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Pico And Nanosatellite Ground Station Architecture Development Reference Process

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Abstract

The CubeSat concept contributed to the consolidation of standards to small satellites that sets a role model for the construction of the space segment. However, projects and research in the ground segment of these satellites in Latin America still did not reach the same level of achievements as the space segment. This work aims to present the developments done at INPE in the development of a reference process to assist in the creation of ground stations that could be used for those interested in tracking and receiving data from small satellites in service. This reference process can be used by graduate and undergraduate students in general to provide the ground segment of the next generation of small satellites. It illustrates a case study focused on Brazilian´s CubeSat projects so it can become later an active and constant participation in whole Latin America. The development of small satellites projects are flourishing in various Latin America universities. Moreover, Brazil showed a significant improvement in the development of such satellites with results as the NanoSat-Br1 and the AESP-14. Henceforth, this work presents a reference process based on systems engineering (Concurrent Systems Engineering Laboratory - LSIS at LIT) as a decision-making guide for the development of a ground station architecture for small satellites that meets the needs of having a ground segment itself. The results are presented as a systems engineering process guide for the development of ground stations for Pico and Nano satellites.

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Introduction

Reference processes plays a key role in modeling domains since it holds generic functionalities and can be reused more than once in different circumstances. This model benefits from existing process reference models precluding one from reinventing the process model but only reusing it as a starting point in creating a process model for a specific purpose.

The underlying domain of this is paper is focused in ground stations for small satellites and the objective is to develop a reference process based on systems engineering. This intends to guide in decision making regarding the development of the architecture of a CubeSat ground station that meets the current needs of its developers. All of this to have autonomy over the planning and performing telecommunications testing stages, and the subsequent operation of this kind of satellites, besides having an effective ground segment, inexpensive, flexible and dynamic.

The CubeSat development projects in university environment in Latin America have grown significantly in the last decade; in 2002 there were fewer than two active projects, and now, in 2016, this number exceeds 20. Also, in Brazil it was shown a significant increase in the development of such satellites with NanoSat-Br1, still in orbit, and the AESP-14 design. However, advance in the development of such projects in Brazil is focused largely the space segment more than in the ground segment, this can be seen in CubeSat designs cited above, where the satellite has been developed by a national team, and its grounds stations were obtained fully a foreign trading company [1].

This paper analyzes the significant aspects related to the development of the ground segment of space missions for small satellites, and the importance of its creation rather than the acquisition of a company. For this, reference stations were contrasted to characterize an ideal station, and on that basis has been adapted a reference procedure for the development of stations taking into account the needs of CubeSat's developers in Brazil.

The work is organized as follows. A group of sessions presents the ground segment for satellite which is then specialized to cubesats and more specifically to ground stations in Brazil. Afterwards, the Systems Engineering approach is discussed and used to define a ground station architecture development reference process which is then applied and some results attained so far. The paper then closes with its main conclusions.

Ground Segment for Satellite Missions

The ground segment of space missions consists of all infrastructures and communications equipment associated with the fixed or mobile stations around the world. These stations can be connected by various data links, allowing tracking and commanding the satellite as well as receiving and processing telemetry mission and distributing information for operators and end users [2].

Within the scope of the ground segment, there are four key components to be able to control, track, receive and process data from the satellite, namely: hardware, software, personnel and operations. [3]

The standard ESA ECSS-E-70 Part 1A which deals with terrestrial systems and operations, meets these four components in two main elements [4]:

a) Ground operations organizations that includes human resources to perform various operational tasks and prepare the data for mission operations, that is, procedures, documentation, mission parameters, mission description data.

b) Ground systems: correspond to all infrastructure elements on the ground that are used to support the preparatory activities prior to the operation of the mission, conduct of mission operations and post-operational activities.

CubeSat Ground Stations

According to Ishikawa [5], a ground station is of paramount importance for the success of the mission is the first and last piece of the communication link. Its main purpose is to conduct the following-up of the satellite and receive their data to subsequently perform the analysis. To Holdaway [3], keeps track of the satellite to determine its position in orbit, a ground station includes highly complex functions, as follows:

a) Telemetry operations to acquire and record satellite data and status;
b) Command operations to interrogate and control the various functions of the satellite;
c) Control Operations to determine orbital parameters, to schedule the satellite passages, and monitoring and on-board computer loading;
d) Data processing operations to present all scientific and engineering data in the formats required for the successful evolution of the mission;

e) Enabling voice and data links to other ground stations worldwide and processing centers

The university ground stations, usually to low-orbiting satellites, can be splitted into subsystems, as shown in Figure 1. The figure shows, using a block diagram, the relationship of the subsystems at the ground station, and the station's relationship with the other segments that make up a space mission.

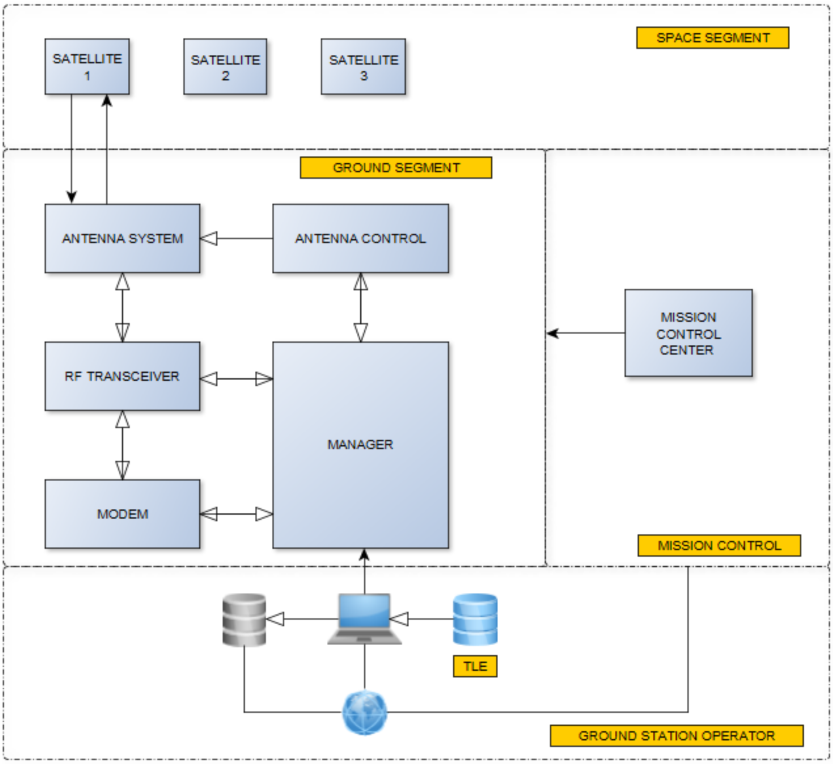

Fig. 1. A Generic Ground Station block diagram.

The development of a Cubesat Ground station process obey to reduce costs, but even being important, the expenses related to a ground station usually are not the main concern. The most notorious improvement is the universities' capacity building development related to ground segment as well as national autonomy.

Since the creation of Cubesat standard by Dr. Jordi Puig Suardi and Dr. Robert J. Twiggs, the academy (Universities and Schools) have been benefited with the concept "put the hands in the real work", because in the past it was very hard to obtain the same knowledge without a practical activity. Nowadays, thanks to this approach, space studies concepts are easier to learn. This revolution of a new way to transmitting knowledge has generated the possibility of fast enhancement of staff, facilities, components, and projects focused in small satellites.

Based on the Cubesat standard, which leaves open the possibility to the Cubesat as you wish, it is desired to extrapolate the same concept to the ground stations. Being free to explore possibilities allows one to extrapolate designs for suitable to the national infrastructure and context.

Ground stations for CubeSat in Brazil

It is important to the paper context include the ground stations around the Brazilian territory. Unfortunately there is no a large number of ground stations, and 1/3 of these equipments were purchased.

1. Ground Station PY2AEC (INPE-ITA)

It is a fixed low orbit satellites ground station for tracking and control, based on the technology of Software Defined Radio (SDR), located in the ITA in the Department of Aerospace Science and Technology (DCTA) in São José dos Campos, São Paulo. The station, which currently remains in the ITA, belongs to the group of active ground stations INPE / MCTI according to the general report of the assets of INPE, and operates on amateur radio frequencies with PY2AEC prefix, determined by the National Telecommunications Agency (Anatel). [6]

The ET INPE-ITA, see Figure 2, was bought as a kit in 2013, to the Dutch company Innovative Solutions In Space (ISIS), in order to be part of the ground architecture of Brazil's first CubeSat, NanoSatC-BR1 [7]. In addition to integrating the NanoSatC-BR1 of the project, the ITA station was selected to act as the control center of the second Brazilian CubeSat, and first to be built entirely in the country, the AESP-14. [8] Future ET INPE-ITA will have another interaction software, still in development, in order to monitor the control of CubeSat ITASAT-1. [9]

Fig. 2. ITA Ground Station from ISIS.

2. Ground Station PY2DGS (ITA)

Built in 2014, is characterized as a portable station for tracking and control for low-orbiting satellites operating in Half Duplex. Currently its operation center is in the ITA in São José dos Campos, São Paulo.

As shown in Figure 3 the ET PY2DGS-ITA is a station built with COTS components of simple design, and low cost, was incorporated in the electronics applied department at ITA by the Professor Dr. Douglas Soares' team, which is why the station takes as the name of the amateur radio prefix. The main purpose of development of portable ground station were operational testing of telemetry and remote control in soil CubeSat AESP-14.

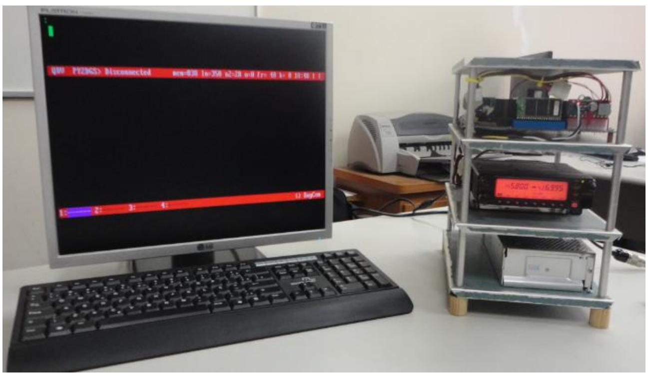

Fig. 3. Portable Ground Station at ITA.

3. Ground Station PY3EB (INPE / CRS)

Located at INPE of Santa Maria in the South Regional Center for Space Research (Rio Grande do Sul) since 2012, it is a fixed station for tracking and control, manufactured by the same company of ET INPE-ITA, the ISIS®. The characteristics of this station belong to the first generation stations for small satellites tha ISIS® designed, the biggest difference is that it uses as analog radio transceiver one instead of using SDR technology, however, the other subsystems of the INPE-CRS station are similar in the INPE-ITA station design. In Figure 4. it can be seen the antenna system topologically identical to station in the ITA.

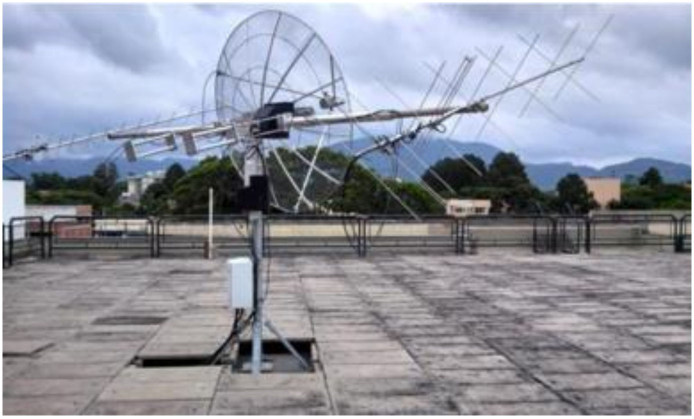

Fig. 4. INPE Antenna system of – CRS Ground Station. [10]

4. Ribras (Rede Integrada Brasileira de Rastreamento de Satelites)

The Brazilian Network Integrated Satellites Tracking (RIBRAS) is a Federal university project to Satellite Tracking. Initially RIBRAS shall consist of the Federal Institutes located at the centers of circles, see Figure 5.

The diameter of the circles is around 200 km high with sight elevation from 12 degrees. The main objetive of this project is to suppport the QB50[5] operations, the IFF and the IFMT (Cuiabá) will be the master and sub-master of orchestration and management of communications. An advantage of this

[5] The QB50 mission will demonstrate the possibility of launching a network of 50 CubeSats built by Universities Teams all over the world as a primary payload on a low-cost launch vehicle to perform first-class science in the largely unexplored lower thermosphere. For more details: https://www.qb50.eu/

project is its way of communication, all ground stations will be linked with each other via the Internet. Currently the network is only a project idea, and it is not available.

Fig. 5. Potential ground station of RIBRAS. [11]

How Systems Engineering may Contribute?

Systems Engineering is an interdisciplinary collaborative approach to derive, to evolve and to verify a balanced life cycle system solution that satisfies the stakeholder expectations. Systems engineering makes possible the realization of high complexity systems, i.e., systems that are composed of a great number of elements, connections and interfaces.[12]

The purpose of Systems Engineering is to optimize cost, performance, schedules, infrastructure, training, logistics, testing procedures, installations, manufacturing, operation, maintenance and disposal of product or system, i.e., make in advance of its development the analysis of the entire system life cycle. This is accomplished by identifying the problem generated by the need, recreating their life cycle through diagrams, maps, charts, graphs, and simulations, through which generate requirements for addressing the design of the physical and functional solution. Systems Engineering is not project management, but helps in managing.

According to Systems Engineering, it is needed to identify upfront the system of interest, where a system is defined as a combination of interacting elements organized to achieve one or more stated purposes. In this way, the system is a set of parts interacting for a mission, generating a system function, which is the result of their parts interaction. The relations between the parts must be done in a special way, not only a structural relationship is accepted; it must be a logical, temporal, causal or sequential dynamic behavioral interaction. The complete systems engineering process covers some tasks to generate a space system, this includes: (1) define the system, (2) investigate alternatives, (3) model the system, (4) integrate the system, (5) launch the system, (6) assess performance and, (7) make a re-validation.

This paper briefly covers the first three tasks to develop the reference process, and aims to apply theoretical foundations of Systems Engineering mentioned above to develop a ground station architecture for small satellites.

Ground Station Architecture Development Reference Process

For the development of the reference process the first step to know the system of interest is to identify the conventional ground station operations, worth-mentioning that the ground station is part of a space mission operational concept. The operational concept of a traditional space mission can be observed in Figure 6.

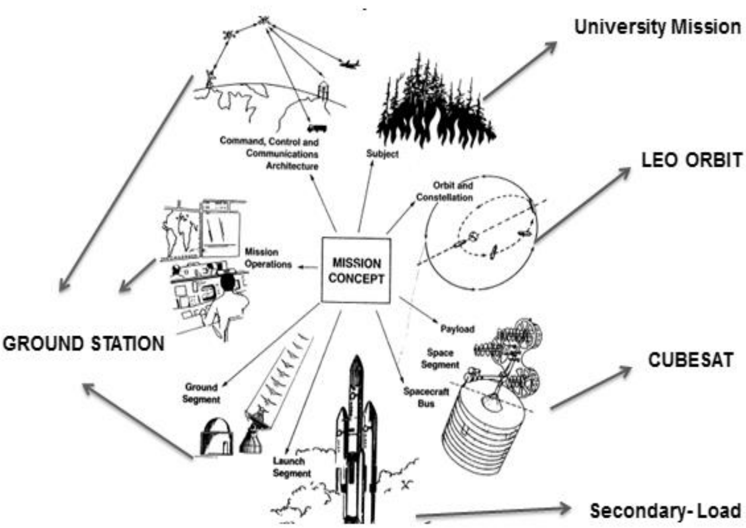

Fig. 6. A traditional Cubesat mission concept, adapted from [13].

With regards to ground stations, NASA [14] states that the small satellites use a variety of architectures of ground systems, including legacy systems with

hierarchical topology. The relevant factor for ground systems is the cost of infrastructure and personnel. Thus to reduce these costs, it is common in the ground stations of small satellites mix or package the conventional control centers and ground stations tracking in a single unit and a single geographic location. These ground stations are controlled and communicate with the satellite in the radio frequency bands (mostly allocated in the amateur service).
To accomplish the functions (send telecommands, receive telemetry, perform satellite tracking and process data from the Cubesat) having only one ground station generally is enough, but this station must meet certain special characteristics to work effectively to the ground segment.

The systems Engineering process is based on the current process of the Systems Concurrent engineering Laboratory (LSIS) at the Laboratory of integration and testing (LIT). This process is open to apply in any system and project to be resolved in the laboratory, but the process in this case will be very wide and there are shared stages with the process used to develop the space segment. Therefore, it was customized specifically to the developers needs and the results of application could improve the development of the whole project, it means, the space mission using Small Satellites.

The typically 'V' model of Systems Engineering is shown Figure 7, where it starts by defining the problem and goes up to deploying the system, if everything is ok. However, to simplify the model to create only the idea system it was decided execute the two first stages of the model, i.e. Define Problem and Define System.

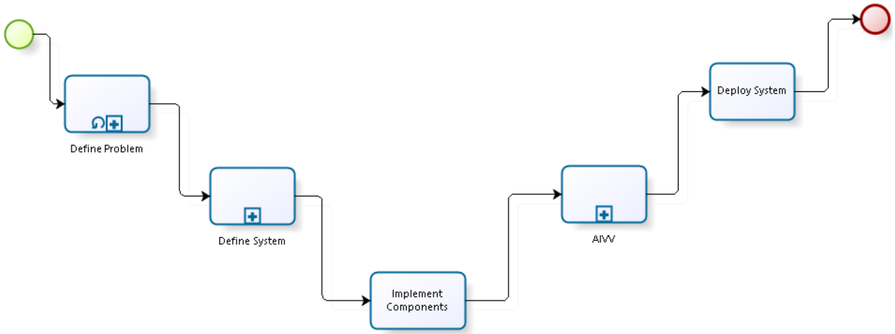

Fig. 7. The INPE-LIT Systems Concurrent engineering Laboratory (LSIS) process 'V' model.

As mentioned this process is very long, but it was decided just take in account the two first stages, explained below.

1. ***Define the Problem***:

The problem definition is one of the most important stages of the process, from here all needs, expectations, and request or demands should be taken into account to reach the system. The first stage of the System engineering consists basically of the needs statement taken according each stakeholder, it means this stage will define the system idea and the real need, and it should be done the identification of stakeholders and requirements elicitation through iterative meetings, generation of a series of goals and mission objectives. After this, it is necessary to establish the effectiveness measures to create mechanisms for system validation by the Stakeholder, and acceptance criteria to certificate the final product, depending on the particular operating environment. This stage is finally concluded by generating the concept operations, which shows the system behavior into their operational work, the Figure 8 shows the iterations and the current processes occurring in the problem definition.

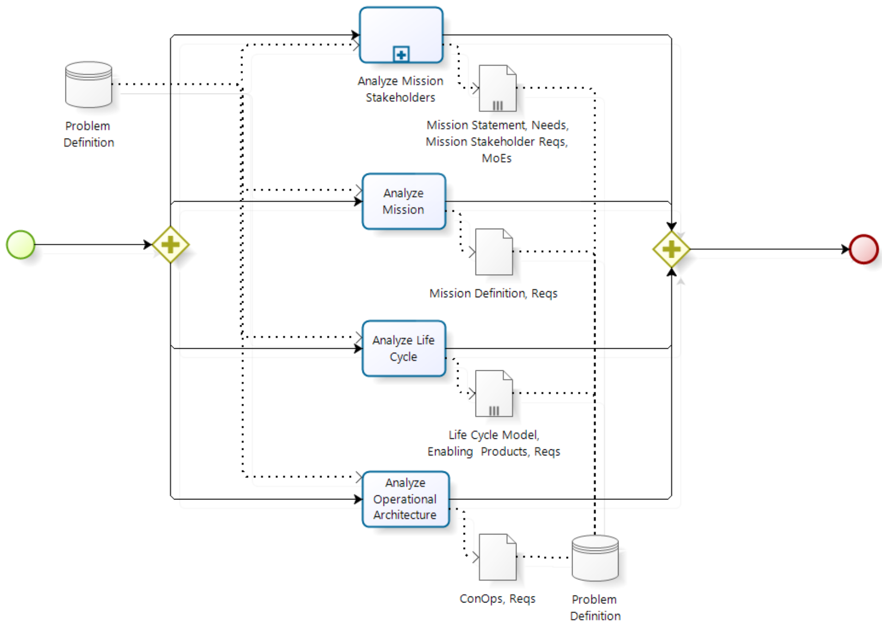

Fig. 8. The process of "Define problem"

2. *Define the System*

This phase deals with qualitative and quantitative analysis of requirements documents obtained by the results of each of the sub-stages of mission analysis, therefore this stage feeds on the problem definition. For context reasons, a requirement is a statement that identifies a capacity, physical characteristics or quality factors that limit the needs of the product or process for which a solution a solution is pursued. As shown in the Figure 9, the objective of this macro-phase, is getting to the definition of the system design, using all tools developed in the last stages.

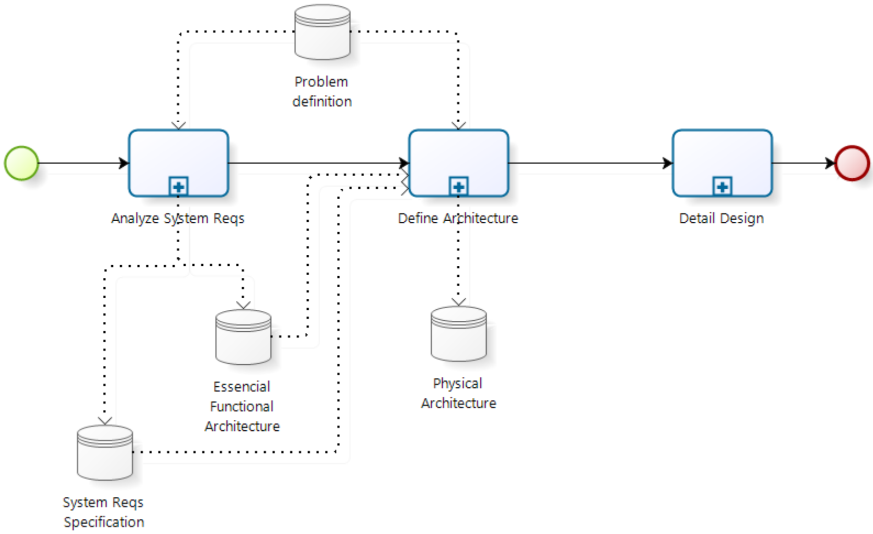

Fig. 9. The process of "Define System".

The system engineering work in this paper stops at this point here, however there are many more tools and steps that were not covered for this work like risk analysis and detailed design. This approach will be the beginning for the realization of ground stations for CubeSat. However, the reference process does not end here, in importance level the next stage is very significant to satisfy the principal need in the Brazilian cubesat community. The fredoom of the companies. Thus until have complete the detail design, the developer is plunged into a difficult decision which is the definition of the system components, thus, at this stage, the effort of the systems engineering are focused. As shown in the figure 10. This reference process is focused in the final solution taking into account all requirements and constrains to for having the best selection of elements, which constitute the system, call Develop system.

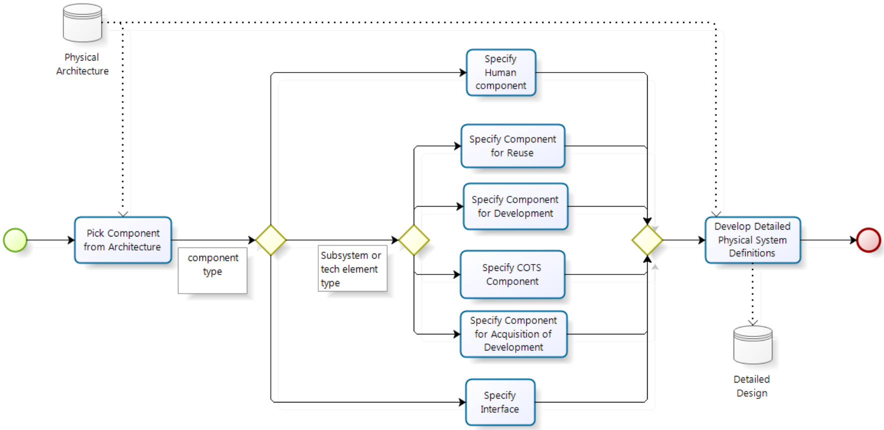

Fig. 10. The process of "Develop System"

There are two ways to constitute a ground station for CubeSat, the first one, is applicable when some universities have a project where create a ground station is a requirement, and the second one, if the ground station is just for tracking outside of any project. Thus in this way, the reference process could have some help, because many macro phases are similar, and creating two systems at the same time could improve the time and the performance of the whole system. But is mandatory for the project have two different teams, and each one converge in the same point. The Figure 11, shows the reference process designed for the AESP-14, and the peripheral stages could be using ofr both.

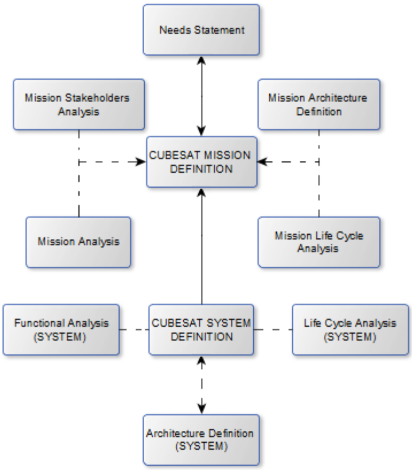

Fig. 11. A reference process used for the AESP-14 CubeSat design.

Application of the Suggested Reference Process

The reason why the reference process has validity is the number of projects concerning the application Pico and Nano satellites, as mentioned in the introduction, currently the number of projects in Latin America surpasses 20 small satellites. In order to establish a standard ground station to tracking and control the CubeSats in Brazil, were detailed parameters of designs and CubeSats that has been made in the country. From those 20 projects mentioned by 2015, five of these projects correspond to projects developed in Brazil, see Table 1.

Satellite	NanosatC-BR1	AESP-14	SERPENS-SA	SERPENS-SB	TANCREDO1	ITASAT
Units	1U	1U	1.5U	1.5U	1	6
Frequency Up (Mhz)	435.131	145.800	145.980	145.980	437.500	145.800
Frequency Down (Mhz)	145.686	437.500	437.365	437.365	437.500	437.500
Power out (Watt)	0,2	1	0,5	0,5	0,5	0,2
Comm. Protocol	AX.25	AX.25	PUS/CSP	AX.25	AX.25	AX.25
Modulation	BPSK-AFSK	G3RUH FSK	MSK	FSK	AFSK/FM	AFSK/FM
Rate (bps)	1k2/9k6 1k	9k6	1k2/9k6	9k6	1k2	1k2

Tab. 1. Features of current Brazilian small satellites projects

Therefore it can be observed the progress in the development of such satellites and the need for compatibility not only with the satellite project, otherwise, this stations will be opened with the ability to track satellites currently orbiting, satellites that are in development, and future satellites of the whole American continent.

Four out of five Brazilian small satellites projects are CubeSat and one of them is a TubeSat type. Each project is different from another; the systems have been designed or purchased by each team, which features a range of characteristics, which should be supported by the ground station.

Some Results Attained so Far

This section presents some results concerning the functional analysis and the Physical Analysis.

1. Functional Analysis

With the application of the reference process, it can be generated the functional tree, as foreseen in Figure 12. For the ground station, the blocks describe its main function with shallow details. However, it can be seen that at this stage of system development, the entire operation of the planned ground station is already covered.

Taking the functional tree, it can be built the operational mode and state diagrams for the station, where the states are the operating characteristics of the system, and modes are the functions that run the system under these characteristics, e.g. operational status and, data acquisition mode. This kind of analysis increases system knowledge, thus it can be performed the assignment of functions to tangible components for creation of a physical system tree as shown in Figure 9.

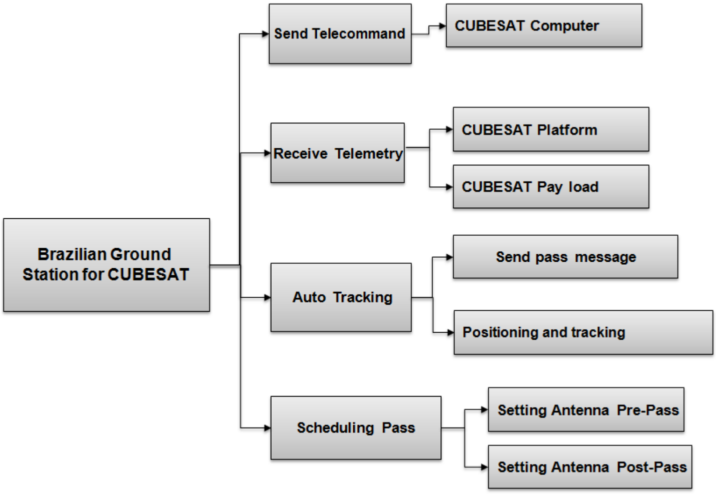

Fig. 12. Functional tree for ground stations.

2. *Physical Analysis*

Once the necessary functions were defined in the previous step for the ground station operation with its modes and states, an allocation of these functions is performed to physical elements. These linked elements, as seen in Figure 9, determine the characteristics of the system of interest and therefore, the most appropriate architectural solution to the ground station**.**

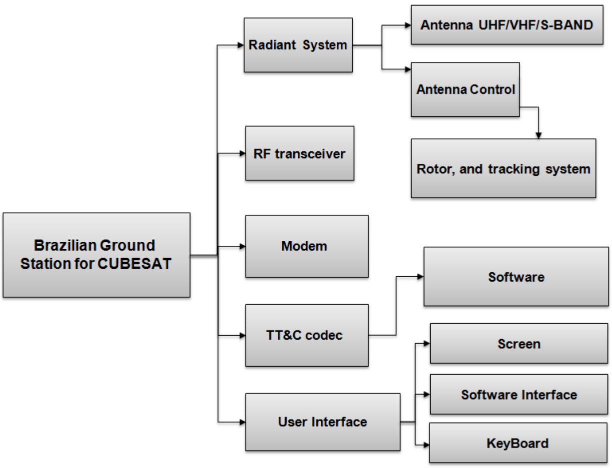

Fig. 13. Physical tree for a planned ground station.

Conclusions

This paper presented a reference process for the architecture development of ground stations used mainly for small satellites. Systems engineering has only been used here in the initial development of the ground system, as more parameters are needed to realize into a final product.

The reference process focused on engineering and management is presented graphically through modeling tools, aiming to provide a source of detailed information for development, which can be used in academia for those interested to track and receive data from the current small satellites, like CubeSat, currently in operation. The process ranges from the identification of needs of stakeholders, mission analysis and definition of requirements to the system specification and subsystems.

The system engineering reference process briefly discussed can generate mechanisms to know what the functional and physical architecture of the ground station might be. This creates a model for later use in the selection of the detailed physical design solution.

The freedom of concept mentioned in this paper clarifies the need to make research also in the Cubesat ground segment. This project wants to promote initiatives in the educational community to invest more in this segment since Brazil and some Latin American countries have not created their own solutions yet and a good part of their ground stations tend to be bought so far. The next steps of this work will be dedicated into establishing a tangible solution.

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