Characterization of the space segment for the T2L2 project

Muriel Ravet[1], Etienne Samain[1], Robert Dalla[1], Patrick Aubry[2], Philippe Guillemot[2], Jean-Louis Oneto[1],Jean-Marie Torre[1], Jean-François Mangin[1], Jocelyn Paris[1]

[1] OCA
2130 Route de l'observatoire,
06460 Caussols, FRANCE

[2] CNES
18 Avenue Edouard Belin,
31401 Toulouse, FRANCE

Introduction

The T2L2 experiment allows the synchronisation of remote clocks on Earth, and the monitoring of a satellite clock, with a time stability of the order of 1 ps over 1000 s and a time accuracy better than 100 ps. The principle is based on the propagation of light pulses between the clocks to synchronise. The ground segment is a satellite laser ranging station with a special instrumentation able to time light pulses accurately as compared to the ground clock to synchronize.
T2L2 has been proposed on MicroSatellite Myriade under development at CNES. So, the study of the space optics has been conducted for a MicroSatellite having an altitude of 800 km. At this altitude, the field of view is 120° and speed aberration is in the range of 10 arcseconds.
The phase B study of the space segment was concluded at the beginning of 2004. This study permitted to design an instrument having a mass in the range of 10 kg and a power consumption of 40 W.
It comprises the following elements:

A detection unit based on an avalanche photo-diode working in a Geiger mode.
A time tagging unit able to time the photo-diode output in the satellite clock time scale with a precision better than 3 ps.
A high index corner cube (100 mm diameter) having a large field of view.

Optical package description

The aim was to design a corner cube, determining its size, shape, refractive index, dihedral angle error, and its optic efficiency to satisfy the necessary field of view of 120° at an altitude of 800 km. The choice has been an unique corner cube having an high refractive index for the reflection unit and a truncated vertex for the photodetection.
To determine parameters of optics, the calculated link budget takes into account many parameters like optical power of the laser, orbit of satellite, laser station, atmospheric transmission but also the return transmission of flux which depends on reflector cross-section.

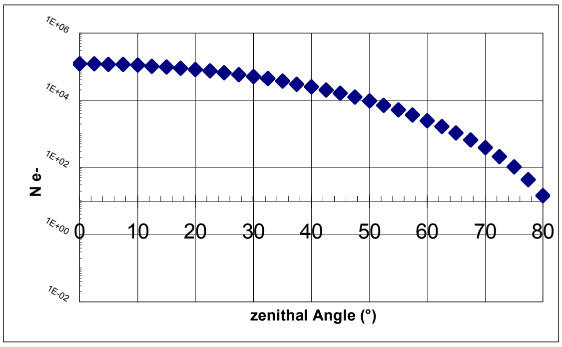

Figure1 : Link budget

The link budget is an estimation of return photons number detected on laser station as a function of zenithal angle. So, it allows to determine the specifications of this optical model. Adjusting the optic parameters to have at least 1 photon for all angles $-60° \leq \theta \leq 60°$, the reflection optics must be a corner cube having a refractive index of 1.8, a diagonal of 120 mm and the back side is covered by an Aluminium protected coating because of necessary 120° field of view. Its triangular shape is important to improve the link budget for the high angle θ. The dihedral angle errors must be less than in the range of 2.
For an altitude of 800 km, speed aberration is in the range of 10 arcseconds. In order to compensate for it, a cylindrical lens has been added in front of the corner cube to get a divergence of 10 arcseconds.
The curvature radius is 1.6 km with refractive index of 1.8. The spot of diffraction is spread along the direction of the satellite speed vector. This lens serves also a window to protect the corner cube against radiation.

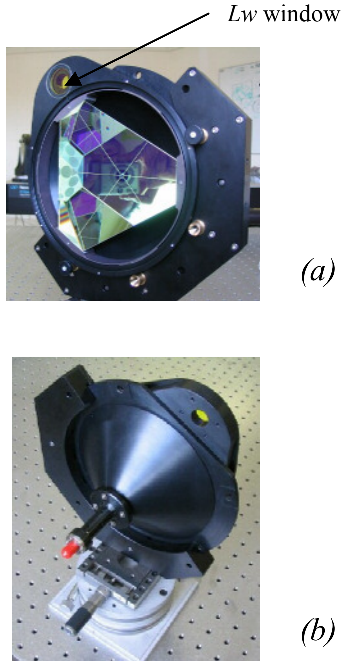

Figure 3 : Prototype
(a)front : reflector ; (b)back : detection optics

The detection unit is a photodiode operating in a Geiger Mode for the chronometry and a linear photo-detection to quantify the photon number and to polarize the Geiger diode. Behind the window (*Lw*), the equipped linear detection optics with a spectral filter is fixed which improves the S/N ratio. The non-linear detection optic allows to collect and to forward a little quantity of light to the photo-detector system. The beam at the truncated vertex have 120°aperture. The vertex is truncated on few millimetres. An optical fiber is set behind the corner cube vertex. This option has been chosen to have the detection point and the reflection point at the same location. This aspect is fundamental for chronometric error budget. Moreover, this choice doesn't generate any shadows in front of the corner cube. One needs a 5 m delay line in order to compensate the linear detection transit time. An optical fiber with a large numerical aperture, a large diameter and a low time dispersion is necessary. This leads to the choice of a multimode graded index fiber. Its characteristics are numerical aperture of 0.29 so a field of views of 34° and core diameter of 100 µm. A 3 lens afocal coupling optics has been inserted between the corner cube vertex and the optical fiber in order to reduce the 120° field of view to the fiber acceptance angle. At intermediate focus, a radial density compensates the variation of the photons number on the non linear detector into contact with the photons number on the linear detector in the direction of incidence angle.

Reflection optics studies

An interferometric analysis has been performed to verify the corner cube surface accuracy and quality. The reflected wavefront has a distorsion of peak-to-valley
1.28λ (rms 0.28λ) corresponding to 2" deviation or 0.7" error between 2 surfaces of corner cube.
For the 3 reflective surfaces, the surface accuracy is PV λ/6 with the test wavelength 0.632 µm, or alternatively the root-mean-square surface accuracy of about λ/36 and a surface

quality of about 40/20. For input face, the PV surface accuracy is λ/2 and a surface quality of about 40/20. And for the surface output (truncated vertex), the p-v surface accuracy is λ/4 and a surface quality of about 10/5.

A testing bench (fig. 4) was realized to study the corner cube polarization.
The principle was to materialize a plane wave having a diameter of 140 mm in order to cover the whole diameter of the corner cube. A 1 mW laser source is used at a wavelength of 532 nm with a linear polarization. So, we created an expander with an afocal system based on 2 convergent achromats.
The return beam is sent through non-polarizing cube beamsplitters on energy meter.

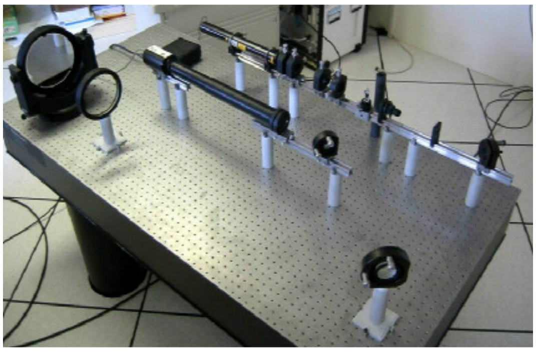

Figure 4 : Testing Bench

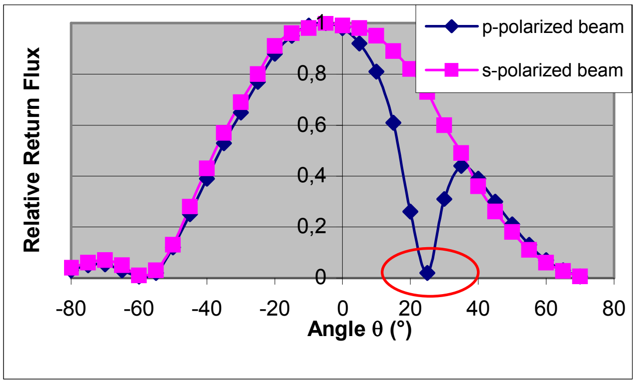

Figure 5 : Polarization studies

The curve (fig.5) shows the measured polarization as a function of the angle of incidence θ. The reflectance factor is near zero for θ = 30° i.e when the angle between the internal beam (the refracted) and the normal to the rear face is 70° for a p-polarized light at wavelength of 532 nm. The problem is coming from the primary layer of the reflection coating of the corner cube which was added to improve the adherence of the metalized layer to the special high index glass.
The simulation of the coating as a function of incidence angle in the glass is consistent with the measures, and shows a zero reflectance factor for p-polarization and for an angle of 70°, as induced by the experiment. Suppressing the primary layer in the simulator, a correct curve is obtained. A study will be undertaken to find the suitable layers for avoiding this problem.

With this testing bench, we will also deduce the real link budget of this prototype.
The energy meter will be replaced by a CCD and we will collect the spots of diffraction for different angle θ. Then, calculating the position of laser station in spot, we will deduce the light intensity in this point. So, we will plot the experimental estimation of return photons number as a function of incidence angle θ.

Detection optics studies

An experiment is realized to verify the variation of the flux on the detection fiber as a function of incidence angle θ. The incident beam is represented by a green He-Ne laser coupled with an afocal system which give a 2mm collimated beam.

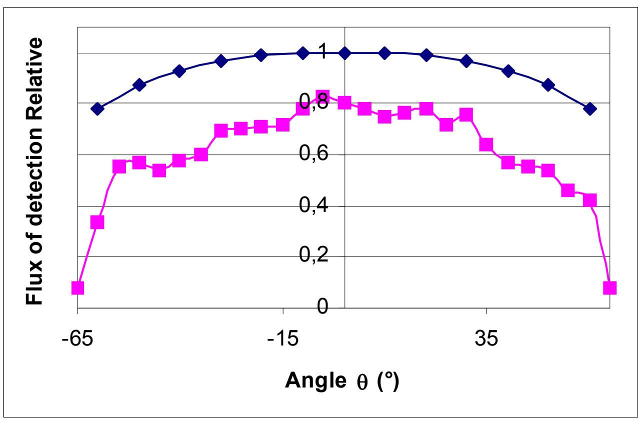

Figure 6: Variation of relative detection flux as a function of θ

The variation of theoretical flux is given by the diamond blue curve and the square red one represents the experimental measures. The fit between the 2 curves is relatively good, and shows that the detection system is able to work up to 60°. The beam crosses 10 optic surfaces before it reaches the detector. Every surface has a transmission factor of 98%: this gives a $0.98^{10}=0.82$ in accordance with the experimental curve.

Using a streak camera, we studies the temporal deformation of laser pulse after the detection optics with and without the optical fiber. The laser source is taken on doubled Nd: YAG laser (150 mJ; 10 Hz; 40ps). We don't observe special influence of the incidence angle on the shape of pulse without fiber. Nevertheless, the fiber widening of laser pulse is of order of 2 ps/m.

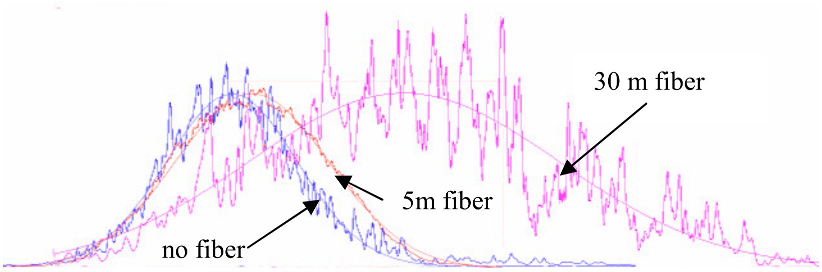

Figure 7 : Influence of fiber length

After have crossed the detection optics, the laser flux is sent on an avalanche photo-diode that we study.

Photodiode K14

This study is on the photo-detector K14 lent by Czech Technical University in Prague. Because the K14 diode could be used in the space segment, we have undertaken an irradiation study of the component.

The first experiment consists to analyse the noise rate of diode during the irradiation. The sent dose corresponds to the dose if the diode K14 was in the space during 3 years.
To do that, the diode is excited with a pulse generator at 100 Hz and the noise events are recorded with a frequency meter during all the experiment. The pulse delays are firstly adjusted to get an output rate in the range of 50 Hz.

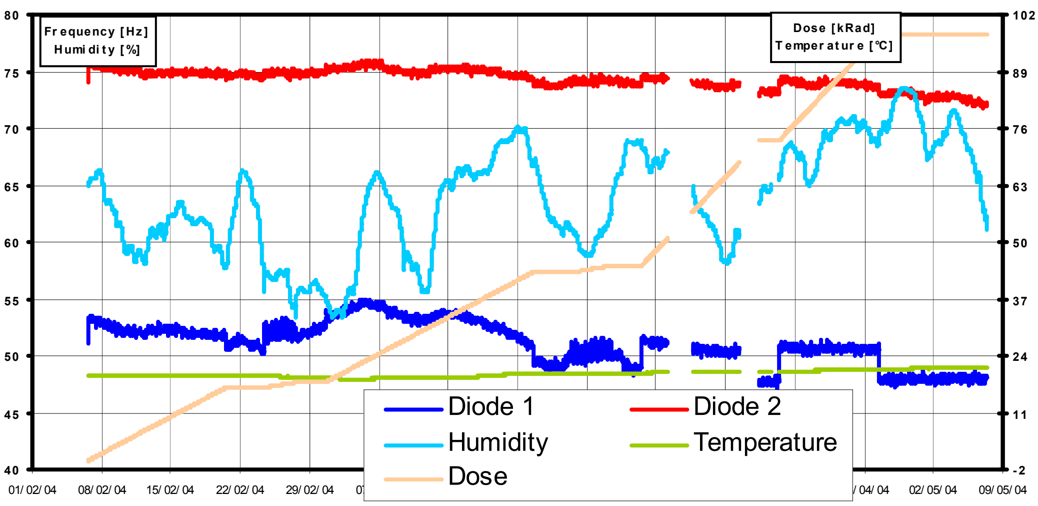

Figure 8: irradiation of the K14 diode

The source used is a cobalt 60 source which emits γ-Rays. The results are satisfactory. A small noise variation seems linked to the irradiation flux but the diode is insensitive to the accumulated irradiation because the noise is unchanged. So, after 3 months of irradiation on diode K14, it's still working !

Now, we have to measure the chronometry of the diode and to verify that there is no precision variation and that the quantum efficiency is unchanged.

Conclusion

The ground segment linked to the MéO station (the ex-Lunar laser ranging station) at Grasse and a prototype of the space segment allowed us to do a real simulation of the T2L2 time transfer.
This simulation permitted to evaluate very precisely the global performances of the link with a realistic atmospheric propagation.