Design of a Nanosatellite Laboratory Model as a Proof of Concept for a Future University Space Mission

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Abstract. A brief review of Microsatellite activities in Mexico and the world-wide technological tendencies in the field of small Satellites are presented in this paper. Afterwards, the proposal to design and develop a Nanosatelite (NS) laboratory model is presented. The NS model will evolve gradually towards a 3.5 Kgs Mexican Nanosatelital project, attractive in terms of development time as well as in manufacture and launching costs. Later, the preliminary design of NS subsystems and its current validation performed in laboratory are indicated. Finally, comments about the required steps to reach an operative model are also given.

Keywords: Nanosatellite, Instrumentation, laboratory model, satellite subsystems, satellite design.

1 The national experiences in the microsatellite field

Mexico has made two important efforts towards the development, launching, and operation experimental Microsatellites. They tried to call the attention of the country's political class and the society in general. Both efforts intended to form qualified human resources and to show the in-house development capacities in Science and Technology. In addition, the initiatives uncovered the opportunities and benefits to develop a national space program which might help to solve problems related with communications, national resources monitoring, disasters evaluation, and so on.

The first initiative was the UNAMSAT project, technically supported by the AMSAT International Organization to achieve the development of a fast mission. This project incremented the added-value of the 17 Kgs, [1], by designing and constructing an astronomical payload intended to research the amount of dark matter existing in the universe. Unfortunately the mission could not reach enough operational results in space.

The second effort was the Satex project, which aimed the development of a fully designed and manufactured 50 Kg domestic Microsatellite, [2] and [3]. The project contemplated several payloads in communications, remote sensing, and fault-tolerant hardware and software, [4]. The ambitious goals, the difficulties to operate a project distributed in several universities and research institutions from all over the country, as well as the budget limitations, avoided, until now, the project to be completed at all.

It is important to highlight that both projects intended to enhance future national activities in the area of satellite technology. They expected to push activities towards projects of greater added-value to offer High-Tech solutions and services in the medium term. However, as Mexico has not long term technological policies in this field, the activities in this area have depended and will depend on the successes of small projects like the referred ones. Part of the problem has been magnified by the economic complications experienced by the country, which have taken to the reduction of financial support for Science and Technology activities. This, in turn, has increased the competition between research groups in the search for budgetary resources, and it has affected significantly emergent areas that do not even have great successes or results that allow them to attract important financial support, like in the case of satellite technology.

1.1 International trends in the small satellite area

In the last two decades the information technologies have evolved to such a degree that the capacities of a 50 kgs Microsatellite of the 90s can now be replaced with a 5 kgs Nanosatellite. This takes us to establish that in one decade the small satellite systems have managed to shrink their mass in an order of magnitude carrying out similar capabilities. Two outstanding project are the 6 kgs SNAP-1 first three-axis stabilized Nanosatellite developed by the University of Surrey, UK, [5], and the 3 kgs Quakesat Nanosatellite fabricated by the University of Stanford to investigate the early detection of earthquakes, [6]. However, many interesting technology validation Nanosatellites are now under development, [7].

It is important to notice that a good number of NS and Picosatellites (PS) projects around the world are taking advantage of the experiences acquired in the development of previous missions elsewhere in the world. In this way, many projects successfully build and operate very low cost satellites which are developed at Universities by academic staff in collaboration with undergraduate and postgraduate students, [8], [9], and [10].

This working scheme has allowed the University of Surrey (UoS), UK, and his local enterprise Surrey Satellite Limited (SSTL), to become the worldwide recognized international leaders in the small satellites arena, [11]. In this way, few of their major and successful developments are: Snap-1, the first three axis stabilized Nanosatellite; Topsat, the first high resolution remote sensing 120 Kgs satellite, [12]; and the world's first

first high resolution remote sensing 120 Kgs satellite, [12]; and the world's first satellite constellation for disaster monitoring, [13] and [14].

In addition, UoS is currently developing projects that will lead the field in the next years with projects like: Gemini, a low-cost geostationary Minisatellite platform based in SSTL's heritage of LEO technologies, [15]; constellations for Earthquake prediction; Synthetic Aperture Radar Minisatellites; Infrared Imaging Minisatellites; Microsatellites and Minisatellites for communications; and swarms of Nanosatellites, [16].

Nevertheless, universities and international organizations from other countries also work in a competitive way in the small satellite field such as: Space Systems Development Laboratory from the University of Stanford, USA; University of Toronto Institute for Aerospace Studies from Canada; Moscow Aviation Institute from Russia; Stutgart University from Germany; Indian Space Research Organization from India; Japan; China; Brazil, among others.

2 The beginnings of the Nanosatellite project

Participants of the Satex project motivated by the successfully results obtained in the developing of on-board instrumentation and operational software for the mission, took the opportunity to transfer the generated know-how to the development of a small sized Nanosatellite of about 3.5 Kgs of mass, figure 1.

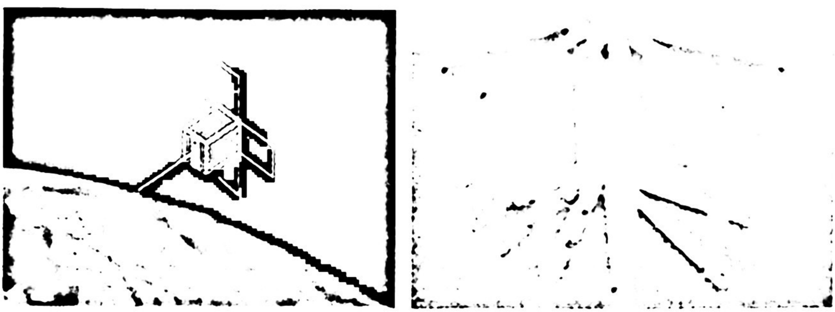

Fig. 1 a) Artistic view of the Nanosatellite platform,
b)Nanosatellite structural subsystem composed of aluminium frames

The initiative started in March 2004 through a postgraduate lecture imparted at the School of Engineering (DEPFI) from the National Autonomous University of Mexico (UNAM). The lecture is still going on under the title "Analysis and Design of Nanosatellites and Picosatellites". The initial subjects consisted in the study and analysis of worldwide important papers in the fields of Microsatellites, NS and PS. Followed by the presentation and discussion of the main ideas to construct a Nanosatellite vehicle based on the Satex mission experiences. Afterwards, the lecture was oriented to the Nanosatellite subsystem analysis, parts selection, design, and evaluation of projected solutions. In some cases digital simulation of circuits was performed with the support of commercial software tools. A key issue was the validation in laboratory of some proposed electronic solutions. In our case, validation was performed when possible, accordingly with parts availability. In addition, the class was requested to write a final report expected to facilitate the insertion of newcomers to the project through the continuity of the lecture at DEPFI, UNAM.

The design process employed in the project took advantage of international trends for both the Nanosatellite and Picosatellite fields, regarding the widely use of commercial-off-the-shelf (COTs) electronic parts, [17]. In order to protect them from the space environmental conditions, electronic and physical shielding was considered. It was also adopted the international trend to extensively employ automotive as well as personal communications electronic parts, because they share important characteristics with space qualified components. Besides, COTs parts are easier to obtain and cheaper when compared against military or space qualified parts. Among the good qualifications of automotive electronic parts are the followings: temperature range, shock tolerance, low power, small package and CMOS technology availability which is the best suited for space applications by its radiation tolerance when used in low earth orbit, [18].

Even though the main goal is to develop a Nanosatellite proof of concept design it was decided to include as much as possible good quality parts and protections to ease the transition to a Nanosatellite flight prototype.

3 The nanosatellite project

Under this scenario, the Nanosatellite proof of concept design constitutes an effort that assimilates some of the domestic experiences in order to promote a new Mexican satellite initiative. The last takes advantage of new available technologies to offer a very light satellite platform with competitive capabilities compared to those from Microsatellites developed in the 90s.

Additional project goals towards the generation of an attractive Nanosatellite platform are the reduction of: development time (1 year in average), manufacture cost ($ 60,000 USD, excluding the payload cost), and launching cost accordingly with the vehicle mass. This is a very important issue to balance the technological goals of the project with the objectives from the potential supporters (economical, political, etc.).

The subsystems inherited from the Satex mission are the followings: a flight computer, a structural subsystem reconverted to be used as Nanosatellite structure, sensors (magnetic field, temperature, current, and voltage), as well as software for both satellite operations and Earth Station, [2]. It must be highlighted that the development of the operations software for small satellites is a very time consuming activity, characterized by long and continuous working sessions. In this way, according with comments from experts in the satellite field, software development for a small satellite implies about the 70 % of the workload for the whole project, [19]. So, the possibility to use or to adapt available software can importantly reduce the project workload as well as the mission development time.

3.1 The Nanosatellite Platform

The Nanosatellite platform includes all the necessary support subsystems for the satellite. In other words, the platform allows the space vehicle to provide the service for which it was made-up. For that reason, the Nanosatellite platform is composed by: structural subsystem, power subsystem, communications subsystem, flight computer, telemetry sensors, as well as room and resources (energy, communications, and automation capabilities) to lodge different payloads.

Once the platform becomes integrated with payloads, operative software, and the terrestrial segment, a complete satellite system is obtained.

3.2 The Nanosatellite laboratory model

The main objective of the NS proof of concept is to attract the attention of both potential financial supporters and academic authorities. The goal will be to continue the growth of the laboratory model in order to generate a NS engineering model. This is the reason why the current laboratory model does not include all of the NS subsystems. However, it contains few of the harder to accomplish satellite subsystems such as: the satellite operations software, earth station software, on-board computer, and part of the power subsystem. On the other hand, the paper design of the NS model is more advanced than the NS laboratory model for obvious reasons.

3.2.1 Structural Subsystem

The Nanosatellite structure constitutes an inheritance from the Satex project, where it was employed as the container of a reconfigurable flight computer. The structural subsystem, apart from offering physical protection to the NS subsystems, will connect the NS to the launching system through a mechanical interface. Figure 1b) shows the NS structure formed by aluminium frames designed to be connected one after each other in a piggyback fashion.

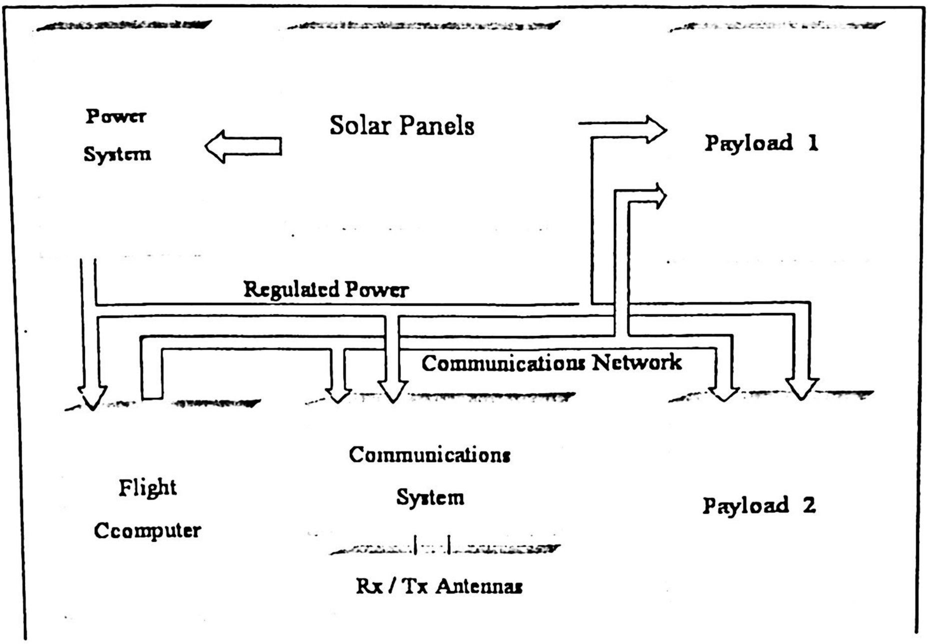

Fig. 2 Block diagram of NS subsystems

The first NS frame will be dedicated to the power subsystem along with telemetry sensors. The second will contain the communications subsystem, and the third frame is assigned to the flight computer, whereas the remaining frames can be assigned to hold satellite payloads (payload frames can be replaced both in amount or size according with mission needs). Once the NS is assembled its body dimensions can be 18x13x10 cm, depending on the payload needs.

Once the satellite body is assembled, four of the main NS faces will be covered with solar panels attached with stainless steel screws. The two remaining NS walls are let empty, whereas one of them is employed to accommodate the mechanical interface with the launching system.

Considering that one of the most important restrictions in satellites is its available power, the NS design considers the incorporation of 4 deployable double-sided solar wings. The wings will have a spring type mechanism that in orbital conditions will hold the panels in an orthogonal position with respect to the satellite walls. In addition, the spring mechanism will allow the panels to be parallel folded to the satellite walls with the application of a handy compression to the panels. The solar wings will be held in that closed position by means of a nylon string. Once in orbit, the flight computer will send an order to burn the nylon string generating the automatic deployment of solar wings to the position shown in figure 1.

3.2.2 Power Subsystem

The NS power subsystem is formed by following three modules: generation, battery charge regulation, and power distribution. The generation module will charge a set of military qualified Li+ batteries. The module is formed by the solar panels which will be fabricated in our facilities, starting either with a base of space aluminium or composite material. The Nanosatellite will contain twelve solar arrays, figure 2, four will be double sided deployable solar panels and four will be directly mounted to the satellite body. The solar panels will employ GaAs COTs solar cells from Boreal Laboratories Ltd., whose cells are designed and utilized by the space industry. Each cell has the following characteristics: dimensions of 2x2.5 cm, 0.5 V output, and 100 mAmp/cm^2 at the beginning of life. More detailed information regarding the electronics of the power generation module, the battery charging scheme, and the power distribution unit of this subsystem is found in [20].

3.2.3 Flight Computer

The flight computer (FC) is a heritage from the Satex project. The hardware and software for this subsystem was fully generated through several years of work at UNAM, figure 3

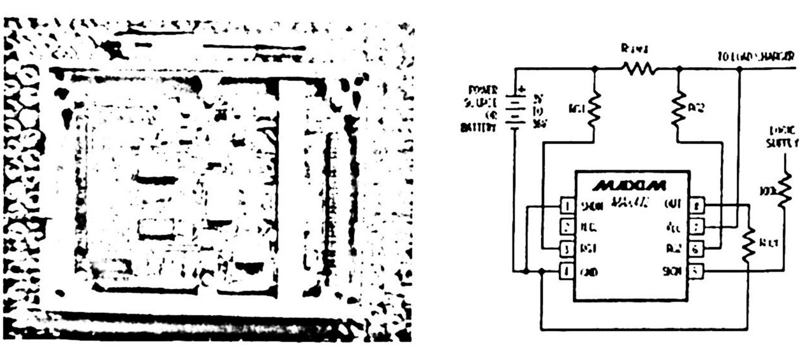

Fig. 3 a) NS flight computer installed in its aluminium frame,
b) Selected current sensor for the UN

As it is known, space applications have very severe restrictions of design; particularly in terms of weight, volume, and electrical available power. In addition, other common difficulties with all types of spacecrafts should be taken into account: vibration during the launching, the effects of radiation, [21], and vacuum, as well as the extreme temperatures, among others. All these constraints were considered during the development of the FC for both hardware and software.

The FC is a 5 volts stand-alone microcomputer based in the COT Industrial 16 bit RISC processor from Siemens. The processor has extended range of temperature and is latch-up protected with dedicated electronics. In addition, the FC memory is protected against data losses produced by Single Event Upsets (SEUs), in this case with the help of a military qualified error detection and correction (EDAC) unit, 29C516E from TEMIC.

The FC also contains the following peripherals: 64 Kb ROM for NS basic software, 1.2 Mb of SRAM protected by EDAC, 40 MHz military qualified oscillator, military qualified digital logic, watch dog timer, interrupt controller, three serial channels, 10 bits A/D conversion channels, 76 I/O lines, as well as a high quality multi-layer PCB.

3.2.3.1 Flight Software

The on-board already available software provides facilities for: up-loading new applications software, orbital management functions, telemetry acquisition, telemetry handling, telemetry packaging, telemetry transmission, command reception, command processing, mission reception, communications with ground, EDAC software, and watch-dog software, [22].

3.2.4 Sensors

The NS laboratory model will be equipped with telemetry sensors that will provide operative information regarding the satellite platform. It must be highlighted that one of the usual problems faced in satellite instrumentation is related with the amount of cables going and coming among the satellite equipment. This inconvenience is particularly present during the sensor wiring stage, because in traditional instrumentation there are at least two cables by sensor. If we take in to account that, by instance, a small Nanosatellite needs around 40 sensors, there would be required to place 80 cables all over the satellite PCBs. To avoid this problem NS employs 1-wire sensor technology, [23]. This allows saving weight and room in the platform. The 1-wire technology allows digital communications for data exchange among the flight computer and the sensors, therefore eliminating the insertion of noise in telemetry readings. Each 1-wire device contains a serial number formed by 64 bits for identification within a single 1-wire bus. Although, the connection among all the sensors can be done over one single 1-wire bus, the UN employs two of them for clearness reasons. One of them will be in charged of all the temperature sensors and the other will be in charged of the voltage and current measurements.

Experiences from successful small satellite projects show that the expected internal temperature from an operative satellite in orbit is between 0 and 5 degrees Celsius. This value is obtained with the help of external heat protections of the satellite, as well with the internal heat dissipation facilities which force the physical contact among the satellite equipment.

The DS18S20Z 1-wire temperature sensor will be used aboard UN. It operates in a rank of temperatures from -55 to +125 degrees Celsius, with a 9 bits resolution. Each UN printed circuit board will enclose 6 temperature sensors, which will offer useful information to validate the satellite thermal model. Voltage measurements will be accomplished by the 1-wire DS2450, analogical to digital converter, which contains 4 channels of 16 bits.

Because the 1-wire currents sensors are not available, the UN will employ the analogical current sensor MAX472 along with the 1-wire DS2450, analogical to digital converter. The output voltage of the MAX472 is directly proportional to the measured current and its output current equation for a typical application is given by:

$$V_{out} = \frac{R_{sense} . R_{out} \times I_{out}}{RG}$$

Where R_{SENSE} needs to be selected in order to obtain a minimal voltage drop associated to the maximum current to be sensed.

3.2.5 Communications Subsystem

The communications system chosen for the NS vehicle will be based on the TEKK KS-900/960 data radio and the Bay Pac 9600 modem. Both of them modified for space flight. The equipments are attractive because they have successfully flown in the QuakeSat Mission, in 2004, [6]. In addition, the radio has the following characteristics: 2 Watts RF output, varactor controlled Direct FM modulation, -30 to +60 °C operation, 0.199 Kg weight and 7.5-12 V operation.

Nevertheless, the NS laboratory model has been initially communicated with the ground station software through wire lines to allow a quickly validation procedure. Later we will migrate to a low power wireless system to validate the NS software.

4 Current validation tests performed in laboratory

Some of the NS subsystems have undergone certain preliminary testing. Among them: the flight computer, FC operational software, Earth station software, and communications subsystem based on low power wireless electronics. However, few other subsystems are just about to be implemented either in breadboards or directly in PCBs (for those parts only available in surface mount package) for first round testing. Like in the cases of: power subsystem, sensors, solar panels, and payloads.

On the other hand, we have plans to perform few integration tests among available subsystems. Particularly, a campaign of preliminary tests between the flight computer, its operations software, and the Earth Station software has been planned. Those results will be soon published.

5 Concluding Remarks

This article has presented the efforts made towards the design of a NS laboratory model. The nanosatellite project has been fed with knowledge and equipments (hardware and software) developed in past domestic experiences in the space field. In this way, the project has been fully designed with extensive use of COTs parts tested in previous space missions and reported in international publications. However, the project also has important advances in the construction of NS subsystems which demand large development time, such as: the flight computer, flight software, Earth station operations software, etc. In the case of complementary subsystems they are just about to initiate preliminary operative tests. Therefore, in the short term we expect to have a basic laboratory model. The goal will be to use the NS model to make presentations in order to promote the project and search for financial support to construct the flight model. The financial support also would be used to prepare a pair of payloads, to make the NS qualification tests, as well as to finance its launching. By the way, the last will be economic, because the launching cost is related to the satellite mass, which in this case will be of approximately 3.5 kgs.

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