light sources at considerably reduced measurement periods. By using the freely programmable robots, nearly any measuring head paths and near- and farfield measurements whatsoever are possible. The ozone-proof version of the goniometer also allows, in addition, the measurement of UV lamps, and due to the adjustable temperature range of 25 °C to 35 °C, luminescent lamps can also be measured at the respective luminaire temperature.

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View inside the robot goniophotometer with an LED array as light source in the equipment centre and the two measuring robots in basic position. The group of people provides a size comparison.

Joint Optical Metrology Center

The TU Braunschweig and the PTB have founded the Joint Optical Metrology Center (JOMC). Scientists from the field of electrical engineering of the TU and the Optics Division of the PTB will in future work together in this consolidation on the research and development of optical metrology.

Within the JOMC, selected projects are to be worked on: from a novel idea and the evaluation of the suitable metrological concept to the realisation of a prototype. It is the vision of the JOMC to expand the limits of optical measurement technology and to establish new metrological applications, preferably in the visible and near-infrared. Frequency ranges previously unused in metrology will become accessible. The research in JOMC is to lead to innovative technologies and processes as well as to prototypes with novel properties at reduced production costs and standardised, validated behaviour. As initial focal points, the working fields quantitative detection and identification of nanoparticles, fluorescence labelling and identification in bio- and medical technology, gas sensors, quantitative detection of electromagnetic fields and quantum communication will be worked on.

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Novel DUV scatterometer ready for operation

A novel scatterometer for the dimensional characterisation of nanostructured surfaces has been developed and set up at PTB. It is used in particular in the deep ultraviolet wavelength range (DUV).

By means of a scatterometer, the diffracted or scattered radiation is analysed on a sample without employing imaging optics (objectives). The measurements are in principle not limited by the resolution limit of imaging methods which, in optical microscopy, lies in the order of magnitude of half a wavelength. Thus, scatterometry is particularly suited to the quantitative determination of the cross sectional profiles of periodically nanostructured surfaces.

The new scatterometer was so designed that as many characteristics as possible of the scattered radiation are detected. It enables the highly accurate measurement of the radiant power and the polarisation condition as well as the direction of propagation (diffraction angle). All scatterometric quantities of reflectometry, ellipsometry and diffractometry which are dependent on the angle of incidence can be measured with the new instrument. The complex evaluation allows the quantitative characterisation of the nanostructured surfaces also far below the resolution limit of optically imaging methods.

As radiation source, a titanium-sapphire laser system with frequency multiplication is used. In addition to the tunable fundamental wavelength of between 772 nm and 840 nm it is possible to access the 2nd, 3rd and 4th harmonic. In the DUV, there is thus a usable variable wavelength range of 193 nm to 210 nm available.

For the important lithography wavelength of 193 nm, the PTB can thus offer additionally so-called "at-wavelength-metrology". This comprises, among other things, polarisation-/depolarisation- and transmission-measurements (Müller-Matrix-measurements) on structured and unstructured samples. As a result of the very good agreement of first polarisation measurements with simulation calculations, the design parameters of a nanostructure sample could be confirmed.

Thanks to this highly automatic system, the PTB has now available a measuring device, unique worldwide, for the metrology of photolithographic masks of current and future technology generations.

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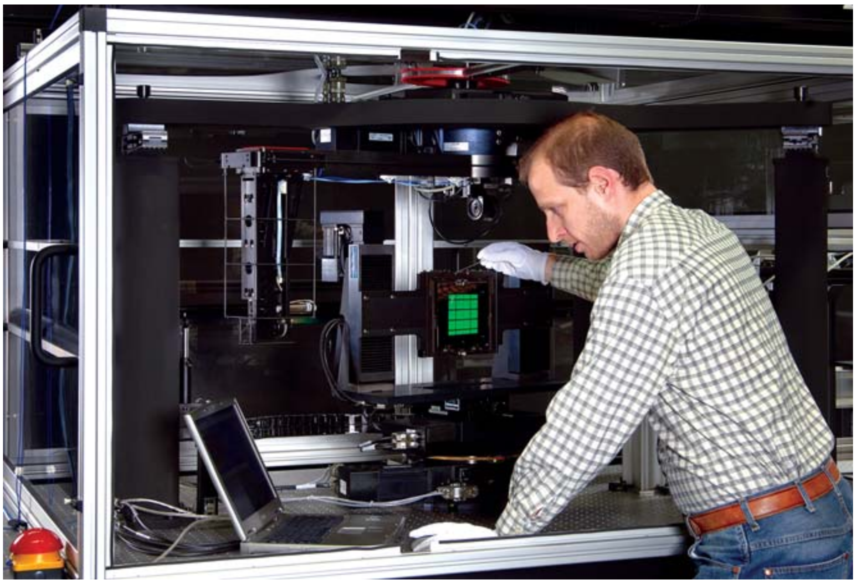

Installation and aligning of a lithography photomask (appearing green in the diffracted light) in the new DUV scatterometer.

Joint European Metrology

The national metrology institutes of Europe are now moving closer together within the field of research: On 11 January 2007, the first 26 institutes signed the memorandum of association of "EURAMET e.V." in a ceremonious act in Berlin. An essential goal of this association will be to develop a joint European Metrological Research Programme. Currently, intensive negotiations are being conducted with the European Commission with regard to substantial research funding.

The association EURAMET e.V., which is seated in Braunschweig and whose domicile is at PTB, will replace EUROMET (which has so far been the organisation of the national metrology institutes) and will now be a legal entity with considerably extended tasks and goals. It is intended to develop and coordinate a – so far unprecedented – European research programme of metrology – a programme which will then be implemented by the national metrology institutes. The individual competencies and resources of the institutes can thus be brought together.

The national metrology institutes are currently negotiating with the European Commission regarding research funding within the framework of Article 169 of the Treaty establishing the European Community. EURAMET is thereby one of four named candidates whose projects are on the Commission's shortlist. A decision is expected in 2008.

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PTBnews 07.1
English edition
April 2007
ISSN 1611-163X

Published by
Physikalisch-Technische Bundesanstalt (PTB)
Braunschweig and Berlin
Germany

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D-38116 Braunschweig
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Website: http://www.ptb.de/
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