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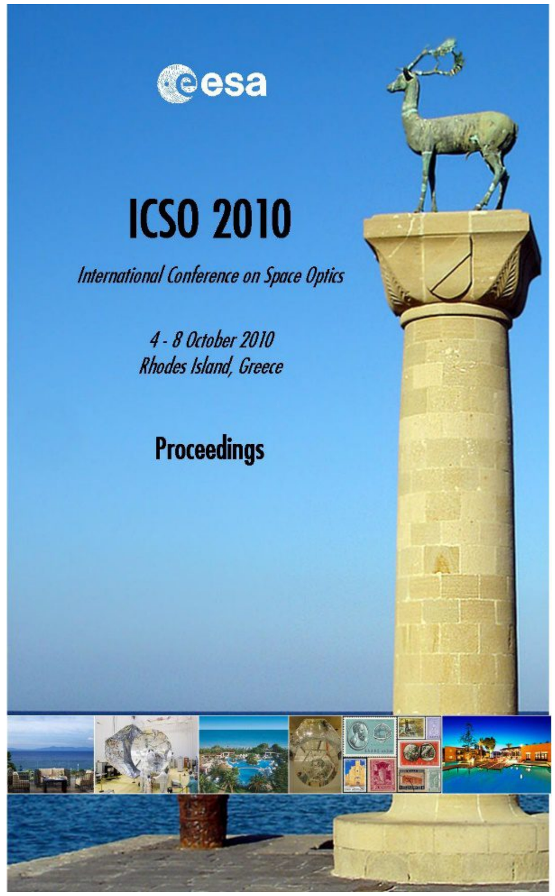

The Brazilian wide field imaging camera (WFI) for the China/Brazil earth resources satellite: CBERS 3 and 4

L. C. N. Scaduto, E. G. Carvalho, R. G. Modugno, R. Cartolano, et al.

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THE BRAZILIAN WIDE FIELD IMAGING CAMERA (WFI) FOR THE CHINA - BRAZIL EARTH RESOURCES SATELLITE – CBERS 3 & 4

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The purpose of this paper is to present the optical system developed for the Wide Field imaging Camera - WFI that will be integrated to the CBERS 3 and 4 satellites (China Brazil Earth resources Satellite). This camera will be used for remote sensing of the Earth and it is aimed to work at an altitude of 778 km. The optical system is designed for four spectral bands covering the range of wavelengths from blue to near infrared and its field of view is ±28.63º, which covers 866 km, with a ground resolution of 64 m at nadir. WFI has been developed through a consortium formed by Opto Electrônica S. A. and Equatorial Sistemas. In particular, we will present the optical analysis based on the Modulation Transfer Function (MTF) obtained during the Engineering Model phase (EM) and the optical tests performed to evaluate the requirements. Measurements of the optical system MTF have been performed using an interferometer at the wavelength of 632.8nm and global MTF tests (including the CCD and signal processing electronic) have been performed by using a collimator with a slit target. The obtained results showed that the performance of the optical system meets the requirements of project.

INTRODUCTION

The CBERS Program is the result of a cooperation agreement signed in 1988 between Brazil and China involving INPE (National Institute for Space Research) and CAST (Chinese Agency of Space Technology), with the purpose of development of remote sensing satellites. One of the reasons for this partnership was the necessity of constant monitoring of the vast territory of both countries with a remarkable agricultural potential and lots of natural resources. The CBERS has a sun-synchronous orbit with an altitude of 778 km and performs about 14 revolutions per day [1, 2].
Three satellites of this program (CBERS 1, 2 and 2B) were already launched and satisfactory results were obtained.
The WFI camera under development is part of the payload of the next two satellites – CBERS 3 & 4. Besides this camera, Brazil is responsible for the MUX camera (Multispectral Camera) which is also being developed by Opto Eletrônica S.A. company. The two other imaging cameras of these satellites are under Chinese responsibility.
The WFI camera is composed by the OEB (Opto-Electronic Block) and the SPE (Signal Processing Electronics). Fig. 1 shows these equipments in an auxiliary device that simulates its position when integrated in the satellite structure. The OEB is composed by two identical optical channels both called OMB (Opto-Mechanical Block) and a mechanical frame (Fig. 2).
Each optical channel is composed of the collecting lens, optical housing and the focal plane assembly, where are located the CCD detector with spectral filters, the Proximity Electronics and the Calibration Unit. The composition of the images of the two OMBs covers the total field of view of the camera.
A consortium formed by two Brazilians companies: Opto Eletrônica S.A. and Equatorial Sistemas is in charge of the development of this camera. The former is responsible for development, manufacturing and assembly of the optical system, focal plane device, proximity electronic and an internal calibration system that compose the two OMBs. The latter is responsible for the development of the Ground Support Equipment (GSE), the Electronic Control Unit, SPE, and the OEB mechanical structure and integration.
The CBERS 3 &4 WFI Camera is different from the previous one. This camera is designed for four spectral bands covering the wavelength range from blue to near infrared (from 450nm to 890nm) and covers a ground swath of 866 km, with a ground resolution of 64 m at nadir. The separation of the spectral bands is performed by four spectral filters, one for each line of the CCD sensor. The sensor contains 6000 pixels of 13x13 µm per line.
The goal of this work is to present on ground test results obtained for the Modulation Transfer Function (MTF) evaluated on the WFI Engineering Model.

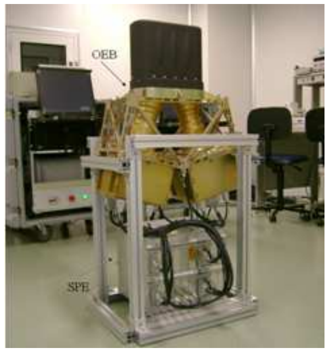

Fig. 1.WFI Camera with OEB and SPE equipments (Courtesy Equatorial Sistemas S.A.).

Fig. 2. Opto Mechanical Block (Courtesy Opto Eletrônica S.A.).

WFI OPTICAL REQUIREMENTS

Some of the requirements for the optical system design of the WFI camera are shown in Table 1 [3].

Table 1. Optical System Requirements [3].

Characteristics	**Requirements**
Effective Focal Length – EFL	149.85 mm
Relative aperture	5.9
Field of view – FOV	±28.63º
Spectral bands	B13: 450 – 520nm; B14: 520 – 590nm; B15: 630 – 690nm; B16: 770 – 890nm;
Optical System MTF	> 0.65 at 38.5lp/mm (all bands)
Global MTF	> 0.23 at 38.5lp/mm for B13, B14 and B15 bands, and > 0.18 at 38.5lp/mm for B16 band.
Distortion	< 3.0%
Polarization Sensitivity	< 7.0 %
Field Illumination	Constant within ± 3.0%
Band-to-band registration	< 5.2 μm
Mean Temperature of Operation	17.5ºC
Temperature Range	15ºC – 20ºC

OPTICAL SYSTEM CHARACTERISTICS

The optical system development and the performance analyses (including optical system MTF, distortion, polarization sensitivity and stray-light) was executed using ZEMAX® software.
Fig. 3 shows the refractive optical system of each optical channel with 10 elements. The first element is a window aimed to work as a shield for thermal and radiation protection of the optical channel.

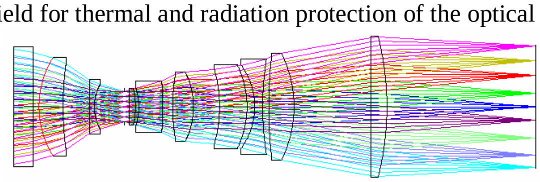

Fig. 3. Collecting lens system.

The MTF curves for the four spectral bands at the mean temperature of operation (17.5 ºC) are shown in Fig. 4. Fig. 5 shows MTF versus spatial frequency and MTF versus focus position for the spatial frequency of 38.5lp/mm and for the wavelength range from 450nm to 890nm in the overall temperature range (15ºC to 20ºC). It is showed that the MTF for the four spectral bands is > 0.65 at 38.5lp/mm, the optical design is almost athermal in this temperature range and the depth of focus is about 100µm.

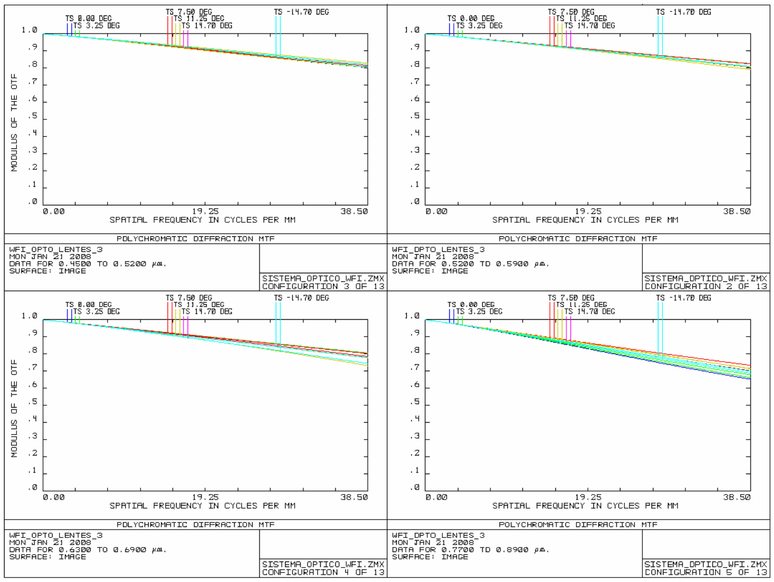

Fig. 4. Theoretical optical systems MTF versus spatial frequency for each spectral band at 17.5ºC, vacuum.

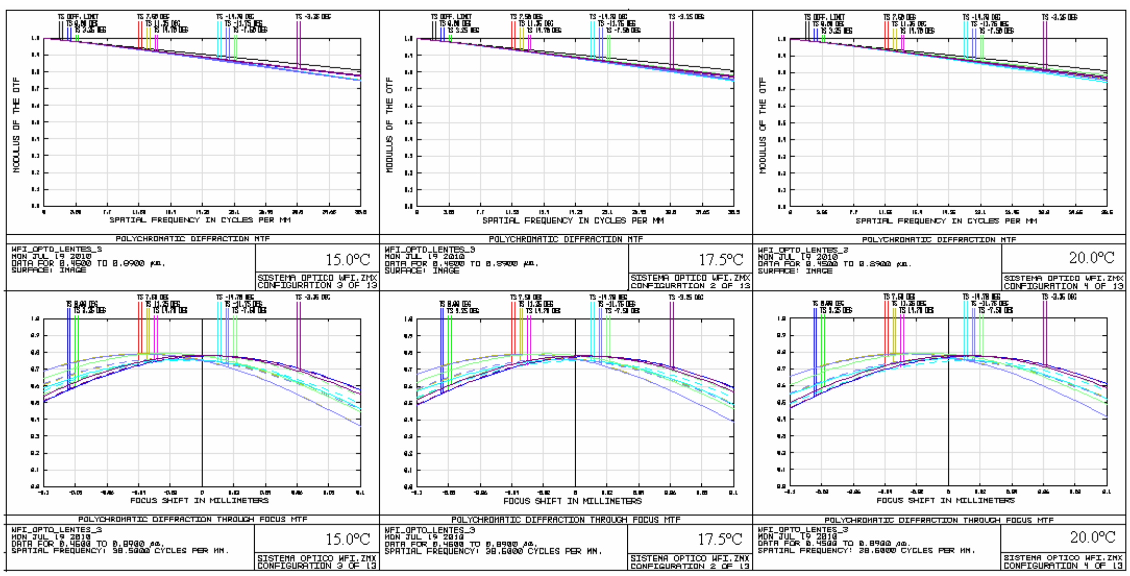

Fig. 5. Optical systems MTF versus spatial frequency and MTF versus focus shift at 15.0ºC, 17.5ºC and 20.0ºC, vacuum.

EXPERIMENTAL SETUP

The two experimental setups used to obtain the MTF of the system are described below. The MTF is of high importance on the evaluation of the spatial frequencies transferred from object to the image of an imaging optical system.

Imaging systems generally have some sort of detector, electronics, signal processing, etc. Analogous to the optical elements, the detector and the signal processing electronic are characterized by a MTF. The total MTF of the system is given by the multiplication of the MTF of all individual subsystems contained in it [4].

A. Interferometer Measurements

The Optical System MTF was estimated by using a ZYGO GPI/XP interferometer that works at the 632.8nm wavelength. The measurement of the optical MTF was performed only in this wavelength and it was used as a preliminary analysis that was carried out during the alignment phase. The experimental setup was the double-pass configuration, where the WFI optical system was placed between the interferometer and a reference flat.
The wavefront emitted by the interferometer crosses the optical system, reflects on the reference flat and returns through the optical system back to the interferometer, where it interferes with the reference beam to obtain the interferometric pattern. From this pattern the software can calculate the system MTF for the reference wavelength. The peak-to-valley wavefront error (P-V) and rms value can be analyzed for the evaluation of the system. Fig. 6, (a) exhibits the experimental setup.

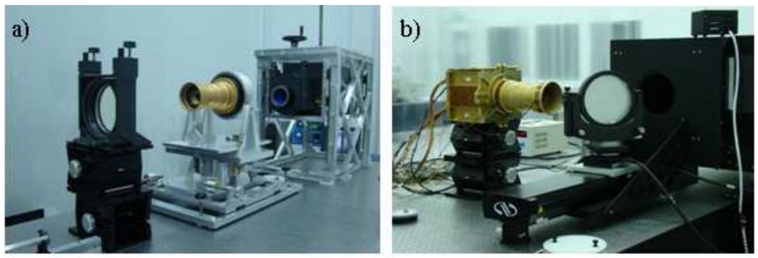

Fig. 6. Experimental setup: a) optical system MTF measurement using interferometer; b) global MTF measurement using collimator (Courtesy Opto Eletrônica S.A.).

B. Collimator Measurements

The system MTF was obtained by using an off-axis collimator (EFL = 2897 mm) and a slit target with 38µm in width (Fig. 6, b). This target is positioned in the focal plane of the collimator and then is moved in steps of 20µm, which allows for determining the Line Spread Function (LSF) of the target image around a specific pixel in discrete steps of 1 µm. MTF is calculated by the module of the Fourier Transform (FT) of the LSF [4].
The measurement was obtained at room temperature fixed at 17.5 ºC and 0.905 atm. The influence of the environment pressure was compensated by the adjustment of the collimator target position. Tests with the OMB inside a thermal-vacuum-chamber were performed and the results confirmed the efficiency of this compensation.
The same procedure was repeated over some pixels along the CCD line in order to obtain the MTF related to the field. The MTF obtained from this procedure is equivalent to a combination of the MTF of target (MTF_{target}), optical system (MTF_{lens}), collimator ($MTF_{collimator}$), CCD (MTF_{CCD}), amplification and signal processing electronic ($MTF_{electronics}$) (1).

$$MTF = MTF_{target} \times MTF_{collimator} \times MTF_{lens} \times MTF_{electronics} \times MTF_{CCD} \quad (1)$$

The Global MTF is obtained by the previous one if the target and the collimator MTF are compensated (2).

$$MTF_{System} = MTF_{lens} \times MTF_{electronics} \times MTF_{CCD} \quad (2)$$

RESULTS AND DISCUSSIONS

The interferograms and MTF obtained by Zygo interferometer, in the central and extreme field positions, are illustrated in Fig. 7 for the optical channel OMB-6 and in Fig. 8 for the optical channel OMB-7.
Results indicated that the optical systems performance, in all of the fields, comply with the requirement for this wavelength and presented a MTF value up to 0.65 at 38.5lp/mm. These results just indicated that the alignment was satisfactory and are very useful for successive comparisons during the steps of the alignment process. However, it is necessary a complete performance evaluation in all spectral bands, to be sure that the system is well aligned and presents a satisfactory performance.

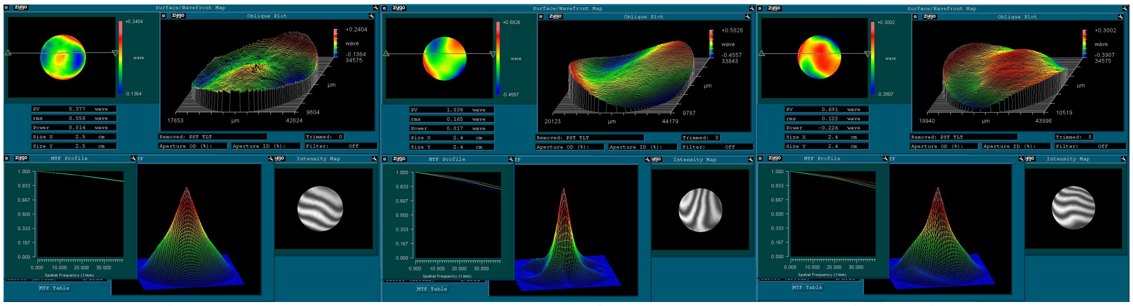

Fig. 7. Interferograms and optical system MTF curves for the OMB-6 at central field, left and right extreme fields.

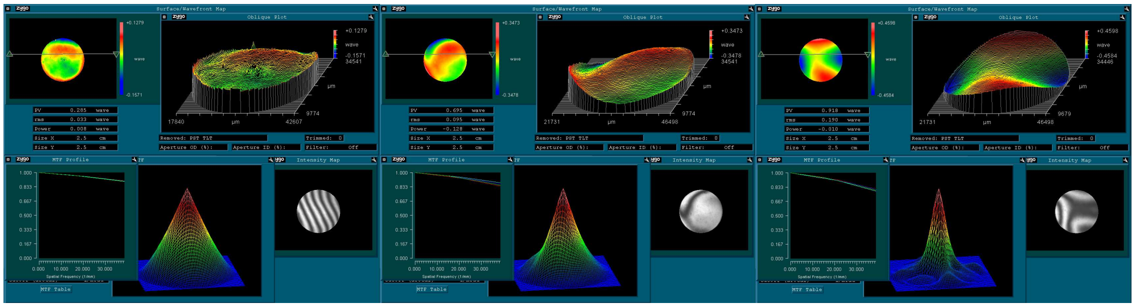

Fig. 8. Interferograms and optical system MTF curves for the OMB-7 at central field, left and right extreme fields.

The Table 2 exhibits the results obtained for the global MTF, in which the spatial frequency is 38.5 lp/mm for the OMB-6 and OMB-7 optical channels. The measured MTF versus frequency curves can be seen in Fig. 9.
The results obtained for both tested OMBs of the Engineering Model by using the collimator were satisfactory compared to the required values for all spectral bands.

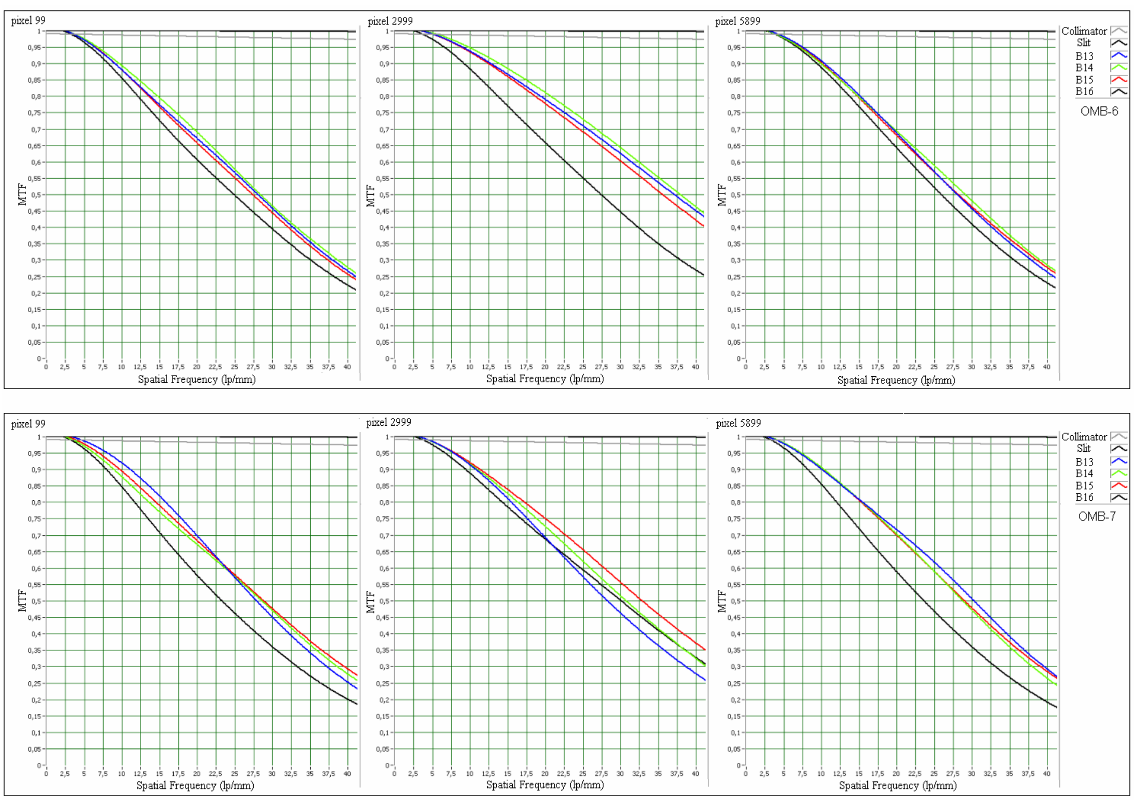

Fig. 9. Measured MTF for a) OMB-6 and b) OMB-7.

Table 2. Global MTF at 38.5lp/mm.

	OMB - 6				OMB - 7			
Bands / Pixel	B13	B14	B15	B16	B13	B14	B15	B16
99	0.29	0.31	0.29	0.24	0.27	0.30	0.32	0.23
2999	0.46	0.49	0.45	0.30	0.30	0.35	0.40	0.35
5899	0.29	0.31	0.30	0.25	0.31	0.30	0.31	0.22

CONCLUSIONS

The results obtained during the on ground tests for the WFI-OMBs Engineering model agree with the theoretical design results.
The proposed optical system meets the requirement of optical system MTF and Global MTF.
Analysis and tests of other performance requirements were also addressed.
This model was also submitted to environmental tests such as vibration and thermal tests.
Nowadays the project of this camera is on the Qualification Model (QM) phase. The QM OMBs have already been manufactured and aligned, and the on ground tests are currently taking place.

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