Microwave applications

Applications

• Reminder: Friis formula
• RADAR
• Telecommunication applications

• Heating
• Medical applications
  • diathermy, hyperthermia, Thermography, Tomography
Friis' formula

Consider an isotropic source. The power density radiated by this source at a distance $R$ is equal to:

$$ p = \frac{P_c}{4\pi R^2} $$

Friis' formula

If we consider a real antenna (non isotropic), we obtain

$$ p = \frac{P_{ge}(\theta, \varphi)}{4\pi R^2} $$

g_{e}: gain of the antenna
Friis' formula

The received power at a point $R$ is given by:

$$P_c = \frac{P_g g_c(\theta, \phi)}{4\pi R^2} ds$$

Which yield for an receiving antenna having an effective aperture $A_e$

$$P_c = \frac{P_g g_c(\theta, \phi)}{4\pi R^2} A_e(\theta, \varphi)$$

Thus finally, we obtain Friis' formula

$$\frac{P_r}{P_c} = g_r(\theta, \varphi) g_c(\theta, \varphi) \left( \frac{\lambda}{4\pi R} \right)^2$$

Reminder

The antenna gain and effective aperture are linked by:

$$A_e(\theta, \varphi) = g(\theta, \varphi) \frac{\lambda^2}{4\pi}$$
Radio Detection And Ranging

\[ \frac{P_r}{P_f} = \frac{g^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \]

Equivalent RADAR surface

\[ \frac{\sigma}{\lambda a^2} \]

- **MIE REGION**
- **RAYLEIGH REGION**
- **OPTICAL REGION**

resonances

**Tx**, **Rx**, **Diplexer**

Detection Analysis Results
Equivalent RADAR surface : Optical limit

- Sphere: \( \pi a^2 \)
- Cone (axial incidence): \( \frac{\lambda^2 \tan^4 \theta}{4\pi} \)
- Disk: \( \pi a^2 \cos^2 \theta J_1^2(4\pi a/\lambda \sin \theta) \)
- Large planar surface: \( \frac{4\pi A^2}{\lambda} \)
- Circular cylinder: \( a\lambda \cos \theta \sin^2 \left(\frac{2\pi L}{\lambda} \right) \frac{1}{2\pi \sin^2 \theta} \)
Pulse RADAR

\[ R = \frac{c_0 t_{\text{tar}}}{2} \]

Chirp RADAR

\[ R = \frac{c_0 t_{\text{tar}}}{2}, \quad c_0 \Delta f = 2m \]
Chirp RADAR

Doppler effect

A moving source
**Doppler RADAR**

\[ f_r = f_o \left(1 + \frac{v \cos \alpha}{c}\right) \]

Thus, for \( \alpha = 0 \) and for the emitter and receiver placed at the same location, and for a car moving away from the RADAR

\[ f_r = f_o \left(\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}\right) \approx f_o \left(1 + 2 \frac{v}{c}\right) \]

Thus \( v = \frac{c \Delta f}{2 f} \)

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**Example: frequency shift in a cell phone**

For a cell GSM 900 phone system (Tx 890-915 MHz, RX 935-960 MHz) and a vehicle having a velocity of 140 km/h, there will be a spread of the spectrum of 248 Hz

\[ f_o \rightarrow [f_o - \Delta f; f_o + \Delta f] \quad ; \quad \Delta f = \frac{f_o v}{c} \]
Attenuation in free space
Friis' formula

\[ P_r = P_f g_1 g_2 \left( \frac{\lambda}{4\pi L} \right)^2 \]

- \( P_r \) is the received power
- \( P_f \) is the transmitted power
- \( g_1, g_2 \) are the antenna gains
- \( \lambda \) is the wavelength
- \( L \) is the distance between the antennas

Attenuation in the atmosphere
Inhomogeneity of the atmosphere

\[ n_0 \sin \theta_0 = n_1 \sin \theta_1 \]
\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
\[ \eta \sin \theta_1' = r_0 \sin \theta_1' \]
\[ n_0 r_0 \sin \theta_0 = n_2 r_2 \sin \theta_2 \]
\[ nr \sin \theta = n_0 r_0 \sin \theta_0 \]
Inhomogeneity of the atmosphere

(a) \( R = 0 \) m
(b) \( R = 4 \text{ km} \)

Fictive Earth radius

Diffraction on obstacles

\[ |R_1| + |R_2| - |R| = \frac{\lambda}{2} \]
Diffraction on obstacles

1st Fresnel ellipsoid:

\[ h_0 = \sqrt{\frac{\lambda L_1 L_2}{L}} \]

\[ \rho = \frac{1}{2} \sqrt{\lambda L} \]

Obstacle free link
Obstacle free link

Assumptions:
- \( \tau = \rho \)
- \( L' = L \)

Equations:
- \( R = 4/3R \)
- \( R = 4/3R \)
Lateral propagation

Vertical plane propagation
Full-3D propagation

Models (1/3)

- 2D ray tracing
  - Reasonable approximation of lateral propagation when Tx is below most bldg. heights
  - User Interface to ease the investigations

- Developed at EPFL/Swiss Telecom
Lateral propagation

Vertical plane propagation
Application d’un logiciel pour la planification des liaisons avec les mobiles. Comparaison de plusieurs modèles de diffraction avec les valeurs mesurées (tiré d’une thèse de doctorat)

DÉPARTEMENT D’ÉLECTRICITÉ
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Satellite communication
The 3rd Kepler law allows to determine the revolution period $T$ of a satellite as a function of its elliptical orbit half axis $a$ or its altitude $h=a-R$

$$T = 2\pi \sqrt{\frac{a^3}{GM}} = 2\pi \sqrt{\frac{(h+R)^3}{GM}}$$

Geostationary orbit:

- $T = 1$ sideral day
- $T = 23$ h $56$ m $4$ sec
- Thus $h = 35786$ km

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**Satellite**

- **H** Geostationary height of satellite: 36,000 km
- **R** Earth's radius: 6,378 km
- **2L** Distance A-Sat-B: 76,000 km
- **c** Speed of light: 300,000 km/s
- **t** Transmission time: 260 ms
- **a_0** Basic free-space transmission loss on one path section: approx. 200 dB at 6 GHz

**Data for geostationary satellites**