ABSTRACT

ATK has developed a unique high-speed Michelson FTIR ground-based sensor capable of collecting chemical spectra at 1000 interferograms per second at 4cm\(^{-1}\) spectral resolution. This resolution can provide remote detection and analysis of chemical products from energetic reactions where multiple unknowns are mixed with the reaction products. This paper describes the current efforts under way at ATK to modify this sensor for space-based applications. The resultant small satellite payload would be a rapid spectrum-collection instrument capable of collecting time-changing chemical signatures that are unique to various reactions and targets. Examples where very high-speed temporal-spectral information is needed is standoff chemical detection and diagnostics of test stand rocket motor tests for performance and materials selection determinations, used for technology assessment. The proposed payload will offer a variable frame rate up to 1000 frames per second with 4cm\(^{-1}\) resolution from 2 to 25 micron bands.

1. INSTRUMENT INTRODUCTION

Traditionally, high-speed spectroscopy is performed using instruments that are based on dispersive optical elements. Resolution of such instruments is in the >30cm\(^{-1}\), which is not suitable for performing chemical detections and identifications in the presence of unknown interferents. Additionally, theses dispersive instruments are set up for imaging where the spatial and spectral data are collected on the two orthogonal dimensions of the focal plane array. The interpretation of data collected in this manner can be difficult to resolve. A Fourier Transform Interferometer (FTIR) does not suffer the distortion problems of dispersive systems, but existing commercial designs do not operate at high speeds. ATK has solved the high resolution/high speed problem by developing a hyperspectral/hypertemporal FTIR instrument. This instrument uses a Michelson FTIR interferometer design with a novel high-speed rotating mirror technology with stability suitable for fielded platforms. The system records 1000 interferograms per second over the 2.5 to 5 micron wavelength band with a resolution of 4cm\(^{-1}\). The hardware development goals will include imaging capability, even though the current design employs a single detector.

2. PRESENT DESIGN DETAILS

a. Fast- scanning FTIR spectrometer

A picture of the present instrument is shown in figure 1. The basic design is a two-beam Michelson interferometer with common optics for the infrared measurement beam and the visible reference laser. The visible laser provides a measurement of the optical path difference (OPD). The unique features of this FTIR design are a moving mirror operating at a very high speed, and it employs fast analog-go-digital sampling of both visible and infrared signals combined with digital signal processing. ATK has built mid-wave infrared (MWIR) and long-wave infrared (LWIR) prototypes that have demonstrated high spectral resolution (4cm\(^{-1}\)) with very short measurement times (1 millisecond). These units have a 1 degree (17 mrad) field of view and a 25 mm clear aperture diameter.
conditions. We have initiated an effort to qualify this instrument for space-based applications such as remote sensing based on small satellites. This effort includes thermal and optomechanical changes. Data collection and electronics changes are not covered in this current effort.

a. Mechanical issues

The present design of the instrument uses several sub-assemblies which result in numerous adjustments for the precision mechanical placement of optical elements. In some cases, commercial off-the-shelf optical mounts are used to align the optical elements. This design is sufficient for a laboratory instrument. We have made mechanical design changes to pave the way for space qualification of this instrument. These design changes are a direct result of our experience in developing space-based hyperspectral imagers such as the successful Moon Mineralogy Mapper instrument which flew around the Moon on India’s Chandrayaan-1 mission.2

The main design change is the use of one common optical bench for all the elements. This has several advantages: The optical bench gives the instrument a rigid structure where mounting surfaces can be machined with high precision relative to each other. This allows better positioning of optical components and can eliminate many adjustments. The optical bench also allows for an easier time in the alignment and test of the instrument since all the components could be in place at once. Mass reduction efforts are also easier to achieve on one structure. Thermal load management can also be an advantage with one single structure.

Precision mounting of optical elements on this optical bench is done with flexure-based mounts. These space-proven mounts prevent distortion and deformation of optical elements. These mounts are combined with adjustable elements to provide the degrees of freedom necessary for adjustment of the optical elements.

b. Thermal issues

Three main areas for thermal performance improvement were identified to be the IR detector, the scanning motor, and the diode laser.

The boxed area in Figure 2 below shows the area of thermal interest in the IR detector.

3. SPACE QUALIFICATION

The hyperspectral/hypertemporal instrument described above is designed to operate in laboratory and field conditions. We have initiated an effort to qualify this instrument for space-based applications such as remote sensing based on small satellites. This effort includes thermal and optomechanical changes. Data collection and electronics changes are not covered in this current effort.

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The boxed area in Figure 2 below shows the area of thermal interest in the IR detector.
In the present design the IR detector is in contact with the LN2 Dewar. Space qualification of this design will involve the use of either thermoelectric cooling (TEC) or a space-qualified cryocooler. At around the 77K temperature, the TEC solution will come with a high power cost. At the same time, a cryocooler would provide the most efficient means of controlling to 77K, but would input noise to the system through vibration and electrical signals of the motor. The final choice of the IR detector and the temperature operating range will dictate the thermal control design for the space qualification of the instrument.

The next area of thermal concern is the scanning motor shown in figure 3.

The scanner motor produces noticeable heat, and is rigidly mounted to and in thermal contact with the interferometer body. It is estimated to be at 120 - 150 degrees F (322 – 338K) after one to two hours of operation. We are analyzing the effect of this on the interferometer performance, but are looking into isolating the scanner motor from the interferometer body and the diode laser. The final design of this motor will be influenced by the scanning mirror design.

The reference diode laser (shown in figure 4) has a built-in TE cooler and temperature control circuit to temperature stabilize the laser wavelength. This solid state diode laser was selected over a HeNe gas laser for its ruggedness and compactness. However, the laser shuts off in extreme temperatures. The heat from the scanner motor is a major contributor in addition to the cold environment in the other extreme case. We are pursuing external thermal control methods to keep the laser within its operating range.

c. Optical issues

One of the areas in need of improvement from the present design is the rotating mirror. ATK has an alternate design in the works that uses a rocking, plane mirror to modulate the OPD. This design is more compact, and causes less stress on the oscillating mirror (160g vs. 40,000g for the current design). This reduced stress eliminates the need for a beryllium mirror and instead can use an aluminum mirror. This configuration also uses less drive power as the mirror can be used at its resonant frequency of 500 Hz. This optical design produces a FOV of +/- 1 degree which is acceptable for most imaging applications. We are in the process of designing this mechanism based on our knowledge base of space qualification requirements.
The collection optics will also be redesigned with all-reflective optics to accommodate the wavelengths of interest.

An intriguing extension of this technology is to replace the single IR detector with an imaging focal plane array. Large space-qualified focal planes that run at the speeds necessary to read out the interferograms at the 1 KHz rate do not exist. Building a 4X4 detector array based on single detectors is a possible approach we are researching.

4. SUMMARY

ATK has initiated an effort to space qualify its field-tested hyperspectral/hypertemporal spectroradiometer. The first phase of this effort has culminated in identifying area of needed improvement in optomechanical and thermal designs. The next step involves identifying a small satellite mission for this payload to come up with specifications for the next design stage.

5. ACKNOWLEDGEMENTS

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6. REFERENCES