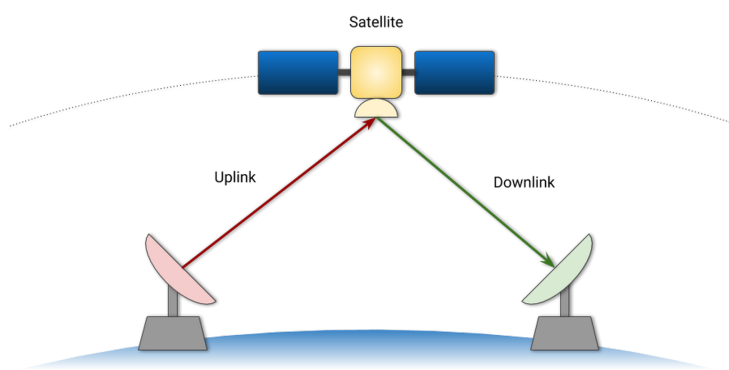


# 1. Design of a communication link

## 1.1. Introduction

This simple tutorial will explain the necessary steps to evaluate a communication link between a transmitter and a receiver. In this case, the tutorial focuses on the downlink, *i.e.* the case when the satellite is transmitting and the ground station is receiving. The uplink will be briefly discussed at the end of the document, but the process remains the same, choosing the appropriate data.



## 1.2. Design process for downlink

To design a communication link, several steps should be taken to finally evaluate the quality of the link. If there's not enough margin, the signal is going to be too weak to be recognised by the receiving system.

### 1.2.1. Choice of link type

The first step consists of choosing key parameters for the link. The frequency of transmission selected is  $8.0\text{ GHz}$  in the **X band**. To evaluate the data rate, various parameters are needed:

- € total amount of data sent  $D$
- € a margin factor  $M$
- € a fractional reduction  $F$
- € the maximum time during which the ground station is in view  $t_{\text{max}}$
- € the required initiation time  $t_{\text{initiate}}$

It is possible to evaluate the data-rate with the following formula:

$$R_D = \frac{D \cdot M}{F t_{\text{max}} - t_{\text{initiate}}}$$

Considering a data package of  $20.0\text{ kB}$  with a margin factor of  $2.0$  a maximum time of  $840.0\text{ s}$  with a fractional reduction of  $0.5$  and an initiation time for the satellite of  $100.0\text{ s}$  the resulting data-rate is  $125.0\text{ B/s}$

## 1.2.2. Transmitting system

### 1.2.2.1. Transmission power

The transmitting system on the satellite is characterised by various parameters. First of all, the transmission power is selected (after evaluating the link margin, this will be one of the parameters to increase performance). In this case, it is  $80.0\text{ W}$  which corresponds to  $44.7712125472\text{ dB}$  (the peak consumption of the transmitter component was chosen).

### 1.2.2.2. Estimation of losses between transmitter and antenna

To estimate the losses between the transmitter and the antenna  $L_{tx}$ , some considerations can be done, taking into account the length of cabling between the transmission system's components. In this preliminary sizing activity, these losses are estimated to be  $2.11 \text{ dB}$

#### 1.2.2.3. Choice of transmitting antenna

There are many different types of antennas, all differentiating for shape, gain, beamwidth. For this example, the downlink is evaluated, hence the transmitting antenna is the one mounted on the satellite. It is an omnidirectional antenna with gain  $G_t$  of  $2.15 \text{ dB}$  and beamwidth of  $56.0 \text{ deg}$

#### 1.2.2.4. The EIRP (Equivalent Isotropic Radiated Power) of the antenna

Considering the values previously calculated, the EIRP (Equivalent Isotropic Radiated Power) can be calculated with the following formula (in dB):

$$EIRP_{tx} = P_{tx} + G_{tx} - L_{tx}$$

The resulting EIRP is  $4.8112125472 \text{ dB}$

#### 1.2.3. Link losses

A signal loses power when travelling through space for various reasons. Losses include dispersion in space, atmosphere absorption, offset of the antennas, etc. For this case, the following losses have been considered as inputs:

€ Ionosphere loss  $(L_{ion}) = 0.4 \text{ dB}$

€ Atmosphere loss  $L_{atmo} = 2.1 \text{ dB}$

€ Rain loss  $L_{rain} = 0.1 \text{ dB}$

€ Polarisation loss  $L_{pol} = 0.3 \text{ dB}$

Other losses were estimated with the following mathematical models.

#### 1.2.3.1. Pointing losses

Pointing losses can be estimated considering the angular offset of communication systems  $e$  and their bandwidth  $\theta$  with the following formula (in dB):

$$L_{point} = 12 \left( \frac{e}{\theta} \right)^2$$

Hence, with a pointing error of  $5.0 \text{ deg}$  and a beamwidth of  $56.0 \text{ deg}$  the resulting pointing losses are  $0.443786982249 \text{ dB}$

#### 1.2.3.2. Path losses

Part of the losses of a signal when travelling between the transmitter and the receiver is only due to their distance and the type of link. The path losses are calculated with the formula:

$$L_{path} = 22 + 10 \log_{10} \left( \frac{S}{\lambda} \right)^2$$

where  $\lambda$  is the wavelength and  $S$  is the slant range, calculated as:

$$S = R_E \cdot \left[ \sqrt{\frac{(h + R_E)^2}{R_E^2} - \cos^2(\delta)} - \sin(\delta) \right]$$

Hence, considering an orbital mean altitude  $h$  of  $122.0 \text{ km}$ , a ground station minimum elevation angle  $\delta$  of  $2.0 \text{ deg}$  the slant range is  $836.8172248 \text{ km}$ . Using this value, together with a wavelength of  $0.0375 \text{ m}$  the resulting path losses are  $79.57600175 \text{ dB}$

#### 1.2.3.3. Total space losses

Summing up all the contributes, it is possible to express the total space losses as:

$$L_{space} = L_{ion} + L_{atmo} + L_{rain} + L_{polar} + L_{point} + L_{path}$$

The resulting value is  $82.689335083 \text{ dB}$

#### 1.2.4. Receiving system

##### 1.2.4.1. Choice of receiving antenna

Since the analysis is focused on the downlink, the receiving antenna is ground based. The system chose is a parabolic antenna with gain  $24.0 \text{ dB}$  and beamwidth  $5.0 \text{ deg}$

##### 1.2.4.2. System noise temperature

To evaluate the receiving system noise temperature, it is possible to use the following formula:

$$T_{rx} = T_{ant} + T_0 \frac{F - L_{rx}}{L_{rx}}$$

In the case presented, the receiving antenna noise temperature is  $73.0 \text{ K}$  the reference temperature is  $290.0 \text{ K}$  the noise figure  $F$  is  $8.0 \text{ dB}$  and the losses between the receiving antenna and the receiver are  $4.0 \text{ dB}$ . This results in a receiving system temperature of  $200.5 \text{ K}$

#### 1.2.4.3. Evaluation of the Eb/N0

The ratio between received power and noise can be evaluated with the following formula:

$$\frac{E_b}{N_0} = EIRP_{tx} + G_{rx} - L_{space} - 10 \log_{10}(T_{rx}) - 10 \log_{10}(k_B) - 10 \log_{10}(R_D)$$

Considering the data already presented, and keeping in mind that  $k_B = 1.38064852 \times 10^{-23} \text{ J/K}$  the  $E_b/N_0$  ratio is  $9.7308022477 \text{ dB}$ . Now, depending on the modulation algorithm chosen, a minimum  $E_b/N_0$  will be necessary so that the Bit Error Rate (BER) remains to acceptable levels. In this case, the required value is  $1.0 \text{ dB}$ . The link margin is calculated with:

$$LM = \left( \frac{E_b}{N_0} \right) - \left( \frac{E_b}{N_0} \right)_{required}$$

giving a value of  $9.7308022477 \text{ dB}$ . This value is higher than the requirement of 6 dB for a good link.

### 1.3. Design for uplink

The process to design the uplink is analogous, although the transmitting system will be the ground antenna and the receiving system will be the satellite. For this case, the link margin is  $4.1279508167 \text{ dB}$ , which is again above the requirement of 6 dB for a good connection.

## 2. References

€ Space Mission Analysis and Design (SMAD), 3rd Ed., James R. Wertz and  
Wiley J. Larson (1999)