Multislit Optimized Spectrometer: Fabrication & Assembly Update

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ABSTRACT

The NASA ESTO funded Multi-slit Optimized Spectrometer (MOS) Instrument Incubator Program will advance a spatial multiplexing spectrometer for coastal ocean remote sensing from lab demonstration to flight like environment testing. Vibration testing to meet the GEVS requirements for a geostationary orbit launch will be performed. The multiple slit design reduces the required telescope aperture leading to mass and volume reductions over conventional spectrometers when applied to the GEO-CAPE oceans mission. The MOS program is entering year 3 of the 3-year program where assembly and test activities will demonstrate the performance of the MOS concept. This paper discusses the instrument design, fabrication and assembly. It outlines the test plan to realize a technology readiness level of 6. Testing focuses on characterizing radiometric impacts of the multiple slit images multiplexed onto a common focal plane, and assesses the resulting uncertainties imparted to the ocean color data products. The MOS instrument implementation for GEO-CAPE provides system benefits that can lead to cost savings and risk reduction while meeting the science objectives of understanding the dynamic coastal ocean environment.

Keywords: Spectrometer, ocean color spectrometer, imaging spectrometer, GEO-CAPE

1. INTRODUCTION

The Multi-slit Optimized Spectrometer (MOS) is being designed, built, and tested under a NASA Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP) grant to show capabilities in support of geostationary remote sensing of the coastal ocean. This spatial multiplexing imaging spectrometer can satisfy the science requirements for GEO-CAPE and can significantly reduce cost and risk for a mission implementation.

The National Research Council identified the "imperative to monitor" the coastal oceans by calling for the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission [1]. GEO-CAPE's ocean science objectives [1] are to

- quantify the response of marine ecosystems to short-term physical events (e.g., storms and tidal mixing),
- assess the importance of high temporal variability in coupled biological-physical coastal-ecosystem models,
- monitor biotic and abiotic material in transient surface features (e.g., river plumes and tidal fronts),
- detect, track and predict the location of sources of hazardous materials (e.g., oil spills, waste disposal and harmful algal blooms), and
- detect floods from various sources, including river overflows

Meeting these objectives requires high spatial resolution images [2]: <250 m (threshold) or <375 m (baseline). Resolving the dynamics of the short term coastal processes driven by tides, currents, storm surges, and algal blooms requires high temporal sampling [2]: <3 hr (threshold) or <1 hr (baseline). The geostationary vantage point enables the hourly temporal sampling over the field of regard at high spatial resolutions.

Achieving the hourly revisit times and high spatial resolution with the requisite signal-to-noise-ratios (SNR) [2] via conventional spectrometer formats leads to large systems with a proportionately large cost for a geostationary launch. This paper updates progress on the NASA Earth Science Technology Office funded Multi-Slit Optimized Spectrometer (MOS) Instrument Incubator Program [3]. MOS can accomplish the ocean science mission with a comparatively smaller instrument while meeting the revisit time, spatial resolution, and high SNR's required in the GEO-CAPE Oceans

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Science Traceability Matrix [2]. This paper reviews the design, fabrication progress and integration and test plans to advance the MOS opto-mechanical subsystem to TRL 6.

2. MULTISLIT OPTIMIZED SPECTROMETER

2.1 Concept and Benefits

One method being looked at to enable NASA science missions for lower cost is a hosted payload instrument on a commercial geostationary bus. According to NASA Common Instrument Interface Project: Hosted Payload Guidelines Rev-A, “The instrument should be less than or equal to 150 kg.” In order to meet this requirement in addition to meeting the signal to noise ratio necessary for ocean science measurements and still revisit the entire CONUS coast in less than 1 hour, the MOS instrument employs 4 slits (Figure 1) that are imaged separately onto a large area 2-D focal plane array. The slits are scanned across the scene as shown in yellow in the Figure 1 until slit 1 starts to overlap the first position of slit 2. Then a quick jump is initiated to step the entire set over to the red region to begin the slow scan again. This is repeated until the entire CONUS coast is scanned. The multiplexing of the slits enables instrument weight savings in telescope aperture and scan mirror size.

2.2 MOS Design

The MOS instrument is a UV-Visible-NIR hyperspectral prism spectrometer based on a novel design form. The mirrors are protected silver coated silicon carbide. The 4-slit plate assembly is made from electroformed nickel. The prism is fused silica. For testing purposes, MOS utilizes a contributed Teledyne Imaging Sensors 2K by 2K HyViSI^{TM} H2RG focal plane array and SIDECAR^{TM} ASIC to provide test images and measurements of opto-mechanical performance.

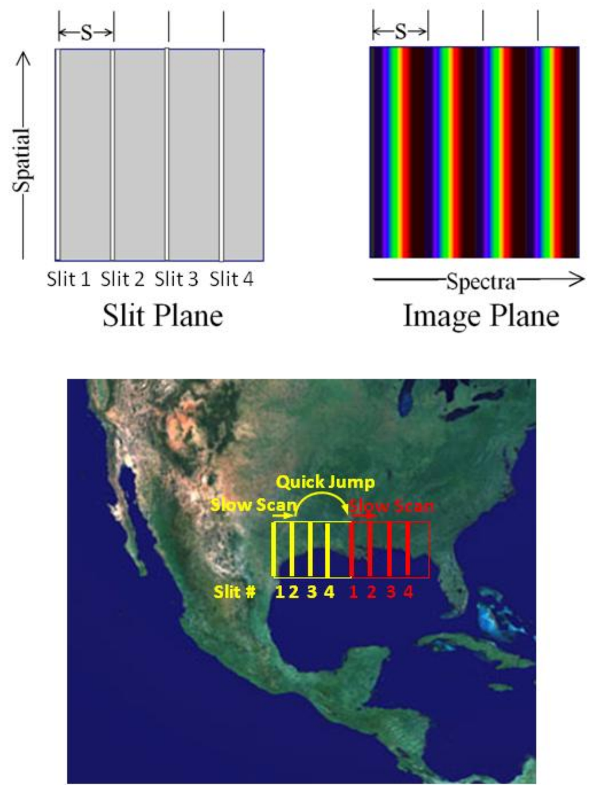

Figure 1. MOS simultaneously images the spectra from multiple slits on an area focal plane array. From a geostationary orbit a scan mirror moves the slit set from west to east collecting spectra continuously until the area between adjacent slits is fully covered (yellow field of regard). The scan then jumps to the red field of regard and executes the same continuous collection scan. The 4-slit case shown above requires ¼ the time to cover the field of regard compared to a single slit spectrometer while achieving the same signal to noise ratio.

2.3 Fabrication and Assembly

Figure 2 shows the CAD design of the opto-mechanical subassembly. The athermal design comprises light weighted reaction bonded SiC walls and baseplate, mirrors and prism mounting pedestal. The design uses flat, spherical and aspherical optical surfaces with roughnesses ranging from 5 Å rms to 20 Å rms. All mirrors exceed the allocated surface figure requirements. The mirrors attach to the structure using coplanar invar inserts. The optical system has been aligned and the assembly moved onto performance testing.

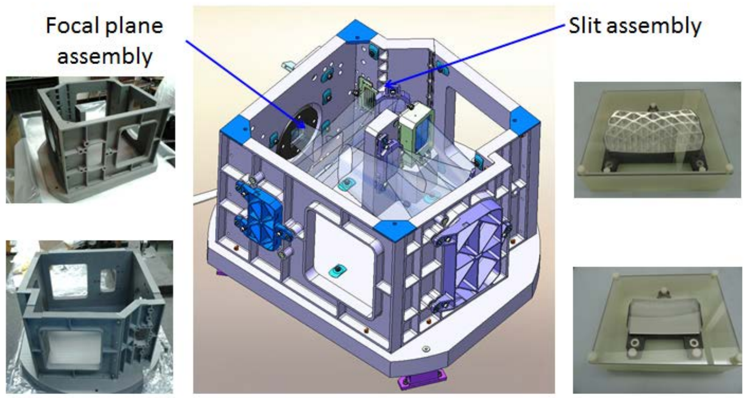

Figure 2. Flight-like structure and mirrors have an athermal design fabricated out of all silicon carbide. The mirrors (2 shown on right) have a protected silver optical coating with high reflectivity over the ultraviolet to visible spectral range. The SiC structure incorporates mounting, fixturing, and fiducialization features that enable a rapid and deterministic optical alignment process.

2.4 Testing

Key to the MOS operational concept demonstration is to show that each slit and subsequent dispersed image behaves independently from the other slits in order to combine the data in post-processing to develop a full image of the coasts. The cross-talk between slits is the critical parameter to be characterized to demonstrate the utility of the concept. This measurement is the Out Of Channel Response (OOCR). For the stressing case to the ocean measurements with MOS, a scene with bright clouds in 3 of the slits and the dark ocean in the fourth slit is shown in Figure 3. The FRED model incorporates surface roughness, ghosts, and structures to predict that the OOCR in the open ocean illuminated slit is significantly less than the required 1%. Testing simulates the mixed cloud, dark ocean illumination conditions. MOS will be tested over its full spectral range to quantify the OOCR performance. Neutral density filters and colored glass with ocean-like profiles are placed at individual slit locations to simulate cloud, coastal ocean, or deep ocean scenes.

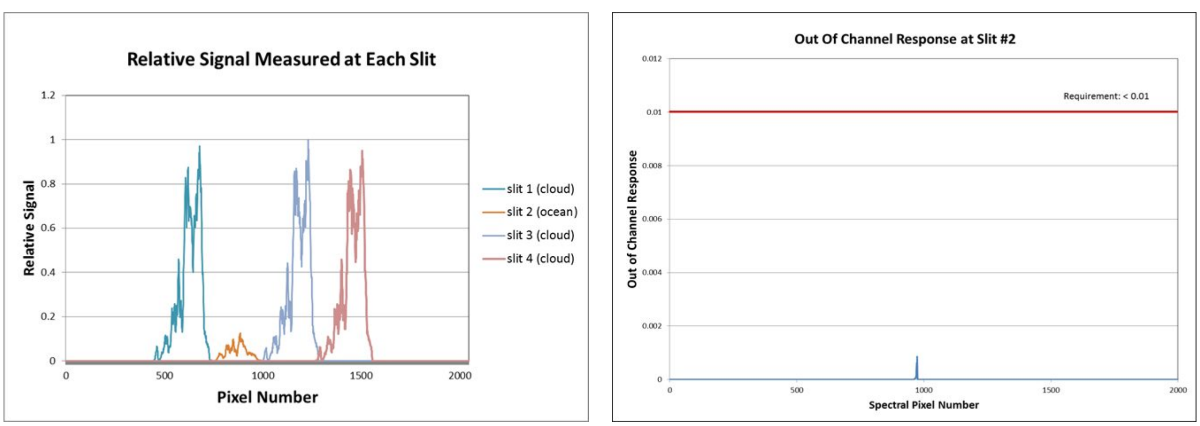

Figure 3. The chart on the left shows the worst illumination case of slits 1,3, and 4 being illuminated by bright cloudy scenes while slit 2 images a low radiance ocean scene. The chart on the right shows the predicted out of channel response (i.e. combined relative contributions due to slits 1, 3, and 4) of less than 0.001 against a requirement of less than 0.01 for this worst case scenario.

Technology Readiness Level 6 requires demonstration of the sub-system in a flight-like environment. The flight-like environment for MOS following the NASA Goddard General Environmental Verification Specification (GEVS) is defined in the Table 1 based on a spaceflight point design previously reported [3].

Table 1. The relevant operational spaceflight environment follows the NASA Goddard GEVS requirements.

Parameter	Value
Vacuum	< 1 x 10^{-5} torr
Nominal operating temperatures	20°C ± 1°C
Operational Test Range	14°C to 26°C
Non-operational Test Range	-10°C to +45°C
Vibration	14.1 Grms, 20-2000 Hz

A detailed Structural, Thermal and Optical Performance (STOP) analysis was performed using the operational parameters in Table 1. Table 2 shows the prediction for critical spectrometer performance metrics. The silicon carbide structure and mirrors perform very well over the defined operational temperature range. Measurements of the parameters listed under thermal vacuum conditions will validate the STOP model as required to achieve TRL 6 for the MOS opto-mechanical subsystem.

Table 2. Structural-Thermal-Optical-Performance predicts that under operational conditions simulated in thermal vacuum testing the GEO-CAPE mission requirements are supported. The smile and keystone design residuals are near the measurement limit.

Parameter	Requirement (µm)	Prediction (µm)
Spatial Stability	<5.5	2.0
Spectral Stability	<1.4	0.14
Defocus	<34	6
Keystone	<8	0
Smile	<27	0.4

2.5 Data product validation

The Oregon State University co-authors will validate the data product performance based on laboratory performance characterization. They have developed a simulator tool that incorporates an input scene such as a Hyperspectral Imager for the Coastal Ocean (HICO) image from the International Space Station into a model and degrades the image based on the MOS laboratory measurements. This process is detailed in a separate talk in this section.

3. SUMMARY

MOS demonstration and testing to TRL 6 enables an option for the GEO-CAPE ocean mission that can meet the requirements of a geostationary hosted payload with a potential lower cost implementation than conventionally available for a dedicated mission. The project is expected to meet all defined milestones and validate model performance to advance the TRL 6 by the spring of 2014. An athermal multi-slit prism spectrometer design comprising silicon carbide mirrors and structure is being demonstrated with the intent of supporting future ocean science missions.

4. ACKNOWLEDGEMENTS

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