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Radiocommunication Systems

Report 1

Satellite Communication Analysis

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1 Introduction

Communication has always been regarded as one of the defining factors that pushed Mankind forward as a species, with global-wide communication being a crowning achievement of modern society. Such a feat is now considered commonplace, however, due to the development of technology capable of facilitating the entire process, with satellite communication being chief among them.

The purpose of this lab report is to examine data received by means of Satellite Communication, interpret its effectiveness, and attempt to explain possible weaknesses that are identified in the course of the experiment (hardware limitations, unfavorable weather conditions).

2 System Overview

The hardware used for the experiments described in this report consists of a parabolic dish antenna mounted on the roof of the building of the Department of Electrical and Computer Engineering at FEUP pointing at a satellite. The received signal from the dish get focused into the Low Noise Block (LNB) which amplifies he signal and then passes it through a coaxial cable into a -20 dB splitter which divides the signal into two outputs. One output signal receives 1% of the power and goes into a TV receiver to display the signal on a TV. The second output receives 99% of the power and goes into a spectrum analyzer which conducts the measurements for the lab. An overview of this system is shown in figure 1

The conducted experiments consist of two parts. For the for part of analyzing the system hardware parameters several measurements were conducted. They are display in table 1

Measurement	**Power at Signal Frequency**	**Power at Noise Frequency**	**Explanation**
Nominal	-44.51 dBm	-59.96 dBm	Measurement under standard conditions
Cable 2	-41.02 dBm	-55.64 dBm	Cable replaced by another cable
Both Cables	-47.73 dBm	-63.17 dBm	Using both cables in series
Absorber	-55.54 dBm	-55.60 dBm	Absorber material in front of LNB
S.A. alone	-90.22 dBm	-89.37 dBm	LNB switched off

Table 1: Measurements for System Analysis

With these measurements the calculations explained in chapter 4 were conducted.

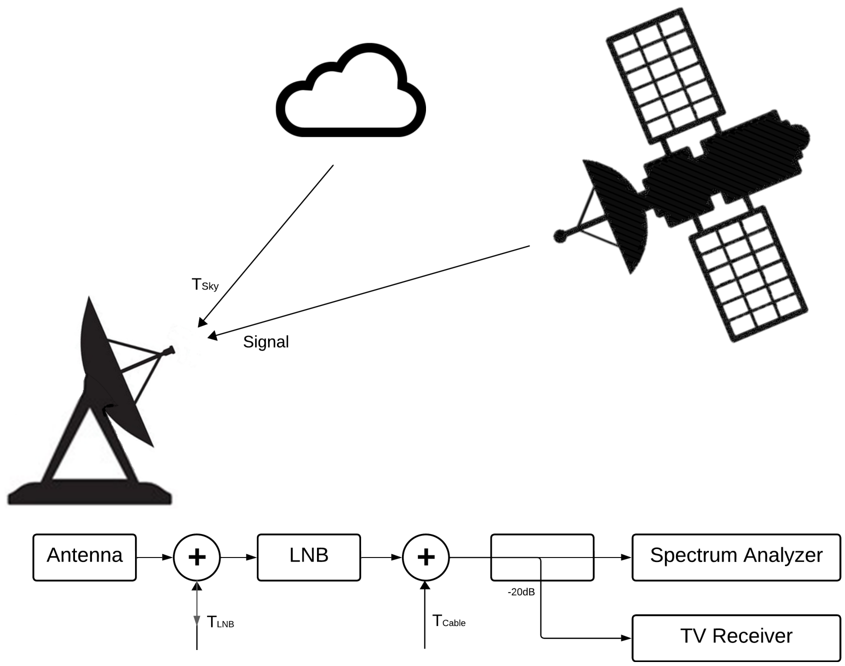


Figure 1: System Overview

The second part of the experiments regarding the different environmental factors on the signal quality made a long therm collection of data necessary. For that, the power levels under nominal conditions were collected over a duration of multiple weeks in intervals of 20 seconds. The analysis of this data is presented in chapter 5 of this report.

3 Satellite Choice

The measurements were conducted for communications with the EUTELSAT Satellite Hotbird 13C.

This satellite is geosynchronous the a position of 13°E and 0°N. With the known satellite coordinates and antenna position (41.17828 ° N, 8.59497 ° W), the antenna direction can be calculated.

$$\Theta_E = 41.17828°,\ \Phi_E - \Phi_S = 13° - (-8.59497°) = 21.59497°$$

$$\frac{r_T}{r_S} = 0.15127,\ r_S = 42\,164\,km$$

$$\gamma = arccos[cos(\Theta_E) \cdot cos(\Phi_E - \Phi_S)] = 45.5863°$$

$$Elevation : \alpha = arctan(\frac{cos(\gamma) - \frac{r_T}{r_S}}{sin(\gamma)}) = 37.5231°$$

$$Azimuth : \beta = \pm arccos(\frac{-tan(\Phi_E)}{tan(\gamma)}) = +148.9861$$

$$Distance\ Earth\ Surface\ -\ Satellite : d = r_s(1 + (\frac{r_t}{r_S})^2 - 2 \cdot \frac{r_t}{r_S} \cdot cos(\gamma))^{\frac{1}{2}}$$
$$= 37\,974.64\,km$$

These formulas assume a spherical earth which causes some inaccuracies but for this application they are sufficient.

Knowing the elevation and the frequency used ($\approx 11.2\ GHz$) the sky temperature can be assumed using a graphic from the lecture that provided in figure 2. The resulting sky temperature is $T_{Sky} = 17\,K$

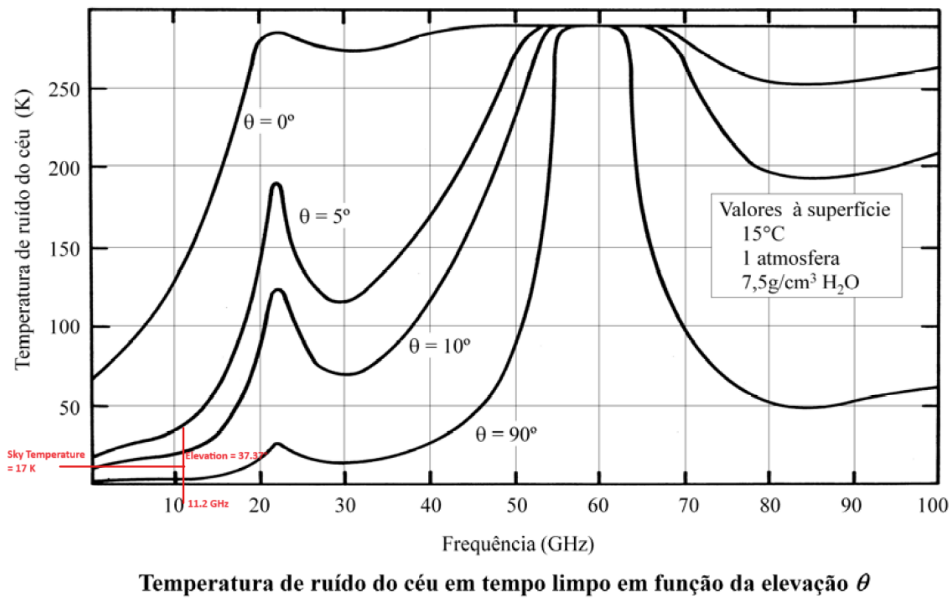


Figure 2: Sky Temperature depending on Elevation and Frequency [1]

The satellite used broadcasts multiple TV and radio channels over a wide spectrum. For these experiments, we measured at the frequency of 11.158 GHz for the signal power level. This is the center frequency of a channel with a 3 dB bandwidth of 27.5 MHz. But we only measured the power within a bandwidth of 20 MHz. The noise power levels were obtained with 20 MHz bandwidth around the center frequency of 11.212 MHz where no channels are present.

4 Characteristics of RF Chain

4.1 Cable Loss

To calculate the loss caused by the cable connecting the LNB with the spectrum analyzer, a measurement with another cable was conducted in addition to a measurement with the original and the second cable connected in series. This has been done both on the signal and on the noise frequency. Then the value can be calculated as follows:

$$L_{Cable} = P_{Cable\,2} - P_{both\,Cables}$$
$$Signal: \; -42.02\,dBm - (-47.73\,dBm) = 6.71\,dB$$
$$Loss: \; -55.64\,dBm - (-63.17\,dBm) = 7.53\,dB$$
$$Average \approx 7.1\,dB$$
$$linear\,Value: \; l_{Cable} = 10^{\frac{-7.1\,dB}{10}} = 0.195$$

4.2 Antenna Gain

The gain of the antenna can be calculated from its size ($D = 1.8\,m$) and efficiency ($\epsilon = 0.6$, estimated value) with the following formula:

$$G_{A\,in\,dB} = 10 \cdot log_{10} \cdot (\frac{\epsilon \cdot \pi \cdot \frac{D^2}{4}}{\frac{\lambda^2}{4\pi}})$$
$$= 10 \cdot log_{10} \cdot (\frac{0.6 \cdot \pi \cdot \frac{(1.8\,m)^2}{4}}{\frac{(26.9\,mm)^2}{4\pi}}) = 44.2\,dB$$

4.3 Gain of the LNB

The gain of the LNB shall be calculated to check the claim of the manufacturer. This can be done using the measurement with the absorber material in front of the antenna. In this case, the power received by the antenna is known, because it is only the noise from the absorber that depends on the temperature ($T_0 = 290\,K$). Also, the influence of the whole RF chain needs be considered:

$$P_{absorber,\,linear} = [(T_0 + (f_{LNB} - 1) \cdot T_0) \cdot g_{LNB} \cdot l_{cable} + T_0 \cdot (1 - l_{cable}) + T_0 \cdot (f_{SA} - 1)] \cdot B \cdot K$$

Because of high gain of LNB the relatively small influence of the noise added by cable and spectrum analyzer can be neglected which leads to:

$$P_{absorber,\,linear} = f_{LNB} \cdot g_{LNB} \cdot L_{cable} \cdot T_0 \cdot K \cdot B$$

In dB this leads to:

$$P_{absorber,\,db} = NF_{LNB} + G_{LNB} - L_{cable} + 10 \cdot log_{10}(T_0 \cdot K \cdot B)$$

Solving for the gain of the LNB leads to:

$$G_{LNB} = -10 \cdot log_{10}(T_0 \cdot K \cdot B) - NF_{LNB} + L_{cable} + P_{absorber,\,db}$$
$$G_{LNB} = 100.97\,dB - 0.5\,dB + 7.1\,dB - 55.54\,dB \approx 52\,dB$$

4.4 Noise Figure of the Spectrum Analyzer

To calculate the noise figure of the spectrum analyzer, we use the measurements conducted with the LNB switched off. In this case the LNB doesn't add any noise so the measured power value comes from just from thermal noise and the nose of the spectrum analyzer itself:

$$P_{S.A.\,alone} = 10 \cdot log_{10}(f_{S.A.} \cdot T_0 \cdot K \cdot B) = -90.22\,dB$$

This can be divided into thermal noise and the noise figure of the spectrum analyzer:

$$-90.22\,dB = 10 \cdot log_{10}(T_0 \cdot K \cdot B) + NF_{S.A.}$$

Solving for the noise figure of the spectrum analyzer leads to:

$$NF_{S.A.} = -90.22\,dB - (-100.97\,dB) \approx 11\,dB$$

4.5 Link Budget

To check for plausibility of the measurements the expected received power obtained by calculating the link budget got compared with actually received power level.
Theoretically expected receive power:

$$P_{expected} = EIRP + FSL + G_{RX} + G_{LNB} - L_{Cable}$$

$$= 43\,dBW + 10 \cdot log_{10}(\frac{\lambda^2}{4\pi d}) + 44.2\,dB + 52\,dB - 7.1\,dB$$

$$= 73\,dBm - 118.2\,dB + 44.2\,dB + 52\,dB - 7.1\,dB = -42.9\,dBm$$

This value is the power over the whole channel bandwidth of 27.5 MHz. The conducted power measurement only had a bandwidth of 20 MHz and therefore needs to be adjusted.

$$Adjustment\ Factor = 10 \cdot log_{10}(\frac{27.5\,MHz}{20\,MHz}) = 1.38\,dB$$

Adding this adjustment factor to the nominal measurement leads to:

$$P_{nominal\ corrected} = -44.51\,dBm + 1.4\,dB = -43.13\,dBm$$

The obtained value is very close to the theoretical value, which shows that the measurements are correct.

4.6 System Temperature

The system temperature expresses the combined noise of the transmission system in one equivalent noise temperature. This T_S can be calculated in two different ways. These two values can be compared to verify the plausibility of the estimated values of the LNB noise figure and the antenna efficiency.

The first way is calculating back from the received noise power to the noise power at the LNB input:

$$P_{Noise\,LNB} = P_{Noise,\,nominal} + L_{Cable} - G_{LNB} = 10 \cdot log_{10}(T_S \cdot K \cdot B)$$

$$= -59.96\,dBm + 7.1\,dBm - 52\,dB = -104.86\,dBm$$

$$\Rightarrow T_S = \frac{10^{\frac{-104.86\,dBm}{10}}}{K \cdot B} = 118\,K$$

The second way of calculating T_S is adding up all the different noise sources: The sky temperature, the antenna, the LNB, the cable and the spectrum analyzer. The effect of the last two, the cable and the spectrum analyzer, is so low that it can be neglected because the signal got amplified before with the high gain of the LNB. This leads to:

$$T_S = \epsilon_{Ant} \cdot T_{Sky} + (1 - \epsilon_{Ant}) \cdot T_0 + T_{LNB}$$

Now different values for ϵ_{Ant} and $T_{LNB} = (10^{\frac{NF_{LNB}}{10}} - 1) \cdot T_0$ can be tried to achieve a value of T_S equal to the first calculation. With $\epsilon_{Ant} = 0.65$ and $NF_{LNB} = 0.1\,dB$ an adequate value can be achieved:

$$T_S = 0.65 \cdot 17\,K + (1 - 0.65) \cdot 290\,K + [(10^{\frac{0.2\,dB}{10}} - 1) \cdot 290\,K] = 119\,K$$

With this new value for ϵ_{Ant} the calculation of the antenna gain can be corrected to:

$$G_{A\,in\,dB} = 10 \cdot log_{10} \cdot (\frac{0.65 \cdot \pi \cdot \frac{(1.8\,m)^2}{4}}{\frac{(26.9\,mm)^2}{4\pi}}) = 44.6\,dB \rightarrow increase\ of\ 0.4\,dB$$

5 Data Analysis

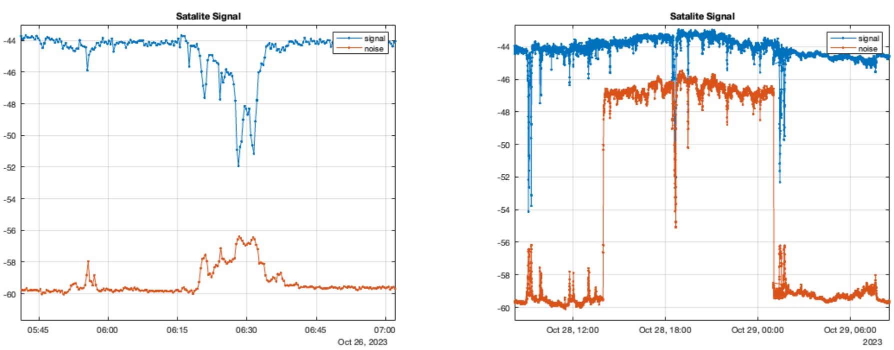
During this section we will analyze the influence of atmospheric conditions on quality of the signal. We will also comment on some irregularities that happened during the data collection that affected the signal.

The signal and noise values were collected as described in 2 and the temperature and rain were collected from the visualcrossing.com website [3] between the days of 25th October and 24th November. Data between 3rd and 6th November was not collected due to a system malfunction.

5.1 Influence of Rain

Rain can significantly impact the quality of satellite TV reception due to a phenomenon known as rain fade. As raindrops fall, they act as tiny reflectors, scattering the satellite signal and causing interference. This interference weakens the signal reaching the satellite dish, resulting in pixelation, dropped frames, and even complete signal loss in severe cases. The impact of rain fade depends on various factors, including the intensity of the rainfall, the size of the raindrops, and the frequency of the satellite signal. Heavier rain and larger raindrops tend to cause a more significant signal degradation. Additionally, satellite TV signals operate at higher frequencies, making them more susceptible to rain fade compared to terrestrial TV signals.

In figure 3a we present a segment of collected data of the 26th October. Note that around 5:55 AM there is a peak in noise and a valley in signal at the exact same moment. Something similar happens at 6:30 AM. This changes in signal to noise ratio - SNR - are cause by different types of rain. The first cause is a short but intense rain, and the second moment represents a continuous rain. In this special case, continuous rain is more intense than spontaneous, yet, in normal cases, continuous rains tend to be less intensive than short periods of rain. In figure 3b we observe an unprecedented increase in noise without affecting the normal behavior of the signal. This suggests that the signal loss was not caused by the rain but rather by an external source of interference, possibly another satellite.



(a) Effect of rain in the signal

(b) Interference on the connection

Figure 3: Variation of noise and signal

In order to corroborate our assumption about the rain influence, we plotted the SNR and the rain quantity and evaluated the severity of the signal loss. Figure 4 we have the signal and rain quantity both normalized for better view. Here we see high quantities of rain cause a decrease on the SNR, sometimes even causing a loss of signal. In this case, we considered a signal loss when the SNR is below 6dB. In figure 4 the loss of signal is marked in yellow, where the darker yellow is a more severe loss. I.e, if the loss is only a few instances, the user might even notice it, yet if the signal fails several times in a short period of time, a user will definitely have a bad experience. Returning to the case evaluated in figure 3a, we see that the early morning of the 26th October was a particularly rainy period, thus the decrease in signal and increase in noise and consequent signal loss is justified.

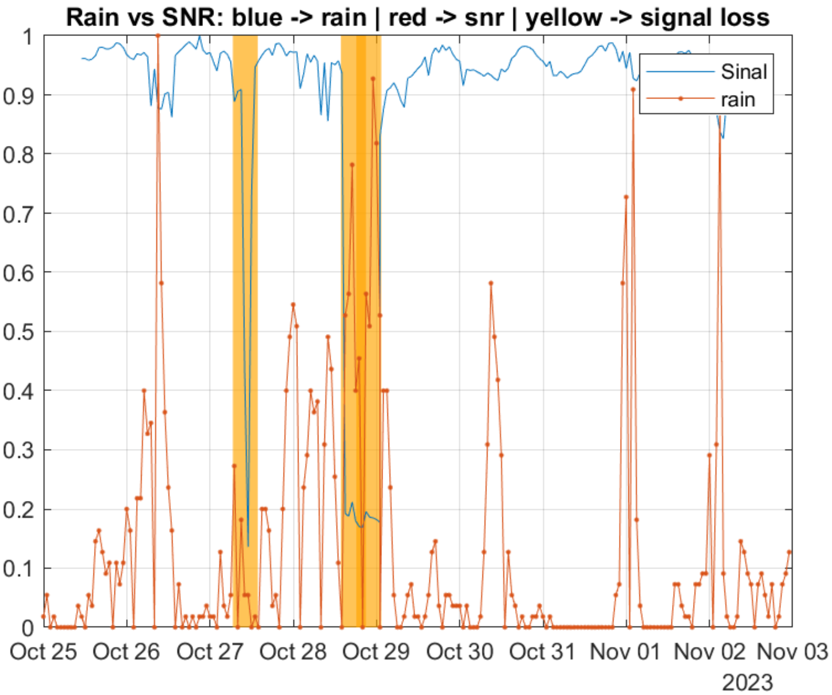


Figure 4: Influence of rain on the SNR and signal loss severity

5.2 Influence of temperature

To evaluate the influence of temperature on the signal, we selected data between 30 of October and November 2^{np} due to its more pronounced variation of temperature. Figure 5 presents the temperature, signal and noise of the data collected.

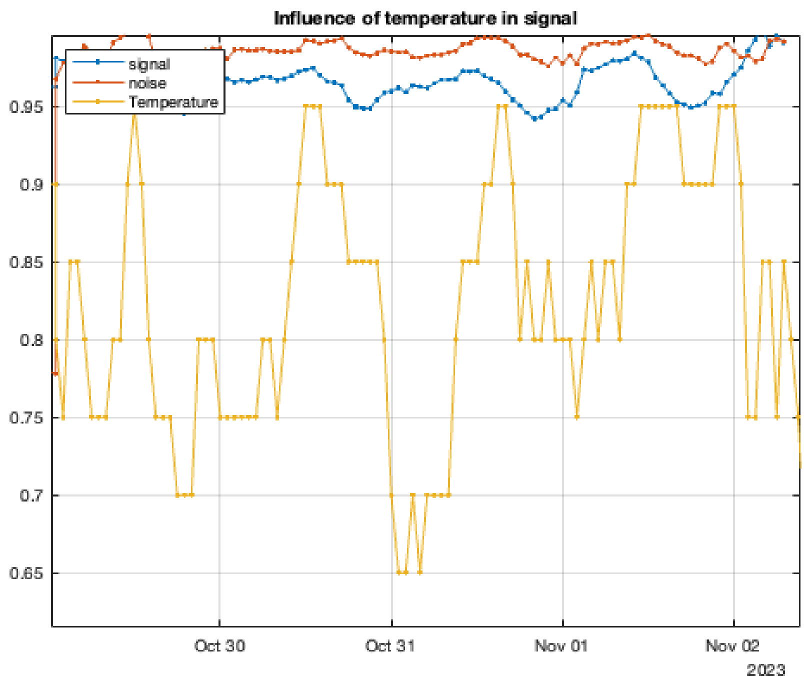


Figure 5: Influence of temperature in the signal and noise

If we look closely, we can see a variation ones per day in bot signal and noise that follows the curvature behavior of the temperature relative to the time when data was collected. In fact, the LNB gain seems to increase with temperature. Note that these results are merely empirical, we were not able to find any studies to corroborate this result. Appends once per day since the temperature reaches it's highest peaks in the middle of the afternoon and the lowest pick at the middle of the night, therefor the gain will increase/decrease between those moments.

5.3 Influence of satellite orbit in signal

Geosynchronous and geostationary satellites are positioned in orbit such that they appear stationary relative to a fixed point on the Earth's surface. However, due to the tilt of the Earth's axis, geosynchronous orbits can present variations in the apparent position of the satellite throughout the year. As the Earth rotates, this satellite's position relative to the ground station may change, causing fluctuations in the signal strength. This effect is more noticeable near the equator, where the apparent movement of the satellite can be more pronounced. The specific term for this phenomenon is diurnal variation, and it's a natural consequence of the Earth's rotation and the satellite's fixed position in the sky. As the satellite appears to move slightly in the sky over the course of a day, the angle between the ground station's antenna and the satellite changes, affecting the signal strength. This causes the signal strength to vary according to the angle of the satellite: better signal when pointing directly to the antenna and worst when it's not. Therefore, a maximum in signal strength would appear twice a day when the antenna was pointed at the satellites position directly above the equator. Or a maximum would occur once per day if the antenna was aimed at the satellite at the point where it is the most far from the equator (spot marked with an X in figure 6).

In our data we weren't able to find clear signs effects, probably because the influence of diurnal variation is small in comparison to all the other factors, like rain and temperature, influencing the signal strength.

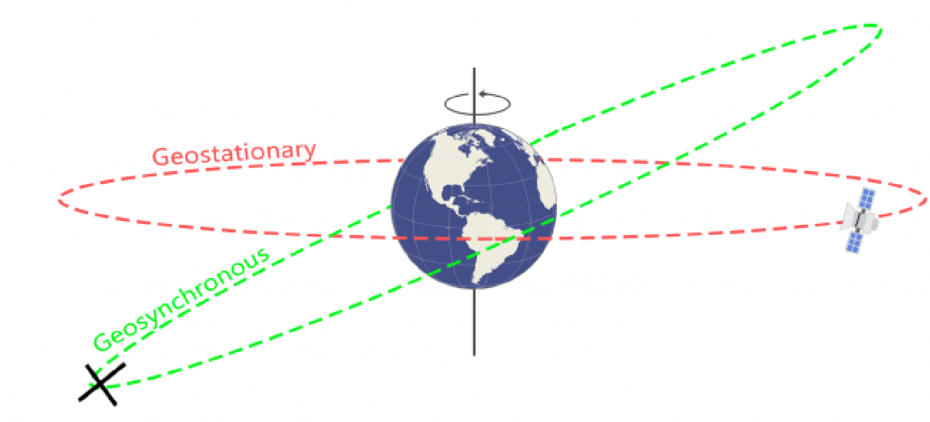


Figure 6: Geosynchronous orbit vs Geostationary orbit [2]

6 Conclusion

To summarize, the purpose of this lab report was to perform an in depth analysis of satellite communication, which involved calculating numeric values for the system's characteristics (like the gains of various components and the losses due to factors like the temperature), as well as the link budget to verify the plausibility of the measurements taken. These goals were achieved successfully.

We also explored the received data itself, contextualizing it in the conditions it was received in and understanding how said conditions, like the weather, atmospheric temperature and the orbit of the satellite, affected our ability to receive the signal.

References

[1] Mário Jorge Moreira Leitão; Apontamentos de Projecto de Sistemas de Telecomunicações

[2] What is a Geosynchronous Orbit? - everything RF. (n.d.). https://www.everythingrf.com/community/what-is-a-geosynchronous-orbit

[3] Corporation, V. C. (n.d.). Weather Data & Weather API — Visual Crossing. https://www.visualcrossing.com/