1 | Worksheet

1.1 Friis

The reason why there is a loss through free space, is that the signal density gets lower, as it spread over a larger area, which happens when the distance, that the signal has travelled, gets longer.

A example, is when using a isotropic antenna, the signal density is equal all the way around the antenna, forming a sphere around the antenna. As the power of the signal in total always is the same, the density of the signal power is depended on the surface of the sphere. As the signal travels longer away from the antenna, the sphere gets bigger and the surface bigger to, which means that the signal density gets lower. So the free space loss, is the factor describing the signal that is not going in the direction of the receiving antenna.

Friis transmission equation is used to calculate the power, that is received at the receiving antenna, out from the gains in the antenna, the power of the transmitted signal and the free space loss.

$$P_r = P_t G_t G_r (\frac{\lambda}{4\pi d})^2 \tag{1.1}$$

Where:

P_r	is the received power at the receiving antenna	[W]
P_r	is the transmitted power at the transmitting antenna	[W]
G_t	is the gain in the transmitting antenna	[1]
G_r	is the gain in the receiving antenna	[1]
λ	is the wavelength of the transmitted signal	[m]
d	is the distance between the transmitting antenna and the receiving antenna	[m]

It is used to calculate the loss through the free space and does not take into account other waves, than the direct wave. The free space loss is equal to $(\frac{\lambda}{4\pi d})^2$ and is multiplied by the gains in both antennas and the power transmitted, to get the received power level.

The free space loss comes from the spreading of the signal, which is compared to the spheres, which in the signal spread in, surface, which is calculated by $\frac{1}{4\pi d^2}$. Furthermore, there also comes the loss, when the signal is received at the receiver, where the effective antenna area is equal to $\frac{\lambda^2}{4\pi}$. These two losses give in total the free space loss. (Hans eberts pdf)

This is the simple form of friis formulae and it is only correct, if these conditions is met:

- d is much greater than λ. If d is smaller than λ, there will be gain in power through the transmission between the antennas, which is a violation of the law of conservation of energy.
- The transmission goes through freespace, with no multipath. So no obstacle in the transmission line or around it (See worksheet about Line of sight (LOS)).
- The antennas is aligned and have the same polarization.
- The bandwidth is narrow enough, so that a single wavelength can be specified.
- P_r and P_t is the available power at the antennas, and do not take into account the loss through the cable running from antennas. Furthermore, the power will only be fully delivered and received, if the antennas and transmission lines are conjugate matched.

When the antennas are not aligned and/or do not have the same polarization, the simple version of the equation cannot be used. Another problem, is if the impedances is mismatched, which gives a reflection at the antennas, which is another loss in the system. Also there is loss through the air, where the air absorb some of the power from the signal. With these losses, the equation is expanded to:

$$P_r = P_t G_t(\theta_t, \phi_t) G_r(\theta_r, \phi_r) (\frac{\lambda}{4\pi d})^2 (1- \mid \Gamma_t \mid^2)(1- \mid \Gamma_r \mid^2) \mid a_t \cdot a_r^* \mid^2 e^{-\alpha d} \tag{1.2}$$

Where:

P_r	is the received power at the receiving antenna	[W]
P_r	is the transmitted power at the transmitting antenna	[W]
$G_t(\theta_t, \phi_t)$	is the gain in the transmitting antenna	[1]
$G_r(\theta_t, \phi_t)$	is the gain in the receiving antenna	[1]
λ	is the wavelength of the transmitted signal	[m]
d	is the distance between the transmitting antenna and the receiving antenna	[m]
Γ_t	is the reflection constant a the transmitting antenna	[1]

Γ_r	is the reflection constant a the receiving antenna	[1]
a_t	is the polarization vector of the transmitting antenna	[1]
a_r	is the polarization vector of the receiving antenna	[1]
α	is the medium of transportations absorption coefficient	[1]

The new terms comes from different losses in the system, when the system is not ideal.

1.2 Two Ray Plane Earth

In contrast to the Friss pathloss model, the Two-ray-ground-reflection path loss model [Tom Henderson, 2011], considers both the direct wave and the reflected ground wave. Also the Two-ray-ground-reflection path loss model does not depend on the frequency, as the Friss pathloss model does. The received power depending on the distance is given in the following Formula:

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{L \cdot d^4} \tag{1.3}$$

Where h_t^2 and h_r^2 are the heights of the transmitter and receiver antennas respectively. And L is the system loss.

If the distance d is less then a critical point d_c:

$$d < d_c \tag{1.4}$$

Where d_c is given as:

$$d_c = \frac{4\pi \cdot h_t h_r}{\lambda} \tag{1.5}$$

If this condition is true then the two-ray model predicts oscillations which are caused by the constructive and destructive combination of the two rays. This condition is true for small distances d.

1.2.1 Critical point calculation

For the measurements done, the condition is tested:

$$d < d_c \tag{1.6}$$

For 2m and 2m heights of transmitter and receiver antennas, for both 858MHz and 2.58GHz

For 2m and 2m heights of the transmitter antenna and receiver antenna. This for a frequency of 858MHz:

$$d_c = \frac{4\pi \cdot 2m \cdot 2m}{0.3494m} = 143.86m \tag{1.7}$$

So for 2m and 2m, for all distances from 1m to 30m between the sender and the receiver, the results when using the Two-ray propagation model, shall experience oscillations caused by the constructive and destructive combination of the two rays.

While the the same for 2.58GHz:

$$d_c = \frac{4\pi \cdot 2m \cdot 2m}{0.1161m} = 432.94m \tag{1.8}$$

Again the condition is not met, for all distances, for 2m and 2m.

858Mhz

In the following a table **??** is made to illustrate if the condition stated in 1.6, is met for all distances, 1m,2m,4m,8m,15m and 30m, between the transmitter and receiver ,for the frequency 858MHz, with 0.01m set and compared with 0.01m, 0.08m, 0.34, and 2m transmitter and receiver height positions h_t and h_r.

	858MHZ	
h_t,h_r	Met	Not met
0.01m, 0.01m, d_c = 0.0036m		At all distances
0.01m, 0.08m, d_c = 0.028m		At all distances
0.01m, 0.34m, d_c = 0.12m		At all distances
0.01m, 2m, d_c = 0.72m		At all distances

Table 1.1: My caption

For 0.08m:

	858MHZ	
h_t,h_r	Met	Not met
0.08m, 0.08m,d_c = 0.23m		At all distances
0.08m, 0.34, d_c = 0.97m		At all distances
0.08m, 2m, d_c = 5.76m	1,2 and 4m	At 8,15 and 30m

Table 1.2: My caption

So for 0.08m and 2 the condition $d < d_c$ for distances of 1m, 2m and 4m, is met. While for 0.08m and 0.08, and 0.08m and 0.34, the condition is not met and the results with Two ray model shall not experience oscillations caused by the constructive and destructive combination of the two rays.

For 0.34m

	858MHZ	
h_t,h_r	Met	Not met
0.34m, 0.34m, d_c = 4.16m	1,2,4	At 8, 15,30m
0.34m, 2m, d_c = 24.48m	1,2,4,8,15	At 30

Table 1.3: My caption

For 2m

	858MHZ	
h_t,h_r	Met	Not met
2m,2m. d_c = 144m	At all distances	

Table 1.4: My caption

2.58GHz

For 0.01m

	2.58GHz	
h_t,h_r	Met	Not met
0.01m,0.01m $d_c = 0.010$		At all distances
0.01m, 0.08m $d_c = 0.0865$		At all distances
0.01m,0.34m $d_c = 0.36$		At all distances
0.01m,2m $d_c = 2.16$	1m and 2m	At 4,8,15,30m

Table 1.5: My caption

For 0.08m

	2.58GHz	
h_t,h_r	Met	Not met
0.08m,0.08m $d_c = 0.69$		At all distances
0.08m, 0.34m $d_c = 2.94$	1, 2m	At, 4,8,15 and 15m
0.08m,2m $d_c = 17.31$	1,2,4,8 and 15m	At 30m

Table 1.6: My caption

For 0.34m

	2.58GHz	
h_t,h_r	Met	Not met
0.34m,0.34m $d_c = 12.51$	At 1,2,4 and 8m	At 15, 30m
0.34m, 2m $d_c = 73.6$	At all distances	

Table 1.7: My caption

For 2m

	2.58GHz	
h_t,h_r	Met	Not met
2m,2m $d_c = 432.9$	At all distances	

Table 1.8: My caption

[Poole, 2016]

Bibliography

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Appendix