Mobile Radio Propagation

Large-scale Path loss

Wireless Communication

4th Chapter

Introduction

- The mobile radio channel places fundamental limitations on the performance of a wireless communication system
- The wireless transmission path may be
  - Line of Sight (LOS)
  - Non line of Sight (NLOS)
- Radio channels are random and time varying
- Modeling radio channels have been one of the difficult parts of mobile radio design and is done in statistical manner
- When electrons move, they create EM waves that can propagate through space.
- By using antennas we can transmit and receive these EM wave
- Microwave ,Infrared visible light and radio waves can be used.

Properties of Radio Waves

- Are easy to generate
- Can travel long distances
- Can penetrate buildings
- May be used for both indoor and outdoor coverage
- Are omni-directional-can travel in all directions
- Can be narrowly focused at high frequencies(>100MHz) using parabolic antenna

Properties of Radio Waves

- Frequency dependence
  - Behave more like light at high frequencies
    - Difficulty in passing obstacle
    - Follow direct paths
    - Absorbed by rain
  - Behave more like radio at lower frequencies
    - Can pass obstacles
    - Power falls off sharply with distance from source
- Subject to interference from other radio waves

Propagation Models

- The statistical modeling is usually done based on data measurements made specifically for
  - the intended communication system
  - the intended spectrum

- They are tools used for:
  - Predicting the average signal strength at a given distance from the transmitter

  - Estimating the variability of the signal strength in close spatial proximity to a particular locations

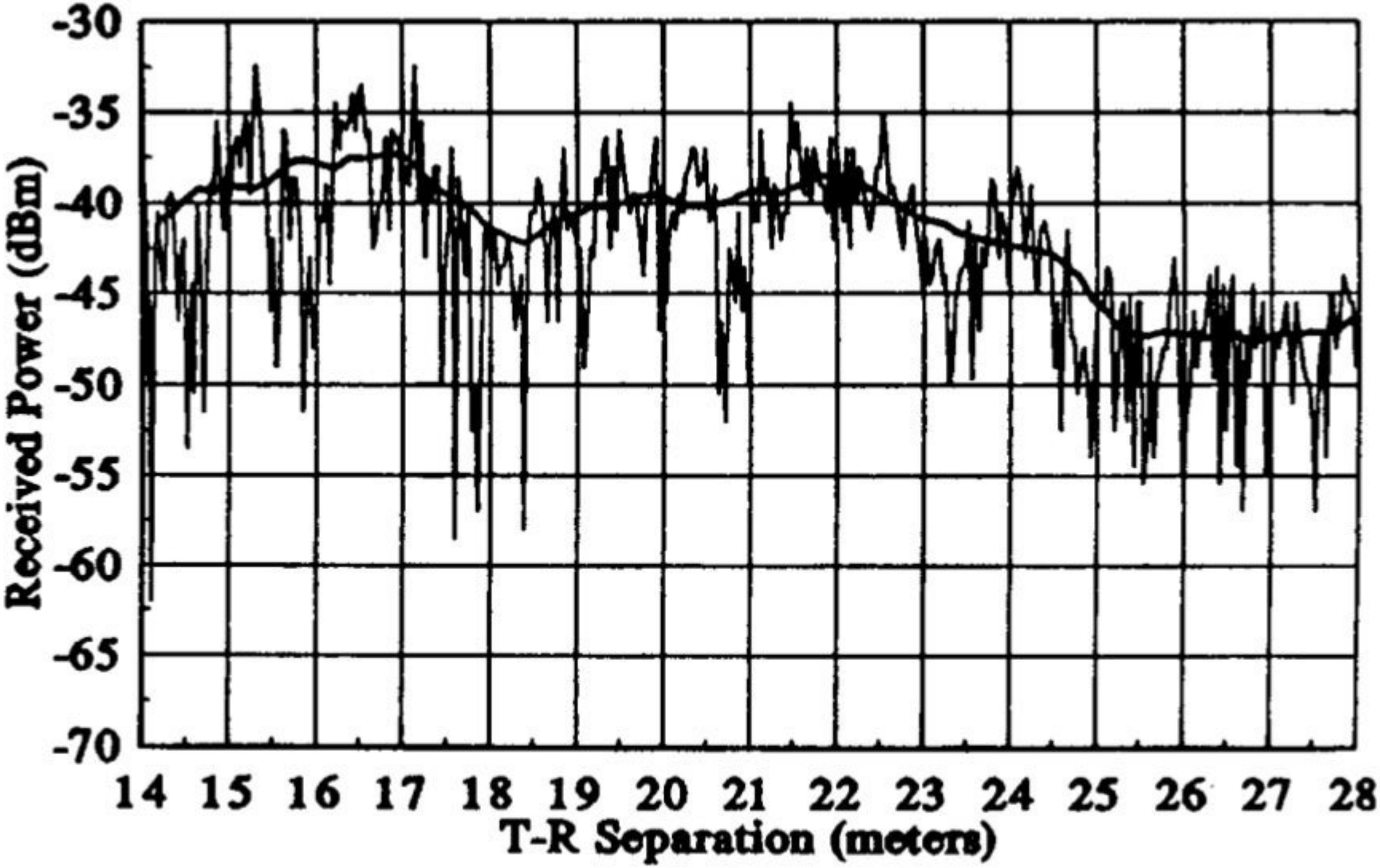
Propagation Models

- Large Scale Propagation Model:
  - Predict the mean signal strength for an arbitrary transmitter-receiver(T-R) separation
  - Estimate radio coverage of a transmitter
  - Characterize signal strength over large T-R separation distances(several 100's to 1000's meters)

Propagation Models

- Small Scale or Fading Models:
  - Characterize rapid fluctuations of received signal strength over
    - Very short travel distances(a few wavelengths)
    - Short time durations(on the order of seconds)

Small-scale and large-scale fading



Free Space Propagation Model

- For clear LOS between T-R
  - Ex: satellite & microwave communications

- Assumes that received power decays as a function of T-R distance separation raised to some power.

- Given by Friis free space eqn:

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

'L' is the system loss factor

L >1 indicates loss due to transmission line attenuation, filter losses & antenna losses

L = 1 indicates no loss in the system hardware

- Gain of antenna is related to its effective aperture A_e by

$$G = 4\pi A_e / \lambda^2$$

Free Space Propagation Model

- Effective Aperture A_e is related to physical size of antenna.

$$\lambda = c/f.$$

- c is speed of light,
- P_t and P_r must be in same units
- G_t ad G_r are dimensionless

- An isotropic radiator, an ideal radiator which radiates power with unit gain uniformly in all directions, and is often used as reference

- Effective Isotropic Radiated Power (EIRP) is defined as

$$EIRP = Pt\ Gt$$

- Represents the max radiated power available from a transmitter in direction of maximum antenna gain, as compared to an isotropic radiator

Free Space Propagation Model

- In practice Effective Radiated Power (ERP) is used instead of (EIRP)

- Effective Radiated Power (ERP) is radiated power compared to half wave dipole antennas

- Since dipole antenna has gain of 1.64(2.15 dB)

$$ERP=EIRP-2.15(dB)$$

- the ERP will be 2.15dB smaller than the EIRP for same Transmission medium

Free Space Propagation Model

- Path Loss (PL) represents signal attenuation and is defined as difference between the effective transmitted power and received power

Path loss PL(dB) = 10 log [Pt/Pr]

= -10 log {GtGr λ^2/(4π)^2d^2}

- Without antenna gains (with unit antenna gains)

PL = - 10 log { λ^2/(4π)^2d^2}

- Friis free space model is valid predictor for P_r for values of d which are in the far-field of transmitting antenna

Free Space Propagation Model

- The far field or Fraunhofer region that is beyond far field distance d_f given as : $d_f=2D^2/\lambda$
- D is the largest physical linear dimension of the transmitter antenna
- Additionally, $d_f >> D$ and $d_f >> \lambda$
- The Friis free space equation does not hold for d=0
- Large Scale Propagation models use a close-in distance, d_o, as received power reference point, chosen such that $d_o >= d_f$
- Received power in free space at a distance greater then do

$$Pr(d)=Pr(do)(do/d)^2 \quad d>d_o>d_f$$

Pr with reference to 1 mW is represented as

$$Pr(d)=10\log(Pr(do)/0.001W)+20\log(do/d)$$

Electrostatic,inductive and radiated fields are launched, due to flow of current from anntena.

Regions far away from transmitter electrostatic and inductive fields become negligible and only radiated field components are considered.

Example

- What will be the far-field distance for a Base station antenna with
- Largest dimension D=0.5m
- Frequency of operation fc=900MHz,1800MHz

- For 900MHz
- *λ =3*10^8/900*10^6)=0.33m*
- *df= 2D^2/ λ =2(0.5)^2/0.33=1.5m*

Example

- If a transmitter produces 50 watts of power, express the transmit power in units of (a) dBm, and (b) dBW. If 50 watts is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the antenna, What is P_r (10 km)? Assume unity gain for the receiver antenna.

solution

Given:
Transmitter power, $P_t = 50$ W.
Carrier frequency, $f_c = 900$ MHz

Using equation (3.9),
(a) Transmitter power,

$$P_t(\text{dBm}) = 10\log[P_t(\text{mW})/(1\text{ mW})]$$
$$= 10\log[50 \times 10^3] = 47.0\text{ dBm}.$$

(b) Transmitter power,

$$P_t(\text{dBW}) = 10\log[P_t(\text{W})/(1\text{ W})]$$
$$= 10\log[50] = 17.0\text{ dBW}.$$

The received power can be determined using equation (3.1).

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50(1)(1)(1/3)^2}{(4\pi)^2(100)^2(1)} = 3.5 \times 10^{-6}\text{ W} = 3.5 \times 10^{-3}\text{ mW}$$

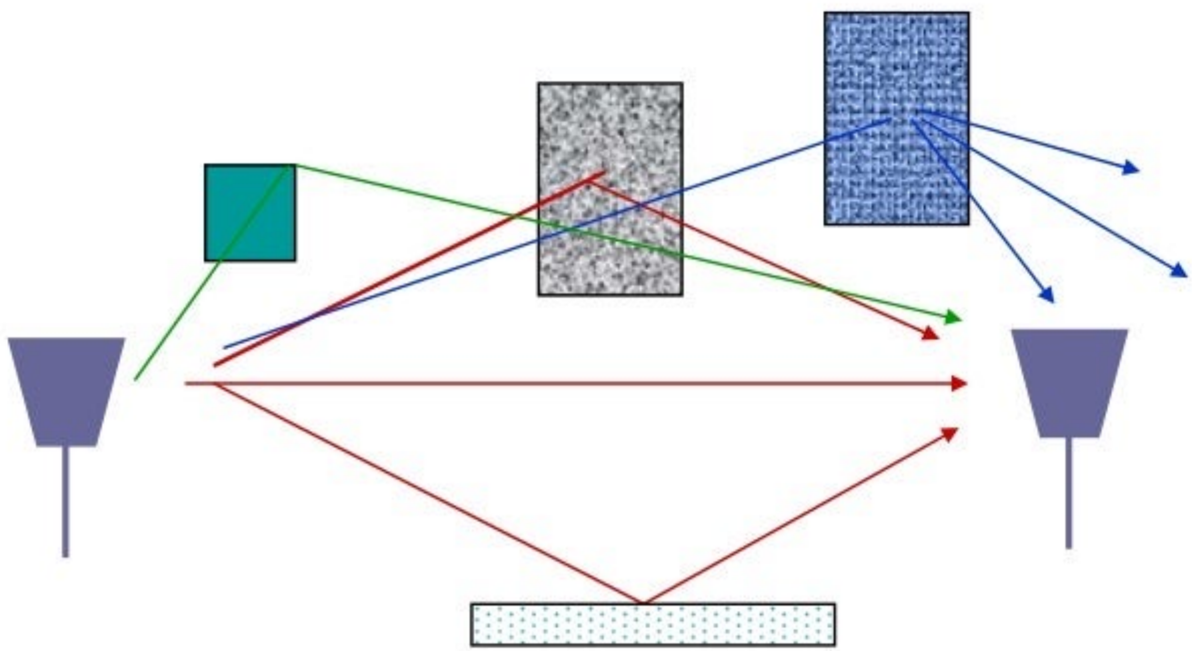
$$P_r(\text{dBm}) = 10\log P_r(\text{mW}) = 10\log\left(3.5 \times 10^{-3}\text{ mW}\right) = -24.5\text{ dBm}.$$

The received power at 10 km can be expressed in terms of dBm using equation (3.9), where $d_0 = 100$ m and $d = 10$ km

$$P_r(10\text{ km}) = P_r(100) + 20\log\left[\frac{100}{10000}\right] = -24.5\text{ dBm} - 40\text{ dB}$$
$$= -64.5\text{ dBm}.$$

Propagation Mechanisms

- Three basic propagation mechanism which impact propagation in mobile radio communication system are:
  - Reflection
  - Diffraction
  - Scattering



Propagation Mechanisms

- Reflection occurs when a propagating electromagnetic wave impinges on an object which has very large dimensions as compared to wavelength e.g. surface of earth , buildings, walls

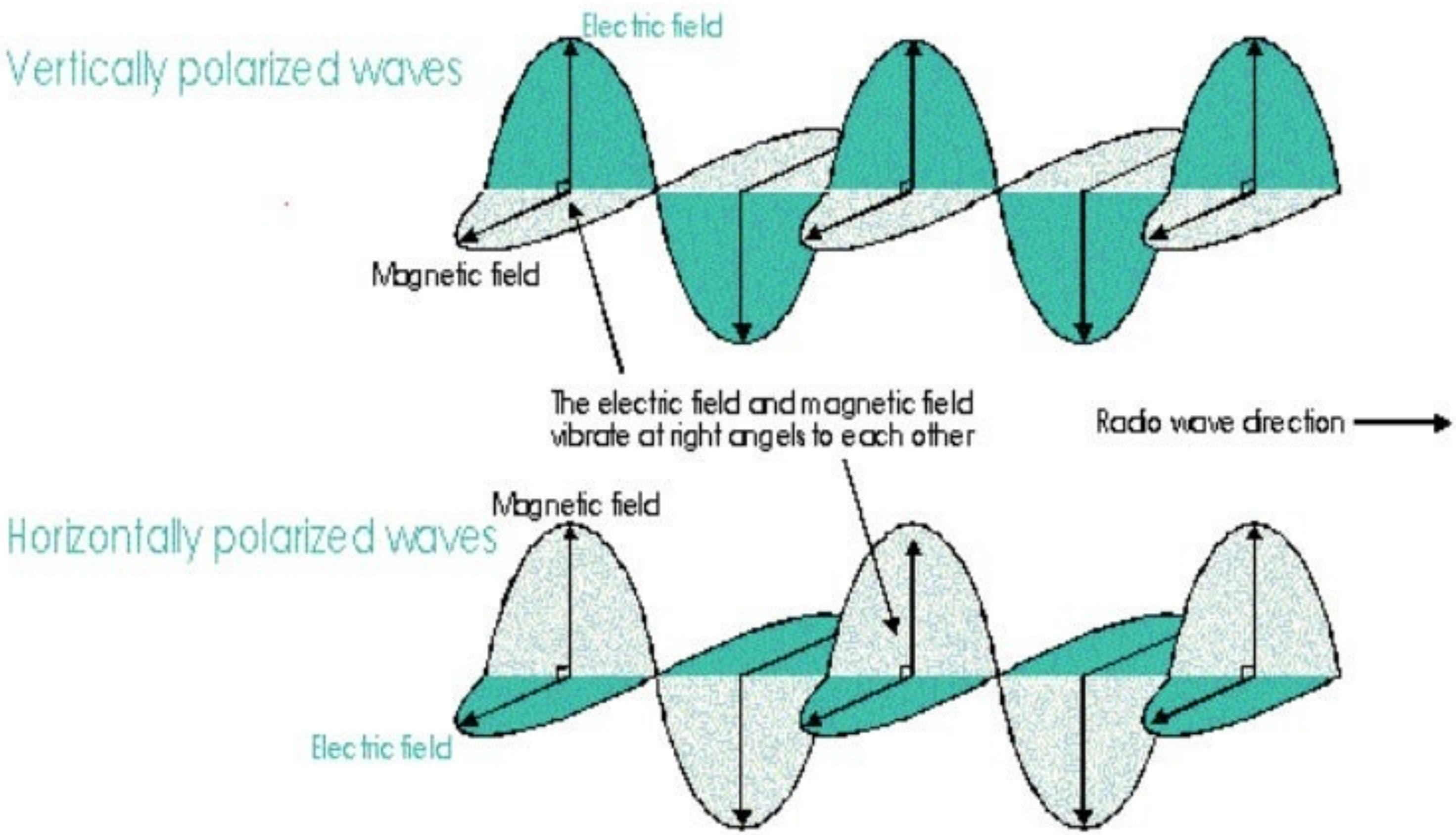
- Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities(edges)
  - Explains how radio signals can travel urban and rural environments without a line of sight path

- Scattering occurs when medium has objects that are smaller or comparable to the wavelength (small objects, irregularities on channel, foliage, street signs etc)

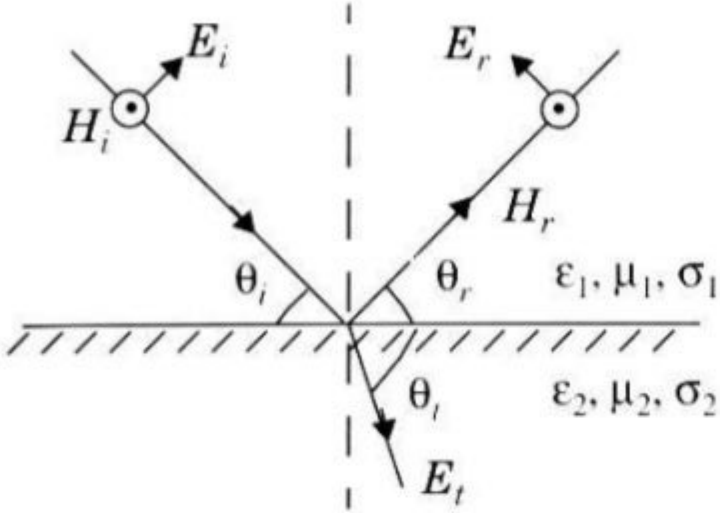
Reflection

- Occurs when a radio wave propagating in one medium impinges upon another medium having different electrical properties
- If radio wave is incident on a perfect dielectric
  - Part of energy is reflected back
  - Part of energy is transmitted
- In addition to the change of direction, the interaction between the wave and boundary causes the energy to be split between reflected and transmitted waves
- The amplitudes of the reflected and transmitted waves are given relative to the incident wave amplitude by Fresnel reflection coefficients

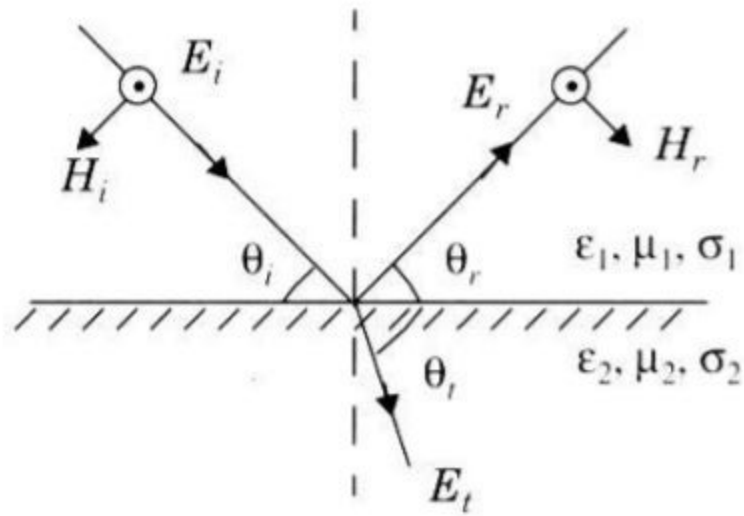
Vertical and Horizontal polarization



Reflection- Dielectrics



(a) E-field in the plane of incidence



(b) E-field normal to the plane of incidence

Figure 4.4 Geometry for calculating the reflection coefficients between two dielectrics.

Reflection

- $\Gamma(\|) = \frac{E_r}{E_i}/ = \frac{\eta_2 \sin\theta_t - \eta_1 \sin\theta_i}{\eta_1 \sin\theta_t + \eta_1 \sin\theta_i}$ (Paralell E-field polarization)
- $\Gamma(\perp) = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_i - \eta_1 \sin\theta_t}{\eta_1 \sin\theta_i + \eta_1 \sin\theta_t}$ (Perpendicular E-field polarization)
- These expressions express ratio of reflected electric fields to the incident electric field and depend on impedance of media and on angles
- η is the intrinsic impedance given by $\sqrt{(\mu/\varepsilon)}$
- μ=permeability,ε=permittivity

Reflection-Perfect Conductor

- If incident on a perfect conductor the entire EM energy is reflected back
- Here we have $\theta_r = \theta_i$
- $E_i = E_r$ (E-field in plane of incidence)
- $E_i = -E_r$ (E field normal to plane of incidence)
- Γ(parallel)= 1
- Γ(perpendicular)= -1

Reflection - Brewster Angle

- It is the angle at which no reflection occur in the medium of origin. It occurs when the incident angle θ_B is such that the reflection coefficient Γ(parallel) is equal to zero.
- It is given in terms of θ_B as given below

$$Sin(\theta_B) = \sqrt{\frac{\varepsilon_1}{\varepsilon_1+\varepsilon_2}}$$

- When first medium is a free space and second medium has an relative permittivity of $\varepsilon_r\ then$

$$Sin(\theta_B) = \frac{\sqrt{\varepsilon_{r-1}}}{\sqrt{e_r^2 - 1}}$$

- Brewster angle only occur for parallel polarization

Ground Reflection(Two Ray) Model

- In mobile radio channel, single direct path between base station and mobile and is seldom only physical means for propagation
- Free space model as a stand alone is inaccurate
- Two ray ground reflection model is useful
  - Based on geometric optics
  - Considers both direct and ground reflected path
- Reasonably accurate for predicting large scale signal strength over several kms that use tall tower height
- Assumption: The height of Transmitter >50 meters

Ground Reflection(Two Ray) Model

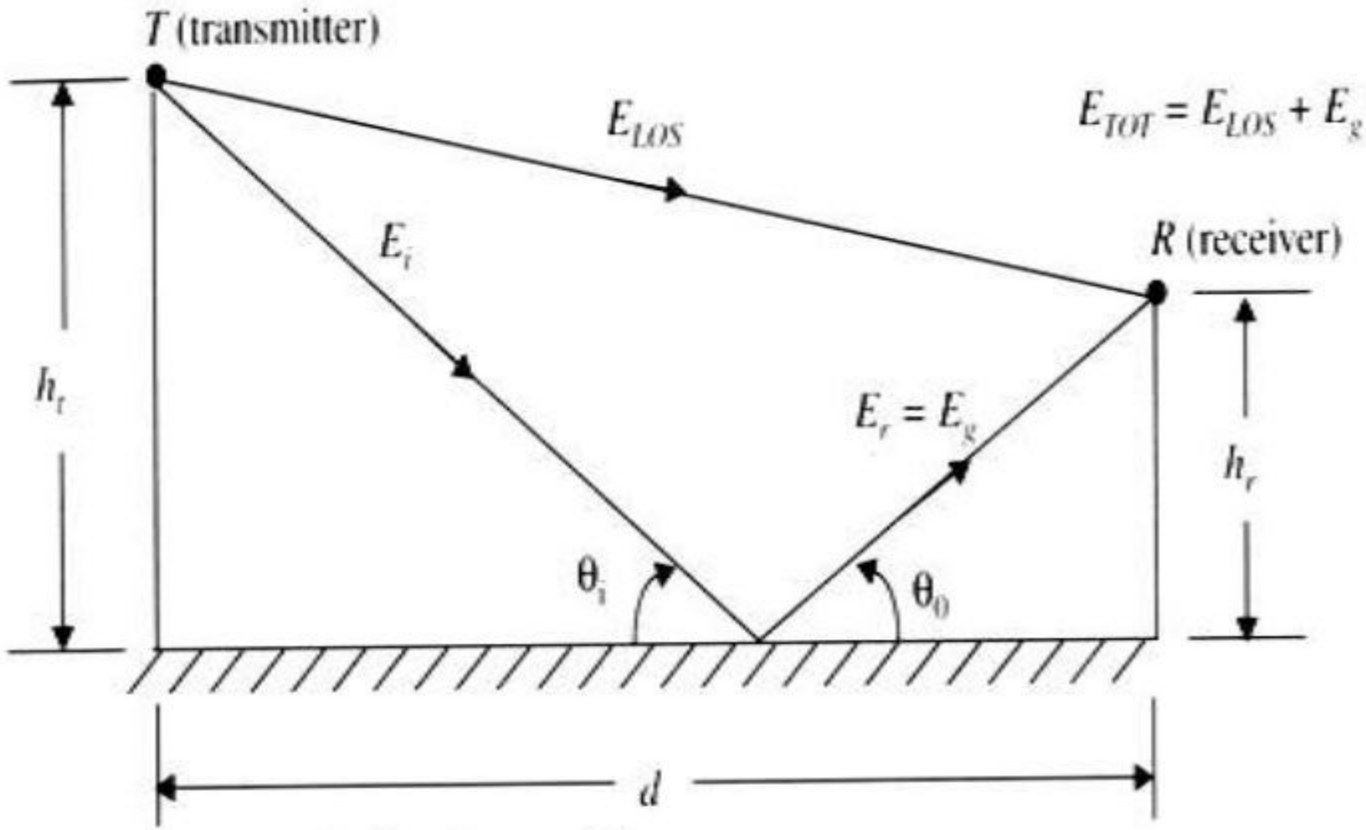


Figure 4.7 Two-ray ground reflection model.

Ground Reflection(Two Ray) Model

$$\vec{E}_{TOT} = \vec{E}_{LOS} + \vec{E}_g$$

let E_o be $|\vec{E}|$ at reference point d_o then

$$\vec{E}(d,t) = \left(\frac{E_0 d_0}{d}\right)\cos\left(\omega_c\left(t - \frac{d}{c}\right)\right) \quad d > d_0$$

$$E_{LOS}(d',t) = \frac{E_0 d_0}{d'}\cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) \qquad E_g(d'',t) = \Gamma\frac{E_0 d_0}{d''}\cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

$$\vec{E}_{TOT}(d,t) = \left(\frac{E_0 d_0}{d'}\right)\cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + \Gamma\left(\frac{E_0 d_0}{d''}\right)\cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

$$E_{TOT}(d,t) = \frac{E_0 d_0}{d'}\cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + (-1)\frac{E_0 d_0}{d''}\cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

Ground Reflection(Two Ray) Model

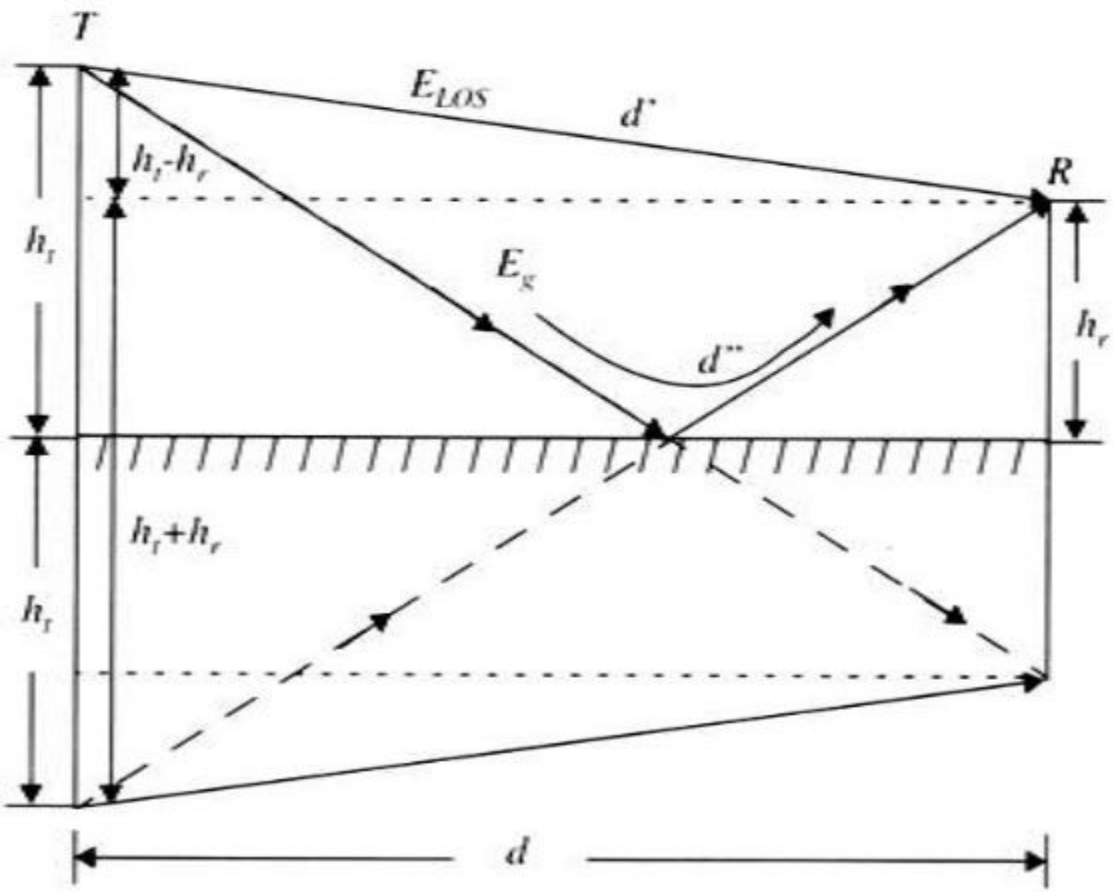


Figure 4.8 The method of images is used to find the path difference between the line-of-sight and the ground reflected paths.

Path Difference

$$
\begin{aligned}
\Delta = d'' - d' &= \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2} \\
&= d\sqrt{\left(\left(\frac{h_t + h_r}{d}\right)^2 + 1\right)} - d\sqrt{\left(\left(\frac{h_t - h_r}{d}\right)^2 + 1\right)} \\
&\approx d\left(1 + \frac{1}{2}\left(\frac{h_t + h_r}{d}\right)^2\right) - d\left(1 + \frac{1}{2}\left(\frac{h_t - h_r}{d}\right)^2\right) \\
&\approx \frac{1}{2d}\left((h_t + h_r)^2 - (h_t - h_r)^2\right) \\
&\approx \frac{1}{2d}\left(\left(h_t^2 + 2h_t h_r + h_r^2\right) - \left(h_t^2 - 2h_t h_r + h_r^2\right)\right) \\
&\approx \frac{2h_t h_r}{d}
\end{aligned}
$$

Phase difference

$$\theta_\Delta \text{ radians } = \frac{2\pi\Delta}{\lambda} = \frac{2\pi\Delta}{\left(c/f_c\right)} = \frac{\omega_c \Delta}{c}$$

$$\left|E_{TOT}(t)\right| = 2\frac{E_0 d_0}{d}\sin\left(\frac{\theta_\Delta}{2}\right)$$

$$\frac{\theta_\Delta}{2} \approx \frac{2\pi h_r h_t}{\lambda d} < 0.3 \text{ rad}$$

$$E_{TOT}(t) \approx 2\frac{E_0 d_0}{d}\frac{2\pi h_r h_t}{\lambda d} \approx \frac{k}{d^2} \text{ V/m}$$

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

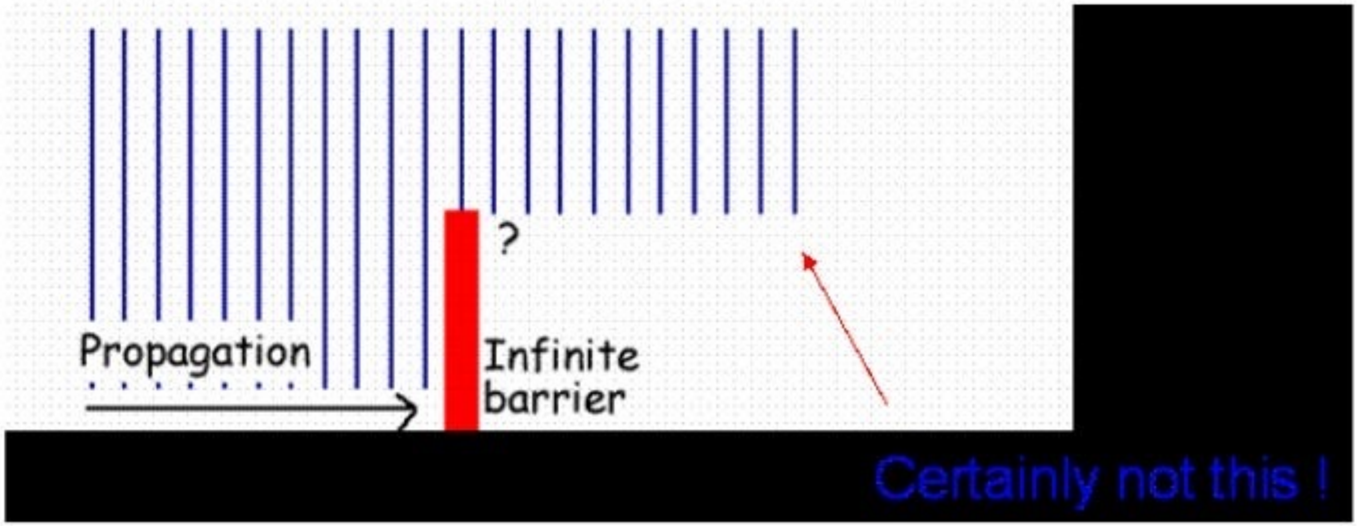
Diffraction

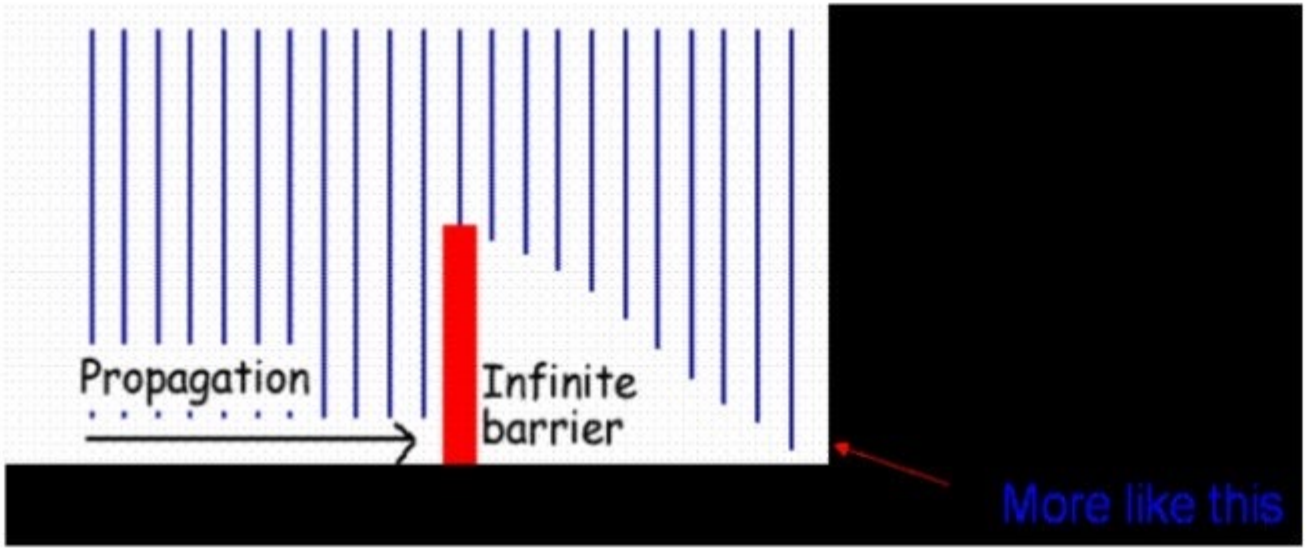
- Diffraction is the bending of wave fronts around obstacles.

- Diffraction allows radio signals to propagate behind obstructions and is thus one of the factors why we receive signals at locations where there is no line-of-sight from base stations

- Although the received field strength decreases rapidly as a receiver moves deeper into an obstructed (shadowed) region, the diffraction field still exists and often has sufficient signal strength to produce a useful signal.

Diffraction





Knife-edge Diffraction Model

- Estimating the signal attenuation caused by diffraction of radio waves over hills and buildings is essential in predicting the field strength in a given service area.

- As a starting point, the limiting case of propagation over a knife edge gives good in sight into the order of magnitude diffraction loss.

- When shadowing is caused by a single object such as a building, the attenuation caused by diffraction can be estimated by treating the obstruction as a diffracting knife edge

Knife-edge Diffraction Model

Consider a receiver at point *R located in the shadowed region. The field strength at point R is a vector sum of the fields due to all of the secondary Huygens sources in the plane above the knife edge.*

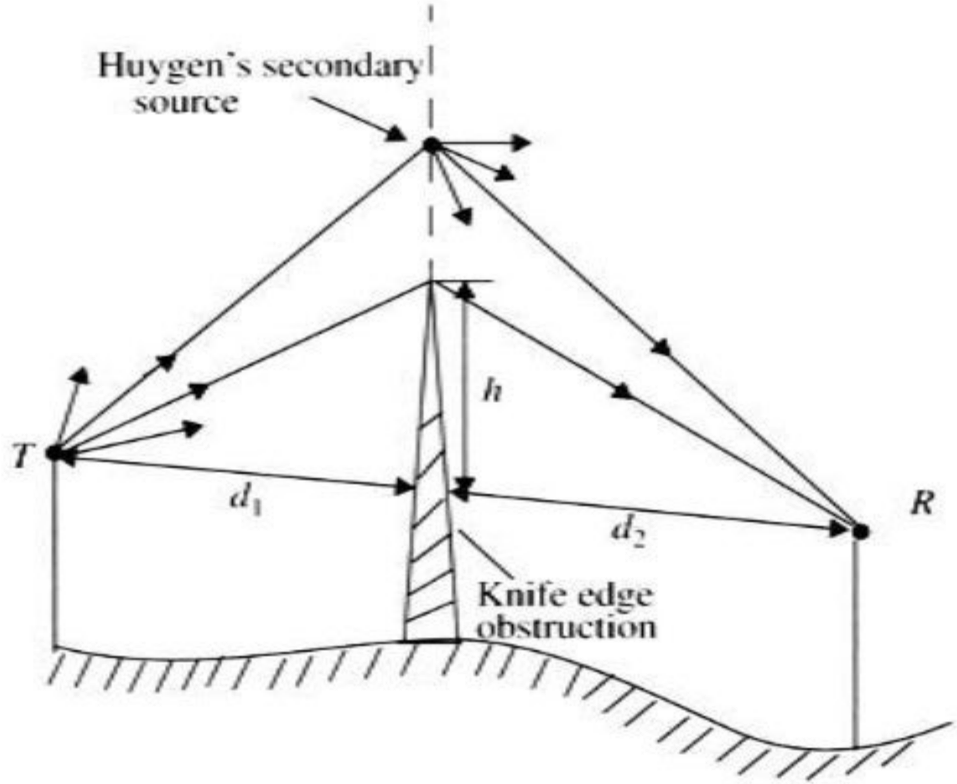


Figure 4.13 Illustration of knife-edge diffraction geometry. The receiver *R* is located in the shadow region.

Knife-edge Diffraction Model

- The difference between the direct path and diffracted path, call *excess path length*

$$\Delta \approx \frac{h^2}{2}\frac{(d_1 + d_2)}{d_1 d_2}$$

- The corresponding phase difference

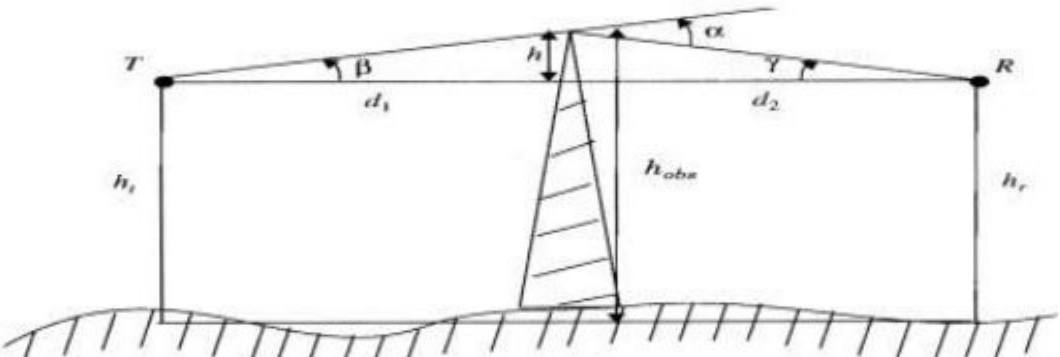
$$\phi = \frac{2\pi\Delta}{\lambda} \approx \frac{2\pi}{\lambda}\frac{h^2}{2}\frac{(d_1 + d_2)}{d_1 d_2}$$

- *Fresnel-Kirchoff* diffraction parameter is used to normalize the phased term and given as

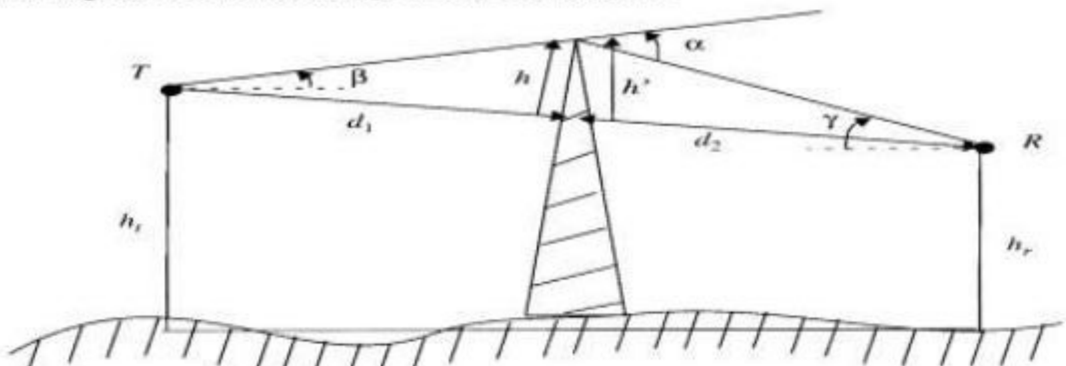
$$v = h\sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}} = \alpha\sqrt{\frac{2 d_1 d_2}{\lambda(d_1 + d_2)}}$$ Which gives $\phi = \frac{\pi}{2}v^2$

- where $\alpha = h(\frac{d_1+d_2}{d_1 d_2})$

Knife-edge Diffraction Model



(a) Knife-edge diffraction geometry. The point *T* denotes the transmitter and *R* denotes the receiver, with an infinite knife-edge obstruction blocking the line-of-sight path.



(b) Knife-edge diffraction geometry when the transmitter and receiver are not at the same height. Note that if α and β are small and $h << d_1$ and d_2, then h and h' are virtually identical and the geometry may be redrawn as shown in Figure 4.10c.

(c) Equivalent knife-edge geometry where the smallest height (in this case h_r) is subtracted from all other heights.

Figure 4.10 Diagrams of knife-edge geometry.

Fresnel zones

- Fresnel zones represent successive regions where secondary waves have a path length from the TX to the RX which are nλ/2 greater in path length than of the LOS path. The plane below illustrates successive Fresnel zones.

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

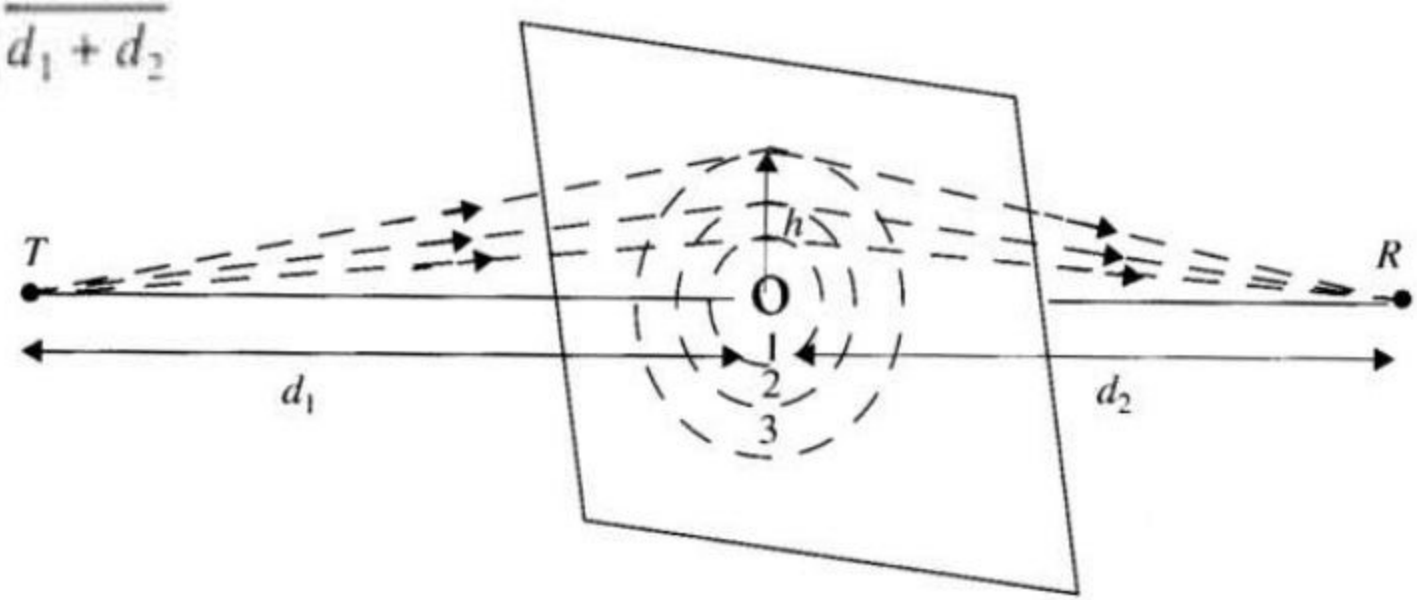
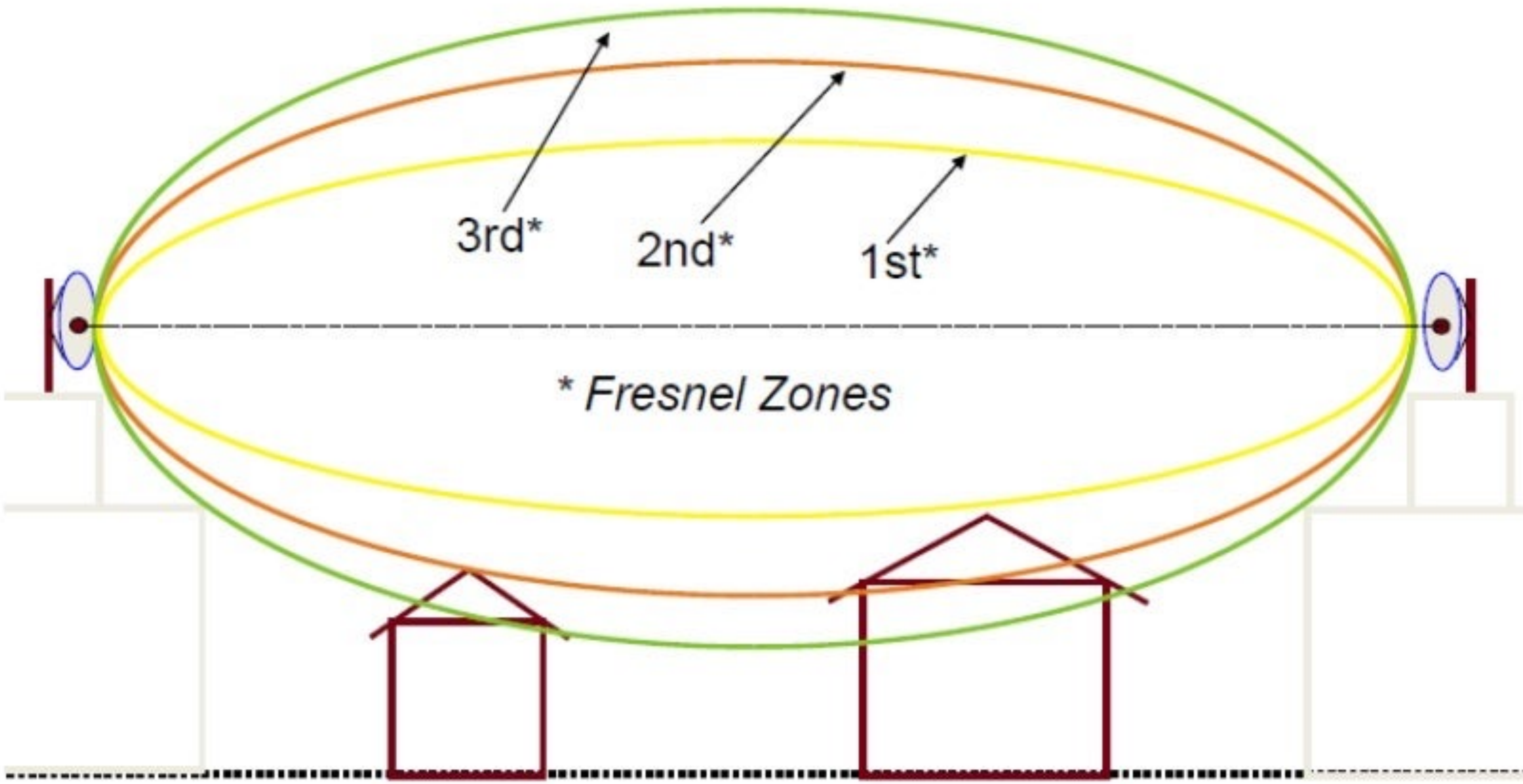


Figure 4.11 Concentric circles which define the boundaries of successive Fresnel zones.

Fresnel zones



Diffraction gain

- The diffraction gain due to the presence of a knife edge, as compared to the free space E-field

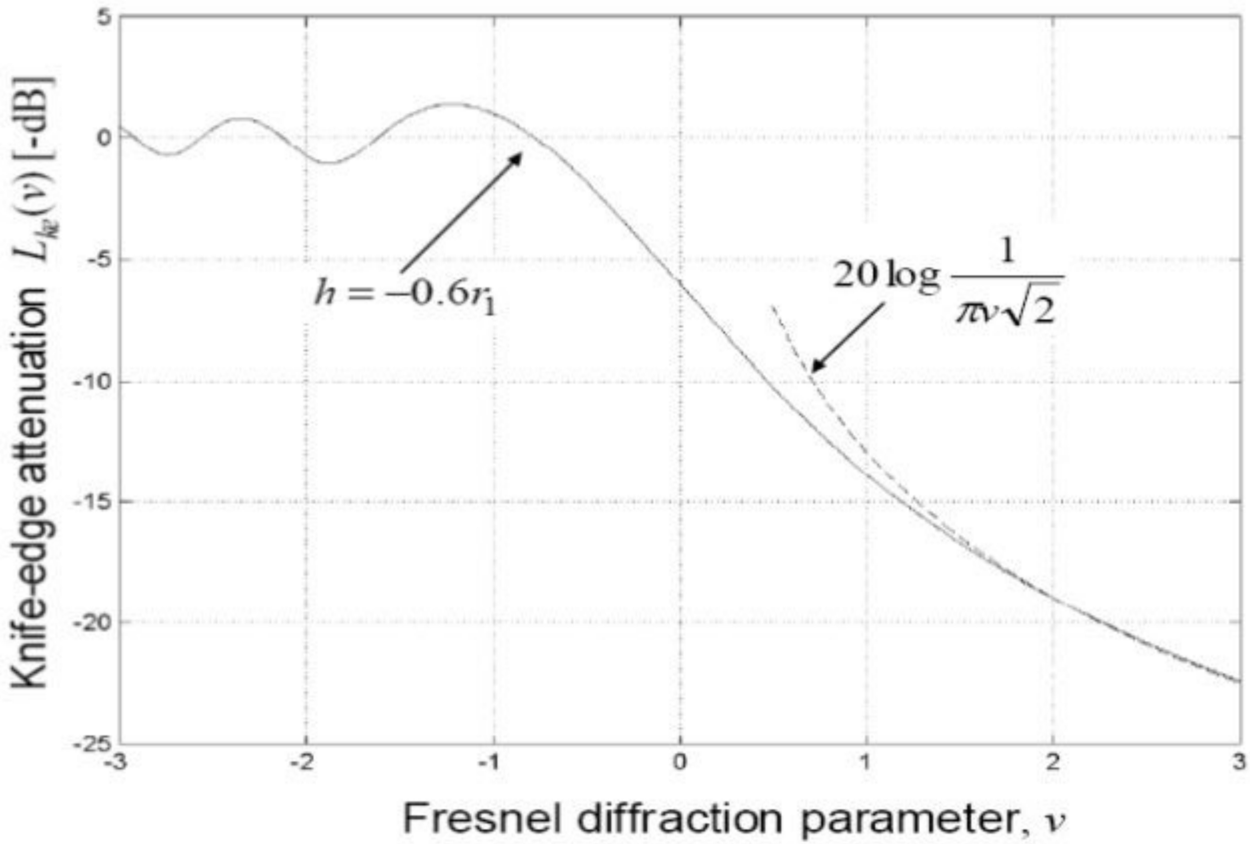
$$G_d(\mathrm{dB}) = 20\log|F(v)|$$

- The electric field strength, *Ed, of a knife edge diffracted wave is given by*

$$\frac{E_d}{E_o} = F(v) = \frac{(1+j)}{2}\int_v^{\infty}\exp((-j\pi t^2)/2)dt$$

- *Eo : is the free space field strength in the absence of both the ground and the knife edge.*
- *F(v): is the complex fresnel integral.*
- *v: is the Fresnel-Kirchoff diffraction parameter*

Graphical Calculation of diffraction attenuation



Numerical solution

- An approximate numerical solution for equation

$$G_d(\mathrm{dB}) = 20\log|F(v)|$$

- Can be found using set of equations given below for different values of v

$G_d(dB)$	v
0	≤ -1
$20\log(0.5-0.62v)$	[-1,0]
$20\log(0.5\,e^{-0.95v})$	[0,1]
$20\log(0.4-(0.1184-(0.38-0.1v)^2)^{1/2})$	[1, 2.4]
$20\log(0.225/v)$	> 2.4

Example

Example 4.7

Compute the diffraction loss for the three cases shown in Figure 4.12. Assume $\lambda = 1/3$ m, $d_1 = 1$km, $d_2 = 1$ km, and (a) h = 25 m, (b) $h = 0$, (c) h = −25 m. Compare your answers using values from Figure 4.14, as well as the approximate solution given by Equation (4.61.a)–(4.61.e). For each of these cases, identify the Fresnel zone within which the tip of the obstruction lies.

Given:

$\lambda = 1/3$ m

$d_1 = 1$ km

$d_2 = 1$ km

(a)h = 25 m

Using Equation (4.56), the Fresnel diffraction parameter is obtained as

$$v = h\sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}} = 25\sqrt{\frac{2(1000 + 1000)}{(1/3) \times 1000 \times 1000}} = 2.74.$$

From Figure 4.14, the diffraction loss is obtained as 22 dB.

Using the numerical approximation in Equation (4.61.e), the diffraction loss is equal to 21.7 dB.

The path length difference between the direct and diffracted rays is given by Equation (4.54) as

$$\Delta \approx \frac{h^2}{2}\frac{(d_1 + d_2)}{d_1 d_2} = \frac{25^2}{2}\frac{(1000 + 1000)}{1000 \times 1000} = 0.625 \text{ m}.$$

To find the Fresnel zone in which the tip of the obstruction lies, we need to compute n which satisfies the relation $\Delta = n\lambda/2$. For $\lambda = 1/3$ m, and $\Delta = 0/625$ m, we obtain

$$n = \frac{2\Delta}{\lambda} = \frac{2 \times 0.625}{0.3333} = 3.75.$$

Therefore, the tip of the obstruction completely blocks the first three Fresnel zones.

(b) $h = 0$ m

Therefore, the Fresnel diffraction parameter $v = 0$.

From Figure 4.14, the diffraction loss is obtained as 6 dB.

Using the numerical approximation in Equation (4.61.b), the diffraction loss is equal to 6 dB.

For this case, since $h = 0$, we have $\Delta = 0$, and the tip of the obstruction lies in the middle of the first Fresnel zone.

(c) $h = -25$ m

Using Equation (4.56), the Fresnel diffraction parameter is obtained as −2.74.

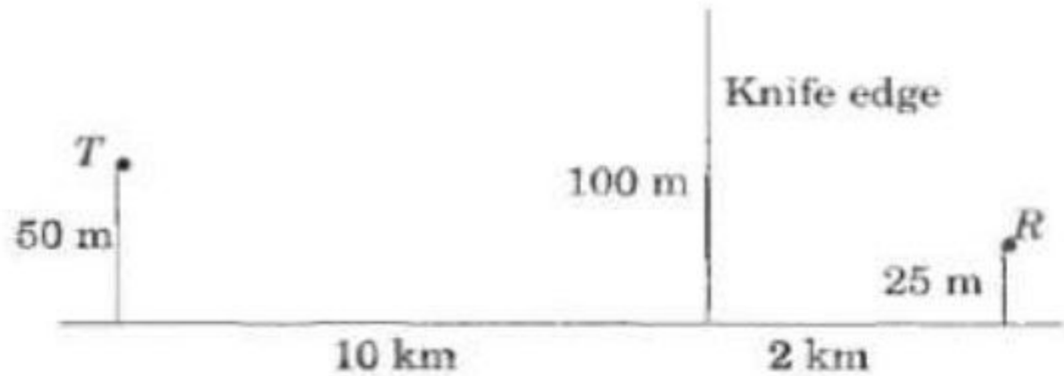
From Figure 4.14, the diffraction loss is approximately equal to 1 dB.

Using the numerical approximation in Equation (4.61.a), the diffraction loss is equal to 0 dB.

Example

Example 4.8

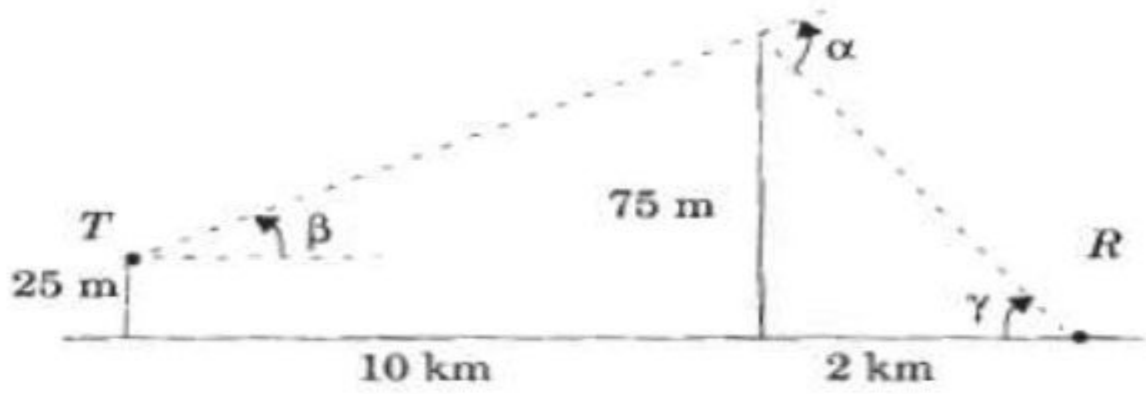
Given the following geometry, determine (a) the loss due to knife-edge diffraction, and (b) the height of the obstacle required to induce 6 dB diffraction loss. Assume $f = 900$ MHz.



Solution

(a) The wavelength $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{900 \times 10^6} = \frac{1}{3}$ m.

Redraw the geometry by subtracting the height of the smallest structure.



$$\beta = \tan^{-1}\left(\frac{75 - 25}{10000}\right) = 0.2865^\circ$$

$$\gamma = \tan^{-1}\left(\frac{75}{2000}\right) = 2.15^\circ$$

and

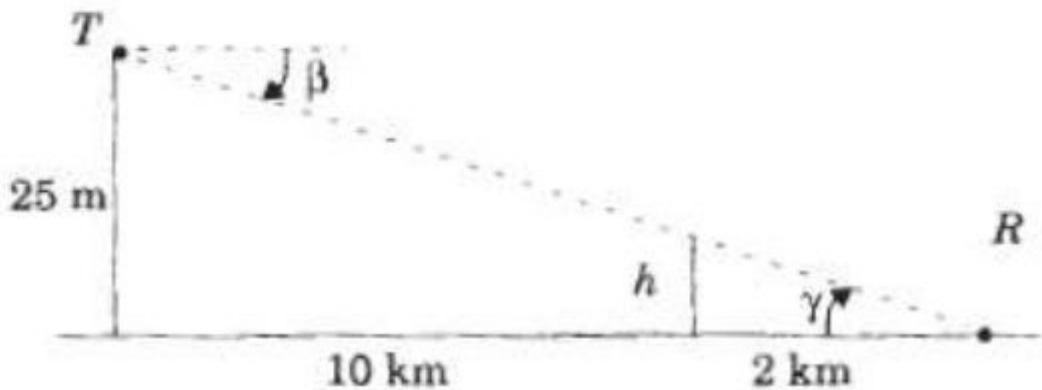
$$\alpha = \beta + \gamma = 2.434^\circ = 0.0424 \text{ rad}$$

Then using Equation (4.56)

$$v = 0.0424\sqrt{\frac{2 \times 10000 \times 2000}{(1/3) \times (10000 + 2000)}} = 4.24.$$

From Figure 4.14 or (4.61.e), the diffraction loss is 25.5 dB.

(b) For 6 dB diffraction loss, $v = 0$. The obstruction height h may be found using similar triangles ($\beta = \gamma$), as shown below.



It follows that $\dfrac{h}{2000} = \dfrac{25}{12000}$, thus $h = 4.16$ m.

Multiple Knife Edge Diffraction

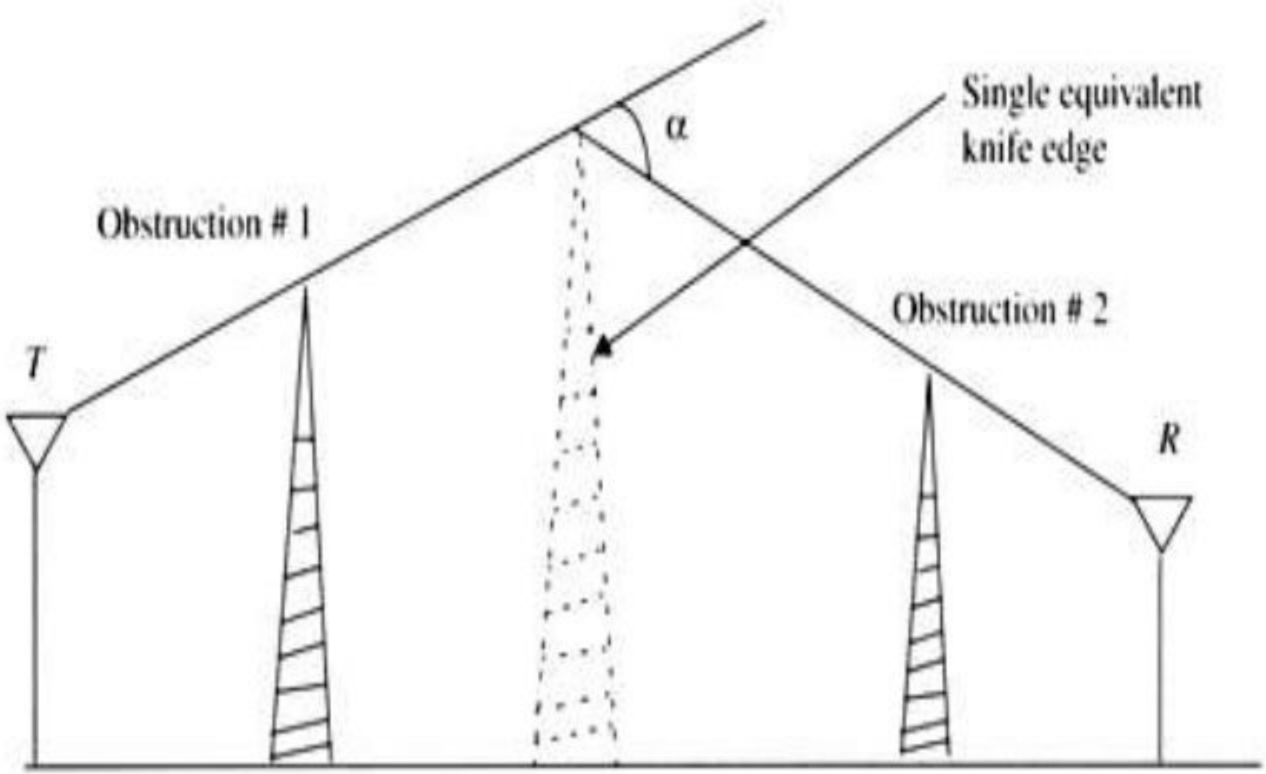


Figure 4.15 Bullington's construction of an equivalent knife edge [from [Bul47] © IEEE].

Scattering

- Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large.

- Scattered waves are produced by
  - rough surfaces,
  - small objects,
  - or by other irregularities in the channel.

- Scattering is caused by trees, lamp posts, towers, etc.

Scattering

- Received signal strength is often stronger than that predicted by reflection/diffraction models alone

- The EM wave incident upon a rough or complex surface is **scattered** in **many** directions and provides more energy at a receiver
  - energy that would have been absorbed is instead reflected to the Rx.

- flat surface → EM reflection (one direction)
- rough surface → EM scattering (many directions)

Scattering

- Rayleigh criterion: used for testing surface roughness
- A surface is considered smooth if its min to max protuberance (bumps) h is less than critical height hc

$$h_c = \lambda/8 \sin\Theta_i$$

- Scattering path loss factor ρ_s is given by

$$\rho_s = \exp[-8[(\pi * \sigma_h * \sin\Theta_i)/ \lambda]^2]$$

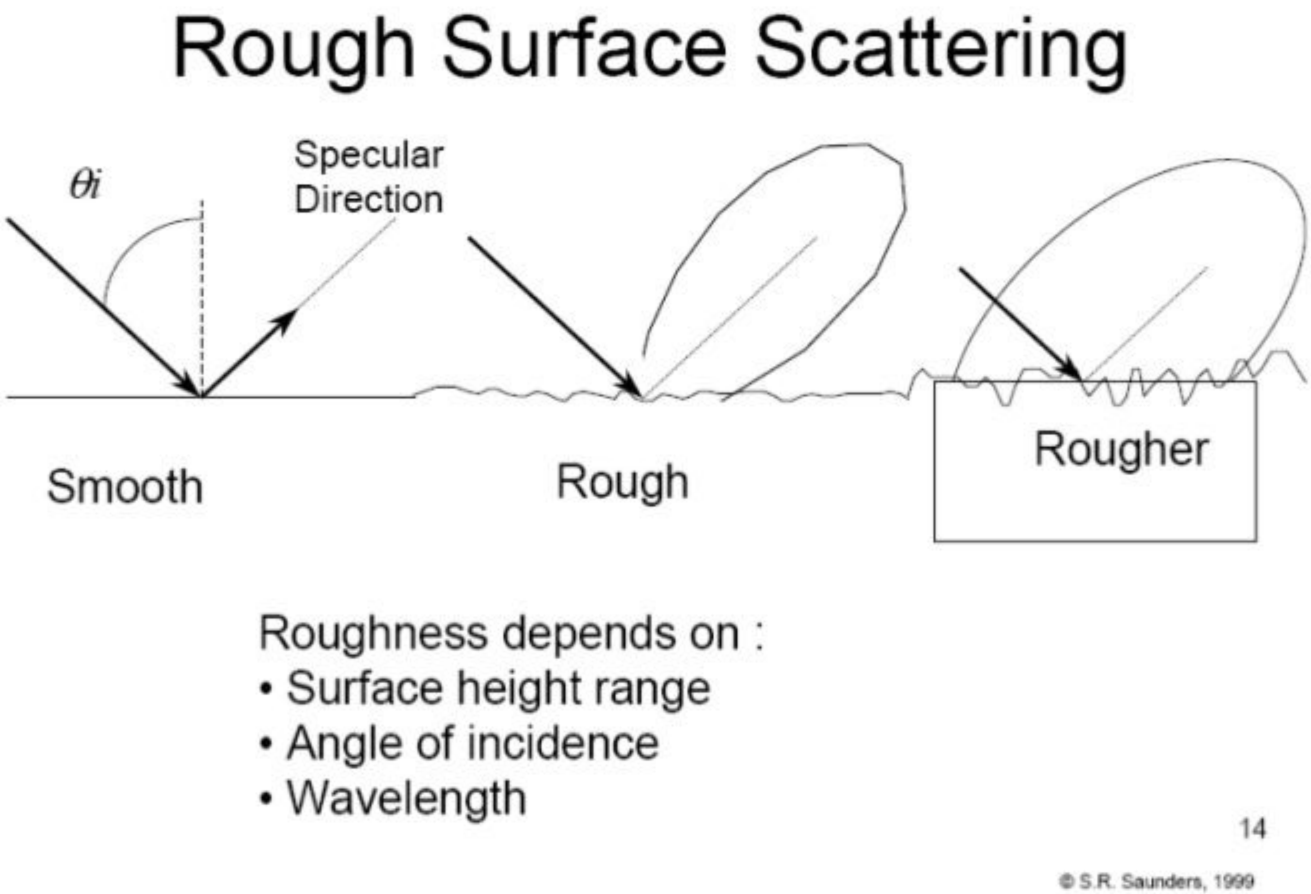
Where h is surface height and σ_h is standard deviation of surface height about mean surface height.

- For rough surface, the flat surface reflection coefficient is multiplied by scattering loss factor ρ_s to account for diminished electric field

- Reflected E-fields for h> h_c for rough surface can be calculated as

$$\Gamma_{rough} = \rho_s \Gamma$$

Scattering


Rough Surface Scattering
θi
Specular
Direction
Smooth
Rough
Rougher
Roughness depends on :
• Surface height range
• Angle of incidence
• Wavelength
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© S.R. Saunders, 1999

Outdoor propagation Environment

- Based on the coverage area, the Outdoor propagation environment may be divided into three categories

  1. Propagation in Macro cells
  2. Propagation in Micro cells
  3. Propagation in street Micro cells

Outdoor propagation Environment

Macrocells versus Microcells

	Macrocell	Microcell
Cell Radius	1 to 20 km	0.1 to 1 km
Tx Power	1 to 10 W	0.1 to 1 W
Fading	Rayleigh	Nakgami-Rice
RMS Delay Spread	0.1 to 10 μs	10 to 100ns
Max. Bit Rate	0.3 Mbps	1 Mbps

Outdoor propagation Models

- Outdoor radio transmission takes place over an irregular terrain.
- The terrain profile must be taken into consideration for estimating the path loss

  e.g. trees buildings and hills must be taken into consideration
- Some common models used are

➢ Longley Rice Model

➢ Okumura Model

➢ Hatta model

Longley Rice Model

- Longley Rice Model is applicable to point to point communication.
- It covers 40MHz to 300 GHz
- It can be used in wide range of terrain
- Path geometry of terrain and the refractivity of troposphere is used for transmission path loss calculations
- Geometrical optics is also used along with the two ray model for the calculation of signal strength.
- Two modes
  - Point to point mode prediction
  - Area mode prediction

Longley Rice Model

- Longley Rice Model is normally available as a computer program which takes inputs as
  - Transmission frequency
  - Path length
  - Polarization
  - Antenna heights
  - Surface reflectivity
  - Ground conductivity and dialectic constants
  - Climate factors
  - A problem with Longley rice is that It doesn't take into account the buildings and multipath.

Okumura Model

- In 1968 Okumura did a lot of measurements and produce a new model.
- The new model was used for signal prediction in Urban areas.
- Okumura introduced a graphical method to predict the median attenuation relative to free-space for a quasi-smooth terrain
- The model consists of a set of curves developed from measurements and is valid for a particular set of system parameters in terms of carrier frequency, antenna height, etc.

Okumura Model

- First of all the model determined the free space path loss of link.
- After the free-space path loss has been computed, the median attenuation, as given by Okumura's curves has to be taken to account
- The model was designed for use in the frequency range 200 up to 1920 MHz and mostly in an urban propagation environment.
- Okumura's model assumes that the path loss between the TX and RX in the terrestrial propagation environment can be expressed as:

$$L_{50}(\mathrm{dB}) = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$

Okumura Model

- **Estimating path loss using Okumura Model**

1. Determine free space loss and $A_{mu}(f,d)$, between points of interest
2. Add $Amu(f,d)$ and correction factors to account for terrain

$$L_{50}(\mathrm{dB}) = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$

L_{50} = 50% value of propagation path loss (median)

L_F = free space propagation loss

$A_{mu}(f,d)$ = median attenuation relative to free space

$G(h_{te})$ = base station antenna height gain factor

$G(h_{re})$ = mobile antenna height gain factor

G_{AREA} = gain due to environment

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Okumura Model

- $A_{mu}(f,d)$ & G_{AREA} have been plotted for wide range of frequencies
- Antenna gain varies at rate of 20dB or 10dB per decade

$$G(h_{te}) = 20 \log \frac{h_{te}}{200} \qquad 10\text{m} < h_{te} < 1000\text{m}$$

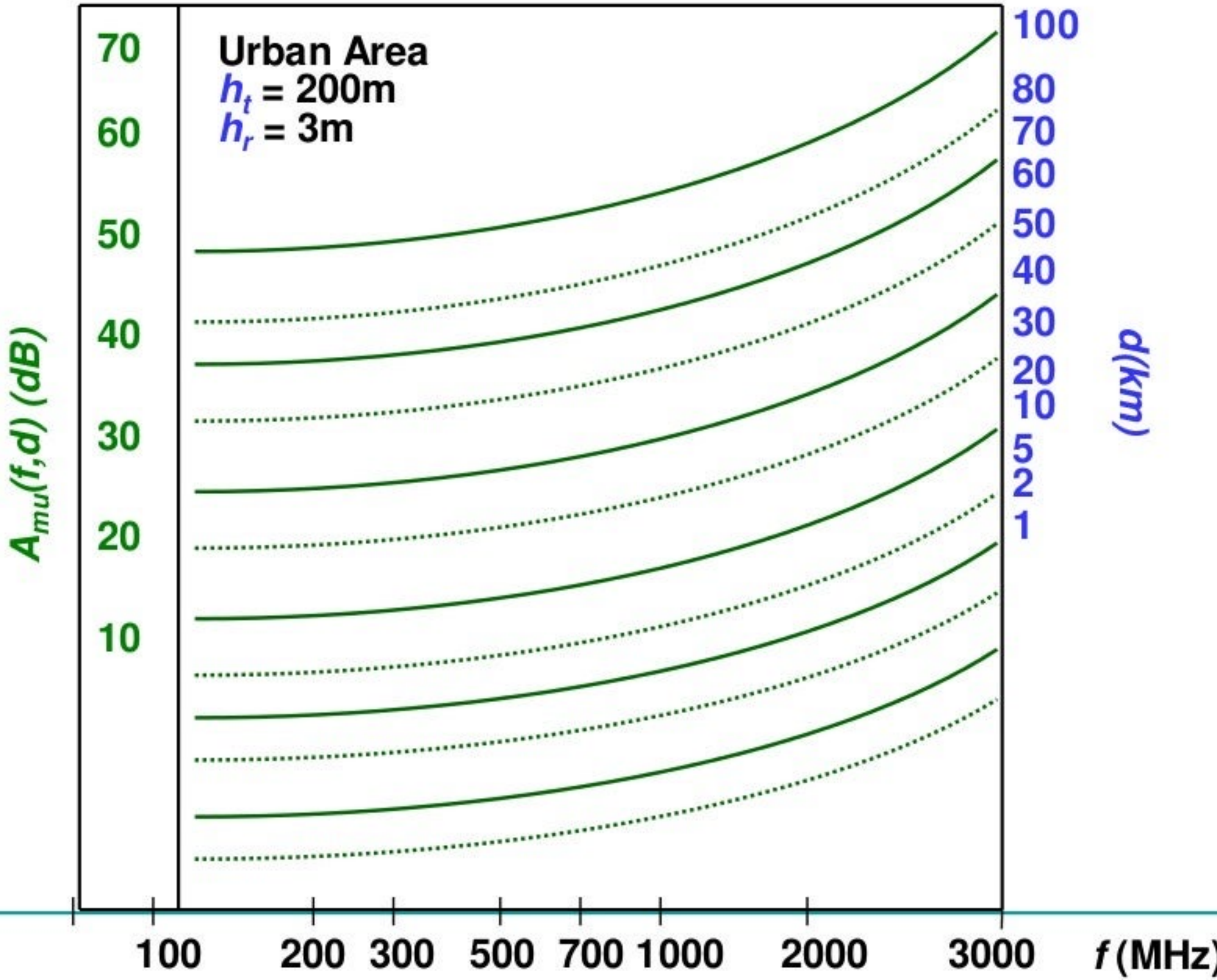
$$G(h_{re}) = 10 \log \frac{h_{re}}{3} \qquad h_{re} \leq 3\text{m}$$

$$G(h_{re}) = 20 \log \frac{h_{re}}{3} \qquad 3\text{m} < h_{re} < 10\text{m}$$

- **model corrected** for

Δh = terrain undulation height, isolated ridge height average terrain slope and mixed land/sea parameter

Median Attenuation Relative to Free Space = $A_{mu}(f,d)$ (dB)



Correction Factor G_{AREA}

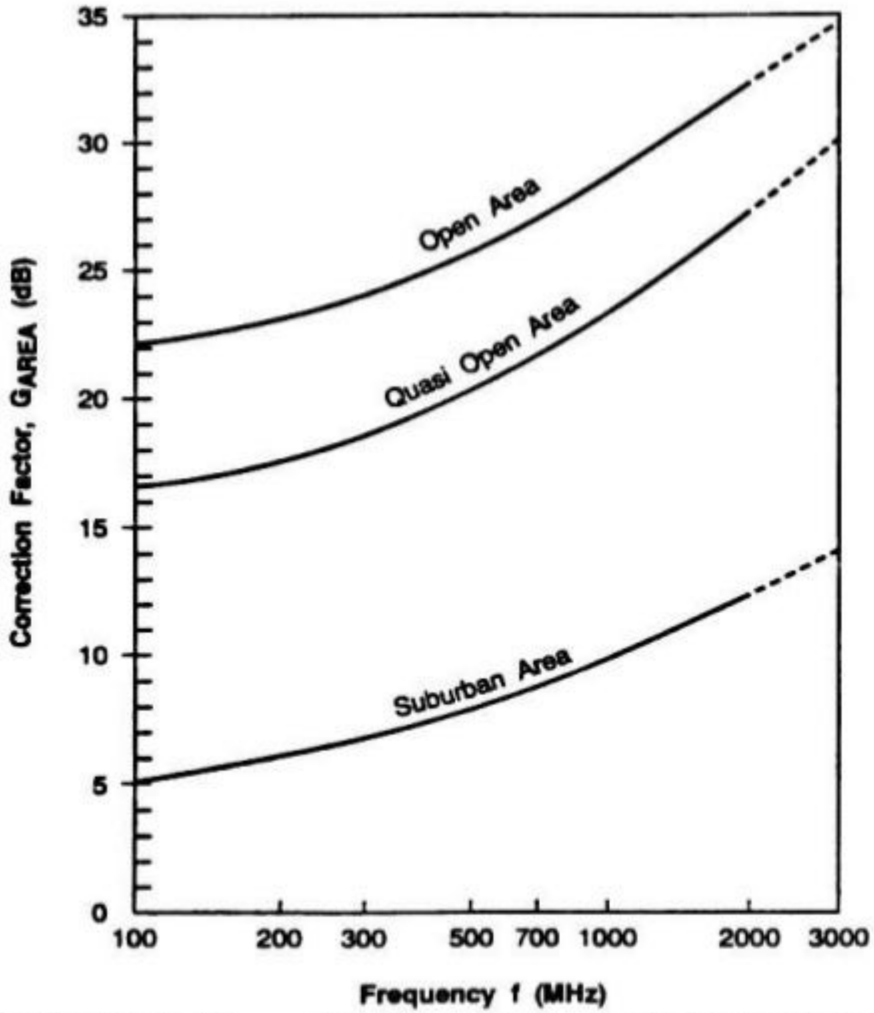


Figure 4.24 Correction factor, G_{AREA}, for different types of terrain [from [Oku68] © IEEE].

Example

Find the median path loss using Okumura's model for $d = 50$ km, $h_{te} = 100$ m, $h_{re} = 10$ m in a suburban environment. If the base station transmitter radiates an EIRP of 1 kW at a carrier frequency of 900 MHz, find the power at the receiver (assume a unity gain receiving antenna).

Solution to Example 3.10

The free space path loss L_F can be calculated using equation (3.6) as

$$L_F = 10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] = 10\log\left[\frac{(3\times 10^8/900\times 10^6)^2}{(4\pi)^2\times(50\times 10^3)^2}\right] = 125.5 \text{ dB}.$$

From the Okumura curves

$$A_{mu}(900 \text{ MHz}(50 \text{ km})) = 43 \text{ dB}$$

and

$$G_{AREA} = 9 \text{ dB}.$$

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) = 20\log\left(\frac{100}{200}\right) = -6 \text{ dB}.$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) = 20\log\left(\frac{10}{3}\right) = 10.46 \text{ dB}.$$

Using equation (3.80) the total mean path loss is

$$\begin{aligned} L_{50}(\text{dB}) &= L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \\ &= 125.5 \text{ dB} + 43 \text{ dB} - (-6) \text{ dB} - 10.46 \text{ dB} - 9 \text{ dB} \\ &= 155.04 \text{ dB}. \end{aligned}$$

Therefore, the median received power is

$$\begin{aligned} P_r(d) &= EIRP(\text{dBm}) - L_{50}(\text{dB}) + G_r(\text{dB}) \\ &= 60 \text{ dBm} - 155.04 \text{ dB} + 0 \text{ dB} = -95.04 \text{ dBm}. \end{aligned}$$

Hata Model

- Most widely used model in Radio frequency.
- Predicting the behavior of cellular communication in built up areas.
- Applicable to the transmission inside cities.
- Suited for point to point and broadcast transmission.
- 150 MHz to 1.5 GHz, Transmission height up to 200m and link distance less than 20 Km.

Hata Model

- Hata transformed Okumura's graphical model into an analytical framework.

- The Hata model for urban areas is given by the empirical formula:

$$L50,_{urban} = 69.55 \text{ dB} + 26.16 \log(f_c) - 3.82 \log(h_t) - a(h_r) + (44.9 - 6.55 \log(h_t)) \log(d)$$

- Where $L50,_{urban}$ is the median path loss in dB.

- The formula is valid for

  150 MHz $<= f_c <=$ 1.5GHz,

  1 m $<= h_r <=$ 10m, 30m $<= h_t <=$ 200m,

  1km $<$ d $<$ 20km

Hata Model

- The correction factor $a(h_r)$ for mobile antenna height hr for a small or medium-sized city is given by:

$$a(h_r) = (1.1 \log f_c - 0.7)h_r - (1.56 \log(f_c) - 0.8) \text{ dB}$$

- For a large city it is given by

$$a(h_r) = 8.29[\log(1.54h_r)]^2 - 1.10 \text{ dB} \qquad \text{for } f_c <= 300 \text{ MHz}$$

$$3.20[\log(11.75h_r)]^2 - 4.97 \text{ dB} \qquad \text{for } f_c >= 300 \text{ MHz}$$

- To obtain path loss for suburban area the standard Hata model is modified as

$$L_{50} = L_{50}(\text{urban}) - 2[\log(f_c/28)]^2 - 5.4$$

- For rural areas

$$L_{50} = L_{50}(\text{urban}) - 4.78\log(f_c)^2 - 18.33\log f_c - 40.98$$

Indoor Models

- Indoor Channels are different from traditional channels in two ways

 1. The distances covered are much smaller

 2. The variability of environment is much greater for a much small range of Tx and Rx separation.

- Propagation inside a building is influenced by:

 - Layout of the building
 - Construction materials
 - Building Type: office , Home or factory

Indoor Models

- Indoor models are dominated by the same mechanism as out door models:

  - Reflection, Diffraction and scattering

- Conditions are much more variable

  - Doors/Windows open or not
  - Antenna mounting : desk ceiling etc
  - The levels of floor

- Indoor models are classifies as

  - Line of sight (LOS)
  - Obstructed (OBS) with varying degree of clutter

Indoor Models

- Portable receiver usually experience

  - Rayleigh fading for OBS propagation paths

  - Ricean fading for LOS propagation path

- Indoors models are effected by type of building e.g. Residential buildings, offices, stores and sports area etc.

- Multipath delay spread

  - Building with small amount of metal and hard partition have small delay spread 30 to 60ns

  - Building with large amount of metal and open isles have delay spread up to 300ns

Partition losses (same floor)

- Two types of partitions

  1. hard partitions: Walls of room
  2. Soft partitions : Moveable partitions that donot span to ceiling

- Partitions vary widely in their Physical and electrical properties.

- Path loss depend upon the types of partitions

Partition losses (same floor)

Partition Losses (Same Floor)

Material Type	Loss (dB)	Frequency
All metal partition	26	815 MHz
Concrete Block wall	13	1300 MHz
Empty Cardboard boxes	3 – 6 dB	1300 MHz
Dry Plywood (0.75 inches)	1 dB	9.6 GHz
Dry Plywood (0.75 inches)	4 dB	28.8 GHz

Partitions losses (between floors)

- Partition losses between the two floors depend on

1. External dimension and material used for buildings
2. Types of construction used to create floors
3. External surroundings
4. No of windows used
5. Tinting on the windows

- Floor Attenuation Factor (FAF) increases as we increase the no of floors

Partitions losses (between floors)

Table 4.4 Total Floor Attenuation Factor and Standard Deviation σ (dB) for Three Buildings. Each Point Represents the Average Path Loss Over a 20λ Measurement Track [Sei92a]

Building	915 MHz FAF (dB)	σ (dB)	Number of locations	1900 MHz FAF (dB)	σ (dB)	Number of locations
Walnut Creek						
One Floor	33.6	3.2	25	31.3	4.6	110
Two Floors	44.0	4.8	39	38.5	4.0	29
SF PacBell						
One Floor	13.2	9.2	16	26.2	10.5	21
Two Floors	18.1	8.0	10	33.4	9.9	21
Three Floors	24.0	5.6	10	35.2	5.9	20
Four Floors	27.0	6.8	10	38.4	3.4	20
Five Floors	27.1	6.3	10	46.4	3.9	17
San Ramon						
One Floor	29.1	5.8	93	35.4	6.4	74
Two Floors	36.6	6.0	81	35.6	5.9	41
Three Floors	39.6	6.0	70	35.2	3.9	27

Log distance path loss model

- Path loss can be given as

$$PL(\text{dB}) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

where n is path loss exponent and σ is standard deviation

- n and σ depend on the building type.
- Smaller value of σ indicates better accuracy of path loss model

Log distance path loss model

Table 4.6 Path Loss Exponent and Standard Deviation Measured in Different Buildings [And94]

Building	Frequency (MHz)	n	σ (dB)
Retail Stores	914	2.2	8.7
Grocery Store	914	1.8	5.2
Office, hard partition	1500	3.0	7.0
Office, soft partition	900	2.4	9.6
Office, soft partition	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/Cereals	1300	1.8	6.0
Metalworking	1300	1.6	5.8
Suburban Home			
Indoor Street	900	3.0	7.0
Factory OBS			
Textile/Chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8

Ericsson Multiple Break Point Model

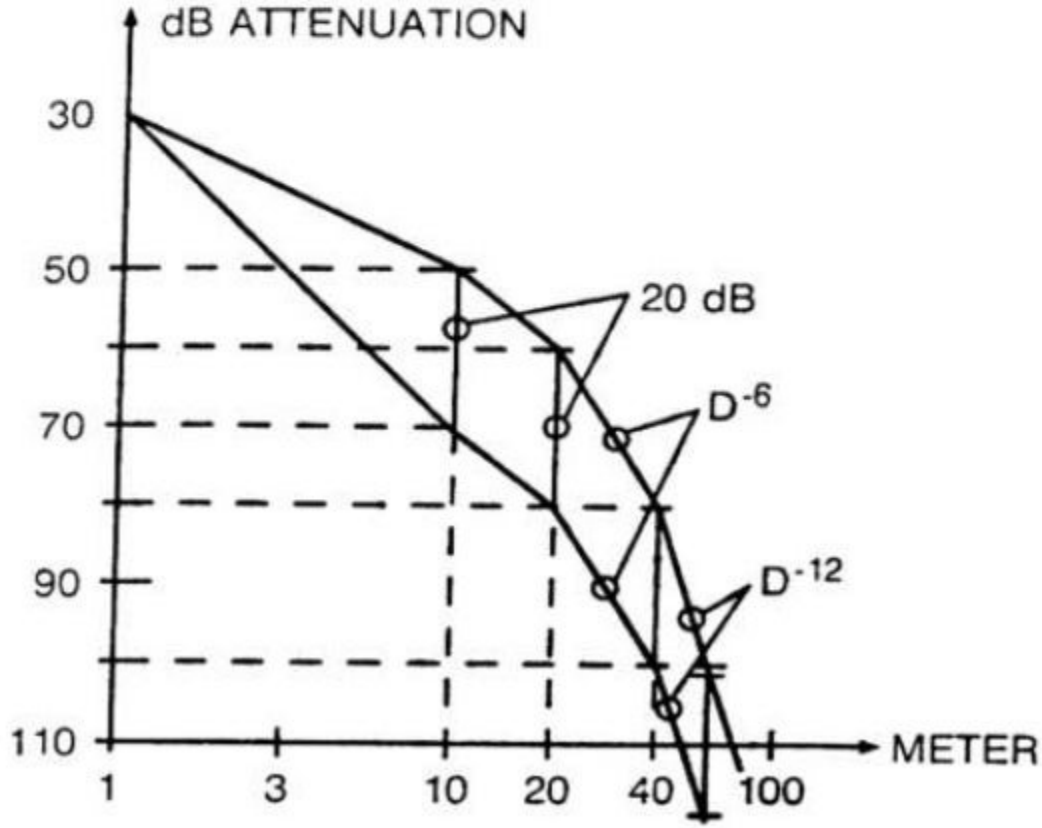


Figure 4.27 Ericsson in-building path loss model [from [Ake88] © IEEE].

Attenuation factor model

- Obtained by measurement in multiple floors building

$$\overline{PL}(d)[\mathrm{dB}] = \overline{PL}(d_0)[\mathrm{dB}] + 10n_{SF}\log\left(\frac{d}{d_0}\right) + FAF[\mathrm{dB}]$$

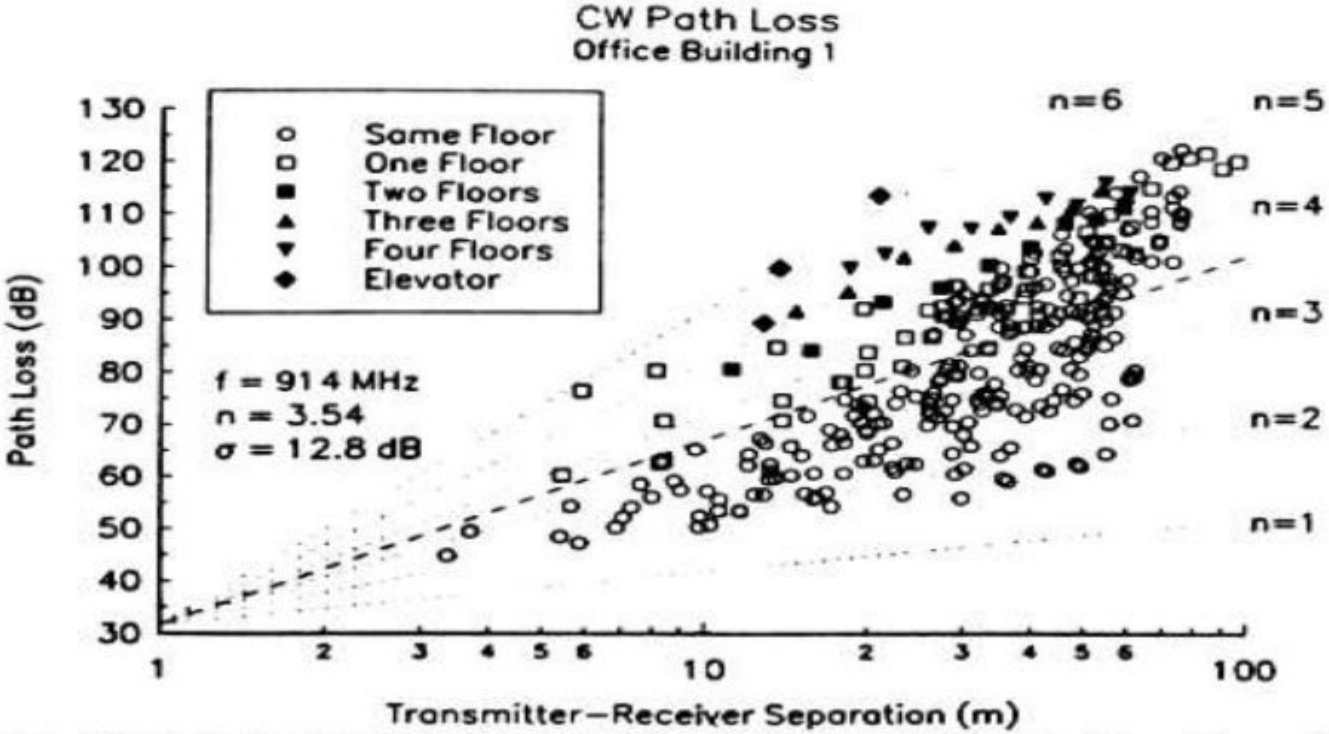


Figure 4.28 Scatter plot of path loss as a function of distance in Office Building 1 [from [Sei92b] © IEEE].

Attenuation factor model

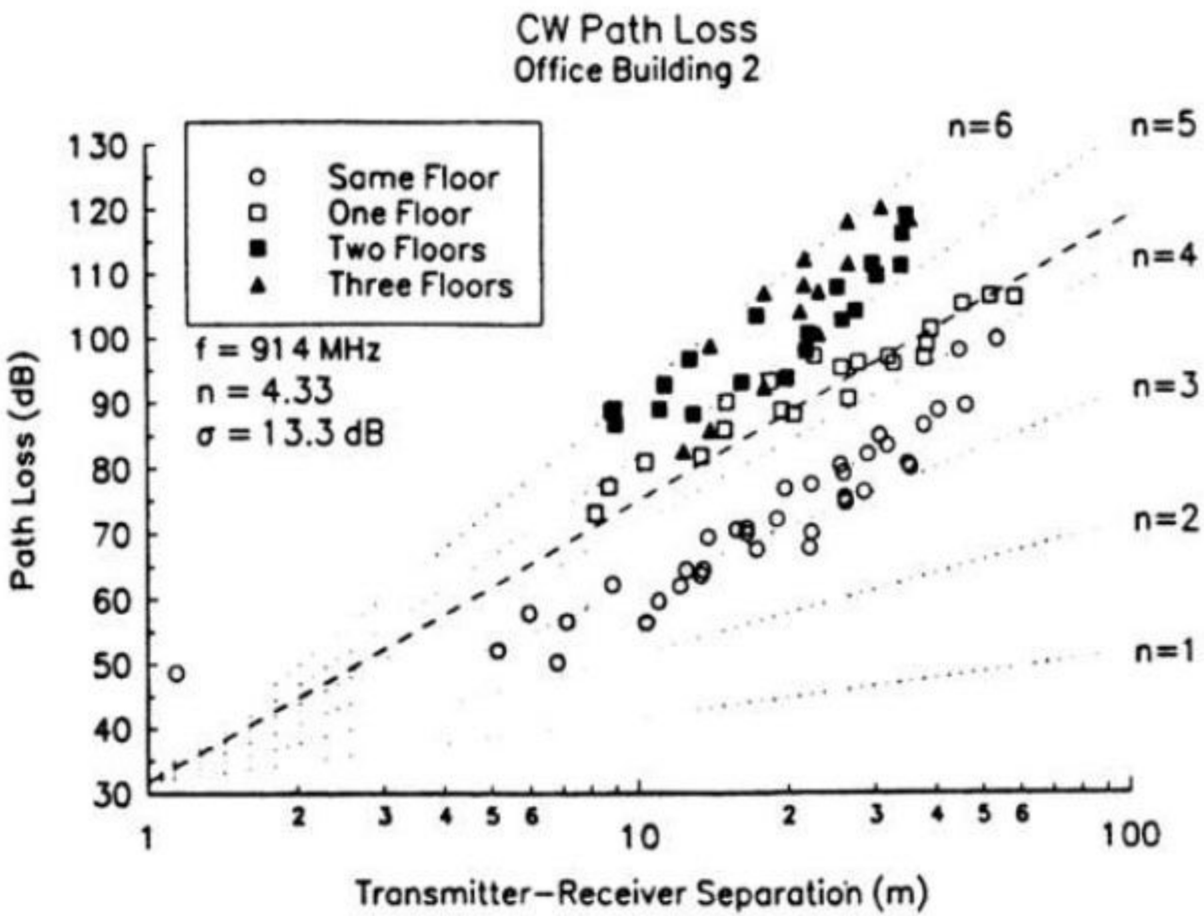


Figure 4.29 Scatter plot of path loss as a function of distance in Office Building 2 [from [Sei92b] © IEEE].

Signal penetration into building

- <u>Effect of frequency</u>

- Penetration loss decreases with increasing frequency

- <u>Effect of Height</u>
- Penetration loss decreases with the height of building up to some certain height.

- At lower heights the Urban clutter induces greater attenuation
- Up to some height attenuation decreases but then again increase after a few floors
- Increase in attenuation at higher floors is due to the Shadowing effects of adjacent buildings