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THE MULTISPECTRAL INSTRUMENT OF THE SENTINEL2 PROGRAM

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ABSTRACT

The Sentinel-2 program will provide a permanent record of comprehensive data to help inform the agricul-tural sector (utilisation, coverage), forestry industry (population, damage, forest fires), disaster control (management, early warning) and humanitarian relief programmes. Sentinel-2 will also be able to observe natural disasters such as floods, volcanic eruptions, subsidence and landslides.
In the Sentinel-2 mission programme, Astrium in Friedrichshafen is responsible for the satellite's system design and platform, as well as for satellite integration and testing. Astrium Toulouse will supply the Multi-Spectral imaging Instrument (MSI), and Astrium Spain will be in charge of the satellite's structure and will produce its thermal equipment and cable harness. The industrial core team also comprises Jena Optronik (Germany), Boostec (France), Sener and GMV (Spain).
Sentinel-2 is intended to image the Earth's landmasses from its orbit for at least 7.25 years. In addition, its onboardresources will be designed so that the mission can be prolonged by an extra five years. From 2012 onwards, the 1.1-metric-ton satellite will circle the Earth in a sun-synchronous, polar orbit at an altitude of 786kilometres, fully covering the planet's landmasses in just ten days.
The multi-spectral instrument (MSI) will generate optical images in 13 spectral channels in the visible and shortwave infrared range down to a resolution of 10 metres with an image width of 290 kilometres.
The instrument is composed of two main parts:
• The telescope assembly , combining in one instrument both VNIR and SWIR channels, is mounted on the upper plate of the Bus
• The Video and Compression Electronic Units mounted inside the Bus.
This telescope is based on a Three Mirror Anastigmat optical concept. This three mirror optical combination is corrected from spherical aberration, coma and astigmatism. It provides a large field of view with very good optical quality.
The telescope mirrors and structural baseplate are made of Silicon Carbide material in order to minimise thermo-elastic distortions. Isostatic mounts decouple the instrument from potential deformations of the platform upper plate.
The optical beam is spectrally separated thanks to a dichroic filter towards two different focal planes with different detector technologies: Silicon is used for the VNIR domain whereas Mercury Cadmium Telluride is equired for the SWIR spectral domain.
The VNIR detector is a CMOS device. The SWIR detector is a hybridised component where the MCT photosensitive arrays are hybridised on top of a CMOS circuit. The separation of the individual spectral bands(10 spectral bands, for the VNIR detectors and 3 spectral bands for the SWIR detectors) is performed by specific
strip filters mounted on top of the detectors.
The telescope is thermally decoupled from the external environment and the platform thanks to a thermal enclosure. A calibration and shutter mechanism avoids direct sun incidence inside the telescope during launch, specific platform manoeuvres and safe mode.
The video signals coming out of the VNIR and SWIR focal planes are digitised and compressed inside the Videoand Electronic Units prior to be sent to the bus.

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1. THE MSI MAIN FEATURES

The design of the MSI instrument is mainly driven by the Spatial Sampling Distance (SSD) of 10 m; the swath of 290 km which requires a large field of view of 20.6°and the 13 spectral bands within a large spectral domain from 0.4 to 2.4 µm.

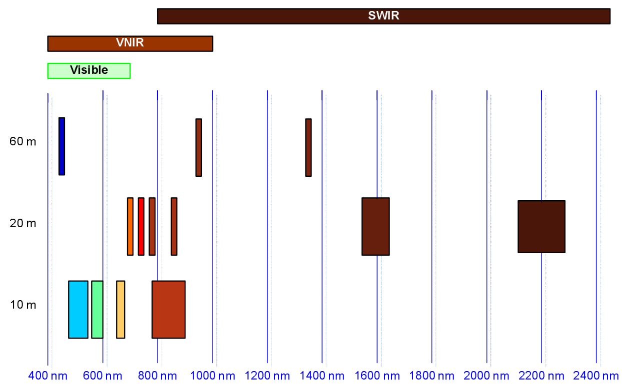

Figure-1 : Sentinel-2 Mission spectral and SSD requirements

The MSI instrument is based on a push-broom concept. It features a unique mirror silicon carbide off-axis telescope with a 150 mm pupil feeding two focal planes spectrally separated by a dichroic filter. CMOS and hybrid HgCdTe detectors are selected to cover the Visible and Near Infra Red (VNIR) and Short Wavelength Infra Red (SWIR) channels. The MSI instrument includes a sun calibration and shutter mechanism. The 1.4 Tbits image video stream, once acquired and digitized is compressed inside the instrument.
The instrument carries one external sensor assembly that provides the attitude and pointing reference to ensure a 20 m pointing accuracy on the ground before image correction.

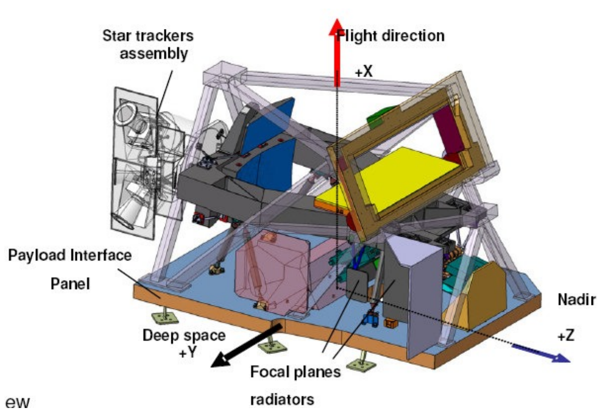

Figure-2 : MSI internal configuration

The main instrument design drivers are recalled here after:

Requirement	Design impact
SSD at 10 m	Push broom
SNR and MTF > 0.15	Pupil diameter of 150 mm
Swath width > 290 km	Optical field of 20.6° 29 000 pixels for one 10 m Band in focal plane
Spectral domain : 0.4-2.4 µm	2 detector technologies : Si and HgCdTe use of a dichroic
Cut-off wavelength at 2.4 µm	Cooling of SWIR detector at about 200 K
13 spectral channels	In field separation within VNIR and SWIR focal planes stripped filters : 10 channels in VNIR , 3 in SWIR
Spectral requirements	High filtering performances Telecentric optical design

Figure-3 ; Main MSI design drivers

The overall mass of the MSI instrument is 230Kg; its power consumption is 200W in Imaging mode and 60 W in stand-by mode

2. OPTOMECHANICAL ARRANGEMENT

The optical configuration is based on a Three-Mirror Anastigmat (TMA) telecentric telescope, which can achieve the requested performance and geometric constraints with a minimum of optical elements. The telescope comprises three aspheric mirrors: M2 mirror is a simple conic surface, whereas the other mirrors need more aspherisation terms.

Mirror size	M1	M2	M3
Dimensions in mm	440×190	145×118	550×285

Figure-4: Dimensions of the MSI mirrors

The entrance pupil is rectangular. It is equivalent to a 150 mm diameter full pupil. It is located on the M2 mirror, which gives the best balance between M1 and M3 dimensions, and is suitable for image telecentricity.
Since the VNIR and SWIR detectors are different, the complete imaging of the required spectral bands is done using a dichroic separation inside the splitter unit.

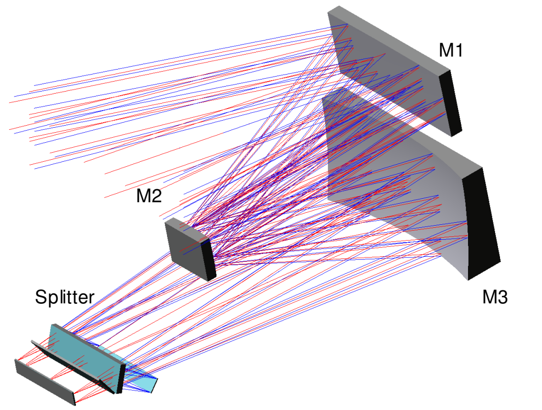

Figure-5: 3D view of the telescope

The spectral filtering onto the different VNIR and SWIR spectral bands is ensured by slit filters mounted on top of the detectors. These filters provides the required spectral isolation

3. MECHANICAL AND THERMAL ARCHITECTURE

This design aims at maintaining separated functions to allow parallel development of the main assemblies and simple alignment at instrument level. It also minimises number of structural items to cope with stability, manufacturing, and assembly constraints. The separated assemblies (TMA telescope, SWIR and VNIR focal planes, Calibration and Shutter Mechanism, Primary and Secondary Structure can be developed, integrated and tested separately prior final integration of the instrument.

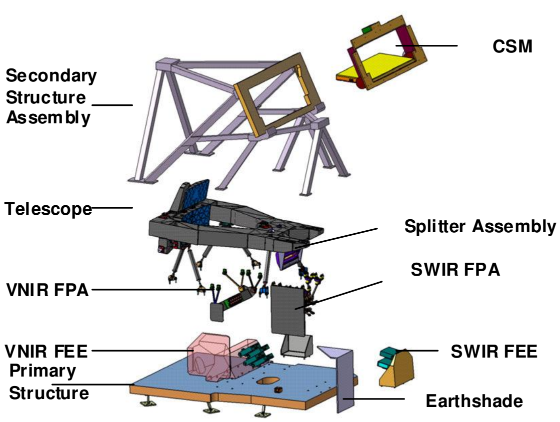

Figure-5: Main assemblies of the MSI

The telescope mirrors and structural baseplate are made of Silicon Carbide material in order to minimise thermo-elastic distortions. Isostatic mounts decouple the instrument from potential deformations of the platform upper plate.

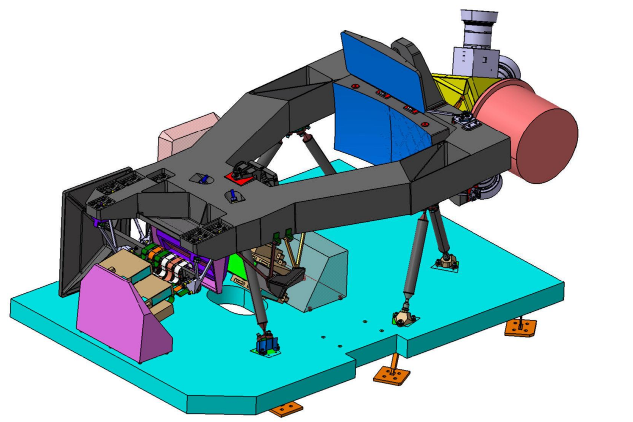

Figure-6: Telescope mechanical configuration

The thermal design ensures an homogenous environment for the telescope and a high temperature stability of both focal planes.

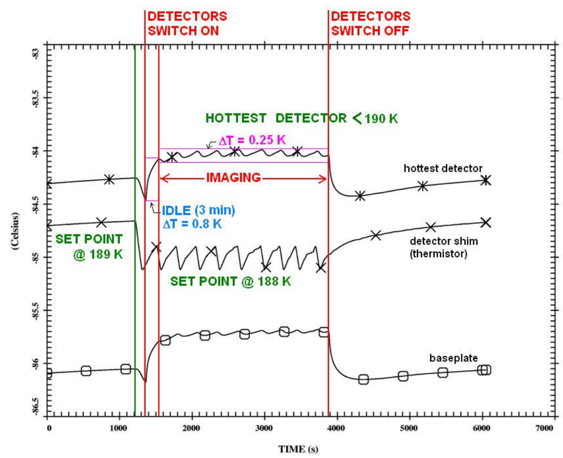

Figure : SWIR detectors temperature evolution during imaging

4. VNIR AND SWIR FOCAL PLANE ASSEMBLIES

Both focal planes accommodate 12 elementary detectors in two staggered rows to get the required swath The SWIR focal plane operates at -80°C whereas the VNIR focal plane operates at 20°C. Both focal planes are passively cooled down. A monolithic SiC structure provides support to the detectors, the filters and their adjustment devices and offers a direct thermal link to the radiator

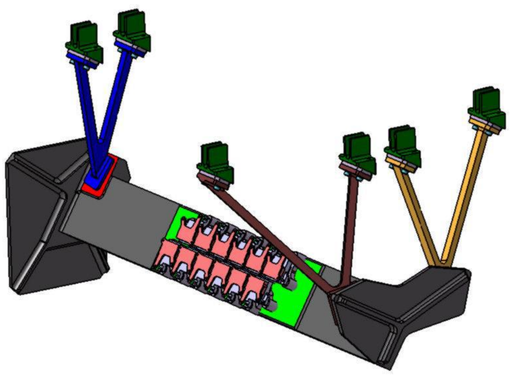

Figure-6: Focal plane configuration

5. KEY COMPONENTS: FILTERS AND DETECTORS

Key components have been identified as key performance drivers for the mission
Dedicated Strip filters mounted on top of each VNIR or SWIR detector provides the required spectral templates for each spectral bands.

Figure-7: VNIR and SWIR spectral filters
(Courtesy of Iéna-Optronik)

The VNIR detector is made of a CMOS die, using the 0.35 µm CMOS technology, integrated in a ceramic package. The detector architecture enables Correlated Double

Sampling for the 10 VNR spectral bands and Time Delay Integration (TDI) mode for the 10m bands. Black coating on the die eliminates scattering.

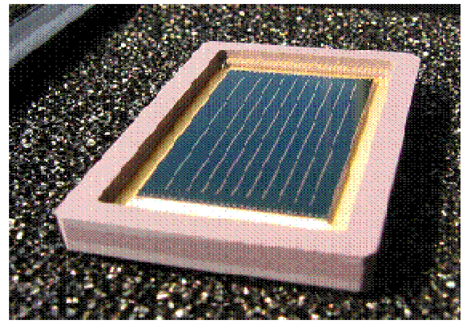

Figure-8: CMOS detector with back coating

The SWIR detector is made of an HgCdTe photosensitive material hybridized to a silicon readout circuit (ROIC) and integrated into a dedicated hermetic package. The SWIR detector has three spectral bands for which the spectral efficiency is optimized. B11 and B12 bands are operated in (TDI) mode.

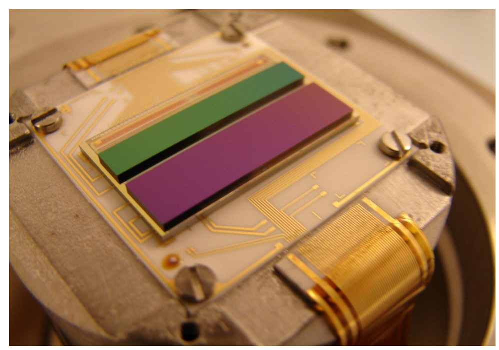

Figure-9: SWIR detector EM model at hybridization stage
(Courtesy of Sofradir)

6. DETECTION CHAIN AND ELECTRONIC ARCHITECTURE

The main driver of the detection chain architecture is the implementation of 48 analogue-to-digital low noise video chains.
The Front End Electronics Modules (FEEM) extract, condition and transmit the video signals towards the Video and Compression Unit (VCU)
The VCU controls the FEEMs and receives analogue video data from the FEEMs; it digitizes and pre-processes the data received from the FEEMs; it performs pixel equalisation, video data compression and formatting, and transmits the data packets to the Spacecraft; it performs the thermal control and housekeeping tasks; Finally it distributes the power supply to the FEEMs and the detectors.

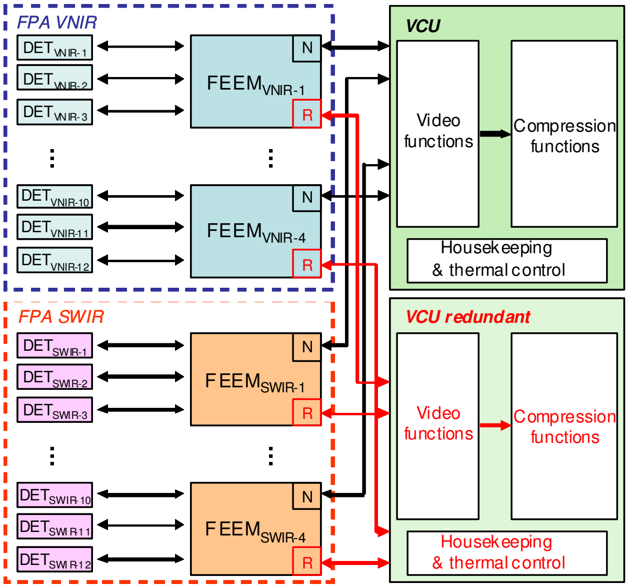

Figure-10: Schematic of the detection chain including the FEE modules distribution, the nominal and redundant VCU functions.

7. MAIN PERFORMANCE OF THE INSTRUMENT

The Signal to Noise performance is above 100 for all spectral bands.

	MSI specification	SNR performance
B1 60m	129	577
B2 10m	154	171
B3 10m	168	202
B4 10m	142	183
B5 20m	117	155
B6 20m	89	138
B7 20m	105	161
B8 10m	174	204
B8a 20m	72	130
B9 60m	114	111
B10 60m	50	256
B11 20m	100	128
B12 20m	100	133

Figure –11 : radiometric performance of the MSI instrument

The Modulation Transfer Function is above or close to 0.15 for all 10m bands. It is above 0.20 for the other bands.

	Specification	Along track MTF	Along track MTF
B1	*0.15*	0.33	0.38
B2	*0.15*	0.16	0.25
B3	*0.15*	0.15	0.15
B4	*0.15*	0.15	0.21
B5	*0.15*	0.21	0.33
B6	*0.15*	0.20	0.32
B7	*0.15*	0.21	0.32
B8	*0.15*	0.13	0.19
B8a	*0.15*	0.16	0.25
B9	*0.15*	0.24	0.31
B10	*0.15*	0.50	0.30
B11	*0.15*	0.20	0.35
B12	*0.15*	0.17	0.32

Figure –12 : Along track and across track Modulation Transfer Function of the MSI instrument

8. CONCLUSION

The design phase of the MSI instrument is currently under finalisation. The completion of the industrial team is underway in order to deliver the flight model mid 2011.
The MultiSpectral Instrument is the next generation of the European land imagers. Its performance will set new standards for the future multispectral / hyperspectral space cameras.