VIMS Instrument Overview

This section is intended to give the reader a broad overview of the technical aspects of the VIMS instrument (Brown et al 2005). It is not intended to be a detailed technical description nor a complete operator's manual. For a detailed technical description, the reader is directed to papers in the open literature (Miller et al 1996, Reininger et al 1994).

VIMS-V is a multispectral imager covering the spectral range from 0.30 to 1.05 micrometers. VIMS-V is equipped with a frame transfer CCD matrix detector on which spatial and spectral information is simultaneously stored. The CCD is passively cooled in the range -20/+40 degrees C. Radiation collected from VIMS-V telescope is focused onto the spectrometer slit. The slit image is spectrally dispersed by a diffraction grating and then imaged on the CCD: thus, on each CCD column a monochromatic image of the slit is recorded. On-chip summing of pixels allows implementation of a large number of operating modes for different observing conditions.

The maximum capabilities of VIMS-V are a spectral resolution of 1.46 nm and a spatial resolution of .167 millirads while in the high-resolution mode of operation. On-chip summing of 5 spectral x 3 spatial pixels enables the normal mode of operation whereby VIMS-V achieves a spectral resolution of 7.3 nm and a spatial resolution of .5 millirads. The total field of view of the instrument is 2.4 deg x 2.4 deg, although matching with the IR channel imposes the use of a 1.8 deg x 1.8 deg FOV. In table 1 are listed the main characteristics of the instrument.

VIMS-V is composed of two modules, the optical head and the electronic assemblies, housed in separate boxes. The VIMS-V optical head consists of two units: a scanning telescope and a grating spectrometer, ideally joined at the telescope focal plane where the spectrometer entrance slit is located. The telescope mirrors are mounted on an optical bench that also holds the spectrometer. In fact, the optical bench is the reference plane for the whole instrument.

The telescope primary mirror is mounted on a scan unit that accomplishes two specific tasks: a) pointing and b) scanning. The scanning capability enables the .5 millirads IFOV of the nominal mode of operation by a two-step motion of the primary mirror during each integration time; images are produced by scanning across the object target in the down track direction (push-broom technique). The pointing capability is used to image selected target regions in a range about 1.8 degrees around the optical axis, and to observe the Sun, through the solar port, during in-flight radiometric calibration.

An in-flight calibration unit is located at the entrance of the telescope. The unit consists of: a) two LEDs for a two-point calibration of the spectral dispersion and b) a solar port for direct solar imaging and hence for radiometric calibration. Because the remote sensing pallet is body-mounted to the spacecraft, to image the Sun the spacecraft is reoriented to form a 20 deg angle with the boresight direction of the instrument and the instrument scan mirror needs to be moved to an angle of 4.8 degrees from boresight. Under these conditions light from the Sun passes through a cutout in the instrument baffle and then through a prism that attenuates the solar radiation and redirects it towards the telescope primary mirror. Due to budget constraints, the high-resolution mode was been implemented and tested, but not calibrated. Calibration will be accomplished during the cruise phase to Saturn.

The VIMS infrared channel is the culmination of an effort by the NASA Jet Propulsion Laboratory in collaboration with the French and Italian space agencies to develop an improved imaging spectrometer for use in spacecraft studies of planetary surfaces and atmospheres. This collaboration resulted in several similar instruments optimized for different planetary targets, most notably the OMEGA instrument, the Mars Observer VIMS, and the CRAF VIMS. Mars Observer VIMS and CRAF VIMS are Cassini VIMS most immediate forebears, but changes made in the VIMS instrument design in response to NASA's demands to reduce the cost of the strawman Cassini VIMS resulted in a substantial heritage from Galileo NIMS. Despite that heritage, which goes so far as to include parts from the Galileo NIMS engineering model, Cassini VIMS is a substantial step beyond NIMS in the evolution of visual and infrared imaging spectrometers.

The major differences between the Cassini VIMS and the Galileo NIMS lie in the incorporation of a separate visual channel using a frame-transfer, silicon CCD detector with separate foreoptics and analog/control electronics, the inclusion of a radically improved infrared detector with improved order sorting and thermal background rejection, an improved infrared focal plane cooler design, an improved main electronics design, a two-dimensional, voice-coil-actuator-driven, scanning secondary mirror in the infrared foreoptics, a fixed, triply blazed grating in the infrared, a redundant 16 megabit buffer, and a redundant, lossless, hardware data compressor using a unique compression algorithm developed by Yves Langevin. These improvements result in an instrument with substantially greater capability for planetary imaging spectroscopy--so much so that Cassini VIMS is the most capable and complex imaging spectrometer presently flying on a NASA planetary spacecraft.

The IR channel optics that was successfully deployed as of August 15, 1999, some 50 hours before the time of closest approach during the Cassini Earth Swingby. The visual and IR channels are mounted to a palette that holds them in optical alignment and helps to thermally isolate the instrument from the Cassini spacecraft. Thermal isolation is particularly important for the infrared channel because thermal background radiation from the IR spectrometer, combined with shot noise from leakage current in the InSb photodiodes of the 256 element linear array detector of the IR channel are the chief sources of noise in measurements obtained with the IR channel. The nominal operating temperature for the IR focal plane is 55-60 K and for the IR foreoptics and spectrometer optics 120 K.

The Cassini VIMS instrument is mounted on the Cassini spacecraft by means of a palette (called the Remote Sensing Palette or RSP) on which are also mounted the Cassini Imaging Science Subsystem (ISS), the Composite Infrared Spectrometer (CIRS), and the Ultraviolet Imaging Spectrometer (UVIS). Mounting of all the Cassini remote sensing instruments on a common palette allows relatively precise boresight alignment of the four instruments, enhancing synergy between the 4 instruments.

Science Objectives

The VIMS science investigation is focused on the study of the Saturn system and on objects that Cassini encountered during it's cruise to Saturn. The Cassini trajectory uses gravity assists from Venus, Earth and Jupiter to eventually get the Cassini spacecraft to Saturn, so additional opportunities for scientific study of planetary bodies present themselves well ahead of the Cassini Saturn orbital insertion maneuver.

The Saturn System provides a unique challenge for VIMS. VIMS's capability to acquire the full range of visual-near-infrared wavelengths in two-dimensional maps over a wide variety of illumination and emission angles enables a diverse investigation of chemical, dynamical, and geophysical phenomena. Important targets for VIMS include the surface and atmosphere of Titan, the cloud-rich atmosphere of Saturn, Saturn's rings, and a plethora of icy moons. Observations of both the day and night sides of these objects should lead to increased insights into various phenomena involving both reflection and emission of radiation. Occultations of the Sun and stars by these objects should provide new insights into the nature of tenuous stratospheric hazes on Saturn and Titan, the structure of faint rings, and atmospheric composition.

Calibration Description

The main VIMS ground calibration took place at the Jet Propulsion Lab during the months of January and February 1996. The detailed plan for the VIMS ground calibration evolved over a period of approximately 4 years, being completed in mid 1995, roughly 6 months before the actual measurements were to commence. The time frame for the ground calibration was driven by the planned delivery date of the fully integrated VIMS instrument in the September-October period, 1996. Because the VIMS Visual Channel was not completed at the time of the main calibration, only the IR channel was calibrated. The Visual channel was calibrated separately at Officine Galileo (Firenze, Italy) (the instrument provider), in the spring of 1996, and later a small number of operational/performance tests were carried out in late summer of 1996 after the Visual and IR channels were integrated at JPL. As a result of the slip in the schedule for the delivery of the Visual Channel, a substantial recalibration of the instrument has been undertaken while the VIMS is in route to Saturn. The details of the efforts to calibrate the VIMS instrument in flight appear later in this document.

The main ground calibration of the IR channel was carried out in 6 separate areas: radiometric/flat field response, geometric, polarimetric, spectral, and solar port response. In the early phases of the genesis of the VIMS ground calibration plan, measurement of VIMS stray light rejection performance was also envisioned, but practical difficulties in performing those measurements under vacuum and at the operational temperatures required necessitated elimination the ground based measurements in favor of measurements in flight. Those measurements are discussed later in this document.

The actual measurements were carried out in the JPL thermal vacuum testing facility in the largest thermal vacuum tank available. The in-flight thermal environment for VIMS was simulated by cooling the interior surfaces of the thermal vacuum tank with liquid N2, and providing a cold target that filled the fields of view of both the visual and infrared channel's passive coolers with a high emissivity surface cooled to 4 K. In retrospect, the thermal environment of the JPL thermal vacuum tank and the cold target was quite accurate because the temperatures of the instruments optics and focal planes in flight are within a few K of those measured while the instrument was in the test environment. Described in more detail below are the main results of Each of the major calibration tests listed above. For more information on the VIMS calibration during the galilean satellites flyby, see McCord et al 2004.

RADIOMETRIC CALIBRATION

VIMS IR Channel

The radiometric response of the VIMS IR channel was carried out before launch in the thermal vacuum facility at the Jet Propulsion Laboratory. A team of scientists, supported by the instrument engineering team at JPL, designed and carried out these measurements. The team members responsible are Thomas B. McCord (lead), Robert Brown, Angioletta Coradini, Vittorio Formisano, and Ralf Jaumann. Also contributing were Giancarlo Bellucci, Bonnie Buratti, Frank Trauthan, Charles Hibbitts and Gary Hansen. Two sessions were conducted, one in January and the other in July of 1996. In-flight calibration efforts were conducted during the Venus, Earth and Jupiter flybys and for two star observations. A workshop was held in Hawaii in February 2001 to review the information obtained. Additional people contributing post launch were Kevin Baines, Roger Clark, and Robert Nelson. More information on the calibration test and data results can be found in Coradini et al 2004.

The equipment facility during the ground calibration included a JPL thermal vacuum chamber cooled by liquid nitrogen and containing the instrument, which viewed the outside through a window with known optical transmission. A reflecting collimator fed light from several sources to the instrument. The calibrated sources were a glow bar and a tungsten lamp and their energy delivered to the instrument was controlled by adjustable iris diaphragms at the exit of the lamps. The light sources and delivery system were covered to eliminate outside light and, during the first session, the tent was purged with dry nitrogen to reduce the effects of the atmosphere gas absorptions (mainly CO2 and H20). Measurements were made at several instrument and focal plane temperatures, but most measurements were made with the focal plane temperature in the range 60.7 to 61.69 K. Data were acquired at several light levels and integration times, including zero.

The characteristics of the instrument that were explored were dark current (detector thermal carrier generation and electronic off-sets), background signal (mostly thermal radiation from the chamber window and from outside), linearity of response, ratio of responses at the two gain states, performance of the detector for two different bias levels, and overall radiometric response over the spectral range. The instrument was determined to be linear within the measurement error to detector saturation. The dark current, background, gain ratios and behavior at different bias are reasonable, stable and as expected. The overall spectral responsivity was most difficult to calibrate due to several factors, including an unexpected and unknown (at the time) change in a light source during the calibration effort. This effort has been enhanced during in-flight calibration efforts and the responsivity calibration seems to be converging.

In-flight calibrations were conducted at Venus only for the visual channel because the cooler cover was not yet removed from the IR channel radiator. The entire instrument calibration was tested at the Earth-Moon (for the Moon only) and the Jupiter fly-bys and for two star observations. The data are still being analyzed at this writing for the in-flight calibrations, but the general result so far is to further refine the calibrations and to gain better understanding of the instrument performance, which remains as expected.

One interesting characteristic experienced is the difficulty of achieving precise and stable calibration for sources smaller than the spectrometer slit width (sub-pixel sources). This is because the effective spectral resolution of the spectrometer and the exact location of the source image on the detectors depend on the size of the source and its exact location in the focal plane. Thus, it will be difficult to precisely predict radiometric performance for sub-pixel sources. Nevertheless, for sources that fill the slit, the instrument behavior is normal and as expected. The spectro-radiometric response function as currently known is given in figure 6.1. Improvements and changes are expected with time and more analysis. Thus, the reader is referred to the VIMS Planetary Data System (PDS) archive for appropriate calibrations to be used with flight data.

VIMS Visual Channel

The VIMS visual channel was constructed and calibrated in Italy, at Officine Galileo (Firenze, Italy). The VIMS-V was has been calibrated in two phase: 1) at the Officine Galileo (Firenze, Italy) premises, prior to the integration with the infrared channel; 2) at JPL after the integration on the remote sensing palette. The activity carried out at JPL was mainly devoted to geometric measurements; that is, co-alignment of the two channels and measurement of the relative radiometric response. Furthermore, the instrument spatial response (measurement of the image quality through the instrument Modulation Transfer Function and Point Spread Function) were evaluated as part of the Full Functional Tests performed at Officine Galileo (Firenze, Italy) prior to the calibration activity.

VIMS-V was placed inside a vacuum chamber equipped with a thermally stabilized radiator connected to the CCD and capable of keeping the CCD at a temperature in the range -20/+40 deg C under a residual pressure of lower than 10-4 mbar. The chamber has a window (TVC window) with transparency better than 0.9 throughout the entire spectral range. VIMS-V was mounted on two computer-controlled rotating tables for fine positioning around azimuthal and elevation angles. Two lamps were used to cover the full spectral range: a Xenon lamp for the range 0.3 - 0.4 microns, and a Tungsten lamp between 0.4 and 1.035 microns. The lamp with its housing, which includes a condenser and a diffusing screen to improve light uniformity, was positioned at the input slit of a Jobin-Yvon HR640 monochromator capable of better than 0.05 nm resolution (band width at half height) over the VIMS-V spectral range. The monochromator output was then used to illuminate a slit, pinhole or test targets (corresponding to a specific type of test) placed at the focus of an off-axis collimator. The collimated beam was fed to the instrument inside the vacuum chamber. Unfortunately, the collimated beam has as unknown spectral irradiance; thus, we had to devise a method to measure it. This was achieved using a beam splitter, of known optical properties, placed in the optical path at 45 deg C in front of the chamber window. The reflected portion of the beam was collected by a calibrated photodiode to monitor the irradiance output of the light source set up. An additional calibrated photodiode was placed every 50 nm (or 50 monochrometor steps) directly in front of the collimator to have direct calibration at the collimator aperture.

With the available collimator only 1/6th of the full VIMS-V FOV could be instantaneously illuminated, thus a time consuming procedure was implemented to repeat a full spectral sweep (0.3 to 1.05 microns in 1 nm steps) to cover the field of view of the instrument. The radiometric calibration of VIMS-V was as follows. The Unit Response of the instrument is defined as the output in Digital Numbers when the instrument entrance pupil is fed with a light beam of 1 W per square cm, and this beam is collected entirely into a single spectel and into a unit solid angle, for an integration time of 1 s. This quantity was directly measured along with its dependence on wavelength. The spectral calibration was performed in order to evaluate the spectrally weighted center of each channel as well as the spectral width. The spectral width of each Spectel is of 5 times 1.46 nm = 7.33 nm. For a detailed discussion on the calibration see Capaccioni et al. (1998).

We note that the radiometric transfer function obtained at OG during on ground calibration of VIMS-V when applied to the Moon and Venus illuminated side is insufficient to remove instrumental effects. Moreover two problems are apparent: a shift in wavelengths of about two nominal pixels and an inadequate removal of instrumental effects, particularly at short wavelengths. So we measured a new unit response function using the Venus and Moon data in the following way.

We use an Apollo 16 landing site telescopic reflectance spectrum (McCord and Adams, 1973) on a bright area on the Moon surface. This choice is supported by the fact that Apollo 16 landing site is on the lunar highlands where the albedo is particularly high.

GEOMETRIC CALIBRATION

For VIMS, the primary data product is, for each resolved pixel of a given target, the determination of both the pixel position and the full spectrum from 0.35 to 5.2 microns. To build such spectral images, for each picture element of any given 64 x 64 frame, the viewing direction of each of its 352 contiguous spectral elements (spectels) must be known. Thus, the prime goal of the geometric calibration of VIMS was to determine the relative viewing directions of all 96 VIMS-V and 256 VIMS-IR spectels within the full VIMS Field of View (FOV), in a frame to be referenced to the Cassini spacecraft.

A complexity originates from the basic difference in the way the spectral images are obtained by the two channels: VIMS-V operates in a push-broom mode, acquiring an entire cross-track line simultaneously spread over its spectral dimension (from 0.35 to 1.0 microns) along the second dimension of its CCD detector. The second spatial dimension is acquired either using the S/C drift or the scanning of the VIMS-V telescope secondary mirror. VIMS-IR uses only a linear array detector, thus it acquires one pixel only spread over its spectral dimension (from 0.85 to 5.2 microns). The cross-track spatial dimension is acquired by scanning the telescope secondary mirror (whiskbroom mode), while the along track dimension is acquired (as for VIMS-V) using either spacecraft drift or scanning the IR telescope's secondary mirror in two dimensions. With two distinct scanning mechanisms, telescopes, and spectrometers, the boresight alignment and the Instantaneous Fields Of View (IFOV) within the full FOV are not identical by design, and in principle, wavelength dependent. The geometric calibration is thus intimately coupled to the determination of these spectral registration effects.

Due to the late delivery of VIMS-V, the ground geometric calibration was performed in steps: the in-depth geometric calibration of VIMS-IR was performed first, prior to the integration with VIMS-V, followed by the geometric calibration of VIMS-V after its integration. After integration, a large misalignment was observed, requiring a global mechanical realignment of both the IR and V channels (out of the calibration chamber), followed by a few final control measurements (back to the calibration chamber) prior to integration with the Cassini spacecraft. Some in-flight calibrations were performed to assess the actual geometrical characteristics of both channels, when the instrument had reached its proper in-flight thermal regime, late during the cruise towards Jupiter.

During the ground calibration, VIMS was mounted on a fixed platform, thermally controlled and under vacuum. A collimator and optical bench assembly was constructed outside of the thermal-vacuum chamber, and viewed through a large window. For the geometric calibration, we chose to image with VIMS, two types of targets, both mounted on an X-Y stage to allow coverage of the entire VIMS FOV. In the target projector plane, one VIMS pixel (0.5 mrad) corresponded to ~ 1 mm. To cover the entire VIMS FOV, the target was 64 mm in size, and the stage was moved by steps of 0.1 mm (1/10 VIMS pixels). The first type of target consisted of linear blades to measure potential spectral registration effects by analyzing for each spectel the pixel response while the blade was moved across the pixel. The other target placed in the projector focal plane consisted of an opaque metallic target with a grid of sub-pixel sized pinholes (0.1 mm in diameter) evenly spaced, and back-illuminated by a tungsten lamp. The complete calibration data products are in the form of tables, one for each spectral channel, giving the viewing direction of each VIMS pixel. Below we summarize some of the main results.

The IFOVs of both channels were very accurately measured. Averaged over all wavelengths within a given channel, IFOVIR = 0.495 +/- 0.003 mrad, and IFOVVIS = 0.506 +/- 0.003 mrad. Although the differences look small (~ 2 %), they result in a relative VIMS-VIS/VIMS-IR misalignment over the entire 64-pixel FOV that is larger than one pixel, requiring a thorough geometric re-sampling of all image cubes larger than 32 pixels. Prior to launch, the last geometric measurement showed a boresight alignment between VIMS-V and VIMS-IR of better than 0.3 pixels at all wavelengths. Images coincide independent of wavelength to within < 0.5 pixel in frames up to 12 x 12 pixels.

The first measurements in flight were performed using both channels to observe the Moon during the Cassini Earth-Moon fly-by (08/18/1999). Those showed a boresight misalignment of VIMS-IR with respect to VIMS-V (-1 pixels, +2 pixels). Because the VIMS-IR had not reached its nominal thermal regime during the Earth-Moon flyby, it was concluded that at least part of misalignment was the result of thermal gradients in the IR channel that would lessen as the Cassini spacecraft moved farther from the Sun and the IR channel cooled. A recent calibration using the Pleiades cluster and the star Fomalhaut (late March, 2001) showed boresight offsets of (-1,0) pixels. The Pleiades observation shows the misalignment variation within the FOV, as illustrated in Figure 8 showing the various stars in the visual (blue pixels, averaged over the first 30 VIS spectels) and the near IR (red pixels, averaged over the first 40 spectels).

The ground calibration yielded for most IR spectels, the VIMS FOV, leading to spectral geometric 'distortion' maps. For images up to 32 x 32 pixels, all spectral images coincide to better than 1/3 pixel Larger discrepancies appear in the bottom right and top left corners of the frame, where spectral misalignments up to half a pixel are present. This is illustrated in the Figure 9, scaled in mrad, for three IR wavelengths (spectels 103, 150 and 206, at 0.98 microns, 1.75 and 2.68 microns, in red, blue and green respectively), enlarging the four corners and the center of the FOV geometric spectral responses.

Finally, the spectral registration effects measured for the IR spectels were demonstrated very low, as illustrated in the figure: the huge sensitivity of the measurements allow detection of effects at a scale smaller than 1/10 pixel. With this resolution, the larger effects we see between contiguous spectels actually amount for 1/10 px, and in fact result from atmospheric contributions during the calibration (variation of H2O and CO2 features). The only large-scale effect present (black curve) has a very low frequency (at the scale of the entire spectral range), and likely results from optical aberrations within the IR spectrometer. It is both smooth and small enough to minimize the risk of misinterpreting potential large optical contrasts in the observed scene in terms of false spectral signatures.

SPECTRAL CALIBRATION

The goals of the spectral calibration of VIMS were to measure the spectral response of each VIMS spectral channel to determine the central wavelength and spectral profile of each detector, and its spectral stability as a function of temperature and spatial position within the field of view of the instrument. To achieve this, the tests included: 1) scanning a nearly monochromatic line (using a calibrated grating monochrometer) over the VIMS wavelength range to map the spectral profile of each VIMS detector, 2) transmission spectra of materials with sharp absorption bands, and 3) measuring reflectance spectra of minerals and other targets with VIMS.

The monochrometer scans were useful for a single position in the full VIMS field of view because the relatively large field of view of the VIMS could not be covered with the narrow exit slit of the monochrometer, and small shifts in wavelength were observed in the monochrometer as a function of distance along the slit. This results because a change in direction along the slit results in a slight change in the field position in VIMS that corresponds to an angular movement. Such changes require a change in the light path through the monochrometer with a corresponding change in the effect output wavelength of the monochrometer. Thus the monochrometer tests were done on axis only. The monochrometer was typically scanned at 1 nm increments to map out the profile of each VIMS spectral bandpass.

Calibrated transmission filters consisting of a mylar sheet displaying sharp absorption bands in the 1-3.5 micron region, with broader features at longer wavelengths, and Corning glass filters containing rare-earth elements which give sharp absorption features in the visual and near-infrared wavelength regions, and broader absorptions at longer wavelengths were used to cover the full VIMS field of view. Because of their uniformity and stability, the filters were used to determine the stability of the VIMS wavelength response as a function of spatial position, temperature, and time (because two tests were done over a period of about 6 months).

To measure VIMS response to real targets with spectral features, a set of minerals and other materials were assembled into a spectral target and measured in reflectance. Because the calibration geometry was optimized for other tests, the setup for reflectance measurements was not ideal, so these tests are more qualitative. The light source used to illuminate the samples was set up at relatively large angles to the normal to the surface of the highly scattering surface of the spectral target, the exact viewing geometry is difficult to assess. Furthermore, only vertical samples could be measured, so it was not possible to measure the reflectance of unconstrained, loose particulate samples. Measurements were made of rocks and solid samples that typically had large grains, thus the absorption bands were deep and saturated, but the spectra of these rocks are quite identifiable with the VIMS.

The spectral calibration tests showed that VIMS is a remarkable instrument, producing spectra comparable in quality to specialized laboratory spectrometers. The large spectral range of the VIMS, ~0.2 to 5.1 microns includes the region of increasing thermal emission at room temperature making the light reflected from the sample difficult to separate from the background thermal emission. The spectral range of VIMS is greater than the spectral output any single convenient laboratory light source, so tests were often done multiple times with different light sources.

Spectral calibration of VIMS occurred in three separate steps. The Visual channel was calibrated separately in Italy prior to integration with the IR channel at JPL. The IR channel was calibrated in the thermal vacuum tests at JPL January 28 to February 5, 1996. The integrated instrument was further tested at the JPL thermal vacuum facility July 16-17, 1996. This final test was limited and only included filter transmission and mineral target tests.

The spectral calibration resulted in a specification of the wavelength position and bandpass of each VIMS spectral channel across the instrument field of view and as a function of temperature. The VIMS-IR spectral response is identical across the full field of view to within about a nanometer (nm) over the temperature range tested. The VIMS-IR sampling interval is about 16 nm in the IR, thus a 1-nm shift is a small fraction is < 7% of the sampling interval. The VIMS-V has a sampling interval of ~7 nm and tests show stability to better than about 0.3 nm.

POLARIMETRIC CALIBRATION

The VIMS instrument contains no specific polarimetric capability, such as filters or grids, but the design of the grating spectrometer makes it inevitable that the instrument's response will be linearly polarized to some extent. The purpose of the polarimetric calibrations was to characterize this sensitivity, so that its effect on the accuracy of spectra obtained for both polarized and non-polarized targets in the Saturn system can be assessed. In general, spacecraft pointing constraints will determine the roll attitude of the ORS instruments during targeted observations, leaving little opportunity for observations at multiple roll orientations.

Measurements for the polarization characterization of the VIMS IR channel were carried out in the 10 ft thermal-vacuum tank in Bldg 144 at JPL, during Jan 17-20, 1996. A target projector was set up with a 26 mm diameter IR linear polarizing filter at the focal plane of a collimator. The target was illuminated by the 1-inch output aperture of an integrating sphere, producing a polarized image of the exit aperture of the sphere at the VIMS focal plane. The polarizer consisted of a ZnSe substrate with a deposited aluminum wire grid, and its polarization efficiency is documented from 2.5 microns to beyond 10 microns. The average single-polarizer throughput is 38%, while the maximum cross-polarized throughput over the 2.5- to 5.0 microns range is 1.5%. No data on the filter transmission were available below 2.5 microns. A calibrated tungsten source with a Teflon-coated sphere provided adequate SNR out to about 2.5 microns, while a glowbar source with a gold integrating sphere provided adequate SNR at all wavelengths beyond 1.5 midrons.

Measurements were made at 5 spatial positions of the source in the target plane, on boresight and near the 4 corners of the VIMS field. For each source position, measurements were made at 7 settings of the polarizer, at 30 degs intervals between +90 degs and -90 degs, followed by a sequence of background measurements with the shutter on the light source closed. Only the VIMS IR channel was available for these measurements. Three cubes per measurement were co-added and background-subtraction spectra were extracted both for a central spot in the image of the source and for a larger region which included the full output aperture of the sphere. This was accomplished at each orientation of the polarizer and for each source position.

SOLAR PORT CALIBRATION

The Solar Calibration Port (henceforth cal port) was installed within the VIMS IR telescope in order to permit the instrument to obtain a strongly attenuated spectrum of the sun during the Cassini mission, which would in turn facilitate reduction of VIMS spectra to an accurate scale of relative reflectance. The cal port is pointed at an angle offset by 20 degrees from the instrument boresight towards the -Z direction, aligned with the UVIS solar occultation port. Attenuation of the incident solar beam by a factor of approx. 2.5 x 10-7 is achieved by (i) the small aperture of the cal port, compared to the main beam and (ii) a series of one 70 degs and five 90 degs reflections from right-angle prisms made of ZnSe. Most of the incident flux is returned out of the entrance aperture by internal reflection in the prisms. The beam exiting the cal port is focussed by the IR telescope optics onto the VIMS-IR entrance slit, and then enters the spectrometer in the normal way. But because the cal port aperture samples only a portion (~0.3%) of the full instrument aperture, the collimated beam illuminates only a small part of the diffraction grating. The optical design ensures that this region overlaps the short- and medium-wavelength blaze regions on the grating, in the ratio 1:3. The solar port does not illuminate the long-wavelength blaze.

The predicted throughput of the stack of prisms varies smoothly from 1.35 x 10-4 at 0.85 microns to 1.09 x 10-4 at 3.0 microns and 1.04 x 10-4 at 5.0 microns, for radiation linearly polarized in a plane perpendicular to the plane containing the incident and exit beams and to the rulings on the VIMS diffraction grating. The transmission of the orthogonal polarization is less than 1.0 x 10-7. The output spectrum of a target seen through the cal port differs from that produced by the same source seen on the instrument boresight due to a combination of polarization and partial illumination of the grating blazes. The purpose of the solar cal port calibrations is to establish the ratio of the spectrum of an unpolarized broadband source as seen through the cal port to that of the same source on the instrument boresight.

The simulated solar source used for the calibration runs was a high-power xenon lamp, illuminating a large, white, teflon-coated integrating sphere. The output of the sphere illuminated a 1 mrad diameter circular aperture in the focal plane of the calibration projector (equal to the angular size of the sun at 9 AU), after a 90 degs reflection from an aluminum plate. One side of this plate was polished and oriented for specular reflection of the high-intensity beam onto the target for the cal port runs, while the other was sand-blasted to provide diffuse reflected illumination of the target for the boresight runs.

All measurements were made on July 12, 1996, in the 10 ft thermal-vacuum chamber at JPL. Inside the tank, a deployable periscope-like arrangement with two aluminum mirrors was used to redirect the input beam into the cal port's entrance aperture. The input signal to VIMS thus experienced identical atmospheric paths, with the same number of reflections, for both cal port and boresight runs. Only the IR channel was available for these runs; the VIS channel was calibrated separately at Officine Galileo (Firenze, Italy). For each observation multiple 8 x 8 image cubes were taken, centered manually on the image of the target.

A total of 100 separate solar port image cubes were background subtracted and averaged in sets of 10, and all pixels co-added to produce spectra. Twenty boresight cubes were processed in identical fashion. Figure 10 shows the average boresight and solar port spectra, at the DN levels originally recorded. The resulting ratio spectrum is displayed in Fig. 15, normalized to an average value of unity. Data for 9 channels at the three filter segment boundaries have been interpolated in both plots.

The ratio spectrum shows that the cal port sensitivity is relatively low shortward of IR channel 50 (1.7 microns), increases rapidly between channels 50 and 70 to a peak at channel 80 (2.2 microns), and then declines smoothly at longer wavelengths. Oscillations near 2.7 and 4.3 microns are due to imperfect cancellation of CO2 absorption features in the raw spectra. The high-frequency structure beyond of 4.0 microns is an artifact of the array readout.

The decline in sensitivity of the cal port relative to the main aperture at longer wavelengths is attributable to the lack of illumination of the long-wavelength grating blaze, and to the increasing polarization sensitivity of the IR channel beyond 3 microns (see Sec 7.1.5). The steep drop shortward of 2 microns is, on the other hand, unexplained. Neither the ZnSe prisms nor the several aluminum reflections seem to be capable of causing this effect. Additional experiments showed no indication of a misalignment in the projector illumination pattern. Previous calibration runs on June 26, 1996, which did not use the external Al plate, did not achieve sufficient SNR at the longest wavelengths. Nevertheless, these earlier results are not consistent with the final runs at short wavelengths, for reasons that are presently unknown. Thus, the solar port ratio spectrum in Fig. 15 must be considered provisional, and subject to revision on the basis of in-flight experience.

Viewed through the IR solar cal port, images of a circular target are noticeably elongated. FWHM dimensions are ~2.0 pixels in X, but increase steadily from 2.8 pixels in the Z direction at 1 microns to 4.1 pixels at 5 microns. This may be compared with FWHM sizes for the boresight images of 1.5 x 2.2 pixels for the same target. The elongation of the solar port images is due to diffraction at the elongated rectangular aperture of the cal port (30 mm x 5 mm). Image centroids are fairly stable, varying in X by at most 0.3 pixels and in Z by at most 0.2 pixels. Because of the variable size and slightly wavelength-dependent position of the solar image, it is recommended that solar cal port images be co-added over at least an 8 x 8 pixel region in order to obtain a stable, well-defined spectrum. No precise information is available from the ground calibrations on the absolute pointing of the solar cal port, but this is believed to be within 0.5 degrees (17 pixels) of nominal and will be readily verified with in-flight observations of the sun."

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