NPL Programme for Earth Observation and Climate Change

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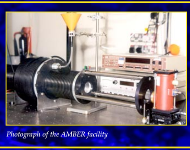
AMBER (Absolute Measurement of Black body Emitted Radiance)

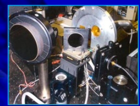
NPL has championed the use of radiometrically calibrated filter radiometers as a means of measuring and disseminating spectral radiance and irradiance. In particular for the direct determination of the thermodynamic temperature of black bodies for temperature scales and as a means of calibrating sources used for Earth Observation. This technique has been extended into the thermal infrared (and near ambient temperature black bodies) with a facility called AMBER (Absolute Measurement of Black body Emitted Radiance)[iii]. As the title states, this measures the emitted radiance in a defined spectral band, using a radiometrically calibrated filter radiometer, rather than by calculation and thermometry. The facility obtains its traceability to the SI directly through radiometric standards in the form of a cryogenic radiometer rather than through the ITS-90.



Photograph of the AMBER facility

Calibration of Detectors

One of the biggest challenges in the calibration of GERB was the calibration of spectral response of each of 256 pixels of the blackend thermopile array. This calibration required measurements over the spectral range 300 µm to 30 µm in fine spectral detail. Uncertainties of < 1% were required.



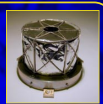
Calibration of GERB detectors

Black Bodies

NPL has and continues to develop a range of black bodies for use as transfer standards. In this work it has also characterised the spectral properties of many black coatings to allow it to optimise the emissivity of a source for its intended application and operational environment.

TIFRI Black Body

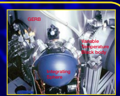
The TIFRI black body is a novel concept in black body design supported under a contract to ESA. It allows a low mass, low operational power whilst maintaining high emissivity and high accuracy as an infrared spectral radiance calibration source. The concept makes use of a reflecting mirror to enhance the emissivity of a nominally low mass black disc.



The TIFRI Black Body

Calibration of the GERB instrument

The GERB series of instruments were calibrated in terms of absolute spectral radiance using sources specifically designed and calibrated at NPL. The instrument measures spatially resolved Earth radiance in two channels, Solar reflected and thermal emitted with target uncertainties of 1% and 0.5 % respectively. NPL provided black bodies and a lamp illuminated spectral radiance standard (TSARS). In the latter case the uncertainty required was significantly lower than was being provided to any other customer.

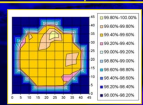


Calibration of the GERB instrument using a black body and lamp illuminated integrating sphere

Transfer Standard Absolute Radiance Source (TSARS)

NPL has developed a range of new radiance transfer standards specifically targeted to meet the requirements of the Earth Observation community, known as the Transfer Standard Absolute Radiance Source (TSARS). TSARS consists of an integrating sphere that is illuminated by a number of external lamps and that has a large area circular exit port. This is common with other such sources, however, NPL has put significant effort into selecting and positioning sources to improve the uniformity (the uniformity is better than ± 0.4% across the 75 mm diameter exit port). In addition, a set of filter radiometers has been included to allow active stabilisation and monitoring of performance.

NPL Transfer Standard Absolute Radiance Source (TSARS)



Uniformity plot of the TSARS.

Calibration of GOME 2 –FM3

To demonstrate the flexibility and performance of TSARS, a collaborative project was established with TNO TPD in Delft. As part of this project, one of the TSARS was taken to TNO TPD in Delft to be included in the radiometric calibration of the Global Ozone Monitoring Experiment (GOME 2)[iv] – FM3. Overall agreement to <± 1% with both TNO TPD and NASA was achieved[v].

TSARS on the Nadir port of the GOME2-FM3 vacuum chamber

Field Spectroscopy

The NPL TSARS can achieve calibrations with uncertainties < 1%, (as demonstrated during the calibration of GOME 2 – FM3). Since it is portable, it allows similar levels of uncertainty in "field situations" e.g. field spectrometers, aircraft radiometers. In collaboration with the NERC EPFS (Equipment Pool for Field Spectroscopy), and the user community, NPL will review existing calibration techniques and subsequently seek to establish "best practice" guidance for such field spectroscopic applications. A practical review of current practice in a wide range of field spectroscopic applications and a series of laboratory-based simulations will be carried out to identify and quantify potential sources of error and where necessary new standards will be developed.

Example of spectroscopic field measurements

Fundamental Physical Constant

Energy = σT^4

$$\sigma = \frac{\pi^2 k^4}{60\hbar^3 c^2}$$

The NPL primary standard cryogenic radiometer and consequently all its optical radiation measurement scales can be linked back to fundamental physical constants through a measurement of the Stefan-Boltzmann constant σ.

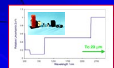
Primary Standard

At NPL all optical radiation measurement is traceable to the cryogenic radiometer, a technology pioneered by NPL in the 1970s/80s. The cryogenic radiometer is used to calibrate the radiant power responsivity of solid-state detectors as transfer standards.

The NPL mechanically cooled cryogenic radiometer.

Spectral responsivity Scale

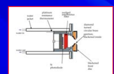
Solid-state detectors that are calibrated against the NPL Primary Standard cryogenic radiometer, in effect establish a spectral responsivity scale, and form the top of the calibration chain. This is extrapolated to the UV and IR spectral regions through specially designed pyroelectric detectors.



The NPL Spectral Responsivity scale and various detectors that are calibrated at NPL

Filter Radiometry.

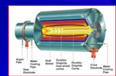
Usually the transfer standard calibrated directly against the cryogenic radiometer is a trap detector[i]. Trap detectors are then used to calibrate other detectors and in particular filter radiometers and, from there, other scales or services for users[ii].



Schematic of a filter radiometer

Primary Source

For spectral emission scales the filter radiometers are used to measure the temperature of a high temperature black body (up to 3500 K) and this, through Planck's law, provides a known source of spectral radiance. In this way the source emission scales, based on the black body, are linked to the more accurate detector scales.



Schematic of the inside of the NPL Ultra High Temperature Black Body (UHTBB).

Spectral Emission Scales

The Spectral Radiance and Irradiance Primary Scales (SRIPS) facility is used to transfer the scale from the black body to lamp and integrating sphere sources through an intermediate spectrometer. These sources are then used as spectral radiance and irradiance standards for the calibration of customer instruments. For specific applications measurements can also be made directly with a filter radiometer.

Photograph of the Spectral Radiance and Irradiance Primary Scales (SRIPS) facility

Traceable Radiometry Underpinning Terrestrial - and Helio - Studies (TRUTHS)

TRUTHS is a proposed satellite based mission to make SI traceable measurements of solar radiation incident on and reflected from the Earth and to transfer its calibration accuracy to other satellite based EO instruments. The key concepts to the TRUTHS mission are:

- The use of existing technology in novel manner (next generation technique for Earth Observation calibration), measuring the radiation from the Sun, Earth and Moon 10 times more accurately than any current or proposed satellite.
- The first optical satellite to fully calibrate itself against a primary standard in space.
- Unique in its goal to transfer its high accuracy to other satellite missions.
- The first mission to fully combine total solar irradiance, solar spectral irradiance and Earth spectral radiance measurements.

Schematic diagram showing the concept of the TRUTHS mission

National Laser Radiometry Facility (NLRF)

The NLRF of NPL contains a suite of lasers providing continuously tuneable radiation from 210 nm to 11 µm. These provide a source of radiation which can be tailored to service many applications, particularly those requiring high spectral selectivity.

- Continuously tuneable CW laser radiation from 210 nm to 11 µm
- Radiant power stabilised to <0.001 % drift in power over many hrs
- Used for spectral radiance, irradiance and power calibrations, also reflectance and transmittance.

Photograph of the National Laser Radiometry Facility at NPL

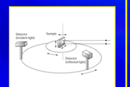
Calibration of CHRIS

During the calibration of CHRIS (Compact High Resolution Imaging Spectrometer), - currently in flight on the ESA Proba platform - several primary facilities were used. The ultra high temperature black body (UHTBB) was used directly to provide a known radiance and also used to simulate solar irradiance for calibration of an on-board calibration monitor. In addition, out-of-field stray light was characterised using highly collimated beam of laser radiation from the NPL NLRF. During the calibration CHRIS was maintained in a class 100 environment within an NPL laboratory.

CHRIS (Compact High Resolution Imaging Spectrometer) being calibrated at NPL

Bidirectional Reflectance Distribution Function Measurements

The Bidirectional Reflectance Distribution Function (BRDF) of reference white reflection plaques is of critical importance to the EO community. They are regularly used to convert Solar Irradiance into radiances for calibration of instrumentation pre- and in- flight. They also commonly provide the reference target for calibration of field instruments. At NPL we have two facilities for BRDF calibrations, one laser based and a second using conventional sources. Measurements are routinely made over the spectral range 300 to 2500 nm, with an uncertainty of <0.2 % in the visible. We are also carrying out work to develop improved (stable) reference white diffusers and have recently demonstrated the potential of a new standard in an experiment for CEOS.



Schematic of NPL's National Reference Reflectometer

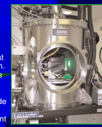
Gonio RAdiometric Spectrometer System (GRASS)

Recognising the increasing demand for field BRDF measurements to improve the land classification models and surface albedo determinations NPL is planning to build, in conjunction with NERC, a new field goniometer optimised for rapid deployment, traceability and rapid measurement time.

Concept of the GRASS instrument, the arrows depict the various viewing angles required

Spectral Response Calibration of Satellite Instruments

NPL provided the expertise and support equipment to determine the spectral response of the GERB (Geostationary Earth Radiation Budget) instrument, currently flying on Meteosat Second Generation, at Imperial College London. This amongst other measurements involved the transportation to Imperial of a large frame Kr+ laser and support equipment from NPL. This laser illuminated an integrating sphere to provide a few high accuracy monochromatic spectral radiance measurements of the GERB instrument and demonstrated the relative flexibility of the NLRF as a calibration tool.



GERB in the vacuum tank being irradiated by the laser radiance.

Spectro-photometry for the 21st century

At NPL we are preparing for the future to provide the EO community with a wide range of services. These include:

- Gonio-metric measurements (reflectance and transmittance)
- Small and large samples
- Wide spectral range (200 nm to 100 µm)
- Wide dynamic range
- High accuracy
- Low cost – fast time

Samples of NPL's reflectance and transmission standards

Reflectance and Transmittance Measurements

NPL provides a wide range of materials characterisation services. In particular calibration of spectral transmittance of filters and reflectance of mirrors (polarised and non-polarised) over the spectral range 200 nm to 100 µm. For example, the witness mirrors for GERB and MODIS were calibrated at NPL.

NPL's Reflectance measurement facility

NPL's Vision.

The UK has a strong record in the leadership of environmental and climate change issues. Whilst not directly funding large numbers of space based EO missions, the UK has selectively supported a number of key instruments in recent times which are providing landmark data sets e.g. ATSR series, GERB and CHRIS, and has contributed to most other European missions in some form. The UK is also highly respected for its validation and in-situ "ground truth" based activities for land, ocean and atmosphere, and for the establishment by NERC of "centres of excellence" to coordinate research activities within logical themes. In addition to its scientific strength, the UK has also traditionally recognised the importance of commercialisation of remote sensed data and been pro-active in developing a "user" base within public bodies.

NPL's vision is to be a European centre to provide an independent service to validate and QA EO data for both end users and data providers.

i N.P. Fox. Trap detectors and their properties. Metrologia, 28: p. 197-202, 1991

ii N.P. Fox. Developments in optical radiation measurement at NPL: part 1. SPIE. 2001.

iii E. Theocharous, N. P. Fox V. Sapritsky, S. Mekhontsev, S. Morozova, Absolute Measurements of Blackbody Emitted Radiance, Metrologia, 35, 549-554, 1998.

iv http://www.esa.int/export/esaME/gome-2.html

v H. M. Pegrum, E. R. Woolliams, N. P. Fox, Luud van Riel, G. Otter, M. Kowalewski. Calibration of the NPL Transfer Standard Absolute Radiance Source (TSARS) and its use with GOME 2 – FM3 spectral radiance measurements. SPIE Conference Sensors, Systems, and Next Generation Satellites VIII, Gran Canaria, Proc SPIE 5570-72 (2004) (Accepted for publication)

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