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James Dyer

Steve Brown

Roy Esplin

Glen Hansen

Scott Jensen

John Stauder

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Authors

James Dyer, Steve Brown, Roy Esplin, Glen Hansen, Scott Jensen, John Stauder, and Lorin Zollinger

Contamination Control of the SABER Cryogenic Infrared Telescope

James Dyer[a], Steve Brown, Roy Esplin, Glen Hansen, Scott Jensen, John Stauder, and Lorin Zollinger

Space Dynamics Laboratory/Utah State University
Logan, Utah 84332

ABSTRACT

The SABER instrument (Sounding of the Atmosphere using Broadband Emission Spectroscopy) is a cryogenic infrared sensor on the TIMED spacecraft with stringent molecular and particulate contamination control requirements. The sensor measures infrared emissions from atmospheric constituents in the earth limb at altitudes ranging from 60 to 180 km using radiatively-cooled 240 K optics and a mechanically-refrigerated 75 K detector. The stray light performance requirements necessitate nearly pristine foreoptics. The cold detector in a warm sensor presents challenges in controlling the cryodeposition of water and other condensable vapors. Accordingly, SABER incorporates several unique design features and test strategies to control and measure the particulate and molecular contamination environment. These include internal witness mirrors, dedicated purge/depressurization manifolds, labyrinths, cold stops, and validated procedures for bakeout, cooldown, and warmup. The pre-launch and on-orbit contamination control performance for the SABER telescope will be reviewed.

Keywords: Contamination, cryogenic, infrared, outgassing, radiometer, SABER, TIMED

1. INTRODUCTION

SABER (Sounding of the Atmosphere using Broadband Emission Spectroscopy) is a 10-channel infrared radiometer that is one of four instruments used in the NASA TIMED mission to study the structure, energetics, chemistry and dynamics of the mesosphere and lower troposphere. The TIMED spacecraft was launched into a 625 km circular polar orbit (72.1° inclination) via a Boeing Delta II rocket from Vandenberg Air Force Base on December 7, 2001. SABER was designed for a 2-yr mission life with a 100% duty cycle. The instrument is designed to detect infrared emissions from the earthlimb at 60-200 km tangent heights using high off-axis rejection optics and cryogenically-cooled (75 K) detectors. Challenging contamination control requirements were derived from the sensor performance specifications. As of July, 2002, the SABER instrument is performing on-orbit as designed and it is expected to meet or exceed all of its science objectives. This paper will review the contamination control design implementations and integration and test requirements that have contributed to SABER's successful on-orbit performance.

2. SABER INSTRUMENT DESCRIPTION

2.1. General

The SABER telescope is an on-axis Cassegrain design with a picket-fence tuning fork chopper at the first focus and re-imaging optics that focus the image onto the focal plane (Figure 1). Altitude profiles in the earthlimb are acquired using a single-axis scan mirror mounted in the baffle assembly.[1,2] High off-axis rejection performance was obtained by extensive straylight analyses and optimization during design and the

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[a] jim.dyer@sdl.usu.edu; phone: (435)797-4516; fax: (435)797-4495; Space Dynamics Laboratory, 1695 North Research Parkway, North Logan, Utah, 84341

Figure 1. Schematic of SABER Instrument
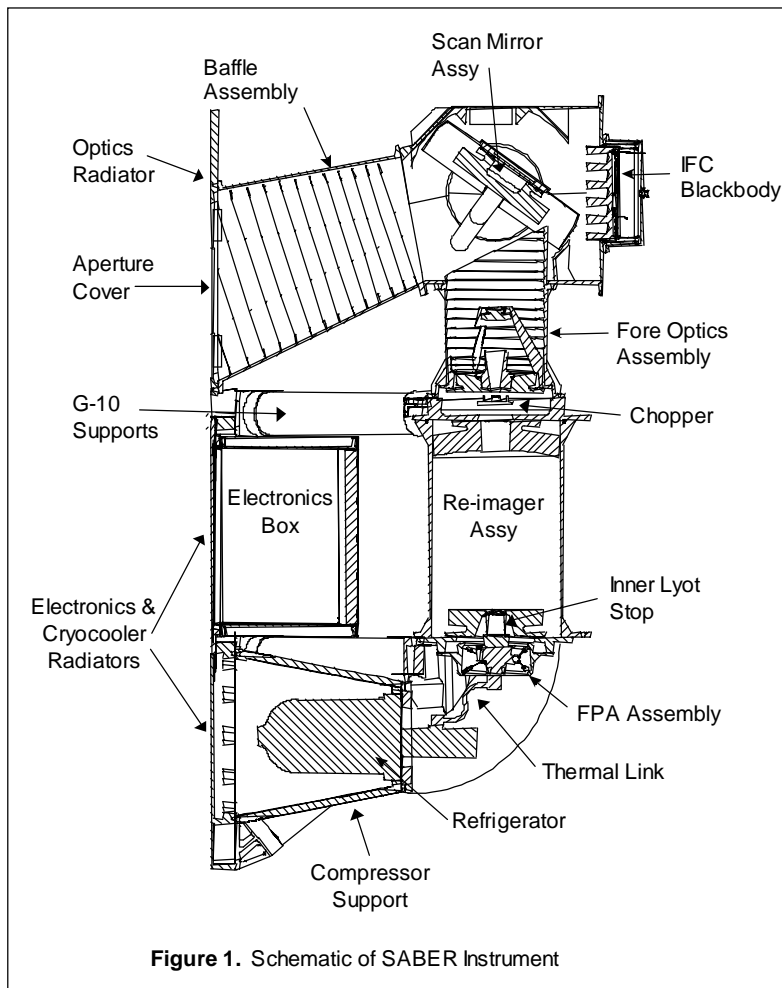
required use of nearly pristine, superpolished fore-optics.[3,4] Furthermore, an intermediate field stop and an inner Lyot stop are incorporated to eliminate the stray light and diffraction effects that are typically associated with on-axis telescope designs.[5] The scan mirror has approximately 100° range of motion that allows it to scan across the entrance aperture or rotate to a position for on-orbit calibration using the in-flight calibrator (IFC) blackbody.

The SABER telescope is passively cooled via the optics radiator that is attached to the baffle. The spacecraft is always oriented with the SABER panel facing away from the sun to avoid unnecessary heating of the telescope. The on-orbit operational temperature of the optics radiator is 208-235 K, resulting in telescope operating temperatures of 215-250 K.[6]

The 10-channel detector is mounted at the focus of the re-imager assembly. It is supported using a Kevlar fiber support technology (FiST) developed at Space Dynamics Lab for high mechanical stiffness and very low parasitic thermal loads.[7] The detector is cooled to 75 K using a TRW miniature pulse tube refrigerator.

A separate radiator panel is used to maintain the operating temperatures of the electronics and cryocooler compressor in the 240 - 270 K range. This panel also provides the structural base for the telescope and refrigerator. It is connected to the spacecraft using titanium bolts and G-10 spacers to reduce the effects of varying spacecraft temperatures.

2.2.   Mirrors and Optical Compartments

The SABER telescope bench, housings, and mirror substrates are made of aluminum. The mirrors were fabricated by SSG, Inc. Straylight analyses indicated that the most critical mirrors for off-axis rejection are the scan mirror, the primary mirror, and the secondary mirror. These mirrors were therefore plated with

electroless nickel, then superpolished and overcoated with electrolytic gold to obtain the lowest achievable BRDF (bi-directional reflectance distribution function). The tertiary and quartenary mirrors on the re-imager assembly are diamond-turned and post-polished

A radiometric model was used to incorporate the optical and straylight analyses with upper atmosphere emission models and detector performance specifications. Ideally, the nonrejected radiance (NRR) would be less than or approximately equal to the noise equivalent radiance (NER) over the 60 – 180 km tangent height instantaneous field of views. This level of performance is met by the 7 longest wavelength channels when using near-pristine mirrors and a data processing subtraction for the straylight contribution from non-signal chopper apertures.[8] For the 3 shortest wavelength channels (OH(A) @ 2.06 μm, OH(B) @ 1.63 μm, and $O_2(^1\Delta)$ @ 1.27μm), the NRR > NER, but the predicted line-of-sight radiance exceeds the NRR, indicating that science requirements can still be met. The radiometric models resulted in an on-orbit mirror cleanliness goal of Level 200 for the re-imager optics and near-pristine (better than Level 200) for the scan mirror, primary mirror, and secondary mirror. Two witness mirrors were added to the scanner compartment to allow monitoring of the scan mirror cleanliness during integration and testing.

The In-Flight Calibration blackbody is primarily used to correct for responsivity changes caused by changes in telescope and focal plane temperatures. It also has the ability to correct for slight changes in reflectance due to molecular contamination of the optics. A review of the infrared properties of contaminant films and the SABER detector bandpasses indicated that less than 10% loss in signal would be produced by 0.5 μm total film thickness, or 100 nm per optic.[9] The baffles and interior surfaces of the SABER optical compartments are painted with Aeroglaze Z306 flat black polyurethane paint on 9929 epoxy primer. The risk of longterm outgassing of residual solvents or unpolymerized pre-cursors from the black paint is controlled by vacuum-baking all painted components at 90 C for 3 days prior to assembly of the telescope.[10]

2.3.   Detectors and Refrigerator Compartment

The SABER detector array fabricated by EG&G contains discrete HgCdTe, InSb, and InGaAs detectors. As shown in Figure 2, the detector is supported using a FiST assembly integrated with the M3 mirror mount. The detector base plate incorporates a purge port connection so that it can be purged with dry nitrogen during handling or storage at atmospheric pressure. (The detector purge capability was included in response to a tests by EG&G that indicated that the HgCdTe responsivity and dark noise can be affected by exposure to atmospheric moisture.) The detector array surface is enclosed within the inner Lyot stop. The Lyot stop is designed to eliminate the scattering produced by the Cassegrain telescope secondary mirror support vanes and central obscuration. When assembled to the telescope, the Lyot stop is located within a central aperture of M3. Prior to installation of the Lyot stop, the detector surface is cleaned to Level 100 cleanliness. This is accomplished by inspection and cleaning under a microscope to remove all particles larger than 20 μm. This limits the allowed obscuration of a detector channel by a single particle to less than 0.1% of the detector area. The exterior surfaces of the detector base, Lyot stop, and M3 support ring are polished and gold plated to reduce the emissivity and thermal loading of the detector by M3 and the surrounding telescope body.

The detector assembly is connected to the pulse tube refrigerator via a flexible aluminum thermal link. The refrigerator cold post, thermal link, detector base, and Lyot stop operate at ≤ 75 K and are the only surfaces in SABER that are cold enough to form water cryodeposits during on-orbit operation. The thermal link and pulse tube cold post are blanketed with approximately 20 layers of multilayer insulation (MLI). The equilibrium temperature of the warmest outer layers of MLI is assumed to be only slightly cooler than the compartment walls at approximately 250 – 260 K. This warm MLI represents a potential source of water vapor that may redistribute onto the detector assembly via the openings in the FiST assembly.

The detector band centers listed in Table 1 were compared to the reflectance of ice cryofilms measured by Wood, *et. al.*[11] Although none of the SABER bands overlap the strongest ice absorption band at 3.1 μm, it

Figure 2. Detector Assembly on Kevlar Fiber Support Structure
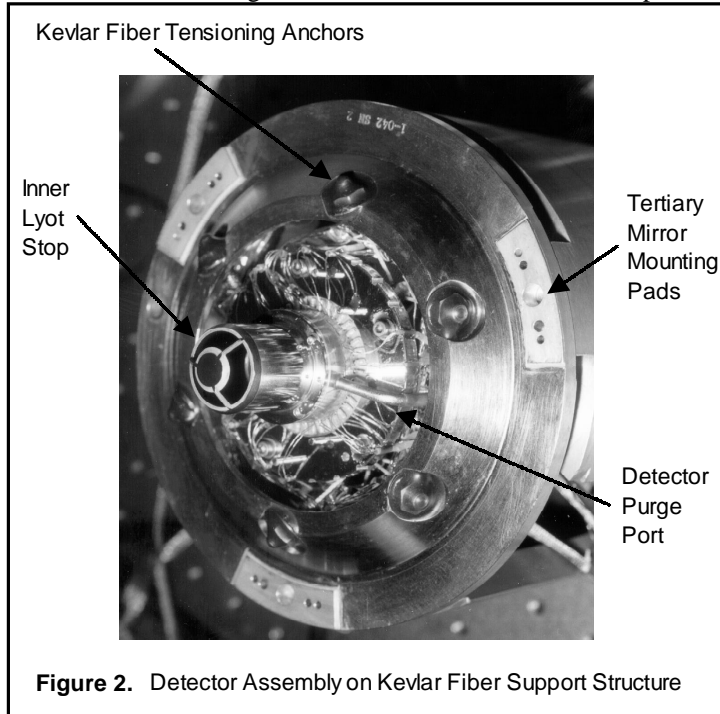
Detector No.	Channel Name	Band Center (μm)
1	CO_{2N}	15.21
2	CO_{2W}	14.92
3	CO_{2W}	14.92
4	O_3	9.3
5	$H2O$	6.8
6	NO	5.4
7	CO_{2B}	4.27
8	OH_A	2.06
9	OH_B	1.63
10	$O_2\,(^1\Delta)$	1.27

Table 1. SABER Detector Bands

was observed that channels 1, 2, 3, 5 and 7 can be affected by weak ice absorption bands. This concern made it necessary to implement isolation barriers, a purge and vent system, and instrument bakeout and validation procedures that will be described below.

2.4. Aperture Cover and Radiators

The optics radiator and main baseplate radiator were coated with IITRI Z-93P white inorganic thermal control coating. After application and curing of the coating, the radiators were cleaned using a light CO2 jet spray and N_2 blowoff to remove loosely adhering Z-93P particles. Prior to launch, exposure to contamination was minimized by maintaining protective covers over the radiators.

A lightweight telescope aperture cover was designed using leaf springs and a sliding retaining bar on the cover as shown in Figure 3. The cover is deployed and jettisoned into space by using a radiator-mounted wax-actuated pin puller to disengage the retaining bar. The cover provided a tight but non-hermetic seal by using a coil-reinforced captured Teflon O-ring on the cover. The seal contact area on the radiator plate was covered with silver Teflon tape to minimize cold stiction and
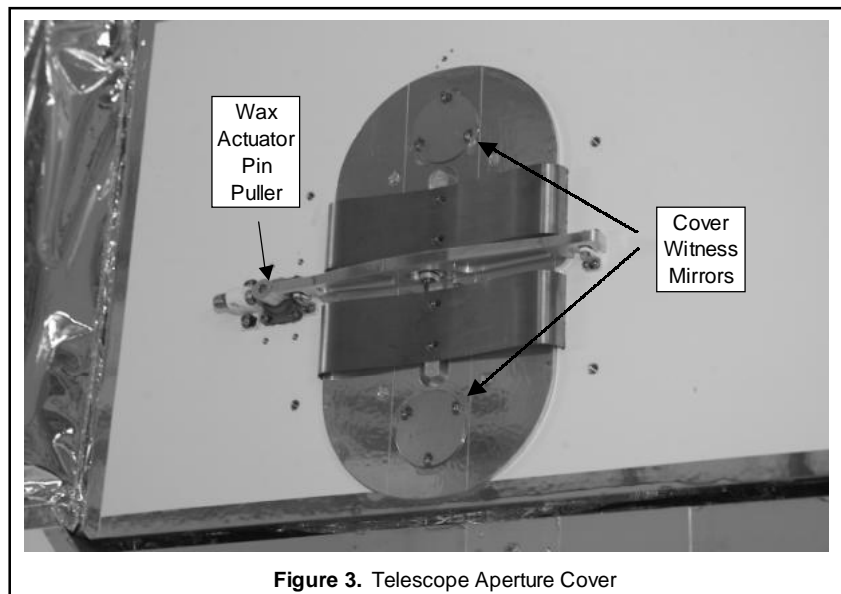
Figure 3. Telescope Aperture Cover

particle generation. Vibration and cold deployment testing verified that this design produced minimal particulates and reliable deployment.

The radiator performance budget can tolerate on-orbit particulate contamination levels as high as Level 1000. The pre-launch external s/c and payload dispenser cleanliness requirement was therefore set at Level 750 A. The primary mechanism for molecular contamination-induced radiator degradation is by solar vacuum ultraviolet exposure and photochemical-induced deposition and darkening phenomena.[12] Nevertheless, the molecular contamination is a low risk for these radiators and telescope aperture because: 1) there are no thrusters on TIMED; 2) there are no sources (including solar arrays) in the field-of-view of the radiators or apertures; 3) the SABER radiators are always oriented away from the sun; and 4) the estimated return flux of contaminant molecules at this orbit is low when compared to the 2 yr mission lifetime. Accordingly, the prelaunch cleanliness standard applied to external surfaces of SABER was VC-IV (Visibly Clean – Highly Sensitive with UV inspection per NASA SN-C-0005). The bare metal exterior surfaces of the cover and nearby spacecraft surfaces were sampled prior to launch; analyses indicated that they met contamination requirements.

2.5.   Contamination Requirements Summary

The instrument cleanliness requirements and validation processes are summarized in Table 2.[13]

Table 2. SABER Cleanliness Requirements and Validation

Instrument/ Subsystem	Location	Cleanliness Requirement MIL STD 1246 NASA SN-C-0005	Validation Method
Optics	Mirrors	< Level 200 M1, M2 and scan mirror Level 200 M3 & M4 < 100 nm film/optic	Mirror BRDF prior to telescope assembly Witness mirror counts after integration and test; visible inspections Spectral monitoring during cold tests
Optical compartments	Baffles, field stops, optically black surfaces	Level 200 VC-HS+UV	Preceding sensor assembly: tape lifts, visible inspection; solvent rinses with particle count Preceding integration onto s/c: visible inspection of baffle assembly
Focal plane assembly	Inside detector assembly (before Lyot stop installation)	Level 100 No particles >20 μm	During assembly, prior to sealing: cleaning and verification performed under microscope
Refrigerator assembly	External surfaces	Level 300 VC-HS+UV	Preceding blanketing: particle counts by tape lift and visible inspection
Multilayer insulation	External to sensor optics	VC-HS	Visible inspection prior to installation
External support structure	External to sensor optics	Level 500 VC-HS+UV	Prior to integration with spacecraft: particle counts by tape lift, visible inspection
Aperture cover	Internal surface	Level 200 VC-HS+UV	At last opportunity to open cover in controlled environment: witness mirror counts, DRIFTS
	Door release mechanism and external surfaces surrounding seal	Level 300 VC-HS+UV 3 μg/cm² NVR	At last opportunity to inspect/clean cover by SABER personnel prior to launch (Expect pre-launch degradation toward s/c Level 750)

Instrument/ Subsystem	Location	Cleanliness Requirement MIL STD 1246 NASA SN-C-0005	Validation Method
Electronics	Exterior surfaces of SABER	Level 500 VC-HS+UV	Prior to integration with spacecraft: particle counts by tape lift, visible inspection
Radiators	Telescope & mounting plate radiators (SABER's external s/c panels)	VC-HS+UV	At last opportunity to inspect/clean by SABER personnel prior to launch (At VAFB)
Spacecraft	Exterior surfaces	Level 750 A Visibly Clean	Visibly clean inspections, tapelifts, DRIFTS pre-launch

2.6.   Contamination Risk Mitigation

The challenging requirements of near pristine optics and minimum water cryodeposition on the cold detector assembly led to the incorporation of special hardware features and operations.

2.6.1.   Special cleaning strategies

The SABER optical compartment structures were precision-cleaned at the parts level after completion of painting, bakeout, fit-checking, and alignment operations (with drilling and pinning). The precision cleaning technique consisted of detergent and DI water scrub and rinse, followed by swabbing and rinsing with filtered 2-propanol, then CO_2 jet spray cleaning to remove partially adherent particles, followed by white light and black light inspection and touch up. The final steps were repeated as necessary in a Class 100 clean tent prior to double-bagging for transfer to the sensor assembly area. During assembly, special care was taken to capture and remove any debris generated by fastener insertion and general handling. The sensor assembly was performed in Class 100 cleanrooms with frequent cleanliness inspections and "touch-ups". Mirrors were sometimes re-cleaned *in-situ* using GN_2 blowoff or CO_2 jet spray. The integration plan recognized the need for multiple cleaning operations. After the first clean buildup and preliminary boresight and mechanical testing, the optics were disassembled and re -cleaned in preparation for stray light validation tests. The sensor then underwent three engineering cold test cycles prior to being disassembled and final-cleaned in preparation for environmental acceptance tests and sensor calibration cold tests.

2.6.2.   Stray light performance validation

The initially-measured BRDFs of the individual SABER mirrors were incorporated into the stray light model and indicated little or no performance margins. Visible stray light testing of the integrated optics was then performed at a special SDL facility in order to check the integrity of the straylight model and the as-built sensor design. Fortunately, the testing indicated that the integrated system performance *exceeded* the performance predicted using actual BRDF data.[14] This is attributed in part to the difficulty in obtaining an average BRDF from small local measurements, the possibility that the mirrors were not pristine in the BRDF test facility, and the fact that the BRDF measurements were made at normal incidence instead of the critical angles for each mirror. The stray light measurements were used to infer average BRDF's for each mirror, and to upgrade the radiometric model for better predictions of on-orbit performance.

2.6.3.   Scan mirror orientation

The SABER telescope incorporated the unique capability of being able to stow the most critical and vulnerable mirror in an orientation that eliminated exposure to the telescope aperture and outside environment. When the scan mirror is rotated to the IFC blackbody position, the scanner baffles completely obstruct the line-of-sight to the telescope aperture. This position was used as the "stowed" configuration during all sensor handling operations and was very effective at controlling the accumulation of particulate debris. The stowed position was also used during launch an d on-orbit cover deployment.

2.6.4.   Witness mirrors

Removable witness mirrors were incorporated into the sensor design at an early stage so that the cleanliness of the optics could be monitored during integration and testing. As indicated in Figures 1 and 3, the scanner compartment and the telescope aperture cover each accommodated two superpolished witness mirrors. The mirrors in the scanner were 5.7 cm diameter and the aperture cover mirrors were 3.2 cm diameter. In principle, one mirror in each location was for total integrated exposure while the other mirror was changed more frequently to measure interval exposure during distinct operations. The mirrors would then be removed at the last scheduled access prior to launch and replaced with black covers. In practice, the witness mirrors for the scanner were installed after the final optics cleaning in May '99 and were not accessible again until the preparations for integration with the spacecraft at the Johns Hopkins University Applied Physics Lab (JHU/APL) in September '99. Both scanner mirrors were removed at this time and the percent obscuration of the mirrors was measured using a 100X microscope to count and size particles. The cleanliness of each witness mirror was conservatively estimated at no greater than 0.00086% and 0.0022%, or Mil Std 1246 Level 146 and Level 181, respectively.   This is excellent performance, considering that the period of exposure included the environmental testing and several cold cycles (pre-vibe, warm and cold boresight tests, thermal-vacuum cycling, and cold calibration).

The witness mirrors used on the telescope cover were installed at JHU/APL prior to installation of the sensor onto the spacecraft.   The exposure sequence for the witness mirrors on the cover became complicated by unforeseen removals and re-installations to accommodate launch delays and spacecraft storage phases. Nevertheless, the measured cleanliness of the cover witness mirrors were also consistently better than Level 200. It should be noted that the individual cleanliness measurements during separate pre-launch storage phases could not be accurately co-added. This was due to complications caused by clean mirror defects and speckle that look similar to small particles, making it impossible to obtain precise background subtractions for each measurement.

2.6.5.   Purge and vent manifolds

The vulnerability to water outgassing and the need to control particulate redistribution within the detector assembly and optical cavities led to the design and optimization of a purge and vent system (Figure 4).   In order to make the purge system effective, the dry purge gas needed to be distributed uniformly into critical compartments and the escape paths had to be minimized so that a slight positive pressure (4-6 Torr) could be maintained at a reasonable flow rate.   This was accomplished using a purge manifold that distributed dry nitrogen to five locations: two ports in the fore-optics and scanner compartment, and one port each for the re-imager compartment, the pulse tube/thermal link compartment, and the detector.   The telescope purge lines are 1/8" Teflon tubing. The detector uses 1/16" tubing to restrict the gas flow to <3% of the total purge (nominally 0.5 scfm at 4 psi delivery pressure). The purge manifold includes a 5 μm filter and each purge fitting on the telescope uses a sintered
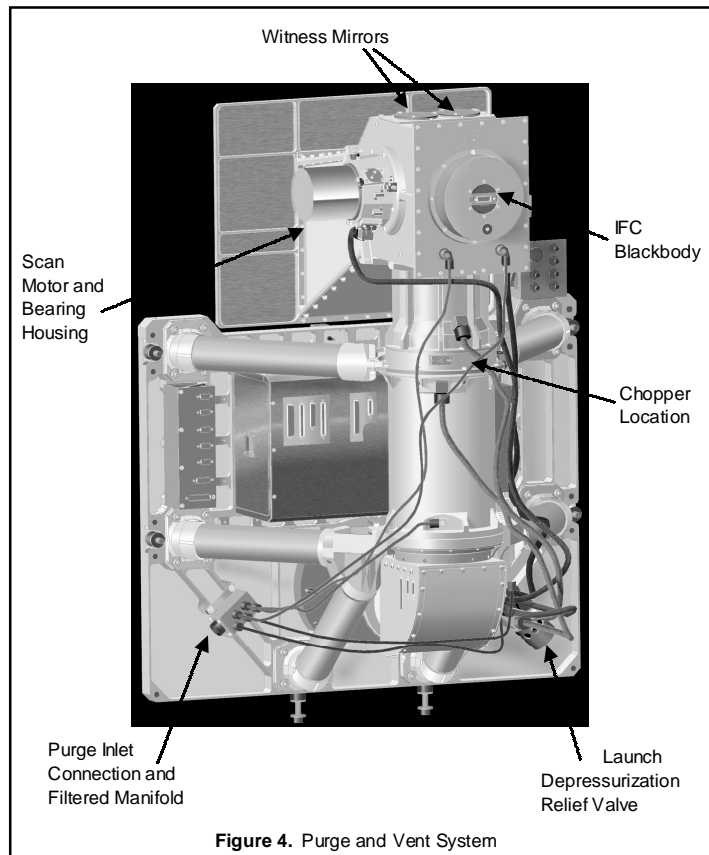

Figure 4. Purge and Vent System

metal gas snubber filter disk to provide additional filtering, and eliminate stray light leaks. Once installed, the purge was operated continuously whenever the sensor was not under vacuum.

It was also anticipated that rapid launch depressurization could also a significant contamination risk if not managed correctly. Therefore, a very low pressure/high flow relief valve was designed and tested to maintain positive pressure during purge operations and control sensor depressurization vent paths during launch. The spring load on the valve was adjustable to allow 0.2 - 0.7 scfm flow rates at 3 – 6 Torr pressure differential. However, when exposed to rapid decreases in pressure, the relief valve would open sufficiently to allow a SABER-sized volume to completely evacuate within 60 seconds. The vent port fittings attached to the telescope used a black labyrinth that would not impede gas flow but still minimize the entry of stray light. The vents were strategically located in critical areas of the telescope: 1) The scanner motor and encoder each had a vent on its body so that gas flow and particulates (from the bearings) would be directed away from optics; 2) A vent port was located on each side of the small field stop aperture (between M1 and M4) to reduce the flow of gas across the chopper and reduce the possibility of damage; and 3) A vent port is located on the thermal link compartment to direct particulates from the MLI away from the detector and optics. The vent ports are connected to the relief valve with 3/8" Teflon tubing. The entire back of the SABER sensor was completely enclosed in a 40 layer MLI blanket with a 5 mil outer layer to immunize the sensor from the spacecraft thermal and outgassing environment. Since the vent valve is inside the MLI "tent", purging under this configuration created a local N_2 environment outside of the telescope housing as well as inside. Furthermore, the isolation afforded by the SABER thermal, mechanical, and optical design eliminated the need for spacecraft bakeout requirements.

2.6.6. Sensor bakeout procedures

At the beginning of each cryo-vacuum acceptance test, the sensor and all internal contents of the associated test chambers were vacuum-baked at 50 C for 48 hours to reduce the outgassing of the MLI and internal surfaces. The internal equipment consisted of approximately 400 kg of hardware, with the sensor comprising 75.5 kg and roughly 33% of the total MLI. Uniform heating was obtained by operation of all internal heaters under 20 Torr N_2 to overcome the insulating effects of MLI. It typically required 8 hrs to reach 50 C, at which point the high vacuum pumps were initiated. After 48 hrs at 50 C, pressure rate-of-rise and residual gas analyzer characterizations were performed. A typical rate-of-rise measurement after 48 hrs bakeout was $\leq 2 \times 10^{-5}$ Torr/min. The residual gas analyzer indicated that the outgassing was predominantly water, as expected. For a 6000 L test chamber the calculated *total* outgassing rate at 50 C was approximately 2×10^{-3} Torr L/s or 2 μg water/s. After 48 hrs, the bakeout would begin to slow down, and the outgassing rate would only drop by 1 to 1.5% per hour.

2.6.7. Spectral monitoring during cold tests

The system bakeouts were performed to minimize the possibility of ice deposition on the detector assembly. During engineering and final calibration cold tests, a special test procedure was performed to allow comparison of the relative spectral responsity RSR of individual detector channels and look for degradation trends that might be due to ice deposition. As described previously, channels 1-3, 5, and 7 overlap the sides of broad weak absorption bands of ice. Channels 4 and 6 conveniently fall in "window" regions where ice does not absorb infrared radiation. Periodically during calibration, the RSR of the susceptible channels was compared to measured RSR's of the window channels to look for a consistent decreasing trend that would be indicative of ice-induced spectral absorption. However, during calibration the RSR ratios changes were small and inconsistent. This inability to correlate the small changes was probably due to the relatively short duration of calibration cold tests and the possibility that concurrent slight changes in detector or sensor temperatures was having stronger effects than ice-induced degradation.

3. PRE-LAUNCH PREPARATIONS

3.1. Integration with Spacecraft

The SABER sensor was shipped to JHU/APL for integration with the spacecraft in September '99. The GSE test chamber was used for shipment (under purge) and for a preliminary cold verification test prior to s/c integration. Continuous sensor purging was maintained via the spacecraft purge system up until launch.

A protective cover was kept on the SABER radiators during all spacecraft handling operations. Spacecraft tests included vibration and EMC testing at JHU/APL followed by acoustic and thermal vacuum testing at Goddard Space Flight Center.

3.2. Extended Storage

In February 2000, the spacecraft was on schedule for shipment to Vandenberg AFB but delays in the preparation of TIMED's launch partner, JASON-1, required that TIMED be bagged and stored in its purged shipping container for approximately 17 months. In the summer of 2001, the TIMED spacecraft was removed from storage, functionally tested, and shipped to VAFB in preparation for a September launch. Final launch preparations were under way in the Class 10,000 highbay at SLC-6, when additional problems with JASON-1 forced another 3 month launch delay.

3.3. Cover Deployment Tests

Cover deployment tests were performed periodically during the spacecraft integration, test, and storage phases to ensure that the cover mechanism still worked properly and the seal had not become stuck by thermal-vacuum cycles or longterm storage. Deployment tests were always performed in certified Class 10,000 cleanroom environments that were measurably cleaner. The deployment tests used a pair of GSE cover retainers that limited the deployment to approximately 1 mm of travel. Assessments were made that indicated that the brief opening under purge presented little contamination risk to the interior of the telescope. This assessment was validated by analysis of cover witness mirrors that were also removed and exchanged in the Class 10,000 environment spacecraft integration environment.

3.4. Launch Site Operations and Measurements

Final SABER and TIMED spacecraft cleaning was performed several times at SLC-6 due to launch delays. In July '01, contamination samples were collected during the first "final closeout" of the SABER cover and radiators. Tape lift samples from the accessible metal surfaces of the spacecraft ranged from 0.001% obscuration to 0.046% obscuration, consistent with Mil Std 1246 Level 200 to Level 350. Solvent wipe samples were also collected and quantitatively analyzed by the ultra-sensitive diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) technique.[15] Results ranged from < 0.01 to 2.1 $\mu g/cm^2$ (Level A/100 to Level B). The highest NVR detected appeared to be residual perfluorinated polyether (Braycote or Krytox) that was probably transferred to the spacecraft frame from contaminated gloves and is difficult to remove using 2-propanol. This contamination is not a concern due to the low volatility of the material. Interestingly, the trace contaminant detected on the rarely-handled SABER aperture cover leaf spring appeared to be a phthalate ester (plasticizer) residue at 0.004 $\mu g/cm^2$, consistent with the general observation that organic ester contamination on spacecraft can be minimized but is probably impossible to eliminate.

The spacecraft contamination analyses indicated that the pre-launch cleanliness exceeded requirements. After final spacecraft preparations, a dual payload attach fitting (DPAF) was used to encapsulate TIMED prior to stacking with JASON-1. The combined payloads were double bagged and installed into the Delta II fairing without interrupting the purge. Encapsulation in the DPAF housing is probably a significant asset for contamination sensitive hardware, since it provides additional protection against spacecraft contamination during launch.

4. EARLY ON-ORBIT RESULTS

As of July, '02, the SABER instrument is performing as designed and is expected to meet or exceed all science objectives.[16] Preliminary results indicate that measurements extend to higher altitude than expected, suggesting that the stray light rejection is good. Additional work will be necessary to update the straylight model with on-orbit performance so that on-orbit mirror cleanliness levels can be derived.

On-orbit responsivity calibrations using the IFC blackbody indicated a gradual degradation that was primarily associated with channels 1-3, 5, and 7 during the first 14 weeks. A gradual increase in the ΔT between the detector assembly and miniature pulse tube refrigerator was also observed. These observations

suggested that ice was being deposited on the thermal link and FiST assembly. In Figure 5, the relative detector responsivity degradation measured after 14 weeks of on-orbit operation shows good agreement with the infrared transmittance spectrum generated for 1 μm ice film using CALCRT.[17] The degradation
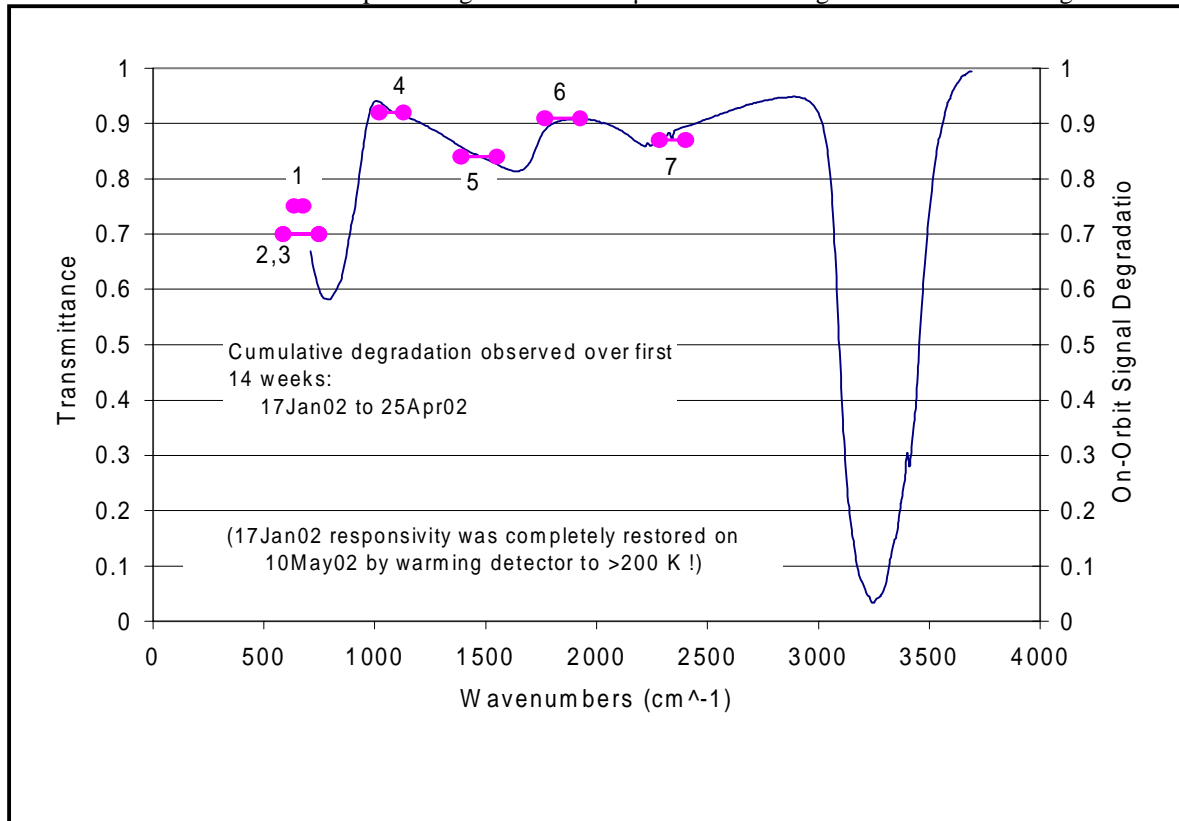
profiles as a function of time were also qualitatively similar to CALCRT predictions based on a constant deposition rate. (One μm deposition in 14 weeks equates to an average local partial pressure of 6.7 x 10^{-10} Torr, assuming water vapor at 200 K). The long wavelength data (channels 1-5) exhibited a steady degradation, whereas the shorter wavelength channels displayed a slight oscillation due to thin film interference effects that were also predicted by the CALCRT model. Based on these spectral and thermal correlations, it was decided to warm up the detector in May '02 to approximately 231 K by turning off the refrigerator for 3 days. The ice completely sublimated, and all channels were restored to the initial signal levels that were measured on 17 Jan 02. Current measurements indicate that water cryodeposition has resumed, but at approximately 1/3 the previous rate. The effects of this low rate of ice deposition are being corrected and managed by using the IFC blackbody and models of the spectral response over each detector channel bandpass, as well as anticipated periodic warm-ups of the detector.

5. CONCLUSIONS

The SABER instrument design and contamination control strategies have been successful, and the sensor is performing very well on-orbit. The challenging requirements of delivering near-pristine optics to space have been overcome by a functional instrument design and realistically-feasible cleaning and validation techniques. The stringent sensor contamination control requirements did not create significant burdens on spacecraft design or integration processes. The ability to make accurate infrared measurements using a 75 K detector via a low power pulse-tube refrigerator in a radiatively-cooled 225 K telescope has also been demonstrated. Sensor bakeouts followed by continuous nitrogen purge during ground operations were successful at reducing water on-orbit outgassing and cryodeposition rates to manageable levels, despite the passage of over 2 years between the last sensor bakeout and launch.

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