Technische Universität Braunschweig

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Fundamentals of Mobile Radio Communications

Exercise 5: Wave Propagation Effects

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1 Reflection

1.1 Calculate the Fresnel reflection coefficients and the resulting losses in TE and TM polarization for the following materials, assuming they are lossless. The dielectric material properties are valid for f = 900 MHz.

$$r_{\mathrm{TE}} = \frac{E_{0r}}{E_{0i}} = \frac{\text{reflected field strength}}{\text{incident field strength}}$$

Using $\varepsilon_{r,\mathrm{air}} = 1$, we get:

$$r_{\mathrm{TE}} = \frac{\cos\theta_i - \sqrt{\varepsilon_r - \sin^2\theta_i}}{\cos\theta_i + \sqrt{\varepsilon_r - \sin^2\theta_i}}$$

$$r_{\mathrm{TM}} = \frac{\varepsilon_r\cos\theta_i - \sqrt{\varepsilon_r - \sin^2\theta_i}}{\varepsilon_r\cos\theta_i + \sqrt{\varepsilon_r - \sin^2\theta_i}}$$

with incident angle θ_i and the relative permittivity ε_r of the reflecting material.

These coefficients can be transformed into logarithmic losses:

$$L_{\mathrm{dB,refl}} = -20\log_{10}|r| = -20\log_{10}\left|\frac{E_{0r}}{E_{0i}}\right|$$

Remark: The abbreviations TE and TM refer to transverse electric and transverse magnetic polarization and describe the wave polarization with respect to the plane of incidence (see fig. 1). For transverse electric polarization, the **electric field vector** is perpendicular to the plane of incidence, whereas for transverse magnetic polarization, the **magnetic field vector** is perpendicular to the plane of incidence.

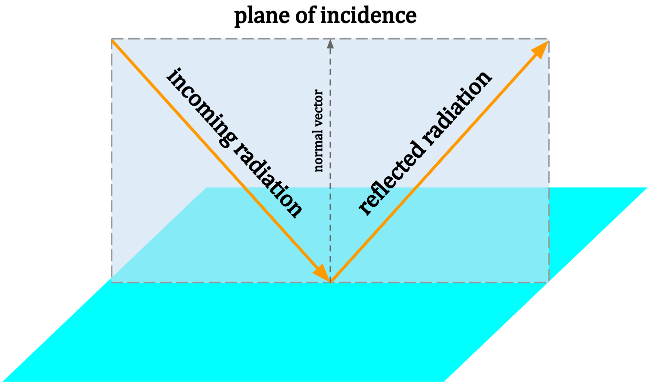

Figure 1: Relationship between incident and reflected wave and the corresponding plane of incidence

1.1.1 Concrete ($\varepsilon_r = 6.4$), $\theta_i = 20°$

1.1.2 Ground / Soil ($\varepsilon_r = 7$), $\theta_i = 85°$

1.2 Calculate the received power through ground reflection and the direct path. Use those values to calculate the total received power.

The setup consists of a transmitting base station ($h_\mathrm{t} = 30\,\mathrm{m}$, $\mathrm{EIRP} = 46\,\mathrm{dBm}$, $f = 900\,\mathrm{MHz}$) and a receiving UE ($h_\mathrm{r} = 1.7\,\mathrm{m}$) which have a horizontal distance d of 5 km. Assume a relative permittivity of $\varepsilon_r = 7$ (ground/soil) and TE polarization. Also, assume that there are no obstacles between transmitter and receiver.

1.3 Explain the concept of the "dual slope approach".

The previously used approach to calculate the total power does not take interference of waves into account. In the near region, **path loss** is increasing with the second power of distance (like in FSPL), but the effect of interference can decrease the loss by up to 6 dB (constructive interference) or can lead to a total cancellation (destructive interference, loss gets very high).

In far region, the path loss is increasing with the fourth power of distance and can be approximately calculated as

$$PL = \frac{P_t}{P_r} = \frac{d^4}{G h_t^2 h_r^2}$$

for $d \gg \frac{4\pi h_t h_r}{\lambda}$ and $G = G_t G_r$. (This can be explained by the destructive combination of direct and reflected path, which are approximately same in magnitude and 180° different in phase.)

The dual slope approach in this case therefore describes the decrease in power (or increase of path loss) with two slopes (in logarithmic scale):

in near region: $PL \propto d^2$ (corresponds to 20 dB per decade)

in far region: $PL \propto d^4$ (corresponds to 40 dB per decade)

1.4 What does "break point" in that context mean? Calculate it for $f = 1800\,\text{MHz}, h_r = 1.5\,\text{m}, h_t = 20\,\text{m}$.

1.5 Fresnel reflection coefficients only apply to smooth materials. If the surfaces are rough, additional scattering will occur. What materials are considered to be rough?

Fraunhofer criterion for smooth surfaces:

$$\sigma < \frac{\lambda}{32 \cos \theta_i}$$

with standard deviation of surface roughness σ and incident angle θ_i.

Ingrain wallpaper ($\sigma = 2$ mm), $\theta_i = 30°,\ f = 1800$ MHz:

$$\frac{\lambda}{32 \cos \theta_i} =$$

Ingrain wallpaper ($\sigma = 2$ mm), $\theta_i = 30°,\ f = 60$ GHz:

$$\frac{\lambda}{32 \cos \theta_i} =$$

2 Diffraction

When considering obstacles in the propagation path of waves (e.g. obscured LOS), single knife edge diffraction can be used to model the effects in a simple way. The obstacle will be approximated as a single, infinitely thin edge (so called knife edge). In our example, we consider the following dimensions:

- $h_t = 20\,\text{m}$
- $h_r = 1.7\,\text{m}$
- $h_{\text{obstacle}} = 10\,\text{m}$
- $r_1 = 250\,\text{m}$
- $r_2 = 150\,\text{m}$
- $f = 900\,\text{MHz}$

Compute the diffraction loss.

Knife edge diffraction loss:

$$L_{\text{dB,d}}(\nu) = 6.9 + 20\log_{10}\left(\sqrt{(\nu - 0.1)^2 + 1} + \nu - 0.1\right)\ \text{dB}$$

with parameter

$$\nu = h \cdot \sqrt{\frac{2(s_1 + s_2)}{\lambda(r_1 \cdot r_2)}}$$