Measurements of Infrared Sources with the Missile Defense Transfer Radiometer

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Outline

• Introduction
• Missile Defense Transfer Radiometer (MDXR)
  • Brief functional mode and calibration review
  • Calibration accuracy – successes and discoveries
  • Results from calibration of user chambers
• Conclusions
Chamber Calibrations and Transfer Radiometers

- The blackbody source and the chamber output are separately calibrated to validate and calibrate the chamber output model.
- Model calibration/validation is necessary because the transfer radiometers can not calibrate at all desired test conditions.

Low Background (20 K) or Medium Background (80 K) IR Test Chamber
## MDXR Capability Overview

<table>
<thead>
<tr>
<th>Capability</th>
<th>BXR</th>
<th>MDXR</th>
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</thead>
<tbody>
<tr>
<td>spectral definition</td>
<td>filter-based</td>
<td>Cryo-FTS and filters</td>
</tr>
<tr>
<td>stability assessment</td>
<td>Limited</td>
<td>ACR and blackbody</td>
</tr>
<tr>
<td>polarization capability</td>
<td>rotatable linear polarizer</td>
<td>rotatable and fixed linear polarizers</td>
</tr>
<tr>
<td>calibration modes</td>
<td>irradiance, polarimeter</td>
<td>irradiance, radiance, polarimeter, FTS, absolute power</td>
</tr>
<tr>
<td>detector base temperature</td>
<td>9 K</td>
<td>2 K</td>
</tr>
<tr>
<td>radiometric uncertainty (k=1)</td>
<td>3.5 %</td>
<td>2.5 %</td>
</tr>
</tbody>
</table>
When observing an external source

Defining aperture (7 cm dia)

External Source Illumination

When observing the internal blackbody source

Blackbody source 0.5 mm aperture 200-400 K
MDXR beam path – top view

- Variable field stop wheel
- Optics plate – actively cooled
- Primary paraboloid
- Defining aperture (7 cm dia)

Detector side

Beam entry side
Absolute Cryogenic Radiometer mode

• ACR is cooled to 2 K by a heat strap to a liquid He cryotank.
• For power measurements around 10 nW the peak-to-peak noise is around 200 pW.
• Reproducibility of average power level was approximately 11 pW (k=1).
MDXR beam path – detector side

Tertiary paraboloid

Filter wheels (spectral and polarization)

Translating periscope

BIB detector(s)

ACR

3-axis stage

Secondary paraboloid

Variable field stop wheel

Cryo-FTS
The same model validation and calibration method is used for the whole calibration chain.

First, the 10CC is modeled and compared with measurements made by the MDXR ACR.

Then, the calibrated 10CC output is used to calibrate the MDXR filter radiometer.
The MDXR filter mode calibration is done on a band by band basis.

The filter set by which the MDXR is calibrated is the same that is used to calibrate the customer’s infrared test chamber.

The horizontal extent of the lines represent the approximate spectral width of the filter bands used for calibration measurements.
Radiometric calibration of Cryogenic FTS mode

- Irradiance from internal MDXR blackbody viewed with an internal 7 cm collimator is used to calibrate the CFTS mode of operation.

\[
S_{RF}(\nu) = \frac{S_{\text{measured}}(\nu)}{S_{\text{Planck}}(\nu) \cdot \Phi_{\text{geom}} \cdot C_{\text{Diff}} \cdot R_{\text{mirror}}(\nu)^2}
\]
## CFTS Calibration Uncertainties

<table>
<thead>
<tr>
<th>Relative uncertainty source</th>
<th>Value at 10 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal BB stability (A)</td>
<td>0.0035</td>
</tr>
<tr>
<td>User source stability (A)</td>
<td>0.002</td>
</tr>
<tr>
<td>Detector nonlinearity (B)</td>
<td>0.0025</td>
</tr>
<tr>
<td>Alignment internal/external (B)</td>
<td>0.001</td>
</tr>
<tr>
<td>Polarization correction (B)</td>
<td>0.003</td>
</tr>
<tr>
<td>Defining aperture area (B)</td>
<td>0.00007</td>
</tr>
<tr>
<td>Internal collimator geometry (B)</td>
<td>0.001</td>
</tr>
<tr>
<td>Internal collimator diffraction correction (B)</td>
<td>0.0018</td>
</tr>
<tr>
<td>Internal collimator mirror reflectance (B)</td>
<td>0.0057</td>
</tr>
<tr>
<td>BB temperature (B)</td>
<td>0.0046</td>
</tr>
<tr>
<td>BB emissivity (B)</td>
<td>0.001</td>
</tr>
<tr>
<td>Quadrature sum</td>
<td><strong>0.0096</strong></td>
</tr>
</tbody>
</table>

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### CFTS relative expanded uncertainty (k=1)

![CFTS relative expanded uncertainty](chart1.png)

### Noise floor, 10 minute averaging (W/μm)

![Noise floor, 10 minute averaging](chart2.png)
“Simple” chamber with one blackbody source and mirrors; data for one of the larger apertures.

BXR-Chamber X calibration uncertainties are 0.035 to 0.045.

MDXR-Chamber X calibration uncertainties are 0.025 to 0.030.

BXR and MDXR agree to within their combined uncertainties.

The more careful design and build execution of the MDXR makes the observed trend vs. wavelength believable.
The absolute values of the calibration factors from the CFTS and filter based operational modes agree with each other within their combined uncertainties.

The trends as a function of temperature and wavelength are also consistent.
MDXR Chamber X Calibration Uncertainties

- Combined relative uncertainties ($k = 1$).
- The observed trends in the MDXR data are meaningful as shown by the computed uncertainties.
- Where noise doesn’t dominate, the measurements from the CFTS have about 1% uncertainty.
ACR Calibration Results for Chamber X

- ACR Calibration has about a 4% 1-sigma uncertainty.
- The broadband measurements made by the ACR are also in full agreement with the CFTS and Filter Radiometer calibrations of Chamber X.
Again the absolute values of the calibration factors from the CFTS and filter based operational modes agree with each other within their combined uncertainties.

This chamber’s calibration factors show more spectral variation (beam combiner?).
Smaller apertures (less than #6) show systematic variation in calibration factor.

Consistency for different filter bands validates the diffraction correction calculation for Chamber Y/MDXR optical system.

Data could be used to make corrections to aperture areas.
The CFTS was used to measure chamber output irradiance at high spectral resolution (1 cm$^{-1}$ to 2 cm$^{-1}$) for both polarizations.

The results were used to verify the line shape, line width, polarization, and wavelength scale of the user monochromator.

Results show triangular line shapes with 61 nm to 64 nm FWHM, wavelength scale found to agree within 0.07 %.
Conclusions

• MDXR has been successfully deployed to calibrate users’ cryogenic infrared test chambers since 2010

• MDXR has demonstrated reduced calibration uncertainties compared to BXR

• *Increased spectral coverage and higher resolution measurements are possible with CFTS mounted in MDXR*

• *Onboard blackbody source and ACR are used to enable improved calibration and onsite stability monitoring*