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SP-SAT: DEVELOPMENT OF AN EDUCATIONAL SATELLITE

In Bolivia, as in several other Latin American nations, there is a growing trend of burgeoning space projects and a rising interest among young students in the aerospace domain. Consequently, there arises an imperative to cultivate a new generation of space professionals. However, the exorbitant costs associated with the equipment utilized in these projects render them inaccessible to a vast majority of interested students, including CubeSat kits, educational satellites, satellite kits, among others. Consequently, alternatives like educational satellites have emerged to simulate the satellite design, construction, testing, launch, and operation processes on a scale conducive to student involvement. The primary challenge faced by students lies in integrating the essential subsystems of a satellite, encompassing power supply, sensors, and communication systems, within the confines of limited space. Considering this, the design and construction of an educational satellite with its respective signal reception equipment was developed. The equipment designed and manufactured is a low-cost one so that universities and educational centers could acquire it. This equipment educational kit is called SP-SAT (Space Program — educational satellite kit). This real satellite simulator offers a wide variety of educational activities. The kit's equipment is distributed in two systems: 1) Space Segment, which consists of an Onboard Computer (OBC), Electrical Power System (EPS), Communications System (COMM), Experiment Plate (PYL), Complete PLA plastic structure (3D printed), rods, bolts, and nuts. 2) Ground segment: This segment includes all the equipment that is part of the ground station, which will receive data from the satellite.

Keywords: *classroom satellite, educational satellite, picosatellites, low-cost satellite.*

INTRODUCTION

The aerospace field has historically catalyzed some of humanity's most remarkable achievements. Regrettably, its development lags in numerous South American nations, primarily attributable to economic constraints. Nonetheless, several academic institutions in South America have endeavored to advance aerospace engineering through initiatives focused on low-cost projects, often commencing with picosatellite missions.

Satellites are categorized based on their application, characteristics, orbit, and weight. Regarding application, they include meteorological, communication, navigation, earth observation, and astronomical satellites. Character classifications encompass military, governmental, and civil satellites. Orbit types consist of low, medium, geosynchronous, and highly elliptical orbits. Weight classification, often considered the most utilized, is detailed by mass, with large satellites exceeding 1000 kg, medium satellites rang-

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ing from 500 to 1000 kg, and small satellites falling below 500 kg. Further subcategories include minisatellites (100 to 500 kg), microsatellites (10 to 100 kg), nanosatellites (1 to 10 kg), picosatellites (100 g to 1 kg), femtosatellites (10 to 100 g), attosatellites (1 to 10 g), and zeptosatellites (0.1 to 1 g), as specified by [9] and supported by [3, 7].

Nowadays, the imperative to develop Pico, Nano, and Microsatellites is paramount, serving as a means to facilitate access to space and sustain space exploration endeavors for academic institutions and smaller nations [6]. Programs such as The Open Prototype for Educational NanoSats (OPEN) are dedicated to fostering the advancement of educational, governmental, and commercial nanosatellites. This initiative is grounded in the recognition that such endeavors not only stimulate societal progress but also significantly contribute to educational enrichment [1]. Different investigations, such as [10], have elucidated various educational outcomes stemming from student engagement in a small spacecraft development program. These include enhanced confidence in contributing to scientific endeavors, improved ability to articulate scientific concepts, strengthened collaborative skills, heightened confidence in succeeding in future science courses, increased capacity for independent work, and the cultivation of patience in navigating the deliberate pace of research.

An exemplary instance of a small spacecraft development program is exemplified by the creation of an "Educational Satellite" — a simulated model mirroring the subsystems of an actual satellite intended for terrestrial purposes. This model serves as a practical tool for familiarizing students with aerospace concepts, enabling them to engage in cost-effective simulations of space missions, as well as to design and evaluate customized components. Studies such as [4] aim to devise more accessible solutions for picosatellites, leveraging kits such as the PocketQubes. Currently, there exist many educational satellites available from different companies, the best known being EyasSat. This is a fully functional nanosatellite designed for teaching spacecraft systems engineering in the classroom and laboratory. EyasSAT was co-developed between the U.S. Air Force Academy and Colorado Satellite Services. EyasSAT demonstrates six traditional satellite subsystems of a satellite bus: Structural, Electrical Power (EPS), Data Handling (DH), Communications (COMM), Attitude Determination and Control (ADCS), and Thermal subsystems [2].

Unfortunately, obtaining these educational satellites implies an elevated cost, ranging from 8000 up to 12000 dollars. For this reason, this paper presents a low-cost kit that aims to inspire and motivate university and other young students to get familiarized and involved with satellite missions. Specifically, the design and manufacturing of an economical satellite called SP-SAT is presented along with its technical, user, software, and hardware specifications.

SP-SAT: EDUCATIONAL SATELLITE

The "Educational Satellite" provides the experience of being involved in a space mission by allowing the user to perform measurements and different experiments at a height of 1000 to 2000 meters.

An "Educational Satellite System" is a simulator of a real satellite integrated inside a small cylindrical volume (6.6 × 11.1 cm). This SP-SAT provides all the necessary subsystems to work properly. The communications system is capable of transmitting the acquired data at a height of up to 2000 meters. The SP-SAT contains the components of the satellite as well as a ground station to receive data directly on a computer. The SP-SAT allows students to focus on the experiment and optimization of the subsystems instead of the internal workings of the satellite.

The Educational Satellite System is a model of an artificial satellite designed for terrestrial use, having the same subsystems as a space satellite. This allows us to introduce students to the subject of aerospace by simulating real missions without leaving Earth and encourages the development of custom experiments.

The SP-SAT provides all the operational components at the mechanical, electronic, and software levels, thus representing an ideal tool for teaching and experimentation in schools as well as in universities. The communications system allows the transmission of information concerning the incorporated experiments to a ground station, which receives the data by connecting directly to a computer with the corresponding software installed.

Components of SP-SAT. The SP-SAT contains two main systems: the space and ground systems. On the one hand, the space system consists of those compo-

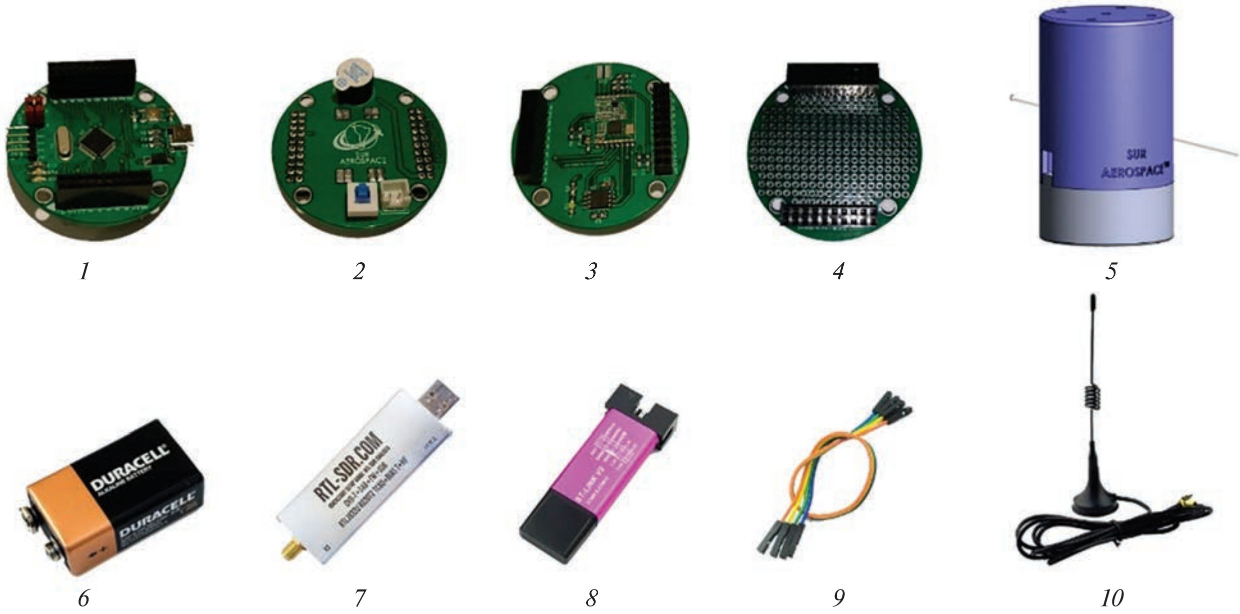


Figure 1. Components of Space System (Satellite)

Table 1. **Space and Ground Systems**

#item	Component	Subsystem	Description	Quantity
1	Onboard computer	CD&H	Computer (printed circuit board) with: Arm Cortex-M3 MCU with 64 Kbytes of Flash memory, 72 MHz	1
2	Electric power system	EPS	Printed circuit board of DC-DC 3.3 V (regulator)	1
3	Communication system	COMM	Printed circuit board with radio RFM26 433 Mhz (modulation OOK, FSK, GFSK)	1
4	Board for experiment	PYL	Printed circuit board (empty)	1
5	Structure	MEC	Complete structure (PLA) with joining elements (bolts, screws, rods)	1
6	Battery	EPS	9 V	1
7	Radio receiver	GS	RTL-SDR V3	1
8	Advanced programmer	CD&H	ST-link V2	1
9	Programmer cable	CD&H	4 pin	1
10	Antenna	PYL	Frequency RX 433 Mhz	1

nents that perform the functions of a satellite during a space mission. These components are:

• Command and Data Handling and Onboard computer (OBC) contains both the hardware and software to carry out any important operations in the satellite. This subsystem is usually considered the brain of the entire satellite.

• Electrical power system (EPS). Its main function is to provide electrical energy to the whole satellite.

• Communications system (COMM). This subsystem works with the received and transmitted signals. Specifically, it receives, amplifies, processes, and transmits the signals.

• Payload or experiment (PYL). The payload refers to the entire set of instruments and tools used for the satellite to fulfill its objective or mission. In this kit, the plate is empty. The reason for this is that students can place the specific experiment they want to perform. These experiments can have components such as sensors, cameras, etc.

• Mechanical structure (MEC); finally, there is the satellite component in charge of protecting it. The kit structure is composed of a 3D printed shield with Polylactic acid (PLA) with their respective clamping elements rods, screws, bolts, and nuts.

On the other hand, the ground system refers to those components and elements that allow the programming of the satellite and the reception of data from the satellite, such as:

• Ground station (GS)
• Advanced programmer
• Complementary software.

The aforementioned components will be displayed in Table 1, where items 1 to 6 correspond to the Space System, and items 7 to 10 correspond to the Ground System. Figure 1 displays the finished components of the SP-SAT with the corresponding numbering shown in Table 1. Items 1 to 6 correspond to the Space System, while items 7 to 10 correspond to the Ground System.

Assembly. The components that are part of the SP-SAT were designed in the most optimal way possible to eliminate the need for connection cables. The PC104 component was implemented for the various subsystems. This component enables the interconnection of the different subsystems. The assembly order for the components of the SP-SAT is specified in Figure 2. All boards possess two triangular markings that indicate their orientation. It is very important that these markings are aligned while assembling.

Electronic assembly order (see Figure 2):

- Experiment(s) board(s)
- Communications Board
- Onboard computer
- Energy supply board

General assembly order (see Figure 2):

- Screw
- Structurecasing
- Electronic components
- Battery

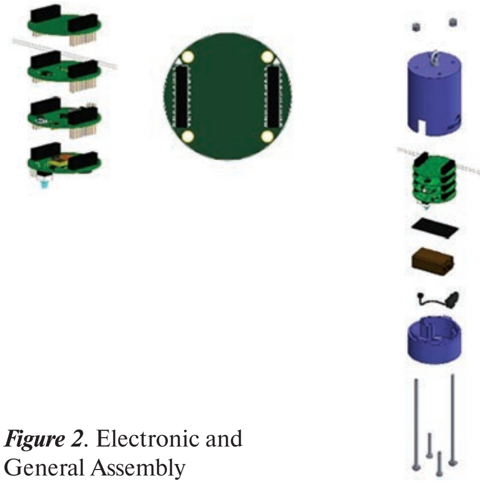


Figure 2. Electronic and General Assembly

- Battery connector
- Base structure
- Bolts

Software Installation. For the correct operation of the SP-SAT, there is a series of online libraries that allow its programming through Arduino and Matlab-Simulink, as well as software for the operation of the SDR and the ST-link V2 in-circuit programmer. The software repository (GitLab and GitHub) [5] provides additional up-to-date information on the SP-SAT, along with the libraries and sample code for the supported platforms.

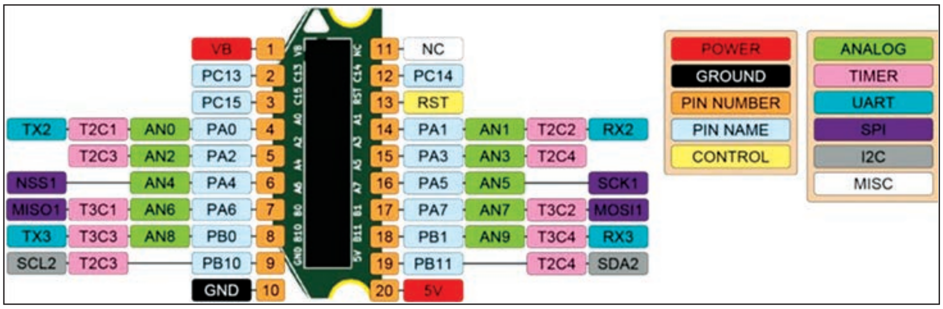
• Arduino: Compatibility with Arduino IDE version 1.8.x through the Arduino — STM32 extension.

• Matlab-Simulink: Compatibility with Matlab-Simulink version R2017b or above through the extension RTL-SDR Support from Communications Toolbox.

• ST-Link V2: it allows the programming and debugging of the code through specialized software, like SystemWorkbench for STM32 (SW4STM32).

General Geometry of the Boards. A relatively small size configuration was sought in order to keep the satellite's weight down. The educational satellite's printed circuit board, together with its structure, weighs 310 grams. For this reason, all the boards have the same dimensions. The dimensions of printed circuit boards are: the surface diameter is 53.34 mm, and the distance between PC104 connectors is 33.02

PINOUT-CONNECTOR A



PINOUT-CONNECTOR B

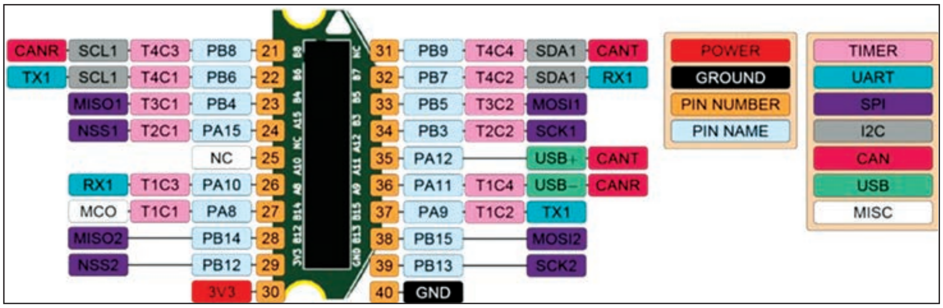


Figure 3. Pinout Connector

mm, which are 25.4 mm in length. The total board width is 19.5 mm.

APPLICATIONS

As you can see in Figure 3, according to the design and the pinout disposal, there are lots of ports available to use and configure according to the requirements of different kinds of experiments. Considering the natural and main purpose of the SP-SAT, it is a device that can communicate with different types of sensors to transmit the measurements' information, simulating the real behavior of a satellite system. Some examples of it include measurement and calculations of the concentration of gases in the atmosphere using a carbon monoxide sensor such as an MQ7 sensor.

Currently, students of Electronic and Telecommunications Engineering in Bolivia are working with SP-SAT for various subjects and analyses. To test the operation and range of the satellite kit, tests can be carried out using drones that raise the device to a certain height and verify whether the STL-SDR receiving device can capture the information sent by the SP-SAT.

CONCLUSIONS

As a result of this project, it was possible to design and manufacture a satellite educational platform designed in Bolivia to train university students. This platform is fully operational and has been tested for operation up to 2000 meters between the satellite and the ground station. The built and assembled satellite can be seen in Figure 2.

The field of aerospace plays an increasingly important role in the development of South American countries, where more and more projects of this kind are executed. These projects generally start as pico-satellite missions, but the final objective is to develop these technologies so that more useful satellites can be designed and built. This is the case of Argentina and Brazil, which started with small projects, but over the years and with the gained experience. Now, both countries manufacture satellites for Earth observation and communications at the service of their own country and other countries. The present project is intended as a starting point for university students to gain experience in space technology and to generate the motivation required to execute increasingly complex projects.

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SP-SAT: РОЗРОБКА ОСВІТНЬОГО СУПУТНИКА

У Болівії, як і в деяких інших латиноамериканських країнах, спостерігається тенденція до зростання кількості космічних проєктів і підвищення інтересу молодих студентів до аерокосмічної галузі. Як наслідок виникає потреба у вихованні нового покоління космічних професіоналів. Однак непомірна вартість обладнання, що використовується в цих проєктах, зокрема комплектів CubeSat, навчальних супутників, супутникових наборів, робить їх недоступними для переважної більшості зацікавлених студентів. Як наслідок з'явилися альтернативи, такі як навчальні супутники, що дозволяють моделювати процеси проєктування, конструювання, тестування, запуску та експлуатації супутників у масштабах, що сприяють залученню студентів. Основний виклик, з яким стикаються студенти, полягає в інтеграції основних підсистем супутника — джерел живлення, давачів і систем зв'язку — в обмеженому просторі. З огляду на це було розроблено дизайн та конструкцію навчального супутника з відповідною апаратурою приймання сигналу. Розроблене та виготовлене обладнання є досить недорогим, щоб його могли придбати університети та освітні центри. Це обладнання має назву SP-SAT (Space Program — educational satellite kit) — «Космічна програма — навчальний супутниковий комплект». Цей справжній супутниковий симулятор пропонує широкий спектр освітніх заходів. Обладнання комплекту поділяється на дві системи: 1) космічний сегмент, який складається з бортового комп'ютера (OBC), системи електроживлення (EPS), системи зв'язку (COMM), плати інструментарію експерименту (PYL), повної пластикової конструкції PLA (3D-друк), стрижнів, болтів і гайок; 2) наземний сегмент, який включає все обладнання, що входить до складу наземної станції, яка буде приймати дані з супутника.

Ключові слова: навчальний супутник, освітній супутник, пікосупутники, недорогий супутник.