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The NPL Absolute Measurement of a Blackbody Emitted Radiance (AMBER) Facility

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Introduction

Infrared instruments (like those used in earth observation/remote sensing) are calibrated in terms of radiance using ambient temperature blackbodies. The radiance is calculated from the blackbody temperature as measured by one or more contact thermometers. The true temperature of the surface of the blackbody may not (is unlikely to) be represented by the values measured by the contact thermometers due to temperature gradients across thermal barriers. Furthermore, there may be issues with the emissivity calculations because the emissivity is usually sacrificed for large area blackbodies (e.g. "surface emitting" blackbodies) and the emissivity calculations may be in error due to complex cavity shapes. The NPL AMBER (Absolute Measurement of a Blackbody Emitted Radiance) facility was developed to overcome some of these limitations.

The NPL AMBER facility

The AMBER facility was designed to obtain its traceability to SI units directly through radiometric standards (the infrared relative spectral responsivity scale and the NPL cryogenic radiometer). However, the responsivity of infrared detectors is known to change with time (1, 2), so AMBER is frequently re-calibrated using a Gallium fixed point blackbody (the Ga melting point is a fixed point on the ITS90 temperature scale with a value of 302.9146 K).

The AMBER facility has a modular design. This means that its sub-assemblies can be used independently. It also allows easy upgrading of components and the accommodation of third party's components. Furthermore, by changing the wavelength at which AMBER operates, AMBER can be used to measure the radiance temperature of blackbodies operating over a wide temperature range. Finally, AMBER is relatively compact and transportable.

The NPL AMBER facility consists of:

i. The Reference Thermal Sources (RTS), which consists of a gallium fixed-point blackbody and a variable temperature blackbody.
ii. The Low Background Projector (LBP). This is a liquid N_2-cooled evacuated chamber which houses a liquid N_2-cooled blackbody, a mechanical chopper with reflecting blades, a reflective shutter to define a radiometric zero and CaF_2 and ZnSe A/R coated lenses (selection depends on the wavelength range at which AMBER is operating)
iii. The Fixed Solid Angle assembly (FSA). This is based on an Invar structure and a thin film 50 mm diameter aperture.
iv. Infrared Filter Radiometers. Four filter radiometers are available for operation with AMBER. Their spectral responsivities peak at 2.4 µm, 3.7 µm, 4.7 µm and 10.1 µm.

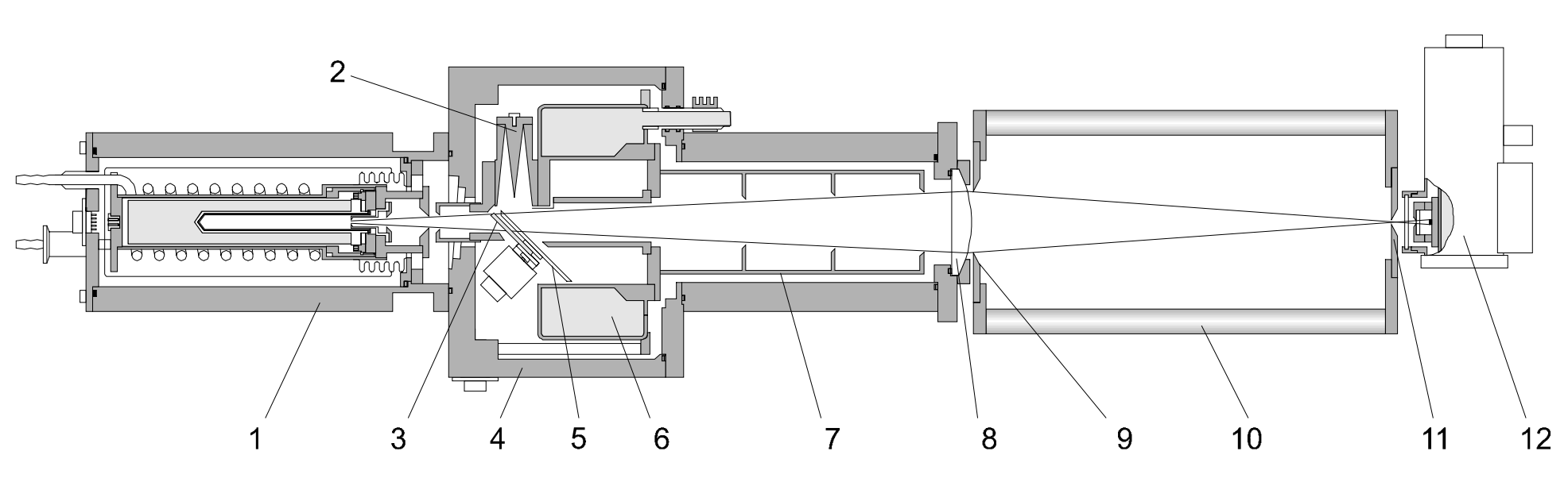

Figure 1: The layout of the AMBER facility. Gallium fixed-point blackbody (1), internal 77 K reference blackbody (2), reflective shutter (3), low background projector (LBP) vacuum enclosure (4), mechanical chopper with gold-plated reflective blades (5), liquid nitrogen reservoir (6), system of three cooled baffles to reduce stray light (7), anti-reflection-coated ZnSe lens (8), 50 mm diameter aperture (9), three Invar bars (10), 3 mm diameter aperture (11) and 10.1 µm filter radiometer (12).

AMBER Facility Applications

The AMBER facility can be used to compare the radiance temperatures of two (ambient temperature) blackbodies, compare the radiance temperature of a blackbody with that of the gallium fixed-point as predicted by ITS 90, compare the responsivities of infrared radiometers (radiation thermometers), calibrate the response of infrared radiometers against ITS 90 at the gallium fixed-point and calibrate third party's infrared radiometers using the calibrated blackbodies.

The AMBER facility has been used to calibrate the radiance temperature of a number of blackbodies which are used to calibrate the response of infrared radiometers for space applications. Figure 2 shows AMBER during the calibration of a space blackbody. The blackbody being calibrated is located in the vacuum chamber and is being viewed by AMBER though a ZnSE window.

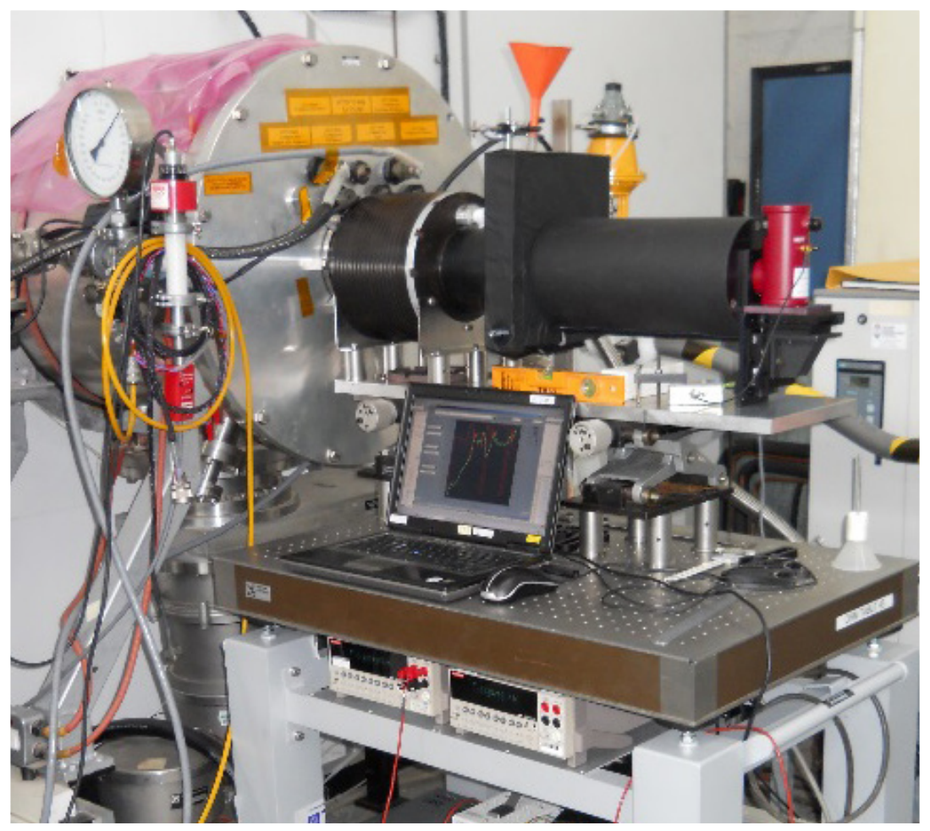

Figure 2: AMBER shown during the calibration of a space blackbody which is operating in the vacuum chamber.

AMBER has also been used to compare the performance of blackbodies which are used as the calibration standards of terrestrial radiometers which are used to validate the calibration of space-borne radiometers measuring the surface temperature of Earth. Figure 3 shows AMBER measuring the radiance temperature of a number of blackbodies during the 2016 FRM4STS blackbody comparison (3).

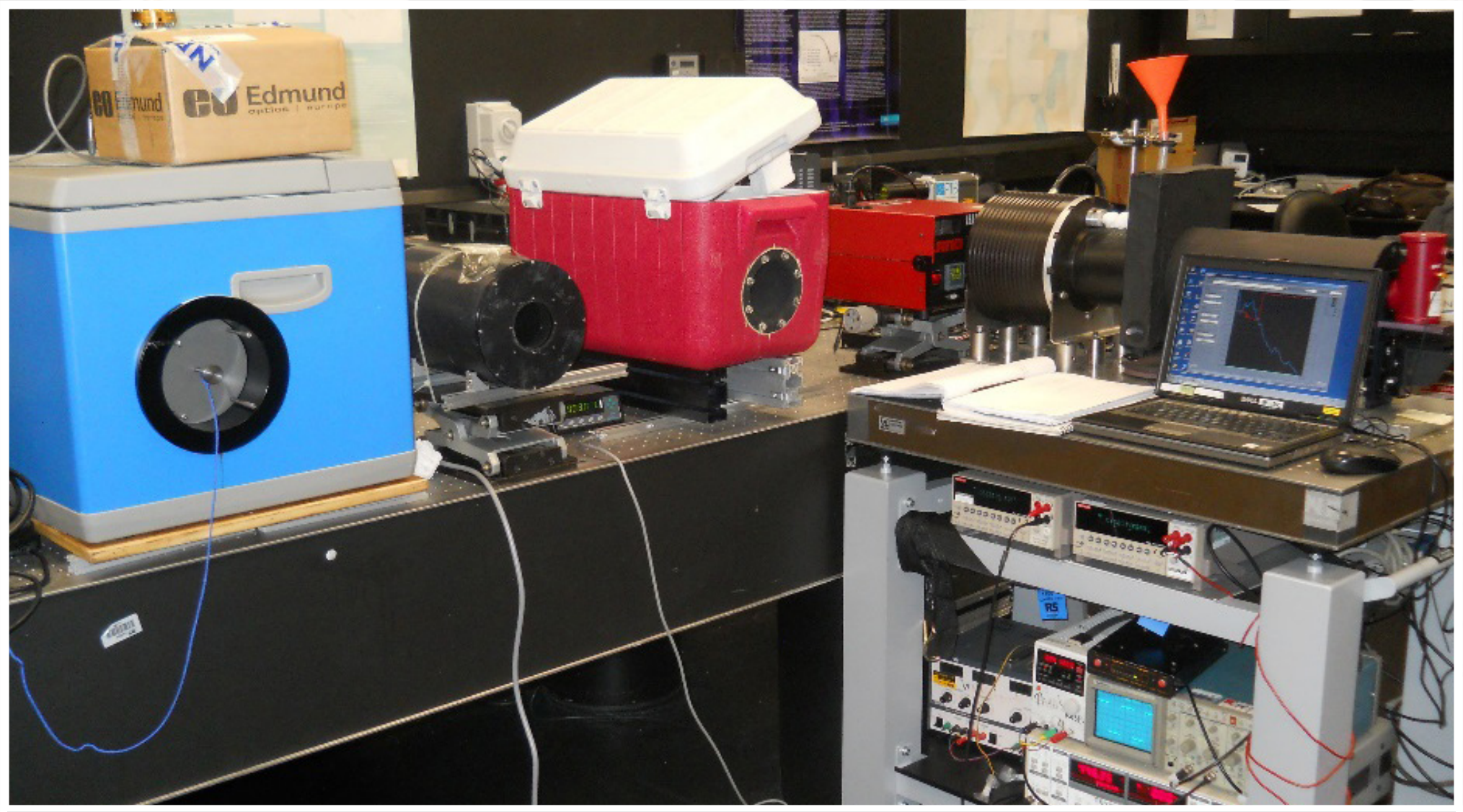

Figure 3: AMBER measuring the radiance temperature of a number of blackbodies during the 2016 FRM4STS blackbody comparison

Figure 4 shows AMBER measuring the radiance temperature of the PTB ammonia heat-pipe reference blackbody during the 2012 scale comparison between NPL and PTB. This comparison showed that the NPL and PTB scales agree well within the combine uncertainties over the in the –57 °C to +50 °C temperature range examined.

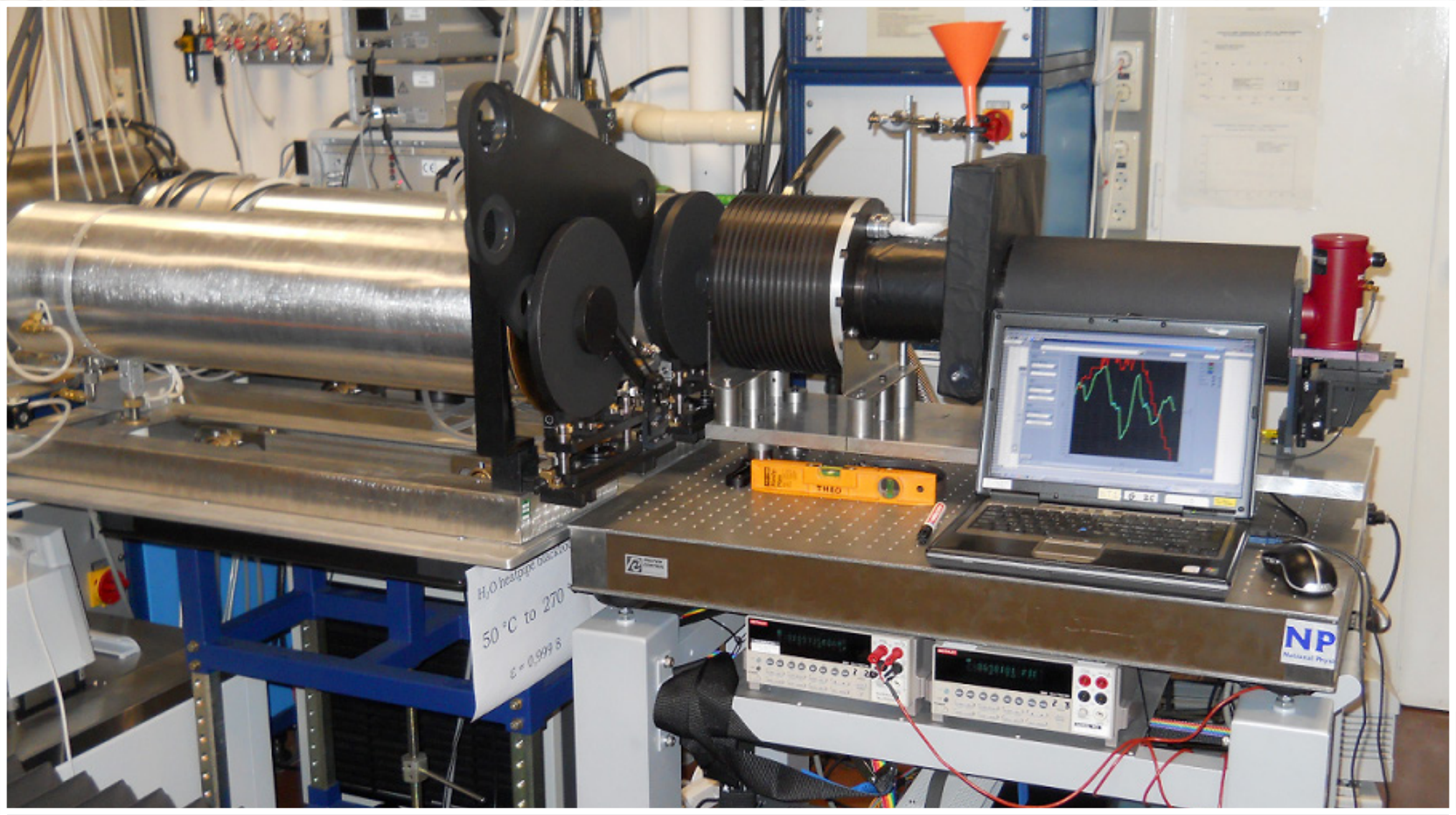

Figure 4. Photo of AMBER monitoring the PTB ammonia heat-pipe blackbody during the 2012 radiance temperature scale comparison

The use of AMBER can prevent a number of pitfalls from occurring in measurements, examples of which are listed below:

- The true temperature of the surface of the blackbody may not (is unlikely to) be represented by the values measured by the contact thermometers.
- For large area blackbodies (e.g. "surface emitting" blackbodies) the emissivity is usually sacrificed.
- Emissivity calculations may be in error due to complex cavity shapes.

Table 1 shows the systematic (Type B) uncertainty contributions arising when the radiance temperature of a test blackbody maintained in the –30 °C to +60 °C is measured using AMBER, with AMBER utilizing the 10.1 µm filter radiometer (3).

Contribution	Standard Uncertainty / mK	Comment
Uncertainty in the Ga blackbody radiance temperature	32	Taken from Ga blackbody uncertainty budget (see table 3)
Uncertainty due to the lock-in amplifier non-linearity in the –60 °C to 50 °C temperature range [10]	36	0.1% non-linearity in the lock-in amplifier (maximum in the -50 °C to 30 °C temperature range). Depends on the difference between the Ga melting point temperature and the temperature of the target being measured.
Uncertainty in the relative spectral responsivity calibration of 10.1 µm filter radiometer	6	From the calibration of the relative spectral responsivity of the 10.1 µm filter radiometer
Uncertainty due to the definition of the "radiometric zero"	4	From monitoring the AMBER output when the 77 K blackbody is being viewed
Uncertainty in the measurement of the ZnSe AMBER window transmission	1	Common to all blackbody measurements, hence the uncertainty due to this window is small.
Uncertainty in the measurement of the ZnSe AMBER lens transmission	1	Common to all blackbody measurements, hence the uncertainty due to this window is small.
AMBER stability/drift over the period of a measurement	18	based on 0.05% drift over a measurement period i.e. 5 minutes
Uncertainty due to ambient temperature fluctuations	12	See E. Theocharous and N. P. Fox "CEOS comparison of the IR Brightness temperature measurements in support of satellite validation. Part II: Laboratory comparisons of the brightness temperature of blackbodies", NPL Report OP4, September 2010.
Uncertainty due to chopper frequency fluctuations	2	Based on a 0.2 Hz drift in the chopper frequency during a measurement cycle.
Combined uncertainty (*k*=1) 53 mK		

Conclusions

The AMBER facility has been available for some 18 years and its performance has improved continuously. AMBER can operate at four different wavelengths, can define radiometric zero, the absolute spectral irradiance responsivity of filter radiometers is measured on the NPL infrared spectral responsivity measurement facility and is verified using a dedicated gallium fixed-point blackbody. Measurement resolution is better than 1 mK, whereas measurement uncertainty is approximately 53 mK in the –40 °C to +50 °C temperature range.

References

1. E. Theocharous, "On the stability of the spectral responsivity of cryogenically cooled HgCdTe infrared detectors", Infrared Physics and Technology, **48**, 175-180, 2006.
2. E. Theocharous and O. J. Theocharous, "Practical limit of the accuracy of radiometric measurements using HgCdTe detectors" *Applied Optics*, **45**, 7753-7759, 2006.
3. E. Theocharous and N. P. Fox "CEOS comparison of the IR Brightness temperature measurements in support of satellite validation. Part II: Laboratory comparisons of the brightness temperature of blackbodies", NPL Report OP4, September 2010.

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