# VIIRS Initial Performance Verification

## Subassembly, Early Integration and Ambient Phase I Testing of EDU


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*Abstract*—**This paper will examine the initial results of performance verification testing of the first VIIRS sensor, the Engineering Development Unit (EDU). The EDU was completed and began the initial stages of integration testing in late 2004. As the EDU progresses through ambient and thermal vacuum testing, test data are collected, analyzed, and evaluated. Raytheon SBRS evaluates the data for compliance with sensor specifications. Northrop Grumman evaluates the data to ensure the 21 NPOESS System EDRs to which the VIIRS sensor contributes are satisfied. Initial performance estimates that have been derived from sensor models and updated based on subassembly testing are then measured against test data, at each stage of the test plan.**



*Keywords— NPOESS; VIIRS; remote sensing; infrared; visible; imagery; radiometry*


## I. INTRODUCTION

The NPOESS Integrated Program Office (IPO), in a Shared System Performance Responsibility (SSPR) capacity with prime contractor Northrop Grumman Space Technology (NGST) and sensor supplier Raytheon Santa Barbara Remote Sensing (SBRS), is developing the Visible Infrared Imager Radiometer Suite (VIIRS) for the National Polar-Orbiting Operational Environmental Satellite System (NPOESS). The NPOESS next generation environmental remote sensing platform is slated to replace the current military and civilian operational polar-orbiting environmental systems in 2010. The NPOESS program is a tri-agency office established by the Department of Defense (DoD), the Department of Commerce (DOC), and National Aeronautics and Space Administration (NASA), as mandated by a 1994 Presidential Directive [4]. NPOESS will provide operational data products for military, civilian, and science applications, as well as direct downlink at no cost to worldwide users. The first VIIRS sensor will be integrated onto a NASA-provided, Ball Aerospace-built spacecraft, the NPOESS Preparatory Program (NPP) satellite. The NPP mission will provide risk reduction for the operational NPOESS constellation as well as continuation of NASA's earth sciences program. The following six planned VIIRS sensors will fly on each of the Northrop Grumman-built NPOESS spacecraft.

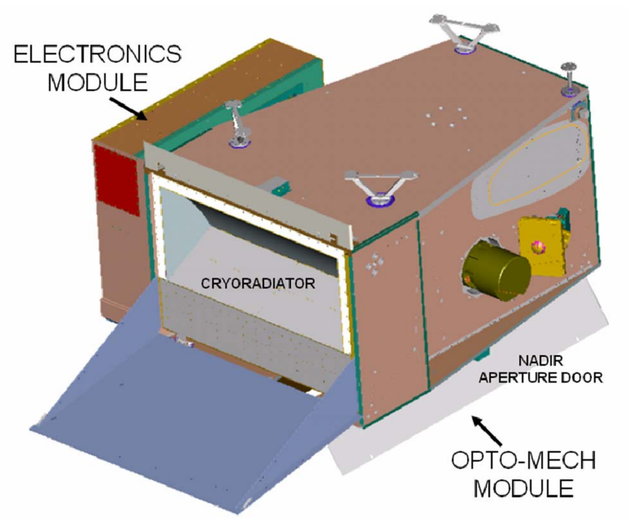


Fig. 1. General configuration of VIIRS instrument

The VIIRS sensor is a nadir-viewing, cross-track scanning, continuously operating electro-optical imaging instrument. It is designed to measure earth and atmospheric spectral radiance in the infrared and visible spectrum from an altitude of 833km, and must operate on-orbit for seven years without servicing [3]. High radiometric accuracy and tight band-to-band registration are necessary to meet the broad set of requirements. The sensor collects radiometric and imagery data in 22 bands within the visible and infrared spectral regions (from 0.4 to 12.5 µm). The sensor has been optimized to facilitate production of 21 environmental data records (EDRs) including land, ocean, and atmospheric environmental parameters. These EDRs include cloud characteristics such as temperature, cover and layers; aerosol size and distribution; land characteristics such as

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14. ABSTRACT

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ground surface temperature, snow cover, vegetation coverage; and body of water features such as ocean color/chlorophyll. Two of the VIIRS sensor's most important EDR products, called Key Performance Parameters (KPPs), are sea surface temperature (SST) and imagery. The sensor must meet established requirements for these EDRs to be declared operationally effective.

## II. PERFORMANCE REQUIREMENTS

Early in the program, a set of prioritized EDRs and associated performance characteristics were chosen and defined in the Integrated Operational Requirements Document, version 1 (IORD-I), and were later updated in Version 2 [1]. As an example, attributes for the SST EDR, set forth in the Sensor Requirements Document (SRD) [2] and maintained in Appendix D of the NGST NPOESS System Specification [9] (from which the NGST VIIRS Performance Specification [10] is derived), include horizontal cell size and sampling interval as well as accuracy, precision, and uncertainty [4] for both skin and bulk SST. Raytheon derived optimal system specifications and hardware designs from the EDR requirements [5], and the derived sensor specifications are contained in the VIIRS Sensor Performance Specification [6]. Raytheon is on contract to meet these specifications, while NGST is required to ensure the top level EDRs are met.

Satisfying all the VIIRS EDRs with one instrument was a very challenging prospect, and the current VIIRS sensor design reflects a considerable effort in balance of competing performance requirements and optimization. Fine horizontal spatial resolution (HSR, aka inverse Modulation Transfer Function or MTF), excellent moderate horizontal cell size (HCS) and wide dynamic range to meet Department of Defense imagery needs had to be balanced with low infrared noise equivalent temperature differences (NEdT) and high optical Signal to Noise Ratio (SNR) for ocean color and sea surface temperature EDRs, which also required excellent calibration and band-to-band registration. Prior to the Critical Design Review in March 2002, Raytheon developed an end-to-end testbed to provide an initial verification of system performance. Since October 2002, NPOESS System Engineering at NGST has been responsible for subsequent EDR algorithm development and end-to-end system performance verification, tracking both EDR software and VIIRS hardware changes. Development of all VIIRS EDR algorithms that support the NPP mission is complete, and the baseline "science" versions of these algorithms are currently being converted into equivalent "operational" codes optimized for ground processing speed. System-level testing of complete VIIRS EDR algorithm chains is scheduled to occur in FY06.

## III. COMPREHENSIVE TEST PLAN

The VIIRS General Test Plan [3] details the overall test plan for the sensor and how verification will be performed at the sensor level after the OptoMechanical and Electronics Modules are integrated. Data collected from these tests will be used to verify compliance with the VIIRS Sensor Performance Specification. The test plan describes the test progression and contains a matrix identifying which tests are to be conducted under certain environments. It also provides a description of each test, test objectives and requirements satisfied, sensor configuration, and related equipment. The Performance Verification Plan [7] describes in detail how the requirements in the Sensor Specification will be verified.

There are three major types of sensor tests: Sensor Integration (SI), Functional and Performance (FP), and Radiometric Characterization (RC) tests. Initially, the sensor undergoes two Safe-to-Mate tests prior to electronic connection of the Electronics Module to the OptoMechanical Module. Next, four SI tests are conducted to verify that the combined sensor unit is ready for performance testing. Ambient Characterization tests are conducted in two phases and comprise 13 distinct tests. Finally, there are six Pre-Thermal Vacuum tests and 13 Thermal Vacuum tests along with thermal cycling and thermal balance tests.

VIIRS performance testing is conducted initially under laboratory ambient conditions [Fig 2] followed by tests in the thermal vacuum chamber. Sensor Ambient Characterization tests for sensor performance verification include Spatial Performance (MTF, HSR, HSI, and IFOV), Spectral Band Registration, Dynamic Range and Radiometric Sensitivity, Polarization Sensitivity (Near Field Response and Stray Light Response), and Response versus Scan Angle. Thermal Vacuum Characterization tests, which are performed at three temperature plateaus, include Spatial Performance (MTF, HSR, HSI, and IFOV), Spectral Band Registration, Radiometric Sensitivity, Radiometric Response Characterization, Crosstalk (reflective bands characterized in ambient pre-TV), and Relative Spectral Response (reflective bands characterized in ambient pre-thermal vacuum testing).

Lessons learned from execution of these tests for the EDU, and from subsequent EDU test data analyses, are used to enhance the test program for the Flight Units.

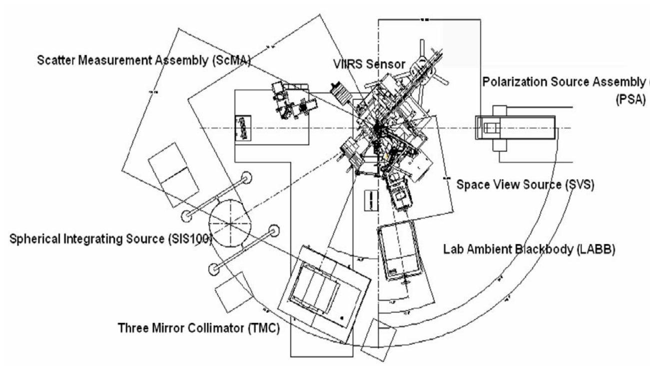


Fig. 2. VIIRS ambient testing laboratory plan view

## IV. EXPECTED PERFORMANCE

All VIIRS model predictions at this stage in the program are based on a combination of component data, subassembly data, error budgets, and analysis. Raytheon uses a detailed Parametric Performance Model in which all relevant hardware parameters are input to yield Signal to Noise Ratio (SNR), Noise Equivalent delta Temperature (NEdT), and dynamic range estimates. Northrop Grumman has independently developed a general-purpose Visible/Infrared Radiometric Imaging Sensor Model that supports its NPOESS Integrated Weather Products Testbed (IWPTB). When tailored for VIIRS, the NGST sensor model similarly reports predicted SNR and NEdT (confirming Raytheon's model) and is also used to produce simulated VIIRS RDRs and SDRs (Raw Data Records and calibrated Sensor Data Records, respectively) for use in NGST's end-to-end EDR performance testing. Explicitly included in the NGST sensor model are time-dependent noise sources (e.g., 1/f-noise, drifts, jitter) and calibration errors due to inexact knowledge of sensor response, as a function of cross-track scan angle in particular.

The Raytheon and NGST models were built using initial hardware performance parameters based on the sensor design; and as hardware is fabricated, assembled, and tested, the design numbers are replaced with as-built values, and the models are validated against actual EDU and Flight Unit test data. Model predictions based on performance values as of January 2005 reveal that, at the SDR level, the VIIRS sensor at end of life (EOL) is expected to satisfy all SNR, NEdT, and dynamic range requirements with margin in worst case conditions at the edge of swath (EOS). At the EDR level, performance predictions from IWPTB are similarly encouraging in general, although some EDR algorithms are recognized as pushing the current state-of-the-science, and the EDR performance of others, such as ocean color/chlorophyll, remains continually at risk due to very stringent calibration requirements.

Figure 5 summarizes the band set, associated driving EDRs for each band, radiance gain settings, typical radiance levels, required and predicted band-average performance in terms of SNR or NEdT (K), and EOL performance margin for Flight Unit 1 as of January 2005. The dual gain bands employ two different electronic gains using the same detector set to cover the entire required dynamic range, and performance requirements and predictions are presented separately for each electronic gain state. Bands M1-11 and I1-3 performance are presented as Signal to Noise Ratio (SNR, dimensionless). Bands M12-16 and I4-5 performance are presented as NEdT (K). Values represent expected performance of Flight Unit 1 operating at f/6.2. The term "f/#" is called the f-number, or "focal ratio", where # = effective focal length divided by the diameter of the entrance aperture. The EDU system as built is f/6.0, but to achieve the utmost radiometric stability representative of the flight units, the EDU must be operated at f/9.0 during radiometric testing and used to verify flight unit performance by extrapolation of the data. This is due to post-CDR design changes to the flight units that were required to prevent the detectors from viewing the warm insides of the telescope, thereby eliminating an undesired Modulated Instrument Background (MIB) in the infrared. Reference 8, "Design Evolution of the NPOESS VIIRS Instrument Since CDR", explains this issue and the resulting redesign in detail. System performance modeling also accounts for other lower-impact differences between the EDU and Flight Unit hardware.

Recent spatial performance estimates based on as-built VIIRS hardware indicate similarly positive results. Horizontal spatial resolution (HSR) is defined in terms of the ground spatial frequency where MTF is equal to 0.5, via the following function: MTF(1/(2*HSR)) = 0.5. Data based on optics, scan motion, field stop, and electronics were utilized in the sensor MTF prediction. Results show that for all bands in both the scan and track directions, horizontal spatial resolution (HSR) and horizontal sampling interval (HSI) values are expected to meet requirements with margin across the entire swath (Figures 3 and 4).

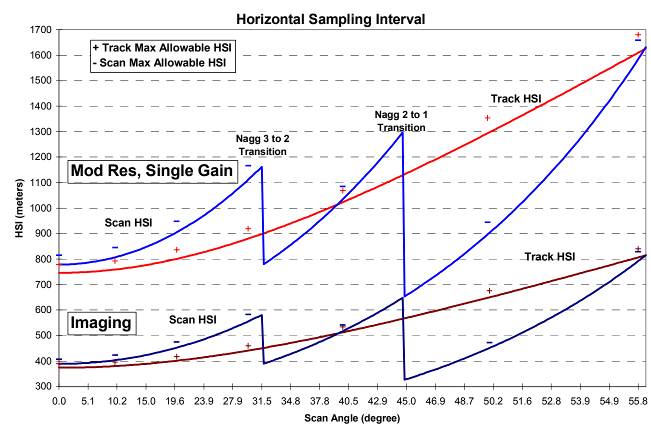


Figure 3. Track and scan HSI for moderate and imaging bands.

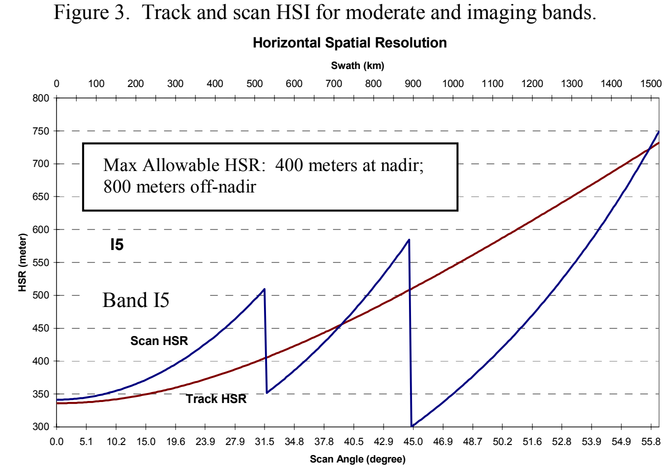


Figure 4. Track and scan HSR for imaging band I5.

The discontinuities in track direction HSI and HSR are the result of changes in sample aggregation performed by the VIIRS digital processing electronics. Sample aggregation is done on-board to reduce the sensor's data rate, and reduced in integer steps (3 to 2 sample aggregation, and 2 to 1 sample aggregation) at discrete scan angles to maintain ground resolution across the swath.

The results of the recently completed VIIRS STOP (Structural, Thermal, Optical Performance) analysis show that MTF is relatively insensitive to launch & on-orbit perturbations and confirms that the sensor will very likely meet requirements for all spectral bands. The STOP analysis suggests that meeting all the band-to-band requirements in all possible NPOESS orbits will be challenging. EDU test data on band-to-band registration are needed to mature these performance predictions.

## V. CONCLUSION

A comprehensive performance modeling and test program is in place to verify VIIRS performance. Performance predictions to date indicate that VIIRS will likely meet the vast majority of its requirements. The VIIRS EDU is expected to be similar to the FU in most areas of function and performance. The EDU has proven its worth as several developmental issues were experienced during its build and test. The identification and resolution of these issues prior to the build of the first flight unit will greatly enhance the overall VIIRS mission. The value of the EDU cannot be overstated in a program of this scale. Results from the EDU test program currently underway will be used to refine our prelaunch characterizations and performance predictions for VIIRS on-orbit performance.

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## REFERENCES


[1] NPOESS IPO, Integrated Operational Requirements Document II (IORD II), version 6, 2002.

[2] NPOESS IPO, VIIRS Sensor Requirements Document (SRD), version 2b, 4 November 1999.

[3] Raytheon Santa Barbara Remote Sensing, VIIRS General Test Plan, TP154640-103, 16 August 2004.

[4] C. Welsch, H. Swenson, S. A. Cota, F. DeLuccia, J. M. Haas, C. Schueler, R. M. Durham, J. E. Clement, and P. E. Ardanuy, "VIIRS (Visible Infrared Imager Radiometer Suite): A Next-Generation Operational Environmental Sensor for NPOESS", International Geoscience and Remote Sensing Symposium (IGARSS) Proceedings, 8-14 July 2001.

[5] P. E. Ardanuy, P. S. Kealy, S. A. Mango, C. F. Schueler, W. L. Barnes and R. E. Murphy, "NPOESS VIIRS Key EDR Performance", 2004.

[6] Raytheon Santa Barbara Remote Sensing, Sensor Performance Specification, PS154640-101 Rev B, 3 February 2004.

[7] Raytheon Santa Barbara Remote Sensing, Performance Verification Plan, TP154640-101, 8 January 2002.

[8] T. Scalione, H. Swenson, F. De Luccia, C. Schueler, E. Clement, and L. Darnton, "Design Evolution of the NPOESS VIIRS Instrument Since CDR", International Geoscience and Remote Sensing Symposium (IGARSS) Proceedings, July 2003.

[9] Northrop Grumman Space Technology, NPOESS System Specification, Appendix D.

[10] Northrop Grumman Space Technology, Performance Specification for the Visible/Infrared Imager Radiometer Suite (VIIRS), EM17-0001, Rev. 15 December 2004.


| | | Band | Wave-length (µm) | Driving EDRs | Gain Range | Lmax or Tmax | Ltyp or Ttyp | FU w/ MIB Fix, F/: 6.20 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | SNR @ Ltyp or NEDT(K) @ Ttyp | | |
| | | | | | | | | Required | Predicted | SNR Margin (%) |
| VIS/NIR FPA | Silicon PIN Diodes | M1 | 0.412 | Ocean Color | High | 135.0 | 44.9 | 352 | 434 | 23.3 |
| | | | | Aerosols | Low | 615.0 | 155.0 | 316 | 717 | 126.6 |
| | | M2 | 0.445 | Ocean Color | High | 127.0 | 40.0 | 380 | 419 | 10.3 |
| | | | | Aerosols | Low | 687.0 | 146.0 | 409 | 702 | 71.5 |
| | | M3 | 0.488 | Ocean Color | High | 107.0 | 32.0 | 416 | 562 | 35.1 |
| | | | | Aerosols | Low | 702.0 | 123.0 | 414 | 739 | 78.6 |
| | | M4 | 0.555 | Ocean Color | High | 78.0 | 21.0 | 362 | 480 | 32.6 |
| | | | | Aerosols | Low | 667.0 | 90.0 | 315 | 685 | 117.1 |
| | | I1 | 0.640 | Imagery | Single | 718.0 | 22.0 | 119 | 164 | 37.6 |
| | | M5 | 0.672 | Ocean Color | High | 59.0 | 10.0 | 242 | 294 | 21.4 |
| | | | | Aerosols | Low | 651.0 | 68.0 | 360 | 549 | 52.5 |
| | | M6 | 0.746 | Atmospheric Corr'n | Single | 41.0 | 9.6 | 199 | 320 | 60.7 |
| | | I2 | 0.865 | NDVI | Single | 349.0 | 25.0 | 150 | 251 | 67.1 |
| | | M7 | 0.865 | Ocean Color | High | 29.0 | 6.4 | 215 | 462 | 114.9 |
| | | | | Aerosols | Low | 349.0 | 33.4 | 340 | 525 | 54.5 |
| | CCD | DNB | 0.700 | Imagery | Variable | 500.0 | 6.67E-05 | 5.0 | 5.7 | 14.0 |
| S/MWIR | PV HgCdTe (HCT) | M8 | 1.240 | Cloud Partical Size | Single | 164.9 | 5.4 | 74 | 122 | 65.2 |
| | | M9 | 1.378 | Cirrus/Cloud Cover | Single | 77.1 | 6.0 | 83 | 171 | 107.2 |
| | | I3 | 1.610 | Binary Snow Map | Single | 72.5 | 7.3 | 6 | 123 | 1956.7 |
| | | M10 | 1.610 | Snow Fraction | Single | 71.2 | 7.3 | 342 | 463 | 35.3 |
| | | M11 | 2.250 | Clouds | Single | 31.80 | 0.12 | 10 | 20 | 95.4 |
| | | M12 | 3.700 | SST | Single | 353 | 270 | 0.396 | 0.182 | 117.4 |
| | | I4 | 3.740 | Imagery Clouds | Single | 353 | 270 | 2.500 | 0.549 | 355.5 |
| | | M13 | 4.050 | SST | High | 343 | 300 | 0.107 | 0.058 | 85.3 |
| | | | | Fires | Low | 634 | 380 | 0.423 | 0.316 | 33.8 |
| LWIR | PV HCT | M14 | 8.550 | Cloud Top Properties | Single | 336 | 270 | 0.091 | 0.067 | 35.4 |
| | | M15 | 10.763 | SST | Single | 343 | 300 | 0.070 | 0.030 | 132.7 |
| | | I5 | 11.450 | Cloud Imagery | Single | 340 | 210 | 1.500 | 0.414 | 262.5 |
| | | M16 | 12.013 | SST | Single | 340 | 300 | 0.072 | 0.029 | 146.7 |

Figure 5: Flight Unit 1 SNR/NEdT Performance, Band Average, Nominal Tolerancing at End of Life.