

Development of HWIL Testing Capabilities for Satellite Target Emulation at AEDC*

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1. Introduction

Ground testing is a cost-effective means of risk mitigation for multimillion dollar satellite systems. Space chambers are routinely used to provide emulation of both the space environment and target radiometrics for space sensor systems.

Programs involved in space situational awareness (SSA) such as space-based space surveillance (SBSS) and space-based infrared systems (SBIRS) have the objective of keeping U.S. space assets, which are so critically important to defense and homeland security activities, performing their operational missions. These programs need a method to test satellite sensors in a hardware-in-the-loop (HWIL) environment. Current test capabilities provide sensor calibration but do not exercise the sensor-control logic-response loop within a satellite or interceptor. Long-term requirements include satellite interceptor, close approach maneuvering test, and target recognition software. Testing in a ground system avoids the significant cost of on-orbit test targets and resulting issues such as debris mitigation and other in-space testing implications.

The 7V and 10V cryo-vacuum chambers at the Arnold Engineering Development Center (AEDC) provide a significant ground-test capability for radiometric calibration, performance characterization, and complex mission simulation for space sensor systems. [1,2,3] They can provide the opportunity to exercise a sensor system over a wide range of operating parameters so that its flight capabilities can be more completely determined and evaluated. The 7V Chamber performs calibration and characterization of surveillance and seeker systems, as well as some mission simulation. The 10V Chamber has been upgraded to provide real-time target simulation during the detection, acquisition, discrimination, and terminal phases of a seeker mission.

The objective of the satellite emulation (SE) initiative at AEDC is to modify this existing capability to support the ability to discern and track other satellites and orbital debris. This would develop a new capability based on existing facilities to include satellite emulation to test satellite interceptor sensors and controls in an HWIL capability. It would provide a baseline for realistic testing of satellite surveillance sensors, which could be operated in a controlled environment. Many sensor functions could be tested, including scene recognition and maneuvering control software, using real interceptor hardware and software. Statistically significant and repeatable datasets produced by the satellite emulation system can be acquired during such tests and saved for further analysis. A particular mission scenario, for instance, can be run a number of times to examine the operational repeatability of the sensor platform in viewing target satellites. In addition, the robustness of the discrimination and tracking algorithms can be investigated by a parametric analysis using slightly different scenarios; this could be used to determine critical points where a sensor system might fail. This paper discusses the current test capability and a proposed enhancement to perform satellite emulation testing.

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2. 7V Sensor Characterization Chamber

2.1 7V Chamber Calibration and Characterization Capability

The 7V Chamber is a state-of-the-art cryogenic/vacuum facility that provides calibration and high-fidelity mission simulation against a low-infrared (IR) background. A comprehensive test methodology has been developed that includes characterization against a flood source or cold background, evaluation of the sensor response to point sources, spectral calibration of the seeker, and evaluation of the mission simulation performance. Performance data include such issues as target acquisition against complex backgrounds, resolution of closely spaced objects, discrimination of real targets from decoys, target centroiding, and end-game dynamics for aim-point/hit-point determination. An isometric view of the 7V Chamber and a photograph of the optical bench being moved into the 7V Chamber are shown in Figs. 1 and 2.

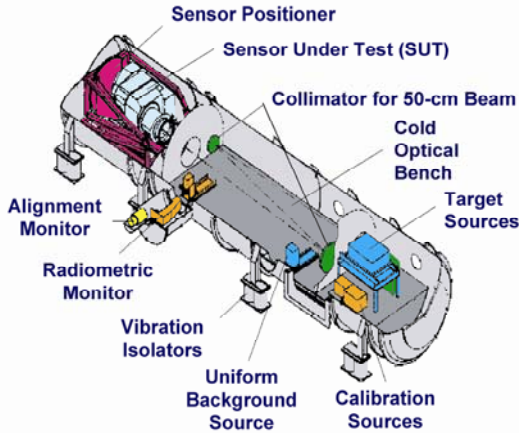


Figure 1. 7V optical bench, isometric view

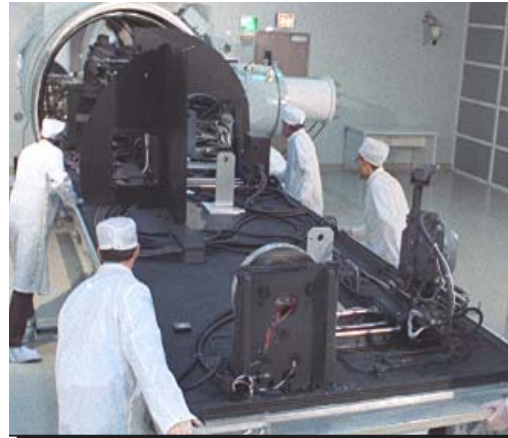


Figure 2. 7V optical bench being inserted into chamber

2.2 7V Chamber Facility Description

The 7V Chamber is 7ft in diameter and 21ft long and contains a cryogenically cooled liner (20 K) to simulate deep-space conditions and provide low radiometric background in conjunction with simulated pressure altitudes beyond 200 miles (less than 10^{-7} torr). It offers state-of-the-art radiometric calibration for both broadband and spectral output with point and extended sources. The chamber is housed within an ISO class 6 cleanroom and is vibration-isolated via an airbag suspension system. The rigid design of the optical bench, coupled with the pneumatic suspension system, provides an optical line-of-sight vibrational stability of 3 μ rad. The chamber control room can support classified data acquisition requirements.

The schematic of the 7V Chamber shown in Fig. 3 shows the relative orientation of the critical components and systems in the chamber. The sensor under test (SUT) can be mounted on a three-deg-of-freedom (3-DOF) positioner and housed in an antechamber. The sensor is interfaced to the cold test volume through an interleaved cold baffle; this allows the sensor to make pitch, roll, or yaw movements without compromising the low radiometric background. The sensor can also be mounted directly to the chamber or to the sensor isolation valve.

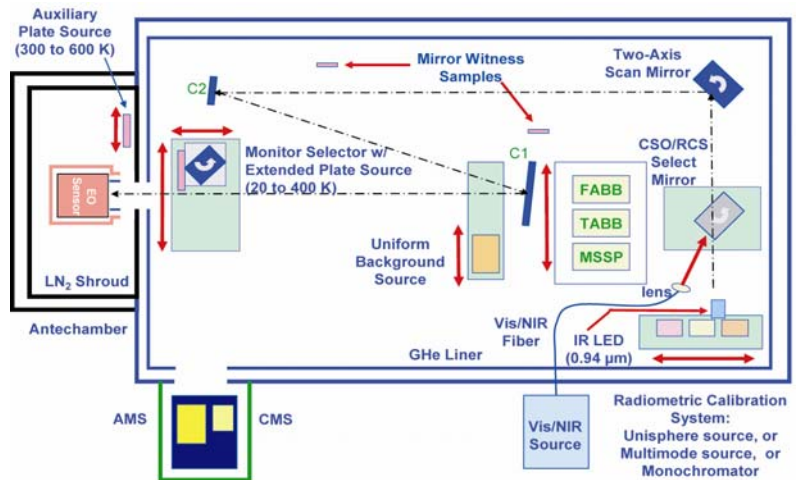


Figure 3. 7V block diagram

The sensor is interfaced to the cold test volume through an interleaved cold baffle; this allows the sensor to make pitch, roll, or yaw movements without compromising the low radiometric background. The sensor can also be mounted directly to the chamber or to the sensor isolation valve.

Source Systems

The long focal length of the 7V Chamber establishes the capability to provide excellent simulation of point-source images to the SUT. The variety of source systems available provides the capability to evaluate all critical aspects of a sensor mission for both surveillance-type sensors and seekers, high-fidelity static and dynamic target simulation with single or multiple targets. The use of resistive emitter projector arrays and blackbody sources provides a dual approach to performance evaluation. Collimated radiation from the target and calibration sources is provided by a diffraction-limited, two-element mirror system with a 50-cm-diam and 1.4-deg circular field of view (FOV). A high-speed scan mirror or a two-axis scan table can position the target statically or dynamically within the entire collimator FOV.

The 7V Chamber contains high-fidelity radiometric source systems that can be used to provide point source targets. The multimode and unisphere sources are shown in Fig. 4. The two-axis blackbody (TABB) and fixed-axis blackbodies (FABB), shown in Fig. 5, are also available for calibration. These can be used to obtain response linearity and dynamic range data and can also provide a measure of the sensor sensitivity in terms of responsivity, signal-to-noise ratio, crosstalk, or acquisition range. All of the sources contain aperture wheels to allow irradiance variation at a constant source temperature.

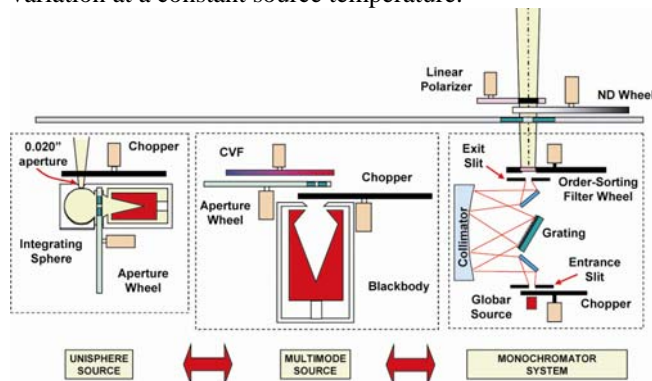


Figure 4. Calibration sources

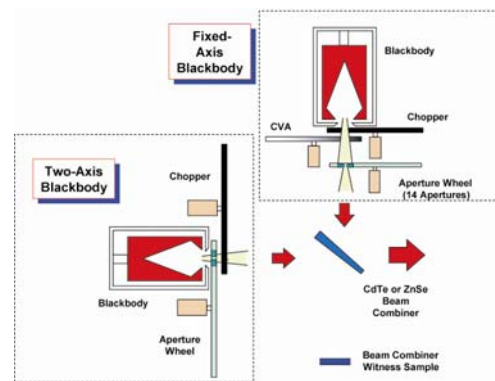


Figure 5. Sources for CSO testing

Several source systems in the 7V Chamber can be used to evaluate mission issues. The closely spaced object (CSO) targets (from the TABB and FABB sources) are used to determine in a static or dynamic fashion when the sensor can resolve targets that are in close proximity. Full mission simulation from full acquisition to intercept and careful evaluation of critical mission issues can be provided using those in conjunction with the cryogenic multispectral scene projector (MSSP) resistor array, supplied through the USAF/Kinetic Kill Vehicle Hardware-in-the-Loop Simulator (KHILS) with their PC-based Array-Control Electronics (PACE) control electronics as shown in Fig. 6. The MSSP is used to project expandable targets for terminal homing (end game) simulation over a portion of the SUT FOV, as illustrated in Fig. 7.

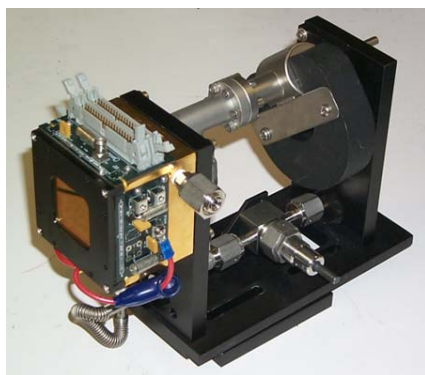


Figure 6. S101 MSSP emitter array for 7V

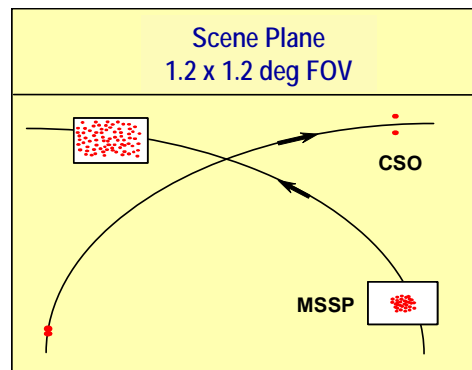


Figure 7. CSO and target cluster simulation

Calibration Systems

The Alignment Monitor System (AMS) is a resident reference infrared sensor for the 7V Chamber. It is a valuable tool that can be used for chamber target and background diagnostics and position calibration as well as for

diagnosing problems such as stray light, narcissus, and target output anomalies. It uses a cryogenic camera equipped with a 256 x 256 Indium Antimonide (InSb) focal plane array (FPA) that covers a 0.75-deg-square portion of the collimator FOV. The AMS, its image analysis electronics, and a subpixel centroiding algorithm provide absolute target position to an angular accuracy of 3.5 μ rad.

The Calibration Monitoring System (CMS) provides in-situ calibration of all 7V sources for both radiometric and spectral output traceable to the broadband standard of the National Institute of Standards and Technology (NIST). The CMS includes a conical-cavity blackbody and an aperture wheel for a large dynamic range. The CMS detector is an SiAs detector that responds over a wavelength band from 2 to 26 μ m. To measure output of the 7V radiometric sources, a selector mirror reflects part of the collimated radiation into a 10-cm imaging mirror that focuses the source onto the detector. Bandpass filters can be inserted using a filter wheel in front of the detector.

Spectral calibration is accomplished using a circular variable filter (CVF) to provide monochromatic energy at wavelengths ranging from 2 to 14 μ m. Higher resolution spectral measurements over a wider wavelength range can also be performed using a two-grating monochromator. Critical spectral parameters of the SUT, such as spectral response, throughput, cut-on and cutoff wavelengths, and out-of-band leakage, can be evaluated with these systems.

An extensive calibration measurement history has provided excellent statistics to document the radiometric accuracy of the sources to better than three percent and has shown outstanding repeatability over the past six years of operation.

2.3 7V Chamber Status and History

AEDC has recently completed several upgrades and enhancements to the 7V Chamber.[2] Optics and source systems were acquired to help develop an independent short-focal-length collimator (SFLC) system (Fig. 8), which is critically needed to expand the dynamic projection over the entire sensor FOV. An optics package was purchased from an obsolete Northrop Grumman chamber (Fig. 9); this package will be modified to meet the 7V needs. The design effort is under way to integrate this with a suite of sources (Fig. 10) that may include a dual-band resistor array system, a blackbody source for uniformity measurements, and an external monochromator source such as a Fourier transform spectrometer (FTS). An upgraded AMS is being pursued that would extend its range into the long-wavelength infrared (LWIR) region and include a larger format array to provide additional FOV coverage. One of the other upgrade options that is being considered is a scene generation system that could implement closed-loop testing.

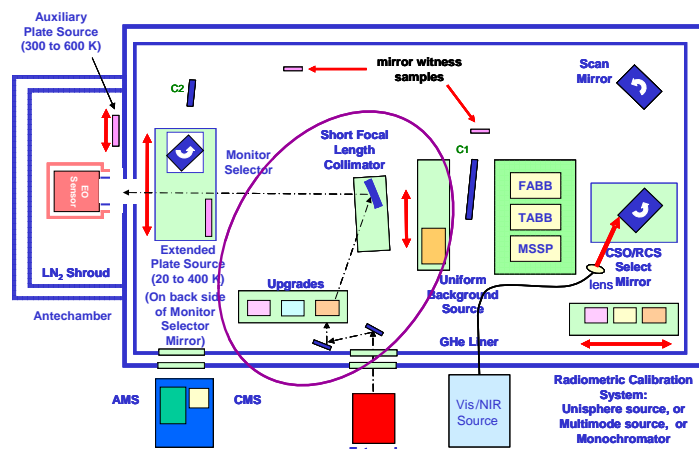


Figure 8. Upgrades to 7V Chamber

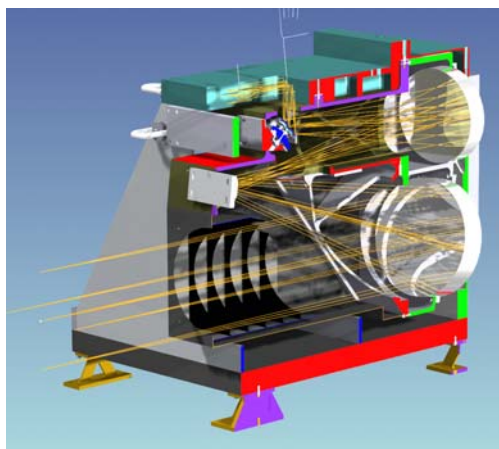


Figure 9. Original optics package

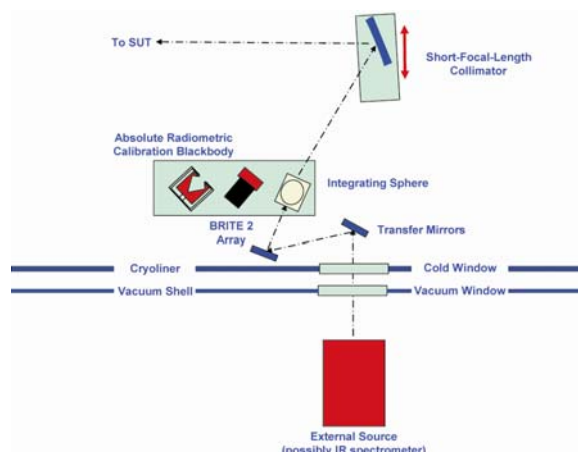


Figure 10. Source systems for full FOV coverage

The 7V Chamber has supported the functional checkout and calibration of approximately 48 interceptor, airborne, and space-based sensors. In addition to the sensor tests, checkout efforts are performed on a periodic basis to maintain operational performance, establish calibration stability, and evaluate major system modifications or system additions. All sensor tests performed in the 7V Chamber since 1993 are listed in Table 1.

As objectives in the flight-test program become more complex, chamber testing and evaluation becomes increasingly important. Unique configurations are sometimes invoked to meet simulated inflight sensor test conditions. The integration and reinstallation of 7V Chamber components after recent system upgrades was completed in April 2006, and a facility checkout test is scheduled to occur in July 2006 to verify operability of all 7V Chamber systems and restore the baseline sensor test capability. Calibration of the upgraded 7V Chamber with the NIST BXR will be pursued as a verification test.

3. 10V Closed-Loop Sensor Test Chamber

3.1 10V Chamber Mission Simulation Capability

The 10V Chamber, originally developed as a sensor test bed under the Strategic Defense Initiative Program, has been upgraded to provide a closed-loop ground-test capability that can assess multiband electro-optical sensor performance under realistic operational scenarios against evolving threats. The 10V Chamber leverages existing facilities and expertise from several government agencies including AEDC, Army/Aviation & Missile Research Development Engineering Center (AMRDEC), and USAF/ KHILS to investigate SUT performance issues during ground testing at cryogenic conditions.

3.2 10V Chamber Facility Description

The 10V Chamber is a horizontal cylinder, 10 ft in diameter and 30 ft long, containing a cryogenically cooled (20-K) liner that maintains the low radiometric background of space and acts as a cryopump for contaminants. To control particulate contamination of the test article or chamber equipment, the facility uses a clean room similar to that of the 7V.

Each optical bench is supported on columns, or piers, which penetrate the vacuum shell through vibration isolation diaphragms to a large seismic mass below the chamber. This seismic mass acts as a common optical table tying all optical systems, including the test article, rigidly together. It is supported on pneumatic isolation mounts to dampen high-frequency ground motions and vibration from mechanical systems in the chamber. The entire vibration isolation system provides a measured line-of-sight stability of less than one μ rad under static operating conditions.

The 10V sensor test facility (Fig. 11) simulates the mission range from target acquisition to target intercept, but it will have inherent flexibility and low radiometric background so that it can be used to support testing of surveillance systems as well. The 10V includes a high-fidelity target system

Table 1. 7V Chamber sensor testing history

Pumpdown #	Date	Purpose	Type
8	Mar-94	Upgraded 7V Chamber IOC	Checkout
9	May-95	Interceptor Support Test	Checkout
10	Jul-95	Interceptor 1 Brassboard Sensor Test	Sensor
14	Oct-96	Interceptor 1 Flight Sensor Test	Sensor
17	Dec-97	Interceptor 2 Flight Sensor Test	Sensor
18	Jan-98	Interceptor 2 Flight Sensor Test	Sensor
20	Aug-98	Interceptor 1 Flight Sensor Test	Sensor
21	Sep-98	Interceptor 2 Flight Sensor Test	Sensor
23	Mar-99	Interceptor 1 Flight Sensor Test	Sensor
26	Jun-00	NIST Radiometer Characterization	NIST BXR
27	Jul-00	Wide-Area Blackbody Calibration	Calibration
29	May-01	NIST Radiometer Test	NIST BXR
30	June-01	Wide-Area Blackbody Calibration	Calibration
31	July-01	Airborne 1 Sensor Characterization	Sensor
34	Jan-03	Interceptor 3 Sensor Calibration	Sensor
36	Aug-03	NIST Radiometer Test	Checkout
37	Oct-03	Airborne 2 Sensor Calibration	Sensor
38	Dec-03	Interceptor 3 Sensor Calibration	Sensor
40	Nov-04	Surveillance Sensor Characterization	Sensor
41	Dec-04	Surveillance Sensor Characterization	Sensor
42	Jan-05	Surveillance Sensor Calibration	Sensor
43	Feb-05	10V RSMS Calibration	Checkout

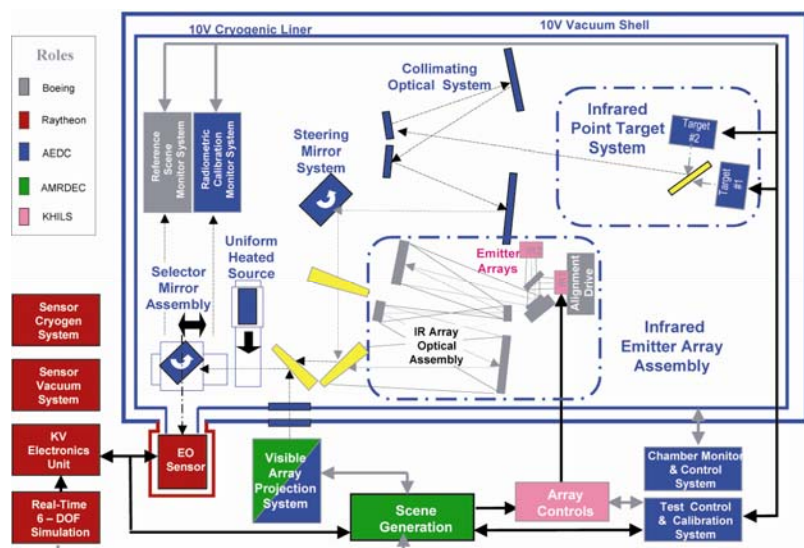


Figure 11. 10V block diagram

containing multiple independent point-source targets for acquisition and tracking phase simulation and a complex scene projector for terminal homing phase and IR background simulation. The test methodology is similar to that of the 7V, except that a scene generator system is used to control targets and seeker operation in a real-time, closed-loop manner. In addition to the simulation of mission scenarios, the test capability simulates the motions (such as dither, divert, or step-stare) of the sensor in responding to the scene being presented to it. All mounting and positioning systems, as well as the scene projection systems, are designed to operate in the cryo-vacuum environment without significant unwanted radiation.

An isometric view of the 10V chamber, shown in Fig. 12, indicates the location of the radiometric monitor, scene monitor, collimator, point-source target projectors, dual-band infrared projector, visible projector, and SUT in relationship to the 10V Chamber vacuum shell, cryogenic liner, and seismic mass.

Optical System

The 10V optical system consists of three subsystems to collimate radiation from the point-targets, infrared, and visible array projectors. The collimator for the point-target sources is an all-aluminum optical system that provides a 25-cm working beam diameter with a 1.4-deg circular FOV. The very long focal length of this collimator provides extremely high target position resolution of less than one μ rad.

The two point-source targets will be optically overlaid using a large germanium infrared beam combiner. A similar beam combiner will combine the point-source projection with the resistor array projection. The visible projection system will be folded into the 10V optical path using a cold dichroic beam combiner in the collimated beam between the SUT and the other 10V components.

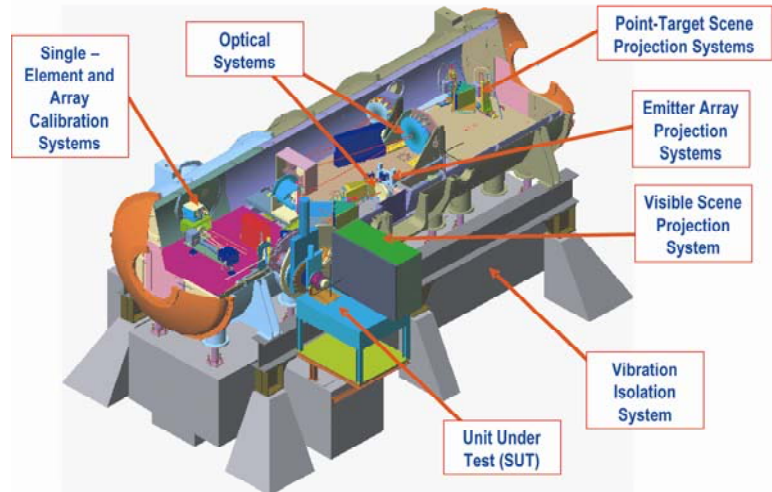


Figure 12. 10V isometric view

Source Systems

The blackbody target concept is shown in Fig. 13. The cavity-type sources include an aperture wheel to allow the target size and irradiance to be varied. Dynamic intensity changes of three orders of magnitude in target radiance will be accomplished by use of a CVA wheel. The wheel provides simulation of target increase caused by range closure and dynamics such as coning. A CVF will provide an adjustable spectral cut-on to simulate the desired target temperature by delivering the appropriate photon flux for each of the two infrared target bands. A two-stage cryogenic linear translator system will be used to simulate target motion within a 1-deg-square FOV of the SUT.

The infrared complex scene projection system will provide in-band background imagery and additional point-source threat objects to the SUT. A schematic of the dual-band concept using MSSP arrays in cryo-vacuum packages to simulate the flux band ratio of the target is shown in Fig. 14. KHILS has done considerable work in characterizing this dual-band approach. [4] The emitter array drive electronics accept digital image radiance commands from the scene generation system, perform real-time nonuniformity correction (NUC), and output analog voltage commands to each array element.

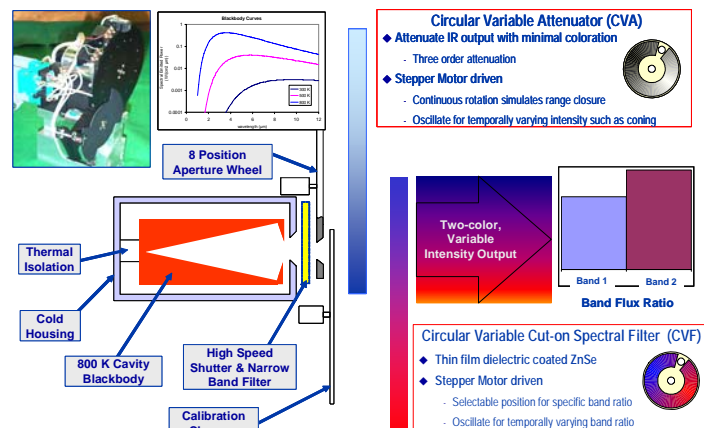


Figure 13. Blackbody point-source circular variable filter

The visible projection system is based on a digital micromirror device (DMD) spatial light modulator and has been developed by Optical Sciences Corporation (OSC) for AMRDEC in Huntsville, AL. [5] The visible collimator is a custom-designed optical assembly capable of transferring the DMD projection to the SUT. The entire assembly is mounted on a three-axis alignment system (pitch/yaw/roll) to co-register the visible pixels to the dual-band infrared arrays. It is not rated for cryogenic operation but will be thermally controlled near ambient temperature and housed outside the vacuum chamber. Gray scale intensities (12 bit) will be generated using synchronized pulse width modulation (PWM) in combination with a variable intensity illumination source.

Alignment and Calibration Systems

All target systems can be radiometrically calibrated in-situ in the 10V Chamber during the test entry to verify that the target and background infrared outputs match realistic operational mission conditions.

The Radiometric Calibration Monitoring System (RCMS), based on the 7V CMS, samples the output from the blackbody sources and infrared scene projectors to ensure radiometric accuracy and uniformity. A selector mirror allows the radiation from the 10V Chamber collimated beam to be intercepted and directed into the RCMS. The RCMS uses a Gallium-doped Silicon (SiGa) detector that will respond over a band from 2 to 18 μm . The detector is calibrated in-situ by a secondary standard blackbody (with aperture wheel) calibrated at NIST. Spectral calibration of each source is accomplished using a two-segment CVF that will provide narrow-band energy over 5 to 14 μm . There is also a 14-position filter wheel populated by appropriate bandpass filters.

The Reference Scene Monitor System (RSMS) performs the calibration and alignment of target position to verify that the projected target positions and tracks meet mission simulation requirements. This device was based on the 7V AMS but was enhanced to include a visible medium-wavelength infrared (MWIR) alignment and expanded FOV coverage capability. The RSMS covers a circular FOV of 1.5 deg and provides absolute target position to an angular accuracy of 2.5 μrad . A visible (InSb) and an IR (SiAs) focal plane are used to examine alignment between projection systems and view the projection of the test scenario. A filter wheel in front of the IR focal plane array is used to limit the radiation to the in-band components of the unit under test and reduce the intensity for the NUC of the MSSP arrays. A wide bandpass position facilitates the detection of stray radiation in the chamber at long wavelengths.

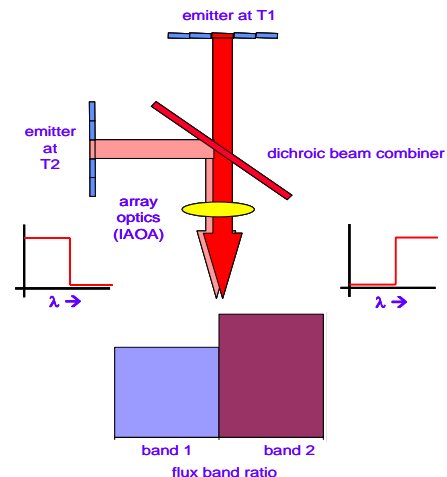


Figure 14. Dual emitter array projector

IR Target/Background Scene Projection System

The implementation of various types of projected targets for an interceptor test is demonstrated in Fig. 15. In acquisition/discrimination mode the two blackbody point sources are the primary method for simulating the significant target objects (i.e., reentry vehicles, decoys, etc.) until the mission enters terminal phase; they can be positioned anywhere in the sensor FOV using two-axis translators. A steering mirror changes the line of sight of the sensor system to simulate seeker motion as it views this projection, and the target irradiance is increased as the range closes between the target complex and the sensor system.

Once the simulation demands extended targets, the blackbody shutters are closed and a dual resistive emitter

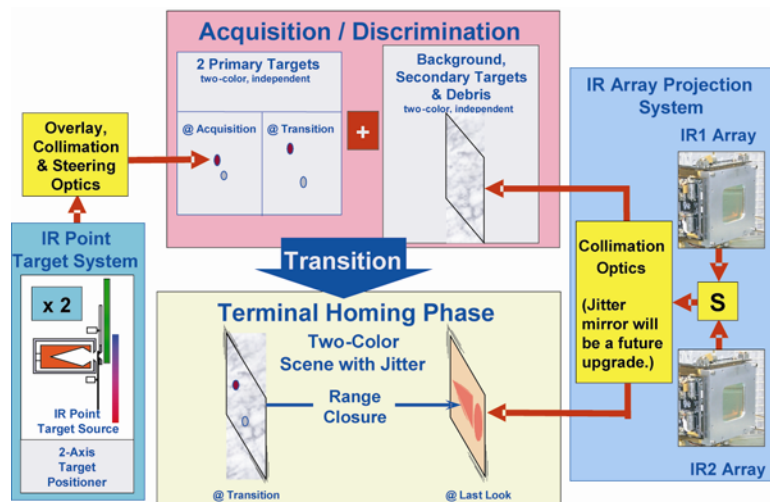


Figure 15. Target/background scene projector schematic

array system presents the dual-band projection of complex background scenes as well as other lower fidelity targets, carrying the projection of extended targets until the mission has ended. The content of the array scenes will be controlled to simulate line-of-sight variations. Radiation from the arrays is spatially combined using a dichroic beam combiner. A visible projector is used to simulate acquisition/discrimination phase sun-lit targets, visible backgrounds, and a star field. The SUT is mounted in a vacuum enclosure that is physically attached to the 10V Chamber but vibrationally isolated from it. There it receives the combined visible and IR projections. Another view of the basic operational methodology is shown in Fig. 16.

The scene generation system is one of the most critical systems in this facility, as it must interpret the mission scenario map and furnish the proper projected radiated scene for each frame to the sensor system. This has been developed by AMRDEC and involves radiometric models of the physical phenomena needed to describe the scene (emissivity, target and object temperatures, trajectories, spin and coning rates, etc), as well as the computer hardware and software needed to control the 10V target simulation system. A schematic of this system is shown in Fig. 17.

Facility monitoring and control for the 10V chamber, point-source targets, and calibration equipment are provided by the Target Control and Calibration System (TCCS). The TCCS serves as the interface between the scene generation system and blackbody point-source targets; it will execute all goniometric and radiometric calibration functions for the visible projector, infrared blackbodies, and infrared projectors.

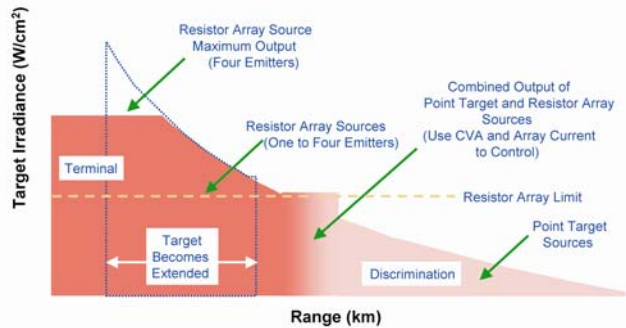


Figure 16. Management of scene projection

3.3 10V Chamber Status and Test History

All of the required systems for 10V Chamber upgrade have been developed, and installation and integration are complete (checkout testing is in progress). The initial 10V Chamber checkout test of the upgraded chamber occurred in November 2005, and the second 10V Chamber checkout test was completed in April 2006. The third test included HWIL testing of the SUT and was completed in June 2006. The 10V Chamber facility initial operating capability (IOC) is scheduled for the last quarter of FY2006. Funding for follow-on testing is expected.

4. Satellite Emulation Capability

There is at present a great concern for the monitoring of all orbital objects, including satellites and debris, as seen in programs such as those being developed for SSA. Development of space-based assets for space awareness and surveillance does not currently include a ground-test methodology for simulating satellites and other orbital objects in realistic mission scenarios. Current test capabilities emulate re-entry targets. Changing mission requirements have placed an emphasis on space-based assets. This capability produces the necessary signals for an SUT to discern its ability to perform detection, acquisition, discrimination, and terminal phases of a sensor platform's mission on other orbital objects. Existing systems do not address this capability. The addition of a pertinent scene generation and projection capability to the existing space environment test infrastructure presents a cost-effective method of answering this need.

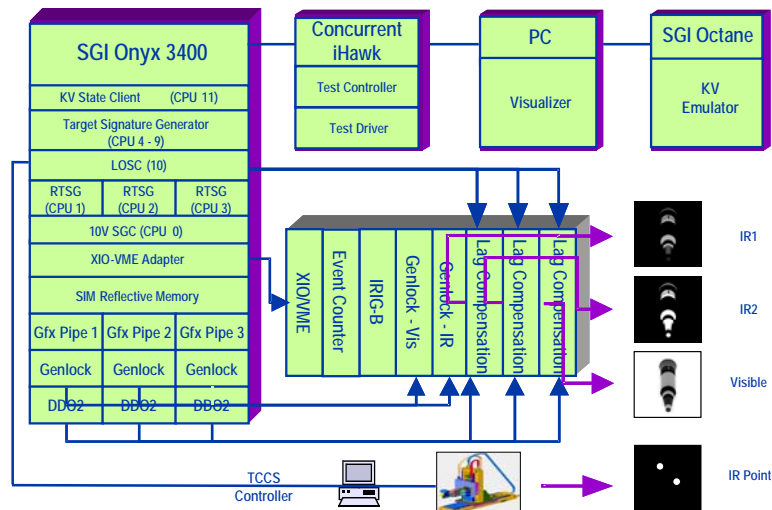


Figure 17. Scene generation system

The proposed capability will address the test requirements for developing these systems by providing emulation of the satellite and other objects in the context of the space environment. The ability to discern the identity, location, and direction of these objects by using a sensor platform is dependent on the fidelity of those sensors and their ability to operate in the extremes of the space environment. It is also dependent on the knowledge of the radiometric signature of the satellites to be monitored. The proposed test and evaluation capability in conjunction with the existing infrastructure will provide the ability to reduce the technical risk associated with the tracking and identification of orbiting objects from space sensor platforms. A schematic of the 7V Chamber as configured for satellite emulation activities is given in Fig. 18.

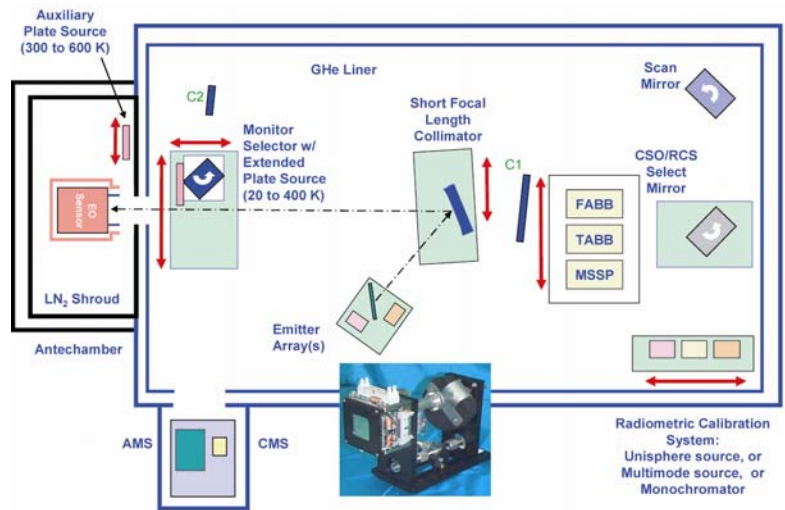


Figure 18. 7V block diagram

The radiometric characteristics of satellites are expected to be somewhat

similar to the targets and decoys that make up a typical interceptor mission scenario, since they are near ambient temperature. However, their spectral reflectivity and emissivity must also be considered, as well as other characteristics (Figs. 19 and 20). Therefore, the projection systems employed in the 7V and 10V Chambers should be capable of providing the simulation of satellites as well. This simulation may currently be adequate for the geostationary or geosynchronous (GEO) platforms, but other systems may require greater radiometric intensity or shorter time response. These requirements must be examined in detail to assess the capability of the AEDC space test chambers to properly address SSA tasks. The radiometric properties of target satellites (spectral emissivity, temperature, etc.) and the spectral bands of the detection platforms must be known, and this will require extensive analysis of the pertinent classified databases. Measurements of satellite material properties that have been altered by the combined orbital effects of the space environment are needed as inputs to the satellite model.

AF Space Command is the user most likely to benefit from this capability, judging by inputs received during early program coordination. The AEDC technology department will provide some of the funding for requirements definition. There is potential for multiservice use with both Army and Navy systems. During the requirements definition phase, as many potential users as can be identified will be contacted for review of the requirements that have been established and to discern whether unique additional requirements exist.

The government team (AEDC, AMRDEC, and KHILS) that has been so successful in the recent development of the 10V HWIL upgrade is vital to the development of a satellite emulation test facility (Fig. 21). A working relationship has also been developed with the Satellite Assessment Center (SatAC), a part of AFRL/DE. This group works a software tool entitled Intelligence Data Analysis Systems for Spacecraft (IDASS). This group works with the National Air and Space Intelligence Center (NASIC) and performs satellite image analysis and functional modeling of satellites, and they continue to develop the IDASS tool. AFRL/DE provides

- Orbit, Attitude, Engagement
 - Altitudes, attitudes, type orbits
 - Relative engagement ranges and velocities
 - Tenuous exoatmospheric engagements
 - Terminator crossings
- Optical Properties (Vis/IR)
 - BRDF/BSDF (surface scatter)
 - Spectral reflectance
 - Spectral emissivity
 - Polarization (induced by refl./scat.)
- Thermal Properties
 - Temperatures (body, solar panels, thermal radiators)
 - Spatial “hot” spots on radiators, power, etc.
- Physical Properties
 - Materials, coatings, paints
 - Max linear extend (point vs. extended targets)
 - Projected area/surface area
- Radiometric (self emission + solar, lunar, earth reflection/scatter)
 - Spectral radiant intensity (point-source approximation, anisotropic)
 - Sensor spectral irradiance
 - Spectral radiant exitance (extended source domain, integration over emitter IFOV)
 - Polarization effects from reflection and scatter processes (solar flux, etc.)

Figure 19. Satellite phenomena

several needed components for the development of the Satellite Emulation Capability (SEC), including contacts to SSA programs, a working satellite model (relied on by NASIC), and a satellite information database.

5. Conclusion

The 7V and 10V space simulation test chambers at AEDC are part of a world-class cryo-vacuum sensor characterization facility where radiometric calibration and mission simulation tests can be performed to provide critical preflight evaluation. These facilities use a variety of projection techniques to simulate point-target and complex backgrounds in a low-background environment. While the 7V has a significant sensor test history covering the last several years, the 10V is being developed to provide a closed-loop test capability by FY06. Calibration of the high-fidelity radiometric sources used in these chambers is traceable to the National Institute of Standards and Technology and provides relative uncertainties on the order of two to three percent, based on measurement data acquired during many test periods.

The objective of the SE project is to upgrade this existing capability to support the ability to discern and track other satellites and orbital debris. This would develop a new capability based on existing facilities to include satellite emulation to test satellite interceptor sensors and controls in an HWIL capability.

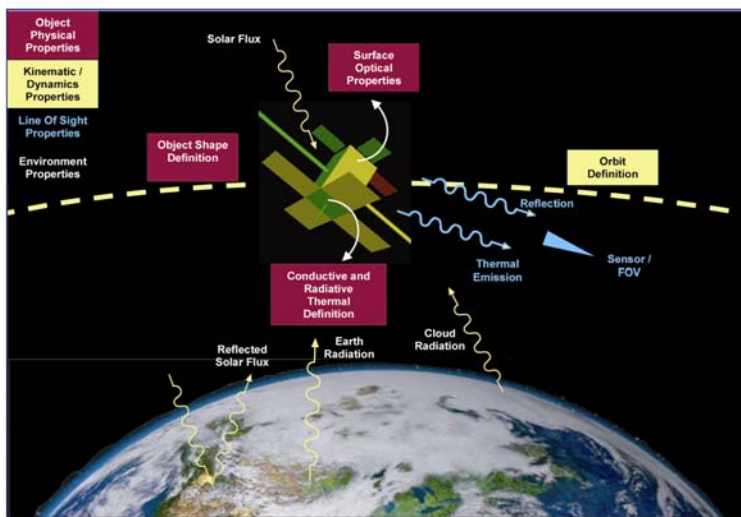


Figure 20. Schematic of satellite characteristics

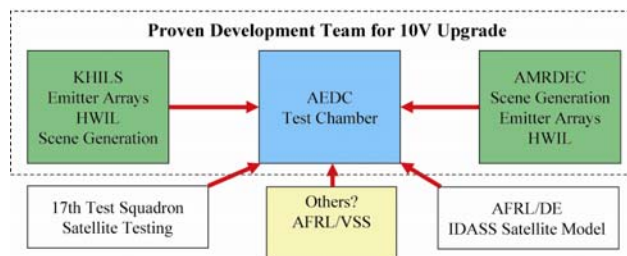


Figure 21. Satellite Emulation Team

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7. References

1. Lowry, H. S., Nicholson, R. A., Simpson, W. R., Mead, K. D., and Crider, D. H., "Ground Testing of Space-Based Imaging Sensors in AEDC's Space Chambers," AIAA-2004-2194.
2. Lowry, H. S., Nicholson, R. A., Simpson, W. R., Mead, K. D., Crider, D. H., and Breeden, M. F., "Test and Evaluation of Sensor Platforms in the AEDC Space Sensor Test Chambers," AIAA-2005-7634.
3. Lowry, H. S., Crider, D. H., Breeden, M. F., Goethert, W. H., Bertrand, W. T., and Steely, S. L., "Application of Scene Projection Technologies in the AEDC Cryo-Vacuum Space Simulation Chambers," *Technologies for Synthetic Environments: Hardware-in-the-Loop Testing IX*, edited by Robert Lee Murrer, Jr., to be presented in SPIE Proceedings Vol. 6208 (2006).
4. Flynn, D. S., Sisko, R. B., Sieglinger, B. A., and Thompson, R. A., "Radiometrically Calibrating Spectrally Coupled Two-Color Projectors," *SPIE Proceedings*, Vol. 5092, pp. 155-164 (2003).
5. Beasley, D. B., et. al., "Advancements in the Micromirror Array Projector Technology," *SPIE Proceedings*, Vol. 5092, pp. 71-82 (2003).