Universidade do Porto
Faculdade de Engenharia
FEUP

PROTOCOL OF COMMUNICATIONS FOR VORSAT SATELLITE

- Link Budget -

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

AA – Atmospheric Absorption
AML – Antenna Misalignment Losses
CCIR – International Radio Consultative Committee
EIRP – Equivalent Isotropic Radiated Power
FEUP – Faculty of Engineering of University of Porto
FSL – Free Space Loss
GEO – Geosynchronous Earth Orbit
GS – Ground Station
HPA – High Power Amplifier
LEO – Low Earth Orbit
LHCP – Left Hand Circular Polarization
LNA – Low Noise Amplifier
RFL – Receiver Feeder Losses
RHCP – Right Hand Circular Polarization
UHF – Ultra High Frequency
VHF – Very High Frequency
VORSat – VHF Omni Directional Radio Range Satellite
XPD – Cross-Polarization Discrimination

1. 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.

With the following table, it is intended to provide a clear view of the major impairments this kind of communication may suffer, as well as their origin. A detailed explanation will be given below, in order to determine and justify all the values achieved for the calculations for VORSat.

Table 1.1 – Major losses in satellite communications.

<table>
<tr><td rowspan="11">TRANSMISSION LOSSES</td><td rowspan="9">PROPAGATION LOSSES</td><td colspan="3">FREE SPACE LOSSES</td></tr>
<tr><td rowspan="7">ATMOSPHERIC LOSSES</td><td>Ionospheric effects</td><td>Faraday rotation
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="2">LOCAL LOSSES</td><td>EQUIPMENT LOSSES</td><td>Feeder losses
?????</td><td></td></tr>
<tr><td>ENVIRONMENT LOSSES</td><td colspan="2"></td></tr>
</table>

Losses in the received signal may have their origin in its propagation from the satellite to the ground station or the opposite, although the uplink will not be studied in this case once VORSat will only have downlink signal. They also may appear in the ground station itself or in the satellite.

1.1 PROPAGATION LOSSES

There are three major issues to take into account as far as propagation losses concern.

- Free space losses
- Atmospheric losses
- Pointing losses

1.1.1 FREE SPACE LOSSES

Free space loss is the dominant component in the loss of the strength of the signal. It doesn't refer to attenuation of signal, but to its spreading through space.

In order to perform all the mandatory calculations on the link power budget for any satellite, a key component must be taken into account, the Equivalent Isotropic Radiated

Power (EIRP), which may be considered the input power in one end of the link. EIRP is also introduced precisely at the beginning of all calculations so it can be understood the source of each component and to allow the correct comprehension of all the deductions presented.

The maximum power flux density at a distance r is given by:

$$\psi_M = \frac{G_T.P_S}{4\pi r^2}$$

where:

ψ_M → maximum power flux density
G_T → transmission antenna gain
P_S → radiated power from the antenna
r → distance between the satellite and the receiving station

Considering an isotropic radiator with an input power equal to $G.P_S$ the same flux density would be produced.

$$EIRP = G_T.P_S$$

Once EIRP is usually expressed in dBW, it is possible to write:

$$EIRP\ (dBW) = P_S\ (dBW) + G_T\ (dB)$$

The first step in the calculations for free space loss (FSL) is to determine the losses in clear-sky conditions. These are the losses that remain constant with time. As said before, FSL derive from the spreading of signal in space.

The received power is given by:

$$P_R = \psi_M.A_{eff}$$

where:

P_R → received power
A_{eff} → effective aperture of the receiving antenna

From the equations above, it is possible to write:

$$\psi_M = \frac{EIRP}{4\pi r^2}$$

The effective aperture of the antenna is provided by:

$$A_{eff} = \frac{\lambda^2 G_R}{4\pi}$$

So, the received power may also be calculated by:

$$P_R = \frac{EIRP}{4\pi r^2} \frac{\lambda^2 G_R}{4\pi}$$

$$P_R = EIRP.G_R.\left(\frac{\lambda}{4\pi r}\right)^2$$

In dB, this equation can be rewritten as:

$$P_R = EIRP + G_R - 10\log\left(\left(\frac{4\pi r}{\lambda}\right)^2\right)$$

In this equation, EIRP refers to the transmitter, G_R to the receiver and the last term of the second member of the equation to the free space spreading losses.

Once

$$\lambda = \frac{c}{f}$$

FSL are given by the following expression:

$$FSL = 10\log\left(\left(\frac{4\pi rf}{c}\right)^2\right)$$

When the frequency *f* is represented in MHz and the distance *r* in km, the above expression for free space loss comes as:

$$FSL = 32{,}4 + 20\log(r) + 20\log(f)$$

VORSat will operate at a frequency of 2.45 GHz and its signals will be received from very different distances, as a result of its LEO. So, the following graphic can be made.

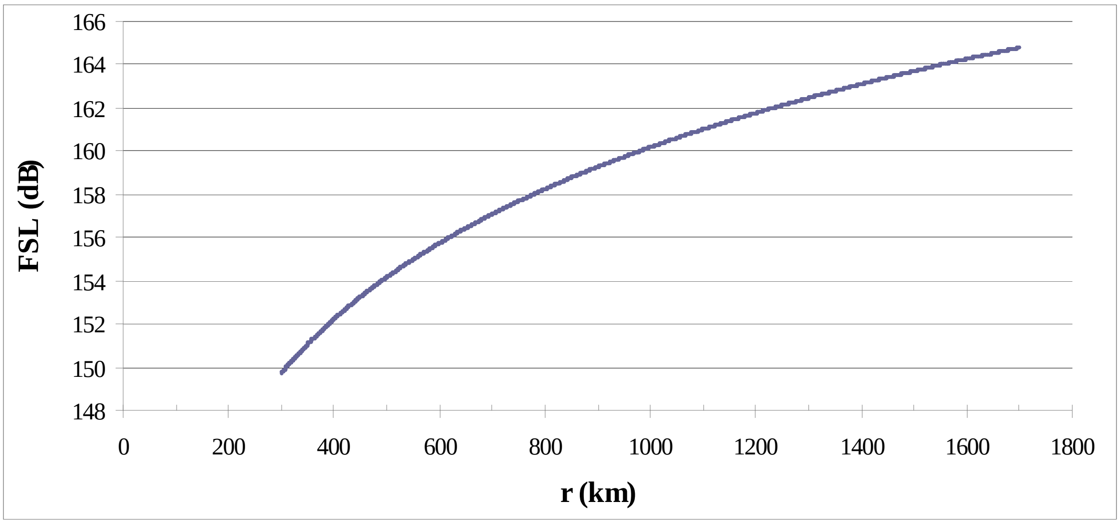

Figure 1.1 – Variation of the FSL with the distance, considering f = 2.45 GHz.

For VORSat link budget calculations, a value of 161.47 dB will be used.

1.1.2 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 weather-related, while absorption comes in clear-sky conditions.

Likewise, these losses can be due to ionospheric, tropospheric and other local effects.

1.1.2.1 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;
- Scintillation effects;
- 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.

<u>Polarization rotation</u>

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).
This is not a serious problem in frequencies above 10 GHz. It will not be a problem in the case of VORSat also because this problem arises only in linear polarization. As said before, VORSat is being designed for circular polarization, hence the Faraday rotation will only add to the rotation.

<u>Scintillation effects</u>

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.

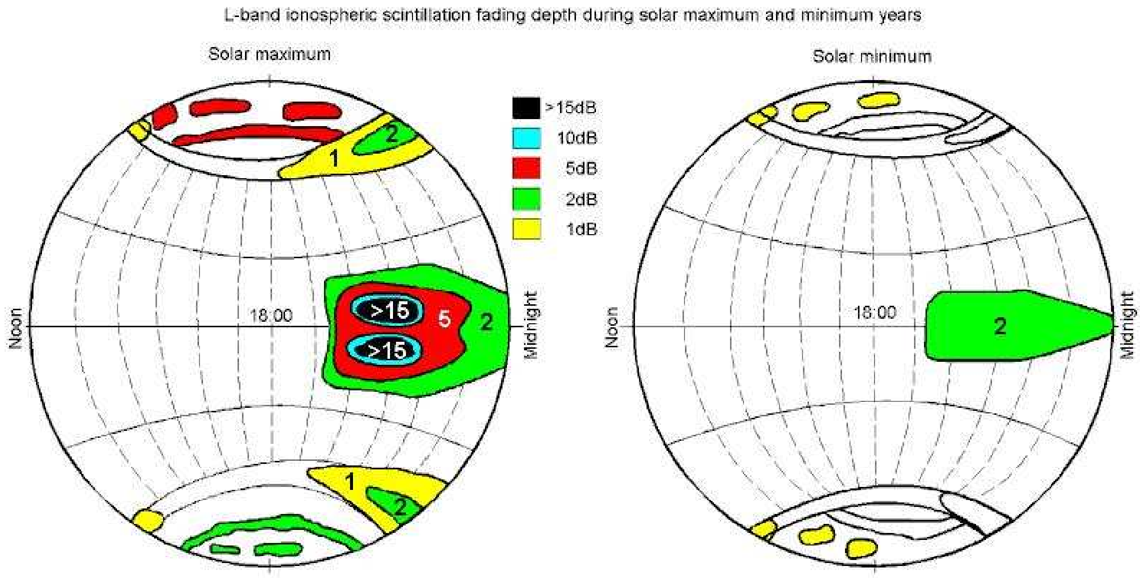

Figure 1.2 – Ionospheric scintillation fading depth.

The graphic above shows how ionospheric scintillation affects signals operating in the L-Band (1 GHz – 2 GHz). It is not exactly the frequency of VORSat, but it is close. It is possible to observe that Portugal, in its northern mid-latitude, is barely affected and this item may be neglected.

1.1.2.2 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.
They will also be scattered into various directions which means that there is a small percentage that doesn't reach the receiver antenna at the ground station. The main scatterer particles in troposphere are hydrometeors like raindrops, hail, ice, fog or clouds, and these particles represent a problem for frequencies higher than 10 GHz.
Both this kind of absorption and scattering rise with frequency, hence neither represent a serious problem for VORSat.

Rain attenuation

It makes no sense to determine the attenuation caused by rainfall because they will be very punctual events, since rain only causes severe attenuation in situations of heavy rain. Thus, even though one satellite transmission may be strongly affected due to rain, its orbit period of nearly 90 minutes minimizes that loss because the same ground station will have several other opportunities to receive VORSat's signals.
For GEO satellites it becomes mandatory to perform these calculations, once the satellite's position in relation to the GS is permanent.

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:

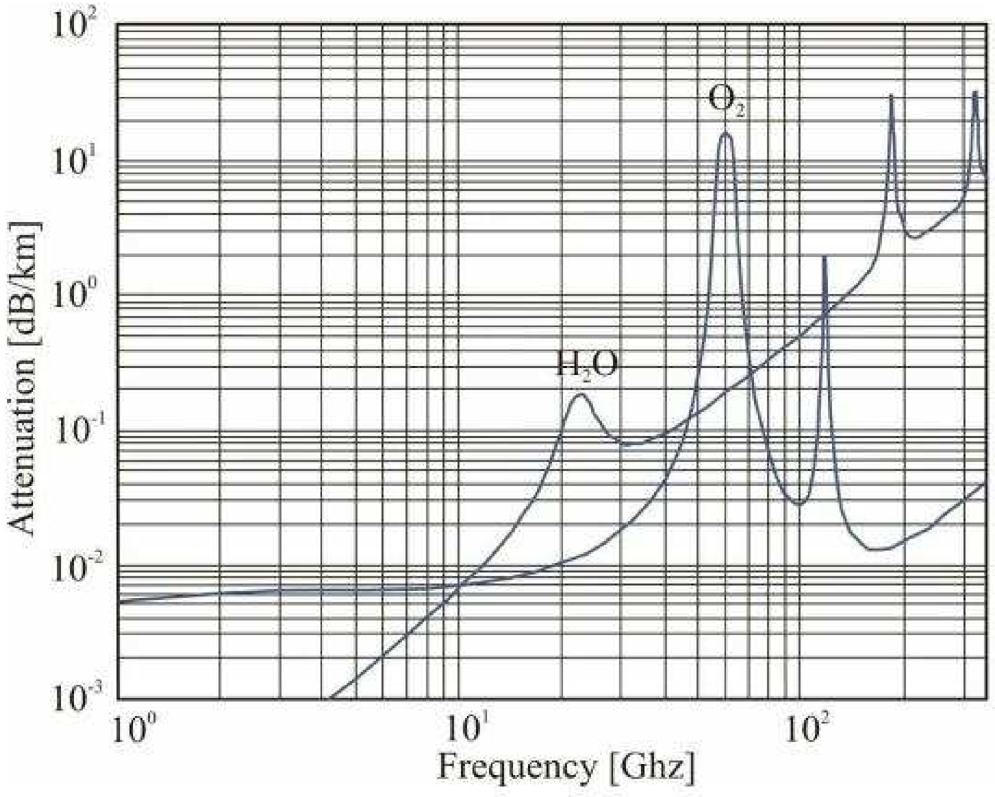

Figure 1.3 – Attenuation vs. frequency

As it is possible to verify, both two peaks are observed at the frequencies 22.3 GHz for water vapour (H_2O) and 60 GHz for oxygen (O_2), wide far of the frequency of VORSat signals, at 2.45 GHz. At this frequency, the atmospheric absorption is extremely low, around 0.006 dB/km, depending almost exclusively from oxygen because the water vapour contribution is significantly smaller.
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 (θ = 90º). For lower angles, the atmospheric absorption (L_{abs}) is given by:

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

When VORSat is near the zenith, L_{abs} is 0.12 dB, but since it will pass through its sub-satellite point in several elevation angles, one ought to determine the L_{abs} also for the worst case, the threshold of visibility, θ = 10º.
Then, applying the previous formula, $L_{abs|10^o} \approx 0.69$ dB. This value is superior to the $L_{abs|90^o}$ and it makes sense, once the atmospheric layer the signal has to overcome is thicker. The values for attenuation decrease rapidly with the increase of the elevation angle, according to the graphic shown below.

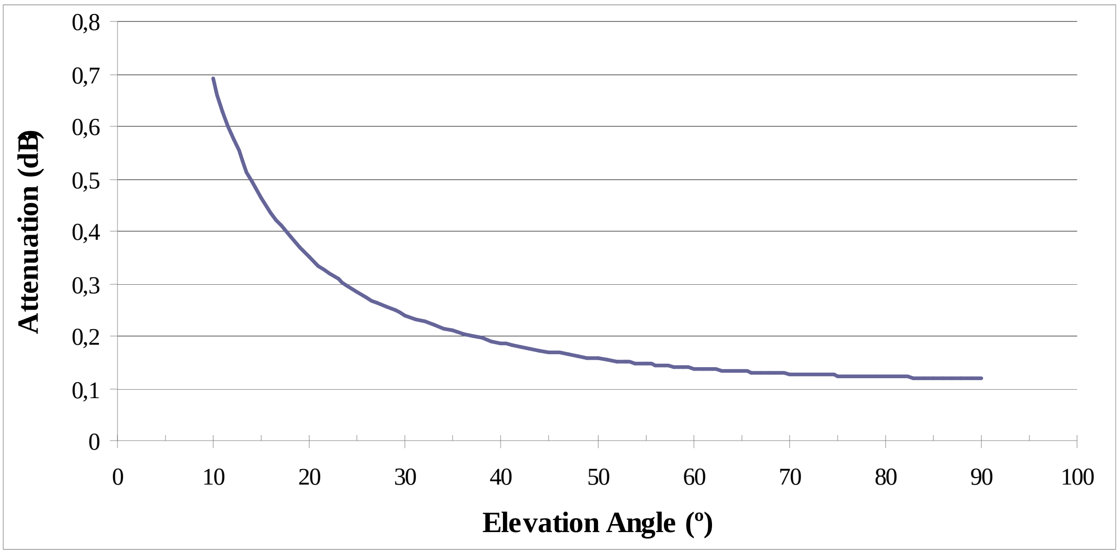

Figure 1.4 – Variation of the attenuation with the variation of the elevation angle of the satellite.

A value of 1 dB will be used for calculations.

<u>Polarization</u>

Satellite communications use linear and circular polarization, but undesirable effects may transform it into an elliptical polarization.
VORSat is being designed to transmit in circular polarization, what makes it less prone to depolarization issues.
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).

- Cross-polarization discrimination

When an electric field of magnitude E_1 is transmitted through a depolarizing medium, the received signal will have a copolar component (E_{11}) and a cross-polar component (E_{12}).

It is defined as follows:

$$XPD\ (dB) = 20\log\left(\frac{E_{11}}{E_{12}}\right)$$

- Polarization isolation

This applies to two orthogonal signals that go by the same depolarizing medium. Both will have copolar and cross-polar components at the receiver. Polarization isolation is the ratio of the received copolar power to cross-polar power, and it is defined as:

$$I\ (dB) = 20\log\left(\frac{E_{11}}{E_{21}}\right)$$

- Rain and ice depolarization

Drops of rain also add depolarization. The ideal drop of rain has a spherical shape so that the necessary energy to keep it together is minimal. However, the real shape of a drop is flattened, where there is a major axis relatively to the others, forming a spheroid. Since rainfall results in random directions of rain drops, which will vary even with the wind, they will be canted. This results in the rotation of polarization of the radio waves. This rotation may reach up to 10º, what may become a quite serious problem in linear polarization, but not that much in circular polarization because, such as in ionospheric depolarization, this value will only add to the rotation.

On the top of each rain area there is an ice layer which can cause depolarization. Ice crystals usually have the shape of a needle or a plate. When their disposition is random there is no depolarization, but when there's an alignment it may occur.
International Radio Consultative Committee (CCIR) recommends the use of a statistical value of 2dB added to the XPD determined for rain. Furthermore, ice effects may be despised for time percentages inferior to 0.1%.

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 (Fig 1.4). 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.
Figure 1.5 shows also an optimal window between 1 GHz and 10 GHz, rather useful for satellite transmissions due to its fairly low noise temperature.
Considering VORSat's operation at 2.45 GHz, the temperature of cold sky can be approximated of 10 K.

Atmospheric effects in satellite transmissions increase with the increase of frequency (Fig 1.6). As said previously, the effects of the atmosphere in signal attenuation become serious for frequencies above 10 GHz, and the same applies for noise temperature.

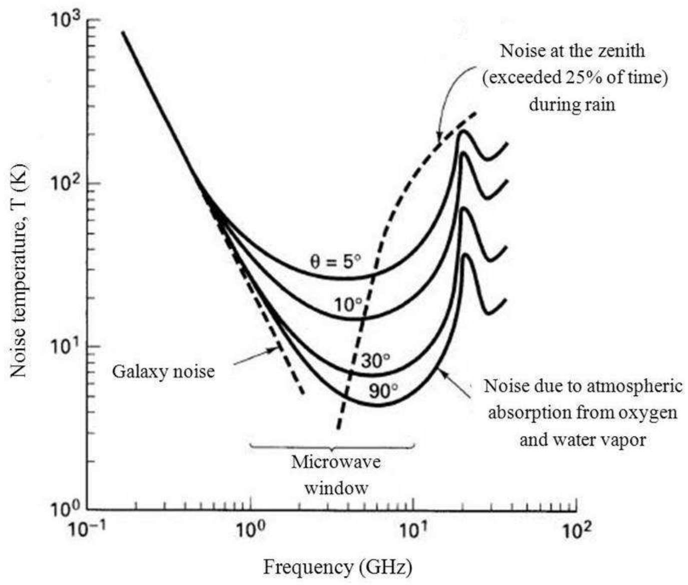

Figure 1.5 – Galaxy noise influence in noise temperature.

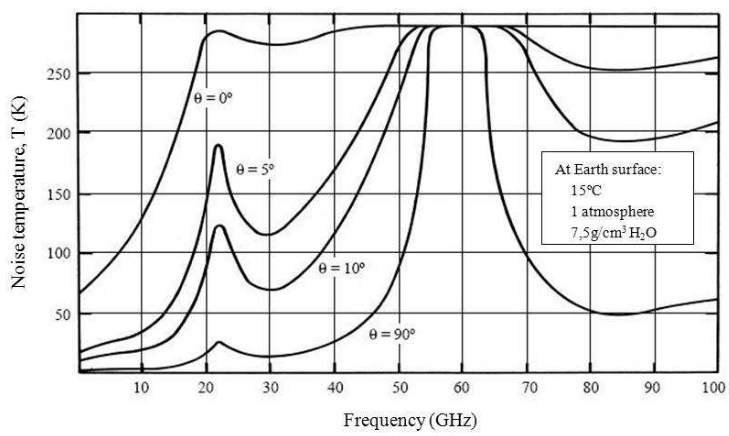

Figure 1.6 – Noise temperature variation with frequency.

For the frequency f = 2.45 GHz, this value is much more reduced.

1.1.2.3 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.
This is not the case for the ground station placed at FEUP, once it is free of possible external interferences and it is located at an elevation of 125 m above the sea level, what

makes it one of the highest points nearby. That allows this GS to be able to receive VORSat's transmission from its lowest elevation point.
Nevertheless, this problem is much weightier in other communications systems, such as mobile services.
For satellite communications this factor may be negligible.

1.1.3 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 8 000 ms^{-1}.

There are two ways for misalignment:

- Off-axis loss at the satellite;
- Off-axis loss at the GS.

The first one is considered during the design of the satellite.
The second type of misalignment is the antenna pointing loss and it is usually quite small, not reaching even 1 dB, being this value a good approximation for pointing misalignment loss.
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.

1.2. LOCAL LOSSES

These losses refer to loss of signal quality in each ground station.

1.2.1 EQUIPMENT LOSSES

The receiving and emitting equipments also introduces some losses to the signal.

<u>Feeder Losses</u>

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).

Receiver feeder losses (RFL) added to FSL and are not necessary but to relate EIRP with the HPA output, which means that knowing the EIRP will allow the calculations without being aware of the RFL values.

So, for the calculation of the link budget of VORSat, these losses are not taken into account.

1.2.2 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.

Portugal has mid latitude and is at the temperate northern region, which has no extreme values for atmospheric conditions. Hence this factor may be neglected.

1.3 OTHER IMPAIRMENTS

There are also other factors that may condition satellite communications. Even though they may have a minor importance in CubeSat's transmissions, they may become relevant in other cases.

Sun Outage

Sun outages are punctual losses of communication between satellites and the Earth due to satellite's obscuration by the sun. It means that the ground station *sees* the sun behind the satellite, in what is called a "transit".
It occurs in 5 or 6 days near the equinoxes and last for a maximum of 8 minutes each, in a total of 60 minutes per year. The noise temperature of the system becomes very high and communications suffer negative consequences at about 100 minutes per year (0.02%).
Sun outage affects other kinds of satellites, but not LEO's.

Satellite eclipses

These eclipses happen when the satellite crosses the cone of shadow of the Earth. They occur within 23 days before and after the equinoxes, at March 21st and September 23rd.
They last 70 minutes at their maximum and some strong thermal variations are produced. During the eclipse, the satellite operates only with batteries and some transponders are disconnected.
However, this problem only affects geosynchronous satellites due to their fixed position relative to the Earth.

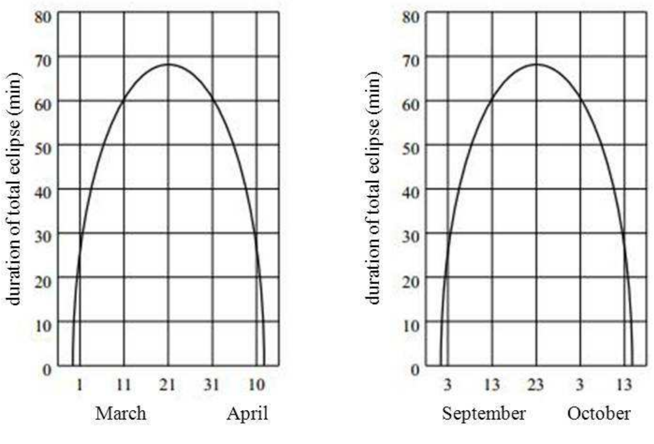

Figure 1.7 – Dates and duration of eclipses

2. 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:

$$T_S = T_A + T_{comp}$$

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:

$$T_A = T_m \left(1 - 10^{-A/10}\right) + T_C \, . \, 10^{-A/10}$$

Usually, for clouds it is considered T_m = 280 K and for rain T_m = 260 K.

Other components also provoke attenuation of the signal. In order to calculate T_{comp} it is necessary to determine the effective noise temperature and the gain of each stage of the ground station receiver path, according to the Friis formula:

$$T_{comp} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 \, G_2} + \frac{T_4}{G_1 \, G_2 \, G_3}$$

The effective noise temperature of each component is provided by:

$$T_N = (F - 1) \, T_0$$

where:

T_N → Effective noise temperature
F → Noise figure
T_0 → Reference temperature (290 K)

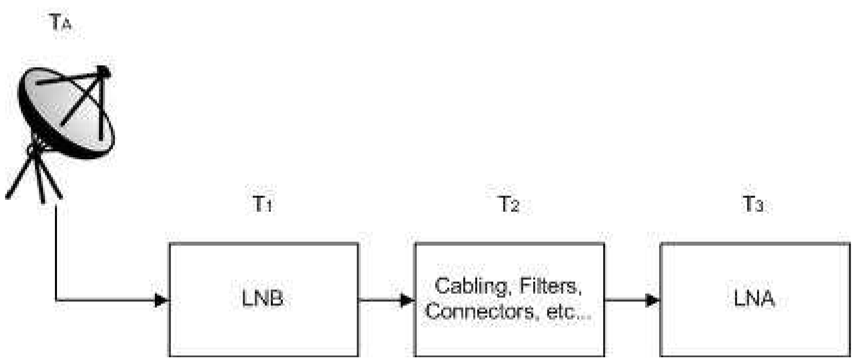

Figure 2.1 – Reception scheme of GS at FEUP

The following calculations for this specific case can be made.
Considering:

T_m = 280 K
T_C = 10 K (given by sky noise)
L_{abs} = 1 dB

the antenna temperature is:

$$T_A = 280\,(1 - 10^{-1/10}) + 10\ .\ 10^{-1/10}$$

$$T_A = 65.5\ K$$

The first stage of downlink reception is the Low Noise Block Converter (LNB), which is connected to the Low Noise Amplifier (LNA) by short cables and connectors.

The value for the noise figure F in dB will be converted for decimals by:

$$F = 10^{F(dB)/10}$$

In the case of the cables, the noise figure is obtained through the attenuation, by the following expression:

$$F = 1 + \frac{(L - 1)\,T}{T_0}$$

Considering T the physical temperature of the component when $T = T_0$, then $F = L$.

The effective noise temperatures are:

$$T_1 = (0.6\ dB - 1)\ 290 = 42.98\ K$$

$$T_2 = (5\ dB - 1)\ 290 = 917.07\ K$$

$$T_3 = (0.5\ dB - 1)\ 290 = 35.38\ K$$

Knowing that G1 = 28 dB and G2 = -5 dB (the cables only attenuate the signal):

$$T_{comp} = 42.98\ + \frac{917.07}{10^{2.8}}\ + \frac{35.38}{(10^{2.8}\ x\ 10^{-0.5})}$$

$$T_{comp} = 44.61\ K$$

The system noise temperature is:

$$T_S = T_A + T_{comp} = 110.11\ K$$

3. LINK BUDGET CALCULATION

The necessary knowledge has been provided in previous sections, as well as some indicators about the values these calculations are going to use.
VORSat will have no uplink. Ergo, what is shown next represent only downlink communication.

Considering:

P_T → Transmission power
L_T → Transmission loss
G_T → Transmission antenna gain

EIRP will be provided by:

$$EIRP = P_T - L_T - G_T$$

It becomes possible to elaborate the following table:

Table 3.1 – Calculation of EIRP.

Transmission Power	25		dBm
Transmission Loss	1		dB
Transmission Antenna Gain	4,5		dB
EIRP		30,5	dBm

The following proceeding is the calculation of free space loss. This is the factor that influences the most satellite communication. In order to achieve an approximate value for FSL in the worst case scenario, it is obligatory to determine the maximum distance between VORSat and the ground station.

The image represents schematically how to calculate that distance and how it varies with the elevation angle.

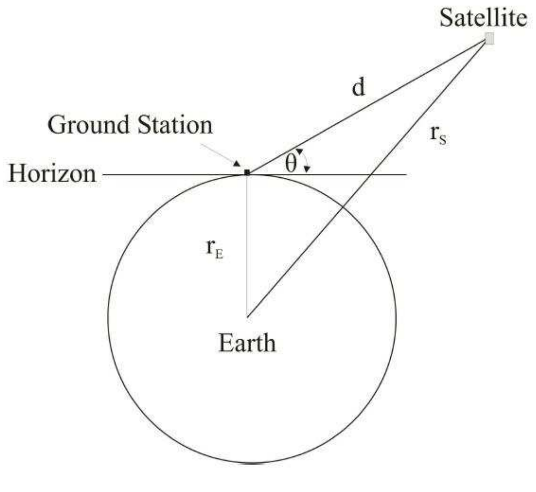

Figure 3.1 – Variation of the distance VORSat – GS with the elevation angle.

In figure 1.1, the letters represent:

r_E → Mean radius of the Earth
θ → Elevation angle
d → Distance GS – Satellite
r_S → Distance centre of the Earth – Satellite

From the cosine law:

$$r_S^2 = d^2 + r_E^2 - 2.d.r_E.\cos(\theta + \pi/2)$$

and isolating d in one side of the equation, a dependence of θ is obtained:

$$d = -r_E.\sin(\theta) + \sqrt{(r_E^2.\sin^2(\theta) + r_S^2 - r_E^2)}$$

Assuming the worst case for θ and r_S:

$r_E = 6\ 371$ km
$\theta = 10^o$
$r_S = 6\ 671$ km

d is approximately 1 160 km.

From the graphic for FSL, at the distance 1 160 km, FSL = 161.47 dB.

Empirical calculations confirm this value for f = 2.45 GHz and $c = 3\text{x}10^8\ \text{ms}^{-1}$:

$$FSL = 10\log\left(\left(\frac{4\pi df}{c}\right)^2\right) = 161.51\ \text{dB}$$

Atmospheric losses have also to be determined.
As said previously, this kind of losses is caused by ionospheric, tropospheric and local effects.

Major problems in ionospheric effects are polarization rotation and scintillation effects.
Polarization rotation won't be a problem once the 2.45 GHz of VORSat are significantly below the threshold of 10 GHz when satellite communications start to suffer relevant problems.
Likewise, scintillation effects are barely felt in Portugal as already mentioned.
Therefore, ionospheric effects may be neglected.

From other layer in atmosphere come different impairments for satellite communication. Tropospheric effects can be due to attenuation, rain attenuation, gas absorption, depolarization and sky noise.
Attenuation is not relevant for frequencies below 10 GHz.
Rain attenuation won't be calculated because these events will be quite punctual and will affect few passages of VORSat.

Gas absorption will cause loss of signal. Considering the specific attenuation of oxygen at f = 2.45 GHz as 0.006 $dBkm^{-1}$ and the maximum thickness of troposphere of 20 km, the atmospheric absorption (L_{abs}) at $\theta = 10^o$ will be:

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

$$L_{abs|10^o} = 0.69\ dB$$

The losses for gas absorption are L_{abs} = 0.69 dB. However, a value of 1 dB will be used in calculations in order to include other losses such as rain attenuation, thereby providing a margin of approximately 0.31 dB.

It is hard to predict the exact amount of losses caused by depolarization. CCIR recommends the use of 2 dB added to the XPD determined for rain.
VORSat will transmit circular polarized signals.
Table 3.2 indicates polarization losses for several transmitting and receiving antenna combinations. So, for circular polarization transmissions, the worst case in reception implies a loss of 3 dB, half the signal power.

Table 3.2 – Polarization losses for different polarizations in antennas.

Transmit Antenna Polarization	**Receive Antenna Polarization**	**Ratio of Power Received to Maximum Power**		
		Theoretical	Practical Horn	Practical Spiral
		Ratio in dB	Ratio in dB	Ratio in dB
Vertical	Vertical	0	*	N/A
Vertical	Slant (45° or 135°)	-3	*	N/A
Vertical	Horizontal	-∞	-20	N/A
Vertical	Circ (RHCP/LHCP)	-3	*	*
Horizontal	Horizontal	0	*	N/A
Horizontal	Slant (45° or 135°)	-3	*	N/A
Horizontal	Circ (RHCP/LHCP)	-3	*	*
Circ (RHCP)	Circ (RHCP)	0	*	*
Circ (RHCP)	Circ (LHCP)	-∞	-20	-10
Circ (RHCP/LHCP)	Slant (45° or 135°)	-3	*	*

NOTE: The symbol * means the values are the same as theoretical. It is important to refer as well that switching the transmitting and the receiving antennas the same results will be obtained.

It is excluded the case where the signal from a right hand circular polarization (RHCP) is received by a left hand circular polarization (LHCP) antenna, or vice-versa. This case clearly doesn't allow any signal reception.
Thus, for VORSat's link budget calculations the depolarization loss is 3 dB.

Local effects won't be considered in these calculations once the surroundings of the GS placed at FEUP have almost no interference in signal reception.

Propagation losses calculations end with the pointing losses. This is a statistical estimation, and 1 dB is considered a good approximation.

Propagation losses are the combination of all the items mentioned so far.

$$L_{prop} = FSL + L_{abs} + L_{pol} + L_{aml}$$

$$L_{prop} = 166.47 \text{ dB}$$

Table 3.3 – Calculation of the propagation loss.

Free Space Loss	161,47		dB
Atmospheric Absorption	1		dB
Polarization Loss	3		dB
Antenna Misalignment Loss	1		dB
Propagation Loss		166,47	dB

Other factors that may affect signal transmission are local losses. They include losses due to the equipment and to the environment in the GS area. However, these losses are irrelevant to the link budget calculations for VORSat.

Considering an isotropic antenna in the reception, the received power will be given by:

$$P_r = EIRP - L_{prop}$$

$$P_r = -135.97 \text{ dBm}$$

Next step for calculations is the determination of the figure of merit of the receiver, G/T_S, where:

- G → Antenna gain of the receiver
- T_S → System noise temperature

The figure of merit provides information on the performance of the receiver, as it increases with the figure of merit.

$$\frac{G}{T_S} = \frac{35 \text{ dB}}{110.11 \text{ K}} = 14.59 \text{ dBK}^{-1}$$

After G/T_S, it becomes possible to determine the ratio of received power (P_r) to noise spectral density (N_0), where:

- k → Boltzmann constant ($k = 1.38 \times 10^{-23}$ JK^{-1} = -228.6 dBW/K/Hz)

$$\frac{P_r}{N_0} = \frac{GPri}{kTs} = 77.22 \text{ dBHz}$$

In a tabular form, this calculation may be presented as:

Table 3.4– Calculation of P_r/N_0.

Free Space Loss	-161,47		dB
Atmospheric Absorption	-1		dB
Polarization Loss	-3		dB
Antenna Misalignment Loss	-1		dB
G/Ts	14,59		dB/K
EIRP	30,5		dBm
k	228,6		dB/K/Hz
Pr/N0		77,22	dBHz

E_b/N_0 is provided by the value of P_r/N_0 divided by the data rate of the downlink. Considering the bit rate as 9600 bit/s (it will depend also on the forward error correction technique to implement):

$$\frac{E_b}{N_0} = \frac{P_r}{N_0} \times \frac{1}{9600} = 37.40 \text{ dB}$$

If the bit error rate (BER) is less than 10^{-5} with QPSK modulation, and noting that $E_b/N_{0|BER=10^{-5}} = 9.6$ dB, the downlink margin is:

$$M_D = 37.40 - 9.6 = 27.80 \text{ dB}$$

The following table for the link budget may be implemented:

Table 3.5 – Link budget.

DOWNLINK @ 2.45 GHz			
Feature	**Data**	**Result**	**Unit**
Maximum Distance	1160		km
Transmission Power	25		dBm
Transmission Loss	1		dB
Transmission Antenna Gain	4,5		dB
EIRP		30,5	dBm
Free Space Loss	161,47		dB
Atmospheric Absorption	1		dB
Polarization Loss	3		dB
Antenna Misalignment Loss	1		dB
Propagation Loss		166,47	dB
Satellite Antenna Gain	35		dB
System Noise Temperature	110,11		K
Figure of Merit		14,59	dB/K
Boltzmann Constant	-228,6		dB/K/Hz
Pr/N0		77,22	dBHz
Bit Rate	9600		bit/s
Eb/N0		37,4	dB
BER	10^{-5}		
Eb/N0 @ 10^{-5}	9,6		dB
Downlink Margin		27,8	dB

LIST OF REFERENCES

[1] xxxx