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3STAR CUBESAT FOR THE GEOID MISSION

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3STAR is the new cubesat educational project developed at Politecnico di Torino. 3STAR is thought in response to the European Space Agency call for proposals for the GENSO Experimental Orbital Initial Demonstrator (GEOID) mission, held by its Education Office. GEOID is a mission consisting in launching and operating several satellites to test the Global Educational Network for Satellite Operations (GENSO) system and to serve as test-bed for the HUMSAT (HUManitarian SATellite) international satellites constellation. HUMSAT will work as a communication-support network for areas without infrastructures or for developing countries. Moreover, the HUMSAT project is aiming at providing a wide range of applications such as climate change monitoring, remote disaster tracking, and public health communications. 3STAR will be one of the first twelve satellites of the GEOID constellation. The 3STAR mission consists of a 3U cubesat orbiting the Earth and acting as a data-relay platform and a space-based test bed for an Earth remote sensing experiment. The payloads of this satellite are two. The first is the HUMSAT payload, a communication equipment (basically a UHF transceiver, one antenna, and one data storage device) that meets the HUMSAT requirements, nonetheless remaining extremely simple and reliable. The second payload is the P-GRESSION (Payload for GNSS REmote Sensing and SIgnal detectiON) experiment, whose main goal is to perform measurements by means of radio occultation techniques and scattering theory, using GNSS signals. In this paper the 3STAR project and its main payloads are described along with a preliminary description of the GEOID/HUMSAT mission and an overview of the 3STAR system characteristics, Including the dedicated ground control station.

The approach to the design is based upon a modular structure development.

The paper will describe the 3STAR system into the details, highlighting the methods employed to develop the program, as well as the first results obtained.

I. INTRODUCTION AND BACKGROUND

3STAR is an educational project developed by a multidisciplinary team of students from several engineering departments of Politecnico di Torino. In particular, the project will be developed at the Department of Aerospace Engineering (DIASP) of Politecnico di Torino by the students of the AeroSpace Systems Engineering Team (ASSET), in collaboration with students from the Electronics Department (DELEN) represented by the Remote Sensing Group (RSG) and the Navigation Signal Analysis and

Simulation Group (NavSAS), the Automotive Engineering group and the Management Engineering group. The final goal is to test a network of ground stations, and to provide data relay communication services for areas with poor infrastructures and/or affected by calamities.

The 3STAR mission has been thought within an ESA call for proposals for the GENSO Experimental Orbital Initial Demonstration mission (GEOID). This is an initiative for the promotion of Space activities in European University, by settling an orbiting constellation of Cubesats to be operated by the GENSO network, which is a worldwide network of radio amateurs and university ground-stations that supports the operations of university satellites. The GEOID initiative is strongly linked to HUMSAT program that has been proposed to the European Commission by a team of Universities, supported by ESA and United Nations.

At the Politecnico di Torino, several teams are involved in designing space missions and systems. Among these, the AeroSpace Systems Engineering Team (ASSET) of the Department of Aeronautics and Space Engineering, has been carrying out programs on small space platforms for many years. In the last decade, the team has focused the attention on the development of small satellites for educational and research purposes.

The first program was the PiCPoT nano-satellite, which has been completed in 2006. The project was completed in collaboration with other Departments, in particular the Electronics and the Energetics Departments. The PiCPoT satellite was developed and launched. Therefore it represents a good success for the developers' team. Unfortunately, it never reached its intended orbit due to a failure in the launch vehicle occurred a few seconds after liftoff. Despite the unsuccessful launch, the project represents an important stepping stone in terms of knowledge, experience and educational relevance.

The heritage of PiCPoT has been reaped by the e-st@r program, which is now approaching the finish line. The e-st@r program, mainly educational, has been selected by the ESA Education Office as one of the nine university Cubesats on the Vega maiden flight. The e-st@r project has been carried out by a team of about 30 students, graduate and undergraduate, with some PhD students also participating in the program. Some of those students are also amongst the members of the proposing team for the 3STAR project. Professors and researchers of the ASSET team worked as supervisors, dealing also with management issues. The launch of the Cubesat is now scheduled to take place around the first quarter of 2012.

Students from two other groups of Politecnico di Torino - Electronics Department (DELEN) will be involved on the 3STAR project, RSG and NavSAS groups. RSG is active in the field of remote sensing and is actually involved in the development of the ground segment for the Italian ROSA GPS receiver for Radio Occultation, and the implementation of a tomographic procedure for the characterization of Water Vapour high resolution fields for Interferometric SAR compensation purposes. Several expertise can be found in the two groups in the following areas: communications, navigation, signals/channels management, remote sensing, electromagnetic wave propagation, HW/SW tools for the design of prototype front-ends, software-defined radio receivers, GNSS receivers, full software GNSS signal generator; configurable NAV/Com platform hosting off-the shelf GNSS chipsets and several communication channels (WiFi, GPRS, Bluetooth).

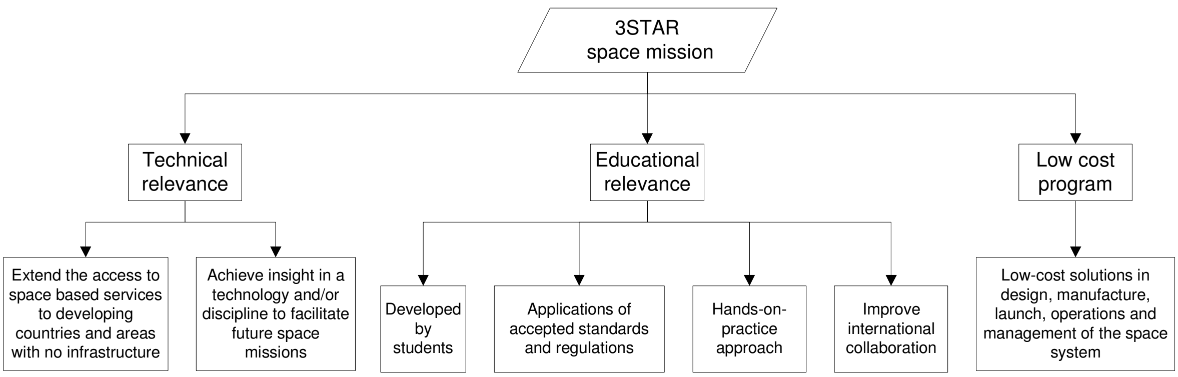

Figure 1: 3STAR project drivers

Other students from the Automotive Engineering Department and the Management Engineering Department expressed their willingness to be part of the proposing group, bringing their knowledge and experience to further enriching the cultural background of the team.

II. THE 3STAR MISSION

The mission objectives for the 3STAR project have been derived by means of the typical system engineering process, which starts with the definition of the mission statement.

The mission statement for the 3STAR project can be summarized as follows:

> *"The project aims at educating and inspiring space engineering students on complex systems development and operations, international cooperation and team work. The mission wants to contribute to the humanitarian exploitation of Space, by supporting communications capability in developing countries and/or allowing areas without infrastructure to access space-based services, and to enhance the knowledge on remote sensing applications for future small space missions."*

The following objectives can be obtained from the mission statement:

- The program shall have educational relevance: hands-on practice education and training of students on a real spacecraft project
- The mission shall carry one or more payload related to the peaceful and humanitarian exploitation of space.
- The mission shall demonstrate one or more remote sensing applications based on non-space qualified systems.

The 3STAR program is a project developed at university level, so the main objectives are both the scientific and the educational relevance of the activity. The main constraint is represented by the limited available budget for the program development.

Figure 1 illustrates the guidelines which are assumed as high level objectives and constraints for the program.

Figure 2 shows the logical process implemented to define the scientific objectives of the mission. Taking into account these assumptions, the mission and system requirements can be established, and the technical specifications can be derived for both the space and the ground segments.

The primary objective for 3STAR program is to support and contribute to the HUMSAT mission. In particular, several primary program sub-objectives can be defined:

- To provide telecommunications services in support to humanitarian and emergency applications
- To monitor parameters related to climate change
- To settle international collaboration among universities and research centres from all over the world
- To validate the GENSO network on a large-scale basis
- To promote high-level education on space systems

An additional objective is to perform on orbit remote sensing measurements, employing different remote sensing techniques for Earth observation, atmosphere profiling for climate studies, and eventually warning services.

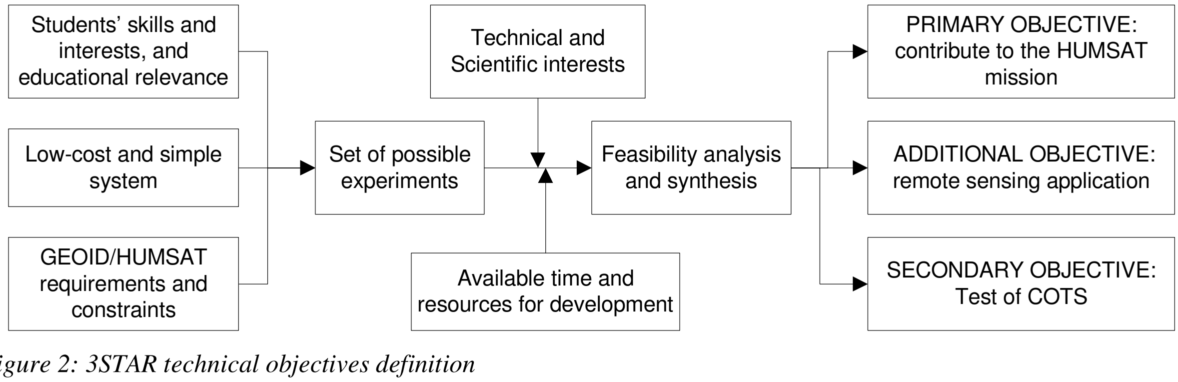

Figure 2: 3STAR technical objectives definition

Secondary objectives are the set-up of permanent space education project based on small-missions development and the test of low cost technologies in orbit to facilitate future small space missions.

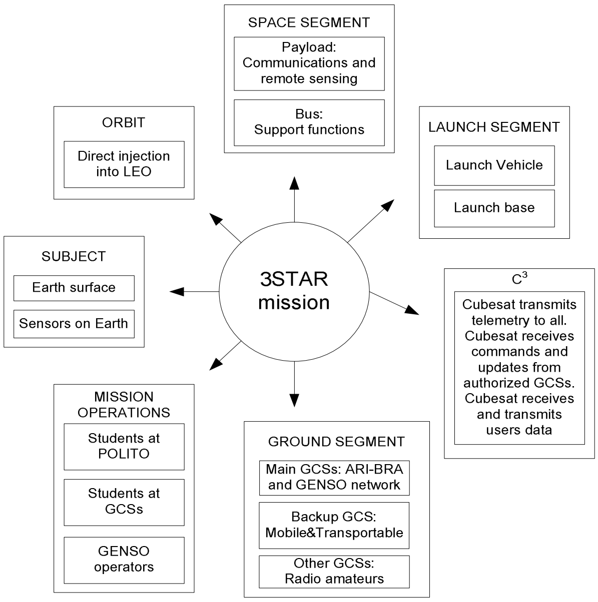

Figure 3: 3STAR mission architecture

III. MISSION ARCHITECTURE

Figure 3 shows the 3STAR mission architecture and its elements:

- The Space segment is composed by a 3U Cubesat encompassing 3STAR bus and two payloads
- The Ground segment is composed by a main ground station, a mobile and transportable backup station, and the GENSO stations network. Radio-amateurs can receive Cubesat signal but they can't command it.
- The Launch segment, made by launch vehicle and launch site are not now defined as also the parameters of LEO orbit.
- The Subjects are the Earth surface and the Earth atmosphere, and sensor over the surface.
- Communications are maintained and managed according to the HUMSAT requirements and IARU regulations.
- Operations will be managed by operators at GENSO stations and by the student at the main and back up station.

Preliminary mission simulations have been performed with a reference orbit and a reference ground station. The main parameters of the orbit and the ground station are listed in Table 1 and Table 2.

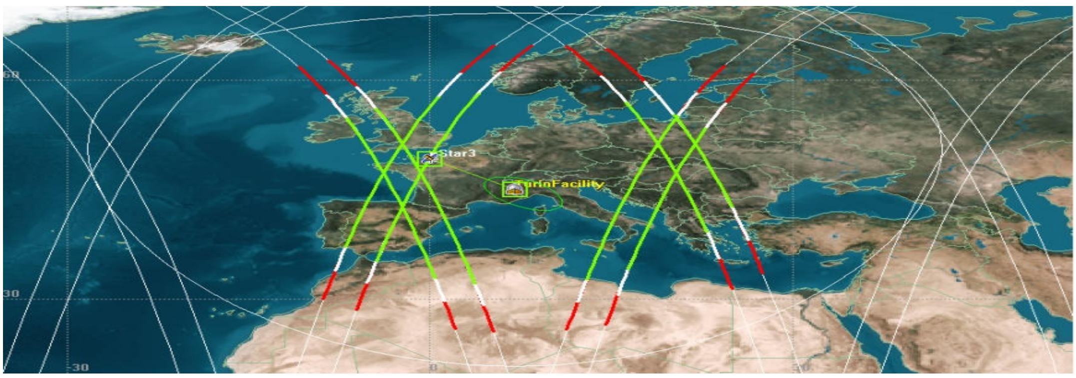

Figure 4: 3STAR access area over Torino at different elevation angles above the horizon.

Table 1: Torino ground station

Latitude	deg	45°03´N
Longitude	deg	7°40´E
Altitude	[km]	0.3

A preliminary study on the coverage and access figures of 3STAR passing over the Torino Ground Station has been carried out. Torino is placed in a region with a particular geomorphologic situation. In particular, it is close to the Alps on one side but sees a very flat region on the other side. For this motivation, a parametric study on the viewing conditions has been performed to assess the viewing conditions with the 3STAR satellite.

The minimum elevation angle between the satellite and the facility has been considered at 5°, 10°, and 15°. In these conditions the access time and the distance between the satellite and the facility have been computed. This study is performed to preliminary assess the available time in view for communication purposes, which will reflect into a further study on the transmission and communication power needed on-board.

Table 2: orbit parameters

Semi-major Axis	[km]	45°03'N
Circular Altitude	[km]	7°40'E
Inclination	[deg]	0.3
Eccentricity	[-]	0

A comparison summary of the major outcomes of the analysis is presented in Table 3, and the simulation of the passages over Torino, performed with STK®, are shown in Figure 4.

Table 3: access analysis results

Max. Elevation [deg]	Mean Access Duration [s]	Mean Range [m]
5	573	1572
10	443	1395
15	331	1287

The implementation of two payloads, and the requirement for the HumSat one to operate while the other isn't switched on, delineates the need of several mission phases, and operative modes. Different operative modes have been defined as shown in Table 4.

Table 4: 3STAR Operative modes

Operative mode	Description
LEOP	Cubesat immediately after launch and during commissioning is tested to prepare next mission phase
HUMSAT Mission	Cubesat is used as an element of Humsat constellation
P-GRESSION Mission	Cubesat is used as a remote sensing space platform
Basic Mission	Cubesat is used as space test bed for COTS equipment
Safe Mission	Off-normal mode, set in case the cubesat presents some failures and needs to be restored
Dormant	During launch the Cubesat's systems are deactivated. The Cubesat may be turned on the dormant mode also upon request of international authorities or HumSat mission control board

These modes will be controlled by the GCS and will be managed to the OBC system of the satellite.

IV. THE 3STAR SYSTEM

The educational program features, the low budget constraints and the GEOID/HUMSAT program requirements have brought to choose a 3U cubesat configuration. The service module design is derived from the e-st@r cubesat, taking into account the fact that there are more boards in the space segment.

The satellite carries a HumSat payload consisting of a UHF transceiver, one dipole antenna, and one data storage device. As additional payload, the cubesat serves a remote sensing experiment, called P-Gression and developed in collaboration with DELEN Department. The approach to the new design is based upon a modular structure development. The preliminary satellite layout is illustrated in the Figure 5 and Figure 6 by means of some CATIA models.

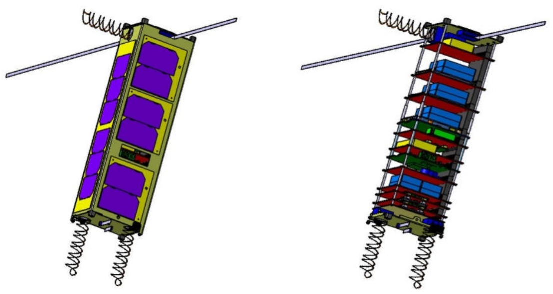

Figure 5-6: 3STAR preliminary external and internal layout.

The central cube of 3STAR represents the service module, hosting the main subsystems: electrical power, commands and data handling, communications, and attitude determination and control subsystems. The upper part hosts the HumSat payload and all necessary support devices: communication equipment, power storage, payload cool unit. The bottom part includes the remote sensing experiment, hosting the receivers, the data handling functions and the dedicated power supply unit. A number of antennas are spread in different parts of the cubesat, as shown in Figure 5-6.

A preliminary scheme of the 3STAR system is shown in Figure 7. For the space segment a distributed bus architecture has been designed: 3STAR bus is constituted by Command & Data Handling (C&DH) subsystem, an Electrical Power Subsystem (EPS), a Communication subsystem devoted to receive commands from the main ground station and send packets with cubesat status, telemetry, and payload data.

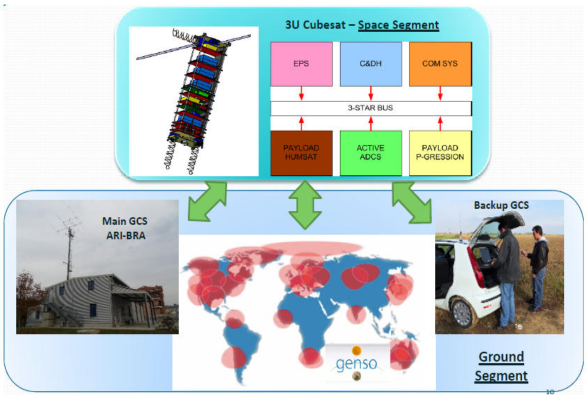

Figure 7: 3STAR system blocks scheme

Moreover, an active Attitude Determination and Control subsystem (ADCS) will be implemented in order to guarantee the antenna pointing requirements for the payloads. Few configurations are being considered for this ADCS. The magnetic rods, or magnetic torquers, configuration is the most attractive one. Indeed it guarantees the highest reliability and it is the configuration for which more experience is available in the team due to previous programmes developed at Politecnico di Torino. Sun sensors, Inertial Measurement Unit, and Tri-axial Magnetometer have been used for attitude determination and a dedicated microprocessor controls and manages the whole subsystem.

Concerning the EPS, several options have been considered and a trade-off analysis led to design a custom board in order to manage the power supplied by off the shelf GaAs triple junction solar panels and stored in Li-Ion batteries packs.

The Thermal Protection System (TPS) is passive. Each board has its own sensors to check and control the temperature ranges requirements, and the whole structure will be covered with a film of specific surface finishes to maintain the thermal balance of the satellite within the requirements.

The On-Board Computer (OBC) is the decision maker of the system and it gathers and handles the information, manages the commands, and controls HUMSAT payload data. It is based on an ARM microcontroller with Real Time Operating System (RTOS), chosen on the basis of the knowledge gained on e-st@r cubesat.

The ground segment is made of the main GS, the mobile and transportable backup GS and the GENSO stations network. Moreover, the Main GS and the Backup GS are also able to receive data from the P-GRESSION Payload. For these ground stations the running software has already been implemented and tested for the previous projects.

V. 3STAR PAYLOADS

The 3STAR satellite hosts two different payloads, the first is a communication payload designed to satisfy HUMSAT mission requirements, while the second one is an additional payload called PGRESSION and developed at Politecnico di Torino.

The HUMSAT Payload

As previously stated, also due to the mission requirements, a HumSat payload has been included in the 3STAR cubesat. The HumSat payload is needed to accomplish the HumSat mission, as presented in Figure . The payload hardware includes a UHF transceiver and its dipole antenna, one or more data storage devices, and the data handling electronics. The electrical power is available from the service module.

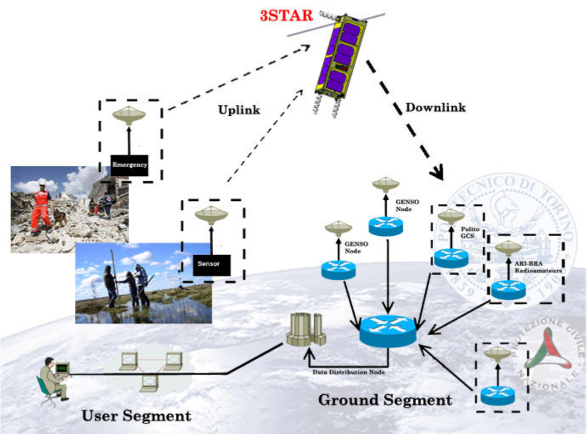

Figure 8: 3STAR in the GEOID/HUMSAT network (credits ESA)

The P-GRESSION Payload

P-GRESSION stands for Payload for Gnss REmote Sensing and Signal detectION.

It is a low-cost experiment that will be performed in the framework of the GEOID initiative, with two main purposes. The first is the Earth's atmosphere and surface remote sensing using GNSS signals; the second is the passive detection of ground-based radar signals made by radio frequency front ends working in the same radar frequency bands. Both experiments will be based on a Software Defined Radio approach, since after standard radio acquisition, all the operations will be performed by software on the intermediate frequency digitalized signal samples.

For the GNSS remote sensing experiment, two different techniques will be implemented. The first, called "radio occultation", is devoted to the profiling of the atmospheric refractivity, temperature, water vapor, and electron density. This technique can be applied to track GNSS signals emerging from the receiver's local horizon. The atmospheric profiles generated by this method are characterized by having a high level of accuracy and high vertical resolution. These profilesare very important for climate and meteorological purposes.

For the GNSS reflectometry experiment, scattering theory is required to extract information from a GNSS signal reflected from the Earth's surface and received on-board the 3STAR Cubesat. The versatility of this technique enables a wide range of uses, from world-wide monitoring to warning services. An emblematical example can be the sea-surface winds monitoring, helping in the identification of adverse meteorological conditions far from coastal zones. Another implementation would be the collection of information about soil moisture content, giving a large set of benefits, both from a prevention and early warning point of view. For instance, drought monitoring, farm production, irrigation planning, flood protection, fire prevention, and meteorological forecasts.

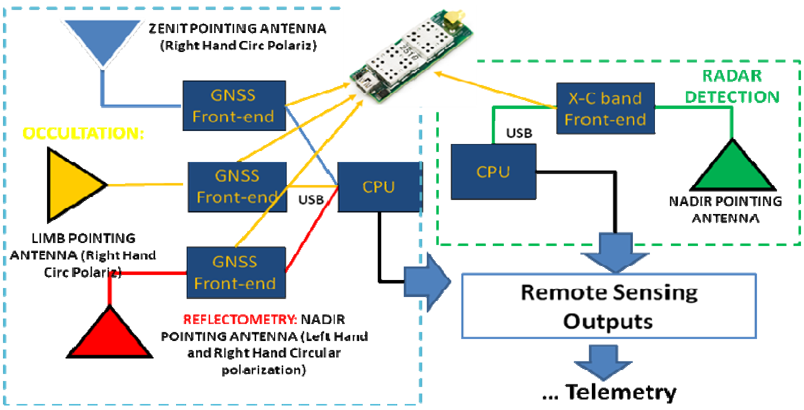

Figure 9: preliminary PGRESSION block scheme.

Soil moisture content is a key to describe the fundamental interaction between the Earth's surface and the first atmospheric layer. Moreover, sea altimetry measurements can be exploited from the reflected signal, and can be used as a powerful prevention technique to monitor tides and to identify natural hazards (i.e., tsunamis). The same concept can be applied to monitor sea-ice, investigating its topographic changes in the Arctic and Antarctic regions, and dry ice stratification, providing further data for the improvement of polar climatology knowledge. For both the GNSS-based experiments, global world coverage of observations is assured in all weather conditions. Finally, the current development/improvements of future global GNSS systems like the European Galileo, will enlarge the number of offered GNSS signals, improving the resolution in time and space of the remote sensing observables as a consequence.

The second purpose of the experiment is the use of similar Radio Frequency front-ends for the detection of signals coming from ground-based radars, in C/X frequency bands. These signals may interfere with generic satellite payloads, often degrading their performances. So it is important to recognize these sources to avoid corrupted measurements and as primary consequence discard observations affected by high uncertainty.

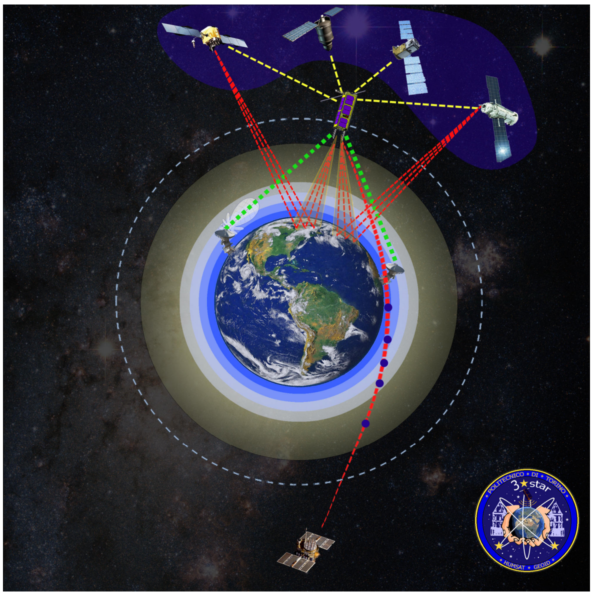

Figure 10: P-GRESSION applications.

In order to perform the GNSS remote sensing experiment, we need a low-cost sensor. Compared to traditional active sensors for remote sensing, the total cost of the payload is reduced using GNSS signals as electromagnetic source. For both topics, the acquisition systems we selected are based on Low-Cost GNSS Software Defined Radio receivers that can be easily mounted on-board 3STAR. The GNSS receiver will be the fully software N-Gene navigation receiver developed by the NavSAS group of the Politecnico di Torino.

It has to be interfaced with a Radio Frequency front-end, which transfers the received signal samples to an on-board processor via USB interface. Then, depending on 3STAR telemetry channel capability, the pre-processing can be made on-board, and partial results can be downloaded toward ground segment for final processing. One or more receivers/antennas are necessary, depending on the application implemented (GNSS Reflectometry or GNSS Radio Occultation).

The monitoring of such sources from 3STAR can be performed using C/X band front-ends which collect, *downconvert* and sample analog signals from small antennas pointed toward the Earth's surface offset from nadir. As in the previous case, data can be *preprocessed* on-board thus following a Software Radio Defined approach and downloaded toward ground for post-processin. Moreover, considering particular ground-based transmitters, such front-ends can be used not only for detection but also for calibration purposes of well known radar systems. Figure 10 shows the PGRESSION application. Figure 9 shows a preliminary blocks scheme of the PGRESSION Payload.

VI. <u>DEVELOPMENT PLAN, APPROACH, AND ORGANIZATION</u>

The 3STAR program shall follow the schedule illustrated in Figure 11 and Figure 12. The planning has been organized taking into account the experience gained with the e-st@r project and considering the possibility to transfer methods, technological results and hardware from the e-st@r cubesat to the 3STAR project. This means that the e-st@r hardware design has been adapted to the maximum extent to be the core of 3STAR, providing the necessary interfaces for the two payloads. This approach allowed to shorten the schedule originally planned.

Phase 0 and phase A have been implemented as a single design phase. In this combined phase 0/A, the mission analysis and the mission\system requirements definition have been accomplished. Students of the Space Mission Design academic course have been involved in this phase. At the end of the phase, the preliminary requirements review has been fixed and the preliminary requirements document has been issued.

Phase B deals with the preliminary design of the cubesat. Phase B ends with the preliminary design review (PDR), which represents one of the most important milestones in the program development. During this phase, development prototypes for the items of 3STAR whose general design can be partially inherited from the e-st@r satellite will also be developed and built, together with the required ground support equipment. The hardware inherited from the e-st@r satellite will be purchased and test campaigns to verify the correct functioning of them will be carried out. In Phase C the detailed design of the platform-system and the payloads will be developed. In this phase, MSc students from aerospace engineering will be involved for the satellite service module and HUMSAT payload detailed design definition.Students from the Electronics area will deal with the detailed design of the PGRESSION payload and its applications. To this end, in particular, students will be involved in developing the software for the extraction of Earth's atmosphere and surface geophysical information and the software for identification of ground-based radar systems and transmitters. The work will be done by a number of students selected to do their final MSc thesis on the project. Phase C conclusion is the Critical Design Review (CDR) but a continuous monitoring of the activities is planned. The phase C is also the phase in which specific seminars and workshops will be planned and organized.

VII. CONCLUSIONS

3STARS is the new space educational program within space programs at Politecnico di Torino. It represents a new chance for students and researchers to design and develop a low cost space system.

The whole program is performed to develop and manufacture a 3U Cubesat and a ground station within three years.

The mission of 3STAR has been thought within an ESA program proposed by Education Office and named GEOID, acronym of GENSO Experimental Orbital Initial Demonstration. The initiative purpose is the promotion of Space activities in European University by settling an orbiting constellation of Cubesat to be operated by GENSO Stations Network. Moreover, the 3STAR program is devoted to support the HUMSAT program, which has been proposed to the European Commission by a team of Universities, supported by ESA and United Nations. First of all, educational aspects of the program are taken into account. In fact, the hands-on practice approach allows students to learn how to handle real engineering problems and solve them in the most effective way. In addition, the international spirit of the project gives the opportunity to meet other university space mission developers and to cope with external entities, in order to improve social and professional skills. 3STAR is mainly devoted to support Humsat/Geoid objectives by implementing a store -and-forward communication system. Another challenging aspect is to implement a remote sensing applications and test a simple and cheap system for remote sensing on-orbit. The hardware and software related to the experiment is completely developed within the Politecnico di Torino.

It is important to underline the fact that the educational aspect of the project is strongly related to the low-cost feature of the program. Although the project must follow all the international space standards, technical solutions, design, manufacture, launch, operations, and management shall be simple and cheap.

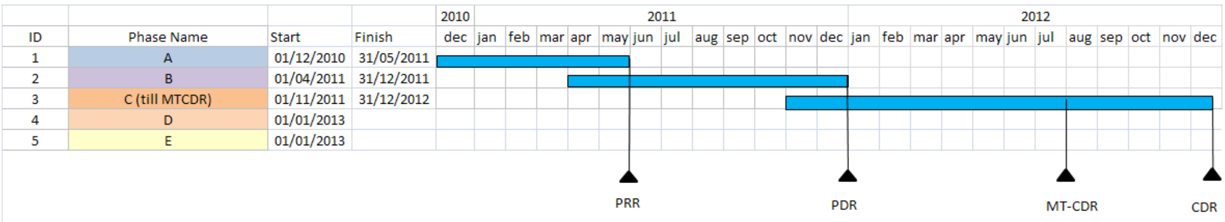

Figure 11: schedule plan for 3STAR mission.

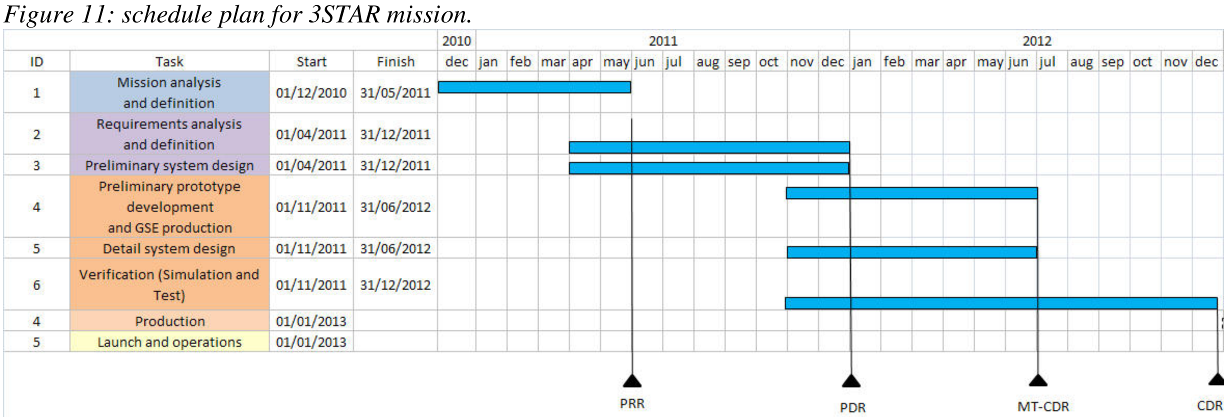

Figure 12: detailed schedule plan for 3STAR mission.