LELEC2910 : Project report

Cubesat feasibility assessment using Rapids software

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Antenna and Propagation

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Contents

1 Introduction **2**

2 Attenuation **2**

2.1 Total attenuation and goals 2
2.2 Clouds 3
2.3 Rain 4
2.4 Gases and water vapour 5
2.5 Conclusion 5

3 Link budget calculation **6**

3.1 Overall equation for link budget 6
3.2 Fiding the missing parameters 7
3.3 Assesing the link budget 8

1 Introduction

Signals travelling between earth and space undergo different effects cumulated across the different layers that make up the earth's atmosphere. Analysing the effects due to propagation through the troposphere, we are particularly interested in the attenuation caused by gases(oxygen and water vapour), rain and clouds. These simulations are typically useful while designing a satellite with a certain quality of transmission/reception of datas. Some part of this report are based on the work already provided for the project of course LELEC2795. Though this report will go deeper in the calculation and try to forecast the link budget associated with 2 antenna base stations.One in Svalbard[1] and the other one in Graz. [2]
It is important to keep in mind that the results from those simulations have not been verified yet for 75GHz as no real data are available due to the fact that the actual "real" project is still in development.

The end goal is to send a cubesat in a non geostationary orbit at an altitude of 2800km, this paper therefore assesses the feasibility of this project by trying to forecast its link budget for the 2 different base stations.

Figure 1: The left figure displays the locations of Svalbard whereas the right hand side figure provides the localisation of Graz

2 Attenuation

2.1 Total attenuation and goals

The total attenuation increases for higher frequencies signals as well as for lower elevation angles, as showcased on the graphs of figure 2[3]. In general, higher frequency signals are more prone to water based attenuation. This graph includes the attenuation due to gazes, clouds and rain.

The approach followed on this report will be to isolate the attenuation from the different sources, identify their causes and compare their levels in dB. The result expected should give similar result to the figure 3[4].

[1]An island belonging to Norway, already famous for being one of the most ideal place in Europe to have antennas. Indeed it has a very high availability and propitious weather conditions.
[2]Situated in Austria
[3]Another typical curve can be found on figure 3 taken from LELEC2910-Antennas and Propagation, Christophe Craeye and Danielle Janvier
[4]Taken from LELEC2910-Antennas and Propagation, Christophe Craeye and Danielle Janvier

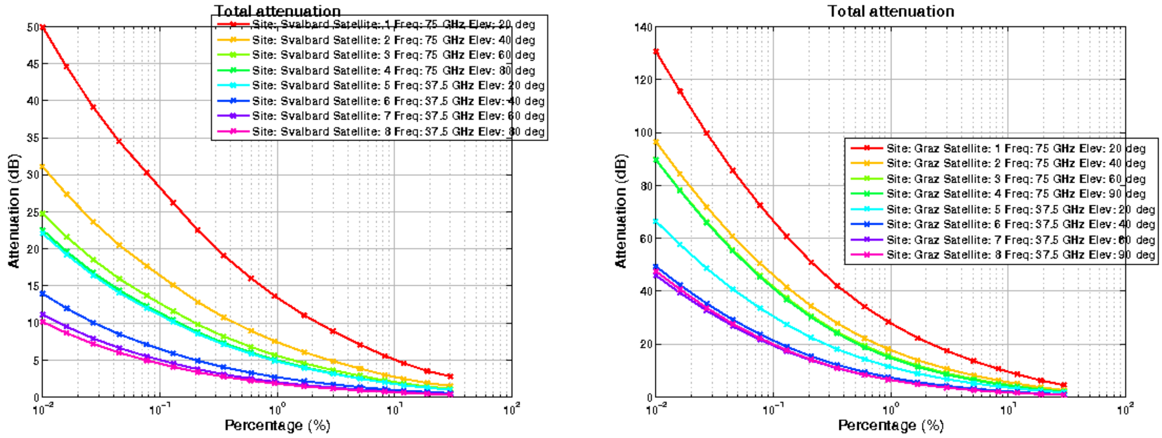

Figure 2: The left figure displays the CCDF of total attenuation for our base station in Svalbard (in Norway). The right one shows the total attenuation for the other base station of interest in Graz (In Austria). As one can see, Svalbard offers much better weather conditions (50 dB or more of attenuation only occurs 0,01 % of the time) in comparison to Graz for this project.

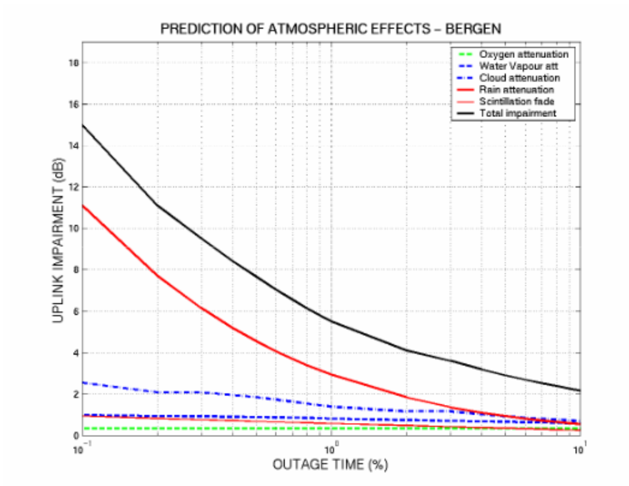

Figure 3: The graph shows the total attenuation and the contribution of the various components for a typical case from theory for a given frequency and a given angle

2.2 Clouds

As one can observe in figure 5, the curve of the attenuation due to clouds is strongly linked to the curve of the water content. This is expected from the theory because the attenuation due to clouds is proportional to the water content (g/m^3) in clouds. We can observe several features:

- the attenuation for clouds typically varies from a fraction of dB up to several dB.
- the level of attenuation strongly increases with frequency. The wavelength becoming smaller the effect of interactions with water molecules increases.
- the attenuation decreases with the elevation angle this is expected because this implies lower reflections

The observation above are validated by the formula:

$$A(P) = \frac{L(P)\,K_l}{\sin \alpha_1}$$

$$K_l = \frac{0.819 f}{\varepsilon''(1+\eta^2)} \qquad \text{(dB/km)/(g/m}^3\text{)}$$

$$\eta = \frac{2+\varepsilon'}{\varepsilon''}$$

The dielectric permittivity of water is given in the recommendation

Figure 4: Formula for cloud attenuation

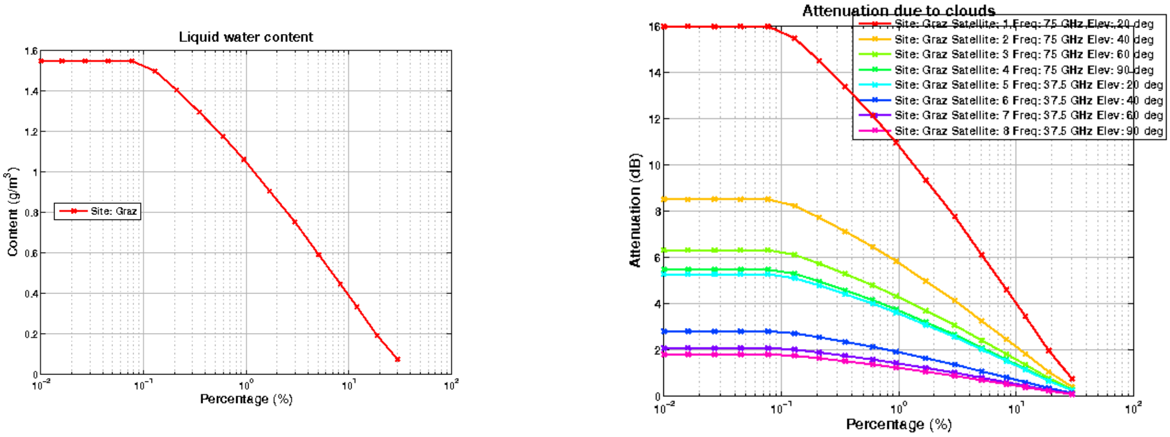

Figure 5: A graph of the liquid water content is displayed on the left while on the right another graph shows the attenuation due to clouds. Both graphs are for the base station situated in Graz, simply because the weather have a bigger impact at that base station

2.3 Rain

Figure 6 represent the attenuation due to rain. We can deduce some features from this graph:

- this attenuation varies from several dB up to 110 dB which will occur 0.01% of the year for 75 GHz. This is the more important contribution to the attenuation.
- the lower the percentage is, the more it takes into account rarer effects such as heavier rain with big rain drop and then implies higher attenuation

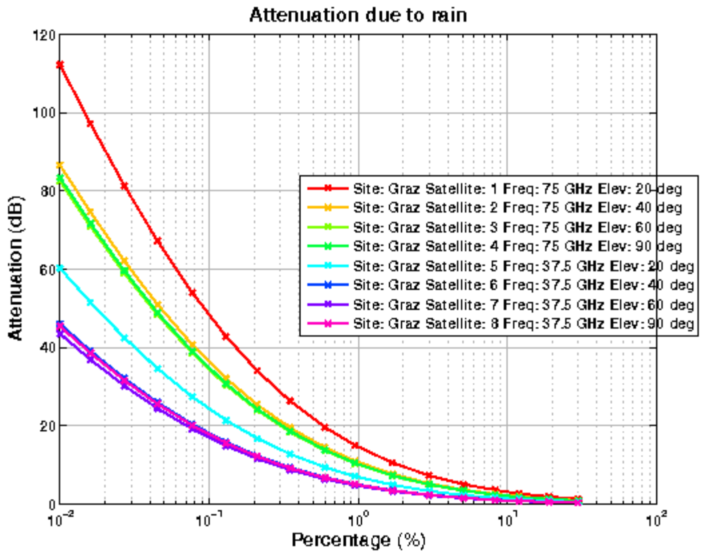

Figure 6: Attenuation due to rain for the base station in Graz

2.4 Gases and water vapour

Our signals travelling through the troposphere the absorption in the figure 7[5] at 37.5 GHz and 75 GHz must be multiplied by the number of kilometres it has travelled through gases to obtain the real absorption from which we can deduce the attenuation. This absorption is almost constant through the entire year.

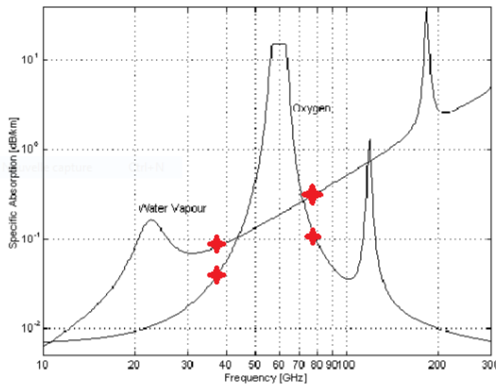

Figure 7: Typical absorption per Km for water vapour and oxygen through the troposphere, the crosses in red approximatively represent the studied situation, so for 37.5GHz and 75GHz

2.5 Conclusion

One can see that in general, the rain impact is more important than the other factor except for the high frequency with the small elevation angle. We can also see the that the losses due to the gases and water vapour is stable with an higher loss for the high frequencies, which is explained in the previous section.

[5]Taken from LELEC2910-Antennas and Propagation, Christophe Craeye and Danielle Janvier

On an other hand, if we compare the gap between the cloud and the rain impact for the two elevations, we can see that this gap is bigger for an elevation equals to 60 degrees. It is because the rain have a bigger impact over the travel of the signal.

The results obtain for the future Graz base station is relevant since we can see a correlation with our result and the graph shown in the lecture on figure 8.

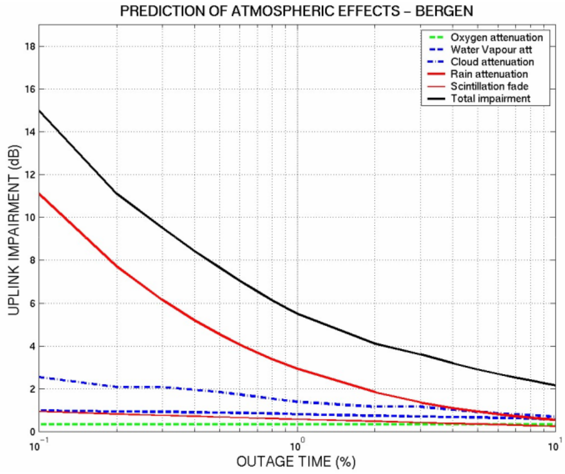

Figure 8: Example of the various effects and their statistics

3 Link budget calculation

3.1 Overall equation for link budget

This section will describe the calculations required to forecast the EIRP (Equivalent Isotropic Radiated Power) required for successfully detect the signal with a minimum SNR (Signal to Noise ratio) of 10dB. The calculations will be based of the parameters displayed on figure 9.

Earth-satellite mean distance: 2800 km	
W band	
frequency	75 GHz.
Polarization	Dual polarization (RHCP* and LHCP*)
Antenna boresight	Nadir
EIRP	?? dBW
Receive antenna gain	51 dBi
Antenna efficiency	57%
LNA noise temperature	500K
Receiver bandwidth	50 Hz
Min C/N for detection	10 dB
Q band	
frequency	39.5 GHz.
Q Band Polarization	Dual polarization (RHCP* and LHCP*)
Boresight	Nadir
EIRP	?? dBW
Receive antenna gain	To be evaluated, same antenna as for W band
Antenna efficiency	60%
LNA noise temperature	450K
Receiver bandwidth	50 Hz
Min C/N for detection	10 dB

Figure 9: Parameters provided for this link budget, the Q band transmission operates at 37.5 GHz and not at 39GHz

It is convenient to start by the W band transmission as all the parameters required for the link budget are provided, though the main equations are the same for both calculations.

$$SNR = \frac{P_R}{N} = \frac{EIRP \times G_R}{NL} \tag{1}$$

$$EIRP = \frac{SNR_{min}}{G_R} NL \tag{2}$$

Which would give in dB:

$$EIRP[dBW] = SNR_{min}[dB] - G_R[dB] + 10log(k_b BT) + 10log((\frac{4\pi r}{\lambda})^2)[dB] + TotalAttenuation[dB] \tag{3}$$

3.2 Fiding the missing parameters

For the W band,as we have all the values for each parameters and having the total attenuation through the simulations carried out on the Rapids software, all the calculations can be done. Whereas for the Q band, we have some missing pieces of information that can easily be retrieved from the data provided for the W band transmission.

$$G_R = \frac{4\pi A}{\lambda^2}\eta \tag{4}$$

From equation 4[6], A, the area of the antenna can easily be found using the W band transmission (A=0.2812 m) values,and assuming the antenna is the same for Q band transmission, we can calculate the corresponding G_R for the 37.5 GHz transmission ($G_R = 45.202dB$).

[6] η is the antenna efficiency

3.3 Assesing the link budget

Putting everything together, and replacing by the values provided we get 2 equations, one for each type of transmission;
For 75GHz

$$EIRP[dB] = 10 - 51 + (-184.62) + 198.88 + TotalAttenuation[dB] \tag{5}$$

For 37.5GHz

$$EIRP[dB] = 10 - 45.20 + (-184.62) + 192.87 + TotalAttenuation[dB] \tag{6}$$

Result of the required EIRP are displayed on figure 10 for Svalbard and on figure 11 for Graz for a certain availability during the year and for a certain angle. Taking into account that the Cubesat can at most deliver a peak power of 65W[7], all the values much higher have been highlighted in red, the ones close to that values are in orange and lastly the green ones are the acceptable values.

Svalbard					
Elevation	Frequency	Availabitlity			
		99%	99,50%	99,90%	99,99%
		Required EIRP [dBW]			
20 degrees	75GHz	-13,1	-10,71	-0,5	22,61
	37,5GHz	-22,04	-21,11	-16,83	-4,86
60 degrees	75GHz	-21,05	-19,98	-15,14	-2,01
	37,5GHz	-24,89	-24,47	-22,41	-15,83
		In watts			
		4,90E-02	8,49E-02	8,91E-01	1,82E+02
		6,25E-03	7,74E-03	2,07E-02	3,27E-01
		7,85E-03	1,00E-02	3,06E-02	6,30E-01
		3,24E-03	3,57E-03	5,74E-03	2,61E-02

Corresponding attenuations [dB]			
13,64	16,03	26,24	49,35
4,91	5,84	10,12	22,09
5,69	6,76	11,6	24,73
2,06	2,48	4,54	11,12

Figure 10: Calculation of the EIRP for Svalbard , the right side table's values are directly fetched from the simulation files

Graz					
Elevation	Frequency	Availabitlity			
		99%	99,50%	99,90%	99,99%
		Required EIRP [dBW]			
20 degrees	75GHz	1,71	7,44	33,99	103,86
	37,5GHz	-15,33	-12,67	0,45	39,47
60 degrees	75GHz	-11,06	-7,36	10,72	62,99
	37,5GHz	-20,37	-18,63	-9,69	18,99
		In watts			
		1,48E+00	5,55E+00	2,51E+03	2,43E+10
		2,93E-02	5,41E-02	1,11E+00	8,85E+03
		7,83E-02	1,84E-01	1,18E+01	1,99E+06
		9,18E-03	1,37E-02	1,07E-01	7,93E+01

Corresponding attenuations [dB]			
28,45	34,18	60,73	130,6
11,62	14,28	27,4	66,42
15,68	19,38	37,46	89,73
6,58	8,32	17,26	45,94

Figure 11: Calculation of the EIRP for Graz ,the right side table's values are directly fetched from the simulation files

As one can expect, the Svalbard station is much more feasible link budget wise whereas Graz showcase more difficult conditions. [8]

[7] According to https://fr.wikipedia.org/wiki/CubeSat

[8] It is obvious that a 99,99% Availability during the year is completely ruled out for both 75GHz and 37,5GHz transmissions