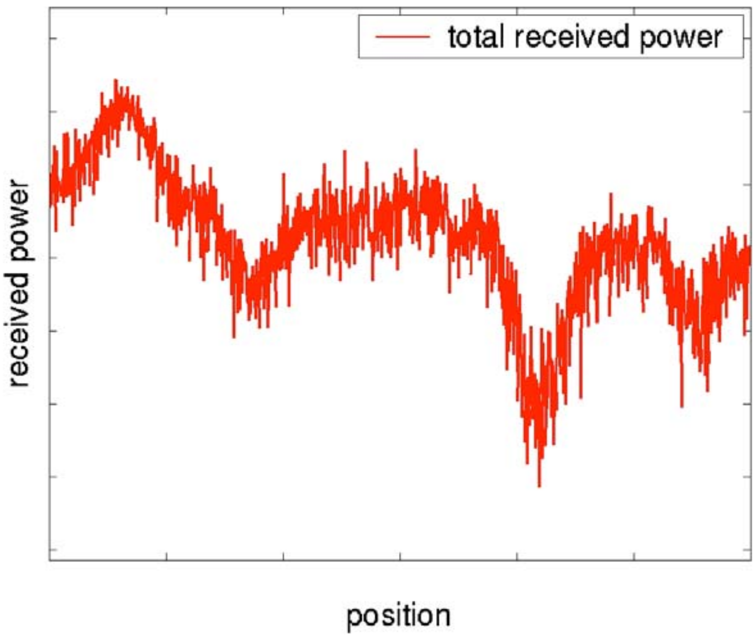
Chapter 3
Radio Wave Propagation Fundamentals

Prof. Dr.-Ing. Thomas Zwick
Dr.-Ing. MarwanYounis
Dipl.-Ing. Grzegorz Adamiuk
Dipl.-Phys. Michael Baldauf

Universität Karlsruhe (TH)
Research University • founded 1825

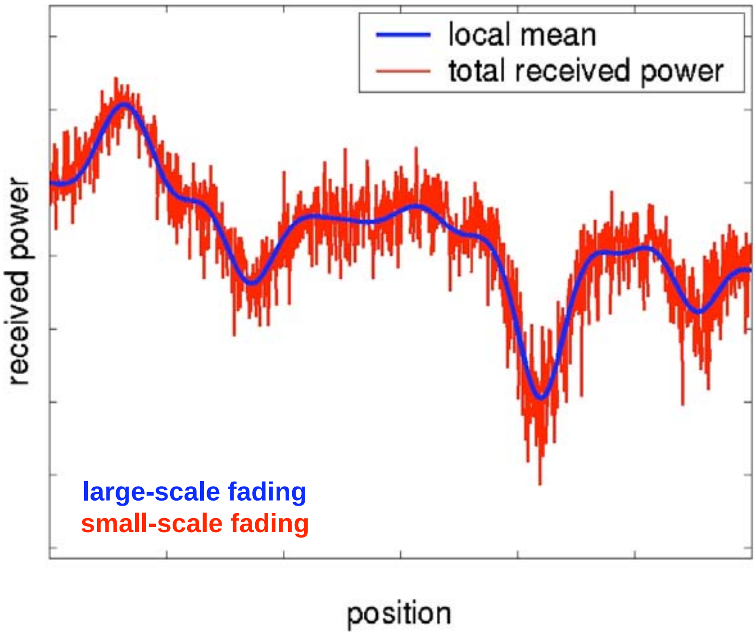
Institut für Höchstfrequenztechnik und Elektronik

The received Signal

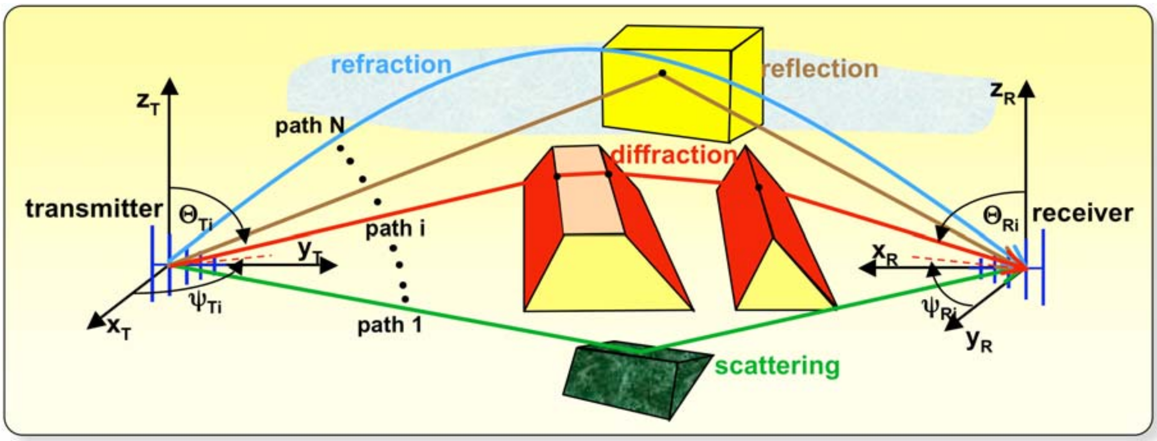


Universität Karlsruhe (TH)
Research University • founded 1825
Institut für Höchstfrequenztechnik und Elektronik

The received Signal



Propagation Phenomena - Overview



free space propagation:
- line of sight
- no multipath

reflection:
- plane wave reflection
- Fresnel coefficients

scattering:
- rough surface
- volume scattering

diffraction:
- knife edge

refraction in the troposphere:
not considered

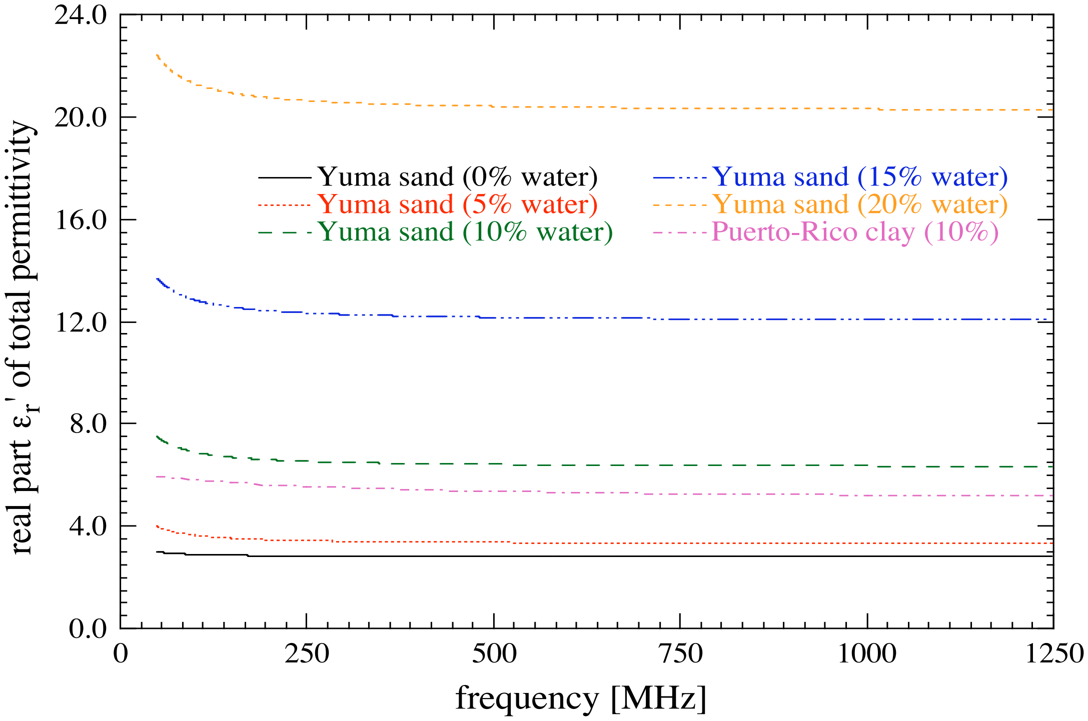
Timetable (preliminary)

Date		14:00-15:30		15:45-17:15
20.10.2008	Marwan	**Introduction**	Marwan	**Antennas**
27.10.2008	Michael	Tutorial dB Calculations		
03.11.2008	Marwan	**Antennas**	Marwan	**Antennas**
10.11.2008	Grzegorz	Tutorial Antennas		
17.11.2008	Grzegorz	Tutorial Antennas		
24.11.2008	Grzegorz	**Wave Propagation**	Grzegorz	**Wave Propagation**
01.12.2008	Grzegorz	**Wave Propagation**	Grzegorz	Tutorial Wave Propagation
08.12.2008	Michael	Tutorial Wave Propagation		
15.12.2008	Marwan	**Channel**	Marwan	**Channel**
22.12.2008	Marwan	**Channel**		
		Christmas and New Year		
12.01.2009	Michael	Tutorial Channel	Michael	Tutorial Channel
19.01.2009	Marwan	**Noise**	Michael	Tutorial Noise
26.01.2009	Marwan	**Noise**	Marwan	**Noise**
02.02.2009	Grzegorz	Tutorial Noise		
09.02.2009	Grzegorz	Tutorial Review		

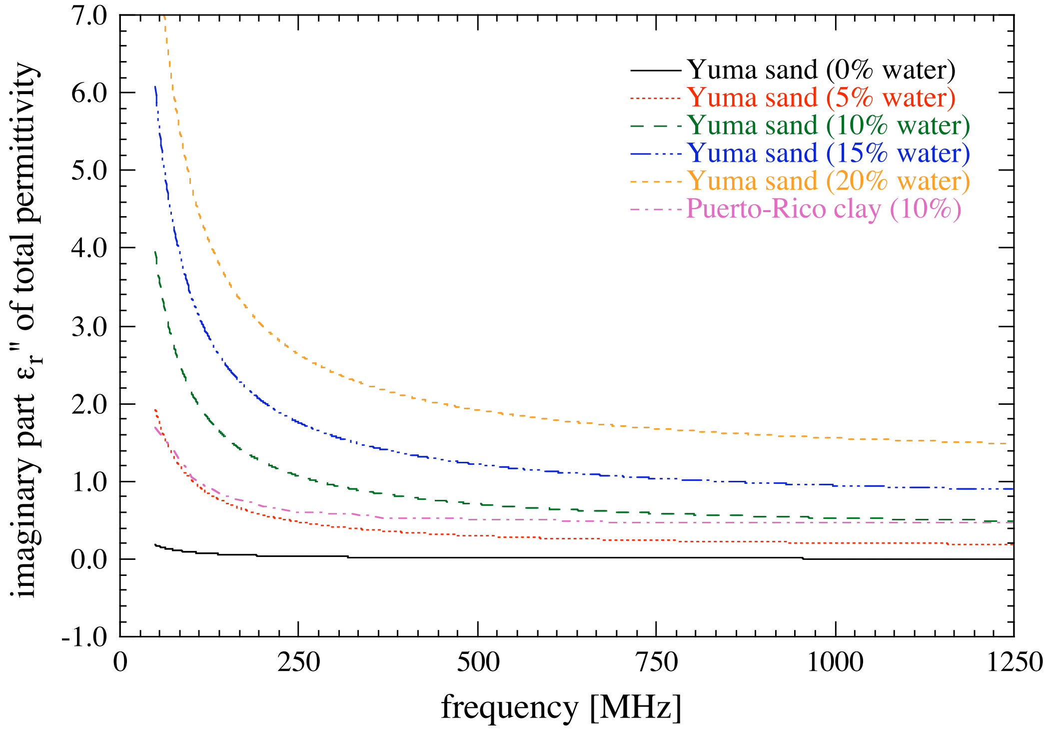
http://www.ihe.uni-karlsruhe.de/859.php

Reflection and Transmission

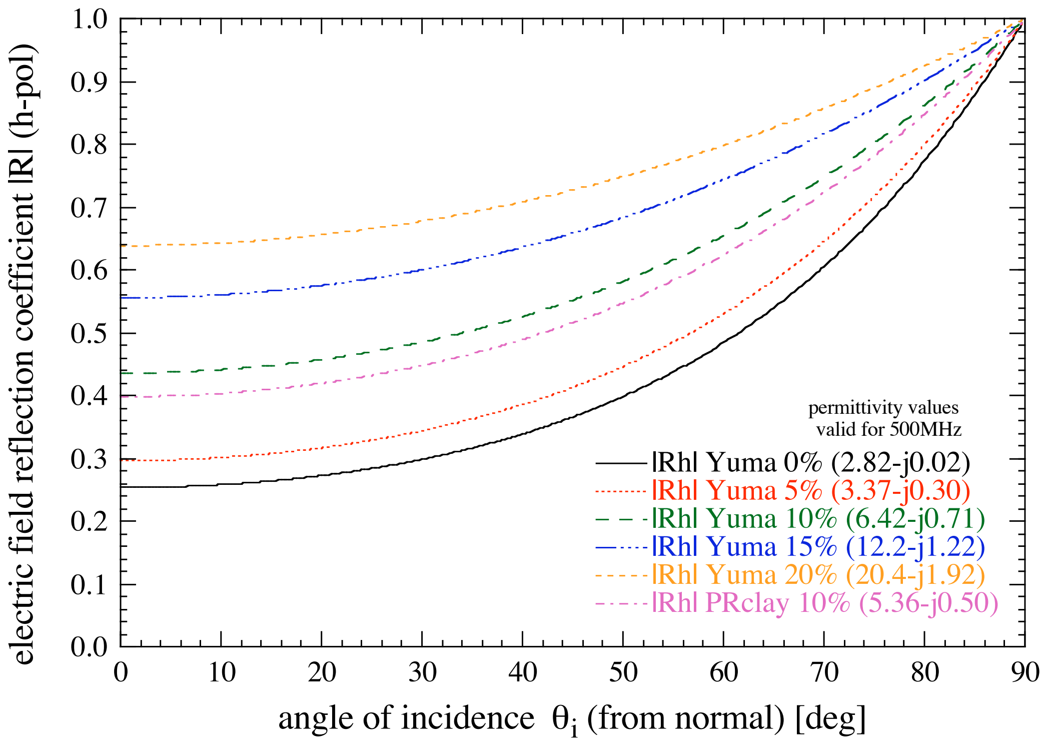
Real Part of ε_r of Total Soil Permittivity



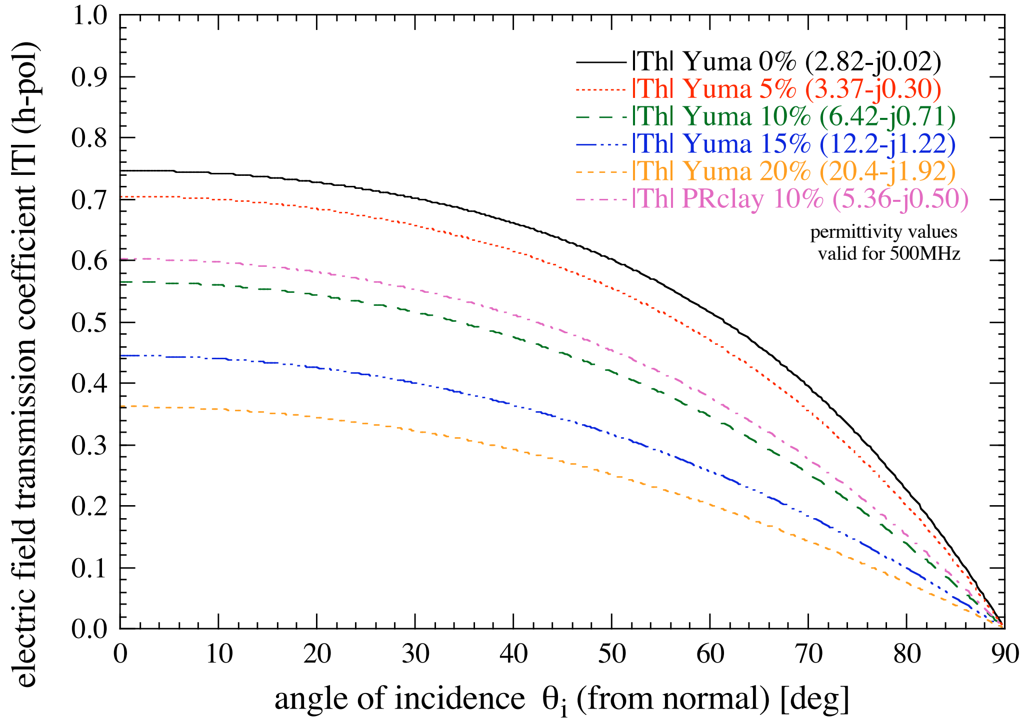
Imaginary Part of ε_r of Total Soil Permittivity



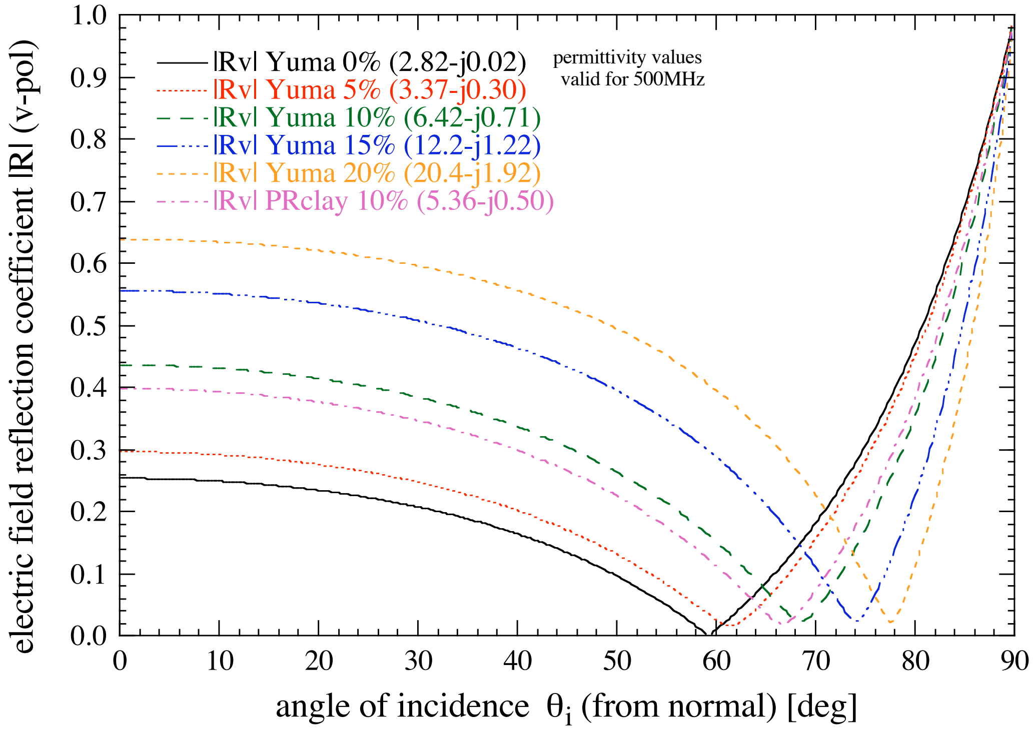
Fieldstrength Reflection Coefficient R_h



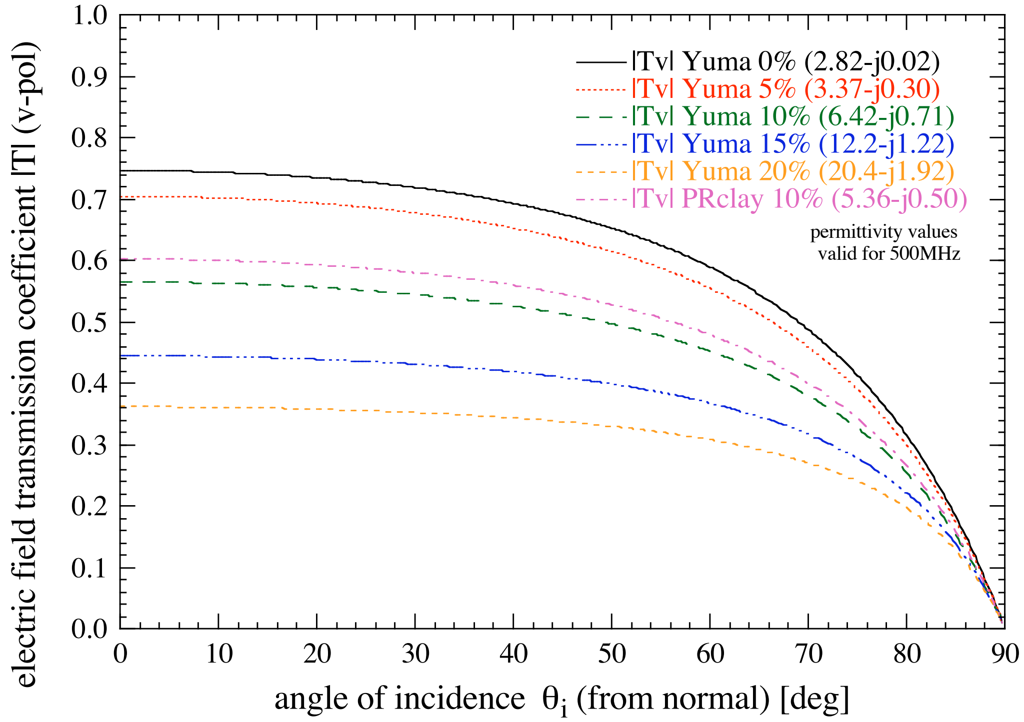
Fieldstrength Transmission Coefficient T_h



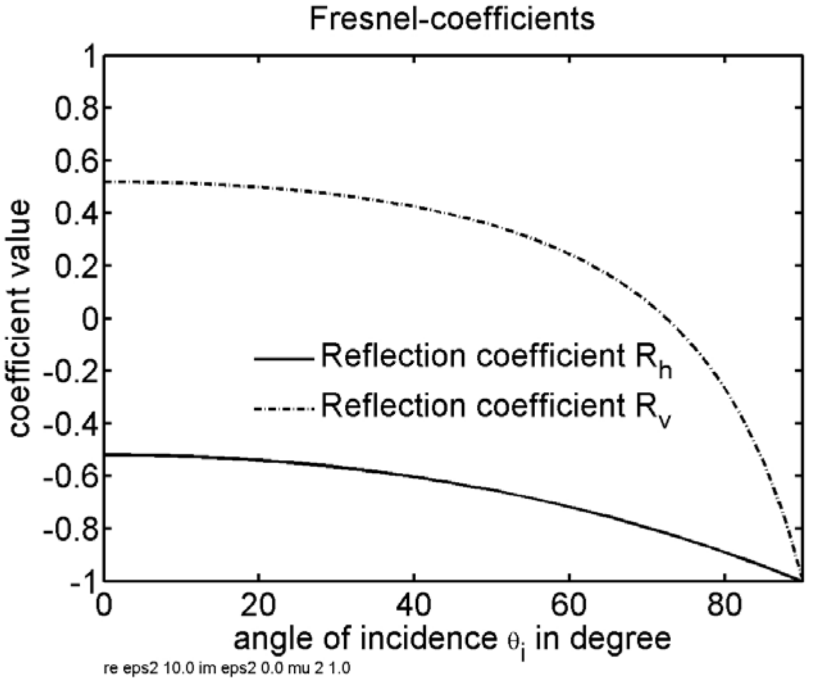
Fieldstrength Reflection Coefficient R_v



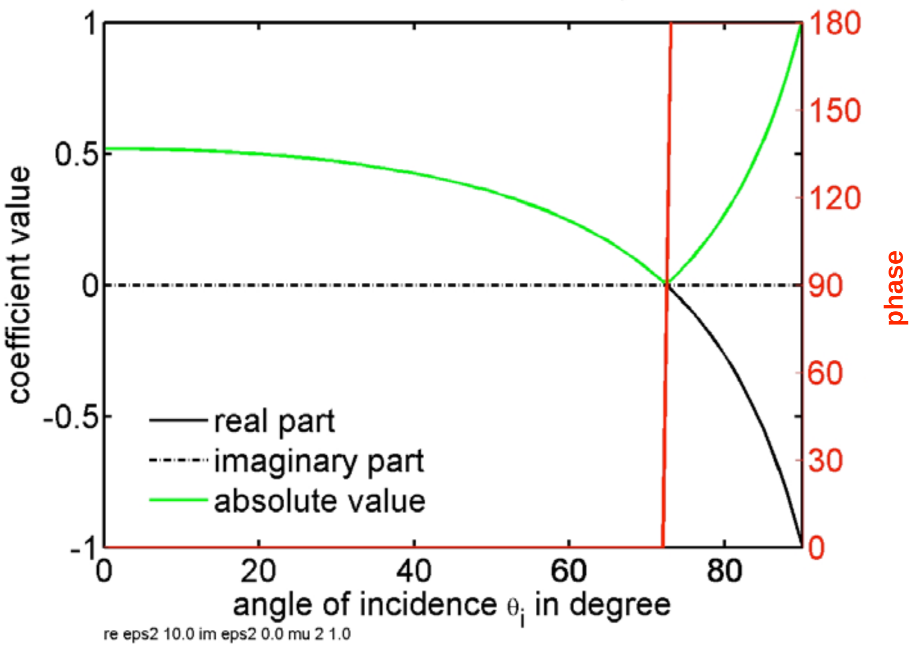
Fieldstrength Transmission Coefficient T_v



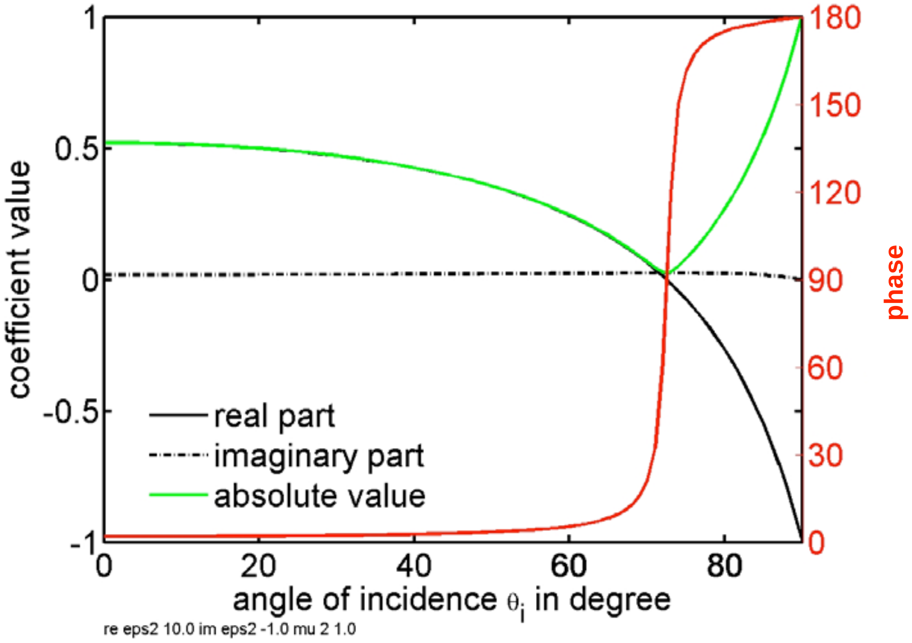
Reflection Coefficient R_v and R_h



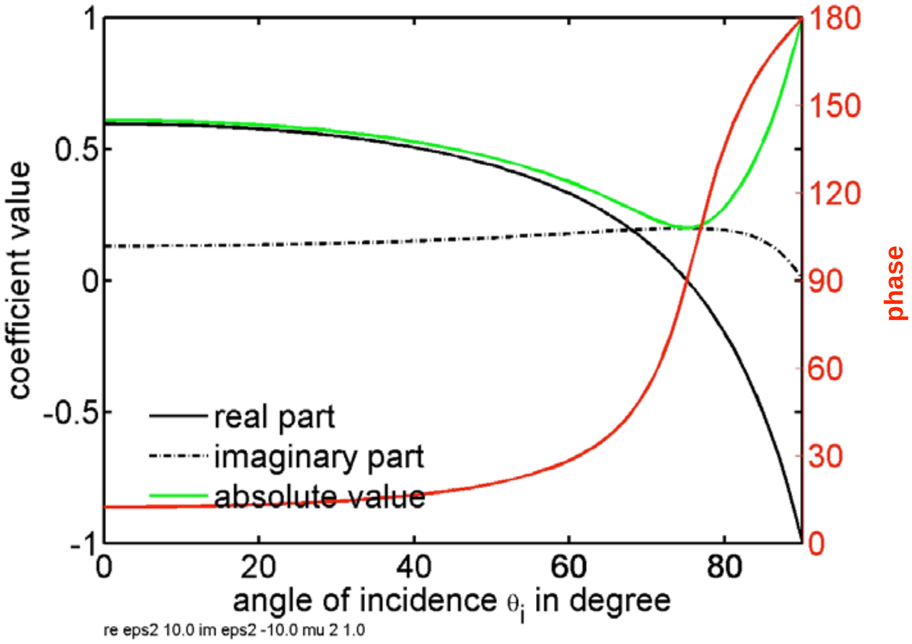
Reflection Coefficient R_v no losses



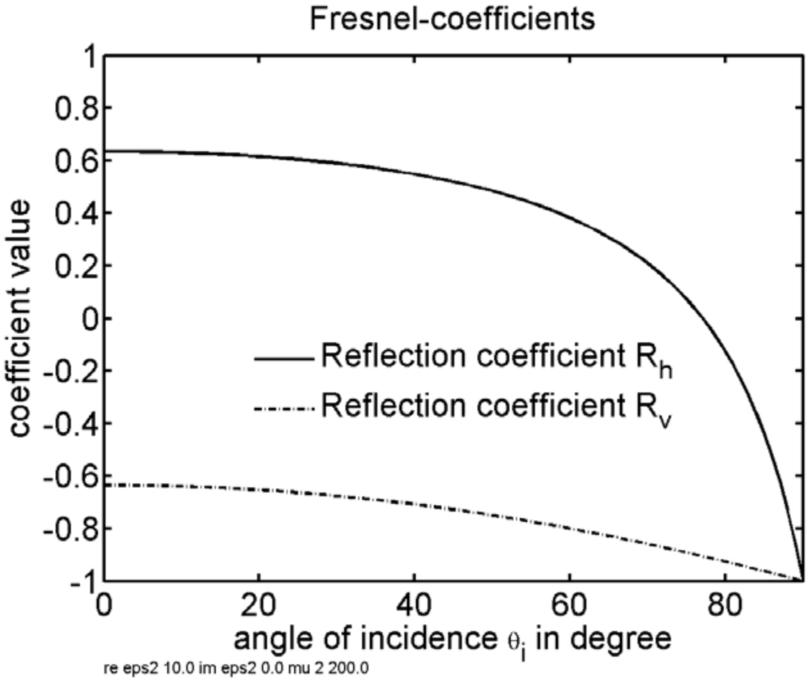
Reflection Coefficient R_v with losses



Reflection Coefficient R_v with losses

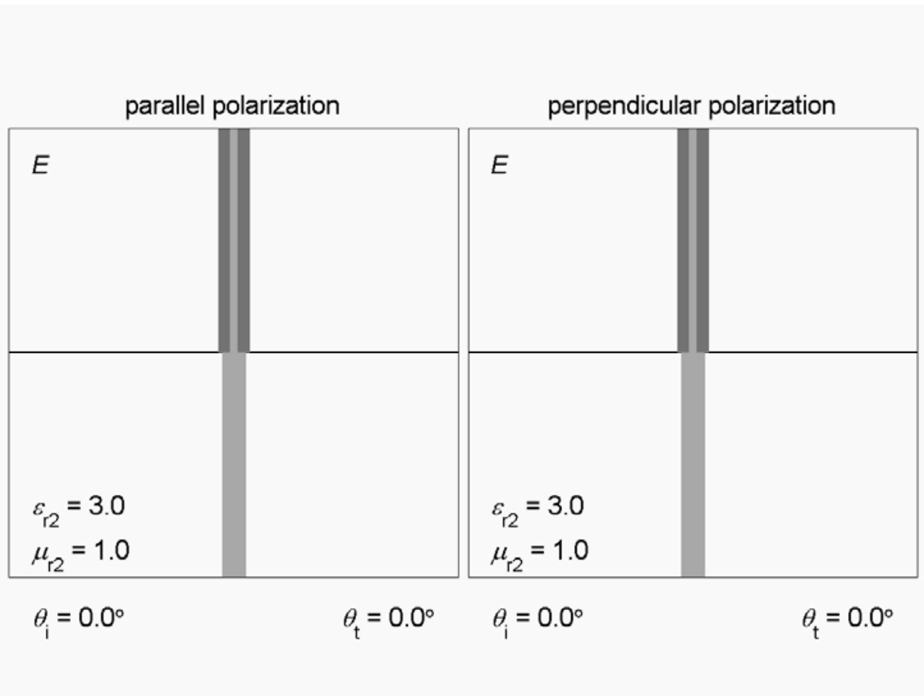


Reflection Coefficient R_v and R_h

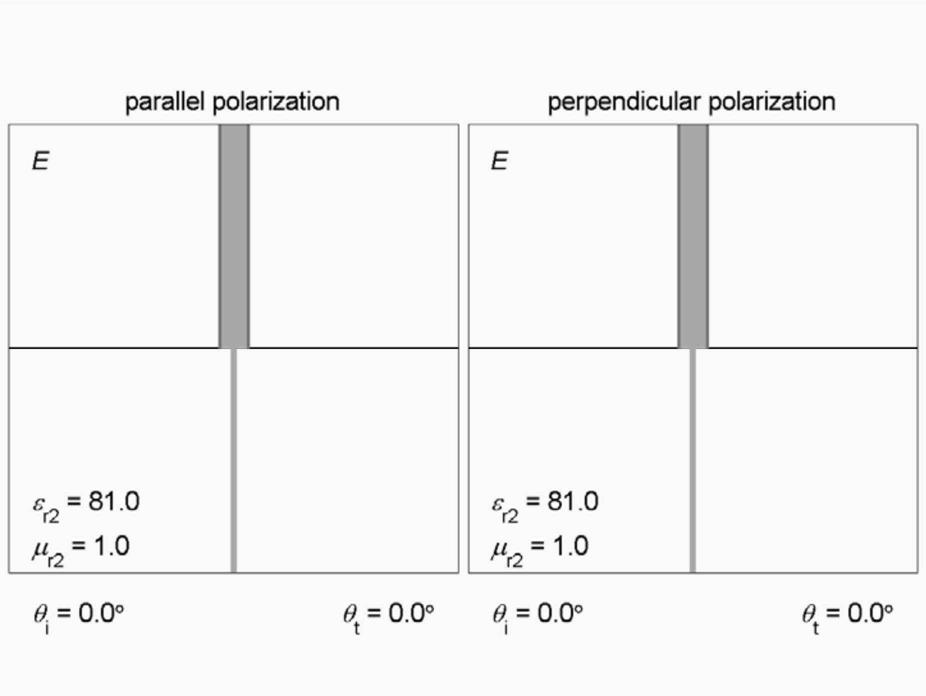


different permeabilites in media 1 and media 2

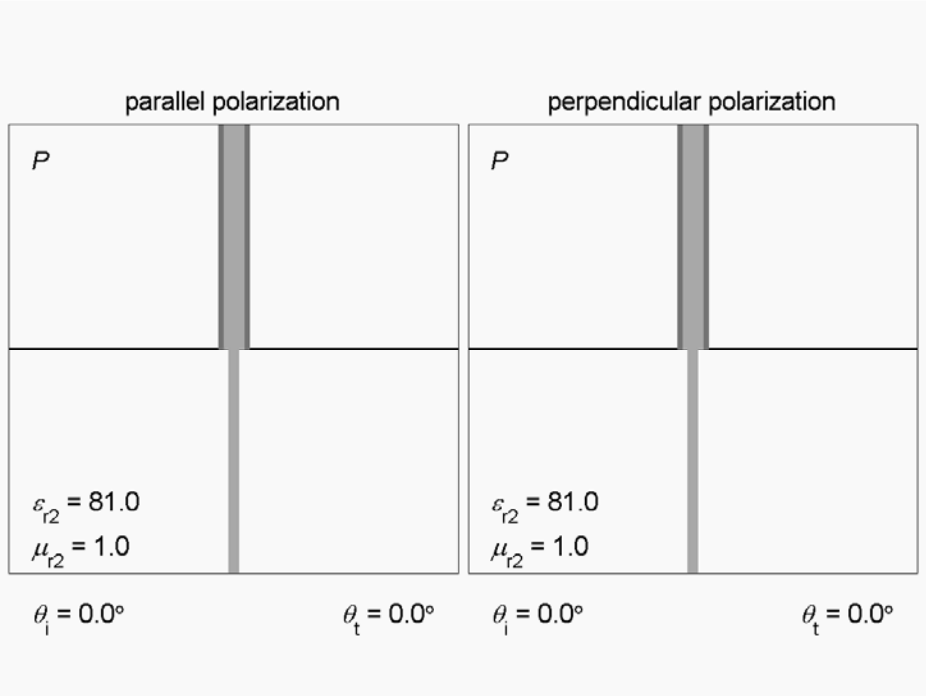
Visualization



Visualization

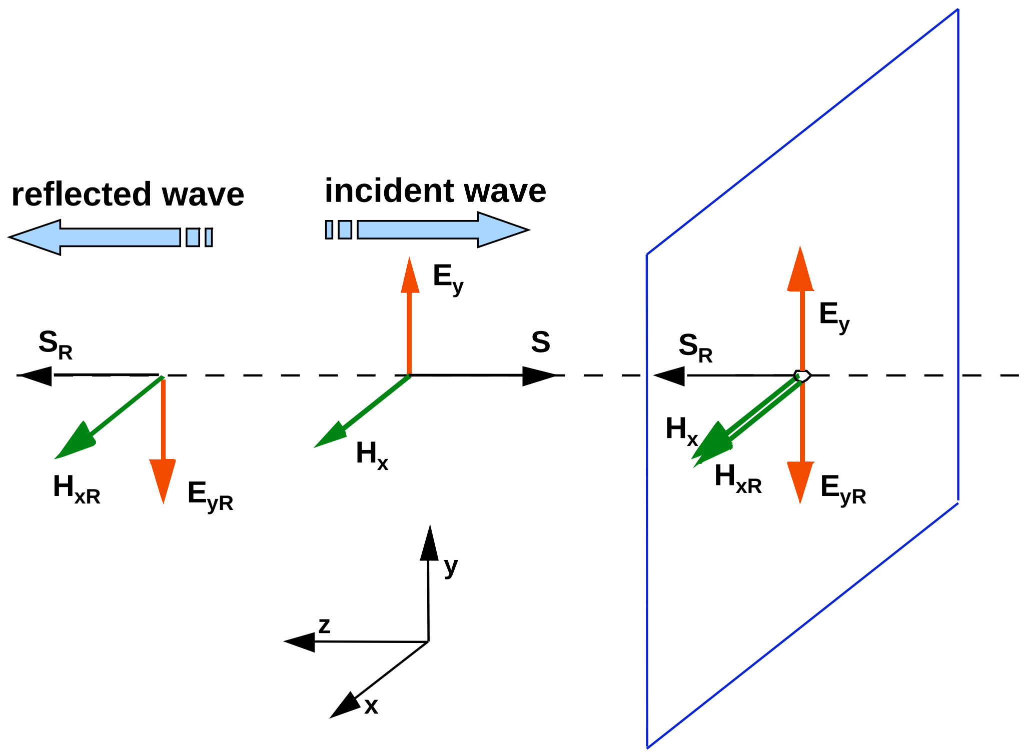


Visualization

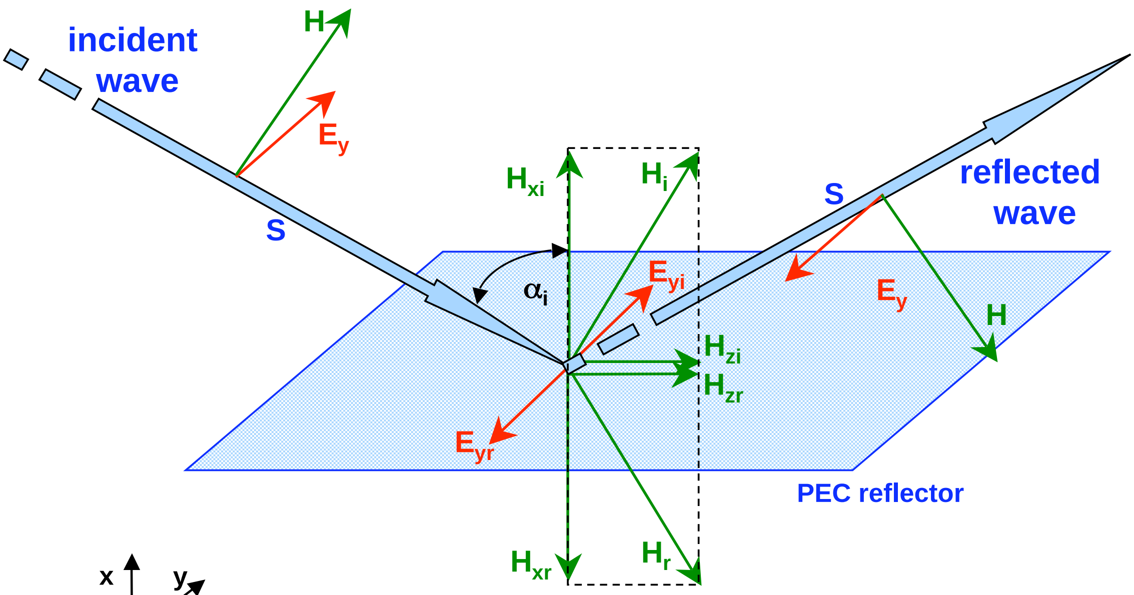


PEC

Orthogonal PEC Reflection



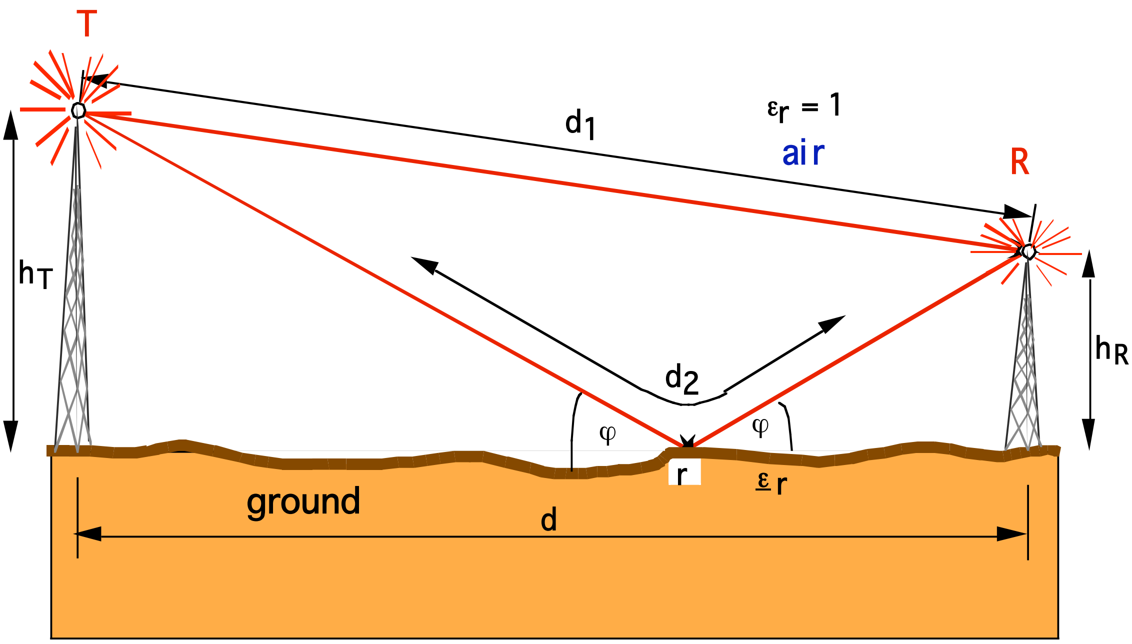
Reflection, Orthogonal Polarization, PEC Plane



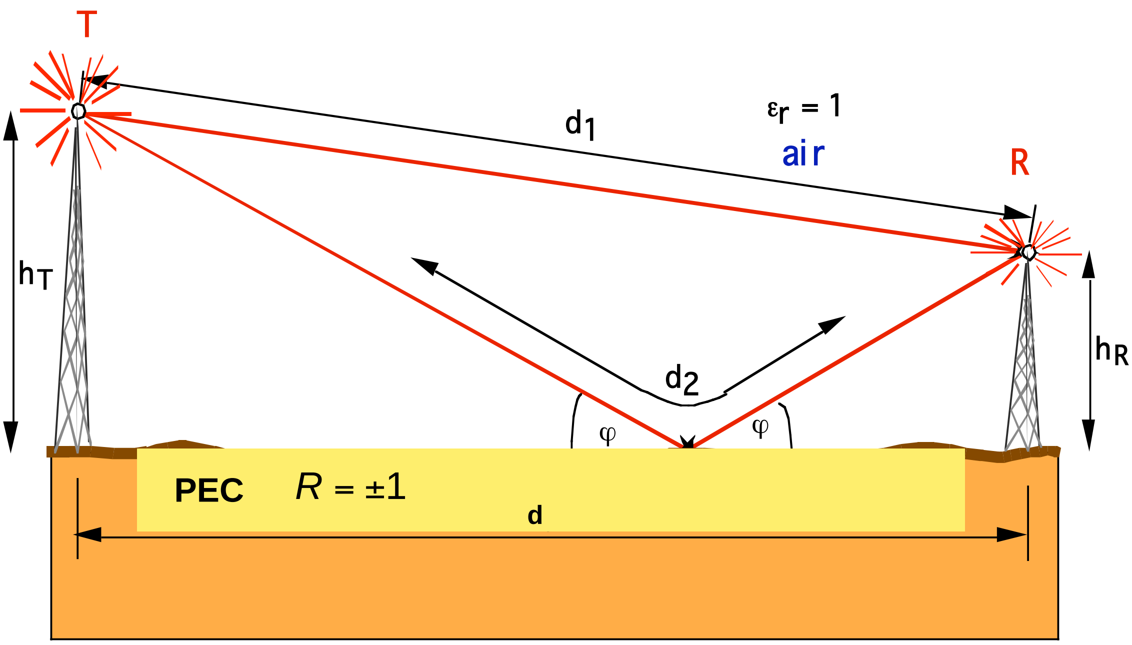
$\alpha_i = \alpha_r$

Two-Ray Model

Two-Ray Propagation



Two-Ray Propagation

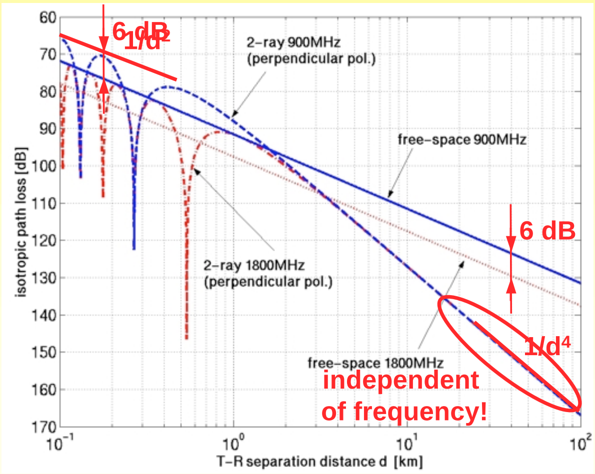


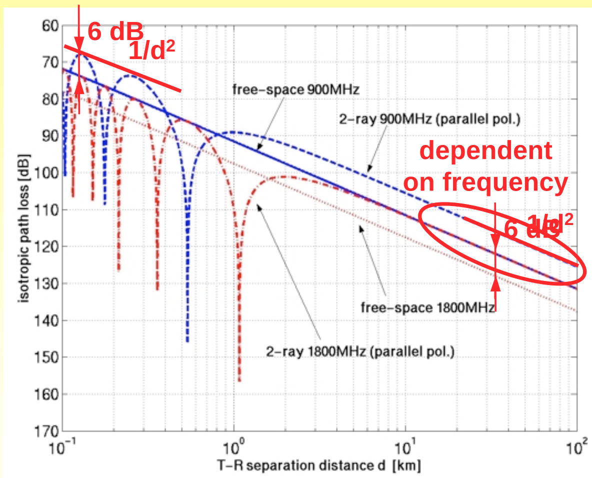
Universität Karlsruhe (TH)
Research University • founded 1825

Institut für Höchstfrequenztechnik
und Elektronik

Path Loss Prediction of the 2-Ray Propagation Model

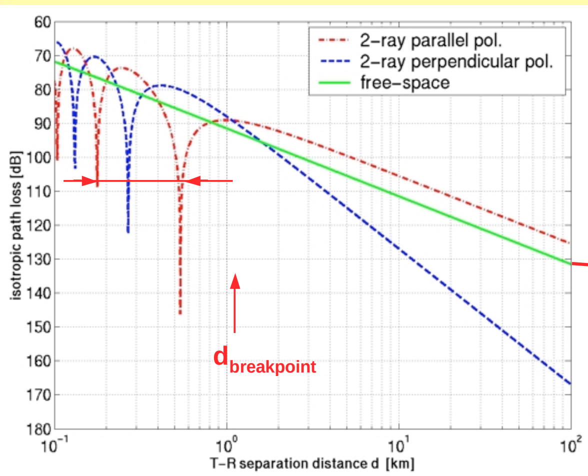
perpendicular polarization | **parallel polarization**

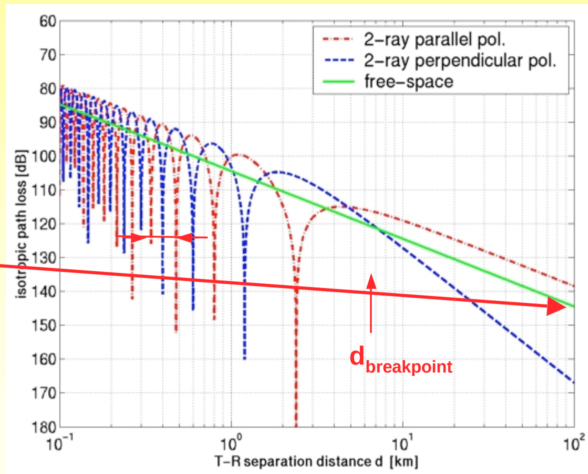




2-Ray Propagation Model: f = 900MHz & 4 GHz

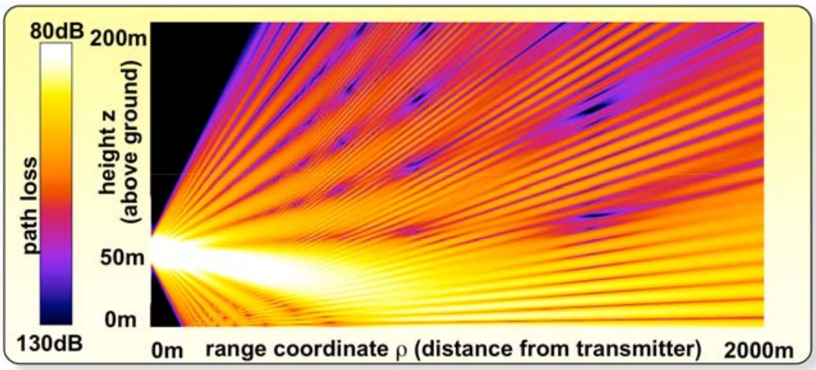
f = 900 MHz | **f = 4 GHz**





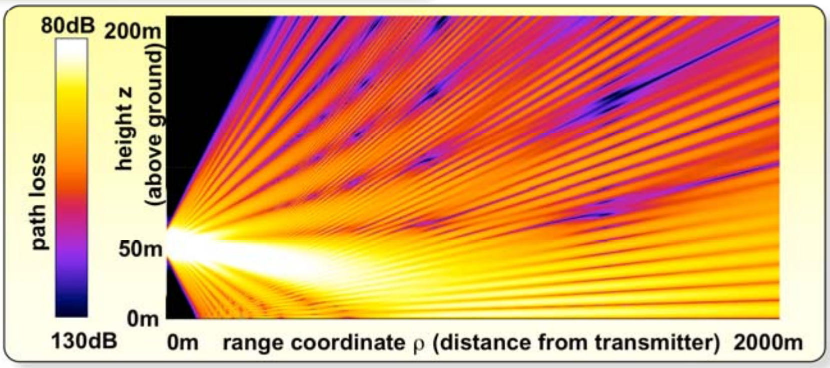
distances of the notches are >> λ

Path Loss Prediction (Vertical Cross Section)



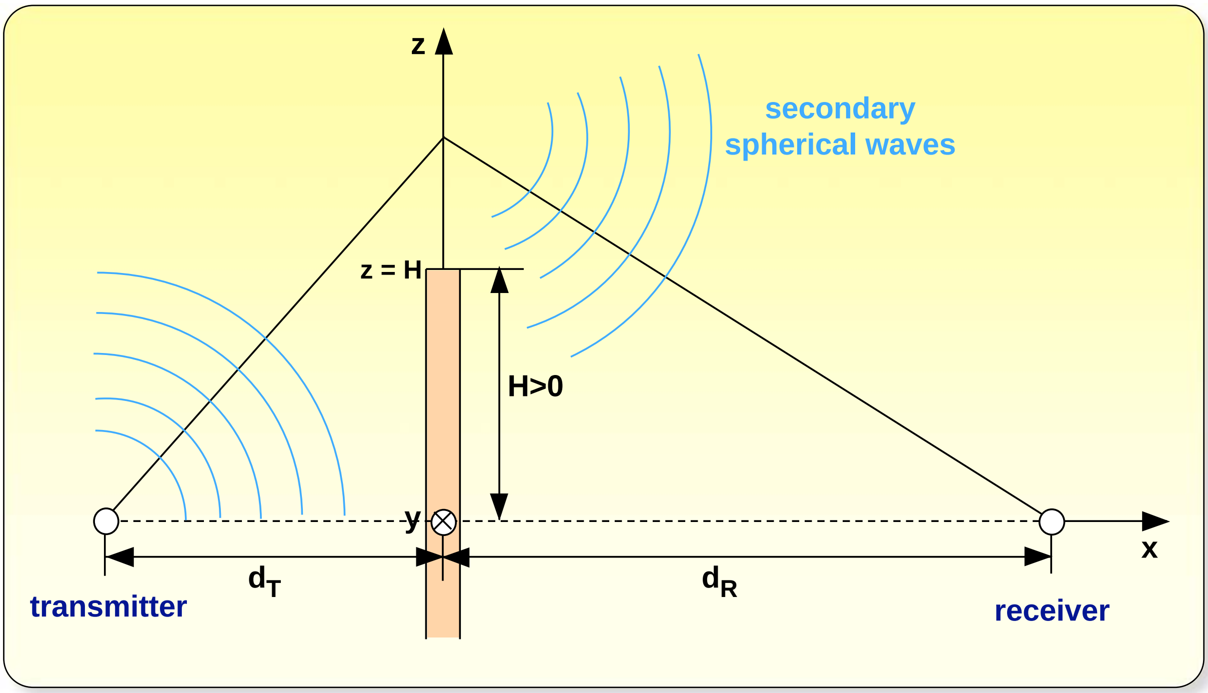
vertical (parallel) polarization

horizontal (perpendicular) polarization

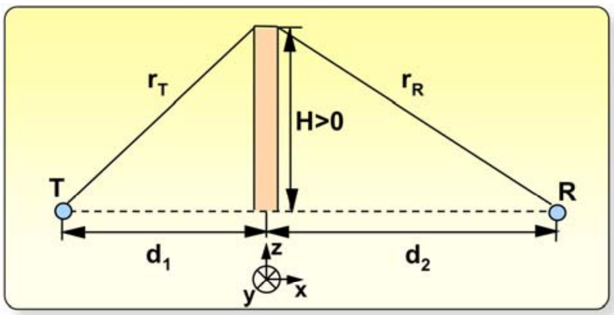


Diffraction

Knife-Edge Diffraction Geometry



Knife-Edge Diffraction

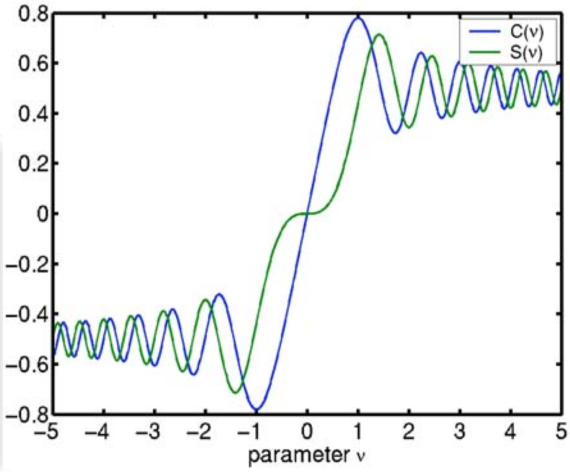


fieldstrength relative to free space (no obstacle):

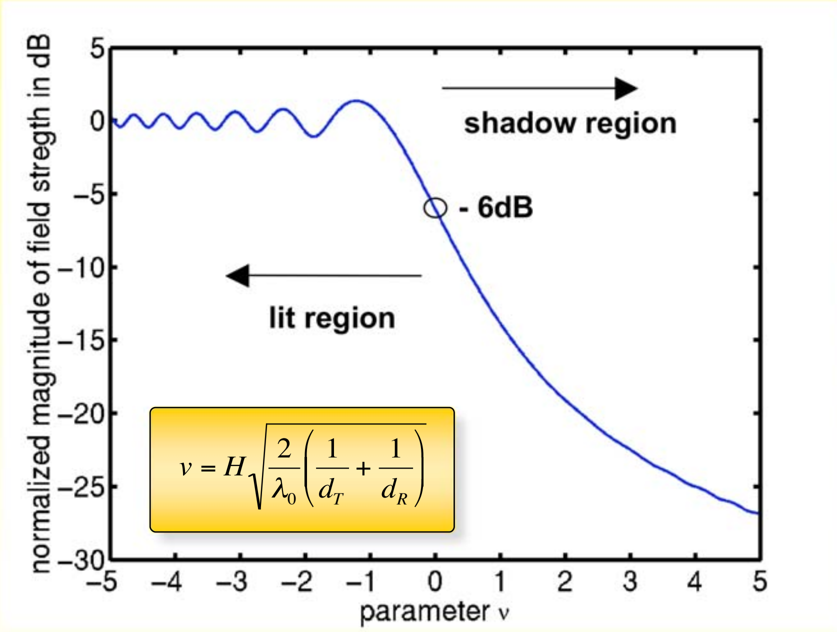
$$\left|\frac{E}{E_{H\to-\infty}}\right| = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{1}{2}-C(\nu)\right)^2+\left(\frac{1}{2}-S(\nu)\right)^2}$$

$$\nu = H\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)}$$

Fresnel Integrals

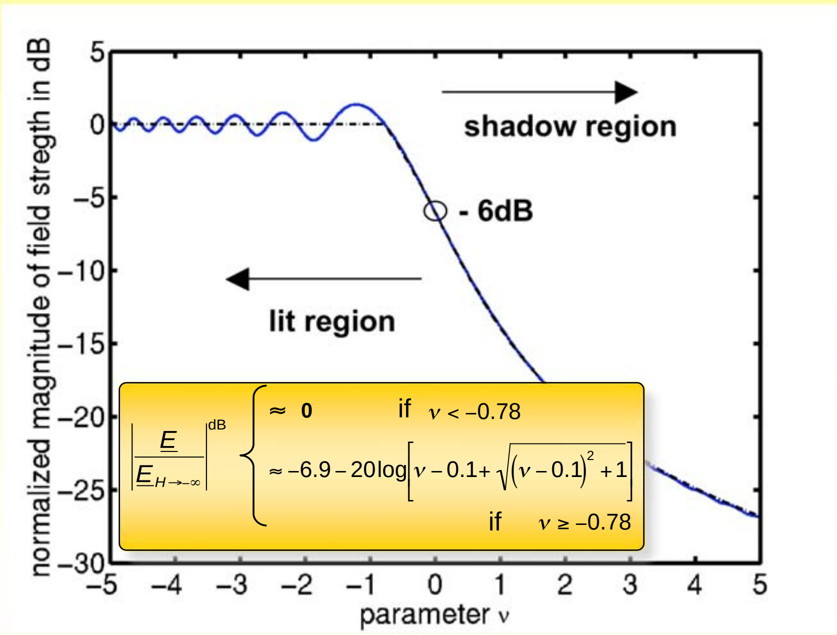


Knife-Edge Diffracted Electric Field



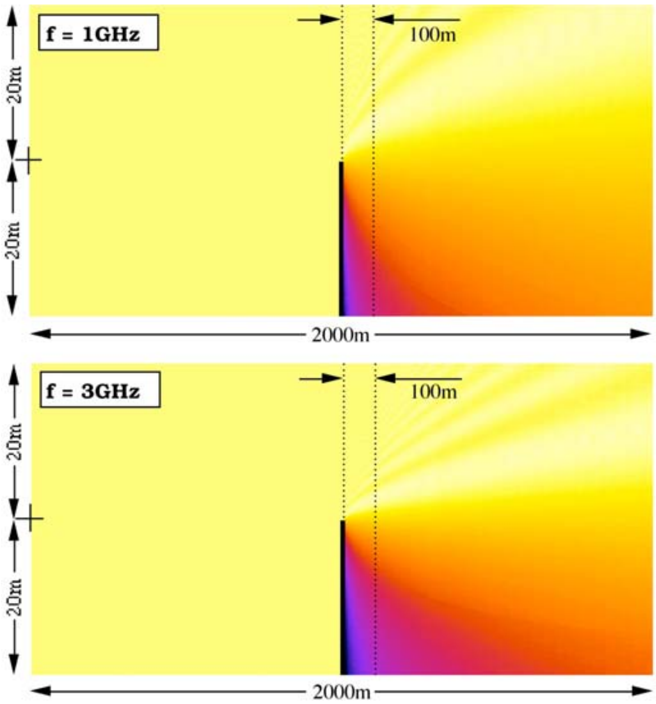
$$v = H\sqrt{\frac{2}{\lambda_0}\left(\frac{1}{d_T}+\frac{1}{d_R}\right)}$$

Knife-Edge Diffracted Electric Field

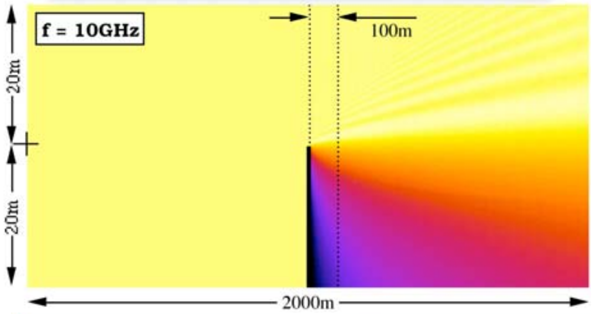


$$\left|\frac{E}{E_{H\to-\infty}}\right|^{\mathrm{dB}} \begin{cases} \approx \mathbf{0} & \text{if } v < -0.78 \\ \approx -6.9 - 20\log\left[v - 0.1 + \sqrt{(v-0.1)^2+1}\right] & \text{if } v \geq -0.78 \end{cases}$$

Diffraction and Frequency Dependence (Vertical Cross Section)



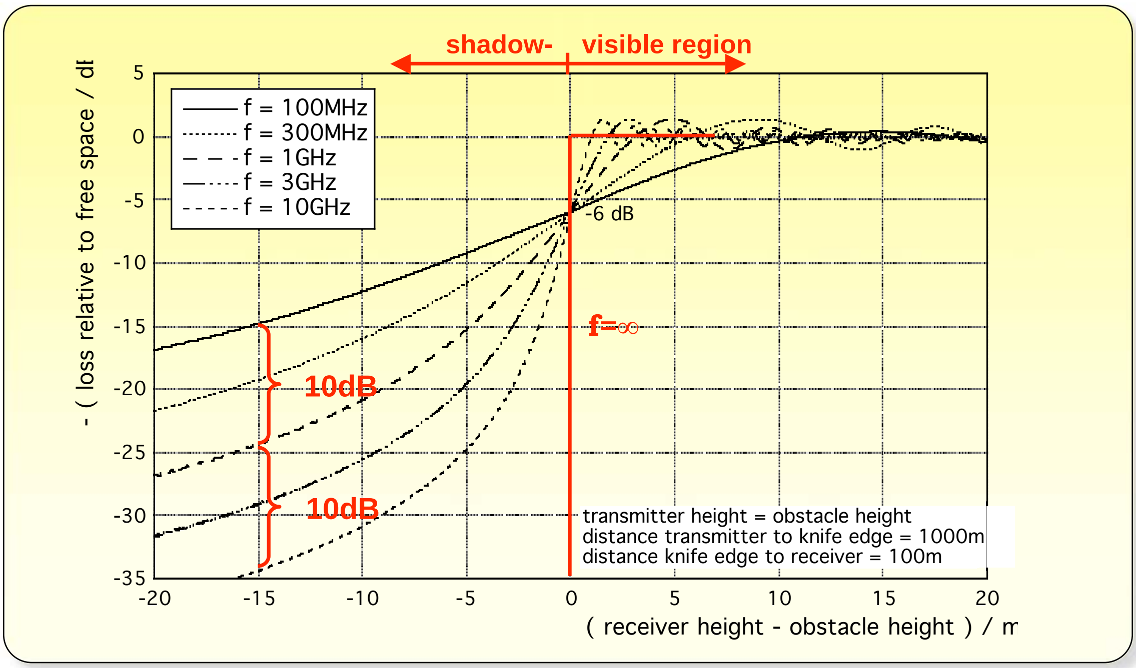
- field strength normalized to free space level
- isotropic Tx antenna
- semi-infinite absorbing knife edge
- f = 1 GHz, 3 GHz, 10 GHz



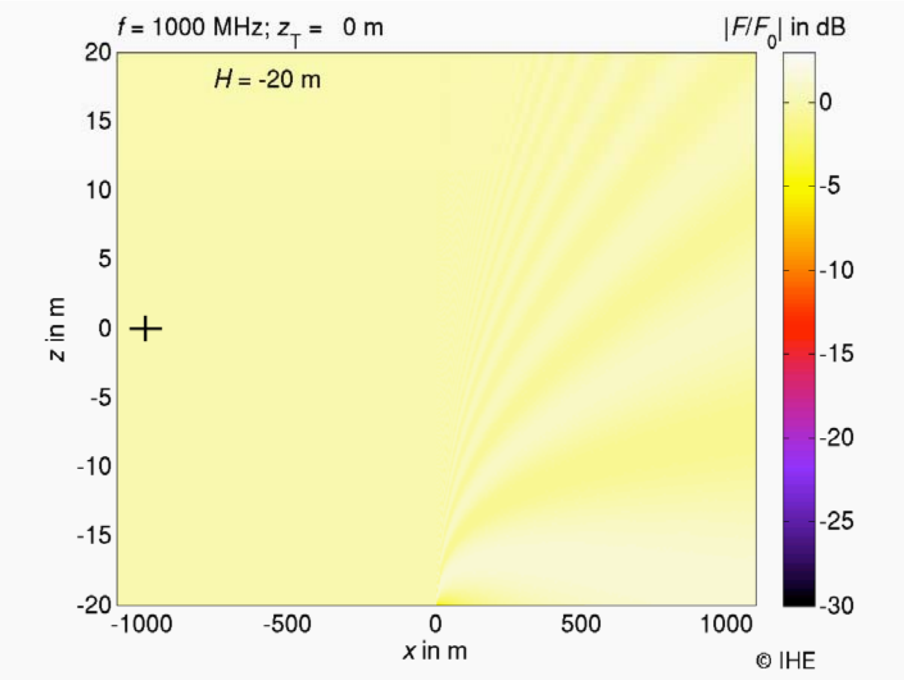
diffraction loss (in E) increases with frequency

$\propto \sqrt{f}$ **for** $\nu >> 1$

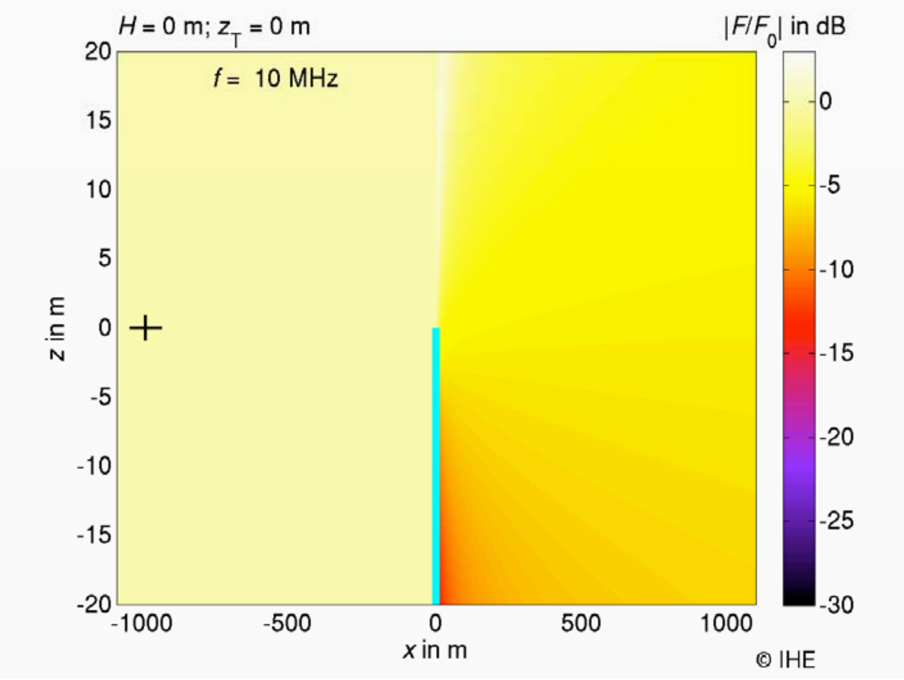
Height and Frequency Dependence



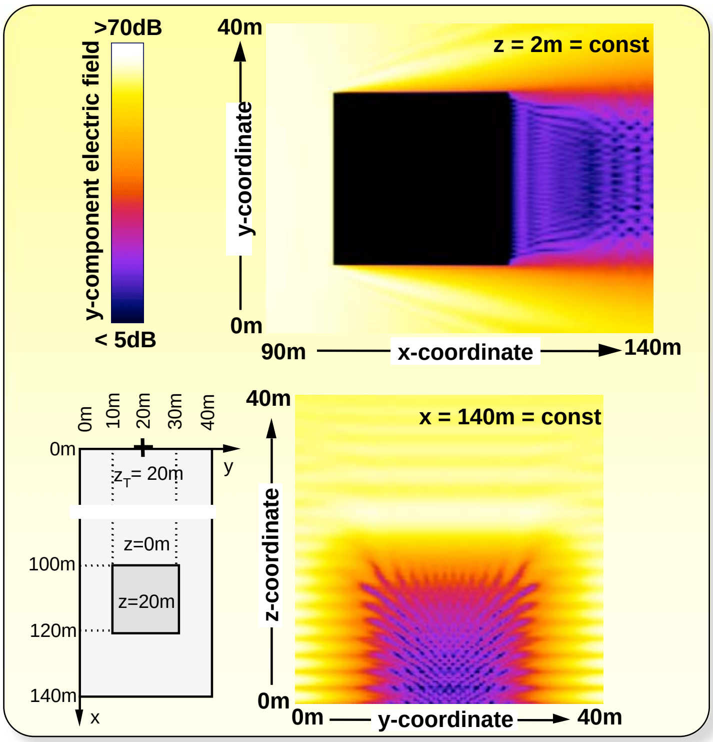
Movies



Movies



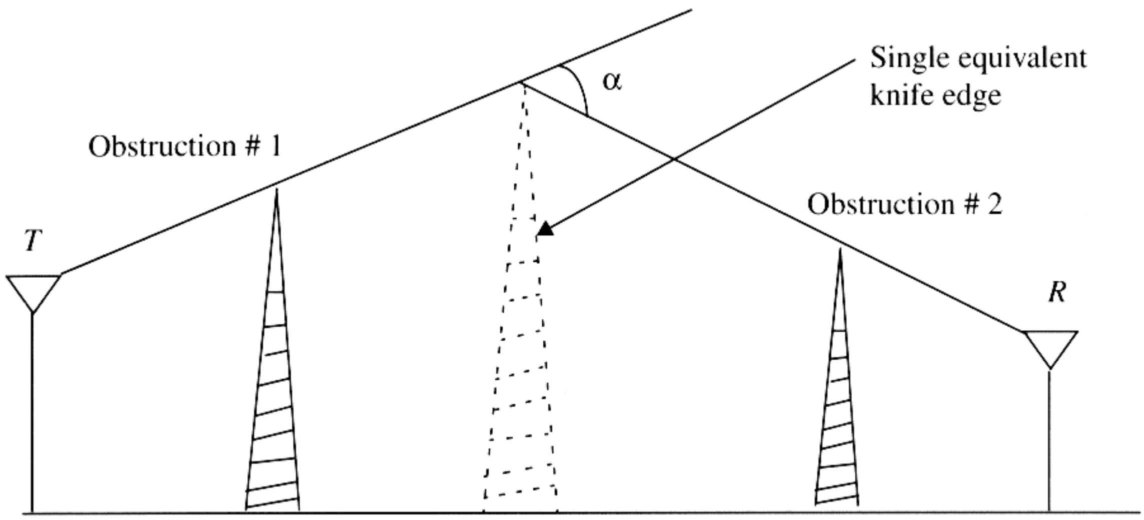
Diffraction Around a Building Block



- **three dimensional diffraction phenomena**
- **edge length: 20m**
- **distance to Tx: 100m**
- **P_T = 0 dBm**
- **G_T = 0 dBi**
- **horizontal polarization**
- **f = 500MHz**

complex propagation effects in urban terrain

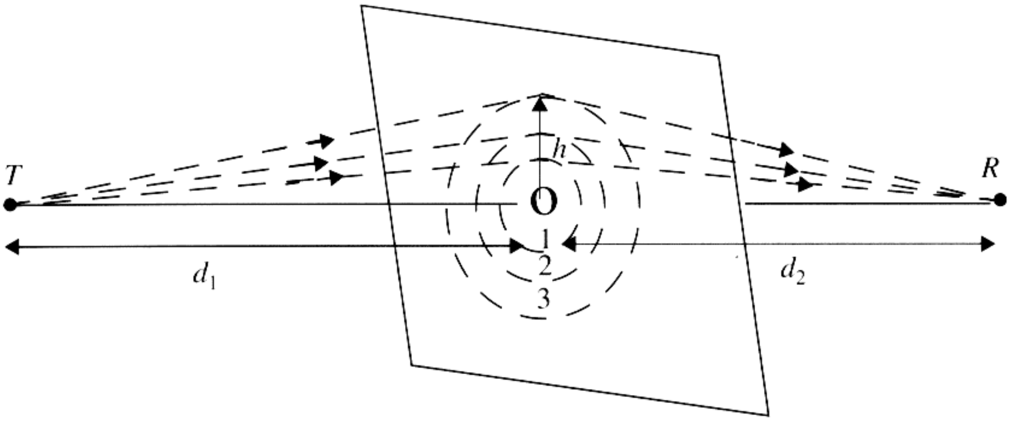
Multiple Knife Edges



Bullington's construction of an equivalent knife edge [from [Bul47] © IEEE].

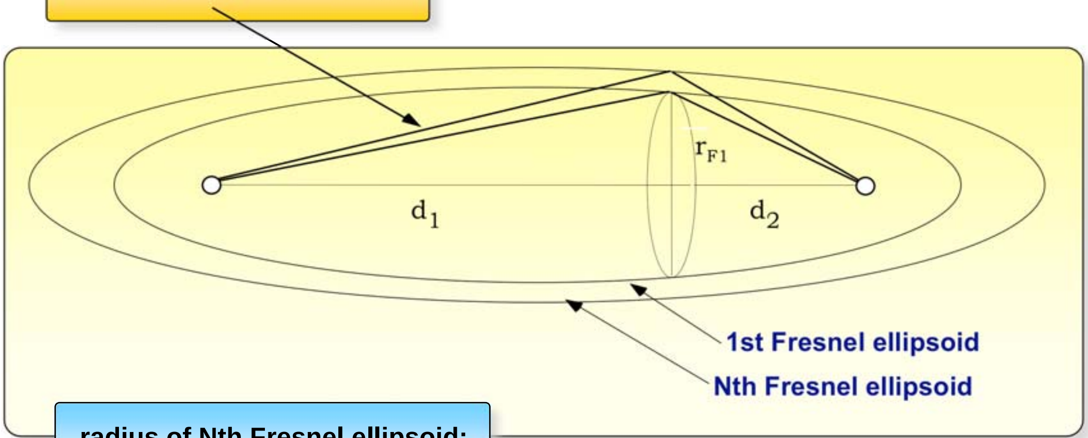
→ **to optimistic**

Fresnel Zones



Definition of Fresnel Ellipsoids

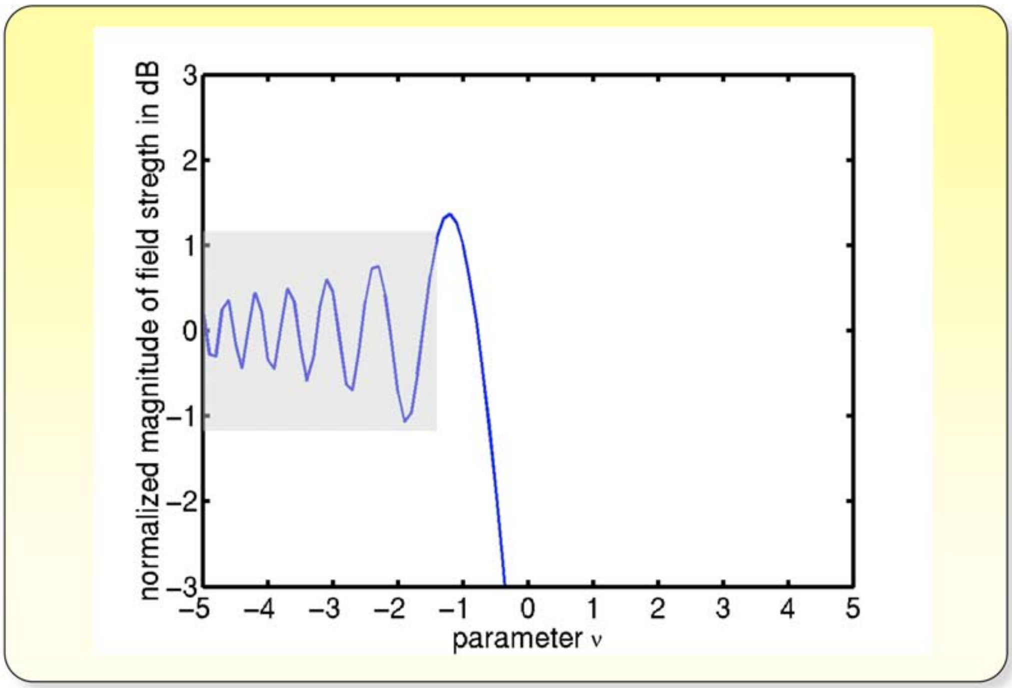
$distance = d_1 + d_2 + N \cdot \lambda/2$



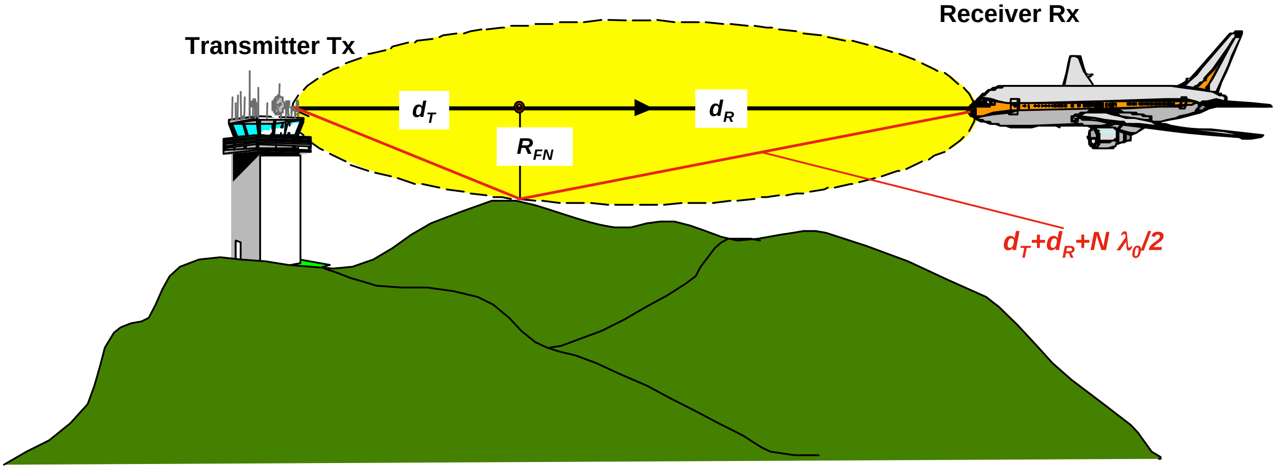
radius of Nth Fresnel ellipsoid:

$$R_{FN}(N,\lambda,d_1,d_2) \approx \sqrt{N\lambda \frac{d_1 d_2}{d_1 + d_2}} \quad , \quad N = 1,2,..$$

Knife-Edge Diffracted Electric Field



First Fresnel - Ellipsoid

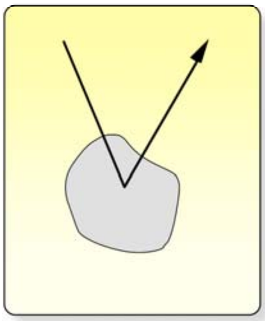


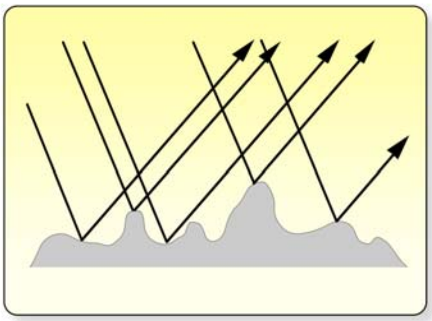
Scattering

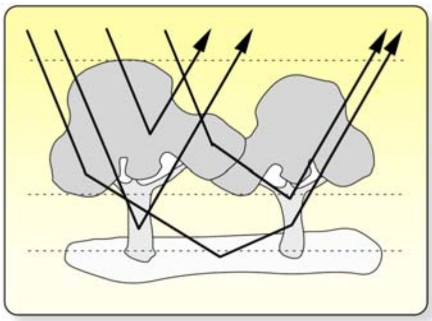
Different Types of Scattering

point scattering

distributed scattering





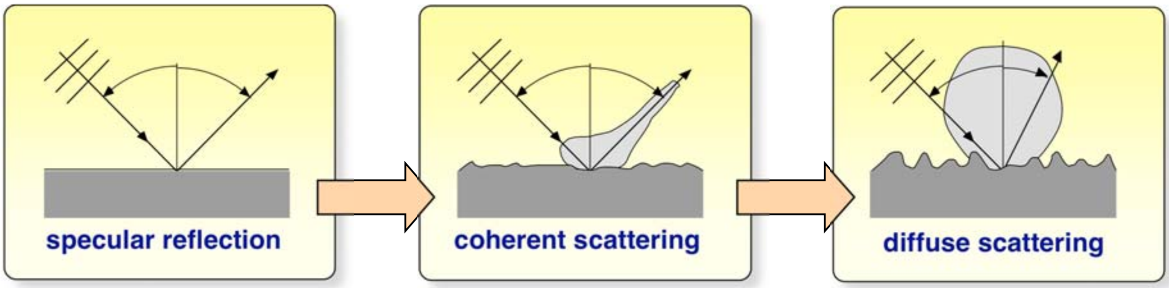


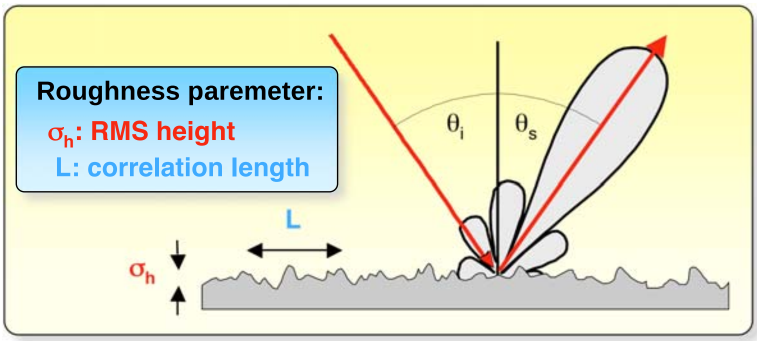
Simple targets (sphere, cylinder, etc.)

scattering from rough surfaces

volume scattering

The Transition form Specular Reflection to Incoherent Scattering



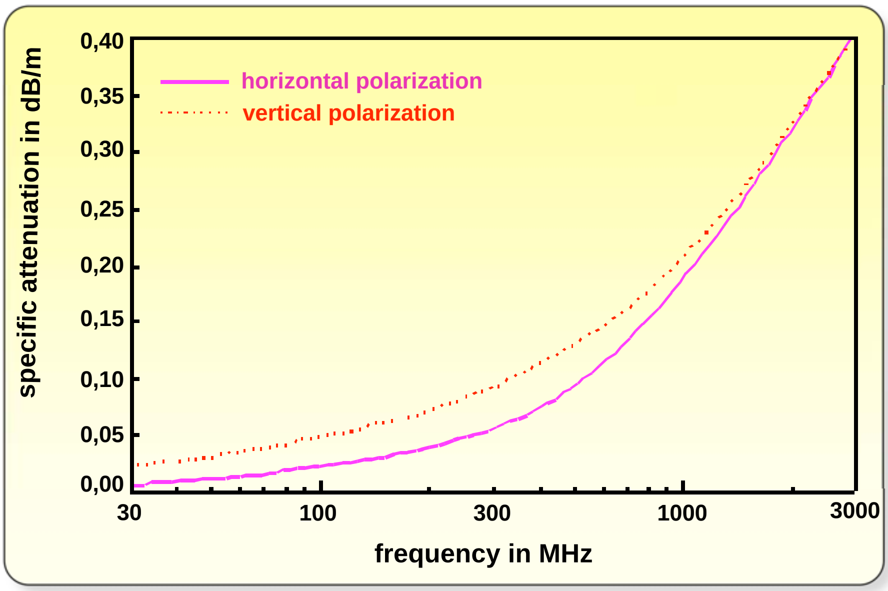


Roughness criteria:

Rayleigh: $\sigma_h \leq \dfrac{\lambda_0}{8\cos\theta_i}$

Fraunhofer: $\sigma_h \leq \dfrac{\lambda_0}{32\cos\theta_i}$

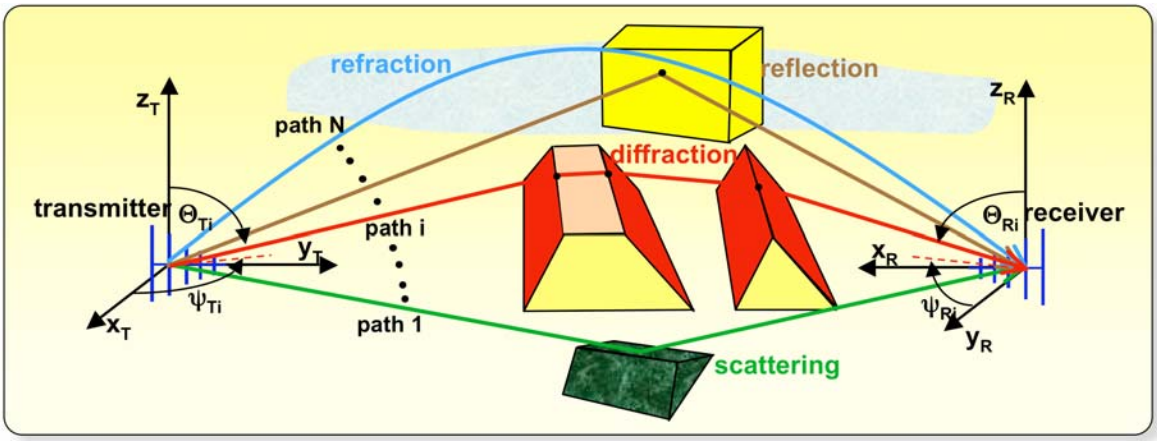
Attenuation in forested areas



- **empirical model**
- **Tx, Rx within forest or close to forest border**
- ***additional* specific attenuation, i.e.: must be added (!) to free space attenuation**
- **ITU-Rec.-833 1992**

Multipath propagation

Propagation Phenomena - Overview



Free space propagation:
- line of sight
- no multipath

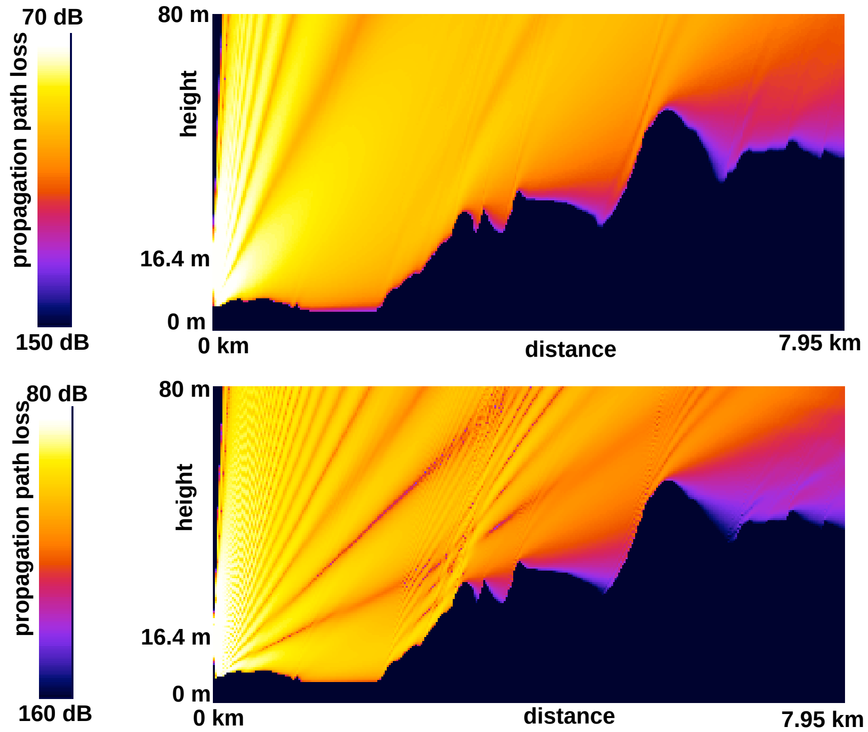
Diffraction:
- knife edge

Reflection:
- plane wave reflection
- Fresnel coefficients

Scattering:
- rough surface
- volume scattering

Refraction:
not considered

Isotropic Path Loss Prediction over Natural Terrain (Vertical Cross Section)



- *f* = 435 MHz

- Tx height: 16.4 m
- vertical polarization

- *f* = 1900 MHz