Diploma Thesis

Evaluation of the SwissCube Optics

Prepared by:
Sarajlic Mirsad

Responsible professor:
Mr. François Wildi

Approved by:

•
Heig-VD
Yverdon-les-Bains
Switzerland
•
14/12/2007
•

heig-vd
Haute Ecole d'Ingénierie et de Gestion
du Canton de Vaud

Université Neuchâtel unine Hes·so Haute Ecole Spécialisée de Suisse occidentale EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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1 REFERENCES

1.1 Normative references

[N1] *WP 4150 C PL optics* , N.Scheidegger

[N2] *S3 Phase B-C Payload's Optic,* July 2007, M. Sarajlic

[N3] *MT9V032_Datasheet,* Micron

1.2 Informative references

[R1] *Modern Lens Design,*2005, Warren J. Smith

[R2] *Memo_Payload frame thermal elongation,* July 2007, G. Roethlisberger

[R3] *Mounting Optics in Optical Instruments,* 2002, Paul R. Yoder,J

2 TERMS, DEFINITIONS AND ABBREVIATED TERMS

2.1 Abbreviated terms

FOV:	Field of view
FWHM:	Full width half maximum
RMS:	Root mean square
SEA:	Solar exclusion angle

3 TABLE OF FIGURES

4 INTRODUCTION

4.1 Framework

SwissCube is a picosatellite which is developed by Swiss students and based on the CubeSat standard. This standard was defined by the Stanford University and the California Polytechnic State University in 1999. The normalised sizes are a 10 cm edge-length and a weight of less than 1kg. The normalisations guarantee a standardised deployment system and reduce the launch costs.

The science mission of the SwissCube satellite and its payload is to perform space-based observations of the airglow occurring in the upper atmosphere at approximately 100 km altitude.

Figure 1 Airglow phenomena

The functions of the payload's optical system include:

- The necessity to filter and attenuate the parasitic light
- The projection of the image on the detector with as less aberrations as possible

Furthermore, it has to satisfy its mechanical requirements and should be low cost. The optical system is divided in two parts:

- The lens design (including fixation) which is used to focus the image on the detector
- The baffle tube used to attenuate straylight

4.2 Scope

During the preceding semester work, the payload's optical system was designed, manufactured and assembled.

The goal of this diploma's thesis consists of designing and assembling a model to test and evaluate the optical system of the payload and perform the tests required to confirm the requirements on the payload's optics.

This report presents the different test procedures and the test results.

5 TASKS

This section summarises the work which was expected for the diploma's thesis [N1].

The main tasks were:

- Understand the science and project requirements on the payload;
- Identify available facilities and prepare ground equipment needed for testing;
- Characterize performance of the payload optics in term of sensitivity or output drifts as a function of temperature and precision of assembly;
- Characterize performance of the payload baffle attenuation as a function of the incident angle of the straylight;
- Characterize performance of the payload filter in terms of output drifts as a function of the incident angle of the targeted signal;
- If the optical system does not meet the requirements, do a second iteration on the optical design for the payload;
- Design a transportable test bed to test the performance of the payload optics once the whole satellite has been assembled;

6 TEST OBJECTIVES

In order to validate the requirements on the payload, it was necessary to separate the testing of the payload in different phases and perform several tests on each of the elements before testing the whole assembly. The tests were focused on:

- The optical system
- The baffle
- The filter
- The sensor
- The whole assembly

The test procedures described hereafter are divided into three main parts:

- Test of the optical design
- Test of the attenuation of the filter, the baffle and the complete system
- Test of the alignment of the payload's optics in real environment conditions

7 OPTICAL DESIGN

7.1 Introduction

The optical design is an assembly of 3 plano-convex lenses. The design has been done with Zemax and optimized to project the best image of the airglow on the specified sensor. All the lenses are off-the-shelf components and can be found on the market. The first design of the payload's opto-mechanical system is shown in **figure 2**.

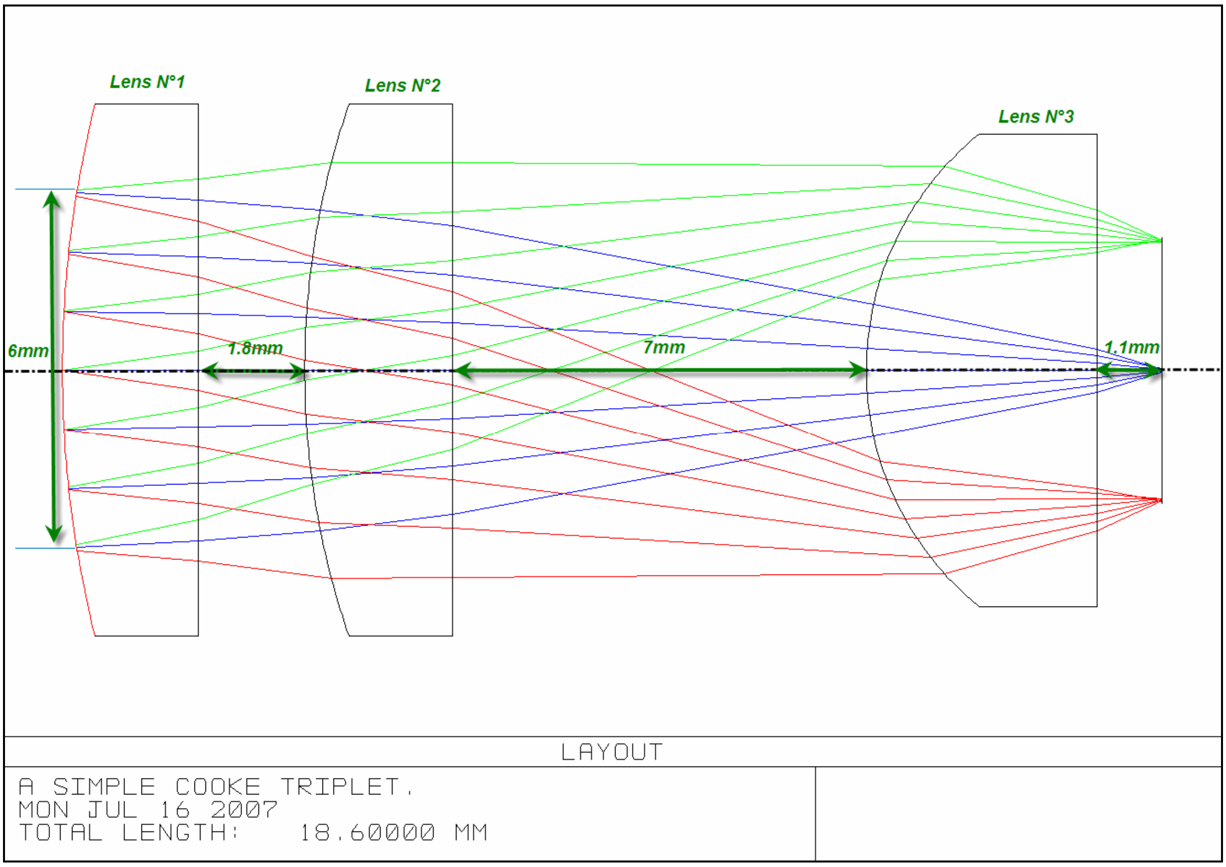

Figure 2 Layout of initial optical design of the paylaod

7.2 Identification and configuration of the test article

The optical design has been tested without coating and not in vacuum[1].

The principal goal was to verify that the ordered lenses perform as simulated with Zemax. .

The specifications of the optical system are described below:

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[1] The refraction index of the air (1.002) is quite similar to the vacuum (1.0)

Parameter	Unit	Value	Tolerances or max value	Remarks
Total FOV	°	25	±3°	Required FOV to guarantee limb detection
Aperture	Ø mm	4	≥ 4	Minimum diameter for having sufficient light power
Attenuation made by the optical tube for a SEA >30°		$<10^{-4}$	±20%	Attenuation of the stray light
Vignetting	%	<50%	50%	Maximum optical losses
Wavelength	nm	766	±10	Wavelength of the nightglow
Spot Radius FWHM	µm	48		Spot radius egal to 2 x pxl pitch/FWHM for guarantee no under-sampling

Table 1 Optical design specifications

7.3 Test set-up identification

The inconvenience with the work on the assembled payload is that there is no possibility to move the lenses or the sensor. However, it is necessary to be able to move each lens separately to analyse which design gives the best results.

Therefore, a simple and easily transportable test bed had to be designed. It includes several elements:

- Support for the lenses, compatible with "micro-bench" modules
- Laser source at 760nm
- Collimator or beam expender
- System, holding the support for the lenses which allows rotating the lens support by 12.5 degrees and measuring the rotation angle
- Detector with a sufficient resolution (minimum 188x120 / 24um pxl pitch)
- Support for the detector with the possibility to control the detector position in three directions
- Interface PC- PCB
- Diaphragma of 4 mm
- Instruments for measurements (Vernier caliper, multimeter, etc…)
- Power source
- Instruments of measure (Vernier caliper, multimeter, etc…)
- Alimentation

The alignment of all elements along one axis is provided by a rail on which the tools for the tests are fixed. Each element can slide freely along the direction of this axis.

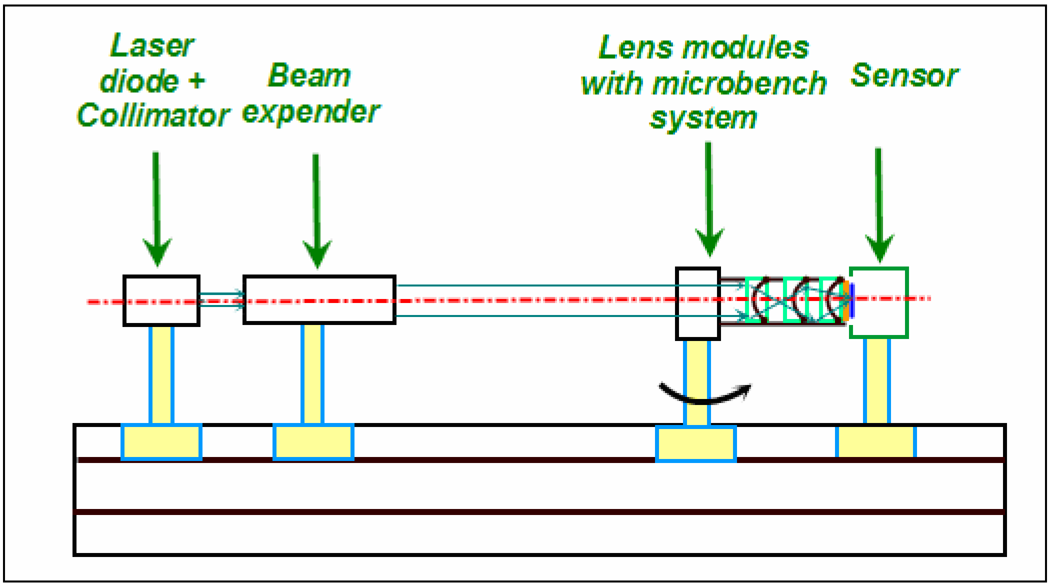

Figure 3 Test bed for optical tests

The sensor used for the measurements is the final payload sensor [N3]. An interface (GUI of the sensor) has been programmed to operate this sensor and offers the possibility to configure any register and hence the binning factor of the image. A second interface (GUI of the spot calculation) has been written to determine the position and the barycentre of the laser spot. It also includes an algorithm which calculates the spot radius.

Performance	Unit	Micron MTV9V032
Array size	pixels	752x480 / 188x120[2]
Pixel pitch	µm	6x6 / 24x24[2]
Total FOV	°	29.4x18.8
Dynamic range	dB	100

Table 2 Sensor specifications

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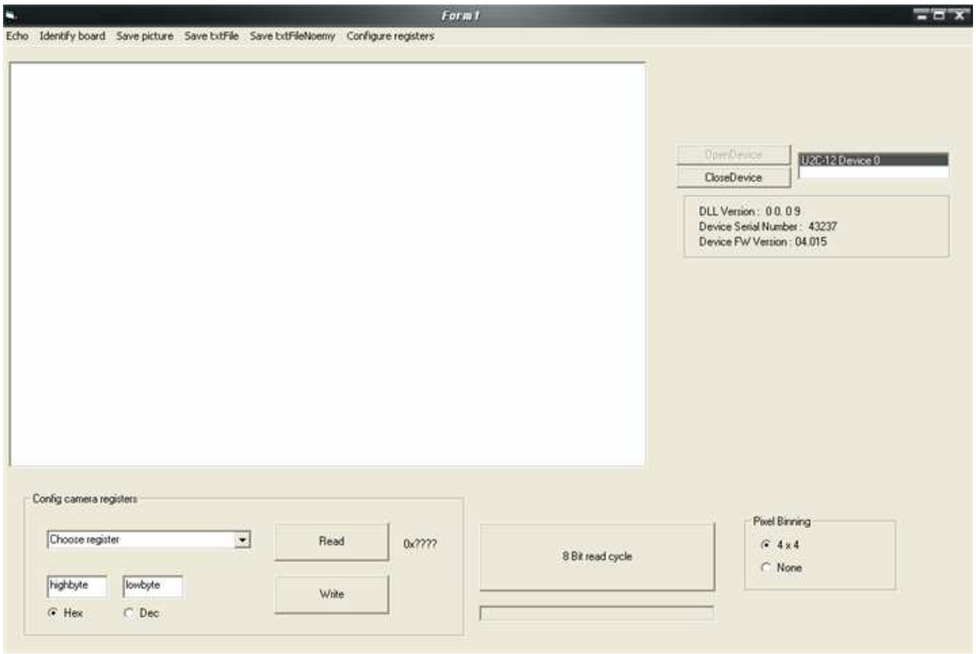
[2] Including a binning of 4x4 pixels



DLL Version : 0.0. 0.9
Device Serial Number : 43237
Device FW Version : 04.015

● Hex ○ Dec

Pixel Binning: ● 4 x 4 ○ None

Figure 4 GUI of the sensor

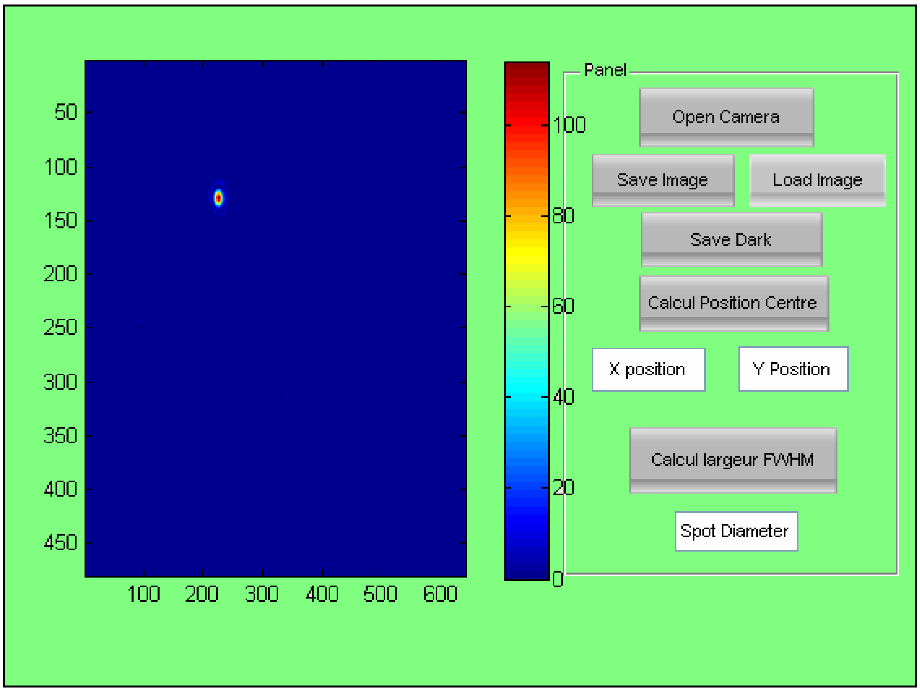


Figure 5 GUI of the spot calculation

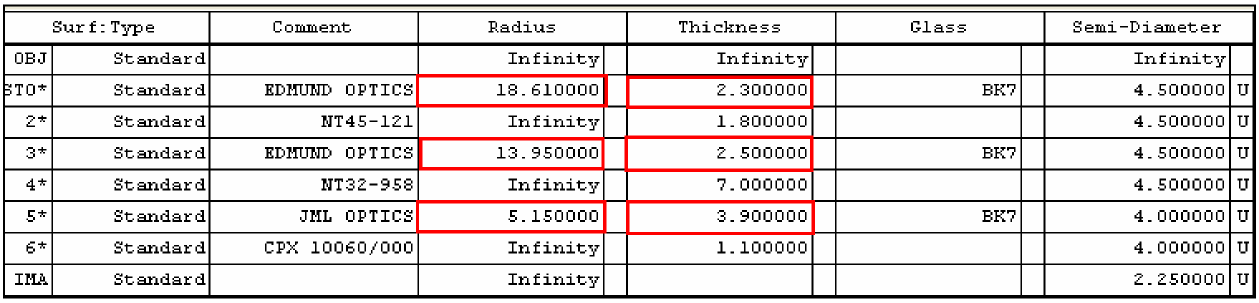
7.4 Test conditions

For the optical tests it's necessary to guarantee the cleanliness of the lenses and to work in a dark room in order to avoid perturbation of the measurements by straylight.

7.5 Step by step instruction for operation

7.5.1 Verification of the dimensions of the lenses

The lens data used for the simulation with Zemax have to be compared to the data given by the manufacturers and the real lens dimensions to ensure that the performance of the simulation corresponds to the performance of the optical system with the ordered lenses in theory.



Surf:Type		Comment	Radius		Thickness		Glass		Semi-Diameter	
OBJ	Standard		Infinity		Infinity				Infinity	
STO*	Standard	EDMUND OPTICS	18.610000		2.300000		BK7		4.500000	U
2*	Standard	NT45-121	Infinity		1.800000				4.500000	U
3*	Standard	EDMUND OPTICS	13.950000		2.500000		BK7		4.500000	U
4*	Standard	NT32-958	Infinity		7.000000				4.500000	U
5*	Standard	JML OPTICS	5.150000		3.900000		BK7		4.000000	U
6*	Standard	CPX 10060/000	Infinity		1.100000				4.000000	U
IMA	Standard		Infinity						2.250000	U

Figure 6 Datas of the lenses by Zemax

The data given by the manufacturers are described below:

Parameter	Unit	Value	Tolerances	Remarks
Lens N°1 + N°2				
Diameter	Ø mm	9	+0.0/-0.1	
CT N°1	mm	2.3	±0.1	Centring Thickness of lens N°1
CT N°2	mm	2.5	±0.1	Centring Thickness of lens N°2
Clear aperture	%		90% of diameter	Aperture where the rays passed
E.F.L. N°1	mm	36	±1% of E.F.L.	Effective focal length of lens N°1
E.F.L. N°2	mm	27	±1% of E.F.L.	Effective focal length of lens N°2
Lens N°3				
Diameter	Ø mm	9	+0.0/-0.18	
CT	mm	3.9	±0.25	Centring Thickness of lens N°3
Clear aperture	%		90% of diameter	
E.F.L. N°3	mm	10	±5% of E.F.L.	Effective focal length of lens N°3

Table 3 Datas of the lenses by the manufacturers

The radiuses of a lens can be calculated from its effective focal length and its refractive index.

$$\frac{1}{f} = (1-n)*\frac{1}{r}$$

Where *f* is the focal length

n is the refractive index (1.51 for BK7)

r is the radius of the lens

The table hereafter gives the calculated and measured radiuses of the lenses. The thickness of each lens has been measured with a micrometer whereas its radius has been measured with a spherometer. The measurements were repeated 3 times on different lenses to guarantee their correctness.

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Lens N°	Theoretical Radius [mm]	Calculated Radius [mm]	Measured Radius [mm]	Theoretical thickness [mm]	Measured thickness [mm]
1	18.61	18.36	**17.64**	2.3	**2.33**
2	13.95	13.77	**13.30**	2.5	**2.48**
3	5.15	5.1	**4.9**	3.9	**4.06**

Table 4 Results of the lens measurements

There is a big difference between the theoretical radiuses given by Zemax and the effective radiuses of the lenses. This is due to two points:

- The catalogue of Zemax contains errors
- The delivered lenses do not correspond to the data given by the manufacturer

Hence, the measured dimensions have been used for the tests presented in the following sections.

7.5.2 Validation of the optical system

Once that the test bed has been assembled and that the tests conditions are implemented, it's possible to begin the tests.

First it is necessary to collimate the rays provided by the laser diode source at 760 nm and introduce a stop with a diameter of 4 mm on the first lens. For ray collimation, a doublet is placed between the laser source and the beam expender. The max diameter of the rays entering in the beam is 1mm. The beam expends the entering rays by a factor of 20. Hence, the beam has a diameter of 20mm after the beam expender. The control of the collimation is made with a autocollimator.

The lenses and the sensor are placed as precise as possible according to the design done with Zemax. It's important to fix correctly the supports once that the design is in place to prevent decentring of the lenses or the sensor during the measurement.

The reading of the image with the GUI shows the variation of the spot diameter as a function of the field of view.

The pass criteria for the validation of the optical system are that the measured spot diagram has to be similar to the spot diagram designed with Zemax and that the spot radiuses are smaller than 48 um.

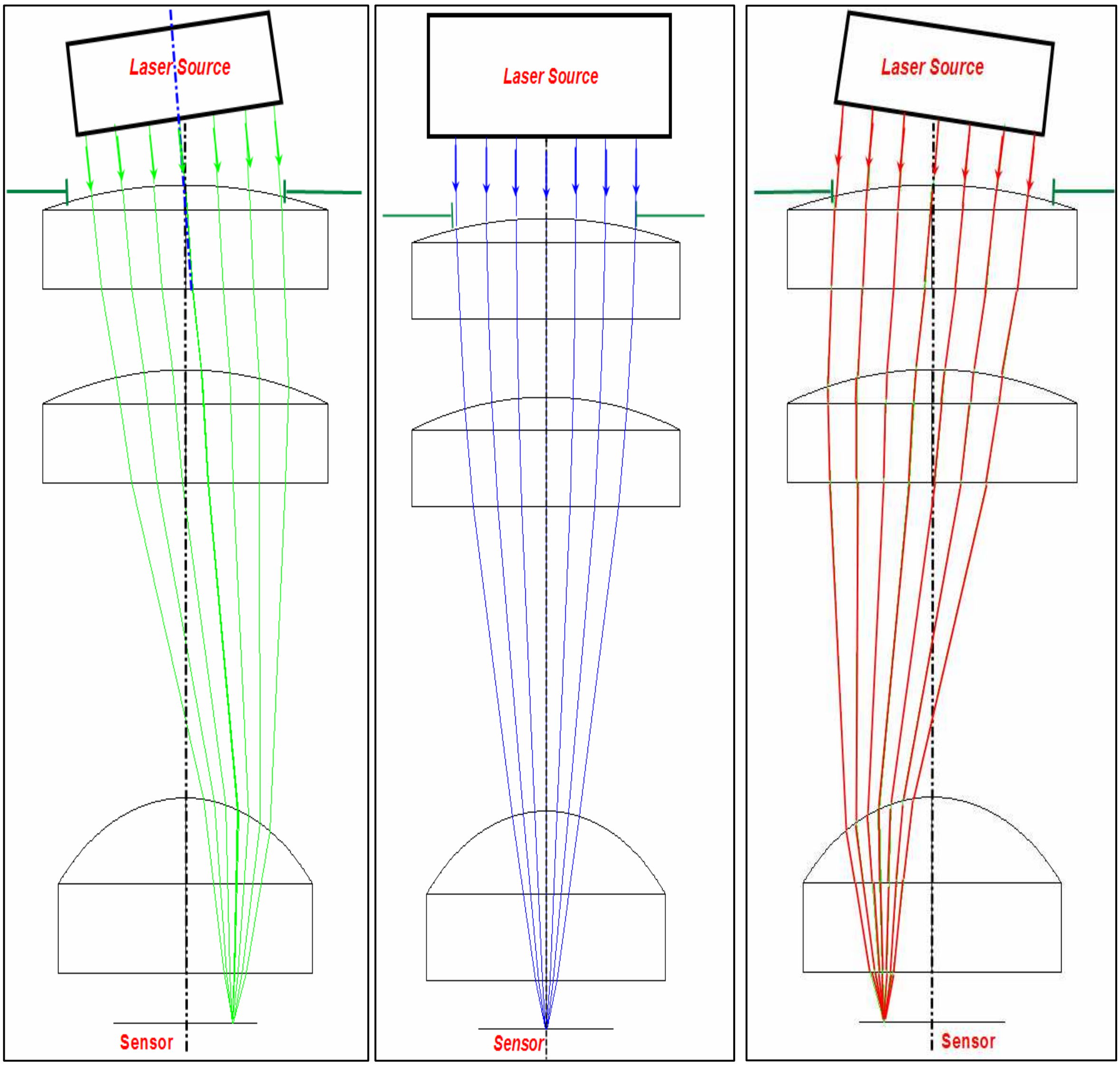


Figure 7 Variation of the angle of the entering rays

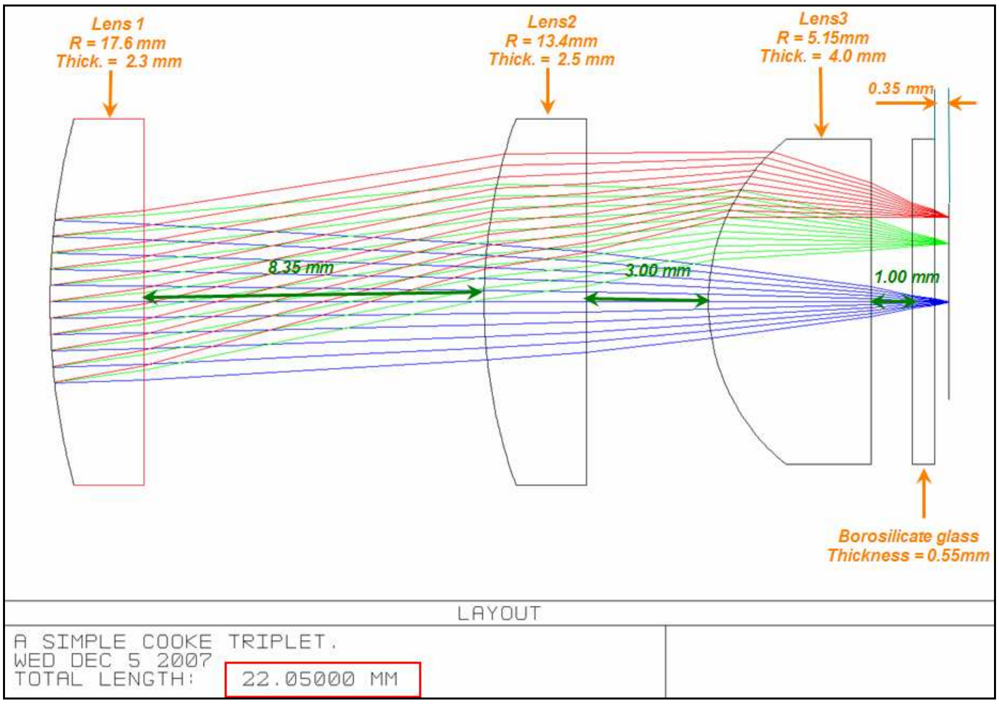
Three important considerations have not been taken into account for the first optical design:

First, there is a glass of borosilicate in front of the sensible surface of the sensor which hasn't been considered in the first design of the payload's optics. This glass is 0.55mm thick.

Second, the radiuses of the lenses are not correct. The real radiuses had to be introduced in the simulation.

Third, the mechanical design of the payload, does not allow placing the sensor closer than 0.3 mm from the last lens.

After considering all these "new" limitations, the program Zemax made another optimisation for the design. The distance between the lenses and the spot diagram changed. The final optical design is longer but the spot stay in the requirements.



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A SIMPLE COOKE TRIPLET.
WED DEC 5 2007
TOTAL LENGTH:   22.05000 MM
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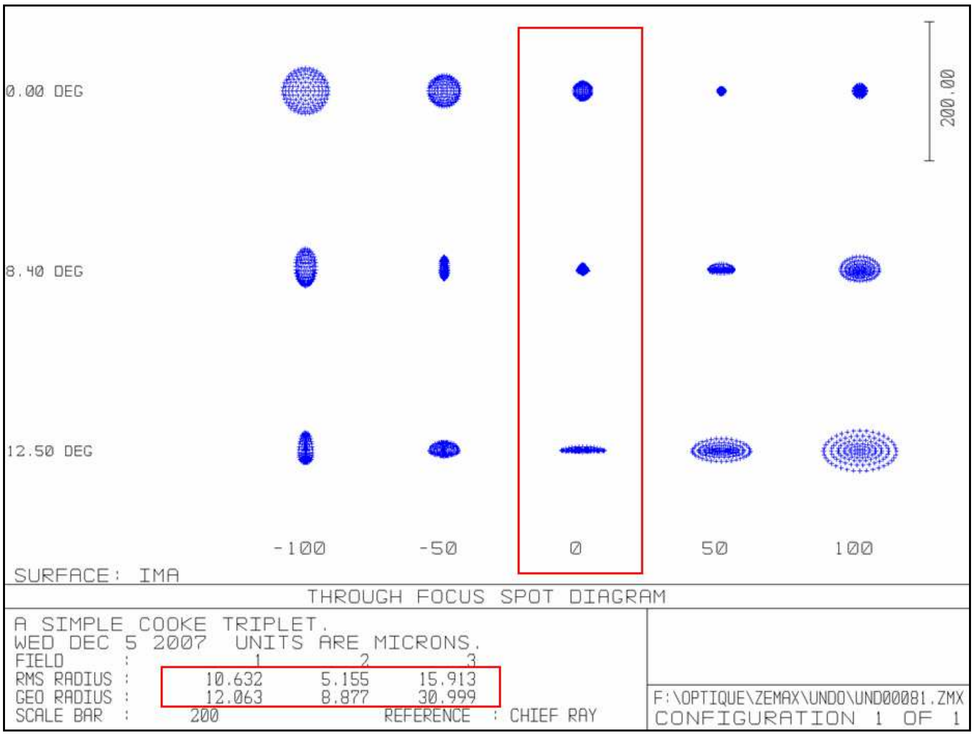
Figure 8 Layout of the final optical design



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A SIMPLE COOKE TRIPLET.
WED DEC 5 2007  UNITS ARE MICRONS.
FIELD      :        1          2          3
RMS RADIUS :   10.632      5.155     15.913
GEO RADIUS :   12.063      8.877     30.999
SCALE BAR  :   200          REFERENCE  : CHIEF RAY
F:\OPTIQUE\ZEMAX\UNDO\UND00081.ZMX
CONFIGURATION 1 OF 1
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Figure 9 Spot diagram through focus of the final lens design

After placing the lenses according to the simulation, the sensor is adjusted until a smallest spot is provided. Then the sensor is fixed. The readout of the image has been done without binning to estimate precisely the diameter of the spot.

The registers of the sensor which had to be modified to obtain the results showed below are:

- Row Noise Correction Control 0x70 = 13 = disable
- Automatic Exposition and Gain control 0xAF = 00 = disable

Some imprecision can be described which show that the real design does not correspond exactly to the simulation:

- The tolerances of the distance between the lenses are relatively important (0.1 mm).
- There is no coating on the lenses which couldn't attenuate the ghosts in the system.

After several tries of positions of sensor, an acceptable point of focalisation has been found. Then the image is saved and the payload is rotated by 8.4 ° in one direction. The same operations are repeated for different angles. Finally the MatLab GUI calculates the spot radiuses of all saved images.

Source position/ lens design	Spot diameter [µm]	Spot Radius [µm]
-12.5°	30	15
-8.4°	36	18
0°	42	21
8.4°	36	18
12.5°	24	12

Table 5 Results spot diagram measures of the optical design

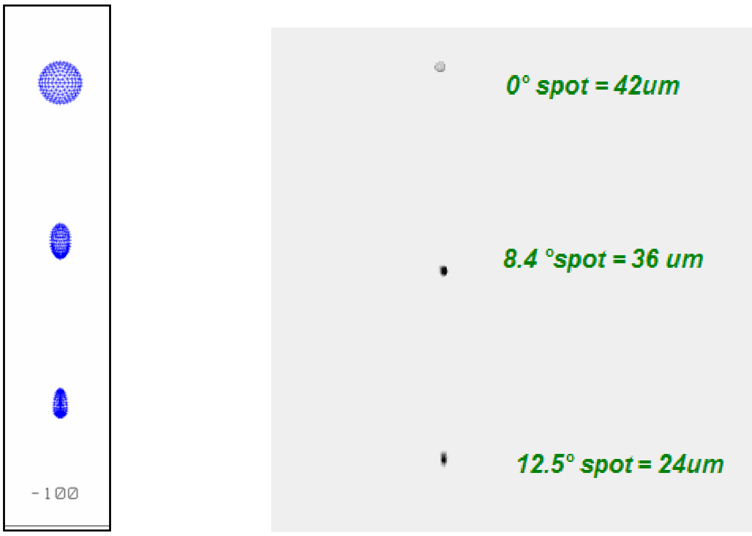

Figure 10 Comparison of the simulate spot (left) with the measured spot (right)

The analyse shows that the measured spots at different angles have a radius of less than 48um. This requirement is satisfied.

Furthermore, the spot has a similar shape as simulated. However, the focus plane of the real optical system is shifted by -100um compared to the simulation with Zemax. The design is indeed extremely sensible on the position of the sensor. Thus, it will be necessary to have a flexible and robust fixation for the sensor to assure that its position remains correct.

At 12.5° the rays focalised on the outside of the sensible area of the sensor. This means that all sensible are of the sensor is used and that the field of view of the optical design is correctly optimized.

Figure 11 Spot radius at 12.5° image with the sensor

8 ATTENUATION

8.1 Introduction

The intensity of the airglow is really low. So it is logical to have a very sensitive sensor. However, it is not desirable to measure another thing than the airglow. That is why an attenuation system was designed to attenuate the others light sources. The principal straylight source which has to be attenuated is the sun.

There are no hard requirements for the attenuation, the specification for the baffle to attenuate straylight by a factor of 10^{-4} for a SEA of at least 30° it's more a guideline.

The attenuation system consists of three main parts:

- The baffle, which the first part of the payload system. It reflects and attenuates all rays outside of the instrument's field of view.
- The pass-band filter, which is positioned just after the baffle. It transmits only the wavelength of the airglow (765 nm)
- The spacers of the lenses. They attenuate any rays which are reflected on their darkened surfaces. The rays which reach the lens system have already been attenuated by the baffle and the filter.

8.2 Identification and configuration of the test article

The tests on the attenuation allow determining the total attenuation of the stray light of the system with the baffle and treatments on the spacers.

The attenuations tests will start with the estimation of the attenuation factor of each of the payload elements after their treatment (blackening, sanding). These parts are principally the elements of the baffle and the spacers used for the fixation of the lenses.

Once that the attenuation factor of these parts is known, a measure of the attenuation introduced by the assembled baffle as a function of the SEA can be analysed. Finally the attenuation done by the complete system can be measured. The filter is not included in these tests because its manufacturing was not ready during the attenuation tests.

This table below describes the estimations of the performances which could be obtained with the parts of attenuation system. These estimations were made during the conception of the attenuation system.

Parameter	Unit	Value	Tolerances or max value	Remarks
Attenuation Factor	-	10^{-2}	±3%	Attenuation of one spacer after one reflection
Baffle Attenuation	-	10^{-4}	±10%	Attenuation made bye the baffle only at 30°SEA
Optics Attenuation	-	10^{-4}	±10%	Attenuation made bye optical design at 30° SEA

Table 6 Attenuation specifications

8.3 Test set-up identification

For the attenuation tests it is necessary to have a source which provides a constant and uniform light intensity on the surface which should be analysed. The light emitted by the laser diode source has a wave front with a Gaussian shape. Therefore, an integration sphere is placed after the payload. The integration sphere diffuses the rays in all direction and homogenises their intensity over the entire surface of the sphere. A photometer measures the output of the integration sphere, whereas a supplemental module allows varying the orientation of the payload and hence the simulated SEA.

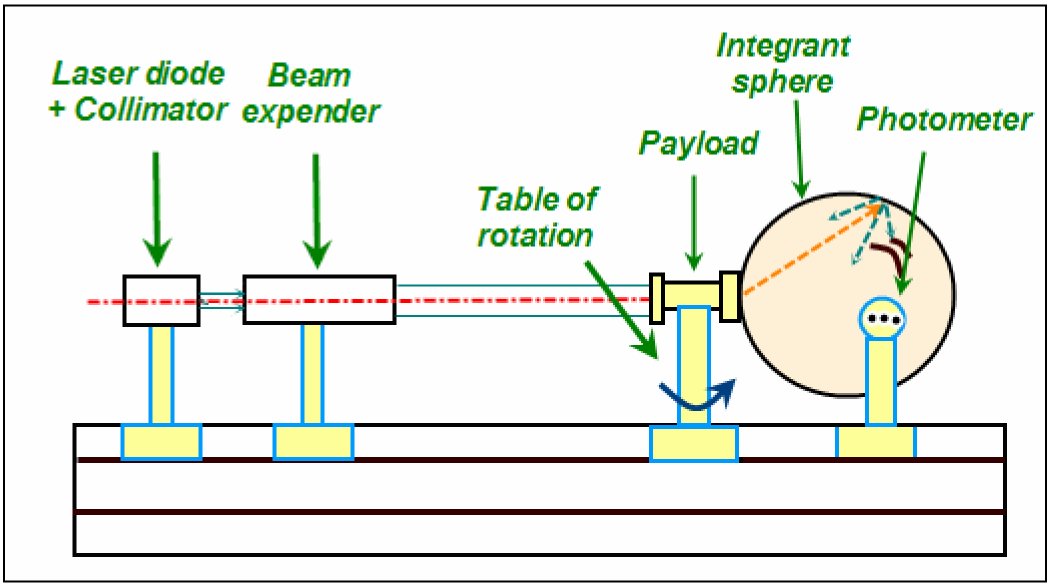

Figure 12 Test bed for attenuation tests

8.4 Test conditions

As for the testing of the optical design, it is necessary to work in an obscured environment in order to prevent perturbation of the measurements by further straylight. The environment must be darkened to prohibit supplemental reflections and ghosts in the optical system.

8.5 Step by step instruction for operation

8.5.1 Attenuation factor of the spacers

The estimation of the factor of reflection after one reflection on a blackened and sanded surface has been estimated to 1 % of the total flow emitted by the laser source. [N2] Prior to the verification of the attenuation of the whole baffle system, this factor of transmission has to be verified.

The test procedure is as follows: A laser source emits a constant light at a wavelength of 760 nm which is measured by a photometer. A lens is placed after the source for focalise the rays in one point. A spacer is placed at this point of focalisation. This piece is placed in such a way that it the light beam is reflected one time only. A second measurement with the photometer placed after the spacer allows comparing the emitted intensity and the reflected intensity of the laser beam and gives the factor of transmission of one spacer. The measure is not extremely precise because it is possible that there are multiple reflections within one spacer before the laser beam reaches the photometer for the second time

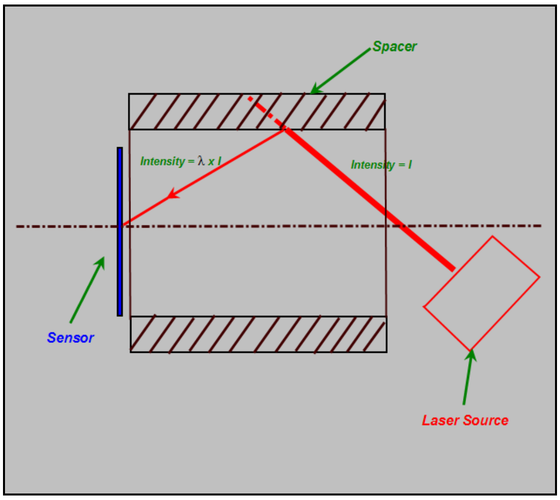

Figure 13 Test bed for attenuation factor

Two spacers were tested. One was a spacer of the baffle and had not been blackened correctly: some white spots appeared on the spacer surface. Thus, the factor of reflection is higher than expected. The spacer is made in Titanium. The other spacer is a spacer from the optical part. The difference over the baffle spacer is that it is made of aluminium and it is not sanded.

Table 7 shows the results of the measurement of the factor of reflection for different emitted laser beam intensities.

Piece N°	Intensity emitted [W]	Intensity received [W]	Reflection [%]
Spacer baffle	$649*10^{-6}$	$92*10^{-6}$	**14.2**
Spacer baffle	$2.38*10^{-3}$	$377*10^{-6}$	**15.8**
Spacer optical design	$330*10^{-6}$	$70*10^{-6}$	**21.2**
Spacer optical design	$2.52*10^{-3}$	$498*10^{-6}$	**19.7**

Table 7 Results of attenuation factor tests

The factor of reflection of the spacers of the baffle is estimate at 15 %, whereas the factor of reflection of the spacers of the optical design has been measured at 20 %. These high values are most probably due to the following points:

- The blackening of the spacers of the baffle has not been done correctly. White spots on their surface increase the factor of reflection.
- The spacers of the optical design have not been sanded.

8.5.2 Baffle attenuation

Straylight with an angle which is higher than the SEA has to be reflected at least twice before it reaches the last vane. Each reflection of a beam on a vane or spacer surface attenuates its intensity.

In order to measure this attenuation, the payload is placed parallel to the straylight. At 0° no rays are attenuated and it can be considered that intensity is maximal. If the incident angle of the straylight is changed by rotating the payload, the intensity of the beam that reaches the last vane is modified too.

If a comparison is made between the rays entering at 0° and the measurements for rays entering with a different angle of incidence, the attenuation of the baffle can be determined. However, for have a good precision of the measure, the photometer shall be placed directly after the baffle. Because of mechanical constraint, this placement was not possible. So the photometer is placed behind the payload. This new position include that the measures are not precise due to the fact that the rays which pass the baffle can be reflected by the tube which should hold the lenses. This tube hasn't a factor of transmission of 100%. Hence, the attenuation of the baffle can be determined with a tolerance estimated of about 20%.

The success criteria for the test on the baffle attenuation factor shall be that the attenuation of a straylight with an incident angle of 30° should be attenuated by a factor of 10^{-4} before it enters in the optical design

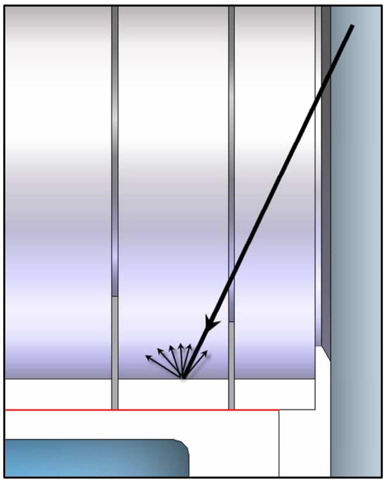

Figure 14 Reflection of a ray on a baffle spacer

Measured angle	Absolute angle	Intensity measured [μm / cm^2]	Attenuation [-]
105	**-22**	2.2	**1.24E-01**
110	-17	2.84	1.60E-01
112	-15	2.62	1.48E-01
114	-13	2.31	1.31E-01
116	-11	2.73	1.54E-01
118	-9	4.59	2.59E-01
120	-7	7.4	4.18E-01
121	-6	9.18	5.19E-01
122	-5	10.3	5.82E-01
123	-4	12.1	6.84E-01
124	-3	15	8.47E-01
125	-2	16.6	9.38E-01
126	-1	17.5	9.89E-01
127	0	17.7	1.00E+00
128	1	16.9	9.55E-01
129	2	16.2	9.15E-01
130	3	14.4	8.14E-01
132	5	10.54	5.95E-01
134	7	7.47	4.22E-01
136	9	4.05	2.29E-01
138	11	2.28	1.29E-01
140	13	1.61	9.10E-02
145	18	1.09	6.16E-02
150	**23**	1.06	**5.99E-02**
155	28	0.109	6.16E-03
160	**33**	0.00642	**3.63E-04**
165	38	0.0045	2.54E-04

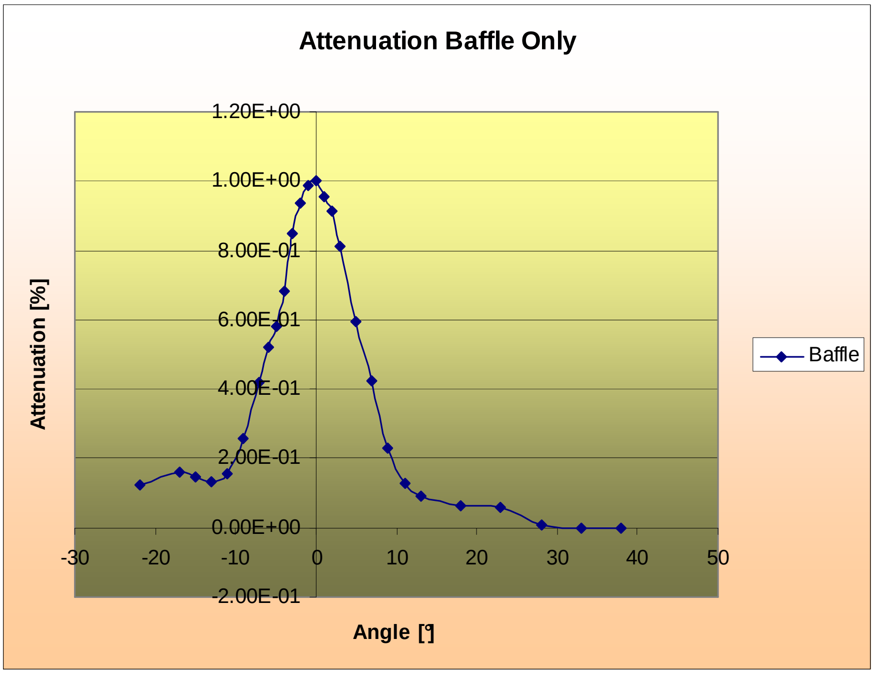

Figure 15 Baffle attenuation graph

F**igure 14** shows the attenuation introduced by the baffle as a function of the incident angle of the straylight. The graph is not symmetric. This might be due to the white spots on the spacers of the baffle or reflections of ghost images.

At 33 ° the attenuation is about 10^{-4}. It's an acceptable result knowing that we have 20% of transmission on spacers while baffle design was made with a base of 1% transmission on the spacer.

8.5.3 Straylight attenuations with the complete system

If the payload is completely mounted, it is possible to measure the attenuation within the assembled system. This measure does not include the filter and follows the same procedure as the determination of the attenuation with the baffle only. The only difference between these two measurements is that the focusing optics is mounted as well.

The success criteria of this test is that the attenuation of straylight with an incident angle of 30° is attenuated by a factor of 10^{-8} before it reaches the sensor

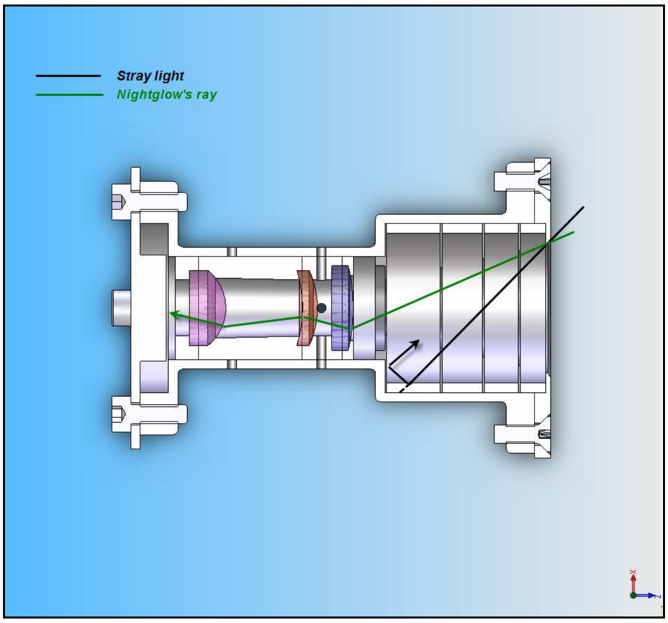

Figure 16 Cross section of the payload

Measured angle	Absolute angle	Intensity measured [µm / cm^2]	Attenuation [-]
107	**-21**	0.463	**2.74E-02**
112	-16	1.77	1.05E-01
117	-11	10.93	6.47E-01
119	-9	12.8	7.57E-01
121	-7	14.6	8.64E-01
123	-5	15.8	9.35E-01
124	-4	16	9.47E-01
125	-3	16.3	9.64E-01
126	-2	16.6	9.82E-01
127	-1	16.7	9.88E-01
128	0	16.9	1.00E+00
129	1	16.9	1.00E+00
130	2	16.6	9.82E-01
131	3	15.9	9.41E-01
133	5	15.1	8.93E-01
135	7	14.4	8.52E-01
137	9	12.2	7.22E-01
139	11	10.18	6.02E-01
144	16	1.55	9.17E-02
149	**21**	0.295	**1.75E-02**
154	26	0.0204	1.21E-03
159	31	0.00263	1.56E-04
164	**36**	0.00123	**7.28E-05**

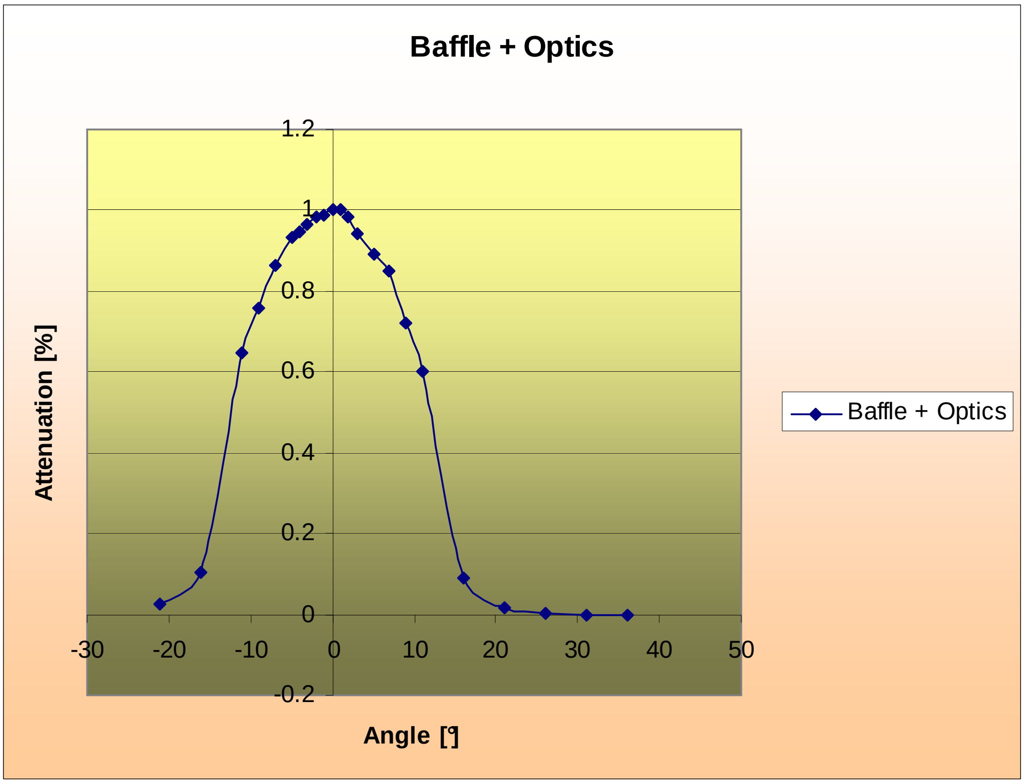

Table 8 Baffle + Optics attenuation graph

There is no big difference between the measurements of the attenuation introduced by the baffle only and those done by the assembled payload. For an angle of incidence higher than 30°, the factor of attenuation is rather constant and about 10^{-4} variation, the attenuation varies only very slightly. The values are declining very slightly to about 11 degrees. From there, the values decline more sharply to 30 °. Finally there isn't real variation of values between 30 and 36°.. The Maximum Value legible on the bench is 36 °. These results can be explained by the fact that the half field of view of the system is at 12.5 °. Consequently, until this angle, the whole of the 1st lens is visible directly from the rays. Then its visible surface decreases and fewer rays fall directly into the system. From 30 °, no light falls directly into the lens and all rays are attenuate by the baffle. .The maximum value of attenuation is at 36°.

It is therefore obvious, that the targeted attenuation can not be achieved. Nevertheless, it might still be reduced by one or two orders of magnitude if the treatment of spacers is done correctly and the lenses are coated. Current results can only improve in the future. The problem is that it is not possible to know how much.

9 TEST BED FOR PAYLOAD ALIGNMENT TESTS

9.1 Introduction

The purpose of the payload alignment test is to demonstrate that the payload is satisfies its performance requirements in its operational modes under the thermal and load conditions encountered during the mission

The parameters which will be tested during thermal-vacuum tests and tests on the static and dynamic load are

- Spot radius and position in function of the incident angle of a laser beam at 760 nm

These parameters determine the angular resolution and the FOV of the payload.

9.2 Identification and configuration of the test article

The tests will be performed on the SwissCube payload mounted on the completely assembled satellite. No satellite disassembly is required to perform this test.

During thermal-vacuum tests, integrated temperature sensors attached to the optical structure of the SwissCube payload will be used to give precise record of the temperature of the optical system.

The laser source should be placed outside of the thermal chamber to avoid variations of its wavelength which is directly proportional to the temperature of the source.

A borosilicate glass gives the optical interface between the outside and inside of the thermal chamber.

9.3 Test set-up identification

Several elements are required to ensure that the tests are performed under good conditions:

- Laser diode at 760nm
- Collimator
- Beam expender
- Straylight protection tube
- SwissCube CMOS detector interface
- Rail of fixation
- Support of SwissCube with three degrees-of-freedom (one rotation and two translations)

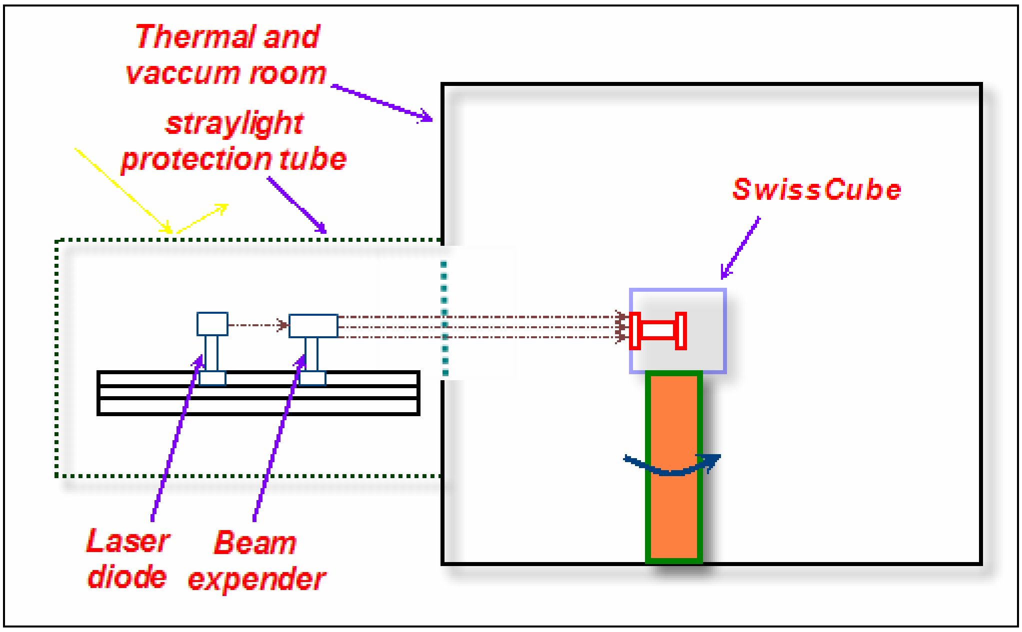

Figure 17 Test bed for Payload test alignment with SwissCube mounted

9.4 Test conditions

During alignment test, the optical path from the laser source to the SwissCube detector shall be protected from any straylight. The glass of borosilicate should be clean and without rays so that there are no diffusing light and no ghosts in the system.

9.5 Step by step instruction for operation

During alignment test, the optical path from the laser source to the SwissCube detector has to be protected from any straylight. The glass of borosilicate has to be cleaned to reduce the effects of diffused light and ghosts in the system.

9.6 Step by step instruction for operation

- The first step to check the alignment of the payload's optics is to verify that the sources are well collimated. For that an autocollimator is placed in front of the beam expender to verify the collimation.

- Before mounting the payload on the SwissCube adjust the focus plan by moving the sensor forward or backward.

- The SwissCube satellite is then placed inside the thermal chamber with its payload aligned with the laser beam. If the SwissCube is correctly placed, the spot should be displayed in the centre of the sensor.

- Note the angle of the SwissCube. This angle is the reference 0°.

- Measure the spot radius and its position

- Modify the angle of the SwissCube. The incident angle of the laser source will automatically change.

- Measure the spot radius and its position

Source position/ lens design	**Spot diameter [µm]**	**Spot Radius [µm]**
-12.5°		
-8.4°		
0°		
8.4°		
12.5°		

Table 9 Table of measures

10 CONCLUSION

The test procedures and results of the tests performed on the SwissCube payload were presented in this report. A brief discussion on the objectives of this diploma's thesis is presented hereafter

- **Characterize performance of the payload optics in terms of sensitivity or output drifts as a function of temperature and precision of assembly;**

  The performances of the payload depending on the temperature or precision of assembly have not been tested. The test bed has been designed and built, but there are no results because the thermal tests were not foreseen during the work of diploma. Concerning the precision of assembly the results and the manipulations show that the tolerances of decentring of the lenses are large[3]. Nevertheless the position of the sensor is extremely sensible due to the aperture of the system.

- **Characterize performance of the payload baffle attenuation as a function of the incident angle of the straylight;**

  The best attenuation obtained is 10^{-5} at 35° SEA. The results are far from those expected. Nevertheless it is possible to gain 1 or 2 order of magnitude if the treatments on the spacers are done correctly and the lenses have the required coating.

- **Characterize performance of the payload filter in terms of output drifts as a function of the incident angle of the targeted signal;**

  This test could not be performed because the filter has not been delivered during the diploma's thesis.

- **If the optical system does not meet the requirements, do a second iteration on the optical design for the payload**;

  The second optical design has been done and satisfies its specifications.

- **Design a transportable test bed to test the performance of the payload optics once the whole satellite has been assembled;**

  The test bed has been designed. A test procedure has been written. An inventory has been done. A box will be designed to provide an easy way to transport the different elements of the test bed.

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[3] From the order of 0.1mm for each lens

10.1 Improvements

After doing the second iteration of the whole payload system, another validation of the attenuation tests will clarify the results and the effective factor of attenuation which can be obtained.

A better way for the fixation of the sensor has to be designed in order to prevent that the payload board moves during the launch.

The final design presents distortions in the image. The coefficients of the grid distortion can be used and a correction of the distortions can be implemented in the readout interface of the sensor.

Yverdon-les-Bains, the 14th December 2007

Sarajlic Mirsad

11 APPENDICES

- Zemax results of the final optical design
- Lens distances and dimensions
- Inventory of pieces for the transportable test bed
- Technical drawings for the elements composing the transportable box
- Datasheet of used instruments for the tests
- CD including all files related to the project

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