astrea

ESEIAAT

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UNIVERSITAT POLITÈCNICA DE CATALUNYA

Cubesat Constellation
Astrea

Report

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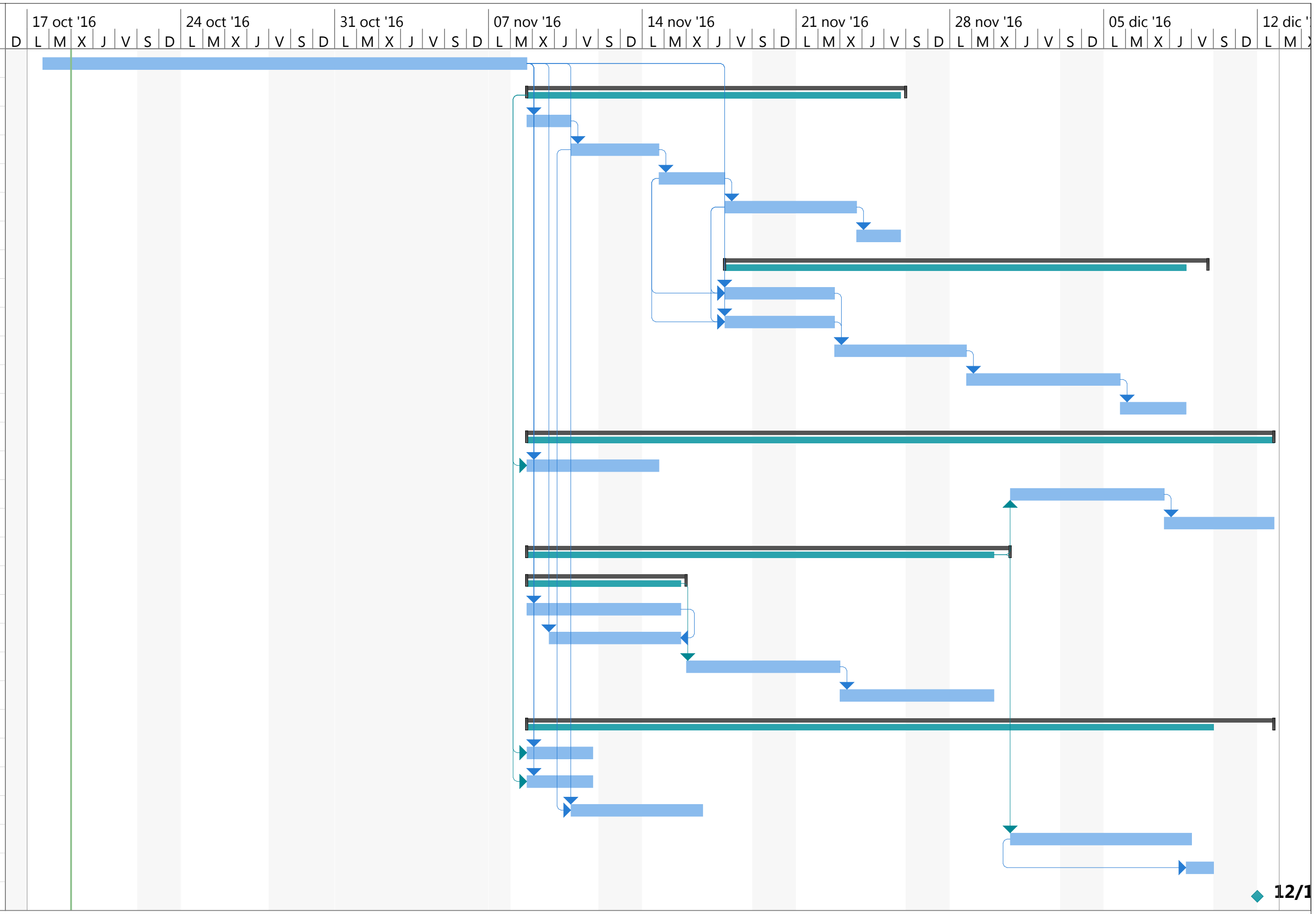
Table 1.1: Prelations and Time

2 Gantt of the section

Id	EDT	Nombre de tarea	Duración	Comienzo	Fin
1	1	PRELIMIARY DESIGN	28 horas	lun 17/10/16	mar 08/11/16
2	**2**	**Structure and mechanics**	**5 días**	**mar 08/11/16**	**vie 25/11/16**
3	2.1	Structure	6 horas	mar 08/11/16	jue 10/11/16
4	2.2	Deployments	6 horas	jue 10/11/16	lun 14/11/16
5	2.3	Thermal protection	9 horas	lun 14/11/16	jue 17/11/16
6	2.4	Comercial availability	12 horas	jue 17/11/16	mié 23/11/16
7	2.5	Choose option	6 horas	mié 23/11/16	vie 25/11/16
8	**3**	**Electrical Power System**	**6 días**	**jue 17/11/16**	**vie 09/12/16**
9	3.1	Solar arrays	9 horas	jue 17/11/16	mar 22/11/16
10	3.2	Batteries	9 horas	jue 17/11/16	mar 22/11/16
11	3.3	Power management	12 horas	mar 22/11/16	lun 28/11/16
12	3.4	Comercial availability	15 horas	lun 28/11/16	lun 05/12/16
13	3.5	Choose option	9 horas	lun 05/12/16	jue 08/12/16
14	**4**	**Propulsion Systems**	**9 días**	**mar 08/11/16**	**lun 12/12/16**
15	4.1	Requirements	12 horas	mar 08/11/16	lun 14/11/16
16	4.2	Comercial availability	15 horas	mié 30/11/16	mié 07/12/16
17	4.3	Choose option	9 horas	mié 07/12/16	lun 12/12/16
18	**5**	**Payload**	**6 días**	**mar 08/11/16**	**mié 30/11/16**
19	**5.1**	**Communication systems**	**2 días**	**mar 08/11/16**	**mar 15/11/16**
20	5.1.1	Data Handling Systems	15 horas	mar 08/11/16	mar 15/11/16
21	5.1.2	Antenna	12 horas	mié 09/11/16	mar 15/11/16
22	5.2	Comercial availability	15 horas	mar 15/11/16	mar 22/11/16
23	5.3	Choose option	15 horas	mar 22/11/16	mar 29/11/16
24	**6**	**AOCS**	**9 días**	**mar 08/11/16**	**lun 12/12/16**
25	6.1	Attitude Determination	9 horas	mar 08/11/16	vie 11/11/16
26	6.2	Attitude control	9 horas	mar 08/11/16	vie 11/11/16
27	6.3	Orbital Control	12 horas	jue 10/11/16	mié 16/11/16
28	6.4	Comercial availability	20 horas	mié 30/11/16	jue 08/12/16
29	6.5	Choose option	4 horas	jue 08/12/16	vie 09/12/16
30		FINISH	0 horas	lun 12/12/16	lun 12/12/16



Proyecto: planning
Fecha: mié 19/10/16

Tarea	Resumen del proyecto	Tarea manual	solo el comienzo	Fecha límite
División	Tarea inactiva	solo duración	solo fin	Progreso
Hito	Hito inactivo	Informe de resumen manual	Tareas externas	Progreso manual
Resumen	Resumen inactivo	Resumen manual	Hito externo	

3 Satellite design

3.1 Structure and mechanics

The design and operation of a CubeSat is a complex process that must be completed keeping in mind the different subsystems it has as well as their role within the satellite. Additionally, since these systems will operate in space, they have to be prepared to withstand the extreme conditions, and be certified to work properly under them.

The satellite used by Astrea must have high compatibility between all the systems to avoid potential problems during operation and has to be tested (either all the systems together or one by one) and ensure their correct functioning.

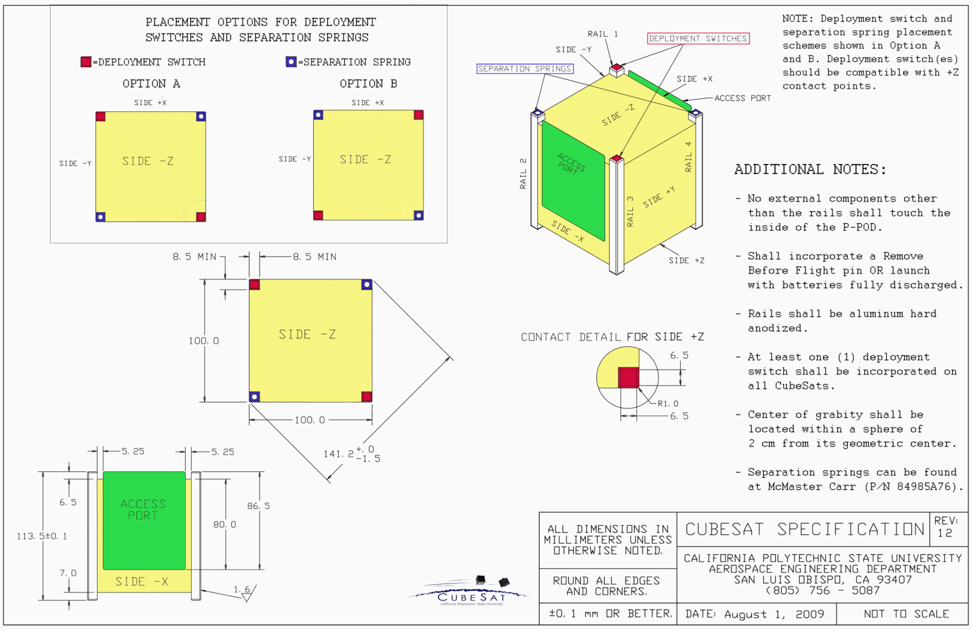


Figure 3.1: Dimensions of a 1U CubeSat [?]

3.1.1 Structure

The mission of the structure is to sustain and protect all the electronic devices carried by the satellite in order to fulfill the mission requirements. In order to ensure that all the electronic and mechanic systems can be mounted upon the structure, a high compatibility between these systems is required.

The structure used will be provided 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 (-40ºC to 80ºC) and it is highly compatible with almost every physical system that will be used. Additionally, it is a low mass structure (304.3g) and it can support different configurations within it.

Since the configuration within the CubeSat will not be as common as other configuration options within of current operational CubeSats because the mission of the project is to relay fast and reliable communication with the ground station and the other satellites, it is a really important point that the structure is highly flexible regarding the arrangement of the subsystems that it will carry.

3.1.2 Thermal protection

The thermal protection system consists of various insulating materials that aim 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. Operating in space, the CubeSat is vulnerable to suffer extreme temperatures, both below zero and above zero, and thermal protection must guarantee that all subsystems are protected. Furthermore, the thermal protection system should also dissipate the heat produced by the other systems.

Thermal protection system is needed to mantain the temperature of the CubeSat inside the range operational temperatures of the differents subsystems. In space, the CubeSat can suffer extreme temperatures, both below zero and above zero, and thermal protection must guarantee the correct operation of all devices. Furthermore, thermal protection remove heat caused by other systems.

Currently, the most used element as thermal protection in the aerospace industry is the multilayer insulation (MLI), a set of multiple thin insulation layers. The MLI fulfills all the requirements that were previously stated and its main objective is to reduce the heat generated by radiation since the heat generated by convection or conduction does not have such a high impact on the on-board systems.

After a market study, Dunmore Aerospace company has been chosen to provide us its MLI product. Specially, the product is the Dunmore Aerospace Satkit and it is made for small satellites for low earth orbit.

3.1.3 Study of the commercial available options

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 3.1 is presented below.

Brand and model	Features	Total price (€)
Structure		
ISIS 3U structure	Low mass (304.3g) Highly compatible High temperature range	3900
Gomspace GOMX-Platform	High mass (1500g) Comes fully equipped (basic systems) High temperature range	**TO REQUEST!**
Structure		
FILL IN	**NANDO**	**TO REQUEST!**

Table 3.1: Options studied

Finally, the options chosen are presented in the table 3.2.

System	Brand and model	Price per unit (€)
3U Structure	ISIS	3900)
Thermal Protection 1	EMPTY	EMPTY

Table 3.2: Options chosen

3.2 Electrical Power System

The electric power system of the satellite must provide and manage the energy generated efficiently in order to have all the systems operating under normal conditions. The Electrical Power System of a Cubesat is, probably, the most fundamental requirement of the satellite payload, since its failure would result in the mission failure. The functions of the EPS are to control and distribute power to the Cubesat, to suppy a continuous source of electrical power for through the lifetime of the mission, to protect the satellite against bus failiures and to monitor and communicate the system status to the on-board computer. The role of the EPS is very diverse and the following subsystems have to be analyzed in detail.

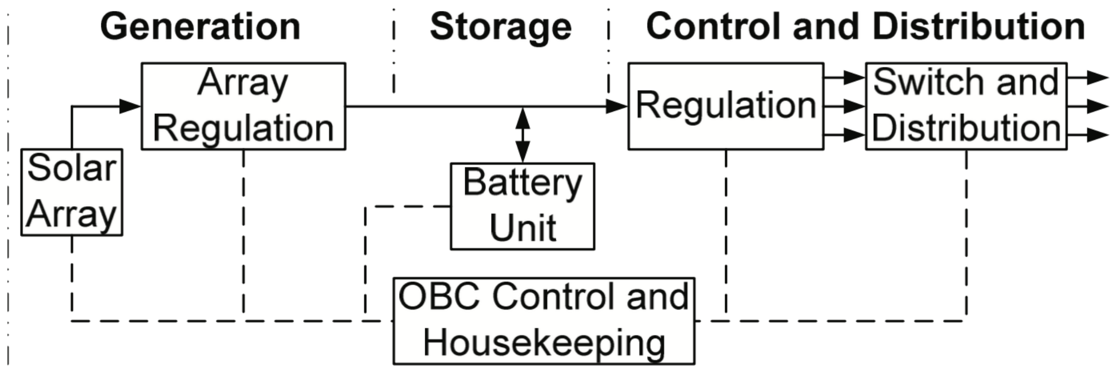


Figure 3.2: Basic schematics of the EPS [?]

3.2.1 Solar arrays

The primary source of electrical power has to be photovoltaic cells, given the size of the CubeSat. The photovoltaic cells will collect and convert the energy of the sun into electrical energy. Since they are main power source, they have to be correctly selected to prevent failure. Among the characteristics we seek for our mission, we are looking specially wheter the solar cell has a decent amount of power collection, low mass, protective radiation shield, deployment system, great temperature range and compatibility with the other systems.

The selected option for the Astrea mission will be a set deployable solar panels provided by EXA (Agencia Espacial Civil Ecuatoriana). These panels are low mass (135g each), have a protective radiation shield (NEMEA Anti Radiation Shield protects the solar panels of EM, High Gamma, X-Ray, Alfa, Beta and low neutron radiation), a very high temperature range (from -80 to 130ºC), a gentle release and deployment with artificial muscles (developed by EXA) and provide a power of 16.8W each (19.2V@0.5A).

Every cubesat will have 4 deployable solar panels providing it with 67.2W of power to supply peak demands while it is operating. Additionally, it is worth mentioning that these solar arrays are compatible with the hardwared used in each of the satellites.

3.2.2 Power management

The role of the power management systems is to distribute the power and supply the energy to the different systems used in the CubeSat.

3.2.3 Batteries

Batteries are essential for a proper mission operation. They will provide the spacecraft subsystems 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 high typical energy and power, since the subsystems will not usually operate under peak conditions.

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 time of the orbit. Thus, the batteries must store and supply the energy needed for this time.

Among all the commercial options, Astrea has chosen the *NanoPower BP4* batteries. The CubeSat will have two of these batteries, with a total capacity of 20800mAh or 77Wh. Each battery has a total of 4 cells, highly stackable and come with a temperature sensor and a heater that will automatically turn on if the temperature is worsening the whole operation of the system.

3.2.4 Study of the commercial available options

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 3.3 is presented below.

Brand and model	Features	Total price (€)
Structure		
EXA-Agencia Espacial Ecuatoriana	Total power of 67.2W (4units) Mass of 270g (p.unit) Included thermal protection At least 4 years lifetime	17000
ISIS	Total ower of 30W (4units) Mass of 150g (p.unit) No thermal protection At least 2 years lifetime	**TO REQUEST!**
Batteries		
Gomspace NanoPower BP4	Total capacity of 77Wh Automatic heat regulation Highly stackable Mass of 270g (p.unit)	**TO REQUEST!**

EXA-Agencia Espacial Ecuatoriana	Total capacity of 53.2Wh Automatic heat regulation Highly stackable Total mass of 155g	6300

Table 3.3: Options studied

Finally, the options chosen are presented in the table 3.4.

System	Brand and model	Price per unit (€)
Solar arrays	EXA-Agencia Espacial Civil Ecuatoriana	17000
Batteries	Gomspace, Nanopower BP4	**TO REQUEST!**
Power Management	Gomspace, Nanopower	**TO REQUEST!**

Table 3.4: Options studied

3.3 Payload

3.3.1 Antennas

The antennas are an essential part of the communication subsytem and their principal rike is ti transmit and receive the data. In order to provide fast and reliable communication, several options have been studied and the solution is presented on the lines below.

3.3.1.1 Patch antenna

FALTA DESCRIPCIÓ

Patch antenna	
Features	**Value**
Bands	L,S,C,X
Frequency range	1-12 GHz
Bandwidth	20 MHz
Gain	6 dBi
Polarization	Circular
Maximum power consumption	10 W
Impedance	50 Ohms
Operational temperature range	-65°C to +100°C
Mass	<250 grams

3.3.1.2 Turnstile antenna

FALTA DESCRIPCIÓ

Nando, ¿esto se puede arreglar un poco?

The frequency range is one of the most important parameters, because it must take into account satellite-satellite and satellite-earth communication. The initial requirement of the antenna frequency range is that it should be between 1-10 GHz. This is due to limitations in satellite-ground communication due to atmospheric conditions. Finding an antenna that meets this stringent requirement is very complicated, and a margin must be given to find an optimal market option.

The bandwidth is the frequency range where the highest power of the signal is found. The higher this bandwidth the better performance we will have.

The gain of an antenna is the ratio between the power density radiated in one direction and the power density that would radiate an isotropic antenna. The best option is to have a high gain.

Polarization is the orientation of the electromagnetic waves when leaving the antenna. There are three types of polarization: linear, circular and elliptical.For better perfomance, an antenna that receives and an antenna that transmits must have the same polarization. In project case, the best option is circular polarization because it is able to keep the signal constant regardless of the appearance of different problems such as movement with respect to the ground station.

The weight of the antennas should be as small as possible because the total weight of the cubesat should not exceed 4 kg. Most of the antennas of the market have a similar weight and does not cause us an extra problem when choosing the antenna of the project.

The power consumption parameter is an important requierement because most of the power is consumed by the different subsystems. The stage of greater power consumption due to the antenna corresponds to its deployment, while once it is deployed, consumption is greatly reduced. In most cases, the power required for deployment ranges from 2-10 W.

The operational temperature range is important to the correct work of the antenna, because if the antenna was in a temperature outside this range, it would not be able to perform the communication of optimal form. An habitual temperature range use to be between XXXX

After a market study, the antennas chosen to perform the communication have been a Microstrip Patch Antenna developed by Antenna Development Corporation and a turnstile antenna ANT430.On the back and lower face of the cubesat will be implemented turnstile antennas, while on the lateral sides will be implemented the antennas patch.

On the lower face of the cubesat is necessary to use an antenna turnstile because a thruster must be incorporated.

The following table shows the main parameters of those antennas.

Turnstile antenna	
Features	**Value**
Frequency range	400-480 MHz
Bandwidth	5 MHz
Gain	1.5 dBi
Polarization	Circular
Maximum power consumption	10 W
Impedance	50 Ohms
Operational temperature range	-40°C to +85°C
Mass	30 grams

Table 3.6: Main features of the turnstile antenna

3.3.2 Data Handling Systems

The communication system allows us to realize the reception and trasmission of data, voice signals, etc. It consists of a group of transponders, that are the combination of a transmitter and a receiver and whose functions are receiving, separating, amplify, process, reamplify and retransmit signals.

The telemetry subsytem analyses the information about the ground station and other sensors of the satellite in order to monitor conditions on board. It allows report to ground station about the conditions of the on board systems.

The command and control subsystem allows the ground station to control the satellite.

3.3.3 Study of the commercial available options

System	**Brand and model**	**Price per unit (€)**
Patch antenna	ADC, Microstrip	TO REQUEST!
Turnstile antenna 1	Gomspace, ANT430	TO REQUEST

TRANSCEIVER	EMPTY	TO REQUEST
DHS	EMPTY	20000

Table 3.7: Options studied

3.4 Propulsion Systems

3.4.1 Requirements

There is a big risk of a collision with space debris while a spacecraft is operating in Low Earth Orbits. The Inter-Agency Space Debris Coordination Committee recommended to the United Nations (section 5.3.2 'Objects Passing Through the LEO Region'): "Whenever possible space systems that are terminating their operational phases in orbits that pass through the LEO region, or have the potential to interfere with the LEO region, should be de-orbited (direct re-entry is preferred) or where appropriate manoeuvred into an orbit with a reduced lifetime. Retrieval is also a disposal option." and "A space system should be left in an orbit in which, using an accepted nominal projection for solar activity, atmospheric drag will limit the orbital lifetime after completion of operations. A study on the effect of post- mission orbital lifetime limitation on collision rate and debris population growth has been performed by the IADC. This IADC and some other studies and a number of existing national guidelines have found 25 years to be a reasonable and appropriate lifetime limit."

Thus, a proper propulsion system is needed both for maintaining the satellite's orbit and for de-orbiting after the mission's lifetime.

Given the size of the CubeSat, not many effective options are available and a committed solution has to be found in order to follow the recommendations by the IADC.

3.4.2 Orbit decay

Orbit decay prediction powered by the Bureau of Meteorology by the Australian Government.

To calculate the orbit decay the following parameters are used:

Solar Radio Flux at 10.7cm (F10.7). It is a clear indicator of solar activity and has proven very valuable in forecasting space weather. The extreme UV that impact the ionosphere also modify the upper atmosphere, thus F10.7 data is needed to account for these variations. The value used in this calculation is: 79.54. REF: http://www.spaceweather.gc.ca/solarflux/sx-5-mavg-en.php

Cubesat mass of up to 4kg.

The K-index, and by extension the Planetary K-index, are used to characterize the magnitude of geomagnetic storms. Kp is an excellent indicator of disturbances in the Earth's magnetic field and is used by SWPC to decide whether geomagnetic alerts and warnings need to be issued for users who are affected by these disturbances.

The principal users affected by geomagnetic storms are the electrical power grid, spacecraft operations, users of radio signals that reflect off of or pass through the ionosphere, and observers of the aurora.

The geomagnetic index used in this calculation is: 12.

RE-ENTRY EVERY 106.25 DAYS!

Calculations based on day 100, with an altitude of 400Km. Already lost 100Km:

3.4.3 Thrusters

Thruster is a main part of the structure because it is needed to allow the satellite to realise different maneuvers how incorporate it adequatly to the orbit after the deployment of the rocket, can obtain the optimal orientation or to mantain the satellite in the orbital and avoid its fallen.

The main parameters that must consider are thrust, total specific impulse,power required, weight of the propulsion subsystem and its volume.

At the moment, the most used and more modern thrusters for satellites are: ionic, pulsed plasma, electrothermal and green monoprop thrusters. An important aspect to consider is that we are interested in is reducing the mass required although this will cause minor accelerations than conventional engines but it will be suitable for small satellites.

After a market study, an ionic thruster has been elected how the best option. The causes of this election are that the volume of the all propulsion subsystem and its weight are very small, specifict impulse is very high,thrust is acceptable and power requiered can be supplied by the solar panels.

The following table shows the main parameters of this thruster.

BIT-1 ION THRUSTER	
PARAMETERS	**VALUE**
Total thruster power	10 W
Thrust	100 uN
Specific impulse	2150 s
Thruster Mass	53 g
Propellant mass flow	4.9 ug/s

Grid input voltage	2 kV
Ion beam current	1.5 mA
Propellant utilization	41 percent
Energy Efficiency	27 percent

3.5 Communication module

100kbps:

1mbps:

¿solo 9600bps?:

Links interesantes universidades:

3.6 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).

3.6.1 Attitude Determination

EMPTY

3.6.2 Attitude Control

EMPTY

3.6.3 Orbital Control

Thrusters

3.6.4 Study of the commercial available options

Brand and model	Features and description	Money (€)
Solar Panels		
Fabricant 1	EMPTY	2000000

Chuscas 1	EMPTY	20000
Truñaas 1	EMPTY	20000
Cuescas 1	EMPTY	20000

Table 3.9: Options studied

3.7 Link Budget

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

- Space to Ground link.
- Space to Space link between Astrea satellites.
- Space to Space link between client ans Astrea satellites.

The link budget calculations are mostly calculated using the following fonts: [1].

3.7.1 Communications Basics

[2] When evaluating a wireless link, the three most important questions to be answered are:

1. How much radio frequency (RF) power is available?
2. How much bandwidth is available?
3. What is the required reliability (as defined by Bit Error Rate, or BER)?

The upper limit in terms of data rate is given by Shannon's Channel Capacity Theorem:

$$C = Blog_2(1 + S/N) \tag{3.1}$$

where:

$$C = \text{channel capacity (bits/s)}$$
$$B = \text{channel bandwidth (Hz)}$$
$$S = \text{signal strength (watts)}$$
$$N = \text{noise power (watts)}$$

Transmission Losses In any satellite transmission, there are always losses from various sources. Some of those losses may be constant, others are dependent of statistical data and others vary with the weather conditions, especially with rain.

<table>
<tr><td rowspan="13">TRANSMISSION LOSSES</td><td rowspan="10">PROPAGATION LOSSES</td><td colspan="3">FREE SPACE LOSSES</td></tr>
<tr><td rowspan="8">ATMOSPHERIC LOSSES</td><td rowspan="2">Ionospheric effects</td><td>Faraday rotation</td></tr>
<tr><td>Scintillation effects</td></tr>
<tr><td rowspan="5">Tropospheric effects</td><td>Attenuation</td></tr>
<tr><td>Rain attenuation</td></tr>
<tr><td>Gas absorption</td></tr>
<tr><td>Depolarization</td></tr>
<tr><td>Sky noise</td></tr>
<tr><td colspan="2">Local effects</td></tr>
<tr><td colspan="3">POINTING LOSSES</td></tr>
<tr><td rowspan="3">LOCAL LOSSES</td><td rowspan="2">EQUIPMENT LOSSES</td><td>Feeder losses</td><td rowspan="2"></td></tr>
<tr><td>?????</td></tr>
<tr><td>ENVIRONMENT LOSSES</td><td colspan="2"></td></tr>
</table>

Figure 3.3: Principal losses in the received signal [?]

3.7.2 Propagation losses

3.7.2.1 Free Space Losses

Range and Path Loss Another key consideration is the issue of range. As radio waves propagate in free space, power falls off as the square of range. For a doubling of range, power reaching a receiver antenna is reduced by a factor of four. This effect is due to the spreading of the radio waves as they propagate, and can be calculated by:

$$L = 20log_{10}(4\pi D/\lambda) \tag{3.2}$$

where:

$D =$ the distance between receiver and transmitter

$\lambda =$ free space wavelength = c/f

$c =$ speed of light$(3\text{x}10^8 m/s)$

$f =$ frequency (Hz)

3.7.2.2 Atmospheric Losses

This kind of losses derives from the absorption of energy by atmospheric gases. They can assume two different types:

- Atmospheric attenuation.
- Atmospheric absorption.

The major distinguishing factor between them is their origin. Attenuation is weatherrelated, while absorption comes in clear-sky conditions. Likewise, these losses can be due to ionospheric, tropospheric and other local effects. [?]

Ionospheric Effects All radio waves transmitted by satellites to the Earth or vice versa must pass through the ionosphere, the highest layer of the atmosphere, which contains ionized particles, especially due to the action of sun's radiation. Free electrons are distributed in layers and clouds of electrons may be formed, originating what is known as travelling ionospheric disturbances, what provoke signal fluctuations that are only treated as statistical data. The effects are:

- **Polarization rotation**: When a radio wave passes through the ionosphere, it contacts the layers of ionized electrons that move according to the Earth's magnetic field. The direction these electrons move will no longer be parallel to the electric field of the wave and therefore the polarization is shifted, in what is called Faraday rotation (θ_F). ;
- **Scintillation effects**: Differences in the atmospheric refractive index may cause scattering and multipath effect, due to the different directions rays may take through the atmosphere. They are detected as variations in amplitude, phase, polarization and angle of arrival of the radio waves. It is often recommended the introduction of a fade margin so atmospheric scintillation can be a tolerated phenomenon.;
- Absorption;
- Variation in the direction of arrival;
- Propagation delay;
- Dispersion;
- Frequency change

These effects decrease usually with the increase of the square of the frequency and most serious ones in satellite communications are the polarization rotation and the scintillation effects, and those are the ones that will be treated in this dissertation. [?]

Tropospheric Effects [?] Troposphere is composed by a miscellany of molecules of different compounds, such as hail, raindrops or other atmospheric gases. Radio waves that pass by troposphere will suffer their effects and will be scattered, depolarized, absorbed and therefore attenuated.

Attenuation: As radio waves cross troposphere, radio frequency energy will be converted into thermal energy and that attenuates signal.

Rain attenuation: Ground stations had been chosen in order that the attenuation caused by rainfall will be very punctual. Also, the fact that there are three ground stations makes really difficult that a satellite can not communicate to the ground in all the orbit period.

Gas absorption: Under normal conditions, only oxygen and water vapour have a significant contribution in absorption. Other atmospheric gases only become a problem in very dry air conditions above 70 GHz. Thereby, losses caused by atmospheric absorption vary with frequency and the collection of data already received allows the elaboration of the graphic that follows:

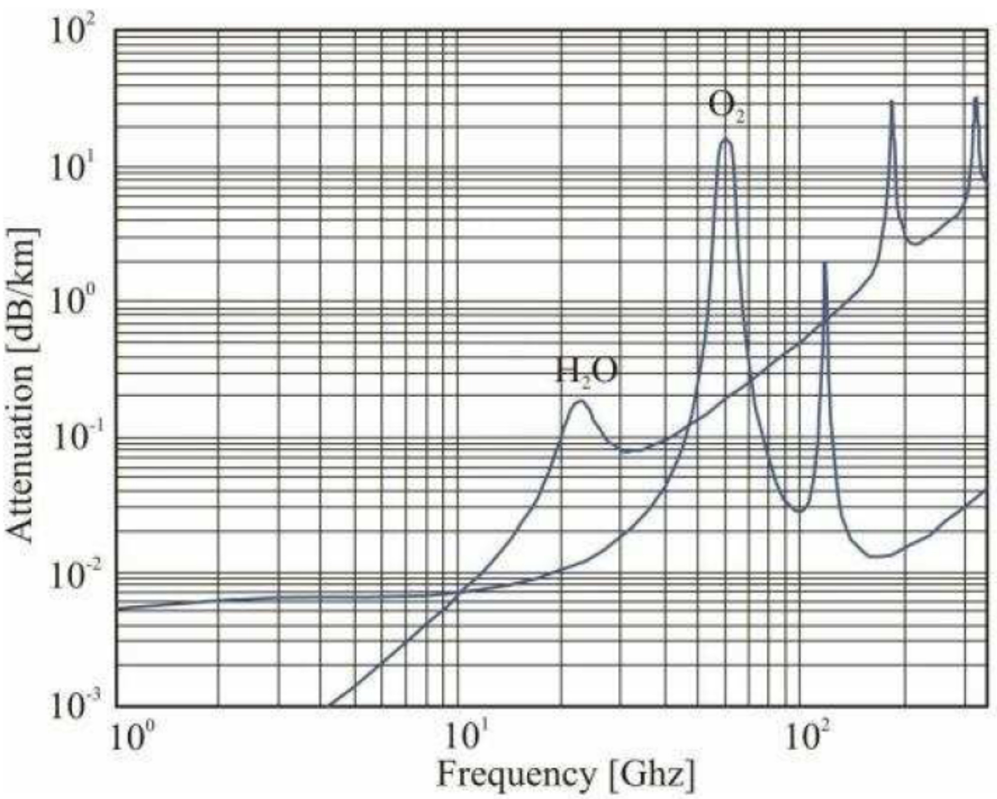


Figure 3.4: Specific attenuation for different frequencies [?]

Local Effects

3.7.2.3 Pointing Losses

3.7.2.4 Multipath and Fade Margin

Multipath occurs when waves emitted by the transmitter travel along a different path and interfere destructively with waves travelling on a direct line-of-sight path. This is sometimes referred to as signal fading. This phenomenon occurs because waves travelling along different paths may be completely out of phase when they reach the antenna, thereby cancelling each other.

The amount of extra RF power radiated to overcome this phenomenon is referred to as fade margin. The exact amount of fade margin required depends on the desired reliability of the link, but a good rule-of-thumb is 20dB to 30dB.

3.7.3 Local Losses

3.7.3.1 Equipament Losses

3.7.3.2 Environment Losses

3.7.4 Modulation Technique

Modulation technique is a key consideration. This is the method by which the analogue or digital information is converted to signals at RF frequencies suitable for transmission. Selection of modulation method determines system bandwidth, power efficiency, sensitivity, and complexity. Most of us are familiar with Amplitude Modulation (AM) and Frequency Modulation (FM) because of their widespread use in commercial radio. Phase Modulation is another important technique. It is used in applications such as Global Position System (GPS) receivers and some cellular telephone networks. [2]

For the purposes of link budget analysis, the most important aspect of a given modulation technique is the Signal-to- Noise Ratio (SNR) necessary for a receiver to achieve a specified level of reliability in terms of BER.

A graph of Eb/No vs BER is shown in Figure 3.5. E_b/N_o is a measure of the required energy per bit relative to the noise power. Note that E_b/N_o is independent of the system data rate. In order to convert from E_b/N_o to SNR, the data rate and system bandwidth must be taken into account as shown below:

$$SNR = (E_b/N_o)(R/B_T) \tag{3.3}$$

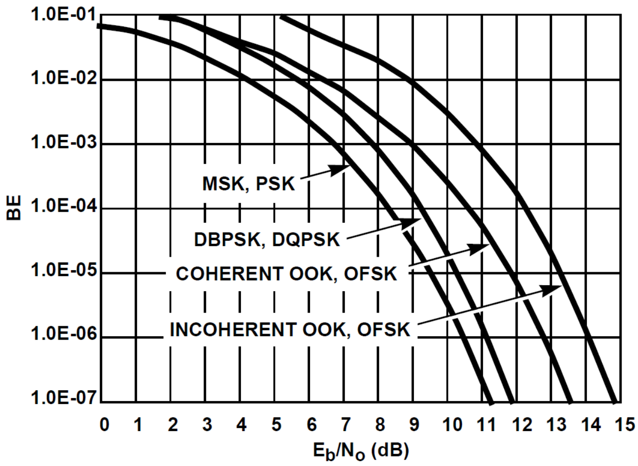


Figure 3.5: Probability of bit error for common modulation methods[?]

where:

$$E_b = \text{Energy required per bit of information}$$
$$N_o = \text{thermal noise in 1Hz of bandwidth}$$
$$R = \text{system data rate}$$
$$B_T = \text{system bandwidth}$$

3.7.5 System Noise

Channel Noise All objects which have heat emit RF energy in the form of random (Gaussian) noise. The amount of radiation emitted can be calculated by [?]:

$$N = kTB \tag{3.4}$$

where:

$$N = \text{noise power (watts)}$$
$$k = \text{Boltzman's constant}(1.38\text{x}10^{-23} J/K)$$
$$T = \text{system temperature, usually assumed to be 290K}$$
$$B = \text{channel bandwidth (Hz)}$$

This is the lowest possible noise level for a system with a given physical temperature. For most applications, temperature is typically assumed to be room temperature (290K). Equations 3.1 and 3.4 demonstrate that RF power and bandwidth can be traded off to achieve a given performance level (as defined by BER).

3.7.6 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.

$EIRP = P_T - L_T - G_T$

4 References

[1] Carlos Jorge and Rodrigues Capela. Protocol of Communications for VORSAT Satellite - Link Budget. (April), 2012.

[2] Application Note. Tutorial on Basic Link Budget Analysis. *Intersil*, (June 1998):1–8, 1998.