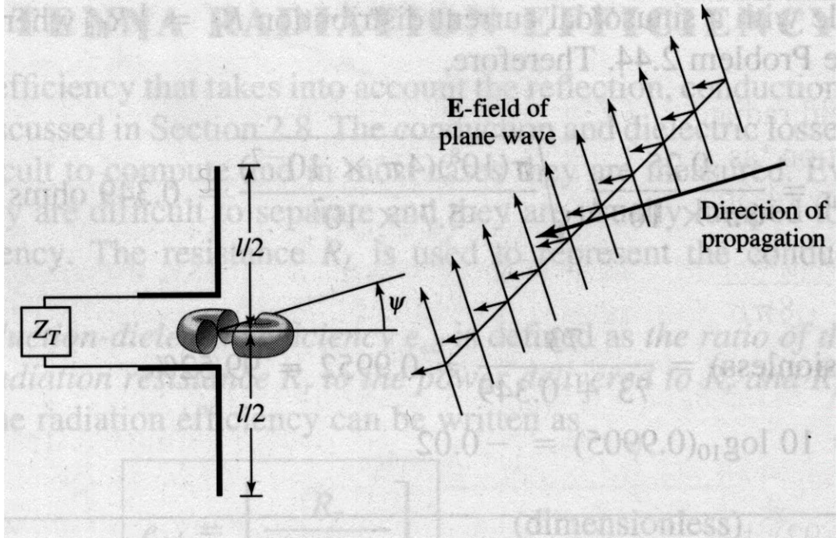
Communication Systems.

(Lecture 2: Basic propagation)

Gert Frølund Pedersen
Aalborg University

Antenna (vector) effective length



(a) Dipole antenna in receiving mode

Effective length is a far-field Quantity, relating the open voltage On the antenna terminals with the Wave impinges upon it

$$\vec{l}_e(\theta,\phi) = \vec{a}_\theta l_\theta(\theta,\phi) + \vec{a}_\phi l_\phi(\theta,\phi)$$

$$\vec{E}_a = \vec{a}_\theta E_\theta + \vec{a}_\phi E_\phi = -j\eta \frac{kI_{in}}{4\pi r} l_e e^{-jkr}$$

Antenna (vector) effective length

Ex. Far-field radiated by a small dipole (1/10 of a wave length) Is:

$$\vec{E}_a = \vec{a}_\theta j\eta \frac{kI_{in}l\ e^{-jkr}}{8\pi r}\sin(\theta)$$

$$\Rightarrow l_e = -\vec{a}_\theta \frac{l}{2}\sin(\theta)$$

By comparing to Eq 2-92, relating l_e and E_a:

$$\vec{E}_a = \vec{a}_\theta E_\theta + \vec{a}_\phi E_\phi = -j\eta \frac{kI_{in}}{4\pi r} l_e e^{-jkr}$$

Friss Transmission Equation

Valid in the Farfield.

The Power density in a distance, R, from a transmitting isotropic antenna is:

$$W_{isotropic} = \frac{P_t e_t}{4\pi R^2}$$

For a non-isotropic antenna it is:

$$W_{non-isotropic} = \frac{P_t G(\theta_t, \phi_t)}{4\pi R^2}$$

Friss Transmission Equation

The Effective area of an impedance match antenna is:

$$A_r = e_t D_r(\theta_r \phi_r)\frac{\lambda^2}{4\pi}\left|\hat{\rho}_r \cdot \hat{\rho}_t\right|^2$$

Power collected by a receiving antenna:

$$P_r = A_r W_t = G_r(\theta_r,\phi_r)G_t(\theta_t,\phi_t)\frac{\lambda^2}{(4\pi R)^2}P_t\left|\hat{\rho}_r \cdot \hat{\rho}_t\right|^2$$

Gert Frølund Pedersen
gfp@es.aau.dk

Friss Transmission Equation

If the impedance matching is included, Friis equation is:

$$P_r = (1-|\Gamma_r|^2)(1-|\Gamma_t|^2)G_r(\theta_r,\phi_r)G_t(\theta_t,\phi_t)\frac{\lambda^2}{(4\pi R)^2}P_t|\hat{\rho}_r\cdot\hat{\rho}_t|^2$$

Or alternative:

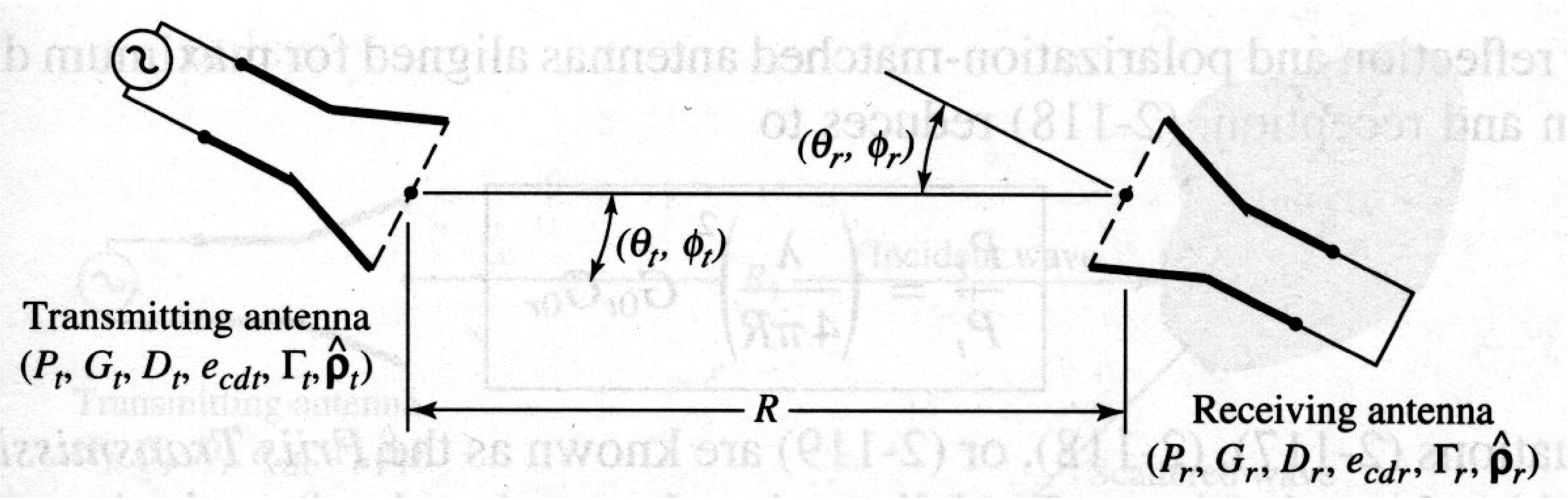
$$P_r = e_{cdt}e_{cdr}(1-|\Gamma_r|^2)(1-|\Gamma_t|^2)D_r(\theta_r,\phi_r)D_t(\theta_t,\phi_t)\frac{\lambda^2}{(4\pi R)^2}P_t|\hat{\rho}_r\cdot\hat{\rho}_t|^2$$

$\left[\frac{\lambda}{(4\pi R)}\right]^2$ Is called the free-space loss factor – where did it come from?

Friss Transmission Equation

Friis equation

$$P_r = (1-|\Gamma_r|^2)(1-|\Gamma_t|^2)G_r(\theta_r,\phi_r)G_t(\theta_t,\phi_t)\frac{\lambda^2}{(4\pi R)^2}P_t|\hat{\rho}_r\cdot\hat{\rho}_t|^2$$



Radar Range Equation

The "radar cross section" is defined as "*the area intercepting that amount of power which, when scattered isotropically, Produces at the receiver a density which is equal to that Scattered by the actual target*"

$$\lim_{R\to\infty}\left[\frac{\sigma W_i}{4\pi R^2}\right] = W_s$$

$$\sigma \quad in \quad [m^2]$$

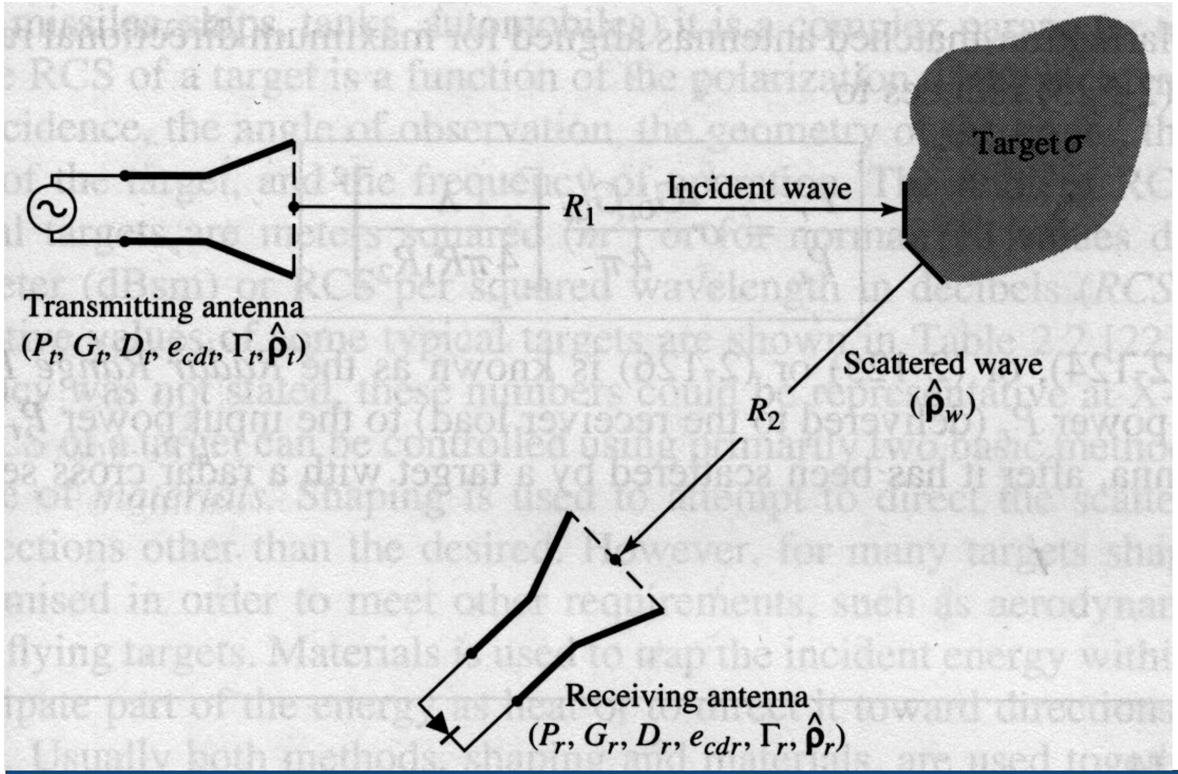
$$\sigma = \lim_{R\to\infty}\left[4\pi R^2 \frac{W_s}{W_i}\right]$$

$$W_s \quad power \quad density \quad in \quad [W/m^2]$$

Radar Range Equation

Captured power by the object:

$$P_c = \sigma W_t = \frac{G_t(\theta_t, \phi_t) P_t}{4\pi R_1^2}$$



Radar Range Equation

Captured power by the object:

$$P_c = \sigma W_t = \frac{G_t(\theta_t, \phi_t) P_t}{4\pi R_1^2}$$

P_c is re-radiated isotropically by the object:

$$W_s = \frac{P_c}{4\pi R_2^2} = \sigma \frac{G_t(\theta_t, \phi_t) P_t}{(4\pi R_1 R_2)^2}$$

Radar Range Equation

Power received from the object:

$$P_r = A_r W_s = \frac{\sigma G_r(\theta_r \phi_r) G_t(\theta_t \phi_t)}{4\pi} \left[\frac{\lambda}{4\pi R_1 R_2} \right]^2 P_t$$

Including the impedance and polarisation matching:

$$P_r = (1 - |\Gamma_r|^2)(1 - |\Gamma_t|^2) \frac{\sigma G_r(\theta_r \phi_r) G_t(\theta_t \phi_t)}{4\pi} \left[\frac{\lambda}{4\pi R_1 R_2} \right]^2 |\hat{\rho}_r \cdot \hat{\rho}_s| P_t$$

Radar Cross Section (RCS)

Farfield parameters characterising the scattering properties.

Dived in:

1. Mono-static or backscattering
2. Bi-static

RCS can be controlled by:

1. Shaping
2. materials

Radar Cross Section (RCS)

Typical RCS values:

Table 2.2 RCS OF SOME TYPICAL TARGETS

Object	Typical RCSs [22] RCS (m^2)	RCS (dBsm)
Pickup truck	200	23
Automobile	100	20
Jumbo jet airliner	100	20
Large bomber *or* commercial jet	40	16
Cabin cruiser boat	10	10
Large fighter aircraft	6	7.78
Small fighter aircraft *or* four-passenger jet	2	3
Adult male	1	0
Conventional winged missile	0.5	−3
Bird	0.01	−20
Insect	0.00001	−50
Advanced tactical fighter	0.000001	−60

Propagation over reflecting surface

To cases will be considered:

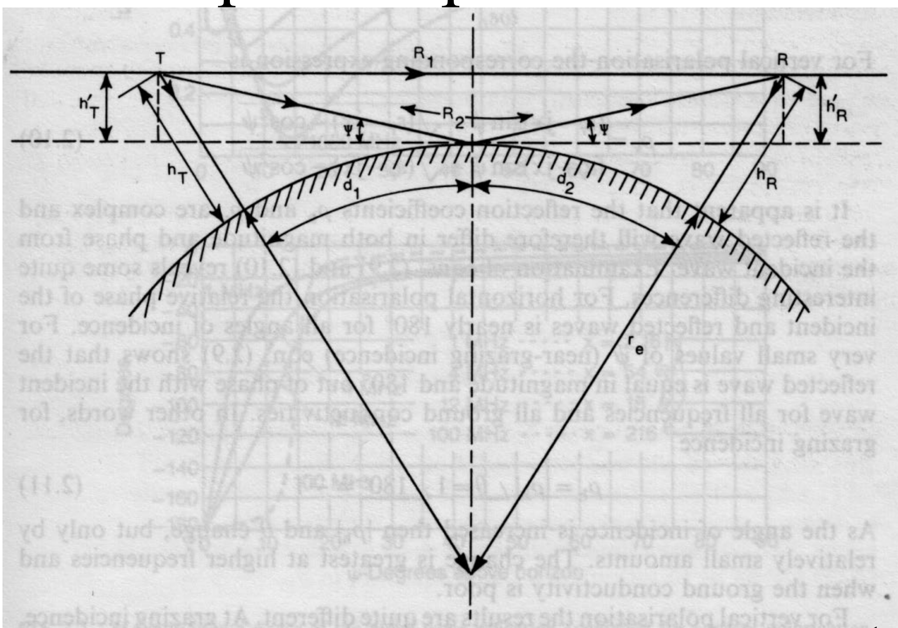
1 spherical reflecting surface

2 Flat reflecting surface

Both including the general complex reflection coefficient

Propagation over reflecting surface

Simple but practical model



Reflection coefficient

$$\rho_h = \frac{\sin(\psi) - \sqrt{\frac{\varepsilon}{\varepsilon_0} - \frac{j\sigma}{\omega\varepsilon_0} - \cos^2(\psi)}}{\sin(\psi) + \sqrt{\frac{\varepsilon}{\varepsilon_0} - \frac{j\sigma}{\omega\varepsilon_0} - \cos^2(\psi)}}$$

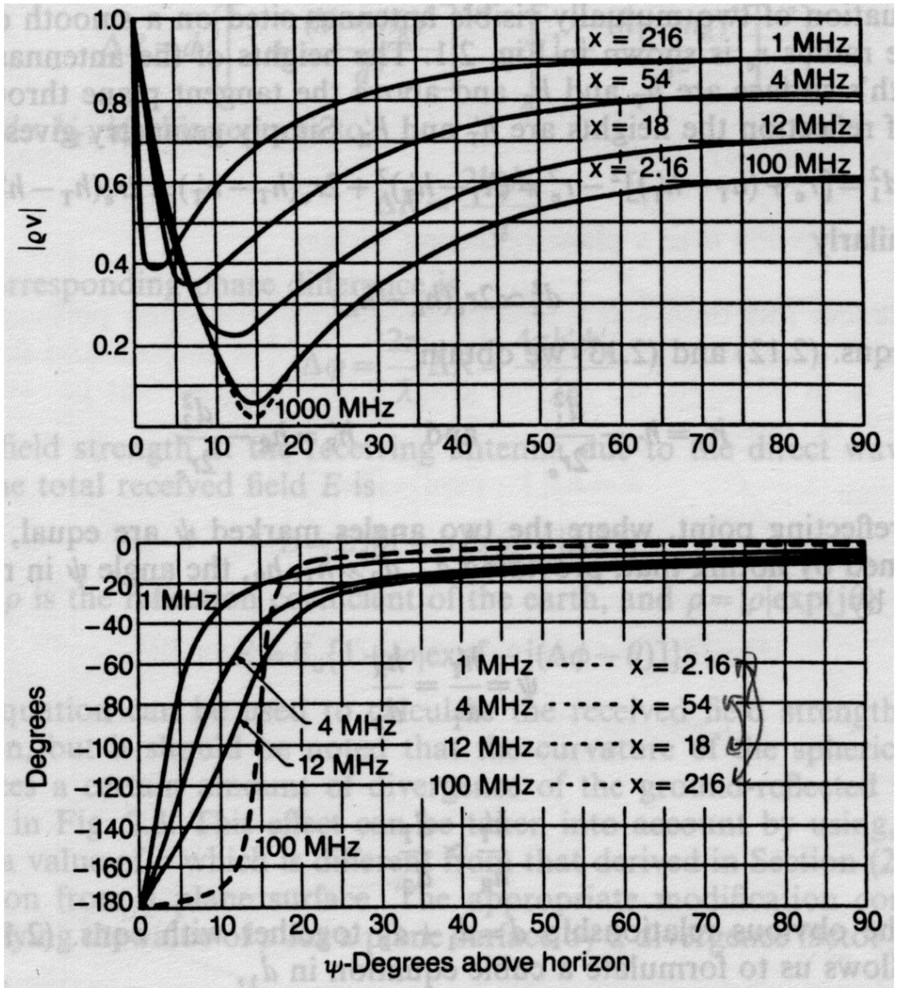
$$\rho_v = \frac{(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0})\sin(\psi) - \sqrt{\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0} - \cos^2(\psi)}}{(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0})\sin(\psi) + \sqrt{\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0} - \cos^2(\psi)}}$$

Propagation over reflecting surface

Note,

1. The earth is not a perfect conductor nor a perfect dielectric
2. The reflection coefficient is DIFFERENT for the two polarisations (very different up to 180 degrees but NOT for small angles!).
3. The reflection coefficient is complex!

Propagation over reflecting surface



Magnitude and Phase of the plane-wave reflection coefficient for Vertical polarisation

$$\varepsilon_r = 15 \quad \sigma = 0.012$$

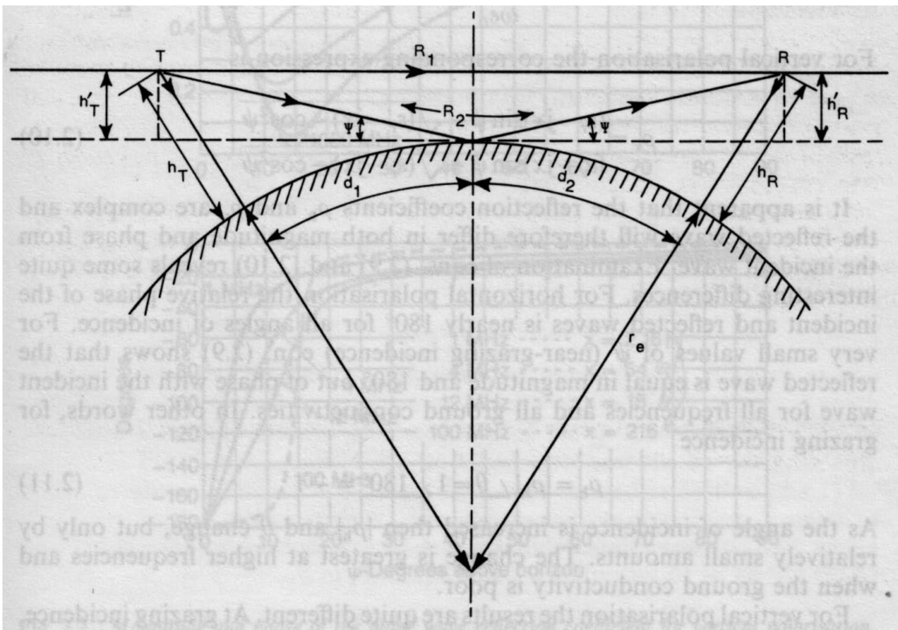
Propagation over reflecting surface

Table 2.1 TYPICAL VALUES OF GROUND CONSTANTS

Surface	*Conductivity σ (siemens)*	*Dielectric constant ε_r*
Poor ground (dry)	10^{-3}	4–7
Average ground	5×10^{-3}	15
Good ground (wet)	2×10^{-2}	25–30
Sea water	5	81
Fresh water	10^{-2}	81

Propagation over reflecting surface

Simple geometry gives: $$d_1^2 = \left[r_e + (h_T - h_T')\right]^2 - r_e^2$$



Which can be formulated as a cubic equation, and solved with standard methods.

$$2d_1^3 - 3dd_1^2 + \left[d^2 - 2r_e(h_T + h_R)\right]d_1 + 2r_e h_T d = 0$$

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gfp@es.aau.dk

Propagation over reflecting surface

$$if \quad d >> h'_T, h'_R$$

$$E = E_{direct} \left\{ 1 + |\rho| e^{-j(\Delta\phi - \theta)} \right\}$$

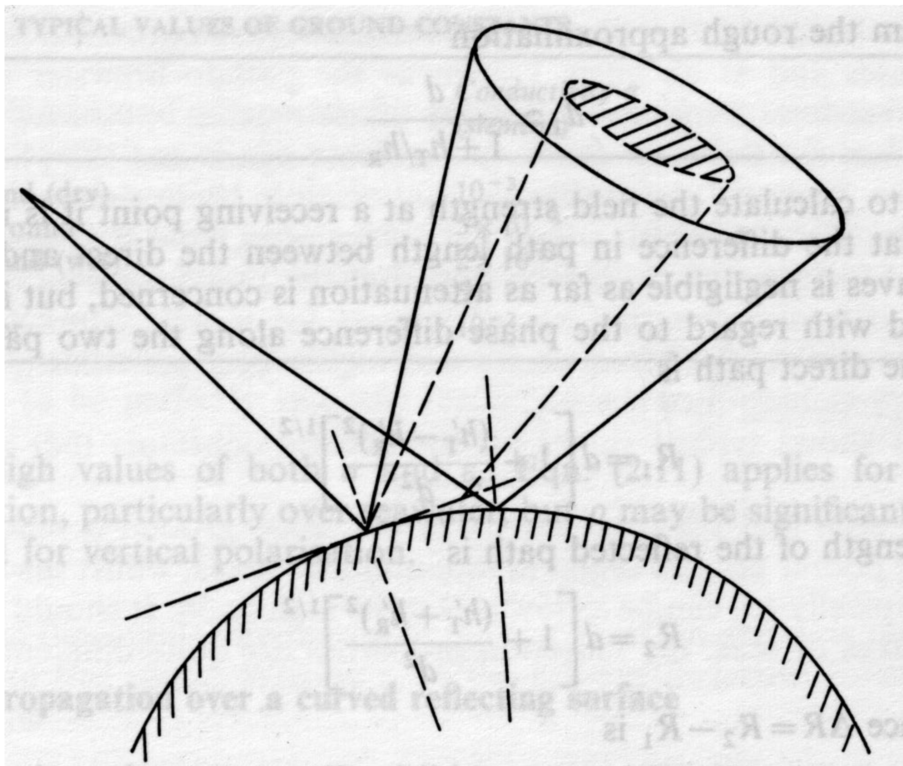
$$\theta \quad angle \quad of \quad reflection \quad coefficient$$

$$\Delta\phi = \tfrac{2\pi}{\lambda} \Delta R$$

The above equation can be used to calculate the field at any place in the farfield but the divergence from the curvature of the earth is not included.

Propagation over reflecting surface

The divergence of the reflected rays can be included by a divergence factor – usual in the order of 0.5



Propagation over flat reflecting surface

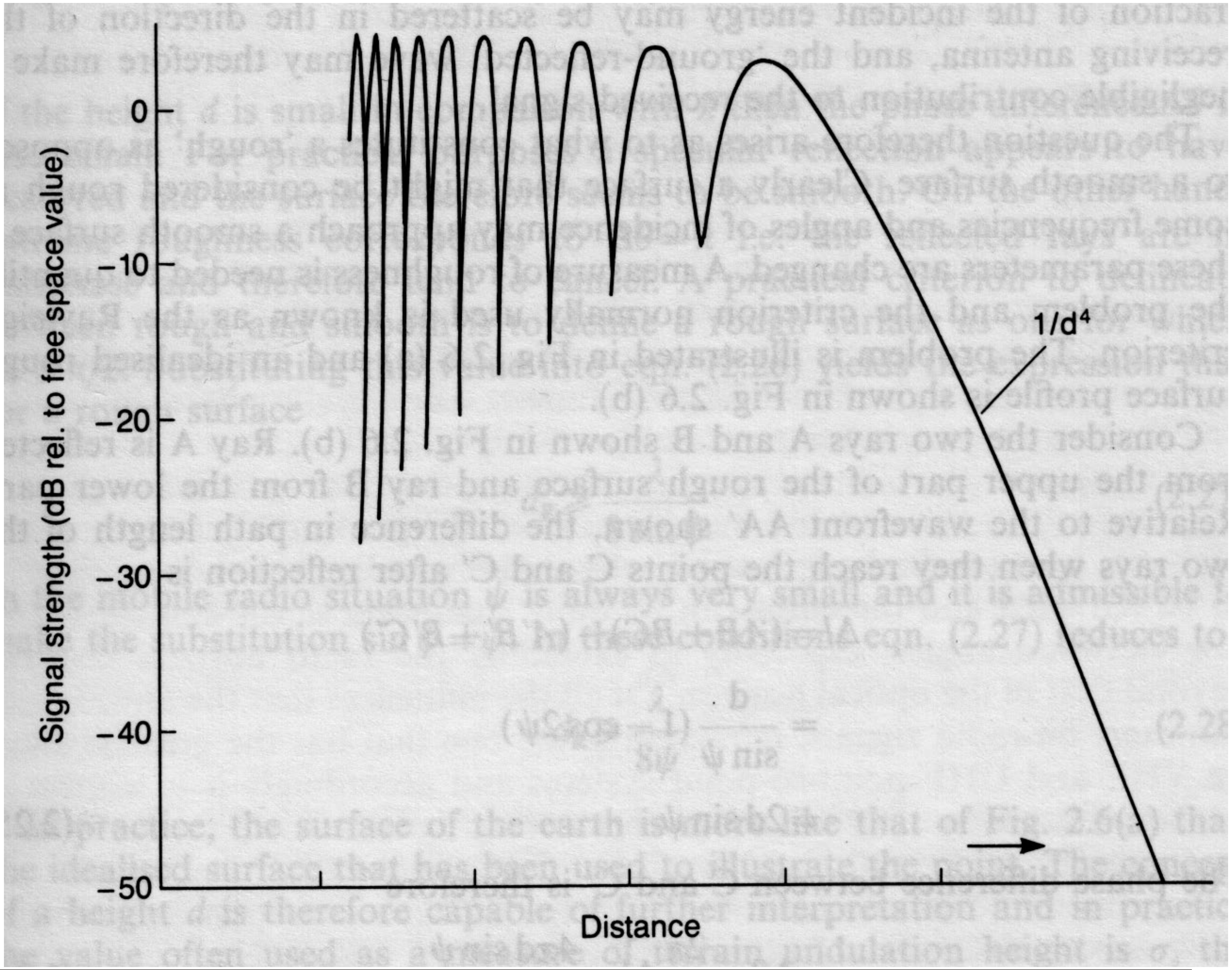
$$
\begin{aligned}
&if \quad d >> h'_T, h'_R \\
&|E| = |E_{direct}| \sin(\tfrac{\Delta\phi}{2}) \\
&P_r = 4P_t \left(\tfrac{\lambda}{4\pi d}\right)^2 G_r G_t \sin^2(\tfrac{2\pi h_T h_R}{d\lambda}) \\
&\cong G_r G_t \left(\tfrac{h_T h_R}{d^2}\right)^2 P_t
\end{aligned}
$$

Note, the difference to Friis equation:

1. λ is out of the equation.
2. The power diminish as the fourth power of the distance

Propagation over flat reflecting surface

$$P_r \cong G_r G_t \left(\frac{h_T h_R}{d^2}\right)^2 P_t$$



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gfp@es.aau.dk

Problems

2.1 For an X-band (8.2 – 12.4 GHz) rectangular horn, with aperture dimension of 5,5 cm and 7,4 cm , find its maximum effective aperture in cm^2 when its gain over isotropic is:

a) 14,8 dB

b) 16,5 dB

c) 18,0 dB

Problems

2.2 A communication satellite is in the stationary orbit about the earth (22.300 statute miles ~ 36.000 km). Its transmitter generates 8 Watt. Assume the transmitting antenna is isotropic. Its signal is received by a 210 foot diameter tracking parabol antenna on the earth. Also assume no resistive losses in either antenna, perfect polarization match and perfect impedance matching at both antennas. At a frequency of 2 GHz, determinate the:

a) Power density in Watts/m^2 incident on the receiving antenna.

b) Power received by the ground based antenna whose gain is 60 dBi

Problems

2.3 Transmitting and receiving antennas operating at 1 GHz with gains of 20 and 15 dBi respectively, are separated by a distance of 1 km.

Find the maximum power delivered to the load when the input power is 150 W. You can assume the antennas are polarization matched.

Problems

2.4 Repeat Problem 3 for the case of a reflecting ground and antenna height of both the receiver and transmitter of:

I. 3 meters

II. 5 meters

III. 10 meters