Radio Communication Theory

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3.1 Radio Link Budget

3.1.1 Unit conversion mW and dbm

In order to convert power from expressed in mW to dBm, the following formula is used:

$$\mathrm{P_{dBm}} = 10\log_{10}\left(\mathrm{P_{mW}}\right) \tag{1}$$

A doubling in mW is approximately the same as adding 3 dBm. 100mW is equivalent to 20 dBm, 500mW is approximately equal to 26.9 dBm, and 1 W, which is 1000mW, is equal to 30 dBm.

3.1.2 Free-space basic transmission loss

Free-space basic transmission loss is given as

$$\frac{P_t}{P_r} = \left(\frac{4\pi \mathrm{fd}}{300}\right)^2 \tag{2}$$

where P_r is the power received by an isotropic antenna, P_t is the power transmitted by an isotropic antenna, f is the frequency in MHz and d is the distance in meters between transmitter and receiver. Free-space basic transmission loss is the relation between energy produced by the transmitter and energy detected at the receiver with line of sight through the air without taking external factors, i.e. obstacles, into account. The loss comes in the form of the inverse square law.

3.1.3 Radio link budget

For the radio link budget, we want a margin above 30 dB where the margin is calculated as follows:

$$Margin = TX_{power} + Link_{loss} + RX_{Sensitivity} \tag{3}$$

Where TX_{power} is the transmission output power minus the transmission line loss plus the transmission antenna gain. $Link_{loss}$ is the path loss plus miscellaneous losses and $RX_{Sensitivity}$ is the receiver antenna gain minus the transmission line loss minus the required minimum signal power.

	Link Loss
Path loss (dBm)	74.72218302
Misc. (dB)	15
SUM	89.72218302
Margin	-11.27781698

	TXPower
Tran. output power (dBm)	20
Tran. line Loss (dB)	0.02
Trans. antenna gain (dBi)	2.15
SUM	22.13

	RXSensitivity
Rec. antenna gain (dBi)	2.15
Trans. line loss (dB)	0.02
Req. min. signal power (dBm)	-121
SUM	123.13

	Constants
f (MHz)	433
c (m/s)	300000000
d (m)	300
wire length (m)	0.1

Figure 1: Calculation of margin

Margin (433Mhz)	-11.28
Margin (2.4Hhz)	3.6
Margin (5.8 Ghz)	11.26

Figure 2: Margins for different frquencies

Here, the constants in the 4th column of figure 2 are used to calculate the margins for the 3 different frequencies, only by changing the frequency in the sheet. It is assumed that the receiver and the transmitter both are dipoles and have the same gains independent of whether they are receiving or transmitting. It is also assumed that there is a 10 cm wire, of the most commonly used type, inside the receiver which is used to calculate the line loss. It seems strange that the higher the signal frequency or distance between transmitter and receiver, the higher the margin, thus making it easier to fulfill the requirements of having a margin larger than 30.

3.2 Near field absorption and Fresnel zones

3.2.1 Near field absorptions

Near-field absorption is when radio waves are absorbed as electromagnetic waves by a conductive material. This happens in the field near the transmitter typically within one wavelength of the signal. This mechanism can be used to create systems such as RFID tags, contactless payment, wireless charging, etc.

Signal attenuation is how a signal loses strength as it passes through a medium. The signal attenuation is a linear relation between the distance through the medium d, the signal frequency f, and the attenuation coefficient α of the medium. Knowing these, the attenuation can then be found as

$$\text{Attenuation} = \alpha \cdot l \cdot f \tag{4}$$

3.2.2 Fresnel zones

In radio communication, signals can follow non-straight lines between the transmitter and receiver due to reflections. This can result in two signals, sent at the same time, arriving at a receiver at two different times, which due to the reflection and the extra travel time, causes one signal to a phase shift from the other. Depending on the magnitude of the phase shift, this can lead to either constructive- or destructive interference. Fresnel zones help to distinguish between which zones will lead to which type of interference if the signal gets reflected inside it. The first three Fresnel zones are depicted in figure 3[1].

For drone C2 and telemetry this means that your radio signal either can be amplified or nullified, depending on which Fresnel zone the reflective obstruction is located in. So to ensure that a signal will be properly received, simply having a straight line between the transmitter and receiver, will not necessarily be enough. You should also take into consideration which obstructions are located in which Fresnel zones.

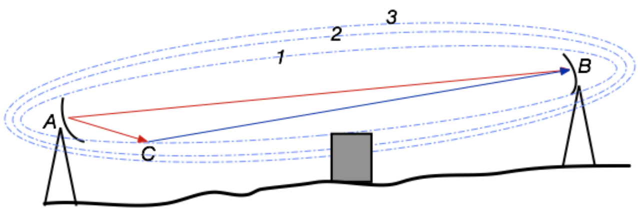


Figure 3: Illustration of first three Fresnel zones

3.2.3 Plotting Fresnel zones

The Fresnel zone radius at a given distance can be calculated by

$$F_n = \sqrt{\frac{n \lambda d_1 d_2}{D}} \tag{5}$$

where n is the specified zone, λ is the wavelength of the signal at interest, d_1 is the distance from TX to a point of interest on the straight line from TX to RX, d_2 is the distance from RX

[1] https://en.wikipedia.org/wiki/Fresnel_zone#/media/File:1st_Fresnel_Zone_Avoidance.png

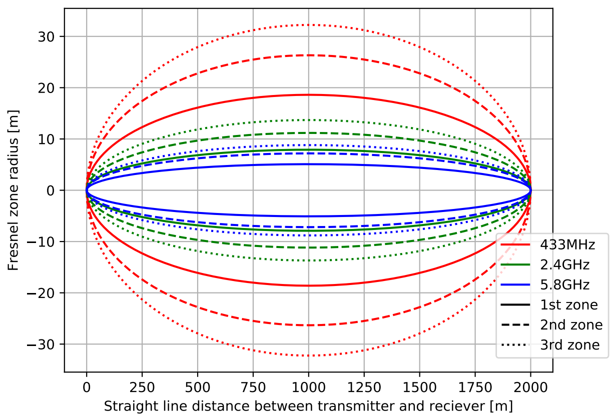


Figure 4: First 3 Fresnel zones for 433MHz, 2.4GHz and 5.8GHz

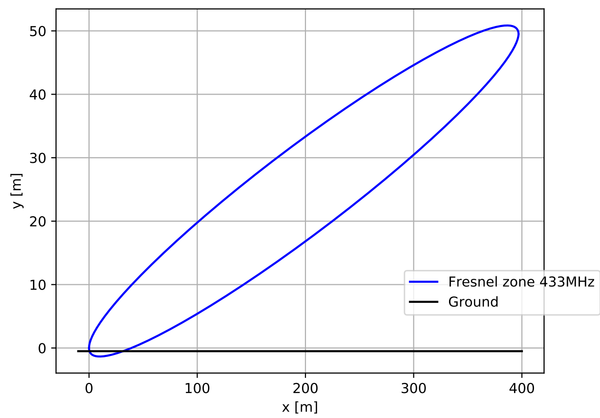


Figure 5: 1st Fresnel zone for 433MHz signal

to a point of interest on the same line and $D = d_1 + d_2$. Figure 4 shows the first three Fresnel zones plotted for 433MHz, 2.4GHz, and 5.8GHz. Here it is seen that a higher frequency causes Fresnel zones to be smaller.

3.2.4 Fresnel zone loss

Plotting the Fresnel zone from the specified parameters, we noticed that the 1st Fresnel zone of the 433MHz signal was colliding with the ground, as evident from figure 5. Judging from the figure the ground doesn't quite look to occupy 40% of the zone, even close to the operator.

However, we found the calculations of the Fresnel zones to degenerate near the ends of the edges of the ellipsoids, where the TX and RX are placed. This can also be seen both in figure 4 and 5, where the transmitters are always placed at the origin of the plot which is also where the radius of all Fresnel is zero. This is contradictory to the fact that Fresnel zones do have a radius at the transmitter, and in fact, extend a little bit backward from the transmitter and receiver. From Wikipedia[2] we see that the equation for Fresnel zones is an estimate that is not valid close to the edges, which explains this discrepancy.

To calculate the minimum required distance to the metal roof to stay clear of the first Fresnel zone we again use (5) with the specified values of $D = 200$, $d_1 = 100$, $d_2 = D - d_1$, $n = 1$, $\lambda = c/f$.

$$F_{1,433\text{MHz}} = \sqrt{\frac{\frac{c}{433\text{MHz}} \cdot 100\text{m} \cdot 100\text{m}}{200\text{m}}} = 5.89\text{m} \tag{6}$$

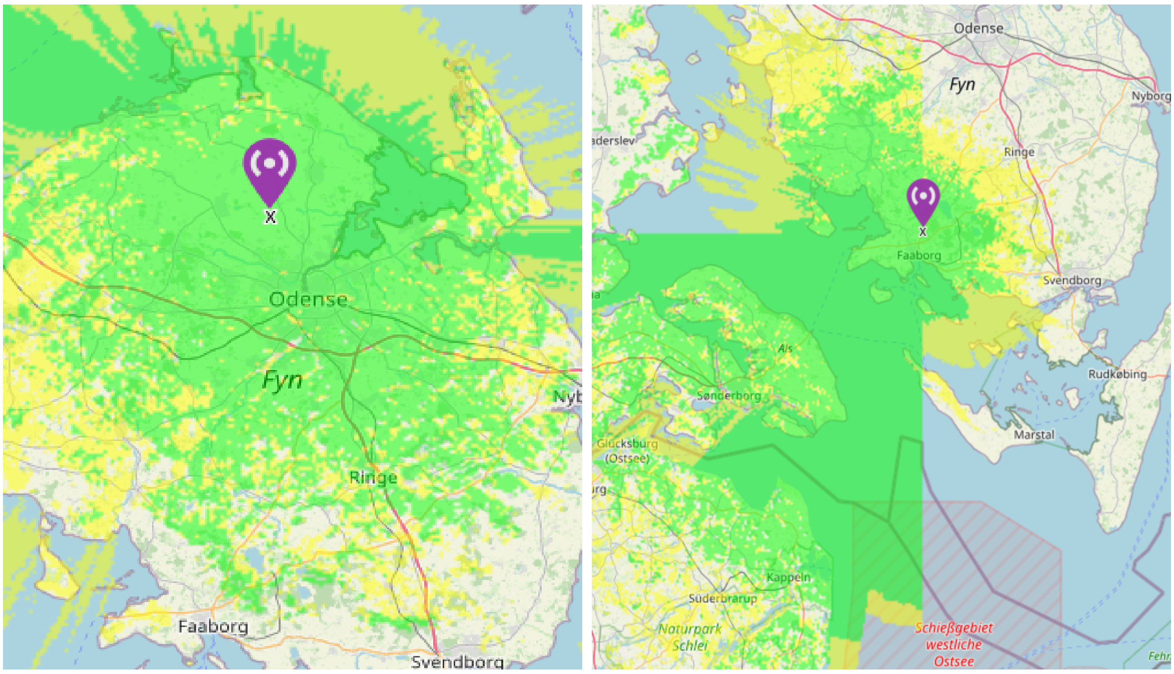
$$F_{1,2.4\text{GHz}} = \sqrt{\frac{\frac{c}{2.4\text{GHz}} \cdot 100\text{m} \cdot 100\text{m}}{200\text{m}}} = 2.5\text{m} \tag{7}$$

$$F_{1,5.8\text{GHz}} = \sqrt{\frac{\frac{c}{5.8\text{GHz}} \cdot 100\text{m} \cdot 100\text{m}}{200\text{m}}} = 1.61\text{m} \tag{8}$$

3.3 Simulation of path loss based on terrain contours

The link and coverage have been simulated at the HCA airport shown in figure 6b with the parameters shown in figure 7. It does not exactly align with the path loss from exercise 3.1.3, but that may be due to the error in its formula, which stated that the loss would be much bigger than shown on the map. Notice that at Svanninge Bakker, the area is generally more obstructed than the one at HCA Airport due to its higher number of elevations.

[2] `https://en.wikipedia.org/wiki/Fresnel_zone`



(a) Transmitting from HCA Airport (b) Transmitting from Svanninge Bakker

Figure 6: Map for the Radio Mobile Online coverage test

Centre Site	New Site 1	
Antenna Height (m above ground)	2	6.56 ft
Antenna Type	Omni	
Antenna Azimuth (°)	0	
Antenna Tilt (°)	0	
Antenna Gain (dBi)	2.15	
Mobile Antenna Height (m)	2	6.56 ft
Mobile Antenna Gain (dBi)	2.15	
Description	HCØ 433 MHz**	
Frequency (MHz)	433	
Tx power (Watts)	20	43.01 dBm
Tx line loss (dB)	0.02	
Rx line loss (dB)	0.02	
Rx threshold (μV)	0.2	-120.98 dBr
Required reliability (%)	70	
Strong Signal Margin (dB)	10	
Strong Signal Color		
Weak Signal Color		
Opacity (%)	50	
Maximum range (km)	100	62.1371 mi
Rendering	Low resolution (Fast)	
Use land cover	☑	
Use two rays	☑	

Figure 7: Parameters for creating the coverage test on figure 6