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Optical Communications in the Mexican Small Satellite Project

F. J. Mendieta[1], A. Arvizu[2], R. Muraoka[2], Enrique Pacheco[1], Juan C. Murrieta[3], J. Sanchez[4], P. Gallion[5]
[1]Agencia Espacial Mexicana, Av. Xola esq. Universidad S/N, México D.F. 03020, México
Tel. +52 5557239433 mendieta.aem@gmail.com
[2] CICESE, Carretera Ensenada-Tijuana 3918, Ensenada, B.C. 22860, México
[3]ITSON, 5 de Febrero 818 Sur, Colonia Centro, Ciudad Obregón, Sonora, México
[4]VIVETEL, Justo Sierra 9216, Zona Centro, Tijuana, B.C. México, 22000
[5]Telecom ParisTech, 46 rue Barrault, 75013 Paris, France

Abstract— **We present the Mexican small satellites program, the current activities in the design and implementation of a satellite-to-ground optical communications payload for a nanosatellite and the preliminary results at the laboratory level and short distance ground-to-ground testing of the on board and ground segments.**

Keywords; optical communications, laser satellite communications, free space communications

I. INTRODUCTION

Recent developments in small satellite stabilization and attitude control, as well as in formation flight dynamics, allow the implementation of optical inter-satellite links, in the new scenario of broadband-demanding applications. Advances in the atmospheric telecommunications channel modeling, and in advanced modulation and coding formats, allow the implementation of optical satellite-to-ground links, taking advantage of the space-ground network techniques [1].

We first present the Mexican small satellites program aiming to reinforce regional competitivity and to enhance human resources formation in the aerospace sector, through the development of nanosatellite systems with advanced payloads, and the support elements for teaching and training in satellite technology [2].

We next present the current activities in the design and implementation of a satellite-to-ground optical communications payload consisting of an IR downlink optical transmitter for data communications, including both on board and optical ground station segments; including an uplink as a beacon for pointing purposes.

This requires a very good stability and attitude capabilities from the nanosatellite, which we are developing in parallel, as well as the digital tools for signal distribution and processing. Finally we present preliminary results at the laboratory level and short distance ground-to-ground testing of the on board and ground segments.

As our program is intended both to provide a device ready to fly in a nanosatellite mission scenario, as well as an educational prototype, we mention the activities in the generation of instructional contents in order to create an interactive educational environment.

II. MEXICAN SMALL SATELLITES PROGRAM

Mexican experiences with space technology started from the 1970's with the establishment of the Mexican Commission for Outer Space (CONEE), developing suborbital missions, mainly for meteorological and remote sensing.

Experiences with communications satellites began in the 1980's with our first domestic geostationary system called "Morelos", followed in the 1990's by the so-called "Solidaridad", also government owned. Afterwards a privatization occurred and the SATMEX company has been providing value-added communications services to Mexico and Central America. Most recently, in the 2010's the Mexican government becomes again owner of an advance satellite system consisting of 3 satellites: 2 in L band and 1 in C and extended Ku band.

Although these systems have been purchased from international satellite constructors, several actions regarding technology transfer and joint developing of spacecraft and ground segment subsystems have taken place, constituting important activities in the capacity building for Mexico in the space sector [1].

In the 1980's with the "Morelos" Geostationary Satellite System, contracted with NASA and Hughes, several space experiments for the NASA GAS-CAN program were developed in cooperation with Utah State University. Also the University Program for Space Research and Development (PUIDE) was constituted, developing 2 microsatellites: UNAMSAT 1 and 2, for scientific applications.

During the "Solidaridad" program, in the 1990's, contracted with ESA and Hughes, several Mexican Universities and Research Centers developed the SATEX 1 microsatellite, with a Ka band receiver and an optical communications transmitter demonstrators. This 50 kg microsatellite included an optical communications payload in the 830 nm wavelength, downlink only, inspired both on the previous experiences in free space optics and inspired on JPL developments [2], comprising a ground based beacon (532 nm) for pointing using an on-board 4 quadrant detector and mirror based beam steering.

From the Satex-1 experiences, in the 2000's several small satellite projects, were conducted by university groups, such as SATEDU (nanosatellite for stabilization testing) CONDOR (microsatellite for scientific payload) and SENSAT (nanosatellite for optical communications and hyperspectral applications demonstrator)

The SENSAT is based on the cubesat philosophy and, as our aim is the development of advanced payloads to provide skills in key areas, we are developing an optical communications payload for laser transmission from satellite to ground, using a beacon at the ground station for pointing purposes, similarly as in the SATEX 1 project. This of course requires a very good stability and orientation capabilities from the nanosatellite, which we are developing in parallel, as well as the digital tools for signal distribution and processing.

Funding for the development of this project was obtained from the Mexican and the Baja California State government to reinforce regional competitivity and to enhance human resources formation in the aerospace sector, aiming to the development of an educational nanosatellite system and support elements for teaching and training in satellite technology [3].

III. THE SENSAT OPTICAL PAYLOAD

On a previous paper [4] we have described the SENSAT project which optical payload (shown on figure 1) consists of an (uplink) optical beacon (@ 532nm) and a (downlink) optical data beam (@ 830 nm).

In order to track the optical beacon we use as a sensor a high sensitivity quadrant APD (see figures 1 and 2) which outputs are amplified and digitized in order to drive an actuator to focus the spot on the center of the quadrant APD. Our tracking system consists of three subsystems: the mechanical, the optical and the electronical subsystems respectively. We have developed two versions of our tracking system that we describe below.

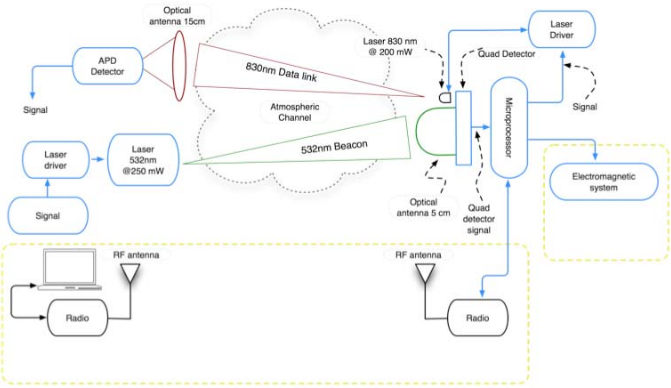
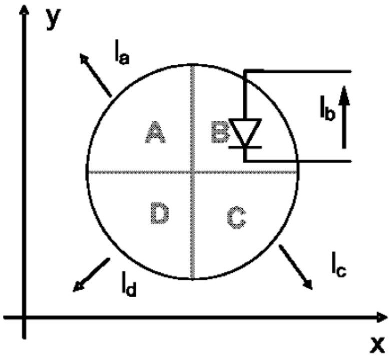


Figure 1. Block diagram of the optical communications link of the Sensat nanosatellite. OP: optical payload

A. Mechanical subsystem

This subsystem (shown on figure 3) is made of five aluminum pieces. The piece number 1 has two-axes movement controlled by means of some electromagnets and one string to hold such piece on the "zero" position when the electromagnets are not energized and also to maintain a force over the piece number 5.



$$x = \frac{I_a + I_d - (I_b + I_c)}{I_a + I_d + I_b + I_c}$$

$$y = \frac{I_a + I_b - (I_d + I_c)}{I_a + I_d + I_b + I_c}$$

Figure 2. Quadrant APD and operation equations.

On the figure 4 it is shown the figure 4 (top view) which function is to hold the electromagnets and several Hall effect sensors that are used to know the tilt of piece number 1 in any moment.

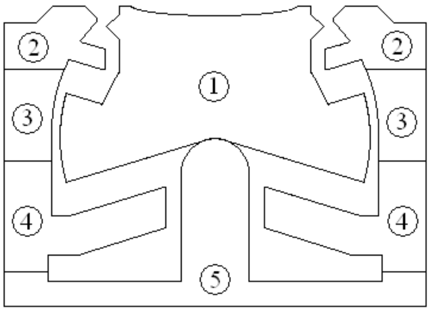


Figure 3. Mechanical subsystem.

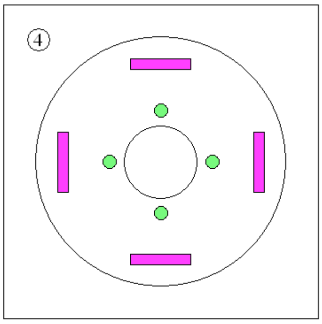


Figure 4. Top view of the mechanical subsystem showing piece number 4.

B. Optical and electronic subsystems

The optical subsystem is divided on two main sections: the receiver and transmitter stages. On the figure 5 is shown the block diagram of the receiver stage which main function is to track the optical beam (@532nm).

This stage consists of an optical antenna, an optical filter, and the quadrant APD. The electronic subsystems consists of preamplifier current-to-voltage conversion stages for the quadrant APD outputs, several PGA stages and the electronic drivers required to energize the electromagnets using a PWM signal generated using a microcontroller.

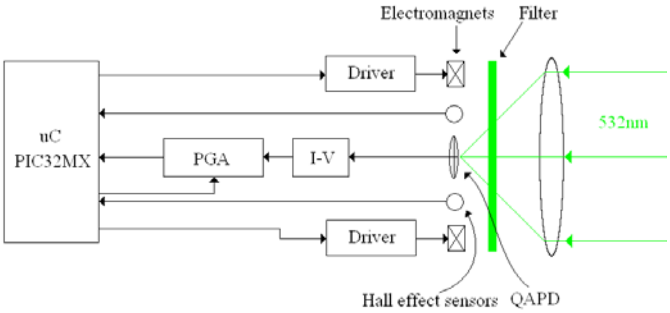


Figure 5. Optical and electronical subsystem.

The transmitter stage is shown on figure 6 and consists of an 830 nm laser (SDL-5430) and its driver (WLD3343) with a collimator lens.

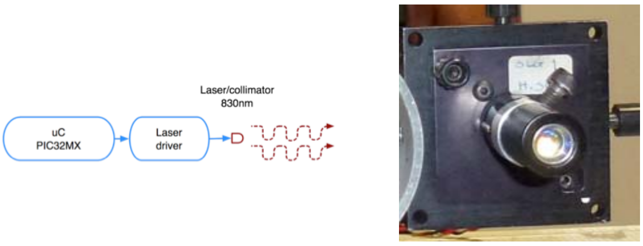


Figure 6. Transmitter stage at 830 nm.

We currently work on the development of a modified version to contain the laser within the mechanical structure as shown on figure 8, the dimensions of this are of 10 cm per side.

The 32-bit microcontroller shown on figure 5 contains an internal A/D converter and will have the following functions:

- To make the A/D conversion of the signals from the Hall effect sensors and from the quadrant APD..
- To calculate the position (in two dimensions) of the optical beam impinging on the quadrant APD and to use such information to focus the spot on the center of the APD.
- To modulate the laser for the downlink using either OOK or PPM signaling.
- To establish the communication with the on-board computer.

On the figure 7 is shown the distribution of the components in the mechanical subsystem. Because of space restrictions the downlink laser must be out of this structure. The items of the electromagnetic tracking system, in colors shown: Orange: Hall effect sensor, Red: permanent magnets, Blue: ferromagnetic material, Green: electromagnets, Yellow: springs, Dark green: QuadAPD

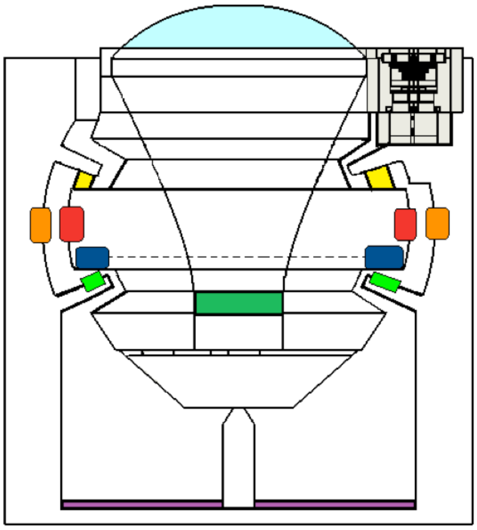


Figure 7. Mechanical, optical and electronic subsystems.

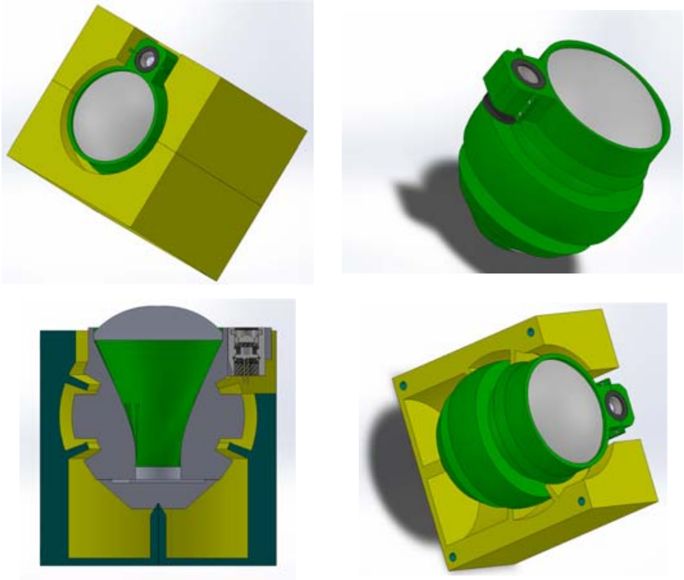


Figure 8. Gimbals and telescope with laser.

IV. GROUND-TO-GROUND TESTING: POWER BUDGET

In order to test our designed subsystems we have made several experiments with horizontal free space optical links.

On figure 9 is shown the block diagram of such experiments. And on table I is the power budget calculation for a ground-to-ground link.

TABLE I. PRELIMINARY TEST FOR DOWNLINK

Wavelength	830 nm
Power	150 mw
Range	16 Km
Divergence	1 mrad
Transmitter diameter	9 mm
Receiver diameter	35 cm
Sensitivity	-96 dBm
Visibility	8 Km
System margin	6 dB
Pointing losses	2.6 dB
Propagation losses	15.5 dB
Atmospheric losses	20 dB
Geometric losses	33.2 dB
Optical losses	2 dB
Receptor gain	122.5 dB
Transmitter gain	90.6 dB
Margin	39.4 dB
Received power	-57 dBm

V. ELECTROMAGNETIC TRACKING SYSTEM

The experimental electromagnetic test-bed receives the signals from the quadrant detector in order to track the impinging laser beacon.

The signals from the APD are conditioned and then they are processed by the microcontroller that output signals PWM to control the electromagnets. There are feedback signals from the Hall effect sensors that monitor the displacement from the base.

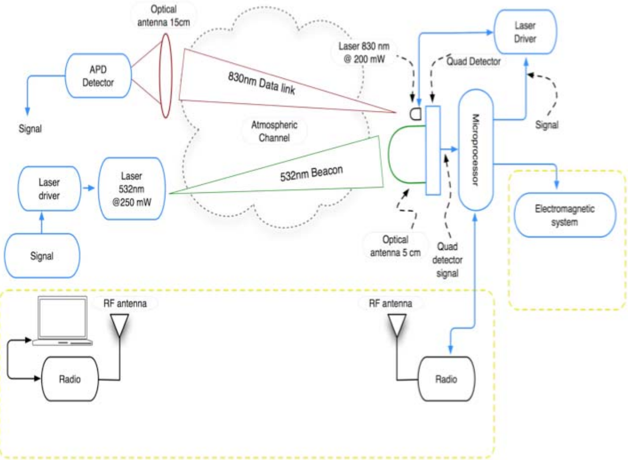


Figure 9. lock diagram of experimental set-up.

Figure 10. Optical components of the downlink subsystem.

Figure 11. Photograph of the optical beacon and receiver.

Figure 12. Photograph of the optical beacon at 250 mW.

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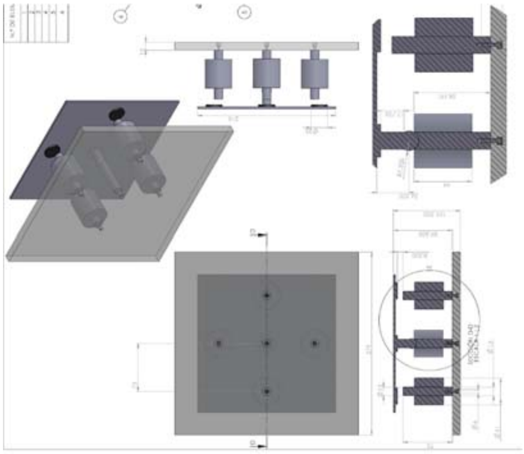

Figure 13. Electromagnetic Test-bed.

CONCLUSION

Small satellites are acquiring increasing interest in a diversity of applications: communications, earth observation, scientific payloads, and technology demonstrators, requiring broader bandwidths both for intersatellite and space-to-ground communications, as well as for relying high speed data from remote sensing payloads.

Developments in stabilization and attitude control for small platforms, as well as in formation flight dynamics, allow the implementation of optical links, in this new scenario of broadband-demanding applications.

For the satellite-to-ground applications, advances in the atmospheric telecommunications channel modeling, and in modulation and coding formats, allow the implementation of high speed links from small satellites, taking advantage of the networking techniques.

Our project contributes in both space and ground systems development for this new scenario, as well as a technology demonstrator of advanced payload engineering in small platforms, which contribute to capacity building in the space sector in Mexico, with an important repercussion in human capital development with modern information technology resources.

Finally the recent establishment of the Mexican Space Agency (AEM) will be an important element for the development of an innovative space technology in several focused fields, such as the small satellite technology, where the AEM will play a decisive role in promoting advanced payloads, such as optical communications, aiming to more complex projects in the future, in close collaboration with international teams.

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