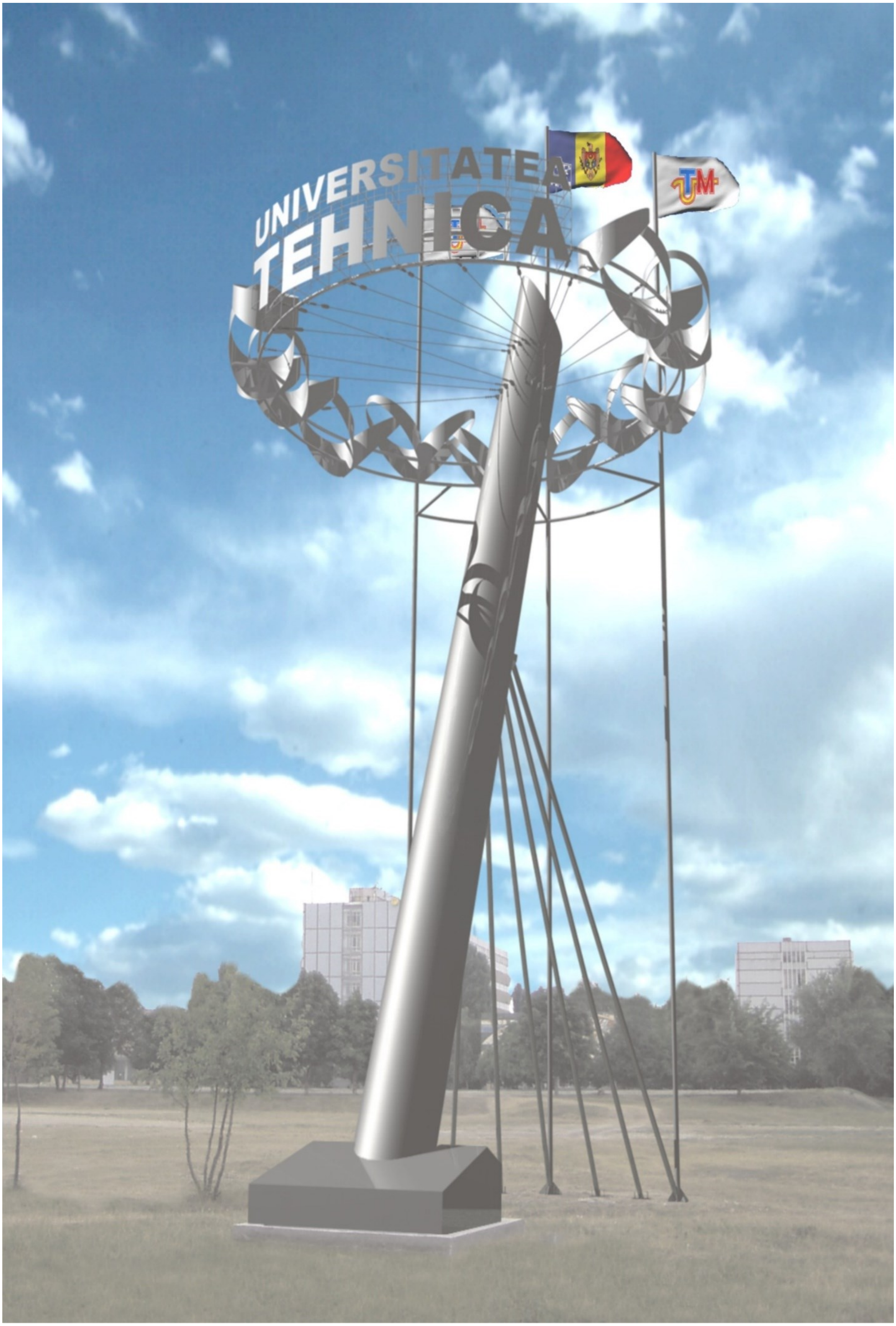
UNIVERSITATEA
TEHNICA

Technical University of Moldova

TUMnanoSAT project in the 4th round of KiboCUBE program

final report

THE CHALLENGES AND EXPERIENCE OF THE TECHNICAL UNIVERSITY OF MOLDOVA REGARDING NANOSATELLITE DEVELOPMENT

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Project director ___________________ **PHD Hab., professor Viorel Bostan**

Chisinau 2022

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PREFACE

On August 12, 2022, the Technical University of Moldova wrote another page in its history by placing in terrestrial orbit, on board the International Space Station, the first nanosatellite of the Republic of Moldova - TUMnanoSAT, designed, developed, built and tested within the university. It is a historic first for the Republic of Moldova, which marks the success of the efforts of a group of young researchers from TUM, supported in this ambitious project by the development partners. Appreciated by specialists as a resonant space experience for the international community, this event brought together at the Tekwill Center of Excellence of TUM top personalities from the country's leadership, prominent representatives of the scientific community, the academic environment, the diplomatic corps, representatives of the Japan Aerospace Exploration Agency (JAXA) and the United Nations Office for Space Affairs (UNOOSA), but also the young generation passionate about space technologies.

The Prime Minister of the Republic of Moldova, Natalia GAVRILIȚA, said in her speech: "This is a historic event, which will bring a number of benefits both for the scientific field and for citizens. The effort put in during the last 14 years has led us to this moment, when a dream has become a reality. The exploration of outer space brings countless benefits to people, the economy, science, but also state institutions".

Present at the event, the Ambassador of Japan in Chisinau H.S. Yoshihiro KATAYAMA confirmed the Japanese state's support of the innovation and research projects of the Republic of Moldova: "I want to congratulate you on the occasion of the success achieved and express my special respect for the work done by a talented team, which was crowned with a beautiful result . I am sure that this step will be followed by other projects with the support of the Japanese state". His Excellency emphasized the contribution of the KiboCUBE program to the launch of the first satellite from Moldova, noting: "Kibo in Japanese means hope. Allegorically speaking, today Moldova launched not only a satellite, but also a hope for the future. Of course, the Japanese people will continue to be with you in other projects as well."

The need to constantly boost the scientific sector motivated the Technical University of Moldova to be a promoter of the development and promotion of space technologies. About 14 years ago, a group of researchers and engineers from TUM, led by academician Ion BOSTAN, had a very beautiful dream - to place the Republic of Moldova in the list of countries capable of approaching space technologies. For this, the National Center of Space Technologies was created through programs subsidized by the government and the Academy of Sciences of Moldova, it was possible to build a communication infrastructure with satellites, an educational infrastructure. There followed two attempts by the TUM Space Technologies Center to win the project competition within the "KiboCUBE" Program intended for developing countries and in the second attempt we succeeded. This project has a major impact on the improvement of the quality of engineering studies based on modern space technologies, the attraction of young researchers and students in activities that contribute to the development and consolidation of scientific research in the field of space exploration and the integration of the Republic of Moldova into the community of countries that develop space technologies.

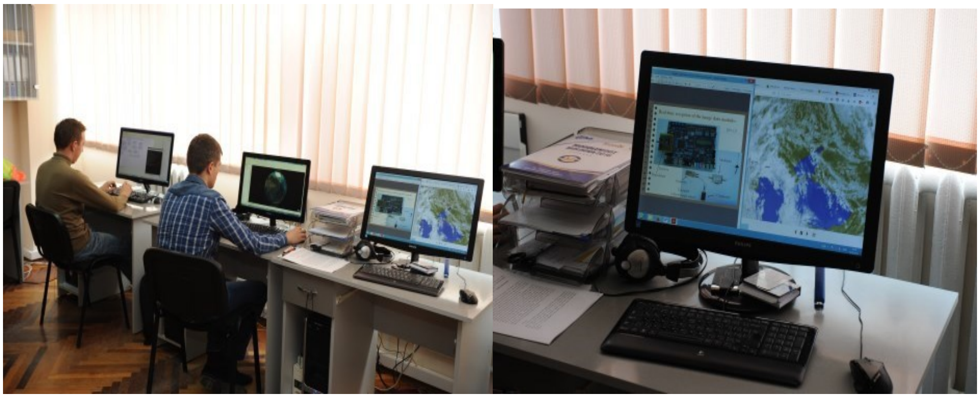
This report constitutes a review of the accumulated experience and the challenges faced by the TUM Space Technologies Center team when developing the TUMnanoSAT nanosatellite within the KiboCUBE program, supported by JAXA and UNOOSA. The report is intended to familiarize the readers with the proposed approaches and solutions to the design and realization of the subsystems of the nanosatellite, as well as with the organizational problems at its launch. This report is addressed to students, masters and doctoral students, as well as engineers designing equipment and installations based on advanced technologies.

On this occasion, we would like to thank the UNOOSA and the JAXA. This project has been made possible thanks to KiboCUBE, the programme on CubeSat deployment from the International Space Station Japanese Experiment Module Kibo and that created this extraordinary opportunity for us.

1. NATIONAL CENTER FOR SPACE TECHNOLOGIES (NCST)

The first steps in the research undertaken on projects in the field of satellite technologies were undertaken with the launch of the State Program Valorization of renewable energy resources under the conditions of the Republic of Moldova and the development of the Moldovan Satellite approved in 2009 for financing from the State Budget (academic coordinator I. Bostan) The program provided for the development of the first satellite of the Republic of Moldova with four distinct projects in the field of satellite technology development [17-22, 26, 27].

For the development of research capacities, simultaneously with the formation in 2009 of scientific collectives with a certain research-design experience in the field of satellite technologies, during the year 2009-2012, an extensive design and construction plan of the technical-material infrastructure was designed and implemented, which would allow the achievement of the purpose and objectives of the scientific mission of the satellite. Thus, in 2009, the creation of the National Center for Space Technologies began, which was formalized by TUM Senate Decision no. 6 of 31.01.2012 with the following structure.

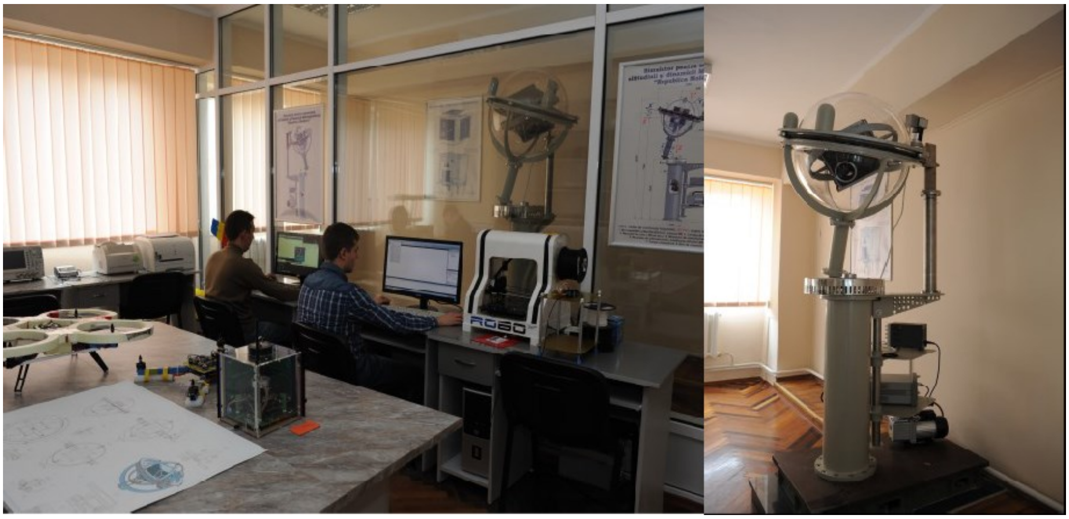


a) b)

Figure 1.1. Views from the on-board subsystems laboratories for nano and microsatellites (a) and data and image processing (b).

1.1. Onboard Subsystems for Nano and Microsatellites Laboratory (SBNMS)

The SBNMS laboratory is specialized in research and development of on-board subsystems, including: the scanner for capturing images; the electrical energy supply system of MS through PV conversion of solar energy; systems for determination, orientation and attitude control of the MS in flight on orbit; data reception and transmission equipment; on-board computer, etc. The elaborations of the board components of the MS are carried out on the basis of alternatives, assuring students, master's and doctoral students decision-making equity and competitive freedom of creation. Thus, on the principles of alternatives, the competition of ideas and innovative technical solutions of the teams of young researchers involved in the educational research-development projects of the on-board subsystems of the MS is ensured.



a) ***b)***

Figure 1.2. The assembly and experimentation laboratory of on-board subsystems and MS (a); simulator with MS mounted in the external gyroscope (b) .

Simultaneously with the elaborations carried out in the original, the research teams based on the case studies propose variants of the available COTS board components accompanied by analyzes of compatibility, mass, dimensions, cost, including ensuring the interchangeability and reliability of the MS as a whole.

The SBMS laboratory is equipped with high-performance computers, including computer-aided design stations (figure 1.1, a) with the application of modern design software in 3D format and comparative analyses, including computer simulations of technological processes.

1.2. Data and Image Processing Laboratory (PDI)

The PDI laboratory is intended for familiarizing students, doctoral students and young teaching staff with modern methods and techniques for processing data and images from the Satellite and for disseminating the results of the processing in various applications and fields. In the research carried out in the PDI laboratory, a special role is attributed to the study of the peculiarities of processing satellite images endangered by geometric and radiometric distortions, as well as the methods and modern processing techniques. Figure 1.1, b) shows the view of a geometric and frequency processing station of the images captured from the satellite.

1.3. Laboratory for assembly and experimentation of on-board subsystems and assembled MS (AEMS)

The AEMS laboratory is equipped with fine mechanics assembly equipment and electronic measurement equipment (figure 1.2, a), where the first microsatellite (MS) was assembled (figure 1.3, a; 1.3, b). The photovoltaic panels of the MS were designed within the NCST and manufactured using the GalnP-GalnAS-Ge photovoltaic cell (P=50W, η>25%) resistant to cosmic radiation. Silonex Solar Sensors model SLCD-6N18, Maxim Integrated Product temperature sensors model DS18B20 and compatible with the attitude determination subsystem MS model MAI-200 are installed in the PV panels. Also, in AEMS, in an isolated space, the simulator is mounted on a fixed foundation for the experimental research in laboratory conditions of MS kinematics and dynamics with motion of the space sphere with a fixed point, which reproduces the rotation movement of the satellite around 3 axes of the orbital reference system.

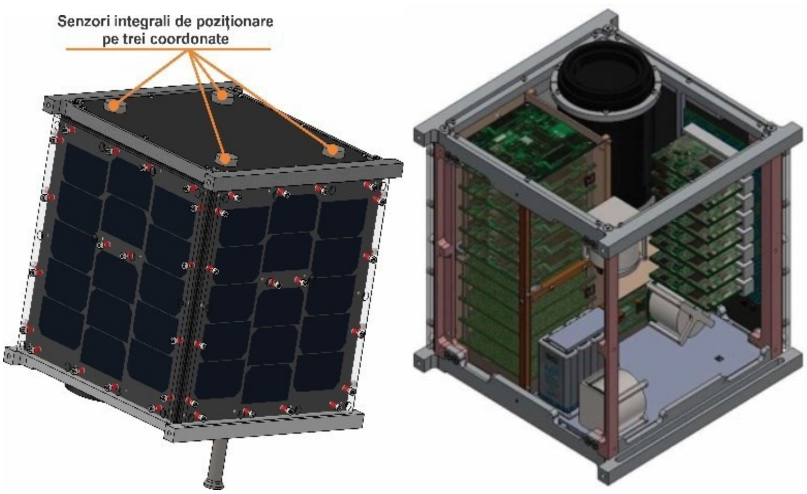


Figure 1.3. The first microsatellite developed at NCST: a) general view and b) its internal structure.

The simulator also allows the experimental research of the intervention of the on-board systems on the orientation of the MS on the orbit, including the determination and calibration of the physical intervention efforts developed by the two on-board systems on the stability and dynamics of the repositioning of the MS on the axes of the orbital coordinate system. The simulator allows the experimental research of MS in laboratory conditions and in a vacuumed environment. The simulator was originally designed within the NCST, TUM, and manufactured at the factories in Chisinau.

1.4. Telemetry Communications Station (SCT)

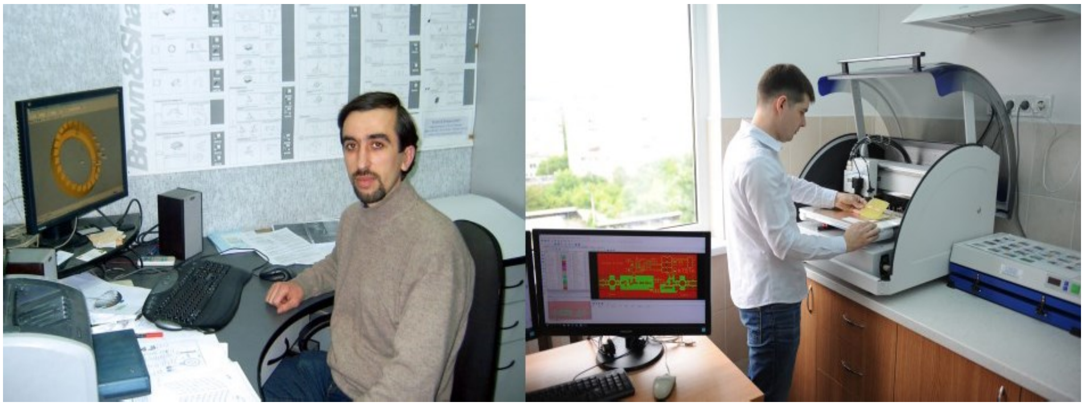
The station is equipped with specialized equipment to ensure the ascending and descending links of the MS in orbit with the telemetry station (figure 1.4, a). The station is connected to a set/cluster of antennas, namely telemetry antennas (figure 1.4, b). The telemetry antennas have the possibility to be oriented on two axes towards the MS in flight on orbit by means of the actuation mechanism model Rotor BIG-RAS/HR [23-25].

a) ***b)***

Figure 1.4. The SCT laboratory: a) the telemetry antenna and b) the cluster of telemetry antennas.

1.5 NCST design-manufacturing platform

Affiliated to the NCST as an autonomous structure is the platform for designing and manufacturing the components of the on-board subsystems of the MS. The platform is equipped with high-performance computer-aided design stations, for computer simulation of the kinematic and dynamic processes of the MS at the stages of design, experimentation and in the perspective of the launch of the MS. During the design of the functional components of the MS to simulate the influence of cosmic disturbances on the positioning of the MS in orbit, the Solid Work Catia, ANSYS, ABAQUS, etc. software were used. The manufacturing of the components of the basic functional subsystems of the MS is carried out at the Advanced Technology Center "Etalon" on modern equipment, for example, on machine tools model Motion Master TB-105, equipped with heads with 5 and 3 degrees of mobility, with Fagor numerical control 8055M, with the application of the SPUTH CAM and ASPIRE VECTRIC Softs, and the manufacturing of the boards with printed wiring is carried out on the LPKF-S103 model prototyping machine with Soft Circuit PRO operation. In figure 1.5, a) is represented computer-aided design and computer simulations of MS kinematics and dynamics in the design, experimentation and launch stage; the manufacture of the components of the on-board subsystems of the MS at the "Etalon" Advanced Technologies Center, and in figure 1.5, b - the computer-aided design station for the prototyping of printed circuit boards of electronic modules. The SBNMS, PDI, AEMS and SCT laboratories are integrated structures in the NCST, and the design-manufacturing platform of the components of the on-board subsystems of the MS is affiliated as an autonomous structure with individual funding. The designated specialized laboratories, the design-manufacturing platform of the on-board subsystem components and the network of satellite communications ground stations as a whole constitute the NCST infrastructure, which will be described in detail in compartment 5.



a) b)

Figure 1.5. Research-design-manufacturing platform of MS on-board subsystem components.

2. KiboCUBE PROGRAM PROMOTED BY UNOOSA AND JAXA

UN/Japan Cooperation Program on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo) "KiboCUBE" is a program of the UNOOSA in collaboration with the JAXA. The program started in 2015 [109]. KiboCUBE is the dedicated collaboration for the use of the Japanese Kibo module on the International Space Station (ISS) for the whole world.

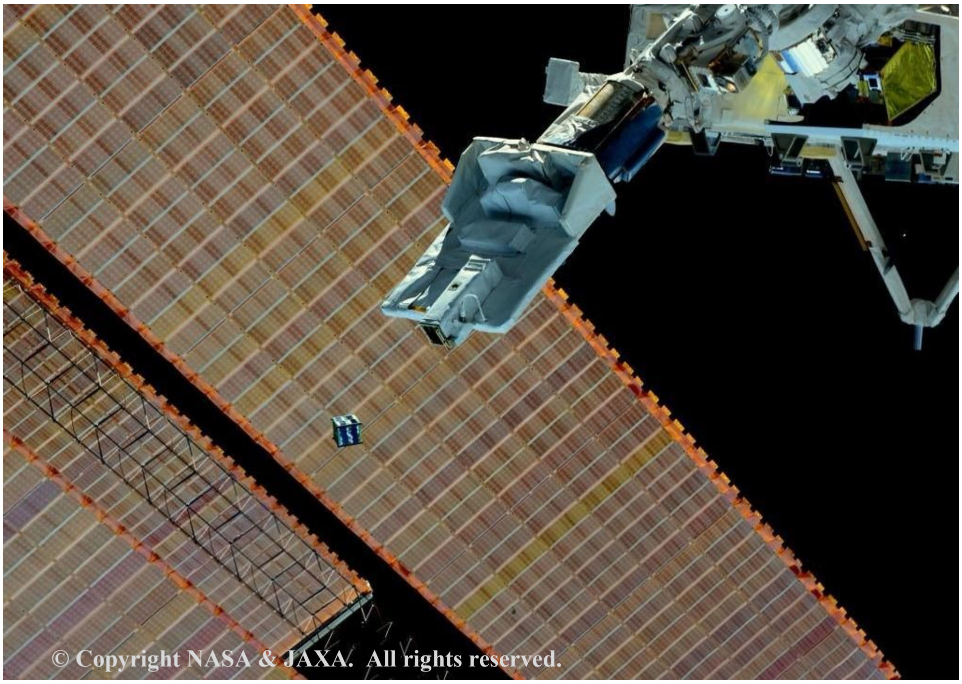


Figure 2.1. Deployment of CubeSat from the ISS. [109]

The KiboCUBE program aims to provide educational or research institutions in developing economies and economies in transition of Member States of the United Nations with opportunities to deploy their own 1U CubeSat which they have developed and manufactured from the ISS Kibo module.

CubeSat deployment from the ISS is easier than direct deployment by a launch vehicle due to the lower vibration environment during launch. Due to these comparatively less demanding interface requirements, UNOOSA and JAXA believe that KiboCUBE will lower the threshold for space activities and contribute to building national capacity in spacecraft engineering, design and construction. This program was launched in 2015 and was carried out annually in rounds, the winners being [110]:

Round 1. University of Nairobi. This round opened in September 2015 and ended at the end of March 2016 and the University of Nairobi was selected as the awardee. Their CubeSat "1KUNS-PF" was deployed in May 2018. This was a technology demonstration mission aimed at testing domestically developed and critical technologies and also testing Earth observation applications to obtain data to monitor agriculture and coastal areas..

Round 2. Universidad del Valle de Guatemala (UVG). This round was opened in September 2016 and closed at the end of March 2017, and the Universidad del Valle de Guatemala (UVG) was selected as the awardee. UVG's "Quetzal-1" CubeSat was deployed in April 2020. The objective of this mission was to demonstrate the technology and test the acquisition of remote sensing data for natural resource management, in particular, to monitor the concentration of harmful cyanobacteria (algal blooms) over internal bodies of water.

Round 3. Mauritius Research and Innovation Council (MRIC) and Surya University. This round opened in September 2017 and closed at the end of March 2018, and the Mauritius Research Innovation Council (MRIC) and Surya University of Indonesia were selected as awardees. CubeSat "MIR-SAT 1" from MRIC was deployed in June 2021. MIR-SAT1 is a technology demonstration mission to test transmission of images and communication systems on board. Surya University's "SS-1" CubeSat is currently under development and will be equipped with an Automatic Packet Reporting System (APRS) that will communicate with the ground for two-way amateur radio frequency communication.

Round 4. Technical University of Moldova. This round was opened in October 2018 and ended at the end of January 2019, and the Technical University of Moldova was selected as the awardee. The CubeSat "TUMnanoSAT" was launched in August 2022. It intends to test the functionality of the satellite's various modules and subsystems under real conditions. Their technology demonstrations include studying the behavior of nanostructure-based sensors, satellite attitude sensors, establishing communications systems, testing solar power systems, and reliability of electronic components under space radiation conditions.

Round 5. Central American Integration System (SICA). This round opened in March 2019 and ended at the end of September 2019, and SICA, the Central American Integration System was selected as the awardee. SICA's CubeSat "Morazan-Sat" is currently under development, it aims to be a proof of concept for the development of a UHF/VHF communications platform. It will demonstrate the ability to monitor weather variables on site using UHF/VHF radio packets, and when the mission is completed, with the help of radio amateurs, UHF/VHF emergency communications capabilities will be tested using the Automatic Packet Reporting System (APRS)..

Round 6. Universidad Popular Autónoma del Estado de Puebla

(UPAEP) and École Supérieure Privée d'Ingénierie et de Technologie Appliquée (ESPITA). This round was opened in December 2020 and closed at the end of May 2021, and the awardees were selected ESPITA, the Private Higher School of Engineering and Applied Technology of Tunisia and UPAEP, the Popular Autonomous University of the State of Puebla in Mexico. UPAEP's 1U CubeSat "Gxiba" is to observe active volcanoes in Mexico and analyze ash dispersion, which could suggest that a local population living in the vicinity of the volcano is being alerted. The objective of ESPITA's TUNSAT 1 is mainly to build the capacity of Tunisia in the aerospace industry and to demonstrate that it is capable of ground-space communication using self-built technologies.

2.1. Participation of the TUM Space Technologies Center in the KiboCUBE program

In 2016, UNOOSA and JAXA announced the opening of applications for the 2nd round of the KiboCUBE program.

The National Center of Space Technologies of TUM has designed the "TUMnanoSAT" family of nanosatellites, in accordance with the international CubeSat standard. The mission of these nanosatellites consists in verifying in real conditions the functionality of the various modules and subsystems of the satellites. The National Center for Space Technologies of TUM submitted a proposal to the 2nd round of the "KiboCUBE" program (figure 2.2).

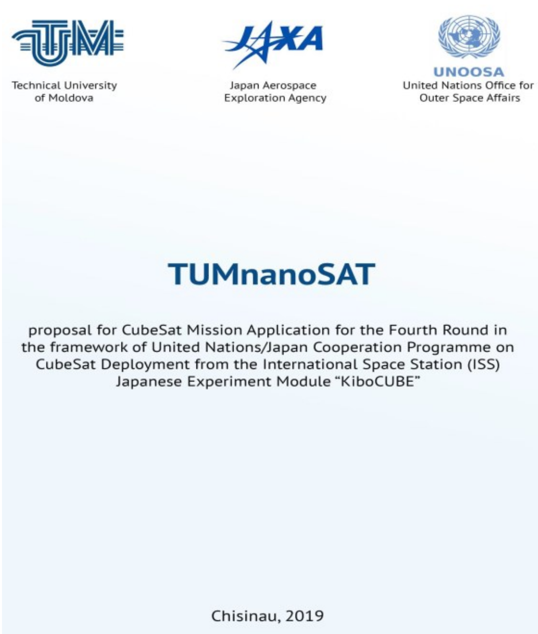
Figure 2.2. The "TUMnanoSAT" project proposal submitted to the 2nd round of the KiboCUBE program.

The National Center for Space Technologies of TUM submitted another satellite project "TUMnanoSAT" to KiboCUBE for the second time in the 4th round which was opened in 2018, (figure 2.3) [58]. The main mission objective of this project is educational awareness. It can be commanded via the ground station network. This network of ground stations will be taken to universities and schools across the country for children to have their first direct interaction with a satellite. The goal is to stimulate young minds by introducing them to aerospace technology and to provide students with the skills and experiences needed to build pico- and nano-satellites.

The nanosatellite "TUMnanoSAT" presented for the 4th round includes the following basic missions:
- to study the operation and behavior, reliability of sensors based on nanostructures in space conditions;
- testing the sensors of the attitude subsystem to determine the attitude of the satellite (magnetometers, micro-gyroscopes, solar sensors) in order to optimize the attitude control algorithms.
- to establish an efficient "satellite-ground station" communication subsystem with the possibility to change the communication speed range to ensure high reliability;
- to check the "satellite-ground station" communication protocol with different levels of access;
- testing the solar energy supply system to obtain the optimal ways of distributing the accumulated energy;
- testing the operational endurance of the CSOT electronic components under space radiation conditions.

The main objective of the "TUMnanoSat" mission is education to obtain practical training until the realization of the flight model and thus to contribute to the development of the space education system among nanosatellites, as well as to improve the development of technical capabilities.

The other educational objectives are the collaboration and contacts with industry, universities and other CubeSat development groups, an insight into the system engineering process, a deeper understanding of the topics. Scientific and research objectives are the demonstration and validation of nanosensor technology in space applications; nanosatellite communication link; space discovery with the help of the photos taken by the camera on board the satellite; attitude determination. Another goal is to test different types of memory under space radiation conditions for future space applications.



Technical University of Moldova

Japan Aerospace Exploration Agency

UNOOSA
United Nations Office for Outer Space Affairs

TUMnanoSAT

proposal for CubeSat Mission Application for the Fourth Round in the framework of United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module "KiboCUBE"

Chisinau, 2019

Figure 2.3. The "TUMnanoSAT" project proposal submitted to the 4th round of the KiboCUBE program.

2.2. Launch of the TUMnanoSAT project within the KiboCUBE program

The activity of the National Center for Space Technologies within TUM (NCST) has reached a new dimension, being selected by the JAXA and the UNOOSA for the 4th round of the KiboCUBE

Program for the launch of the nanosatellite "TUMnanoSAT" from the International Space Station (ISS) with the help of the Japanese KiboCUBE experimental module [102]. In this context, on September 9, 2019, NCST-TUM hosted a JAXA-TUM meeting, during which the start of the project to launch the first satellite of the Republic of Moldova into space under the KiboCUBE program was prepared under the auspices of UNOOSA and JAXA. In this project JAXA is the coordinator of activities of NCTS on the launch of CubeSat nanosatellites from the International Space Station using the KiboCUBE experimental module.

Having as guests Masayuki GOTO, JAXA, technical coordinator of the KiboCUBE project, Tetsuro MIZUNO, Japan Manned Space Systems Corporation (JAMSS), His Excellency, the Ambassador of Japan in Chisinau, Masanobu YOSHII, accompanied of representatives of the diplomatic corps, the meeting was attended by an extended team of NCST: the director of the Center, acad. Ion BOSTAN, vice director, university professor, Dr. Nicolae SECRIERU, Ion AVRAM – coordinator for radio communication issues; Oleg LUPAN - head of department, coordinator for nanosensors issues, accompanied by a team of young researchers in the field - master's students, doctoral students, doctors of science, responsible for certain aspects in the development and manufacture of the nanosatellite "TUMnanoSAT". This is Irina COJOCARI – NCST scientific researcher: satellite orientation, stabilization; Valentin ILCO – NCST junior researcher, communication subsystem, CubeSat systems integration; Alexei MARTINIUC – master's student, NCST junior researcher: OBC, OBC software and communication; Vladimir MELNIC – PhD student, NCST scientific researcher: satellite orientation, stabilization; Nicolai LEVINEȚ – master's student, NCST junior researcher: OBC, OBC software and communication; Sergiu CANDRAMAN - PhD student, NCST scientific researcher: payload of orientation, stabilization and attitude determination of satellites; Andrei MĂRGĂRINT – master's student, radio satellite-ground station communication.

TUM Rector Viorel BOSTAN emphasized that the project is of major importance for NCST-TUM, which designed the "TUMnanoSAT" family of nanosatellites, in accordance with the international CubeSat standard. It will have a major impact on the improvement of the quality of engineering studies based on modern space technologies, the attraction of young researchers in the development and consolidation of scientific research in the field of space exploration and the integration of the Republic of Moldova into the community of countries that develop space technologies.

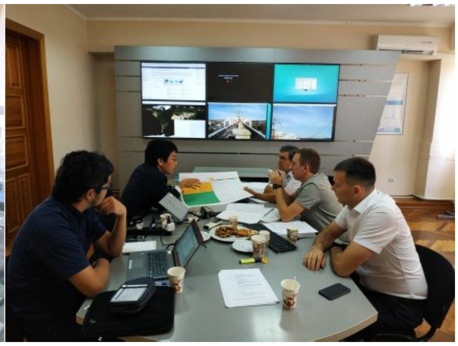
 

Figure 2.4. Sequences from the JAXA-TUM meeting during which the project to launch the first satellite of the Republic of Moldova into space was launched.

Figure 2.5. Sequences from the 70th International Astronautical Congress (IAC) when the project to launch the first satellite of the Republic of Moldova into space as part of the KiboCUBE program was officially launched.

The official start of the project to launch into space the first satellite of the Republic of Moldova within the KiboCUBE program was given on the second day of the 70th International Astronautical Congress (IAC), held from 19-25 October 2019, in Washington D.C. The agenda included a presentation at the JAXA stand with the generic name "KiboCUBE Joint Event of UNOOSA and JAXA", which reflected the collaboration between the UNOOSA and the JAXA regarding the use of the ISS KiboLancer for launching CubeSat-type nanosatellites. TUM rector, university professor, dr. hab. Viorel BOSTAN, and Valentin ILCO, researcher at the National Center for Space Technologies, represented the Technical University of Moldova at the world's largest meeting of space professionals.

During the event, Ms. Simonetta Di Pippo, former Director of UNOOSA, and Dr. Hiroshi Yamakawa, President of JAXA, emphasized that the KiboCUBE Program, which completed its fifth round of applications this year, offers institutions in developing countries the opportunity to to develop a 1U cube satellite for launch from the International Space Station (ISS) using the Japanese KiboCUBE experimental module. The representatives of the winners of this program, Mr. Luis Zea, co-director, Universidad del Valle de Guatemala, winner of the 2nd stage of KiboCUBE, and Viorel Bostan, rector, Technical University of Moldova, winner of the 4th round of KiboCUBE, provided information on the achievements and future of KiboCUBE – a example of good practices in the relationship between UNOOSA, JAXA and program participants.

In his speech, university professor, dr. hab. Viorel Bostan referred to the activity of the National Center of Space Technologies within TUM, selected for the IV round of the KiboCUBE Program for the launch, in 2020, of the TUMnanoSAT nanosatellite from the International Space Station with the help of the Japanese KiboCUBE experimental module.

Established in 2012, it is the only space research center in the Republic of

Moldova, with six laboratories, an astronomical observatory and two fully functional ground stations located 200 km apart. The Center's team includes 35 people directly involved in development-research-implementation activities (doctorate students, master's students, undergraduate students) and over 60 students - in the satellite communication process. In the objective chapter, the rector mentioned the demonstration and validation of the technology for nanosensors in the space application; development of "satellite-ground station" communication protocol with different access levels through the ground station network; valorization of the scientific potential of higher education institutions in the Republic of Moldova; encouraging young people to show interest in aerospace technologies and, respectively, multidisciplinary and continuous training of specialists and students at the highest level. Regarding the perspective objectives, involvement in national and international projects in consortium with different partners for common missions was emphasized; expanding the nanosatellite series with 1.5U, 2U models for different missions; design of various satellite modules for nanosensors reasearch in space conditions; expanding the ground infrastructure by connecting other stations or joining the network of ground stations for data decoding and further promoting space technologies in the Republic of Moldova within an extensive space education program.

3. CHALLENGES REGARDING THE ORGANIZATION OF RESEARCH, DESIGN AND DEVELOPMENT ACTIVITIES OF THE SATELLITE WITHIN THE KiboCUBE PROGRAM

The complexity and proportions of a project such as that of research, development and elaboration of a satellite presuppose activities on multiple segments with different teams in order to achieve the desired result. The stages of the direct realization of the TUMnanoSAT satellite, from the idea to the final assembly, can be represented in the diagram in figure 3.1.
However, it must be taken into account that, in addition to the basic works directly related to the satellite (design, development, testing campaign), related activities are also necessary, such as:

- ✓ coordination and preparation of reports for preliminary and final critical reviews, which were carried out with development partners from JAXA;
- ✓ design, development and testing of satellite communication ground stations;
- ✓ carrying out frequency coordination procedures;
- ✓ carrying out the activities related to the permissive documents for import/export actions in different stages;
- ✓ other related activities (promotion of space sciences, coordination with local authorities and UNOOSA).

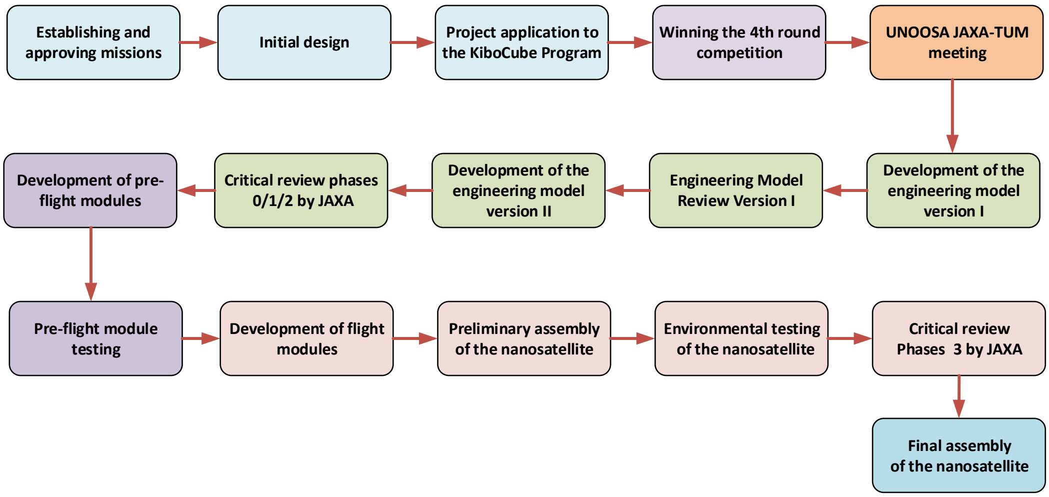


Figure 3.1. Stages of project development.

The mentioned activities must be carried out in accordance with the stages of the satellite's development, therefore, in each stage, some permissive acts may be required, as well as certain infrastructure elements to be prepared for the validation of the satellite's subsystems. The mentioned activities are described in the diagram in figure 3.2, respecting the approximate agreement in relation to the development of the satellite (derived from the previous diagram).

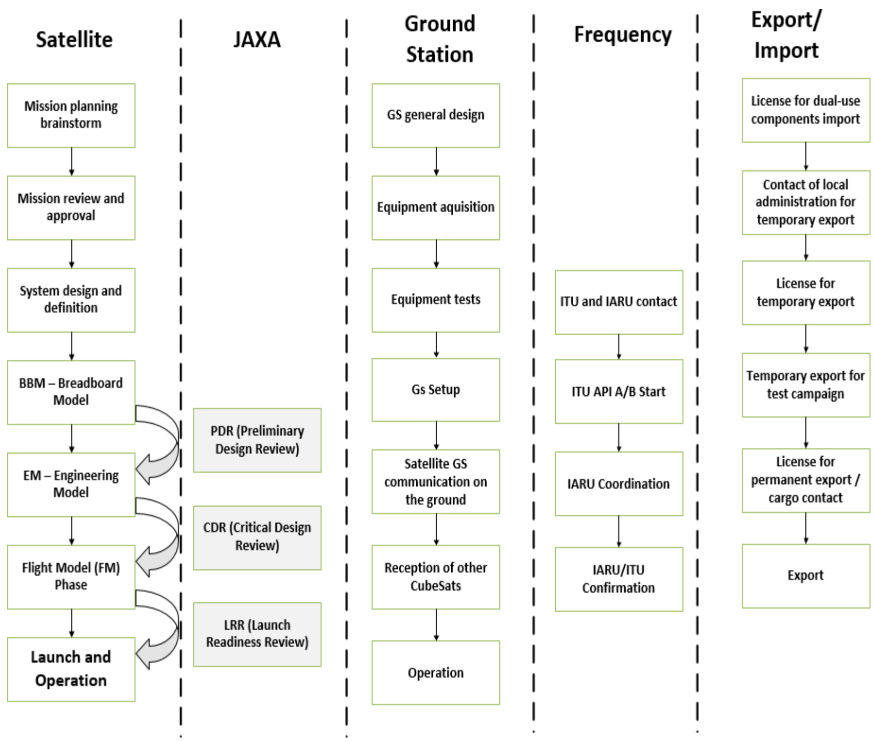


Figure 3.2. Activities related to the development of the TUMnanoSAT satellite.

As can be seen in the diagram in figure 3.2, there is a development with many simultaneous activities, on different segments. In other words, at the moment when a working group was created in the first stage, which carried out research activities to establish potential missions, another group carried out the analysis of the existing ground stations in order to establish a general architecture of the station to be designed.

For a much clearer picture, some key stages during the development of the satellite will be represented on each segment, starting directly from the design and development activities of the satellite itself.

If we refer to small missions, the development flow of a satellite includes three forms of it:

BBM – Breadboard Model, also called "the satellite on the table". In this stage, the basic functionality of the satellite is verified, using components close to those to be used or that substitute some functionalities. The subsystems do not yet follow any safety requirements and interface criteria. Both the functionality of individual subsystems and intercommunication between these systems are tested. At the end of this stage there is a preliminary review of the project with the necessary corrections to move to the next stage and the next iteration.

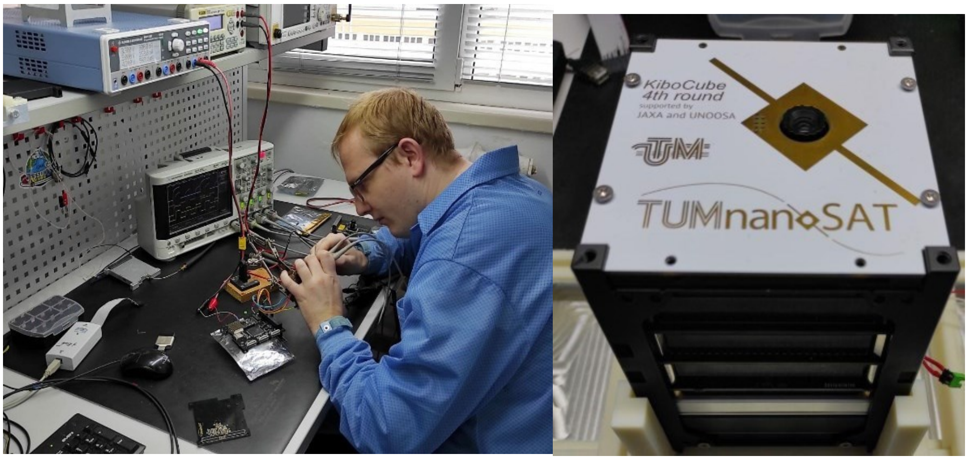


Figure 3.3. TUMnanoSAT in the stage of BBM and EM.

Figure 3.4. Reports for critical review to JAXA.

EM – Engineering Model. The engineering model of the satellite - at this stage, there are actually several iterations. The subsystems are already close to those that will be used in the flight model. Mechanical interface criteria are followed as much as possible. Subsystem and assembly testing is performed to validate use in space conditions.

FM – Flight Model. The flight model of the satellite is in the form in which it will be launched into space. All subsystems must follow the requirements imposed by both the launcher and the International Space Station (if launching from the ISS). All validation tests are performed specifically on the flight model.

Each of these stages culminates in a report (either preliminary or final) for critical review of the results. During the development of the TUMnanoSAT satellite, these revisions were made in accordance with JAXA and ISS requirements. For example, at the end of critical revision #1, iteration. After the completion of the testing campaign, the final testing and validation by JAXA of the satellite takes place.

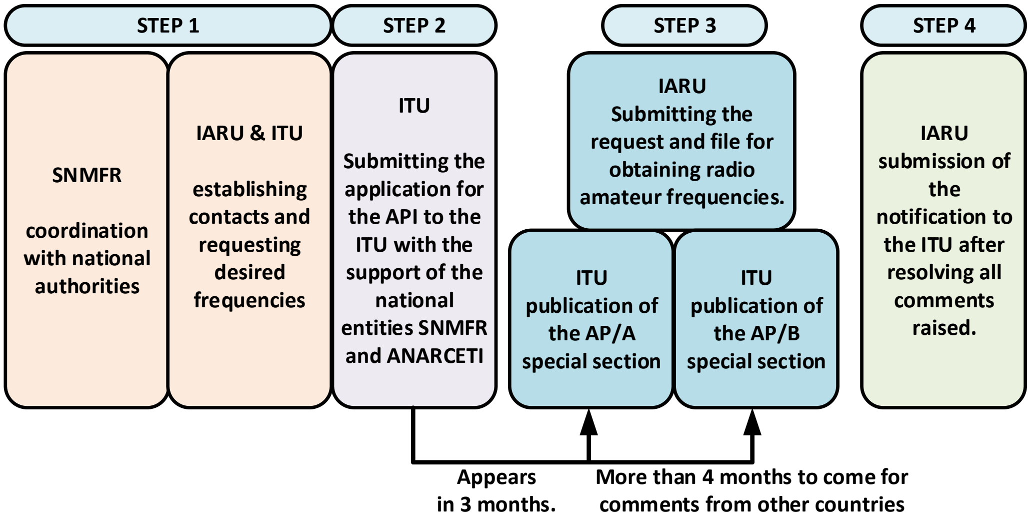


Figure 3.5. Steps for frequency coordination.

ID number (SNS)	adm	ORG or Geo.area	Satellite name	Earth station	long_nom	Date of receipt	ssn_ref	ssn_no	ssn rev/ Sup	ssn rev no	removal	Part/ Art.	WIC/IFIC (ific.mdb)	WIC/IFIC date
119545144	MDA		TUMNANOSAT		N-GSO	30.07.2019	API/A	12415					2907	29.10.2019
119545144	MDA		TUMNANOSAT		N-GSO	30.07.2019	API/B	1277					2918	14.04.2020

Figure 3.6. Confirmation of frequency coordination with IARU and ITU.

The design and development activities of satellite communication ground stations are described in detail in Chapter 5 – Experience in the development of ground infrastructure. At this stage we only mention that NCST already had a well-organized ground infrastructure when the satellite development work started.

To coordinate the frequencies several steps had to be followed and several entities both national and international had to be contacted. In general, if we are talking about small missions, satellite developers opt to use a frequency intended for radio amateurs. In the context of TUMnanoSAT development, this frequency was in the 430-:-440 MHz range. To coordinate this frequency, follow the steps according to the diagram shown in figure 3.5.

In the first stage, the local authorities that manage such activities are contacted. In our case, we are talking about several entities. First of all SNMFR – the National Radio Frequency Management Service, which is responsible for keeping records of radio stations, channels and radio frequencies and the technical management of the radio frequency spectrum with non-governmental use. Then by ANRCETI - the National Agency for Regulation in Electronic Communications and Information Technology (ANRCETI) which is the central public authority that regulates the activity in the sectors of electronic communications, information technology and postal communications, which also carries out communication with ITU. And last but not least, ARM - Association of Radio Amateurs from Moldova, for contact and coordination with IARU.

In the next step, the request for API (Advance Publication Information) is submitted. API is a mandatory procedure according to section 1 of article 9 of the Radio Regulations for all satellite networks that are not subject to coordination. For non-geostationary satellite networks, this procedure is applicable to all those frequency bands/services not subject to coordination. For geostationary satellite networks, this procedure applies only to the use of non-coordinating intersatellite links communicating with a non-geostationary space station. The network characteristics required for submission are published by the ITU Bureau in a special API/A section.

Then the file is submitted to the IARU with the technical description of all the parameters related to the satellite communication system, as well as the description of the technical parameters of the terrestrial communication stations with satellites. After processing the request and the information, IARU issues a communication, which allows the use of the requested frequency (figure 3.6).

REPUBLICA MOLDOVA

AUTORIZAȚIE

INDIVIDUALĂ DE EXPORT AL MĂRFURILOR STRATEGICE
(CU DUBLĂ DESTINAȚIE)

E 0000142

1. Exportator (Exporter)	Universitatea Tehnică a Moldovei	2. Nr. și data de înregistrare la exportator (No. and date of registration at exporter)		04-58 din 19.01.2022	
Adresa: (Address)	MD-2004, bd. Ștefan cel Mare și Sfânt, 168, mun.Chișinău, Republica Moldova	3. Nr. și data de înregistrare la Agenția Servicii Publice (No. and date of registration at the Public Services Agency)		04/AE din 19.01.2022	
Telefon/ e-mail (Phone, e-mail)	(+373)22-23-78-61 rectorat@adm.utm.md	4. Partener extern/Țara (Foreign partner/Country)		„Japan Aerospace Exploration Agency" Japonia	
		5. Țara plătitoare (Paying country)	Cod (Code)	6. Țara importatoare (Importing country)	Cod (Code)

Figure 3.7. Export authorization for TUMnanoSAT.

At the same time, the ITU issues the API/A information, assigning a unique identifier. Once API/A is published, ITU countries can offer different comments regarding the use of this frequency, with specified parameters, in order to minimize possible interference. During the development of TUMnanoSAT, about 18 countries provided comments, which were then resolved and discussed individually.

After the debates of all the comments, the final submission of the information to the ITU takes place and at the same time the notification of the development partners – JAXA and UNOOSA. In the context of the development of TUMnanoSAT, this information was also transmitted to NASA, the department responsible for radio communications on the International Space Station.

At the same time, there must be at least one responsible/authorized person in the specific case of using radio amateur frequencies. Authorized in the given case means that the person must hold a radio amateur license. Within the NCST, all those involved in the development of the communication subsystem and the development of earth stations have such a certificate after passing the radio amateur exams.

Another important moment relates to the export activities of the satellite when it was to arrive in Japan. According to national legislation, the satellite falls under the scope of strategic (dual-use) goods, respectively, in order to be able to export it, an export authorization must be obtained. This process involves the submission of a file with all the technical details of the satellite and information about the country where it will arrive. At the same time, the import of some components also requires authorization, but this time for import. NCST applied for both such licenses.

However, taking into account the fact that the entire testing and validation campaign was carried out in Romania, the Institute of Spatial Sciences in Măgurele, a permissive act was also necessary for the temporary export regarding the realization of this testing campaign. Such a document is the ATA carnet, an international customs document on the basis of which goods under the temporary export and transit regime circulate freely, according to a simplified customs procedure. The ATA carnet is issued by the Chamber of Commerce and Industry. These are just a few permissive documents for the import/export procedures that the TUMnanoSAT satellite development project needed.

3.1. Management of project development activities

To streamline the work process within the teams, during the development of the satellite and related activities, it was decided to use a platform for project and task management. Within NCST, an existing Gitlab solution was chosen, which allowed both the continuous development of the satellite and ground station software (using the version control component within the platform) and the organization of other activities through the task tracking component (figures 3.8, 3.9).

Within the mentioned platform, it was decided to organize the satellite's tasks by subsystems within each subsystem. The tasks for each subsystem were organized into some current tasks and issues tables, which allowed for efficient visualization of the status of each compartment at daily and weekly meetings. The work method was of the "kanban" type (a method of managing work flows). At the same time, some benchmarks were set for the compartments, with well-established deadlines for meeting the time limit. Figures 3.10, 3.11 shows some benchmarks with current problems and the level of progress. This approach was the key to the success of this project.

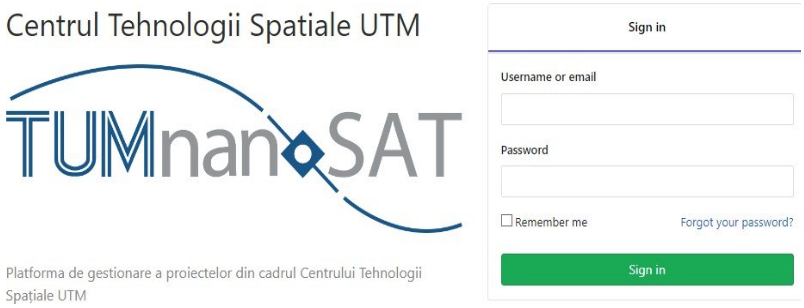


Figure 3.8. NCST TUM project management platform.

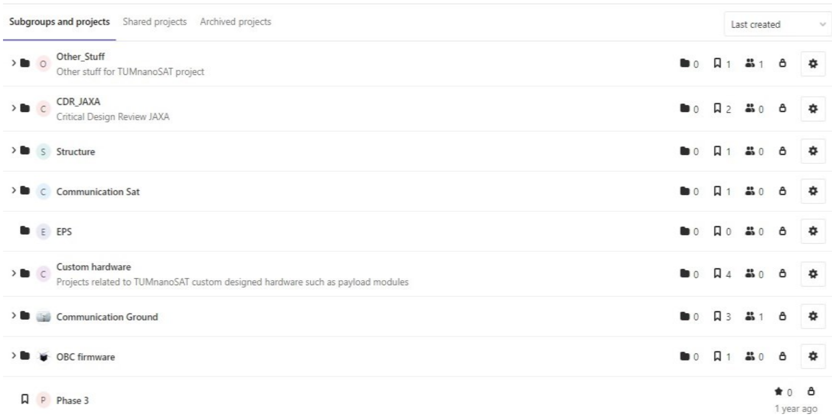


Figure 3.9. Project management component of the satellite and ground station development.

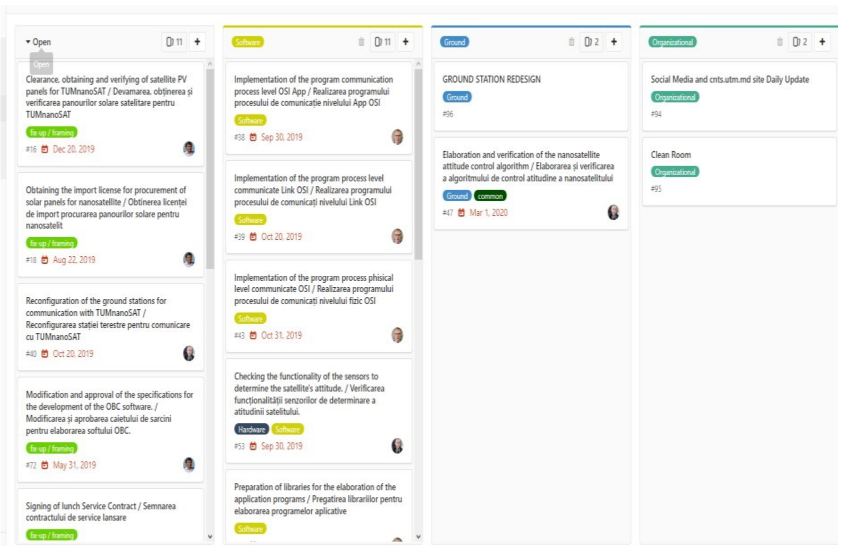


Figure 3.10. Assigned tasks and their status

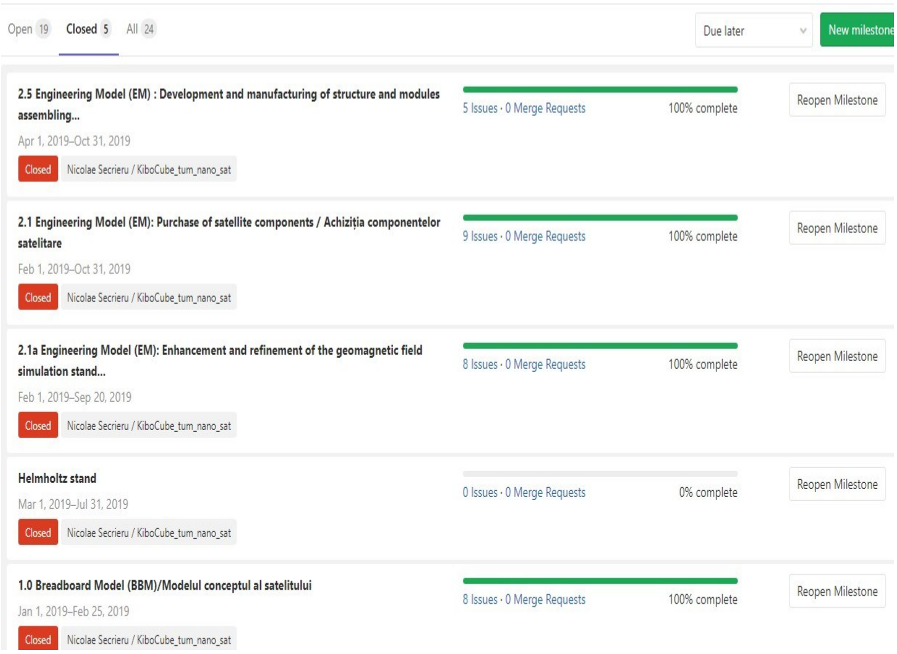


Figure 3.11. Timelines for activity management.

3.2. Nanosatellite registration activity.

The registration of the nanosatellite, being a first in the Republic of Moldova, generated a series of organizational activities and government decisions, which led to the solution of this problem:

1) It was decided that the Public Institution "National Radio Frequency Management Service" (I.P. SNMFR) should carry out the prior registration of the satellite within the International Telecommunications Union, according to its powers established within the Electronic Communications Law 241/2007. https://www.itu.int/net/ITU-R/space/snl/bresult/radvance.asp?sel_satname=&sel_esname=&sel_adm=&sel_org=&sel_ific=2907&sel_year=&sel_date_from=&sel_date_to=&sel_rcpt_from=&sel_rcpt_to=&sel_orbit_from=&sel_orbit_to=&sup=&q_reference=&q_ref_numero=&q_sns_id=&nmod=asc&norder=adm

2) According to the UNOOSA Guidelines for the Registration of Space Objects states that depending on national legislation, satellite missions may require licensing / authorization by a national authority. This agency (I.P. SNMFR) can be the national radio and telecommunications regulatory entity, the national space agency or the national science and technology entity. (https://www.unoosa.org/documents/pdf/psa/bsti/2015_Handout-on-Small-SatellitesE.pdf)

3) I.P. SNMFR, as the entity empowered to keep the register of objects launched into space, can use the S.I.A. for this purpose. "State register of frequencies and

radio communication stations", held by SNMFR in accordance with HG No. 944 of 11-10-2010 regarding the approval of the Technical Concept of the Automated Information System "State Register of Frequencies and Radio Stations" - SIA "RSFSR". Art.2 point 3 of the Convention on the registration of objects launched into outer space provides that the Content of each register and the conditions under which it is kept are determined by the state of registration in question, in this sense there is the flexibility of using the existing register, maintained by I.P. SNMFR. The satellite being registered in SIA "RSFSR", the public section of which can be accessed below, applying the strict filters (band 430-440 MHz, amateur service). The letter, that confirmed registration in the "State register of frequencies and radio communication stations", is presented în the annex 1.

4) SNMFR being designated as the entity empowered to keep the register of objects launched into space, SNMFR completes and submits the UNOOSA type form file (see annex 2). Afterwards, the completed form is sent to the permanent mission of the Republic of Moldova to the UN to be sent to the Secretary General of the United Nations

4. CHALLENGES AND EXPERIENCE OF TUMnanoSAT TESTING AND VERIFICATION

The test campaign is an extremely important stage, as it confirms whether the project can move forward to the launch stage or whether the developers still need to make changes to the satellite. The reference documents for carrying out the TUMnanoSAT satellite testing campaign were provided by the JAXA coordinators and include several stages represented in the general diagram in Figure 4.1.

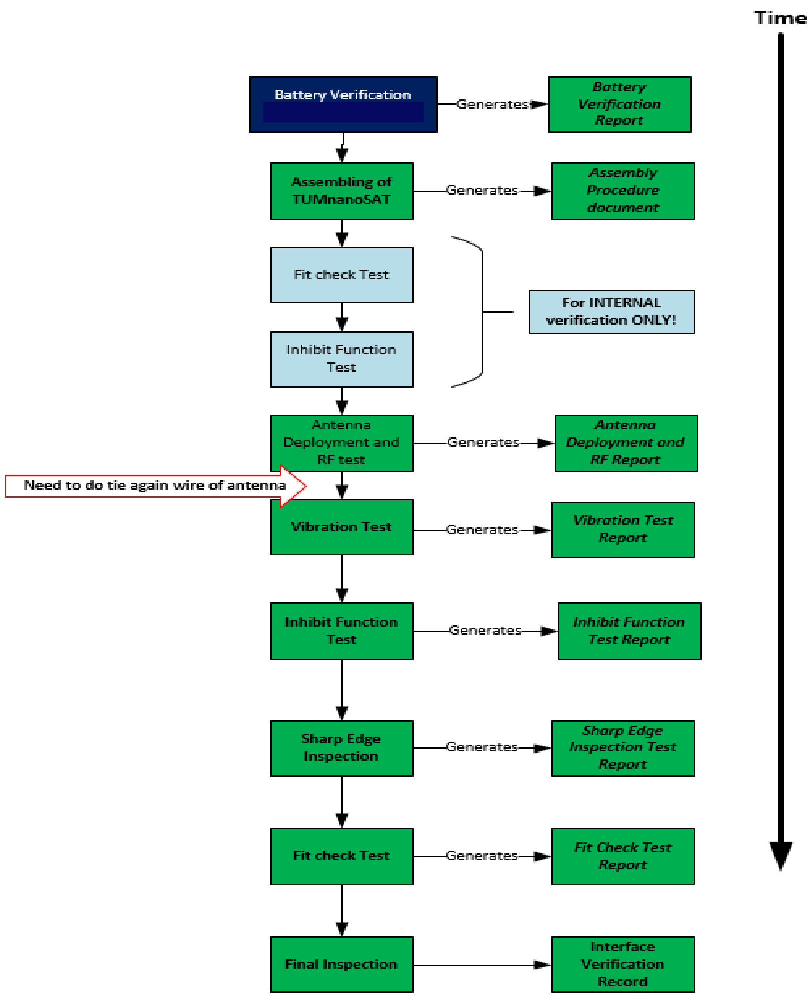


Figure 4.1. TUMnanoSAT satellite test campaign.

Each test step must be carried out according to all the rigors mentioned in the validation documents. At the same time, each test stage results in a report with all the data obtained, which were later verified by the JAXA partners. The tests carried out in phase 3 (testing and validation campaign) are [28, 29]:

- ✓ Checking the batteries - taking into account that the launch takes place from the International Space Station, the batteries are the elements that fall into the highest danger class, respectively, their proper functioning must be demonstrated by carrying out vacuum and vibration tests, as well as of functional tests. As a result, we get the battery test report.

- ✓ Assembly procedure - this procedure is not necessarily a test, but rather a series of steps described in luxurious detail to present the assembly operation with all the elements to be used. Thus, during the review period, it can be checked whether the satellite assembly was carried out correctly. As a result, we get the satellite assembly procedure.
- ✓ Antenna opening and RF emission test – this test is a specific requirement for the ISS, which states that after launch the satellite must not emit for a minimum of 30 minutes and must not have elements, which open (or change dimensions the satellite). As a result, we get the ratio of antenna opening and RF emission.
- ✓ The vibration test – one of the critical tests, especially for the launch stage towards the ISS. 2 types of vibrations are tested – random vibrations and sine vibrations. As a result, we get the satellite vibration test report.
- ✓ Inhibition test - test required to confirm that the disabling elements of the satellite are performed as required. As a result, we get the inhibition test report.
- ✓ Sharp edge inspection - specific test for launch from ISS. Taking into account that the satellite can be manipulated by an astronaut, to avoid any danger of injury, this procedure must be perfected. As a result, we get the sharp edge inspection report.
- ✓ Mechanical fit test - is a relatively simple test to verify the fit of the satellite to the launcher on the ISS. A model of the launcher is used for this test. As a result, we obtain the mechanical concordance ratio.
- ✓ Final inspection - the last inspection stage at which all the measurements and parameter values of the nanosatellite are presented to the committee of coordinators and the launcher in order to validate it for launch.

4.1 Assembly procedure

The TUMnanoSAT satellite assembly procedure was carried out in accordance with the "JEM Payload Accommodation Handbook". The requirements and rigors underlying the assembly procedure were described in the assembly manual documents. Among the basic requirements stipulated by JAXA can be mentioned:

- ✓ The assembly procedure is carried out in a clean environment (with as little contamination of dust particles per unit volume of air as possible).
- ✓ The handling of the object (in the given case of the satellite) is carried out only with gloves that do not contain contaminating particles, such as talc).
- ✓ The operator performing the assembly procedure must be properly equipped.
- ✓ Before mounting a connector, it is necessary to confirm that there is no abnormality in the connection surface, the plug-receptacle phase, the mating and the separation of the connector.

✓ When powering the flight module, it must be ensured that it is in good working order by monitoring the voltage and current.

✓ When performing important tasks in the assembly or adjustment of components, the name or initial of the workers performing the corresponding procedure must be recorded in the procedure document.

✓ When tightening bolts with torque, the torque setting value and torque wrench number should be recorded in the procedure document.

The points mentioned are only some of the criteria included in the assembly document. In the same document, all the necessary steps to be carried out were described in detail. At each stage of the assembly, the necessary components, the tools with which it will be made and the names of the people responsible for the assembly at each stage were highlighted.

As mentioned, the entire assembly procedure is performed in a non-contaminated environment (in a clean room). In the case of the TUMnanoSAT satellite, the assembly can be defined in two stages:

1. The preliminary assembly that was carried out at the Space Technologies Center of TUM.
2. The final assembly which was carried out at the Institute of Spatial Sciences in Măgurele, Bucharest, Romania.

For the preliminary assembly, a clean room, but with a medium level of dust particle contamination, was set up in the TUM Space Technologies Center. The room has 2 sections, in one section there is the transition area where there is a Fan Fiter Unit and the immediate work area which also has a Fan Fiter Unit. Images from the clean room are represented in Figure 4.2. The cleanroom was equipped with all the necessary equipment to ensure power, but also ESD protection during preliminary assembly and various tests.

Figure 4.2. Clean room within NCST TUM.

Figure 4.3. TUMnanoSAT assembly in the clean room at the Space Sciences Institute.

As mentioned, the final assembly took place in the clean room at the Institute of Spatial Sciences in Măgurele, Bucharest. This camera complies with the ECSS-Q-ST-70-01C standard. It has 18 m^2 of effective working space with permanent and continuous monitoring of temperature, humidity, pressure and the number of dust particles that can be contaminating for flight equipment subsystems. At the same time, the chamber also has an air exhaust system for carrying out soldering procedures in case of necessity.

Sequences of activity in the clean room to perform the assembly and directly of the NCST-TUM collaboration, which performed this procedure for the final assembly of the TUMnanoSAT device, are represented in Figure 4.3, and some stages of the assembly manual in Figure 4.4. This manual has been reviewed by JAXA to confirm that it meets the specified requirements for release from the ISS. After the assembly procedure, the final inspection procedure was performed with the measurement of all mechanical parameters to confirm the interface requirements with the JSSOD. The purpose of the JSSOD integration verification test is to confirm the mechanical compatibility between the satellite and the launch module from the JEM Small Satellites Orbital Deployer (J-SSOD). The fit check is performed to inspect the satellite visually and confirm that it can be installed in the J-SSOD without any interference. To perform this test, JAXA sent a model of the launch module to the TUM Space Technology Center. A picture of this model is shown in Figure 4.5. Firstly, the surfaces of the satellite were examined visually, and photos were taken for later comparison with post-test images. The satellite was then installed in the model (shown in Figure 4.6) to confirm that there were no mechanical conflicts.

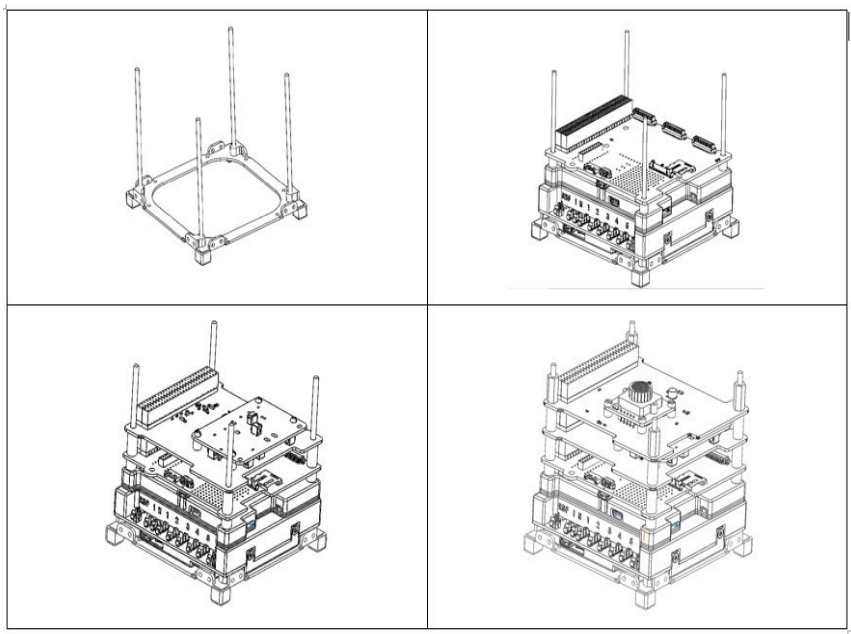


Figure 4.4. Steps in the TUMnanoSAT nanosatellite assembly procedure

Figure 4.5. The model for confirming the fit of the satellite with the JSSOD launcher.

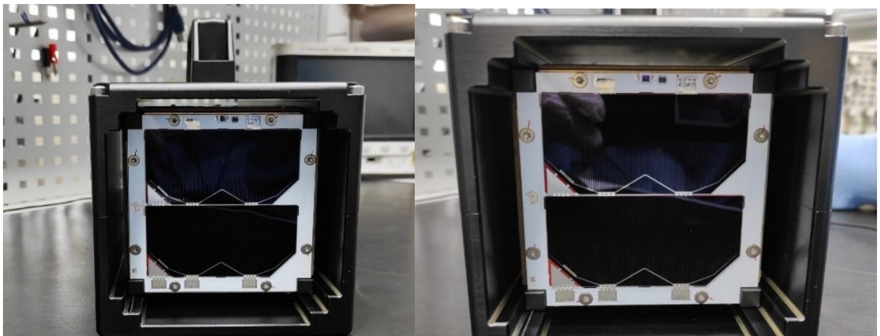


Figure 4.6. The TUMnanoSAT satellite in the JSSOD launcher model.

4.2 Nanosatellite Battery Inhibition Function Test

The battery inhibit function test is one of the most important safety tests for launching from the ISS. This test confirms that the satellite has sufficient inhibition mechanisms to prevent overcharging, overdischarging or short-circuiting the battery mounted on the satellite.

The entire satellite system is used for this test. Inhibit switches are pressed before launch and released after launch. Therefore, the satellite is checked to see if the satellite power system is turned off when the inhibit switches are accessed. The test procedure is carried out according to the following principles:

1. The battery is charged to at least above the minimum voltage to activate the satellite.
2. The voltage is permanently monitored at the inhibit switches. The current is also monitored if possible.
3. If the supply voltage of the solar panel is unstable, a standard power supply is used.
4. Each inhibit switch is accessed. It is checked that the voltage and current become zero. Each inhibit switch is checked separately.

The inhibit switches and their functions are described in table 4.1 (with reference to the electrical diagram of the TUMnanoSAT satellite power system).

Table 4.1. Status of inhibit switches

		Inhibit. 1	Inhibit. 2	Inhibit. 3
Overcharging [a]		FET1 (Deployment SW#1)	Deployment SW#2	FET3 (Deployment SW#3)
Over-discharge[b]	Solar Cell Side	FET1 (Deployment SW#1)	Deployment SW#2	FET3 (Deployment SW#3)
	Load Side			
Short circuit [c]		FET1 (Deployment SW#1)	Deployment SW#2	FET3 (Deployment SW#3)

For continuous voltage monitoring of the assembled satellite, a connector on the -Z surface was used. The test setup for voltage monitoring is shown in Figure 4.7. The inhibit function was tested by accessing each switch individually. When one of the inhibit switches remains on, the satellite will not be activated. A switch is accessed if there is at least 0.75 mm from the rail end on the -Z side as shown in the figure (Figure 4.8). And the total force of the separation spring and trip switches should be from 1.08 to 5.3 [N]. The reaction force of a rail-side inhibit switch must be 0.26 [N] or less per 1U. Stroke and force are measured and documented (Figure 4.8).

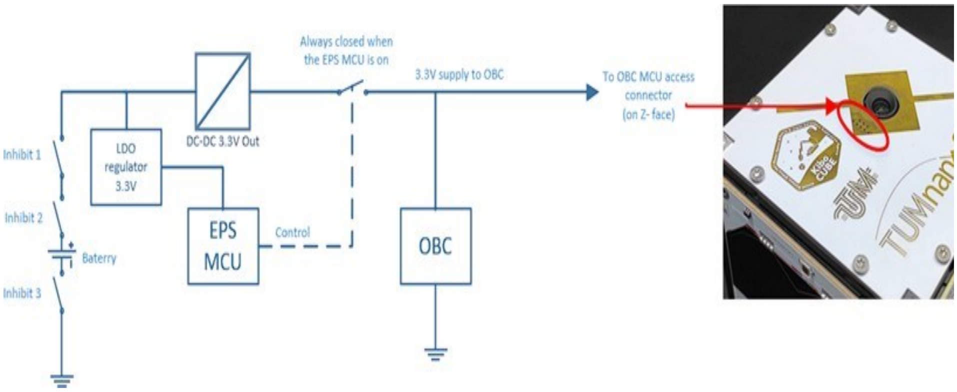


Figure 4.7. Test setup for voltage monitoring when testing inhibit switches.

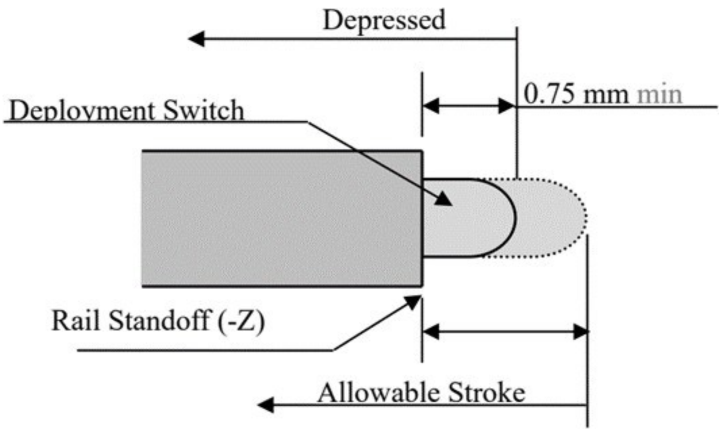


Figure 4.8. Pressed state and allowable travel of the switches inhibition.

In addition to voltage monitoring, the same test checks the double isolation of the PCB, which includes the battery, inhibit switches, and the lines between the battery and the switches. At the same time, the resistance of the outer surface of the insulator between the battery lines was measured. Only after all these tests are confirmed, the satellite is accepted for further checks. The results of a test for a switch are shown in Figure 4.9. According to the image in Figure 4.9, it is observed that as long as the inhibit switches are not accessed, the measured voltage is 3.3V on the corresponding rail. When a switch is flipped, all power to the satellite is turned off. Next, we will outline how this procedure was performed at NCST TUM.

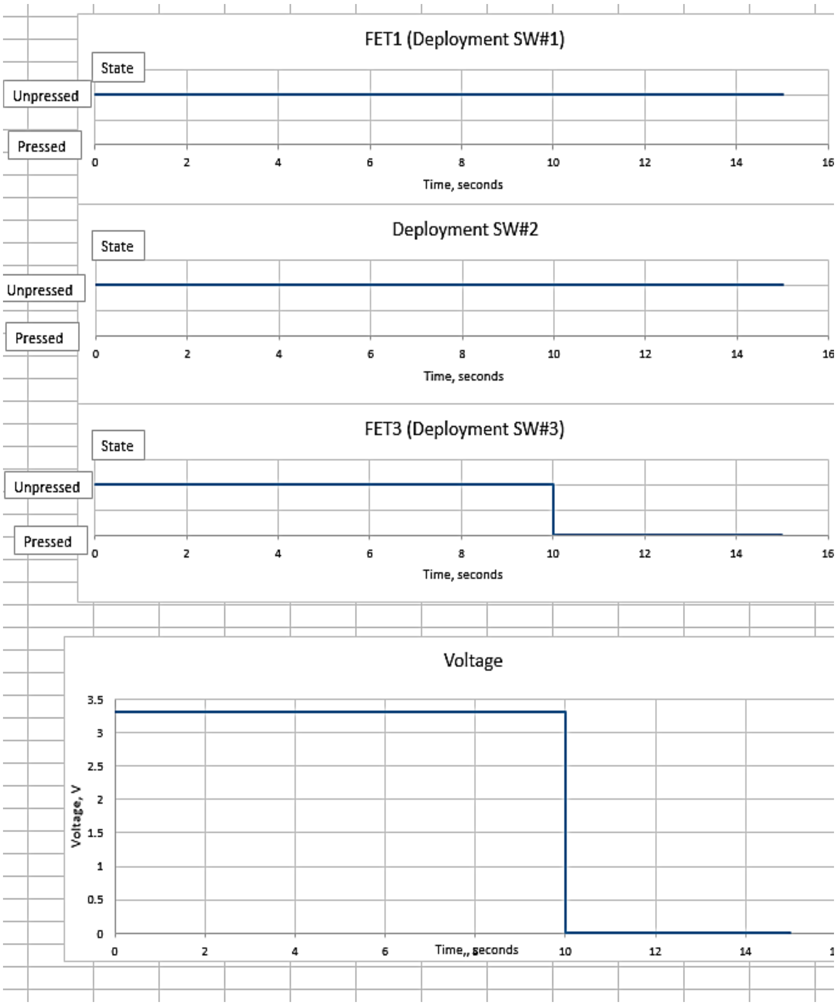


Figure 4.9. Voltage measurement and switch status.

4.3 Antenna release test and RF transmission procedure

The antenna release test is one of the critical tests for launch on the International Space Station and one of the few functional tests. The operational requirements in section 2.3 of the launch document specify the following:

- All deployment devices such as booms, antennas, and solar panels must wait to deploy for at least 30 minutes after the launch/inhibit switches are activated upon ejection of the satellite from J-SSOD. Whenever one of the three launch/inhibit switches is accessed again, the timer must be reset.
- RF transmissions must not transmit for at least 30 minutes after the launch switches are activated upon ejection of the satellite from the J-SSOD. Whenever one of the three launch/inhibit switches is accessed again, the timer must be reset.

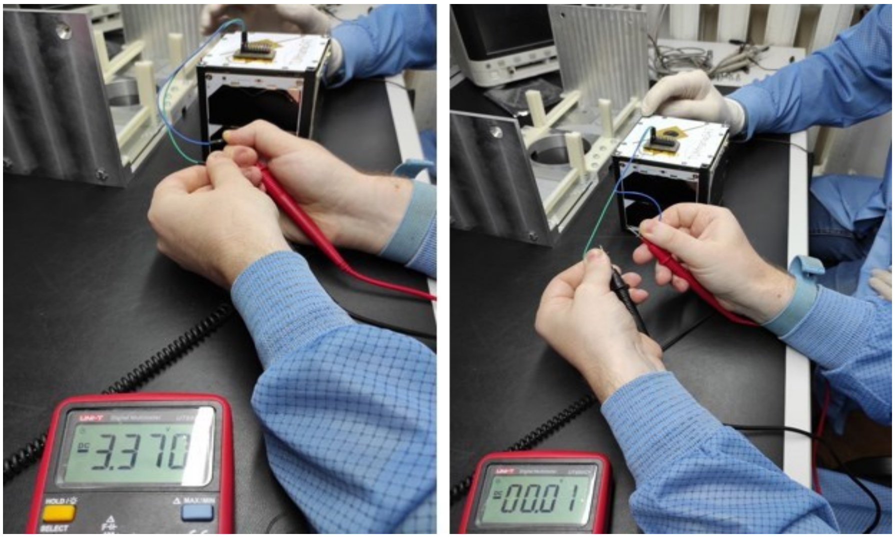


Figure 4.10. Voltage measurement when testing switches.

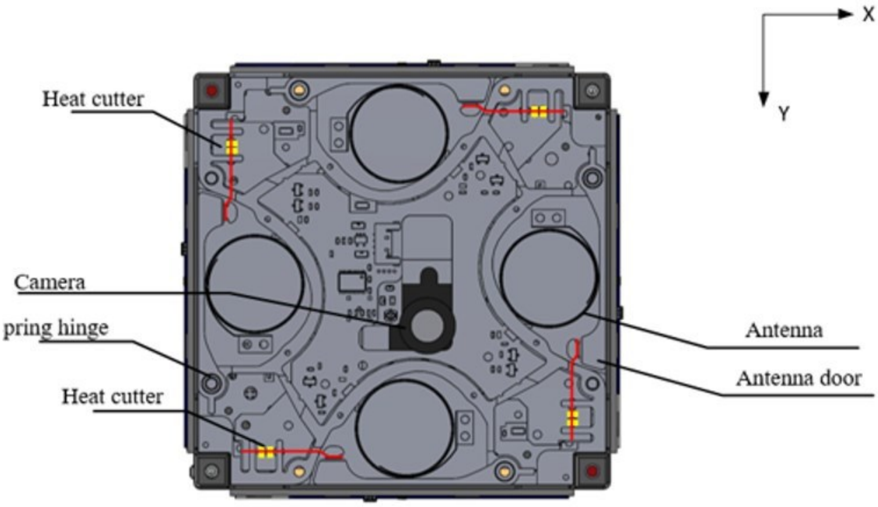


Figure 4.11. Antenna aperture system structure in TUMnanoSAT.

Therefore, the on-board computer (OBC) counts 30 minutes after the satellite launch into orbit, and if the time passes more than 30 minutes and the battery voltage is sufficient for cutting the retention wires, then OBC sends a signal to an actuator. Thus, the PE wire is burned and the antenna release takes place. After that, RF transmissions begin to transmit. În the figure 4.11 it is shown the structure of the antenna opening mechanism used in the TUMnanoSAT satellite, from which can be seen the fixing wires and the resistors that will serve as heaters for cutting them. The wires fix the 4 doors and are passed through springs, and when the wire is burned, they open and the antenna, being composed of flexible metal with memory, they open.

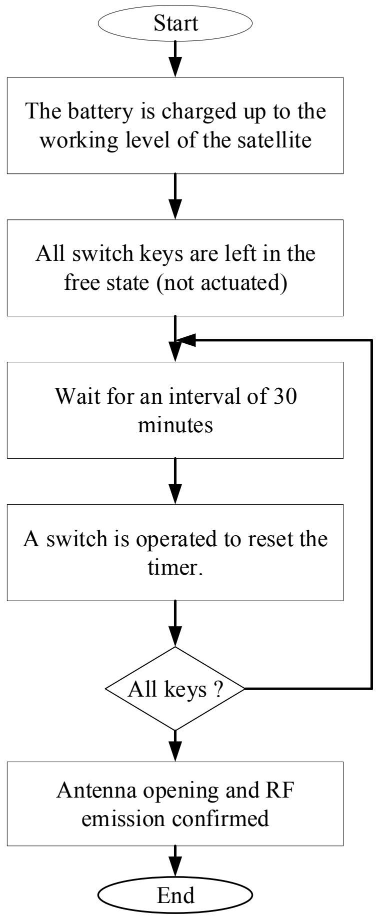


Figure 4.12. Steps to be performed for the antenna opening and RF emission test.

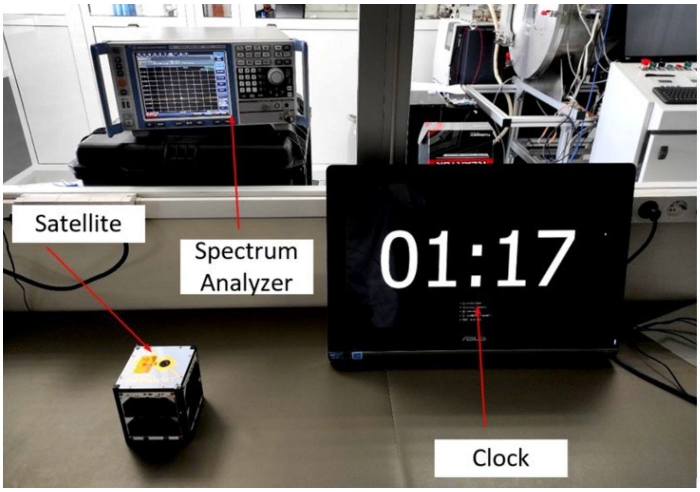


Figura 4.13. Testul de deschidere a antenelor și emisie RF.

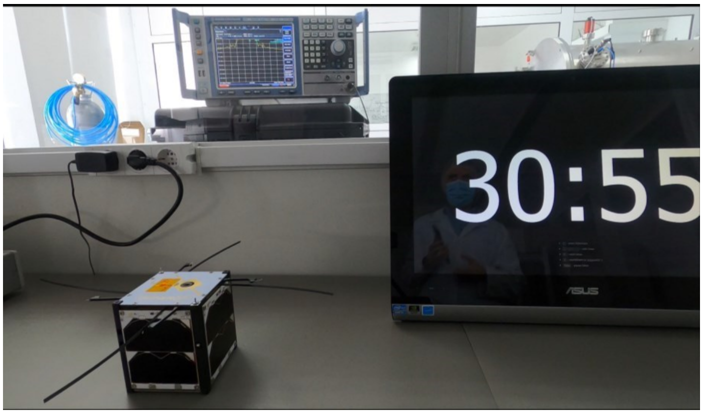


Figura 4.14. Deschiderea antenelor TUMnanoSAT.

The antenna aperture test uses the algorithm shown in Figure 4.12 and requires the satellite itself, a timer and a spectrum analyser to confirm the RF emission 30 minutes after the last switch is turned on. Figures 4.13, 4.14 show the implementation of this test at the ROSA Space Science Institute..

After performing all the above steps, after accessing the last switch, the antenna aperture and RF emission (which can also be observed on the spectrum analyzer screen) was confirmed. The current test demonstrated the compliance of the TUMnanoSAT satellite with the RF emission and antenna aperture requirements.

4.4 Battery/accumulator check test

As mentioned in the overview of the test steps, the battery verification test is a critical one, especially considering that batteries are simple commercial components and not developed exclusively for space. The first stage of battery testing is the stage of detecting and choosing the most suitable cells for use. This stage involves choosing the best cells from a batch of about 20 cells by visual inspection, OCV voltage, capacity, charge/discharge characteristics, charge/discharge temperatures.

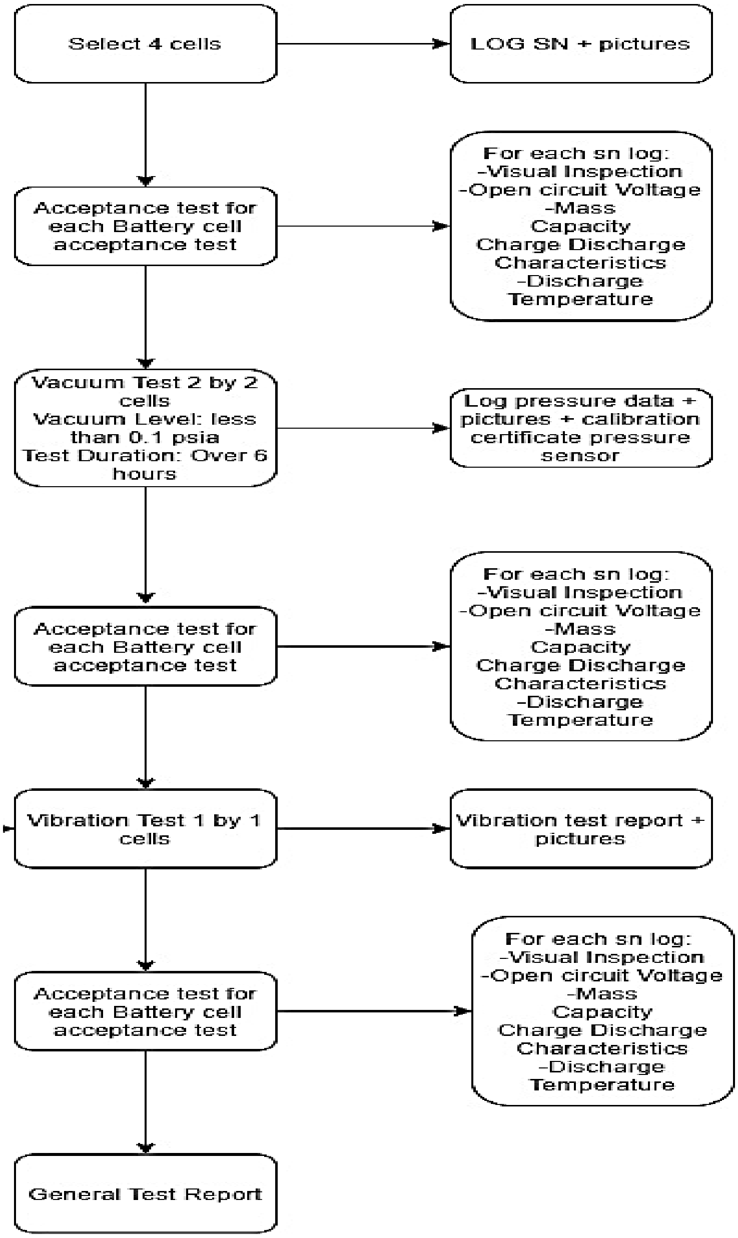


Figure 4.15. Stages of battery testing.

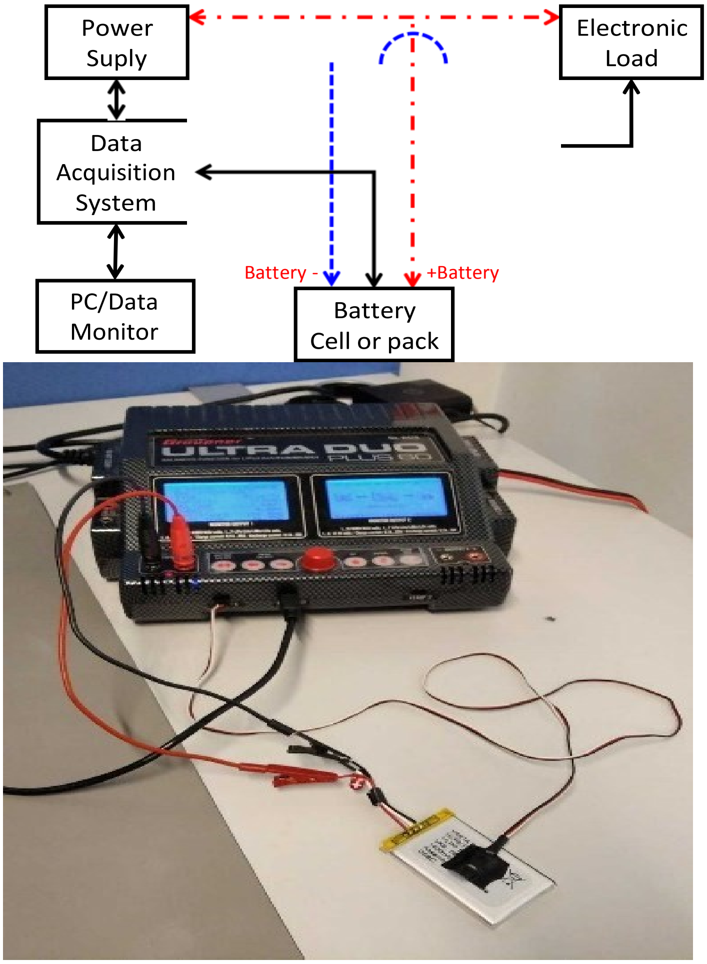


Figure 4.16. Battery test equipment configuration.

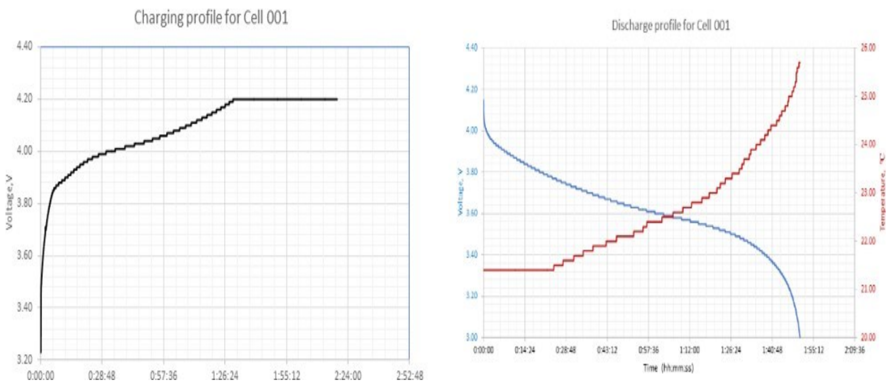


Figure 4.17. Battery charging and discharging profiles.

If they have been chosen, the cells to be used pass the acceptance stage, which consists of the following tests:

- ✓ Random vibration test – this test is performed on all 3 axes with a rotation of 60 seconds and a summary level of 8.6 Grms.
- ✓ Vacuum test – the duration of the test is 6 hours, with a vacuum level lower than 0.1 psi.
- ✓ Functional test – before and after environmental tests (vibration test and vacuum test) several functional tests are performed to see that there is no change in characteristics: visual inspection, OCV testing, cell mass, capacity, load characteristics /download.

If we perform all these tests for battery testing, they should be performed according to the diagram in Figure 4.17.

To improve the characteristics, after each environmental test of the accumulators, the configuration in Figure 4.16 was made. All components in the given configuration are found within the NCST TUM. The charge and discharge profiles of the accumulators, which were raised before the environmental tests, are represented in the graphs in Figure 4.17.

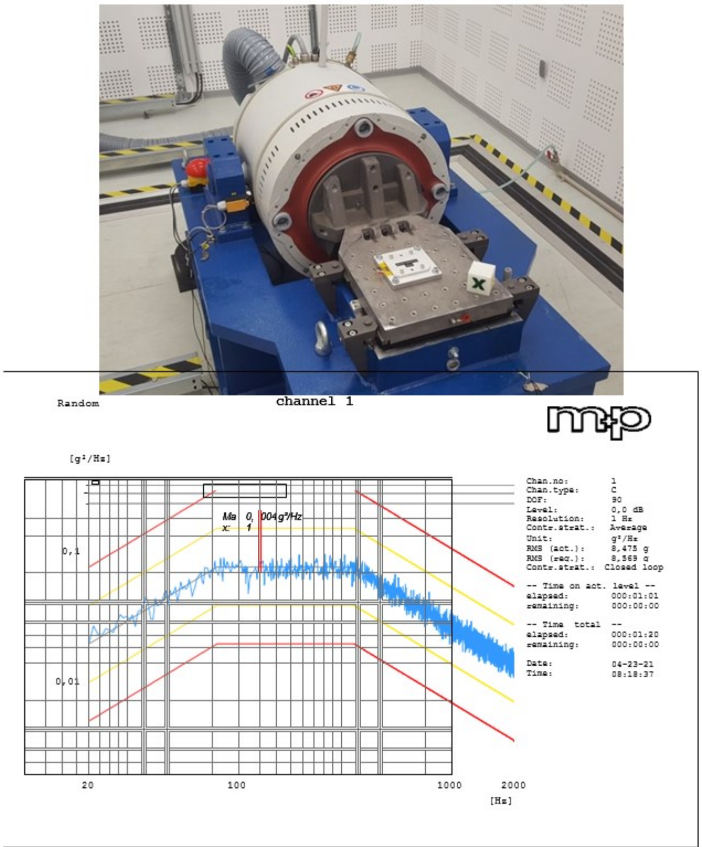


Figure 4.18. Battery vibration testing.

The charge/discharge profiles in Figure 4.17 are typical profiles for LiPo batteries. The whole point of the battery test suite, as emphasized, is to ensure that these profiles will be unchanged after vibration/vacuum. Changing these characteristics would mean a change in the chemical profile of the cells, which would represent a danger. The JAXA criteria warn of a maximum change of 0.1% in OCV voltage, 0.1% in battery mass and a change in battery capacity of maximum 5%. The test setup for the vibration test includes a "shaker" and the battery system, as shown in Figure 4.18.

Figure 4.19. Vacuum battery testing.

The vacuum test of batteries is necessary to detect any anomalies that may occur at high temperatures and very low pressures. For the vacuum test, specific equipment is required to ensure 0.1 psi. The vacuum test must ensure a duration of 6 hours at this level.

After carrying out all the environmental tests, the functional characteristics were raised again, obtaining the following results, which confirmed the validation of the accumulators (table 4.2).

Table 4.2. Battery test results

Test Phase	Visual inspection (Pass or Fail)	Open Voltage[V] (< 0.1%)		Mass[g](< 0.1%)		Capacity[mAh] (< 5%)	
		[V]	Diff. [%]	[g]	Diff. [%]	[mAh]	Diff. [%]
Initial	Pass	4.162	-	24.50	-	1400	-
Post vibration	Pass	4.160	0.04	24.50	-	1372	2.04
Post vacuum	Pass	4.159	0.02	24.48	0.08	1325	3.4

5. EXPERIENCE IN OF NCST GROUND INFRASTRUCTURE DEVELOPMENT

The communication time for CubeSat nanosatellites in LEO orbits is in the best case scenario about 12 minutes per pass. In practice, however, the quality of a pass is very sensitive to the environment. Given the limitations in the amount of information that can be sent over a radio channel, it is recommended to use multiple ground stations to maximize the data exchange between the satellite and the ground station. The TUM Space Technologies Center has developed an infrastructure with two ground stations for communication with satellites. The images of the stations are represented in Figure 5.1.

Figure 5.1. Views of ground stations developed at NCST TUM.

5.1 General architecture of NCST ground stations

The general architecture of a ground station is shown in Figure 5.2. The NCST ground station consists of the antenna array, the steering system and the radio control centre. The antenna array is located on the roof of TUM block 3 and consists of 4 antennas: 2 X-Quad antennas resonant in the UHF band (433 MHz), one X-Quad antenna resonant in the VHF band (145 MHz) and one helix antenna also resonant in the VHF band. All 4 antennas are steered and, as a consequence, there is a need to steer these antennas towards the object of interest. The steering of the antenna array is done by means of a rotor which allows the array to rotate on two axes.

The radio command centre houses the other major components of the ground station. This is where the rotor controller and its power supply are located. The controller is connected to the rotor and to the computing machine at the control centre from which it can receive commands for antenna orientation. The rotor controller also allows the antenna array to be manually oriented in the desired direction.

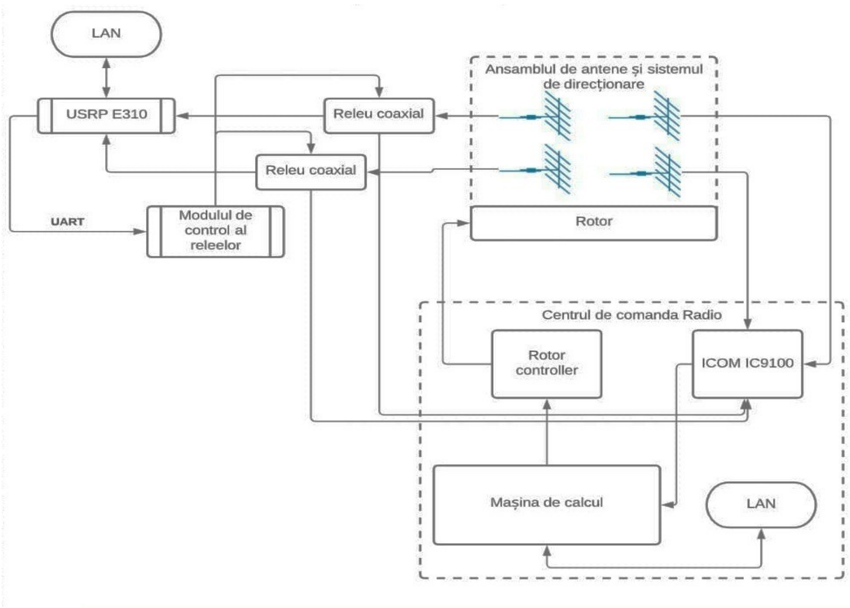


Figure 5.2. Structure of ground stations developed at NCST TUM.

An ICOM IC-9100 radio receiver is also located in the control centre and is connected to one UHF and one VHF antenna in the antenna array. The radio station is connected to the computing machine and can be used for receiving signals, digitalizing the results and sending them to the computing machine for further processing or it can be used for manual reception and transmission of radio signals.

For communication with the educational nanosatellite TUMnanoSAT, the decision was taken to use the SDR architecture. Some of the reasons for selecting the SDR architecture are the possibility of changing the communication protocol with simple software updates; the versatility of the SDR architecture; the ease of configuring the reception algorithm to be compatible with the transceiver on the TUMnanoSAT nanosatellite; the possibility of further automating the communication process with the nanosatellite; the possibility of reconfiguring the ground station and communicating with other satellites if necessary, etc. [47, 60, 64].

The hardware device used to digitalize radio signals is the USRP E310. The USRP E310 is a hardware device designed for SDR architecture. It is installed in the immediate vicinity of the antenna array and, in the case of the reception process, is responsible for digitizing the radio signals received by the antenna array and sending the data obtained via the LAN to the computer where processing takes place. In the case of transmission, on the other hand, the USRP receives the digital data via the LAN from the computer and converts them into radio signals, which are transmitted over the air using the antenna in the appropriate band (Figure 5.3).

The USRP is connected via two coaxial relays to two antennas in the array, one in the UHF band and one in the VHF band. The switching control of the coaxial relays is performed by a module designed exclusively for this purpose.

Figure 5.3. USRP E310 hardware device for SDR architecture.

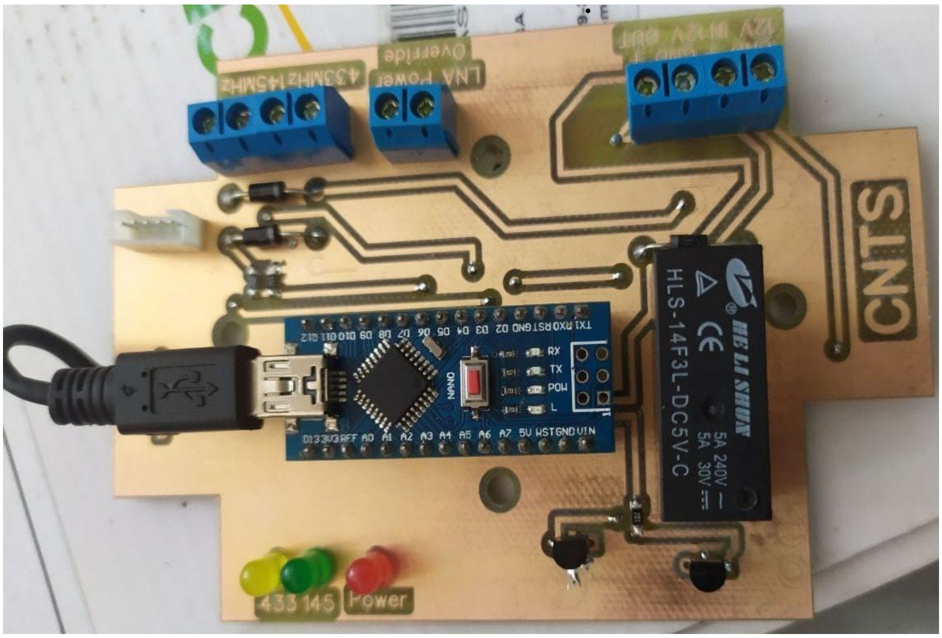


Figure 5.4. Control module of coaxial relays

The control module is very simple and is based on a simple Arduino micro controller. Communication between the relay control module and the USRP E310 is done via the UART interface. To switch the relays it is sufficient to be connected via LAN to the USRP E310 device and run the python script that has been written to communicate with the control module and give the appropriate relay switching command, depending on the user's needs. The relay control module is shown in Figure 5.4.

5.2. Control and Communication Platform for Nanosatellites

The main problem with Open Source or commercial platforms for controlling the nanosatellite mission is the very limited possibility of integrating SDR components into their architecture. As a result, the decision was made to develop an individual platform for controlling and monitoring the mission. The communication and monitoring platform for the TUMnanoSAT nanosatellite is divided into 3 general blocks. The first block is the USRP E310 device which plays the role of leader in the SDR architecture. The second block is the signal processing algorithm, created using the GNU Radio Companion, and the third component is the application itself, which has the role of interacting with the user. The tool that connects the 3 functional blocks mentioned is the ZMQ protocol. In the described architecture, push/pull type sockets are used to make the component parts communicate with each other.

The USRP E310 does not need to perform complex tasks in terms of processing power. The main purpose of this device is to be placed as close as possible to the antennas used in the communication process and to digitize the received signals, then send them over the LAN to the signal processing algorithm or, if we are talking about the scenario where signals are transmitted to the satellite, then the task is to receive the digital packets over the LAN from the signal processing algorithm, convert them to the analogue domain and transmit the signals to the satellite.

The digital signal processing block is actually a very complex python script created using the GNU Radio Companion platform. The main functionality it provides consists of receiving digital packets from the USRP E310, demodulating the signals, extracting symbols, detecting the type of received message (Beacon or Command Response) and then transmitting the processed data to the corresponding ZMQ socket. On the other hand, when signals need to be transmitted, this block receives the command messages via the ZMQ protocol from the upper application layer, packages the messages into the appropriate packets, modulates the signals and sends the resulting samples to the USRP E310 where they are output on air.

The application closes the loop in this architecture. In addition to interacting with the user via the graphical user interface, it also performs other key tasks in the communication process. One of these tasks is running a receiver for beacon messages. This receiver receives packets from the processing algorithm, extracts useful data from these packets and presents them to the user in an easily digestible way. The extracted data is also automatically sent to the database for safekeeping in case further data processing is needed [112].

Another task that needs to be executed at application level is running the receiver for "Command Response" packets. This is the process that receives the data sent by the satellite in response to commands issued to it. Command Response messages can be of one of three types: text response to command; file section; image section.

If the receiver detects that the received message is of type "Text reply to command", then this message is presented to the user and this is the end of its processing. On the other hand, if the received message is an image or file sequence, this message is attached to the corresponding packets received previously and which are part of the same file/image. When the process of receiving a file or image is finished, the result is added to the list of received images/files. The user can then select any of the received images and it will be presented for viewing or can select files from the list of received files and extract useful data from them. When the useful information contained in the files is extracted, it is automatically stored in the database for further processing.

The third task, which the application performs, is to offer the user the possibility to transmit commands to the satellite. The command to the satellite can be entered manually or selected from the list of commands available to be sent. When the command is selected or manually typed, it is validated by the application, then sent via the ZMQ to the signal processing algorithm where it is further processed and sent to the satellite.

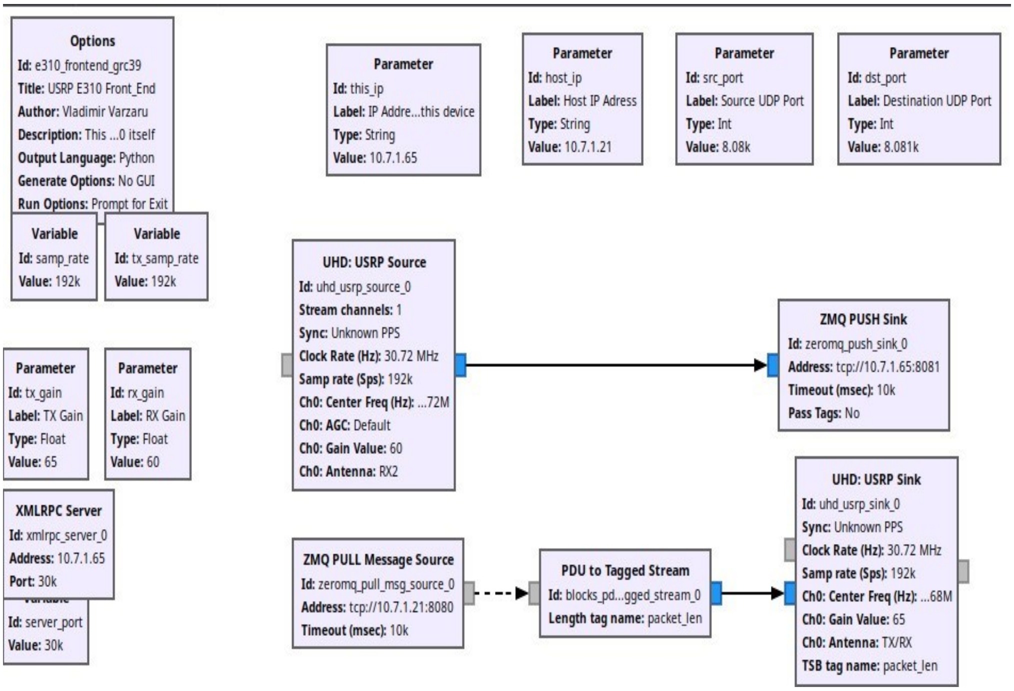


Figure 5.5. GNU Radio algorithm running on the USRP E310 device and converting data from digital to analogue when transmitting and reverse converting when receiving messages.

This application has extended functionality. Firstly, the application allows the transmission of commands to the educational nanosatellite TUMnanoSAT and the reception of responses from it. The commands can be of the type "Configuration commands" (provides the possibility to configure the nanosatellite parameters), "Reset commands" (provides the possibility to reset the nanosatellite subsystems), "Data request commands" (provides the possibility to request useful data files collected along an orbit) or "Image request commands" (provides the possibility to request images from specific orbits).

In addition to the service communication with the nanosatellite mentioned above, the application allows the reception of beacon messages that are emitted by the nanosatellite at a predefined interval. The beacon messages contain a group of more general parameters describing the current state of the satellite subsystems and its overall current state. Beacon messages are encapsulated, using the AX.25 protocol used by amateur radio operators, and are broadcast on the 436.68 MHz center frequency. This information is public and any willing party with a resonant antenna at this frequency and a device capable of decoding AX.25 messages can receive these packets and analyze their contents.

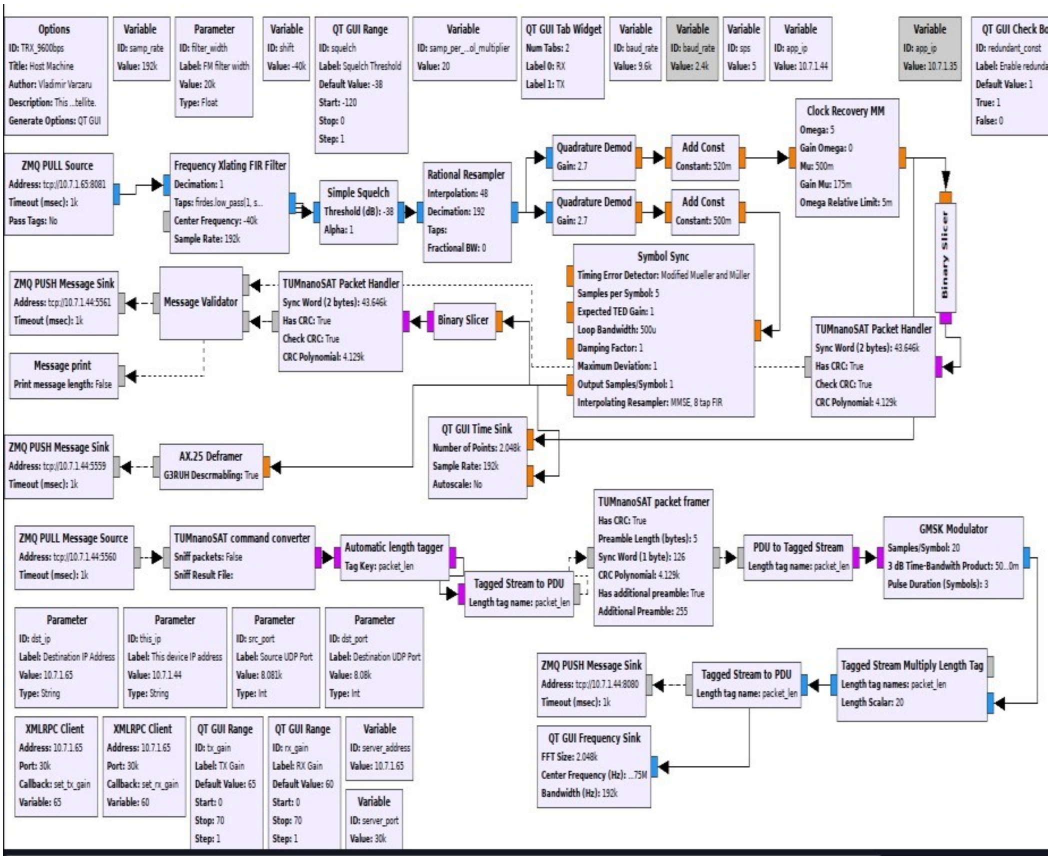


Figure 5.6. GNU Radio algorithm for processing data received from the TUMnanoSAT educational nanosatellite.

GNU Radio and digital processing blocks. GNU Radio is a free and open-source software development toolkit that provides signal processing blocks for implementing SDR architecture. It can be used with low-cost external RF hardware to create software-defined or hardware-free radios in a simulation environment. It is widely used in research, industry, academia, government and hobby to support both wireless communications research and real-world radio systems. Creating an algorithm in the GNU Radio Companion involves selecting blocks, which perform the necessary signal conversions, and interconnecting these blocks in logical order to achieve a desired result. In the case of communication with the TUMnanoSAT nanosatellite. Using this tool, the algorithms that are involved in the communication process were created.

The first algorithm, described above, is shown in Figure 5.5, and the second algorithm in Figure 5.6. For processing the specific packets for the communication protocol with the TUMnanoSAT education satellite, not all the necessary blocks were present in the GNU Radio base library. As a result, several digital processing blocks were created that format the analyzed information and package it into packets that can be received by the transceiver installed on the nanosatellite and vice versa. Some of these blocks are shown in Figure 5.7.

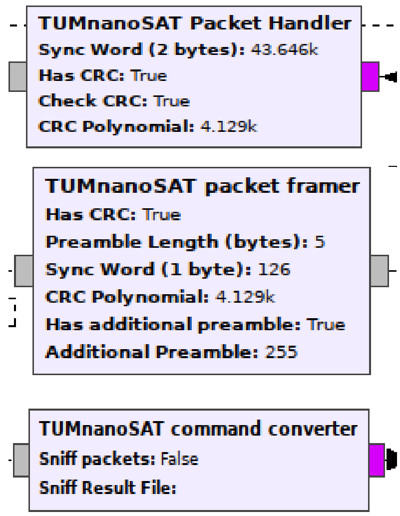


Figure 5.7. Some of the information processing blocks created for communication with the TUMnanoSAT educational nanosatellite.

As mentioned, the Zero Message Queue library was used to interconnect the component parts of the communication algorithm. ZeroMQ is designed as an embeddable network library, but acts as a framework that works concurrently. It provides sockets that carry messages at different transport levels such as in-process, inter-process, TCP and multicast. It allows connecting N-to-N sockets with models such as fan-out, pub-sub, task distribution and request-response. It is fast enough to be used in cluster products. Its asynchronous I/O model provides scalable multicore applications built as asynchronous message processing tasks. It has APIs for a variety of programming languages and runs on most operating systems.

In the case of the communication algorithm with the educational nanosatellite TUMnanoSAT, the push-pull model of the ZMQ protocol is used to interconnect the nodes performing message processing. The push-pull model implies that there is a server that pushes messages to a network socket where they are kept until their timer expires or until they are received by a ZMQ client connected to this socket. On the other hand, other components are involved in the communication process with the TUMnanoSAT educational nanosatellite, and the part responsible for storing the data for further processing are the databases where the received information is stored.

Two databases are used to store the useful information received from the TUMnanoSAT nanosatellite. "Telemetry_data" and "Beacon" are the two databases involved in keeping the received data. The "Beacon" database consists of a single table with 3 fields and is intended to store the received information from the beacon packets. The second database, "Telemetry_data", consists of 4 tables, one table for keeping information from each subsystem and is intended for keeping information extracted from telemetry files downloaded from the nanosatellite following data request commands.

Dividing the data received from the nanosatellite into two categories and keeping them in two separate databases is done for security reasons. The "Beacon" database is the database to which other persons who have received and decoded data from the TUMnanoSAT nanosatellite will be able to send data. This data will also be accessible and presented to the public on the TUMnanoSAT nanosatellite mission website. Therefore, the database will be accessible from outside the local NCST network. On the other hand, the "Telemetry_data" database will keep useful data from the nanosatellite for internal use and this data should not and will not be accessible from outside the network, it will be available only locally.

An important step before storing the information received from the TUMnanoSAT nanosatellite is the process of correctly and clearly requesting the information so that the nanosatellite's on-board computer is able to determine which of the collected data needs to be segmented, packaged and sent to the ground station. In order to carry out this process correctly, a grid of commands and responses to be used when requesting information must be established.

5.2.1 Establishing the command-response grid between TUMnanoSAT and the ground station

A command-response grid was established for communication with the TUMnanoSAT nanosatellite. The commands were divided into 4 general categories: data request, image request, configuration and reset. Two special commands have also been established in addition to the 4 categories: ping, check connection. The grid of commands and responses is given in Table 5.1.

Table 5.1. Grid of command-responses

Category	*Command*	*Parameter*	*Responce*	*Description*
Request data	Request data Payload	Orbit Nr.	The file corresponding to the subsystem recorded on the selected orbit or **ERR NO DATA**	These commands allow the download of useful date files for the selected subsystem from the requested orbit.
	Request data OBC			
	Request data ADCS			

	Request data EPS			
Request image	Request image JPG Request imageRAW	Orbit Nr.	Image in the selected format from the requested orbit or **ERR NO DATA**	These commands allow you to download images in JPG or RAW format from a requested orbit.
Configuration	Delay	Pause value in milli-seconds.	**OK** or **ERR**	The command allows the configuration of the network between packets for sending files and images. If the retention is too low, packets are corrupted, and if too high, time is lost.
	MissionStart	Timestamp for selected time	**OK Rebooting now** or **ERR**	The command allows you to configure when to start counting seconds from the start of the mission.
	RF baudrate	Requested baudrate	**OK** or **ERR**	This command allows you to change the the transmission rate of their date in 2400 bps or 9600 bps
	Reboot OBC	NOW	**OK Rebooting now** or **ERR**	Command allows processor restore on-board computer
	Record frequency	Subsystem / space/ H/M/L (High/ Med/ Low)	**OK** or **ERR**	This command allows you to change the frequency at which data is written to files for the selected subsystem. For each subsystem the H/M/L regimes represent different time duration.

	Snap	NOW	**OK Taking Picture** or **ERR**	The command allows you to force the image camera to take a picture when the command is received.
	Update RTC	Timestamp	**OK Rebooting now** or **ERR**	This command allows you to correct the satellite's on-board computer clock.
Reseting and other	Reset All	NOW	**OK** or **ERR**	This command allows resetting all subsystems of the nanosatellite to their initial parameters.
	Reset Camera			This command allows you to force reset the nanosatellite's onboard camera.
	Reset File system			This command allows you to reset the file system, which involves formatting the memory card on the nanosatellite.
	Connect Check	-	**OK** or Nothing	This is a special command to check the connection with the transceiver installed on the nanosatellite, which is the verification of the physical level of communication.
	PING	-	OK + callsign + Timestamp + orbital current + inscription frequencies for each subsystem + memory used on SD.	This command is addressed to the on-board computer and allows to check the communication application level as well as to find out some important parameters about the nanosatellite.

In order to know what commands need to be sent to the satellite at a specific point in time, what volume of data can be downloaded and what data is available at the time of communication, it is necessary to calculate and simulate the useful data budget of the nanosatellite.

5.2.2 Calculating and simulating the budget of the useful data requirements

In order to calculate the maximum amount of data that can be downloaded from the satellite, a number of parameters must be defined, such as the duration of the communication session, the data transmission rate, the energy budget level of the satellite, the working period of the communication module.

To define the available communication period, we start from the notion of the radio visibility "window". The average duration of a radio window for a satellite in LEO orbit of the Earth is 7-8 minutes. On the other hand, in order to have a stable link with the satellite, its trajectory must have an elevation above 10 degrees. For this reason, only 85-90% of the visibility window is available for communication. This gives a communication session duration of 7*0,9-:-8*0,9 6,4-:-7,2 minutes, which we will approximate to 8 minutes for simplicity.

The number of orbits the satellite performs in 24 hours was calculated earlier and found to be 16. Of these 16 orbits, because the Earth rotates around its own axis, only 5-:-6 orbits provide the window of visibility for a fixed point on Earth, i.e. the ground station, which we call time resolution. The other orbits already pass over other areas, different from the area where the ground station is located. For this reason, multiplying the number of orbits available by the average effective communication time with the satellite gives 6 * 8 = 48 minutes. So, the time that the satellite is available for communication, when communicating with a single ground station, is approximately 48 minutes over 24 hours.

Next, for the actual calculation of the amount of data that can be downloaded we need to know the data transmission rate from the satellite. Typically, educational satellites communicate with ground stations at a transmission rate between 1200 bps and 9600 bps. A rate lower than 1200 bps does not provide a fast enough link for downloading useful data, and for a rate higher than 9600 bps the energy budget must be increased, which is also very tight for CubeSat nanosatellites. The basic problem, however, with a transmission rate higher than 9600 is the increased probability of bit error. So if you calculate using the 1200 bps data transmission rate, you get 1200 * 48 * 60 = 3456000 bits, which is equivalent to 3456000 / 8 / 1000 = 432 Kbytes. On the other hand, if calculated using 9600 bps: 9600 * 48 * 60 = 27648000 bytes, equivalent to 3.456 Mbytes.

Looking at the calculated data volume, it would appear to be small compared to the data transmission rate we are currently using on a daily basis. In fact, for a CubeSat satellite, which only transmits telemetry data read from sensors and possibly some images, if it has a camera on board, the calculated data volume is, in theory, more than sufficient.

The maximum data volume calculated above is only a theoretical value that is impossible to achieve in practice for several reasons:

✓ In the radio packets sent by the satellite to the ground station there is also other information than the useful one. In addition to the useful information field, which usually occupies most of the packet, there are other fields that define the packet. There are also fields for demodulator clock synchronization, fields for detecting and possibly correcting errors, fields for identifying the packet and other fields specific to the communication protocol that is used to create the radio link between the ground station and the spacecraft.

✓ The energy budget of CubeSat satellites is very tightly controlled and quite conservative. For these reasons, but also because of the thermal management of the communication module, it cannot be operated continuously over an entire satellite visibility window. There must necessarily be breaks between transmissions either because of insufficient power or to prevent the communication module from overheating.

✓ Another factor suggesting the impossibility of continuous data transmission by the satellite is the simple fact that the satellite must receive data request commands to determine which particular information to send, which means pausing the transmission process and waiting for commands from the ground station. An exception is when a full duplex communication algorithm is implemented. In this case, there would be no need to pause to receive commands, but most of the time the communication process between the nanosatellite and the ground station is half duplex. Planning the communication in advance helps to minimize the impact of this factor on the amount of data downloaded.

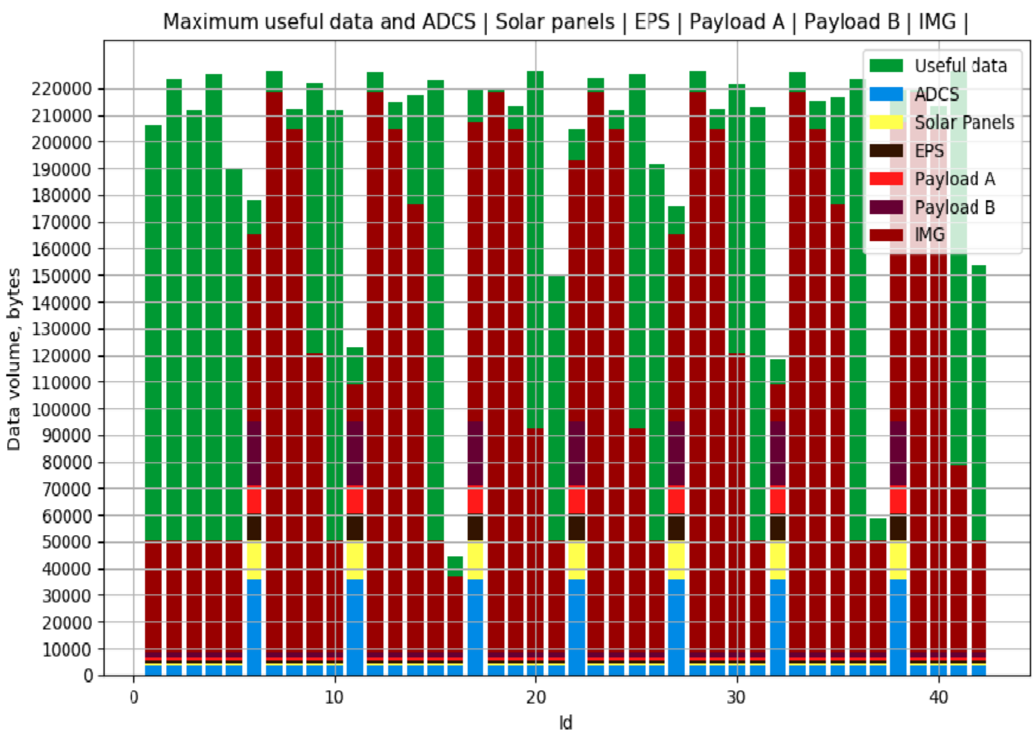


Figure 5.8. Maximum volume of useful data (as per legend, green colour) versus volume of data required to download data captured by selected subsystems (ADCS; Solar Panels, EPS, Payload A, Payload B, Images (2)). Transceiver duty cycle - 55%; excluding passes having an elevation less than 10 degrees; one week period.

✓ If all the factors mentioned above can be somewhat controlled and optimized at the satellite design stage, then there is another unpredictable factor that cannot be calculated in advance and influenced. Weather conditions at the time of the communication have a quite significant impact on the quality of the communication. If there are cloudy skies at the time of the communication, or if there are cloudy skies and rain, the communication with the satellite will be of poor quality. Many packets will be lost or erroneous and this will require the satellite to re-transmit corrupted packets, which again reduces the maximum amount of data that can be downloaded.

All in all, all of the above factors lead to a decrease in the actual amount of data that can be downloaded from the satellite. These factors lead to halving or even further reducing the previously calculated theoretical data volume. For this reason, all communication sessions with educational nanosatellites in LEO orbits require a very rigorous pre-planning of the communication process in order to reduce the impact of the constraining factors and increase the amount of data downloaded from the satellite.

In the design phase of the TUMnanoSAT nanosatellite on-board computer software and communication algorithm, it was necessary to calculate the actual maximum volume of data that could be downloaded from the satellite. This calculation was necessary for several reasons:

✓ To develop the on-board computer software so that it would collect data from on-board sensors at a frequency suitable for this data to be fully downloadable from the satellite. The importance of this factor is to ensure that the collected data does not accumulate in excess without the possibility of being sent to the ground station.

✓ To know how many in-orbit images can be taken so that they can all be downloaded.

✓ To optimize the communication algorithm so as to facilitate the download of the maximum requested data volume.

✓ To effectively plan communication during the TUMnanoSAT nanosatellite visibility windows observed from NCST ground stations.

In order to perform the above calculations, TUMnanoSAT visibility windows were simulated over a period of 4 months.

The simulation was done for visibility windows where the satellite trajectory exceeds 10/20 degrees and 30 degrees elevation and with variable transceiver duty cycle duration (0-:-60%), as well as various requests from the ground station.

Analysis of the results showed that with a transceiver duty cycle of 30% of the data volume required for image transmission, the transceiver occupies approximately all of the available data volume and does not remain in reserve. This suggests that data is lost and fails to transmit all the required packets under the selected conditions. Increasing this parameter to the value of 55% demonstrates the reserve of the available payload data volume remaining at the end of each successive series of orbits, allowing all the necessary data to be transmitted (Figure 5.8).

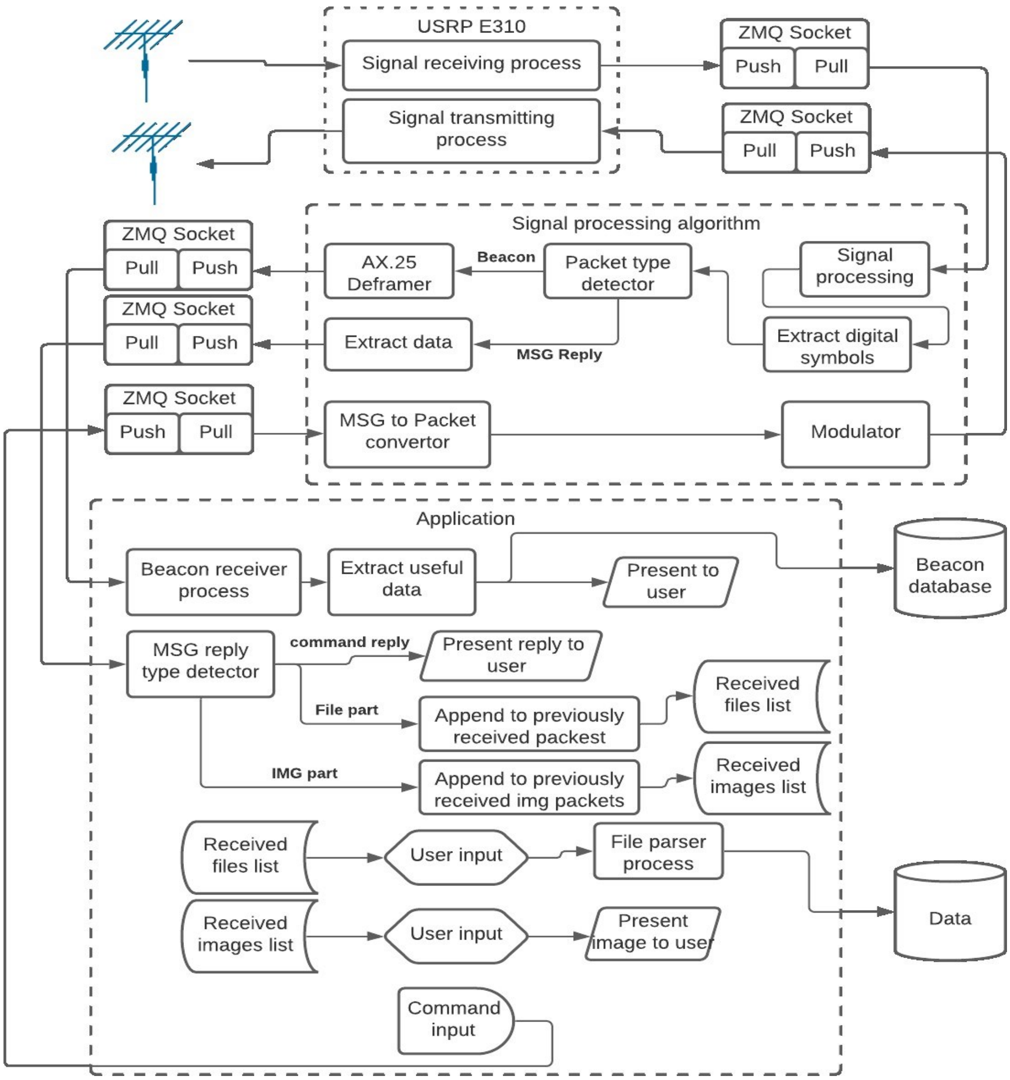


Figure 5.9. General structure of the communication and control platform.

Based on several analyses, it can be stated that all data captured by the TUMnanoSAT nanosatellite subsystems, under suitable conditions, can be downloaded. Also, there remains a reserve of the available useful data volume, and when wishing to download more images from orbit, the duty cycle of the transceiver could be further increased, thus increasing the available data volume.

5.3 The application and graphical interfaces of the platform

In order to facilitate operator interaction with the complex algorithm for communicating with the TUMnanoSAT educational nanosatellite, it was necessary to create the application that provides an explicit, easy-to-use graphical interface that automates the communication process as much as possible. As a solution to this problem the application "Command and Control Center for TUMnanoSAT nanosatellite" was developed, the structure of which is represented in Figure 5.9, and the graphical interface - in Figure 5.10.

This application has extended functionality. First of all, it allows sending commands to the educational nanosatellite TUMnanoSAT and receiving responses from it. The commands can be configuration commands (commands allowing to set the parameters of the nanosatellite subsystems), reset commands (commands allowing to reset the parameters to default values or to reset individual subsystems), data request commands (commands allowing to request from the nanosatellite the data recorded by its subsystems), image request commands (commands allowing to request images taken on a specified orbit).

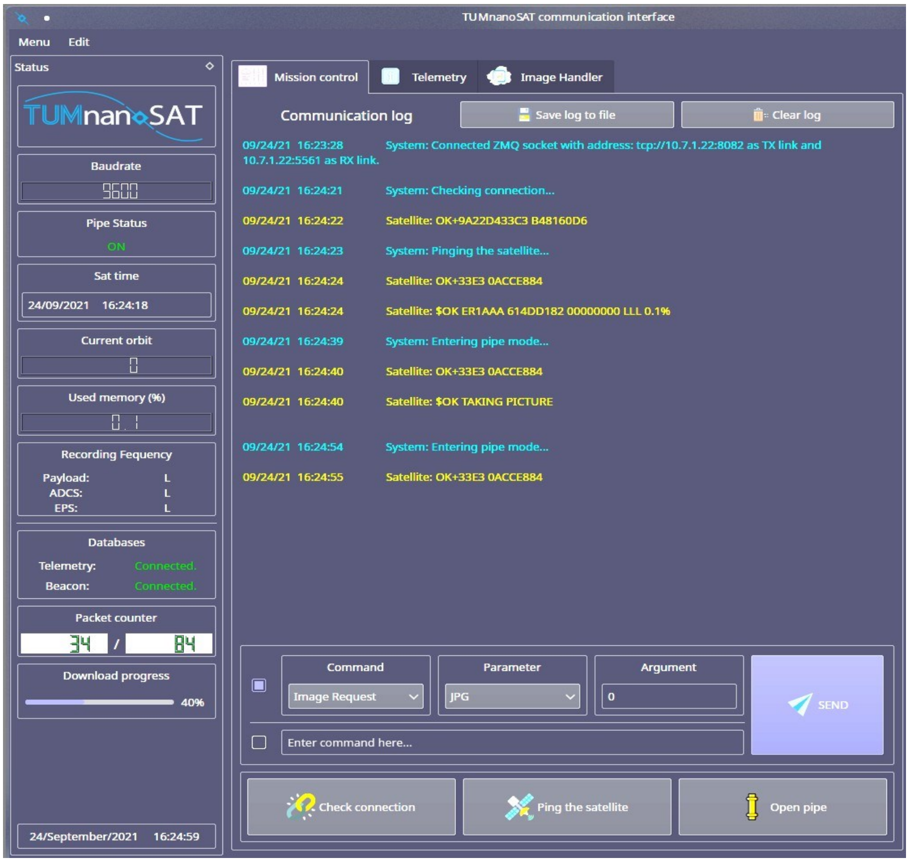


Figure 5.10. Main graphical interface of the TUMnanoSAT nanosatellite communication and control application. Log of the communication session with the TUMnanoSAT nanosatellite and its current status parameters when a "Snap" command was sent, then "Image Request".

In addition to the service communication with the nanosatellite mentioned above, the application allows the reception of the beacon it emits with a determined interval depending on the energy budget available to the nanosatellite. The beacon involves a series of parameters describing the operation of the nanosatellite:

parameters such as the number of pictures taken, the voltage on the battery, the voltage on the solar panels, the error codes if any, the time the nanosatellite has been in operation, the number of times it has been reset and many others. The beacon is transmitted and packaged using the AX.25 amateur radio protocol on 436.68 MHz.

This information is public and any willing party with a resonant antenna in the UHF band with sufficient sensitivity and a device or algorithm capable of extracting information from AX.25 packets can receive and decode the beacon emitted by the nanosatellite.

Figure 5.11. Example of information representation of a beacon message received from the TUMnanoSAT nanosatellite.

In the central part of the application there is a section with 3 tabs. The first tab is called "Mission Control" and is shown in Figure 5.10, and is intended for communicating with the educational nanosatellite TUMnanoSAT or more precisely sending and receiving commands to and from the nanosatellite. At the top of the tab are two buttons, which allow saving the current session history to a file or deleting the session history. Below the buttons is the space where records related to communication with the nanosatellite are made. This is where all commands and actions performed in this tab during the current communication session are recorded.

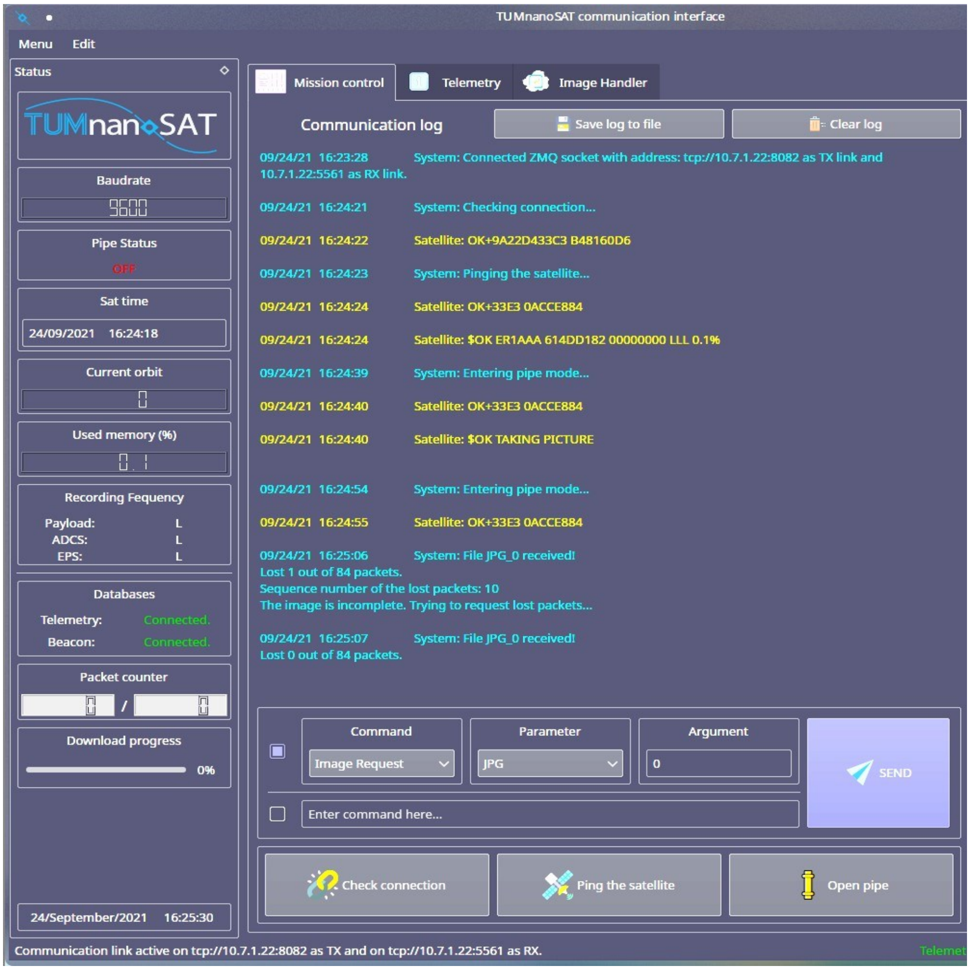


Figure 5.12. Log of the communication session with the TUMnanoSAT nanosatellite and its current status parameters after completion of the requested image reception process.

The second tab in the central part of the application is called "Telemetry" and is shown in Figure 5.11. The tab consists of a set of groups, each group containing a string of parameters that relate to different parts of the nanosatellite system. When receiving the packets emitted by the nanosatellite, specifically the beacon, these fields are filled with the received values and can be analyzed by the ground station operator.

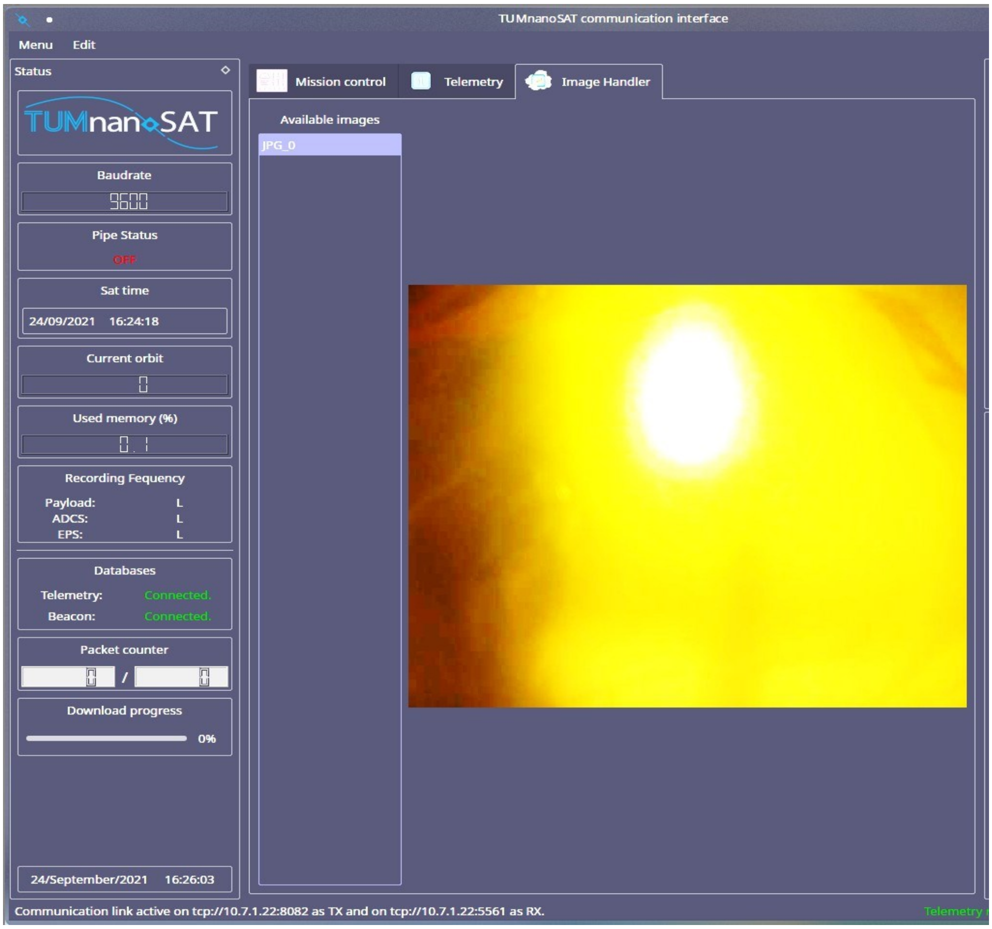


Figure 5.13. Image received from the TUMnanoSAT educational nanosatellite in the testing process.

The third tab in the central part of the application is called "Image Handler" and is shown in Figure 5.11. This tab consists of a list, on the left side, which auto populates with the images received from the nanosatellite, and when typing the name of one of the images present in the list, it is automatically loaded in the right side of the tab and presented to the operator. As can be seen from the given figure, the image with the name JPG4 has been typed and automatically loaded for presentation. The name of the image means that the image downloaded from the nanosatellite was in JPG format and was taken by the nanosatellite when it was in orbit number 4, counted from the beginning of the mission. The "Packet Counter" compartment shows the values 34/84, which means that at the time the image was saved, packet number 34 of the total 84 packets into which the requested image was divided was received. The image reception progress is also doubled in the "Download progress" compartment where the progress bar shows the 40% image download value from the nanosatellite.

In the figure 5.12 it is shown the communication log after finishing the process of receiving the previously requested image. In this log the system shows the operator the information that out of the 84 image packets one was lost on reception, namely packet number 10. After presenting this information, the automatic algorithm resolicits from the nanosatellite the lost packet and after its successful reception the information is presented that the file named "JPG_0" has been fully received and 0 packets out of 84 have been lost.

After receiving the image, the image name appears in the list on the left of the "Image Handler" tab in the main window where it can be typed in and the image is immediately loaded and presented to the user (Figure 5.13).

6. LAUNCH AND PLACEMENT IN ORBIT OF TUMnanoSAT

6.1 TUMnanoSAT launch - the first space experience for the Republic of Moldova

After the nanosatellite "TUMnanoSAT" has passed all functional tests at the Institute of Space Science in Romania, according to the requirements of the JAXA, on February 21, 2022 it was sent to the JAXA. In an online session of the JAXA and TUM's National Space Technology Center on March 2, the final technical inspection was performed and the handover of the TUMnanoSAT nanosatellite to JAXA was formalized. After a special preparation course of "TUMnanoSAT" for launch to the International Space Station, on March 4, 2022, JAXA collaborators mounted the nanosatellite in the JSSOD launch capsule, with which it was shipped to the USA to be transported to the ISS by SpaceX's Falcon 9 launcher on July 15, 2022, at 03.44 (UTC+3), the TUMnanoSAT nanosatellite, built by the Technical University of Moldova, was launched into space to the International Space Station - ISS. This launch was the 25th commercial servicing mission to the International Space Station (ISS) operated by SpaceX. The flight was conducted under the second commercial ISS resupply services contract supported by NASA. Cargo Dragon-2, which is the mission's payload, provides supplies and various equipment, including critical materials to directly support scientific and research investigations by astronauts aboard the ISS.

Figure 6.1. Officialisation of the handover of the TUMnanoSAT nanosatellite to JAXA.

The Dragon freighter also carried the JAXA's JSSOD launch capsule, which also carried the TUMnanoSAT nanosatellite to the ISS, from where astronauts were to transfer it to the Japanese Kibo module. Following a standard procedure, astronauts place it into orbit in space using the robotic arm. This launch of TUMnanoSAT was the first space experience for the Republic of Moldova in an international JAXA and UNOOSA cooperation. On this occasion, in a recent Linkedin post, Kathryn Lueders, NASA's Associate Administrator for Human Exploration and Operations Mission Directorate, brought to the attention of the general public that "NASA's SpaceX CRS-25 mission is on its way to the

International Space Station, carrying on board the TUMnanoSAT nanosatellite developed by the Technical University of Moldova - the first satellite launched by the Republic of Moldova.

Figure 6.2. Launch of the Dragon-2 freighter carrying TUMnanoSAT.

On August 12, 2022, at 12:45 pm, TUM made history when astronauts from the International Space Station placed Moldova's first nanosatellite - TUMnanoSAT - into Earth orbit. It is a historic first for the Republic of Moldova, marking the success of the efforts of a group of young TUM researchers, supported in this ambitious project by JAXA and UNOSSA coordinators [101].
Appreciated by experts as a resonant space experience for the international community, the event brought together at the Tekwill Centre leading personalities from the country's leadership, leading representatives of the scientific community, academia, the diplomatic corps, representatives of the JAXA and the UNOOSA.

Figure 6.3. Kathry Lueders, NASA's associate administrator for the Human Exploration and Operations Mission Directorate

Figure 6.4. Time of TUMnanoSAT placement in orbit tracked at Tekwiil Centre

Figure 6.5. TUM Space Technology Center team that developed the TUMnanoSAT nanosatellite.

At this meeting, the Rector of TUM, Viorel BOSTAN, said: "14 years ago, a group of researchers and engineers from the Technical University of Moldova, led by academician Ion BOSTAN, had a very beautiful dream - to place the Republic of Moldova in the list of countries able to tackle space technologies. Today I am extremely proud for the achievement we have achieved together with the team of students, teachers and researchers of the university - we are now witnessing the placement into orbit of the TUMnanoSAT satellite, developed and assembled at TUM! We can now say with certainty that the Republic of Moldova knows how to build TUMnanoSAT satellites, demonstrating that engineering studies have a great perspective and that TUM meets the highest standards of an elite technical education. On this occasion, I would first like to thank our development partners UNOOSA and JAXA, who have provided us with technical assistance and created this extraordinary opportunity".

The guests of honour, Prime Minister Natalia GAVRILIȚĂ, Minister of Education and Research Anatolie TOPALĂ, H.E. Ambassador of Japan to Moldova Katayama YOSHIHIRO, were present at the event and enthusiastically welcomed the capabilities of the group of researchers and the Technical University of Moldova for the important step taken by the Republic of Moldova in the development of modern technologies, which open new horizons and perspectives for the Republic of Moldova.

6.2 First communication experiences with TUMnanoSAT in orbit

Obviously, after the placement in orbit, another phase with many challenges and difficulties begins, the so-called post-launch phase of operation with the satellite. The first actions are to determine the orbital data, abbreviated TLE (two line elements), from the NORAD monitoring system, which allows the position of the satellite to be determined at any time, for automatic targeting of the telemetry ground station antennas to the satellite. An example of a TLE is shown in Figure 5.6.

TLE used fetched from Space-Track.org 3 weeks, 3 days ago

```
1 25544U 98067A   22224.04253076  .00007856  00000-0  14472-3 0  9996
2 25544  51.6444  59.8886 0005771 111.2346  25.7757 15.50146345353848
```

Figure 6.6. TUMnanoSAT nanosatellite two-line element set (TLE) for monitoring.

It should be noted that a two-line element set (TLE) is a data format, which encodes a list of orbital elements of an object orbiting the Earth for a given time interval, epoch. Using a suitable prediction formula, the state (position and velocity) at any past or future point in time, the next position of the satellite can be estimated with some accuracy. TLEs can describe the trajectories of Earth-orbiting objects only and are widely used as input data for the design of future orbital tracks of space debris for the purpose of characterizing "future debris events to support risk analysis, object approach analysis, collision avoidance maneuvers", on the other hand, automatic targeting of telemetry ground station antennas to the satellite.

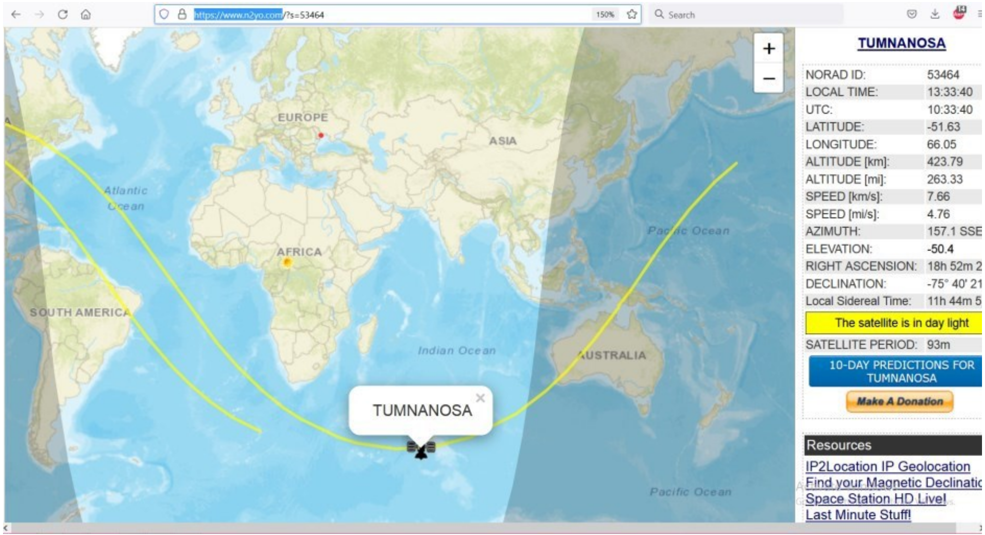


Figure 6.7. Online monitoring of TUMnanoSAT position in orbit.

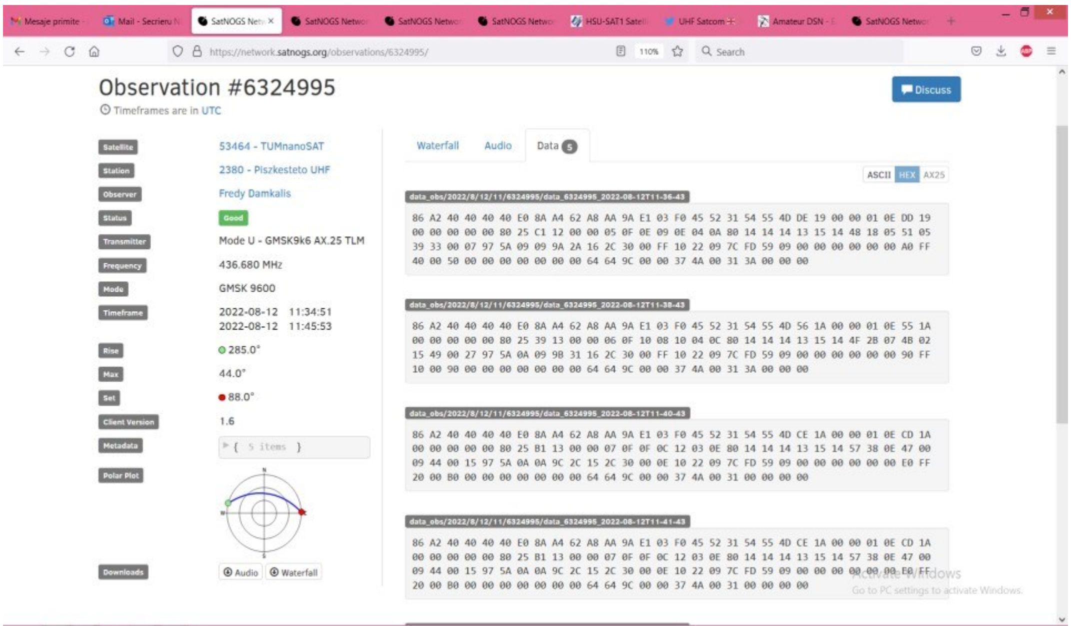


Figure 6.8. A series of early telemetry messages from TUMnanoSAT.

In the TLE database, the trajectory of any satellite can be tracked online using web resources, e.g. https://www.n2yo.com. Figure 6.7 shows the TUMnanoSAT trajectory against the background of the global map, accompanied by positional data in numerical form. In accordance with international regulations for placing CubeSat nanosatellites in orbit, the antenna deployment for the start of radio transmissions is performed after a 30-minute interval. TUMnanoSAT, having been placed in orbit at 12.45 (UTC+3), deployed the antennas and started radio emissions - telemetry beacon with a 2 minute interval, starting at 13.15 (UTC+3). The transmission is in the amateur radio frequency range, F = 436.680 MHz, modulation GMSK 9600, transmission mode "Mode U-GMSK9k6 AX.25 TLM" with 1W power. As the nanosatellite is in a low LEO orbit at an average altitude of h = 408 km, the signals can only be received at certain times in an area called the radio range. Some of the first communications with TUMnanoSAT are shown in Figure 6.8.

This received data shows UMnanoSAT's telemetry beacon, is decoded and analyzed to determine the overall condition of the nanosatellite. Decoding of telemetry data is performed using applications on the ground station platform developed by the TUM Space Technology Center (Figure 6.9).

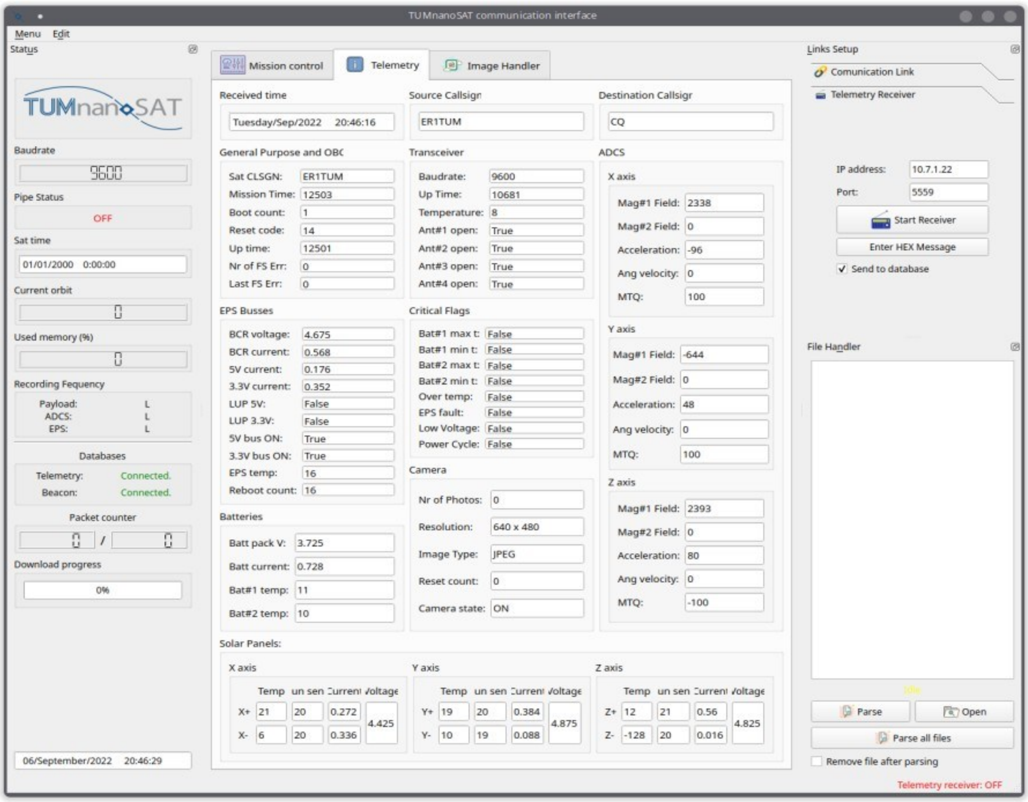


Figure 6.9. Decoding telemetry data from TUMnanoSAT with NCST applications.

As mentioned, the beacon contains several divisions: general part and OBC status, power subsystem status: respective currents and voltages, battery status: temperature, voltage and current, as well as the status of the solar panels on each surface of the satellite.

The TUMnanoSAT telemetry beacon can be received in AX.25 protocol format by any amateur radio operator. This is a rule for all educational satellites. The method for decoding the telemetry beacon is also published. We present an example, the collective amateur radio station "91 - M0EYT / 2E0NOG" UHF-SatCom in England (Figure 6.10) and the time spectral diagram of the TUMnanoSAT radio signals received by them on 1 September 2022 in the interval 02:58:57 -:- 03:03:11 (UTC+0) (Figure 6.11). Table 6.1 gives a portion of the received beacon. Similarly, from this table 6.1 we can see the different events that took place - 1st part of the table, the temperature at the solar panels - 2nd part of the table, the voltage and currents generated by the solar panels - 3rd part and the state of the batteries, the electric current consumed by the satellite on both power lines - 4th part of the table.

Table 6.1. Fragments of three decoded telemetry beacons

Parameters name	***Unit***	***Values***		
Callsign	N/A	ER1TUM	ER1TUM	ER1TUM
Elaplsed mission time	1.0 [seconds]	6502	6622	6742
OBC boot count	N/A	1	1	1
OBC reset flags	N/A	14	14	14
Elapsed time from last boot-up	1.0 [seconds]	6501	6621	6741
File system error counter	N/A	0	0	0
Last file system error code (refer to FATFS specifications)	N/A	0	0	0
RF baudrate	1.0 [bits/sec]	9600	9600	9600
RF transceiver on time from last power-on	N/A	4681	4801	4921
RF transceiver temperature	1.0 [degr. C]	5	5	6
Antenna rods deployment state (4	N/A	15	15	15

least significant bits, 1:released, 0: closed)				
Panel X+ tempereature	1.0 [degr. C]	12	14	16
Panel X- tempereature	1.0 [degr. C]	11	9	8
Panel Y+ tempereature	1.0 [degr. C]	11	14	16
Panel Y- tempereature	1.0 [degr. C]	4	4	4
Panel Z+ tempereature	1.0 [degr. C]	11	10	12
X axis solar panels voltage	0.025 [V]	1,98	1,80	1,98
X- panel current	0.008 [A]	0,41	0,19	0,34
X+ panel current	0.008 [A]	0,10	0,04	0,06
Y axis solar panels voltage	0.025 [V]	1,83	2,03	1,88
Y- panel current	0.008 [A]	0,03	0,04	0,02
Y+ panel current	0.008 [A]	0,19	0,46	0,17
Z axis solar panels voltage	0.025 [V]	1,33	1,27	1,83
Z- panel current	0.008 [A]	0,00	0,00	0,00
Z+ panel current	0.008 [A]	0,02	0,06	0,31
Battery voltage	0.025 [V]	3,78	3,78	3,78
Battery current	0.008 [A]	0,72	0,72	0,72
Battery cell 1 temperature	1.0 [degr. C]	9	9	10
Battery cell 2 temperature	1.0 [degr. C]	8	9	9
Battery charger input voltage	0.025 [V]	3,85	3,85	3,88
Battery charger input current	0.008 [A]	0,31	0,34	0,39
5V rail output current	0.008 [A]	0,18	0,18	0,18
3.3V rail outputcurrent	0.008 [A]	0,35	0,35	0,35

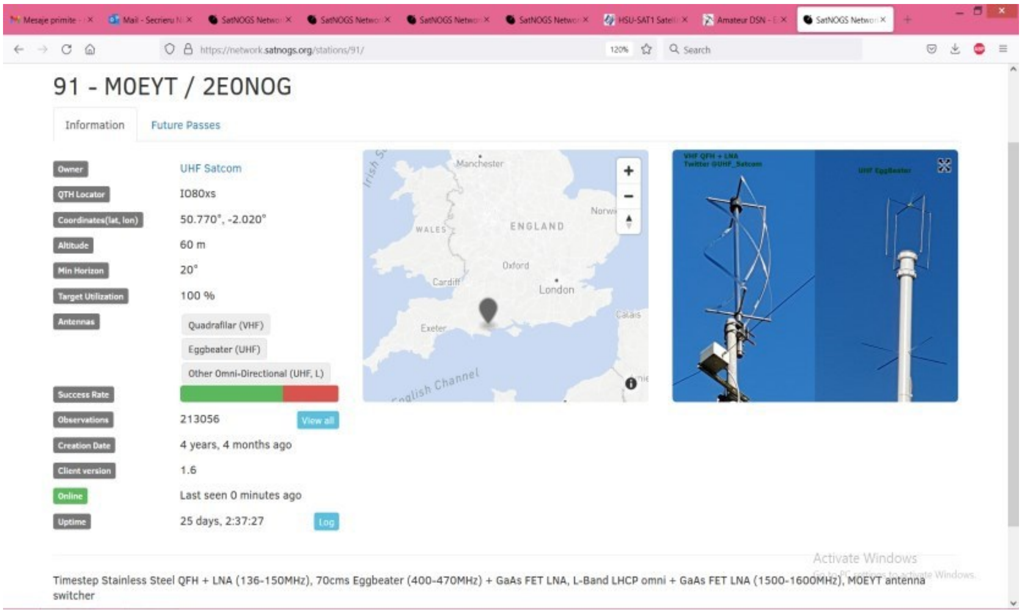


Figure 6.10. Data on UHF-SatCom ground station "91 - M0EYT / 2E0NOG" in England.

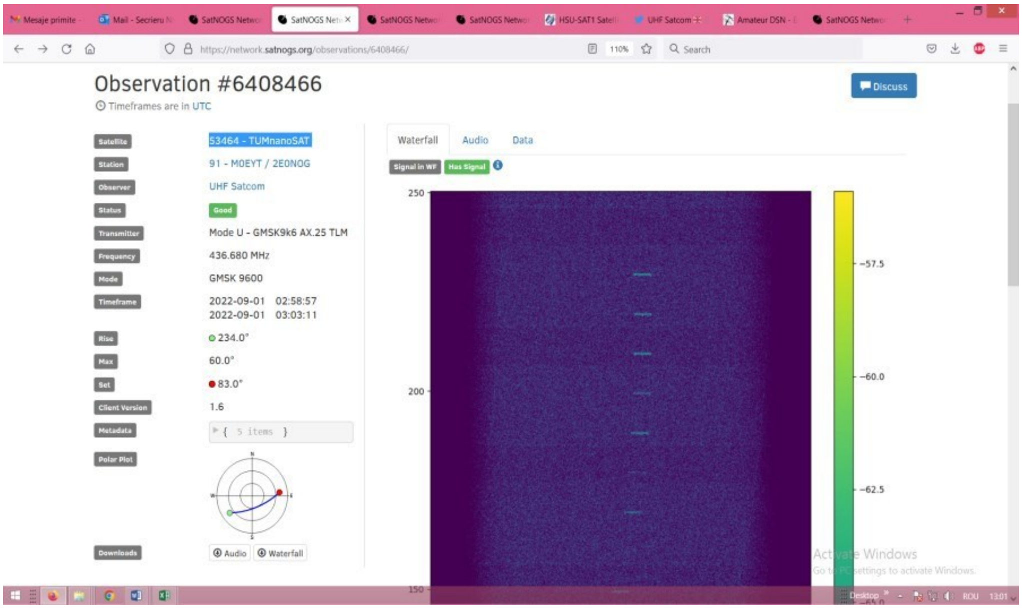


Figure 6.11. Temporal spectrogram of TUMnanoSAT telemetry beacons.

7. TUMnanoSAT KiboCUBE PROJECT EDUCATIONAL AND MISSION PROMOTION ACTIVITIES

7.1 Involvement of students, master students, PhD students in the TUMnanoSAT KiboCUBE project.

In the TUMnanoSAT KiboCUBE project at the TUM Space Centre, students were directly involved in each stage of space mission development: design, development and testing of nanosatellite subsystems, processing and use of space data to promote student interest in space engineering and technologies. The most important results have been reflected in the bachelor, master and PhD theses.

Bachelor theses:

- ✓ Vărzaru Vlad "Development of algorithms and communication programs for ground stations based on software defined radio technology with the nanosatellite "TUMnanoSAT", coordinator Nic. Secrieru.
- ✓ Gușanu Maxim "Elaboration of the software module for the control of the power supply system of the nanosatellite "TUMnanoSAT", coordinator Nic. Secrieru.
- ✓ LUPAN C. "Development of sensors based on Pd/ZnO:Eu columnar films". Coordinator Oleg Lupan.

Master's thesis:

- ✓ Andronic Alexandru "Investigation of the components of the attitude control subsystem of the nanosatellite "TUMnanoSAT" and their verification on the geomagnetic field simulation stand" , coordinator Nic. Secrieru.
- ✓ Baranețchi Anatol "Elaboration of research modules of radiation nanosensors and data acquisition software for the realization of "TUMnanoSAT" nanosatellite missions", coordinator Nic. Secrieru.
- ✓ Zarișneac Petru, gr. IM-191, "Structural analysis of the TUMnanoSat satellite" , coordinator, PHD, assoc. professor Guțu Marin.
- ✓ Vărzaru Vlad, gr. SCE-201M "Development of the communication and control platform for the educational nanosatellite TUMnanoSAT" , coordinator, PHD, assoc. professor Nicolae Secrieru.
- ✓ Marin Chiriac, gr. SCE-211M "Development and research of control algorithms with inertial attitude control system for nanosatellites", coordinator, PHD, assoc. Professor Nicolae Secrieru.

Doctoral/postdoctoral theses that continue to be carried out within the project by members of the project team:

- ✓ Candraman Sergiu "Methods and procedures for microsatellite attitude control in real-time image capture, processing and transmission", coordinator, PHD, assoc. Professor N.Secrieru
- ✓ Magariu Nicolae "Physico-chemical properties and sensor models based on nanometric oxide semiconductors", coordinator, University Professor O.Lupan.
- ✓ Melnic Vladimir "Mathematical modeling and computational simulation of

the dynamic behavior in orbit of the satellite "Republic of Moldova"", coordinator, University Professor V. Bostan.

7.2 Participation in conferences, exhibitions and promotion of the TUMnanoSAT KiboCUBE project.

The results obtained in this project have been widely disseminated in the form of publications (see bibliography), reports and presentations at various scientific forums, participation in exhibitions, which have been awarded with diplomas and medals (see annexes 3).

7.2.1. Dissemination of project results in the form of presentations at scientific forums:

2020 Year:

✓ Nicolae SECRIERU: ”TUMnanoSAT Nanosatellite and KiboCUBE Program” - ”The 13th International Conference on Communications”, 18-20 June, 2020, Politehnica Universitaty, Bucharești. - https://www.comms.ro/index.html#schedule

✓ Vasile CHIRIAC: ”TUMnanoSAT Nanosatellite and KiboCUBE Program” - The Council of European Geodetic Surveyors General Assembly, 17-19 September, 2020, Athens, Greece. - https://www.clge.eu/wp-content/uploads/2020/02/Chiriac_TUMnanSAT_presentation.pdf

✓ Oleg Lupan: *“Au-NPs/ZnO single nanowire nanosensors for health care applications”*. - In: EHB, Iasi, România (Octomber, 2020) 2020 International Conference on e-Health and Bioengineering (EHB) IEEE.

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjFx4akhp3tAhXBjKQKHUu7CDwQFjABegQIAhAC&url=http%3A%2F%2Fwww.ehbconference.ro%2FPortals%2F0%2FEHB2020_Detailed%2520Program.pdf&usg=AOvVaw1md1lKTilr5NuCBQ9grBSi

✓ Oleg Lupan: ”Semiconducting Oxide - Based Micro- and Nano-sensors for Environmental and Biomedical Monitoring” - ”Conference Fee for IEEE International Conference on Nanomaterials: Applications and Properties - NAP 2020” - https://nap.sumdu.edu.ua/index.php/nap/nap2020/pages/view/scientific_program

✓ Vladimir Melnic: ”Experimental Identification of the Mathematical Model of the DC Motor based on the Genetic Algorithm” – In: Proceedings of the Workshop on Intelligent Information Systems WIIS2020, December 04-05, 2020, Chisinau, Republic of Moldova

✓ Gușanu Maxim, Ilco Valentin: "Investigation of accumulation modes and energy consumption of the "TUMnanoSAT" nanosatellite" - "Technical-scientific conference of students, masters and PhD students", March 17, 2020, Chisinau, Moldova, 2020 (in romanian).

✓ Varzaru Vlad, Ilco Valentin: "Realization of the communication of the nanosatellite "TUMnanoSAT" with ground stations based on "Software Defined

Radio" technology" - "Technical and scientific conference of students, master and PhD students", March 17, 2020, Chisinau, Moldova, 2020 (in romanian)

2021 Year:

✓ SECRIERU, Nicolae, TUMnanoSAT, 1U KiboCUBE Nanosatellite developed at the Technical University of Moldova - At: *Conference on Small Satellites, Education section, SSC21-P2-38, August, 5-7, 2021,* Utah University, Utah, USA, (poster & online discussion) (https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4898&context=smallsat)

✓ SECRIERU, Nicolae, The Experience in TUMnanoSAT Launch Preparation, *The 4th International Conferences on Science and Technology Engineering Sciences and Technology ICONST EST 2021*, September, 8-10, Budva, Montenegro, (poster & online discussion) http://iconst.org/Page/GetPdf?filename=iconst_poster_presentation_program2021.pdf

✓ LUPAN, Oleg, Semiconducting Oxide - Based Micro- and Nano-sensors for Environmental and Biomedical Monitoring - At: *The 11th International Conference on "Nanomaterials: Applications & Properties" (NAP-2021)* Odesa, Ukraine, Sept 5-11, 2021. (online presentation)

✓ SECRIERU, Nicolae, The Experience of Preparing to Launch the TUMnanoSAT nanosatellite, At: *the 12th International Conference on Electronics, Communications and Computing* , 21-22 October, 2021, Chisinau, Republic of Moldova, (online presentation).

✓ ILCO, Valentin, Mission Monitor and Control Platform forTUMnanoSAT Ground Segment, At: *the 12th International Conference on Electronics, Communications and Computing* , 21-22 October, 2021, Chisinau, Republic of Moldova, (online presentation).

✓ MELNIC, Vladimir, Synthesis the PID Control Algorithm for Speed Control of the DC Motor based on the Genetic Algorithm, At: *the 12th International Conference on Electronics, Communications and Computing,* 21-22 October, 2021, Chisinau, Republic of Moldova, (online presentation).

✓ LUPAN, Oleg, Electrical Characterization of Individual Boron Nitride Nanowall Structures, At: *the 5 th International Conference on Nanotechnologies and Biomedical Engineering*, November 3-5, 2021, Chisinau, Republic of Moldova, (online presentation).

2022 Year:

✓ Oleg Lupan, PhD, professor. – At: 2022 IEEE 12th International Conference "Nanomaterials: Applications & Properties" (IEEE NAP-2022), Krakow, Poland, September 11-16, 2022. Nano-Heterostructured Materials - Based Sensors for Safety and Biomedical Applications, (oral) - https://ieeenap.org/book-of-abstract/ .

✓ Secrieru Nicolae, associate professor, scientific researcher coord. - At:

Conference on Small Satellites, Education section, SSC22-P2-08, August, 6-8, 2022, Utah University, Utah, USA. (https://smallsat.org/conference/posters#weekdaypostersession2). Promoting Satellite Communications: Training Students in the Design of Nano-Satellite Communications, (poster).

- ✓ Secrieru Nicolae, associate professor, scientific researcher coord. - At: ICONST EST 2022, September, 8-10, Budva, Montenegro,
- ✓ (http://iconst.org/Page/GetPdf?filename=iconst_poster_presentation_program2022.pdf). Blending training of students and promotion of space technologies by designing satellite communications, (poster).
- ✓ Oleg Lupan, PhD, professor. – At: International Conference on Electronics, Communications and Computing, ECCO 2022, Chisinau October 20-21, 2022, Nanosensors and sensors based on heterostructured materials for safety and biomedical applications, (oral, plenary session) - https://ecco.TUM. md/ .
- ✓ Secrieru Nicolae, associate professor, scientific researcher coord. - At: - The 13th International Conference on Electronics, Communications and Computing, October 20-21, 2022, Chisinau, Republic of Moldova. The evaluation of the on-board computer architecture for TUMnanoSAT series of nanosatellites for carrying out missions, (oral) https://ecco.TUM.md/ecco22-track1/
- ✓ Irina Cojuhari, associate professor. - The 13th International Conference on Electronics, Communications and Computing, October 20-21, 2022, Chisinau, Republic of Moldova. The PID Tuning Procedure for Performance Optimization of the Underdamped Second-Order Processes, (oral) - https://ecco.TUM.md/ecco22-track3/
- ✓ Vladimir Melnic, scientific researcher. - The 13th International Conference on Electronics, Communications and Computing, October 20-21, 2022, Chisinau, Republic of Moldova. Tuning the Fuzzy Controller for Speed Control of the DC Motor, (oral) - https://ecco.TUM.md/ecco22-track3/.
- ✓ Valeriu VERJBITKI, scientific researcher. – At: The 13th International Conference on Electronics, Communications and Computing, October 20-21, 2022, Chisinau, Republic of Moldova. The method of measuring the parameters of nanostructured sensors. (oral) https://ecco.TUM.md/ecco22-track1/
- ✓ Cristian Lupan. - At: The 13th International Conference on Electronics, Communications and Computing, October 20-21, 2022, Chisinau, Republic of Moldova. The Reliability to Gamma Radiation of Gas Sensors Based on Nanostructured ZnO:Eu. (oral) https://ecco.TUM.md/ecco22-track1/ .
- ✓ Cristian Lupan, PhD student. In: Technical-scientific conference of students, masters and doctoral students. Vol.1, March 29-31, 2022, Chisinau. Chisinau, Republic of Moldova: Tehnica-TUM, 2022, Research on small Zn-Cu oxide nanostructures for sensors. (oral).

7.2.2. Appreciation and acknowledgment of project results (awards, medals, titles, other appreciations).

2020 Year:

✓ Vladimir MELNIC, Valentin ILCO, Alexei MARTÎNIUC, Nicolae SECRIERU, Viorel BOSTAN, Ion BOSTAN "Platform for microsatellites attitude research in orbital conditions" - Gold Medal at the International Exhibition of Scientific Research, Innovation and Invention "Pro Invent 2020" - Edition XVIII, Cluj-Napoca, 18-20 November 2020.

✓ Nicolai ABABII, Vasile POSTICA, Viorel TROFIM, Oleg LUPAN - "Process for obtaining CuO-Fe2O3 nanowire network" - Gold Medal at the International Exhibition of Scientific Research, Innovation and Invention "Pro Invent 2020" - Edition XVIII, Cluj-Napoca, 18-20 November 2020;

✓ Vasile POSTICA, Thierry PAUPORTÉ (FRANCE), Viorel TROFIM, Nicolai ABABII, Oleg LUPAN - "Process of functionalization of the surface of ZnO nanowires with noble metal nanoparticles" - Gold Medal at the International Exhibition of Scientific Research, Innovation and Invention "Pro Invent 2020" - Edition XVIII, Cluj-Napoca, 18-20 November 2020;

✓ Cristian LUPAN, Viorel TROFIM - "Deposition process of eu-doped and Pd-functionalized ZnO films" - Gold Medal at the International Exhibition of Scientific Research, Innovation and Invention "Pro Invent 2020" - Edition XVIII, Cluj-Napoca, 18-20 November 2020.

2021 Year:

✓ Valentin ILCO, Vladimir MELNIC, Alexei MARTINIUC, Vladimir VĂRZARU, Ion BOSTAN, Viorel BOSTAN, Nicolae SECRIERU. Diploma of merit and silver medal obtained at the International Exhibition of Inventions INVENTICA 2021 from 23.06.2021 - 25.06.2021 for the work "TUMnanoSAT, 1U CubeSat nanosatellite developed at the Technical University of Moldova"

✓ Vladimir VĂRZARU,Valentin ILCO, Alexei MARTINIUC,Vladimir MELNIC, Ion Bostan, Viorel BOSTAN, Nicolae SECRIERU. Diploma of merit and silver medal obtained at the International Exhibition of Inventions INVENTICA 2021 from 23.06.2021 - 25.06.2021 for the work "Center for communication and monitoring of educational satellites".

2022 Year:

✓ Viorel BOSTAN, Valentin ILCO, Alexei MARTÎNIUC, Vladimir VĂRZARU, Oleg LUPAN, Valeriu VERJBIȚCHI, Nicolae MAGARIU, Vladimir MELNIC "TUMnanoSAT's satellite modules for research of the nanosensors properties in space radiation conditions", Diploma of merit and gold medal at the exhibition "14th European Exhibition of Creativity And Innovation EuroINVENT 2022 from 26.05.2022 – 28.05.2022.

✓ Viorel BOSTAN, Ion BOSTAN, Valentin ILCO, Vladimir MELNIC, Alexei MARTÎNIUC, Vladimir VĂRZARU, Nicolae SECRIERU "TUMnanoSAT flight model nanosatellite", Diploma of merit and gold medal at the exhibition "14th European Exhibition of Creativity And Innovation EuroINVENT 2022 from 26.05. 2022 – 28.05.2022.

✓ Viorel BOSTAN, Ion BOSTAN, Nicolae SECRIERU, Marin GUȚU, Vladimir MELNIC, Valentin ILCO, Alexei MARTÎNIUC. "Structural analysis of the TUMnanoSAT microsatellite", Diploma of merit and gold medal at the exhibition "14th European Exhibition of Creativity And Innovation EuroINVENT 2022 from 26.05.2022 - 28.05.2022.

✓ ABABII, N., MAGARIU, N., LUPAN, O. Sensing performance of CuO/Cu2O/ZnO:Fe heterostructure coated with ultrathin hydrophobic polymer for battery application. - 14th European Exhibition of Creativity and Innovation EUROINVENT 2022, Iasi, Romania, 28 May 2022.

7.3 University courses dedicated to satellite technologies.

Another way to promote space technologies are some disciplines for students from bachelor and master cycles at the faculties of "Computers, Computer Science and Microelectronics" and "Electronics and Telecommunications" at the Technical University of Moldova. These disciplines have all the study materials located on the TUM Moodle platform:

✓ ***"Microcontrollers and control microsystems" -*** lecture course and course project **-** ***http://moodle.TUM.md/course/view.php?id=638***

Figure 7.1 Screen shot of the online course "Microcontrollers and control microsystems"

✓ ***"Mobile and Satellite Communications"*** - lecture course and course project: *http://moodle.TUM.md/course/view.php?id=641*

Figure 7.2. Screen of the online course "Mobile and Satellite Communications"

✓ laboratory and practical course in "***Mobile and satellite communications"*** discipline - [Space Technologies Practics with a Nanosatellite](http://moodle.TUM.md/course/view.php?id=494) - http://moodle.TUM.md/course/view.php?id=494

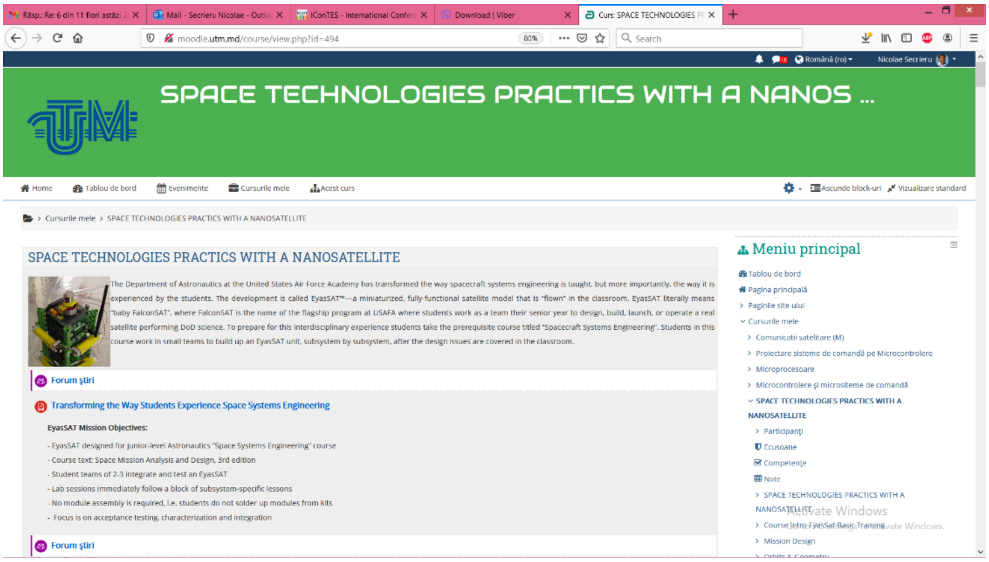


Figure 7.3. The screen of the online course "Space Technologies Practices with a Nanosatellite".

7.4 Promoting of TUMnanoSAT missions on WEB platforms.

All activities and results of the TUMnanoSAT project are promoted on the following WEB platform:

- ✓ Space Technology Center website - https://cnts.utm.md/
- ✓ Website of the Technical University of Moldova -

https://cercetari.utm.md/rezultatele-cercetarilor/ , https://utm.md/?s=TUmnanoSAT

- ✓ TUM Facebook page - https://www.facebook.com/UTMoldova/
- ✓ NCST Facebook page - https://www.facebook.com/UTMCNTS/
- ✓ TUMnanoSAT Twitter page - https://twitter.com/tumnanosat

7.5 Participation in science promotion events.

The results of the TUMnanoSAT project in the framework of the KiboCUBE programme were presented at science promotion events, where visitors had the opportunity to discover how exciting it is to create and the benefits of creation in combination with research-innovation, by admiring the works displayed in the large exhibition "Creation opens the Universe"**.**

- ✓ **"Researchers' Night 2020"** - available: https://www.youtube.com/watch?v=x-Q-HRn2Alw
- ✓ **The "Creation Opens the Universe" exhibition (10th edition) and the "European Researchers' Night" (8th edition)** on 24 September 2021. The event included 15 workshops, interactive activities, workshops, masterclasses, public lectures, a fashion-show, as well as exciting excursions in TUM spaces - it included more than 100 works with the most original ideas and innovations discovered in the bachelor and master projects and PhD theses of TUM disciples. The Space Technologies Centre participated with satellite subsystem samples and satellite subsystem test presentations. (https://TUM.md/blog/2021/09/27/expozitia-creatia-deschide-universul-noaptea-cercetatorilor-europeni-la-TUM/)
- ✓ **At the International Scientific Conference "Modern Technologies: actuality and perspectives",** held within the framework of Science Week, organized by the Academy of Sciences of Moldova and dedicated to the 30th anniversary of the proclamation of the independence of the Republic of Moldova, the 60th anniversary of the founding of the ASM and the 75th anniversary of the creation of the first academic scientific institutions, the rector of the Technical University of Moldova, prof. univ. dr. hab. Viorel BOSTAN, presented the results obtained by TUM researchers in research projects, including the development of the "TUMnanoSAT" nanosatellite**.** - https://TUM.md/blog/2021/06/10/rectorul-TUM-prof-univ-dr-hab-viorel-bostan-la-saptamana-stiintei-la-asm/
- ✓ **"Researchers' Night 2022"** - available: https://TUM.md/blog/2022/10/01/noaptea-cercetatorilor-europeni-2022/

7.6 Promoting the TUMnanoSAT KiboCUBE project at events with pupils and students.

In addition to training students in the TUMnanoSAT KiboCUBE project, various mass events with pupils and students were organized. The most important ones would be the following:

✓ **"Children from Moldova talked directly with astronauts from the Cosmos" -** school students aged 10 to 18, representing a consortium of educational institutions, rural schools and libraries from different localities of the Republic of Moldova saw a great dream come true, to find answers to their questions directly from the source - from astronauts in the cosmos, thanks to a project carried out by the National Center for Space Technologies (NCST), the US Peace Corps in Moldova (USPCVC) and the International Space Station Amateur Radio Service (ARISS). - https:// UTM.md/blog/2021/03/05/vis-implinit-copii-din-moldova-au-dialogat-direct-cu-astronautii-din-cosmos/
https://www.facebook.com/UTMoldova/posts/4196057433760852

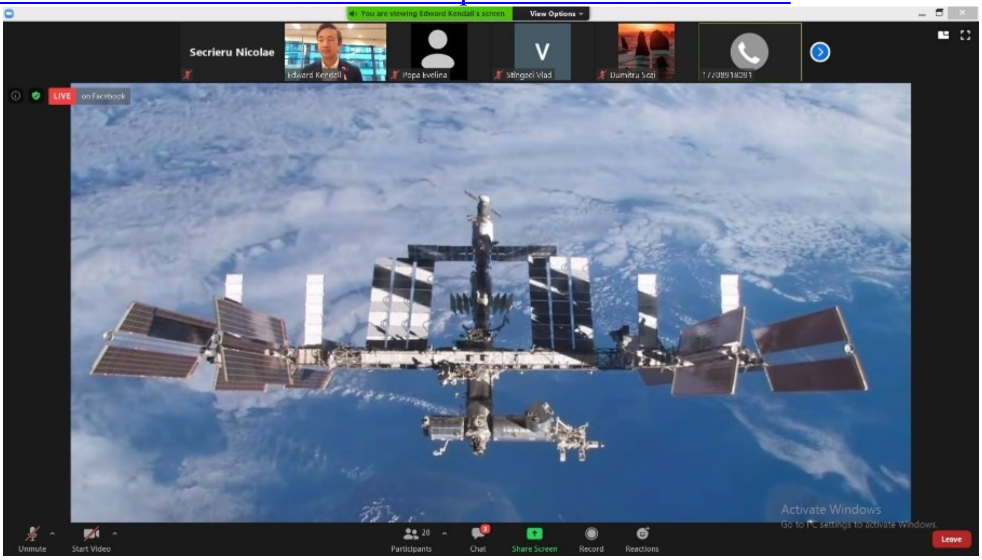


Figure 7.4. International Space Station viewed online by participants.

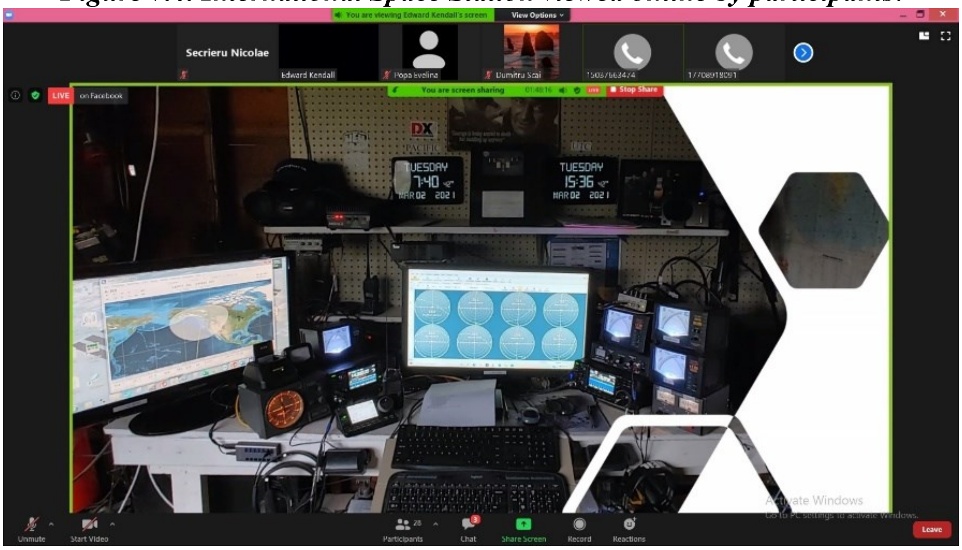


Figure 7.5. Radio station communicating with the International Space Station Amateur Radio Service (ARISS).

NCST representatives gave them a presentation and explained in detail the need for the development of space technologies as an innovative platform for industry, communications, medicine and other fields. That is why TUM scientists involve many high school students, undergraduates, master's and PhD students in satellite-space research, guiding and motivating them to get involved and make use of these important aspects of scientific research. The highlight of the virtual tour was the nanosatellite "TUMnanoSAT", developed within NCST-TUM, which is in the final stage of complex tests, and then this first satellite of the Republic of Moldova will be launched into space, selected by the JAXA and the UNOOSA for the fourth round of the KiboCUBE Programme to launch the "TUMnanoSAT" nanosatellite from the International Space Station (ISS) using the Japanese KiboCUBE experimental module.

Captivated by this impressive presentation, the high school students were eager to see what it's like out there in space. Under their curious eyes, ARISS was contacted and the radio connection for direct dialogue with the ISS was checked. The cosmos "opened up" and astronaut Mike HOPKINS, aboard the International Space Station, appeared in front of the students and greeted them live. Afterwards, the high school students' questions kept coming: Why did he choose this job? What is the daily routine of an astronaut on the International Space Station? What kind of experiments are carried out on board the ISS? What is it like to live and work in space? What does Earth look like "from above"? Do you ever call your family from space? What's the hardest thing to get used to in the absence of gravity? How do you deal with a major medical emergency aboard a spacecraft? Why was the last mission to the Moon in 1972? How long does it take to recover from space travel: physically and psychologically? What advice would you have for students who want to be astronauts? Astronaut Mike HOPKINS gave well-argued answers to each of these questions.

✓ TUMnanoSAT launch and orbiting events. Dozens of children and teenagers from Moldova and Romania attended a unique public lecture organised by Moldcell and the Technical University of Moldova, dedicated to the launch of the first Moldovan satellite "TUMnanoSAT" into space. Passionate about technologies and innovations, the children learned about the idea and process of the satellite, its mission and how the first satellite created in Moldova TUMnanoSAT was launched into space on 15 July 2022 - a historic event for the Republic of Moldova. It was presented how the satellite was transported to the International Space Station (ISS) by SpaceX's Falcon 9 rocket. It was noted that this project is the first space experience for the Republic of Moldova, which was made possible thanks to an international JAXA and UNOOSA cooperation. (https://UTM.md/blog/2022/07/28/lansarea-tumnanosat-un-eveniment-istoric-pentru-republica-moldova/)

Figure 7.6. NCST team with children participating in this event.

✓ GirlsGoIT Summer Camp, The mission of GirlsGoIT is to build the largest community of IT girls in Moldova by organizing learning programs in technical fields and personal development and mentoring. The camp also presented the TUMnanoSAT project supported by the KiboCUBE program. (https://www.facebook.com/photo/?fbid=3237582413148189&set=pcb.3237583169814780)

Figure 7.7. Sequence from this summer camp organized at TUM.

7.7 Promoting the TUMnanoSAT KiboCUBE project in the media.

An important part of the project was also the promoting of modern space technologies for young students. To this purpose, the following events, interviews on science popularization radio/TV shows and other publications were carried out:

✓ **"The first artificial satellite, made by TUM scientists, will be ready soon" -** The first artificial satellite made by Moldovan scientists will be ready soon. Researchers at the Technical University of Chisinau say work is nearing completion and they hope the satellite will be in orbit by the end of this year. It's a research satellite that will transmit information from space. It's made in collaboration with the JAXA, which supports free space projects around the world. - http://tvrmoldova.md/actualitate/primul-satelit-artificial-fabricat-de-cercetatori-de-la-UTM-va-fi-gata-curand/

✓ **"Moldovan satellite in the Space" -** A new satellite has been built in the Republic of Moldova and will be sent into orbit from the International Space Station. It is a nano-satellite that will transmit images and data on the operation of state-of-the-art sensors back to Earth. The cost has been covered by the JAXA and the satellite is scheduled to be launched this year. - https://primul.md/gagarin-in-memoria-moldovenilor

✓ **The Chamber of Commerce and Industry (CCI) has issued, for the first time, the ATA Certificate for the nanosatellite of the Space Technology Centre of the Technical University of Moldova (NCST of TUM).** The ATA Certificate, as a customs document facilitating the temporary export of goods, was requested by the Technical University in connection with the need for functional testing of the nanosatellite for launch into space. On the basis of the Certificate issued by the CCI, the TUMnanoSAT nanosatellite and the necessary accessories are transported to Romania, where they undergo testing operations by the Romanian Institute of Space Sciences, and then returned to the Republic of Moldova. - https://TUM.md/blog/2021/05/14/primul-satelit-al-republicii-moldova-fabricat-in-cadrul-NCST-TUM-a-primit-carnetul-ata/

✓ **"Moldovan satellite to fly into space with SpaceX rocket".** A black container sits on the table of a small laboratory at the Technical University of Moldova. A young man wearing a mask and medical gloves opens the side and very carefully pulls out a cube. It has a 10-centimetre edge and shiny black side panels that, at first glance, resemble the screens of the latest generation of television sets. On the top of the cube is inscribed "TUMnanoSAT". It is the first nanosatellite made in the Republic of Moldova, developed over almost three years by a team of researchers from the National Centre for Space Technologies. On Elon Musk's Falcon 9 rocket, the satellite will be carried into space and launched into orbit from the International Space Station. - https://reportaje.moldova.org/satelitul-moldovenesc-care-va-zbura-in-spatiu-cu-racheta-spacex/

✓ Viorel Bostan, Ion Bostan, Nicolae Secrieru: Press conference dedicated to the expedition of the TUMnanoSAT nanosatellite to the Tsukuba Center of the

JAXA: TUM Space Technology Center, 20.02.2022, (broadcast by all TV stations in Moldova).

Figure 7.8. Sequence from this press conference dedicated to the expedition of the TUMnanoSAT.

✓ Viorel Bostan, with the participation of Natalia Gavrilița, Prime Minister of the Republic of Moldova, Yoshihiro Katayama, Ambassador of Japan to the Republic of Moldova, TUMnanoSAT team: event dedicated to the placement of the first nanosatellite of the Republic of Moldova into Earth orbit by astronauts from the International Space Station. 12.08.2022 , (broadcast by all TV channels in Moldova). - https://utm.md/blog/2022/08/12/premiera-istorica-pe-12-august-2022-la-ora-1245-prin-plasarea-pe-orbita-a-tumnanosat-utm-si-a-trimis-visul-si-speranta-in-viitor/

Figure 7.9. Sequence from this event dedicated to the placement of the first nanosatellite of the Republic of Moldova into Earth orbit.

✓ Viorel Bostan, Oleg Lupan, Vladimir Melnic: Participation in the TVM broadcast "Home" on 15.08.22 with the title: placement in Earth orbit of the first nanosatellite of the Republic of Moldova. - https://www.youtube.com/watch?v=yuXPSCoExBE

Figure 7.10. Sequence from this TVM broadcast "Home".

✓ Oleg Lupan, Good Morning Show, Role of nanotechnologies and space technologies - https://www.youtube.com/watch?v=cSpRbF8PBy4

Figure 7.11. Sequence from this TVM broadcast "Good morning".

✓ Vladimir Melnic, Alexei Martiniuc: "Good Morning" broadcast of 4.10.22 - TUMnanoSAT and the role of space technologies.
https://trm.md/ro/buna-dimineata/buna-dimineata-din-04-octombrie-2022

Figure 7.11. Sequence from this TVM broadcast "Good morning".

CONCLUSIONS

The TUMnanoSAT nanosatellite project under the KiboCUBE programme includes several missions. Starting from the general concept, the Critical Design Review phase developed the 3D model and all the technical documentation of the TUMnanoSAT satellite, produced the TUMnanoSAT flight module, which was finally launched with SpaceX's Falcon-9 and Dragon-2 cargo and placed into orbit from the Japanese Kibo module of the International Space Station on 12 August 2022. TUMnanoSAT had mainly educational objectives involving students, while other objectives were research and technology verification elements.

The report highlights the main challenges and the experience gained during the implementation of this project both in terms of nanosatellite development and ground infrastructure performance - satellite communication stations. As a result of the TUMnanoSAT development, concrete solutions with the main features for the basic modules: communication, control of the power subsystem, on-board computer, which ensure the fulfilment of the planned missions, have been realized. The TUMnanoSAT payload consists of three component parts. The first concerns the accumulation of attitude control data for the purpose of upgrading the respective algorithms for future missions. The second component of the payload concerns the testing of the performance of nanosensors under space conditions developed by the Nanomaterials Research Center in the fields of materials science and nanotechnologies TUM. The test results will be useful in the development of new nanomaterials and nanodevices for various applications. The third component concerns the capture of space images in various formats and their transmission to ground stations.

The basic goal was achieved - the KiboCUBE TUMnanoSAT project at the TUM Space Center directly involved students in every stage of space mission development: design, development and testing of nanosatellite subsystems, processing and use of space data to promote student interest in space engineering and technologies.

We would like to first of all thank our development partners UNOOSA and JAXA, who provided us with technical assistance and created this extraordinary opportunity for us.

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Annex 1. The letter about confirmation of TUMnanoSAT nanosatellite registration

The Ministry of Infrastructure
and Regional Development
of the Republic of Moldova

Public institution
„National Service for the Radio Frequencies Management"

№. 06/1-227 of 07.03.2023

Technical University of Moldova
Mr. Viorel BOSTAN
Rector
National Centre of Space Technology
Mr. Ion BOSTAN
Director

Dear Sirs,

We hereby notify you, that the space object „TUMANOSAT" is registered in the Automated Information System "State Register of Radio Communications Frequencies and Stations" *(Government Decision No. 944 of 11-10-2010)* with the following characteristics:

Space object name:	„TUMNANOSAT"
Space object type:	Nano-satellite
Space object owner or operator:	Technical University of Moldova
Registration Number:	AMSS-000001
Date of Registration:	04.06.2020
Basic orbital parameters:	Nodal period 61.33 minutes Inclination 51.6 degrees Apogee 434 kilometers Perigee 404 kilometers
ITU filing:	ID: 119545144 API/A/12415(BRIFIC2907/29.10.2019)

Director **Andrei GAVRISI**

22/20 Nicolae Dimo str.,MD-2003, Durleşti, Chişinău tel. +373 22 78-57-29 fax. +373 22 78-57-27 e-mail: snfr@snfr.md , www.snfr.md

Annex 2. TUMnanoSAT nanosatellite registration form.

Registration Information Submission Form (as at 1 January 2010)

Note: This form is available from http://www.unoosa.org/oosa/SORegister/resources.html. Please see annex for instructions and definitions. Completed forms should be sent by hardcopy through Permanent Missions to UNOOSA **and** electronically to soregister@unoosa.org.

Part A: Information provided in conformity with the Registration Convention or General Assembly resolution 1721 B (XVI)

New registration of space object	Yes ☐	Check box
Additional information for previously registered space object (see below for reference sources)	Submitted under the Convention: ST/SG/SER.E/ ____ Submitted under resolution 1721B: A/AC.105/INF. ____	UN document number in which previous registration data was distributed to Member States

Launching State/States/international intergovernmental organization

State of registry or international intergovernmental organization		Under the Registration Convention, only one State of registry can exist for a space object. Please see annex.
Other launching States (where applicable. Please see attached notes.)		

Designator

Name		
COSPAR international designator (see below for reference sources)		
National designator/registration number as used by State of registry		

Date and territory or location of launch

Date of launch (hours, minutes, seconds optional)	dd/mm/yyyy hrs min sec	Coordinated Universal Time (UTC)
Territory or location of launch (see below for reference sources)		

Basic orbital parameters

Nodal period		minutes
Inclination		degrees
Apogee		kilometres
Perigee		kilometres

General function

General function of space object (if more space is required, please include text in a separate MSWord document)	

Change of status

Date of decay/reentry/deorbit (hours, minutes, seconds optional)	dd/mm/yyyy hrs min sec	Coordinated Universal Time (UTC)

Sources of information

UN registration documents	http://www.unoosa.org/oosa/SORegister/docsstatidx.html
COSPAR international designators	http://nssdc.gsfc.nasa.gov/spacewarn/
Global launch locations	http://www.unoosa.org/oosa/SORegister/resources.html
Online Index of Objects Launched into Outer Space	http://www.unoosa.org/oosa/osoindex.html

Part B: Additional information for use in the United Nations Register of Objects Launched into Outer Space, as recommended in General Assembly resolution 62/101			
Change of status in operations			
Date when space object is no longer functional (hours, minutes, seconds optional)	dd/mm/yyyy	hrs min sec	Coordinated Universal Time (UTC)
Date when space object is moved to a disposal orbit (hours, minutes, seconds optional)	dd/mm/yyyy	hrs min sec	Coordinated Universal Time (UTC)
Physical conditions when space object is moved to a disposal orbit (see COPUOS Space Debris Mitigation Guidelines)			
Basic orbital parameters			
Geostationary position (where applicable, planned/actual)			degrees East
Additional Information			
Website:			

Part C: Information relating to the change of supervision of a space object, as recommended in General Assembly resolution 62/101			
Change of supervision of the space object			
Date of change in supervision (hours, minutes, seconds optional)	dd/mm/yyyy	hrs min sec	Coordinated Universal Time (UTC)
Identity of the new owner or operator			
Change of orbital position			
Previous orbital position			degrees East
New orbital position			degrees East
Change of function of the space object			

Part D: Additional voluntary information for use in the United Nations Register of Objects Launched into Outer Space	
Basic information	
Space object owner or operator	
Launch vehicle	
Celestial body space object is orbiting (if not Earth, please specify)	
Other information (information that the State of registry may wish to furnish to the United Nations)	
Sources of information	
General Assembly resolution 62/101	http://www.unoosa.org/oosa/SORegister/resources.html
COPUOS Space Debris Mitigation Guidelines	http://www.unoosa.org/oosa/SORegister/resources.html
Texts of the Registration Convention and relevant resolutions	http://www.unoosa.org/oosa/SORegister/resources.html

Annex 3. Diplomas awarded at various exhibitions

"GHEORGHE ASACHI" TEHNICAL UNIVERSTY, IAȘI

NATIONAL INSTITUTE OF INVENTICS, IAȘI

Diploma of Excellence

SILVER MEDAL

Offered to

VALENTIN ILCO, VLADIMIR MELNIC, ALEXEI MARTINIUC, VLAD VARZARU, ION BOSTAN, VIOREL BOSTAN, NICOLAE SECRIERU

Technical University of Moldova

CENTER FOR COMMUNICATION AND MONITORING OF EDUCATIONAL SATELLITES

in recognition of high scientific contribution and loyalty to the XXV-th INTERNATIONAL EXHIBITION OF INVENTICS

INVENTICA 2021

Iasi, Romania

23-25 June 2021

GENERAL MANAGER
NATIONAL INSTITUTE OF INVENTICS
Prof. Neculai-Eugen SEGHEDIN PhD

"GHEORGHE ASACHI" TEHNICAL UNIVERSTY, IAȘI

NATIONAL INSTITUTE OF INVENTICS, IAȘI

Diploma of Excellence

SILVER MEDAL

Offered to

VALENTIN ILCO, VLADIMIR MELNIC, ALEXEI MARTINIUC, VLAD VARZARU, ION BOSTAN, VIOREL BOSTAN, NICOLAE SECRIERU

Technical University of Moldova

TUMNANOSAT, 1U CUBESAT NANOSATELLITE DEVELOPED AT THE TECHNICAL UNIVERSITY OF MOLDOVA

in recognition of high scientific contribution and loyalty to the XXV-th INTERNATIONAL EXHIBITION OF INVENTICS

INVENTICA 2021

Iasi, Romania

23-25 June 2021

GENERAL MANAGER
NATIONAL INSTITUTE OF INVENTICS
Prof. Neculai-Eugen SEGHEDIN PhD

"GHEORGHE ASACHI" TEHNICAL UNIVERSTY, IAŞI

NATIONAL INSTITUTE OF INVENTICS, IAŞI

Diploma of Honor

GOLD MEDAL

Offered to

VIOREL BOSTAN, VALENTIN ILCO, ALEXEI MARTINIUC, VLAD VARZARU, VALERIU VERJBIȚCHI, NICOLAE MAGARIU, OLEG LUPAN

Technical University of Moldova

TUMNANOSAT'S SATELLITE MODULES FOR RESEARCH OF THE NANOSENSORS PROPERTIES IN SPACE RADIATION CONDITIONS

in recognition of high scientific contribution and loyalty to the XXVI-th INTERNATIONAL EXHIBITION OF INVENTICS

INVENTICA 2022

Iasi, Romania

22-24 June 2022

GENERAL MANAGER
NATIONAL INSTITUTE OF INVENTICS
Prof. Neculai-Eugen SEGHEDIN PhD

"GHEORGHE ASACHI" TEHNICAL UNIVERSTY, IAŞI

NATIONAL INSTITUTE OF INVENTICS, IAŞI

Diploma of Honor

GOLD MEDAL

Offered to

VIOREL BOSTAN, ION BOSTAN, VALENTIN ILCO, VLADIMIR MELNIC, ALEXEI MARTINIUC, VLAD VARZARU, NICOLAE SECRIERU

Technical University of Moldova

TUMNANOSAT FLIGHT MODEL NANOSATELLITE

in recognition of high scientific contribution and loyalty to the XXVI-th INTERNATIONAL EXHIBITION OF INVENTICS

INVENTICA 2022

Iasi, Romania

22-24 June 2022

GENERAL MANAGER
NATIONAL INSTITUTE OF INVENTICS
Prof. Neculai-Eugen SEGHEDIN PhD

Diploma of Honor

GOLD MEDAL

Offered to

VIOREL BOSTAN, ION BOSTAN, NICOLAE SECRIERU, MARIN GUȚU, VLADIMIR MELNIC, VALENTIN ILCO, ALEXEI MARTÎNIUC

Technical University of Moldova / Space Technologies Center

STRUCTURAL ANALYSIS OF THE TUMNANOSAT MICROSATELLITE

in recognition of high scientific contribution and loyalty to the XXVI-th INTERNATIONAL EXHIBITION OF INVENTICS

INVENTICA 2022

Iasi, Romania

22-24 June 2022

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