LBIR Fluid Bath Blackbody for Cryogenic Vacuum Calibrations


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Outline

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• Design and characterization of fluid-bath blackbody source for cryogenic vacuum applications
• Low-Background Blackbody Radiance Calibration
• Test Results and Discussion
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Introduction

- **The Low Background Infrared (LBIR) Facility at the National Institute of Standards and Technology (NIST) maintains the IR radiometric power measurement scale for systems that need to be calibrated in a space-like environment.**

- **Absolute detector standards are used to calibrate the effective radiance temperature of blackbody sources, among other things.**

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**Broadband Calibration Chamber**

- Used for broadband calibration of blackbody sources in a space-like environment.

- Internal shrouds are capable of creating 20 K to 300 K background environments.
The calibrated blackbodies are then often used as radiance sources in test chambers that collimate the output for the calibration of remote sensors or for more complicated scene generators for hardware-in-the-loop testing of missiles.

LBIR also provides calibration of the chamber output so that the source/chamber performance can be validated.
Large Aperture Fluid Bath Blackbody

- Goal: Provide national metrology standard grade blackbody source for low-background radiance calibrations.

- High effective emissivity is achieved with a specular black paint and a 60 cm deep conical cavity.

- High temperature accuracy and uniformity are achieved by having the outside of the cavity enveloped in a vigorously stirred and temperature controlled fluid bath whose temperature is measured by a NIST-calibrated Standard Platinum Resistance Thermometer (SPRT).
The blackbody cavity inner wall was coated with Aeroglaze Z302.

The reflectance of sample coupons were measured at an angle of incidence (AOI) of 8 degrees.

Cavity emissivity was computed for the full radiative load from a 12 cm diameter exit aperture.

The cavity emissivity at 10.6 um is calculated to be greater than 0.9999.
The blackbody cavity reflectance was measured using the NIST CHILR laser-based integrating sphere reflectometer at 4 um and 10.6 um wavelengths.

The results show $\varepsilon \geq 0.9999$ at 10.6 um and $\varepsilon \approx 0.999$ at 4 um for aperture radius less than 2 cm.
The SPRT was moved around to various locations in the fluid bath and revealed a temperature deviation of less than 5 mK in the region surrounding the cone.
• Optical load from blackbody cavity surface skin was computed for a full 12 cm exit aperture radiative load.
• In the cavity cone area, the thermal gradient through the aluminum blackbody wall is estimated at \(~1\) mK, and the thermal gradient through paint is estimated at less than 1 mK.
• The temperature uncertainty of the blackbody cavity cone is thus estimated to be less than 10 mK including the 5 mK bath uniformity.
The Basic Radiance Calibration Test Configuration

- **The sizes of the blackbody and detector standard defining apertures are measured with high precision.**
- **The distance between the apertures is also measured with high precision.**
- **No optics are contained in the beam path.**
- **Non-limiting baffles are used to control stray light.**
- **The test configuration is designed to be very simple in order to add minimal complications to the calibration effort.**
The Absolute Cryogenic Radiometer (ACR) traps 99.995% of the photons entering its aperture and converts them into thermal power.

The changes in thermal power are converted into changes in electrical power, thus tying optical power to the electrical power standard.

This can be done at LBIR with an absolute accuracy of 0.02% at the entrance of the ACR defining aperture.

Note: In almost all cases the “quality” of the calibration is determined by all that happens before the ACR defining aperture; that is problems with the blackbody source and the management of stray light.
Radiance Temperature Calibrations

- The Stefan-Boltzmann law is used together with the known test geometry to deduce the radiance temperature.

\[ E_0 = AF \sigma_M T^4 \]

- \( \sigma_M \) is the Stefan-Boltzmann constant, \( A \) is the blackbody aperture area and \( F \) is a configuration factor determined from the radius of the ACR defining aperture, the radius of the blackbody defining aperture, and the distance between the apertures.

- \( E_0 \) is the expected ACR power assuming no diffraction.

- In practice, diffraction corrections are made to the actual ACR power measurements to obtain \( E_0 \). The above equation is then inverted to obtain the radiance temperature of the cavity.

\[ T = \left( \frac{E_0}{AF \sigma_M} \right)^{1/4} \]
• For this test the blackbody aperture was 5 mm, ACR aperture 2 cm, distance ~ 1 m
• Standard uncertainty of mean for ACR power measurement ~ 5x smaller with new electronics for typical 5 minute data collection.
• Repeatability of successive runs over 300 K to 375 K range approximately 10 mK in radiance temperature.
• Large radiance temperature offset ascribed to stray light from secondary reflection from cryogenic shutter assembly
Why does the test configuration show excess power at the ACR?
- Extra power rules out low blackbody cavity emissivity.
- Extra power rules out low ACR absorptivity.
- ~1% diffraction effects are too small to explain the error size.

Higher reflectance of “black” paints at longer wavelengths could lead to more stray light reaching the detector. This is consistent with larger relative power excess at lower blackbody temperatures where the Planckian spectrum shifts to longer wavelengths.
- BRDF indicates reflectance as large as 0.75 at 70 degrees AOI
- Standard total, diffuse, and specular reflectance data measured at 8 degrees AOI do not characterize grazing reflections from chamber shroud.
Additional baffle to be added

Stray reflected light suspected between shutter housing and baffle mount
Conclusions

- Cryogenic vacuum compatible fluid bath blackbody has been constructed for 200 K to 400 K temperature range and 1 cm to 12 cm aperture diameter
- High cavity emissivity measured at 10 um (>0.9999) but only 0.999 at 4 um may indicate thicker paint is needed
- Temperature uniformity of bath, repeatability of bath temperature control and ACR $T_{rad}$ measurements $\leq$ 10 mK
- Initial broadband results with ACR show large radiant power error (4 %) ascribed to stray light

- Future Tests:
  - Short Term: Test new baffling arrangement with Fluid Bath Blackbody
  - Long Term: Improve stray light modeling by incorporating real BRDF data at longer wavelengths in the stray light models.
  - Use fluid-bath blackbody to calibrate radiance responsivity of NIST MDXR transfer-standard radiometer