NIST BXR I Calibration

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Introduction

The Low-Background Infrared calibration facility (LBIR) at the National Institute of Standards and Technology (NIST) currently operates a portable transfer radiometer, the BXR I, that was developed to calibrate collimated infrared sources at several customer test facilities. The BXR I uses collection optics together with several narrow band-pass filters and an arsenic-doped Blocked Impurity Band (BIB) detector to scale a model of the collimated source under test. The band-pass filters cover the spectral range from 2 μm to 15 μm with pass bands of width ranging from 1-3 % of the band center wavelength. The BXR I collects collimated light passing through a 7 cm diameter entrance aperture and a spatial filter with an angular acceptance of 4 mrad (full cone). The collected light is focused onto the detector plane. The instrument noise floor is approximately 0.1 $\mathrm{fW/cm^2Hz^{1/2}}$. Further description of the BXR I is provided by Jung (2000). In the past, a small collimating source, the 1 cm Collimator (1CC), producing a 1 cm diameter output beam was used to provide a rough calibration of the BXR I. However, over the past year we have significantly reduced our calibration uncertainty by using a larger improved collimator.

Collimator

The new collimator, the 10 cm Collimator (10CC), produces a 10 cm diameter infrared beam using a blackbody source together with several gold-plated aluminum mirrors. Light from the blackbody is collected by two identical off-axis parabolic mirrors; one has its focus at the blackbody exit and the other has its focus on a 6 position aperture wheel. In between these two mirrors there is a short section of collimated light that passes through a pair of 8 position filter wheels. Light passing through one of the limiting apertures is then collimated by a primary off-axis parabolic mirror of 1.83 m focal length and 14 cm diameter. The degree of collimation set by the limiting aperture size ranges from 30 μrad to 1 mrad (full cone).

Calibration Methodology

Calibration of the BXR I is transferred from an Absolute Cryogenic Radiometer (ACR) using the 10CC as a stable reference source. The ACR is in turn compared to the NIST primary standard radiometer, the High-Accuracy Cryogenic Radiometer (HACR). The basis of the BXR I calibration is a matching set of narrow band-pass filters, located in the BXR I and 10CC, whose transmission is known. The absolute transmission spectra of all filters were measured at NIST using a Fourier Transform Spectrometer over the approximate wavelength range from 1 μm to 100 μm. The type B uncertainty associated with the measurement is approximately 1%. Because the out-of-band transmission of the filters is not negligible a model of both the 10CC and BXR I is necessary to account for the out-of-band transmitted power. The effect is most significant when calibrating the BXR I with the ACR due to their large difference in spectral response. The latter has a flat response to all wavelengths, whereas the BXR I has a varying spectral response between 2 μm and 30 μm and is relatively insensitive to other wavelengths. Also, the out-of-band power can be significant when calibrating another collimator with the BXR I—in general the two will have differences in their relative spectral output due to differences in source temperature, diffraction effects or efficiency.

ACR measurements of the 10CC through each filter are used to scale a model of its expected broadband relative spectral irradiance. A separate calibration factor is deduced for each filter center wavelength. Variations between the calibration factors as well as the absolute value provide a check of the model. Once the broadband output of the 10CC is calibrated, it is measured with the BXR I through each of its filters. From these measurements a normalization of the modeled relative responsivity of the BXR I is deduced. Once again variations between normalization factors provide a test of the model. As a further test of the model, measurements of the 10CC output with the BXR I through each of the 10CC filters are made and compared to those made through the corresponding BXR I filters. If the model is perfect the two measurements should be identical.

The large 10 cm beam emanating from the collimator is sufficient to overfill the 7 cm diameter entrance aperture of the BXR I. While ideal for calibrating the BXR I, collecting an identical part of the large diameter beam with an ACR poses a challenge. To resolve this issue a moveable aperture wheel and parabolic mirror were positioned in front of the BXR I to redirect a 7 cm diameter section of the 10CC beam into the small 3.5 mm diameter aperture of the ACR. Pending direct measurements of the parabolic mirror reflectance, the measured reflectance of a witness sample mirror is used in the preliminary calibration.

Experimental Procedure

Both the 10CC and BXR I reside in self-contained cryogenic vacuum chambers with flanged UHV optical ports. The ACR, its parabolic collector and the aperture wheel are housed in another cryogenic vacuum chamber, the Broadband Calibration Chamber (BCC). The 10CC and BXR I are bolted to opposite ends of the BCC in nominal alignment with one another. All three chambers are lined with a cryo-shroud to provide a low-background environment. Calibration of the BXR I is made during a single cryo-cycle of the entire system without breaking vacuum. This is possible because the off-axis ACR parabolic reflector is mounted on a two-axis stage that can move the mirror completely out of the beam path. The mirror stage is located in front of the BCC port to which the BXR I is bolted. The aperture wheel is attached to a vertical stage that is located about 30 cm away from the parabolic mirror towards the 10CC. Located between the aperture wheel and mirror stage there is a BIB detector on a two-axis stage. Raster scans with the detector are used to characterize the 10CC output beam and to aid in alignment of the ACR and BXR I apertures with respect to the 10CC optical axis.

Initially, the BCC, BXR I and 10CC are evacuated to a pressure of approximately 10^{-3} Pascal before cooling commences. The 10CC and BCC are cooled first using a closed-cycle He refrigerator. Each contains a cryo-shroud that cools rapidly compared to the optical elements. Once both cryo-shrouds are cold, cooling of the BXR I begins. First its outer shroud is cooled with liquid nitrogen and then the inner shroud and optics are cooled with a continuous flow of He gas transferred from a liquid He storage dewar. Final temperatures of the shrouds and internal optics range from 10 K to 30 K. The BXR contains a ZnSe window in front of its entrance aperture that is held at a temperature of 50 K. The window can be warmed to check for contamination when the BXR I calibrates warmer chambers.

Alignment was achieved by an iterative process involving adjustment of the 10CC pointing mirror, the BXR I optical axis and the ACR aperture wheel. Initially the 10CC beam was aligned with the ACR aperture wheel by imaging the 10CC beam edges and ACR aperture edges with raster scans of the BIB detector. Then, the BXR I pointing was adjusted until its optical axis was aligned with the 10CC beam. To ensure that both the BXR I entrance aperture and the 7 cm diameter ACR aperture sample the same portion of the 10CC beam both apertures must be aligned. This alignment was checked by monitoring the roll-off of the BXR I signal through the 7 cm ACR aperture as the aperture was moved vertically and horizontally. Because the two were slightly out of alignment, the ACR aperture wheel was moved towards the BXR I aperture center, and the entire alignment process, starting with the 10CC beam and ACR aperture, was repeated. Several iterations were required because adjustment of the BXR I pointing translates its entrance aperture slightly. Once aligned the signal measured by the BXR I only dropped by 3% as the ACR aperture wheel was changed from the largest 10 cm aperture to the 7 cm aperture (a small decrease is expected due to diffraction effects and the small geometric divergence of the 10CC beam).

Conclusion

Preliminary measurements have validated many aspects of the BXR I and 10CC models. For example, raster scans of the BIB detector across the 10CC beam revealed that its uniformity is limited primarily by diffraction effects. A scan collected through one of the 10CC narrow band filters revealed the tell-tale spatial oscillations expected from detailed diffraction calculations. One problem with the 10CC model that was revealed is that ACR and BXR I measure 10% to 20% more power than expected from the collimator. An independent calibration of the blackbody source of the 10CC has confirmed that its radiance temperature is significantly higher than that indicated by contact thermometry, which may explain the discrepancy. In spite of this issue an overall calibration uncertainty of 3% to 6% appears possible with the current filter set. However, the out-of-band transmission of the filters will significantly increase the uncertainty when calibrating a customer collimator at relatively low source temperatures and short wavelengths. Many customers are interesting in calibrations at temperatures as low as 180 K. By contrast, the BXR I calibration at NIST is performed at source temperatures ranging from 500 K to 600 K. To extend the calibration range of the BXR I to lower temperatures a new filter set having broader pass bands and better out-of-band rejection is being procured.

References

Jung, T. M., Carter, A. C., Lorentz, S. R., Datla, R. U., NIST-BMDO Transfer Radiometer (BXR), *Infrared Detectors and Focal Plane Arrays VI, Proceedings of SPIE Vol. 4028 99*, 2000.