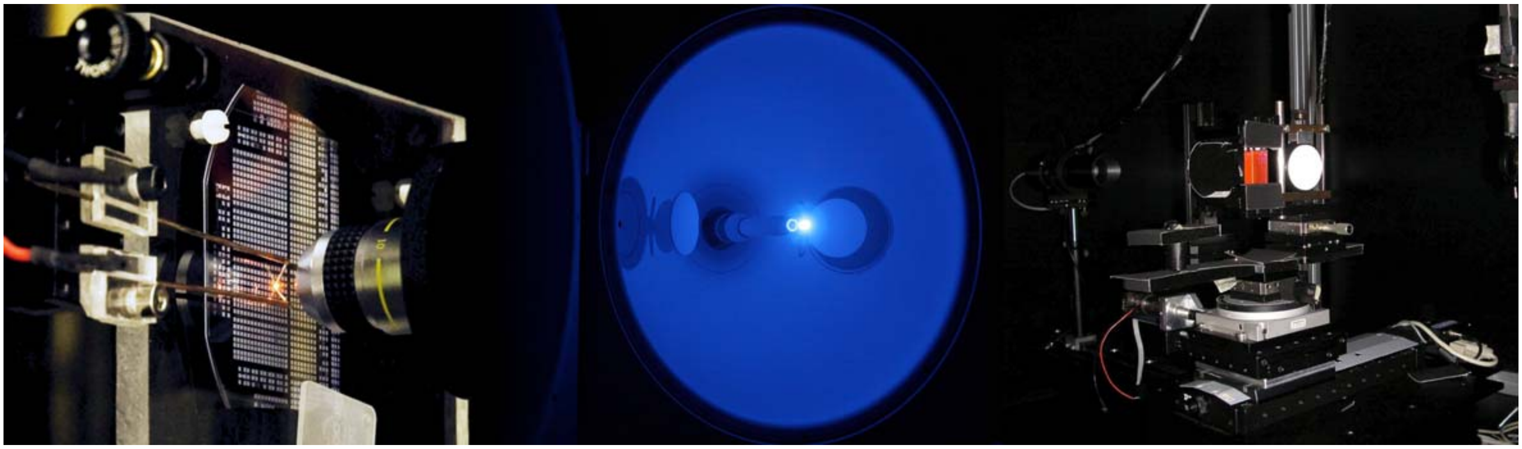
Helsinki University of Technology

Faculty of Electronics, Communications and Automation

Metrology Research Institute Report 34/2009

Espoo 2009

ANNUAL REPORT 2008



TEKNILLINEN KORKEAKOULU
TEKNISKA HÖGSKOLAN
HELSINKI UNIVERSITY OF TECHNOLOGY
TECHNISCHE UNIVERSITÄT HELSINKI
UNIVERSITE DE TECHNOLOGIE D'HELSINKI

Helsinki University of Technology
Metrology Research Institute Report 34/2009
Espoo 2009

ANNUAL REPORT 2008

Editor Ulla Sikander

Helsinki University of Technology
Faculty of Electronics, Communications and Automation
Metrology Research Institute

Teknillinen korkeakoulu
Elektroniikan, tietoliikenteen ja automaation tiedekunta
MIKES TKK Mittaustekniikka

Distribution:
Helsinki University of Technology
Metrology Research Institute
P.O. Box 3000
FIN-02015 TKK
Finland

Tel. +358-9-451 2433
Fax. +358-9-451 2222
E-mail: ulla.sikander@tkk.fi

ISSN 1237-3281

Picaset Oy
Helsinki 2009

CONTENTS

1 INTRODUCTION ... 2
2 PERSONNEL ... 3
3 TEACHING ... 6
3.1 Courses ... 6
3.2 Degrees ... 7
3.2.1 Doctor of Science (Technology), D.Sc. (Tech.) 7
3.2.2 Licentiate of Science (Technology), Lic.Sc. (Tech.) 7
3.2.3 Master of Science (Technology), M.Sc. (Tech.) 8
3.2.4 Bachelor of Science (Technology), B.Sc. (Tech.) 8
4 NATIONAL STANDARDS LABORATORY ... 9
5 RESEARCH PROJECTS ... 10
5.1 Electronic Instrumentation ... 10
5.2 Optical Radiation Measurements ... 11
5.3 Fiber-Optics ... 19
5.4 Applied Quantum Optics ... 20
6 INTERNATIONAL CO-OPERATION ... 22
6.1 International Comparison Measurements ... 22
6.2 Conferences and Meetings ... 25
6.3 Visits by the Laboratory Personnel ... 27
6.4 Research Work Abroad ... 27
6.5 Visits to the Laboratory ... 27
7 PUBLICATIONS ... 27
7.1 Articles in International Journals ... 27
7.2 International Conference Presentations ... 29
7.3 National Conference Presentations ... 31
7.4 Other Publications ... 31

1 INTRODUCTION

The Metrology Research Institute is a joint unit of the Helsinki University of Technology (TKK) and Centre for Metrology and Accreditation (MIKES). The Finnish name of the Institute is MIKES TKK Mittaustekniikka and it acts as the Finnish national standards laboratory for optical quantities. In the beginning of 2008, a new organisational structure of TKK was implemented and as a consequence the Metrology Research Institute is now part of the Department of Signal Processing and Acoustics at the Faculty of Electronics, Communications and Automation. These changes were made in anticipation of another organisational change to be implemented from the beginning of 2010: merging of three universities in the Helsinki area under the name Aalto University.

During 2008, many staff members participated in the NEWRAD 2008 Conference in Korea. Petri Kärhä gave there an invited talk on the effects of distance dependence in radiometric measurements. The results obtained make an important contribution for improving the reliability of the data obtained from the global solar UV measurement networks. Silja Holopainen gave a talk on non-Lambertian behaviour of fluorescence from solid amorphous samples. This surprising finding needs to be taken into account when analysing results of fluorescence calibrations. Additional research contributions are described in more detail in Sec. 5 of this Annual Report.

The number of calibration certificates issued in 2008 was 63. This is about 50% larger number than the yearly number during three previous years. One doctoral degree and seven M.Sc. degrees were achieved in 2008. These are exactly the same numbers as in 2007.

Erkki Ikonen

2 PERSONNEL

Helsinki University of Technology (TKK)
Faculty of Electronics, Communications and Automation
Department of Signal Processing and Acoustics
Metrology Research Institute (MIKES TKK Mittaustekniikka)
P.O.Box 3000, FI-02015 TKK, Finland

Visiting address: Otakaari 5 A, Espoo (Otaniemi) Finland

Switchboard +358 9 451 1
Telefax +358 9 451 2222

http:/metrology.tkk.fi

In 2008, the total number of employees working at the Metrology Research Institute was 22.

	Telephone	**E-mail**
Ikonen, Erkki, Dr.Tech. Professor, Head of Laboratory	451 2283 050-550 2283	erkki.ikonen(at)tkk.fi
Sikander, Ulla Secretary	451 2433 040-769 8013	ulla.sikander(at)tkk.fi
Ahonen, Petteri, student Research assistant	451 2185	mpahonen(at)cc.hut.fi
Forss, Nicklas, student Research assistant	451 2441	nicklas.forss(at)tkk.fi
Hieta, Tuomas, M.Sc Research scientist		ahieta(at)cc.hut.fi
Holopainen, Silja, M.Sc Research scientist	451 2285	silja.holopainen(at)tkk.fi
Högström, Richard, M.Sc. Research scientist	451 6074	rhogstro(at)cc.hut.fi

Jaakkola, Teemu, student Research assistant	451 2405	teemu.jaakkola(at)tkk.fi
Kunnas , Antti, student Research assistant	451 2441	aikunnas(at)cc.hut.fi
Kärhä, Petri, Dr.Tech. Senior research scientist, Quality manager	451 2289 050-511 0307	petri.karha(at)tkk.fi
Manninen, Pasi, Dr.Tech. Research scientist	451 2308	pasi.manninen(at)tkk.fi
Manoocheri, Farshid, Dr.Tech. Senior research scientist, Head of calibration services	451 2337	farshid.manoocheri(at)tkk.fi
Ojanen, Maija, Lic.Sc. Research scientist	451 2336	maija.ojanen(at)tkk.fi
Paatelma, Jonna, student Research assistant	451 4870	jkpaatel(at)cc.hut.fi
Poikonen, Tuomas, M.Sc. Research scientist	451 2280	tuomas.poikonen(at)tkk.fi
Puranen, Mikko, Lic.Sc. Research scientist	451 2323	mikko.puranen(at)tkk.fi
Rantoja, Kaija, student Research assistant	451 2405	kaija.rantoja(at)hut.fi
Ristiluoma, Satu, M.Sc. Research assistant	451 2441	ssristi(at)cc.hut.fi
Shpak, Maksim, M.Sc. Research assistant	451 2281	mshpak(at)cc.hut.fi
Sildoja, Meelis-Mait, M.Sc. Research scientist	451 2284	msildoja(at)cc.hut.fi

Simonen, Tarmo, student Network and PC Administrator	451 5378	tsimonen(at)cc.hut.fi
Sormanen, Aleksi, student Research assistant	451 2323	aleksi.sormanen(at)tkk.fi

Docents and lecturers:

Häkkinen Esa	Helsinki Institute of Technology	+358 9 310 8311
Jokela Kari	STUK, Radiation and Nuclear Safety Authority	+358 9 759 881
Kalliomäki Kalevi	Centre for Metrology and Accreditation	+358 106054 410
Kauppinen Jyrki	University of Turku	+358 2 333 5670
Ludvigsen Hanne	Helsinki University of Technology	+358 9 451 2282
Ståhlberg Birger	University of Helsinki	+358 9 191 1

3 TEACHING

3.1 Courses

The following courses were offered by the Metrology Research Institute (MIKES TKK Mittaustekniikka) in 2008. Those marked by * are given biennially.

S-108.1010	Fundamentals of Measurements A 4 credits (Petri Kärhä)
S-108.1020	Fundamentals of Measurements Y 3 credits (Petri Kärhä)
S-108.2010	Electronic Measurements 3 credits (Petri Kärhä)
S-108.2110	Optics 5 credits (Erkki Ikonen)
S-108.3011	Sensors and Measurement Methods 5 credits (Pasi Manninen)
S-108.3020	Electromagnetic Compatibility 2 credits (Esa Häkkinen)
S-108.3030	Virtual Instrumentation* 5 credits (Petri Kärhä)
S-108.3110	Optical Communications 5 credits (Farshid Manoocheri, Goery Genty)
S-108.3120	Project Work 2-8 credits (Erkki Ikonen, Tuomas Poikonen)
S-108.3130	Project Work in Measurement Science and Technology 2-10 credits (Erkki Ikonen, Tuomas Poikonen)

S-108.3140	Project Work in Optical Technology 2-10 credits (Erkki Ikonen, Tuomas Poikonen)
S-108.4010	Postgraduate Course in Measurement Science and Technology 10 credits (Petri Kärhä)
S-108.4020	Research Seminar on Measurement Science and Technology 2 credits (Erkki Ikonen)
S-108.4110	Biological Effects and Measurements of Electromagnetic Fields and Optical Radiation* 4 credits (Kari Jokela)
S-108.4120	Special Course in Measurement Science and Technology* Measurements of Paper Industry 2-6 credits (Erkki Ikonen)

3.2 Degrees

3.2.1 Doctor of Science (Technology), D.Sc. (Tech.)

Pasi Manninen, *Characterization of Diffusers and Light-Emitting Diodes Using Radiometric Measurements and Mathematical Modeling*

Opponent: Dr. Peter Blattner, Federal Office of Metrology (METAS), Switzerland

3.2.2 Licentiate of Science (Technology), Lic.Sc. (Tech.)

The Licentiate degree is an intermediate research degree between M.Sc. and D.Sc.

Pasi Manninen, *Modified Inverse-Square Law for Precision Radiometry*

Maija Ojanen, *Analysis Methods for Radiation Temperature Measurements*

Tuomo Korkolainen, *Interferometric Calibration of Gauge Blocks*

3.2.3 Master of Science (Technology), M.Sc. (Tech.)

Tiia Kaijansinkko, *Techno-Economic Analysis of Transmission Networks in Terrestrial Trunked Radio Systems*

Outi Leinonen, *Automatic Anesthesia Breathing Circuit Functionality Test*

Janne Laurén, *Optimizing Production Testing of Three-Axis Accelerometer*

Jani Kivilähde, *Mobile Development Environment for Image-Based Measurement of Tree Attributes*

Ilkka Vaalasranta, *Nonvolatile Memory Technologies and Reliability*

Arto Hietanen, *Calibration and Testing System for a Dual Axis Accelerometer*

Maksim Shpak, *Temperature Measurements in Micrometer Scale*

3.2.4 Bachelor of Science (Technology), B.Sc. (Tech.)

Lassi Viitala, *Radiotekniikalla toteutettu lämpötilan mittausverkko* (guided by Petri Kärhä)

Jussi Mäkynen, *Virtajännite-muuntimen suunnittelu valonlähteen monitorointi-ilmaisimelle* (guided by Pasi Manninen)

Anssi Matilainen, *Lähi-infrapuna-alueen ilmaisimien karakterisointimenetelmät* (guided by Maija Ojanen)

4 NATIONAL STANDARDS LABORATORY

Metrology Research Institute is the Finnish national standards laboratory for the measurements of optical quantities, as appointed by the Centre for Metrology and Accreditation (MIKES) in April 1996.

The Institute gives official calibration certificates on various optical quantities in the fields of Photometry, Radiometry, and Spectrophotometry. During 2008, 63 calibration certificates were issued. The calibration services are mainly used by the Finnish industry and various research organizations, but the number of foreign customers is gradually increasing. There are three accredited calibration laboratories in the field of optical quantities.

The Institute offers also other measurement services and consultation in the field of measurement technology. Various memberships in international organizations ensure that the laboratory can also influence e.g. international standardization so that it takes into account the national needs.

The Metrology Research Institute performs its calibration measurements under a quality system approved by MIKES. The quality system is based on ISO/IEC 17025.

Further information on the offered calibration services can be obtained from the web-pages of the laboratory (http://metrology.tkk.fi/). Especially the following sub-pages might be useful:

Price list for calibration services: http://metrology.tkk.fi/files/pricelist.pdf

Quality system: http://metrology.tkk.fi/quality/

Additional information may also be asked from Farshid Manoocheri (Head of Calibration Services) or Petri Kärhä (Quality Manager):

Farshid.Manoocheri(at)tkk.fi, Tel. +358-9-451 2337

Petri.Karha(at)tkk.fi, Tel. +358-9-451 2289

5 RESEARCH PROJECTS

5.1 Electronic Instrumentation

Design of a current-to-voltage converter based on switched capacitors

A current-to-voltage converter based on switched capacitors was designed and constructed for measuring photocurrents from photodiodes. The main components of the device are a PIC microcontroller with a connector for programming, eight FET switches, and two switched capacitors (Fig. 1). The microcontroller controls the switches so that two capacitors are charged and discharged alternately. The gain of the current-to-voltage converter can be adjusted by changing the switching frequency or capacitance of the capacitors. Preliminary tests of the first prototypes show that the device can operate as a current meter. Further study on the linearity and noise properties of the device will be carried out.

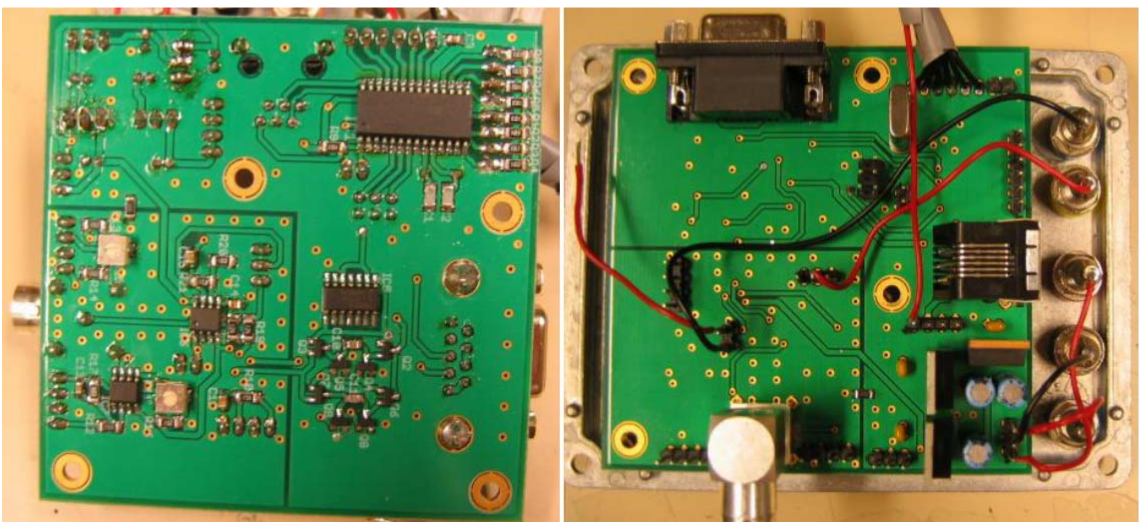


Figure 1: Printed circuit board for current-to-voltage converter implemented with surface mounted components

Radar measurements

Portable Ka-band instrumentation radar for foliage attenuation measurements has been designed. It uses direct dielectric resonator-oscillator-multiplier pulse modulation giving a half-power pulse width of 17 ns. The dual conversion scalar receiver utilizes either a digital storage oscilloscope in envelope detection format or a special gated comparator arrangement providing 1 m resolution and associated LED seven-segment display for data analysis. The calibrated dynamic range is better than 37 dB with an equivalent noise floor of 0.005 dBsm at 25 m test range distance. First experiments indicate an effective beam width close to 1°. The total weight is below 5 kg and the unit can be mounted on a conventional photographic tripod. Power is supplied from a 12 V/6 A h sealed lead acid battery giving an operating time in excess of 10 h.

The uncertainty of the pulsed power measurement instrumentation has been evaluated. The output level of pulsed radar transmitter and receiver test sets can be defined with spectrum analyzers and diode detectors. Modern analyzers, which have 10 MHz or wider resolution bandwidths and cover appropriate input frequency ranges, can be used in the Ka and V-band radar domains for pulse widths above 200 ns. A practical uncertainty of 2 dB is obtainable. External mixers seem to show larger-level discrepancies, up to 5 dB, and may give only 20 dB of dynamic range. Their conversion loss may vary by 8 dB over just 500 MHz. Diodes work at higher power levels, but rise-time definitions are complicated. Above -15 dBm input levels, we can get uncertainties comparable to spectrum analyzers, but the true dynamic range can be just 15 dB, and temperature effects may hamper outdoor trials. Below 200 ns pulse widths, radar-receiver test-generator level calibration remains very challenging in the millimeter-wave bands due to inadequate sensitivity, regardless of the measuring instrumentation.

5.2 Optical Radiation Measurements

Optical temperature measurement of miniature silicon emitters

Microbridges, also known as microglows or micro-filaments, are miniature silicon filaments that are used e.g. in analysers as light sources. A microbridge is brought up to incandescence by passing an electrical current through it. Temperature determination of an operating microbridge with a contact measurement is complicated due to the small size of the bridge and the heat loss via the contact probe.

In this work, we have developed and tested a method to determine the temperature of a microbridge by measuring its emission spectrum. The measurement setup consists of a monochromator, detectors for the visible and near-infrared spectral regions and focusing optics based on a microscope objective. The setup was used to measure temperatures of microbridges that have dimensions of 400 × 20 × 4 μm^3. They are made of highly doped single-crystal silicon. The bridges have thin protecting layers of silicon dioxide on all sides.

Determination of the temperature is possible using Planck's radiation law if the emissivity of the object is known. Emissivity of silicon at high temperatures is often assumed to be constant in the visible and near-infrared regions. However, a microbridge is thin and thus semi-transparent. The thin layers of silicon dioxide also introduce interference effects. As a consequence, microbridges do not behave like grey bodies (Fig. 2). To solve this problem, a semi-empirical model was constructed to describe the emissivity of the multi-layer structure. To determine the optical constants of silicon needed, radiation spectra of a piece of SOI wafer were measured at known temperatures. In particular, the extinction coefficient of the highly doped silicon at high temperatures in the near-infrared region was not found in the literature and was determined from the measurements. The results were fitted to the emissivity model. At present, we can measure the temperature with an uncertainty of ±50 K.

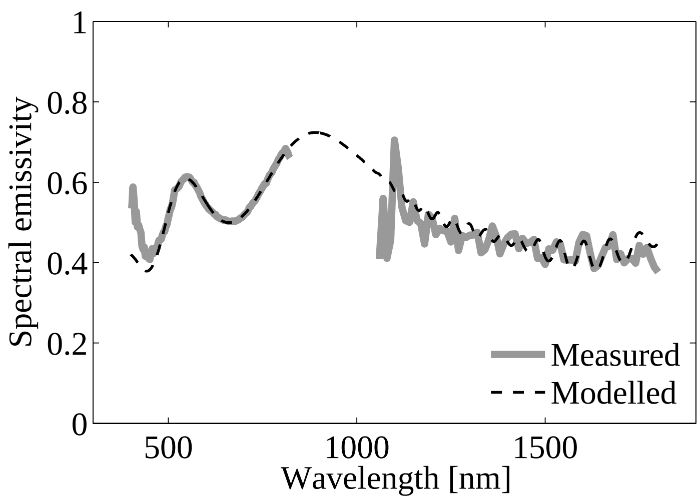


Figure 2: Modelled and measured emissivities of the microbridge at 1100 ºC. Measurements between 820 nm and 1050 nm were very noisy and the results were thus removed from the graph.

Radiation temperature measurements

The results of the comparison of the radiation temperature scales with PTB in 2007 were reported at the NEWRAD conference (Fig. 3). The comparison was carried out in the range of 1570 K to 2770 K using four filter radiometers of MIKES, one filter radiometer of PTB, and linear radiation thermometers of both MIKES and PTB. The agreement was partial: Two filter radiometers and the linear radiation thermometer of MIKES agreed well with the equipment of PTB, while two filter radiometers deviated from the other equipment. To get a deeper understanding of the reasons of the deviation, the results were studied in terms of both temperature and radiance. The deviation was found constant in terms of radiance.

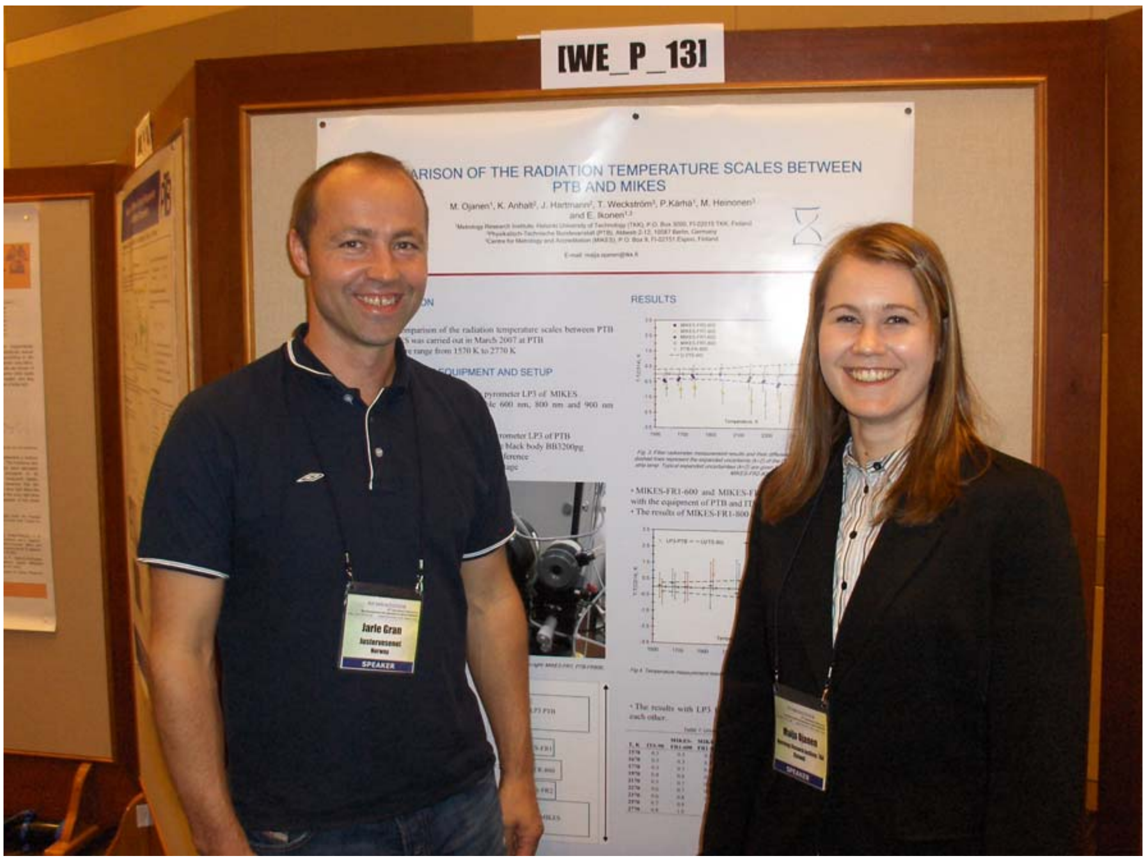


Figure 3. Jarle Gran from Justervesenet (Norway) visiting Maija Ojanen's poster at the NEWRAD 2008 conference

The radiation temperature measurements were studied also at lower temperatures. Two one-diode silicon filter radiometers with nominal wavelengths of 800 and 900 nm, and an InGaAs filter radiometer with a nominal wavelength of 1550 nm were tested at temperatures from 770 K to 1020 K. The silicon filter radiometers were found to have low noise. They could thus be used in accurate measurements of the above mentioned temperatures with a current meter calibrated for low currents.

Metrology of LED light sources

During 2008, the MRI participated in the APMP supplementary comparison of light-emitting diodes (LEDs). The measurement quantities of the comparison were the averaged LED intensity, total luminous flux of LEDs and emitted colour of LEDs. The comparison included 14 LEDs with four colours. As a part of the LED project, the colour rendering properties of white LED light sources were studied. For that purpose, a literature review of a new colour rendering metrics was done and a LabVIEW program for calculating the colour rendering index defined by the Commission Internationale de l'Eclairage was developed. The project also involved a study on the measurement of low light (mesopic) levels. The conventional $V(\lambda)$ function of photometry cannot be used in mesopic light levels because the spectral sensitivity curve of the human eye is shifted toward shorter wavelengths. A dual-channel mesopic photometer for measuring light levels between the scotopic and photopic photometry was designed. Using that photometer, mesopic illuminance levels in highway and street lighting at night can be measured.

Improving the measurement setup for LED luminous flux

The measurement setup for LED luminous flux has been improved regarding the total luminous flux measurement mode of low power LEDs. In this measurement mode, a lamp holder is used for placing the LED in the center of the sphere. By doing so, also the backward emission of the LED is taken into account in the measurement. The original lamp holder that the sphere manufacturer sent us for LED measurements, was not an actual LED holder but more suitable to be used in bigger integrating spheres with incandescent lamps. Using the supplied lamp holder with the 30-cm integrating sphere caused very high screening due to the size of the lamp holder and different spectral throughput compared to the two other measurement modes.

A new, much smaller lamp holder was designed (see Fig. 4) using another supplied lamp holder as a basis and by designing a new head piece for it and socket terminals for the LED. Special attention was paid to minimize the near-field absorption of the backward emission of the LED to improve the reliability of the measurement. The conical head piece was machined from aluminum and was painted with barium sulfate ($BaSO_4$). The holder was equipped with two parallel terminals for the LED, of which either one can be used.

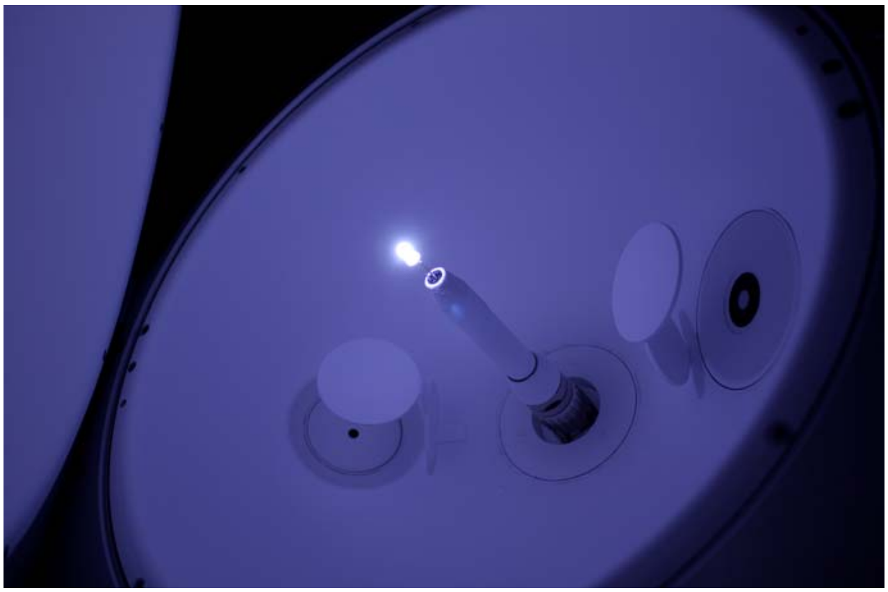


Figure 4. A photograph of a LED comparison measurement showing the new improved LED holder in operation. The screening due to the new holder is barely visible. Only the two baffles form shades inside the sphere, preventing the detector and auxiliary port from seeing the light source directly.

The spectral throughput of the integrating sphere was measured using the auxiliary LED port and a white LED. The results show that the use of the new lamp holder results in almost identical spectral throughput as in the other two measurement modes. This makes the analysis easier, because the same color correction factor can be used for the same LED, regardless of the measurement mode. The new lamp holder, being much smaller than the earlier one, also results in larger signal levels and better integration inside the sphere. The most important improvement is the reduced screening due to the lamp holder. The screening of the new lamp holder is only about 6 % of the original. In Fig. 4 can be seen that the screening is barely visible around the base of the lamp holder, whereas the original lamp holder caused visible screening, reaching the shades produced by the two baffles.

Effects of UV radiation on MAterials 2 (UVEMA-2)

This two-year project funded by TEKES is a continuation of an earlier project. The work is carried out in collaboration with the Finnish Meteorological Institute, Tampere University of Technology and several industrial partners. The role of the Metrology Research Institute is to build an improved version of the device that can be used for studying the effect of wavelength on the UV ageing of materials.

The improved device, as its predecessor (Fig. 5), is based on a concave flat-field holographic grating and a 1-kW Xe-lamp. The major improvement is that the sample can be heated up to 80 °C to accelerate the ageing. The output spectrum is limited to wavelengths 280 – 420 nm to avoid the problems associated with higher order refraction. The extended wavelength regions of the prototype do not contain useful information and are thus sacrificed to increase dispersion. There will be an additional sample port for the zero order refraction.

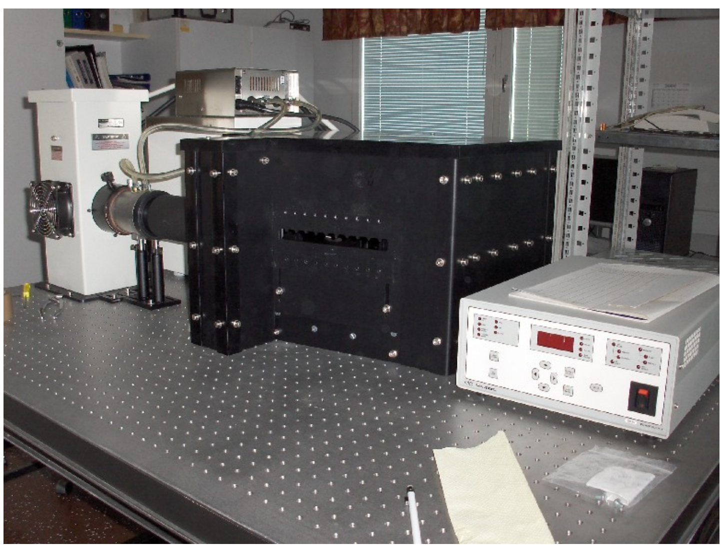


Figure 5. Prototype of the facility built. In the new version, there will be an opportunity to heat the sample up to 80 °C.

During 2008, the device was designed and all the parts were purchased. The work will continue with assembly and testing.

Goniofluorometer for characterization of fluorescent materials

The colour of a fluorescent specimen depends on the illuminating source and the observer. It can be calculated for the desired source and observer with the help of the source and observer independent bispectral radiance factors.

A goniofluorometer has been characterized for measuring bispectral luminescent radiance factors in the wavelength range of 250 – 800 nm. Investigations have been initiated on possible non-Lambertian behaviour of the opaque fluorescent standard materials. Extensive measurements of the fluorescence spectra of several well known fluorophores such as fluorescein, rhodamine 101, and quinine sulphate as liquid samples have been performed. Measurement results show that the fluorescence measurements of liquids are possible but especially a high fluorophore concentration in the sample may cause unwanted effects on the emission spectrum. Also the measurement geometry was revealed to have a significant effect on the emission spectrum whereas moderate changes in the intensity of incident beam do not affect the spectra significantly.

Detector responsivity at infrared

Many radiometric applications require the determination of the spectral radiant power responsivity function of infrared (IR) detectors. Applications of IR detectors in various fields such as thermal imaging, night vision and surveillance, low temperature measurements, and testing of micromechanical devices have brought demanding requirements for accurate calibration of infrared standard detectors. To accommodate accurate measurement of spectral power responsivity in the wavelength range from 0.2 µm out to 15 µm a spectrometer facility has been developed at the Metrology Research Institute. In the year 2008, a new reference pyroelectric detector has been developed.

Predictable Quantum Efficient Detector

Development of a new primary standard, the PQED (Predictable Quantum Efficient Detector), for optical power measurements has been launched within several European national metrology institutes. The new standard is based on low doped silicon photodiodes operated at liquid nitrogen temperatures and under reverse bias. To achieve low level of optical losses, two candidate structures for the device have been developed and calculations of the specular reflectance have been carried out (Fig. 6). It is shown that a simple two-photodiode arrangement is capable of reducing the specular reflectance to values lower than 1 ppm and is suitable for the PQED needs, if diffuse reflectance from the photodiodes is of the same order of magnitude as the specular reflectance.

A second detector structure with a single diode and a hemispherical mirror is considered, if the diffuse reflectance from the custom-made photodiodes turns out to be too high, more than 1 ppm.

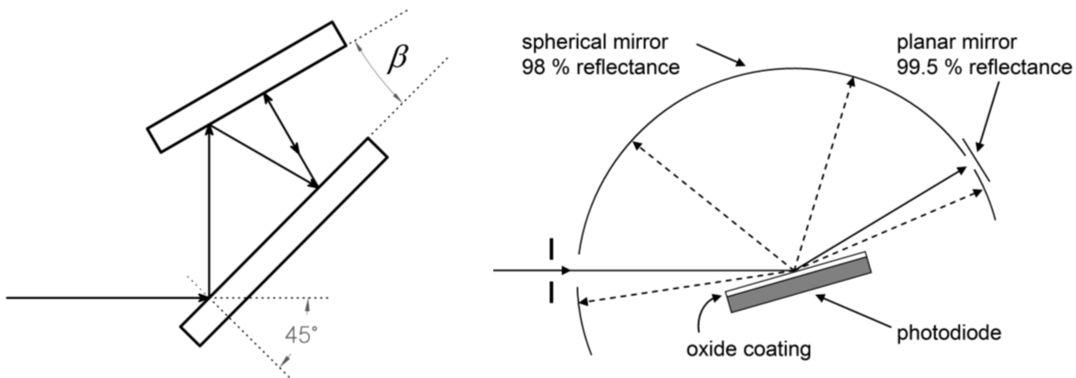


Figure 6. Two-photodiode structure (left) and the hemispherical structure (right) of the detectors.

A method for uncertainty analysis for linking a bilateral key comparison to the CIPM key comparison

A method for analyzing the uncertainty in linking a bilateral key comparison to another key comparison with several participants was developed for the analysis of bilateral key comparison EURAMET.PR-K1.a.1 (see Sec. 6.1). Equations were derived for the uncertainties of the unilateral and mutual degrees of equivalence for the linked participant in the bilateral comparison. It was shown that the uncorrelated uncertainty components of the linking participant play a critical role in determining the additional uncertainties due to the linking process. The uncorrelated uncertainty of the link NMI was found to account for more than 80 % of the additional uncertainty due to the linking process in the degrees of equivalence of the linked NMI. In this case, the uncertainty of the linked NMI typically contributed 90 % of the uncertainty of the unilateral degrees of equivalence. If an NMI with uncertainty below the cut-off uncertainty in CCPR-K1.a would be the linked NMI, the uncertainties of their degrees of equivalence would be largely affected by the uncorrelated uncertainty of the linking NMI.

Uncertainty analysis of spectral integrals

New research has begun related to uncertainty analysis of spectral integrals used for certain parameters and quality factors in photometry and colorimetry. In this research, statistical Monte Carlo simulation is used as the basis of the uncertainty analysis. However, the error models used in the simulations must be carefully evaluated that they actually represent the real uncertainties of the measurements. The first parameter, for which the new error models are tested, is the spectral quality factor f_1' of photometers. The parameter f_1' defines the average quality of the spectral matching with the $V(\lambda)$ function and gives an order of magnitude indication of how large errors are obtained, when measuring ordinary broadband light sources with different spectral power distributions. The uncertainty simulations continue and the error models will be later extended to other spectral integrals.

5.3 Fiber-Optics

Measurement of Erbium-doped fiber nonlinearity using continuous-wave self-phase modulation method

Erbium-doped fiber amplifiers have been the standard device for amplification of optical signals in long-haul wavelength-division multiplexed systems after their discovery in the late 1980s. When pushing the limits of current technology by means of increased optical power and tighter wavelength spacing in wavelength multiplexing systems, it is evident that nonlinear interactions will become more significant and limiting factors. As a result, the fiber parameters related to nonlinearities of other than standard single mode fibers have become increasingly important as their properties can vary considerably

The intensity dependent nonlinear coefficient n_2/A_{eff} of a short erbium-doped, amplifying fiber was determined using a method thoroughly studied for measurements of passive fibers (see Fig. 7). Measurement uncertainty of 3.0% was achieved using the modified continuous-wave self-phase modulation method. During the research, we discovered limitations and conditions imposed by the erbium doped fiber as compared with the measurement of a pure silica core fiber. The developed measurement method is advantageous as compared with other techniques due to its reliability and ease of implementation with amplifying fibers.

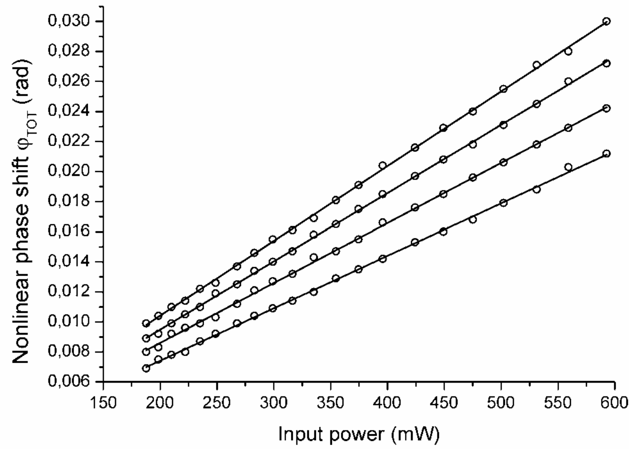


Figure 7. Measured nonlinear phase shifts at different erbium doped fiber lengths as a function of the optical input power in the erbium doped fiber. Fiber lengths of 0, 2 m, 4 m and 6 m, from the lowest to highest curve, were used where the nonlinear phase shift increases with the fiber length.

5.4 Applied Quantum Optics

Multiple coherent components in relativistic heavy-ion collisions

High-energy nuclear collisions are conventionally analyzed using a chaotic source component and a single coherent source component of the emitted pions. However, three-pion correlations from S+Pb collisions provide experimental data, where the analysis using a single coherent component leads to inconsistent results (see Fig. 8). As described in this work, the inconsistency can be removed by a small, but significant, change in the theoretical description of the three-pion correlations allowing multiple coherent source components (E. Ikonen, *Phys. Rev. C* **78**, 051901(R) (2008)). The new theoretical description is equivalent to such an extension of the conventional chaotic source current model where the amplitudes of the elementary current terms are allowed to vary.

The new theory is inspired by research on partially coherent pulsed photon sources, which have interesting similarities with the pion source provided by a relativistic heavy-ion collision. When the present knowledge on such pulsed synchrotron radiation sources is used in the analysis of nuclear collisions, a lot of detailed information can be extracted from the results of three-pion correlation experiments.

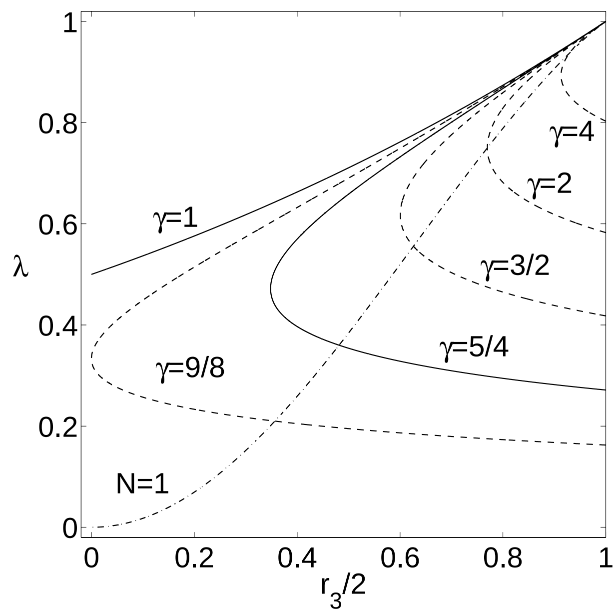


Figure 8. Zero-momentum-difference intercept of the two-pion correlation function λ as a function of the normalized three-pion correlator $r_3/2$ for different values of the intensity distribution parameter γ. For the S+Pb collisions, a value of $r_3/2 \approx 0.2$ has been measured while $\lambda_{exp} \geq 0.4$ is determined from two-pion correlation experiments (H. Boggild et al., *Phys. Lett. B* **455**, 77 (1999)). The conventional analysis (curve labeled $N = 1$) with a single coherent component can be used to derive from $r_3/2 \approx 0.2$ a value of $\lambda \approx 0.1$, which is much less than the lower limit λ_{exp}. The result with multiple coherent components is satisfactory $\lambda \approx 0.5$, corresponding to rectangular intensity distribution of pion-bursts ($\gamma = 9/8$).

6 INTERNATIONAL CO-OPERATION

6.1 International Comparison Measurements

Since 2005 the Metrology Research Institute participates in key comparisons under the name MIKES (Centre for Metrology and Accreditation).

Key comparison CCPR-K2.a, spectral responsivity 900-1600nm, pilot NIST

Draft A-3 is nearly completed and Draft B will be distributed during 2009.

Key comparison CCPR-K2.c, spectral responsivity 200-400 nm, pilot PTB

There has been a delay due to damage of a transfer standard detector, but the measurement is now completed and pre-Draft A process is in progress.

Key comparison CCPR-K5, spectral diffuse reflectance, pilot NIST

Draft A was distributed to all participants during 2008. The comments deadline was passed in December 2008 and Draft B is expected during 2009.

Key comparison CCPR-K6, spectral regular transmittance, pilot LNE

The participants carried out their measurements during the year 2000 and the final report of this comparison was published in the beginning of 2009 [G. Obein and J. Bastie, *Metrologia* **46**, Tech. Suppl. 02002 (2009)]. Each participant performed measurements of five filters of different optical densities at eight wavelengths between 380 nm and 1000 nm. The comparison of the results of measurements carried out by the pilot laboratory before and after the circulation of the filters points out that the stability of most of the filters was rather poor. As a consequence, altogether 13 participants out of 15 had two or more measurement values outside the expanded uncertainty limits. The deviation of three MIKES data points from the key comparison reference value of three filters at the wavelength of 380 nm was larger than the calibration and measurement capability (CMC) listed in the BIPM key comparison database. However, these results do not cause any re-evaluation of the CMC uncertainties of MIKES, because of the stability problems of the filters, long time elapsed since the measurements, and improvements in the measuring equipment in the meantime.

Key comparison EURAMET.PR-K6, spectral regular transmittance, pilot LNE

MIKES acts as one of the seven EURAMET link laboratories in this regional key comparison to be linked to CCPR-K6. The measurement results from the year 2000 of CCPR-K6 will be used for the linkage.

Key comparison EURAMET.PR-K3.a, luminous intensity, pilot PTB

MIKES and pilot measurements of four transfer standard lamps of luminous intensity were completed during 2008. The return measurements by MIKES are scheduled for 2009.

Key comparison EURAMET.PR-K4, luminous flux, pilot PTB

MIKES measurements of four transfer standard lamps of luminous flux were completed during 2008. The pilot measurements and return measurements by MIKES are scheduled for 2009.

Supplementary regional comparisons APMP.PR-S3.a, APMP.PR-S3.b, and APMP.PR-S3.c, LED related quantities, pilot KRISS

The measured quantities in these comparisons include the CIE averaged luminous intensity B, total luminous flux, and chromaticity coordinates x, y of LEDs. The MIKES measurements were completed during 2008.

Bilateral key comparison EURAMET.PR-K1.a.1, spectral irradiance, pilot MIKES

The bilateral comparison EURAMET-K1.a.1 of the spectral irradiance scales between MIKES (Finland) and NIMT (Thailand) in the spectral range of 290 to 900 nm was completed. MIKES acted as the pilot and link to the results of the key comparison CCPR-K1.a. The comparison artefacts were three transfer standard lamps. The lamps were 1 kW tungsten halogen FEL type lamps. The measurements at MIKES were made in December 2006 and in February 2008 to monitor a possible drift. NIMT calibrated the transfer standard lamps in November 2007. The spectral irradiance values measured by NIMT and MIKES agree generally within the expanded uncertainty.

The only exceptions are results at wavelengths 450 nm and 500 nm, where the average difference exceeds the k = 3 and k = 2 uncertainty limits, respectively. The difference between the NIMT results and the key comparison reference value (KCRV) of CCPR-K1.a is seen in Fig. 9. The final report of the comparison has been accepted for publication in *Metrologia* as Technical Supplement [M. Ojanen, M. Shpak, P. Kärhä, R. Leecharoen, and E. Ikonen, Report of the Spectral Irradiance Comparison EURAMET.PR-K1.a.1 between MIKES (Finland) and NIMT (Thailand)].

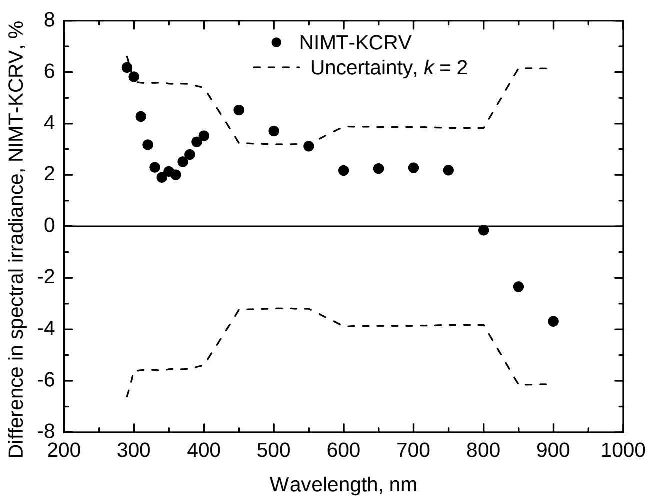


Figure 9. Degrees of equivalence of NIMT. The expanded uncertainty is marked with the dashed lines.

Bilateral comparison MIKES - NMC A*STAR in spectral irradiance using a multi-wavelength filter radiometer

The spectral irradiance scales of NMC A*STAR (Singapore) and MIKES (Finland) in the spectral range from 280 nm to 900 nm were compared at NMC A*STAR using an automatic multi-wavelength filter radiometer (MWFR). The comparison artefacts were three tungsten halogen lamps: One 1 kW FEL lamp of MIKES, one 1 kW FEL lamp of NMC, and one Osram 400W HLX64665 lamp of NMC. The results were analyzed using the algorithm developed at the Metrology Research Institute. The agreement of the standard values assigned to the lamps by both NMIs with the measured values using the MWFR were well within their expanded measurement uncertainties. The report of the research has been accepted for publication in *Metrologia* (Y. J. Liu, G. Xu, M. Ojanen, and E. Ikonen, Spectral Irradiance Comparison Using a Multi-Wavelength Filter Radiometer).

Bilateral comparison of spectral diffuse reflectance

A comparison between the absolute gonioreflectometric scales at the Metrology Research Institute and the Physikalisch-Technische Bundesanstalt (PTB) has been accomplished. Six different reflection standards were measured for their 0/45 spectral radiance factor between 250 nm and 1650 nm in 10 nm intervals. Also, the 0/d reflectance factor between 400 nm and 1600 nm in 100 nm intervals was determined from the goniometric reflectance measurements over polar angles with subsequent integration within the hemisphere above the sample. The report of the results was submitted for publication.

6.2 Conferences and Meetings

The personnel participated in the following conferences and meetings:

Physics Days 2008, March 27 – 29, 2008, Turku, Finland; *Tuomas Poikonen*

Joint research project (Quantum Candela) kick off meeting, April 15 – 16, 2008, Teddington, UK; *Erkki Ikonen, Farshid Manoocheri*

EURAMET TC Phora meeting, April 17 – 18, 2008, Teddington, UK; *Farshid Manoocheri, Erkki Ikonen*

Joint research project (Regenmed) kick off meeting, May 21 – 22, 2008, Teddington, UK; *Farshid Manoocheri*

Physics Summer School 2008 of the Estonian Physical Society, Nelijärve, Estonia, June 20 – 22, 2008; *Meelis Sildoja*

EURAMET Information Event and EMRP Committee Meeting, Brussels, Belgium, June 25 – 26, 2008; *Erkki Ikonen*

CIE Expert Symposium and CIE Division 2 TC meetings, July 6 – 11, 2008, Torino, Italy; *Erkki Ikonen*

EMRP Committee Meeting, October 2, 2008, Berlin, Germany; *Erkki Ikonen*

NEWRAD 2008 Conference, October 12 – 16, 2008, Daejeon, South-Korea; *Erkki Ikonen, Petri Kärhä, Silja Holopainen, Farshid Manoocheri, Maija Ojanen, Pasi Manninen, Meelis Sildoja*

NEWRAD Scientific Committee Meeting, October 15, 2008, Daejeon, South-Korea; *Erkki Ikonen (Chairman)*

High Temperature Fixed Point Workshop, October 17, 2008, Daejeon, South-Korea; *Maija Ojanen*

CCPR Working Group CMC meeting, October 12, 2008, Daejeon, South-Korea; *Erkki Ikonen*

CCPR Working Group KC meeting, October 16 – 17, 2008, Daejeon, South-Korea; *Erkki Ikonen*

CCPR Working Group SP meeting, October 17, 2008, Daejeon, South-Korea; *Erkki Ikonen*

EURAMET TC Phora meeting on EMRP Energy Targeted Program, October 14, 2008, Daejeon, South-Korea; *Erkki Ikonen*

Joint research project (Quantum Candela) interim meeting, October 30, 2008, Braunschweig, Germany; *Farshid Manoocheri*

Physics Autumn School 2008 of the Estonian Physical Society, October 31– November 2, 2008, Kääriku, Estonia; *Meelis Sildoja*

BioFuels Metrology 2008 Workshop, November 6 – 7, 2008, Strasbourg, France; *Erkki Ikonen*

International Congress of Metrology, Scientific and Technical Committee meeting, November 18, 2008, Paris, France; *Erkki Ikonen*

EMRP Energy and Strategy sub-Committee meetings, December 17 – 18, 2008, Berlin, Germany; *Erkki Ikonen*

6.3 Visits by the Laboratory Personnel

Erkki Ikonen, Petri Kärhä, Farshid Manoocheri, Tuomas Hieta, Silja Holopainen, Teemu Jaakkola, Pasi Manninen, Maija Ojanen, Jonna Paatelma, Tuomas Poikonen, Mikko Puranen, Meelis-Mait Sildoja, Maksim Shpak and additionally, Jari Hovila, Antti Lamminpää and Markku Vainio, as our laboratory's partners in cooperation, Research Group Development Day, visit to Metrosert Ltd, Tallinn, Estonia, April 11, 2008

Erkki Ikonen, PTB Berlin, PTB Braunschweig, Germany, June 23 – 24, 2008

Pasi Manninen, PTB Braunschweig, Germany, September 28, 2008

6.4 Research Work Abroad

Silja Holopainen, PTB Braunschweig, Germany, November 1 – December 31, 2008

6.5 Visits to the Laboratory

Dr. Saulius Nevas, PTB, Germany, January 2, 2008

Dr. Jarle Gran, Justervesenet, Norway, May 21, 2008

Dr. Toomas Kubarsepp, Metrosert, Estonia, May 21, 2008

Dr. Edgar Schmidhammer, EPCOS AG, Germany, June 27, 2008

Dr. Peter Blattner, METAS, Switzerland, November 19 – 21, 2008

7 PUBLICATIONS

7.1 Articles in International Journals

M. Sildoja, F. Manoocheri and E. Ikonen, "Reducing photodiode reflectance by Brewster-angle operation", *Metrologia* **45**, 11-15 (2008).

S. Holopainen, F. Manoocheri and E. Ikonen, "Goniofluorometer for characterization of fluorescent materials", *Appl. Opt.* **47**, 835-842 (2008).

P. Kärhä and T. Jaakkola, “Simple active method for reducing magnetic interference in a thermoelectrically cooled photomultiplier tube”, *Rev. Sci. Instrum.* **79**, 043102, 3 pages (2008).

M. Ojanen, V. Ahtee, M. Noorma, T. Weckström, P. Kärhä and E. Ikonen, “Filter radiometers as a tool for quality assurance of temperature measurements with linear pyrometers”, *International Journal of Thermophysics* **29**, 1084-1093 (2008).

P. Manninen, P. Kärhä and E. Ikonen, “Determining irradiance signal from an asymmetric source with directional detectors: application to calibrations of radiometers with diffusers,” *Appl. Opt.* **47**, 4714-4722 (2008).

M. Puranen and P. Eskelinen, “A short-pulse Ka-band instrumentation radar for foliage attenuation measurements,” *Rev. Sci. Instrum.* **79**, 106106, 3 pages (2008).

E. Ikonen, “Chaoticity parameter lambda and multiple coherent components in relativistic heavy-ion collisions,” *Phys. Rev. C* **78**, 051901 (Rapid Communication), 4 pages (2008).

A. G. Nasibulin, A. Ollikainen, A. S. Anisimov, D. P. Brown, P. V. Pikhitsa, S. Holopainen, J. S. Penttilä, P. Helistö, J. Ruokolainen, M. Choi and E. I. Kauppinen, ”Integration of single-walled carbon nanotubes into polymer films by thermo-compression,” *Chemical Engineering Journal* **136**, 409-413 (2008).

V. Ahtee, R. Lettow, R. Pfab, A. Renn, E. Ikonen, S. Götzinger and V. Sandoghdar, “Molecules as sources for indistinguishable single photons,” *Journal of Modern Optics* (in press).

T. Poikonen, P. Kärhä, P Manninen, F. Manoocheri and E. Ikonen, ”Uncertainty analysis of photometer quality factor f_1’,” *Metrologia* (in press).

M. Sildoja, F. Manoocheri and E. Ikonen, “Reflectance calculations for predictable quantum efficient detector,” *Metrologia* (in press)

M. Ojanen, M. Shpak, P. Kärhä, R. Leecharoen and E. Ikonen, “Report of the Spectral Irradiance Comparison EURAMET.PR-K1.a.1 between MIKES (Finland) and NIMT (Thailand),” *Metrologia* **44**, Tech. Suppl., 16 pages (in press).

T. Hieta and E. Ikonen, “Measurement of Erbium-doped fiber nonlinearity using continuous-wave self-phase modulation method,” *IEEE/OSA Journal of Lightwave Technology* (in press).

T. Widmaier, T. Salmela, P. Kuosmanen, J. Juhanko, P. Kärhä and J. Uusimäki, “Reducing thickness variation of hot rolled steel strip by non-circular backup roll geometry,” *Ironmaking and Steelmaking: Products and Applications* (in press).

7.2 International Conference Presentations

E. Ikonen, T. Poikonen, P. Kärhä, P. Manninen and F. Manoocheri, “Determination of f_1’ and its uncertainty with biased and random error models,” *Proceedings of the CIE Expert Symposium on Advances in Photometry and Colorimetry* (Turin, Italy, 2008) pp. 55-60 (talk).

P. Kärhä, “Back to the basics: Distance dependence of radiometric measurements,” *Proceedings of the 10th international conference on New Developments and Applications in Optical Radiometry (NEWRAD 2008)*, Daejeon, South-Korea, October 13-16, 2008, pp. 253-254 (invited talk).

P. Manninen and P. Orreveteläinen, “Colour changes of light-emitting diodes under pulse-width modulation dimming,” *Proceedings of the 10th international conference on New Developments and Applications in Optical Radiometry (NEWRAD 2008)*, Daejeon, South-Korea, October 13-16, 2008, pp. 221-222 (poster).

S. Holopainen, F. Manoocheri and E. Ikonen, “Goniofluorometer for measuring absolute fluorescence quantum yield,” *Proceedings of the 10th international conference on New Developments and Applications in Optical Radiometry (NEWRAD 2008)*, Daejeon, South-Korea, October 13-16, 2008, pp. 153-154 (talk).

S. Holopainen, F. Manoocheri, E. Ikonen, K.-O. Hauer and A. Höpe, “Comparison measurements of 0/45 radiance factors between 250 and 1650 nm,” *Proceedings of the 10th international conference on New Developments and Applications in Optical Radiometry (NEWRAD 2008)*, Daejeon, South-Korea, October 13-16, 2008, pp. 323-234 (poster).

F. Manoocheri and E. Ikonen, "Confirmation of paper moisture using an infrared spectrometer," *Proceedings of the 10th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2008),* Daejeon, Korea, October 13-16, 2008, pp. 121-122 (poster).

M. Sildoja, F. Manoocheri and E. Ikonen, "Reflectance calculations for two-photodiode predictable quantum efficient detector", *Proceedings of the 10th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2008)*, Daejeon, Korea, October 13-16, 2008, pp. 67-68 (poster).

M. Ojanen, K. Anhalt, J. Hartmann, T. Weckström, P. Kärhä, M. Heinonen and E. Ikonen, "Comparison of the radiation temperature scales between PTB and MIKES," *Proceedings of the 10th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2008),* Daejeon, South-Korea, October 13-16, 2008, pp. 285-286 (poster).

Y. J. Liu, G. Xu, M. Ojanen and E. Ikonen, "Spectral irradiance comparison using a multi-wavelength filter radiometer," *Proceedings of the 10th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2008)*, Daejeon, South-Korea, October 13-16, 2008, pp. 239-240 (talk).

E. Ikonen, T. Melkas, J. Laasasenaho, J. Kivilähde and M. Merimaa, "Measurement of forest-sample-plot biomass using camera and laser illumination," *Bio-Fuels Metrology 2008 Workshop*, Strasbourg, France, November 6-7, 2008 (poster).

T. Widmaier, P. Kuosmanen, T. Salmela, P. Kärhä and J. Juhanko, "Improved steel strip quality by 3D ground backup rolls," *Proceedings of the 53rd Internationales Wissenschaftliches Kolloquium, Prospects in mechanical engineering, Technische Universität Ilmenau*, Ilmenau, Germany, September 2008, pp. 229-230.

A. Heikkilä, J. Juhola, M. Kaunismaa, J. Hakkarainen, O.Meinander, O. Tolonen-Kivimäki, U. Feister. S. Kazadzis, A. Bais, J. M. Vilaplana Guerrero, C. Guirado, J.Rodríguez, P. Kärhä, T.Ture, S. Syrjälä and J. Koskinen, "Outdoor weathering of glass fibre reinforced polyester and vinyl ester composites: first results after one year exposure," *13th European Conference on Composite Materials (ECCM13),* Stockholm, Sweden, June 2-5, 2008 (poster).

A. Heikkilä, O. Meinander, O. Tolonen-Kivimäki, A. Lindfors, J. Kaurola, T. Koskela, K. Lakkala, A. Naula-Iltanen, A. Sormanen, J. Juhola, M. Kaunismaa, U. Feister, N. Puglisi, A. Dell'Acqua, J. Verdebout, J.-P. Putaud, N. Kouremeti, S. Kazadzis, A. Bais, J. M. Vilaplana Guerrero, C. Guirado, J. Rodríguez, P. Kärhä, T. Ture, S. Syrjälä and J. Koskinen, "Towards life-time estimations for outdoor polymeric materials in the changing climate," *ESF/FMHS Entre-Sciences Conference "New methodologies and Interdisciplinary Approaches in Global Change Research*", Porquerolles, France, November 5-10, 2008 (poster).

7.3 National Conference Presentations

T. Poikonen, P. Manninen, P. Kärhä and E. Ikonen, "Luminous flux measurement of light emitting diodes," *the XLII Annual Conference of the Finnish Physical Society 2008*, Turku, Finland, March 27-29, 2008 (poster).

7.4 Other Publications

S. Holopainen (editor), *Annual report 2007*, Metrology Research Institute, Helsinki University of Technology, Espoo 2008, Metrology Research Institute Report 33/2008, 35 p.

P. Manninen, *Characterization of diffusers and light-emitting diodes using radiometric measurements and mathematical modeling*, TKK Dissertations 139, Espoo 2008, 89 p.

HELSINKI UNIVERSITY OF TECHNOLOGY
METROLOGY RESEARCH INSTITUTE REPORT SERIES

HUT-MRI-R23/2004	S. Nevas, F. Manoocheri, and E. Ikonen Gonioreflectometer for measuring spectral diffuse reflectance.
HUT-MRI-R24/2005	M. Noorma, V. Ahtee, A. Lamminpää, P. Kärhä, F. Manoocheri T. Weckström, and E. Ikonen Radiometric temperature measurements with absolutely characterized filter radiometers in irradiance mode.
HUT-MRI-R25/2005	M. Noorma Development of detectors and calibration methods for spectral irradiance and radiometric temperature measurements.
HUT-MRI-R26/2005	O. Kimmelma (editor) Biennial report 2003-2004.
HUT-MRI-R27/2005	S. Nevas, S. Holopainen, F. Manoocheri, E. Ikonen, Y. Liu, T. H. Lang and G.Xu Comparison measurements of spectral diffuse reflectance.
HUT-MRI-R28/2005	P. Kärhä, J. Hollmen, S.Karling, J. Kujala, P. Kuosmanen, J. Lindqvist Opinnäytetyön ohjaus Teknillisessä korkeakoulussa.
HUT-MRI-R29/2005	Markku Vainio, Mikko Merimaa, Kaj Nyholm Modulation transfer characteristics of injection-locked diode lasers.
HUT-MRI-R30/2006	J. Envall, P. Kärhä, and E. Ikonen Calibration of broadband ultraviolet detectors by measurement of spectral irradiance responsivity.
HUT-MRI-R31/2006	S. Holopainen (editor) Annual report 2005.
TKK-MRI-R32/2007	S. Holopainen (editor) Annual report 2006.
TKK-MRI-R33/2008	S. Holopainen (editor) Annual report 2007.
TKK-MRI-R34/2009	U. Sikander (editor) Annual report 2008.

ISSN 1237-3281

Picaset Oy, Helsinki 2009