1 | Fresnel Zones

Fresnel zone [ZyTrax, 2016] [Solutions, 2016] calculations gives a mean to calculate on how to avoid the interference from the strongest radio signals that are not direct line signals. This can be caused by reflections of obstacles, these reflected signals will have a different phase and when added with the direct line signal, may cause power loss. There are an infinite amount of Fresnel zones, and all will impact the direct line signal.

In terms of a radio signal travelling from a transmitter to a receiver it can travel along different paths. It can travel directly without any reflection, or it could reflect of the ground and thereby carry on to the receiver, or it could be reflected by a hill, and carry on to the receiver. These reflections can cause a signal loss from the transmitter to the receiver. The receiver does not differentiate between the reflected and the direct line signals, and therefore it will consider both the reflected and the direct line signal as the intended signal [Solutions, 2016]. It is important to notice that there will be a phase shift of 180°, if the wave is linearly polarized and hits a surface that is parallel to the waves polarization.

If these signals reflect of an obstacle and are out of phase with the direct line signals, they may end up having phase cancellation effect which could end up minimizing the power of the signals. For example two identical radio signals out of phase will cancel each other out and therefore no signal will be received, by the receiver. So therefore when calculating Fresnel zones it must be taken into consideration which out of phase signals from reflections have the most effect on the direct line signal, and make sure that it does not lose a lot of power.

There are an infinite amount of Fresnel zones, but the most important Fresnel zone is the first one. This is due to that the strongest signals are the ones that are closets to the direct line signal and they always lie in the first Fresnel Zone. Which also means that the second, third and so on Fresnel zones are further and further from the Direct signal and obstacles in these will have a lesser impact [Seybold, 2005]. This can be seen on the following Figure, which is illustrated with 2 Fresnel zones, Fresnel zone 1 and 2:

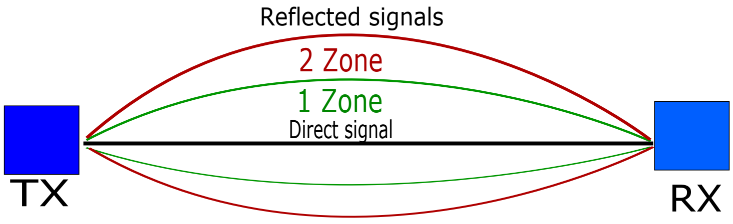

Figure 1.1: Illustration of the First and Second Fresnel zone, along with the Direct signal travelling from the Transmitter TX to the Receiver RX

As it can be seen the first Fresnel zone is closets to the direct signal and will have the strongest cancelling effect, if not taken into consideration. It has the least amount of delay in the reflected signal of the first Fresnel zone as it travels least from the transmitter to the receiver. Inside the first Fresnel zone phase delay due to increase in path distance of the reflected wave are 0°-90°, when remembering the phase change done by the reflection itself that means the signal is 180°-270° out of phase in total. When the reflected signal then interfere with the direct signal destructive interference occur. In terms of the second Fresnel zone, it creates longer phase delay, in total between 270° to 450° out of phase. This become constructive interference. The phase cancelling effect in even numbered Fresnel zones are good while odd numbered zones are bad. A rule of thumb in terms of the first Fresnel zone is that 60% *of the first Fresnel zone must be cleared of any obstacles*, as this reduces the destructive interference significantly [Seybold, 2005][Solutions, 2016].

Fresnel zone 1

As mentioned 60% of the first Fresnel zone must be cleared of objects, an illustration of this can be seen on the following Figure:

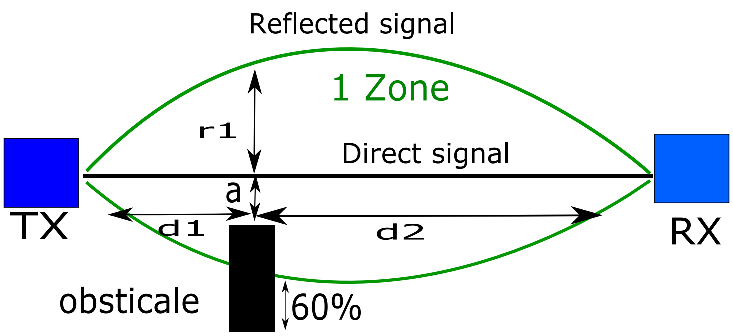

Figure 1.2: Illustration of the First Fresnel zone cleared 60%, with an building representing the obstacle

The obstacle on the Figure above could illustrate a building where d_1 is the distance from the transmitter TX to the building while d_2 is the distance from the receiver RX to the building. The radius of the first Fresnel zone is r_1. The distance from the direct signal to the obstacle is a. With this in mind the rule of thumb states that $a > 0.6 \cdot r_1$.

Fresnel Zone calculations

The general equation for calculating the Fresnel zone radius at any point a in between the endpoints is given as [Seybold, 2005]:

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \tag{1.1}$$

Where:

F_n	The n^{th} Fresnel Zone radius	[m]
d_1	The distance of a from TX	[m]
d_2	The distance of a from RX	[m]
λ	The wavelength of the signal	[m]

A conservative calculation of the 60% rule of thumb is to use the maximum radius of the first Fresnel zone to calculate maximum obstacle heights.

The wavelength λ can be expressed as:

$$\lambda = \frac{c}{f} \tag{1.2}$$

Where:

c	The speed of light in a vacuum	[$3 \cdot 10^8 ms^{-1}$]
f	Signal frequency	[Hz]

The maximum radius is found at the point where $d_1 = d_2$. Then by using this as well as setting $n = 1$ as it is the first Fresnel zone. An expression for the maximum radius can be found and if Equation 1.2 is inserted into Equation 1.1 that yields:

$$r = 8.67 \cdot \sqrt{\frac{D}{f}} \tag{1.3}$$

Where:

D	Total distance = $d_1 + d_2$	[km]
f	Signal frequency	[GHz]

As an example to calculate the clearance radius of the first Fresnel zone of two antennas operating 5.5 GHz, with a distance D of 500m. The 60% clearance radius a is given as:

$$a = 0.60 \cdot 8.67 \cdot \sqrt{\frac{0.50}{5.5}} = 1.57m \tag{1.4}$$

Then by subtracting the antenna height form a, the maximum obstacle height with respect to the 60% clearance can be calculated. So if the the antenna height is 10m, then by subtracting 10m-1.57m we get 8.43 m, which is the maximum obstacle height.

2 | Link Budget

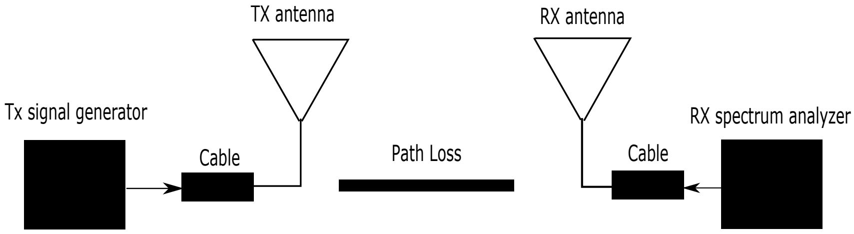

Figure 2.1: Link budget illustration

A link budget is calculated to find the loss though the whole system, so the needed transmission power is found or the needed antenna gain is found, for a specific transmission power.

Such a calculation is given as:

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{PL} - L_{MISC} + G_{RX} - L_{RX} \quad (2.1)$$

Where:

P_{RX}	Power Received	[dBm]
P_{TX}	Power transmitted	[dBm]
G_{TX}	Transmitter antenna gain	[dBi]
L_{TX}	Transmitter losses (cable,coax)	[dB]
L_{PL}	Path Loss	[dB]
L_{MISC}	misc losses(polarization losses, other losses)	[dB]
G_{RX}	Receiver antenna gain	[dBi]
L_{RX}	Receiver losses (cable,coax)	[dB]

2.0.1 Polarization loss factor (PLF)

Polarization loss plays a factor in the Link Budget calculation. There is Linear Polarization and Circular Polarization. For Linear polarization the antenna can be turned horizontal and vertical direction this is illustrated in the following Figure:

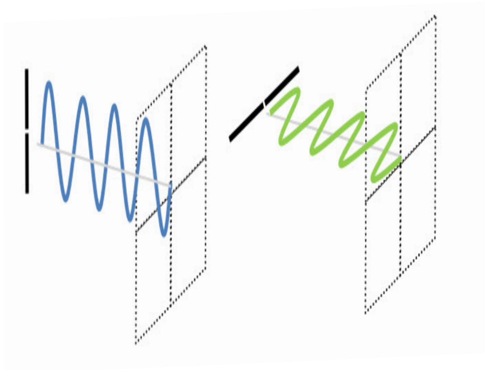

Figure 2.2: Linear horizontal and vertical polarization

The PLF for Linear Polarized antennas can be calculated by the equations given on the following Figure depending on the angle of the the antennas, an illustration of the PLF for max, non and signal loss with dependence on an angle:

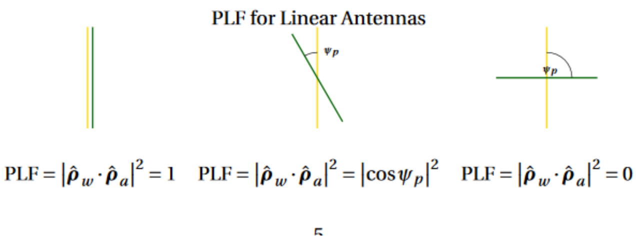

Figure 2.3: Minimum, maximum and PLF loss depending on the angle

As it can be seen if the two antennas are pointing directly at each other with the same polarization there will be no PLF. While if one antenna is vertically polarized and the other is horizontally polarized, then no power will be transferred. While there will be some power loss if the two antennas are not 100% polarized, meaning there is an polarization miss match ,there will be some power loss depending on the angle.

PLF loss calculated

For the measurements conducted the PLF factor is calculated with an angle ψ of 5°, as the two antennas are not pointing directly at each other, this gives the following PLF loss factor:

$$cos(\psi)^2 = cos(5)^2 = 0.9962 \tag{2.2}$$

Then to get it in dB:

$$10 \cdot log(0.9962) = -0.0381dB \quad (2.3)$$

2.0.2 Cable Loss

As a part of the Link Budget cable loss is also included. The cable loss is depended on the length of the cable, where the longer the cable the more cable loss there will be as the signal will lose travelling strength through the cable. Where for each cable it is indicated in the data sheet how much power is lost per meter at different frequencies, this is different for each type of cable.

Calculated cable loss

Two different types of cables where used these are:

- rg223/u
- SUCOFLEX_104

The length for the rg223/u cable is of 1m, while for the SUCOFLEX_104 cable, two SUCOFLEX_104 cables where used with different lengths of 1.5m and 2.20m.

The cable loss for the rg223/u cable is read from the data sheet then interpolated, from the data sheet it is given that the attenuation factor is given in dB per 100 meters.

In the data sheet it can be read that for 1000MHz a loss of 13.4dB per 100 m, while for 3 GHz it is 24.8dB per 100 m. There has been made an interpolation of the Attenuation factors, so that a more precise Attenuation factor can be calculated so for 2.58 GHz and 856 MHz the following Attenuation factors have been calculated, for 1 m:

$$Attenuationfactor\_2.58 = \frac{22.4}{100} = 0.224dB \quad (2.4)$$

$$Attenuationfactor\_858 = \frac{12.7}{100} = 0.127dB \quad (2.5)$$

While for the SUCOFLEX_104 cable the following formula has been used to calculate the Attenuation factor, for both 1.5m and 2.20m:

$$a_{25} = a \cdot \sqrt{f(Ghz)} + b \cdot f(Ghz) \quad [db/m] \quad (2.6)$$

Where:

a	Nom.attenuation = 0.2291	[-]
b	Nom.attenuation = 0.0071	[-]

The attenuation factor for 858 MHz is equal to 0.327 dB while for 2.58 GHz it is 0.579dB for 1.5m. While for 2.20m the attenuation factor for 858 MHz is equal to 0.480 dB, while for 2.58 GHz it is 0.850 dB. In the following an Table of the cable loss can be seen:

Table 2.1: Cable loss table

	Mono 2.58 Ghz	Mono 858 MHz	Patch 2.58GHz	Patch 858MHz	Demo board 868 MHz
Cable loss: rg223_u	-0.224dB	-0.127dB	-0.224dB	-0.127dB	-
Cable loss: SUCOFLEX_104 (1.5m)	-0.579dB	-0.327dB	-0.579dB	-0.327dB	-
Cable loss: SUCOFLEX_104 (2.5m)	-0.850dB	-0.480dB	-0.850dB	-0.480dB	-
Cable loss: Demoboard		-	-	-	-2dB
Total Loss	-1.6530dB		-1.6530dB	-0.9340dB	-2dB

2.0.3 LOS, nLOS and NLOS

Other factors to consider when calculating a link budget is if there is **Line-Of-Sight(LOS)**, which means that if there is an obstacle in between the transmitter antenna and the receiver antenna it does not block the signal, as the two antennas can see each other, this is illustrated on the following Figure:

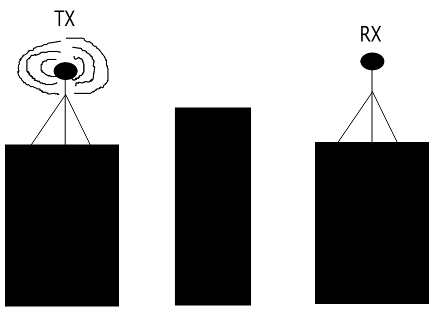

Figure 2.4: LOS illustration

Where the counter-part is **Non-Line-Of-Sight(NLOS)**, which means that the path is interfered, which could be by a building standing in-between the transmitter antenna and the receiver antenna, where the two antennas cannot see each other, this is illustrated on the following Figure:

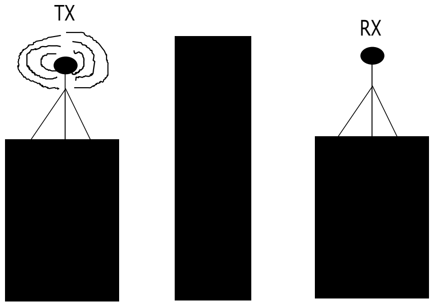

Figure 2.5: NLOS illustration

Another one is **Near Line Of Sight(nLOS)**, which means that the path is partially interfered, which could be by a building. Which is illustrated on the following Figure:

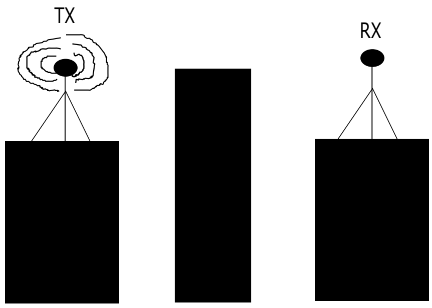

Figure 2.6: nLOS illustration

The different Line-Of-Sights, play a big factor when considering the Fresnel Zones which is further explained in Chapter 1, which also plays a big part in the received Power. As explained in the Fresnel Zone chapter there must be 60% clearance in the first Fresnel zone, as the strongest signals are in the first Fresnel zone ,this could be a problem if there is too much **NLOS**, as the antennas would need to be risen higher.

3 | Far field and near field

An graphical illustration of the Far field and Near field [Bevelacqua, 2016][Dr. J. Patrick , Pat] can be seen on the following Figure:

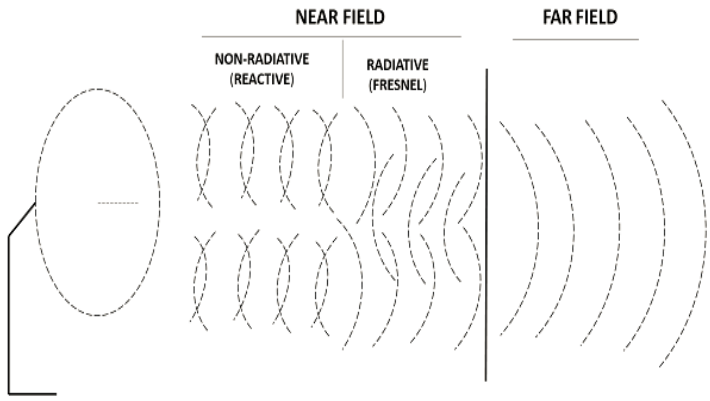

Figure 3.1: Illustration of Near field and Far field [tutorialspoint, 2016]

3.0.1 Far field region

The Far field region is the region that is furthest from the antenna. The Far field region R is given by the following formula:

$$R > \frac{2 \cdot D^2}{\lambda} \tag{3.1}$$

Where:

D	Is the maximum dimension of the antenna	[m]
λ	Wavelength	[m]

The Far field region R provides the limit between Far field and Near field. The Far field region must also satisfy the following two equations:

$$R \gg D \tag{3.2}$$

And

$$R \gg \lambda \tag{3.3}$$

The first two equations given in 3.1 and 3.2 ensure that the power radiated in a given direction from different parts of the antenna are approximately parallel. This helps to ensure that waves in the Far field behave like plane waves. Plane waves only radiate towards the forward direction, and are in parallel.

The third equation given in 3.3 makes sure that the reactive Near fields are gone. The reactive near field is the region surrounding the antenna where the reactive field(standing waves or stored energy) are dominant. In a reactive field two oppositely waves are travelling, which are non-radiative, they do not radiate power, they store the energy. This means that the receiver antenna will not receive power in the Near field, as it does not radiate. The much larger sign $\gg$ stands for 10 times larger.

3.0.2 Near field region

In the Near field there are two regions the Non-radiative(Reactive) and Radiative(Fresnel) regions. The boundary for the Non-radiative(Reactive) is given in the following Equation:

$$R < 0.62 \cdot \sqrt{\frac{D^3}{\lambda}} \tag{3.4}$$

While the Radiative(Fresnel) region is the region between the Near and Far fields. In this region unlike for the Far field region the shape of the radiation pattern may vary considerably with distance. The Radiative(Fresnel) region is given by the following Equation:

$$0.62 \cdot \sqrt{\frac{D^3}{\lambda}} < R < \frac{2 \cdot D^2}{\lambda} \tag{3.5}$$

The above can be summarized in the following Figure:

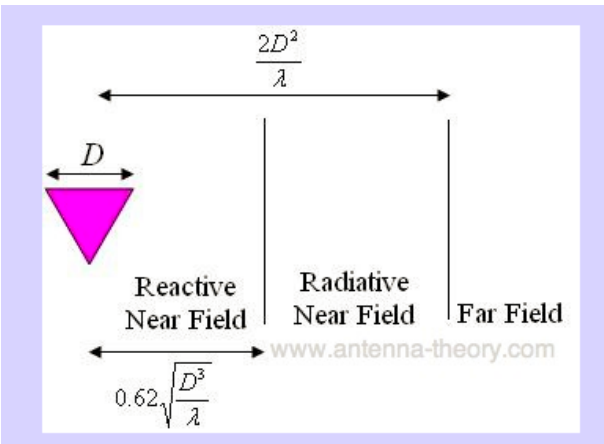

Figure 3.2: Illustration of Near field and Far field [Bevelacqua, 2016]

3.0.3 Far field Near field calculation

Patch 858Mhz

In order to calculate if the measurements are done in the Far field, the maximum dimension of a given antenna must be known. The maximum dimension D is 0.105m, this given for the patch antenna of 858MHz. Then in terms of being in the Far field:

$$R > \frac{2 \cdot D^2}{\lambda} \tag{3.6}$$

The wave length λ for 868Mhz is given as:

$$\lambda = \frac{3E8ms^{-1}}{0.868Ghz} = 0.3453m \tag{3.7}$$

Then:

$$R > \frac{2 \cdot (0.105m)^2}{0.3453m} = 0.0639m \tag{3.8}$$

While the minimum R is 1m, as the minimum distance between the transmitter and receiver antenna is 1 m. And as it can be seen, the first Far field equation 3.6 is fulfilled.

The two other Far field equations 3.2 and 3.3, the first one being:

$$1m \gg 0.105m \tag{3.9}$$

Which is on the limit, to being in the Far field. While the third one given in 3.3:

$$1m \gg 0.3453m \tag{3.10}$$

This is not fullfiled, and therefore it is not in the Far field the equation given in 3.4 is used.

Patch 2.58Ghz

The dimension D is 0.037m. The wave length λ for 2.58GHz is given as:

$$\lambda = \frac{3E8ms^{-1}}{2.58GHz} = 0.1161m \tag{3.11}$$

Then, for 1m:

$$1m > \frac{2 \cdot (0.037m)^2}{0.1161m} = 0.0235m \tag{3.12}$$

Again the first equation is fulfilled. While the second:

$$1m \gg 0.037m \tag{3.13}$$

As it can be seen is fulfilled. While the third one:

$$1m \gg 0.1161m \tag{3.14}$$

4 | Mini Project

4.1 Basic RF imperfections

4.1.1 Complex baseband Representation

When representing a baseband signal, it can be done the following way:

$$s(t) = I(t) \cdot \sqrt{2} \cdot \cos(2\pi f_c t) - Q(t) \cdot \sqrt{2} \cdot \sin(2\pi f_c t) \tag{4.1}$$

- $I(t) = S_A(t) \cdot \cos(s_p(t))$
- $Q(t) = S_A(t) \cdot \sin(s_p(t))$

From the above representation is it important to note that all the information of the signal lies in the I and Q part. Both I and Q are real value low frequency signals. All the information lies in the I and Q, and can be represented as AM or FM. All the RF, can therefore be neglected, as all the information is in the I and Q part.

The complex valued base band signal, denoted the complex envelope in where all the signal information lies in is defined as:

$$s_{BB}(t) = I(t) + j \cdot Q(t) \tag{4.2}$$

While the original bandpass signal given in *Equation: (3.15)* from the complex envelop signal, can be obtained as:

$$s(t) = \sqrt{2} \cdot \Re[s_{BB} \cdot \exp(j \cdot 2\pi f_c t)] \tag{4.3}$$

4.1.2 I/Q mismatch

4.1.3 Noise

4.2 Model of PA

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