

Baffle Design and Analysis of Stray-light in Multispectral Camera of a Brazilian Satellite

Lucimara C. N. Scaduto^(1,2), Érica G. Carvalho^(1,2), Lucas F. Santos^(1,2), Fátima M. M. Yasuoka⁽²⁾,
Mário A. Stefani⁽²⁾, Jarbas C. Castro^(1,2)

⁽¹⁾Instituto de Física de São Carlos – IFSC-USP

⁽²⁾Opto Eletrônica S.A.

lucimara_ifsc@yahoo.com.br

Abstract

A partnership between Brazil and China in the space area is introducing the technology of remote sensing in Brazil. The result is the necessity of a variety of studies in complementary areas. The multispectral camera of the satellites CIBERS 3&4 is being developed with total national technology. Due to its orbit and its disposal for monitoring from the ground, the camera is exposed to solar radiation, becoming necessary a study of the influence of the stray light inside of optical system for performance evaluation. With purpose of reduce this inconvenience, that causes degradation of the image formed by the system, an optical baffle was projected and must be connected to the camera.

Introduction

The program CBERS – China Brasil Earth Resources Satellite is a partnership between Brazil and China in the space area. Through this agreement, Brazil has acquired proper satellites for monitoring its territory. The satellites CBERS 1 and 2 have been already working. With the images captured for these satellites, studies have been done about agricultural area, hydric resources, monitoring of Amazonian forest, among others. Because of an extension of the initial agreement, CBERS 3 and 4 will be launched.

The camera connected in CBERS 1 and 2 had been developed in China, however, the development of the camera that will be connected to CBERS 3 and 4 is under responsibility of Brazil. The company Opto Eletrônica S.A. in partnership with INPE (Instituto Nacional de Pesquisas Espaciais) is responsible for the project of the MUX camera (Multispectral camera). It is a multispectral camera of twenty meters of resolution in the ground, designated to the environmental monitoring. Due to the project of MUX is pioneering in Brazil, and also due to little available information about the cameras developed outside of the country, it has been necessary to create national technology for the development of space optical equipment. This is the first camera produced with national technology totally. For its development, it is necessary to control the stray light inside of the optical system, so that the degradation of the image quality can not occur.

The goal of this work is the development of an optical baffle in order to reduce the disturbing light from the sun and the analysis of stray light in the optical system of the camera.

Experimental Setup

Optical Baffle Characteristics

The baffle is a mechanical system, whose function is to shield the light coming from sources outside the field of view (FOV) of the camera. The light outside the angular view of the system must execute multiple number of reflections on its surfaces, minimizing the intensity of the light that effectively reach the optical system. It consists basically of a tube, which has vanes in internal walls. These vanes are used to reduce the intensity of light that is reflected on the walls. Some requisites are necessary to construct a baffle, which are explained in literature and summarized below.

According to Heinisch & Jolliffe [1] no optical components are allowed to view any sunlit wall or vane edge directly, that is, at least two reflections from blackened surfaces are required between the stray light source and the optical element. The light from inside the baffle is required to execute a maximum number of surface reflections from blackened surfaces before entering the optical system. A minimum number of edges directly exposed to the sun is used. Surfaces, which are not optical components in the field of view, are covered with a black material.

In structures, which allow diffuse reflection of the light, the position of the vanes is made in the way that no element of the optical system can view directly illuminated surface [2]. The method used in this case is showed in figure 1A [4]. The height of the first vane is defined according to length, diameter of the tube and FOV of the system. The vane 2 is defined to the intersection of line AB with the line determining the FOV limit. The line DC shows the path of scattered light from the aperture of the first vane to the wall. The vane 3 is determined to the intersection of line AC with the FOV. Same procedure are accomplished for the others vanes. In this case, the internal surfaces of the baffle, as well as vanes should be roughen and blackened.

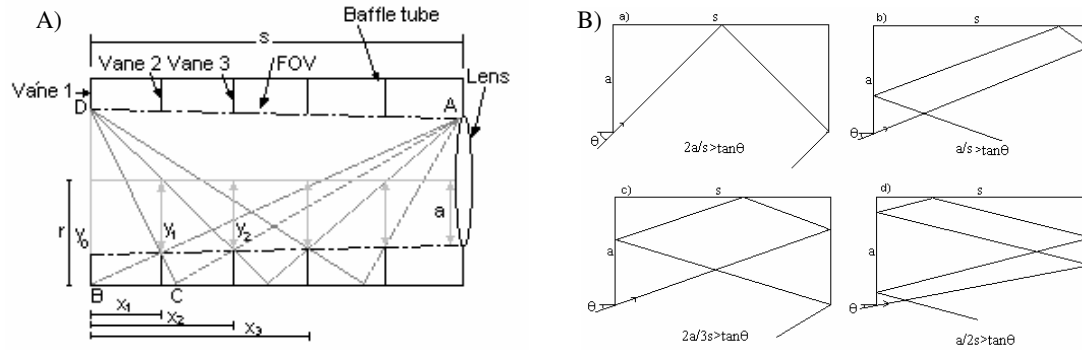


Figure 1. A) Ray trace for determining the position of the vanes in the case of diffusely reflecting surface; B) Position of the vanes for minimum number of specular reflection: a) two reflections; b) three reflections; c) four reflections; d) five reflections.

According to the geometry of the figure 1 A, if x_n is the distance from vane n to the outer end of the baffle tube, the height of vane n is y_n with $x_0 = 0$ and y_0 denoting the value of the outermost vane, it is possible to determine the position and height of the vane by the equations [2]:

$$x_{n+1} = (y_0 - y_{n+1}) \frac{s}{y_0 - a}, \quad y_{n+1} = r - \frac{r + a}{1 + z_n}$$

and:

$$z_n = 2a \left[r - r_0 + x_n \frac{y_0 - a}{s} \frac{y_0 + r}{y_0 + y_n} \right]^{-1}.$$

Where a is the radius of the lens, r is the radius of the tube and s is the distance from the lens to the outermost vane. When the baffle have diffusely reflecting surfaces, an optimum vane placement is more difficult to determine compared to the specularly reflecting surfaces. Thus, it can not guarantee more than two bounces from a diffusely reflecting baffle before reaching the first lens of the system [3]. If the baffle has specularly reflecting surfaces, one of the criteria used for the placement of the vanes is described in figure 1B [3]. These criteria allow determining the placement of the vanes if we have a ray at an input angle θ . If the surfaces have reflectivity ρ , the attenuation, for n bounces, is given by $a = (\rho)^n$ [3].

The multispectral camera

This camera has a 4.4° of angular semi aperture and resolution in ground of twenty meters. It has four spectral bands, which cover the electromagnetic spectrum from blue to infrared. Due to the high optical performance required, the optical design of this camera must designed near the diffraction limit. The image sensor is a quadrilinear CCD sensor that has one line for each band.

The operation orbit of the camera is around 780 Km, the region considered "low-earth orbit". In this region, the camera is subject to severe environmental conditions, that is, thermal requirements and solar and space radiation exposition. These factors demand cares in the choice of the materials to be used and in the prevention of

degradation of the image generated due to stray light in the optical system. Figure 2 shows the components of this camera.

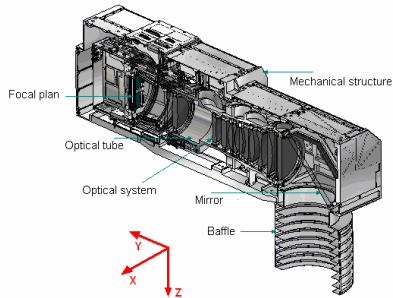


Figure 2. MUX Optical system.

Results and Discussions

Using the hypotheses presented previously, the optical baffle structure is being proposed in order to be located in the entrance of the optical system of the camera. This baffle has conical profile with angular aperture of $4,4^\circ$. Essentially three parts compose the baffle of the MUX camera: main cone, flanged support and seven vanes.

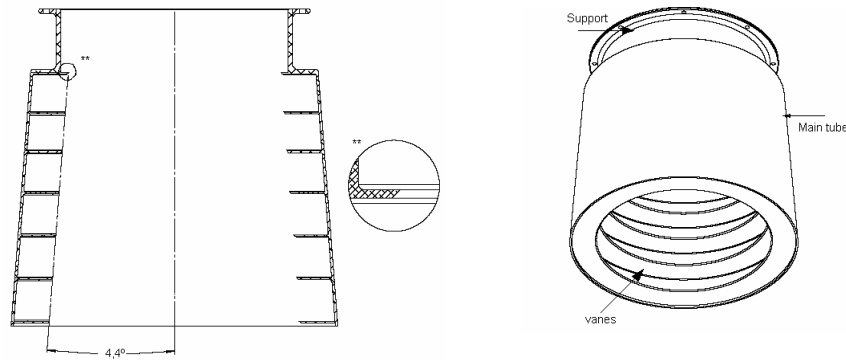


Figure 3. Profile of baffle and three-dimensional vision.

The Figure 3 shows the baffle proposed. The flanged support is used to fix this structure in the body of the camera. The vanes contain bevels on the object side of the vane. These are made to reduce the amount of stray light in the edges. The position of the bevels on the vane varies with the location of the vanes in the system. In the front section of a baffle system the bevel should be on the object side of vanes, the side that will receive direct radiation from the off-axis sources. The bevel must be on the opposite side at deeper location into the system, where the direct radiation from the unwanted sources can be prevented from reaching the beveled edge [5].

The mechanical components of the camera structure as well as the baffle system are metallic material. A treatment of these surfaces for reduction of reflected light becomes necessary. Some types of special treatment and paints are available. In this baffle, we decide to chrome the internal surfaces of the structure and later to paint it with appropriate ink. This type of treatment becomes the surfaces blackened and reduces the percentage of reflected light about 5%, providing to the surfaces a lambertian behavior.

Since the MUX camera will be launched in the daytime, the system will be subject to a great amount of solar light. Moreover, the light scattered for the land, which is out of FOV of the optical system, harms the formed image. Thus, a detailed study of the stray light intensity must be made in order to take care to guarantee the signal/noise relation in the sensor and to provide good operating of the equipment. These studies will be performed using software that makes the analyses through Monte Carlo ray tracing simulation.

After the definition of the structure of the baffle that will be connected to the optical system of the camera, simulations has been made to evaluate the attenuation of the light in function of the incident angle. In one of the simulation, a collimated source was placed in the entrance of the baffle and, in the other extremity, a detector was placed. In another analysis, detectors had been located in the position of the first lens of the system and in the focal plane in the region where is placed de sensor. Figure 4 shows a graph of intensity of light in function of the angle of incidence for several angles. The intensity shown in the graph corresponds to a total intensity of the emitting source of 1W. The simulations had been carried with a simplified modeling of the optical system where the entrance mirror is not used. The presence of this component makes the system to be asymmetrical.

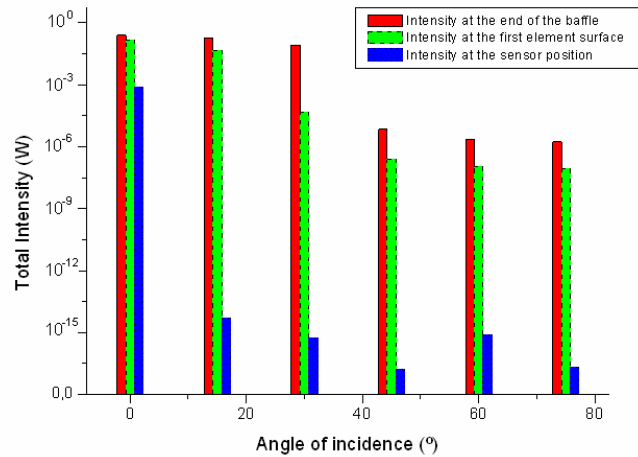


Figure 4. Intensity of light in the baffle end, first element surface and sensor position in function of the angle of the incident beam.

We analyze the intensity of light on the first element of the optical system and on the sensor placement, according to data of the sun positions related to the camera during the year, which varies from 14° to $29,1^\circ$ related to the plan of the orbit (corresponding to the axis Z in the plan YZ) and angles bigger then 42° related to the direction Z in plan XZ (Figure 2). The results are present in table 1.

Incident angle related to Z direction in the XZ plan, α ($^\circ$)	Incident angle related to Z direction in the YZ plan, β ($^\circ$)	Total intensity in the first surface of the system (W)	Irradiance in the CCD (W)
42	14	$8,66 \cdot 10^{-7}$	$2,36 \cdot 10^{-13}$
42	29.1	$1,38 \cdot 10^{-6}$	$3,94 \cdot 10^{-12}$
55	14	$4,11 \cdot 10^{-7}$	$5,50 \cdot 10^{-14}$
55	29.1	$4,13 \cdot 10^{-7}$	$3,64 \cdot 10^{-13}$

Table 1. Results obtained in the simulations.

In these simulations, we take an angle bigger then 42° just to analyze the behavior of the model. For light inside of FOV, the intensity of light in the CCD region is of the order of 10^{-4} W (figure 4). These results show us that the baffle designed reduce the stray light intensity to about 10^{-12} W. This noise is considerably lower then the signal that must be detected.

Conclusions

The results obtained demonstrate that the baffle considered presents good performance, reducing the sunlight intensity in the focal plane about 10^{-12} W. New simulations will be carried and the intensity of scattering light inside the field of view of the system will also be analyzed.

Acknowledgements

The authors thank the Instituto Nacional de Pesquisas Espaciais – INPE.

Reference

- [1] R. P. Heinisch and C. L. Jolliffe, Light Baffle Attenuation Measurements in the Visible; Applied optics, Vol. 10, No 9, pp. 2016, September 1971;
- [2] Young Sun Lee, Yong Ha Kim, Yu Yi and Jhoon Kim, A Baffle Design for an Airglow Photometer on Board the Korea Sounding Rocket-III, Journal of the Korean Astronomical Society, pp. 165-172, 2000;
- [3] Freniere E. R., First-order design of optical baffles, SPIE, vol. 257, pp. 19-28, 1980;
- [4] Smith W. J., Modern Optical Engineering, McGraw-Hill, New York, 1990;
- [5] Breaut R. P., Problems and Techniques in stray radiation suppression, SPIE Vol.107, pp. 2-23, 1977.