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DEVELOPMENT OF THE NEW GENERATION OF GEOSTATIONARY OCEAN COLOR IMAGER

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I. INTRODUCTION

The Geostationary Ocean Color Imager II (GOCI-II) is the next generation of GOCI, which is one of the main payloads of the Korean COMS satellite. GOCI was the first ocean color sensor in the world operating on the geostationary orbit. Since COMS launch in June 2010, GOCI is monitoring ocean color around the Korean Peninsula in order to detect, monitor, quantify, and predict short term changes of coastal ocean environment for marine science research and application purpose.

GOCI-II has improved functional, radiometric and geometric performances in comparison with GOCI. It acquires Earth images in 12 visible and near-infrared narrow spectral bands between 380 nm and 865 nm with a spatial resolution of about 300 m over the Korean sea (250 m at Nadir). It provides a full Earth Disk coverage as well as Moon and star imaging capabilities.

As GOCI instrument and COMS satellite, GOCI-II is developed by AIRBUS Defence & Space in close collaboration with the Korean Aerospace Research Institute (KARI) and Korea Institute of Ocean Science and Technology (KIOST). It will be delivered in 2017 and launched in 2019 on the Geostationary Earth Orbit Korea Multi-Purpose Satellite: GEO-KOMPSAT-2B simply called GK2B. It will be operated on a geostationary orbit located at 128.2°E.

The paper presents the main GOCI-II design features, with a specific focus on the new developments dedicated to GOCI-II. This concerns in particular the 7.3 Mega-pixels CMOS Image Sensor, specifically designed, developed and qualified for GOCI-II.

II. GOCI-II OVERVIEW.

A. Mission Overview

Main mission is to observe ocean color around the Korean peninsula in continuity of GOCI mission with enhanced capabilities and performances and also to cover full Earth disc.

Most of the applications concern:

- monitoring of marine environments around Korean peninsular,
- production of fishery information (Chlorophyll, etc.),
- monitoring of long-term/short-term change of marine ecosystem.

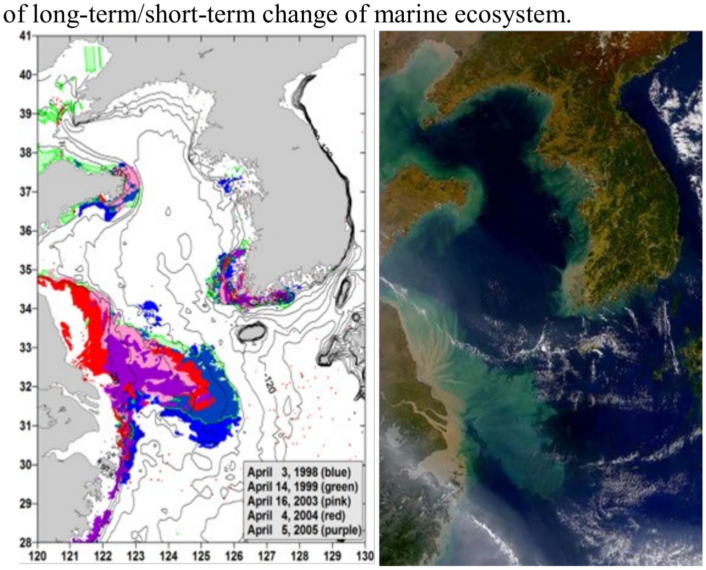


Fig. 1: Example of GOCI images for monitoring of turbidity.

The spectral channels and their primary uses of GOCI-II are summarized in the table below.

Band	**Band Center**	**Primary Usage**
B1	380 nm	CDOM, absorbing aerosol correction
B2	412 nm	CDOM, chlorophyll
B3	443 nm	Chlorophyll absorption maximum
B4	490 nm	Chlorophyll and other pigments
B5	510 nm	Chlorophyll, absorbing aerosol in oceanic waters
B6	555 nm	Turbidity, suspended sediment
B7	620 nm	Phytoplankton species detection
B8	660 nm	Baseline of fluorescence signal, Chlorophyll, suspended sediment
B9	680 nm	Fluorescence signal
B10	709 nm	Fluorescence base signal, atmospheric correction, suspended sediment
B11	745 nm	Atmospheric correction, vegetation index
B12	865 nm	Atmospheric correction, aerosol optical depth
B13	Wideband	Star Imaging for the INR performance

B. Comparison between GOCI and GOCI-II

The new generation GOCI-II instrument provides an important step with respect to the previous generation flown on the COMS satellite. The GOCI-II mission is indeed not only to provide the continuity of the Ocean Color observations around the Korean peninsula but also to improve the quality of the generated products and to extend the observation area. For this, the main required enhancements with respect to GOCI are the following:

- Smaller Ground Sampling Distance (GSD from 500 m to 250 m)
- Field of Regard extended to the whole Earth disk (Full Disk imaging in Global Observation mode)
- More spectral bands (from 8 bands to 12 bands dedicated to Ocean Color imaging)
- Improved straylight performances
- Improved calibration capabilities thanks to possibility of Moon imaging
- Improved INR capabilities thanks to possibility of Star imaging
- Improved autonomy and flexibility (24h programming, autonomous thermal control, …)

Requirements	GOCI	GOCI-II
Mission Life Time	7 years	10 years
Duty Cycle (Local Area : LA)	8 times / day	10 times / day
Duty Cycle (Full Earth Disk : FD)	-	1 time during day time
Observation Time	≤ 30 minutes for LA	≤ 30 minutes for LA ≤ 240 minutes for FD
Spatial resolution (GSD)	≤ 500 m @ center of Ref. LA (130°E, 36°N)	≤ 250 m @ Nadir (Ref. LA : 2.500 km x 2.500 km)
Spectral Range	400 nm – 900 nm (VIS, NIR)	370 nm – 900 nm (VIS, NIR)
Number of spectral bands	8 narrow bands (10 to 40 nm)	12 narrow bands (10 to 40 nm) 1 wide band for star imaging
SNR @ nominal ocean radiance	Between 750 and 1200	Between 750 and 1200
MTF @ Nyquist frequency	> 0.3	> 0.25
Calibration	Sun calibration (once / day)	Sun calibration (once / day) Moon calibration (once / month)
Mass / Power Volume	85 kg / 116 W 1.0 m x 0.8 m x 0.8m	150 kg / 250 W 1.5 m x 1.0 m x 0.9m

Fig. 2: Comparison of GOCI and GOCI-II requirements

C. Design overview

The GOCI-II instrument consists of a Sensor Unit (SU) and one Electronic Unit (IEU) deported inside the satellite platform. The total mass is about 150 kg.

The baseline instrument concept is a compact TMA telescope with a 200 mm pupil diameter, featuring a 7.3 Mega-pixels CMOS array. The 12 narrow band spectral channels are obtained by means of a filter wheel. A 13th wideband spectral channel is implemented for star imaging.

A payload interface plate (PIP) supports a highly stable full Silicon Carbide (SiC) telescope, the two-dimensional Focal Plane Array (FPA) and a Front End Electronics (FEE), the pointing mirror mechanism, the filter wheel mechanism and also the shutter / calibration wheel mechanism.

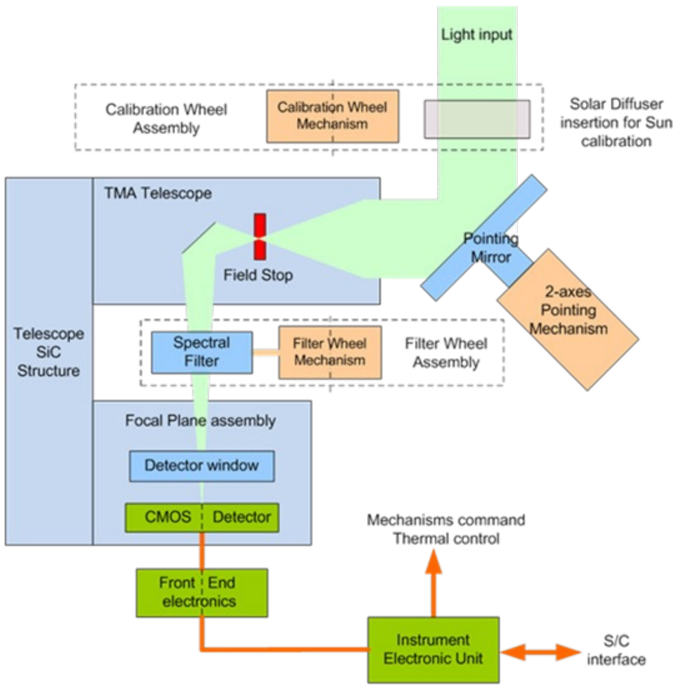


Fig. 3: Functional architecture of the GOCI-II instrument

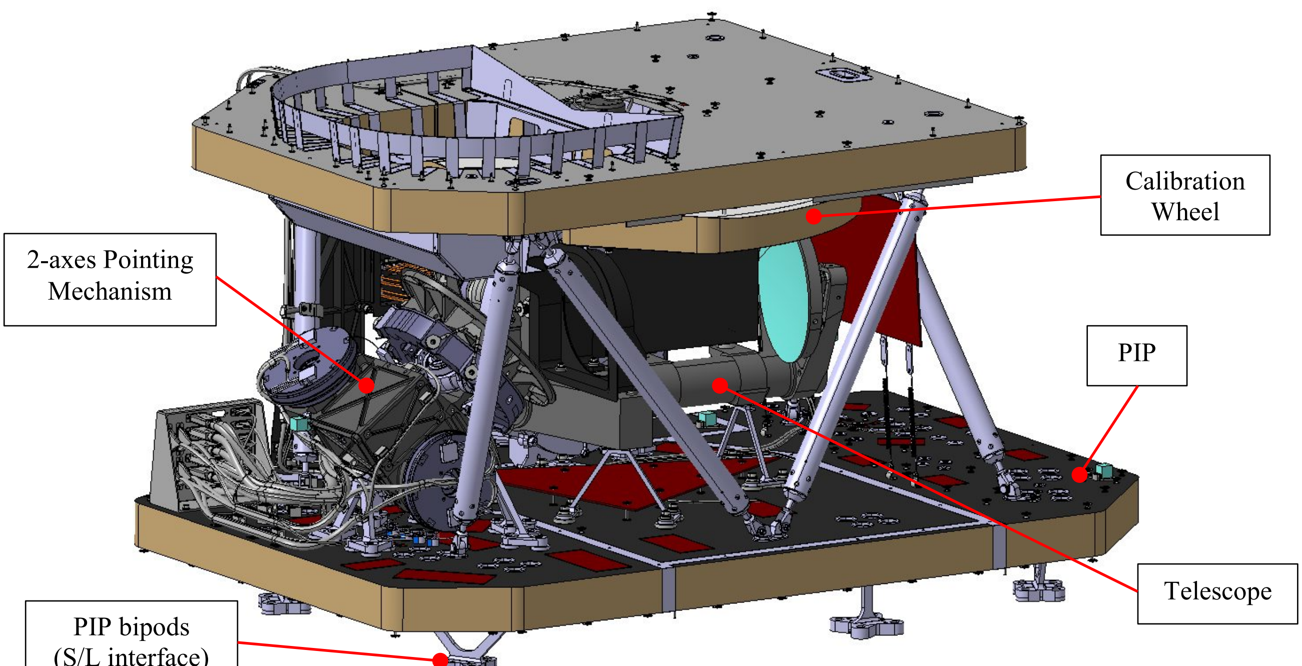
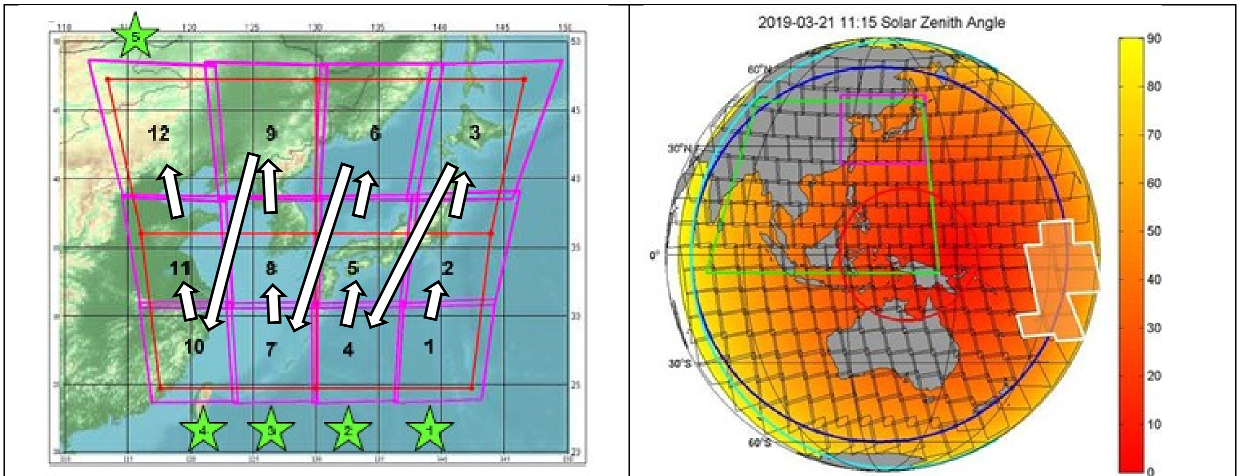


Fig. 4: GOCI-II instrument overview

D. Imaging and Operating Principles

The operating principle consists in imaging a portion of the specified image frame, termed slot. A 2-axes Pointing Mechanism provides a bi-dimensional scanning on the Earth. By successive pointing, the array is moved in the field of view to cover the complete image (local area around Korea or full Earth disk in global observation mode). Each slot is imaged over the 12 spectral channels, plus a dark position for offset monitoring and correction. The image is acquired for two gain levels corresponding to sea and cloud radiance levels, respectively. The image data are sent in quasi-real-time to the ground. One single slot acquisition period takes less than 100 seconds in Local Observation mode and less than 60 seconds in Global Observation mode. Star images are done from time to time to calibrate the instrument Line of Sight and feed the image ground processing (INR). The instrument in-orbit radiometric calibration is achieved by a combination of Solar Calibration (possible every day) and Moon calibration (monthly).



Reference LA imaging (12 slots) with 5 Star imaging | Full Disk imaging by less than 240 slots

Fig. 5: Two imaging modes are available: Local area acquisition and Full Disk acquisition

The instrument operations are managed by a programmable timeline uploaded in the instrument electronics. The timeline covers 24h operations (mechanism motions, slot acquisitions, detection electronics on/off) and is automatically repeated by default. The figure below illustrates a typical set of operations that can be autonomously executed by the instrument and shows the instrument flexibility for Earth observation and calibration activities. The coverage of the Reference Local Area is done in a short time frame (20 minutes in 12 slots) giving the user up to 10 minutes per hour for complementary acquisitions: star imaging for efficient INR processing and Full Disk slots to fulfill global coverage mission during daytime with optimal illumination conditions.

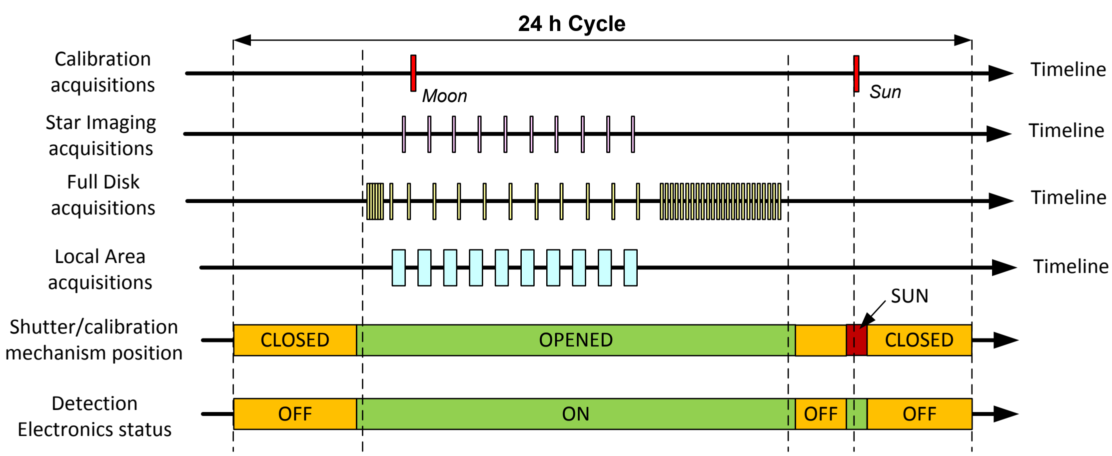


Fig. 6 : Typical example of GOCI-II imaging operation over 24 hours

E. Main challenges of GOCI-II development

Although the overall instrument architecture and operation principles are inherited from the first GOCI, the specified performance enhancements required major new developments of key components:

- New dedicated CMOS Image Sensor to fit the smaller sampling distance with increased number of pixels while keeping high level radiometric and MTF performances. This detector was developed in partnership between AIRBUS D&S and ISAE, as presented in details in chapter III.
- New 2-axes Pointing Mechanism (POM - fig 7 below) to manage the enlarged instrument Field of Regard and the increased pointing mirror size and mass, while keeping a high stability, an accurate restitution of the pointing direction and the capability of being launched without Launch Locking Device. The POM was designed and developed by AIRBUS D&S in Toulouse. A fully representative qualification model has been build and the qualification tests will be completed before the end of the summer 2016.

Fig. 7: CAD model of GOCI-II 2-axes Pointing Mechanism

- The electronic unit (IEU) that has to manage more detection chains and has to provide higher level of autonomy and flexibility for the user, while keeping low size and mass (7.5 kg). The IEU was developed by AIRBUS D&S electronics division. The full functional and performance validation was reached in 2015 on an EM model and the Flight Model has been delivered mid-2016.
- The dedicated TMA telescope with enlarged pupil and improved straylight performances (Field stop implementation) while keeping compactness and diffraction limited performances. The SiC telescope structure and mirrors are designed by AIRBUS D&S and manufactured by MERSEN BOOSTEC. Mirror polishing is done by AMOS (Belgium) and coating by SCHOTT (Switzerland).
- The optical filters were newly designed by OBJ in Germany with barrels made by SODERN. After full qualification on dedicated models, the Flight Models have been delivered mid-2016.

Fig. 8 : Telescope during alignment

Fig. 9 : Picture of GOCI-II filter wheel

- Two Sun diffusers made of HOD material are also implemented to enhance radiometric calibration
- In addition, several key elements (harness, structures, EGSE) have been subcontracted to the Korean industry

III. THE GOCI-II CMOS IMAGE SENSOR

In order to meet the demanding radiometric performance requirements, a 7.3MPixels CMOS image sensor has been specifically designed for GOCI-II mission. Die design and architecture have been carried out in partnership with the “Institut Supérieur de l’Aéronautique et de l’Espace” (ISAE). Following design phase, the silicon wafers (Fig-10) have been manufactured and processed in an Asian semiconductor foundry.

The 7.3MPixels CMOS image sensor features:

- 2720 rows by 2718 columns of 6.8µm pitch pixels with 10 analogue outputs to answer at the closest to spatial resolution and acquisition duration requirements (Fig-11)
- Pixel topology optimization to meet detection efficiency and Modulation Transfer Function challenging requirements
- Adjustment of in pixel conversion factor (CVF) including design and manufacturing tolerances for Signal-to-Noise Ratio and dynamic range budgets

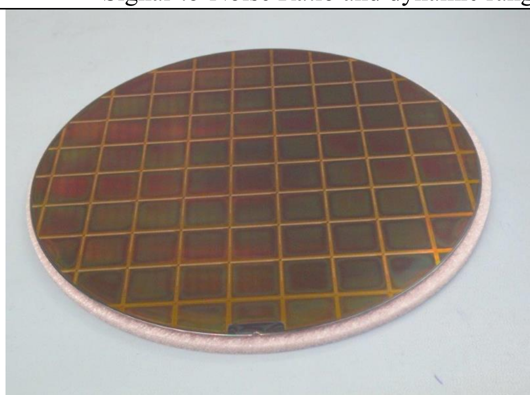


Fig. 10: Wafer

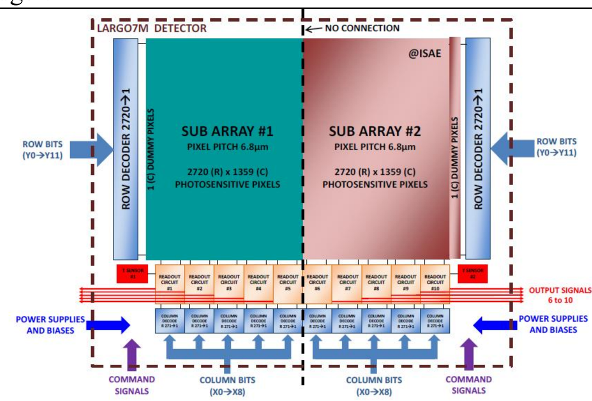


Fig. 11: Die architecture

Fig-12 illustrates one of the first GOCI-II detector mock-ups. The manufacturing and test flows follow the ECSS-9020 standard. A dedicated ceramic package has been designed (Fig-13). Wafer sawing, die gluing and wire-bonding (Fig-14) are performed in ISO5 environment. Two dedicated test benches have been designed by Airbus D&S one to test the electrical behavior of the detectors during the manufacturing (Fig-15) and the other to operate detectors during the burn-in phase (Fig-16). A key performance linked to manufacturing is die flatness: die gluing optimization process leads to very low flatness (<5µm) fully in line with GOCI-II instruments requirements (Fig 17).

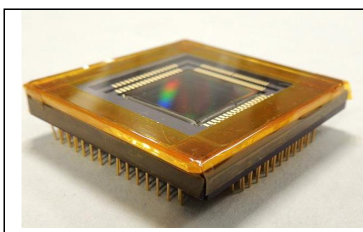


Fig. 12: Detector mock-up (temporary window)

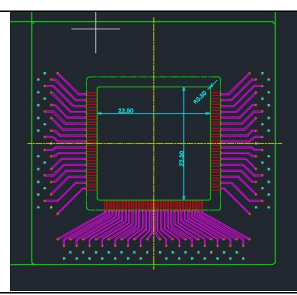


Fig. 13: Package drawing

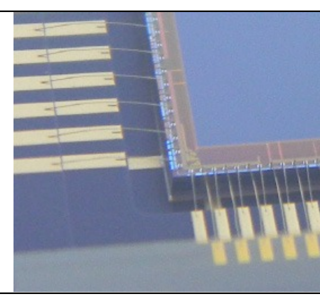


Fig. 14: Wire bonding

Fig. 15: Test bench for functional test

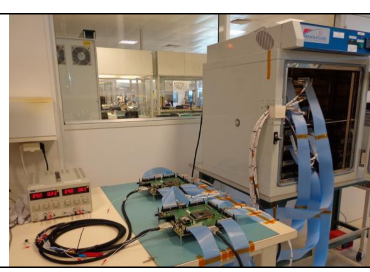


Fig. 16: Set-up for burn-in

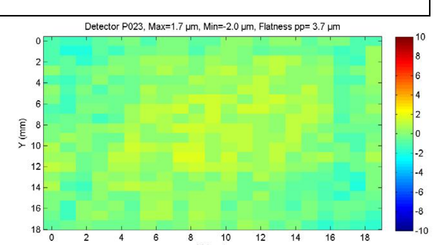


Fig. 17: Die flatness lower than 5µm peak-to-valley

Once manufactured, the detectors have been tested at Airbus D&S Toulouse facilities using a high performance electro-optical test bench in-house designed and developed (Fig-18). Tests are performed in ISO5 environment The test bench is fully automated and allows the determination of noise, CVF, dark current, linearity, sensitivity and its non-uniformity for the 12 GOCI-II spectral bands (Fig-19). Test sequence duration is about 1 hour per detector including automated post-processing sequence for electro-optical parameters extraction.
Temperature is controlled at 20°C thanks to Thermal Electric Cooler equipment.
For selection of detector flight model, screening on several tens of detectors has been carried out: this includes a specific data analysis taking into account the GOCI-II operating mode. Main selection criteria are SNR, cosmetic defects and visual inspections (Fig-20 and Fig-21).

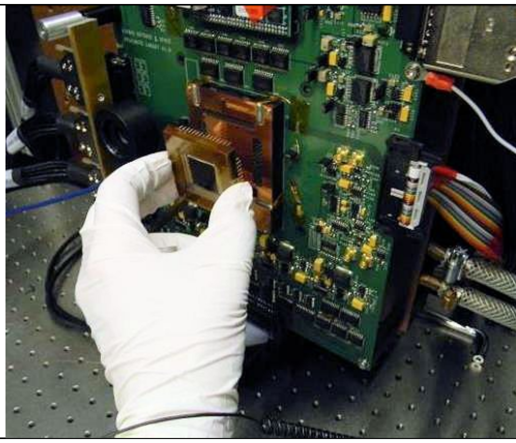


Fig. 18: Detector mounting onto proximity board

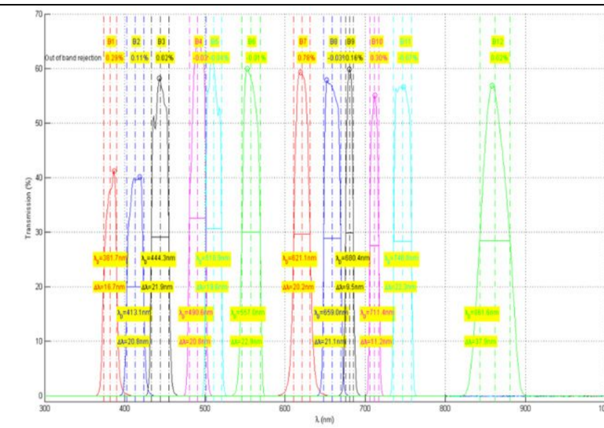


Fig. 19: 12 GOCI-II spectral bands characteristics

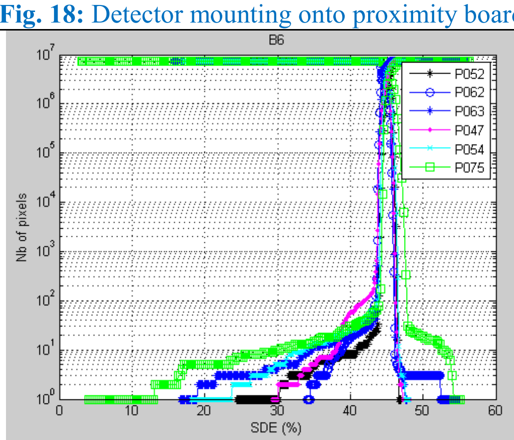


Fig. 20: Cumulative histograms for data analysis

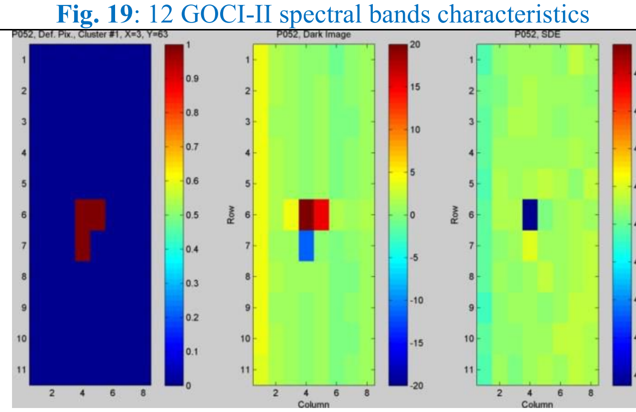


Fig. 21: Cosmetic defects determination for FM selection

A qualification program has been conducted on several models of the 7.3MPixels image sensors following space standards. It includes:

- Lot Acceptance Tests with shock/vibration tests (Fig. 22), temperature cycling and operating life tests
- Radiation tests with Total Ionizing Dose (Fig. 23), protons damages and latch-up tests (Fig. 24).

Electro-optical tests as well as visual inspections are performed prior and after each qualification test. The qualification also includes a Destructive Physical Analysis.
All qualification models successfully passed the qualification tests.

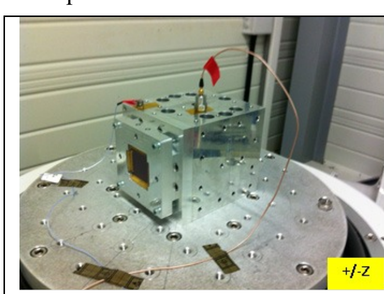


Fig. 22: Detectors during mechanical tests

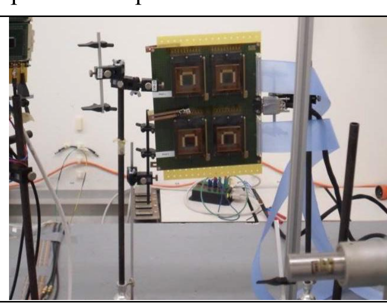


Fig. 23: Detectors during TID irradiation

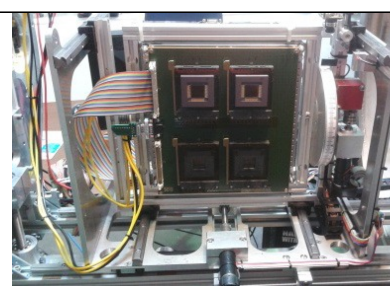


Fig. 24: Detectors during latch-up test (heavy ions

Before final integration onto GOCI-II instrument, the flight detector model has to be assembled onto focal plane. The assembly activities consist of:

- Soldering onto a Printed Circuit Board (PCB) connected to the Front End Electronics thanks to flexible links (Fig. 25)
- Gluing on silicon carbide SiC frame for thermal and accommodation aspects. Specific tooling have been used to align the detector die with respect to the mechanical SiC frame with an accuracy lower than 20µm (Fig. 26)

Fig. 27 shows the GOCI-II Flight Model focal plane before integration onto the instrument.

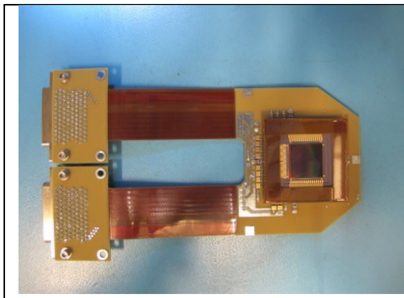


Fig. 25: Detector reported onto PCB with flexible links

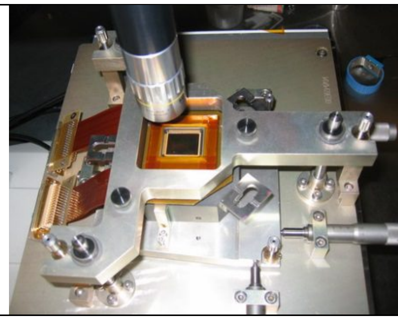


Fig. 26: Detector positioning during gluing onto SiC piece

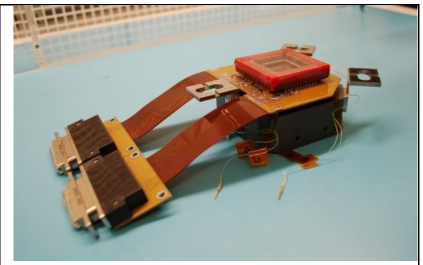


Fig. 27: GOCI-II detector assembly

IV. GOCI-II DEVELOPMENT SCHEDULE.

The GOCI-II development started in July 2013 and the instrument Flight Model delivery is scheduled mid-2017. The design, procurement and integration phase take place in AIRBUS Defence & Space in Toulouse (France) with the help of a detached Joint Development Team from KARI and KIOST.
A GOCI-II EM instrument made of EM electronics, including fully representative detector and mechanisms was built for early verification of the detection chains and full instrument functional validation. The EM instrument was delivered to KARI beginning of 2016.
The completion of the GOCI-II Flight Model integration is scheduled by the end of 2016. The first set of performance acceptance tests will be done in AIRBUS D&S premises in ambient conditions. Then the instrument will be shipped to KOREA beginning of 2017 and all the environmental tests (mechanical, thermal vacuum, EMC) will be performed with the KARI facilities in close collaboration between the French and Korean teams.
After the completion of the acceptance tests, the instrument will be formally delivered to KARI. It will then be mounted on GK2B satellite and launched aboard ARIANE V in 2019.

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