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METIMAGE – A SPECTRO-RADIOMETER FOR THE VII MISSION ONBOARD METOP-SG

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I. INTRODUCTION

METimage is a cross-purpose medium resolution, multi-spectral optical imaging instrument dedicated for operational meteorology, oceanography, and climate applications. It is implemented as passive imaging spectro-radiometer, capable of measuring thermal radiance emitted by the Earth and solar backscattered radiation in a broad spectral range. The instrument is mounted on MetOp-SG satellite A.

We present the METimage instrument design and discuss the achievable instrument performance.

II. MISSION CONTEXT

The METimage instrument is designed to serve the VIS/IR Imaging Mission (VII) of the EUMETSAT Polar System – Second Generation (EPS-SG) [1]. EPS-SG shall provide global observations which cover a broad spectral range (from UV to mid infrared), are related to different spatial coverage (global and regional), and are characterized by a variety of different time scales, in order to continue and enhance the services offered by the EPS system. EPS-SG is Europe’s contribution to the Joint Polar System (JPS), which is composed of EUMETSAT’s EPS-SG satellites, NOAA’s JPSS satellites and shared ground systems and services. By global coverage and a variety of passive and active sensors at low Earth orbits a significant improvement of the numerical weather prediction is targeted.

The MetOp-SG satellites – two series of satellites, with three units in each series – constitute the space segment of EPS-SG. The Satellite A series focuses on optical instruments and atmospheric sounders, while the Satellite B series focuses on microwave instruments. The three satellites in each series provide a total nominal lifetime of 21 years. The METimage instrument is embarked on the Satellite A nadir panel, see Fig. 1.

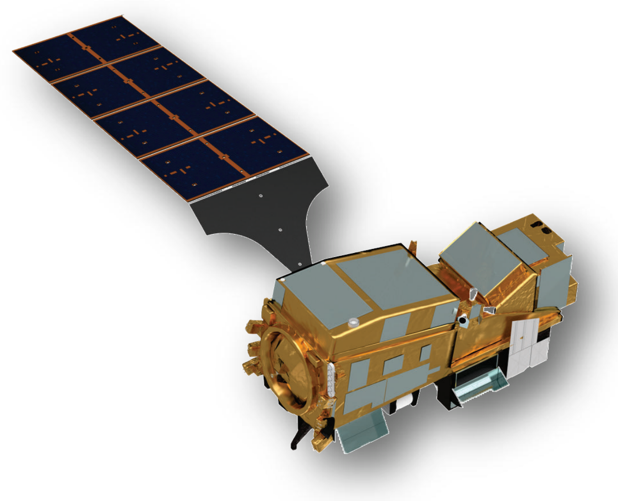

Fig. 1 METimage onboard MetOp-SG Satellite A. (Courtesy Airbus Defence & Space SAS)

III. INSTRUMENT & OBSERVATION CONCEPT

METimage is a passive imaging spectro-radiometer, capable of measuring thermal radiance emitted by the Earth and solar backscattered radiation in 20 spectral bands from 443 to 13.345nm. The instrument onboard MetOps-SG satellites A is placed in a Sun-synchronous polar orbit with an average altitude of 830km. Full Earth coverage is achieved within the 14 orbits of 1 day.

METimage achieves global coverage with 500m square pixels by continuous scanning orthogonal to the flight direction. Due to the scan motion, the image moves sequentially over the detector channels. By proper timing of the sampling, a certain pixel in the image is measured sequentially by different spectral channels, see Fig. 2.

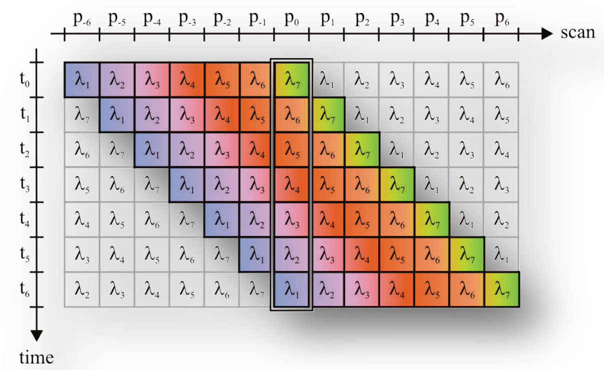

Fig. 2 METimage scanning principle, illustrating the sequential measurement of a pixel p within 1 scan over time t.

The METimage instrument is designed to cover a large across track swath of ~2670km, corresponding to ±53deg scan angle, with a constant spatial sampling angle across the swath and a spatial resolution of 500m at nadir. It is implemented as in-beam scanner with static telescope and synchronous field de-rotation. The scanner is rotating continuously clockwise about the telescope axis. The scan period of 1.729s is defined by the satellite orbit and the spatial resolution. Field de-rotation, realized by a set of planar mirror reflections, ensures a regular imaging geometry over the full scan range.

The scanning principle also allows for regular views to dedicated calibration sources without interrupting the scientific observation, see Fig. 3. A two point calibration scheme is implemented, i.e. each signal channel can be re-calibrated with two different calibration sources at different signal levels. A dark signal level (deep space view DV) is provided for offset correction while the bright sources (solar calibration device SCAD, thermal calibration device TCAD) provide the gain calibration. The calibration sources are placed in front of the scan mirror to allow for the calibration of the complete optical and electrical detection chain.

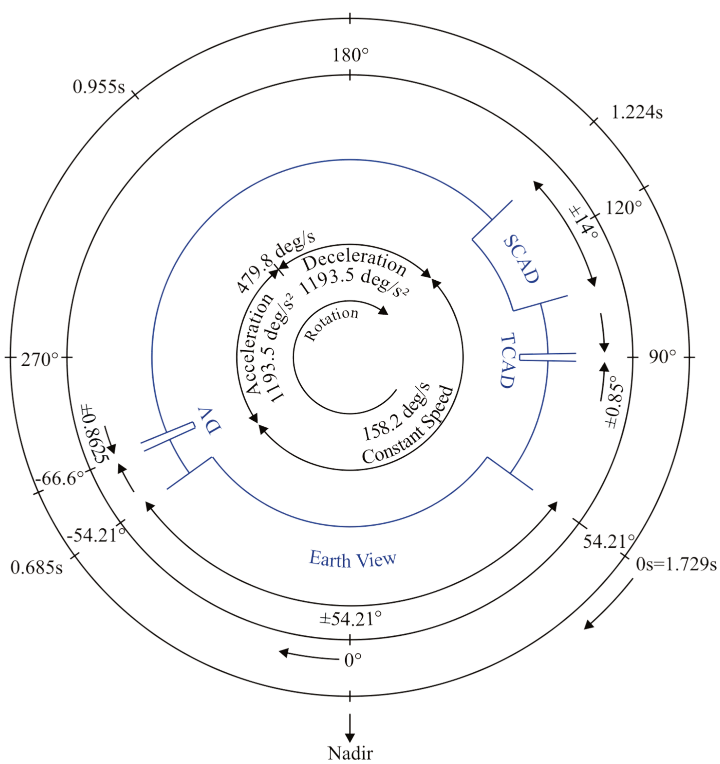

Fig. 3 METimage observation principle, illustrating the Earth view as well as the calibration views.

The telescope is designed to offer an instantaneous field of view (IFOV) of 1.6deg. This supports the scanning of 24 ground pixel of 500m resolution in flight direction and provides 10 slots for spectral channels or TDI stages for each of the 3 focal planes (spectral bands VNIR, SMWIR and LVWIR). The spectral band separation between the focal planes is accommodated by 2 dichroic beam splitters, the channel separation within each band is implemented by spectral bandpass filters.

The instrument key parameters are given in Tab. 1.

Tab. 1 Key instrument parameters.

Orbit parameters				
	• Orbit	Sun synchronous, polar		
	• Orbit height	830km (average)		
Observational parameters				
	• Scan range	±53deg		
	• GSD	500m (at 830km, nadir)		
	• Swath	12km ALT x 2670km ACT		
Spectral bands				
solar bands	VNIR channels	CWL [nm]	FWHM [nm]	add. TDI stages
	• VII-4	443	30	
	• VII-8	555	20	
	• VII-12	670	20	
	• VII-15	752	10	1
	• VII-16	763	10	1
	• VII-17	865	20	
	• VII-20	914	20	1
	SMWIR channels	CWL [nm]	FWHM [nm]	TDI stages
	• VII-22	1240	20	
	• VII-23	1375	40	
	• VII-24	1630	20	
	• VII-25	2250	50	
thermal bands	• VII-26	3740	180	1
	• VII-28	3959	60	1
	• VII-30	4050	60	1
	LVWIR channels	CWL [nm]	FWHM [nm]	TDI stages
	• VII-33	6725	370	
	• VII-34	7325	290	
	• VII-35	8540	290	
	• VII-37	10690	500	
	• VII-39	12020	500	1
	• VII-40	13345	310	1
Telescope parameters				
	• Input aperture	170mm, circular		
	• Focal length	1660mm		
	• FoV	1.6deg, circular		
Detector parameters				
	• VNIR	CMOS, 250µm x 250µm read-out pixel size 96 x 4 read-out pixels per channel (ALTxACT) ambient operational temperature		
	• SMWIR/ LVWIR	MCT, 90µm x 90µm read-out pixel size 51 x 6 read-out pixels per channel (ALTxACT) 60K operational temperature		
External interfaces				
	• Mass	296kg		
	• Power	465W	nominal operations mode	
		287W	survival & LEOP mode	
	• Data rate	18 Mbps	day	
		9 Mbps	eclipse (VNIR channels off)	
	• Data volume	82 Gbit	over 1 orbit	

IV. INSTRUMENT DESIGN

The orbit and observational parameters together with the detector parameters lead to a TMA design for the telescope. The pupil stop is between the scanner mirror and M1, a field stop is placed on the intermediate image after M2 to limit the out-of-field stray light. The rotation of the scan mirror is compensated by a beam de-rotator following the telescope. The de-rotator is electrically synchronized with the scanner and rotates at half of the scanner frequency. It is implemented with as 5 mirror system to minimize polarization effects. A set of dichroic beam splitters separates the beam into 3 spectral bands and folding mirrors direct the beams to the VNIR detector and the IR intermediate images. At these intermediate images the spectral channels are spatially separated by filter stripes, and re-imaged onto the IR detectors to cope with the detector geometry (magnification of 0.135). Inside this re-imaging optics a cold pupil stop reduces slightly the aperture to remove the direct light coming from the (warm) entrance pupil stop. The overall METimage optical design is depicted in Fig. 4.

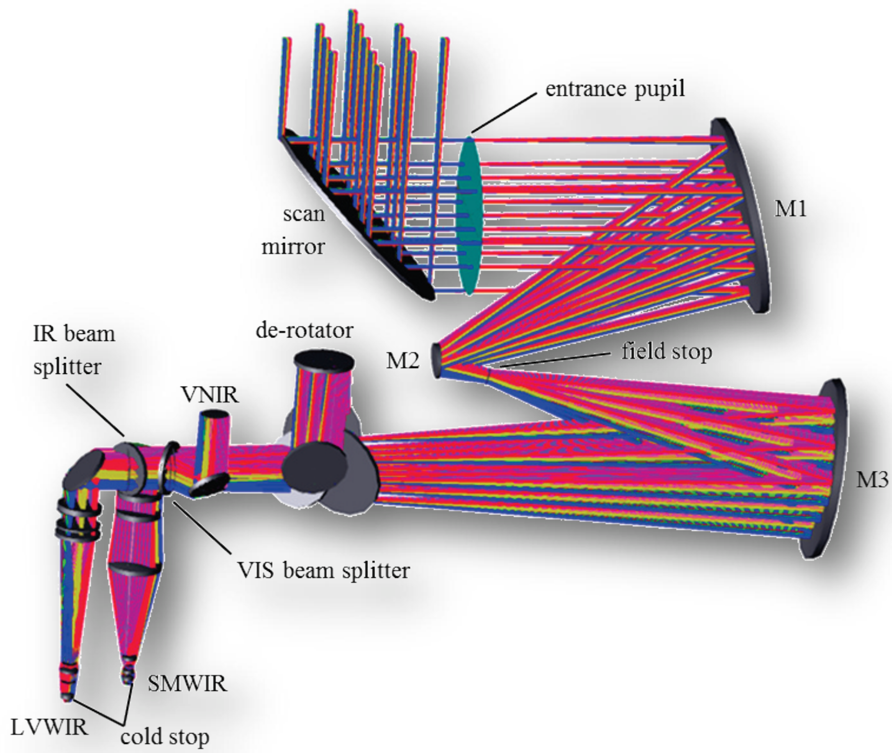

Fig. 4 METimage optical design.

The instrument consists of the optical head as well as of the electronic units located inside the spacecraft's payload equipment bay. The optical is constituted of four major parts (see Fig. 5):

- A compartment at ambient temperature which is realized as a box-like structure supporting the calibration devices, the mechanisms, the optical elements up to the beam splitters, as well as the cryogenic subsystem.
- A cryogenic subsystem which includes the IR optics from the filters up to the detectors as well as the cryostat with the cold-redundant cryo-coolers.
- An external electric assembly carrying the detectors front end electronics as well as the temperature acquisition electronics.
- A baffle for the solar calibration device to avoid any light entering from Earth or spacecraft.

The instrument structure is made of Aluminum/CFRP sandwich panels and is actively thermal controlled. The Earth view baffle is defined by the instrument's scan range and by the deep space view at -66.6deg.

The thermal calibration device (TCAD) is a black plate with well-known emissivity and high accuracy temperature control (sensors with 1mK accuracy over lifetime). The solar calibration device (SCAD) is implemented as a reflective diffusor made of Spectralon. To cope with aging effects, the diffusor is illuminated only once in several days. In addition a reference diffusor is available to determine the degradation over time. Details on instrument calibration are given in [2].

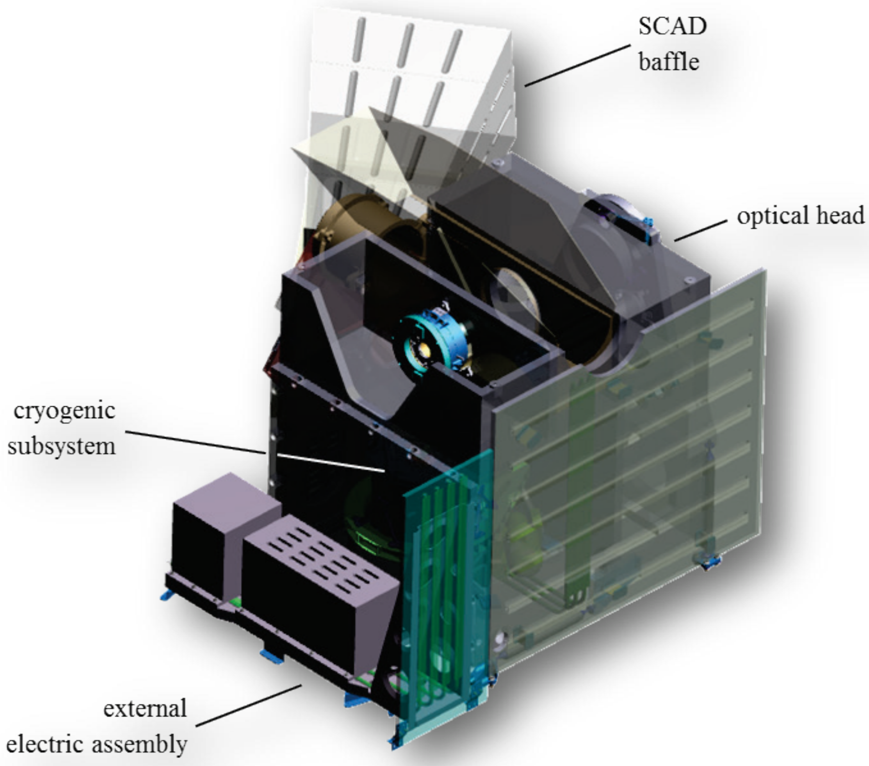

Fig. 5 METimage optical head (structural parts transparent, MLI not shown).

The scan mirror and the de-rotator optical assembly are mounted on respective mechanisms, which are properly aligned and actively controlled to ensure the electrical synchronization. The telescope optics is implemented on a separate structure to allow for proper alignment.

The cryogenic subsystem is implemented on a separate structure to allow for a stand-alone integration and verification but also to ease the integration into the optical head structure, see Fig. 6.

The cryostat design with 2 inner shields ensures a detector temperature of 60K and temperatures of up to ~80K for the re-imaging optics. Two windows allow the optical paths to enter the cryostat. The refractive re-imaging optics for each IR band is mounted inside a Titanium structure which interfaces the cryostat housing with GFRP struts to minimize the thermal loads. The IR detectors are coupled to the pulse tube cryo-coolers via highly conductive thermal links. The cryo-cooler compressors are linked via heat pipes to the radiator.

The beam splitters and fold mirrors as well as the VNIR filter assembly and FPA are implemented on a separate bench. This bench is mounted on the cryostat to make feasible the alignment of the re-imaging optics to the beam splitters and to improve the spatial co-registration between the VNIR channels and the IR channels.

The proximity electronics are used for detector output signal pre-amplification. They are mounted as close as possible to the detectors and are interfacing the front end electronics (FEE), which is located in the external electric assembly. The FEE performs the analog to digital conversion and data serialization.

The data acquired from the Earth view and the calibration views is provided via the FEE to the METimage central electronics (MCE). The MCE controls the entire instrument, including thermal control, mechanism synchronization, cryo-cooler operation, or data handling. It performs SNR bit trimming to reduce the overall data volume. The MCE is located inside the payload equipment bay and is connected to the optical head via a harness of ~3m length. The TM/TC interface to the spacecraft is via SpaceWire.

Fig. 6 Cryogenic subsystem.

VII. INSTRUMENT PERFORMANCE

The key performance parameters of the METimage instrument are summarized in Tab. 2 [3]. The instrument is designed to fulfill these requirements in an optimum way. Verification of the requirements is discussed in [2].

Tab. 2 Key performance parameters.

Parameter	Solar channels (VII-4…25)	Thermal channels (VII-26…40)
• Inter-channel co-registration	< 0.2 spatial samples	
• Polarization sensitivity	< 5%	< 11%
• Radiometric noise	SNR up to 400	NedT up to 0.05K
• Radiometric accuracies		
○ Bias	< 5%	< 0.5 K
○ Inter-channel	< 1%	< 0.1 K
○ Inter-spatial	< 1%	< 0.1 K

- The inter-channel co-registration defines the spatial relation between the pixels in each image and each combination of spectral bands. It is critical to achieve and imposes stringent requirements on relative alignment and stability to the optics of the three spectral bands because this requirement has to be fulfilled without resampling. Field masks of 1x1mm^2 size are introduced at the telescopes focal plane to minimize the effect of aberrations of the IR re-imaging optics.
- In order to meet the polarization sensitivity requirement, dedicated optical design solutions and careful optical coating selection is required
- The radiometric noise requirements are crucial for sizing the instruments optics aperture diameter and the detector integration capacitances. The critical parameters are the overall instrument transmission but also the knowledge of the various noise contributors. The dominant noise sources are shot noise and read out noise for the solar channels just as detector read-out noise and dark

current related noise contributions for the infrared channels. TDI is implemented for some channels to meet the requirement (see Tab. 1).

- The radiometric accuracy is defined in terms of bias, inter-channel and inter-spatial accuracy. The bias accuracy defines the accuracy of the measurement, the inter-channel radiometric bias accuracy defines the uniformity within the various spectral channels of the same spatial sample, and the inter-spatial radiometric bias accuracy defines the uniformity within the various spatial samples of the same spectral channel.

A particular driver for the instrument performance is the on-ground storage of the second and third instrument flight model. The instrument is stored onboard the spacecraft and subject to yearly maintenance activities. A critical parameter is the particulate and molecular contamination during the storage period. The second and third flight models have to be re-calibrated prior to launch to ensure a proper instrument characterization.

VIII. CONCLUSIONS & OUTLOOK

The METimage instrument is in the detailed design phase. The instrument concept has been established, the main subsystem contractors have been selected, and the detailed design of the major subsystems is ongoing. The major challenges are the stringent requirements on the optics in terms of performance, straylight and alignment as well as the required calibration and verification effort.

The next milestones are the CDR as well as the delivery of the EFM and the STM. The launch of the first flight model onboard MetOp-SG satellite A1 is planned for 2021, the 2 further flight models follow in 7 years intervals.

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