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# MKV Carrier Vehicle Sensor Calibration

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## ABSTRACT

The Multiple Kill Vehicle (MKV) system, which is being developed by the US Missile Defense Agency (MDA), is a midcourse payload that includes a carrier vehicle and a number of small kill vehicles. During the mission, the carrier vehicle dispenses the kill vehicles to address a complex threat environment and directs each kill vehicle toward the intercept point for its assigned threat object. As part of the long range carrier vehicle sensor development strategy, MDA and project leaders have developed a pathfinder sensor and are in the process of developing two subsequent demonstration sensors to provide proof of concept and to demonstrate technology. To increase the probability of successful development of the sensor system, detailed calibration measurements have been included as part of the sensor development. A detailed sensor calibration can provide a thorough understanding of sensor operation and performance, verifying that the sensor can meet the mission requirements. This approach to instrument knowledge will help ensure the program success and reduce cost and schedule risks. The Space Dynamics Laboratory at Utah State University (SDL) completed a calibration test campaign for the pathfinder sensor in April 2008. Similar calibration efforts are planned in 2009 for the two demonstration sensors. This paper provides an overview of calibration benefits, requirements, approach, facility, measurements, and preliminary results of the pathfinder calibration.

**Keywords**: MKV, pathfinder, carrier vehicle, calibration

## 1. INTRODUCTION

The Space Dynamics Laboratory at Utah State University (SDL) is calibrating three demonstration sensors developed by Lockheed Martin (LM) for the multiple kill vehicle (MKV) program sponsored by the Missile Defense Agency (MDA). The MKV system is a midcourse payload that includes a carrier vehicle (CV) and a number of small kill vehicles. The three CV sensors are designed to radiometrically detect and track targets viewed against a target background. The first sensor is a pathfinder sensor with a 256×256 pixel, dual-band focal plane array (FPA); the other two sensors use the same canister design as the pathfinder with newly developed 512 × 512 pixel, dual band FPAs. The optics and canister assembly are planned to be identical for both systems.

SDL performed engineering testing and an abbreviated ground calibration on the 256 pathfinder sensor from 6 March to 14 April 2008. This testing effort included participation from other organizations that are part of the MKV CV sensor team, including MDA, Lockheed Martin Space Systems Company (LMSSC), Millennium Engineering and Integration Company, MIT/Lincoln Laboratory, and BAE Systems. All of the organizations were actively involved with oversight, review, and data collection.

Because of the sensors' similarities, the 256 pathfinder sensor calibration is being used to optimize the integrated calibration measurement system in preparation for the calibration of the two 512 CV sensors. It provides preliminary data to evaluate sensor performance, and helps identified improvements and fixes to the sensor and calibration activities in preparation for the full 512 CV sensor calibration testing.

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This paper presents an overview of calibration benefits, requirements, approach, facility, measurements, and preliminary results of the 256 pathfinder calibration.

### 1.1. Instrument Overview

The MKV system is a midcourse payload that includes a carrier vehicle (CV) and a number of small kill vehicles. During the mission, the carrier vehicle dispenses the kill vehicles to address a complex threat environment, and directs each kill vehicle toward the intercept point for its assigned threat object. The CV sensor uses a telescope to image the scene energy onto a dual-band, HgCdTe focal plane that provides two spatially co-located radiometric measurements in two infrared spectral bands, referred to as Video 1 and Video 2.

### 1.2. Calibration Objectives

The goal of the 256 pathfinder calibration was to perform all calibration measurements on the 256 pathfinder sensor that are planned for the full 512 CV sensors. The measurements were abbreviated to reduce test duration while meeting the goals of the 256 pathfinder sensor calibration testing. Specific calibration objectives included verifying operation of the sensor and supporting hardware at SDL, verifying calibration test configurations, test procedures, and operation of hardware, and verifying data collection automation and management systems. The ground calibration plan is documented in the MKV CV Sensor Calibration Plan (SDL/07-196).

## 2. 256 PATHFINDER CALIBRATION

### 2.1. Calibration Overview

Radiometric sensors require characterization and calibration to verify proper instrument operation, to create algorithms for data reduction, and to estimate measurement uncertainties. SDL is calibrating the MKV CV sensors by characterizing their overall responsivity in terms of separate radiometric parameters, which include radiometric responsivity, spectral responsivity, spatial responsivity, and temporal responsivity. Together, these radiometric parameters comprise a complete calibration of the radiometric sensor (Wyatt, 1978).

Sensor calibration provides a thorough understanding of sensor performance. This information can then be used to provide an independent comparison of sensor performance to mission requirements. In addition, results from the analyses can be used to obtain anomaly resolution, improve sensor performance, and establish a baseline for future testing and follow-on sensor systems.

### 2.2. Mission Measurement Requirements

Program-defined performance specifications and characteristics of the MKV CV sensor were used to determine which calibrations tests should be performed, the calibration hardware used, methods of data collection, and the algorithms necessary to produce the desired calibration data. The performance specifications and characteristics identified for verification during calibration are listed in Table 1.

Table 1. Performance specifications and characteristics verified during the 256 pathfinder calibration.

| Subsystem/System | Performance Specifications and Characteristics | |
|---|---|---|
| Telescope | Short-wave (SW) and long-wave (LW) passband<br>Optical throughput<br>Pixels per blur | Operating temperatures<br>IFOV mapping<br>Optical distortion over FOV<br>Point response function (PRF) over FOV |
| Focal Plane Array | Operating temperature and stability<br>Pixel pitch<br>Integration times<br>Nonlinearity<br>Collection efficiency<br>SW and LW passband<br>SW and LW noise equivalent quanta (NEQ) | Dynamic range<br>Spatial crosstalk<br>Spectral crosstalk<br>Pixel operability<br>1/f knee<br>Offset nonuniformity<br>Electronics output quantization |
| System Level | Noise equivalent flux density (NEFD)<br>Focus verification<br>Stray light<br>Saturation recovery<br>Saturation wrap-around | Radiance measurement accuracy (RMA) and irradiance measurement accuracy (IMA)<br>Polarization sensitivity<br>Focal plane response time<br>Electronics output quantization |

## 2.3. Calibration Parameters

The performance specifications and characteristics that need to be verified to meet mission objectives determine the parameters that must be calibrated for a sensor. Table 2 is a matrix relating calibration parameters to the sensor performance specifications and characteristics for the 256 pathfinder sensor. This matrix was used to define the test configurations and algorithms.

Table 2. Calibration measurement parameters vs. sensor performance specifications and characteristics.

| Calibration Parameters | MKV CV Sensor Performance Specifications and Characteristics | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Telescope | | | | | | | Focal Plane | | | | | | | | | | | | | | System | | | | | | | | |
| | SW and LW Passband | Optical Throughput | Pixels per Blur | Operational Temperature | IFOV Mapping | Optical Distortion over FOV | Point Response Function (PRF) over FOV | Operating Temperature & Stability | Pixel Pitch | Integration Times | Nonlinearity | Collection Efficiency | SW and LW Passband | SW and LW NEQ | Dynamic Range | Spatial Crosstalk | Spectral Crosstalk | Pixel Operability | 1/f Knee | Offset Nonuniformity | Electronics Output Quantization | Noise-Equivalent Flux Density (NEFD) | Focus Verification | Stray Light | Saturation Recovery | Saturation Wrap-Around | RMA and IMA (Goal) | Polarization Sensitivity | Focal Plane Response Time | Electronics Output Quantization |
| Spectral Response | X | | | | | | | | | | | | X | | | | | | | | | X | | | | | X | | | |
| Fixed Pattern Noise Stability | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | |
| Linearity | | | | | | | | | | | X | | | | | | | X | | | | X | | | | | X | | | |
| Dynamic Range | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | X |
| Waveband Crosstalk | | | | | | X | | | | | | | | | | | X | | | | | | | | | | | | | |
| Noise, NEFD, Noise Equivalent Radiance (NER) | | | | | | | | | | | | | | X | | | | X | | | X | X | | | | | X | | | X |
| Point Response Function (PRF) | | | X | | | X | X | | | | | | | | | | | | | | | X | X | | | | X | | | |
| Modulation Transfer Function (MTF) | | | X | | | | | | | | | | | | | | | | | | | | X | | | | | | | |
| Response Uniformity | | X | | | | | | X | | | | X | | | | | | X | | X | | | | | | | X | | | |
| Integration Time Normalization | | | | | | | | | | X | | | | | | | | | | | | X | | | | | X | | | |
| IFOV Line-of-Sight Mapping | | | | X | X | X | X | | X | | | | | | | | | | | | | | X | | | | | | | |
| Medium-Term Repeatability | | | | | | | | X | | | | | | | | | | X | | | | X | | | | | X | | | |
| Long-Term Repeatability | | | | | | | | | | | | | | | | | | X | | | | X | | | | | X | | | |
| Near Angle Scatter | | | | | | | | | | | | | | | | X | | | | | | X | | X | | | X | | | |
| Responsivity | | | | | | | | | | | | | | | | | | | | | | X | | | | | X | | | |
| Focus | | | | | | X | X | | | | | | | | | | | | | | | | X | | | | | | | |
| Large Angle Scatter (±4 deg) | | | | | | | | | | | | | | | | | | | | | | | | X | | | X | | | |
| Saturation Blooming, Wrap-Around & Recovery | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | X | |
| Polarization | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | |

Calibration parameters that are used to characterize the sensor are grouped into two categories: calibration equation parameters and radiometric model parameters. A unique calibration equation and radiometric model are created for each sensor based on mission requirements and sensor performance. Together, these equations and parameters describe the radiometric responsivity, and the spatial, spectral, and temporal responsivities of the sensor.

The calibration equation contains parameters that are needed to relate sensor output to measured flux in engineering units. Separate calibration equations exist for the radiance (watts/cm$^2$·sr) and irradiance (watts/cm$^2$) measurements. The measured flux is then related to the true scene flux using calibration parameters from the radiometric model, which includes all parameters not included in the calibration equation that are needed to characterize the spectral, spatial, and temporal responsivity domains of the sensor.

### Radiance Calibration Equation

The radiance calibration equation converts the raw output from the instrument analog-to-digital converter (ADC) to radiance. This equation includes subtraction of background and dark offset. The equation also includes a peak-radiance responsivity term, which is the sensor's radiance responsivity at the peak of the spectral response curve. This is a result of peak-normalizing the sensor power spectral response curve.

For pixel $k$ , the radiance calibration equation is given by Equation (1).

$$L_{M,k,t} = \frac{1}{\Re_L} r_{k,t} = \frac{1}{\Re_L}\left[\frac{B_k G_I}{F_{FF,k}}\left[F_{Lin,k}\left(r_{T,k,t}\right) - F_{Lin,k}\left(r_{O,k,t}\right)\right]\right] \tag{1}$$

Where $L_{M,k,t}$ is in-band measured radiance [W/cm$^2$sr], $\Re_L$ is peak-radiance responsivity [counts per W/cm$^2$sr], $r_{k,t}$ is corrected pixel response [counts], $B_k$ is bad pixel mask function [unitless], $G_I$ is integration time normalization [unitless], $F_{FF,k}$ is flat-fielding or nonuniformity correction [unitless], $F_{Lin,k}(\ )$ is nonlinearity correction function [unitless], $r_{T,k,t}$ is raw pixel response for source temperature $T$ [counts], $r_{O,k,t}$ is raw pixel background response [counts], $k$ is pixel index - parameter is unique to each pixel, and $t$ is time.

### Irradiance Calibration Equation

The irradiance calibration equation converts point source response from the instrument ADC to irradiance. This equation includes subtraction of background and dark offset. The equation also includes a peak responsivity term, which is the sensor's irradiance responsivity at the peak of the spectral response curve. This is a result of peak-normalizing the sensor power spectral response curve.

The irradiance calibration equation is given by Equation (2).

$$E_{M,k,t} = \frac{1}{\Re_E UNF_{irrad}} P\left[r_{k,t}, PRF\right] = \frac{1}{\Re_E UNF_{irrad}}\left[\frac{B_k G_I}{F_{FF,k}}\left[F_{Lin,k}\left(r_{T,k,t}\right) - F_{Lin,k}\left(r_{O,k,t}\right), PRF\right]\right] \tag{2}$$

where $E_{M,k,t}$ is measured irradiance [W/cm$^2$], $\Re_E$ is peak irradiance responsivity [counts per W/cm$^2$], $UNF_{irrad}$ is irradiance uniformity correction over FOR [unitless], $P(\ )$ is point source extraction operation, $r_{k,t}$ is corrected pixel response [counts], is point response function [unitless], $B_k$ is bad pixel mask function [unitless], $G_I$ is integration time normalization [unitless], $F_{FF,k}$ is flat-fielding or nonuniformity correction [unitless], $F_{Lin,k}(\ )$ is nonlinearity correction function [unitless], $r_{T,k,t}$ is raw pixel response [counts], $r_{O,k,t}$ is raw pixel background response [counts], $k$ is pixel index - parameter is unique to each pixel, and $t$ is time.

### Radiometric Model

The radiometric model characterizes the spatial, spectral, and temporal responsivity domains of the sensor. The spatial domain is characterized by the point response function, effective field of view, IFOV line-of-sight mapping (including distortion correction), large angle scatter, and near angle scatter. The spectral domain is characterized by the in-band and out-of-band relative spectral response and spectral waveband crosstalk. The temporal domain is characterized by the medium- and long-term repeatability, noise-equivalent radiance and irradiance (NER & NEI), 1/f noise, and the temporal frequency responsivity parameters.

## 2.4. Calibration Equipment

Measuring each individual parameter of the sensor calibration equations and radiometric model requires different source configurations. Calibration testing of the 256 pathfinder sensor occurred in the SDL calibration test facility. SDL used the multifunction infrared calibrator #5 (MIC5), along with the high-accuracy extended-source (HAES-15) blackbody, shown in Fig. 1, to measure each of the required parameters for the calibration. A portable reference source (PRS) was used to establish baseline response values for sensor lifetime monitoring and health checks. Data from the PRS allowed the data analyst to perform response trending, evaluate the effect of trending results on calibration, evaluate long-term background and radiance response repeatability, and quantify calibration uncertainty for the operational lifetime of the sensor.

The SDL MIC5 incorporates four optical configurations into a single, cryogenically cooled dewar. These source configurations can be altered or exchanged while MIC5 remains cold. An ISO 500 vacuum gate valve was attached to the MIC5 exit port to enable installation and removal of the 256 pathfinder sensor. Transfer radiometer measurements of the HAES-15 output were obtained by NIST in June 2006.

Fig. 1. Calibration equipment.

### 2.5. Test Configurations

Six unique test configurations were used for the 256 pathfinder calibration to determine the required sensor parameters. These configurations included 1) full aperture, high temperature blackbody source configuration, 2) full aperture, full angle, low temperature blackbody source configuration, 3) small signal linearity configuration, 4) point source configuration, 5) step-scan Fourier transform spectrometer (FTS) spectral configuration, and 6) portable reference source (PRS).

These test configurations were driven by measurement requirements relative to source temperature and geometry, and calibration test algorithm implementation. For example, dynamic range requirements dictate the range of blackbody source temperatures required. This range of operating temperatures spanning cryogenic and above-ambient operation cannot be met with a single blackbody system; therefore, two blackbody source systems are needed. Likewise, linearity and spectral response test algorithm requirements dictate that separate configurations be implemented for these tests.

The full-aperture, high temperature blackbody source configuration was provided by an external blackbody placed at the MIC5 collimator entrance port. The full-aperture, full-angle low temperature blackbody source configuration was implemented using the HAES-15 blackbody. The small signal linearity measurement configuration was provided by an extended source blackbody inside the MIC5, combined with a small filament source (Jones source) to provide a small-amplitude modulated signal. A point source configuration was provided by an external blackbody placed behind a pinhole aperture at the MIC5 collimator entrance port. An external step-scan Fourier transform spectrometer (FTS) placed at the MIC5 collimator entrance port was used to present the spectral response measurement configuration.

### 2.6. Data Management

A centrally automated data collection system was used throughout the calibration. The system initiates and automates data collection and captures and stores environmental information for each test event. The data management system executes previously prepared data collection scripts to send commands and receive status from the calibration equipment and the sensor controller as needed to configure calibration sources and associated hardware.

#### Data Quality Assurance Process

All data collected during the calibration were immediately preprocessed in near real time to verify that the data were readable and free from errors, and to create calibration analysis files (CAF) that were used to perform additional quick look analysis. This process ensures that the data obtained are adequate to generate the desired calibration parameters.

Final quick look data validation took place following preprocessing using fully populated CAF files. The final CAF output contains all configuration and environmental information in a header and statistics for pixels of interest and selected pixel time series. This allows the analyst to perform application-specific data analysis for a given task. Data analyses were performed in the interface description language (IDL) analysis environment.

### Data Archive

Copies of the 256 pathfinder sensor raw calibration data were maintained on data storage devices for use during calibration data analysis. All calibration data collected were backed up and archived onto LTO-3 WORM tape media. This archive will be maintained for distribution of data under the direction of MKV project leaders.

## 3. CALIBRATION MEASUREMENTS AND RESULTS

### 3.1. Data Collection Procedures

Eight data collection procedures were used to collect data for the 256 pathfinder sensor calibration: relative spectral response (RSR), linearity, MIC5 external blackbody extended source, MIC5 external blackbody point source, low-temperature extended source (HAES-15), benchmark, portable reference source (PRS), and polarization sensitivity. The calibration tests are described in detail in the MKV CV Sensor Calibration Data Collection Procedures (SDL/07-548 – 555), and summarized in this section. Table 3 lists the various calibration measurements and the time required to perform these measurements.

Table 3. Pathfinder Calibration Measurements

| Measurement | Time |
|---|---|
| Initial Portable reference source measurement | 1 Day |
| Focus verification testing | 1 Day |
| Engineering testing | 4 Day |
| Spectral response measurements | 2 Day |
| Point response function (abbreviated) | ½ day |
| Point source irradiance responsivity | 2 Day |
| Full-aperture high temperature blackbody radiance responsivity | 2 Day |
| Linearity | 4 Day |
| Saturation wrap-around, blooming, recovery | ½ Day |
| Near-angle scatter | ½ Day |
| Polarization sensitivity | ½ Day |
| Special point source measurements | ½ Day |
| Point source medium-term repeatability | ½ Day |
| Point response function (abbreviated) | ½ Day |
| Intermediate Portable reference source measurement | 1 Day |
| HAES-15 extended source radiance responsivity (abbreviated) | 2 Day |
| Low-temperature blackbody medium-term repeatability | ½ Day |
| Final Portable reference source measurement | 1 Day |
| Calibration benchmark measurements (once or twice daily) | NA |

### 3.2. Measurements and Results

### Relative Spectral Response (RSR)

A system level spectral response measurement was provided by an external step-scan Fourier transform spectrometer (FTS) placed at the MIC5 collimator entrance port. Fig. 2 is a photograph of the external step-scan FTS located at the MIC5 entrance port. The Digilab (Varian) model FTS6000 FTS houses a KBr lens to focus the FTS output on the calibrator input aperture. A shutter is used to momentarily block the beam at each FTS mirror step to mark FTS mirror step positions in the data stream.

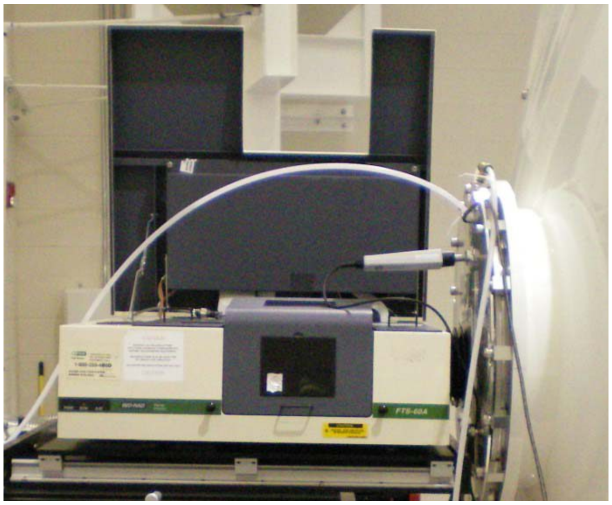


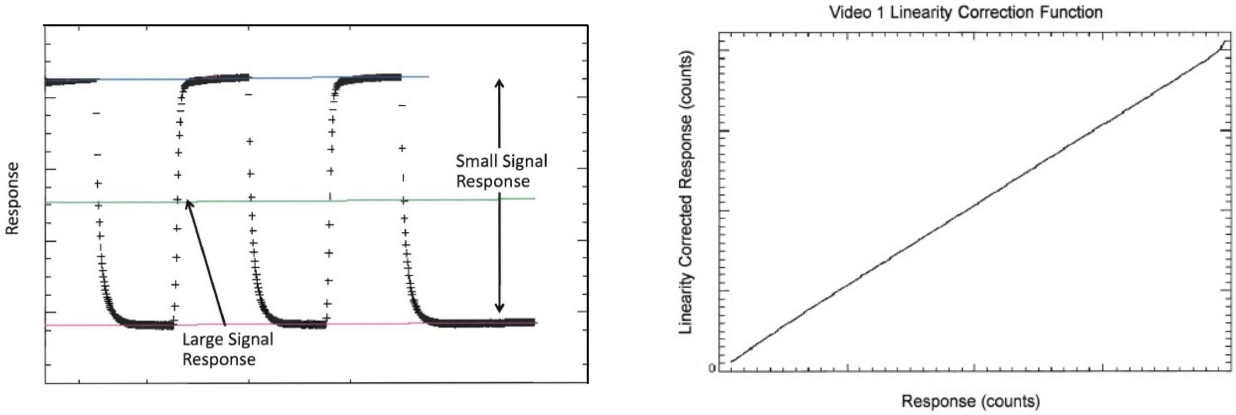
Fig. 2. Step-scan Fourier transform spectrometer located at the MIC5 entrance port.

For this measurement, the sensor measures the FTS interferogram. The spectrum is calculated by taking the Fourier transform of the interferogram. The measured spectrum is then corrected for the spectral output of the spectrometer and the spectral transmittance of the optical path (i.e., combined transmittance of lens, window, and collimator mirrors). This approach was used to quantify the system level, video-dependent spectral response and was used to verify the spectral band edge requirements.

These data were also used to provide a first order assessment of response nonlinearity. For the dynamic range of the RSR measurements, evidence of a nonlinear response appears in the RSR data as a harmonic of the fundamental passband. These results were consistent with response linearity measurements. The results also verified that the band edge position were within design specifications.

## Linearity

To quantify response linearity, the small signal responsivity was measured using the beam addition technique described by Shumaker (1984) and Bird et.al. (2002). This measurement configuration was provided by a large area extended source located inside MIC5 with operating temperatures between 100 K and 600 K, combined with a small filament source (Jones source) to provide a small-amplitude modulated signal. Fig. 3 shows an example of the small signal response superimposed on the large signal response and the post processed linearity corrected response versus raw sensor response. These data show the response is linear for a large portion of the dynamic range.



Small signal response superimposed on large signal response

Post processed linearity corrected response vs. raw sensor response

Fig. 3. Sample linearity results.

### MIC5 External Blackbody Extended Source

For these measurements, an extended source was simulated by selecting a MIC5 open aperture position with an external blackbody positioned at the MIC5 collimator input port, as shown in Fig. 4. The open aperture provided about 3.4 mrad angular divergence, and was selected to illuminate the largest number of pixels possible. The source radiance was determined from the external blackbody temperature and corrected for spectral throughput of the optical path. The range of source measurement temperatures was 320 to 1273 K and the optical path was either under vacuum or purged with gaseous nitrogen to avoid atmospheric absorption. These measurements were used to extend blackbody measurements with radiance temperatures greater than 360 K. Temperatures between 320 K and 360 K provide overlapping measurements that were used for sensor response comparison between low and high temperature blackbodies. Parameters determined from these measurements include array-average peak radiance responsivity and spectral purity over a specified dynamic range.

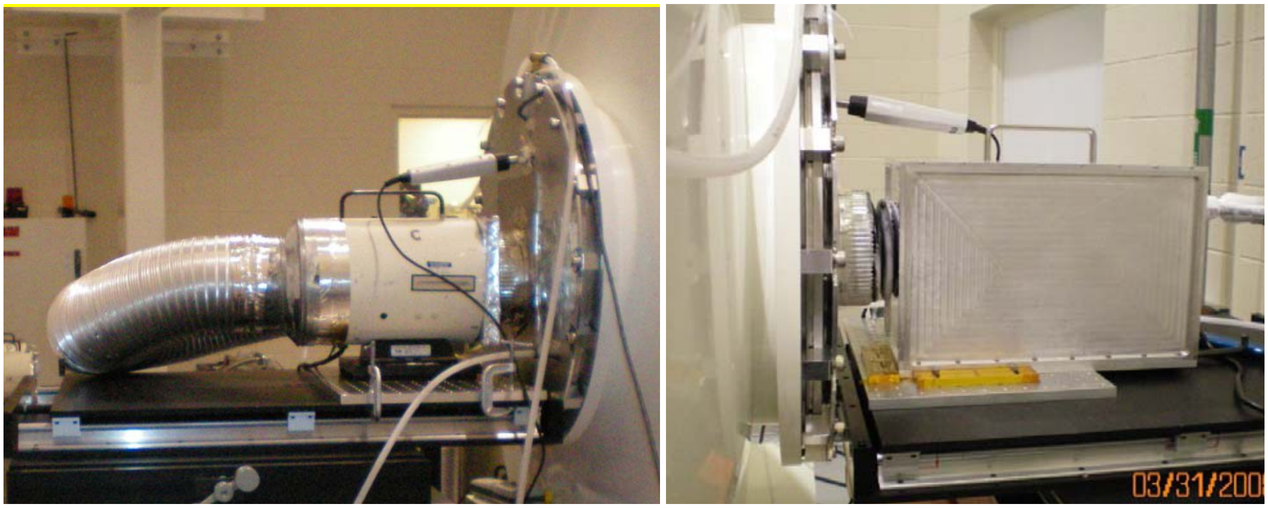
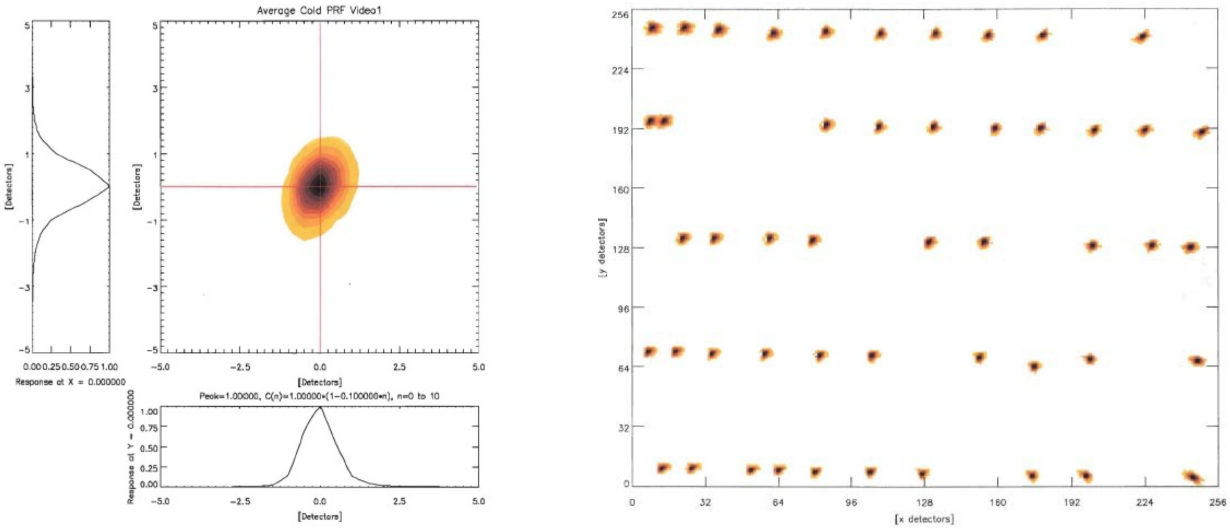


Fig. 4. External blackbody located at MIC5 entrance port.

### MIC5 External Blackbody Point Source

A point source was simulated by back illuminating a small pin hole aperture located at the focus of MIC5 with an external blackbody located at MIC5's entrance port (Fig. 4). The MIC5 pointing mirror steers the point source over the array, and the MIC5 target filter module moves the aperture in a 2 × 2 dither pattern.

The point response function (PRF) is the response of an instrument to a point source, and is measured at multiple MIC5 focus positions. The shape of the PRF is determined from optical diffraction, geometric image quality, detector spatial response, optical scatter, detector-to-detector crosstalk, and jitter. Fig. 5 shows a contour plot of the PRF response near the center of the FOV and a graph of the PRF response over the entire FOV. These data show that the PRF is nearly symmetrical. PRF measurements over the FOV were used to quantify FPA pixel line-of-sight by relating the position of the point response to the angle of the calibrator pointing mirror. Optical distortion was quantified by removing the constant and linear terms from this mapping.



Contour plot of the PRF response

PRF response over the entire FOV

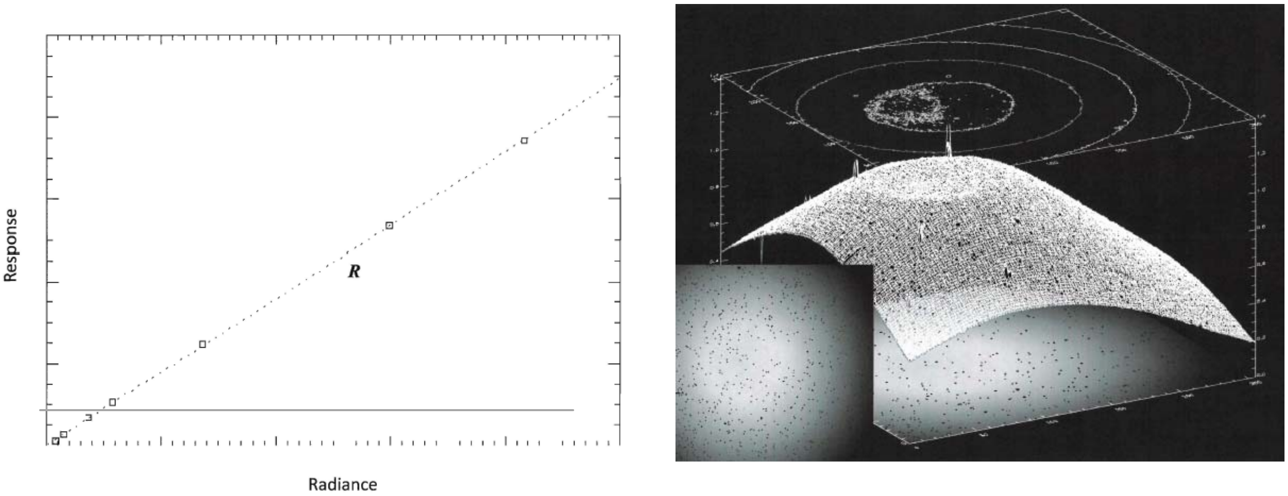
Fig. 5. Point response function (PRF).

### Low-Temperature Extended Source (HAES-15)

The HAES-15 extended source was used to provide a full-aperture, full-angle extended source for the 256 pathfinder sensor testing, with operating temperatures between 100 and 360 K. Fig. 6 shows the sensor interface with HAES-15. To facilitate schedule, a gate valve was mounted between the sensor and HAES-15 to allow for rapid mating and de-mating the sensor without having to warm the extended source.

Fig. 6. CV sensor interfaced with high accuracy extended source.

Data from this configuration were used to quantify radiance responsivity, response uniformity, nonuniformity stability, noise, noise equivalent radiance (NER), integration time normalization, medium-term response repeatability, and (in-part) response dynamic range. Fig. 7 shows example measured radiance responsivity and response uniformity graphs.



Radiance Responsivity, *R*    Response Uniformity

Fig. 7. Radiance responsivity and response uniformity.

### Benchmark

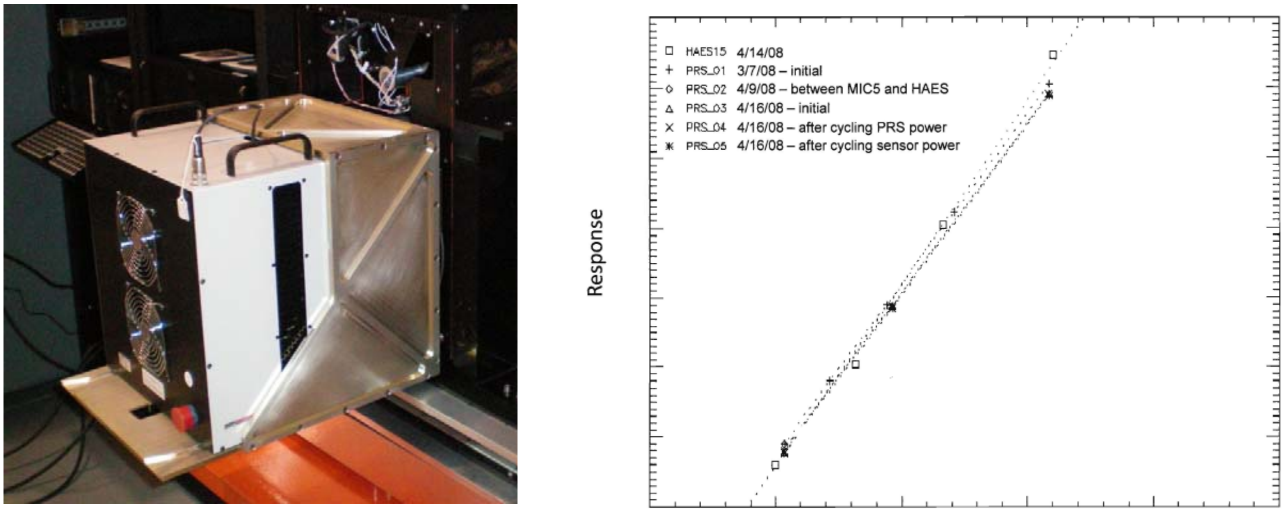
During this procedure, a daily MIC5 external blackbody measurement was made to determine the sensor's response to the large and small aperture source. This measurement provided long-term trending data for both the sensor and the calibrator. The results include long-term array, pixel, and background response trending. This procedure is also to quantify contamination on the calibrator.

### Portable Reference Source (PRS)

The portable reference source (PRS) provides a repeatable reference for trending the sensor response not only during calibration testing at SDL but during the operational lifetime of the sensor. This is required to verify and quantify calibration uncertainty during the operational lifetime of the sensor.

A commercial SBIR 2000 series differential blackbody with a delta temperature operation of 70°C was chosen as the PRS. A mounting bracket was designed and assembled to mount the blackbody head in front of the sensor aperture when configured to make these measurements. The mounting bracket enclosed the optical path to minimize air turbulences in the optical path. Fig. 8 shows the PRS mounted to the sensor when making portable reference measurements.

The PRS measurements provide long-term trending data to characterize the outlying pixel mask, nonuniformity correction, noise, and response versus blackbody temperature, and also establish a baseline response for future field testing. The five PRS measurements obtained during calibration activities to establish a baseline for future response trending when the sensor is operated out in the field are shown in Fig. 8. This graph shows the response of the sensor to each of the portable reference source measurements, along with the HAES-15 extended source for comparison. These data show good agreement between individual portable reference source measurements (obtained throughout the calibration period) and with independent HAES-15 extended source measurements.



Portable reference source

Sensor response to PRS measurements

Fig. 8. PRS mounted to sensor, and sensor response to PRS measurements.

## 4. SUMMARY

The 256 pathfinder sensor calibration was successfully completed at SDL on 14 April 2008, and a classified final report was generated and submitted. This effort provided preliminary data to verify the calibration set up, evaluate sensor performance, and identify areas of improvement to the calibration activities and to the CV sensors.

Initial challenges of the calibration effort were resolved during the initial engineering testing. These included implementation and operation of new calibration hardware and a project-specific data management system. During the testing, the sensor and supporting hardware operated as expected, and calibration test configurations, test procedures, and the data collection automation system were verified.

Preliminary data sets were obtained to perform analyses and evaluate sensor performance. From these measurements, modifications will be made to the sensors and calibration equipment to improve subsequent calibrations.

The 256 pathfinder sensor testing provided a test bed to develop methodologies for efficient calibration of future CV sensors. Mechanical and optical interfaces were developed that will mitigate risks, and processing algorithms and parameters were developed to derive results and set expectations for additional sensors. In addition, the effort demonstrated the ability of a team to efficiently work together to successfully complete the testing and calibration of a sensor. The results from the 256 pathfinder calibration will minimize risk and allow more efficient use of resources in future calibration efforts.

## ACKNOWLEDGEMENTS

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