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Chapter 1

Satellite design

1.1 Structure and thermal protection

1.1.1 Structure

There are several types of commercial structures. According to the needs of the project, the structure that Astrea is looking for has to be very flexible regarding the placement of the subsystems. It has to adapt to the needs of the project continuously given that the satellite does not have a typical configuration.
A basic schematics can be found in the figure 1.1.1.

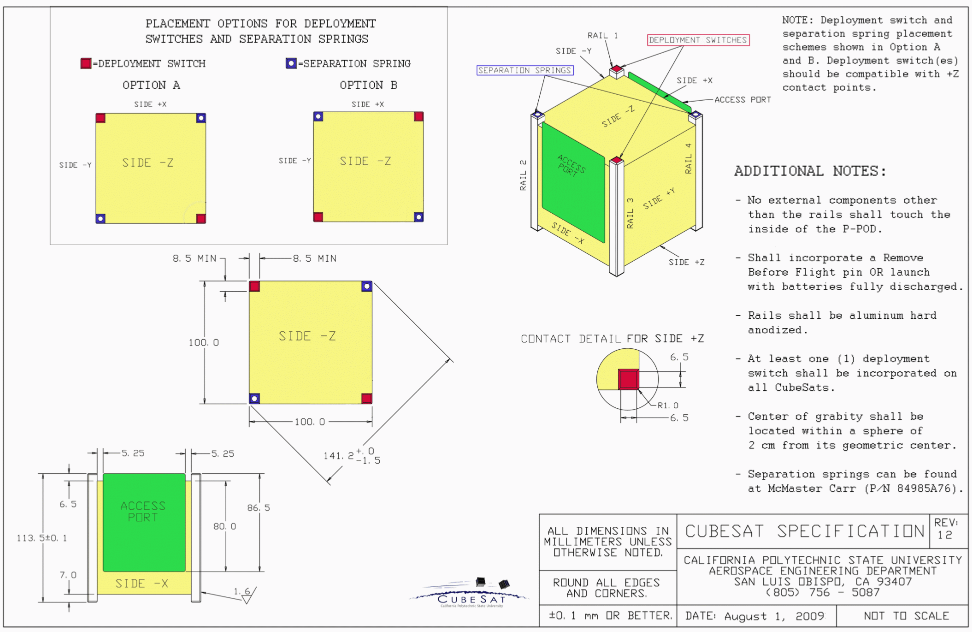

Figure 1.1.1: Dimensions of a 1U CubeSat. Source [?]

Besides this flexibility of the structure, several other parameters have to be taken into account. Given that the satellite will work under extreme environmentally conditions, the structure has to withstand space conditions for at least 4 years. Also, the weight should be kept down since there are lots of systems to be placed and the ratio *mass/satellite* is limited. Finally, the structure should have a way to place all the subsystems (like holes, *trays*, ...).

The two most interesting options that were considered when the structure had to be chosen are presented in 1.1.1.

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	11000

Table 1.1.1: Options studied for the structure

And the option chosen has been the **ISIS 3U structure**, as explained in the report.

1.1.2 Thermal protection

The thermal protection system consists of various insulating materials that aim to protect the CubeSat from heat produced by radiation. Currently, the most used element in the aerospace industry is the MultiLayer Insulation (MLI), a set of multiple thin insulation layers. For the satellite, its main objective is to reduce the heat generated by radiation, given that the heat generated by convection or conduction does not have such a high impact on the on-board systems and is also comparatively small with radiation.

The more layers that the thermal protection has, the more heat is being redressed to the space. An expression for the calculation of the heat flux is presented below

$$Q = UA\Delta T \tag{1.1.1}$$

- Q stands for the radiative heat flow rate between two parallel surfaces
- U is the global heat transfer coefficient
- T is the temperature difference between two parellel surfaces

The heat transfer coefficient can be derived, theoretically, using the following relation

$$U = 4\sigma T^3 \frac{1}{1/\epsilon_1 + 1/\epsilon_2 - 1} \tag{1.1.2}$$

If the emissivity is decreased or the number of layers is increased, the heat transfer coefficient is reduced. It means that the system is more insulated, more protected to radiation. Thus, the MLI system is a perfect choice for the satellite: the mass is really low and the insulation obtained is really high (NASA is actually using it for the development of the actual satellites).Furthermore, this kind of system can also be used as a first protection to dust impacts if the layers are big enough.

Finally, a few options were studied when the thermal protection had to be selected. These options are presented in 1.1.2.

Brand and model	**Features**	**Total price (€)**
Thermal protection		
Dunmore Aerospace Satkit	Lightweight Durability Made for small satellites	1000
Dupont Kapton Aircraft Thermal	Lightweight Durability Non-flammable	1200

Table 1.1.2: Options studied for the thermal protection

1.2 Electrical Power Systems

1.2.1 EPS Scheme

How all the different electric systems are related is presented in the figure 1.2.1.

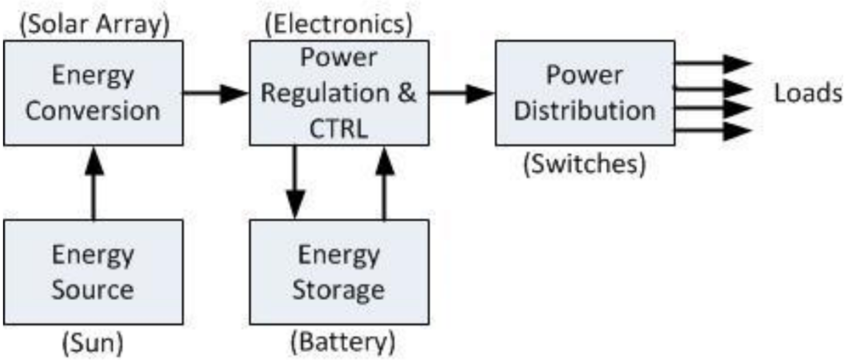

Figure 1.2.1: Basic schematics of the EPS. Source [?]

The need for a system that regulates, manages and distributes the energy to all of the other subsystems is clear. Every system has its energy requirements and several buses are needed in order to maintain all the systems working.

1.2.2 Estimation of the power required

The vast majority of the time, the subsystems of the satellite will work under typical operation conditions. However, the estimation of the power consumption provided in the table 1.2.1 has been made for typical-high conditions in order to have a power margin and a more reliable estimation.

System (number of units)	Typical power consumption per unit (W)
Payload	
Patch antenna (8)	4
Payload power consumption	32
Electrical Power System	
NanoPower P60 Power Module (1)	2
Battery (2)	-
Solar arrays (4)	-
EPS power consumption	2

Data Handling Systems	
Transceiver inner-satellite (3)	4
Transceiver space to ground (1)	4
Data handling system (1)	4
DHS power consumption	15
Propulsion and ACDS	
Thruster (1)	20
ADACS (1)	3
OACDS power consumption	3
Estimated total power consumption	52

Table 1.2.1: Estimation of the power consumption under typical working conditions

Additionally, it is worth mentioning that the thrusters are not included in the final estimated power. The thruster will only be active for shorts periods of time to maintain the orbit, and when it ignites, the other subsystems will not perform in typical conditions. The CubeSat will manage to send only the essential information to the other satellites and, since it is unlikely that their thruster is ignited, the communication is ensured during the maneuver.

1.2.3 Solar arrays

The solar arrays used must have a decent efficiency and capacity to collect the energy from the sun, have to keep their mass relatively low, must have a protective radiation shield to ensure their full efficiency for at least 4 years, a proper deployment system, the ability to withstand space conditions and also must be highly compatible with all the other systems used, especially the power management system (the *NanoPower P60*).

Two options were considered regarding the solar arrays. These options are presented in 1.2.2.

Brand and model	Features	Total price (€) per unit
Solar arrays		
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	9000

Table 1.2.2: Options studied for the solar arrays

The option selected for the mission is a set of deployable solar panels provided by **EXA (Agencia Espacial Civil Ecuatoriana)**. These solar arrays fulfill all the requirements mentioned above: they are low mass (135g per unit), they 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) they can withstand a very high temperature range (from -80°C to 130°C) ensuring that they can operate in space, they have a gentle release and deployment system with artificial muscles (developed by EXA) and they provide a power of 16.8W each (19.2V@0.5A).

Every cubesat will come with at least 4 deployable solar panels providing it with 67.2W of power, approximately. Note that additional panels can be equipped. But they have to be also low mass equipment (about 80g per array) as the deployable solar arrays and highly compatible with the CubeSat.

1.2.4 Power management system

Several options were considered regarding the power management system. These options, with their respective main features, are presented in 1.2.3.

Brand and model	**Features**	**Total price (€) per unit**
Power management		
Crystalspace P1 Vasik	Mass of 80g Full redundancy Low volume 6x outputs Up to 10W input High temperature range	5400
Gomspace NanoPower P60	Mass of 176g 9x configurable outputs 6x inputs per module EMI shielding High temperature range	16000

Table 1.2.3: Options studied for the power management system

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; saving a lot of space.

The motherboard supports up to 4 ACU and PDU modules and has different regulated outputs (3.3V and 5V). It means that with one single motherboard, several conditioning and distributing units can be connected. That ensures that additional equipment (ACU and PDU) could be linked to the motherboard if something failed in the assembly process.

The ACU module 6 different inputs per unit with a high voltage solar input (up to 16V or 32V). Additionally, each input can withstand a maximum current of 2A and current and voltage inputs are measured on each input channel and the measurements can be communicated to the onboard computer.

The PDU module has 9 different outputs per unit that are highly configurable. Each module has 3 configurable output voltages (3.3V, 5V, 8V, 12V, 18V, 24V) and each of the outputs can withstand a maximum current of 1A or 2A (programmable). Additionally, like the ACU module, current and voltage outputs are measured on each output channel and can be effectively communicated to the onboard computer.

All these features make the **NanoPower P60** a very efficient and configurable power management unit that fulfills the mission requirements. Furthermore, given this capacity to configure each input and output channel and the high number of channels that it has, the compatibility between all the systems used in the satellite is ensured. Additionally, the communication between this system and the onboard computer in order to detect potential failures is a really adequate feature.
With the NanoPower P60 we aim to distribute the energy to all of the subsystems of the CubeSat.

1.2.5 Batteries

The batteries are an essential component for this mission. They have to provide the energy that the system requires when the solar arrays are not operational. Therefore, the following options (1.2.4) were considered.

Brand and model	Features	Total price (€) per unit
Batteries		
Gomspace NanoPower BP4	Total capacity of 77Wh (2u) Automatic heat regulation Highly stackable Mass of 270g (p.unit)	3250
EXA-Agencia Espacial Ecuatoriana	Total capacity of 106.4Wh (2u) Automatic heat regulation Highly stackable Total mass of 155g	6300

Table 1.2.4: Options studied for the batteries

Among all the commercial options, 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. Each battery has a total of 16 cells, highly stackable and with a very low mass (155g per unit). They also come with unique thermal transfer bus, that will transfer the heat of the other subsystems to the batteries to keep their temperature under efficient working conditions.

The output voltage can be configured (3.7V and 7.4V) and they are perfectly compatible with the solar arrays. Furthermore, they come with a protective radiation shield (NEMEA) that ensures at least 4 years working under full efficiency conditions in a LEO. It is also worth mentioning that if the company that will assemble the CubeSat faces problems during this part of the process, the batteries can be customized by contacting EXA.

As mentioned above, if the satellite was in the dark during half of the period of the orbit, the estimated energy that it would need would be 50W. Thereby, the capacity of the batteries is more than enough to supply the required energy in the worst case scenario. In fact, 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.

1.3 Propulsion

1.3.1 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.

1.3.2 Study of the commercial available options

The two most interesting options that were considered when the thruster had to be chosen are presented below.These two thruster are among the most used in the aerospace industry for small satellites. The main difference between both are the thrust and the specific impulse. On the one hand, the BIT-1 thruster provides a lower thrust but with a high specific impulse. On the other hand, BGT-X5 thruster provides a high thrust, around 0.5 N but with a lower specific impulse.

Brand and model	**Features**	**Total price (€)**
Propulsion		
Busek ion thruster BIT-1	Volume 1/2 U High Isp (2150 s) Low thrust (100 uN)	58000
Busek BGT-X5	Volume 1 U High thrust (0.5 N) High delta V (146 m/s)	50000

Table 1.3.1: Options studied for the propulsion system

The following table 1.3.2 shows the main parameters of the thruster chosen.

BGT-X5	
PARAMETERS	**VALUE**
Total thruster power	20 W
Thrust	0.5 N
Specific impulse	225 s
Thruster Mass	1500 g
Input voltage	12 V
Delta V	146 m/s

Table 1.3.2: Main features of BGT-X5

1.4 AOCS

1.4.1 Study of the commercial available options

Because AOCS involve so many systems working together, full assembled module was considered in order to avoid compatibility issues.

The two most interesting options that were considered when the AOCS had to be chosen are presented below.

ADACS options		
Features	**CUBE ADCS**	**MAI-400 ADACS**
Power	3.3/5 VDC Peak: 7.045W	5 VDC Peak: 7.23W
Mass	506 g	694 g
Size	90 x 90 x 58 mm	10 x 10 x 5.59 cm
Sensors	3-Axis Gyro Fine Sun & Earth sensor Magnetometer 10x Coarse Sun Sensors Star tracker(optional)	3-axis magnetometer Coarse sun sensor EHS Camera
Actuators	3 reactions wheels 2 torque rods	3 reactions wheels 3 torque rods
Computer	4-48 MHz full ADCS + OBC	4Hz Provides telemetry
Control Board	Works as OBC included	MAI-400 not included

Table 1.4.1: Main ADACS features

After the study of commercial options available, the previous two where the unique that fitted in AstreaSAT requirements, so a decision between these two had to be done. Since all the features tabulated on 1.4.1 were critical, the same weights were given. Finally, CUBE ADCS was chosen.

1.5 Link Budget

1.5.1 Communications Basics

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

1. How much radio frequency (RF) power is available? Up to 2W for S band or up to 12W for Xband.
2. How much bandwidth is available?

   Available 400MHz with 28 channels of 14MHz or 228 channels of 1.75MHz for inter-satellite communication at S band. For X band, there's more than 4GHz available [?]. In fact is limited by the TR-600 transceiver at 56MHz for S band and to 100MHz by SWIFT - XTS at X band.
3. What is the required reliability (as defined by Bit Error Rate, or BER)?

   Required reliability for space systems$E_b/N_o \geq 10$, so $BER = 5.5x10^{-6}$ for a MSK, PSK (worst case) modulation as shown in Fig.1.5.5.

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

$$C = B \cdot log_2(1 + S/N) \tag{1.5.1}$$

where:

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

With all data known, the minimum required sensitivity of a receiver using the Eq. 1.5.1 will be stated in the Link Budget calculation.

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>Local effects</td><td></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 colspan="3">ENVIRONMENT LOSSES</td></tr>
</table>

Figure 1.5.1: Principal losses in the received signal [?]

1.5.2 Propagation losses

1.5.2.1 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 [?]:

$$L = 20log_{10}(4\pi D/\lambda) \tag{1.5.2}$$

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)

1.5.2.2 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:

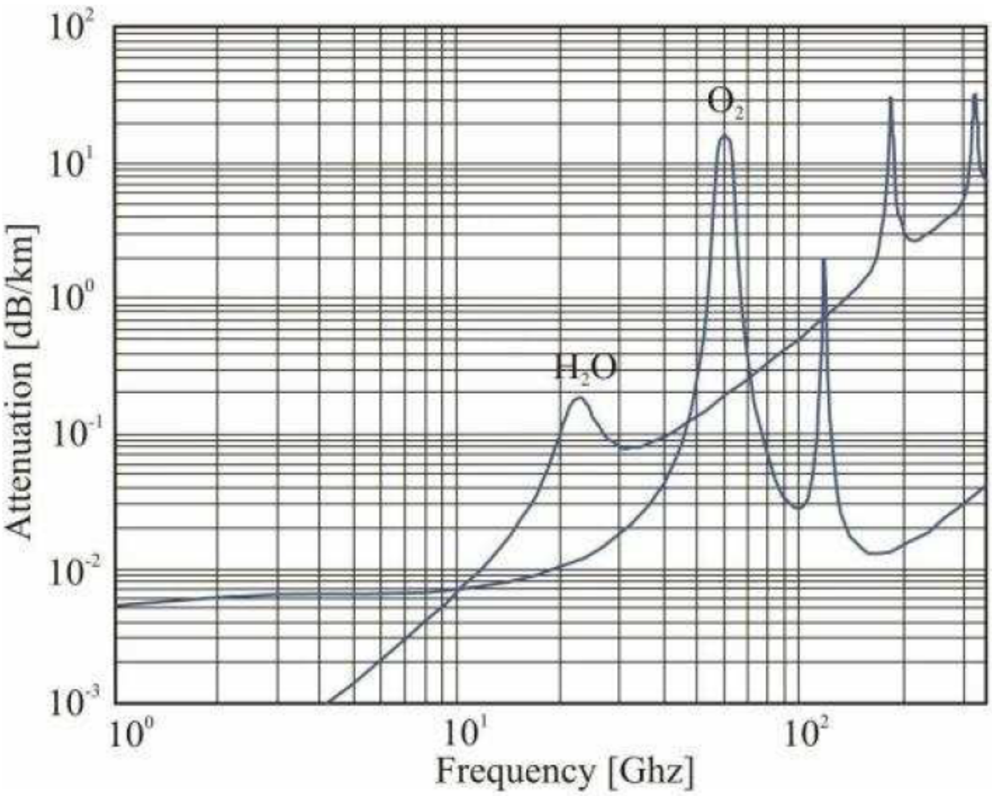

Figure 1.5.2: Specific attenuation for different frequencies [?]

Once these values depend on atmosphere thickness, it becomes necessary to perform all calculations taking into account troposphere's thickest layer (T_{trop}), which has 20 km. It is also mandatory to refer that this graph represents the absorption for a satellite in the zenith, in other words, for an elevation angle of 90º ($\theta = 90^o$). For lower angles, the atmospheric absorption (L_{abs}) is given by [?]:

$$L_{abs}(dB) = L_{abs|90^o}(dB/km)\ cosec(\theta)\ T_{trop}(km) \tag{1.5.3}$$

For AstreaSAT, 5x$10^{-3}dB/km$ attenuation factor is considered for S band due to the O_2 specific attenuation. On the other hand, 4x$10^{-3}dB/km$ attenuation factor is considered for X band due to the H_2O and to the O_2 specific attenuations. An study of the critical elevation angle will lately be performed.

For AstreaSAT ground station, communication starts at an elevation angle of $\theta = 10^o$ (worst case scenario). Consequently, $cosesc(\theta)$ will go from 5.76 to 1 (best reception case). In that case, we assume:

$$L_{abs} = 2 \cdot 4\text{x}10^{-3} \cdot 5.76 \cdot 20 = \mathbf{0.92dB} \quad \text{X band}$$
$$L_{abs} = 5\text{x}10^{-3} \cdot 5.76 \cdot 20 = \mathbf{0.58dB} \quad \text{S band}$$

Polarization: Satellite communications use linear and circular polarization, but undesirable effects may transform it into an elliptical polarization. Depolarization may occur when an orthogonal component is created due to the passing of the signal through the ionosphere. There are two ways to measure its effect, cross polarization discrimination (XPD) and polarization isolation (I) [?]. To overcome this attenuation problems a circular polarization is the best option. AstreaSAT patch antennas will mitigate this problem, therefore this loses are considered negligible.

Sky noise: Sky noise is a combination of galactic and atmospheric effects, according as both these factors influence the quality of the signal in the reception. Galactic effects decrease with the increase of frequency. They are due to the addition of the cosmic background radiation and the noise temperature of radio stars, galaxies and nebulae. This value is quite low and a good approximation is **3 K**.

AstreaSAT noise temperature A good approximation based on Fig.1.5.3 is that Galaxy noise is 3K for S band and almost 1K for X band. Furthermore, for the previous worst case scenario stated before $\theta = 10$, noise temperature due to atmospheric absorption is 19K for both bands (S and X).

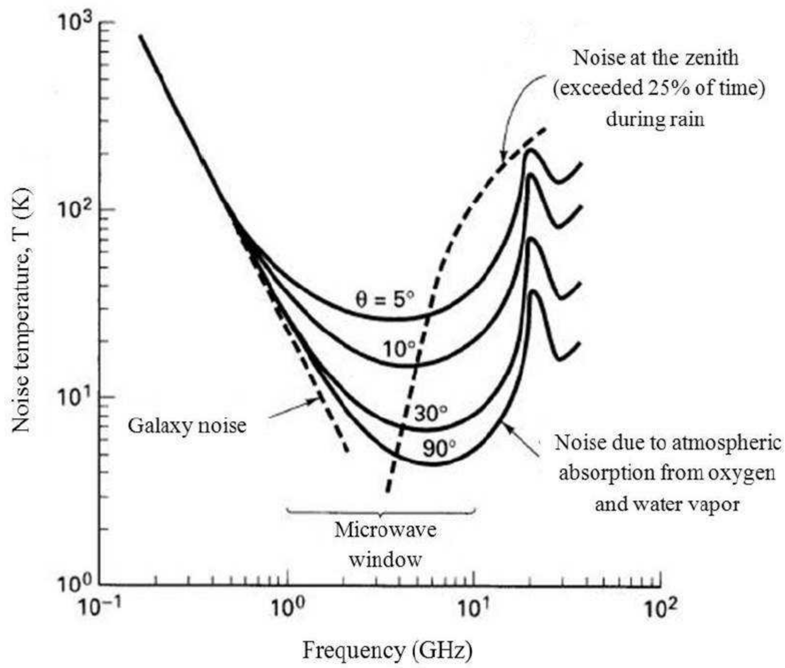

Figure 1.5.3: Galaxy noise influence in noise temperature [?]

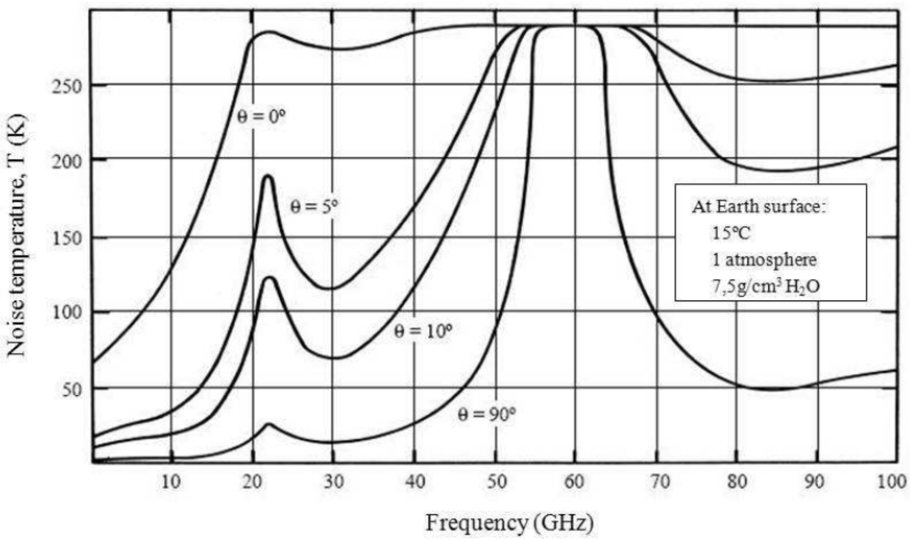

Figure 1.5.4: Noise temperature variation with frequency [?]

Local Effects These effects refer to the proximity of the local ground stations, possible sources that may interfere with the received signal and buildings that may block the signal. If the ground station is on a free external interferences zone, for satellite communications this factor may be negligible.

1.5.2.3 Pointing Losses

Ideal reception implies that the value for misalignment losses would be 0 dB which means maximum gain at the ground station is achieved when both the transmitter and the receiver antennas are 100% aligned. Realistically it is virtually impossible to achieve a perfect alignment between the antennas of the ground station and the satellite, especially in the case of CubeSats, due to their fast movement of nearly 8000 ms^{-1}.

Antenna misalignment losses (L_{aml}) are calculated using statistical data, so these values are an approximation based on real data observed in several GS. Ergo, these values are not calculated, but estimated. [**?**]

Based on a estimation from [**?**] a $L_{aml} = 1dB$ is a good approximation.

1.5.2.4 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.

1.5.3 Local Losses

1.5.3.1 Equipament Losses

The receiving and emitting equipments also introduces some losses to the signal.
Feeder Losses: Feeder losses occur in the several components between the receiving antenna and the receiver device, such as filters, couplers and waveguides. These losses are similar to the ones which occur also in the emission, between the emitting antenna and the output of the high power amplifier (HPA). [?]

1.5.3.2 Environment Losses

This item is related to the specific region of the globe where the ground station is placed (equatorial, tropical, polar...). Depending on its latitude, each region has its own characteristics (e.g. temperature, moisture, thickness of atmospheric ice layer...), which may provoke variation in signal reception. [?]

Communications department, had chosen the best locations over the globe, with stable good weather conditions to neglect this fact.

1.5.4 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. [?]

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.

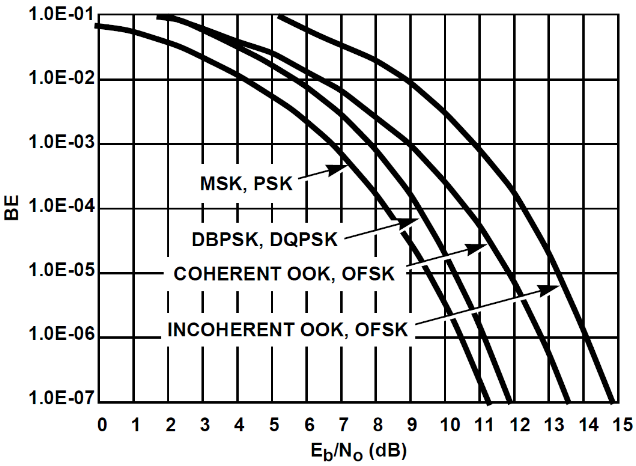

Figure 1.5.5: Probability of bit error for common modulation methods [?]

A graph of E_b/N_o vs BER is shown in Figure 1.5.5. 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:

$$SNR = (E_b/N_o)(R/B_T) \tag{1.5.4}$$

where:

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

AstreaSAT is equipped with Software Defined Radios, it has the ability to change the modulation methods when its flying, for calculus MSK and PSK modulations will be considered, because of their more restrictive conditions.

1.5.5 System Noise

The system noise temperature (T_S) is the sum of the antenna noise temperature (T_A) and the composite temperature of other components (T_{comp}), according to: [?]

$$T_S = T_A + T_{comp} \tag{1.5.5}$$

T_A may be known if the total attenuation due to rain and gas absorption (A), the temperature of the rain medium (T_m) and the temperature of the cold sky (T_C) are also known. Then, the following expression may be applied:

$$T_A = T_m\ (1 - 10^{-A/10}) + T_C\ 10^{-A/10} \tag{1.5.6}$$

Usually, for clouds it is considered $T_m = 280K$ and for the rain $T_m = 260K$. The sky noise tends to be $T_C = 10K$. Taking into account the values from Fig.1.5.3 and Fig.1.5.2 the following estimation can be made:

$$T_A = 280 \cdot (1 - 10^{-(5x10^{-3})/10}) + 22 \cdot 10^{-(5x10^{-3})/10} = \mathbf{22.29K} \quad \text{S band}$$
$$T_A = 280 \cdot (1 - 10^{-2\cdot(4x10^{-3})/10}) + 20 \cdot 10^{-2\cdot(4x10^{-3})/10} = \mathbf{20.48K} \quad \text{X band}$$

According to [**?**] a good components temperature approximation for a typical ground station is $T_{comp} = 65.5K$.

AstreaSAT system temperature will be considered as $T_S = 22.29 + 65.5 = \mathbf{87.79K}$ for S band and $T_S = 20.48 + 65.5 = \mathbf{85.98K}$ for X band. Since both frequencies are part of the microwave spectrum, we see that system temperatures are pretty much the same.

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 [**?**]:

$$N = kTB \tag{1.5.7}$$

where:

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

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 1.5.1 and 1.5.7 demonstrate that RF power and bandwidth can be traded off to achieve a given performance level (as defined by BER). [**?**]