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SYSTEM TRADE-OFF STUDY AND OPTO-THERMO-MECHANICAL ANALYSIS OF A SUNSHIELD ON THE MSC OF THE KOMPSAT-2

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ABSTRACT

The Multi-Spectral Camera (MSC) is the payload of KOMPSAT-2 which is designed for earth imaging in optical and near-infrared region on a sun-synchronous orbit. The telescope in the MSC is a Ritchey-Chretien type with large aperture. The telescope structure should be well stabilized and the optical alignment should be kept steady so that best images can be achieved. However, the MSC is exposed to adverse thermal environment on the orbit which can give impacts on optical performance. Solar incidence can bring non-uniform temperature rise on the telescope tube which entails unfavorable thermal distortion. Three ways of preventing the solar radiation were proposed, which were installing external mechanical shield, internal shield, and maneuvering the spacecraft. After trade-off study, internal sun shield was selected as a practical and optimal solution to minimize the effect of the solar radiation. In addition, detailed designs of the structure and sunshield were produced and analyses have been performed. The results were assessed to verify their impacts to the image quality. It was confirmed that the internal sunshield complies with the requirements and would improve image quality.

Keywords: KOMPSAT-2, MSC, sunshield, space telescope, optical performance, thermal effect

1. INTRODUCTION

The Multi-Spectral Camera (MSC) is being developed as the payload of KOMPSAT-2 (KOrea Multi-Purpose SATellite-2) since January 2000, according to the Mid and Long-term National Space Development Plan (MOST 2000). The MSC will provide high resolution images, 1m in GSD (Ground Sample Distance) at panchromatic channel and 4m in GSD in four broad bands from blue to near-IR regions (Yong et al. 2001). The telescope of the MSC is a large Ritchey-Chretien type, which is composed of hyperbolic primary and secondary mirrors with focal correcting lenses, and the diameter is 60cm. Figure 1 shows a schematic diagram of the KOMPSAT-2 which contains the telescope of the MSC.

Large telescope is sensitive to orbit environment, whose temperature would cycle to the range of about 100 degrees Celsius on every orbit. The temperature rises high when satellite is on the sunny side, and it drops down to further below freezing temperature when satellite is in the Earth's shadow. Therefore, impacts of the thermal effects should be taken into account. Thermal analyses for the MSC have been performed. The thermal effect caused by direct sunlight into the telescope tube has also been studied and described in this paper.

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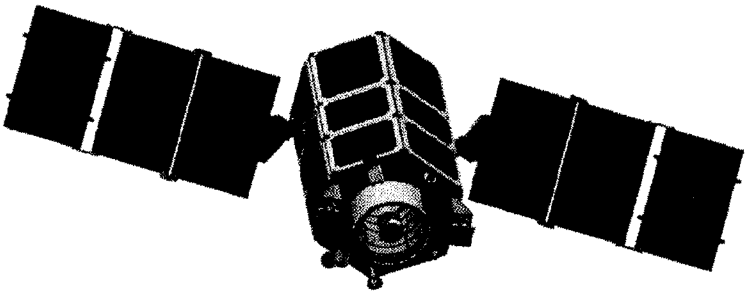


Figure 1. A schematic diagram of KOMPSAT-2. The mouth of the telescope is extruded from the satellite body.

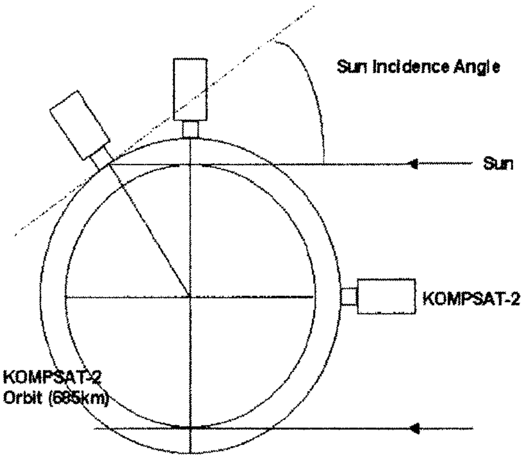
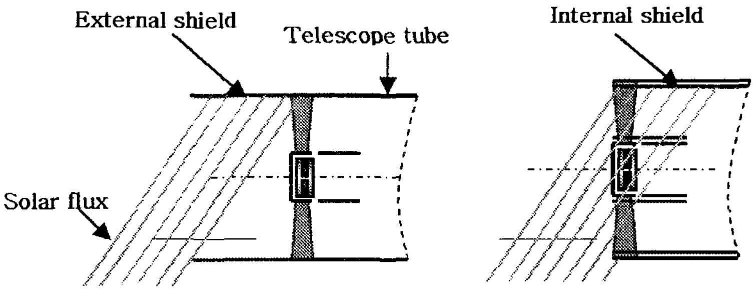


Figure 2. Incidence of solar radiation on KOMPSAT-2 (Kim et al. 2000).

2. SYSTEM TRADE-OFF STUDY ON SUNSHIELD

KOMPSAT-2 will be on a sun-synchronous orbit with the inclination of 98 degrees and will look down the Earth all the time on the orbit (KARI 2000). By this operation concept, solar radiation is allowed to enter directly into the telescope at some sections of the orbit, as shown in Figure 2 (Kim et al. 2000). The direct sunlight enters into the telescope during the transitions between day and night, i.e. just before entering into the Earth's shade and just after coming out of the shade. Duration of the direct sunlight is about 14 minutes per orbit, as the nominal altitude of KOMPSAT-2 is 685km and one orbit lasts about 98.6minutes. The maximum solar incidence angle is 25.4 degrees from the normal to the optical axis when nadir pointing, which allows the direct solar radiance into the telescope to the depth of 310mm.

If the solar radiation is not protected, it will heat up the telescope structure causing several pro lems. Thermal cycling with higher temperature than allowed may cause structural degradation d to de-lamination in telescope structures which are mainly made of composite materials. Moreo temporal and spatial temperature variation results in elastic deformation according to thermal ex



(a) External sunshield (b) Internal sunshield

Figure 3. Schematic diagram of external and internal sunshields.

sion coefficient of the structure. It may be subject to optical performance degradation because the telescope is very sensitive to relative displacement between the optical elements.

Three ways of protecting the solar radiation have been studied. They are attaching an external shield, maneuvering the spacecraft, and attaching an internal shield (EL-OP 2000, Kim et al. 2001).

1. Installing an external shield is an usual and preferable solution in the aspect of protecting direct solar radiation only. As the sunshield can be attached to the platform of the spacecraft, extra mass of the sunshield would not be loaded to the section of the secondary mirror which is most sensitive to optical performance. Therefore, external sunshield can completely protect solar incidence into telescope and doesn't add any extra mass to the secondary mirror section of the telescope.

However, the external shield raised problems according to the KOMPSAT-2 design. There are two x-band antennae beside the telescope aperture, which will be used for downlink of image data to Ground stations. If the external shield is attached to the mouth of the telescope like Figure 3(a), it can block the radio transmission from the x-band antennae to Ground stations because of the long extended tube structure of the sunshield. Though one of the two antennae is used at a time for a data transmission, both should be capable of Ground contact at any situation, regardless of the attitude of the satellite and relative position of a Ground station from the satellite. In case one of the antennae is malfunctioned or one transmission system fails, the other one should be able to contact the Ground station. Even though a material for the sunshield was found which comprised the radio transparent requirements successfully, it may, and normally does, generate complicate processes in production and tests.

Another negative factor is that the length of the satellite including the external sunshield becomes longer than that of the existing thermal vacuum chamber in KARI (Korea Aerospace Research Institute). Therefore, the sunshield should be detached during the environmental test for the whole satellite and re-assembled after the test, which adds more complications to the processes of the test. In addition, as the sunshield would be attached to the platform of the spacecraft, there will be increase of the interface works between venders of the bus and the MSC.

2. The solar radiation into the telescope tube can also be avoided by maneuvering the spacecraft appropriately, by pitch maneuvering of the satellite toward the shade. During ingress into the shade, pitch maneuvering to moving direction of the satellite is required, and backward pitch maneuvering is required during egress. By the maneuverings, direct radiation could not come into the telescope. This method has an advantage that it does not require any additional weight because it is not a mechanical shield. However, modifications of existing control algorithm and software are required,

Table 1. Effects of the solutions for avoiding direct sunlight.

Solution	Method	Effects
External shield	Attached to the platform of the spacecraft	Preferred solution for shielding effectiveness No direct radiation into the telescope Require radio transparent material Require environmental testing in the thermal vacuum chamber without the shield
Spacecraft maneuver	No mechanical shield No additional weight	No direct radiation into telescope Requires modification of spacecraft control
Internal shield	Attached to inner part of the telescope	No spacecraft change No additional height Sophisticated structural and thermal design

which may not be an easy task. The control algorithm and software of KOMPSAT-2 came from those of KOMPSAT-1 as a heritage. Implementing the maneuver algorithm into the ready-existing software can be hazardous as it can introduce bugs and unexpected malfunctions. Though the concept of additional maneuvering of the spacecraft may be simple, in practice, corrections of algorithm and codes would raise concerns on safety because they can lead to unexpectedly wrong maneuvering of the spacecraft and then lead to damage or even loss of the valuable spacecraft.

3. The last choice is installing an internal sunshield inside the mouth of the telescope, as shown in Figure 3(b). It does not hinder the x-band radio transmission and the whole spacecraft can be tested in the thermal vacuum chamber in KARI as the overall height of the spacecraft is not prolonged. Therefore, nothing is changed in the spacecraft side, that is, no extra interface is required for installing an external shield and no spacecraft maneuvering is needed to avoid direct sunlight. Though it allows some of the solar radiation inside the telescope and the backside of the secondary mirror assembly, the internal sunshield would be able to meet the requirements together with better conductive material of the tube. Internal sunshield seems safe and is a best optimized choice among the three ways, considering many aspects of the spacecraft.

In conclusion, three possible solutions have been suggested and their effects have been assessed in the view of satellite system and MSC. They are summarized in Table 1. Among the three solutions, it was found that internal shield was regarded as an optimal choice.

3. DESIGN OF INTERNAL SUNSHIELD

After the trade-off study, an internal sunshield was selected as an optimal choice. Further study has been followed on the internal sunshield to identify and verify thermal effects as well as structural design matters. Detailed design of an internal sunshield has been performed after the in depth analyses.

3.1 Requirements and Restrictions

A sunshield should be designed to comply with the required image performance. According to the design analysis in optical performances, the stability requirements of the telescope were derived as Table 2 in the case of nadir pointing, which were represented by the deviation of the secondary mirror with regard to the primary mirror (Berger 2002, Lee et al. 2002). Despace is change of the

Table 2. Stability requirements of the telescope.

Item	Despace	Decenter	Tilt
Requirement	2μm maximum	15μm maximum	50μrad maximum

distance between the mirrors, where expansion is represented by positive value and contraction is by negative value. Decenter means shift of the optical axis sideway and is represented by a scalar value. Tilt of the secondary mirror is given in radian with respect to the primary mirror. De-spacing should be less than 2μm within imaging orbit, de-center less than 15μm, and tilt should be 50μrad in maximum.

3.2 Material and Structure

The sunshield is designed to be made of composite materials, with the length of 200mm and thickness of 0.7mm (EL-OP 2001). If solar radiation is to be prevented into the tube completely, length of the sunshield should be longer than 300mm. However, additional weight of the sunshield at the end of the telescope would lower the structural stiffness and increase displacement of the secondary mirror due to gravity. Therefore the length of 200mm is regarded as an optimal choice for the sunshield, as it was found that solar radiation reaches the tube deeper than 200mm during merely 2.3 minutes. Moreover, it occurred just before and after eclipses, which are far from the imaging section of the orbit, it would rarely affect image quality. The thickness was optimized from the thermal conductivity along the circumferential direction and minimum stiffness requirement of the sunshield itself.

There is a possibility that cyclic high temperature on orbit can cause not only thermal stress but also weak bonding in laminate, which can lead to delamination. Thus, telescope structure should be designed accordingly to minimize the temperature rise through heat re-distribution (Lee & Kaufman 2001). In order to mitigate the thermal effect on the telescope, several schemes have been incorporated in the telescope design together with the internal sunshield. First of all, a new composite material, Carbon Fiber Reinforced Polymer (CFRP), is selected for the telescope structure, which has high thermal conductivity as well as high strength and stiffness. The thermal conductivity of graphite fiber is more than 500W/mK, much higher than that of copper, 393W/mK, and other conventional composite materials whose values are no more than 50W/mK (Ozaki et al. 1996). This favorable feature makes uniform temperature distribution over the structure, which benefit less thermal distortions.

Another scheme is insulation between the sunshield and the telescope tube. Heat transfer between the sunshield and the telescope tube is prevented in the aspect of conduction and radiation. Conduction is prohibited by detaching the sunshield from the tube. The diameter of the sunshield is decided to secure the optical aperture and to maximize the gap from the tube. Larger gap increases thermal insulation between them. It can be noticed in Figure 4 that the internal sunshield is separated from the tube. Radiation between the sunshield and the tube is blocked out by selecting low radiation materials on the surfaces in-between. Outer surface of the sunshield facing inside of tube is coated by aluminized tape which has very low emissivity (0.05) so that the heat flow by radiation is prevented from the sunshield to the tube. On the other hand, the inner surface of the sunshield is black painted to give high emissivity (0.90), so that the heat contained in the sunshield can be radiated to the inside direction.

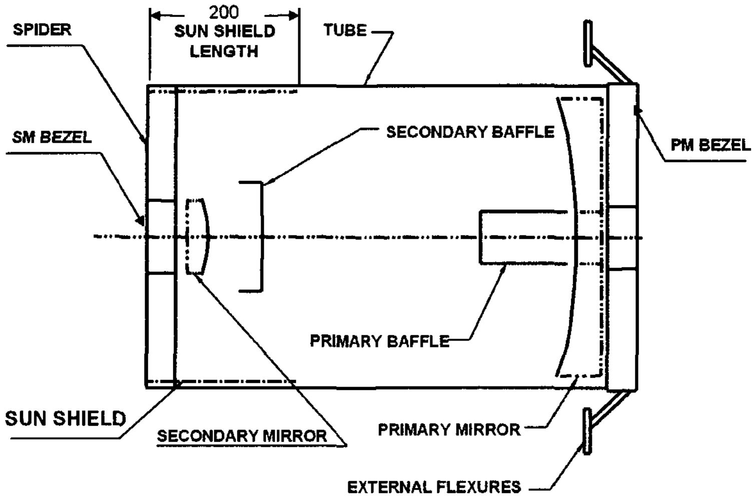


Figure 4. Schematic diagram of the telescope with internal sunshield (Birger 2000).

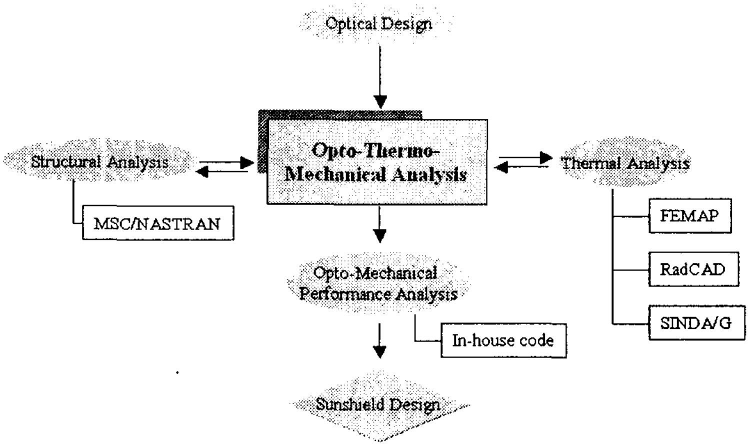


Figure 5. Analysis Flow Diagram for Sunshield Design.

4. THERMAL ANALYSIS AND RESULTS

An opto-thermo-mechanical analysis has been performed to find out the effectiveness of the sunshield on the optical performance. Mechanical displacement analysis follows optical and thermal analysis based on optical influence coefficient table and the temperature distribution to calculate optical wavefront error(WFE). Figure 5 shows the analysis diagram and corresponding software for verifying the sunshield design.

The analysis was conducted for the whole telescope structure and the result was compared to the case when there were no internal sunshield. Three software were incorporated for the ther-

Table 3. Thermal properties of tube and sunshield.

Material	Conductivity K [W/m°C]	Heat Capacity Cp [J/kg°C]	Density ρ [kg/m^3]
Tube	293 (on axis)	800	1.9×10^3
(Orthotropic)	98 (circumferential)		
Sun Shield	80	800	1.9×10^3

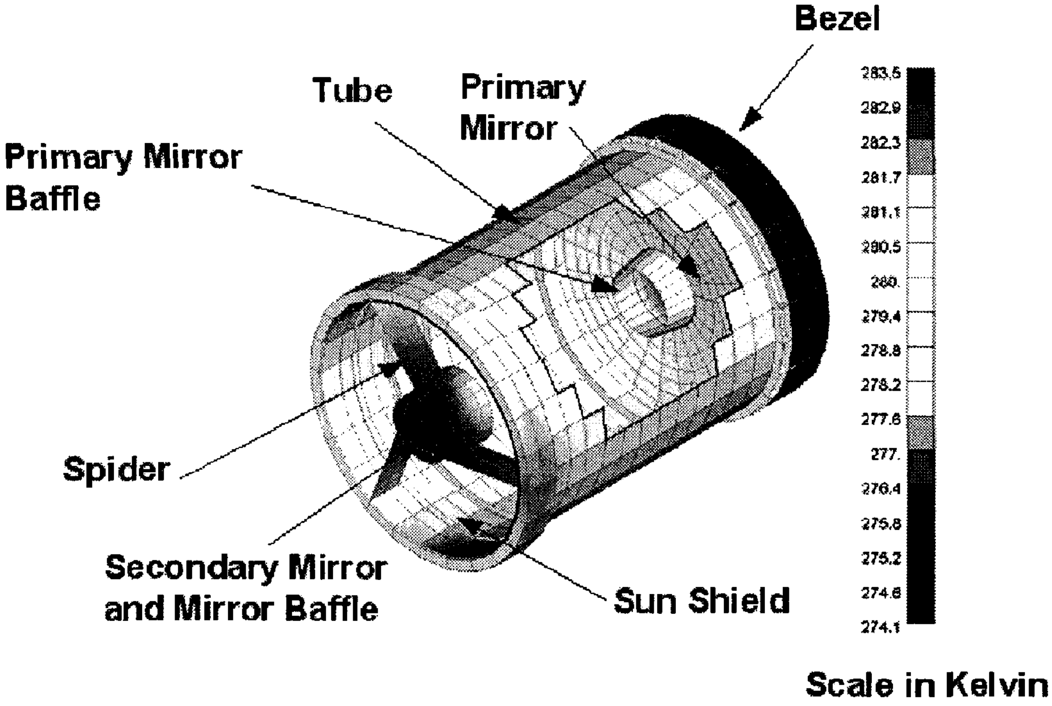


Figure 6. Temperature distribution of the telescope with sunshield at 63° south, as a case study. The bezel is the hottest part and the baffle of the secondary mirror is the coldest part, but the maximum temperature difference is merely 9.4° K.

mal analysis: FEMAP (SDRC 2001) for building the model and calculating the conductive thermal connections, RadCAD (C&R Technologies 2001) for calculating orbital heat load and irradiative thermal conductors, and SINDA/G (Network Analysis Inc. 2002) for calculating temperature field. Table 3 shows thermal properties of the tube and the sunshield. The thermal model includes the baseplate, the tube, the primary and the secondary mirrors, and the mirror baffles together with the sunshield, as shown in Figure 6.

Table 4 shows the maximum and minimum temperatures on the tube and the sunshield over the

Table 4. Extreme temperatures over the orbit.

Case	Item	Maximum	Minimum
With sunshield	Tube	21°C	−1°C
	Sunshield	72°C	−7°C
Without sunshield	Tube	35°C	−2°C

Table 5. Thermal effects on optical performance by displacements.

Case		63° South		67° North	
		Without sunshield	With sunshield	Without sunshield	With sunshield
Tube temperature		5°C	6°C	17°C	15°C
Displacements	Despace	$2.1\mu m$	$1.7\mu m$	$-2.5\mu m$	$-1.5\mu m$
	Decenter	$0.54\mu m$	$0.46\mu m$	$0.40\mu m$	$0.34\mu m$
	Tilt	1.8μ rad	1.7μ rad	1.6μ rad	1.6μ rad
Optical degradation	WFE (rms)	$\lambda/22$	$\lambda/27$	$\lambda/19$	$\lambda/31$

orbit. It clearly shows that the maximum temperature of the tube is dropped down compared to the case when there is no sunshield. The temperature range of the tube, $-1°C \sim 21°C$, also goes well into the required range of the telescope structure which is between $-20°C$ and 50° C (Berger 2002). A temperature distribution of the telescope is shown in Figure 6 as a case when the telescope is located at 63° south. Temperature ranges from 274.1K to 283.5K, which implies relatively uniform distribution, thanks to high conductivity of the composite material.

In order to analyze thermo-elastic deformation between the two mirrors, the temperature distribution results with its thermal geometric model were exported into the structural finite element model, MSC/NASTRAN (MSC Software 2002). Table 5 presents the analysis results at the two points of 63°S and 67°N in latitude, which would be the coldest and the hottest points, respectively, on the probable duty orbit. The results are compared to the case when there is no sunshield. The thermal effects are decomposed into three terms in elastic effects - despace, decenter, and tilt. Optical degradations of despace, decenter, and tilt were $0.0214\lambda/\mu m$, $0.0018\lambda/\mu m$, and $0.00052\lambda/\mu$ rad, respectively, in terms of wavefront error in RMS (root-mean-square) (Nir 2002). According to the analysis results, despacing turns out to be the most sensitive term, and the design with sunshield meets the requirements of the telescope in stability as shown in Table 2. It was revealed that the WFE values become smaller when the sunshield is attached. The combined WFE explicitly shows that sunshield provides less optical degradation. (Lee & Kaufman 2001).

5. CONCLUSION AND DISCUSSIONS

KOMPSAT-2 will go round on a sun-synchronous orbit at the altitude of 685km. The telescope of the KOMPSAT-2 will always look down the Earth, which allows direct sunlight enter into the mouth of the telescope at certain positions on the orbit. The incoming sunlight generates excess heat, which can change the form of the telescope and degrade the image quality. Three possible solutions have been suggested and their effects have been assessed in the view of satellite system and the telescope. Among the three solutions, installing an internal shield is regarded as an optimal choice. It can meet the required thermal and mechanical restrictions and can provide better image performance. It also has advantages that it does not hinder the x-band radio transmission and that the size of the spacecraft is kept the same, which lead to simpler and safer development because there is no interface between the bus and the payload concerning this matter.

Detailed design of the internal sunshield has been produced and analysis has been followed to identify and verify thermal effects to the image quality. The dimension of the sunshield was decided by optimal way, and CFRP (Carbon Fiber Reinforced Polymer) with high conductivity was selected for the tube and the sunshield. To minimize heat transfers, the sunshield is separated from the tube with a gap and each surface is treated to control radiation. It is analyzed and resulted that the internal sunshield provides smaller thermal effects, less structural displacements, and resultantly better image quality.

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