Tuesday, September 22, 2020 | 10:45 a.m.

Technical Session

National Standards Technology Advancement

Opportunities for communication and collaboration between National standards laboratories and the calibration community to improve calibration technologies and methodologies.

- Calibration traceability to standards—NIST and international
- Relationship between primary, secondary, and transfer standards and applications to remote sensing
- Maintenance of a valid calibration throughout instrument life
- Activities within the community aimed at increasing the quality of our satellite-based measurements

10:50

Detector Responsivity by Fibre Coupled Cryogenic Primary Standard at 0.1%

Malcolm White – National Institute of Standards and Technology (NIST)

ABSTRACT: We have previously presented work describing a new optical fibre-coupled cryogenic primary standard facility at NIST. The new radiometer replaced a liquid helium system as the primary standard for the traceable dissemination of the power responsivity of fibre-coupled visible and near-infrared detectors [1]. The facility has been upgraded and now uses polarisation maintaining (PM) fibre throughout, from the Fabry-Pérot fibre-coupled laser diode sources, through the variable optical attenuators with integral shutters and PM fibre beam-splitters [2]. The system is used at wavelengths of 850 nm, 1310 nm and 1550 nm, with an expanded uncertainty of 0.1 %.

This presentation will illustrate how we assessed the main contributors to the uncertainty budget and thus were able to improve the overall uncertainty from 0.4 % to 0.1 %.

We have measured the temperature dependent change of the Fresnel reflection loss and Rayleigh backscatter of PM single-mode fibre as it was cooled to 5 K. This change in Fresnel reflection accounts for a small 0.03 % correction to the room temperature beam-splitter ratio measurement between the radiometer and the device under test (DUT). We used an in-situ beam-splitter measurement technique to measure the Fresnel reflection and we confirmed the results at 1550 nm with an optical frequency domain reflectometer measurement.

Passive optical components such as fibre beam-splitters and couplers exhibit polarisation dependent loss (PDL), whereby the output signal of the device varies as a function of the input polarisation state. In our setup this affects the room temperature beam-splitter ratio between radiometer and DUT. The temperature dependence of the PDL was evaluated, using the Mueller matrix method, for fused biconical and planar polarisation maintaining fibre beam-splitters at 1310 nm and 1550 nm over the range 10 ºC to 40 ºC. The uncertainty in determining this ratio will be discussed during the presentation.

We have also assessed the impact that the temporal and spectral modal stability of the Fabry-Pérot laser diode sources have on the power responsivity of the DUT. The wavelength uncertainty that arises is incorporated into the uncertainty budget.
This work improves and further assures the performance of our optical fibre-coupled cryogenic radiometer facility.

1. M.G. White, Z.E. Ruiz, C.S. Yung, I. Vayshenker, N.A. Tomlin, M.S. Stephens, and J.H. Lehman, “Cryogenic primary standard for optical fibre power measurement”, Metrologia 55(5), 706-715 2018
2. M.G. White, E. Baumann, I. Vayshenker, Z.E. Ruiz, M.S. Stephens, M. Smid and J.H. Lehman, “The nature of fibre coupled detector responsivity measurements at 0.1 % using a primary standard”, Submitted Opt. Express, Feb. 2020

11:10

Broadband, Absolutely Calibrated Microbolometer Array Development

Michelle Stephens, Chris Yung, Nathan Tomlin, John Lehman – National Institute of Standards and Technology (NIST); David Harber, Karl Heuerman, Joel Rutkowski, Cameron Straatsma, Odele Coddington – Laboratory for Atmospheric and Space Physics (LASP), University of Colorado

ABSTRACT: Microfabricated electrical substitution bolometers with vertically aligned carbon nanotube (VACNT) absorbers are being integrated into laboratory standards for optical laser power1 and CubeSats for solar irradiance mesurements2,3. We are building on these successes to extend the single bolometer technology to broadband microbolometer arrays with electrical substitution and VACNT absorbers. A linear array of radiometer elements has been fabricated. Each element is an uncooled bolometer with vanadium oxide (VOx) temperature measurement. Unlike existing VOx microbolometer technology where the thermistor film is incorporated into a narrow band cavity and doubles as the absorber, in these microbolometer arrays we use VACNT absorbers. Additionally, each element can be electrically heated to provide an absolute radiometric calibration through electrical substitution.

The array provides two benefits for Earth Science applications that require spectral data across many wavelengths. The first is the electrical substitution calibration on every pixel. Existing instruments are typically calibrated on the ground but then subjected to severe launch and space environments. On-orbit calibration is achieved with a reference such as a blackbody, lamp, or reference material and by ground verification. On-orbit references increase mass and power and may be degraded by the space environment. This technology eliminates the need for on-orbit references by incorporating electrical substitution calibration. By comparing the temperature rise of the bolometer when illuminated to the temperature rise when a known current is injected into a heater of known resistance, a calibrated irradiance is measured.

The second benefit is an extended spectral range. A typical microbolometer response is from 8 um to 15 um, but a VACNT absorber can extend the response to a wider 0.3 um to 100 um range. A broader spectral response in a single array can serve to reduce the number of detectors needed to span a broad wavelength range. The response above 20 µm improves measurement capabilities for applications such as Earth Radiation Budget. The combination of broadband spectral response and integrated calibration capability makes this single technology applicable to a broad range of scientific measurements.

This talk will describe the design, fabrication, and performance of the microbolometers. To date we have achieved a noise floor of ~100 □K/sqrt(Hz) at 0.1 Hz. We show the expected performance of one of these arrays incorporated with a small telescope is appropriate for use on a smallsat.

Acknowledgements: This work is funded by the NASA Earth Science Technology Office.

1. M.G. White, et al., “Cryogenic primary standard for optical fibre power measurement”, Metrologia 55(5), 706-715 2018.
2. Erik Richard et al., “The compact spectral irradiance monitor flight demonstration mission”, Proc. SPIE 11131, CubeSats and SmallSats for Remote Sensing III, 1113105 (30 August 2019).
3. David Harber et al., “Compact total irradiance monitor flight demonstration”, Proc. SPIE 11131, CubeSats and SmallSats for Remote Sensing III, 111310D (30 August 2019).

11:30

Development of 300 mW Background-Compensated Planar Absolute Radiometer Operating at Room Temperature

Anna Vaskuri, Michelle Stephens, Nathan Tomlin, Christopher Yung, Andrew Walowitz, John H. Lehman – National Institute of Standards and Technology (NIST), Boulder; Cameron Straatsma, David Harber – Laboratory for Atmospheric and Space Physics (LASP), University of Colorado

ABSTRACT: NIST's C-series isoperibol calorimeters [1] operating at room temperature have been used as reference instruments in the laser power calibrations at NIST for over 50 years. These calorimeters operate from 100 µW to 300 mW with an expanded uncertainty of 0.86% (k = 2). Recently developed vertically aligned carbon-nanotube (VACNT) absorbers, with spectrally flat and hemispherical absorptance better than 99.95%, have enabled development of planar absolute bolometers with smaller size and significantly faster measurements compared to traditional laser calorimeters.

In this work, we present the latest progress of the Planar Absolute Radiometer for Room Temperature (PARRoT) [2] currently under construction that will replace the old reference C-series calorimeters. PARRoT is based on the electrical power substitution method and it can measure laser powers up to 300 mW with a predicted expanded uncertainty better than 0.1% (k = 2). The radiometer is operated at room temperature and placed in a 15 cm cube vacuum chamber to minimize convection while still providing a compact and sturdy standard. The laser beam is transmitted to the absorber by an uncoated fused silica window with a 0.5° wedge assuring polarization independent laser power detection. PARRoT is background compensated by differential operation where the reference detector chip is driven by a constant DC power and the measuring detector chip is feedback controlled to follow the temperature of the reference detector chip. The closed loop operation makes the radiometer's response linear across the operational power range. We have optimized the detector chip design by thermal modeling [2]. The modeled electro-optical inequivalence for a centered laser beam is 0.007% and the spatial non-uniformity is ±0.02% within 4 mm radius from the absorber's center, meaning that PARRoT is not sensitive to small alignment offsets.

PARRoT's differential background compensation makes it insensitive to variations in background radiation. That combined with a compact design would allow it to be used as a radiance detector standard for field calibrations and atmospheric measurements outdoors or as a transfer standard between laboratories. Similar bolometers will be launched in a CubeSat satellite next year to measure total solar irradiance [3]. By changing a few resistance values in the electronics, by changing the detector chip's heater resistance, and modifying the thermal conductance of the heat link design, the power range of PARRoT can be modified for different applications without compromising the accuracy. For example, reducing the heater resistance and increasing the heat link's thermal conductance can extend the power range to 2 W. This enables, for instance, direct calibration of the 1 W laser beam power in LIGO (Laser Interferometer Gravitational-wave Observatory) with an expanded uncertainty of 0.1% (k = 2) which would be an order of magnitude improvement to its current calibration against NIST's reference calorimeter via an integrating sphere transfer standard.

Acknowledgements: Jenny and Antti Wihuri Foundation, Finland is acknowledged for the financial support of this research.

1. E. D. West et al., "A Reference Calorimeter for Laser Energy Measurements," J. Res. Natl. Bur. Stand. (U. S.) 76A, 13–26 (1972).

2. A. Vaskuri et al., "Microfabricated bolometer based on a vertically aligned carbon nanotube absorber," Proc. SPIE 11269, 1–12, Synthesis and Photonics of Nanoscale Materials XVII, 112690L (March 2020).

3. D. Harber et al., "Compact total irradiance monitor flight demonstration," Proc. SPIE 11131, 1–8, CubeSats and SmallSats for Remote Sensing III, 111310D (August 2019).

11:50

Alternative Calibration Methods of Radiometric Detectors

Jarle Gran, Trinh Tran, Marit Ulset Nordsveen – Justervesenet; Eivind Bardalen, Per Øhlckers – University of South-East Norway; Ørnulf Nordseth – Institute for Energy Technology; Ozhan Koybasi – SINTEF

ABSTRACT: The usual way of calibrating detectors or devices is to treat them as black boxes. We measure the response when the device is excited with a well-known signal. With this approach we throw away a lot of information that can be used to develop new calibration techniques. In the common European project chipS·CALe (running from June 2019 – May 2022) we aim to develop self-induced silicon photodiodes capable of calibrating themselves in possibly remote operation. The trick is to exploit the intrinsic quantum properties of photodiodes that each photon generates exactly one electron hole pair. This is a valid assumption to about 99.9% of common calibration standard photodiodes used in laboratories today when correcting for reflectance.

Two fundamentally different approaches are explored in the chipS·CALe project. We are developing new simple structure photodiodes with improved quantum efficiency beyond the usual 99.9 % photon to electron conversion efficiency. Because the photodiodes have a simplified structure, their losses can be simulated with 3D simulation models. With simple I-V measurements at one wavelength only, a 3D model fit can be applied, and the responsivity from 400 nm to 850 nm can be predicted.

The second method is based on exploiting the photodiode as an electrical substitution radiometer in addition to its usual quantum mode. The incoming radiation is converted either to a photocurrent, as in a traditional photodiode, or to heat, using electrical substitution to determine the power of the absorbed radiation. The true internal quantum deficiency is measured by this method as it is the same absorber used in both application modes and heat is generated by forward bias of the photodiode using the same ammeter. Special type of packaging is required to operate the photodiode in dual mode and the technique is not in general limited to the use of self-induced photodiodes. However, if using a self-induced photodiode both approaches can be applied independently on the same device and the radiometric measurement of fundamental constants e/hc can be measured as a validation of the equivalence between the two independent methods. As these fundamental constants are three of the defining constants of the new SI, the dual-mode detector will provide a direct link between two practical primary radiometric measurement techniques and the SI.

Acknowledgement

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12:10

The STAR-CC-OGSE System for Pre-flight Sensor Calibration

Paul Green, Sean Devlin, William Kingett, Nigel Fox – National Physical Laboratory, UK

ABSTRACT: Reliable characterisation and radiometric calibration of satellite sensors are critical to their optimal performance on-orbit. Only through a robust understanding of the instrument behaviour, performance and degradation mechanisms will the significant effort and expense invested into the flight hardware be fully exploited. The uses of satellite sensor data, with their increased use in long-term environmental monitoring and climate studies mean that the performance and data quality provided by a single sensor can no longer be considered in isolation but needs to be considered as a part of the international Earth Observation (EO) infrastructure and referenced to common standard, the SI. The drive for improved performance, together with the desire for inter-operability between sensors creates increased demands on the pre-flight characterisation and radiometric calibration of sensors and the facilities needed to undertake these activities.

Sensor pre-flight characterisation and calibration facilities, or optical ground support equipment (OGSE) test sensor performance over a few broad categories including: geometric performance/image quality, channel/band co-registration, spectral calibration/out-of-band rejection, radiometric calibration, polarisation sensitivity, non-linearity, non-uniformity response etc. The specific requirements of the sensor,

determined by its footprint, FoV, spectral extent & resolution, nominal radiance and required sensitivity typically results in a bespoke OGSE needed to meet the specific sensor requirements. For large-scale multi-sensor series programmes, a bespoke solution may remain the preferred solution. However, for single/few unit explorer missions, commercial constellations and more agile sensor development programmes, the expense & post-use redundancy of a bespoke OGSE system may be prohibitive.

NPL has developed a universal OGSE facility, the Spectroscopically Tuneable Absolute Radiometric calibration & characterisation OGSE (STAR-CC-OGSE), a versatile facility for the radiometric calibration and characterisation of satellite sensors. The system is provided fully characterised, calibrated and performance verified, with an easy to use software interface that allows fully automated remote operation. The system can be installed at a customer cleanroom facility or operated at NPL with a customer-supplied sensor. The main components of the STAR-CC-OGSE system are:

- A large aperture integrating sphere source for radiometric calibration
- A collimated beam source, equipped with an interchangeable, position fine-tuneable feature field mask for optical performance characterisation
- A CW laser allowing monochromatic continuous tuneability from 270 nm to 2700 nm, with a broadband (white light) source extending over the same spectral extent.
- A vacuum-compatible SI-traceable radiance detector module containing both broadband photodiodes & a spectrometer, installable in TVAC at the sensor-under-test entrance aperture

The laser illumination interface to the large aperture radiance sphere, collimator beam source or direct to the feature field mask allows fully tuneable monochromatic illumination for all characterisation and calibration modes.

STAR-CC-OGSE is undergoing final performance testing, with delivery to an initial lease customer in Spring 2020. This paper will describe the STAR-CC-OGSE system, the outcome of the verification testing and system performance.