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HIGH PERFORMANCE EQUIPPED MIRRORS FOR MTG FCI-TA & IRS-FTO

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I. INTRODUCTION

The Meteosat Third Generation (MTG) Programme is being realised through the well established and successful Cooperation between EUMETSAT and ESA. It will ensure the future continuity of MSG with the capabilities to enhance nowcasting, global and regional numerical weather prediction, climate and atmospheric chemistry monitoring data from Geostationary Orbit. There will be up to 6 satellites series to cover beyond 20 years of European meteorology. Four MTG-I and two MTG-S satellites will bring to the meteorological community a series of satellites for continuous high spatial, spectral and temporal resolution observations and geophysical parameters of the Earth based on sensors from the geo-stationary orbit.

Leading Edge Earth Observation Missions are demanding Higher Resolution Systems, which in turn result in even more stringent requirements in terms of stability for the Optical Elements. In the case, MTG has resulted in the need to unprecedented requirements in terms of Optical Elements quality and Thermal Control.

THALES SESO will review Optical Elements key issues with associated performance characteristics, related to mirrors and flexures. LIDAX will describe the Thermal Control design, high stability Mirror Supports and Field Stops/Aperture Stops. Joint efforts of these two companies have minimized alignment and stability errors while providing the required optical performance together with stiffness & strength enough to withstand the environmental loads. Meanwhile, an optimum assembly process assures the demanding required cleanliness levels.

This paper describes the key design features and expected performances before STM (Structural Thermal Model) Test Campaign for M1, M2, M3 and M4 Mirrors of MTG FCI-TA (Flexible Combined Imager) and IRS (Infra-Red Sounder) Front Telescope Optics (FTO). These Mirror Assemblies have been developed jointly by THALES SESO and LIDAX during phase B/C of the contract awarded by OHB System AG (formerly Kayser-Threde), who is responsible for the telescope assembly of both FCI-TA and IRS instruments.

II. MODELS & PROJECT STATUS

MTG (Meteosat Third Generation) is a Twin Satellite Concept consisting of:

- Four Imaging Satellites (MTG-I) which include the FCI-TA as one of the instruments.
- Two Sounding Satellites (MTG-S) which include the IRS-FTO as one of the instruments.

The program is currently going through phase C (Detailed Definition). MTG will follow-up the activities of the MSG (Meteosat Second Generation) series of satellites operative today.

Apart from the flight models, two development models are being produced for the Telescope Optics:

- The STM (Structural and Thermal Model), fully representative in mechanical and thermal aspects but with limited optical performance.
- The EQM (Engineering Qualification Model), fully flight standard, tested and integrated with the possibility to be used as a flight model.

The STM is already being manufactured and being assembled to start the STM Test Campaign. The EQM is also in the early phases of manufacturing.

III. MIRRORS ASSEMBLY DESIGN DESCRIPTION

A. Design Concept of the Telescope Optics

The FCI-TO subsystem consists of four mirrors. The mirrors M1 to M3 compose an off-axis three-mirror Korsch like telescope that receives the light from the Scan Assembly (SA). M4 is a folding mirror that directs the light towards the object plane of the Spectral Separation and Detection Assembly subsystem (SSDA).

The IRS-FTO afocal telescope concept is similar to the FCI-TO, consisting of four mirror assemblies with an analogous disposition. For this subsystem the light is directed towards the Interferometer Assembly (IA) in the last step.

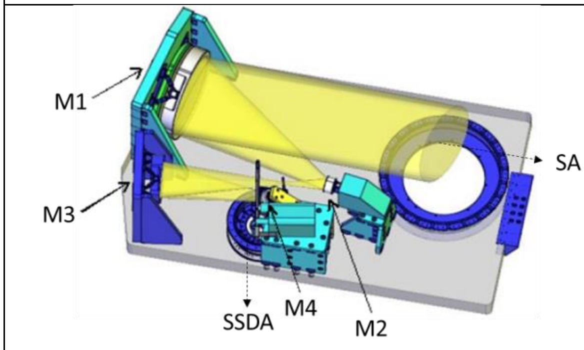
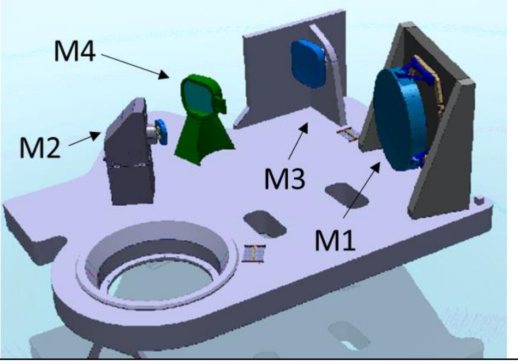
FCI-TA	**IRS-FTO**
	

Fig 1: FCI-TA and IRS-FTO General Concept

B. Design Concept of the Mirror Assemblies

All of the mirror assemblies share the same basic design concept:

- The mirrors are lightweighted Zerodur®.
- Coatings of the mirrors are gold or silver, depending on the mirror.
- The mirrors are integrated on flexures called Mirror Fixation Devices (MFDs) to filter the vibration and optimize stability.
- The MFDs also thermally insulate the mirror from the interface.
- A Radiative Heating Plate (RHP) with a double layer heater on each side is used for thermal control of the mirror.
- The Radiative Heating Plate is supported by brackets (RHPBs) which also act as thermal insulation.
- The MFDs and RHP Brackets are both mounted on Interface Structures (IFSs) or on a single rigid Socle, depending on the mirror assembly.
- MLI is used to minimize heating power losses and reduce coupling with the environment.
- Thermistors are bonded on the mirror backside for thermal control and monitoring.
- Provisions are added for test and handling GSEs.
- Both folding mirrors (M4s) include a Field Stop. The FCI-TA M4 also includes an Aperture Stop.
- Alignment shims are implemented for the Field Stops, Aperture Stops and all mirror assemblies.

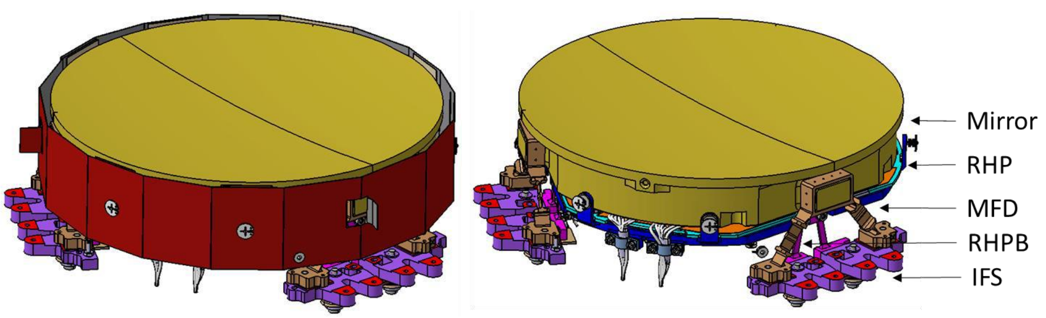


Fig 2: FCI M1 Mirror Assembly (MLI hidden on the right picture)

C. Driving Requirements

Optical Requirements

Optical requirements are quite close for both MTG-I and MTG-S mirrors for mirror definition but polishing quality is more demanding on MTG-I mirrors. As a rough overview, we have to commit the following quality class optics

Main Input Parameters	**M1 (I or S)**	**M2 (I or S)**	**M3 (I or S)**	**M4 (I or S)**
Optical Substrate	ZERODUR Class 0	ZERODUR Class 0	ZERODUR Class 0	ZERODUR Class 0
Shape	Concave elliptic (highly aspheric,)	Convex hyperbolic	Concave elliptic	Flat
Useful Area : X dir* Y dir (mm)	300x300 to 330x330	60x60 to 65x65	130x150 to 150x170	60x40 to 120x100
Off axis distance (mm)	300 to 400	55 to 60	40 to 100	NA
Mid-Spatial Frequency Roughness between 0.1/mm and 10/mm	<1.3 nm RMS (I) <5 nm RMS (S)	<1.3 nm RMS (I) <5 nm RMS (S)	<1.3 nm RMS (I) <5 nm RMS (S)	<1.3 nm RMS (I) <5 nm RMS (S)
High-Spatial Frequency Roughness between 1/mm and 1000/mm	<0.5 nm RMS (I) <2 nm RMS (S)	<0.5 nm RMS (I) <2 nm RMS (S)	<0.5 nm RMS (I) <2 nm RMS (S)	<0.5 nm RMS (I) <2 nm RMS (S)
Residual wavefront error due to manufacturing (nm RMS)	<6 nm RMS (I) <23 nm RMS (S)	<6 nm RMS (I) <12 nm RMS (S)	<6 nm RMS (I) <13 nm RMS (S)	<6 nm RMS (I) <10 nm RMS (S)
Additional residual wavefront error in flight (nm RMS)	<3 nm RMS (I) <5 nm RMS (S)	<3 nm RMS (I) <3 nm RMS (S)	<3 nm RMS (I) <3 nm RMS (S)	<3 nm RMS (I) <3 nm RMS (S)

Table 1: Optical Requirements

Thermal and Mechanical Requirements

Parameter	**Units**	**FCI-TA**				**IRS-FTO**			
		M1	**M2**	**M3**	**M4**	**M1**	**M2**	**M3**	**M4**
Mass	Kg	6.10	0.60	2.01	0.79	5.84	0.60	1.68	0.90
Stiffness	Hz	250	350	350	350	400	500	300	450
Random loads	g rms	16.6	21.0	24.9	22.5	16.2	33.7	24.5	26.5
Maximal heat transfer across I/F	W	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Hot survival temperature	ºC	50	50	50	50	50	50	50	50
Cold survival temperature	ºC	-5	-5	-5	-5	-5	-5	-5	-5
*Mirror in-flight tilt error	µrad	1	5	5	10	75	5	5	10
**Mirror in-flight position error	µm	1	1	1	3	8	1	1	5
Field stop sun intrusion temperature	ºC	-	-	-	127	-	-	-	120
*Field stop in-flight tilt error	µrad	-	-	-	100	-	-	-	100
**Field stop in-flight position error	µm	-	-	-	20	-	-	-	10
*Aperture stop in-flight tilt error	µrad	-	-	-	100	-	-	-	-
**Aperture stop in-flight position error	µm	-	-	-	10	-	-	-	-
***RHP / Mirror coverage	%	>90	>90	>90	>90	>90	>90	>90	>90
****Heaters / RHP coverage	%	>80	>80	>80	>80	>80	>80	>80	>80

Table 2: Thermal and Mechanical Requirements

*Along axes perpendicular to the optical axis
**Along the optical axis
***Percentage of the mirror projection surface covered by the RHP.
****Percentage of the RHP surface covered by the heaters.

D. Overview of the Mirrors

The M1 mirror is equipped with three rectangular bosses at the periphery (each 120°) each and machined directly into the mirror blank. The contour of these bosses is used as fixation interface (with space qualified glue) for the corresponding A-frame flexures (or MFD) made out of INVAR. The M1 mirror is highly light-weighted to fit the mass requirement. This light-weighting type is a semi close back type. A number of cells are machined within the mirror from its rear side. The generic cell shape is hexagonal. The depth of each cell and the internal rib thickness are determined in such way to reach the mass objective. Calculated mass is 3kg for mirror + 3x0, 2kg for the MFDs (for MTG-I) and 2,5kg for mirror + 3x0,18kg for the MFDs (for MTG-S)

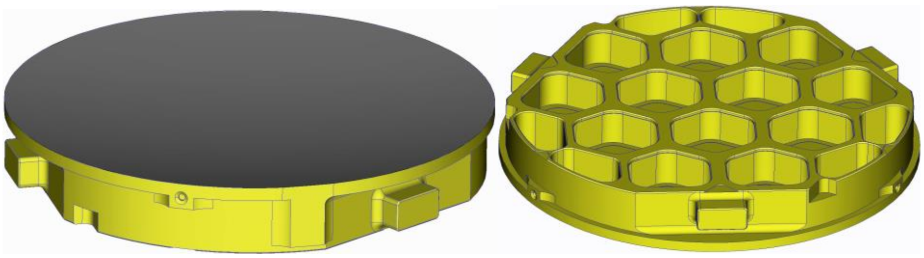


Fig 3.1: sketch of the M1 mirror for MTG-I (similar for MTG-S)

The M2 mirror is equipped with three flat areas at the periphery, machined directly in the mirror. As for the M1, these flat zones are machined directly into the mirror blank and will be glued to the MFD. The M2 mirror is however not light-weighted as it is basically small so light (<0.2kg for MTG-I or MTG-S) and thermal capacity is needed.

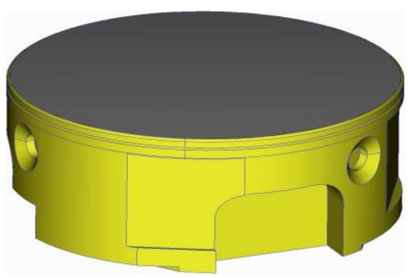


Fig 3.2: sketch of the M2 mirror for MTG-I (similar for MTG-S)

The M3 mirror is equipped with three rectangular bosses at the periphery (each 120°) each and machined directly into the mirror blank. The contour of these bosses is used as fixation interface (with space qualified glue) for the corresponding A-frame flexures (or MFD) made out of INVAR. The M3 mirror is highly light-weighted to fit the mass requirement. This light-weighting type is an open back type. A number of cells are machined within the mirror from its rear side. The generic cell shape is hexagonal. The depth of each cell is determined in such way to reach the mass objective. Calculated mass is 0.7kg for mirror (for MTG-I) and 0.6kg for mirror (for MTG-S)

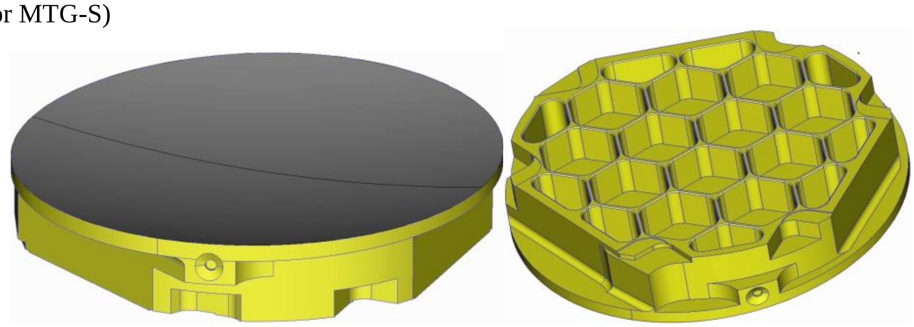


Fig 3.3: sketch of the M3 mirror for MTG-I (similar for MTG-S)

The M4 mirror, although small, must be light-weighted as well in order to reduce its mass to the minimum. This is done by an elliptical unique central cut of dimensions 45 x 30 mm. The M4 mirror mass alone is 70gr only (for MTG-I) and up to 200gr (for MTG-S) as this mirror is much bigger in S compared to I.

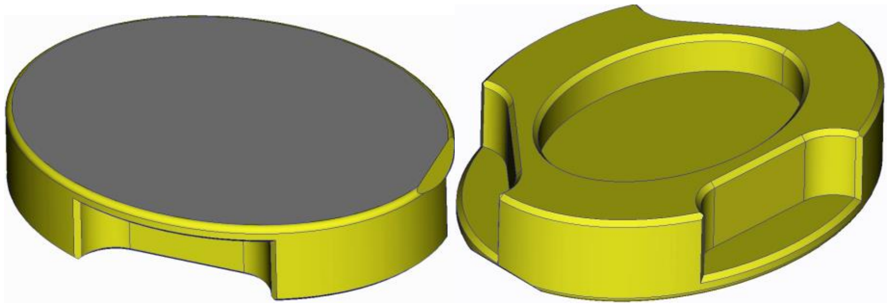


Fig 3.4.a: sketch of the M4 mirror for MTG-I

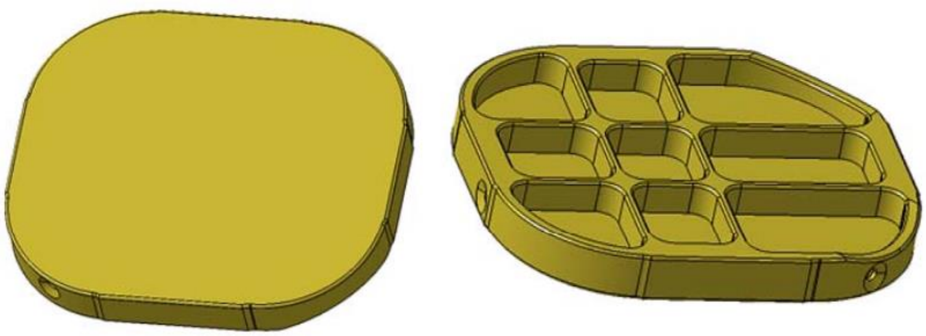


Fig 3.4.b: sketch of the M4 mirror for MTG-S

E. Design of the Thermal Hardware Assemblies

The design of the thermal hardware has proven to be very challenging, mostly because the maximal heat flux permitted to the satellite interface is very low, the random and thermo-elastic loads are high and the space behind the mirror is very limited.

<u>Heaters Coverage</u>
The mirrors have strict heater coverage requirements, which are split in two parts. One part is the required coverage of the Radiative Heating Plates by the heaters (>80%) and the other part is the required coverage of the mirrors by the Radiative Heating Plates (>90%). The fact that the plates share the volume behind the mirrors with the Mirror Fixation Devices and the Interface Structures has made fulfillment of the mirror coverage requirement extremely difficult. The most promising designs in terms of performance had to be abandoned in favor of less volume-hungry designs.

<u>Emissivity Requirements</u>
The face of the RHP Assembly facing away from the mirror has a low emissivity requirement ($\varepsilon < 0.1$) which cannot be achieved by the heater alone. To solve the issue the lower heater had to be covered with adhesive VDA tape which guarantee low emissivity values. The process of bonding adhesive VDA tape on the heater over a complex geometry is complicated and a specific qualification campaign had to be carried out to guarantee the quality and reliability of the bond.

<u>Stiffness Trade-Off</u>
Complying with the high stiffness requirements while keeping mass to a minimum has also proven to be difficult. For the M1 mirrors (the biggest ones) using an additional Stiffening Plate with no thermal function has proven to be more mass-effective than just making a thicker heating plate. For the smaller mirrors the optimal stiffness/mass is achieved without the need of an additional stiffening plate.

<u>Heat Transfer Control</u>
The requirements dictating maximal heat transfer along mirror assembly interfaces have been decisive in the design too. The whole Radiative Heating Plate is supported by brackets (RHPBs) which had to be made of

titanium to thermally insulate the Radiative Heating Plate. In addition to this material constraint, custom titanium washers had to be added on some RHPB contact points with the sole purpose of thermal insulation.

Design for Minimal Mirror Loads
It is also critical to keep the loads induced in the mirror to a minimum. This has proven to be hard as both the mirror fixation devices and the RHP Brackets are fixed to the same rigid Interface Structures. To keep the loads to a minimum, the RHP Brackets have been made flexible and their fixation points on the Interface Structures had to be positioned as far as possible from the Mirror Fixation Devices.

Manufacturing and Assembly for Minimal Mirror Loads
During the integration campaign a special precision shimming is performed to further reduce the loads induced on the mirror. Prior to the definitive Thermal Hardware integration, the parts are assembled once to measure the fit and the exact effects of manufacturing tolerances on the whole assembly. With the values from the measurements precision custom washers are manufactured to compensate these effects. Thanks to these washers the loads induced to the mirror (and the whole assembly) are reduced even further.

F. Design of the Field Stops and Aperture Stop

The M4 mirror assemblies also include the Field Stop of the telescope. For FCI-TA, the telescope Aperture Stop is included in the M4 mirror assembly too. These Field Stops and Aperture Stops are fixed to the frames of the mirror assemblies.

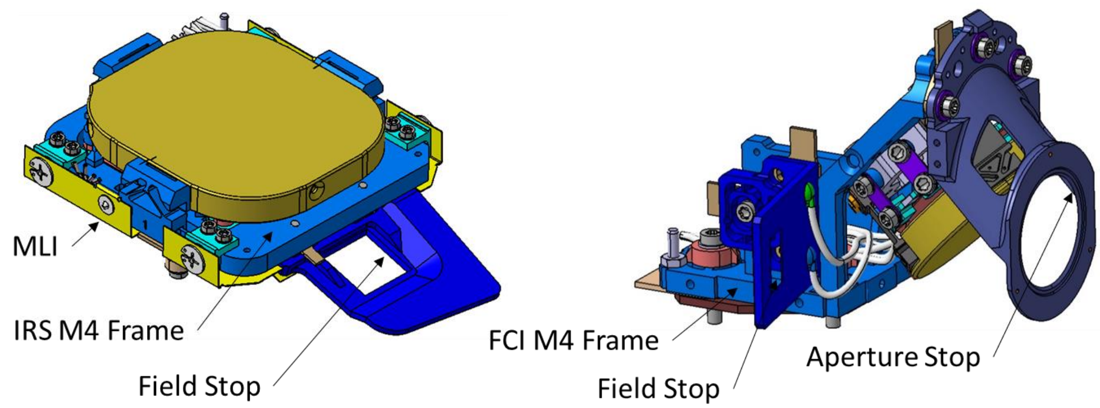


Fig 4: IRS M4 and FCI M4 Mirror Assemblies

Stability Requirements in an Extreme Environment
The Field and Aperture Stops have severe stability and alignment requirements. These requirements are even more challenging considering that at some points of the orbit the sun lights directly at the Field Stops and temperatures of these parts can go up to 127ºC for the FCI M4 FS and 120ºC for the IRS M4 FS. This extreme environment made temperature and heat flow control the main design driver.

Thermal Coatings
As the sun light can directly hit the Field Stops, specific coatings are needed to minimize heat build-up. On one hand, the side of the Field Stops facing the sun is coated with VDA Tape eflecting most of the radiation coming from the sun outwards from the assembly. On the other hand, the inner edge of the FS and the surface of the Field Stops not lighted by the sun is painted with Aeroglaze Z306 black paint to maximize emissivity and heat evacuation by radiation plus to reduce the straylight. The angled geometry of the Field Stops makes the coating and VDA Tape application process very challenging, a strict product assurance control is needed and a specific qualification campaign is performed to ensure the needed quality of the VDA Tape bond.

Materials Choice
Even with the thermal coatings, the Field Stops still receive a very high heat flux. This constraint forced to dismiss more stable materials in favor of Aluminium due to its high conductivity and specific heat. The material choice helped to solve the thermal control issue but created new slippage and stability problems, result of the huge CTE difference between the Aluminium Field Stops and Invar 36 frames. Complex flexures had to be

implemented on the interfaces to keep the Field Stops within stability requirements and additional specific design features had to be added to sustain the demanding thermo-elastic conditions.

Analysis Results

With all the new heat flow and thermo-mechanical coupling features, the design had been subjected to detailed thermal and structural analyses. The results have been compliant with the projects needs and it is expected that the concept is verified successfully during the STM Test Campaign.

G. STM Assembly and Integration Campaign

The complexity of the design along with the small size of the parts has generated a lot of practical challenges during the integration of the assemblies. Heaters, VDA tape layers, MLI stand-offs and thermal sensors and have to be bonded on intricate surfaces while securing perfect finishing and total absence of bubbles. A lot of test sensors have to be fixed and then detached after the testing campaign while operating in millimetric gaps. Innovative workmanship approaches had to be introduced which along with specifically designed integration tooling made possible to comply with the high quality goals of the MTG space program.

V. CONCLUSIONS

The demanding requirements of the MTG space program led to a very challenging design phase for the Mirror Assemblies. Nevertheless this phase has been executed successfully and analyses show promising performance results for the equipment. The STM model is right in the middle of the integration campaign and the designs will be soon verified during the STM Test Campaign.

The manufacturing of the qualification model has already started and first phases of integration will follow soon.

VI. ACKNOWLEDGEMENTS

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