The 3-star project at Politecnico di Torino

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Abstract

The 3-star program is an educational project just started at the Politecnico di Torino. It has been thought in response to the GEOID call for proposal issued by the Education Office of the European Space Agency. The GEOID (GENSO Experimental Orbital Initial Demonstration) initiative wants to settle an orbiting constellation of Cubesats to be operated by the GENSO (Global Educational Network for Satellite Operations) ground-stations network.

GEOID is expected to be the communication backbone of the initial version of the HUMSAT system. The main goal of HUMSAT is to use the constellation of satellites and the GENSO ground stations, to provide support for humanitarian initiatives, especially in developing areas or areas without infrastructure. The HUMSAT project is aiming to provide a wide range of applications such as climate change monitoring, remote disaster tracking or public health communications.

The 3-star will be one of the nine cubesats in the GEOID constellation. As far as the main bus functions are concerned, 3-star is a 3U cubesat derived from the e-st@r spacecraft. In addition, it will carry two payloads: 1) the HumSat payload, consisting of a simple but extremely reliable communication module, to contribute to the service at the basis of the entire mission, and 2) the P-GRESSION (Payload for GNSS remote sensing and signal detection) payload, which has been expressly thought for this mission. The P-GRESSION payload aims at performing measurements by means of radio-occultation technique and scattering theory, using GNSS signals. It may also work as a radar interference detector. As its precursor, the satellite will be equipped with a set of systems needed to guarantee the satellite's vital functions: electrical power, communications, attitude determination and control, command and data handling. The satellite will be launched by 2013, when the GEOID mission is planned to become operative.

Introduction and Background

3STAR is an educational project which will be 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. From the technical point of view 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. A dedicated ground control station is also included in the mission. The final goal is to test a network of ground stations, and to provide communication capabilities in cases of natural disaster, for specific areas of the globe, and for scientific purposes.

The 3-star mission has been thought within an ESA program proposed by Education Office, named GEOID, that is the acronym of GENSO Experimental Orbital Initial Demonstration. GEOID is an initiative for the promotion of Space activities in European University, by settling an orbiting constellation of Cubesat to be operated by the GENSO network. GEOID initiative is strongly linked to HUMSAT program which 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 ended in 2006. The project was carried out in collaboration with other Departments, in particular the DELEN and DENER Departments. The PiCPoT satellite was developed and launched, but unfortunately it never reached its intended orbit due to a failure in the launch vehicle occurred a few seconds after liftoff. Notwithstanding the unsuccessful launch, the project represents an important stepping stone in terms of knowledge 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, and some PhD students also participated in the program. Some of those students are also amongst the members of the proposing team for the 3-star project. Professors and researchers of the ASSET team acted as supervisors, dealing also with management issues. The launch of the Cubesat is now scheduled to take place in second quarter of 2011.

Students from two other groups of Politecnico di Torino - Electronics Department (DELEN) will be involved on the 3STAR project, namely the Remote Sensing Group (RSG) and the Navigation Signal Analysis and Simulation group (NavSAS). The two groups collaborate in research and teaching areas. RSG is active in the field of remote sensing and is actually involved in two projects related to GNSS remote sensing: the development of the ground segment for the Italian ROSA GPS receiver for Radio Occultation, launched onboard the Indian OCEANSAT-2 mission in Sep/2009 and the implementation of a tomographic procedure for the characterization of Water Vapour high resolution fields for Interferometric SAR compensation purposes, in the framework of an European Space Agency project(namely METAWAVE). NavSAS has been involved in 13 projects funded by the GJU/GSA in FP6 and FP7, and it has strong links with industry. Together will be involved on a future founded Training Network in the framework of FP7 PEOPLE Marie Curie Action namely TRASMIT (Training Research and Applications Network to Support the Mitigation of Ionospheric Threats), which will start on February, 2011. 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, VHF, Bluetooth).

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.

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 derived 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.

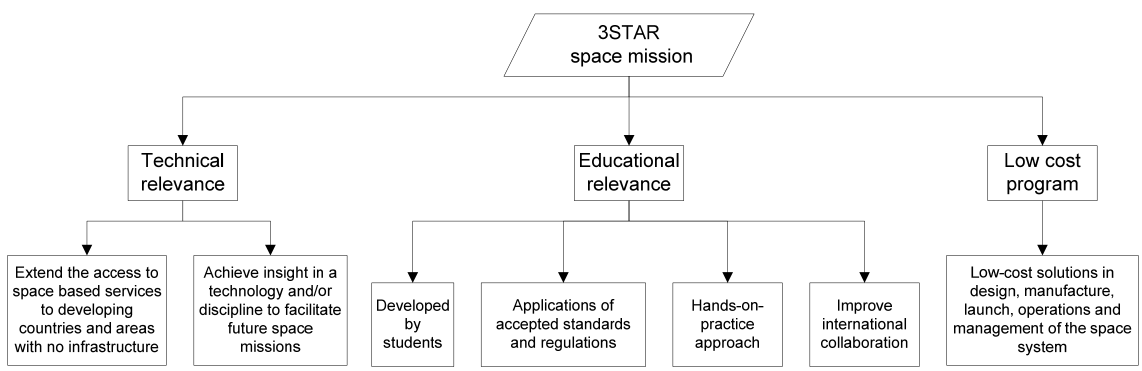

Figure 1: 3STAR project drivers

Figure 2shows the logical process implemented to obtain 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.

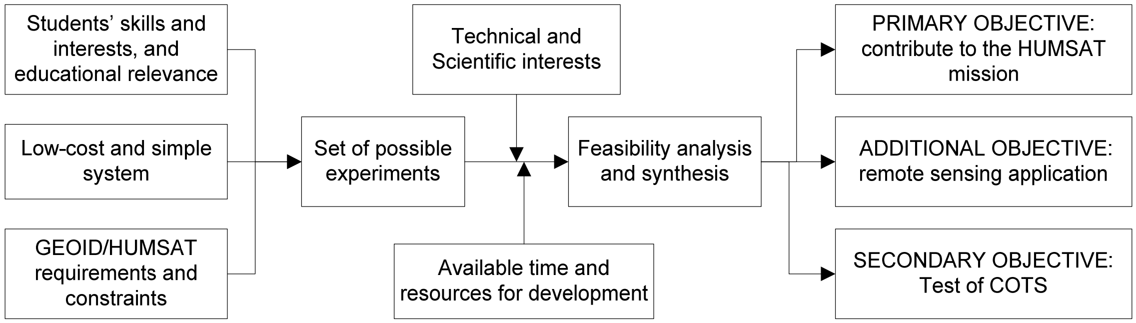

Figure 2: technical objectives definition

The primary objective for 3-star 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

Moreover, also GEOID, strongly linked with HumSat program, adds the following objectives:

- 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.

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.

Mission architecture

Figure 3 shows the 3-star mission architecture and its elements:

- The Space segment is composed by a 3U Cubesat encompassing 3-star 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 Subjects are the Earth surface and the Earth atmosphere, and sensor over the surface.
- Launch vehicle and launch site are not now defined as also the parameters of LEO orbit.
- 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.

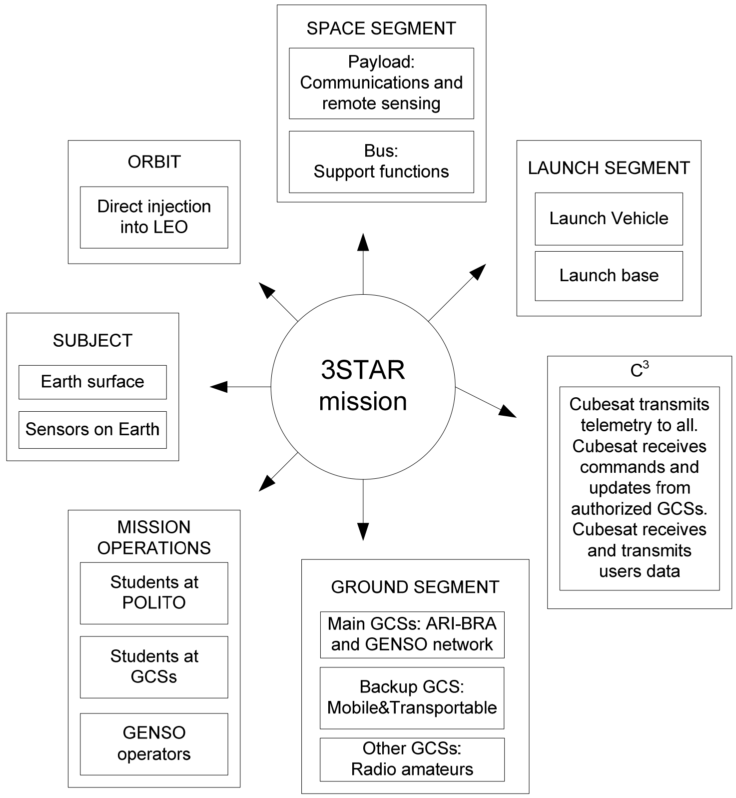

Figure 3: 3-star mission architecture

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.

Table 1: Torino ground station

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

Table 2: orbit parameters

Semi-major Axis	[km]	6978.137
Circular Altitude	[km]	600
Inclination	[deg]	97.40
Eccentricity	[-]	0

A preliminary study on the coverage and access figures of 3-star passing over the Torino Ground Station has been carried out. Torino is placed in a region with a very 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 3-star 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.

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

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

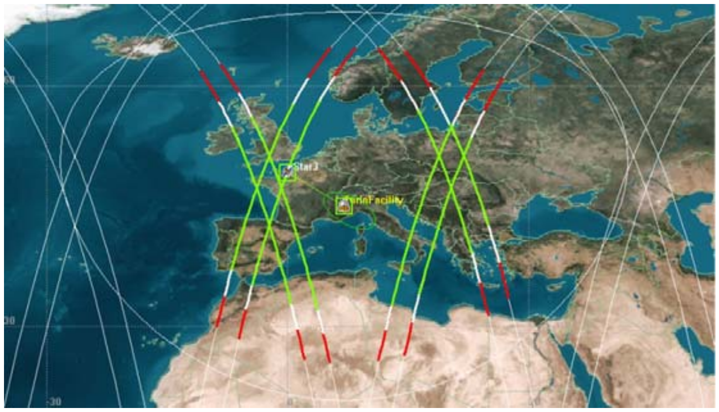

Figure 4: 3STAR access area over Torino at different elevation angles above the horizon

The Cubesat can operate in different ways, depending on the mission phases, taking into account that the 3-star cubesat hosts two payloads. Different operative modes have been defined as shown in Table 4.

Table 4: 3-star 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

The 3STAR satellite

The platform proposed to be part of the GEOID program, and hence of the HumSat constellation, is a 3U Cubesat. The service module is derived from the e-st@r cubesat, apart from some minor differences. 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. The approach to the new design is based upon a modular structure development. The satellite general layout is illustrated in the following figures by means of some CATIA models.

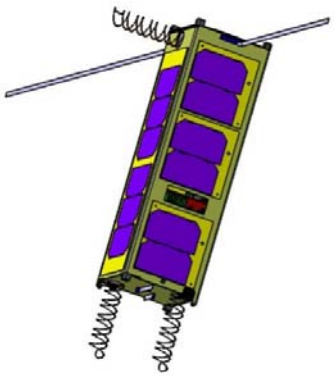

Figure 5: 3-star preliminary external layout

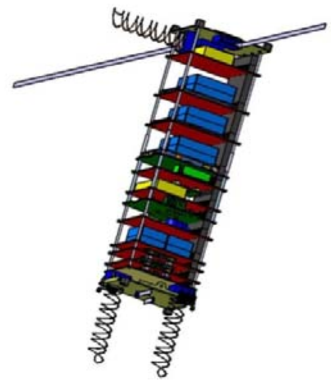

Figure 6: 3-star preliminary internal layout

The central part of 3-star represents the service module, hosting the vital subsystems: electrical power, commands and data handling, communications, and attitude determination and control. The upper part hosts the HumSat payload, and all necessary support functions: 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. The service module is based on the e-st@r cubesat.

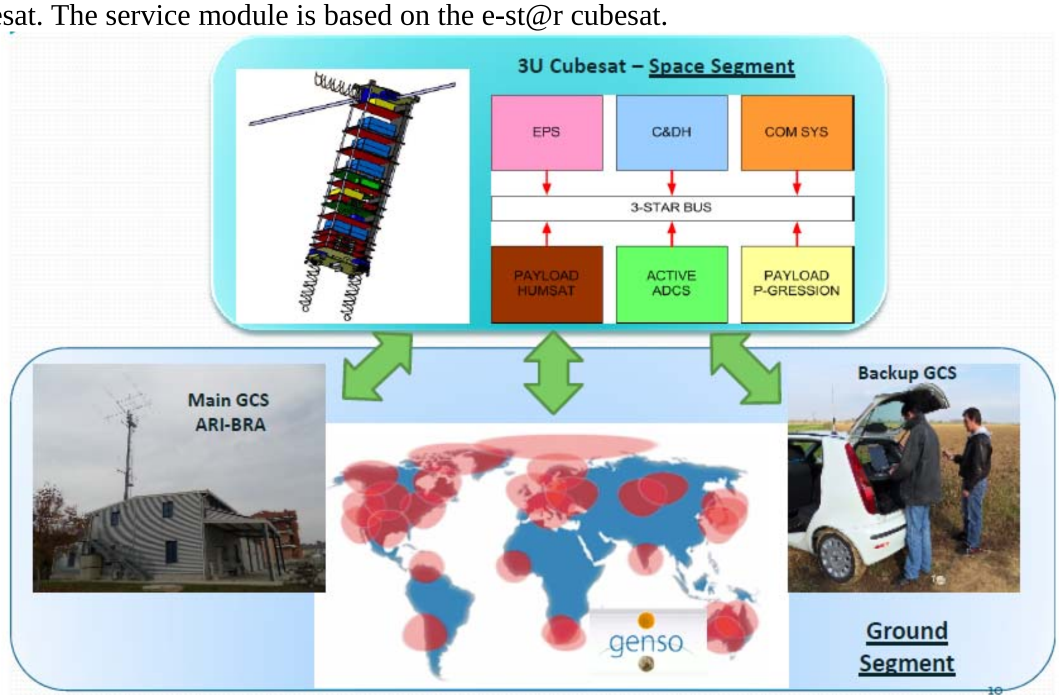

Figure 7: 3-star system blocks scheme

A preliminary scheme of 3-star system is shown in Figure 7. For the space segment a distributed bus architecture has been thought, particularly, 3-star bus is constituted by Command & Data Handling subsystem, an Electrical Power subsystem, a communication subsystem devoted to receive commands from the main ground station and send beacon signal with cubesat status. Moreover, an active Attitude Determination and Control system is carried out in order to guarantee the antenna pointing requirements for payloads.

The ground segment is composed by the main GS, the mobile and transportable backup GS and the GENSO stations network. Moreover, Main GS and Backup GS are also able to receive data from P-GRESSION Payload.

The HUMSAT Payload

A HumSat payload will be included in the 3STAR cubesat. The HumSat payload serves to accomplish the HumSat mission, as depicted in Figure 8. The payload hardware includes a UHF transceiver and its dipole antenna, one or more data storage devices, and the necessary data handling electronics. The electrical power comes from the service module.

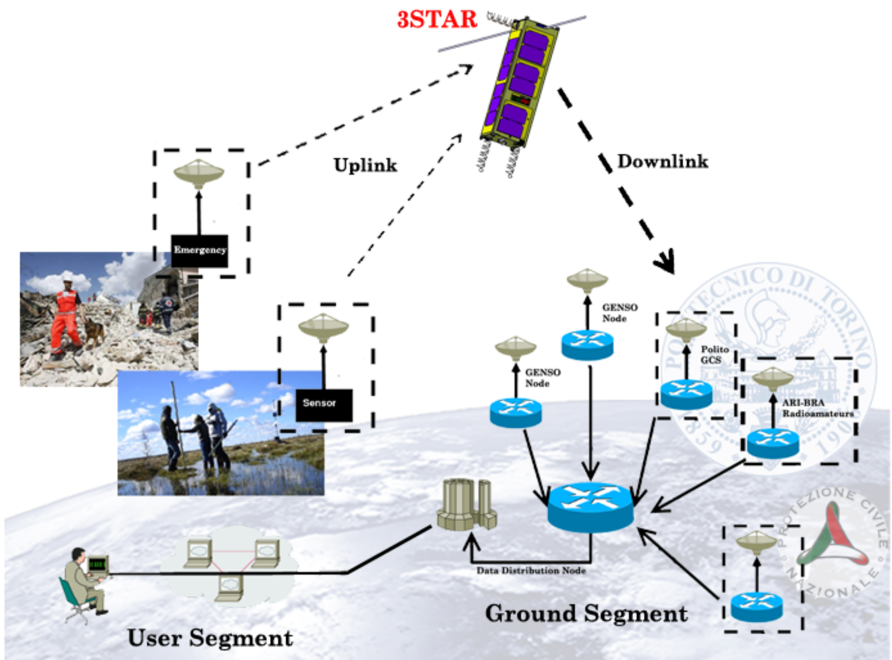

Figure 8: 3STAR in the GEOID/HUMSAT network

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, namely "radio occultation", is devoted to the profiling of atmospheric refractivity, temperature, water vapour and electron density. Such technique can be applied to track GNSS signals emerging from the receiver local horizon. Atmospheric profiles generated by this method are characterized by high accuracy and high vertical resolution, and are very important for climate and meteorological purposes.

For the GNSS reflectometry experiment, it is necessary to apply the scattering theory 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 make possible a wide range of uses, from world-wide monitoring to warning services. An emblematical example can be sea-surface winds monitoring, helping in the identification of adverse meteorological conditions far from coastal zones. Another possibility allowed by this method is to retrieve information about soil moisture content, giving a variety of benefits, both from a prevention and early warning point of view: drought monitoring, farm production, irrigation planning, flood protection, fire prevention, and meteorological forecasts. Therefore, 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. It has to be noted that, 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 consequently the resolution in time and space of the remote sensing observables.

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.

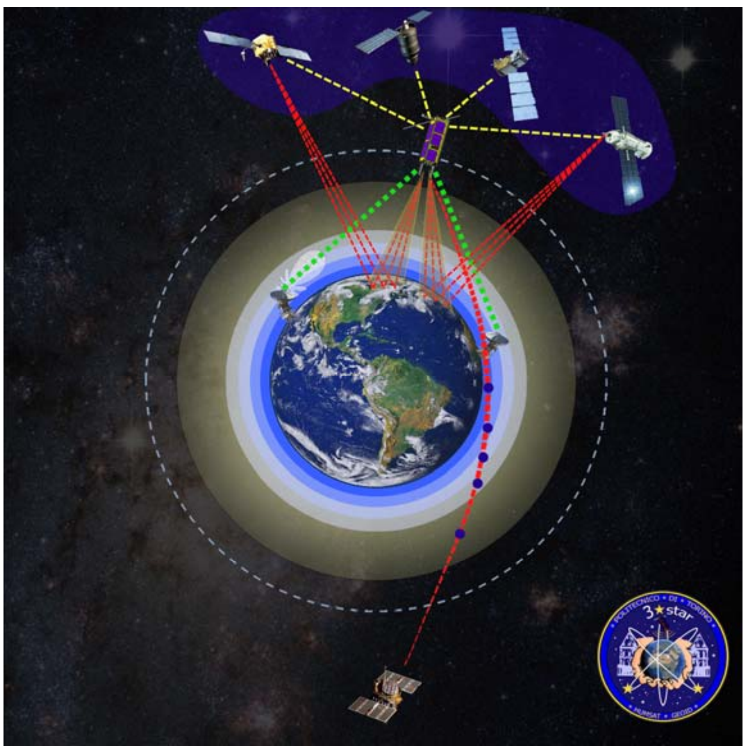

Figure 9: P-GRESSION applications

In order to perform the GNSS remote sensing experiment, we need a low-cost sensor. Respect to traditional active sensors for remote sensing, the total cost of the payload is surely reduced using GNSS signals as electromagnetic source. For both topics, acquisition systems we choose will be based on Low-Cost GNSS Software Defined Radio receivers that can easily mounted on-board the 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-processing. 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 8 shows the P-GRESSION application. Figure 9 shows a preliminary blocks scheme of the P-GRESSION Payload.

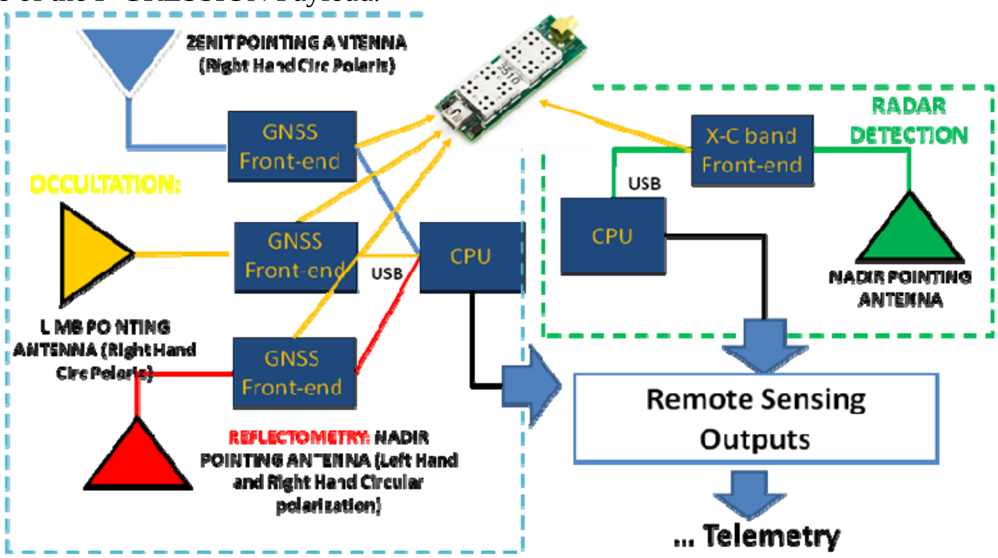

Figure 10: P-GRESSION blocks scheme

Conclusion

3-star is a new program, mainly developed by ASSET and the Remote Sensing Group of the Electronics Department, but various level students are involved not only from electronics and space engineering field but also from automotive and management engineering.

The whole programme will be performed in such a way to develop and manufacture a 3U Cubesat and a ground station within three years.

The mission of 3-star has been thought within an ESA program proposed by Education Office and named GEOID, acronym of GENSO Experimental Orbital Initial Demonstration, that is an initiative for the promotion of Space activities in European University, by settling an orbiting constellation of Cubesat to be operated by GENSO Stations Network. Moreover, the 3-star 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, using 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.

From the technical point of view, 3-star is mainly devoted to support Humsat/Geoid objectives by implementing a store and forward communications system. Further interest

aspect is to implement valuable remote sensing applications and test a simple and cheap system for remote sensing, completely developed within the Politecnico di Torino, on orbit.
3-star is a very low cost project. Technical solution, design, manufacture, launch, operation and management have to be simple and cheap.

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Authors

Sabrina Corpino is assistant professor in the Aerospace System Engineering Area at the DIASP. She is involved in the education activities as well as in the research projects of the AeroSpace Systems Engineering Team (ASSET) at the Department of Aeronautics and Space Engineering (DIASP) of the Politecnico di Torino. She has participated and participates in several national and international research programs in the aerospace field. She worked on the PiCPoT nanosatellite system design, physical simulation, and manufacturing and assembly definition. Since mid 2007 ASSET has been working at the design, manufacturing, test and launch into LEO of another university satellite (CubeSat standard), named e-st@r. Within this project she plays the role of Project Manager; she coordinates the team constituted by other researchers of Politecnico di Torino and some thirty students mainly from the Aerospace Engineering Courses. She also carried out research activities on the design of aerospace systems, in particular of low-cost systems performing scientific missions, and the development of hardware-in-the-loop techniques for systems simulation and verification

Manuela Cucca (PhD) is research assistant at Politecnico di Torino. Recently she worked on the project "Software ROSA for Oceansat-2", related to the development of the Ground Segment for the data processing of GPS data, collected by the Italian payload ROSA on board the Indian OCEANSAT-2 mission. Furthermore, she is carrying on a research activity on GNSS reflectometry. In particular, she is designing a GNSS receiver for scatterometry purposes, with the goal of developing a low cost, portable and easily reconfigurable receiving system; a measurement campaign is soon foreseen both on ground and on a small U.A.V. (Unmanned Aerial Vehicle) aircraft.

Since 2006 **Riccardo Notarpietro** is assistant professor (research area: Electromagnetic Fields) at the Politecnico di Torino. He belongs to the Remote Sensing Group operating inside the Electronics Department. His fields of activities included also electromagnetic wave propagation and radarmeteorology.

He was involved in several national and international research projects. Actually he is the scientific coordinator of the sub-contract between Politecnico di Torino - Electronics Dept. and ISMB (Istituto Superiore Mario Boella) related to the Italian Space Agency project "Software ROSA for Oceansat-2". This project is related to the development of the Ground Segment for the data processing of GPS data collected by the Italian payload ROSA on board the Indian OCEANSAT-2 mission. Within the field of the GPS meteorology he is also involved in the Project METAWAVE ("Mitigation of Electromagnetic Transmission errors induced by Atmospheric Water Vapour Effects", an ESA founded project); in this framework he is developing a tomographic algorithm for the three dimensional reconstruction of high resolution wet refractivity fields using GPS signals collected by a dense receivers network. He is author or coauthor of 11 peer-reviewed papers and of more than 40 contributions to international and national conferences and workshops.

Guido Ridolfi is a PhD candidate at the Department of Aeronautics and Space Engineering (DIASP) of the Politecnico di Torino since January 2009. He is involved in the research projects of the AeroSpace Systems Engineering Team (ASSET) at the Department of Aerospace Engineering (DIASP) of the Politecnico di Torino. His Ph.D. is carried out in the framework of an international cooperation with Delft University of Technology, Space Missions and Systems department. His activity is now mainly focused on the development of methodologies for space missions and systems design, and for supporting of the engineering team. He is currently working as thermal engineer of the e-st@r cubesat.

Fabrizio Stesina is a PhD student at the Department of Aeronautics and Space Engineering (DIASP) of the Politecnico di Torino. He is involved in the education activities as well as in the research projects of the AeroSpace Systems Engineering Team (ASSET) at the Department of Aerospace Engineering (DIASP) of the Politecnico di Torino. He plays the role of System Engineer in the e-st@r program. In this project, he is involved in the design, development, manufacturing and test of a cubesat. He also works in an other ASSET program named TWISTOSC, carried out in collaboration with the Osservatorio Astronomico di Torino and funded by the Italian Space Agency. The project theme is the design of a system made of two tethered nanosatellites whose objective is to take pictures of the solar corona.