PTB news
Metrology
Technology
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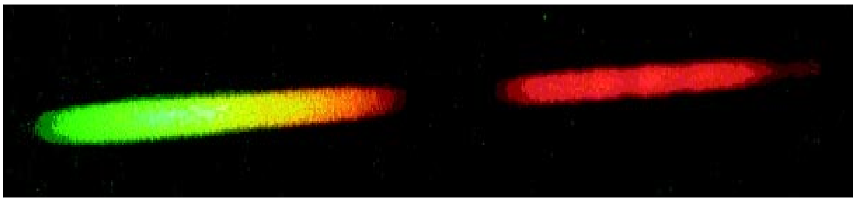
00.3

Optical Frequency Measurements Substantially Simplified

Lasers stabilised to atomic or ionic transitions may eventually lead to optical atomic clocks of unprecedented precision. PTB has developed an optical frequency measurement system that allows one to relate any optical frequency to the frequency of the primary standard of time, the Caesium atomic clock, with atomic clock accuracy.

The novel scheme is based on a femtosecond Titanium: Sapphire laser. It has been used for phase-coherent measurement of the frequency of an optical frequency standard with atomic clock accuracy. The use of such a single oscillator substantially simplifies the complex, bulky harmonic frequency chain employed so far at PTB and elsewhere for this purpose (see PTBnews 96.1). In the frequency domain, the pulse sequence of a femtosecond laser corresponds to a comb of frequencies which are separated by the pulse repetition frequency. The width of this comb which is given by the width of a single pulse is spectrally broadened in a novel type of optical microstructure fiber to cover the entire visible and near infra-red range. The frequency of any one of the comb lines can be obtained by measuring the line separation, i. e., the pulse repetition rate, and a second frequency that gives the position of the entire comb with respect to the frequency origin.



The output of PTB's femtosecond comb generator after spectral dispersion by a grating shows a rainbow covering large portions of the near infrared and visible part of the optical spectrum. The spectrum, which appears continuous in the figure, is in fact composed of a large number of closely spaced spectral lines with accurately known frequencies.

As a first application, the frequency of the Ca stabilised laser used as one of the most accurate realisations of the metre was re-determined. The result was found to agree with previous measurements. PTB now has a dense grid of millions of accurately known reference frequencies which can be used as a universal, self-referenced frequency ruler throughout the entire visible and near infrared spectrum.

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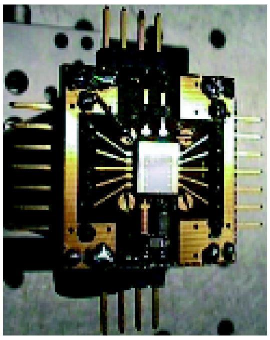
Picosecond Voltage Pulses



This electronic circuit contains the photoconductive switch in the centre. Laser pulses with a width of 100 fs are focused on the switch to generate picosecond voltage pulses.

Electronic devices operate at increasingly higher speeds, involving electrical transients on the picosecond time scale. To test these devices, voltage pulses of only a few picosecond duration are required as ultrashort trigger signals. At PTB, voltage pulses of 1,4 ps width can now be generated with semiconductor switches driven by femtosecond laser pulses.

Picosecond voltage pulses are generated in microstructures which are lithographically produced from semiconductor thin films. In these photoconductive switches, a semiconducting gap with a typical width of 10 µm is formed which can be electrically biased. If the semiconducting gap is illuminated by 100 fs laser pulses, free charge carriers are generated and an electrical current begins to flow. The use of special semiconductor materials with charge carrier lifetimes of only a few picoseconds ensures that the current rapidly decreases, giving rise to the generation of ultrashort voltage pulses. The temporal shape of the voltage pulses is measured with sampling techniques employing also femtosecond laser pulses.

Up to now, PTB has succeeded in generating voltage pulses with a full width at half maximum of 1,4 ps and a rise time of 1,0 ps. As a first application, the picosecond voltage pulses will be used to calibrate the time response of 50 GHz sampling oscilloscopes which become increasingly important for the characterisation of today´s high-speed electronic circuits.

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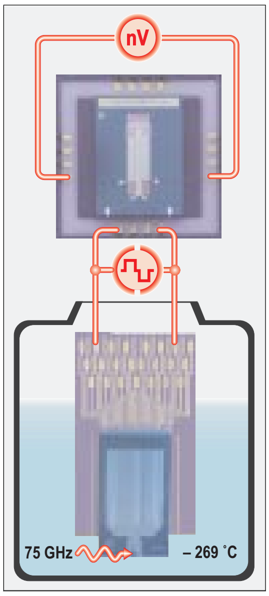
AC Measurements with «Josephson Precision»

With the application of a new Josephson voltage standard as a fast reversible voltage source, thermoelectric effects in thermal converters were verified. Thus, the uncertainty of the measurement of alternating voltage and alternating current is reduced to less than 0,1 µV/V and 0,1 µA/A, respectively.

Precise measurement of alternating voltage and alternating current is performed with thermal converters. The Joule heat in a resistor, produced by the ac quantity, is compared with a well-known dc quantity by measuring the increase in temperature of the resistor. Thermoelectric effects, such as the Thomson effect, however give rise to slightly different temperature profiles for direct or alternating current. These effects can be determined by the «Fast Reversed DC Method» (FRDC). The method is based on the fact that the Thomson effect depends on the direction of the current and it modifies the temperature profile with the thermal time constant of the converter. If the direction of current is reversed with increasing frequencies, the modification of the temperature is suppressed. Thus the Thomson effect can be determined by varying the reversing frequency.

So far the reversible voltage source, necessary for the FRDC method, was realised with semiconductor components and the positive and negative amplitudes had to be adjusted exactly. Now, for the first time the FRDC source has been realised with a Josephson array of the layer sequence superconductor-insulator-normal conductor-insulator-superconductor (SINIS). This SINIS source provides equal output voltages for both polarities with the precision of a quantum standard. The polarity can easily be changed by reversing the bias current of the Josephson array. This technique is not possible with conventional Josephson arrays because of their hysteretic characteristic.



Setup for the determination of themoelectric effects in thermal converters employing a Josephson chip
The chip, which is operated with a frequency of 75 GHz, is cooled by liquid helium (bottom). The reversible voltage source (centre) is connected to both the Josephson chip and the thermal converter (top). The output of the thermal converter is measured with a nanovoltmeter.

Measurements of two different planar multijunction thermal converters with reversing frequencies from 0,5 Hz up to 200 Hz showed thermoelectric effects of less than 0,2 µV/V. Because of the quantised voltage of the Josephson circuit, the standard measurement uncertainty is reduced.

In result the application of the Josephson-FRDC-source reduces the uncertainty of transfer measurements with thermal converters. Further, the good agreement of the new Josephon-FRDC-source with the semiconductor source used so far increases the confidence into the FRDC method.

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Recognition of Tests in Explosion Protection

On invitation by the Deutsche Elektrotechnische Kommission (DKE, German Electrotechnical Commission) and PTB, a conference on test procedures in explosion protection was held in Braunschweig in September this year. The meeting was attended by 55 delegates from 20 countries. They adopted resolutions aiming at the mutual recognition of test results and certificates by extended global harmonisation according to the IECEx certification scheme.

In Europe, the recognition of test results and certificates is regulated by Directive 94/9/EC. The IECEx scheme will become an important instrument for worldwide harmonisation. The scheme provides mutual recognition of test results and certificates among member countries on the basis of IEC standards and harmonised rules of procedure. The two-stage conformity assessment of products will include a type examination as well as an assessment of the manufacturer's quality system. Member countries are obliged to adopt the complete IEC standards as national standards within a transition period of ten years.

Certification bodies recognised within the IECEx scheme may issue national type examination certificates based on «Assessment and Test Reports» (ATRs) made out by other countries. In order to avoid repeated assessment of the quality systems, the conference decided upon the introduction of «Quality Assurance Reports» (QARs). Moreover, the procedures for setting up and evaluating ATRs were further harmonised and simplified. In future, PTB may thus issue ATRs and QARs providing the basis for certification in other countries. Making test repetitions unnecessary considerably simplifies approval procedures in countries importing explosion-proof equipment. That, in turn, facilitates world market access for German and European manufacturers.

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New Method for the Price Calculation of Natural Gases

In Germany, price calculations of natural gases in commercial transactions between public utilities and consumers are performed on the basis of the quantity of energy supplied. In order to avoid that all the gas quality data determining energy have to be measured at each place of consumption, so-called grid reconstruction systems may be used even in complex grids. Calorific values and other gas quality data are measured only at representative points in the grid. The data at the place of consumption are then determined with a program system subject to type approval.

To control the dispatching of gases in pipelines grid reconstruction systems are used. Such systems contain measuring points where the volume flow, standard density, pressure, temperature and calorific value are measured. A program system combines the measured values with data describing the topology of the supply grid (geometry of the pipelines , feed-in and feed-out points, slides, valves, storage facilities, compressors etc.) to determine the dispatched volume flows. In this way the calorific values and other gas quality data may be calculated for any time and place of consumption.

In the past, the correctness of the data relevant to the consumer was ensured by type-approved measuring instruments and peripherals which were not subject to verification. The latter included the program system which was supervised by the verification authorities. The limited means to check the complex systems has now been improved considerably improved by fixing harmonised requirements for design and operation of these systems. The systems are treated as complex measuring facilities including hard- and software and may thus be subject to type approval meeting the requirements of the Verification Act with regard to measurement correctness, durability and testability. Essential requirements concern the software, data transmission and storage as well as testing by sampling at varying points so that measured and calculated values may be compared. These harmonised requirements and regulations provide the gas utilities with means for the projecting, installation and operation of the grid reconstruction systems. They also provide the verification authorities with a basis for uniform enforcement with the purpose to protect the consumer.

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Main pipelines of the gas supply grid in Germany (fig: BGW)

PTB*news* 2000.3
English edition
December 2000

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

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Thermal Conductivity of Masonry Units

External walls essentially determine the heating energy consumption of a building. Poor insulation results in higher heating costs and increased CO_2 emission from the heating system. Decisive for the heat transfer of a wall is its thermal conductivity. PTB has developed a novel instrument to determine thermal conductivities, in particular, for masonry units. The new procedure is less time consuming and more economic than conventional ones.

Under the German Construction Products Act, the thermal conductivity must be determined for each thermal insulating masonry unit type according to fixed directives. Measurements are to be carried out on wall samples or on brick material which are continuously heated on one side and cooled on the other side for this purpose. The ensuing stationary heat flow is the measure of the quantity under test. This procedure is time consuming, tedious and, thus, expensive.

The situation can now be considerably improved with a measuring instrument developed by PTB. A thin strip of nickel placed between two halves of a brick cut for the measurement serves as thermal conductivity sensor. By means of a 4-point resistance measurement at high current, the temperature rise in the strip is determined over a period of about five minutes. The thermal conductivity results from the slope of this signal. This so-called THS (transient hot strip) instrument requires, in addition to the strip, only a current source, a voltmeter and a PC, so that the technical outlay is insignificant. The instrument allows to measure the thermal conductivity with an uncertainty of 2,6 % and has meanwhile been officially approved for construction supervision of perforated bricks.

This development will contribute to improve the competitiveness of both test institutes and brick manufacturers. In addition, the large measurement range of the THS instrument opens up further fields of application as, for example, the investigation of insulating materials and plastics for window frames.

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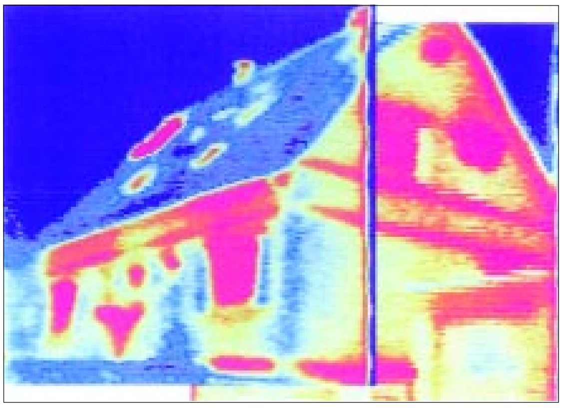

Thermogram of a building (composed of two pictures) showing in red the areas mainly responsible for loss of heat

Modern Laboratories in a Historical Building

The view along the hall of PTB's Hermann von Helmholtz building in Berlin-Charlottenburg displays the filigree steel support structure of the former German Museum for Industrial Safety.

At its Berlin-Charlottenburg location, PTB inaugurated a modern laboratory building, which is also a classified historical monument, on 20 October 2000: The former German Museum for Industrial Safety was reconstructed as Hermann von Helmholtz Building.

The museum had been built from 1900 to 1903. It was heavily damaged during World War II and remained unoccupied for many years in the sequel. About ten years ago, PTB started on the reconstruction of the building which had been classified as a historical monument in the meantime. The building has now been named after the first president of the PTR and houses modern laboratories for metrological work in the fields of medical measurements (biomagnetism), thermal energy measurements, and information technology.

The completion of the Hermann von Helmholtz building marks a major advancement in the task of concentrating PTB Berlin at its Charlottenburg site. The concentration process was initiated by the Federal Ministry of Economics and Technology and PTB soon after the German unification. In the end, it will allow to close down the present other Berlin branch of PTB in Friedrichshagen. This was formerly the location of the GDR Agency for Standardisation, Metrology and Commodities Testing (ASMW), the metrological tasks and duties of which were taken over by PTB in 1990.

Microlitre Dispensing of Human Blood Serum

Human blood certainly is a fairly common substance for medical analysis laboratories. Nonetheless it is difficult to analyse accurately. For instance, to dispense a precise amount of human blood serum presents a significant problem. As a result of a study recently completed by PTB a simple method to determine the density of human serum is now available. This allows commercial volume dispensing devices to be gravimetrically calibrated with blood serum – more accurate microlitre dispensing of human blood serum will thus be possible in future.

Medical analysis has considerably improved the diagnostic possibilities by increasing the number of individual analyses of a patient's serum. In order to limit the total amount of a patient's blood to be collected for this purpose, it is becoming increasingly important to analyse liquid volumes of only a few microlitres. Such small liquid volumes are dispensed with manually controlled piston-operated pipettes and microlitre syringes and with similar automated systems. In accordance with the relevant standards, all these devices are calibrated using water as the dispensing liquid. There are doubts, however, about the validity of these calibrations as far as the dispensing of serum is concerned. The dispensing behaviour of water and serum was therefore investigated by PTB.

Medical analysis laboratories, such as the laboratory of the Hannover Medical School shown here, analyse several thousand specimens of human blood serum each day.

The PTB study is the first to confirm and quantify differences in the dispensing behaviour. Positive displacement pipettes do not react very strongly to a change of the dispensing liquid. The differences found in the dispensed volume at nominal volumes greater than 10 µl were smaller than 1% and sometimes even smaller than 0,1%. In the case of air displacement pipettes, the differences in the dispensed volume were, however, considerably larger, reaching values of about 5%. Therefore, calibration with the serum to be dispensed is urgently required at least for air displacement pipettes.

The gravimetric calibration of dispensing devices with serum requires that the density of the serum be exactly known in each individual case. What has been known to date is that this density varies around a statistical mean value of about 1,024 g/cm^3. The PTB study now presents a very simple way to determine this density from the content of protein and salt, the main components of serum, with a relative uncertainty of only $3 \cdot 10^{-4}$. As these quantities are routinely measured in almost every serum analysis, no additional sophisticated density measurement is required.

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