36-01510.066

ACIS Verification Summary Report

Specification:	ACIS Contract End Item Specification
Requirement Number/Title:	3.2.2.6 Stray Light (VRSD 3.2.2.6)

Requirement Statement: Since the instrument does not contain any light sources, this paragraph is not applicable.

Verification Method:	Analysis

Procedure Number: Refer to Verification Report ACIS-110-A-25VR

Configuration:

Cycle Time:

Verification Discussion/Results:

Although the requirement is stated as being not applicable since the instrument does not contain any light sources, an analysis has been performed to ensure the Detector Housing and Venting Subsystem provide expected levels of light attenuation from sources external to the Detector Housing.

The analysis has shown a light attenuation of a factor of at least 10^6 for sources external to the Detector Housing. This level of attenuation is achieved as a result of proper materials selection and use of light seals in the Detector Housing and Venting subsystem. Those factors, combined with a tortuous path that a photon must follow to reach the Focal Plane active area provide expected levels of light attenuation.

Reference ACIS-110-A-25VR for more details regarding ACIS light attenuation.

ACIS Cognizant Engineer — Date: 6/22/97

ACIS-36-01510.066

AXAF-I CCD Imaging Spectrometer (ACIS)

Verification Assessment Report -Power and Thermal-Control Structure- -Detector Housing Straylight Analysis Report-

Document No. ACIS-110-A-25VR

DPD 727 DR SVR04

Contract # NAS8-37716

June 4, 1997

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CHANGE/REVISION RECORD

Number	Date	Description	Page	
			Rev.	Added
New	June 4, 1997	Initial Release	All	

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APPENDICES

1. INTRODUCTION

1.1 Scope

This document provides a collection of information which results from the implementation of the ACIS Verification Plan, 36-01203. It is intended to show that the delivered instrument meets a specific set of requirements from the ACIS Power and Thermal-Control Structure (PTS) Specification, ACIS-36-02101.

In particular, this report provides the analytical data to support the verification of specific PTS Specification requirements. These requirements were assessed to be best verified by a analysis. The method selected in the verification of each specific requirement is the method which provides the assurance to the program that the requirements have been verified.

The Verification Cross Reference Matrix contained in the ACIS PTS Specification shows how each contractual requirement will be verified. The requirements documented herein have been designated to be verified by analysis and/or a combination of other verification methods.

1.2 Applicable Documents

ACIS Project Documents

36-02101	ACIS Power and Thermal-Control Structure (PTS) Specification
36-01203	ACIS Verification and Calibration Plan

2. METHODOLOGY

2.1 Requirements & Specifications

Verification methods to be used are defined in the verification matrix, compiled as an appendix to the ACIS Power and Thermal-Control Structure Specification, 36-02101.

2.2 Verification Descriptions

Summary level descriptions of each verification activity are located in the ACIS Verification Plan, 36-01203 and the ACIS Power and Thermal-Control Structure Specification, 36-02101. The specific definitions for this report are as follows:

2.2.1 Analysis Definition

Analysis is a method of verification, taking the form of the processing and accumulated results and conclusions, intended to provide proof that verification of a requirement(s) has been accomplished. The analytical results may be based on engineering study, compilation or interpretation of existing information, similarity to previously verified requirements, or derived from lower level examinations, tests, demonstrations, or analyses. Verification by analysis is a process used in lieu of or in addition to testing to verify compliance with specification requirements. The selected techniques may include systems engineering analysis, statistics and qualitative analysis, computer and hardware simulations, and analog modeling. Analytical techniques may be used in lieu of tests for such things as life, storage, failure analysis, safety, interchangability, and some other performance requirements which cannot be verified by test.

3. ANALYSIS

3.1 Applicable Requirements

Requirement Reference — Requirement

1. 3.2.1.5.2c Stray Light
   For light incident on the Focal Plane active area, the Detector Housing and Venting Subsystem shall provide light attenuation of at least a factor of 10^6, from sources external to the DH, excluding the instrument aperture and the MIT provided detector interface connector panel as defined in section 3.1.3 of the Focal Plane-to-Detector Housing ICD, ACIS-36-02203.

2. 3.2.1.5.2d Stray Light
   To prevent light incident on the Detector Housing collimator entry aperture from reaching the focal plane, the Detector Housing shall accommodate a light seal at the Optical Blocking Filters mounting interface in accordance with the ACIS Focal Plane-to-Detector Housing Interface Control Document, ACIS-36-02203.

3. 3.2.1.5.2h Stray Light
   The venting subsystem and light shade shall provide an attenuation of 1×10^{14} for sunlight incident on the vent aperture at an angle of 45° to the vent axis at the +Y panel of the SIM volume.

4. 3.2.1.5.2i Stray Light
   The venting subsystem shall provide an attenuation of 1×10^9 for sunlight reflected from the Earth or moon the for all viewing angles.

5. 3.2.1.5.2j Stray Light
   The electrical feedthroughs in the detector housing shall provide a minimum attenuation of 1000 for incident radiation in the wavelength range of 300 to 1100 nanometers.

3.2 Analytical Discussion

The Power and Thermal-Control Structure straylight analyses are provided for review and comment per contractual data requirement SE03. The straylight analysis is attached in appendix A.

Requirement Reference	Requirement
1. 3.2.1.5.2c	Stray Light

For light incident on the Focal Plane active area, the Detector Housing and Venting Subsystem shall provide light attenuation of at least a factor of 10^6, from sources external to the DH, excluding the instrument aperture and the MIT provided detector interface connector panel as defined in section 3.1.3 of the Focal Plane-to-Detector Housing ICD, ACIS-36-02203.

DISCUSSION

The detector housing is solid aluminum 0.6 inches thick, the venting subsystem is stainless steel with viton seals. This provides more than the required attenuation except for the thermal standoffs. The cylindrical portion of the thermal standoffs are 0.03" thick and are gold coated. Testing with an incandescent lamp shows that a similar sample of gold coated Torlon has an attenuation of 10^4. The cold stub standoffs are inside the collimator and thus protected from stray light. The cold finger standoffs are predominately covered by the thermal straps, torlon snubbers, and the entire detector is covered by the support structure and thermal blankets. The path a photon must take to enter the standoff and can reach the thin section is tortuous indeed. As this tortuous path only has to supply an additional attenuation of 10^2 the requirements are easily met. This discussion verifies compliance with paragraph 3.2.1.5.2c of the PTS Specification, no further action is required.

2. 3.2.1.5.2d Stray Light

To prevent light incident on the Detector Housing collimator entry aperture from reaching the focal plane, the Detector Housing shall accommodate a light seal at the Optical Blocking Filters mounting interface in accordance with the ACIS Focal Plane-to-Detector Housing Interface Control Document, ACIS-36-02203.

DISCUSSION

The Power and Thermal-Control Structure Detector Housing has been designed to incorporate a light seal at the Optical Blocking Filters mounting interface as agreed in the ACIS Focal Plane-to-Detector Housing Interface Control Document. The design and fabrication of this seal have been provided by CSR. This discussion verifies compliance with paragraph 3.2.1.5.2d of the PTS Specification, no further action is required.

3. 3.2.1.5.2h Stray Light

The venting subsystem and light shade shall provide an attenuation of 1×10^{14} for sunlight incident on the vent aperture at an angle of 45° to the vent axis at the +Y panel of the SIM volume.

DISCUSSION

The Power and Thermal-Control Structure venting subsystem and light shade has been designed to provide an attenuation of 1×10^{18} for sunlight incident on the vent aperture at an angle of 45° to the vent axis at the +Y panel of the SIM volume. This information has been provided previously as ACIS ASSA-01 (Appendix A of this document). Positive margins of $1x\ 10^4$ are shown in this analysis. This discussion verifies compliance with paragraph 3.2.1.5.2h of the PTS Specification, no further action is required.

4. 3.2.1.5.2i Stray Light
The venting subsystem shall provide an attenuation of 1×10^9 for sunlight reflected from the Earth or moon the for all viewing angles.

DISCUSSION
The Power and Thermal-Control Structure venting subsystem has been designed to provide an attenuation of $1x\ 10^8$ for light emanating from all sources that provide direct illumination of the vent aperture. In addition, the entrance aperture of the venting subsystem into the detector housing volume does not provide a direct path to the CCDs. Conservative estimates show an approximate $1x\ 10^{11}$ attenuation for light from these sources yielding a margin of about $1x\ 10^2$ for this requirement. This information has been provided previously in ACIS ASSA-01 (Appendix A of this document). This discussion verifies compliance with paragraph 3.2.1.5.2i of the PTS Specification, no further action is required.

5. 3.2.1.5.2j Stray Light
The electrical feedthroughs in the detector housing shall provide a minimum attenuation of 1000 for incident radiation in the wavelength range of 300 to 1100 nanometers.

DISCUSSION
Aside from the CSR provided back plate and the pressure transducers there are no electrical feedthroughs into the Detector Housing. The pressure transducer leads do not extend into the Detector volume and therefore provide no direct path for light entrance. This discussion verifies compliance with paragraph 3.2.1.5.2j of the PTS Specification, no further action is required.

Appendix A

PTS Detector Housing Straylight Analysis (ACIS ASSA-01)

ACIS ASSA-01

Contract # SC-A-124624

AXAF CCD Imaging Spectrometer
(ACIS)

ACIS Stray Light Analysis
for
Detector Housing Venting Subsystem

June 4, 1997

Prepared For:
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This report details the results of the stray light analysis for the venting subsystem. The specified light flux at the focal plane must be below 10,000 photons/cm^2-sec at wavelengths shorter than 1.1 μm. This analysis shows that for all conditions the stray light rejection of the venting subsystem meets this requirement for reflected sunlight from the Earth and moon. The analysis also shows that the stray light rejection from all expected solar angles is well below the critical number.

The venting subsystem is composed of four basic components. Figure 1 shows a sketch of the assembled venting subsystem. The inner-most segment, referred to as the 'snorkel', is a roughly S shaped welded 300 series stainless tube with a 5/8" ID. The second component is the high conductance vent valve. Third is a short stainless tube with bellows leading to the exterior of the I-SIM at the +Y panel. Fourth is the light shade.

The first three components of the venting subsystem have been designed to allow gasses to be safely vented overboard immediately after launch and during orbit. The fourth component, the light shade, has been included for the express purpose of eliminating the light from the sun and limiting the optical field of view of the venting subsystem. The light shade is a two stage design incorporating a Martin Black coating yielding a stray light rejection ratio of 10^9 for radiation 45 degrees off the central axis.

Figure 2 shows a sketch of the light shade. For this analysis the important dimension is the angular field of view through the light shade. Any object will be fully viewed by the venting subsystem if it within the 12 degree field of view. As the angle with respect to the optical axis increases, the attenuation of the light shade increases dramatically. For this analysis, the assumption is that an object's brightness is constant anywhere in the field of view of the light shade. As an object passes out of the field of view the irradiance at the venting subsystem drops off quickly, although no computations have been made to ascertain how quickly.

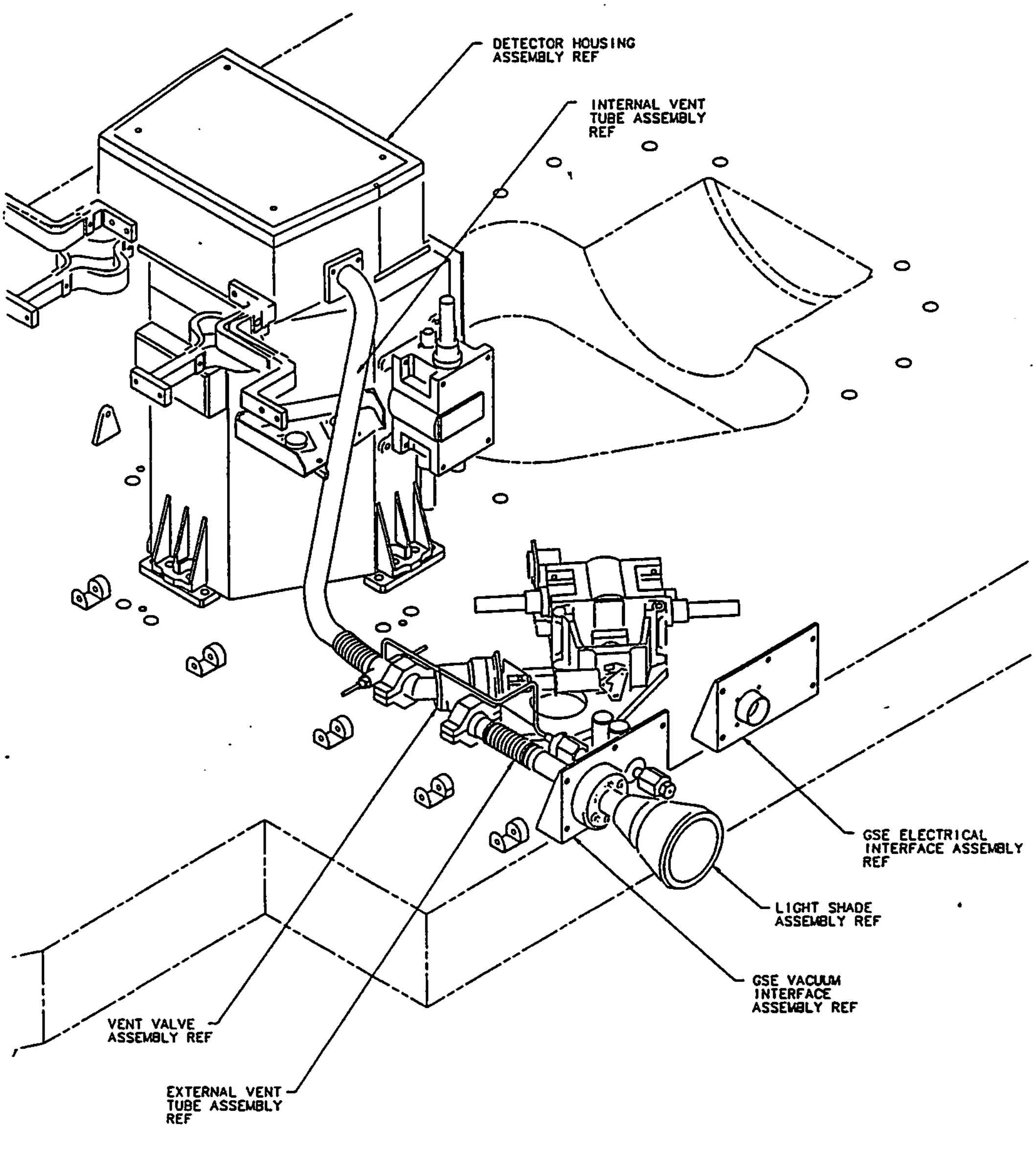

Figure 1. Sketch of Venting Subsystem Showing Internal Vent Tube (Snorkel), High Conductance Vent Valve, External Vent Tube, and Lightshade.

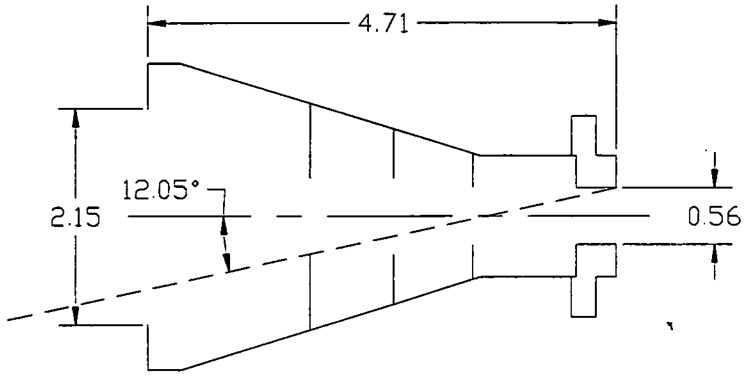

Figure 2. Light Shade Overall Dimensions

SOLAR STRAY LIGHT

The brightest source of stray light on ACIS is the sun, producing an average irradiance at Earth of 0.136 mW/cm^2. The solar spectrum closely matches a blackbody radiating at a temperature of 5800 K. ACIS is sensitive to radiation 1.1 μm and shorter. Using a power weighted average of a blackbody at 5800 K an average photon wavelength has been determined of 0.628 μm or 3.161*10^{18} photons/cm^2-sec for an irradiance of 1.0 Watt/ cm^2.

The light shade has been modeled using the ASAP® (Advanced Systems Analysis Program from BRO Inc.) stray light analysis program. This analysis shows that the shade should produce an attenuation of 10^9 or greater for radiation impinging on the shade at an angle of 45 degree to the optical axis. This attenuation increases with increasing sun to optical axis angle. The lightshade is mounted on the +Y panel of the ISIM with its optical axis parallel to the +Y panel normal. The +Z panel contains the ACIS radiators. These radiators must be oriented 180 degrees from the sun to function properly. The spacecraft is allowed to perform a +/- 30 degree roll about the telescope optical axis resulting in a worst case lightshade to sun angle of 60 to 120 degrees. Table 1 shows the transmittance of each component of the venting subsystem. As may be seen the expected attenuation of the assembled system is of the order of 10^{18}, resulting in negligible photon flux at the detector housing to venting subsystem interface for all operational conditions. From this data it is expected that about one photon per second will exit the venting subsystem into the detector housing.

Table 1. Stray Light Performance of Venting Subsystem Components

Venting Subsystem Component	ASAP Transmittance	Measured Transmittance	Effective Attenuation	Cumulative Attenuation
Snorkel Tube	N/M	3.7E-5	2.7E4	2.7E4
High Conductance Vent Valve	N/M	1E-4	1E4	2.7E8
External vent tube	N/M	0.3	3.3	8.9E8
Lightshade (@ 45	1E-9	N/M	1E9	8.9E17

degrees)				

STRAY LIGHT FROM THE MOON

Lunar stray light is a relatively benign source of radiation. At closest approach the moon will be about a 260,000 kilometers from ACIS. A full moon will produce an irradiance of $3.5*10^{-7}$ watts/cm2 at the light shade entrance. The area of the vent tube is 1.96 cm^2 if the vent is pointed straight at the Moon. This produces a luminant flux of 2400 photons/sec into the detector housing volume. Since this radiant energy enters the detector housing diffusely and must bounce at least once before striking a CCD the worst case radiant flux from the Moon is less than 2400 photons per second. A more detailed discussion of why is found in the next section on Earthshine.

STRAY LIGHT FROM THE EARTH

Scattered light from the Earth is the most troublesome source of stray light for ACIS. This is because of the pointing requirements for the AXAF, the constraints of the radiators and the highly elliptical orbit. The Earth is a very bright source of diffuse radiation. For this analysis it has been assumed that the Earth follows Lambert's law, and has uniform reflectivity of 0.39. This value may vary with cloud cover and Earth rotation. Sun glints from the oceans are also considered as part of this analysis and are assumed to be specular with a reflectance of 0.04. It is also assumed that the lowest altitude where data is to be taken is 40,000 km above the Earth, at lower altitudes the stray light requirements from Earthshine need not be met.

Formulas used in this analysis have been taken from H.C. van de Hulst, Light Scattering From Small Particles. In this case the formulae are for particles much larger than the wavelength, for which the Earth certainly qualifies. The formula used for sun glints is:

$$Irr_{ls}(Alt) := \frac{I_{sol} \cdot R_e^2}{4 \cdot Alt^2} \cdot .04$$

Where: I_{sol} = Solar irradiance at the Earth
R_e = Radius of the Earth in km
Alt = Altitude of AXAF above the Earth

This yields an irradiance at the ACIS light shade of $3.5*10^{-5}$ Watts/cm^2 for an altitude of 40,000 km.

The integrated intensity from the Earth due to scattered light is computed using the following formula:

$$Irr_{ls}(\theta, Alt) := \frac{I_{sol} \cdot R_e^2}{4 \cdot Alt^2} \cdot \frac{8}{3 \cdot \pi} \cdot (\sin(\theta) - \theta \cdot \cos(\theta)) \cdot A_e$$

Where: I_{sol} = Solar irradiance at the Earth
R_e = Radius of the Earth in km
Alt = Altitude of AXAF above the Earth
θ = Angle with respect to the solar propagation direction
ie. 0 is the night side
and π is the full Earth

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Figure 3 is a graph showing how the irradiant intensity varies with altitude. From this figure we see that the worst case irradiance is 10^{-3} watts/cm^2 at the light shade. Sun glints from the oceans represent about 3.5% of the total energy and are therefore not significant for this analysis. The situation presented in Figure 3 is somewhat complicated by the field of view of the lightshade. The 12 degree field of view restricts visibility of the whole Earth at altitudes below 32,000 km, at lower altitudes the energy accepted by the venting subsystem is constant with altitude. This is because the viewed area of the Earth decreases proportionally with the altitude squared. At these altitudes the effective irradiance is 1.4 $*10^{-3}$ Watts/cm^2.

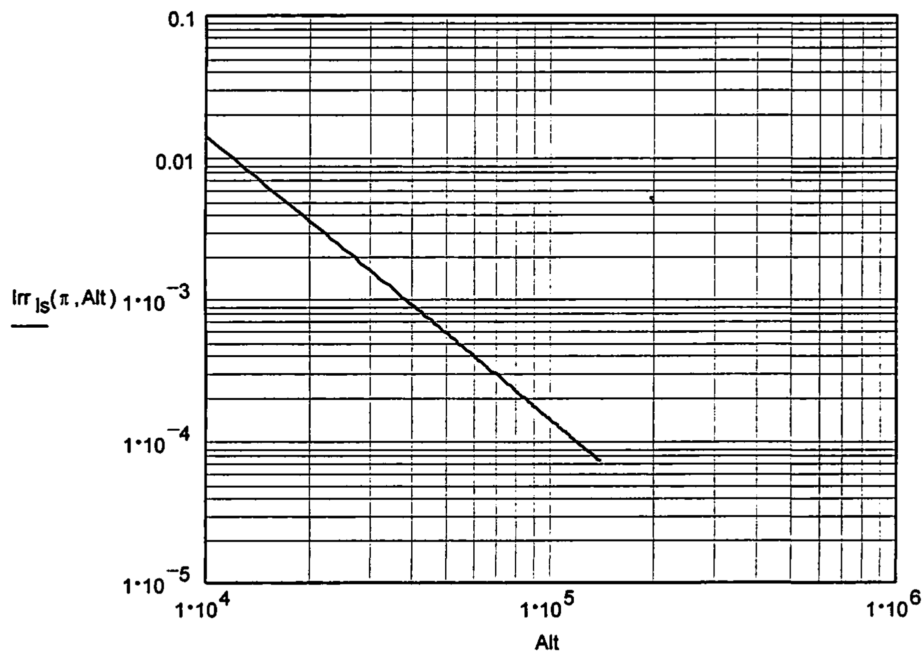

Figure 3. Plot of irradiance versus altitude for the full Earth.

Accounting for the attenuation of the venting subsystem reduces the 40,000 km light load into the detector housing to approximately $3*10^6$ photons/cm^2-sec. This flux exceeds the specified maximum intensity on the CCDs. An estimate of the actual flux at the CCDs is required to ascertain if the 10,000 photons/ cm^2-sec is met.

The interior of the detector housing is gold plated, and the flex-prints are aluminized. This makes the interior of the detector housing very reflective to long wavelength photons but somewhat absorptive for photons with a shorter wavelength. This high reflectivity allows the interior volume to be modeled as an integrating sphere of unusual shape. The lower reflectivity of gold to short wavelengths and the mass of wires, flex prints, cold paddle, frame store shields, and connectors serve to make a more complete model highly complex and suspect while making this assumption conservative. Integrating sphere theory states that the intensity of all points inside an integrating sphere are equal if aperture size is limited to less than 10% of total area, the internal surface is diffuse, and the light performs one bounce prior to measurement. The gold surface is very diffuse to visible light, the CCDs are edge on to the venting subsystem, and the venting subsystem area is less than 1% of total internal surface area. From this it is clear that the basic assumption of integrating sphere properties are met. Assuming for now that this is true for the detector housing, the internal surface irradiance of any point in the cavity is:

$$Irr_{ccd}(\theta, Alt) = Irr_{ls}(\theta, Alt) \cdot tran_{ls} \cdot \frac{A_{vent}}{A_{DH}}$$

where: Irr_{ccd} = the expected irradiance at the CCD surface.
Irr_{ls} = the Earthshine irradiance at the lightshade.
$Tran_{ls}$ = transmittance of the venting subsystem.
A_{vent} = area of the vent aperture in the detector housing
A_{DH} = area of the detector housing interior.
Not including flexprints, cold paddle etc.

Figure 4 shows the intensity profile on the ACIS CCDs at 40,000 km (top trace) as a function of Earth angle.

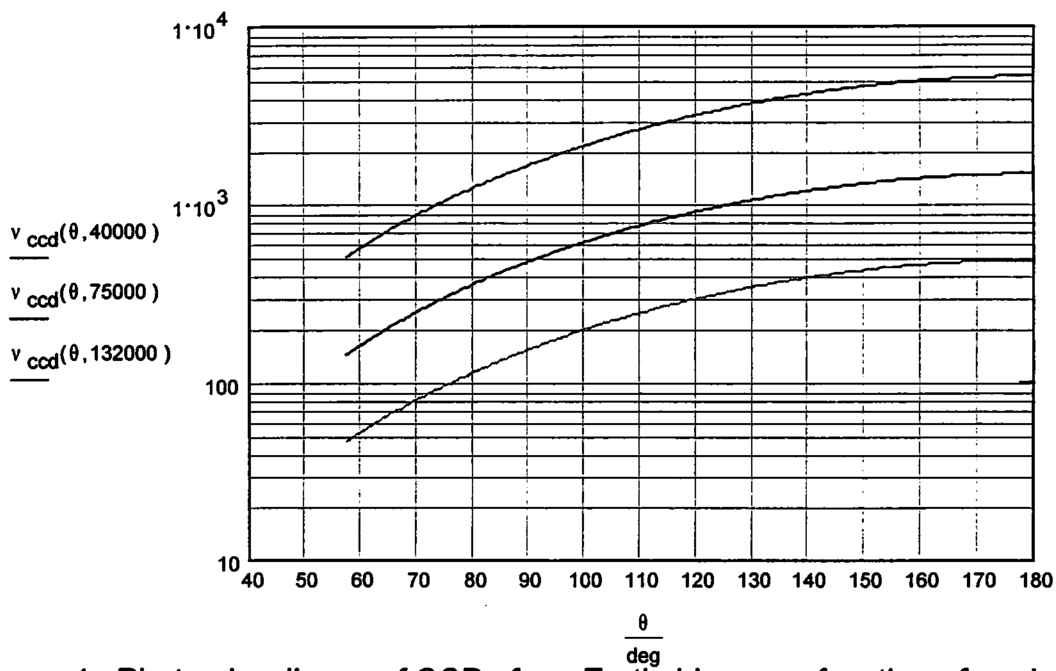

Figure 4. Photon irradiance of CCDs from Earthshine as a function of angle. Units are photons/sec-cm^2.

As may be seen the worst case irradiance is 5200 photons/sec-cm^2 for the full Earth. While this meets the objectives of the venting subsystem it leaves little margin for deficiencies in the assumptions. Further analysis regarding the orbit of the AXAF spacecraft reveals further margin.

The orbit of AXAF is nominally 10,000 X 160,000 km with a 28 degree inclination. This exact orbit, however, may not be achieved. This analysis, therefore, considers the worst case elliptical orbits in turn. Figure 5 shows the nominal orbit of AXAF as an ecliptic orbit. In this orbit the lightshade excludes light from the Earth outside of its field of regard (12 degrees). The +/- 30 degree roll conditions allows Earthshine into the venting subsystem when AXAF is rolled with the +Y panel toward the Earth. Position 'A' shows the closest approach where the full Earth is in the field of regard of the lightshade (the figure shows a view on the night side but the same orientation applies to the sunlit side). Position B is apogee at 160,000 km distance. Position C, shows the unrolled AXAF where the full Earth is just in the field of regard of the lightshade. As shown the closest distance is 75,000 km. Referring to Figure 4, middle

trace, the worst case intensity at the CCD is about 1500 photons/sec-cm^2 . Further, the angular constraint on the radiator with respect to the sun the, eliminates the full Earth view. The maximum angle of regard is 90 +30 +12 = 132 degrees resulting in a worst case focal plane irradiance of about 1000 photons/sec-cm^2 at 75,000 km, or about 3000 photons/cm^2-sec for the worst case orbit with the semimajor axis rotated about the Earth appropriately. The orbit of AXAF is predicted to precess slightly so the worst case orbit could occur sometime in the instrument lifetime..

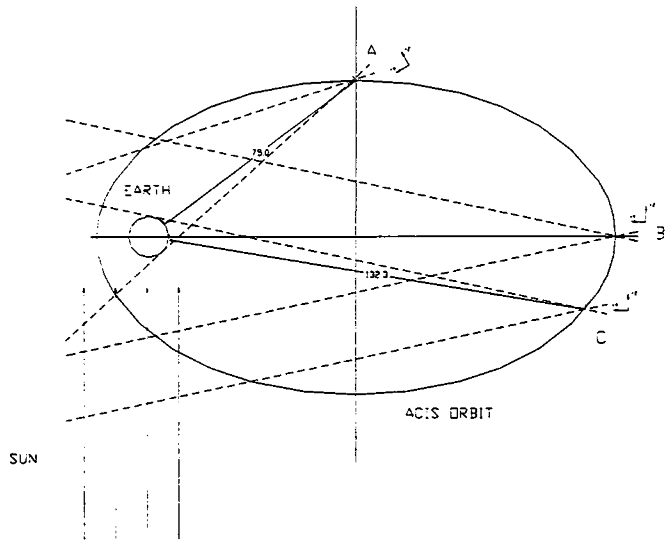

Figure 5. AXAF orbit as an ecliptic orbit (Earth, sun, AXAF in one plane)._

The other extreme condition for the orbit would be a polar orbit. In polar orbit the function of aiming the telescope could place the Earth in full view at any time. A polar orbit perpendicular to the ecliptic, however, would only allow a view of the half illuminated Earth. Referring to Figure 4 shows that at 40,000 km the maximum intensity for a half illuminated Earth is about 1500 photons/ cm^2-sec. As the semimajor axis precesses, the maximum illuminated view of the Earth increases from half illumination to full. The maximum view of the Earth occurs at apogee with the semimajor axis of the AXAF orbit along the earth Sun line and results in a flux of 400 photons/cm^2-sec. As AXAF nears the Earth it leaves the plane of the ecliptic increasing its view of the night side over the top (or bottom) of the planet resulting in worst case flux of about 3000 photons/cm^2-sec. Orbits at intermediate inclinations and precessions will vary between these two extreme orbits.

CONCLUSION

The lightshade venting subsystem combination provides adequate shielding for the focal plane under all conditions. Under certain orbit / telescope pointing conditions the flux at the focal plane approaches 5000 photons/ cm^2-sec at worst case but very rarely exceeds 2000 photons/sec-cm^2. Sun glints from the ocean produce illuminations of about 3.5% that of the full Earth and so are small. The Moon produces about 1000 times less light than the Earth and is again negligible. Light directly from the sun is effectively handled by the lightshade / venting subsystem combination to essentially zero levels of illumination at the CCDs.

The conditions for which the Earth creates 'high' light fluxes on the CCDs are well understood. The 12 degree field of view of the lightshade limits the orientations between Earth, sun and AXAF where Earthshine could be directed down the venting subsystem. Operationally, the

probabilities of the Earth being in exactly the wrong position during a critical measurement are small and the attenuation of the system large enough to limit the flux at the CCDs to acceptable levels.