UPC NanoSat-Lab - Past, Present and Future Activities

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Abstract

The Universitat Politècnica de Catalunya UPC NanoSat Lab is part of the CommSensLab-UPC Specific Research Center of the Department of Signal Theory and Communications, and counts with the support of the School of Telecommunications Engineering (Telecom Barcelona, ETSETB). It is located in the UPC Campus Nord. The lab was originally created in 2007 to promote the testing of novel remote sensors and techniques in space, taking advantage of CubeSats. Over time, the lab has also started the study of Earth-to-space IoT and RF intersatellite link communications, as key enabling technologies for the next revolution of Earth Observation.

At the time of writing this abstract, the UPC NanoSat Lab has developed and launched four CubeSats, and is working in three new missions that will be launched in Q4 2022 - Q1 2023. At present, the Lab is developing an "Open PocketQube Kit" for IEEE as a low-cost educational platform on space-related technologies.

The lab has also a Class 8 clean room equipped with a shaker and thermal vacuum chamber, and Helmholtz coils, air bearing system, and Sun simulator for attitude determination and control system testing to conduct the environmental tests.

Finally, in the MontSec Astronomical Observatory (OAdM),which is managed and operated by IEEC, hosts the UPCNanoSat Lab VHF/UHF and S-band ground station [3], where the data from the [3]Cat-5/A satellite where downloaded.

Since its inception in 2007, about 300 students have been trained in the lab, either as undergraduate students in the "Advanced Engineering Project" of the ETSETB, as Final Degree or Master Thesis projects, as graduate students, or just for an internship.

This paper presents a quick overview of the past, present and future activities of the UPC NanoSat Lab.

Keywords

CubeSats, Laboratory, Testing facilities, Ground Station, Education, Research

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1. Introduction - A quick historical review

The UPC NanoSat Lab was created in 2007 after UPC Chancellor, Prof. Antoni Giró, tasked Professors Juan Ramos and Adriano Camps the development of two tractor projects: one in the field of “aeronautics,” and another one in the field of “space” to collimate the efforts and know-how of several UPC engineering schools, and notably the Aeronautics schools that had been recently created in Terrassa and Castelldefels. Since no specific budget was allocated for these tasks, the beginnings were slow, as activities were conducted in a best effort basis “in the cracks” of the usual projects, using project remnants to feed the new space activities.

The first project was the UPCSat-1, renamed later as ³Cat-1 (pronounced /Cube-Cat One/), a 1 unit (1U) CubeSat including a number of technology demonstrators coming mostly from the Department of Signal Theory and Communications, and the Department of Electronics Engineering, the two that at that time had more background on space-related activities. The project started as a mix of subsystems that were purchased, those that we considered critical such as the On-Board Computer (OBC), the Electrical Power System (EPS), the structure itself etc. and subsystems developed in-house. However, it was soon realized that neither the CubeSat “standard” was a complete standard (as it only defined the mechanical requirements, but not electrical ones, so there were incompatibilities in the connectivity of some of the subsystems purchased), nor some of the subsystems purchased really deserved the name of space qualified (e.g. EPS with some components not really ready for space, or others with serious design “issues” etc.).

In these circumstances, it was decided to step back and start designing the different subsystems inhouse, as the only way to make sure that we knew what was inside… It was somehow a sort of “vertical integration,” because of the severe budget constraints. In our way to try to use commercial off-the-shelf (COTS) components we, little by little, started creating what is now called the UPC NanoSat Lab, and in the office space we occupied in 2007 in the Omega-3 building of UPC Campus Nord, we started bringing in a customized Thermal Vacuum Chamber (TVAC) for the bake-out and thermal cycling tests, a Sun simulator with a COTS Xenon lamp (whose spectra was cross-checked against an Oriel Top of the Atmosphere Sun simulator).

In 2013 we received co-financing to purchase a long-waited electro-dynamic shaker to conduct all the vibration tests. Because of the special requirements (too heavy) the UPC NanoSat Lab was migrated to a basement between the A3 and B3 buildings at UPC Campus Nord.

In May 2018, thanks to a “María de Maeztu” grant awarded to the CommSensLab Research Center (Dept. of Signal Theory and Communications) an ISO 8 clean room was going to be installed. At that time, we were “invited” to move, and thanks to the school of Telecommunications Engineering (ETSETB-UPC) dean, Prof. Ferran Marqués, and UPC Chancellor, Prof. Francesc Torres, a new location was provided in the basement of the C4 building, in the same UPC Campus Nord. Today’s UPC NanoSat Lab was inaugurated on November 2018 [1]. At the time of writing this paper, we are expecting to receive a bigger shaker, to be granted by a private company. This will allow the lab to grow, and also offer a better service to national and international companies, as the original facilities were dimensioned according to the needs of a University lab, with limited budget.

To put things in the historical context, in March 2010, on the occasion of the 10th anniversary of the Bologna Process, the European Higher Education Area (EHEA) was launched. As the main objective of the Bologna Process since its inception in 1999, the EHEA was meant to ensure more comparable, compatible and coherent higher education systems in Europe. It implies the establishment of new teaching methodologies, to the detriment of traditional master classes: Continuous Assessment, and Practical Teaching. After having compared several models for the definition of the new curricula, the ETSETB-UPC identified the Conceive-Design-Implement-Operate (CDIO) initiative as the most complete and coherent model. In the new curricula, the CDIO initiative is implemented with four subjects: Introduction to Information and Communication Technologies (ICT) engineering (or ENTIC), Basic Engineering Project (or PBE), Advanced Engineering Project (or PAE, the capstone project), and the Final Degree Project. Since its inception, a PAE subject called under the generic term “³Cat-NXT” has been offered to the students willing to learn more about space activities, electronic design, programming, testing etc. [2]. The course starts with an intense 11 hour tutorial on different aspects related to spacecraft systems engineering that levels the different student backgrounds, depending on their majors, and provides some basic understanding on the main design considerations that apply to spaceborne systems, that do not apply for -for example- consumer electronics. The topics change every semester according to the UPC NanoSat Lab's main activity, but typically they are connected along 3-4 semesters. This creates a bit of extra overhead to the students, because of the extra work to document and report for the next semester students, but also helps them to understand how a real project in a company is, including internal reporting to a team leader, weekly oral presentations and progress meetings with the faculty, taking minutes of the meeting (MoM), with action items, as well as three main project meetings including Preliminary and Critical Design Review meetings, and Final Review meeting.

Since the ^{3}Cat-NXT PAE subject started, we estimated that about 300 students have followed this course, and many of them have continued space-related activities in the lab during their Final Degree project, and some of them in their Master's Thesis, or even Ph D Thesis. And more interestingly, the lab is not restricted to students from the ETSETB-UPC, students from other UPC Schools or from different countries are welcome to join an international multi-disciplinary, and "multi-generation" (from freshmen to post-docs) working environment.

In the next sections, the UPC NanoSat Lab facilities, and main missions will be explained.

2. UPC NanoSat Lab: Facilities

The facilities of the NanoSat Lab are designed to carry out the assembly, integration and test procedures of up to 6U CubeSat spacecrafts and subsystems. An ISO 8 cleanroom area that includes all the necessary instrumentation and testing equipment to perform verification and validation procedures (Fig. 1).

Fig. 1. UPC NanoSat Lab clean room with TVAC and shaker

2.1. Thermal Vacuum Chamber

A custom cylindrical Thermal and Vacuum Chamber (TVAC) that emulates the outer space conditions is also available. It is mainly used for the environmental test campaigns in CubeSat missions. It has a heating system based on three infrared lamps and a cooling system based on liquid nitrogen that circulates around the thermal shroud. Internal temperature can be controlled from -196 ºC to +300 ºC, while the minimum pressure is 10^{-5} mbar. This allows to simulate the pressure and thermal cycles of a satellite in orbit. The facility is operated by a centralized computer that controls the temperature and vacuum levels depending on a target reference. 2.92 mm (K-type) RF connectors, DB-9, and thermo-couples are available at the feedthroughs. The Device Under Test (DUT) can be hanged from the top of the TVAC or placed on a plate thermally insulted from the shroud, which can rotate thanks to a magnetically coupled motor. The TVAC also features a large quartz window to allow the light from a Sun simulator to illuminate the DUT, and a Germanium lens to observe the temperature distribution in the DUT.

2.2. Shake table

Vibration tests in all three axes can be carried out in the electrodynamic shake table model Data Physics GW-V400 [3]. Sine (frequency sweep), random and some shock tests can be conducted.

2.3. Helmholtz Coils and air bearing

The Helmholtz Coil System is a set of three pairs of coils manufactured by Serviciencia SL, that generate an arbitrary magnetic field which is uniform in a cubic of ~40 cm side. The system includes an air-bearing to test attitude determination and control systems (ADCS) in near zero-g conditions. The current that flows through the coils is generated by a triple power supply controlled by a computer, and it can mimic the Earth's magnetic field while the satellite is orbiting around the Earth (Fig. 2).

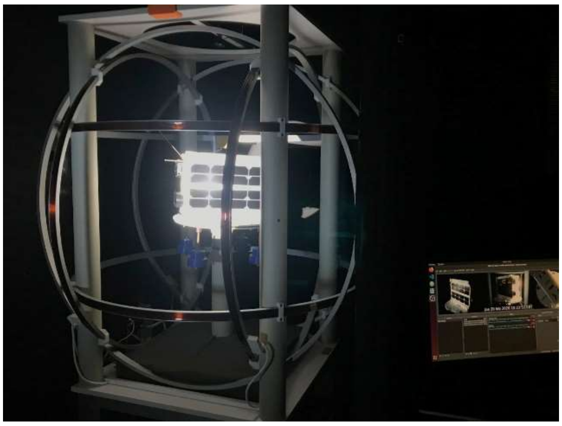

Fig. 2. Helmholtz coils during ADCS testing of a 6U CubeSat

2.4. Ground Station

The UPC NanoSat Lab also designed, manufactured, and operates its own ground station (Fig. 3). It includes quad-antennas at Very High Frequency (VHF) from 144 to 145 MHz; Ultra High Frequency (UHF) from 435 to 438 MHz; and a 3-m dish at S-Band from 2200 to 2290 MHz. It si located at the Observatori Astronòmic del Montsec (OAdM) premises, which is owned and operated by the Institute of Space Studies of Catalonia (IEEC). VHF and UHF are transmit/receive, and exhibit a G/T of - 16 and - 14 dB, respectively. S-band is receive only, and exhibits a G/T of + 9 dB.

Fig. 3. IPC ground station at IEEC Observatori del Montsec Premises.

3. UPC NanoSat Lab Main Projects

In this section, the main satellite missions developed by the lab are explained.

3.1. ^{3}Cat-1

^{3}Cat-1 (Intl. designator 2018-096K) was the first project of the lab: a 1U educational and techdemo mission [4]. It was started in 2007, and it was ready for launch in 2014, but the first Russian invasion of Ukraine prevented it from being launched using a Dnepr rocket. After this failed attempt, it was re-scheduled for a launch in a Falcon 9, but for two occasions the previous launch exploded (June 2015 and September 2016). It was finally launched from Sriharikota Launching Range (India) using a PSLV in November 2018.

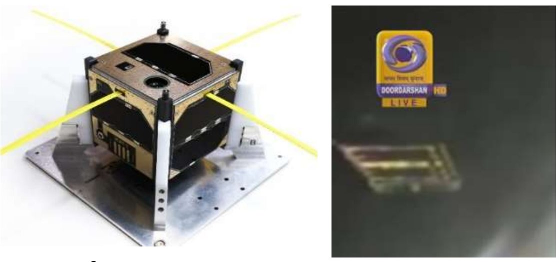

Fig. 4. ^{3}Cat-1 (left), and moment in which it was injected in orbit (right)

^{3}Cat-1 included the following payloads: 1) an “eternal” self-powered beacon using a Peltier cell to generate electricity thanks to the temperature gradient between the inner and outer parts of the satellite, 2) a CellSat photovoltaic solar cell developed by the Micro- and Nano-Technologies group from the Electronics Engineering Dept at UPC, 3) a monoatomic oxygen detector based on the analysis of the resonant frequency of a MEMS device covered by a sensible polymer, 4) an experiment to characterize a Graphene Field Effect Transistor (GFET), 5) an experiment to test the effects of plasma in Wireless Power Transfer (WPT) links, 6) a VGA-resolution CMOS camera, and 7) a Geiger counter.

3.2. ^{3}Cat-2

^{3}Cat-2 (Intl. designator 2016-051B) was a 6U Earth Observation mission [5]. It was launched from Jiuquan Satellite Launch Center using a Long March D2, in August 2016. ^{3}Cat-2 payload was PYCARO, a dual-frequency (L1 and L2), dual-polarization (RHCP and LHCP), and dual-constellation (GPS and Galileo) Global Navigation Satellite Systems-Reflectometer (GNSS-R).

Fig. 5. ^{3}Cat-2 nadir looking antenna array (left), and ^{3}Cat-2 during integration in the DuoPack deployer at ISIS premises.

3.3. ^{3}Cat-3

Leveraging on the ^{3}Cat-2 experience, ^{3}Cat-3 was meant to be a multi-spectral imaging mission for the Cartographic and Geologic Institute of Catalonia (ICGC) [6]. Unfortunately, despite being included in its Strategic Plan, political issues at Catalan and Spanish levels prevented it from being approved, and the mission stopped after a Phase A study. This mission is reincarnated as GenEO, the second mission of the New Space strategy of the Catalan government.

3.4. ^{3}Cat-4

^{3}Cat-4 mission aims at demonstrating the capabilities of smallest nano-satellites for Earth Observation (EO), in particular using GNSS-R and L-band microwave radiometry, as well as for Automatic Identification Services (AIS) [7]. The goals of this mission are mainly educational, technology demonstrator of the Flexible Microwave Payload-1 (FMPL-1) which implements the three RF payloads in a single software defined radio, and scientific, including dual-frequency (L1 and L2) GNSS-R and assessing the required ionospheric corrections, and the creation of RFI maps.

^{3}Cat-4 was selected by the European Space Agency (ESA) Academy for the "Fly Your Satellite!" program (second edition). Its launch is foreseen for Q4 2022 in the maiden flight of Ariane 6.

Fig. 6 shows an artist's view of the satellite with the ~50 cm antenna deployed,

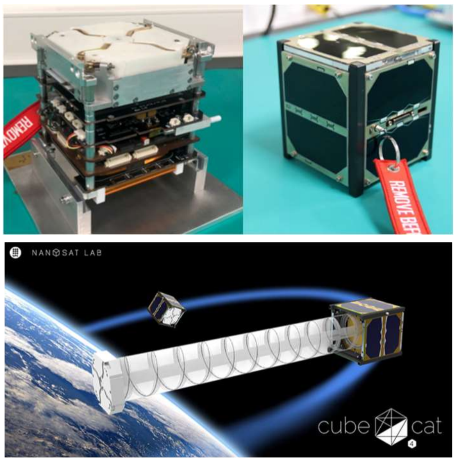

Fig. 6. ^{3}Cat-4 nadir looking antenna in stowed configuration (top left), fully integrated (top right), and artists' view.

3.5. FSSCat: ^{3}Cat-5/A and ^{3}Cat-5/B

^{3}Cat-5/A (Intl. designator 2020-061W) and ^{3}Cat-5/B (Intl. designator 2020-061X) were the two 6U CubeSats forming the FSSCat mission. The "Federated Satellite Systems/^{3}Cat-5" (FSSCat) mission was the winner of the 2017 ESA S^3 (Sentinel Small Satellite) Challenge and overall winner of the Copernicus Masters competition. FSSCat was launched from Kourou Space Port (Guiana Space Centre) using the VEGA 16 SSMS PoC on September 2020.

The primary goals were the generation of coarse resolution soil moisture, sea ice extent and thickness maps using L-band microwave radiometry and GNSS-Reflectometry, enhanced resolution soil moisture maps applying pixel downscaling techniques, and the test of techniques for future satellite federations. Secondary goals were sea surface salinity and wind speed maps. ^{3}Cat-5/A carried UPC's Flexible Microwave Payload–2 (FMPL-2), a software defined radio payload implementing an L-band microwave radiometer and a GNSS-Reflectometer [8]. ^{3}Cat-5/B carried Cosine's HyperScout-2 visible and near infrared + thermal infrared hyperspectral imager [9], enhanced with the PhiSat-1 board, an onboard Artificial intelligence experiment for cloud detection [10]. Both CubeSats include an optical inter-satellite link from Gölbriak Space, and a UHF inter-satellite link tech-demos from UPC to test the concept of satellite federations. FSSCat scientific results can be seen in [11].

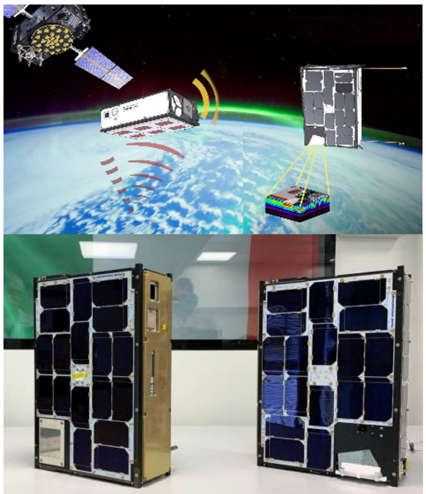

Fig. 7. ^{3}Cat-5/A left and ^{3}Cat-5/B right: FSSCat mission concept (top) and spacecrafts (bottom, courtesy of Tyvak).

3.6. ^{3}Cat-6

^{3}Cat-6/FMPL-3 is an L5/E5a GNSS-R reflectometer hosted payload onboard the GNSS augmentation Signaling (GNSSaS) mission a 6U CubeSat from NSSTC/UAEU (Fig. 8, [12]). It also includes VHF and UHF receivers for ionospheric scintillation studies. It was shipped on October 2020 to UAE, and it is waiting for final integration and launch in Q4 2022.

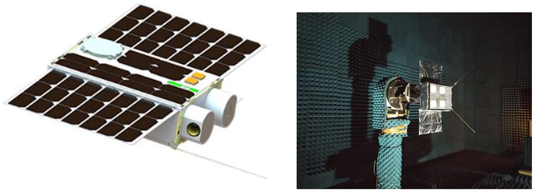

Fig. 7. GNSSaS satellite, and ^{3}Cat-6/FMPL-3 2x2 L5/E5a antenna array for GNSS-R.

3.7. ^{3}Cat-7

^{3}Cat-7/RITA is a combined hyperspectral imager, L-band microwave radiometer, and LoRa IoT communications techdemo hosted payload onboard the AlainSat-1 mission, a 3U CubeSat from NSSTC/UAEU, and one of the winners of the 2nd IEEE GRSS Student Grand Challenge (Fig. 9). It will be shipped to UAE in summer 2022, and launch in expected for Q2 2023.

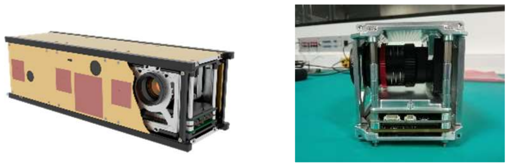

Fig. 8. AlainSat-1 artist's view (left) and flight model of the ^{3}Cat-7/RITA payload.

3.8. ^{3}Cat-8

^{3}Cat-8 is the newest UPC NanoSat Lab project. It is a 6U CubeSat mission featuring a number of technology demostrators: a deployable Fresnel Zone Plate antenna for GNSS-Radio Occultations, a polarimetric camera for ionospheric studies, an electrospray ionic motor, a PocketQube deployer, and an autonomous beacon for improved satellite identification. At the time of writing this paper the final configuration of the satellite is being defined.

3.9. ^{Po}Cat's

The UPC NanoSat Lab is also developing an "Open PocketQube Kit" for the Institute of Electrical and Electronic Engineers (IEEE). These PocketQubes, generically named "^{Po}Cat's" (pronounced /PoCat/), will be delivered by the end of 2022, together with all designs and oftware as an educational tool and to lower the entry barrier of new actors in the space. The payloads of the three PocketQubes are: a VGA camera, an L-band and a 24.25-25.25 GHz RFI monitoring receivers. Two replicas of these ^{Po}Cat's will be deployed from ^{3}Cat-8 and will be used to test Satellite Federation Concepts among them, the mother satellite (^{3}Cat-8), and ground.

4. Conclusions

This paper has presented a brief historical review of the UPC NanoSat Lab, its facilities, and main projects. Apart from the physical space, all these activities have been developed without a specific institutional support, but with the remnants of other projects, or some specific projects financing them, such as FSSCat and ^{Po}Cat's. More than 300 students have followed the Advanced Engineering Course at the ETSETB curricula linked to the UPC NanoSat Lab, while many others from several degrees have developed their Bachelor or Master's final degree project in the lab. The lab is also a foal point of the Catalan New Space Strategy [13]

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