On-Orbit Solar Radiometric Calibration of the Hyperion Instrument

P. Jarecke, K. Yokoyama, P. Barry
Electro-Optics and Technology Department
TRW, Redondo Beach, CA 90266

ABSTRACT

The end-to-end calibration plan for the Hyperion EO-1 hyperspectral payload is presented. The ground calibration is traceable to a set of three high quantum efficiency p-n silicon photodiode trap detectors the responsivities of which are traceable absolutely to solid state silicon diode physical laws. An independent crosscheck of the radiance of the Calibration Panel Assembly used to flood the Hyperion instrument in field and aperture was made with a transfer radiometer developed at TRW. On-orbit measurements of the sun's irradiance as it illuminates a painted panel inside the instrument cover are compared to the radiance scale developed during pre-flight calibration. In addition, an on-orbit calibration lamp source is observed to trace the pre-flight calibration constants determined on the ground to the solar calibration determination.

1. INTRODUCTION

The absolute radiometric calibration of the Hyperion instrument is traceable to a detector based radiometric scale of spectral irradiance. The illuminating radiance used for Hyperion calibration is a Spectralon panel source. The conversion from the irradiance standard to radiance relies on the diffuse reflectance properties of Spectralon and is cross-checked using a transfer radiometer using an independently measured AΩ. The instrument spectral responsivity obtained from this ground calibration is transferred to an in-flight calibration source (ICS) located in the telescope baffle using miniature quartz tungsten halogen lamps. These lamps provide an initial check of on-orbit calibration after launch and a transition to a solar-based measurement of long term responsivity repeatability. Solar and lamp illumination flood a diffuse reflectance surface on the back of the telescope cover. Hence, ICS and solar calibration rely on the ground characterization of the diffuse reflectance. An absolute determination of the solar spectral irradiance with Hyperion measurements is made as a cross-calibration of absolute responsivity.

2. CALIBRATION TRANSFER FROM THE PRIMARY STANDARD

2.1 The Primary Absolute Radiometric Scale

Three detector-based irradiance standards form the basis for the absolute primary radiometric scale. They each are fitted with a different precision entrance aperture. Two of the standards are of the high quantum efficiency (HQE) photodiode trap detector design. The description of the design and validation of the trap detector is described extensively (e.g. in Geist (Ref 2). The two independent HQE trap detectors are a UDT (Graseby) QED-150 that uses three EG&G UV444B Silicon detectors and an SPR-73, that is supplied by Cambridge Instrumentation and Research, Inc (CRI). The SPR-73 uses three windowless Hamamatsu S1337-1010 detectors. The third primary detector standard used here is the LaserProbe Inc. RS-5900 SN 9409-035 electrically calibrated pyroelectric radiometer (ECPR). This absolute self-calibration technology was developed by Doyle (Laser Precision Corp) and Geist (NIST) (Ref 3).

The source of radiant power for realizing an irradiance scale at TRW is the Sylvania FEL 1000 watt Quartz Tungsten Halogen (QTH) lamp. Four lamps (part number OL FEL-C), purchased from Optronics Inc. Two (SN F-543 and SN F-544), were calibrated by Optronics Laboratories, Inc. relative to the same type of lamp which Optronics procured from the National Institute of Standards and Technology (NIST).

2.2. Transfer to the Calibration Panel Assembly (CPA)

To create a secondary standard source of radiance, which fills the full aperture and field of the Hyperion sensor, an assembly is used to hold the FEL lamp at a distance of 0.50 meters from a 0.25 meter square plate of Spectralon. The lamp illuminates the plate at a normal angle and the Calibration Panel Assembly (CPA) is mounted on the door of the vacuum chamber used for radiometric calibration of the sensor. The sensor views the plate from inside the chamber through an uncoated SiO_2 window.

To first order, the radiance from the Spectralon plane is the incident lamp irradiance divided by π if the BRDF of the panel is perfectly Lambertian. It is critical to know the BRDF and reflectance of the plate over the angles and spatial extent viewed by the sensor. The lamp filament varies in distance from the plate over the extent of the view or footprint of the sensor on the plate resulting in a $\pm$ 7 degree variation in angle of incidence; hence, a rolloff of irradiance as large as 2.5 % occurs at the edges of the sensor view of the plate. The BRDF angle of scatter of the lamp irradiance to the sensor varies from 19 degrees to 33 degrees. The rolloff, calculated from BRDF data, is confirmed by using an ASD Field Spec spectral radiometer. The radiometer, used at 5 degrees FOV, was placed viewing the panel at an angle of incidence of 26 degrees which is identical to the Hyperion view.

As a cross-check of the properties of the Spectralon used to convert irradiance to radiance, a transfer radiometer is employed that uses an off-axis parabola mirror and a fold mirror with a precision entrance aperture of 2.22 cm and the SPR-73 trap detector. The expected signal from the trap detector in the transfer radiometer is calculated using the measured lamp irradiance, the reflectance properties of the Spectralon and the throughput of the transfer radiometer. The throughput is determined from the $A\Omega$ of the transfer radiometer, which is calculated from precision measurements of the aperture areas, spectral reflectances and the focal length of the off-axis parabola (OAP) in the radiometer. The agreement between the transfer radiometer predicted and measured CPA radiances is better than the error budget of $\pm$ 1.5 %. A complete description is given in Jarecke (Ref 1).

The Hyperion instrument is calibrated by viewing the CPA through an SiO_2 vacuum chamber window. The ICS radiance is then derived from spectrometer instrument measurements of the illuminated ICS cover panel.

3. ON-ORBIT CALIBRATION

3.1. The Internal Calibration Source (ICS)

The ICS uses four Welch Allyn quartz tungsten halogen (QTH) lamps (1.06 Amp, 4.25 Volt) to illuminate the back of the telescope cover in the closed position. The cover, located at the aperture stop of the telescope, is painted with an IIT Research Institute S13GP/LO-1 diffuse, reflecting, white, silicone, thermal control paint. The lamps are powered in two pairs making a primary and a secondary set. Two lamps per set are required to achieve an adequate level of illumination.

Fifteen lamps were selected for a life test. Each lamp was powered individually with its own solar cell detector, mounting fixture, and constant current power supply. The lamps were operated continuously at a constant current of 0.98A. Relative radiant output was monitored along with the voltage across the lamp terminals and current through the bulb filament. The lamps were operated for 50 hours. At this point the lamp output had decreased by 1 to 6 %. Six lamps of the original set which spanned the range of stability exhibited at 50 hours of operation were selected to be operated beyond the expected 146 hr lifetime of the Hyperion instrument. These six lamps were operated for a total of 218 hours with no failures. After 150 hours of operation, the light output decreased by 4 to 10 % with one bulb decreasing by 17 %

However, one of the primary set of lamps failed after 6 hours of pre-flight thermal vacuum testing. The reason for the failure could not be determined during failure analysis. The secondary set exhibited an initial increase in output after launch which can be modeled by an increase in filament temperature of 100 Kelvins. This is consistent with expected decrease in convection cooling between the filament and the glass envelope experienced in the zero gravity environment of space. Since the initial increase in output over the pre-flight irradiance, the output has decreased by 3 percent during the first 140 days of on-orbit operation as referenced to the solar calibrations.

3.2 Solar Calibration

The responsivity of the Hyperion radiometer has been used to derive a measure of the solar spectral irradiance by viewing the sun on-orbit. The first solar data collect with both the VNIR and the SWIR focal planes operating was on December 12, 2000. The sun nominally is incident on the back of the telescope cover at a 53 degree angle of incidence. The solar calibration data are collected at 53 degrees and the field of view of Hyperion is only 0.43 degrees. To assure that the pointing was correct, the spacecraft was maneuvered so that the sun angle varied over ± 6 degrees about normal to induce vignetting of the solar radiation by the solar baffle. Due to these checks in initial verification of spacecraft pointing, the first solar calibration with certain solar position knowledge occurred on February 16, 2001.

The most uncertain part of the solar calibration is the correction for the spectral diffuse reflectance of the paint. The bi-directional reflectance distribution function (BRDF) of the paint was measured relative to a barium sulfate standard reflectance sample using the TRW Optical Scatter and Contamination Effects Facility at 0.515 µm, 0.63µm, 1.15 µm, and 1.56 µm. The measurements were made on witness samples painted with paint from the same lot as that used to paint the actual cover at the range of angles covering the solar illumination angle (53 ± 6 degrees) identified above. The wavelength dependence of the variation of the diffuse reflectance was measured with both a Cary 5 spectrometer in a hemispherical reflectance mode and with an ASD Field Spec spectral radiometer at the solar calibration scatter angle.

The solar calibration is made at precisely 53 degrees, but a special solar data collection was made by scanning the spacecraft so the sun was occulted by the solar baffle in a way to assure the scatter angle was correct.

Three spectral solar irradiance models were used for the cross-comparison. One is the spectral solar irradiance data which was published in the World Climate Research Programme by C. Wehrli (Ref 4). The second was by G. Thuillier (Ref 5) and the third was by R. Kurcuz (Ref 6). These spectral radiance curves are normalized by equating the total spectral integral over wavelength to the solar constant as defined by the World Radiance Reference, that is absolutely accurate to better than 1 %, by using irradiance scales established by active cavity radiometers operating in ambient conditions.

The comparison of the solar spectral irradiance in the three models above with the Hyperion determination is shown in Figure 1 in the VNIR (500 nm – 850 nm) spectral region where the agreement is about ± 2 %. The solar model data has been smoothed to 10 nm (the Hyperion spectral resolution). Figure 2 shows the ratio of the WRC (Ref 4). solar model to the Hyperion determination in the SWIR spectral region.

Figure 3 shows the long term repeatability of the solar calibration at four VNIR wavelengths. The curves are labeled with pixels numbers 20, 30, 40 and 50 which are at 557 nm, 650 nm, 751nm and 854 nm respectively. Figure 4 shows the long term repeatability of the solar calibration at four VNIR wavelengths. The curves are labelled with pixels numbers 90, 120, 150 and 200 which are at 1044 nm, 1346 nm, 1649 nm and 2153 nm respectively. The earth-sun distance variation has been removed. The stability is at the 1 % level.

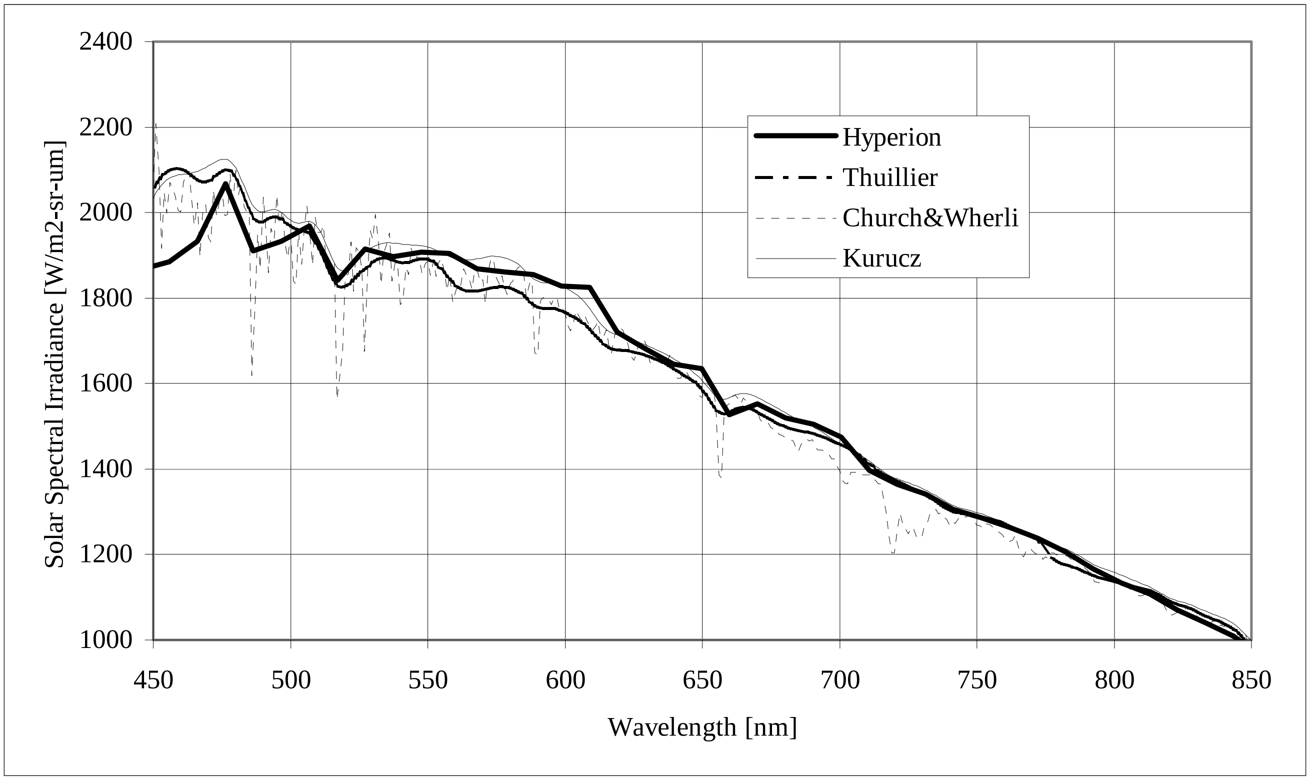

Fig. 1. Comparison of solar models with Hyperion measurement of solar spectral irradiance

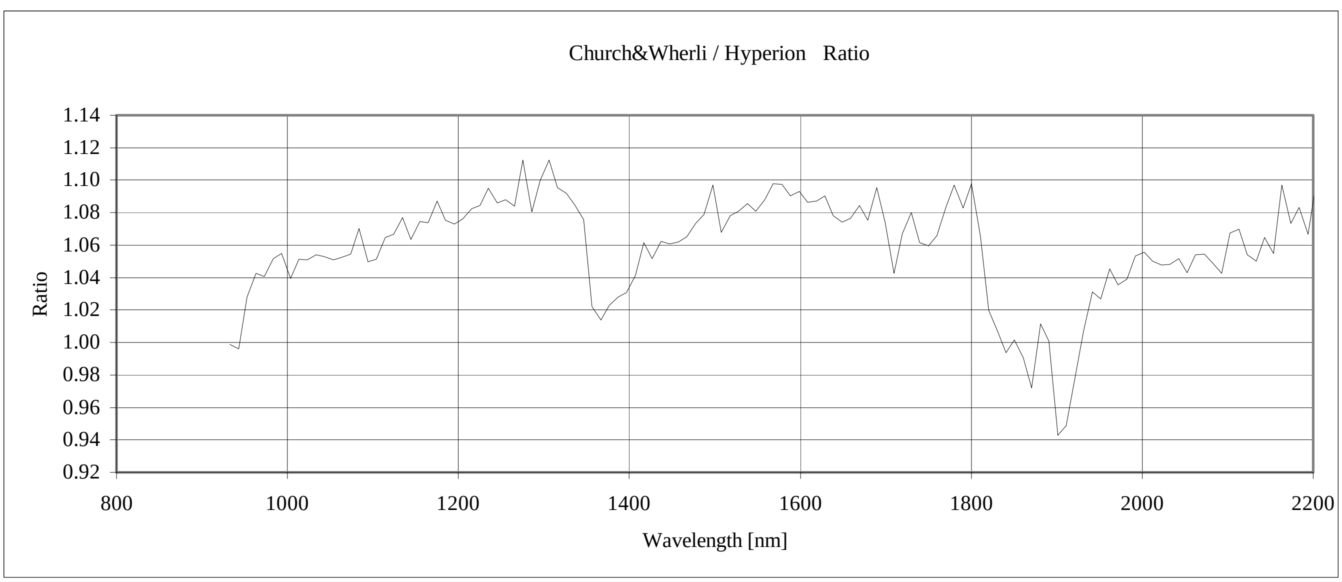

Fig. 2. The ratio of the Church-Wehrli solar model to the Hyperion measurement. The sharp drops in the ratios in the 1100 to 1900 nm region are located at absorption features in the diffuse white paint on the cover indicating the diffuse reflectance data for the paint are too low at the scatter angle used. Beyond 2200 nm the paint absorption becomes too dominant to permit a reasonable solar measurement.

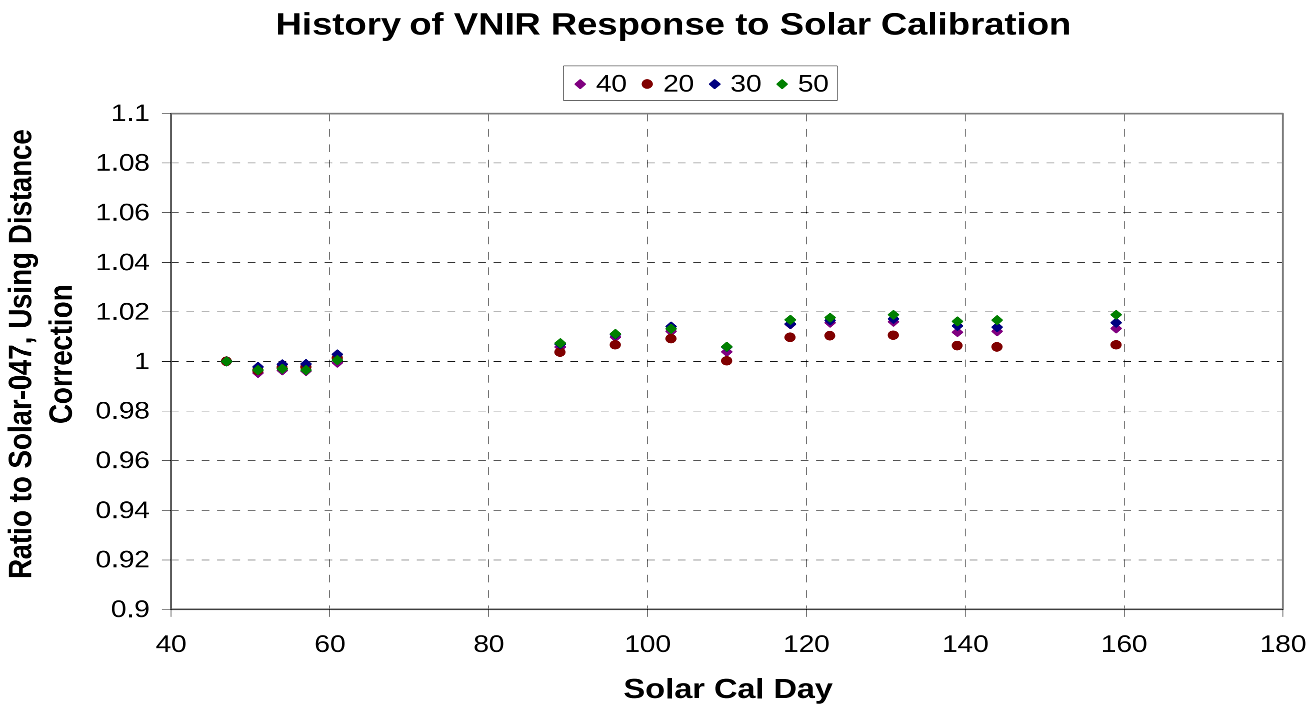

Figure 3. Long term solar calibration repeatability for four Hyperion wavelengths in the VNIR

.

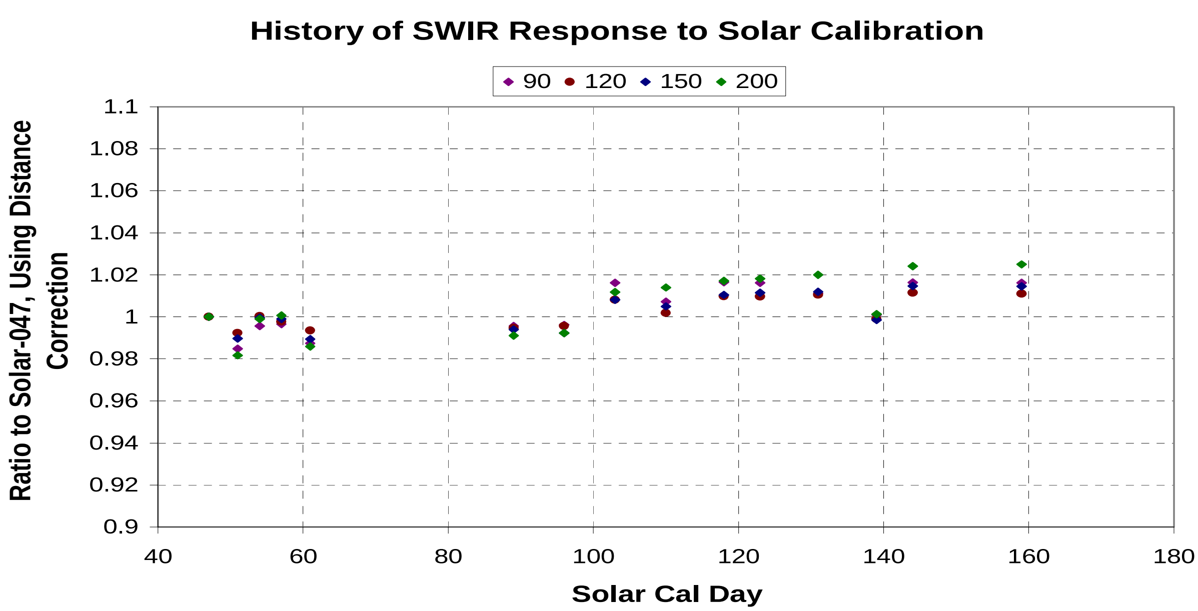

Figure 4. Long term solar calibration repeatability for four Hyperion wavelengths in the SWIR

4. CONCLUSION

As a check of the model for the Hyperion diffuse reflectance panel used for the solar calibration, the results of the ground truth campaign carried out at Lake Frome, Australia on January 5 and 21, 2001 are used. The top of the atmosphere radiances were calculated using an atmospheric effects model and measurements of the spectral reflectance of the ground at the several locations. This replaces the uncertainty of the Hyperion cover panel diffuse reflectance with the ground truth characterization uncertainty, but in an entirely independent way. In addition, cross-calibration has been carried out between platforms with Landsat 7 ETM+. The results, of these comparisons are presented in other papers in this session.

REFERENCES

1. P. Jarecke, K. Yokoyama, "Radiometric Calibration of the Hyperion Imaging Spectrometer Instrument From Primary Standards to End-to-End Calibration" ", *Proc. of SPIE*, Vol. 4135, pp.254-263, August 2000.

2. J. Geist, E. Zalewski and A. Schaefer, "Spectral Response Self-Calibration and Interpolation and Silicon Photodiodes", *Appl. Opt*., **19**, 3795 (1980)

3. M. Doyle, B. McIntosh and J. Geist, "Implementation of a System of Optical Calibration Based on Pyroelectric Radiometry", *Optical Eng*., **15**, 541, (1976)

4. C. Wehrli, World Radiation Center Davos-Dorf, Switzerland, (WCRP) Publication Series No. 7, WMO ITD-No. 149, pp 119-126, October 1986.

5. G. Thuillier, M. Herse, P. C. Simon, D. Labs, H. Mandel, D. Gillotay, and T. Foujols, "The visible solar spectral irradiance from 350 to 850 nm as measured by the SOLSPEC spectrometer during the ATLAS-1 mission", *Solar Physics*, **177**, 41-61, 1998

6. Kurucz, R. L., I. Furenlid, J. Brault, and L. Testerman, Solar Flux Atlas from 296 nm to 1300 nm, National Solar Observatory Atlas No. 1, 1984.