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Optical design of the lightning imager for MTG

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Abstract — The Lightning Imager for Meteosat Third Generation is an optical payload with on-board data processing for the detection of lightning.

The instrument will provide a global monitoring of lightning events over the full Earth disk from geostationary orbit and will operate in day and night conditions.

The requirements of the large field of view together with the high detection efficiency with small and weak optical pulses superimposed to a much brighter and highly spatial and temporal variable background (full operation during day and night conditions, seasonal variations and different albedos between clouds oceans and lands) are driving the design of the optical instrument.

The main challenge is to distinguish a true lightning from false events generated by random noise (e.g. background shot noise) or sun glints diffusion or signal variations originated by micro-vibrations. This can be achieved thanks to a ‘multi-dimensional’ filtering, simultaneously working on the spectral, spatial and temporal domains.

The spectral filtering is achieved with a very narrowband filter centred on the bright lightning O2 triplet line ($777.4 \text{ nm} \pm 0.17 \text{ nm}$). The spatial filtering is achieved with a ground sampling distance significantly smaller (between 4 and 5 km at sub satellite pointing) than the dimensions of a typical lightning pulse. The temporal filtering is achieved by sampling continuously the Earth disk within a period close to 1 ms.

This paper presents the status of the optical design addressing the trade-off between different configurations and detailing the design and the analyses of the current baseline.

Emphasis is given to the discussion of the design drivers and the solutions implemented in particular concerning the spectral filtering and the optimisation of the signal to noise ratio.

Keywords: *Lightning Detection; Meteosat; Spectral Filtering*

I. INTRODUCTION

Lightning Imager (LI) is one of the instruments of the Meteosat Third Generation (MTG) mission and in particular it will be installed on the MTG-I satellites with the Flexible Combined Imager (FCI).

The objective of MTG mission is to provide Europe, by extension, the International Community, with an operational satellite system able to support accurate prediction of meteorological phenomena and the monitoring of climate and air composition through operational applications for the period of time between 2017 and 2037.

Thales Alenia Space as the MTG prime contractor is responsible for the procurement of the Lightning Imager instrument developed and manufactured by Selex Galileo. The primary objective of the Lightning Imager (LI) mission is to add complementary information relevant to the detection and location of cloud-to-ground and cloud-to-cloud lightning to those provided by existing/planned ground based lightning detection systems. So, these continuous lightnings data for the whole hemisphere would represent a new set of data to be used in nowcasting, climatology and atmospheric research.

LI has no heritage in Europe. Two USA Low Earth Orbit missions (LIS and OTD) have already flown and one, the Global Lightning Mapper (GLM) of GOES-R, is currently under development.

The instrument requirements reported in Table I are challenging and they define, together with the concept adopted for the lightning detection, the main drivers for the LI design.

TABLE I – LI MAIN REQUIREMENTS

Parameter	Requirement
FOV	16° diameter shifted northward or 84% of visible Earth disk, including all Eumetsat member states
Spatial sampling	< 10 Km @ Latitude 45° and Sub-satellite Longitude
Dynamic range of Earth background (Lbkg)	$0 \div 296.5 \text{ W/m}^2/\mu\text{m/sr}$ (night ÷ summer solstice at midday)
Optical pulse dynamic range (LLp)	$6.7 \div 670 \text{ mW/m}^2/\text{sr}$
Optical pulse spectral range	$777.4 \pm 0.17 \text{ nm}$
Minimum optical pulse duration	0.6 msec
Optical pulse size	10 Km ÷ 100 Km circular pulse diameter
Maximum number of optical pulses in the FOV	25 in 1 millisecond 800 in 1 second
Instrument Average detection probability (IADP)	90% for latitude 45 deg 70% as average over the FOV 40% over EUMETSAT member states (goal)
LI Mass (total Optical Head and Electronic box)	93 Kg
LI Optical Head Envelope	$718 \times 1200 \times 1456 \text{ mm}^3$

II. LIGHTNING DETECTION CONCEPT

The lightning detection is achieved implementing the following functions:

- Earth image acquisition for continuous monitoring of the lightning's presence in the FOV;
- calculation of pixel by pixel adaptive background to cope with non-uniformities and low terms variations of the image (oceans, clouds, area in night conditions and areas with daylight conditions) and to reject at the same time noise effects and spurious events;
- removal of the background level from the overall pixel signal to obtain the net lightning illumination level;
- use of adaptive threshold; lower thresholds can be used in low noise dark areas of the scene, using higher thresholds only in highly illuminated areas (with corresponding higher shot noise);
- pixels for which the difference between the pixel value and the estimated background signal exceeds the threshold are kept as Detected Transients (DT);
- collection of the DT video data and additional information for the ground processing with a dedicated processing electronics;
- in flight processing of DTs to reduce the number of False Transients (FT) to a level compatible with the platform downlink data rate constraints (30 Mbps).

In addition LI is capable to acquire, process and transmit to ground an Earth background image.

III. INSTRUMENT OVERVIEW

The Lightning Imager is composed of one Optical Head (LOH) and one electronic equipment, the LI Main Electronics (LME).

The LOH consists of four identical Optical Channels (OC), each one including (see Figure 2):

- a protective cover on the baffle aperture to prevent baffle and optics contamination during launch and pre-launch activities;
- a baffle for stray light suppression and thermal load minimization;
- a Solar Rejection Filter (SRF), to minimize both the background level and the thermal load inside the OC;
- a Narrow Band Filter (NBF) to reduce the bandwidth in the range of the lightning spectral pulse (Figure 1);
- an optical system with F# 1.73, 110 mm entrance pupil diameter (determined by radiometry required to achieve the IADP performance) and 190 mm effective focal length (determined by the targeted GSD of 4.5 Km at Sub Satellite Point - SSP - and the size of detector pixels);

- a CMOS detector with 1000 x 1170 pixels, 24 μ m pitch, 1000 frame per second;
- a processing electronics implementing the detection functions.

Each OC images a different portion of the visible Earth surface with the four line of sights tilted 4.75° from the SSP toward North, South, West and East in order to achieve the required coverage (Figure 3).

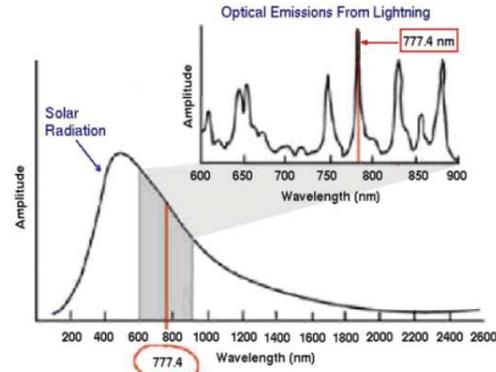


Figure 1 - Optical emission from lightning

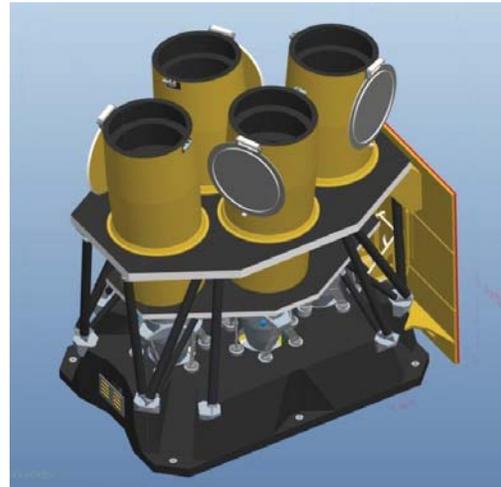


Figure 2 - LI Optical Head

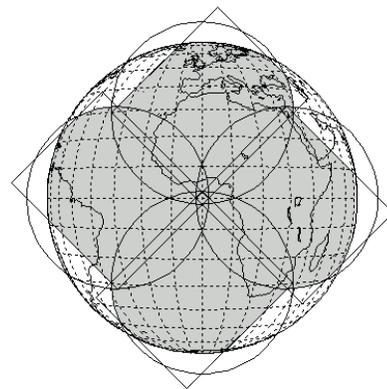


Figure 3 - LI coverage with 4 Optical Channel concept

The Main Electronics performs the overall payload functions, the interface to the platform, the configuration of the processing electronics, the data flow regulation and finally compacts and packetizes the scientific data.

IV. SYSTEM TRADE-OFFS

The main trade-offs for the selection of the LI configuration are:

- Single channel versus multi-channel architecture (this define the FOV of the optical channel).
- Narrow Band Filter position within the optical path: close to entrance pupil for a parallel incidence beam working concept versus close to focal plane for a convergent incidence beam working concept.
- Optical system sizing: optimization of the entrance pupil diameter with respect to lightning Average Detection Probability (ADP), mass and volume constraints and definition of the Ground Sampling Distance (GSD) with respect to ADP and electronics processing load constraints and data rate bottlenecks.
- Optical system design: single primary optics with four relay systems; catadioptric approach; dioptric approach.

A. Single Channel Vs. Multichannel Architecture

The separation of the LI global FOV into multiple optical channel, taking into account the NBF positioned in the entrance pupil, allows mitigating the development risk of the critical items (NBF, detector and proximity electronics) and the optimization of the NBF performances.

Figure 4 shows the FOV layout for a single and double Optical Channel solutions fulfilling the coverage requirement.

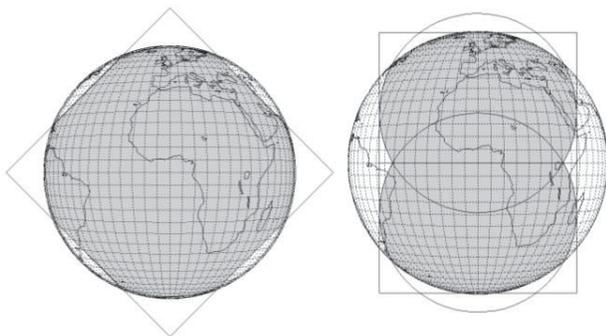


Figure 4 - LI coverage for Single and Double Optical Channels concept

The large FOV (8.7°) of the Single OC concept cannot be sustained by the NBF due to the blue spectral shift induced by the high angle of incidence which is not compatible with the bandwidth requirement. To limit such effect a Galileian telescope can be placed in front of the NBF (Figure 5) reducing the angle of incidence to 5.5° , but enlarging at the same time the filter diameter ($\sim 1.6X$). This makes the achievement of the coating uniformity requirements more challenging. In addition this solution imposes the development of a very large detector

array (about 5 Mpixels) and of a huge processing electronics (5 Gpixel per second to be processed in real-time) both considered unfeasible.

In case the global coverage is achieved by means of two or four Optical Channel, the detector size is reduced and the use of the Galileian telescope, requiring more mass ad envelope than available, is no more required.

The optical system parameters for single and multichannel configurations are reported in Table II.

The larger number of Optical Channels improves the NBF performance and the feasibility of detector and relevant processing electronics.

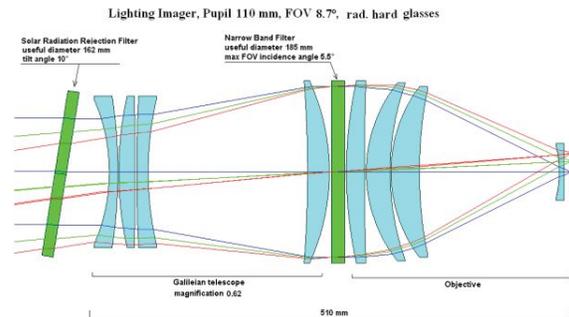


Figure 5 - Single optical channel layout with Galileian telescope

TABLE II – OPTICAL CHANNEL MAIN PARAMETERS VS. LI CONCEPT

# Optical Channels	1	2	4
Entrance pupil	110 mm		
F-number	1.73	1.73	1.73
Focal length	190 mm	190 mm	190 mm
FOV	8.7°	6.6°	5.1°
NBF concept	// beam	// beam	// beam
Max NBF AOI	5.5°	6.6°	5.1°
NBF diameter	185 mm	112 mm	112 mm
NBF Bandwidth	2.1 nm	2.4 nm	1.9 nm
Number of pixels	2200x2200	1850x1250	1170x1000
Pixel pitch	24 μm	24 μm	24 μm

B. Definition of NBF Working Concept

The above mentioned NBF parallel beam concept has been compared with an alternative one, for which the filter is positioned close to focal plane (convergent beam optical configuration).

In this case to limit the spectral shift of the NBF bandwidth, the optical system must be telecentric and with an F# of 4.75, corresponding to a convergent beam of 6° maximum. The resulting pixel pitch of the detector is 65 μm producing a very

large detector size and thus an increase of the effective focal length (~2.7X) compared with the NBF parallel beam concept.

However the trade-off between the NBF working concepts (parallel beam vs. convergent beam) is based on the Signal-to-Noise Ratio (SNR):

$$SNR = SLP / \sqrt{((SBKG + nro^2) * (1 + 1/NAV G))} \quad (1)$$

Where: SLP is the lightning pulse signal; SBKG is the background signal; nro is the read-out noise; NAVG is the background radiance averaging factor and corresponds to the number of background images averaged together.

Maximization of the SNR is achieved by proper specification of NBF bandwidth and in-band transmittance, taking into account, by means of a filter spectral response model (validated versus manufacturer test data), that minimizing the bandwidth leads to a decrease of the peak transmittance and vice versa.

Based on (1) and on the NBF spectral model, it can be demonstrated that SNR cannot be maximized for any illumination condition: in other words it is necessary to decide whether to increase SNR in night-time condition, maximizing the NBF transmittance, or in daylight condition, minimizing the filter bandwidth, the two solutions being in opposition.

The diurnal flash distribution provided by LIS data can be used to calculate a weighted SNR average, thus defining a Factor of Merit (FoM) that is not dependent on the illumination condition (see example in Figure 6), even if this statistics is not part of ESA/TAS requirement specification.

The FoM is calculated as a function of the NBF Full Width at Half Maximum (FWHM) for both the parallel and the convergent beam concepts. Results are reported in Figure 7 and Figure 8 respectively.

The parallel beam concept provides a better average FoM for any value of the FWHM.

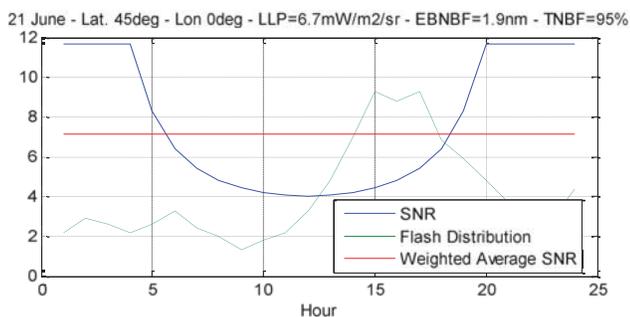


Figure 6 - SNR weighted average

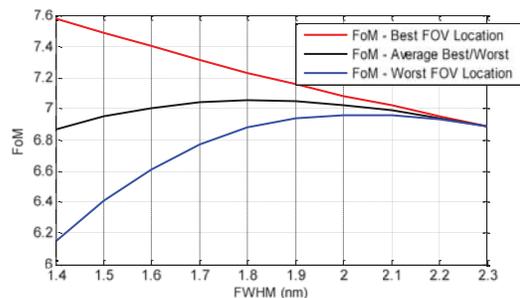


Figure 7 - FoM in parallel beam concept

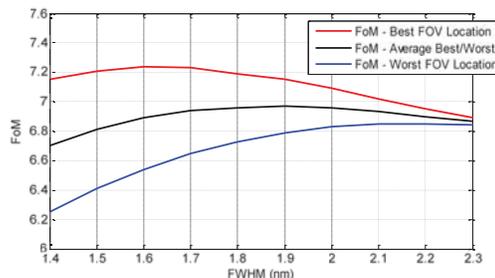


Figure 8 - FoM in convergent beam concept

C. Sizing of Main Optical System Parameters

The requirements for the Optical Channel design are defined on the basis of ADP estimated with the instrument performance model.

This section provides a justification for the definition of the entrance pupil and the GSD.

The ADP increases with the pupil size, as shown in Figure 9, thanks to a direct increase in signal collection. Nevertheless there is a set of constraints limiting the pupil diameter to 110 mm, in particular mass and envelope requirements, optical system complexity and NBF uniformity.

To evaluate the ADP sensitivity to GSD, the focal length is fixed to 190.8 mm (which corresponds to a GSD at SSP of 4.5 km with a 24 μm pixel size) and the pixel size is changed.

Figure 10 shows that the optimal GSD_{SSP} size is 4.5 Km, about half of the lightning reference diameter used for the evaluation.

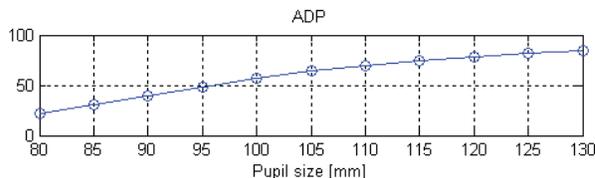


Figure 9 - ADP vs. entrance pupil diameter

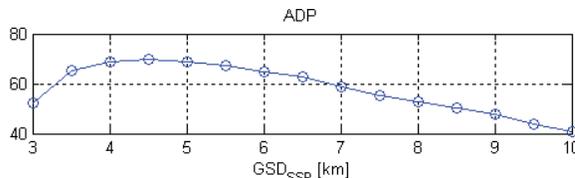


Figure 10 - ADP vs. GSD

V. OPTICAL SYSTEM DESIGN

The results of the previous evaluations and trade-offs limit the study to optical configurations with four detectors and NBF in parallel beam.

A. Optical Configuration Trade-Off

A single primary optics with four relay and four detectors (in field splitting) has been evaluated.

With this configuration some Earth areas are not covered due to detectors borders. Therefore to get proper sampling of the image on the focal plane special arrangement is needed. For example in the following Figure 11 the image in the intermediate focal plane is split in four parts using a fore-optics, wedges, to avoid un-covered Earth areas, mirrors and relay optics.

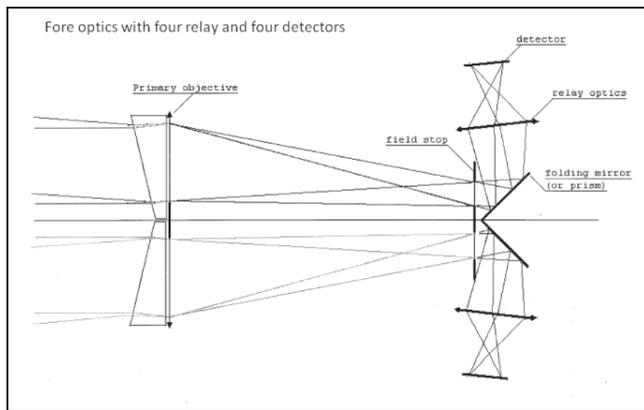


Figure 11 - single primary with four relay approach

The above first order concept might be realized by using a Schmidt-Cassegrain telescope as fore optics. Such an approach has the following advantages and drawbacks:

Advantages :

- The longitudinal envelope is shorter compared to others approaches
- Mirrors are free of secondary images and ghosts.
- The intermediate focal plane and the field stop avoid the light from outside the FOV to illuminate the relay reducing partially stray light contribution.

Drawback:

- Mirror shape and dimension drive the system out of weight and volume requirements. Moreover the relay optics dimension, schematized in Figure 11, are not negligible.

Although the present solution might appears attractive, due to its weight and volume this concept presents no advantages respect to a multi-channels approach that is described in the following.

The catadioptric approach consisting of a Schmidt telescope with relay optics is shown in Figure 12.

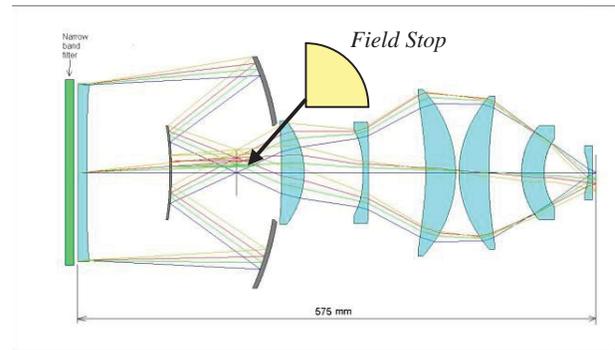


Figure 12: Catadioptric approach: Schmidt with relay

A field stop of suitable shape to image the required Earth portion, is placed in the intermediate focal plane.

Advantages :

- The longitudinal envelope is shorter than an all dioptric (with relay) approach
- The mirrors are free of secondary images and ghost.
- The intermediate focal plane and the field stop avoid the light from outside the FOV to illuminate the second part of the objective reducing partially stray light contribution.

Drawbacks :

- Due the central obscuration the filter diameter and the telescope transversal dimension are larger with respect to the equivalent pupil diameter.
- The obscuration ratio increases the radiation spread over the diffraction pattern outer rings deteriorating the nearby dimmer signals when strong in field sources (e.g. clouds) are focused on the focal plane.
- The FOV is vignetted as the entrance pupil is placed on the telescope Schmidt plate (located close to the narrow band filter) as shown in Figure 13.

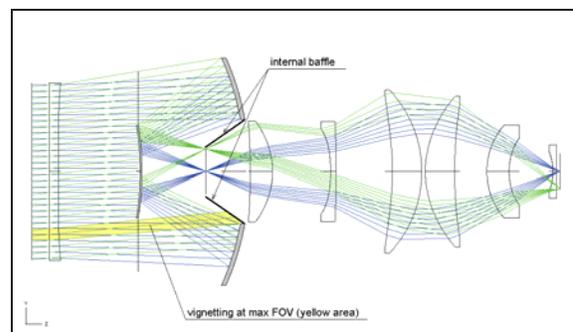


Figure 13: Schmidt telescope vignetting

The blue rays correspond to the axial FOV, the green rays are the ones of the maximum FOV. The yellow area, coming from the maximum FOV, is blocked from internal baffling. This loss of radiation increases with FOV and can be compensated by means of an extra pupil diameter to guarantee the required aperture at the maximum FOV. Nevertheless the

lens equivalent aperture changes with respect to the FOV and it is maximum on axis and decreases with the FOV.

Some of the above drawbacks can be solved using a more complex telescope (three mirrors) increasing however weight, volume and complexity.

Considering the narrow spectral bandwidth, a dioptric design allows compact configurations with reduced complexity when compared to mirrors based solutions.

In Figure 14 a primary objective is coupled with a relay to realize an intermediate focal plane. In the intermediate focal plane a suitable shaped stop is placed while the interference filter is positioned in front of the fore optics.

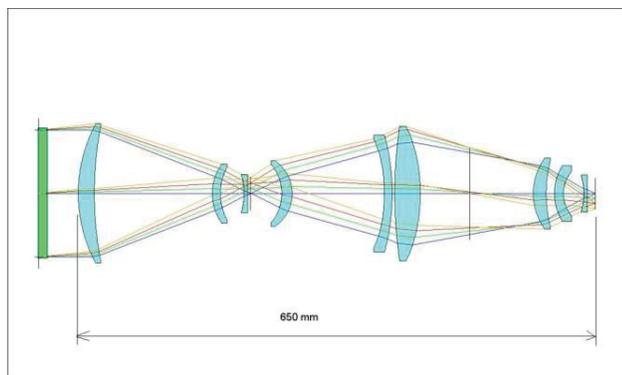


Figure 14: Dioptric with relay optical layout

Advantages :

- The narrow band filter is placed in front of the imager (green plate on Figure 14) and its size is minimized with respect to catadioptric solutions.
- The intermediate focal plane and the field stop prevent the light from outside the FOV to illuminate the second part of the objective reducing partially stray light contribution.

Drawback :

- Increase of longitudinal dimension and weight.

The advantages in stray light reduction do not balance the increase of mass and dimensions of the opto-mechanical system. Moreover, being in permanent view of the Earth, the first objective surface is the major contributor to stray light mainly due to contamination. In this case part of the scattered rays reaches the detector since they are close to incidence direction and cannot be baffled by the field stop.

The tight requirements on the longitudinal dimensions of the optical system and the need of a baffle to reduce fore optics illumination by off axis source are driving the design toward a single stage optical system.

B. Selected Configuration

The selected optical layout is composed by four optical channels, each one with an independent single stage lens, detector and baffle.

Figure 15 shows the optical layout of the baseline solution, whose main optical characteristics are reported in Table III.

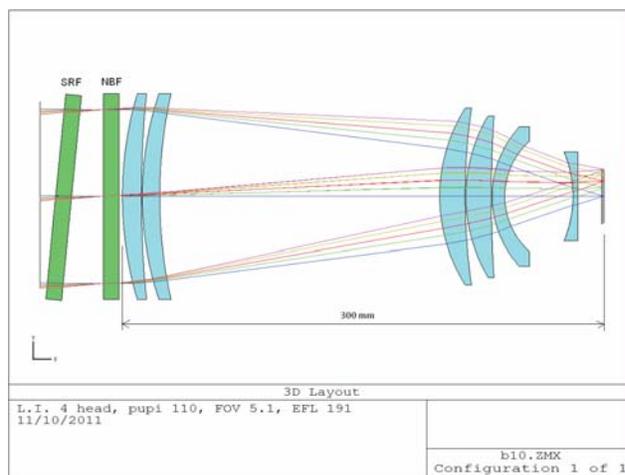


Figure 15 – Selected optical layout

TABLE III – OPTICAL SYSTEM MAIN CHARACTERISTICS

Parameter	Value
Effective Focal length	190.8 mm
Entrance pupil diameter	110 mm
Entrance pupil position	on the NBF filter
Field of View	5.1deg
Transparency (without filters)	95.5%
Transparency (including filters)	81%
Wavelength range	777.15 ÷ 777.65 nm
Max vignetting	0
Pixel pitch	0.024 mm
Thermal range	20±15 °C

The first two parallel plates are the Solar Rejection Filter and the Narrow Band Filter (both in green). The imager is composed of 6 lenses, all made of radiation resistant glass. All the lenses have spherical profile except one.

The lenses diameter are larger sized to insert some “light traps” and to limit the straylight caused from the lenses border and internal objective walls.

The Solar Rejection Filter, the first from left, is placed tilted to mitigate the ghosts images due to multiple reflections between filters.

Using a pixel projection model, the GSD corresponding to the above mentioned optical system parameters is represented in Figure 16 at SSP and at 45°N latitude and SSP longitude.

The dimension of the GSD, considering the rotated FOV are:

GSD at 45° Lat= 6.42 x 6.37 [km]

GSD at SSP = 4.50 x 4.50 [km]

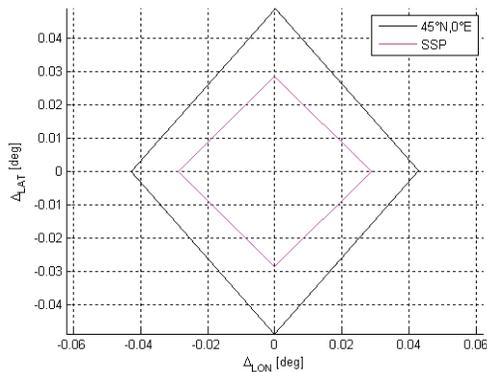


Figure 16: GSD model for reference LP event longitude and latitude

The nominal optical system performances at 20°C are shown from Figure 17 to Figure 21.



Figure 17: MTF

The RMS wavefront error, on axis (Figure 18), is 0.029 waves, corresponding to 22 nm.

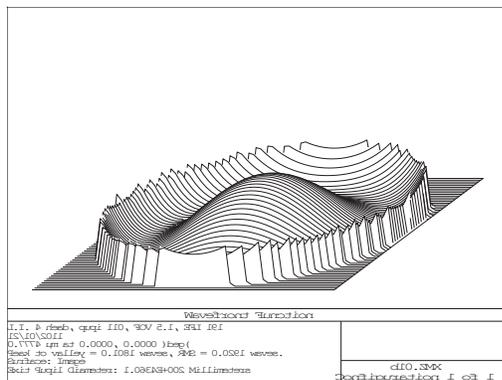


Figure 18: On axis RMS wavefront error function

The RMS wavefront error, at maximum FOV (Figure 19), is 0.072 waves, corresponding to 56 nm.

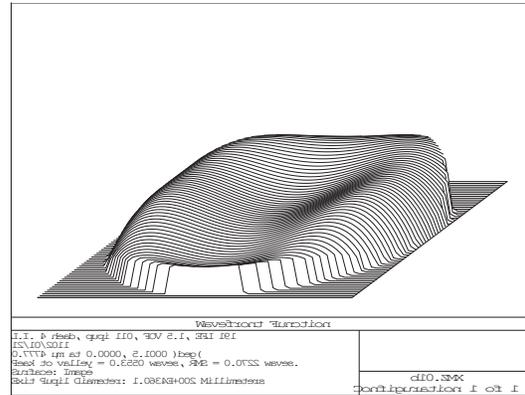


Figure 19: maximum FOV RMS wavefront error function

The instrument performance model indicates that the energy fraction in one pixel should be larger than 0.9 to ensure a proper ADP. Figure 20 shows that there is a margin with respect to the nominal design to account for image quality degradation due to manufacturing, alignment, thermal effects and other perturbations.

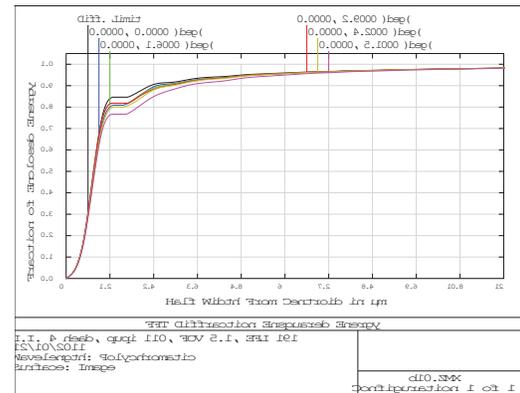


Figure 20: Ensquared energy function

The maximum distortion is less than 0.2% at maximum FOV as shown in Figure 21

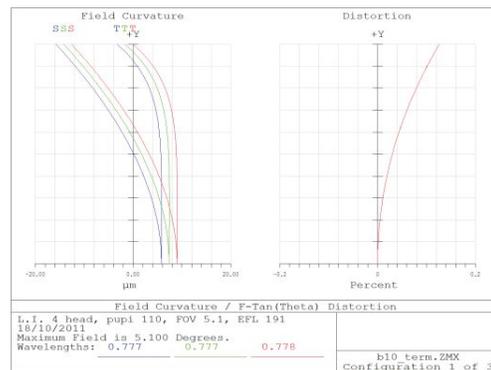


Figure 21: distortion and field curvature

To fulfill the performance requirements in the whole temperature range the optical system has to be athermalized. For that purpose the lens mounting is made of titanium to better fit the optical system expansion coefficient and limit the thermal defocus.

The optical performance computed at the temperature extremes are shown from Figure 22 to Figure 25.

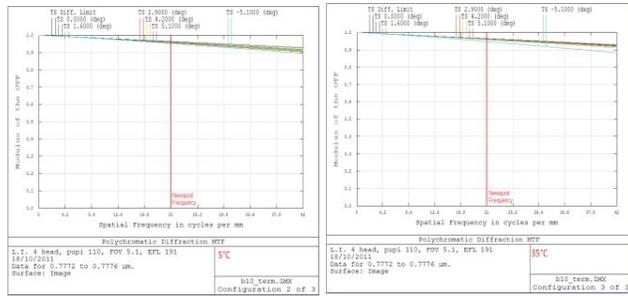


Figure 22: MTF at the operative temperature limits

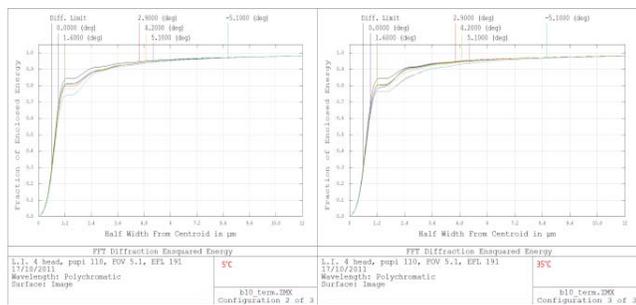


Figure 23: Ensquared energy function at the operative temperature limits.

The worst RMS wavefront error within the operative temperature range, on axis (Figure 24), is 0.039 waves, corresponding to 30 nm.

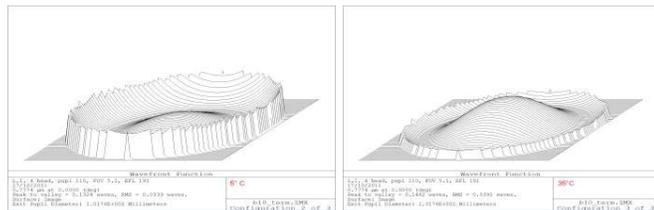


Figure 24: Wavefront function on axis at the operative temperature limits

The worst RMS wavefront error within the operative temperature range, for all the FOV positions (Figure 25), is 0.079 waves, corresponding to 61 nm at maximum FOV.

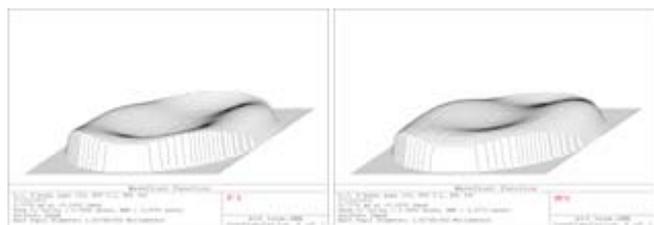


Figure 25: Wavefront function at maximum FOV at the operative temperature limits

The optical system performances at the limit of the operative temperature are almost unchanged with respect the 20°C ones.

The transmittance of the optical system at 777.4 nm has been maximized selecting an anti-reflective coating providing a transmittance of 99.78% for each of the 12 optical surfaces. Taking into account the transparency of the radiation resistant glass (99.7% at 700nm for 10mm thickness) and the overall lenses thickness (65mm), the overall transmittance of the 6 lenses is estimated as:

$$T(777.4nm) = 0.9978^{12} \cdot 0.997^{6.5} = 0.955$$

C. Baffle Design

The preliminary straylight analysis demonstrates that when the Sun directly illuminates the optical system components (i.e. when the Sun is within the baffle cut-off angle) the straylight becomes a critical issue for achieving the required absolute radiometric accuracy.

In order to limit to 2.5% the mission time when this criticality is present, a cut off of 16°, compatible with mass and envelope requirement, has been defined.

The other baffle geometrical parameters are:

- exit diameter (close to filters): 120 mm;
- lying angle (free FOV angle): 5.5°

BAFFLE PARAMETERS		DERIVED DATA	
Cut off angle Alpha [Degs]	16.000	Length [mm]	630.066
Lying angle Omega [Degs]	5.500	Entrance internal height [mm]	120.668
Exit height HOInt [mm]	60.000	Entrance external height [mm]	139.000
		Exit external height [mm]	130.000

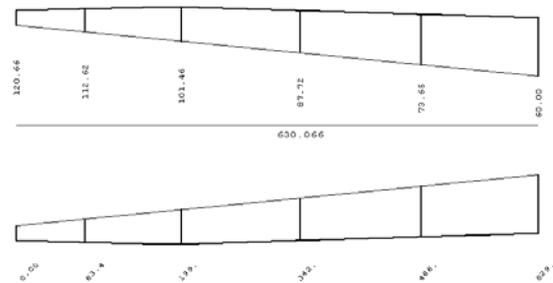


Figure 26: Baffle layout

D. LI Spectral Filters

The Solar rejection Filter (SRF) is devoted to reflect the solar radiation. It also works in synergy with the Narrow Band Filter (NBF) to obtain the required spectral filtering. It is directly exposed to the external space environment. Its mechanical mounting is thermally decoupled with respect the NBF and the optical system; its temperature range is much larger than optical system. The useful diameter is 118 mm.

In Table IV the performance requirements for SRF are provided in terms of transmittance at the scientific band and transmitted, reflected and absorbed energy in the 200 ÷ 2000 nm spectral range that includes almost the whole Sun radiance energy. The latter are estimated according the following formulas, where $S(\lambda)$ is the Planck distribution for an equivalent black body at 5780K.

The calculation of SRF Total Energy Transmitted, Reflected and Absorbed are reported respectively in (1), (2) and (3).

$$TET_{SRF} \% = \frac{\int_{200}^{2000} S(\lambda) * T_{SRF}(\lambda) d\lambda}{\int_{200}^{2000} S(\lambda) d\lambda} * 100 \quad (1)$$

$$TER_{SRF} \% = \frac{\int_{200}^{2000} S(\lambda) * R_{SRF}(\lambda) d\lambda}{\int_{200}^{2000} S(\lambda) d\lambda} * 100 \quad (2)$$

$$TEA_{SRF} \% = \frac{\int_{200}^{2000} S(\lambda) * A_{SRF}(\lambda) d\lambda}{\int_{200}^{2000} S(\lambda) d\lambda} * 100 \quad (3)$$

TABLE IV – SRF PERFORMANCE REQUIREMENTS

Parameter Description	Range (nm)	Value
SRF Transmittance	777.23 ÷ 777.57	> 95%
Total Energy Transmitted (TETSRF)	200 ÷ 2000	< 10 %
Total Energy Reflected (TERSRF)	200 ÷ 2000	> 84 %
Total Energy Absorbed (TEASRF)	200 ÷ 2000	< 6 %

The performances have to be satisfied for the following temperature ranges:

- Operative temperature: -60°C ÷ 150°C
- Storage temperature: -100°C ÷ 150°C

The NBF, placed between the SRF and the first lens, performs the spectral discrimination of the lightning pulse from the Earth background radiance. It is supported by the lenses mounting so its operative thermal range is the same of the optical system. The useful diameter is 112 mm.

In Table V the performance requirements for NBF are provided in terms of:

- Transmittance in the scientific band. Its calculation is reported in (4).
- Equivalent bandwidth. Its calculation is reported in (5)

$$\overline{T}_{NBF} = \frac{1}{777.57 - 777.23} \cdot \int_{777.23}^{777.57} T_{NBF}(\lambda) d\lambda \quad (4)$$

$$EB_{NBF} = \frac{\int_{772.4}^{782.4} T_{NBF}(\lambda) d\lambda}{\overline{T}_{NBF}} \quad (5)$$

The integral has been defined on a spectral range sufficiently wide to allow the manufacturer to optimize the coating design regardless of the proposed pass band shape.

Table V: NBF PERFORMANCE REQUIREMENTS

Parameter Description	Range (nm)	Value
NBF Transmittance (\overline{T}_{NBF})	777.23 ÷ 777.57	> 90%
NBF Equivalent Bandwidth (EB _{NBF})	772.4 ÷ 782.4	< 1.9 nm

The ideal NBF bandwidth would be the scientific bandwidth (0.34 nm). Nevertheless, the actual bandwidth is specified in a figure of 1.9 nm to guarantee the required transmittance in the scientific bandwidth for all the working conditions and considering also the coating manufacturing errors.

These effects/errors are:

- Spectral shift due the AOI (0° to 5.1°)
- Deposition uniformity and wavelength centering error.
- Temperature effect.
- Radiation stability.
- Environmental stability (humidity, thermal cycling).

The NBF performances have to be satisfied for the following temperature ranges:

- Operative temperature : 12°C ÷ 32°C
- Storage temperature : -50°C ÷ 80°C

The out of band rejection requirements for the combined operations of the fully coated SRF and NBF (including substrate contributions) is specified in Table VI.

Requirements are given in the spectral range of the detector sensitivity (assumed from 200nm to 1100nm), with the exception of the 10 nm not covered by (5)

Requirements are provided in terms of:

- Mean out of band transmittance on the spectral range to minimize the background signal out of band, in the detector sensitivity range. The specified value provides a negligible contribution compared with the EBNBF figure.
- Maximum out of band transmittance to avoid any significant pulse spectral radiance contribution out of the required emission lines.

The Combined Out of Band Mean Transmittance calculation is reported in (6).

$$T_{OBM} = \frac{\int_{782.4}^{1100} T_{NBF} \cdot T_{SRF}(\lambda) d\lambda + \int_{200}^{772.4} T_{NBF} \cdot T_{SRF}(\lambda) d\lambda}{(1100 - 782.4) + (772.4 - 200)} \quad (6)$$

Table VI: SRF AND NBF COMBINED OUT OF BAND TRANSMITTANCE REQUIREMENTS

Parameter Description	Range	Value
Combined Out of Band Mean Transmittance (T_{OBM})	200 ÷ 772.4 & 782.4 ÷ 1100	< 0.01%
Combined Out of Band Maximum Transmittance (T_{OBMax})	200 ÷ 772.4 & 782.4 ÷ 1100	< 1%

VI. CONCLUSION

The Lightning Imager will be the first instrument developed in Europe for the detection of lightning events from geostationary orbit. The challenging detection requirements in day and night conditions, combined with the large coverage and the tight mass and envelope make the Lightning Imager a complex instrument from an optical perspective.

Despite the complexity of the requirements an instrument based on four simple dioptric lenses has been identified from an exhaustive trade-off. The results of the optical analyses presented in the paper indicate that the selected configuration is very promising for a successful Lightning Imager mission.

REFERENCES

- [1] Steven J. Goodman, "Geostationary Lightning Mapper for GOES-R and Beyond", STAR Science Forum 2008, <http://www.star.nesdis.noaa.gov/star/>
- [2] Ullrich Finke, "Characterising the Lightning Source for the MTG Lightning Imager Mission", http://www.eumetsat.int/groups/pps/documents/document/pdf_mtg_rep3_0.pdf
- [3] Boccippio, D. J., W. J. Koshak, and R. J. Blakeslee (2002). "Performance assessment of the optical transient detector and lightning imaging sensor. Part I: Predicted diurnal variability. J. Atmos Oceanic Technol. 19, 1318-1332.
- [4] Christian, H. J., R. J. Blakeslee, D. J. Boccippio, W. L. Boeck, D. E. Buechler, K. T. Driscoll, S. J., Goodman, J. M. Hall, W. J. Koshak, D. M. Mach, and M. F. Stewart (2003). "Global frequency and distribution of lightning as observed from space by the optical transient detector", J. Geophys Res. 108, 4005, doi:10.1029/2002JD002347.