# Calibration and Deployment of a New NIST Transfer Radiometer for Broadband and Spectral Calibration of Space Chambers (MDXR)

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## ABSTRACT

The Low-Background Infrared (LBIR) facility at NIST has performed on-site calibration and initial off-site deployments of a new infrared transfer radiometer with an integrated cryogenic Fourier transform spectrometer (Cryo-FTS). This mobile radiometer can be deployed to customer sites for broadband and spectral calibrations of space chambers and low-background hardware-in-the-loop testbeds. The Missile Defense Transfer Radiometer (MDXR) has many of the capabilities of a complete IR calibration facility and replaces our existing filter-based transfer radiometer (BXR) as the NIST standard detector deployed to customer facilities. The MDXR features numerous improvements over the BXR, including: a cryogenic Fourier transform spectrometer, an on-board absolute cryogenic radiometer (ACR) and an internal blackbody reference source with an integrated collimator. The Cryo-FTS can be used to measure high resolution spectra from 3 to 28 micrometers, using a Si:As blocked-impurity-band (BIB) detector. The on-board ACR can be used for self-calibration of the MDXR BIB as well as for absolute measurements of external infrared sources. A set of filter wheels and a rotating polarizer within the MDXR allow for filter-based and polarization-sensitive measurements. The optical design of the MDXR makes both radiance and irradiance measurements possible and enables calibration of both divergent and collimated sources. Results of on-site calibration of the MDXR using its internal blackbody source and an external reference source will be discussed, as well as the performance of the new radiometer in its initial deployments to customer sites.

**Keywords:** infrared, radiometry, calibration, cryogenic, transfer radiometer, Fourier-transform spectrometer

## 1. INTRODUCTION

The Low Background Infrared (LBIR) facility at the National Institute of Standards and Technology operates reference detectors that are used to maintain the national standard for low power infrared radiation in the range from nanowatts to milliwatts. LBIR shares this standard with the user community through two primary methods: calibration of customer sources at our facility against our primary standards and by calibration of infrared testbeds at customer sites against our secondary standard transfer radiometers. The primary standard reference detector used is an absolute cryogenic radiometer (ACR), an electrical substitution device which provides a direct physical connection between the optical Watt and the electrical Watt [1-3]. The transfer radiometers contain our secondary standard detectors, which are Si:As blocked-impurity-band detectors which have been calibrated against the ACR standards. These detectors display significant responsivity from 2 μm to 30 μm and noise floor near the femtowatt level.

Since 2001, LBIR has conducted radiometric calibrations of infrared space chambers at customer sites using the Ballistic-Missile-Defense Transfer Radiometer (BXR), our legacy transfer radiometer [4,5]. The BXR is a filter-based radiometer that can calibrate instruments in particular spectral bands from 2 μm to 14 μm and can also perform polarization-dependent measurements. The BXR has exhibited excellent stability over time but has limitations in its spectral capability and, in addition, must be measured before every deployment at our facility to verify its calibration. In 2003, LBIR began development of a new transfer radiometer with expanded radiometric capability, the ability to internally assess its own calibration, and for use as a backup in case the BXR failed or required repair.

LBIR finished construction of its new transfer radiometer, the Missile Defense Transfer Radiometer (MDXR), at the end of 2009 and has by now completed a range of performance tests, a full on-site calibration and two deployments to

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customer sites. The MDXR incorporates a cryogenic Fourier-transform spectrometer (Cryo-FTS), providing full spectral capability over the range from 3 μm to 28 μm [6]. Like the BXR, the MDXR also contains a set of filter wheels, allowing measurements in particular spectral bands. The Cryo-FTS allows the MDXR to characterize spectrally complex or tunable sources which are not smoothly varying in wavelength and to provide high resolution spectral data on the outputs of customer chambers. The MDXR also incorporates an on-board ACR and a high emissivity blackbody source with integrated collimator, allowing for self-calibration. The MDXR will still need to be calibrated and inter-compared from time to time with instruments at NIST, but unlike the BXR will be able to assess its own stability over the period of numerous deployments.

In addition to its expanded spectral capability and self-assessment ability, the MDXR provides several functional advancements beyond the BXR. The MDXR allows for radiance calibrations, as well as irradiance calibrations similar to those provided by the BXR. The MDXR contains well-defined small area apertures that can be overfilled by the beam under test, so a well-defined solid angle of the source can be sampled in radiance mode. The MDXR internal ACR can make absolute power measurements at the outputs of customer chambers. The BXR has the capability to stabilize its reference detectors at temperatures down to about 9 K, but the MDXR can reach detector temperatures near 2 K using its pumped liquid helium cryostat, allowing optimal operation of its ACR.

**Table 1.** Comparison of capabilities of the new NIST transfer radiometer (MDXR) with those of the legacy transfer radiometer (BXR).

| **Capability** | **BXR** | **MDXR** |
|---|---|---|
| spectral capability | filter-based | Cryo-FTS and filters |
| stability assessment | limited | ACR and blackbody |
| polarization capability | rotatable linear polarizer | rotatable and fixed linear polarizers |
| calibration modes | irradiance, polarimeter | irradiance, radiance, polarimeter, FTS, absolute power |
| detector base temperature | 9 K | 2 K |

During 2010 we performed a full calibration of the MDXR at our NIST facility. Responses of the ACR, BIB detector in filter-radiometer mode, and BIB detector with the Cryo-FTS to the internal blackbody and a calibrated external blackbody source (named the 10-Centimeter Collimator or 10CC) have been measured and compared over a comprehensive matrix of measurement parameters. The blackbodies were measured at a number of setpoint temperatures from 180 K to 600 K, and many of the filter, aperture and polarizer combinations available with the MDXR and 10CC were accessed and measured. The results of the full calibration allow us to compare the scales of the internal MDXR blackbody and ACR, compare the scale of the internal MDXR ACR with that of the 10CC (which has been defined by comparison with the primary standard ACRs at NIST), calibrate the BIB in filter radiometer mode, and calibrate the power scale for the Cryo-FTS using the internal blackbody. The power scale of our legacy transfer radiometer, the BXR, is defined by the 10CC calibrated source, so the full calibration allows a comparison of the internal MDXR power scale with the power scale used for our previous decade of customer chamber calibrations.

During 2010 we also completed the first two deployments of the MDXR to customer sites for calibration and characterization of customer infrared test chambers. The first deployments have established that the MDXR is capable of traveling hundreds of miles to calibrate off-site systems, while maintaining a high level of absolute accuracy (as verified by internal testing of the MDXR at the customer sites). The MDXR significantly expands the calibration and characterization capabilities we can offer customers. Not only did we calibrate blackbody sources within the customer chambers using the filter radiometer mode of the MDXR (similar to the calibrations provided by the legacy BXR transfer radiometer), but the Cryo-FTS provided high resolution spectral filter transmission data and spectra of non-thermal sources. In addition, the MDXR ACR provided absolute measurements of the power from thermal and non-thermal sources as well as radiance-mode measurement of a plate source.

## 2. DESIGN OF THE MDXR

### 2.1 Functional Design

A detailed explanation of the mechanical, optical, and cryogenic assemblies of the MDXR, as well as a description of its detectors and sources has been published previously [7], so only a description of key features will be presented here. The challenge of the MDXR design was to develop a mobile radiometer small enough to be transported to customer sites which could include as complete a calibration suite as possible. Most of the radiometer optics and instruments are attached to an aluminum optics plate with dimensions 610 mm x 406 mm x 25.4 mm (24" x 16" x 1"). The optics plate can tilt in two orthogonal directions relative to the incoming beam and is cooled by flowing liquid helium and surrounded by a liquid nitrogen cooled shroud. The radiometer has a titanium vacuum chamber, a collar with numerous ports for introducing electrical and fiber optic signals from the outside, and is mated to other chambers by a flange with a 250 mm inner diameter. The entire radiometer has a maximum diameter of 610 mm (24") and total length 1219 mm (48").

The optical components of the MDXR populate both sides of the vertically-oriented optics plate. There are two operational configurations of the beam entry side of the MDXR, enabling either the internal source or an external source to be viewed by the MDXR detectors. A collimator plate, comprised of an ellipsoid mirror and a confocal paraboloid mirror, can rotate between two positions. The collimator is rotated into place for use with the internal blackbody and rotated out of the external beam path for calibration of external sources. In all cases, the beam passes through a 7 cm entrance aperture and is focused by the primary paraboloid mirror through a hole in the optics plate to the detector side of the plate, as shown in Figure 1. A view of the detector side of the MDXR optics plate is shown in Figure 2, displaying the beam paths to the Cryo-FTS, ACR and BIB detectors. After passing through a baffle snout from the beam entry side, the beam passes through a field stop wheel with multiple apertures for radiance and irradiance measurements. The ACR can be moved into the beam just beyond the field stop wheel, limiting the uncertainty of the ACR measurements from optical components to the uncertainty of the measured reflectance of the primary paraboloid and the uncertainty of the modeled diffraction correction.

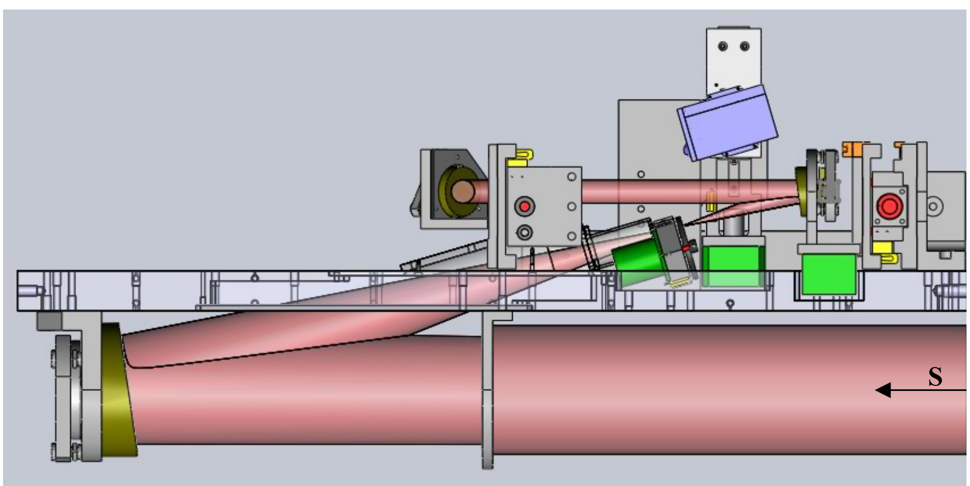


**Figure 1.** Top view schematic of the MDXR showing the beam path (in pink) from an external collimated source (from direction marked by an arrow and labeled S) reflecting off the primary paraboloid and traversing the optics plate to reach the detector side of the optics plate.

For Cryo-FTS and BIB measurements, the ACR can be moved all the way out of the beam using a single axis motorized stage, allowing the beam to proceed to the secondary paraboloid. The secondary paraboloid produces a nominal 1.5 cm diameter collimated beam. The periscope can be moved up to allow the beam to pass through the Cryo-FTS or down to allow it to proceed directly to the BIB detectors, circumventing the Cryo-FTS. In either case, the beam traverses four filter wheels before being focused by the tertiary paraboloid onto the BIB detectors. The filter wheels contain long-pass filters, short-pass filters, band-pass filters, neutral density filters, fixed polarizers and a spectral reference for the Cryo-FTS. The rotating polarizer is attached to a moveable arm positioned before the filter wheels so it can be rotated into and out of the beam path. The BIB detectors are mounted on a 3-axis stage, allowing for centering and focus of the beam as well as measurements where the spatial profile of the beam can be mapped (using a 100 µm diameter detector).

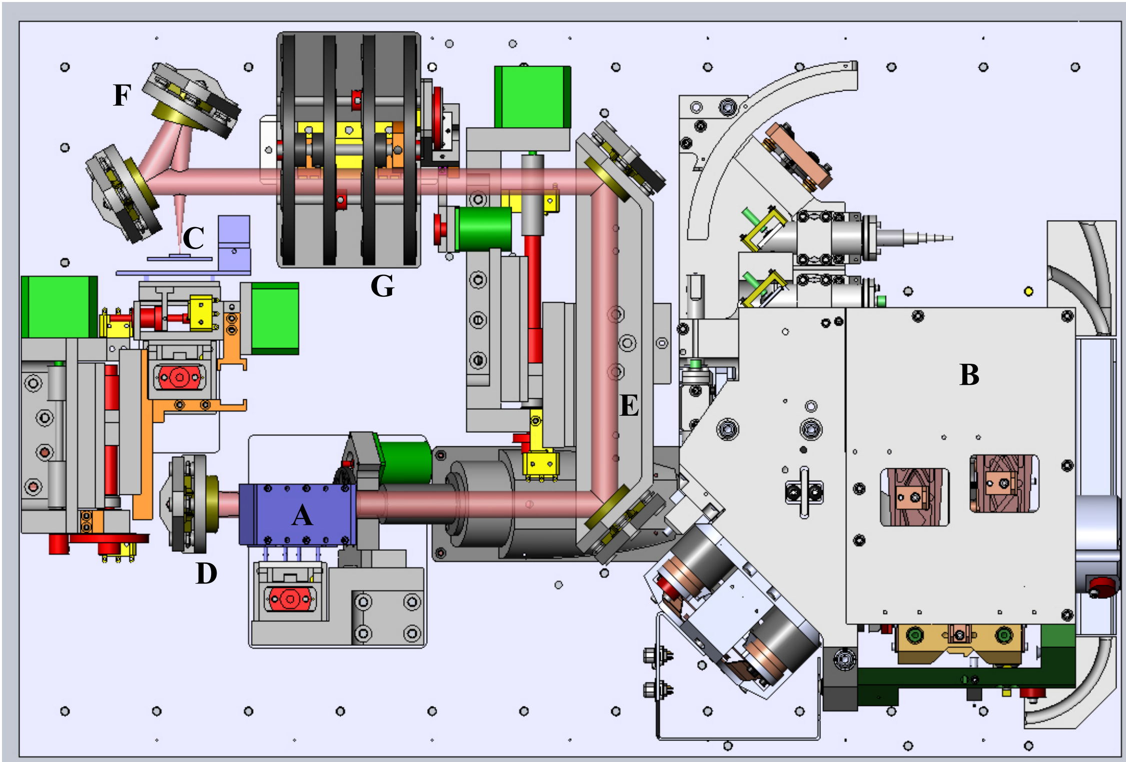


**Figure 2.** Schematic of the detector side of the MDXR showing the ACR (A), Cryo-FTS (B) and BIB detector (C). The beam is directed by the secondary paraboloid (D), periscope (E) and tertiary paraboloid (F). A set of four filter wheels (G) controls the power and spectral range of the signal which reaches the BIB detector. The beam path shown is for the direct BIB detector configuration (without Cryo-FTS) and in this image the beam can be followed from the secondary paraboloid (D) to the BIB detector (C).

### 2.2 MDXR Detectors and Sources

The Cryo-FTS is a fully functional Fourier-transform spectrometer that can operate within the MDXR cryogenic environment. At its operating temperature near 20 K, the Cryo-FTS exhibits negligible thermal background signal and drift compared to conventional Fourier-transform spectrometers, making it an ideal tool for low power calibrations. Fiber optic connections from an external metrology source and controller are used to launch metrology signals to the Cryo-FTS and enable functional tests. The Cryo-FTS employs a KBr beamsplitter and provides data over the wavelength range of 3 µm to 28 µm. In acceptance testing the Cryo-FTS demonstrated resolution less than 1 $cm^{-1}$, scan-to-scan reproducibility less than 1 % and modulation efficiency near 40 %.

The MDXR makes use of Si:As BIB detectors with sizes from 100 µm diameter to 3.2 mm square. The largest detector is used with the Cryo-FTS and for most applications, and the smaller detectors can be used for spatial mapping of the beam and for low-power, high-sensitivity measurements. These BIB detectors have spectral sensitivity from 2 µm to 30 µm, detectivity near $10^{14}$ $cm{\cdot}Hz^{1/2}/W$ at 12 K, response times less than 10 µs and spatial uniformity better than 1 % over 1 mm [8,9]. The BIB signal is amplified by a cryogenic amplifier mounted near the detector board to minimize noise pickup. The detector is kept near 10 K, but the cryoamp, thermally isolated from the detector on a G-10 tower, is kept at temperatures above 130 K.

The MDXR can be used with one of two ACRs: one ACR operates in a power range of 50 nW to over 100 μW, and is intended to be used with for relatively high power sources when the MDXR is looking into an ambient temperature environment; the other ACR operates in a power range of 10 pW to about 20 μW, and is for use with low power sources in a low background environment. The MDXR ACRs have a compact geometry, and they were designed as 12 bounce light traps to improve long wavelength absorptivity.

Designed to operate between 180 K and 400 K, the internal blackbody of the MDXR can assess stability of the radiometer and potentially act as a calibration source once it is fully characterized. The blackbody is composed of a core approximately 32 mm in diameter and 40 mm long which contains a conical cavity painted with a vacuum compatible, specular IR absorbing paint and is heated by a single 25 W compact cartridge heater. The blackbody optical output passes through a 1 mm defining aperture and is collimated by the integrated collimator before reaching the defining entrance aperture of the MDXR. In addition to the blackbody, the MDXR also contains an infrared LED and a broadband-IR filament source for cryoamp and Cryo-FTS functional testing and characterization.

## 3. FULL CALIBRATION HIGHLIGHTS

### 3.1 Calibration Methodology

In our first complete calibration of the MDXR at NIST, we have made measurements to compare the ideal temperature and power scales defined by the internal MDXR blackbody and ACR, compared the internal MDXR scales to the scale of an external calibrated source (10CC), and gathered filter radiometer and Cryo-FTS data during the calibration cooldown on a full array of different MDXR configurations to calibrate the BIB response in these two modes. Using optical models for the MDXR and 10CC, source radiance temperature can be extracted from the MDXR ACR data, expected power from the MDXR blackbody can be estimated from the blackbody cavity contact temperature, and the effect of diffraction on the measured signal can be estimated for all MDXR configurations.

Calibration of the MDXR using its internal blackbody source is a powerful tool for setting an internal power scale, checking for stability of the radiometer with time, and verifying that the radiometer is operating nominally during measurements at customer sites. In theory, the MDXR blackbody could function as an absolute source and the MDXR ACR as an absolute detector. To compare the scales of these two components, the internal ACR was used to measure the output of the internal blackbody and the radiance temperature determined by this method was compared to the platinum resistance thermometer (PRT) contact temperature measured concurrently for the blackbody cavity. For calibration of the MDXR to be truly consistent, the temperature scales of the ACR and blackbody should agree to within the absolute uncertainty of the measurement.

As part of the full calibration, we developed an internal stability test of the MDXR to be conducted before, during and after every customer deployment. In this test, the internal blackbody is operated at 400 K, its maximal temperature, and the response of the ACR, Cryo-FTS and BIB detector in filter radiometer mode are measured. If all components of the MDXR are stable, there should be little drift or scatter in the results of the internal stability test over a period of years as the MDXR ages and travels many miles to customer sites. We can benchmark the stability of the various operational modes of the MDXR as internal tests are repeated over time.

The BIB detector, operated in filter radiometer mode, is the fastest way to measure with the MDXR and allows for power measurement with the highest sensitivity. The ACR, in principle, provides absolute power measurement but has a long time constant (on the order of a few minutes) and a noise floor approximately 1000 times higher than that of the BIB detector. As operated, the BIB detector has a bandwidth exceeding 10 kHz and a noise level near 10 $\mathrm{fW/Hz^{1/2}}$ and used in filter radiometer mode is the most practical way to make low power measurements at the output of customer chambers. During the full calibration, each MDXR configuration (aperture, filters, polarizer and blackbody temperature) of interest was measured with the ACR and BIB, and in this way the BIB was calibrated as a secondary standard against the ACR.

The Cryo-FTS mode of the BIB can be calibrated against the output of the internal MDXR blackbody, assuming the blackbody produces an ideal spectrum. The response of the Cryo-FTS to the internal blackbody at 400 K is used to compute a spectral responsivity calibration curve for the Cryo-FTS as described in a previous publication [10]. This spectral responsivity curve, when multiplied by the spectral response of the Cryo-FTS to any source provides a spectrum scaled in absolute units of power. During the full calibration, each MDXR configuration of interest was measured by the Cryo-FTS to generate power-scaled spectral data.

In addition to calibrating the various MDXR modes, the filters and polarizers in the MDXR and 10CC were characterized during the calibration cooldown. Transmission spectra were measured on all single filters using the Cryo-FTS, as well as numerous filter pairs. There are four filter wheels in the MDXR containing short and long pass filters with cutoffs between 3 µm and 13 µm, so by pairing appropriate positions on two filter wheels at a time it is possible to access many bandpass ranges. Out-of-band test were also made on the filters by pairing short and long pass filters whose passbands do not intersect. Measurements on many of the MDXR configurations were made without polarizers, as well as with the fixed polarizers in the MDXR and 10CC or with the rotating polarizer in the MDXR. In this way, the exact orientation of the fixed polarizers and the relative polarization of the sources could be determined.

By attaching the 10CC calibrated source to the MDXR and measuring the response of the MDXR ACR to the 10CC blackbody, the power scale of the MDXR can be effectively compared to the power scale set by the national primary standard detectors for optical power at NIST. The 10CC has been previously calibrated against the LBIR primary standard ACR which is regularly compared against POWR, the NIST primary standard ACR [2]. As with the internal source, an extensive array of 10CC configurations (10CC aperture, filters, polarizer and blackbody temperatures) were measured by the MDXR ACR, by the MDXR BIB directly, and by the Cryo-FTS. A basic set of measurements at a 10CC blackbody temperature of 600 K using the MDXR ACR and BIB will serve as a stability test against the 10CC (which has historically shown a repeatability less than 0.5 % with the legacy BXR transfer radiometer). The Cryo-FTS spectral responsivity curve determined from the internal calibration data was used to calculate power-scaled spectra for many of the 10CC configurations.

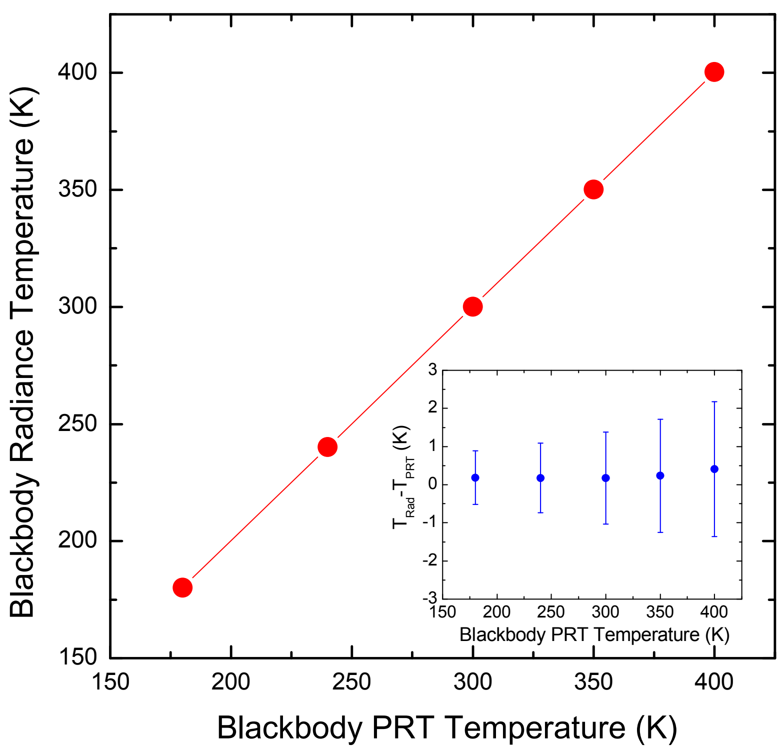


**Figure 3.** The radiance temperature calculated from the MDXR ACR data agrees very well with the temperature recorded by the platinum resistance thermometers on the blackbody cavity, as shown in the main plot. The inset plot displays the difference between radiance temperature and PRT contact temperature as a function of PRT temperature, along with uncertainty bars. The two temperatures agree to within measurement uncertainties over the full MDXR blackbody temperature range 180 K to 400 K.

Complete diffraction calculations for the internal MDXR and 10CC-MDXR configurations involving the MDXR ACR and BIB have been completed, allowing for accurate estimation of the fraction of power from the sources expected to reach the detectors. The diffraction effects have been determined using diffraction analysis and code developed over the last decade [11-13]. The diffraction treatment allows for accurate calculations of the MDXR blackbody radiance temperature and for detailed comparison of the internal MDXR results with those of the 10CC-MDXR. Diffraction effects are most significant for lower blackbody temperatures and smaller limiting apertures.

### 3.2 Calibration Results

The results of the radiance temperature calculations on the internal MDXR blackbody as determined from internal MDXR ACR measurements are shown in Figure 3. In the main plot of the figure, the calculated radiance temperature is graphed against the temperature of the blackbody as recorded by PRTs on the blackbody cavity. In the inset plot, the difference between the radiance temperature and PRT temperature is graphed as a function of the PRT temperature, and estimated measurement uncertainties are indicated by the error bars. The agreement between the calculated radiance temperature and the PRT contact temperature is excellent, and the inset shows that the two temperatures agrees to well within measurement uncertainty. The agreement of these two temperatures indicates agreement of the scales defined by the MDXR blackbody and the MDXR ACR and indicates that within our uncertainty, the blackbody or ACR can be used interchangeably to define the MDXR calibration scale.

The internal stability test for the MDXR, using output from the MDXR blackbody at a temperature of 400 K, was executed a number of times during the full calibration run. From our initial stability tests, it appears that the reproducibility of the BIB data in filter radiometer mode is approximately 0.3 %, the reproducibility of the ACR data is approximately 0.5 %, and the reproducibility of the Cryo-FTS measurements is approximately 1 %.

Analysis of the data from the MDXR viewing the 10CC source shows that there is good agreement between the MDXR internal scale and the scale of the 10CC model. The 10CC blackbody output power incident on the MDXR ACR has been measured, and this power has also been estimated from a model for the 10CC which uses data from the 10CC calibration against the LBIR primary standard ACR. The ratio of the measured power from the 10CC using the MDXR ACR to the prediction of the 10CC model output is shown versus filter band center wavelength in Figure 4. According to the analysis completed to date, the data indicates that the MDXR internal scale agrees with the 10CC model to within 5 % over the power range from 2 nW to 350 nW. Calibration of our legacy BXR transfer radiometer was made using the 10CC source. According to our analysis, the agreement of the MDXR and BXR scales is estimated to be approximately 3 %. The Cryo-FTS data taken on the 10CC calibrated source was analyzed for different filter bands according to a method described previously [10], and show that the integrated spectral power determined from the Cryo-FTS spectral responsivity calibration curve agrees with the power estimated from the 10CC scale to within 2 %. Remaining analysis and modeling may somewhat alter the values given here for agreement of the MDXR data with the 10CC model.

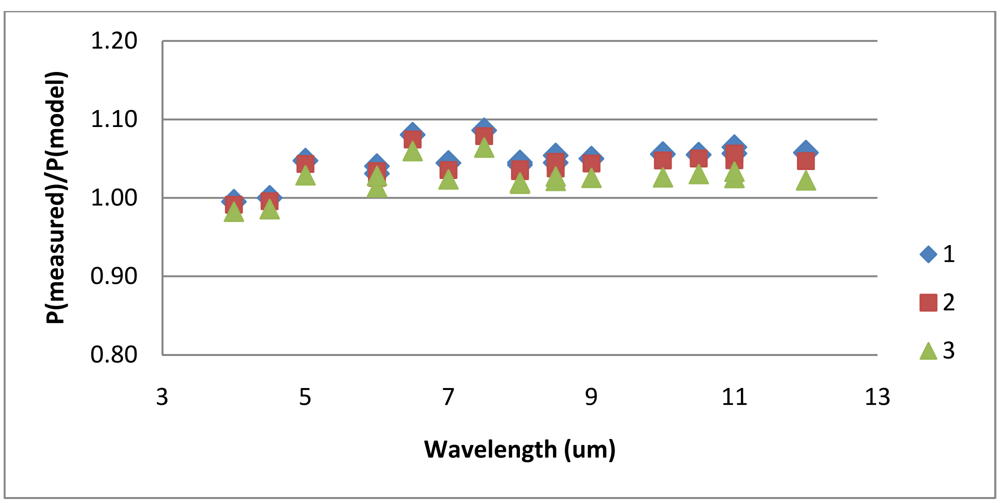


**Figure 4.** Comparison of measurements made of filtered 10CC output by the MDXR ACR to predictions of the 10CC model, for three different apertures on the 10CC blackbody source at a setpoint of 400 K.

The filter and polarizer results from the MDXR calibration run indicate that the characteristics of these components within the MDXR and 10CC are within nominal specifications. The transmission measurements indicate that all filters generally transmit above 80 % in their passband and less than 0.5 % in the wavelength range to be filtered. The out-of-band transmission measurements on paired filters show that out-of-band transmission is generally less than 0.1 %. The relative angle of the fixed polarizers in the MDXR can be calculated from data using both the fixed polarizers and the rotating polarizer, and the data show that the horizontal and vertical fixed polarizers are perpendicular to within 1 degree. Polarization data also establish that the degree of linear polarization of the 10CC source is less than 0.5 %.

## 4. CUSTOMER DEPLOYMENT HIGHLIGHTS

The first two customer deployments of the MDXR have established the stability of the instrument and its versatility for broadband and spectral infrared calibration and characterization. Like the legacy BXR, the majority of MDXR measurements during the deployments were related to calibration of the output irradiance of user chambers using the filter radiometer mode of the MDXR BIB. Unlike the BXR, the stability of the MDXR internal scale could be verified at the customer site before and after calibration, and a host of chamber components could be spectrally characterized with the Cryo-FTS and absolutely measured with the ACR. Internal measurements of the MDXR at customer sites displayed stability similar to that exhibited during the full calibration completed on-site at NIST.

Calibration of the irradiance at the output of customer chambers included measurements by the MDXR in filter radiometer mode where the source in the user chamber was a blackbody. These configurations generally included different discrete filters, circular variable filters, apertures and blackbody temperatures. The filter transmissions were independently determined from MDXR data acquired in both Cryo-FTS and filter radiometer mode. The Cryo-FTS provides high resolution spectral characterization of the filters and the filter radiometer mode provides high sensitivity transmission results. Figure 5 shows a typical product of a chamber irradiance output calibration for a blackbody source using the Cryo-FTS. Figure 6 shows Cryo-FTS transmission data on a series of filters mounted in a user chamber, along with filter radiometer datapoints, exhibiting the agreement of these two methods for measuring transmission. The Cryo-FTS allows such optical elements to be characterized with high spectral resolution at the actual test chamber conditions of beam geometry and temperature.

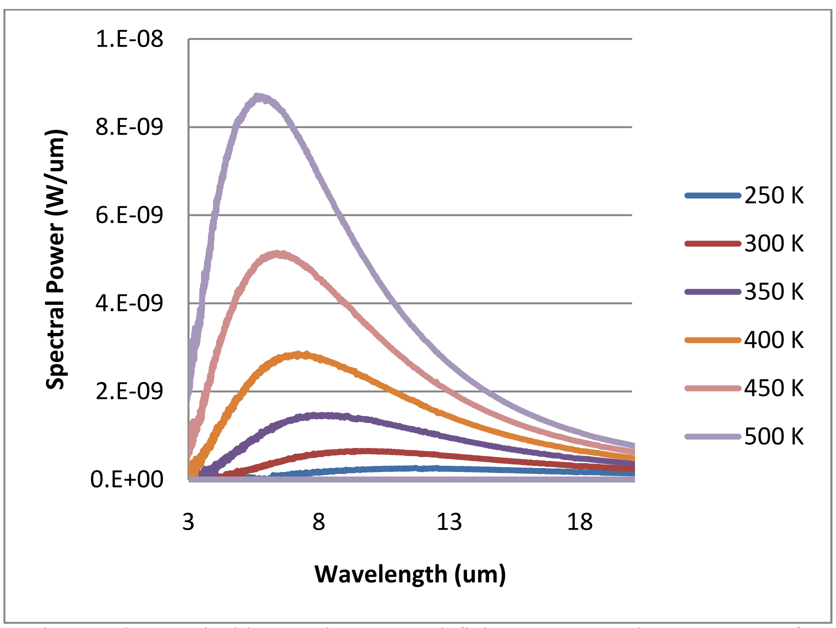


**Figure 5.** Measured spectral power incident on the MDXR defining aperture at the output port of a user chamber for the case of a blackbody source within the chamber at a relatively large aperture setting, for a range of blackbody setpoint temperatures from 250 K to 500 K.

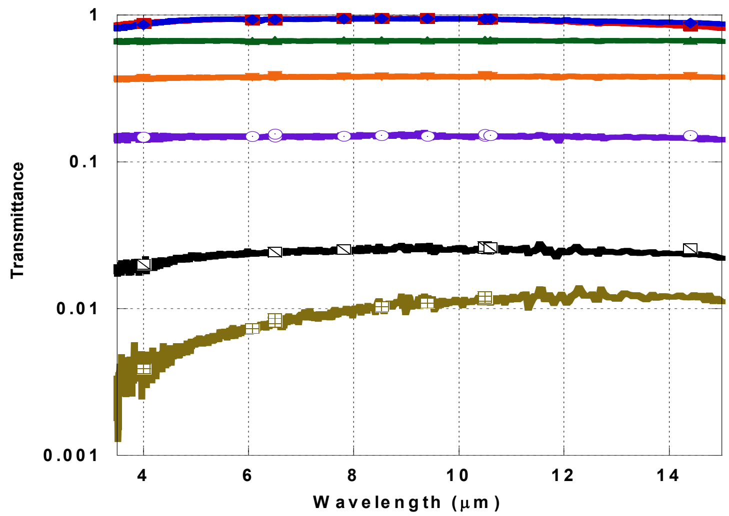


**Figure 6.** The spectral transmittance of a set of 7 neutral density filters mounted in a wheel in front of the blackbody source in a user test chamber. The measurements were done by taking the ratio of the radiometer signal with the filter in place to the signal without the filter, with the blackbody temperature set to 800 K. The solid curves show the data from the Cryo-FTS at 4 $cm^{-1}$ resolution, while the discrete points show the results using different filter radiometer bands centered at each wavelength.

In addition to the calibrations of blackbody sources, the MDXR is also useful for characterizing non-thermal sources and making absolute power measurements with its ACR. In one case, the output from a monochromator in a customer chamber was analyzed using the Cryo-FTS and ACR. Despite a low power output of approximately 10 nW, the Cryo-FTS acquired spectral data and the ACR quantified the absolute power from the monochromator. An example of the monochromator data from the Cryo-FTS is shown in Figure 7. It provides high resolution spectral information on the monochromator output wavelength and spectral width, as well as evidence of any out-of-band leakage. In another case of a non-blackbody source, an emitter-array source in a customer chamber was measured by the MDXR using the BIB in filter radiometer mode and the Cryo-FTS. The emitter-array was spectrally characterized as a function of input current, the spatial location of pixels energized, and the number of pixels energized. Figure 8 shows spectra taken from a 51x51 array of pixels at various drive currents. An initial test of the radiance measurement configuration of the MDXR was also made in another case measuring the output of a plate source in a customer chamber with the ACR.

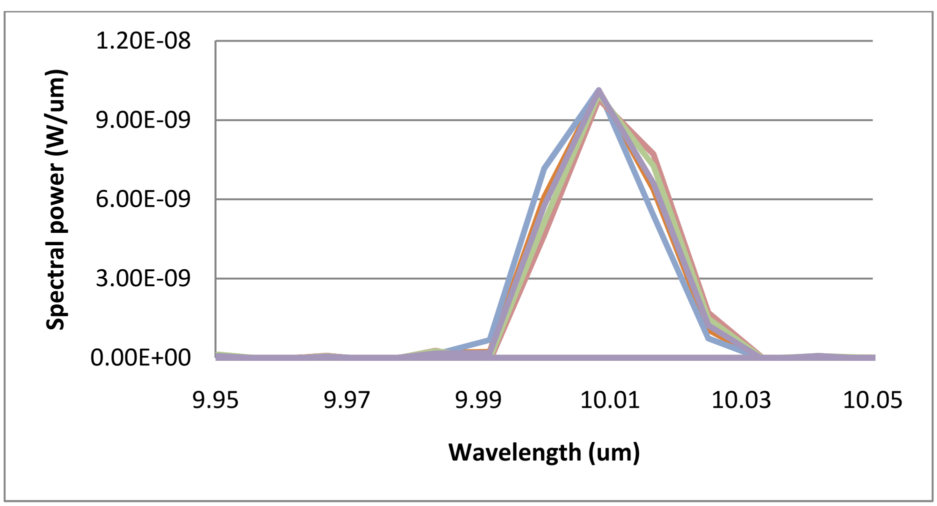


**Figure 7.** Measurement of the spectral power collected by the 7 cm diameter MDXR defining aperture from the output beam of a user chamber with a high temperature source filtered with a grating monochromator. Five spectra were collected by the Cryo-FTS at 1 $cm^{-1}$ resolution on successive scans of the grating in order to test the mechanical repeatability of the system. The results show the expected triangular line shape for a monochromator with rectangular entrance and exit slits.

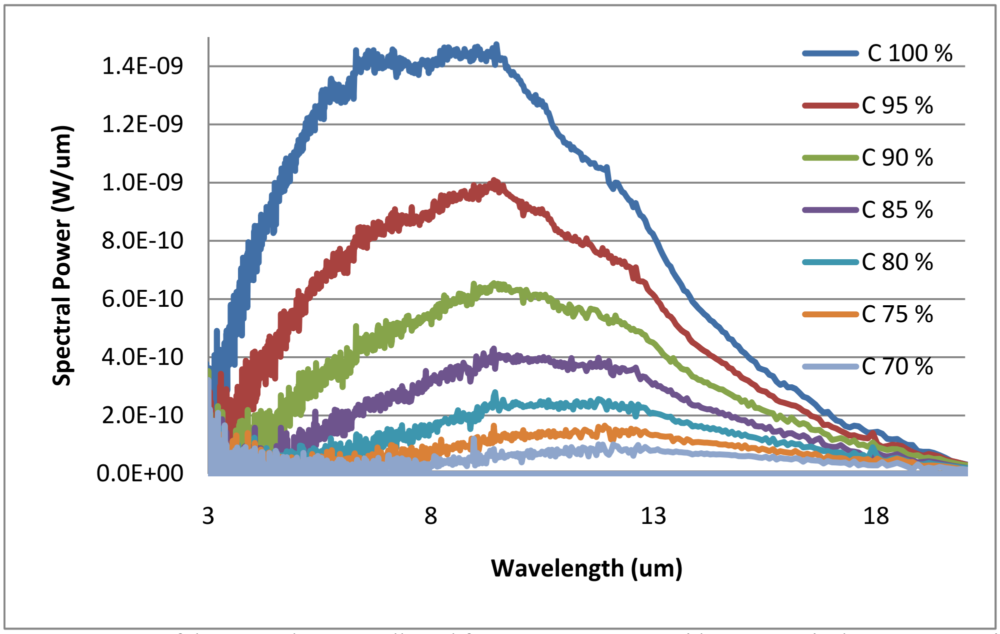


**Figure 8.** Measurement of the spectral power collected from an array source with a 51x51 pixel segment energized at a series of drive currents from 70 % to 100 % of the manufacturer's specification. Comparison with the Planckian spectra in Figure 5 show the much broader spectral distribution associated with this source.

## 5. CONCLUSIONS AND FUTURE PLANS

During its first full year of operation, the MDXR has undergone a complete calibration at NIST and successfully deployed to its first customer sites for calibration and characterization of infrared test chambers. During the on-site NIST calibration, internal stability tests have shown that repeatability for the ACR, BIB filter radiometer and Cryo-FTS modes of the MDXR are approximately 0.3 %, 0.5 %, and 1 %, respectively. During 2010, the MDXR was deployed to two customer sites where it characterized both thermal and non-thermal outputs and more deployments are scheduled for 2011.

A number of equipment, calibration and analysis improvements to the MDXR are planned for the near future. A BIB trap detector with high quantum efficiency is under development and will be added to the MDXR when fully tested [14]. The trap detector could provide spectrally flat response with near unity absorptance like the ACR with the better power sensitivity and high speed of the BIB detector. Changes to the MDXR apertures and baffles are also planned to allow for better radiance measurements by providing more control of light leakage and scatter. The MDXR scale has been compared to the NIST primary standard detector scale for optical power through the use of the 10CC calibrated source. A direct comparison of the MDXR ACR with the NIST primary standard POWR in a single calibration experiment would provide lower uncertainties, and such an experiment is presently under consideration. As more customer calibrations are completed with the MDXR, we will continue to accumulate data on its internal stability as well as the stability of customer chamber calibrations as the transition from the legacy BXR to the MDXR is completed.

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