International Conference on Space Optics—ICSO 2004

Toulouse, France

30 March–2 April 2004

Edited by Josiane Costeraste and Errico Armandillo

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International Conference on Space Optics — ICSO 2004, edited by Errico Armandillo,
Josiane Costeraste, Proc. of SPIE Vol. 10568, 1056809 · © 2004 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2307973

PROGRESS REPORT OF A STATIC FOURIER TRANSFORM SPECTROMETER BREADBOARD

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ABSTRACT

MOLI instrument -for MOtionLess Interferometer- takes advantage of the new concept of static Fourier transform spectrometer. It is a high-resolution spectrometer working over a narrow bandwidth, which is adapted to a wide range of atmospheric sounding missions and compatible with micro-satellite platform.

The core of this instrument is an echelette cube. Mirrors on the classical design are replaced by stepped mirrors -integrated into that interference cube- thus suppressing any moving part. The steps' directions being set over a perpendicular axis, the overlap of both stepped mirrors creates a cluster of so-called "echelettes", each one corresponding to a different optical path difference (OPD). Hence the Fourier transform of the incoming radiance is directly imaged on a CCD array in a single acquisition.

The frequency domain of the measurements is selected by an interferential filter disposed on the incoming optical path. A rotating wheel equipped with several filters allows the successive measurement of spectra around some bands of interest, i.e. O_2, CO_2 and CO absorption bands.

Keywords: Climate change, CO_2 monitoring, Static Fourier Transform spectrometer, Echelette cube, Green-house effect.

1 INTRODUCTION

There is a real need for CO_2 monitoring in order to improve our knowledge of the global carbon cycle in the climate system, and to corroborate national and continental-wide control of carbon emissions. Spaceborne instruments are specially adapted to such a task as they provide worldwide coverage. Indeed, this opens the possibility of having a finer spatial grid of measurements than any other on-ground method. Therefore high-resolution spectrometers are needed for atmospheric sounding if we want to resolve the small variations in concentration of the gas.

MOLI is a Static Fourier Transform Spectrometer which studies reflected Sunlight from the surface of the Earth. An interferential filter in the fore optics of the instrument selects a chosen narrow band spectrum containing CO_2 absorption lines. The output signal provided by MOLI is an interferogram which has to be treated to obtain the CO_2 spectrum. Then an inversion method [1] can be applied to this spectrum to obtain the CO_2 concentration columns.

This article presents MOLI design, together with a progress report of the breadboard under development at CNES. Finally, on ground data processing algorithm is introduced.

2 INSTRUMENT DESCRIPTION

2.1 Technical specification

The instrument has been designed around the following spectral channels:

- B1: $\lambda = 1.6$ µm CO_2 detection (over the earth)
- B2: $\lambda = 2$ µm CO_2 detection (over the sea)
- B3: $\lambda = 2.2$ µm CO detection

However, the purpose of the breadboard is to demonstrate the feasibility of the static Fourier transform spectrometer. Thus it is intended to operate only in the B1 channel in order to simplify the design and lower realisation costs.

Specifications for every band are:

- Bandwidth of $15\,cm^{-1}$, needed to observe about fifteen absorption lines.
- Sampling rate: $0.05\,cm^{-1}$
- Resolution: $0.1\,cm^{-1}$

Pixel size is 8Km and every band is acquired with 50 km grid.

2.2 MOtion Less Interferometer (MOLI)

A resolving power of 50 000, with a high signal to noise ratio cannot be achieved with a grating spectrometer in a reasonable volume. Thus we have developed a new compact concept, especially suited for high resolution spectrometry in narrow bandwidth.

The technical concept is a static Fourier transform spectrometer, which takes advantage of the Fourier transform spectroscopy (high etendue) without the difficulty of a mechanism.

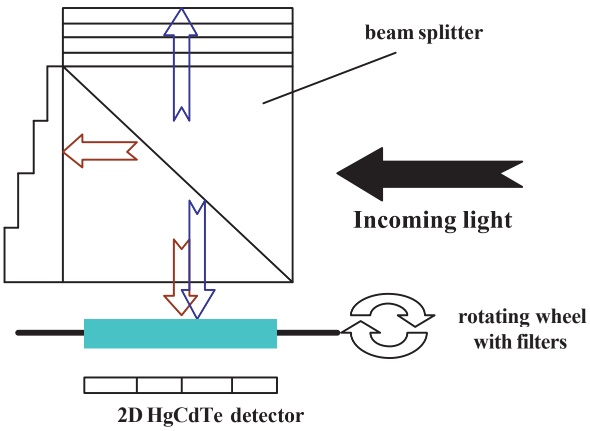

Figure 1 : MOLI spectrometer concept.

This spectrometer can be viewed as a multitude of interferometers in parallel, (see Figure **1**). Each channel acquires a unique path difference. All the channels are imaged at the same time on a HgCdTe CCD array. Hence the interferogram is acquired instantaneously without any moving part.

However a rotating wheel with filters is needed to acquire the three different spectral bands. It is a simple mechanism, re-using existing Polder developments, which is located just in front of the detector.

At the targeted wavelengths, the ocean surface is relatively dark (reflectance<0.01). Targeting the sun glint with a tracking mirror therefore greatly increases the signal to noise ratio over the oceans.

2.3 Data processing

The spectrometer will acquire the positive interferogram of the spectrum. With each interferogram performed, an obscurity level reading will be acquired. Both data sets will be downloaded on earth. Correction of the interferogram and the Fourier transform will be done on earth, to obtain a final spectrum of around 300 elements. On-ground data processing is approached in section 4.

2.4 Performance budget

With the instrument regulated at 20°C, and the detector regulated at 190 K, the most important noise contributor is the background emission of the instrument itself.

The minimum reflectance of the sun glint over the ocean is 0.1. Under these conditions, the signal to noise is approximately 500 for the interferogram. It leads to a signal to noise of 100 for the spectrum and 300 for CO_2 determination.

2.5 End to end performance Simulation of the breadboard

A model has been developed which simulates the interferogram acquired by the breadboard. An atmospheric model is used to generate input data. Several sources of error related to the breadboard modify the incoming light, giving a noisy, irregularly-sampled interferogram. An example is shown in Figure **2**.

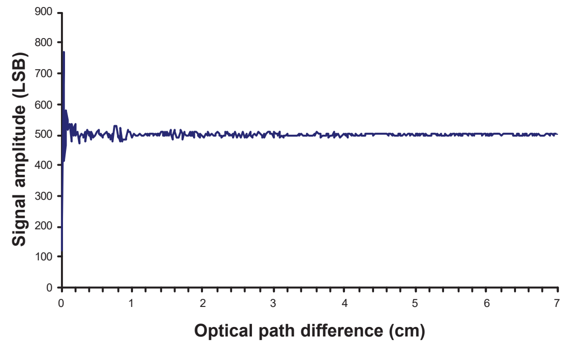

Figure 2 : MOLI breadboard simulated interferogram.

A reconstruction algorithm is then applied to obtain a regular sampled interferogram (see section 4). The FFT can then be applied to obtain the measured spectrum. In Figure **3** the spectrum resulting from the signal processing of a simulated interferogram can be seen. Several CO_2 absorption lines are present on this spectrum. The difference between this and the reference spectrum is also plotted, showing the reconstruction error.

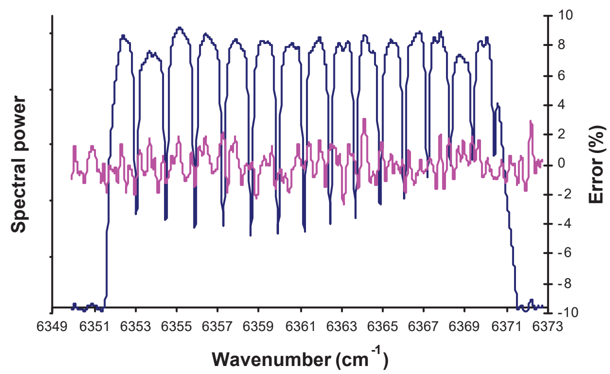

Figure 3 : Spectrum of treated data and its error.

3 THE BREADBOARD

3.1 General view

The main driver of the breadboard architecture is the echelette cube. As a first validation step, the cube will not be assembled. The breadboard will operate in the air with the two sets of echelette mirrors disposed as in a classical Fourier transform spectrometer. We can see that configuration in Figure **4**, which shows a general view of the test bench.

Figure 4 : breadboard without thermal shield.

3.2 Optical layout :

The optical formula is simple. The first group of lenses forms the image of the Earth on a diaphragm. This diaphragm physically limits the field of view. After this, a second group of two lenses re-images the echelette faces of the cube on the detector array. The optical layout is presented in Figure **5**.

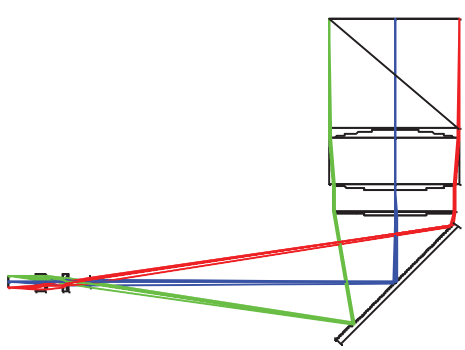

Figure 5 : Optical layout.

The optical system is achromatic for the three bands. The thickness of the filter is adjusted for each band to be in focus (a common achromatic solution is being studied). In addition, the numerical aperture is low (F/8), easing the realisation and the alignment of the optics.

3.3 Echelette cube:

The echelette cube is the most critical part of the interferometer. Indeed it must remain very stable during the mission. A first mock-up of the echelette mirrors –half size- has been achieved. They are presented in Figure **6**.

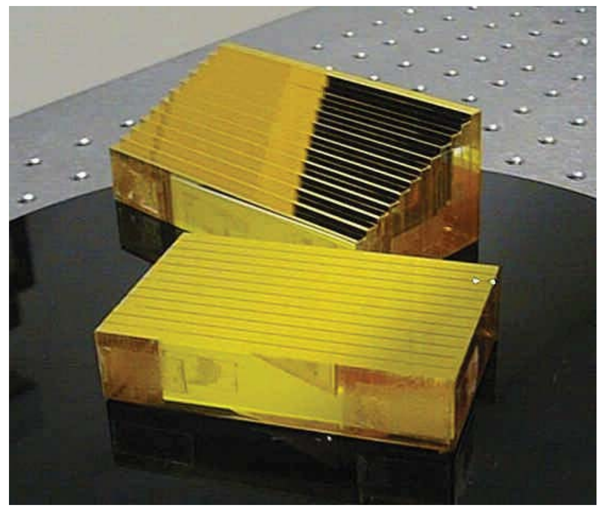

Figure 6 : Echelette mirrors.

The echelette mirrors have been made by molecular adherence technique. The small echelettes have a thickness of 75 µm whereas the large ones have a thickness of 1.5 mm. The tolerance of realisation is around 5µm, however, the cube will be accurately measured in the final configuration. During the manufacturing, no serious problem was encountered and reproducibility measurements show that the realisation accuracy is of 0.5 µm. Completion of the whole cube is anticipated for April 2004.

3.4 Filter:

A filter with high rejection performances (about 0.1 %) is needed. The designed filter is similar to the filters used in telecom applications. The first studies indicate that it meets all the requirements. The filter is expected by middle April 2004.

3.5 Detection

The focal plane used in the breadboard is based on a commercial InGaAs detector. It is a 320x256 pixel CCD array built by Indigo Systems .