International Conference on Space Optics—ICSO 2012

Ajaccio, Corse

9–12 October 2012

Edited by Bruno Cugny, Errico Armandillo, and Nikos Karafolas

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International Conference on Space Optics — ICSO 2012, edited by Bruno Cugny, Errico Armandillo, Nikos Karafolas
Proc. of SPIE Vol. 10564, 105643O · © 2012 ESA and CNES · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2309033

Focus adjustment method for CBERS 3&4 Satellites MUX camera to be performed in air condition and its experimental verification for best performance in orbital vacuum condition

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***Abstract*— The first Brazilian remote sensing multispectral camera (MUX) is currently under development at Opto Eletrônica S.A. It consists of a four-spectral-band sensor covering a 450nm to 890nm wavelength range. This camera will provide images within a 20m ground resolution at nadir. The MUX camera is part of the payload of the upcoming Sino-Brazilian satellites CBERS 3&4 (China-Brazil Earth Resource Satellite). The preliminary alignment between the optical system and the CCD sensor, which is located at the focal plane assembly, was obtained in air condition, clean room environment. A collimator was used for the performance evaluation of the camera. The preliminary performance evaluation of the optical channel was registered by compensating the collimator focus position due to changes in the test environment, as an air-to-vacuum environment transition leads to a defocus process in this camera. Therefore, it is necessary to confirm that the alignment of the camera must always be attained ensuring that its best performance is reached for an orbital vacuum condition. For this reason and as a further step on the development process, the MUX camera Qualification Model was tested and evaluated inside a thermo-vacuum chamber and submitted to an as-orbit vacuum environment. In this study, the influence of temperature fields was neglected. This paper reports on the performance evaluation and discusses the results for this camera when operating within those mentioned test conditions. The overall optical tests and results show that the "in air" adjustment method was suitable to be performed, as a critical activity, to guarantee the equipment according to its design requirements.**

***Index Terms* — Optical design, thermo-vacuum, optical performance, satellite, CBERS.**

I. INTRODUCTION

Since 1988 Brazil and China have maintained a partnership program called CBERS (China-Brazil Earth Resources Satellites), whose main goal is the development of satellites applied to remote sensing of the Earth. Nowadays, the three launched satellites of this program, CBERS 1, 2 and 2B, are no longer operational.

Brazil is in charge of the development of two of the four cameras that will compose the payload of the upcoming two models, CBERS 3 and 4. These two cameras are called Wide Field Imager (WFI)[1] and Multispectral Camera (MUX)[2]. The latter is being totally developed by Opto Eletrônica[3] and the WFI camera is being partially developed by this company under INPE (National Institute for Space Research) supervision.

The effective focal length (EFL) of the camera is 505.8mm, it has 20m of ground resolution and will image a ground swath of 120Km. The MUX camera will provide images in four spectral bands in wavelengths ranging from blue to near IR (B05: 450nm to 520nm, B06: 520nm to 590nm, B07: 630nm to 690nm, B08: 770nm to 890nm).

The alignment, integration and preliminary tests of the MUX camera are performed under atmospheric conditions although the optical system was projected for vacuum operation. The back focal length of the optical system is different in vacuum or air environment due to the difference in the refractive index of these two media.

This paper compares the preliminary performance evaluations of the MUX camera in vacuum and air environments to verify the optical alignment and integration procedures performed in air condition.

II. MUX CAMERA

The MUX camera is composed of the RBNA, RBNB e RBNC equipment.

RBNA is the equipment designed for the image acquisition. It consists of an optical system, an optical housing and the focal plane assembly (Fig. 1 (a)). RBNB is an electronical module in charge of the thermal control, the internal calibration system and the focus adjustment (Fig. 1 (b)).

RBNC, shown in Fig. 1 (c), consists of the CCD reading clocks electronics, analog data digitalization and data output conditioning throw a serial data stream, which is then transmitted to the satellite digital data recorder (DDR).

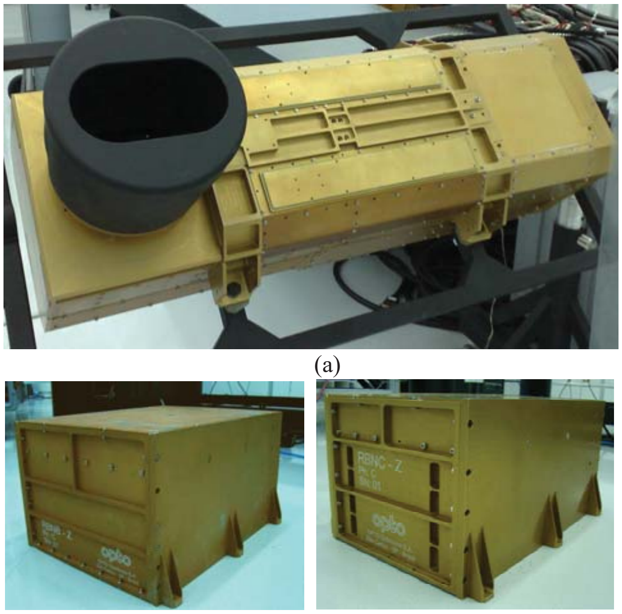

Fig. 1. a) RBNA equipment; b) RBNB equipment; c) RBNC equipment (Courtesy Opto Eletrônica S.A.).

III. Optical Design

The optical system of the camera is composed of an entrance flat mirror, a window that works as a shield for space radiation and as a substrate for a dichroic filter, and a set of twelve lenses. The lens of number twelve of the optical system, the last one before the focal plane, can be displaced for focus adjustment.

The camera CCD sensor has four lines, each one with 1 x 6000 pixels of 13x13μm size. The spectral bands separation is performed by thin films deposited over a window that covers the photosensitive elements of the CCD.

The designed optical system can be considered athermal in the 15ºC to 20ºC temperature range. The theoretical Modulation Transfer Function (MTF) curves of the optical system for the four spectral bands at 17.5ºC are shown in Fig. 2. It shows that the optical system MTF is greater than 0.7 at 38.5lp/mm.

IV. Methodology

A. Theoretical air / vacuum compensation model

A computational model of the MUX optical system connected to a collimator, similar to the real one that is part of the Ground Support Equipment (MUX-GSE), was created using ZEMAX® optical design software. The collimator is based on an off-axis Newtonian telescope architecture with an effective focal length of 2987mm.

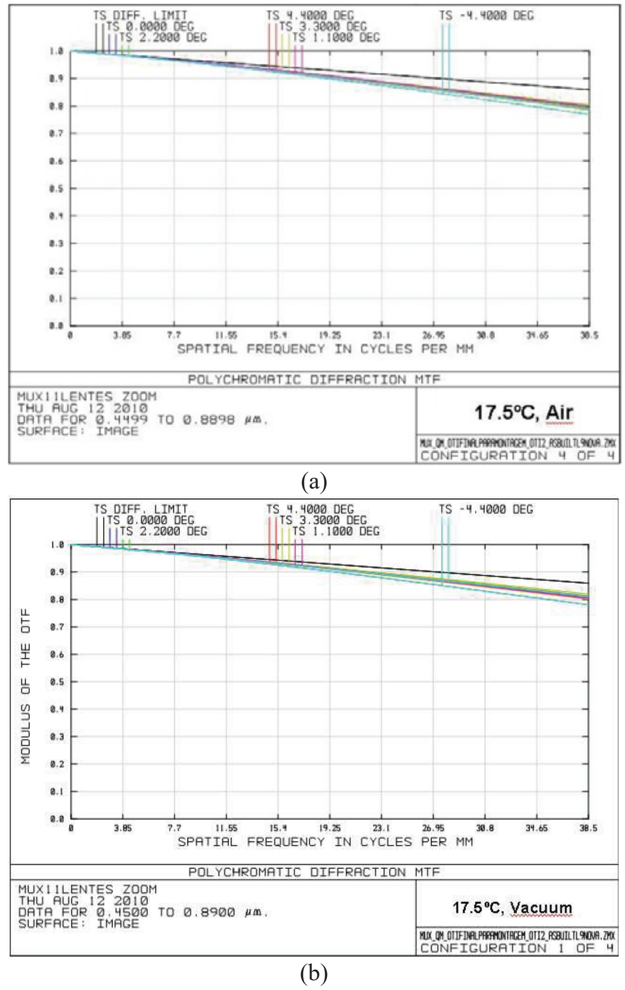

Fig. 2. Modulation Transfer Function (MTF) in the four spectral bands, at 17.5ºC for a) air condition and b) vacuum condition.

The theoretical optical system of the MUX camera was designed to operate in vacuum condition. When the same optical design is evaluated in air condition, the focal plane of the camera must be displaced in order to compensate the difference in the refractive index of the two different environments, recovering the optical performance. However, when the camera is coupled with the off-axis collimator, the back focal length compensation can be performed by changing the collimator's target position without changing the camera focal plane position. This analysis was carried out considering only the ZEMAX® default merit function, of RMS type, with spot radius optimization data. Fig. 3 depicts the model used for the theoretical estimate of the collimator's target positions when the camera is in vacuum and air conditions.

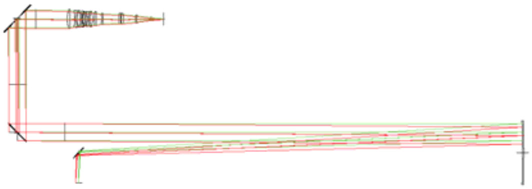

Fig. 3. Theoretical model for the air-vacuum compensation estimate.

Fig. 4. Experimental setup for the integration and performance evaluation in air environment.

B. Preliminary integration and alignment setup in air environment

The alignment between the optical system and the focal plane assembly was performed in air environment using the MUX-GSE collimator. The alignment in the vacuum condition would be extremely more time-consuming and technically more complex. Fig. 4 shows the experimental setup for the preliminary integration and alignment of the MUX camera.

Similarly to what was shown in the theoretical analysis, the experimental setup for the evaluation of the camera performance in air environment was accomplished by displacing the collimator's target position. The total target displacement was calculated through simulations that took into account the environmental conditions at the time the tests were conducted.

C. Experimental setup for in vacuum performance evaluation

Fig. 5 shows the thermo-vacuum chamber designed and integrated by Opto Eletrônica S.A. It has an internal volume of 1.5m^3 and the lowest operational pressure is 4E-5mbar (3.95E-8atm).

This chamber is equipped with a lateral optical window which allows the performance evaluation of the MUX camera inside the thermo-vacuum chamber and submitted to an as-orbit vacuum environment. An auxiliary mirror (Mirror 2 in Fig. 6) was used to aim the collimator's light beam in order to reach the baffle aperture of the MUX camera.

The collimator remains at atmospheric conditions. In this situation, the collimator's target was adjusted for the condition under which the exit beam was collimated.

The RBNA equipment temperature was controlled during the tests using an active thermal control and monitored using thermistors and thermocouples distributed throughout the equipment. The images were acquired by the MUX-GSE Image Display System (IDS) equipment.

Fig. 5. Thermo-vacuum chamber.

Fig. 6 shows the previously described experimental setup for the “in vacuum” performance evaluation of the MUX camera.

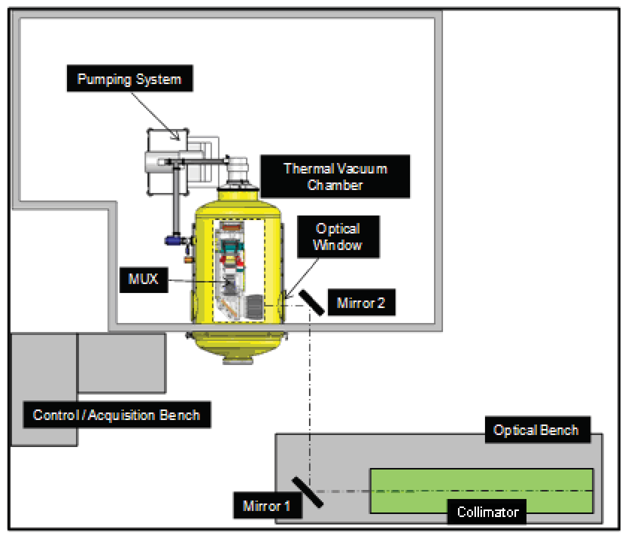

Fig. 6. Experimental setup for the thermo-optical tests.

V. Results and Discussions

Table I shows the value estimated for the collimator's target displacement and the experimental results of the tests performed in vacuum and air conditions.

Fig. 7 shows the Through Focus curves @ 38.5lp/mm for the two tested situations: air and vacuum environments. It is possible to observe that the experimental results are slightly different (6.5µm) from the theoretical ones.

The optimization of the MUX camera for work in vacuum environment and in a narrow temperature range yields difficulties in the preliminary integration of the optical system and its focal plane assembly, as this integration is performed in air condition.

TABLE I. THEORETICAL AND EXPERIMENTAL AIR/VACUUM COMPENSATION RESULTS.

	AIR CONDITION Hall Pressure: 0.9014atm		VACUUM CONDITION Chamber Pressure: 3.95E-8atm	
	TEMPERATURE (°C)			
	MIN	MAX	MIN	MAX
OA	20.2	20.6	21.8	22.2
FP	20.5	21.9	22.1	23.7
EM	19.8	20.0	21.1	21.2
ST	20.0	21.8	21.1	21.6
THEORETICAL TARGET DISPLACEMENT (μm)	-471.5			
	EXPERIMENTAL BEST FOCUS POSITION (μm)			
B05	-457.0		-946.0	
B06	-466.0		-930.0	
B07	-455.0		-914.0	
B08	-473.0		-921.0	
MEAN VALUE	-462.8		-927.8	
EXPERIMENTAL TARGET DISPLACEMENT (μm)	-465.0			

Displacement and focus position values are related with the collimator's target positioner;
OA: Optical Assembly;
FP: Focal Plane;
EM: Entrance Mirror;
ST: Structure;
Spectral bands: B05: 450nm - 520nm; B06: 520nm - 590nm; B07: 630nm - 690nm; B08: 770nm - 890nm.

The theoretical model allows an estimate of the value that the collimator's target must be displaced to compensate the environmental condition. However, the temperature of distinct portions of the RBNA equipment was not maintained exactly the same in the vacuum and air environments. This temperature differences can cause the optical system focus position to vary, exerting an influence in the final results.

Based on specific data of the environmental conditions, the estimated value for the collimator`s target displacement could be assessed (Table I).

The temperature differences among the distinct portions of the equipment during the tests were considered in the theoretical model. Also, this model considered the 1.25ºC of mean temperature difference between the tests carried out in vacuum and air conditions.

Nevertheless, the theoretical model adopted in these analyses did not consider the thermoelastic effects due to temperature changes. The thermomechanical analyses showed that these effects can contribute to the optical system focus displacement.

Several thermo-optical tests were performed for different temperature combinations of the separated portions of the RBNA equipment and the thermal behavior of the equipment could be evaluated; however these results will not be discussed in this paper.

VI. CONCLUSIONS

Even with the small difference between the theoretical and the experimental results, the "in vacuum" focus position evaluation confirmed that the "in air" integration and alignment procedure was efficient for the focus adjustment of the MUX camera.

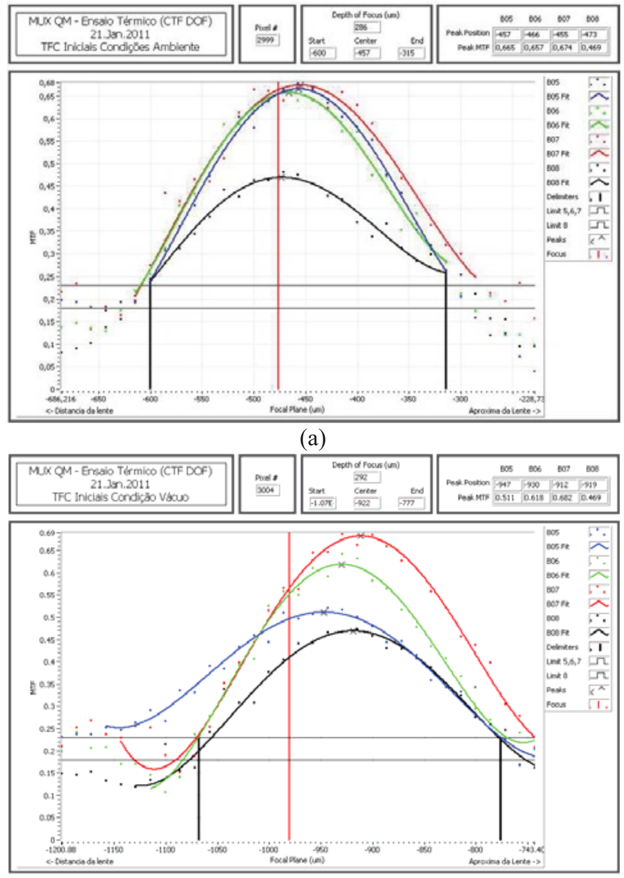

Fig. 7. Experimental Through Focus curves @ 38.5lp/mm: a) air condition and b) in vacuum environmental condition.

Furthermore, it is important to consider that this camera has 90µm of depth of focus, and the 6.5µm of deviation observed in the experimental results represents less than 8% of the total depth of focus of the camera. Therefore, this deviation can be considered reasonable.

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