MET*image* – a multi-spectral imaging radiometer for the EUMETSAT Polar System follow-on satellite mission

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ABSTRACT

The evolving needs of the meteorological community concerning the EUMETSAT Polar System follow-on satellite mission (Post-EPS) require the development of a high-performance multi-spectral imaging radiometer, the so-called Visible–Infrared Imager (VII). Recognizing these needs, Jena Optronik GmbH proposed an innovative instrument concept, METimage. METimage is the candidate instrument to fulfill the VII mission on Post-EPS.

Core item of the METimage instrument is a rotating telescope scanner covering the large swath width of about 2800 km, which is needed for a global coverage by a polar platform. The de-rotated image facilitates in-field spectral channel separation, which allows tailoring individual channel GSD (ground sampling distance) and features like TDI (time delay and integration). State-of-the-art detector arrays and read-out electronics will be employed. The reflecting telescope design is able to support demanding requirements on image quality and ground resolution.

The chosen instrument concept covers a spectral range from 443 nm to 13.345 µm and provides 20 to 22 spectral channels. The ground sampling distance is 500 m and 250 m for selected high-resolution channels from low Earth orbit.

The METimage instrument development is currently in phase B and has undergone its System Requirements Review in summer 2010.

Keywords: remote sensing, Post-EPS, imager

1. INTRODUCTION

METimage is a multi-spectral imaging radiometer implementing the VII (Visible and Infrared Imager) mission as successor of the AVHRR (Advanced Very High Resolution Radiometer) on the current EPS/METOP satellite series, and is the European counterpart of the VIIRS instrument on the USA new-generation weather satellite series (NPP and JPSS).

The METimage concept was defined by Jena-Optronik in a Phase-A study co-financed by DLR Space Agency. In addition technology studies for the two key assemblies "Rotating Telescope" and "Infrared Detectors" have been performed. The Phase-B activities were kicked off end of 2008; the System Requirement Review (SRR) of METimage has been passed successfully in summer 2010.

2. REQUIREMENTS

The primary objectives for the Visible/Infrared Imager (VII) of the Post-EPS mission are to provide high quality imagery data for global and regional Numerical Weather Prediction (NWP), Now-Casting (NWC), and climate monitoring. To meet these objectives, the VII has to provide high resolution cloud products, aerosol products, sea- and ice surface temperature and others. Other mission objectives for the VII are to support the Post-EPS sounders by providing geo-location and cloud characterization, and to provide data continuity of other key imagers in support of long-term climate records. From these objectives the requirements for the VII mission have been derived, among them

- Global coverage within 12 hours
- Large number of spectral bands and wide spectral range
- Demanding figures for dynamic range and signal-to-noise ratio (SNR)
- Polarization insensitivity of 5% for the reflective solar bands (443 nm to 3 µm) and 11% for the thermal emission bands (3 µm to 13.35 µm)
- Spatial resolution of 500 m and 250 m for selected channels
- Co-registration of all spectral bands: spatial >87%, temporal <1 sec

The complete Post-EPS mission requirements can be found in [1].

A set of core channels has been identified by users and scientists as shown in Table 1; these high priority channels are mandatory to achieve the mission goals.

Table 1: Post-EPS priority 1 spectral bands. Implementation of these spectral bands is mandatory to achieve the VII mission objectives.

Central Wavelength (µm)	**FWHM (µm)**	**Primary Use**
0.443	0.03	Aerosol, 'true colour imagery' (blue channel), vegetation
0.555	0.02	Clouds, vegetation, 'true colour imagery' (green channel)
0.67	0.02	Clouds, vegetation, 'true colour imagery' (red channel)
0.865	0.02	Vegetation, aerosol, clouds, surface features
0.94	0.05	Water vapour imagery; Water vapour total column
1.365	0.04	High level aerosol, cirrus clouds, water vapour imagery
1.63	0.02	Cloud phase, snow, vegetation, aerosol, fire
2.25	0.05	Cloud microphysics at cloud top, vegetation, aerosol over land, fire (effects)
3.74	0.18	Cloud parameters, cloud microphysics at cloud top, absorbing aerosol, SST, LST, fire, sea and land ice
6.725	0.37	Water vapour imagery (including wind in polar regions), water vapour profile (coarse vertical resolution)
7.325	0.29	
8.54	0.29	Cirrus clouds, cloud emissivity
10.79	0.5	Cloud parameters including cirrus detection, surface temperatures, surface imagery (snow, ice)
12.02	0.5	
13.345	0.31	CO_2 slicing for accurate cloud top height, Temperature profile (coarse vertical resolution)

3. INSTRUMENT DESIGN

The main drivers for the Post-EPS VII design result directly from the mission requirements. To meet 12-hour global coverage from an 817 km orbit, a large swath of 2800 km, corresponding to a scan angle of about ± 55° around Nadir, must be observed by the instrument. To cover the large Field of View (FOV), METimage is based on a mechanical scanner telescope, using reflective optics to cover the wide spectral range required to implement the channels listed in Table 1.

3.1 Optics

The rotating telescope scanner design consists of a three-mirror anastigmat, rotating at constant speed about an axis parallel to the line-of-sight, followed by a half-angle-mirror (HAM), a plane mirror rotating at half of the telescope speed. Such a system provides a de-rotated image in the focal plane. Calibration sources are mounted at scan angles outside the ±55° earth view, see Figure 1. Compared to a two-mirror telescope, the three-mirror anastigmat design provides a high image quality over a larger FOV, allowing implementation of more detectors on the focal plane. With the in-field separation of spectral bands (see below), a large instantaneous FOV is essential for the number of spectral bands that can be implemented. In addition, the large FOV allows increasing the number of detectors per spectral band, leading to a larger footprint on ground. This allows a reduced rotation speed of the telescope and thus increases the integration time per pixel, resulting in improved radiometric performance.

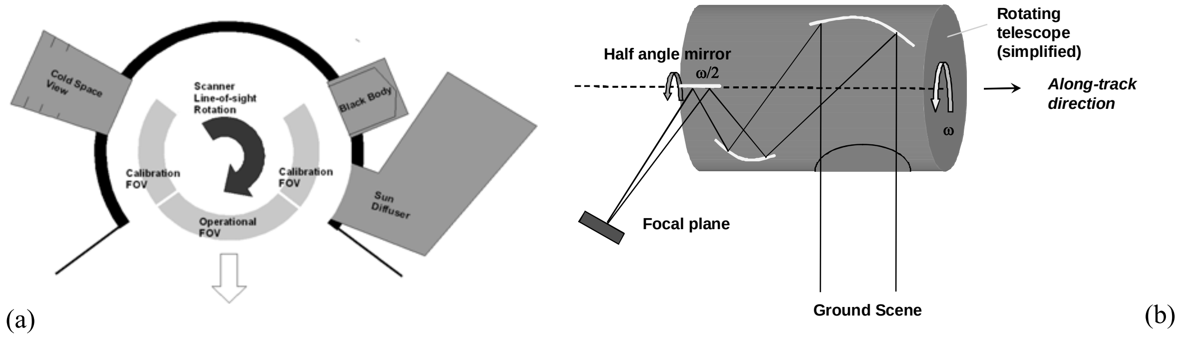


Figure 1: Schematic view of the METimage rotating telescope.
(a) On-axis view of the rotating telescope. Downward facing is the large ±55° earth view (Nadir at center); calibration sources are mounted at scan angles outside the earth view. The telescope is rotating at constant speed, the calibration sources are sampled during each rotation.
(b) Along axis view of the rotating telescope. At the left side of the telescope is the half-angle-mirror, rotating at half the telescope speed, producing a de-rotated image in the focal plane.

Following the main optics is a compact, passively cooled secondary optics, providing both an aperture and a field stop, to minimize the impact of stray light and radiative input to the thermal channels. A beam splitter directs the visible and infrared parts of the incoming radiation to one of the two respective focal planes. The IR focal plane is actively cooled to cryogenic temperatures. Each focal plane accommodates detectors and filters for 10 or 11 spectral bands.

A common problem for most scanning systems is different incident angles on optical surfaces, which result in scan-angle dependent polarization properties. In practice, the polarization dependence will also result in a wavelength dependent change of mirror reflectivity. This effect directly adds to the radiometric error budget for all channels, especially when the calibration sources are at different scan angles than the earth view. For the thermal emissive bands there is an additional error contribution resulting from the angle dependent thermal emission of the HAM. It is therefore important for the optics not only to keep the polarization within the values specified in the polarization requirement, but also to keep the difference between different scan angles as small as possible in order to maintain radiometric accuracy and homogeneity.

3.2 Focal Plane Design

The spectral separation of individual spectral bands is done by in-field separation, where detectors for different spectral bands are located side-by-side in the focal plane. Due to the across-track scanning, the image moves sequentially over all spectral bands on a focal plane (Figure 2). For each spectral band there is a row of detectors in along-track direction, so as for a whiskbroom scanner, the instrument records a number of image lines simultaneously during each scan.

By matching the number of detector elements along-track and the rotation frequency, the scanner produces a gap-free scan pattern of the ground scene. Different ground resolutions are implemented by adapting the size of the detector pixels (Figure 3). In addition, where necessary, there can be multiple detector rows for the same spectral band, thus having multiple exposures to increase the signal-to-noise ratio (time-delayed integration).

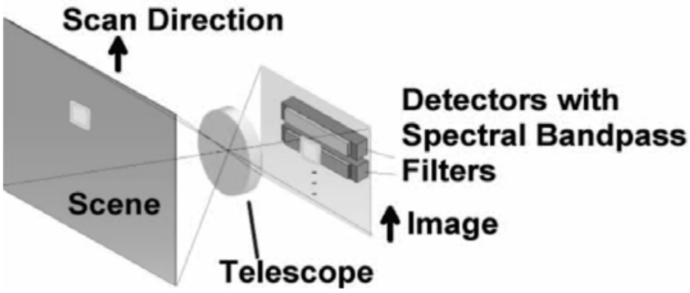
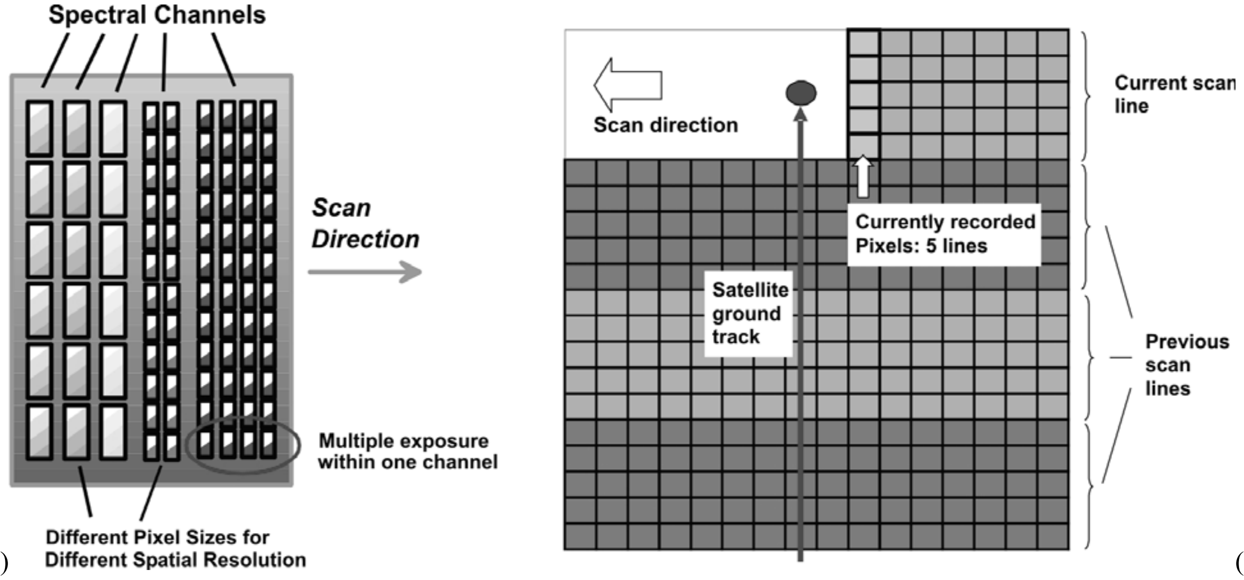


Figure 2: METimage scanning geometry and in-field separation of spectral bands. Due to the scanning of the rotating telescope, the image moves over the spectral bands in the focal plane.



(a) (b)

Figure 3: (a) Detector arrangement in the focal plan. Different detector sizes are used to implement different ground resolution for individual spectral bands. Time delayed integration can be implemented by integrating multiple detector rows for a spectral band. The number of detectors in each spectral band (vertical extension, corresponding to the flight direction of the satellite) defines number of ground traces simultaneously recorded (in this figure six for the low spatial resolution channels and twelve for the high spatial resolution channels).
(b) Scan pattern of a rotating scanner with multiple pixel lines per scan. During each rotation of the telescope, multiple scan lines in along-track direction are recorded simultaneously, while the scan motion of the rotating telescope is across-track. The rotation speed of the telescope must be match to the number of scan lines in order to provide a gap-less image.

Filters are mounted directly in front of the detectors and provide the required spectral shape and resolution. The number of spectral bands that can be accommodated on a focal plane is limited by the usable FOV and the mechanical size of a detector row and filter assembly. The usable FOV is not only limited by the image quality of the optics, but also by the co-registration budget: co-registration errors increase with the distance of detectors within a focal plane (image quality, rotation rate errors, alignment errors, thermal effects, satellite ground speed, and others). With the current design, about 10 or 11 channels can be implemented on each focal plane. The exact number depends on the radiometric requirements and performance of the selected channel combination: some spectral bands will need time-delayed integration to achieve the required SNR, thus using up more space on the focal plane

3.3 Detectors

Detectors are another crucial element in the imaging radiometer. The quality of the detection chain, consisting of detector plus read-out electronics, is decisive for the radiometric accuracy. To achieve the radiometric requirements, METimage will use detectors made from different semiconductor materials. As the spectral sensitivity is dependent on the material, it has to be matched to the target wavelength range. This is especially true in the infrared region. The long wavelength IR channels are the design driver of focal plane temperature and cooling needs. State of the art integrated read-out circuits (ROIC) with integration stages and amplifiers will be mounted directly on the focal plane arrays.

3.4 Calibration

Calibration for the thermal emissive bands is based on a two-point calibration, measuring "zero" by using a cold space view and a high temperature by looking at a high precision blackbody. The blackbody is operated close to instrument temperature, reducing errors due to non-perfect blackness and ageing effects of the black coating. Both calibration targets are scanned during every revolution of the telescope and calibrate all detectors on the cold focal plane. The blackbody can be heated to verify the linearity of the thermal emissive bands detection chains on a regular basis. Blackbody and the primary cold space view are located at opposite positions of the telescope (see Figure 1) and are seen under the same scan angle in order to minimize scan-angle dependent effects. A second cold space view can be implemented at a different scan angle to monitor scan-angle effects and temperature variations of the HAM.

The reflective solar bands are calibrated using the blackbody as optical zero and a solar diffuser as bright source. While the blackbody provides a suitable zero measurement during every revolution of the telescope, the solar diffuser is illuminated only for short time during each orbit (about once every 100 minutes) by the sun, so that a full calibration of the solar channels is only done once per orbit. A common problem with solar diffusers is their ageing under exposure to UV radiation. Even though the planned diffuser for METimage is exposed only for short times and shows relative little ageing under UV exposure, the overall degradation during eight years mission lifetime accumulates to much more than the required 1% lifetime stability. A diffuser monitor device that is well protected from UV radiation is used to calibrate the main diffuser on a regular basis so that the degradation of the main diffuser can be monitored and corrected.

3.5 Mechanical design

The instrument consists of an optical head and detached electronics box. Figure 4 shows the optical head. The mechanical configuration is strongly influenced by the different field-of-view requirements for operational measurements, of calibration sources and radiators for thermal conditioning. The need for high thermal stability is reflected in a structure that is well shielded. It is as far as possible closed to external radiation intake, which also benefits the stray-light suppression.

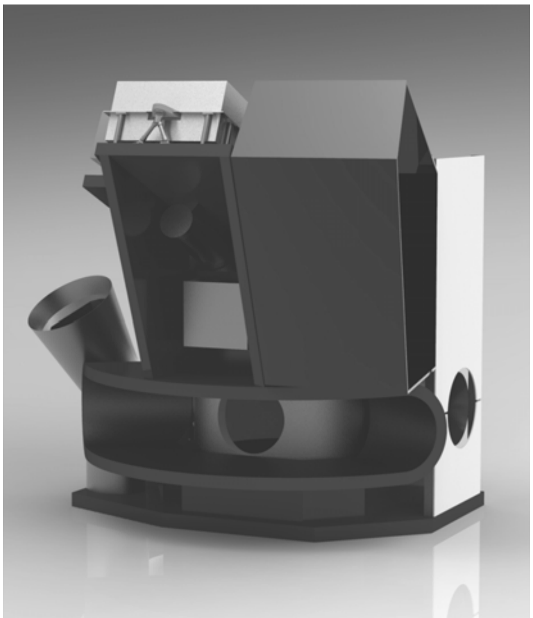


Figure 4 shows a CAD drawing of the current design status of METimage. Front of the picture shows the large operational view (110° earth-view). The right side points toward deep space and shows the radiators and the deep space view for calibration. The baffle for the solar diffuser is visible on the left side of the instrument.

While the necessity for a well adapted optical design is easy to perceive, the intricacies of the mechanical design may not be so obvious. However, the accuracy and stability of the mechanical structure supporting the rotating telescope and the half angle mirror is crucial for core performances related to line-of-sight stability. The requirements for relative stability of subassemblies can be as low as a few arc seconds. Figure 5 shows the schematic block diagram of METimage.

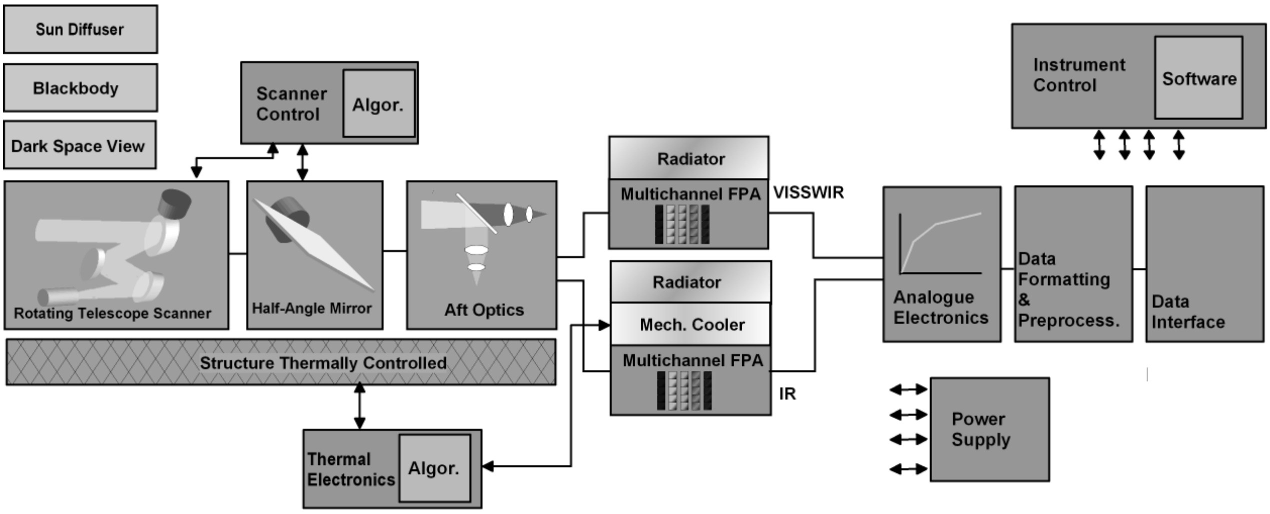


Figure 5: Schematic block diagram of METimage, containing the basic building blocks, i.e. the scanner, which produces the optical image, the secondary optics, and the focal planes.

ACKNOWLEDGEMENTS

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[1] EUMETSAT Post-EPS Mission Requirements Document, EUM/PEPS/REQ/06/0043, available at http://www.eumetsat.int/ (Home > Satellites > Post-EPS > Resources)