Centre for EO Instrumentation

Technology Market Case Study No. 8

Phase Change Cells for Next Generation InfraRed Calibration Sources (NGenIRS)

The Challenge

Several new earth observation missions operating in the thermal infrared wavelength range are on the horizon for scientific, operational and commercial uses. These missions are dependent on on-board blackbody (BB) calibration sources to ensure the traceability of the radiometric calibration to international standards. As well as these 'high-end' space missions, airborne and field sensors for atmospheric and surface measurements and the growing range of commercially available infrared cameras require readily available and low-cost blackbody calibration sources.

Basic design and performance of flight infrared calibration black bodies has changed very little in the last twenty-five years. However, mission requirements for radiometric accuracy, stability and traceability have become far more demanding and there is downward pressure on the mass, power and volume to enable deployment on smaller and cheaper satellite missions. To fulfil these demands requires a step change in the key technologies for IR calibration sources.

The Solution

The accuracy of the measured temperature of the radiating surface is critical in an infrared calibration source, but thermometers and read-out systems are subject to calibration drift over time. Under laboratory conditions, high precision calibration is achieved using phase changes of pure materials e.g. triple point, freezing point, & melting point, as these are highly reproducible and have well characterised temperatures specified by the ITS-90 (International Temperature Scale of 1990).

Key points are the triple point of mercury and water, and melting point of gallium. Typically, the temperature of onboard satellite black body calibrators can change in flight. By embedding phase-change cells in a black body structure in close proximity to the temperature sensors and by warming or cooling the black body, then during the phase change the material will absorb or release heat maintaining a constant temperature.

Figure 1: Left: phase-change cell. Right: phase-change cell immersed in aluminium block, also showing thermometer.

NPL National Physical Laboratory

RAL Space

surrey nanosystems

The thermometer output will show a 'plateau' at this phase change temperature. As this temperature is known, the thermometer can be calibrated in-situ.

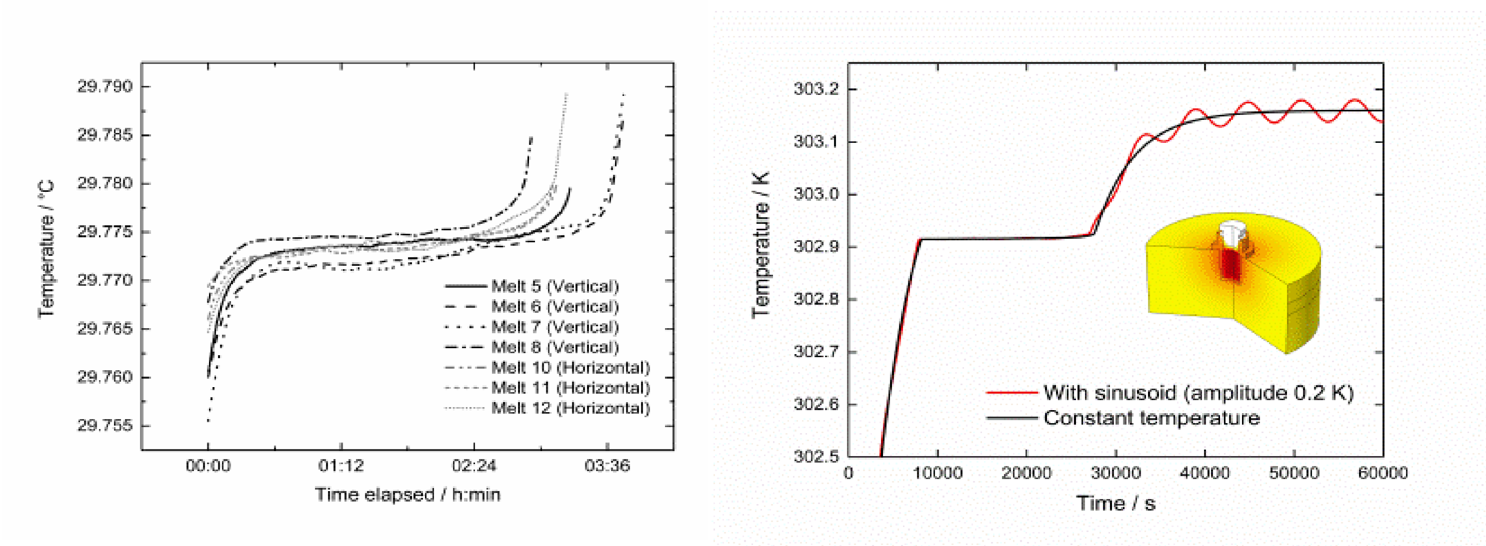

Figure 2: Left: temperature measured inside gallium phase-change cell showing repeatability well within 10 mK. Right: validated model prediction of the corresponding system, with orbital temperature variations included to demonstrate robustness against external thermal perturbations.

Preliminary development work was carried out as part of a collaborative UK Space Agency National Space Technology Programme (NSTP) Pathfinder grant, the output of which is a functional phase-change cell containing <1 gram of gallium, and which gives a melting duration of several hours under realistic conditions (see Figure above). This project built on that earlier work to take the device's technology readiness level from TRL 3 to TRL 5/6.

Support from CEOI

CEOI provided funding to a consortium of RAL Space (project lead), Surrey NanoSystems and the National Physical Laboratory to develop the phase change cell concept further and build / characterise a fully functional prototype to be fitted to a flight black body demonstrator in a format compatible with a flight opportunity. The target technology readiness level was TRL 5/6 and the advances will put UK in a strong position to bid for future flight and terrestrial missions.

Measuring Temperature with High Accuracy

High accuracy thermometry measurements require a new electronic architecture. Building on work done under a UK Space Agency NSTP grant, the electronics were redesigned at system level to prioritise a lower power consumption, ease of assembly, and greater thermal uniformity across the cavity base. A high thermal uniformity is especially desirable

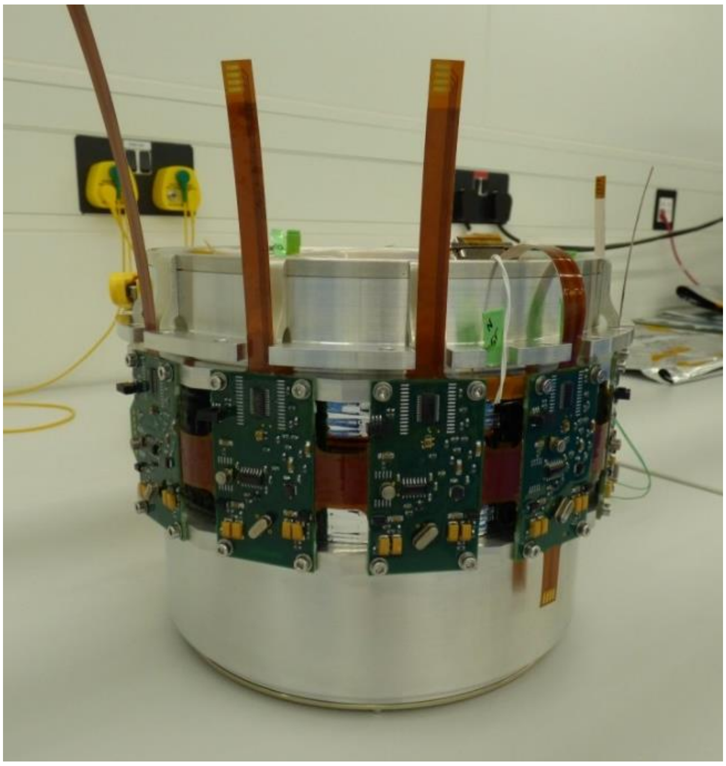

Figure 3: Black body cavity under construction showing the distributed thermometry electronics

as it makes the temperature estimates of the base much more accurate, which in turn lead to a more accurate calibration. To achieve this, the central control node in the heritage design has been replaced by a series of twelve individually configurable thermometry sensors. A prototype of the sensors has demonstrated measurement noise levels below 300μK.

The Results

The project addressed several challenges associated with this type of calibration:

- Contamination of the phase-change material causing change of temperature
- Phase-change material degrading the container causing embrittlement
- Pressure/density changes associated with phase change significantly influencing temperature
- Temperature gradients causing a difference in temperature between the phase-change cell and the nearby thermometer,
- With such small cells, substantial undercools are observed where the phase-change material fails to freeze unless the temperature is extremely low; the cell cannot then be re-melted. This was addressed by seed nucleation of the freeze so that the undercool is restricted to 1 or 2 K.

The project developed a robust, miniature (< 1 gram and < 1 cubic centimetre) fixed point cell based on gallium, with a target calibration uncertainty of a nearby thermometer of 10 mK. Drawing on the extensive knowledge and facilities of NPL, a robust methodology was developed to enable long-term use of these miniature phase-change cells without significant degradation. For the first time, novel coating techniques which provide an inert barrier between the metal cell and the phase-change material while retaining the high thermal conductivity were investigated and successfully tested.

Relation to previous CEOI projects

The consortium has already developed several component technologies through previous CEOI and NSTP studies specifically to address the quality of black body thermometry, temperature traceability and the radiometric performance of the black body cavity advancing the TRL to 2/3.

Figure 4: Breadboard blackbody cavity with carbon nanotube Vantablack © coating developed by Surrey NanoSystems (SNS) under an NSTP-2 project

Wider Deployment

In addition to satellite instruments, low mass / volume / power blackbody calibration sources are required by a range of other infrared sensors and systems, including:

- airborne and field sensors for atmospheric and surface measurements
- commercially available infrared cameras
- future military and security surveillance systems
- future infrared remote sensing systems

The Future

The phase change cells will be incorporated in a TRL 5/6 prototype of the Next Generation InfraRed Calibration Source (NGenIRS), due for completion in 2020. This will put the UK in a strong position to bid for future flight and terrestrial missions, including: the upcoming Land Surface Temperature Mission (LSTM) for the Copernicus Sentinel extension programme for which studies are in progress; Earth Explorer-9 FORUM which plans to measure the Earth's entire emission spectrum from 100 cm-1 to 2760 cm-1 (3.62 μm – 100 μm); and the Sentinel-3 next generation which will replace the current Sentinel-3 satellites. Exploitation of the technology in commercial, defence and security applications will also be considered.

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CEOI

Centre for Earth Observation Instrumentation (CEOI) works with UK academia and industry. Its objective is to develop a world leading, internationally competitive, UK Earth Observation (EO) instrument and technology R&D capability, enhanced through teaming of scientists & industrialists. CEOI is funded by the UK Space Agency with parallel technology investment from industry.

Further information on this & other technologies funded by CEOI can be found at ceoi.ac.uk, or contact: CEOI Director, Prof Mick Johnson: Tel: +44 (0)1438 774421 email mick.johnson@airbus.com.