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Cubesat Constellation
Astrea

Report

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Satellite design

1.0.1 Structure and mechanics

The design and operation of a CubeSat is a complex process that must be completed keeping in mind the huge differences between all subsystems as well as the role they will play during the lifetime of the mission. And since these systems will operate in space, they have to be prepared and certified to withstand extreme temperature and radiation conditions.

The satellite used by Astrea must have high compatibility between all the systems to avoid potential problems and has to be tested (either all the systems together or one by one). Their correct functioning has to be ensured, especially the critical systems such as the solar arrays, batteries and antennas should be fully operational for at least four years.

1.0.1.1 Structure

The mission of the structure is to sustain and protect all the electronic devices carried by the satellite. In order to ensure that all the electronic and mechanical systems can be mounted upon the structure, a high compatibility between these systems is required; therefore, the structure must be very flexible regarding the arrangement of the subsystems.

The structure chosen is manufactured by **Innovative Solutions In Space (ISIS)**. Among its features it is worth mentioning that it can withstand the high range of temperature it will face in the space (from -40°C to 80°C) and it is highly compatible; almost every physical system used can be placed within the structure or on its faces (such as the antennas or the deployable solar arrays). Finally, the mass of the structure is relatively low, and given that the mass of the other subsystems is sometimes a drawback, it is plus point.

1.0.1.2 Thermal protection

The CubeSat is vulnerable to suffer extreme temperatures while operating in space, both below zero and above zero. The thermal protection system consists of a set of layers (MLI) made of insulating materials and it aims to protect the CubeSat from potential thermal shocks. The satellite must remain within an optimal range of temperature, despite of the variation of the external temperature, in order to work properly. Furthermore, the thermal protection system should also dissipate the heat produced by the other systems.

Dunmore Aerospace has been chosen to provide us its MLI product. The product, **Dunmore Aerospace Satkit**, has been designed for small satellites operating in LEO and it will provide the CubeSat with the protection required during operation.

1.0.1.3 Options chosen for the structure and thermal protection

The options chosen are presented in the table 1.0.1.

System	Brand and model	Price per unit (€)	N. of units
3U Structure	ISIS	3900	1
Thermal Protection	Dunmore Satkit	1000	1

Table 1.0.1: Options chosen for the structure and thermal protection

1.0.2 Electrical Power System

The Electrical Power System (EPS) of the satellite must provide and manage the energy generated efficiently in order to have all the systems operating under typical conditions during the lifetime of the mission. The role of this system is to control and distribute a continuous power to the Cubesat, to protect the satellite against electrical bus failiures and to monitor and communicate the status of the EPS to the on-board computer. The EPS of the Cubesat is, probably, the most fundamental requirement of the satellite, since its failure would result in a mission failure.

1.0.2.1 Estimation of the power required

To select the adequate electrical power systems it is essential that the power consumed by the CubeSat is known *a priori*. Thus, to select the solar arrays and the batteries, as well as the power management system, an estimation of the power consumed has to be made.

The total power required is 52W and it has been estimated considering that all the subsystems are working under typical working conditions.

1.0.2.2 Solar arrays

Given that the space of a 3U CubeSat is very limited, the primary source of electrical power has to be photovoltaic cells. The photovoltaic cells will collect and convert the energy of the sun into electrical energy and they have to be fully efficient for at least four years (this is: it has to be ensured that the missions does not run out of power for at least four years).

Every cubesat will come with at least 4 deployable solar panels (manufactured by **EXA-Agencia Espacial Civil Ecuatoriana** providing it with 67.2W of power, approximately, to supply peak demands. Note that these 4 deployable solar panels are a basic requirement. If more space is available on the faces of the satellite, additional panels can be placed providing extra power.

1.0.2.3 Power management system

The role of the power management system is to distribute the power and supply the energy to the different systems used in the CubeSat. Since these systems have different power and energy needs, the power management system has to be highly compatible and must have a high enough number of buses to supply the different voltage and intensity required to the systems.

The selected option for the mission is the **NanoPower P60** by **Gomspace**, a high-power EPS for small satellites that comes with 1 motherboard, 1 ACU module (Array Conditioning Unit) and 1 PDU (Power Distribution Unit), allowing multiple configurations in just one motherboard and saving a lot of space.

1.0.2.4 Batteries

The role of the batteries is to provide the subsystems of the satellite with the power needed when the solar arrays are working less efficiently or not properly. Astrea is looking for decent capacity batteries that provide a *slightly higher* than typical energy and power supply, since all the systems will not usually operate under peak conditions.

Astrea has chosen the **BA01/D** batteries manufactured by **EXA-Agencia Espacial Civil Ecuatoriana**. The CubeSat will have two of these batteries, with a total capacity of 28800mAh or 106.4Wh.

Through the lifetime of the mission, the solar arrays will face an important unfavorable condition; in the worst case scenario, the satellite will be in the dark during half of the period of the orbit. So, it is clear that the batteries are a critical system. If the satellite was in the dark during half of the period of the orbit, the estimated energy that it would need would be 50Wh. Thereby, the capacity of the batteries is more than enough to supply the energy required in the worst case scenario. Furthermore, they will supply energy when the energy demand of the CubeSat is higher than the energy collected by the solar cells. And logically, they will store the energy collected by the solar arrays when the energy demand of the systems is lower than the energy collected.

1.0.2.5 Options chosen for the EPS

Finally, the options chosen are presented in the table 1.0.2.

System	Brand and model	Price per unit (€)	N. of units
Solar arrays	EXA	17000	4
Additional solar arrays	-	4000-12000	depends
Batteries	EXA	6300	2
Power Management	Gomspace NanoPower P60	16000	1

Table 1.0.2: Options studied for the Electric Power System

1.0.3 Propulsion Systems

The propulsion system is an important part of the satellite given the needs of the satellite to perform different maneuvers, such as reach the desired orbit after it has been deployed from the rocket, and to maintain the orbit and avoid falling to the Earth. The main parameters that have to be consider are thrust, total specific impulse, power required, weight of the propulsion system and its volume, since the size and weight of the CubeSat are very restrictive.

At the moment, the most used and modern thrusters for small satellites are: ionic, pulsed plasma, electrothermal and green monopropellant thrusters. An important aspect to consider is that the goal is to reduce the mass required although this will imply smaller accelerations than conventional propulsion systems.

The **BGT-X5**, a green monopropellant propulsion system, has been chosen as the thruster for the CubeSat. With the high thrust and delta V that BGT-X5 provides, the CubeSat will be able to carry out the necessary actions to keep the satellite in orbit, to relocate the satellite or to change its orbit.

1.0.3.1 Propulsion Systems

The option chosen is presented in the table below 1.0.3.

System	Brand and model	Price per unit (€)
Propulsion	Busek BGT-X5	50000)

Table 1.0.3: Option chosen for the propulsion system

1.0.4 Attitude and Orbital Control Systems

Attitude and orbital control subsystem is needed to enable the satellite to keep a specific position within its orbit and to control the antennas in order to remain oriented to assigned area, because the satellite tends to change its orientation due to torque. The AOCS receives telecommands from the central computer and acquires measurements (satellite attitude and orbital position) from sensors. We will also refer to the attitude control as ADACS (Attitude Determination and Attitude control system).

Attitude control for CubeSats relies on miniaturizing technology without significant performance degradation. Tumbling typically occurs as soon as a CubeSat is deployed, due to asymmetric deployment forces and bumping with other CubeSats. Some CubeSats operate normally while tumbling, but those that require pointing in a certain direction or cannot operate safely while spinning, must be detumbled. Systems that perform attitude determination and control include **reaction wheels**, **magnetorquers**, **thrusters**, **star trackers**, **Sun sensors**, **Earth sensors**, **angular rate sensors**, and **GPS receivers**

and antennas. Combinations of these systems are typically seen in order to take each method's advantages and mitigate their shortcomings. (*wikipedia extract*, [?]).

Pointing in a specific direction is necessary for Earth observation, orbital maneuvers, maximizing solar power, and some scientific instruments. Directional pointing accuracy can be achieved by sensing Earth and its horizon, the Sun, or specific stars. Determination of a CubeSat's location can be done through the use of on-board GPS, which is relatively expensive for a CubeSat, or by relaying radar tracking data to the craft from Earth-based tracking systems (*wikipedia extract*, [?]).

1.0.4.1 Orbital Control

Orbital control will be achieved as a combination of two systems. ADCS will orient the thrust, this thrust will be given by the propulsion system and all the operation will be controlled on the On-Board Computer. Principally, the orbit control will be necessary to mitigate orbital debris effect on every satellite.

1.0.4.2 Option chosen for the Attitude and Orbital Control System

Decision Taking into account that we need: low power consumption, low, weight and size, high pointing accuracy and really versatile systems that can integrate multiple subsystems; **CUBE ADCS** is chosen. It has the lowest mass and power consumption, it also offers a higher attitude determination systems and integrates also and On-Board Computer (OBC). **PONER ANEXO** http://www.cubespace.co.za/cubecomputer

1.0.5 Payload

Aim AstreaSAT payload, needs to provide a radio link to the client satellites, for real time data relay with no less than 25MB/s of data rate. For achieving its porpoise, the payload will consist on a pack of arrays of antennas and data handling computers.

AstreaSAT payload will have to have three types of radio links for transmitting in every condition the data received from the clients:

- **Space to Ground link**: Connection between satellite and Ground Station when it is possible.

- **Inter-satellite Space to Space link**: Communication between Astrea satellites for data relay, looking for the nearest satellite with Ground Station link available, to transmit the data.
- **Client Space to Space link**: Communication between client and Astrea satellites.

The radio frequencies that we can use to establish the previous described links are regulated in [49] by frequency, bandwidth and type of communication . So, for the **Space to Ground link** we can use frequencies from **70MHz** to **240GHz**; for **Inter-satellite Space to Space link** plus data relay type of communication, frequencies are **2-2.4GHz**, **4-4,4GHz** and **22-240GHz**. Finally, **Client Space to Space link**, they exist to cases; on the one hand, the client points towards the Earth like a standard satellite, we capture its signal and make the data relay, since it is like a Space to Ground communication and also like a inter-satellite communication, we can combine the two previous restrictions. On the other hand, if the client satellite is below our constellation, we only had inter-satellite communication, therefore **Inter-satellite Space to Space link** rules are applied.

Finally, the Payload will consist on a combination of antennas, transceivers and data handling systems which will combine to create a data relay module.

1.0.5.1 Antennas

The antennas are essential in this mission, since their role is to transmit and receive the data from other satellites as well as the ground stations. In order to provide fast and reliable communication, several options have been studied and information about their main parameters is presented below.
It has to be kept in mind that the mass of the antennas should be as low as possible given that there are already a lot of subsystems in the CubeSat and the mass limitation is about 4kg. Additionally, the power consumption has to be kept as low as possible given the limitations regarding to the power supply of the CubeSat. The antennas must be certified to work under space conditions (high temperature range and radiation protection shield). Preliminary, after a first satellite preliminary design, seems that patch and turnstile antennas will cover the needs of AstreaSAT.

1.0.5.1.1 Patch antenna

A **patch antenna** is a type of radio antenna with a low profile, which can be mounted on a flat surface, It consists of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called a ground plane. They are the original type of microstrip antenna described by Howell in 1972. [?, wikipedia]

1.0.5.1.2 Turnstile antenna

A **turnstile antenna**, or crossed-dipole antenna, is a radio antenna consisting of a set of two identical dipole antennas mounted at right angles to each other and fed in phase quadrature; the two currents applied to the dipoles are 90^o out of phase.

1.0.5.2 Antenna selection

After a market study, the best two antennas to add in the CubeSat are the patch antenna AntDevCov and the turnstile antenna ANT430 Gomspace. The number of units of each antenna are 4 and 2 respectively. The 4 patch antennas will be placed on each side face of the CubeSat and they will occupy a 1U face. The 2 turnstile antennas will be placed on the upper and lower face of the CubeSat and, as they do not occupy space, other systems such as a solar panel or the thruster can be placed on those faces.

1.0.5.3 Payload Data Handling Systems

Every AstreaSAT will act as a router to transmit client data to the ground. This initial raw data, should be temporally stored into the satellite in order to process it, if necessary. Since, to down-link the data, first the satellites need to establish connection, data can not be directly retransmitted to other sources (Ground Station or satellite) as it enters to the satellite. Furthermore, non loss compression algorithms can be applied to reduce the data size load and achieve higher data transmission velocities.

To sum up, Payload Data Handling System of every AstreaSAT (PDHS) will be able to receive, process and send the client data, using the integrated transceivers (transmitter + receiver) for sending the data and the PDHS computer to process it. PDHS have a hard disk associated which will temporally store the client data.

Finally, is necessary to find the transceivers and PDHS computers compatible combination in order to achieve the specifications stated on the Project Charter.

1.0.5.3.1 Transceivers

A transceiver is a device comprising both a transmitter and a receiver that are combined and share common circuitry or a single housing. For the preliminary design, because we know that they should satisfy all the connectivity options, we are restricted to the S, K or higher bands for **Inter-satellite communication** and not restriction virtually at all for **Space to Ground** communication. Nevertheless, together with the communications department, X band is chosen as the frequency to talk to the floor because several factors: the use in

Transceivers options - Inter-satellite comm.(S band)		
Features	**NanoCom TR-600**	**SWIFT-SLX**
Band	70 - 6000 MHz	1.5 - 3.0 GHz
Bandwidth	0.2 - 56 MHz	10+ MHz
Vcc	3.3V	6 - 36V
Max. Power consumption	14W	10.8W
Dimensions	65 x 40 x 6.5 mm	86 x 86 x 25-35mm
Operational temperature range	-40°C to +85°C	-35°C to +70°C
Mass	16,4 grams	250 grams

Table 1.0.4: Main inter-satellite communication transceivers features

NanoCom TR-600 has an additional advantage, GOMspace, the supplier, offers it in combination with the NanoMind Z7000 seen in PDHS computers section. Both integrated on a board able to hold three TR-600 transceivers and one computer. The low dimensions, high bandwidth (associated to high data rates) and low mass of TR-600 versus SWIFT-SLX, makes the first, a great choice for Inter-Satellite communication.

Transceivers options - Space to Ground comm.(X band)		
Features	**SWIFT-XTS**	**ENDUROSAT**
Band	7 - 9 GHz	8.025 - 8.4 GHz
Bandwidth	10 - >100 MHz	10+ MHz
Vcc	3.3V	12V
Max. Power consumption	12W	11.5W
Dimensions	86 x 86 x 45mm	90 x 90 x 25mm
Operational temperature range	-40°C to +85°C	-35°C to +70°C
Mass	350 grams	250 grams

Table 1.0.5: Main space to ground communication transceivers features

SWIFT-XTS is pretty similar to ENDUROSAT, but presents some advantages. The higher Bandwidth, will make possible higher communication data rates. The higher mass respect to ENDUROSAT could be a problem, from the link budget analysis a decision will could be made, because the most important factor is the possibility to transmit with low losses to the ground.

1.0.5.3.2 PDHS computers

PDHS computers will process and store the clients data before the data relay is done.

PDHS computers options		
Features	**NanoMind Z7000**	**ISIS iOBC**
Operating System	Linux	FreeRTOS
Storage	4GB to 32 GB	16GB
Processor	MPCoreA9 667 MHz	ARM9 400 MHz
Vcc	3.3V	3.3V
Max. Power consumption	30W	0.55W
Dimensions	65 x 40 x 6.5mm	96 x 90 x 12.4mm
Operational temperature range	-40°C to +85°C	-25°C to +65°C
Mass	28.3 grams	94 grams

Table 1.0.6: Main PDHS computers features

The main advantage of NanoMind Z7000 over ISIS iOBC is the computing availability, because of its two 667MHz processor Z7000 can handle higher data payloads and processit at higher velocities, reducing in last term delay between communications. Also, Z7000 presents a lower mass, critical think in our mass limitation of 4kg. But the turning point is, as stated before, Z7000 comes integrated on a single board with a maximum of three NanoMind TR-600 transceivers, fact that makes it a perfect option to build a data relay module payload.

1.0.5.4 Study of the commercial available options and options chosen

A broad marked study is needed since all the options have to be considered. For this reason, and with the aim to show all the information and features of each system that has been considered in this section, the table 1.0.7 is presented below.

Brand and model	Features	Total price (€)
Antennas		

Patch antenna AntDevCo	High frequency range (L,S,C,X bands) High bandwidth High mass (120 g)	To request
ISIS monopole deployable antenna	Low frequency range (10MHz) Higher mass than ANT430 (100 g) Deployable Not occupy space	17000
Turnstile antenna ANT340 Gomspace	Low frequency range (400-480 MHz) Low mass (30 g) Deployable Not occupy space	9500
Transceiver inter-satellite		
NanoCom TR-600	SDR including S band High Bandwith Low mass and dimensions Integrated with other PDHS	8545
SWIFT-SLX	Low power consumption High mass and dimensions Narrow bandwidth	7800
Transceiver space to ground		
SWIFT-XTS	High bandwith High mass Standard dimensions	TO BE REQUEST
ENDUROSAT	Narrow bandwidth Lower mass Standard size	22500
PDHS Computers		
NanoMind Z7000	LinuxOS High processing velocity High power consumption Low mass and dimensions	TO BE REQUEST
ISIS iOBC	FreeRTOS OS Less computing velocity High dimensions and mass	9400

Table 1.0.7: Options studied for the payload

Finally, with the aim to clarify all the information of this section, the chosen systems and components are presented in the table 1.0.8.

System	Brand and model	Price per unit (€)	N. of units
Antenna	Patch antenna AntDevCo	TO REQUEST!	8
Transceiver	NanoCom TR-600	TO REQUEST!	3
Transceiver	SWIFT-XTS	TO REQUEST!	1
PDHS	NanoMind Z7000	TO REQUEST!	1

Table 1.0.8: Options chosen for the payload

1.0.6 Communication module

The telemetry subsystem analyses the information of the ground station and other sensors of the satellite in order to monitor the on-board conditions. With this system, the CubeSat is able to transmit the status of the on-board systems to the ground station.

The command and control subsystem (TT&C) allows the ground station to control the satellite.

Every Astrea satellite (AstreaSAT) of the constellation, will need to report its operating status to the ground and receive commands from the ground. TT&C operations will usually be performed when the satellite flights over the coverage of the constellation ground station, but since the satellites are interconnected, there is the possibility to perform this operations via data relay links between satellites. As a collaboration with the communications department, S band frequency is chosen for TT&C operations, since there is no need for high data rates, the lower band will significantly reduce the power consumption.

Communication to the ground will be perform with a NanoCom TR-600 transceiver module attached to AntDevCo Patch antenna, both configured for S band frequency communication.

1.0.7 Link Budget

Astrea constellation main satellite must be able to stablish three different telecommunications link:

- Space to Ground link for payload and TT&C data.
- Space to Space link between Astrea satellites.

- Space to Space link between client and Astrea satellites.

1.0.7.1 Link Budget Calculation

Methodology From the expected requirements fixed on the Project Charter, general radio systems parameters will computed, in order to have a reference to look for the best communications system on board the Astrea satellites. As background, general losses parameters had been calculated on previous sections.

The most important concern on AstreaSAT link Budget is how far every satellite can emit on the desired frequencies. This is a key factor to know the utility of the modules selected. At least, Project Charter communication requirements must be accomplish.

To verify communication system chosen options, let's start calculating the minim required sensitivity for receiving strong enough signal. With this value, it is possible to know how far the satellite can listen to information.

Applying equation **??** and equation **??** on a simple Matlab routine:

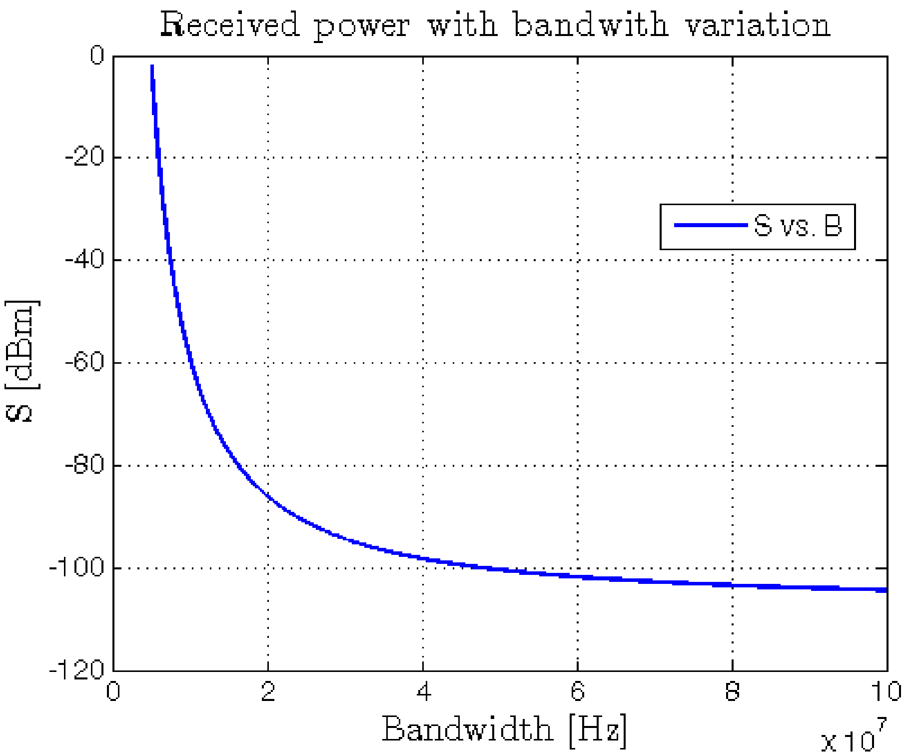

Figure 1.0.1: Sensibility change along Bandwidth variation

As bandwidth increments, Sensitivity decrements, meaning that we need higher powered receivers in order to sense high bandwidth communications.

Range calculation: To know how far the satellite can be received or listen to, Friis equation 1.0.1 will be applied.

$$P_r = P_t + G_t + G_r - FSL - L_{abs} - L_{aml} - L_{point} \tag{1.0.1}$$

$$\begin{aligned} P_r &: \text{Received power} \\ P_t &: \text{Transmitted power} \\ G_t &: \text{Transmitter antenna gain} \\ G_r &: \text{Receiver antenna gain} \\ L_{prop} &: \text{All kind of losses} \\ L_{prop} &= FSL - L_{abs} - L_{aml} - L_{point} \end{aligned}$$

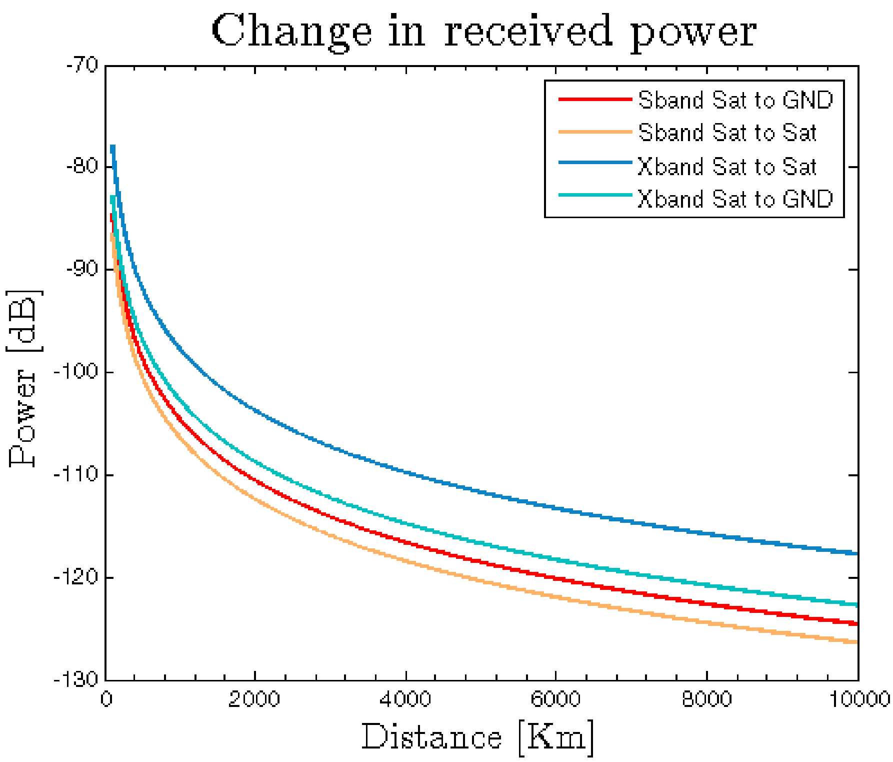

Figure 1.0.2: Received power with distance variation

S band range: On Fig.1.0.2 earth atmosphere and multiple losses (described previously) affect to the received power on ground. Despite all, ground station have powerful antennas that mitigate the losses effect. Therefore, because of the low gain of the antennas between satellites, the link is weaker.

X band range: In this case, X band, because its high frequency is more affected by atmospheric losses. Is it possible to appreciate it on Fig.1.0.2. Link between satellites is stronger that the one with the ground. Finally remark a fact, despite higher frequencies should have weaker links, in this case, the high antenna gains for X band, confer stronger links to the X band.

In order to use satellite communications, will be necessary to use Fig.**??** and 1.0.2. From 1.0.2, given a determinate altitude a power sensibility can be extract. Then, on **??**, taking the previous sensibility calculated, a Bandwidth for operation can be stated. The procedure works on both sites.

1.1 Budget

System	Cost/unit (€)	Total cost (€)	N. of units
STRUCTURE AND MECHANICS			
Structure	3900	3900	1
Thermal protection	1000	1000	1
Total		4900	
ELECTRIC POWER SYSTEM			
Solar arrays	17000	68000	4
Batteries	6300	12600	2
Power management	16000	16000	1
Total		96600	
PAYLOAD			
Patch antenna	18000 1st unit 7000 others	67000	8
Transceiver inter-satellite	8545	25635	3
Transceiver space to ground	5500	5500	1
Data handling system	5000	5000	1
Antenna Deployable	3000	3000	1
Variable expenses	4000	4000	1
Total		110135	
AOCDS			
Thruster	1350	50000	1
ADACS	280	15000	1
Total		65000	
TOTAL		276635	
TOTAL ESTIMATION		297000	
+Fixed cost	(includes all CubeSats)	150000	

The difference between the total cost and the total estimation is due to the fact that every satellite has to go through a process to be ready for operation. This is, the CubeSat has to be assembled and has to be tested as well to ensure that all the systems are working properly. Thus, an estimation of the costs related with this operation has to be made.

The fixed cost for assembling the satellites will be 150000€(cost of renting the building, the electricity, ...) and an additional cost 20000€$/unit$, which will include the wages of the people assembling and testing the satellite and also other variable costs that may appear in the process, is added to every satellite. Furthermore, this extra 20000€includes the costs of transport to launch site.

Several options have been studied for assembling and testing the satellite, and the option chosen is *OpenCosmos*. Astrea is committed to encourage the growth of the local economy and we are sure that *OpenCosmos* would be a perfect partner for the mission. They provide companies and individuals with simple and affordable access to space offering integration and testing services.

1.2 Astrea satellite Final Configuration

System	Weight/unit (g)	Sizes (mm)	N. of units
STRUCTURE AND MECHANICS			
Structure	304.3	100 x 100 x 300	1
Thermal protection	38	Covers all	1
Total	342.3		
ELECTRIC POWER SYSTEM			
Solar arrays	175	98 x 83 x 8.50	4
Batteries	155	90 x 63 x 12.02	2
Power management	126	92.0 x 88.9 x 20.5	1
Total	1136		
PAYLOAD			
Patch antenna	30	90 x 90 x4.35	8
Transceiver inter-satellite	16.4	65 x 40 x 6.5	3
Transceiver space to ground	101.5	86 x 86 x 45	1
Data handling system	28.3	65 x 40 x 6.5	1
Antenna Deployable	83	100 x 83 x 6.5	1
Variable	150	-	1
Total	652		
AOCDS			
Thruster	1350	90 x 90 x 95	1
ADACS	506	90 x 90 x 58	1
Total	1856		
TOTAL ESTIMATION	**3986.3**		

Chapter 2

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