LELEC2910

Propagation project

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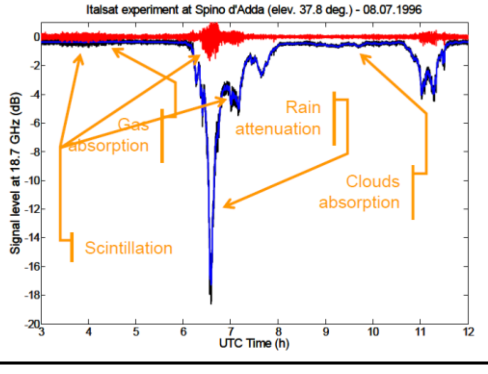
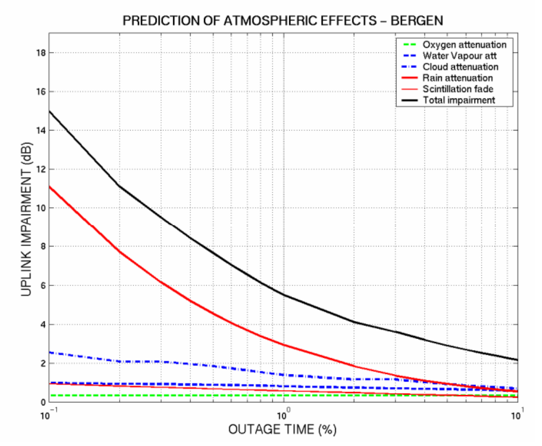
Context

- Satellite-to-ground communication signals are impacted by various atmospheric effects → need to
  - **Measure**/quantify those effects
  - Develop some **models** to predict them
  - Take them into account in **system designs** (e.g., link budgets)
- Example of received power time series with atmospheric effects

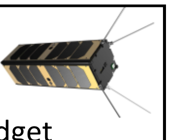


Context

- From received power time series, obtain statistics and develop models for various attenuation components
  - Using Complementary Cumulative Distribution Functions (CCDF) of total attenuation and various components



Project description



- Analysis of measured tropospheric effects and link budget calculation for a Q-band LEO satellite
  - Received power measurements at Louvain-la-Neuve
  - Design of a LEO satellite payload: EIRP calculation in Q band
  - Report in two parts
    - Extraction of excess attenuation time series and statistics from measurements in the K and Q bands
      - Comparison with ITU-R models
      - Comparison between 2 frequencies (19.7 GHz and 39.4 GHz)
    - Link budget computation for a LEO satellite
      - Comparison between 2 ground stations (per group)
    - Detailled guidelines available in the project description
  - Tools & references
    - Jupyter notebook on Moodle, python packages, (RAPIDS software)
    - ITU-R recommendations & other documents on Moodle
    - This presentation!

Content and organisation

November	Mon 11	3-4	Armistice
	Thu 14	7-8	Atmospheric Propagation and Satellite Systems: Introduction Gaseous Absorption
	Mon 18	3-4	Extinction and Depolarization by Hydrometeors
	Thu 21	7-8	Project: introduction and organization
	Mon 25	3-4	Transport Theory and Tropospheric Radiometry
	Thu 28	7-8	Project: supervized session
December	Mon 2	3-4	Tropospheric Scintillation, Refraction and Multipaths
	Thu 5	7-8	Project: supervized session
	Mon 9	3-4	Ionospheric Propagation – Remote Sensing, SatCom and GNSS
	Thu 12	7-8	Project: supervized session
	Mon 16	3-4	Project: preliminary presentation
	Thu 19	7-8	Project: preliminary presentation

Practicalities

- Teaching assistants for propagation project
  - Florian Quatresooz & Ludo Bissot
- Project includes 4 lab sessions
  - One introductive session
  - Three supervised sessions
- Project deliverables
  - Preliminary presentation (non-certificative) during WEEK 14
  - Final report on LELEC2910 Moodle by the exam date
- Evaluation (reminder)
  - Propagation project accounts for 1/3 of the final LELEC2910 grade (6.7/20)
  - No exam on the propagation part in January

Modelling of attenuation CCDFs

RAPIDS software

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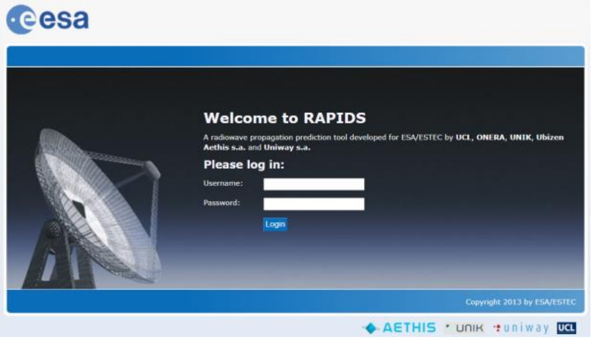
RAPIDS software – Introduction

- Software developed by UCLouvain and other partners for the analysis of satellite-to-ground communications
  - Focus on atmospheric propagation effects, such as rain attenuation, scintillation, etc., in the troposphere
  - Provide annual statistics, based on the application of ITU-R models
  - Reference: https://dial.uclouvain.be/pr/boreal/fr/object/boreal%3A145563



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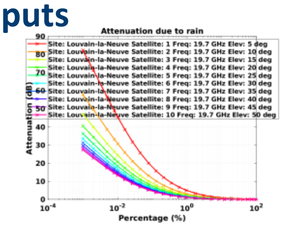
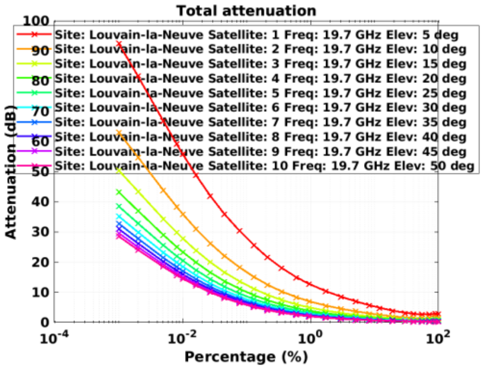
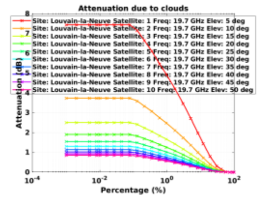
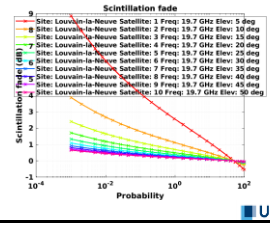
RAPIDS software – Examples of outputs

- Annual CCDF statistics:
  - For a given location,
  - At a chosen frequency,
  - And at specified elevation angles.



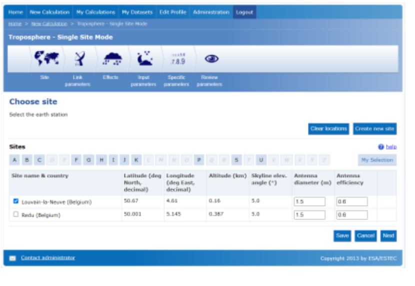




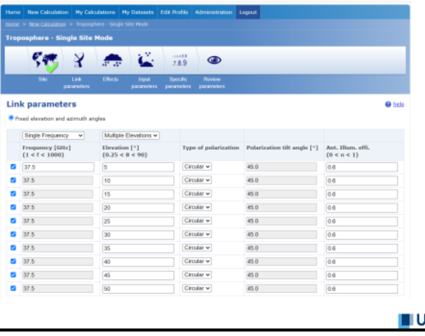


RAPIDS software – Demonstration (1/3)

- 1) Choose the location

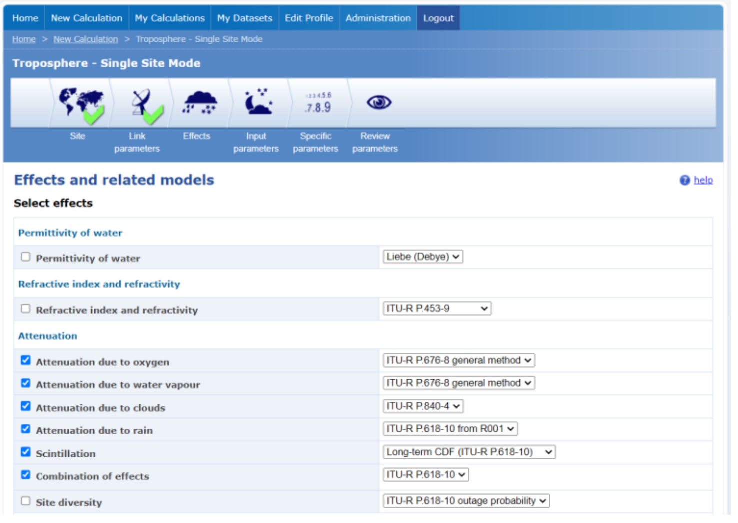


- 2) Select the frequency and elevation angles



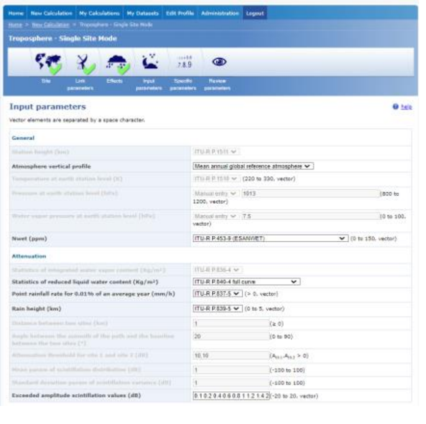
RAPIDS software – Demonstration (2/3)

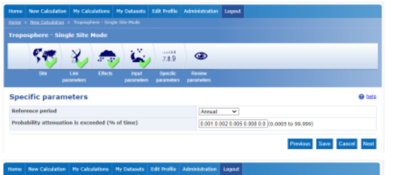
- 3) Choice of ITU-R models for each tropospheric effects

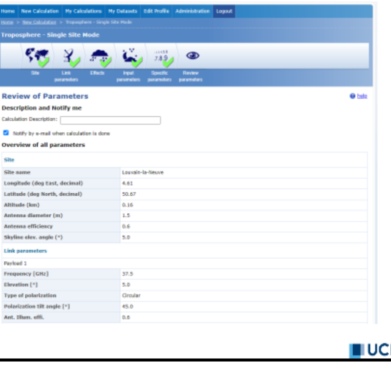


RAPIDS software – Demonstration (3/3)

- 4) Specify other parameters, namely the probabilities at which the attenuation is evaluated
- 5) Run the computation







RAPIDS software – Summary

- This year: no need for you to run RAPIDS computations, as the outputs will be directly given to you
  - For all groups: access to attenuation statistics at LLN, for elevation angles between 5° and 90°, and at
    - 19.7 GHz
    - 39.4 GHz
    - 37.5 GHz
  - Per group, individually: access to attenuation statistics at another station, for elevation angles between 5° and 90°, and at
    - 37.5 GHz
- All data will be accessible on Moodle, after you have registered in a group

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Measurements

Alphasat receiver (part I)

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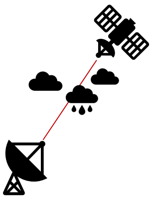
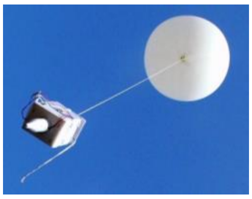
Motivations

- Goal: evaluate and predict propagation effects on space systems
- Available tools:
  - **Beacon receiver → accurate but costly, need long-term measurements**
  - Radiometer → useful to measure gaseous attenuation
  - Ground meteorological instruments → only provides meteorological quantities at the ground
  - Radiosondes → access to vertical profiles of meteorological quantities
  - …



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Alphasat

- Alphasat is a geostationary communication satellite, launched in 2013
  - It is also equipped with beacons emitting at 19.7 GHz and 39.4 GHz
  - Since 2017, UCLouvain has a receiver on the roof of the Maxwell building

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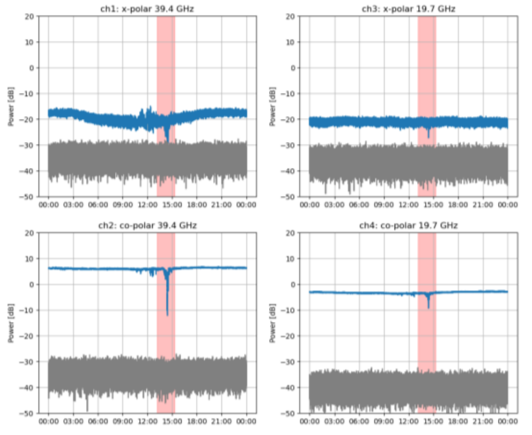
Alphasat measurements

- Measurements of received power on 4 different channels:
  - ch1: cross-polarisation, 39.4 GHz
  - **ch2: co-polarisation, 39.4 GHz**
  - ch3: cross-polarisation, 19.7 GHz
  - **ch4: co-polarisation, 19.7 GHz**
- Example of received signal on 20/12/2020:



- In red: rain event

→ For this project, access to 4 months of measurements:
- September 2019,
- December 2020,
- March 2021,
- June 2021

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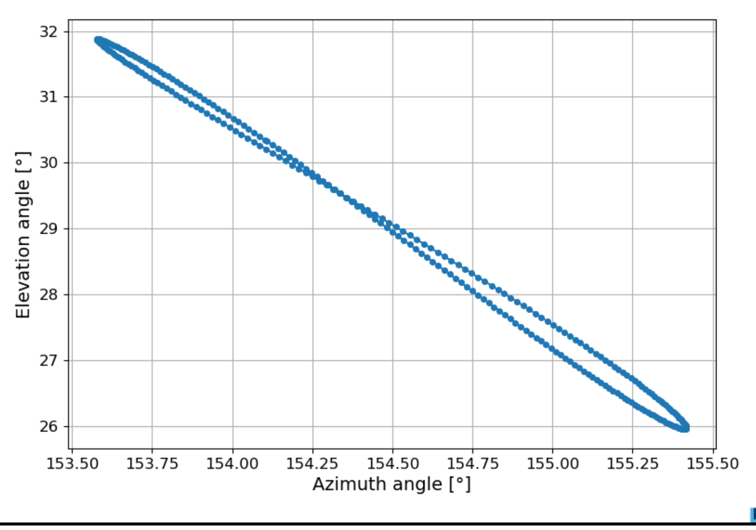
Alphasat satellite tracking

- Tracking of Alphasat satellite, updated every week
  - Example for 05/10/2023: Alphasat as seen from LLN station



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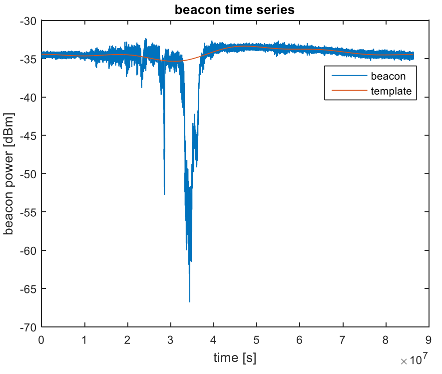
Data processing

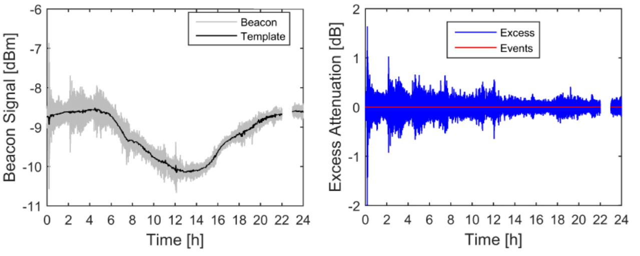
- The absolute 0dB attenuation level is not directly available
  - Receiver non-idealities (gain variations, pointing inaccuracies, temperature effects)
  - Gaseous attenuation unknown in the absence of radiometer

→ Not possible to extract the total attenuation

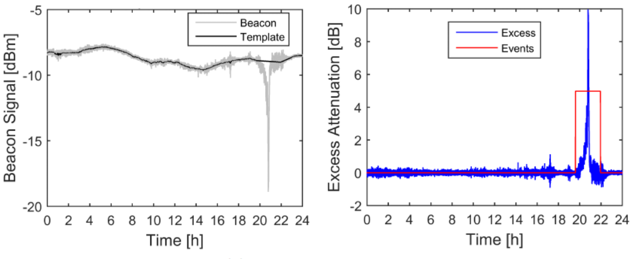
- Instead, extract the **excess attenuation**
  - Corresponds to the attenuation due to rain and scintillation
  - Requires the use of a template to recover the 0dB level
  - Requires the detection of rain events (here, by inspection)



Data processing – illustration



(a) 2015-07-10, clear-sky conditions



(b) 2015-05-02, rain event

Reference: Laurent Quibus, Modelling propagation impairments of Earth-Space links using Numerical Weather Prediction tools

Data processing – step by step

- 0) Load Alphasat measurements (received beacon signal), P_r
- 1) Add rain event detections
- 2) Evaluate the template level P_{temp} , either by low-pass filtering with FFT (keeping a given number of harmonics) or using polynomial fits. Rain events should not be used for the template definition, e.g., by replacing them with linear interpolation between the start and the end of the rain event.
  → There is no unique solution, justify your choices!
- 3) Extract the excess attenuation, defined as $A_{\mathrm{exc}} = P_{\mathrm{temp}} - P_r$
- 4) Compute relevant statistics, compare with the models, explain, discuss, …

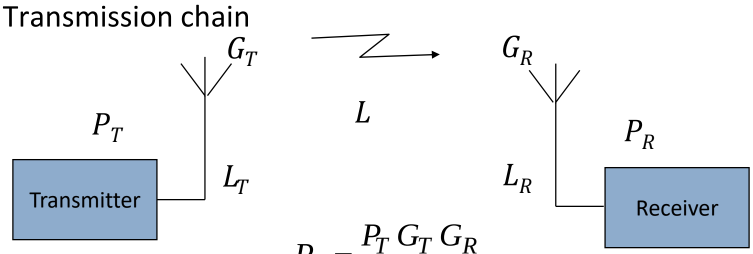
*→ Steps 0 and 1 already completed, can be found in the Jupyter notebook **project_part_I.ipynb***

Link budget

Computation for a LEO satellite (part II)

Free space loss

- Transmission chain



$$P_R = \frac{P_T \, G_T \, G_R}{L \, L_T \, L_R}$$

- where
  - P_R received power
  - P_T emitted power
  - G_T gain of the emitting antenna (dBi)
  - G_R gain of the receiving (dBi)
  - L free space losses → more generally, all **propagation losses**
  - $L_{T,R}$ feeder losses (transmitter, receiver)

Free space loss

- Effective isotropic radiated power (EIRP)

$$EIRP = \frac{P_T G_T}{L_T} = P_{TI}$$

- Effective isotropic received power

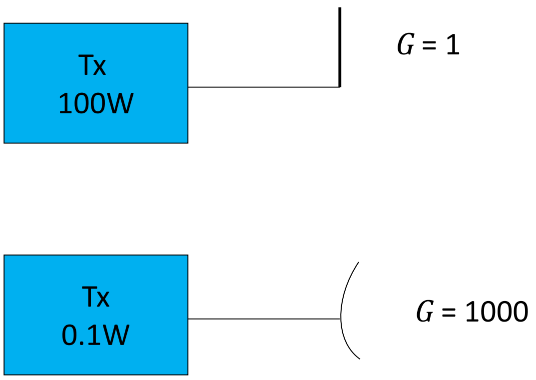
$$P_{RI} = \frac{P_R L_R}{G_R}$$

- Free space losses

$$L_{dB} = 10 \log\left(\frac{P_{TI}}{P_{RI}}\right)$$

Free space loss

- Example: identical EIRP produced by two different systems



Free space loss: from Tx to Rx

- Assuming two antennas with matched polarizations, the power density arriving at the receiving antenna is (taking $L_T = 1$)

$$S = \frac{P_T\, G_T}{4\pi r^2} \quad \left(W/m^2\right)$$

- Power received by Rx antenna (taking $L_R = 1$)

$$P_R = \frac{P_T G_T A_{eR}}{4\pi r^2} \quad (W)$$

  - where A_{eR} is the effective area of the receiving antenna

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

Free space loss: receive antenna

- Effective antenna area ≡ surface multiplied by the efficiency

$$A_{eR} = \eta\left(\frac{\pi D^2}{4}\right)$$

  - where η is the efficiency (typically 0.55 for a parabolic antenna and 0.75 for a horn) and D is the antenna diameter

- For a directive antenna, the gain and the received power depend on the direction (θ,φ) → directivity

$$D(\vartheta,\varphi) = \frac{P(\vartheta,\varphi)}{P_t/4\pi}$$

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Free space loss vs. frequency

$$P_R = \frac{P_T G_T A_{eR}}{4\pi r^2}$$

$$P_R = \frac{P_T A_{eT} A_{eR}}{\lambda^2 r^2}$$

$$P_R = \frac{P_T A_{eT} G_R}{4\pi r^2}$$

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi r)^2}$$

- Assuming that the diameters of the antennas are fixed, A_{eT} and A_{eR} are the fixed variables
  - In that case, the second equation is used → the power increases as the square of frequency

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Free space loss

- Path-loss

$$L = \left(\frac{P_{TI}}{P_{RI}}\right) = \frac{P_T G_T}{\left(\frac{P_R}{G_R}\right)} = \frac{P_T G_T G_R}{P_R}$$

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

$$\boxed{L = \left(\frac{4\pi r}{\lambda}\right)^2}$$

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Link budget

- System design
  - For performance evaluation the signal-to-noise ratio (SNR) is one of the most important metric

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

  - Evaluation of signal level
    - Should account for all system gain/loss (antennas, amplifiers, cables, etc.)
    - Should include tropospheric degradations
    - EIRP is the design target parameter
  - Evaluation of noise power
    - Thermal noise (AWGN)

$$N = kTB \quad (W)$$

$$\frac{P_R}{N} = \frac{EIRP\ G_R}{BN_0 L} = \frac{EIRP\ \boxed{G_R/T}}{BkL_{TOT}}$$

$$\frac{P_R}{N_0} = \frac{EIRP\ G_R/T}{kL_{TOT}}$$

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Link budget: reminder about noise

- Thermal noise

$$N = kTB \quad (W)$$

- Noise figure and temperature
  - Measures the SNR degradation by a quadripole

$$F = \frac{(S/N)_1}{(S/N)_2}$$

$$F - 1 = \frac{T}{T_0} \quad ; \quad T = T_0 (F - 1)$$

- Cascaded quadripoles

$$F_{12} = F_1 + \frac{F_2 - 1}{G_1}$$

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Link budget: SNR margin and service availability

- A security margin is generally added at link level in order to enable some degradation to occur before the link cuts off

$$\frac{P_R}{N_0} = M \left(\frac{P_R}{N_0} \right)_{req}$$

$$M(dB) = \left(\frac{P_R}{N_0} \right) - \left(\frac{P_R}{N_0} \right)_{req}$$

$$M = \frac{EIRP \; G_R/T}{(P_R/N_0)_{req} \, k L_{TOT}}$$

- Tropospheric degradations are random
  - Need to define the service availability to estimate the attenuation

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Link budget: example

Tx power	20	dBW
Tx circuit loss	2	dB
Antenna gain	51.6	dBi
EIRP ($P_T G_T$)	69.6	dBW
Free space loss	202.7	dB
Tropospheric loss (depending on availability)	4	dB
Micellaneous loss	6	dB
Received isotropic power	-143.1	dBW
Rx antenna gain	35.1	dB
Misalignment loss (antenna lobe)	2	dB
Received power P_R	-110	dBW
Rx noise factor F	11.5	dB
Rx noise temperature = 3806 K	35.8	dBK
Antenna temp. (sky noise) = 300K	24.8	dBK
System noise temp. = 4106K	36.1	dBK
Rx sensitivity G/T	-1	dB/K
$N_0 = kT$	-192.5	dBW/Hz
SNR = P_R/N_0	**82.5**	**dB (Hz)**

From GEO to LEO attenuation statistics

- 0) Load GEO statistics from RAPIDS simulations (at the location of interest and the chosen frequency)
- 1) Choice of a LEO satellite and computation of its trajectory
- 2) Determination of the probability occurrence of the LEO satellite at an elevation angle θ, denoted $p(\theta)$
- 3) Conversion of GEO to LEO statistics using a conditional probability

$$\mathrm{p}(A > A_0) = \sum_{\theta} p(A > A_0|\theta)\ p(\theta),$$

where $p(A > A_0|\theta)$ is the probability of exceeded attenuation for an elevation angle θ.

- 4) Link budget computation

→ Step 0 already completed, can be found in the Jupyter notebook ***project_part_II.ipynb***