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MEDIUM-SIZED APERTURE CAMERA FOR EARTH OBSERVATION

Eugene D. Kim(1), Young-Wan Choi(1), Myung-Seok Kang(1), Ee-Eul Kim(1), Ho-Soon Yang(2), Ad. Aziz Ad. Rasheed(3), Ahmad Sabirin Arshad(3)

(1) Satrec Initiative, 461-26 Jeonmin-dong, Yuseong-gu, Daejeon 305-811, Korea,E-mail: edk@satreci.com

(2) Korea Research Institute of Standards & Science, 1 Doryong-dong, Yuseong-gu, Daejeon 305-340, Korea

(3) Astronautic Technology (M) Sdn. Bhd. (ATSB), Suite G-1A, Enterprise 3, Tech. Park Malaysia, Lebuhraya Puchong-Sg. Besi, Bukit Jalil, 57000 Kuala Lumpur, Malaysia

ABSTRACT

Satrec Initiative and ATSB have been developing a medium-sized aperture camera (MAC) for an earth observation payload on a small satellite. Developed as a push-broom type high-resolution camera, the camera has one panchromatic and four multispectral channels. The panchromatic channel has 2.5m, and multispectral channels have 5m of ground sampling distances at a nominal altitude of 685km. The 300mm-aperture Cassegrain telescope contains two aspheric mirrors and two spherical correction lenses. With a philosophy of building a simple and cost-effective camera, the mirrors incorporate no light-weighting, and the linear CCDs are mounted on a single PCB with no beam splitters. MAC is the main payload of RazakSAT to be launched in 2005. RazakSAT is a 180kg satellite including MAC, designed to provide high-resolution imagery of 20km swath width on a near equatorial orbit (NEqO). The mission objective is to demonstrate the capability of a high-resolution remote sensing satellite system on a near equatorial orbit. This paper describes the overview of the MAC and RarakSAT programmes, and presents the current development status of MAC focusing on key optical aspects of Qualification Model.

1. INTRODUCTION

As an international collaborative programme, Satrec Initiative (SI) and Astronautics Technology Sdn. Bhd. (ATSB) have been co-developing a Medium-sized Aperture Camera (MAC) since 2000.[1] Four models were designed to be built along the development course, and three (Test Model, Engineering Model, and Qualification Model) have been made and tested as of January, 2004. Flight Model is to be made in 2004 and is planned to be launched in 2005. MAC is the main payload of RazakSAT, formerly known as MACSAT [2], also being co-developed by SI and ATSB. The key features of RazakSAT are shown in Table 1.

Table 1 RazakSAT specifications

Items	Features	Remarks
Orbit	600-800 km NEqO	685 km Nominal
Inclination	7.5-9°	
Mass	<= 200 kg	Including MAC
Envelope	∅1200 mm x 1200 mm	Hexagonal type
Att. Ctrl. Accuracy	0.2°	
Power Generation	> 330 W	@ EOL
Storage Capacity	32 Gbits	
Data Down Link	30 Mbps (X-band)	QPSK
Mission Lifetime	3 years	

Initiated by ATSB, the proprietary NEqO mission has advantages for monitoring the environment of equatorial regions of Malaysia with unique revisit characteristics from the baseline circular orbit of 7 degrees of inclination. For the designed duration of 3-year mission life, RazakSAT is optimised to accommodate a medium-sized aperture camera (MAC), a push-broom type camera with swath width of 20km. The spacecraft has +/-30 degrees of tilting and 30 Mbps class X-band downlink capability.

RazakSAT is a small satellite with a hexagonal frame structure. Using the heritages of successful KITSAT-3 and STSAT-1 platforms developed by Satellite Technology Research Center/KAIST, the 180kg satellite is three-axis stabilized with 0.2 degree of attitude control accuracy.

2. MAC SYSTEM OVERVIEW

MAC uses a modified Ritchey-Chrétien telescope, which has 300 mm of entrance pupil diameter (Fig. 1). The telescope uses two aspheric mirrors of Zerodur-class ultra-low expansion glass and two correction lenses. The mirrors have no light-weighting architecture in order to reduce the cost and as the telescope is within the mass budget. The mirrors are spaced by truss-type metering structure, and mounted with flexures made of Super Invar in order to secure the optics design in launching & space environments. Invar, Aluminium, and Titanium have been also used for other opto-mechanical parts.

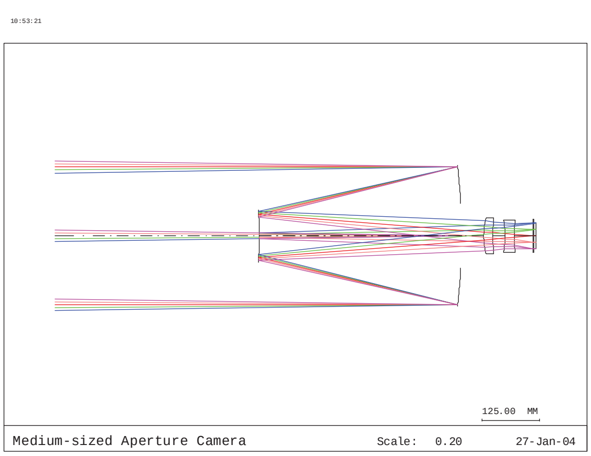


Fig. 1 MAC telescope optics layout

It also employs a simple philosophy of Focal Plane Assembly using five linear CCDs on a single PCB without any beam splitters. (Fig. 2) The five channel includes one panchromatic band with 2.5 m, and multispectral band with 5 m of Ground Sampling Distance (GSD) at a nominal altitude of 685km.

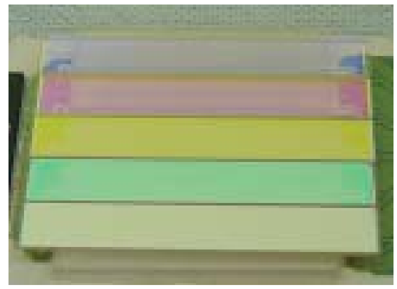


Fig. 2 Five linear CCD channels

The electronics subsystem includes a signal processing unit and a payload management system for power supply, 16-Gbit mass storage, and thermal unit for cold case. MAC weighs approximately 40 kg and consumes 55 W at peak with the heaters on. The main specifications on MAC are summarized in Table 2.

Table 2 MAC specifications

Items	Specifications	Remarks
Spectral Bands	PAN:510-730nm 4 MS:450-890nm	
GSD	PAN:2.5 m MS: 5.0 m	@685 km
Swath width	20 Km	@685 km
MTF	PAN: > 8% MS: > 15%	
Power consumption	<160 W	Peak value
Mass	<40 Kg	

3. DEVELOPMENT OF QUALIFICATION MODEL (QM)

3.1. Modifications from Engineering Model (EM)

After the mirror material was changed from Aluminum, no major change in the optics has been made since EM. A significant change has been made in the alignment procedure from QM telescope. A computer-aided alignment method was adopted to align the secondary mirror, and the mirror was aligned so that the wavefront errors (WFE) at four different off-axis fields of view (FOV) as well as at the on-axis FOV were well balanced. As for the opto-mechanical part, the fastening part of the metering structure has been reinforced after a random vibration test.

3.2. QM telescope assembly & testing

The primary and secondary mirrors of QM telescope were respectively null-tested by an interferometer before assembly. The primary mirror showed deformation in figure error in terms of astigmatism, which was caused by the flexure-mounting, and the telescope system MTF was expected to be lowered. The telescope was assembled starting from the primary mirror part and the secondary part was roughly aligned to acquire the fringes in a double-pass setup. With a proprietary mount for the interferometer, the wavefront errors of the telescope in different fields were measured. Fig. 3 shows the MAC QM in the WFE measurement setup.

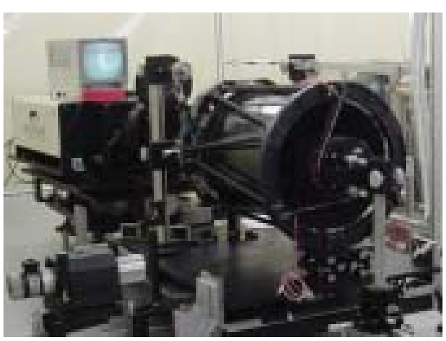
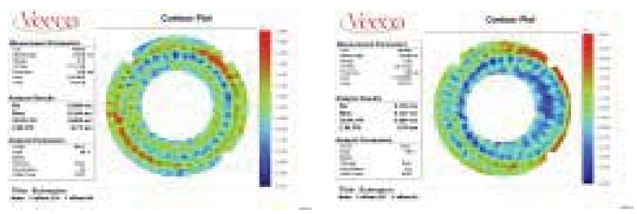


Fig. 3 WFE measurement setup of MAC QM

A computer-aided alignment method was used to precisely align the secondary mirror. Interferograms were taken at five different fields and they were compared with the wavefront of the original design to reversely calculate the five alignment movements of the secondary mirror. With the computer-aided alignment method, the secondary mirror was aligned so that the difference between the on and off-axis was 0.02 wave with a He-Ne source.

Fig. 4 shows the WFE of the aligned telescope at different fields.



(a) On-axis (0.0, 0.0) (b) Off-axis (1.0, 0.0)

Fig. 4 WFE of MAC QM at different fields

The telescope optics MTF was measured by converting the WFE to MTF, and the telescope system MTF including the CCD and electronics was measured with a knife-edge setup. Fig. 5 shows the design MTF of PAN channel (approximately 28% at 71 lps/mm).

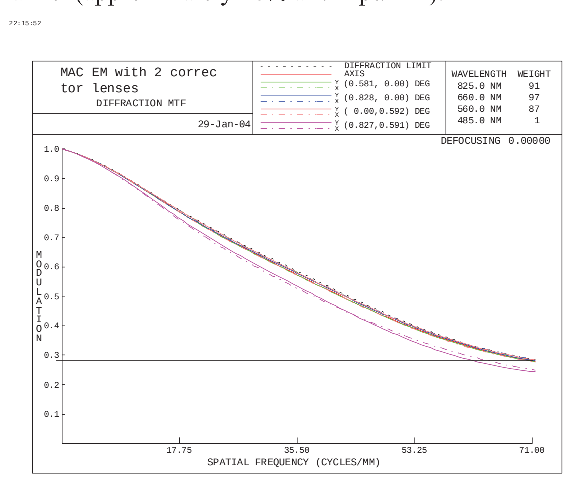


Fig. 5 MAC QM telescope design MTF

As expected from the deformation of the primary mirror, the measured telescope optics MTF for the panchromatic channel was 19% at the Nyquist frequency as shown in Fig. 6.

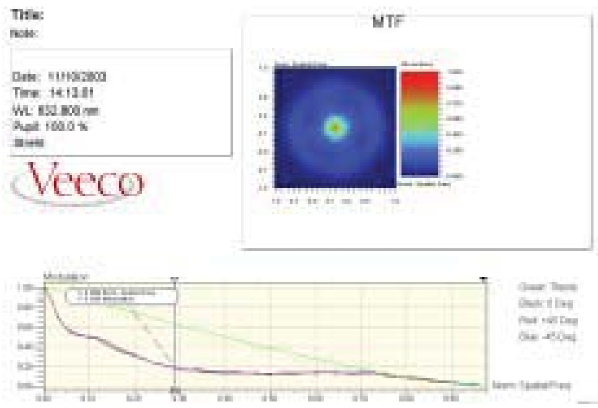


Fig. 6 MAC QM telescope optics MTF

A knife-edge was scanned at the focus of a collimator to measure the telescope system MTF. The edge spread function (ESF) on a single pixel was converted to MTF. The measurement showed 7% of system MTF at panchromatic channel, and 16% for a multispectral channel.

MAC QM was integrated with RazakSAT QM, and a series of launching and space environment tests were performed. No degradation of MAC QM performance was observed from the thermal vacuum test. However, after the random vibration test, it was observed by theodolite measurements that the secondary mirror supporting ring was tilted. The ring links the secondary mirror spiders and the metering structure, and the movement of the ring can be critical as it causes misalignments of the secondary mirror from the design. Hence the metering structure's mechanical interfaces were reinforced with higher strength bolts and adhesives. With the reinforced interfaces, no further degradation of MAC QM's optical performance was observed after further acoustic tests.

4. CONCLUSION

MAC and RazakSAT programmes were introduced and the development status of recently finished QM of MAC was described focusing on the optical performances. A computer-aided alignment scheme was used in the telescope alignment, and it was witnessed that the telescope is well aligned at on and off-axis. The measured telescope optics MTF showed less than expected values, mainly due to a deformation of the primary mirror, leaving an opportunity for improvement on the system MTF. Under the current plan, MAC FM assembly and tests will be completed by the latter half of 2004. Future work includes the modifications to the primary mirror flexure design and change of CCD channel arrangements so the panchromatic channel is at the on-axis position.

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