Wireless Channel

- Radiowave propagation
  - Natural phenomenon: impossible to control
- Antennas
  - Parts of radio system: possible to design

Trend of Propagation Modeling

- Satellite and fixed radio links
  - Line-of-sight propagation
  - Major mechanism: attenuation by medium

- Cellular and WLAN systems
  - Non-line-of-sight propagation
  - Major mechanism: multipath

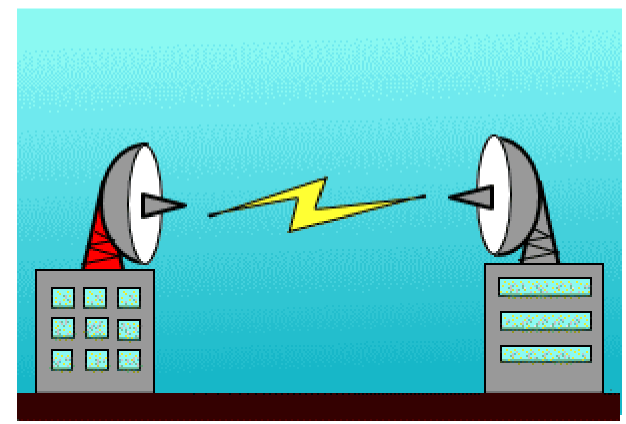
Wireless Channel

Propagation

- Natural phenomenon
- Impossible to control
- Knowledge of mechanism and modeling

Antennas

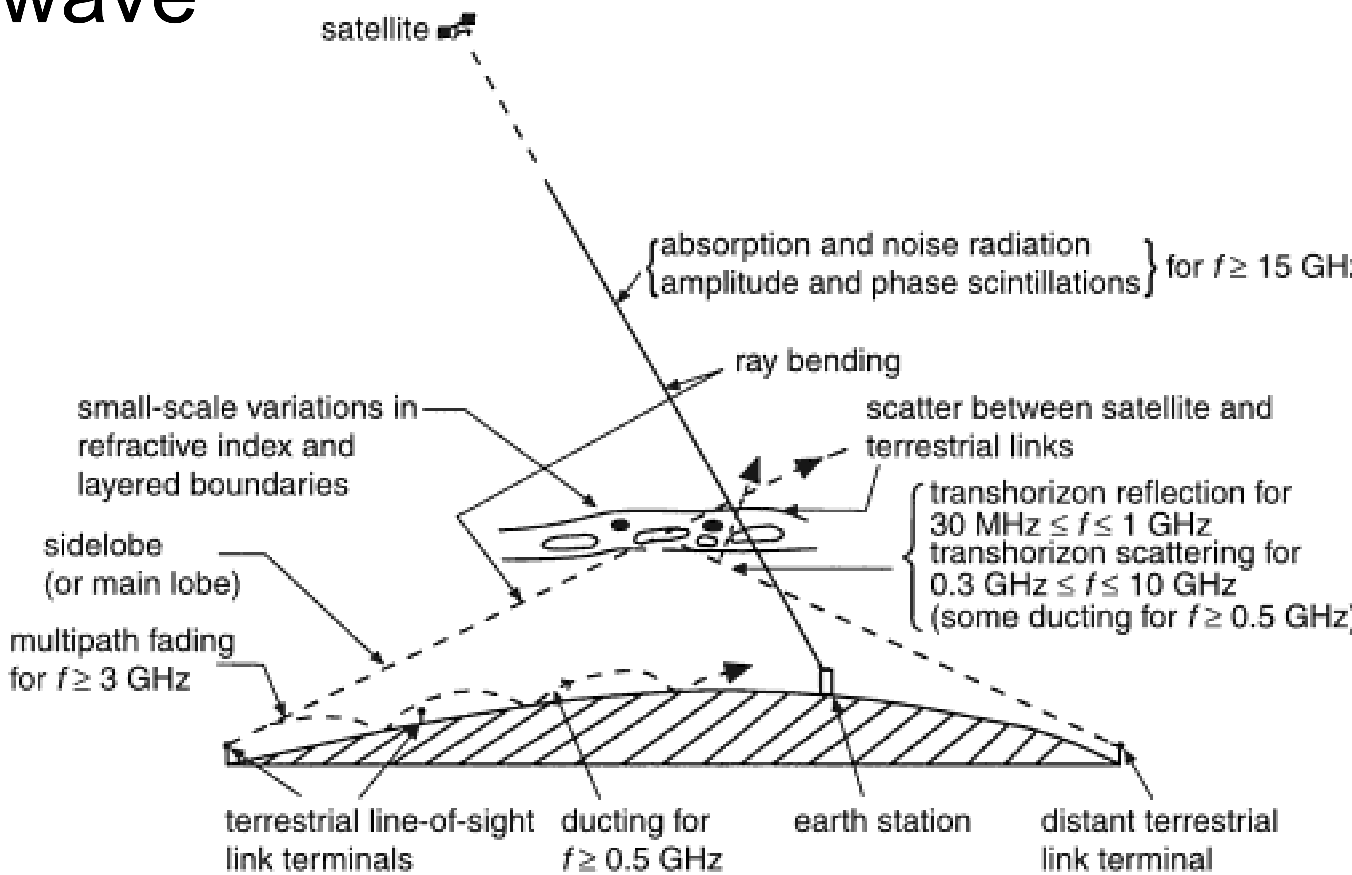
- Parts of radio system
- Possible to design
- Knowledge of design parameters



http://www.tele.soumu.go.jp/j/others/obstacle.htm

Radio Environment
LF - HF

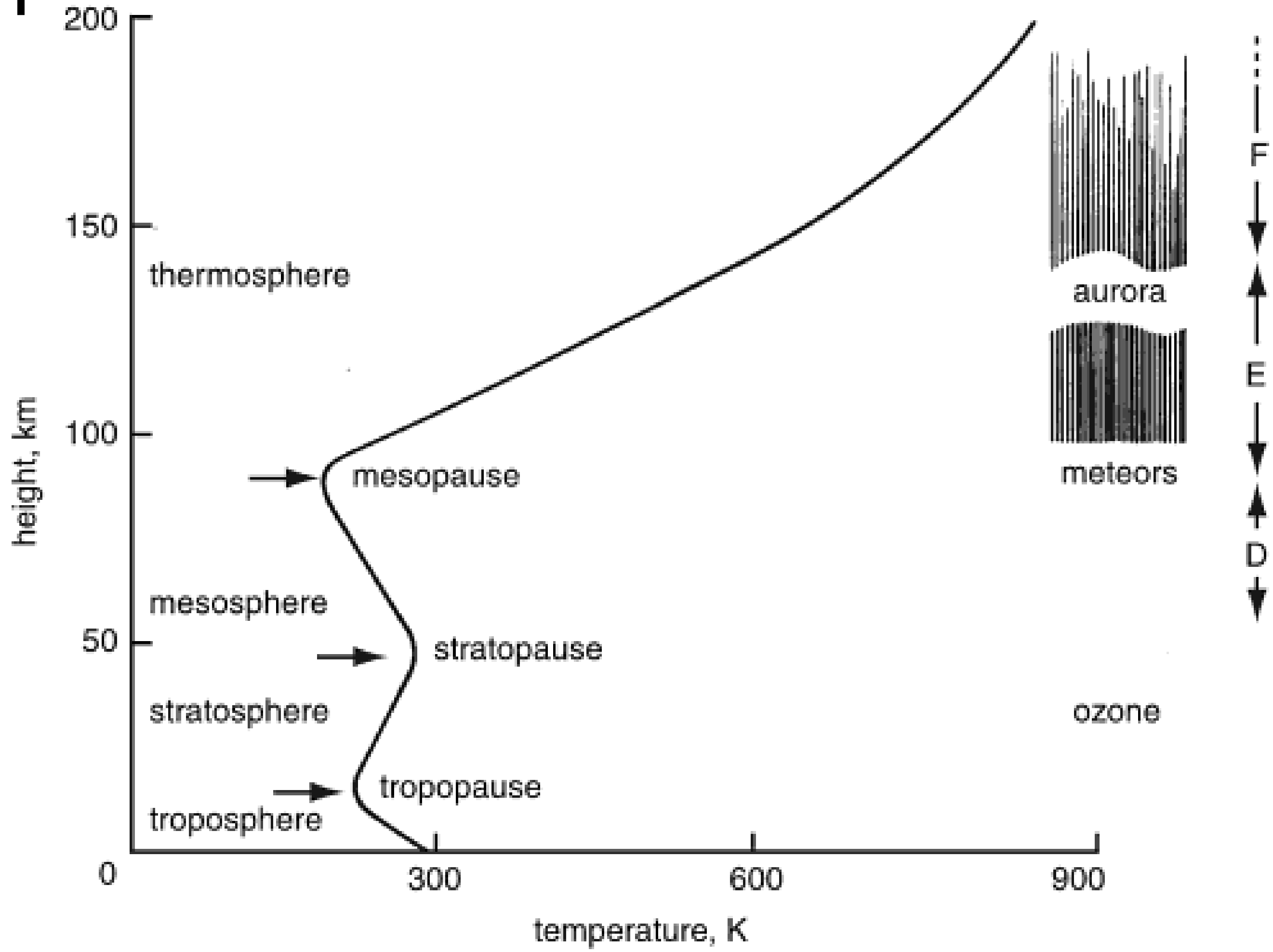
- Ground wave
- Sky wave



From L.W. Barclay, **Propagation of radiowaves**, 2nd eds, IEE, London, UK, 2003.

Sky Wave

- Reflection and refraction due to ionosphere or troposphere



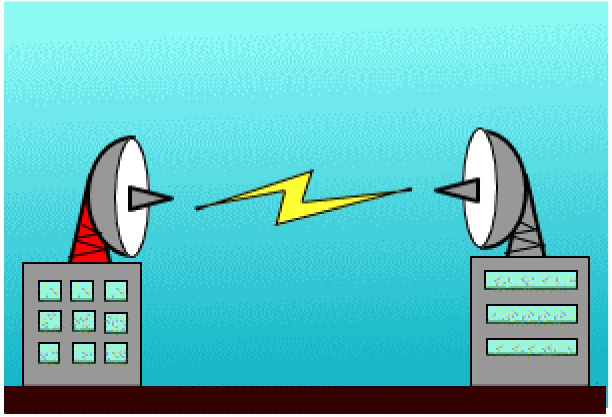
From L.W. Barclay, **Propagation of radiowaves**, 2nd eds, IEE, London, UK, 2003.

Radio Environment
VHF - SHF

- Line-of-sight environment
- Macrocellular environment
- Microcellular and picocellular environment
- Indoor environment

Line-of-Sight Environment

- Satellite communication
- Fixed radio link
- Fixed wireless access (e.g. IEEE 802.16a)



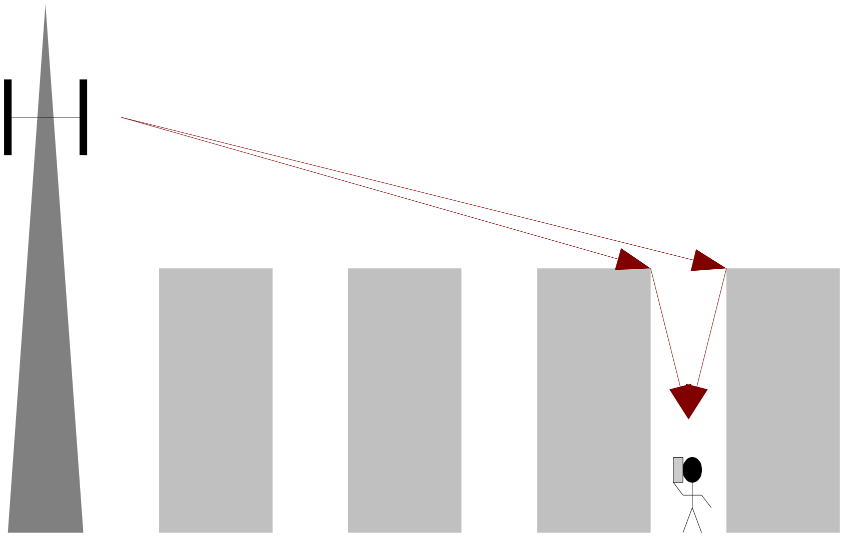
http://www.tele.soumu.go.jp/j/others/obstacle.htm

Free space propagation is the fundamental mechanism

- Attenuation due to medium: rain, atmosphere etc.

Macrocellular Environment

- Cellular systems
- Trunked line systems
    - utility/public mobile radios

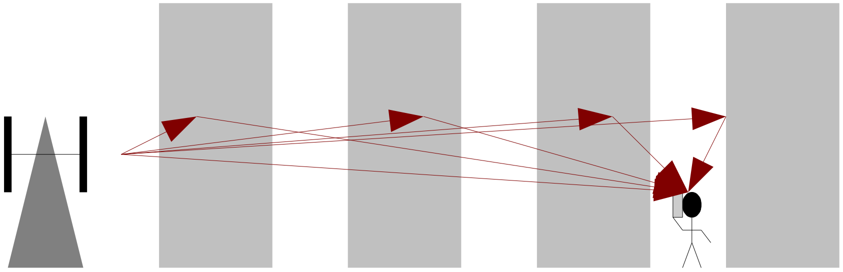


500 m – tens of km

Major mechanism:
Over-the-rooftop propagation (urban)
Terrain irregularity (rural)

Microcellular and Picocellular Environment

- Personal communication systems (PHS, DECT)
- Hot spot (Wireless LAN)



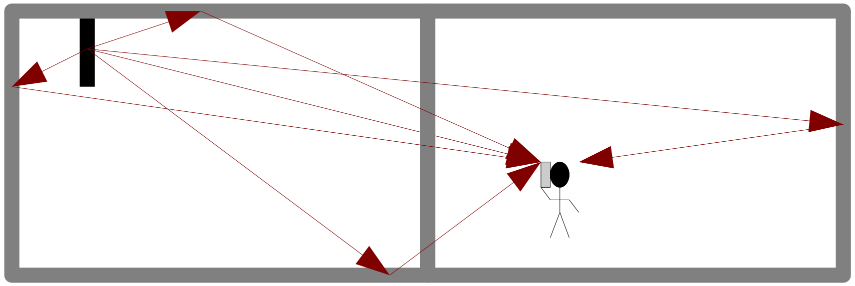
Microcell: 100 – 500 m

Picocell: < 100 m

Major mechanism:
along-the-road propagation/ wall reflection

Indoor Environment

- Wireless LAN
- Cordless phone



Major mechanisms:
  Reflection and penetration by walls
  Scattering by furniture

Fundamental Propagation Mechanisms

- Free space propagation
- Fresnel zone
- Reflection
- Two-path model for ground reflection
- Diffraction

Free Space Propagation

- Friis' transmission formula

$$G = \frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r$$

wavelength

distance

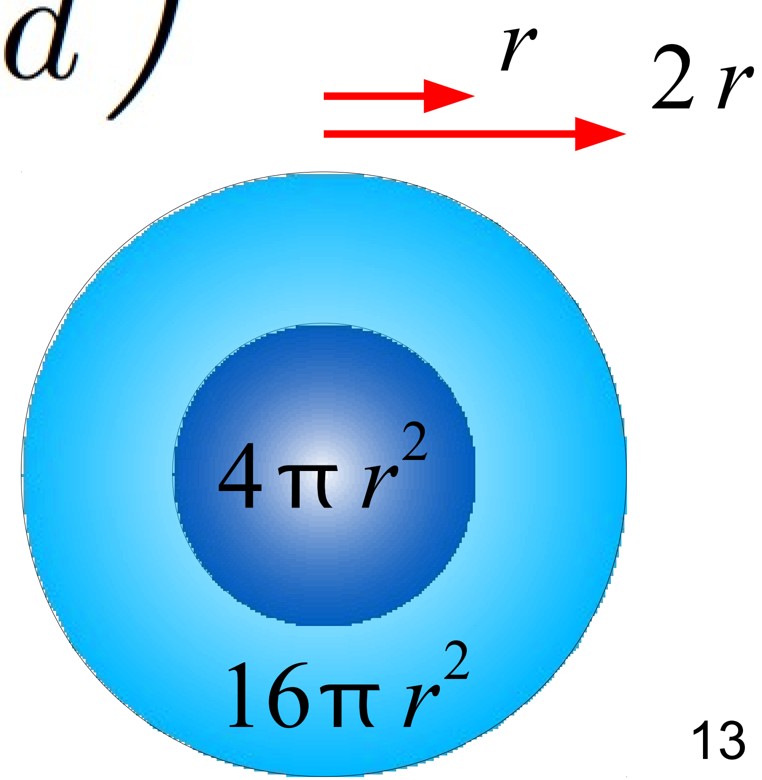
Free space path gain

Antenna gain (Tx and Rx)

Free Space Path Gain

$$G_{\mathrm{f}} = \left(\frac{\lambda}{4\pi d}\right)^2$$

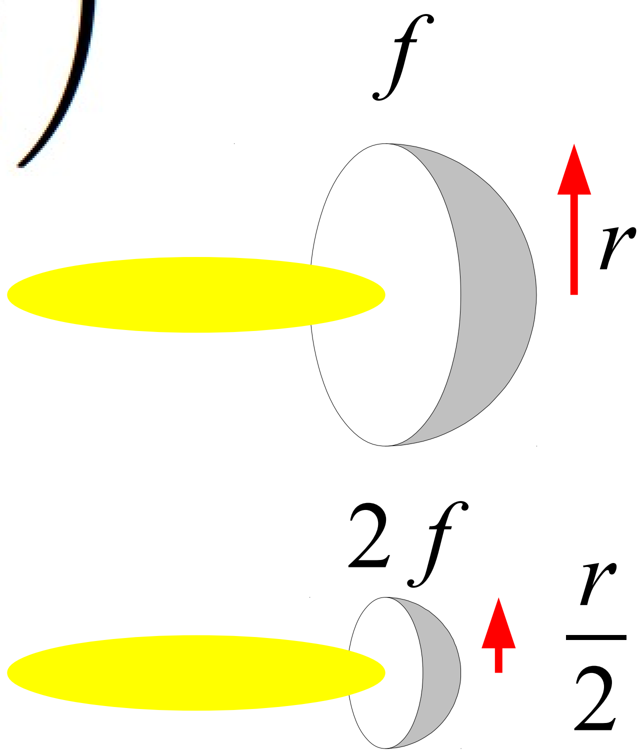
- Proportional to d^{-2}
  - Surface area of sphere
  - Energy conservation



Free Space Path Gain

$$G_\mathrm{f} = \left(\frac{\lambda}{4\pi d}\right)^2$$

- Proportional to λ^2
  - Same gain for same electric area



Free Space Path Gain

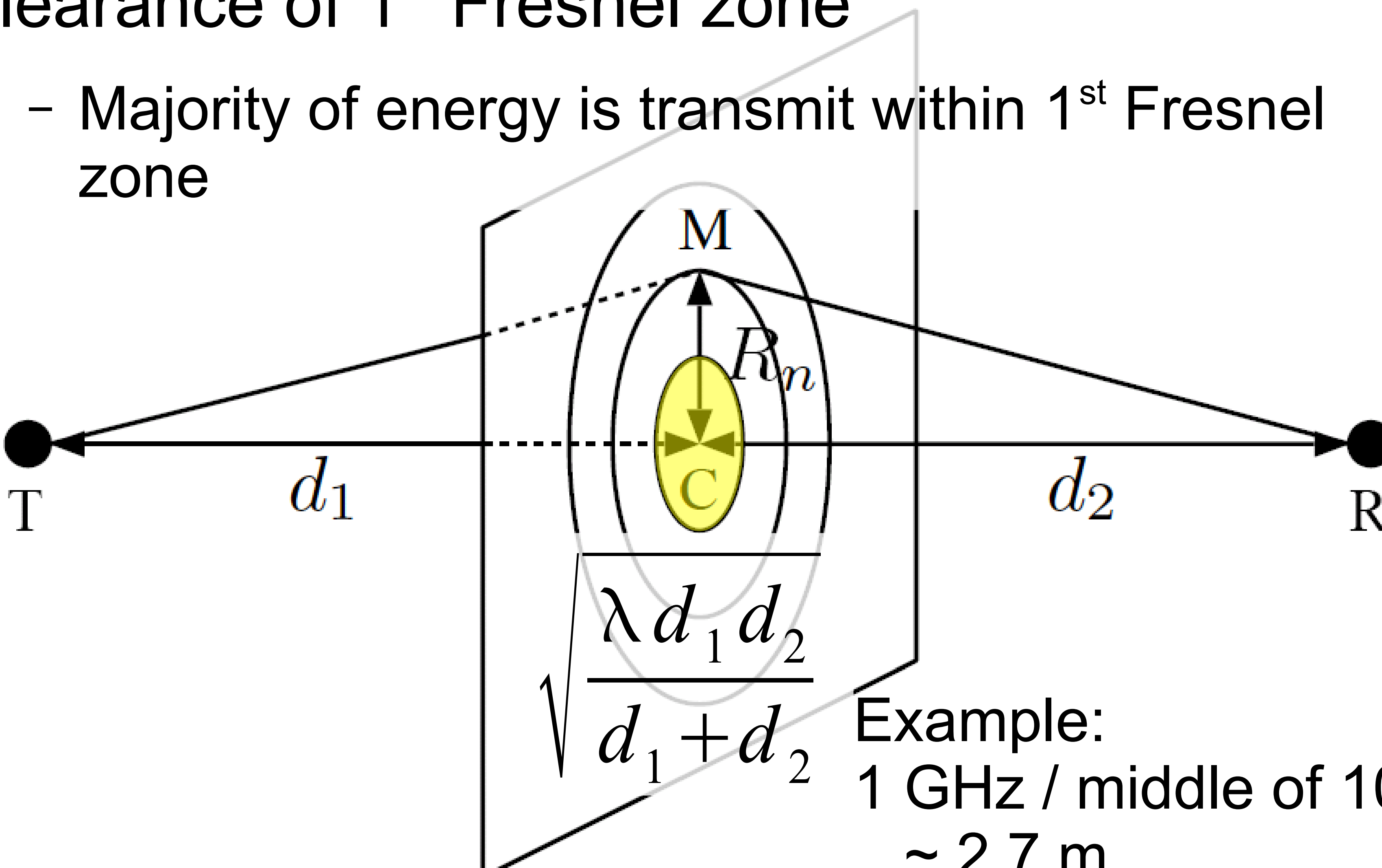
$$G_{\mathrm{f}} = \left(\frac{\lambda}{4\pi d} \right)^2$$

- Examples
  - 1 GHz at 100 m ~ -72.4 dB
  - Distance x frequency
    - x2 ~ 6 dB
    - x10 ~ 20 dB

Definition of Line-of-Sight (LOS)

Clearance of 1st Fresnel zone

- Majority of energy is transmit within 1st Fresnel zone

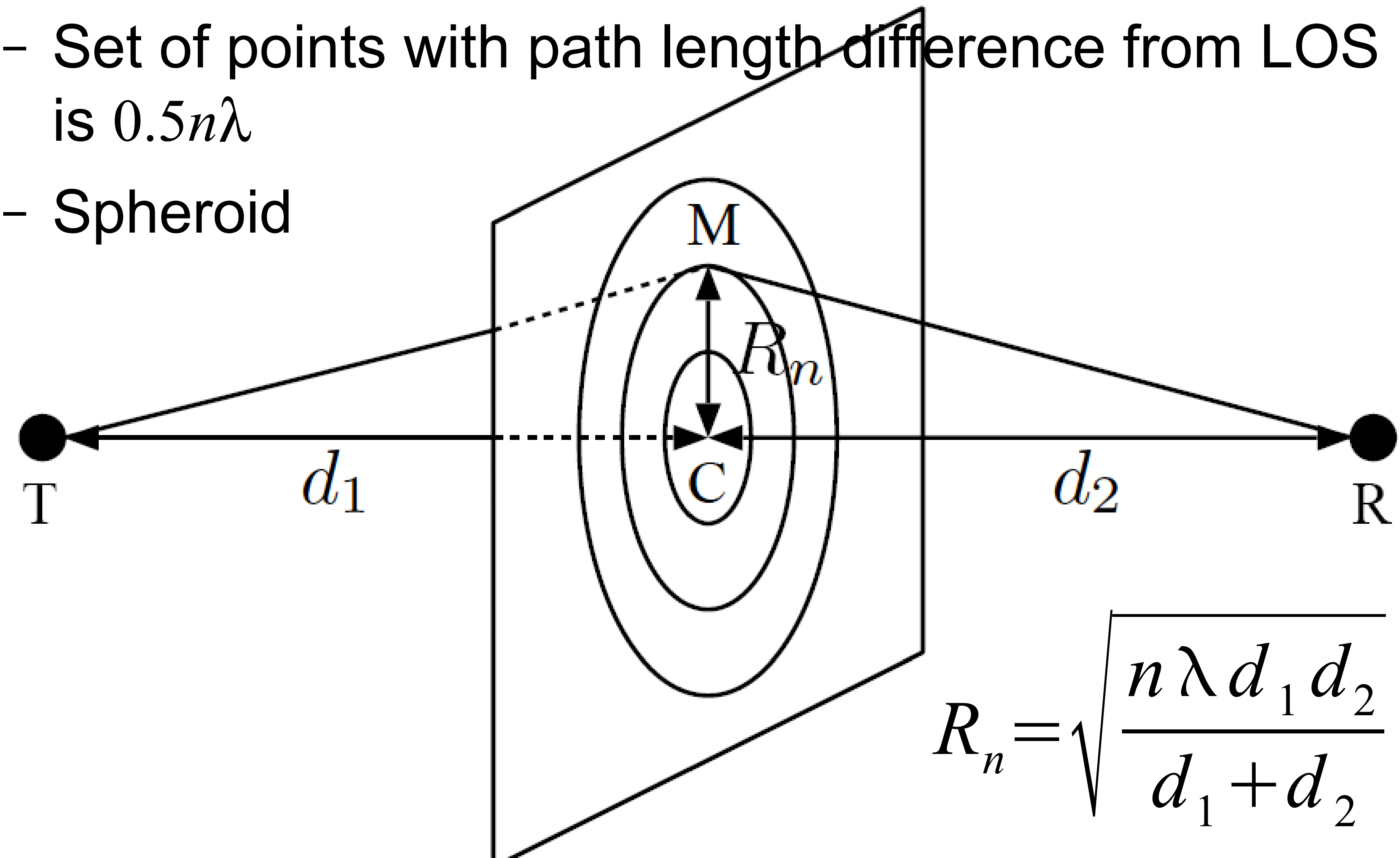


$$\sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}$$

Example:
1 GHz / middle of 100m
~ 2.7 m

Fresnel Zone

- n^{th} Fresnel zone
  - Set of points with path length difference from LOS is $0.5n\lambda$
  - Spheroid



$$R_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

Reflection

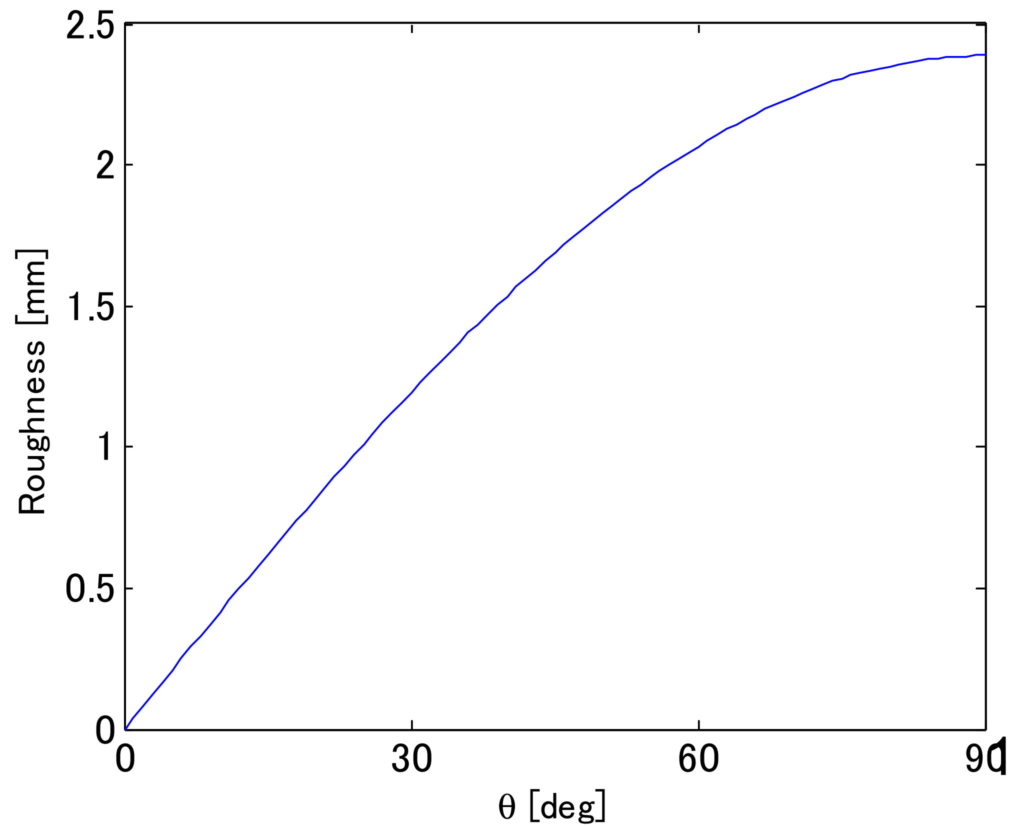
Rayleigh criterion
~ flatness of plane

$$g = \frac{4\pi\,\sigma_h}{\lambda \sin\theta}$$

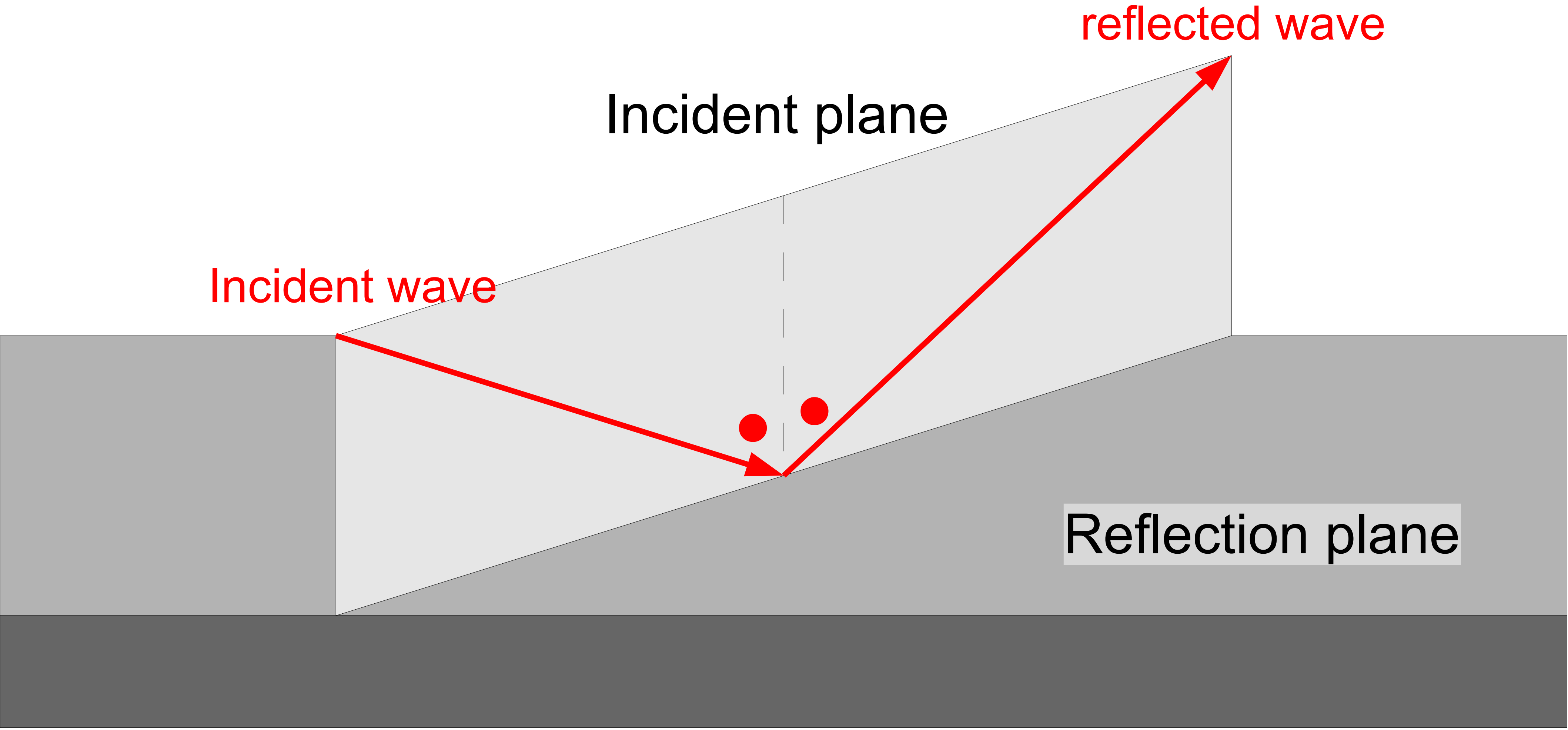
- $g < 1$: flat
- $g > 1$: rough

$$\rho = \exp\left(-\frac{g^2}{2}\right)$$

- Roughness limit at 1 GHz

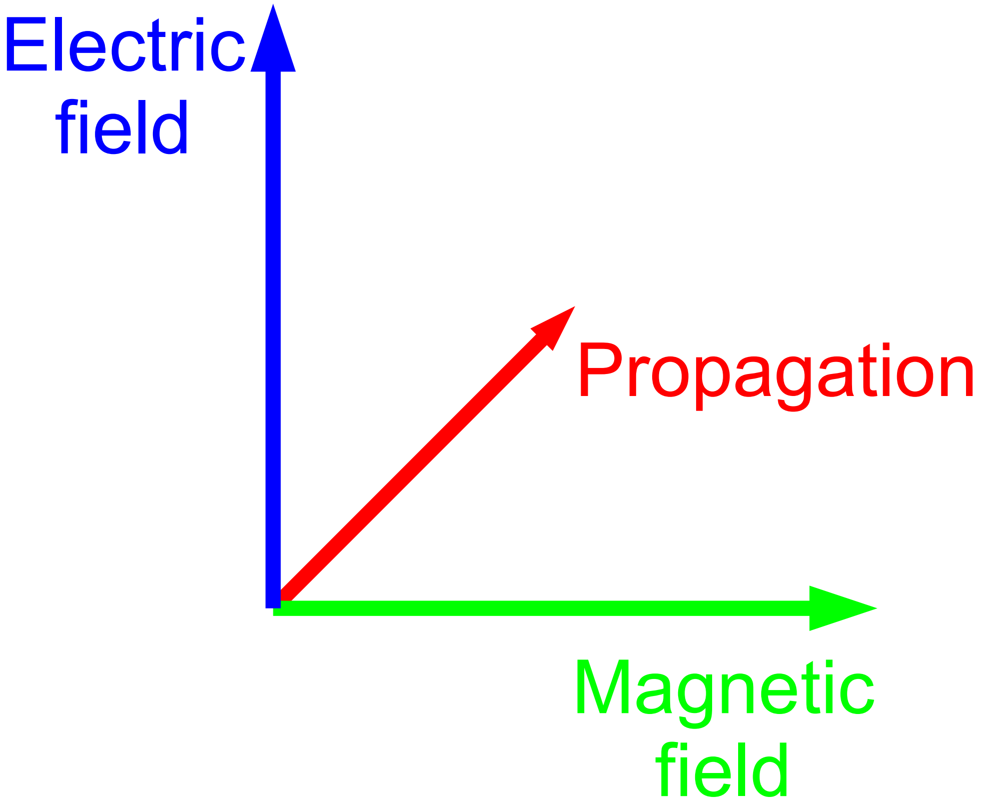


Reflection Law



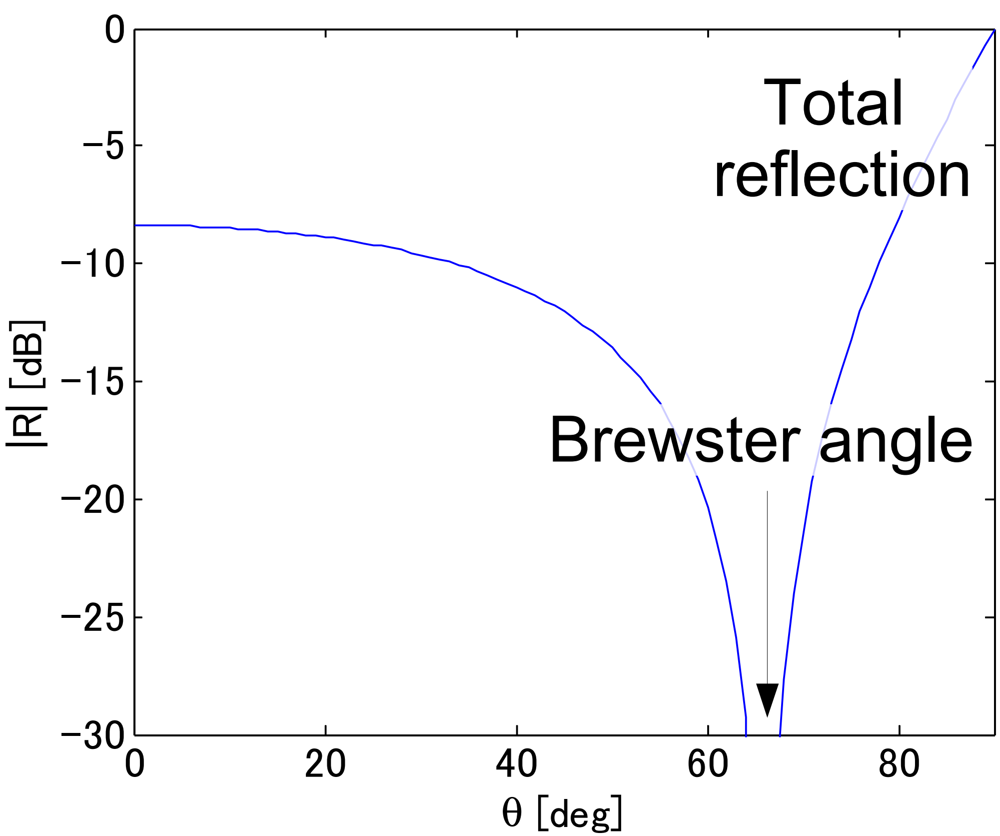
Polarization

- Electromagnetic wave is a lateral wave.
- Polarization is defined as the direction of electric field.

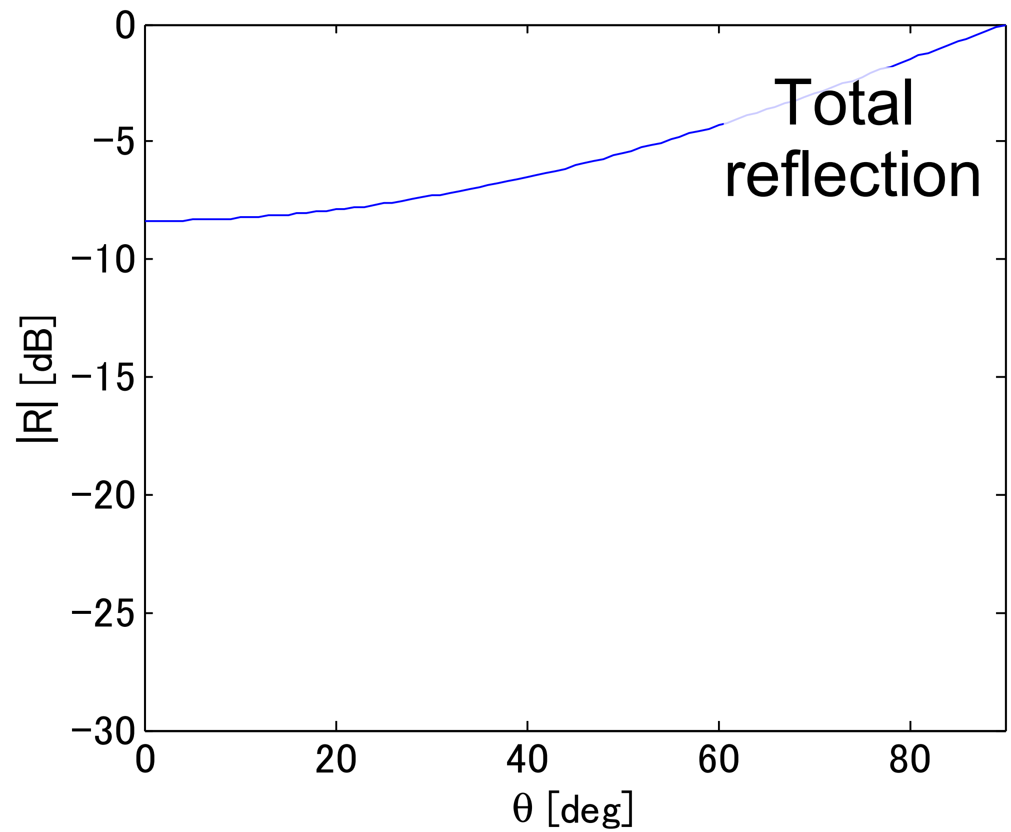


Fresnel Reflection Coefficient

- E-field parallel to incident plane



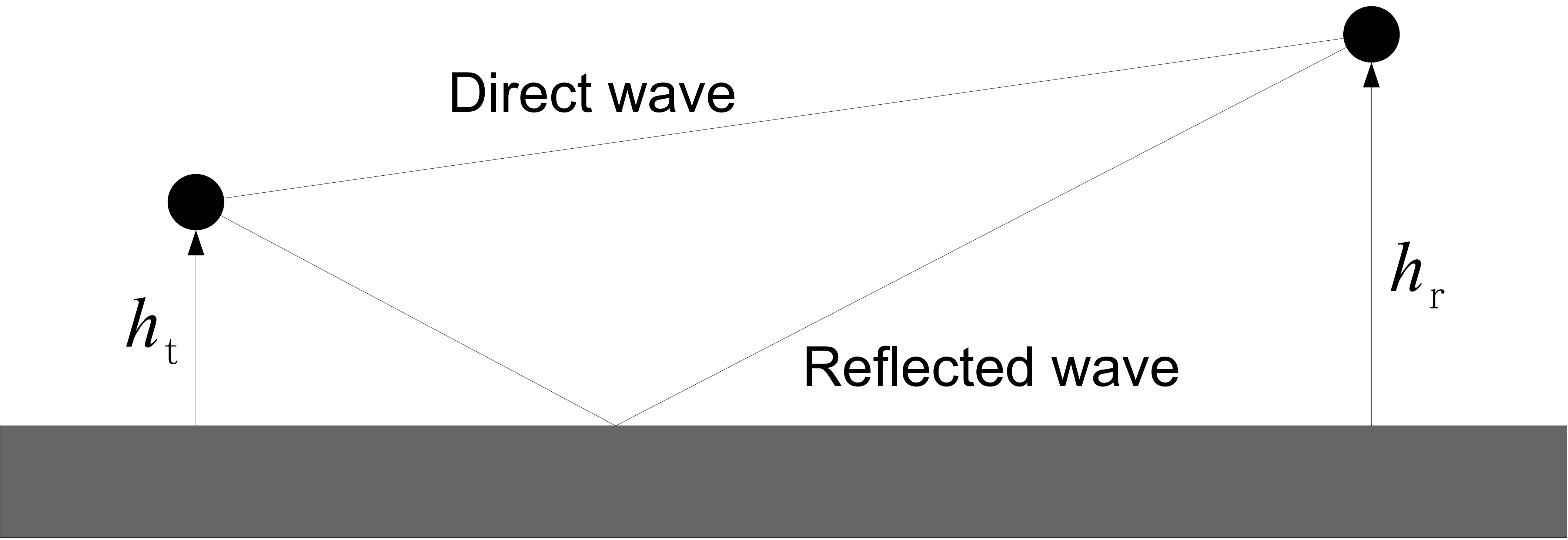
- E-field perpendicular to incident plane



Example for concrete: $\varepsilon = 5.0 - j0.1$

Two-path Model for Ground Reflection

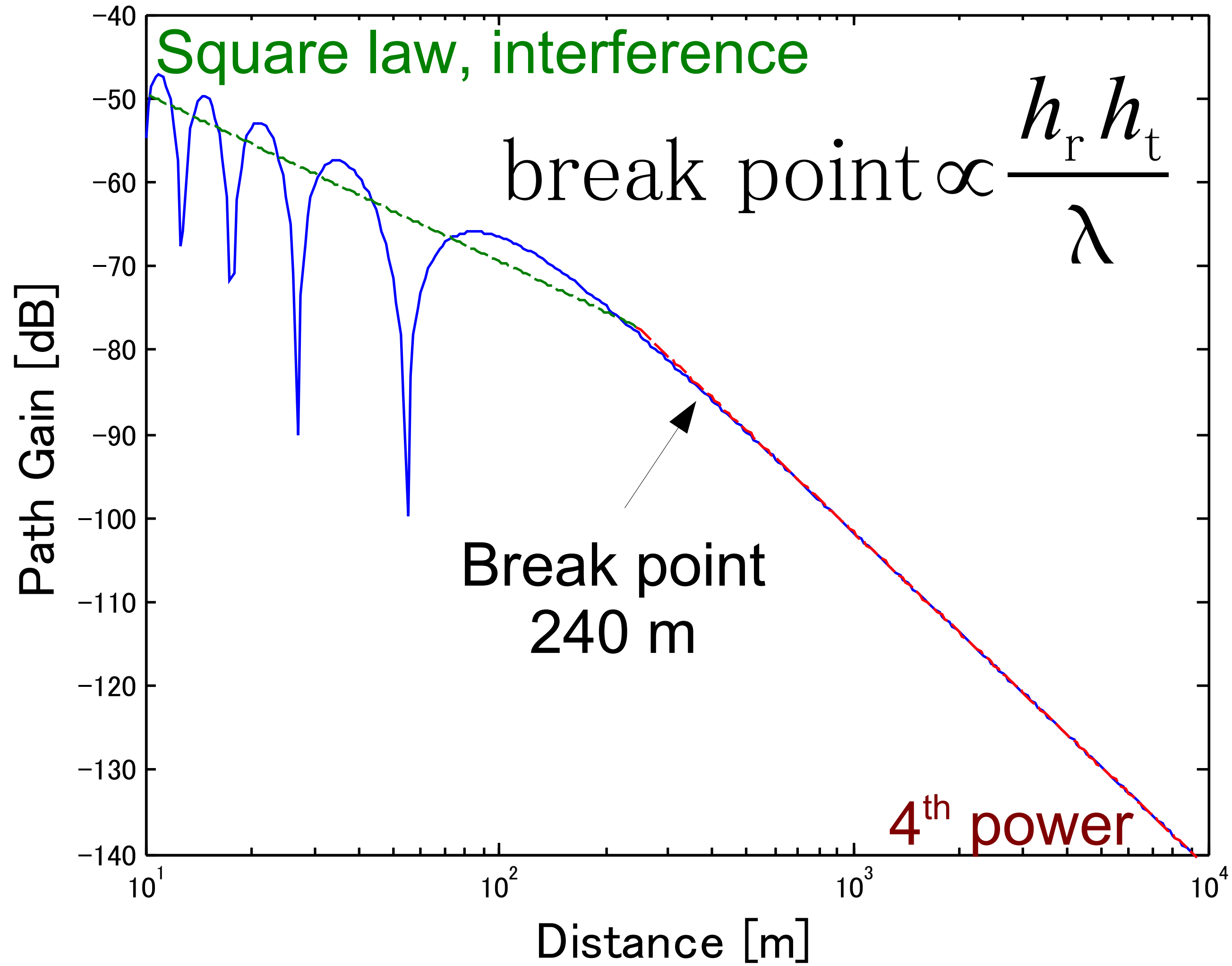
- Interference between direct wave and ground reflected wave



Used for path loss estimation for micro and pico cells

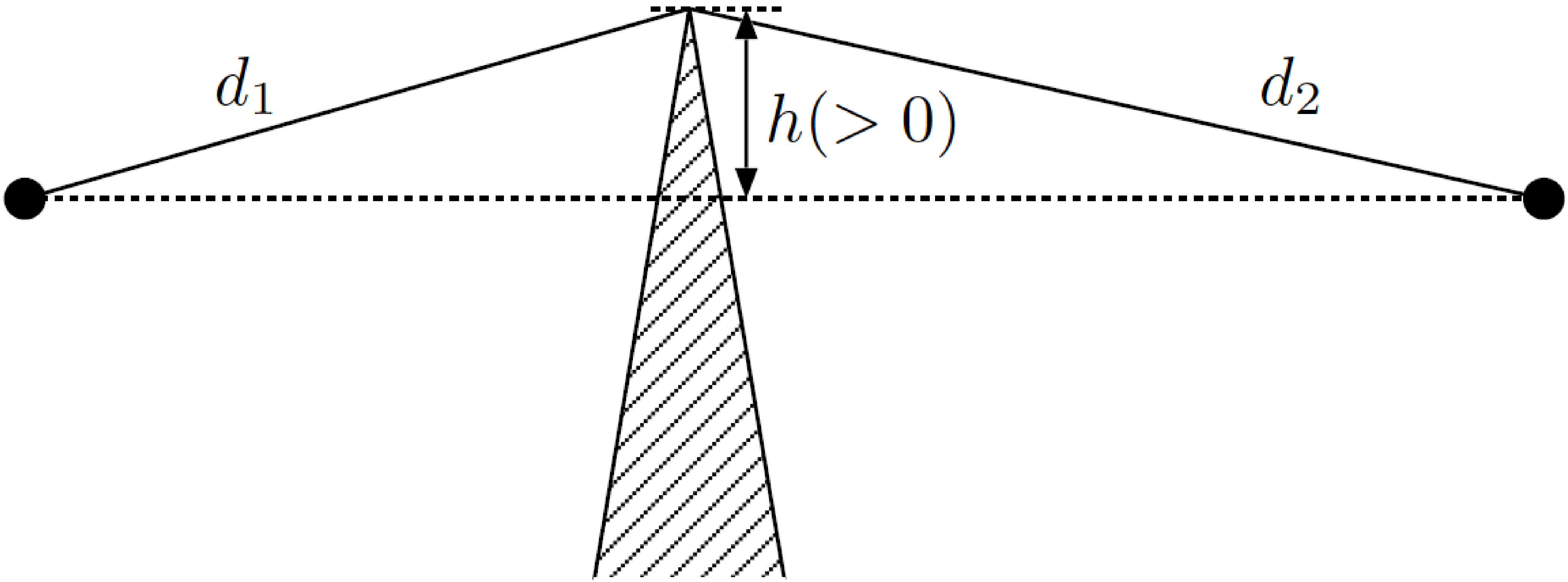
Two-path Model for Ground Reflection

- Example
  1 GHz / Tx 5 m / Rx 1.65 m



Diffraction

- Impact of shadowing 1st Fresnel zone



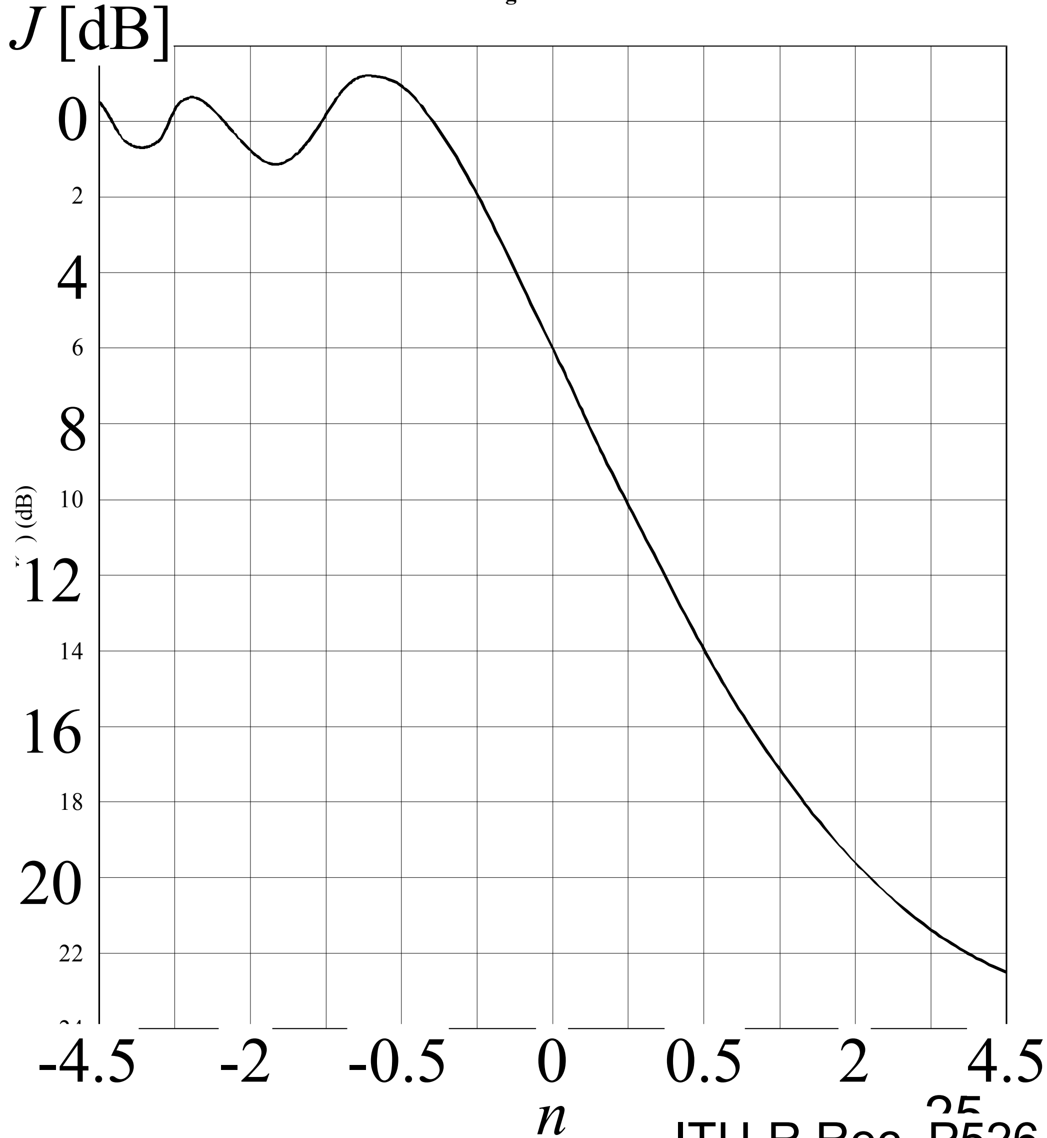
Knife Edge Diffraction Loss

- Shadowing of LOS
  ~ -6 dB
- Shadowing of 1st
  Fresnel zone
  ~ -16 dB
- n is bigger for higher frequency

$$n = \frac{h^2(d_1 + d_2)}{\lambda d_1 d_2}$$

FIGURE 7

Knife-edge diffraction loss



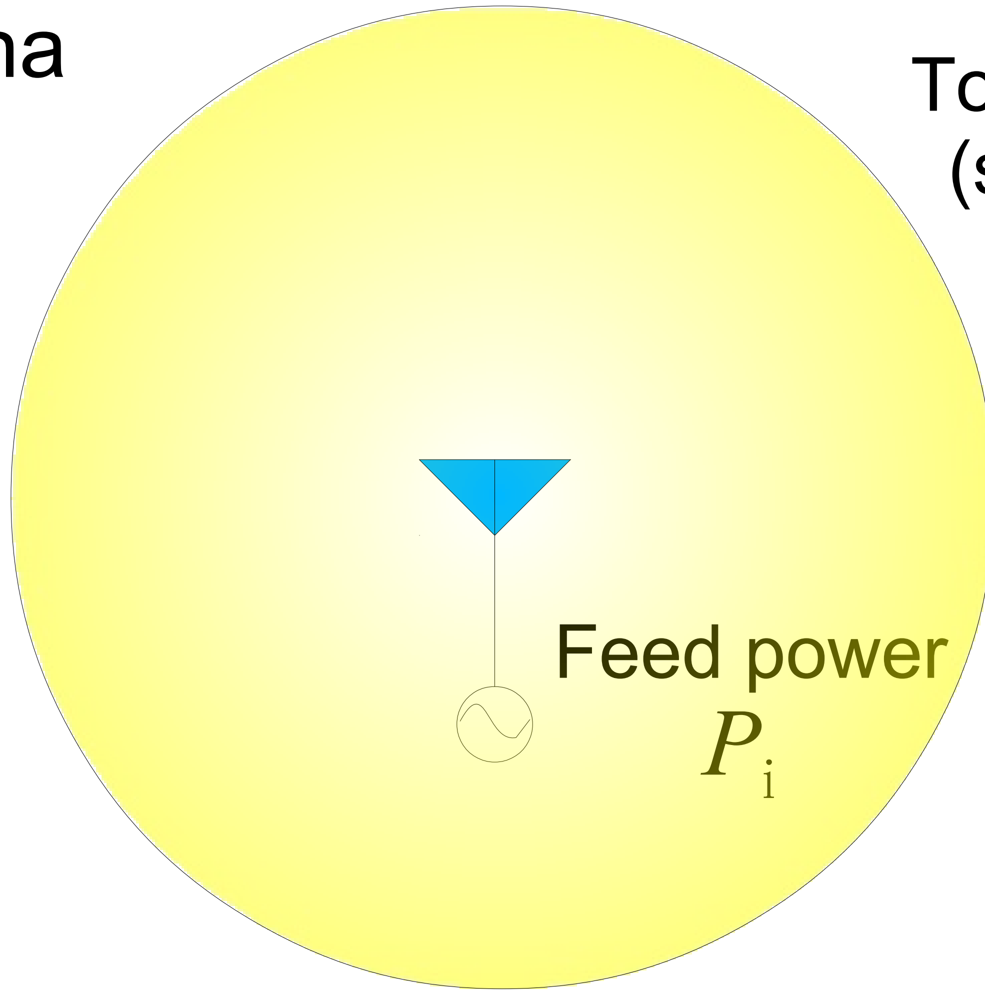
ITU-R Rec. P526-9

Antenna Efficiency

Tx antenna

Total radiated power
(sum over sphere)

P_r



Feed power

P_i

Efficiency $\eta = \dfrac{P_r}{P_i}$

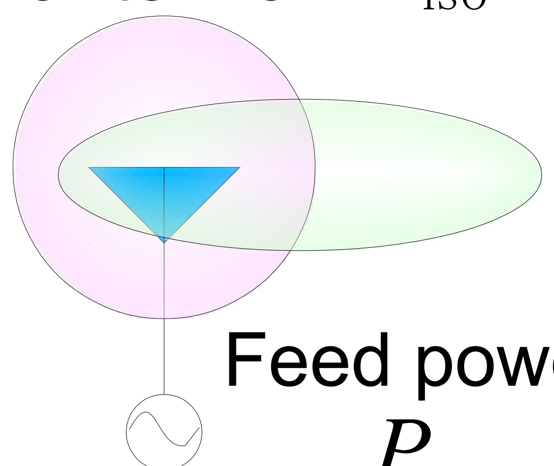
Antenna Directivity and Gain

Directivity
angular power intensity distribution

Total radiated power (sum over sphere)

P_r

Isotropic antenna S_{iso}



Directive antenna $S_{ant}(\theta, \phi)$

Feed power

P_i

Directivity

$$D = \frac{S_{ant}(\theta, \phi)}{S_{iso}}$$

for common P_r

$\times \eta$

Gain

$$G = \frac{S_{ant}(\theta, \phi)}{S_{iso}}$$

for common P_i