Consultative Committee for Photometry and Radiometry (CCPR)

25th Meeting (on-line 10-11 May 2022)

CCPR member report on activities in radiometry and photometry since the last CCPR meeting (2019)

Reply from: National Institute of Standards and Technology, US

Delegate: Maria Nadal

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1. **Summarize recent progress in your laboratory with respect to measurement standards, research projects, and metrology services to fulfill the demands of customers in:**

(a) broad-band radiometric quantities:

Radiance Temperature Calibration of Blackbodies in Vacuum using a Absolute Cryogenic Radiometer

NIST realized a new calibration service for customer-supplied blackbodies that operate in high vacuum. Infrared radiance is measured at specific blackbody setpoint temperatures using the NIST Absolute Cryogenic Radiometer (ACR). The ACR is an electrical substitution radiometer operating at cryogenic temperatures and is a primary standard for radiant power. The Stefan-Boltzmann law is used to convert measured broadband radiance into radiance temperature. A calibration equation relating radiance temperature to setpoint temperature is provided to the customer, and the radiance temperature uncertainty at each setpoint temperature is reported. Radiance temperatures can be calibrated from 180 K to 800 K and calibration data can be provided for multiple blackbody apertures.

Superconducting Nanowire Single-Photon Detectors (SNSPDs)

SNSPDs have emerged as the highest performing single-photon detectors from the ultraviolet to the mid-infrared. NIST is developing and characterizing these detectors and their applications to quantum information science and technology and exoplanet spectroscopy. A new He-3 cryostat system is being developed for broadband measurements of single-photon detectors in the infrared region.

Airborne Lunar Spectral Irradiance (air-LUSI) Instrument

NIST developed and demonstrated the air-LUSI instrument in partnership with NASA, the University of Maryland Baltimore County, and the University of Guelph. This instrument is designed to measure the spectral irradiance of the solar-illuminated Moon from a high-altitude ER-2 aircraft. The measurements will help in realizing the Moon as a reference standard for calibrating satellite instruments used to study and monitor the Earth’s environment and climate. The uncertainty of the measurements of the Moon's spectral irradiance must be improved from a few percent to below 0.5% to calibrate instruments at the level needed for climate monitoring. The air-LUSI effort compliments a longer term NIST effort to provide daily measurements of the lunar spectral irradiance from a high-altitude site on Mauna Loa, Hawaii. Approximately six years of such measurements are planned to account for lunar phase and libration, required to provide an accurate model of the lunar irradiance.

New Calibration Service for Photovoltaic Cells

NIST radiometric standards are the foundation for measuring the performance of photovoltaic cells. The Primary Optical Watt Radiometer (POWR) is the U.S. primary standard for optical power. NIST has recently established a calibration service for photovoltaic cells which can be used for indoor light, outdoor solar, and exo-atmospheric solar measurements. A single cell can be calibrated and used under all three conditions. This work was done in collaboration with the NIST Engineering Laboratory and the National Renewable Energy Laboratory (NREL) in Colorado.

New NIST Calibrated Reference Photovoltaic Cells

NIST recently deployed a packaged photovoltaic cell that is calibrated to give the irradiance spectral responsivity and the short circuit current, I_{sc}, of a 20 mm PV cell under a well-defined reporting condition. The NIST photovoltaic cell calibration method is a primary method called the differential spectral responsivity technique, is performed in irradiance mode, and has direct traceability to the SI using other NIST calibrated specimens. The reference solar cell is mounted onto a small, printed, circuit board and the board is fitted into the body of the housing with good thermal contact and a temperature sensor (thermocouple) for monitoring its temperature.

(b) spectral radiometric quantities:

Improvements in the Reflectance and Transmittance Facilities at NIST

NIST recently completed two major upgrades to its reflectance and transmittance capabilities. The Robotic Optical Scattering Instrument (ROSI) now serves as the national reference instrument for specular and diffuse bidirectional reflectance measurements in the ultraviolet (UV) to short-wave infrared (SWIR) wavelength regions, replacing the aging Spectral Tri-function Automated Reference Reflectometer (STARR). Additionally, a new UV light source and other upgrades to the Reference Transmittance Spectrophotometer (RTS) have resulted in a new uncertainty budget for UV-visible transmittance measurements and reduced measurement times.

New Cryogenic Low-Background Infrared Radiometer (LBIR)

NIST have constructed, calibrated, and tested a portable cryogenic low-background infrared (IR) radiometer for both spectral radiance and irradiance measurements over the 4 µm to 20 µm wavelength range. This radiometer is designed to transfer its detector and source-based radiometric calibration to IR sources designed to operate in vacuum test chamber. NIST researchers demonstrated that this radiometer has reduced radiometric uncertainties and improved spectral coverage compared to previous instruments.

NIST Calibration Service for UV Lamps

NIST has re-established the capability for the irradiance calibration of UV lamps, particularly deuterium lamps, at a 50 cm distance over the wavelength range from 200 nm to 400 nm. NIST is the pilot laboratory for the upcoming CCPR K1.b intercomparison.

New Calibration of Spectroradiometers using Tunable Lasers

NIST conducted research on the feasibility of calibrating spectroradiometers directly against a primary standard trap detector using tunable lasers. The goal is to shorten the long calibration chain when using the conventional source-based calibration approach and thereby reduce the uncertainty on the spectroradiometer's calibration. The research demonstrated the feasibility of this new detector-based approach. This detector-based approach also enables a new, independent realization of spectral irradiance or radiance responsivity scales onto spectroradiometers. Such spectroradiometers can then be used as instrument-based primary or transfer standards to disseminate a spectral irradiance or radiance scale.

New Beamline at the NIST Synchrotron Ultraviolet Radiation Facility III (SURF III)

SURF III produces calculable irradiance traceable to the SI units to less than 1 % absolute uncertainty from 4 nm to 400 nm. There are several beamlines equipped for radiometer, spectroradiometer, and lamp calibrations; reflectometry and transmission measurements; and degradation and lifetime studies. NIST has commissioned a new beamline (BL-3) at SURF III for detector calibrations and reflectometry measurements in the wavelength range from 5 nm to 400 nm. This beamline uses a reflectometer that was originally operated by the Naval Research Laboratory at the National Synchrotron Light Source and has been relocated to NIST and upgraded. It consolidates the functions of two other facilities, SURF BL-9 and the Far Ultraviolet Calibration laboratory, and the original facilities have been decommissioned. In addition to this effort, the building that houses SURF III is undergoing major renovations.

Recent Improvements in the Spectral Irradiance and Radiance responsivity Calibrations with Uniform Sources (SIRCUS)

NIST has improved the uncertainties for SIRCUS in the infrared spectral region for measurement of irradiance by using a black-coated pyroelectric detector having measured spectral reflectance (on a witness detector) from the visible-to-infrared. The pyroelectric detector has a uniform spatial response over its active region. The technique transfers the calibration of a trap detector to the pyro in irradiance mode at the SIRCUS facility, avoiding the need for a spatially uniform infrared reference detector to transfer the power scale (as realized by the primary electrical substitution radiometer) to an irradiance scale.

(c) photometric quantities:

New Photometric Bench

NIST recently replaced its 40-years-old photometric bench. The new laboratory is equipped with an automated 5 m photometry bench, which has a 1.5 m travel translation stage orthogonal to the optical path for changing light sources and a 0.8 m travel translation stage orthogonal to the optical path for changing photometers and other optical sensors. The rail system positions the detectors anywhere between 0 m to 5 m away from the lamps The light source or photometer is switched from one to another automatically depending on the calibration need. The distance uncertainty of the new photometry bench is 50 µm, which is achieved using an absolute linear encoder and a new microscope-based alignment technique. The NIST team has reduced all major uncertainties and significantly reduced the time required for performing standard calibrations.

New Calibration Service for LEDs and Other Solid-Sate Lighting Products

NIST is now offering a faster, more accurate and less labor-intensive calibration service for assessing the brightness of LED lamps and other solid-state lighting products including LED packages and arrays, integrated LED lamps, and small LED luminaries. Customers for the service include LED lamp manufacturers and government and private sector calibration laboratories. NIST scientists have also added a goniophotometer capability which allows measurement of the output of an LED lamp at various viewing angles.

New Standard Reference Optical Radiometer

This new radiometer offers customers the ability to take advantage of the laser-based calibration facility available at NIST. The measurement system includes a photometer head, amplifier, temperature controller, and other accessories. The photometer head includes an optical window, precision aperture, photometric filter, and photodiode, which is sealed and filled with dry nitrogen gas at one atmosphere. It is temperature-regulated using a thermo-electric cooler. The photometer head is specially designed to be free of interference fringes when it is calibrated using the tunable laser facility at NIST.

Development of New Photometer

A new set of photometers were developed and used for realization of the NIST luminous intensity scale. The uncertainty of the luminous intensity scale has been improved significantly by calibrating the new photometers directly against reference trap detectors for spectral irradiance responsivity using tunable lasers. This laser-based calibration facility is also used for calibrating spectroradiometers to achieve a calibration uncertainty that is lower than that provided by conventional lamp-based calibration systems.

Measurement Science and Standards for Germicidal Ultraviolet Light (GUV) Technologies.

NIST accelerated the development of performance measurements and documentary standards for GUV technologies. GUV radiation is effective in inactivating the SARS-CoV-2 virus, particularly for wavelengths near 222 nm as dose levels effective against viruses do not penetrate beyond the dead stratum corneum outer layer of the skin. The healthcare industry has used GUV since the 1920's, originally to help control the spread of tuberculosis, and more recently to reduce the threat of multiple drug-resistant organisms (MDROs) and related secondary infections known as Healthcare Acquired Infections (HAIs). However, the acceptance of UV radiation for germicidal applications continues to be slow primarily due to the lack of safety and efficacy standards for antimicrobial and antiviral applications. NIST current projects in this area include UV radiation irradiance and power scale realizations, UV detector characterization and calibration, UV LED measurement research, UV action spectra measurements for the deactivation of SARS-CoV-2 in collaboration with the US Department of Homeland Security (DHS), a UV – SIM (Inter-American Metrology System) workshop, and a SIM radiometer distribution.

Standard LEDs with Superior Long-Term Stability

NIST developed a large-chip, standard LED with superior long-term stability. The standard LED uses a large, specialty die rated for 50 W, but operated under 3 W to reduce aging effects. The standard LED was seasoned for one year and measured for its long-term stability for three years. The measurement result shows that the long-term stability is approximately 0.1 % over the three-year time. The LED can be used as a transfer standard for luminous intensity, luminance, and total luminous flux.

(d) other area(s) relevant to CCPR:

N95 Mask Disinfection

NIST studied the use of GUV radiation to disinfect N95 respirator masks. This investigation showed that UV cabinets used by hospitals to disinfect equipment like wheelchairs and beds can also be used to disinfect N95 masks for SARS-CoV-2. At the dosages of UV radiation used, a single mask can be disinfected up to 10 times without significantly impacting mask performance. This study demonstrated that masks can be safely recycled during shortages. The collaboration involved NIST researchers, two commercial entities, and the Federal agency responsible for mask standards (NIOSH). NIST Scientists contributed expertise in the measurement of UV dosage and tested the change in flow resistance of the masks upon treatment.

2. **What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please explain the reasons and provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.**
    a. **High-Accuracy Room Temperature Absolute Radiometer**

For nearly forty years, the NIST Sources and Detectors Group have maintained the legacy C-series calorimeter as the free-space continuous-wave laser power detector. These are being replaced by two room-temperature high-accuracy planar absolute radiometers based on vertically aligned carbon nanotubes. This instrument will lower the combined relative expanded measurement uncertainty (k = 2) from 0.84 % to 0.13 %. The new radiometer's performance was validated by comparing its response against a transfer standard silicon trap detector traceable to NIST's primary standard laser optimized cryogenic radiometer and against the C-series calorimeter. On average, these comparisons agreed to better than 0.008 % and 0.05 %, respectively.

3. **Summarize the Capacity Building and Knowledge Transfer activities undertaken by your institute in photometry and radiometry (courses, training, …):**

NIST Course on the Calibration of Ambient Radiation Thermometers

NIST offered a virtual course to SIM countries on the calibration of ambient radiation thermometers (ART). Most ARTs operate in the 8 µm to 14 µm wavelength range to measure the temperatures of surfaces at or near room temperatures, including skin surface temperatures for the detection of elevated body temperature characteristic of a fever. These ARTs have been frequently used to screen people for fevers during the COVID-19 pandemic. The virtual course discussed proper calibration procedures and effective use of such ARTs. Over 50 metrologists from 15 counties in the Americas participated.

NIST Course on UVC Technologies for UV Radiation Disinfection

NIST began a project to support the evaluation and calibration of UVC technologies for disinfection. The project was initiated to support SIM member NMIs and DIs response to the COVID-19 pandemic. NIST assisted SIM members with existing capabilities in light measurements and applications. During the workshop, NIST researchers described measurement methodologies for field measurements, including measurement of excimer lamp (222 nm), low pressure mercury (254 nm), and UV-LED (~265 – 270 nm) devices, and explored ways that SIM laboratories can introduce UVC technologies into their measurement systems.

NIST Photometry Short Course

This course has been offered every two years for over a decade and covers fundamentals in photometry, radiometry, and colorimetry and practical aspects of measurements of luminous flux, luminous intensity, illuminance, luminance, color temperature, and chromaticity of light sources. The last in-person course was offered in September 2019.

Due to the pandemic, the 2022 course was held virtually. The course consisted of three and a half days of lectures and two laboratory sessions in the NIST photometry laboratories using the 5-m photometry bench and the 2.5-m integrating sphere. This course was intended for photometry engineers and technicians at the NMI level working with industries such as lighting, photography, and avionics; calibration and testing laboratories; and instrument manufacturers.

4. **Summarize the research projects currently performed within a collaboration with one or more NMIs or Dis (name of the project, participants):**

    a. **Optical Fiber Power Cryogenic (OFCR) Radiometer**: development of an absolute radiometer expressly optimized for light emitted from in the visible to near infrared, particularly at telecommunications wavelengths. *Collaborating NMIs*: CMI Czech Republic; CENAM Mexico; and NIST (Boulder), US. Reference CCPR-WG-SP Task Group 13

    b. **Calibration of 'photon calibrators' (near 300 mW, 1047 nm) for international gravitational wave observatories**. *Collaborating NMIs*: PTB Germany and NIST (Boulder) US. Reference CCPR-WG-SP Task Group 14

    c. **High power laser measurements (greater than 1 KW):** measurement of laser power by photon momentum comparing traceability to conventional thermal radiometry and photon momentum (photon force) measurements. *Collaborating NMIs*: PTB Germany and NIST (Boulder) US

    d. **Single-photon source and detector development and calibration**: *Collaborating NMIs*: NRC Canada and NIST (Boulder) US

    e. **Scale comparison for UV and visible transmittance:** The results will be used to validate recent improvements to NIST's uncertainty budget. *Collaborating NMIs*: NRC Canada and NIST (Gaithersburg) US

5. **Are there any other research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?**

    NIST is seeking collaborators for the further development of a calibration method that makes direct spectral power calibrations using a planar absolute cryogenic radiometer (ACR) integrated with a Fourier-transform spectrometer. This method of direct spectral calibrations with an ACR could be used to shorten calibration chains for high-resolution spectral power measurements in the infrared.

6. **Have you got any other information to place before the CCPR in advance of its next meeting?**

    a. NIST (Boulder) has demonstrated optical power traceability by means of photon momentum measurements as an alternative path to Planck's constant. This project has demonstrated calibration compared to mass artifacts (near 100 kW, or 1 mg) with unprecedented uncertainty. We are preparing a manuscript documenting traceability to electrical measurements ((that is, not subdividing the kg) with an electronic force balance with NIST representatives of CCM.

b. NIST (Boulder) have developed and fabricated an electrical substitution microbolometer for the Compact Solar Irradiance Monitor satellite (CSIM) that was vital to extending the IR portion of the spectrum in the 2400- 2800 nm region since 2019. Recently the World Metrology Committee on Earth Observation has put out a recommendation to accept this spectrum as the new international standard for satellite calibration referencing.

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