Fundamental problems concerning VHF and UHF propagation: free space propagation

An important stage in designing of mobile radio communications systems (VHF: 30MHz-300MHz; UHF: 300MHz-3GHz) consists in studying the mobile radio channel behaviour. The technical characteristics of the transmitter/receiver and antennae are adjusted/ chosen depending on the radio communication channel. The radio channel modifies randomly in time and frequency. Its behaviour may be predicted, in certain limits, using complex statistical propagation models.

In this lab one deterministic propagation model will be studied: free space propagation model.

Free space propagation

Free space propagation model assumes the existence of a transmitter and a receiver separated by a distance much higher than the electromagnetic radiation wavelength and placed in direct visibility, at great distance with respect to other objects. This is an ideal model and the propagation losses corresponding to this model will act as reference for other complex models with practical applicability in systems designing.

Theoretical abstract

The antennae may be designed with no omnidirectional characteristics thus the antenna directivity can be used to quantify its ability to focus the energy in a particular direction. The antenna directivity *D* is defined as the ratio between the power density at the distance *d* (in the direction of maximum radiation) and the mean power density:

$$D = \frac{W|_d}{W_m|_d}$$

It is more convenient to work in terms of power at receiver and power gain *G*. The latter is defined as the ratio between the power density at distance *d* and the power density at distance *d* if the transmitter antenna was isotropic:

$$G = \frac{W|_d}{\frac{P_T}{4\pi d^2}}$$

where $W|_d$ represents the power density at distance *d* (in the direction of maximum radiation) and P_T - the power supplied at transmission in the antenna. An isotropic antenna radiates the energy uniformly in all directions, being a pure theoretical concept. If an isotropic antenna radiates the power P_T, then the power density induced at the distance d is given by:

$$W|_d = \frac{P_T}{4\pi d^2}$$

Thus, the energy radiated by the isotropic antenna is uniformly distributed on a sphere with the radius *d*. A real antenna placed at the distance *d* will capture a certain amount of this energy, in accordance with its effective area, such that the received signal power becomes:

$$P_R = A \cdot W|_d$$

The relation between the effective area and the power gain is:

$$A = \frac{\lambda^2 G}{4\pi}$$

If the transmission antenna is placed in free space (far from ground and other obstacles), considering that G_T is the gain on the direction of the transmission antenna:

$$W|_d = \frac{P_T G_T}{4\pi d^2}$$

The power available for the receiver antenna characterised by the effective area *A* is:

$$P_R = \frac{P_T G_T}{4\pi d^2} A = \frac{P_T G_T}{4\pi d^2} \cdot \frac{\lambda^2 G_R}{4\pi}$$

where G_R is the receiver antenna gain. Therefore:

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 = G_T G_R \left(\frac{c}{4\pi f d}\right)^2 \qquad (1)$$

which is known as **the free space propagation fundamental equation** or **Friis equation**. The losses due the propagation may be deduced from equation (1) and expressed in dB as:

$$L_F = 10lg\frac{P_R}{P_T} = 10lgG_T + 10lgG_R - 20lgf - 20lgd + k$$

where: $k = 20lg\frac{c}{4\pi} = 147{,}6$.

It is useful to compute the losses in the case of the isotropic antennae (which radiate uniformly in all directions with by G=1) and the primary losses L_B are:

$$L_B[dB] = -32{,}44dB - 20lgf[MHz] - 20lgd[km] \qquad (2)$$

Equation (2) indicates that the received power decreases with 6 dB when the distance doubles.

Remark:

In some situations, an expression that highlights the electrical field intensity at a certain distance with respect to the transmission antenna would be very convenient. Therefore, the relation between the field intensity and the power density is:

$$W = \frac{E^2}{Z_0}$$

where Z_0 is the wave characteristic impedance of the medium, its value being $120\pi \cong 377\Omega$. Therefore, the equation may be written as:

$$\frac{E^2}{Z_0} = \frac{P_T G_T}{4\pi d^2}$$

hence

$$E = \frac{\sqrt{\frac{Z_0 P_T G_T}{4\pi}}}{d} = \frac{\sqrt{30 P_T G_T}}{d}$$

The maximum usable power at reception may be written as:

$$P_R = \frac{E^2 A}{Z_0} = \frac{E^2}{Z_0}\frac{\lambda^2 G_R}{4\pi} = \left(\frac{E\lambda}{2\pi}\right)^2 \frac{\pi G_R}{Z_0} = \left(\frac{E\lambda}{2\pi}\right)^2 \frac{G_R}{120} \quad (3)$$

Remarks:

- For high frequencies (used in mobile communications) propagation losses are very significant, and therefore it is necessary to use high gain antennae. This type of antennae may be easily designed for VHF and UHF bands and represents a solution for point-to-point communications, but not for the mobile communications where an omnidirectional coverage is required.
- The conditions imposed in order to use this model (unobstructed antenna placed in free space, radio waves propagation is not done on multiple paths, aligned antennae and correctly polarised, $d \gg \lambda$) cannot be fulfilled by usual terrestrial communications, so Friis equation is adequate only for satellite communications, when the atmospheric absorption is negligible.
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Contents of the work

Run ***demo1rpr.m*** which creates the plot of the propagation losses as a function of the distance taking the frequency *f* as a parameter. Input data:

- Distance between transmitter and receiver $d = 10m \ldots 10km$;
- Frequency values: *f* = 1 MHz, 4 MHz, 12 MHz, 100 MHz şi 1 GHz;
- Antennae's gains $G_T = G_R = 1$.

Questions

1. Determine the slope for free space propagation losses variation as a function of frequency.
2. Determine the slope for free space propagation losses variation as a function of distance.
3. What can be observed in the proximity of the transmitter (distances ≈ wavelength)?
4. Determine the propagation losses in the case when the distance between the transmitter and the receiver is *d* =1 km, the frequency of the signal is *f* = 900 MHz and the antennae have a gain of 2 dB. **Indication:** use the Matlab function *FrSpcLss*.

5. Consider a radio transmitter with P_T= 50 W. If the antenna of the transmitter is isotropic and the frequency of the emitted signal is 900 MHz, compute the free space received power at the distance *d*=100m from the transmitter. It is supposed that the receiver also has an isotropic antenna.

6. If the power received by an antenna having the gain $G_R = 2$ is $P_R = 7 \cdot 10^{-10} W$, and the frequency of the signal is f=900MHz, determine the intensity of the electrical field at the receiver. **Indication:** relation (3) should be used.