Meteosat Third Generation (MTG)
Status of Space Segment definition

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ABSTRACT

ESA and EUMETSAT have initiated joint preparatory activities for the formulation and definition of the Meteosat Third Generation (MTG) geostationary system to ensure the future continuity, and enhancement, of the current Meteosat Second Generation (MSG) system. The MTG programmatics are being established to ensure a seamless transition between the conclusion of the successful MSG operational system and the start of the new MTG operational system, with particular emphasis on continuity of the imagery missions.

The MTG phase A studies were successfully concluded in December 2008 with a subsequent consolidation phase continuing from January to July 2009. These studies were devoted to the MTG concept definition and requirements consolidation for meeting the User needs in the field of Nowcasting and Very Short Term Weather Forecasting (NWC), Medium/Short Range global and regional Numerical Weather Prediction (NWP), Climate, Air Quality and Composition Monitoring. The following missions have been analysed, measurement techniques studied and preliminary concepts established:

- High Resolution Fast Imagery Mission (improved successor to MSG SEVIRI HRV mission)
- Full Disk High Spectral Resolution Imagery Mission (improved successor to SEVIRI)
- Lightning Imagery Mission
- IR Sounding Mission
- UV-VIS-NIR Sounding Mission

Both space segment architecture and preliminary satellite and instrument concepts were investigated in the course of these studies, and a dual satellite configuration established comprising the Imaging satellite (MTG-I) and the sounding satellite (MTG-S). The study covered all elements to a level of detail allowing to establish a technical baseline, conclude on the feasibility of the system requirements and undertake preliminary programmatic evaluation.

Riders to the Phase A studies have been placed to further consolidate the satellite and payload definition and development, prior to the release of the Invitation To Tender (ITT) for the full space segment implementation in July 2009.

This paper provides an overview of the conclusions of those MTG space segment studies. It summarises the conclusions reached for the satellites, and associated instruments relating to Imaging, IR Sounding and Lightning missions, with respect to achievable performances, including Radiometry and Image Navigation and Registration aspects.

Keywords: Meteorology, Meteosat, Imagery, Infrared Sounding, Lightning, NWP, MTG.

1. INTRODUCTION

The MTG mission capitalises on the continuation and enhancement of the Meteosat Second Generation (MSG) capabilities with respect to nowcasting, global and regional numerical weather prediction, climate and atmospheric chemistry monitoring.

The MTG system will provide Europe's National Meteorological Services and, by extension, the International Users and Science Community, with an advanced operational satellite system, providing improved imaging and new infrared sounding capabilities for both meteorological and climate applications. This system will facilitate enhanced capabilities for monitoring and prediction of meteorological phenomena and the monitoring of climate and air composition through operational applications for the period of time between 2017 and 2037.

The objective of the MTG System is to provide continuous high spatial and temporal resolution observations and geophysical parameters of the Earth System derived from direct measurements of its emitted and reflected radiation using satellite based sensors from the geo-stationary orbit.

The MTG space segment supports the following payloads and associated missions and services:

- Flexible Combined Imager (FCI) missions, allowing to scan either the full disc in 16 channels every 10 minutes with a Spatial Sampling Distance (SSD) in the range 1-2km, i.e. Full Disc High Spectral resolution Imagery (FDHSI) in support of the Full Disc Scanning Service (FCI-FDSS) or a quarter of the Earth every 2.5 minutes with 4 channels at improved SSD of 0.5-1 km (High spatial Resolution Fast Imagery (HRFI) in support of the Rapid Scanning Service (FCI-RSS).
- InfraRed Sounding (IRS) mission covering the full disc, providing hyper-spectral sounding information in two bands, a Long Wave InfraRed (LWIR: 700 - 1210 cm-1) and Mid Wave InfraRed (MWIR: 1600 -2175 cm-1) band with a SSD = 4 km.
- Lightning Imagery (LI) mission, detecting continuously over almost the full Earth disc, the lightning discharges taking place in clouds or between cloud and ground with a sampling distance around 10 km.
- Ultraviolet, Visible & Near-infrared (UVN) sounding mission, covering Europe every hour taking measurements in three spectral bands (UV: 305 - 400 nm; VIS: 400 - 500 nm, NIR: 750 - 775 nm) with SSD of 8 km. The UVN mission is implemented with the GMES Sentinel-4/UVN payload accommodated in the MTG-S satellites.
- Search and Rescue (SAR) Relay Service allowing the continuation of the MSG geostationary search and rescue (GEOSAR) service as part of the Cospas-Sarsat international system, whose aim is to provide distress alert and location information to appropriate rescue authorities for maritime, aviation and land users in distress.
- Data Collection System (DCS) mission which involves, as a continuity of the MSG mission, the collection and transmission of observations and data from surface, buoy, ship, balloon or airborne Data Collection Platforms (DCP).

The competition between potential suppliers of the satellites/instruments being still on-going, does not allow in fairness to discuss any design in this paper, constraining us to explain the challenges ahead to meet the end user requirements. This paper addresses an overview of the outcome of the MTG space segment progress accomplished so far in the frame of the phase A and its extension phase (mission needs in terms of payload/satellite). It highlights the requirements' evolution for the Imaging and Sounding Missions, shows the status of Image Navigation and Registration (INR) aspects and introduces the progress towards the implementation of the MTG development programme.

2. MTG SPACE SEGMENT STATUS TOWARDS THE ITT RELEASE

The MTG user requirements have been discussed extensively elsewhere[1-7]. In this paper, we will focus only on the updated specifications. The "twin" configuration, comprising the MTG imaging satellite, called MTG-I, and the MTG sounding satellite, called MTG-S, has been selected and consolidated as baseline. Both MTG-I and MTG-S satellites will be based on a common three-axis stabilised platform.. This platform will be derived from standard geostationary telecommunication bus making maximum use of heritage equipments wherever practicable with the necessary adaptations for the MTG mission.

EUMETSAT, in coordination with ESA and industry, have established priorities vis-à-vis of the overall mission. The highest priority being for the Imaging missions (HRFI + FDHSI), which will provide continuity to the current MSG mission.
The infrared sounding mission and the lightning imagery mission are the second priority.
The UVN instrument, to be embarked on MTG-S will be provided to MTG by the GMES programme.

The target date for the operational deployment of the MTG space segment element, ensuring continuity of the the imagery mission, is now end 2017. This requires a launch in late 2016 with a one year commissioning phase anticipated for the the new MTG system, including ground and space segments.
Figure 1 shows the baseline MTG deployment strategy. This has a direct impact on the envisaged overall mission development and deployment schedule. High mission and satellite reliability and availability are required combined with the nominal and extended mission lifetime for both the MTG-I and MTG-S satellites.

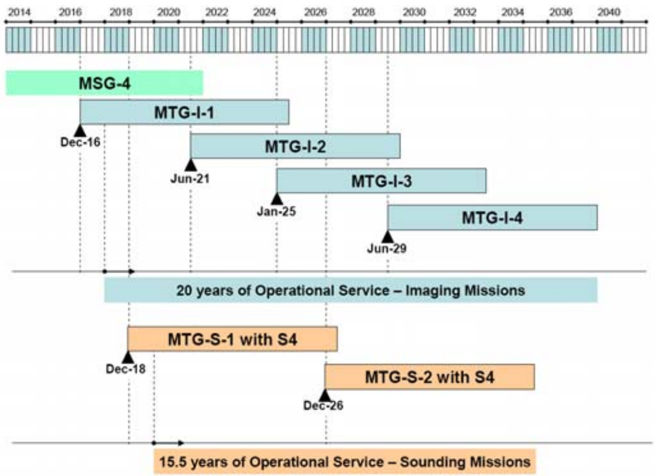


Figure 1: MTG mission nominal deployment plan.

The payload complement of both MTG-I and MTG-S have been presented in last year papers [6, 7]. The imagery mission will consist 4 MTG-I satellites, whereas the sounding mission will be fulfilled with 2 MTG-S satellites.
The MTG-I spacecraft will embark the Flexible Combined Imager (FCI) and the Lightning Imager (LI) to fulfil the user needs in delivering the imagery services. The selection of a Flexible Combined Imager (FCI) is driven by the end users needs to meet the first two imagery mission requirements. The FCI will be operated in an exclusive way to satisfy either FDHSI or HRFI missions.. Only with 2 satellites can both the Local Area Coverage (LAC) elaborated for the HRFI mission and the Full Disc Coverage (FDC) tailored for the FDHSI mission, be met. It is also required that all the channels are delivered in FDHSI and HRFI for the FCI-FDSS.
In addition to the optical payloads, the MTG-I satellite series will embark the Data Collection System (DCS) and Search and Rescue (GEOSAR).

For the sounding missions of MTG-S, the users have defined two missions:

- The Infrared Sounding (IRS) mission focusing on operational meteorology (water vapour tracking & profiling, and temperature profiling), with some relevance to atmospheric chemistry as a secondary application (thanks to the UVN contribution);
- The UV/VIS/NIR sounding (UVN) mission (also called Sentinel 4) is dedicated to atmospheric chemistry and Air Quality. In combination with the IRS, the UVN mission will complement the atmospheric chemistry mission needed by the users.

More discussions are provided in a paper by G. Balzagette [4] from SPIE*Europe* 2008 conference. The UVN instrument[4] will target its observations in latitude range 30°N/65°N, longitude 30°W/45°E (at 40°N), with a repeat cycle of 0.5 hour (goal) / 1 hour (Threshold).

A self-standing paper on MTG critical technology pre-developments is presented at the 2009 SPIE*Europe* conference.

For cost efficiency, and risk mitigation, it is envisaged to utilise many of the technologies and equipments developed for commercial telecommunication platforms as the basis for the MTG platform. Several platform concepts have been analysed in the frame the ESA Space Segment Phase A.
A dual-wing satellite (see Figure 2) has been selected, ensuring a better balanced configuration in terms of solar panel effective area and centre of solar pressure, despite the drawback of loosing a clear field of view to cold space which could be brought by a single solar array spacecraft.. This decision has been taken primarily due to the simplification of the Attitude Orbit and Control System implementation requiring significantly less reaction wheel off-loading manoeuvres and thus reducing potential disturbances to the satellite pointing stability and risk of associated degradation or outages in mission data. The loss of instrument radiating capabilities will be mitigated by the implementation of active coolers.
..
The target mass for the MTG-I and MTG-S satellite is presently kept to the launch capabilities of Soyuz in Kourou to allow later flexibility in the potential selection of the European launcher, i.e. Ariane 5 or Soyuz.. In addition, both spacecraft will be designed to allow the launch with a non-equatorial launcher, i.e. enabling a super-synchronous transfer into the geostationary orbit if necessary.

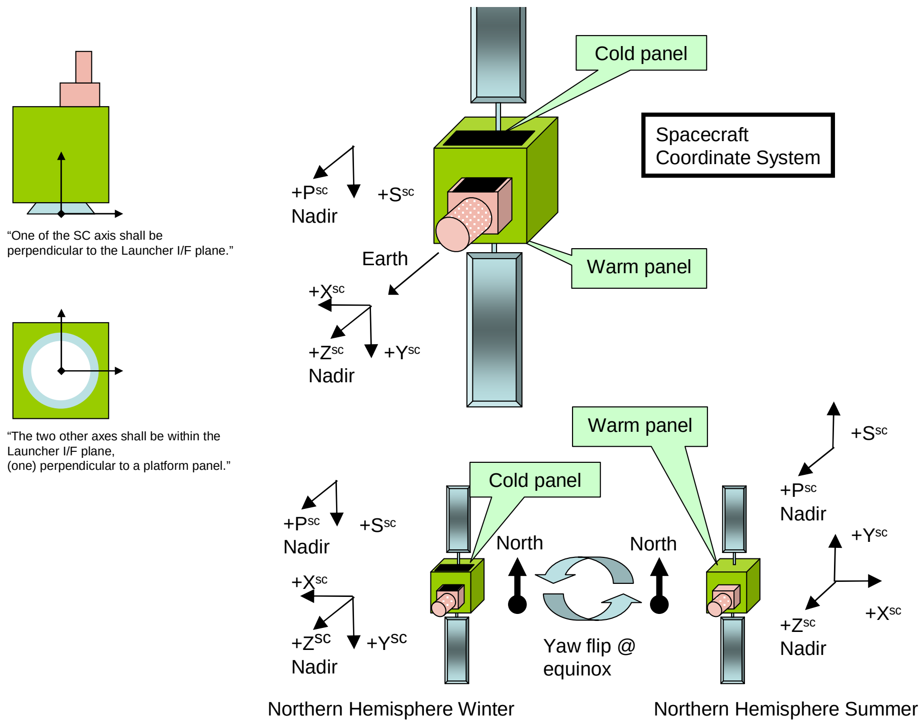


Figure 2: MTG dual wing configuration and coordinate system

It is planned to use a common bus design for the MTG-I and MTG-S satellites with local adaptations as required per mission. It is expected that the following bus subsystems will be largely common for both satellite types:

- Structure (separate mechanical interfaces are foreseen for the two payload complements),
- Thermal (conventional thermal control design envisaged),
- Attitude and Orbit Control (similar design approach for both satellites),
- Propulsion (based on a chemical propulsion system),

- Electrical Power (being modular to adapt the power needs as required per satellite type),
- Command and Data Handling (similar design envisaged for both satellites with adaptation per satellite),
- Telemetry, Tracking and Command (heritage of existing conventional S-band systems).

Extensive discussions have been carried out between ESA, EUMETSAT and Industries, with the aim at fulfilling the user needs without leading the space system into an over-design, thus avoiding risks and unsustainable cost impacts.
For example, it is now agreed that the imagery mission provides data at level 1c (after image rectification) whilst a clear need of having the IRS data at level 1b (before image rectification) has been adopted. For the IRS data delivered at level 1b, ESA has ensured that algorithm delivering IRS data at level 1c is also available for IRS imaging performance assessment. The discussions which focused on the geometric performances took into account image deformations induced by the satellite and instruments pointing, thermo-elastic aspects and micro-vibrations. Thanks to extensive Image Navigation and Registration (INR) simulations, industries were able to provide during phase A and its extension, preliminary analyses including fine modelling of thermo-elastic deformation (minimised by design), correction using observables from star trackers, gyros and landmarks, that allow to consolidate the imagery and sounding achievable geometric performances. The FCI radiometric and spectral requirements remained as presented in referenced papers [6, 7], with the only exception being a relaxation of channel VIS0.8 which central wavelength changed from 860 nm to 865 nm with a bandwidth of 50 nm instead of 70 nm.).

For the FCI, the updated spectral channels and their bandwidth requirements are depicted in Table 1.

Spectral Channel	Central Wavelength, λ_0 (μm)	Spectral Width, $\Delta\lambda_0$ (μm)	SSD (km)
VIS 0.4	0.444	0.060	1.0
VIS 0.5	0.510	0.040	1.0
VIS 0.6	0.640	0.050	1.0 0.5 #1
VIS 0.8	0.865	0.050	1.0
VIS 0.9	0.914	0.020	1.0
NIR 1.3	1.380	0.030	1.0
NIR 1.6	1.610	0.050	1.0
NIR 2.2	2.250	0.050	1.0 0.5 #1
IR 3.8 (TIR)	3.800	0.400	2.0#2 1.0 #1
WV 6.3	6.300	1.000	2.0
WV 7.3	7.350	0.500	2.0
IR 8.7 (TIR)	8.700	0.400	2.0 2.0#2
IR 9.7 (O_3)	9.660	0.300	2.0
IR 10.5 (TIR)	10.500	0.700	2.0 1.0 #1
IR 12.3 (TIR)	12.300	0.500	2.0
IR 13.3 (CO_2)	13.300	0.600	2.0

Table 1: Channel specification for the FCI imager.

The channels VIS 0.6, NIR 2.2, IR 3.8 and IR 10.5 are delivered in FDHSI spatial sampling and HRFI spatial sampling configurations. The spatial sampling and spectral requirements for the HRFI sampling configuration are indicated by #1. The fire application channels are marked with #2. All other channels are delivered in FDHSI sampling configuration. In total, up to 22 image colours and sampling configurations could be delivered by each image cycle, covering all the needs. In the nominal imaging mode, the FDHSI covers the full Earth disk with a 10 minutes Baseline Repeat Cycle (BRC). Rapid Scan Services (RSS) are provided thanks to coverage equivalent to BRC/n referred to as Local Area Coverage (LAC). The LAC coverage can be variably placed anywhere over the Earth (this shall be taken into account for the scan mechanism qualification).

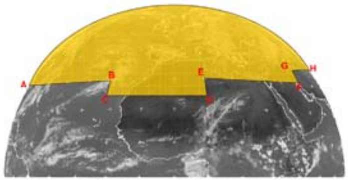
In particular for the FCI, coverage, as depicted in Figure 3, will be used for the RSS. The images will be delivered with the following considerations:

- Imagery data will now be delivered to the users at level 1c, e.g. after image rectification;
- Co-registration error is specified at level 1b as knowledge; The end performances are to be determined after image rectification;
- In-flight absolute and relative image geometric quality of FCI will be assessed after image rectification, so that high accuracy landmark processing can be fully applied;

- The image quality process will be applied also for the IRS data, only for in-flight performance verification. However, the sounding data will be delivered to the users before rectification.

The various data level was fully described in previous papers [3, 5].

The radiometric aspects, the number of channels for both the FCI and IRS missions and all other specifications remain unchanged from previous papers [5-7].



AB	30°N
BC	22°W
CD	25°N
DE	10°E
EF	30°N
FG	50°E
GH	35°N

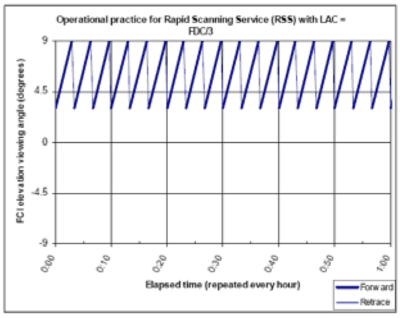


Figure 3: Example of Rapid Scanning Services for the FCI.

One of the challenging requirements of the MTG-I remains the Inter-Channel Co-registration Accuracy (ICRA). The contributors to the ICRA characterisation include at instrument level:
- Detectors (spatial response uniformity of each pixel, pitch uniformity, dispersion and alignment)
- Optics (relay optics magnification, field distortion, alignment, stray light)
- Scan mechanism (actual scan rate and direction, scan rate stability)
- Integration (alignment)
- Satellite (launch stability, thermal stability, ageing, pointing stability in terms of drift and micro-vibrations, master-clock jitter).

A definition for ICRA was described in the last year's papers [6, 7].

The IRS Mission will cover the spectral domain from 700 to 2175 cm^{-1} at design level (for the sake of simplification at detectors level), but the useful bands (extended bands) will cover the limits depicted in Table 2.

Spectral Band	Status	Wavenumber range	Spectral Channel Interval $\Delta\nu$	Spatial Sampling Distance(SSD)
LWIR	Extended	680-700 cm^{-1}	Less than or equal to 0.625 cm^{-1}	4.0 km
	Specified	700-1210 cm^{-1}		
MWIR	Specified	1600-2175 cm^{-1}	Less than or equal to 0.625 cm^{-1}	4.0 km
	Extended	2175-2250 cm^{-1}		

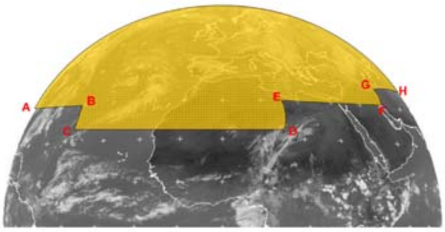
Table 2: MTG IRS reference mission bands and required SSD.

The IRS instrument will be designed such that the part of extended bands which is not in the specified band is also retrievable. The spectral sampling ($\Delta\nu$) for both IRS bands LWIR and MWIR shall be better or equal to 0.625cm^{-1}, with FWHM of the instrument line shape to be better than 0.754 cm^{-1}. To cover the extended bandwidth and meet all the spectral characterisation requirements, it has been agreed to use an Optical Path Difference (OPD) of 8.8 mm, leading to a tighter spectral sampling (0.568 cm^{-1}), thus allowing an apodisation function to take care of meeting the FWHM of the ILS (0.754 cm^{-1}). The IRS data will, however, be made available to end users, unapodised,.

Over the complete spectral bands, resampling to a fixed spectral channel grid common to all spatial samples will be performed on the basis of the spectral calibration algorithm results. For coverage, one of the IRS potential operational scenarios is depicted in Figure 4, allowing interleaved scanning pattern to cover the whole Earth. Similarly to FCI, the IRS will cover the area depicted in Figure 4, down to latitude CD=22°N which may lead to BRC/3 temporal coverage of 20 minutes instead of the classical 15 minutes.

Due to the operational nature of MTG, the availability of the observational missions is required to be >96% with a minimum number of operational interventions and limited outages and a reliability (per mission element) of >0.75 eat the end of life. This is applicable during the entire MTG mission lifetime of 20 years.

To achieve this it was concluded that each satellite shall be designed with nominal in-orbit lifetime of at least 8.5 years each.



AB	30°N
BC	40°W
CD	22°N
DE	15°E
EF	30°N
FG	50°E
GH	35°N

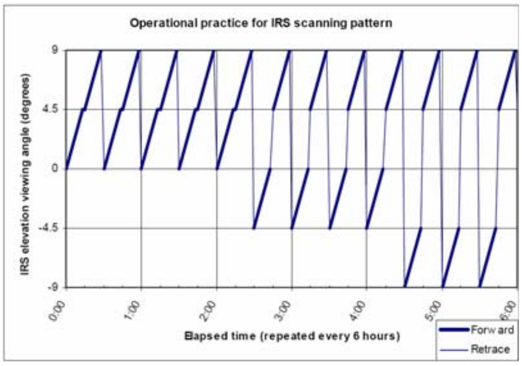


Figure 4: MTG IRS operational scenario scanning pattern

3. MTG PERFORMANCE REQUIREMENTS AND DISCUSSIONS

The MTG achievable performances (radiometric and geometric) have been presented in several previous papers[5-7], resulting from phase A analyses. The analyses of the FCI and IRS radiometric performances have always shown promising results. It has been anticipated that most of the requirements will be met with the available technologies. Only the LWIR bands were showing shortage in terms of dark current noise, leading to cooling down to 55K. For the IRS, radiometric requirement can be met with a 60 minutes repeat cycle (full Earth disc coverage). It is shown that photonic noise and ROIC noise are the most dominant noise contributions that are to be carefully handled for any potential improvement. For that the radiometric noise requirement of the IRS has been updated (Figure 5) to cope with limitations due to photonic noise, thus favoring rather feasible technology for simplification purposes. The FCI noise requirement remained the same (#1 indicating HRFI sampling configuration, #2 representing Fire Application).

Spectral Channel, VIS/NIR	Minimum Signal α_{min}	Maximum Signal, α_{max}	Reference Signal, α_{ref}	Radiometric Noise (SNR)
VIS 0.4	0.01	1.20	0.01	25
VIS 0.5	0.01	1.20	0.01	25
VIS 0.6	0.01	1.20	0.01	30 12 #1
VIS 0.8	0.01	1.20	0.01	21
VIS 0.9	0.01	0.80	0.01	12
NIR 1.3	0.01	0.80	0.01	40
NIR 1.6	0.01	1.00	0.01	30
NIR 2.2	0.01	1.00	0.01	25 12 #1
Spectral Channels IR	**Minimum Signal, T_{min} (K)**	**Maximum Signal T_{max} (K)**	**Reference Signal T_{ref} (K)**	**Radiometric Noise NEdT (K)**
IR 3.8 (TIR)	200 350 #2	350 Fire Range #2	300 350 – Fire Range #2	0.1 - 0.2 #1 1 #2
WV 6.3	165	270	250	0.3
WV 7.3	165	285	250	0.3
IR 8.7 (TIR)	165 330 #2	330 Fire Range #2	300 330 – Fire Range #2	0.1 0.5 #2
IR 9.7 (O_3)	165	310	250	0.3
IR 10.5 (TIR)	165	340	300	0.1 0.2 #1
IR 12.3 (TIR)	165	340	300	0.2
IR 13.3 (CO_2)	165	300	270	0.2

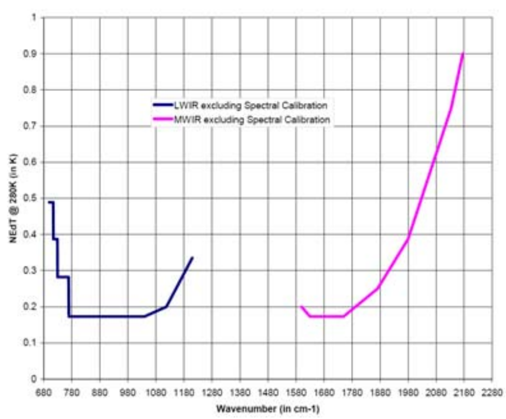


Figure 5: Radiometric noise requirement for FCI and Noise template for IRS.

Based on event triggered readout electronics, the LI instrument could be a single camera or a 4-headed camera (on-going trade-off). The instrument will be optimised for capturing events (spatially expanding between less than 10 up to 100 km) at 45°N with a Detection Efficiency of DE ≥ 90%, whereas elsewhere on Earth, DE ≥ 70% is required, days and nights. With such an instrument, false alarm rate (FAR) of 350 per second could be achieved at raw data level. Thanks to on-ground processing of the data, including background scene tracking and removal, thresholding, event detection at level 1b processing, we expect to achieve a FAR ≤ 2 Hz. The level 1b processing will perform filtering of false events, geolocate the lightning, time-tag the samples (UTC convention) and convert to radiances the acquired data by applying pre-launch calibration factors.

The navigation of FCI observations will use MSG heritage and GOES-N satellites series lessons learned. The navigation of the LI will be based on images taken (background images) by the LI detecting landmarks wherever clear sky is available, and thanks to star tracking, the LI could navigate properly for geolocating LI detected events. The IRS will use its own imaging capabilities for day and night navigation. The UVN will use both the capabilities of MTG-S satellite navigation capabilities, in addition to its own imaging mode (to be investigated).

4. CONCLUSION

The Meteosat Third Generation (MTG) mission will substantially enhance the European capability in operational meteorology and climate applications with the implementation of five observation missions described in this paper. The MTG mission requirements for the space segment have been reviewed and updated in line with achievable performances and remain fully consistent the end user needs.
The preliminary work performed on the MTG mission conceptual design has traded-off the possible designs and achievable performances of the 3 main payloads (FCI, LI and IRS) embarked on 3-axis stabilised satellites. The UVN/Sentinel-4 instrument (provided by the GMES programme) will also be embarked on MTG-S satellite series.
For each mission and associated instrument concept, trade-off's have been carried out, parametric analysis performed and critical areas identified. Major findings are on the focal plane array technology that is the main development axis to focus on and applicable to both FCI and IRS instruments. Associated cryogenic cooling technoloigies, and related implications at Spacecraft level are also highlighted (namely the accuracy and stability of satellite pointing and its related Image Navigation & Registration).
Whilst ESA has launched technology pre-development activities on LWIR detectors and coolers, , the MTG missions present highly challenging performance requirements, which lead to complex optical instruments and overall spacecraft system.
The required performances are confirmed by the feasibility studies to be achievable; however substantial effort in technology development is yet necessary to retire all identified risks. The MTG phase A (and its extension) activities included a review of the technical requirements, selection of a system concept, assessment of feasibility and cost estimate and have been concluded successfully.
The MTG ITT for phase B2-C/D has been released in July 2009. The start of phase B2-C/D activities should commence in early 2010.

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