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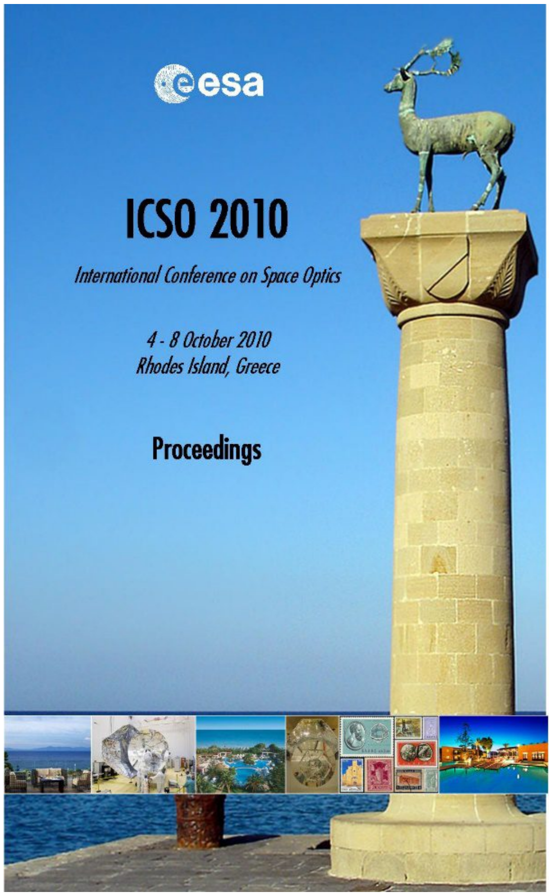

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INSTRUMENT DEMONSTRATION EFFORT FOR THE CLARREO MISSION

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INTRODUCTION

NASA and other national agencies ask the National Research Council (NRC) once every decade to look out ten or more years into the future and prioritize research areas, observations, and notional missions to make those observations. The latest such scientific community consultation referred to as the Decadal Survey (DS), was completed in 2007 [1]. DS thematic panels developed 35 missions from more than 100 missions proposed, from which the DS Executive Committee synthesized 17 missions, with suggested order presented in three time-phased blocks. The first block with aim for near term launch (2010-2013) included four missions. The Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission is one of them.

The CLARREO mission was classified as a Small Mission to be contained in a 300 M US$ budgetary envelope. CLARREO will provide a benchmark climate record that is global, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards. The long term objective thus suggests that NOAA or NASA will fly the CLARREO instrument suite on an operational basis following the first scientific experiment.

The CLARREO missions will conduct the following observations:

1. Absolute spectrally-resolved measurements of terrestrial thermal emission with an absolute accuracy of 0.1 K in brightness temperature (3σ or 99% confidence limits.) The measurements should cover most of the thermal spectrum.
2. Absolute spectrally-resolved measurements of the solar radiation reflected from Earth. The measurements should cover the part of the solar spectrum most important to climate, including the near-ultraviolet, visible, and near-infrared.
3. Independent measurements of atmospheric temperature, pressure, and humidity using Global Positioning System (GPS) occultation measurements of atmospheric refraction.
4. Serve as a high accuracy calibration standard for use by the broadband CERES instruments on-orbit.

Following the DS conclusion, and considering the early development stage of the mission, NASA funded three Instrument Incubator Programs (IIP) to push instrument concepts to a higher level of maturity. A joint proposal between University of Wisconsin (UW) and Harvard University was selected to address the first above objective and part of the fourth one in the corresponding spectral region. In order to achieve this goal, four complementary technologies are to be developed [2]:

(1) On-orbit Absolute Radiance Standard (OARS), a high emissivity blackbody source that uses multiple miniature phase-change cells to provide a revolutionary on-orbit standard with absolute temperature accuracy proven over a wide range of temperatures.
(2) On-orbit Cavity Emissivity Modules (OCEMs), providing a source (quantum cascade laser, QCL, or “Heated Halo”) to measure any change in the cavity emissivity of the OARS.
(3) On-orbit Spectral Response Module (OSRM), a source for spectral response measurements using a nearly monochromatic QCL source configured to uniformly fill the sensor field-of-view.
(4) Dual Absolute Radiance Interferometers (DARI), providing spectral coverage from 3.3 to 50 μm that can be inter-compared to dissect any unexpected systematic errors in overlapping spectral regions.

ABB's GFI (Generic Flight Interferometer) has been selected as the favoured architecture for the DARI, mainly due to the maturity of the design and its space heritage. A GFI with commercial grade components was optimised for the selected spectral range. The architecture of the GFI will ensure a high response stability between calibrations.

INSTRUMENT CONCEPT

ABB is collaborating with UW in order to achieve the DARI goals. The challenge in the FTS sensor development for CLARREO is to achieve ultra-high accuracy (0.1 K 3-sigma) with a design that can be flight qualified, has a long design life, and is reasonably small and affordable. ABB participated in many recent mission definitions involving FTS. Strong similarities between mission requirements at the level of the interferometer module has pushed ABB to standardize a generic flight architecture (GFI) for spectrometers with spectral resolution up to about 0.2 cm^{-1} and aperture up to ~70 mm of diameter [3,4]. The GFI consists in an interferometer module equipped with metrology optics which forms a single assembly that is entirely free of electronic components apart from the scanning actuator. The power dissipation and the heat imprint of the Opto-Mechanical Assembly (OMA) are thus minimized. This OMA is complemented by a 6U Compact PCI control card that conveys the functionality of metrology detection, laser source, actuator drive, servo control, housekeeping, telemetry and command/data handling. The interferometer is based on V-shaped scan arm oscillating about a beamplitter. Cube corners are mounted at the extremities of the scan arm (See Fig. 1) The OMA architecture draws its heritage from a long lived commercial instrument series which started in the mid 80's. This instrument known for its exquisite response stability is used in production plants around the world to provide critical concentration measurements as control feedback for industrial processes. The ACE-SCISAT FTS was the first to implement a space design based on this architecture and is still operating well beyond its design life time of 2 years since its launch in 2003. More recently the TANSO-FTS onboard IBUKI (GOSAT), launched in 2009 by JAXA, was based on an evolution of the ACE-FTS. The GFI is the third generation of flight interferometers based on this design. It also includes some of the latest technology developed for commercial applications. The CLARREO mission is another example of the versatility of the GFI architecture. Its adaptation to the mission requirements required minimal design changes. The changes mainly consisted in replacing the beam splitter substrates and coating with materials that maximize efficiency over the 3 – 50 µm range and some metrology component relocation to address the need for four port operation. The rest of the system remained the same since spectral resolution, throughput and dwell time can all be met by the GFI baseline.

For the ground demonstration, a simplified version of the design was realized. The level of simplification was mainly driven by the available funds and need for demonstration. None of the components used were of space qualified grade. Hence the flight control electronic was replaced by an equivalent commercial control electronic implementing the same servo control algorithms. A fibre coupled stabilised solid state laser and fibre coupled metrology detectors have been added to the commercial control electronic box (see Fig. 2). The OMA uses a simple voice coil that does not carry the inherent redundancy of a flight actuator. The same can be said about the metrology that uses only one of the two possible channels. Also, the mass of some mechanical parts (ex. beamsplitter wall) is not optimized. The OMA is made of standard grade aluminium which is a possible flight implementation of the GFI. Other more expensive materials (ex. SiC, Beryllium) can be used to increase the natural frequencies of the assembly and ensure a larger safety margin to operational vibration.

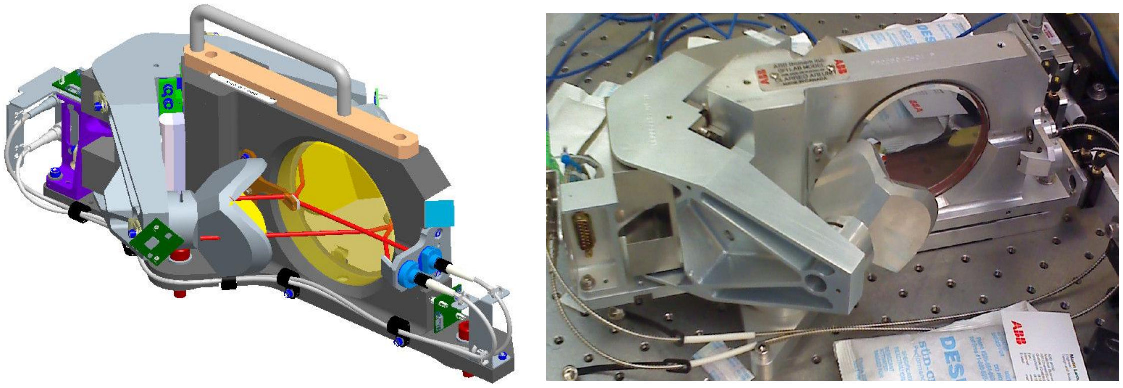

Fig. 1: DARI Opto-Mechanical Module based on GFI

The most critical aspect of the adaptation pertained to the management of surface distortion of the caesium iodide beamsplitter. CsI is among the very few optical materials that transmit light up to 50 µm (200 cm^{-1}). Despite its heritage as a transmission window or lens in other space missions, this material presents additional challenges when used as a beamsplitter due to the increased flatness requirements compared to other applications. This material structural behaviour sits halfway between a glass and a polymer and it exhibits significant creep. Its structural properties are not extremely well represented by tabulated standard values such as Young's modulus or hardness that do not take the effect of time into account. The stress associated with mounting and gluing must be considered carefully. For example, a CsI plate of standard aspect ratio (ex. 7:1) can be permanently bended relatively easily by human manipulation. On top of that, CsI is highly hygroscopic and must be maintained under low humidity to prevent condensation that would have for effect to increase diffuse reflection on its surface.

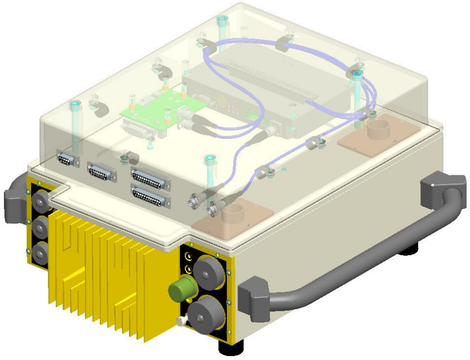

Fig. 2: DARI Control Electronic Module

ABB has been using CsI beamsplitters for more than 20 years in niche commercial instruments versions. Compared to the commercial instruments, the beamsplitter for CLARREO is more challenging because the larger diameter of the beamsplitter combined with a higher modulation efficiency requirement impose that the beamsplitter has a higher flatness. The beamsplitter mounting concept is very similar to the one used successfully in commercial instruments however, the integration procedure was modified significantly to increase the yield of the gluing process given the high price of the custom beamsplitter of the DARI interferometer. During the integration, many intermediate Zygo measurements were made to identify signs of potential stress build-up. Processes developed in a recent Space Technology Development Program (STDP) allowed for a gravity pulled gluing and a strict control of the substrate tilt with respect to the mounting interface of the OMA. This last aspect is required to control the elevation angle of the interferometer output axis.

Table 1 summarizes the main characteristics of the interferometer module. The next section presents the most important performance tests performed on the breadboard.

Table 1: Instrument characteristics

Characteristics	Value
Interferometer type	Dual output and input ports
Interferometer aperture	26 mm
Interferometer divergence	± 2 degree
Optical path difference	Up to ±1.27 cm
Spectral range	3 µm – 50 µm
Spectral sampling interval	≥ 0.4 cm^{-1}
Spectral resolution (FWHM)	≥ 0.86 cm^{-1} at 475 cm^{-1}
Dwell time (scan duration)	1 – 10 seconds
Modulation efficiency	88 % @ 3.26 µm
Scan speed instability	< 0.13% RMS at 2 cm/s of scan speed
Mass	< 7 kg (aluminium demo)
Power	Avg: 18 W / Pk: 23 W (flight design)

TEST RESULTS

At the interferometer level, two important performance characteristics are the modulation efficiency and the speed stability. The modulation efficiency is a measure of how well the interferometer uses the incoming radiation to generate a useful modulated signal. It was measured by sending a collimated beam in the interferometer and then detecting the exiting interference pattern at the output with a photodiode. A chopper was used to distinguish the modulated signal from the unmodulated signal. Narrow optical bandpass filters were used to limit the measurement to specific wavelengths. Measurements were made for 3072 cm^{-1} and 4237 cm^{-1}. Fig. 3 shows one such measurement. At 3072 cm^{-1}, the measured modulation efficiency is (88 ± 2) % and it is (85 ± 2) % at 4237 cm^{-1}. At longer wavelengths, the modulation efficiency will be higher.

The speed stability of the scan arm is also another important parameter. A better speed stability reduces the contribution of sampling errors to the total radiometric noise in the data. The speed stability was estimated with the signal from the metrology laser. The speed instability was measured to be less than 0.13% RMS over the sampling window for both scan directions. Fig. 4 shows the scan arm speed during the speed stability test.

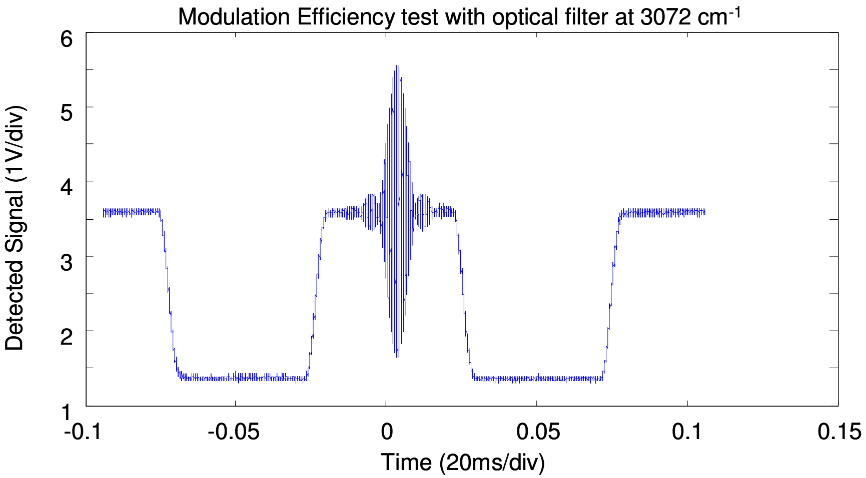

Fig. 3 Modulation efficiency measurement at 3072 cm^{-1}

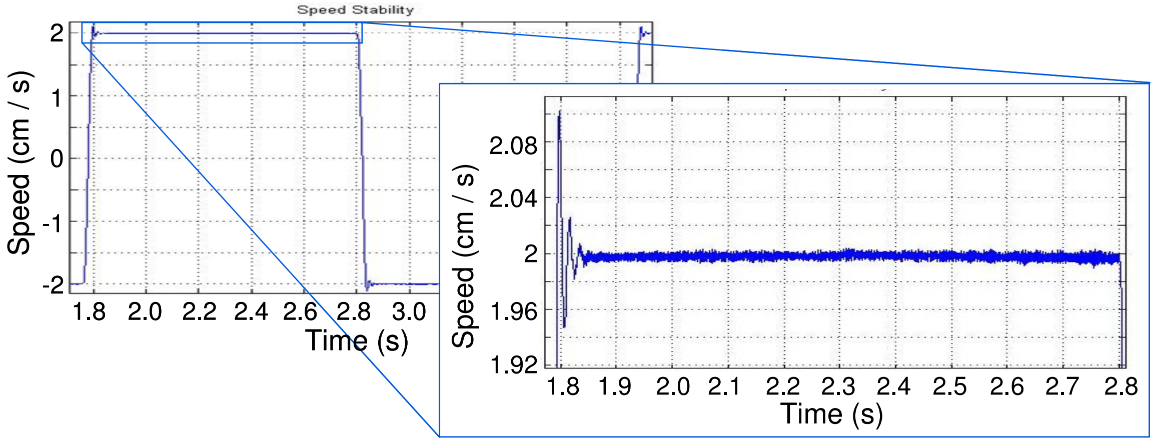

Fig. 4 Speed stability measurement

CONCLUSION

The DARI interferometer has been designed, assembled and tested within 6 months. It will now be integrated in the UW optical setup to evaluate the ability to achieve the 0.1k 3σ accuracy. This work will be used by NASA to refine the mission concept and guide future development. A Mission Concept Review is expected to occur at the end of the summer of 2010 while the start of a phase A would likely happen in the following months.

Despite NASA's sole involvement in the mission so far, the benefit of the CLARREO mission data product is truly international in the sense that it should provide answers to critical issues affecting understanding of global warming that is affecting every part of the globe.

The interferometer will play a vital role in the mission success. The baseline architecture of the GFI is well suited for the requirements of the CLARREO spectrometer and adapting it to serve longer wavelengths was simply a question of changing the beamsplitter since the original design supports the required throughput and resolution and is already designed to have minimal thermal contribution.

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