Path Loss Model in Mobile Cellular Network

Walfish-Ikegami Model

Okumura-Hata Model

Okumura-Hata Model

- Microcellular areas span a few Kms.
- Okumura in 1968 drew some path-loss curve in the range of 100MHz to 1920 MHz
- Masaharu Hata developed empirical path-loss model based on measurement of Okumura known as Okumura-Hata model.
- Here separation between BS and MS is greater that 1Km.

Empirical formulation of data provided by the Okumura model and is valid for frequencies in the range 150MHz-1500MHz

$$L_m(Urban)(dB) = 69.55 + 26.16(\log f_c) - 13.82(\log h_{BS}) - a(h_{MS}) + (44.9 - 6.55\log h_{BS})\log d$$

For large city,

$$a(h_{MS}) = \begin{cases} 8.29(\log 1.54 h_{MS})^2 - 1.1\, dB; & for\ \ f_c \le 300MHz \\ 3.2(\log 11.75 h_{MS})^2 - 4.9\, dB; & for\ \ f_c \ge 300MHz \end{cases}$$

For small and medium city,

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

For suburban and open rural area,

$$L_m(Suburban)(dB) = L_m(Urban)(dB) - 2[(\log(f_c/28)]^2 - 5.4\ dB$$

$$L_m(rural)(dB) = L_m(Urban)(dB) - 4.78\{\log(f_c)\}^2 + 18.33\log f_c - 40.94\ dB$$

The model is suitable for a distance above 1 Km. The model does not support path specific correction

Coverage

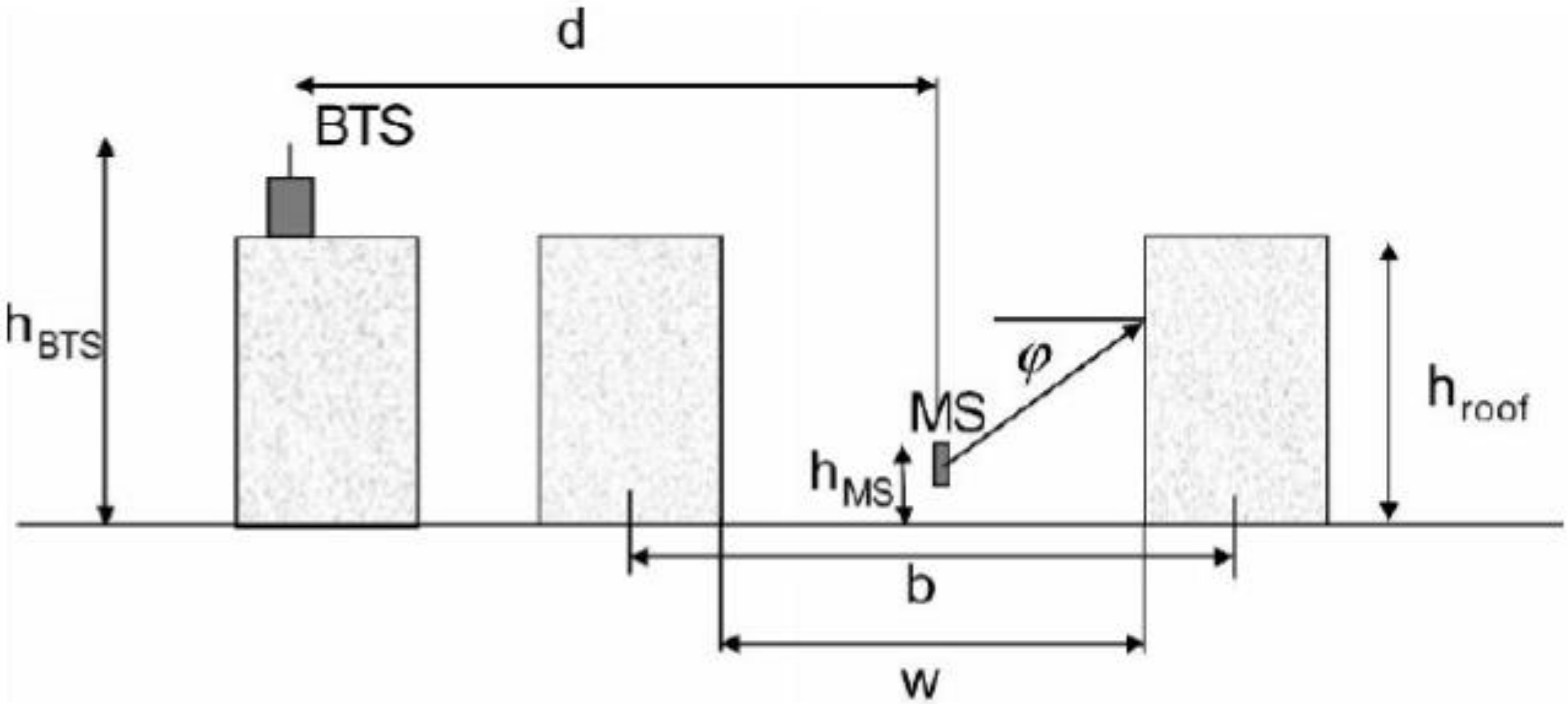
Frequency: 150 MHz to 1500 MHz

Mobile Station Antenna Height: between 1 m and 10 m

Base station Antenna Height: between 30 m and 200 m

Link distance: between 1 km and 20 km.

Walfish-Ikegami Model

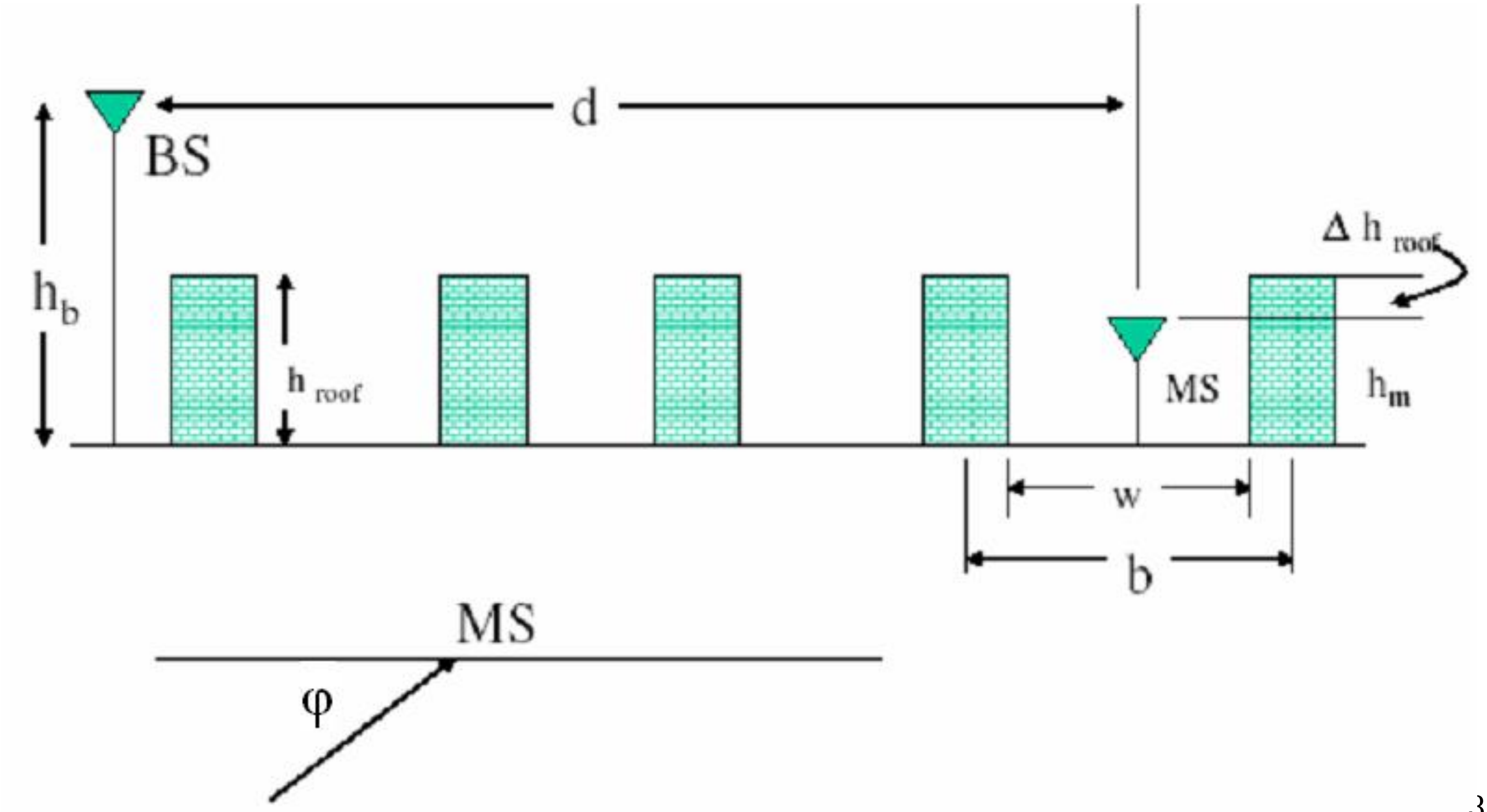


The Walfish–Ikegami model is an empirical propagation model for an urban area, which is especially applicable for micro cells but can also be used for macro cells.

Model Parameters:

The mean value for street widths (w) is given in metres and the road orientation angle (θ *or* φ) in degrees. The mean value for building heights (h_{roof}) is an average over the calculation area and is given in metres. The mean value for building separation (b) is calculated from the centre of one building to the centre of another building and is also given in metres.

Walfish–Ikegami model is suitable for frequencies 800MHz to 2000 MHz where distance can be very small like 200m. Range of BS antenna height 4 to 50m and that of MS is 1 to 3m. Distance in the range of 20m to 5Km.



For LOS case,

L_m(db) = 42.6 +26log(d) + 20log(fc); $d \geq 20$m

For NLOS case, we have to consider,

H_{roof} = Height of roof-top

$\Delta h_{BS} = h_{BS} - h_{roof}$

$\Delta h_{MS} = h_{roof} - h_{MS}$

w: width of street in meter

b: Building separation in meter along the radio path

φ: Road orientation w.r.t. the direction of radio propagation in degrees incident angle relative to the street).

NLOS path loss composed of three terms,

$L_P(DB) = L_0 + L_{rts} + L_{msd}$

The model works best for the BS much taller than the surrounding buildings.

L_0: Free space path loss = 32.4 + 20log(d) + 20log(fc)

Lrts: roof-street diffraction and scatter loss =

$-16.9 - 10\log(w) + 10\log(f_c) + 20\log(\Delta h_m) + L_{ori}$

L_{ori} is the street orientation loss:

$$L_{ori}(\phi) = \begin{cases} -10 + 0.354\phi\,; & 0 \le \phi < 35^0 \\ 2.5 + 0.075(\phi - 35); & 35^0 \le \phi < 55^0 \\ 4.0 - 0.114(\phi - 55)\,; & 55^0 \le \phi < 90^0 \end{cases}$$

L_{msd} = multiscreen diffraction loss

$= L_{bsh} + K_a + K_d \log(d) + K_f \log(fc) - 9\log(b)$

$$L_{bsh} = \begin{cases} -18\log(11) + \left(h_{BTS} - h_{roof}\right); & h_{BTS} > h_{roof} \\ 0; & h_{BTS} < h_{roof} \end{cases}$$

$$K_a = \begin{cases} 54; & h_{BTS} > h_{roof} \\ 54 - 0.8(h_{BTS} - h_{roof}); & d \geq 0.5Km \text{ and } h_{BTS} \leq h_{roof} \\ 54 - 1.6(h_{BTS} - h_{roof})d; & d < 0.5Km \text{ and } h_{BTS} \leq h_{roof} \end{cases}$$

$$K_d = \begin{cases} 18\,; & h_{BTS} < h_{roof} \\ 18 - 15\dfrac{h_{BTS} - h_{roof}}{h_{roof} - h_{MS}}\,; & h_{BTS} > h_{roof} \end{cases}$$

$$K_f = 4 + \begin{cases} 0.7\left(\dfrac{f}{925} - 1\right); & \textit{medium city and suburban centers} \\ 1.5\left(\dfrac{f}{925} - 1\right); & \textit{urban centers} \end{cases}$$

The parameter Ka increases the path loss in case the BTS is below the rooftop. The parameters K_d and K_f are for adjusting the correction between the distance and frequency with multiscreen diffraction.

Example:1

Find cell radius for the following parameters.

f_c =1800MHz

Street width (w) = 20m

Spacing between buildings (b) = 40m

Average roof height (h_{roof}) = 40m

Mobile antenna height (h_m) = 2m

BS antenna height (h_b) = 40m

Street orientation $\varphi = 90^0$

Allowable path loss =140dB

$\Delta h_{BS} = h_{BS} – h_{roof} = 40 – 40 = 0$

$\Delta h_{MS} = h_{roof} – h_{MS} = 40 – 2 = 38m$

Orientation loss,

$L_{ori} = 4 - 0.114(\varphi - 55) = 0.001$

$L_{bsh} = -18\log(11) + (h_{BS} - h_{roof}) = -18.75dB$

$K_a = 54$

$K_f = 4 + 1.5(fc/925 -1) = 5.42$

The roof street diffraction and scatter loss,

$L_{rts} = -16.9 -10\log(w) + 10\log(fc) + 20\log(\Delta hMS) + L_{ori}$

$= -16.9 -10\log(20) + 10\log(1800) + 20\log(38) + 0.001$

$=34.25dB$

Free space path loss,

$L_0 = 32.4 + 20\log(r) + 20\log(fc) = 97.5 + 20\log(r)$ dB

Multi screen diffraction loss,

$L_{msd} = L_{bsh} + K_a + K_f\log(fc) - 9\log(b) = 38.47 + 18\log(r)$ dB

Allowable path loss,

$140 = L_0 + L_{msd} + L_{rts} = 97.5 + 20\log(r) + 38.47 + 18\log(r) + 34.25$

Or, $38\log(r) = -30.23$

Or, $r = 0.16$Km = 160m

Large Scale Path Loss

Propagation model that predict the mean signal strength (not rapid change in amplitude of signal) for an arbitrary transmitter-receiver (T-R) separation distance are useful in estimating the radio coverage area of a transmitter are called large-scale propagation models. Since they characterize signal strength over large T-R separation (several hundreds or thousands of meters).

On the other hand, propagation model that characterize the rapid fluctuations of the received signal strength over very short travel distance (few wavelengths) or short time duration (on the order of seconds) are called small-scale or fading models.

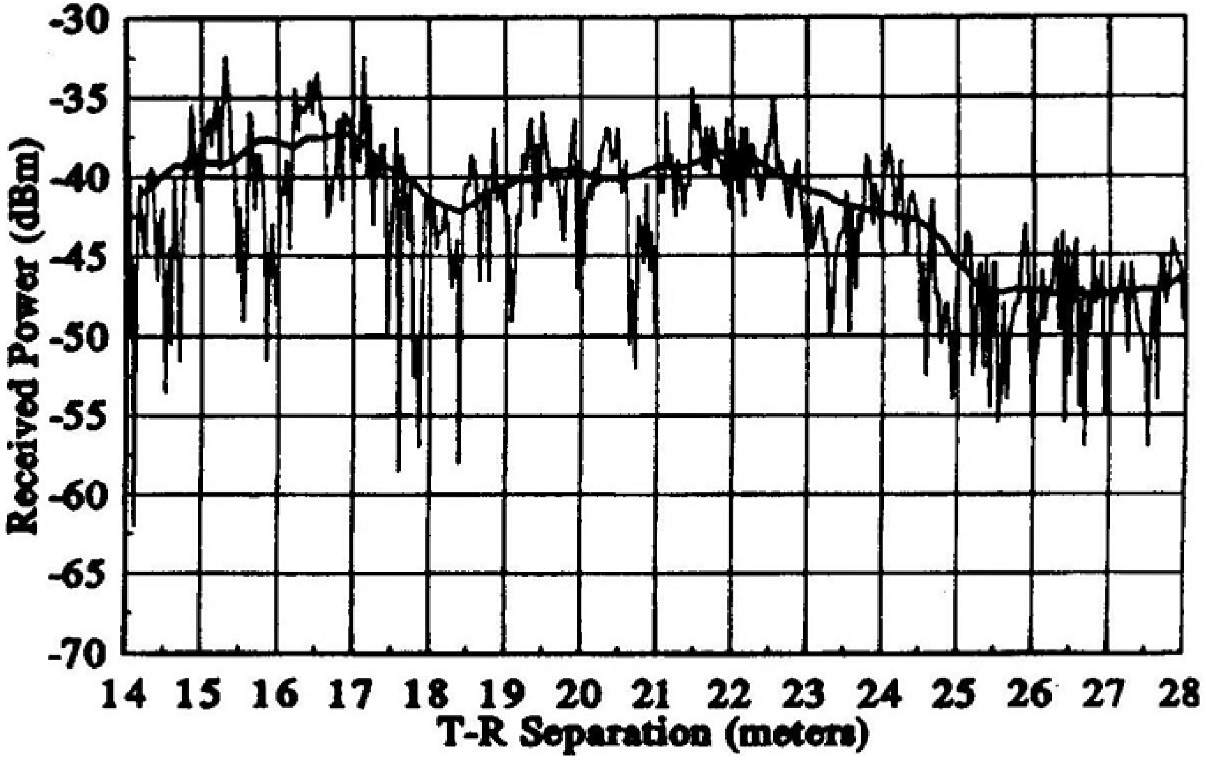
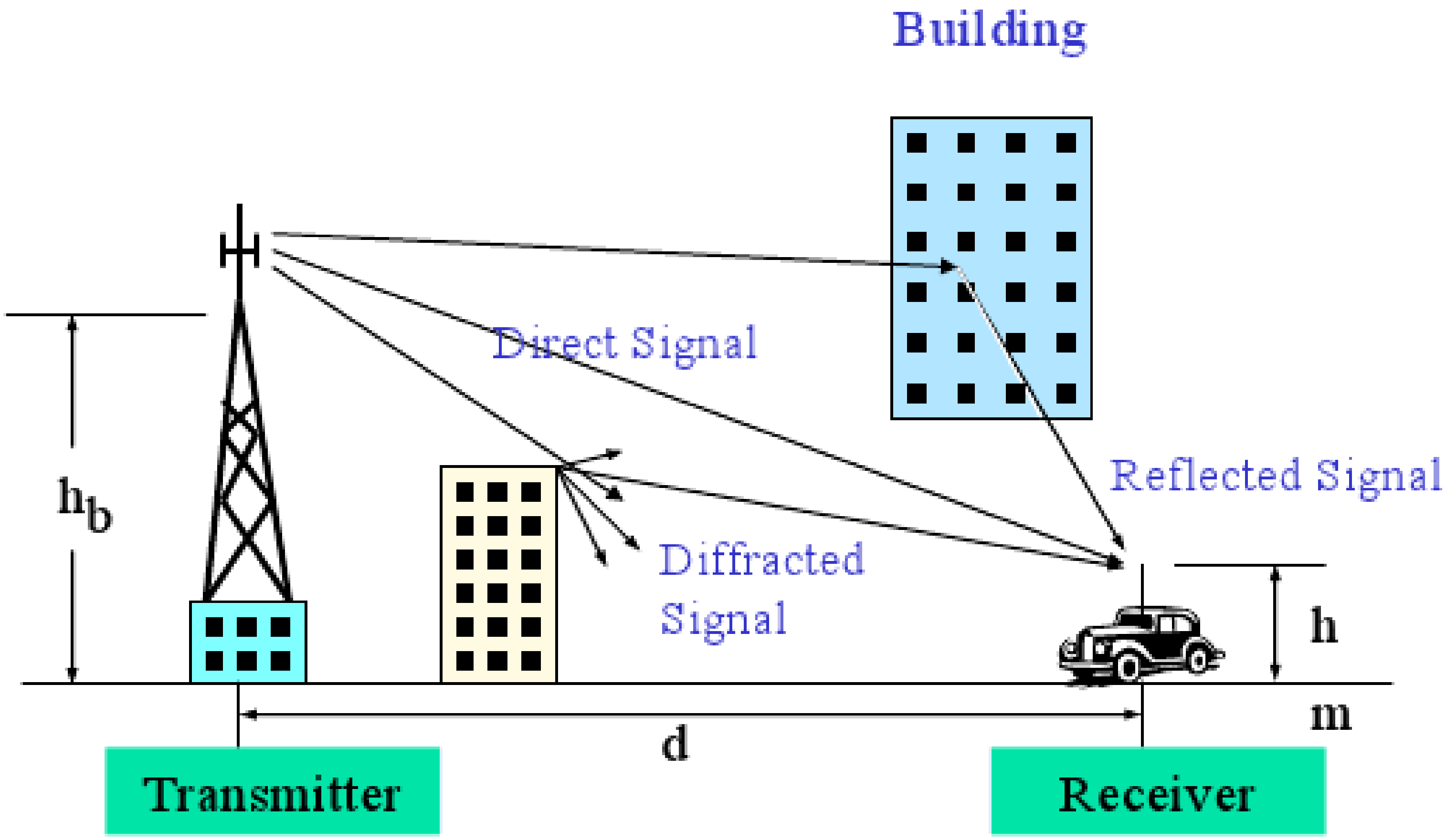
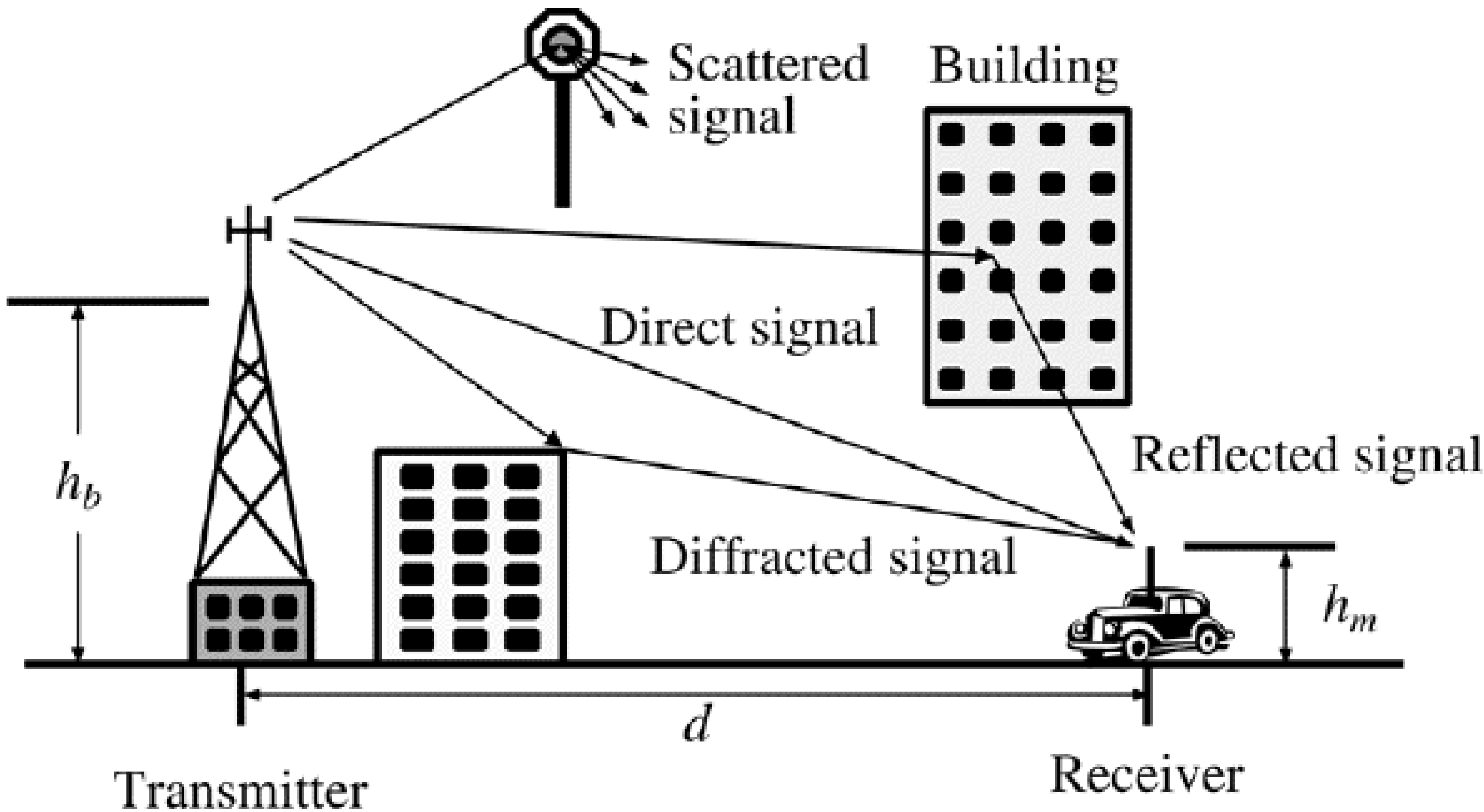


Fig.1 Small and large scale fading

Fig.1 shows the small scale fading (signal fades rapidly) and the more gradual large scale (local average signal) variation for an indoor radio communication system.

The three Basic Propagation Mechanisms




Scattered
signal
Building
Direct signal
Reflected signal
Diffracted signal
h_b
h_m
d
Transmitter
Receiver

The three Basic Propagation Mechanisms

Reflection, diffraction and scattering are the three basic propagation mechanisms which impact propagation in mobile communication system.

Reflection

Reflection occurs when a propagating EM wave impinges upon an object which has very large dimensions compared to wavelength of the propagating wave. Reflection occur from the surface of the earth and from buildings and walls.

Diffraction

Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities (edges). The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle, even when the LOS path does not exist between T and R. Diffraction depends on the geometry of the object as well as the amplitude, phase and polarization of the incident wave at the point of diffraction.

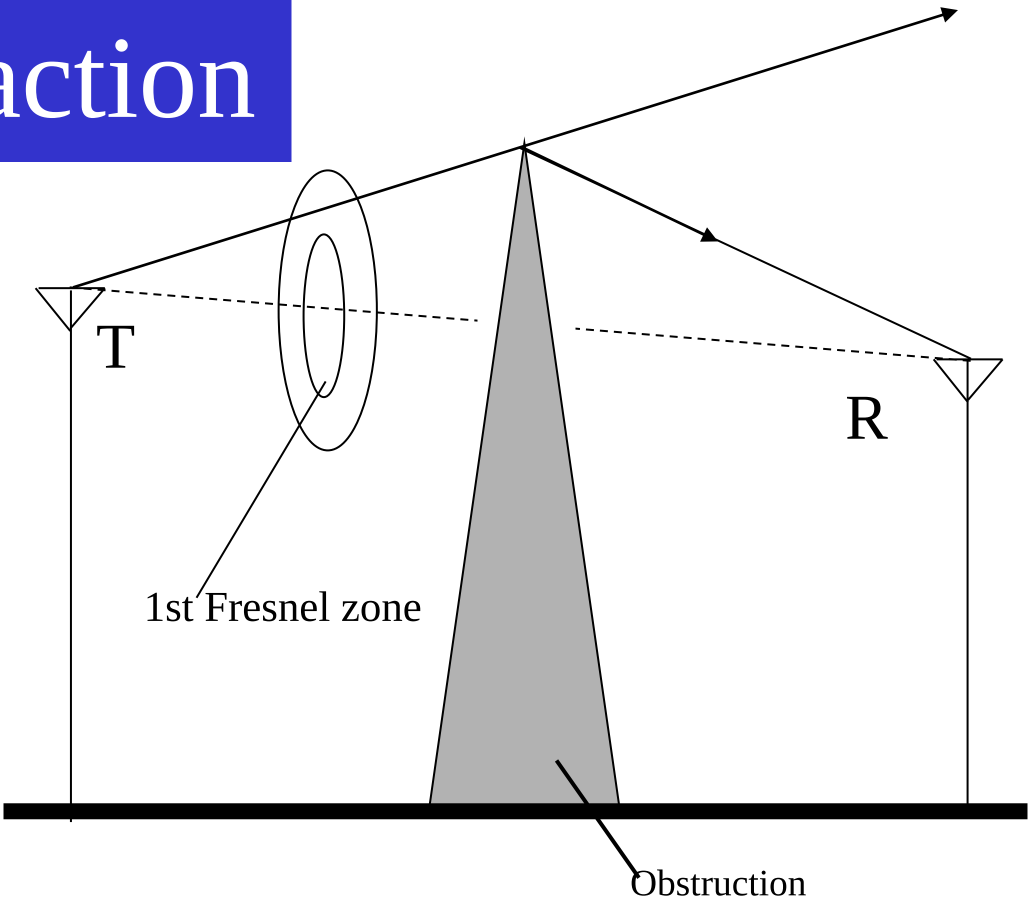
Scattering

Scattering occurs when the medium through which the wave travels consists of objects with dimension 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.

Absorption

Attenuation by solid material (for example wall)

Diffraction

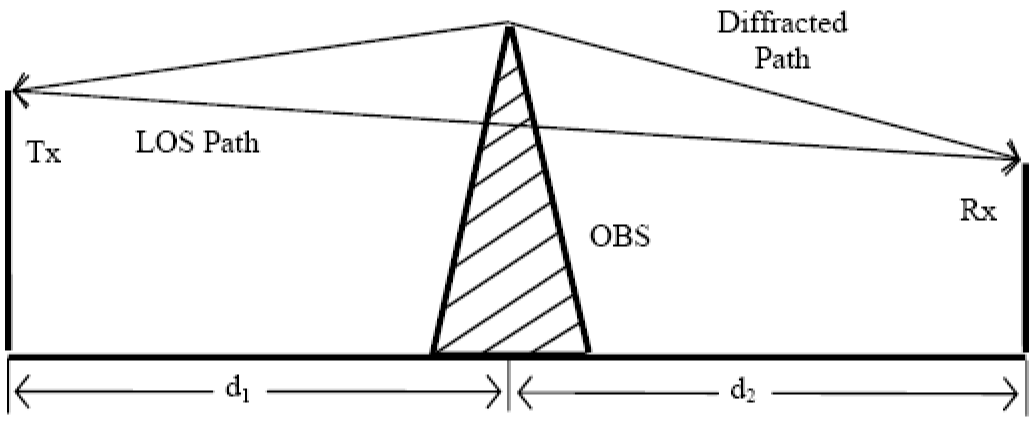


Diffraction occurs when waves hit the edge of an obstacle

- "Secondary" waves propagated into the shadowed region
- Excess path length results in a phase shift

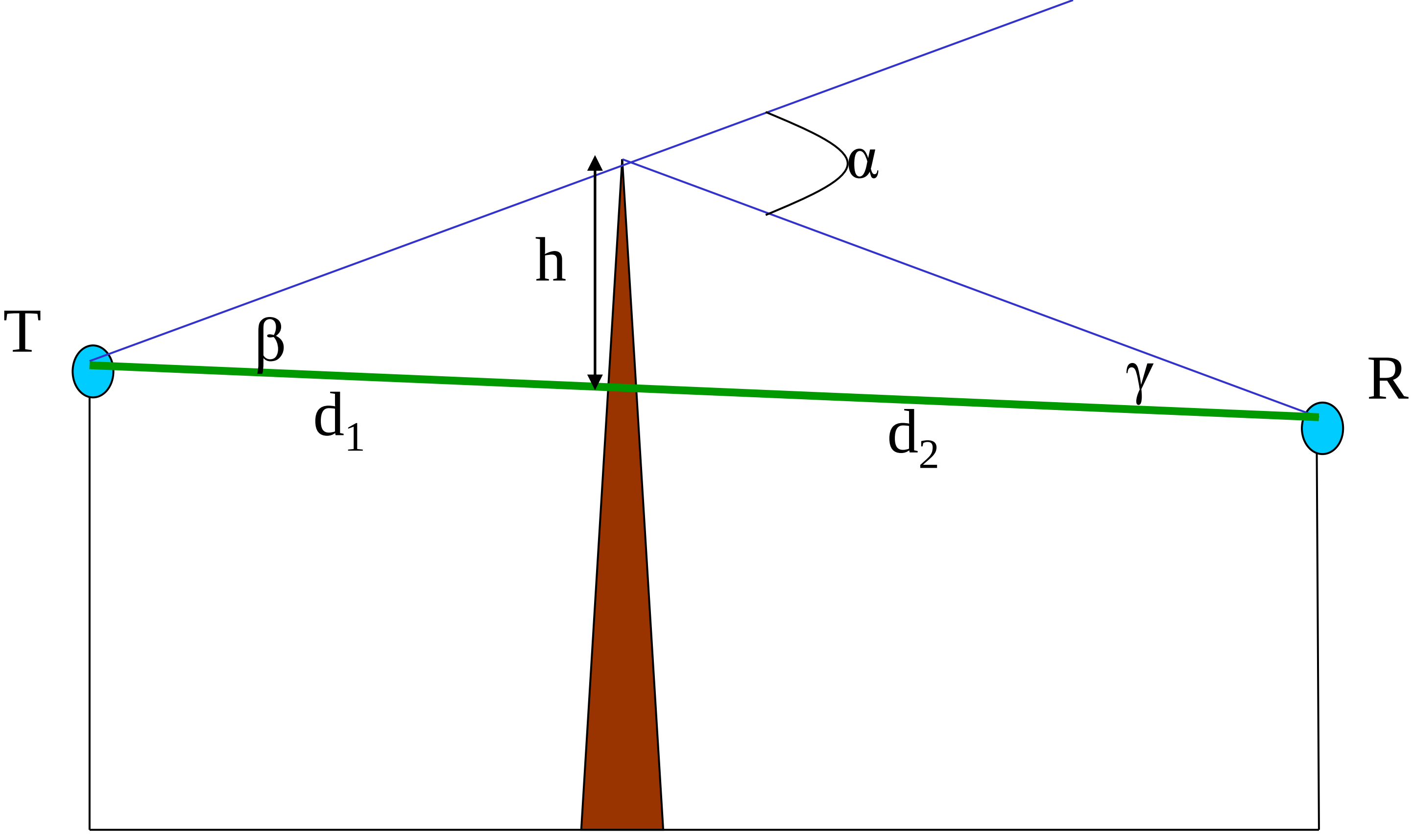
Huygen's Principle

All points on wave front can be considered as point sources to produce secondary wavelets and these wavelets combine (vecctor sum) to form a new wave in the direction of propagation.

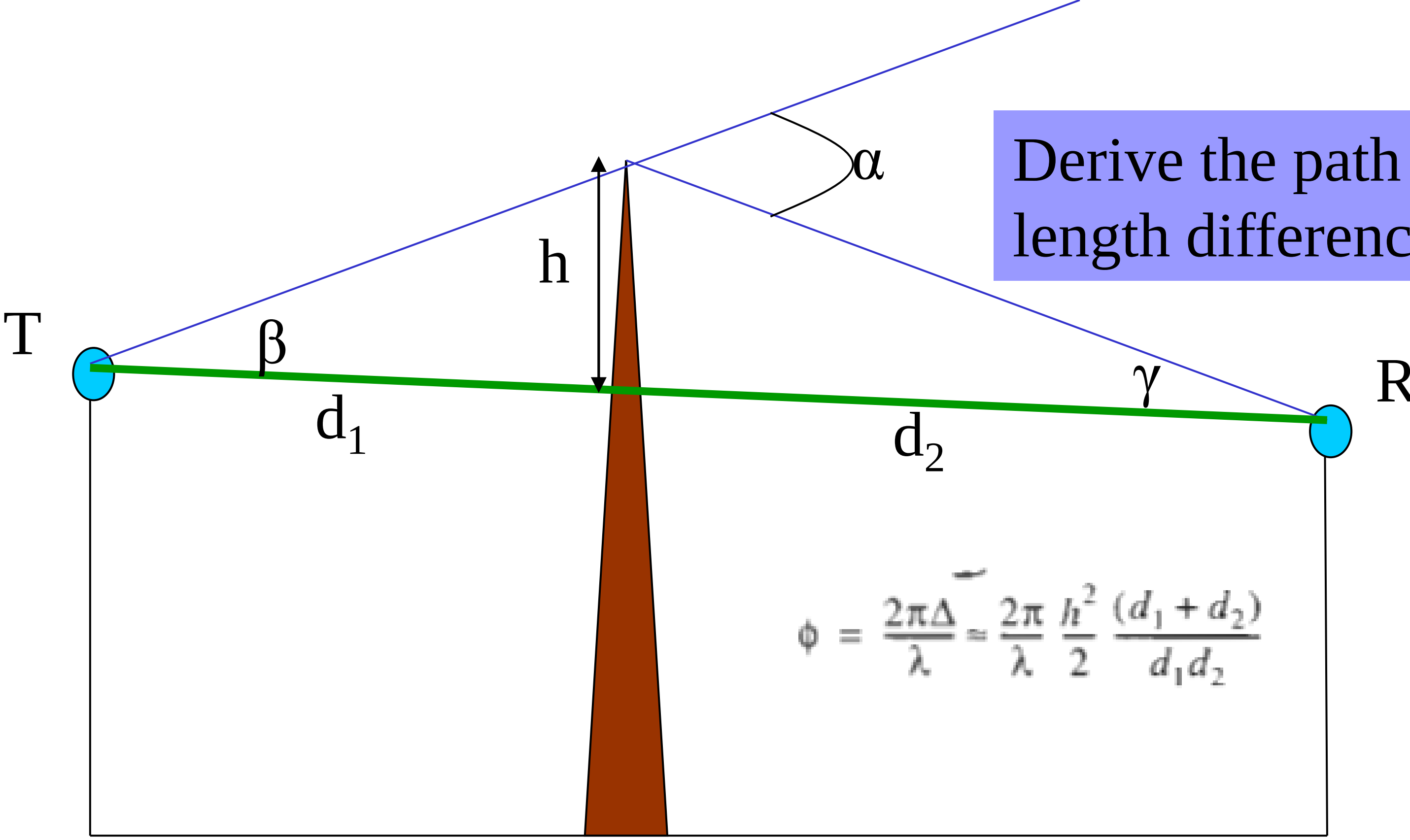


Diffraction

- Phenomena: Radio signal can propagate around the curved surface of the earth, beyond the horizon and behind obstructions.
- Although the received field strength decreases rapidly as a receiver moves deeper into the obstructed (shadowed) region, the diffraction field still exists and often has sufficient strength to produce a useful signal.
- The field strength of a diffracted wave in the shadowed region is the vector sum of the electric field components of all the secondary wavelets in the space around the obstacles.



Consider a transmitter and receiver separated in free space and an obstructing screen of effective height h with infinite width be placed between them at a distance d_1 from the transmitter and d_2 from the receiver. It is apparent that the wave propagating from the transmitter to receiver via top of the screen travels a longer distance than if a direct LOS.



Derive the path length difference,

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

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

The corresponding phase difference,

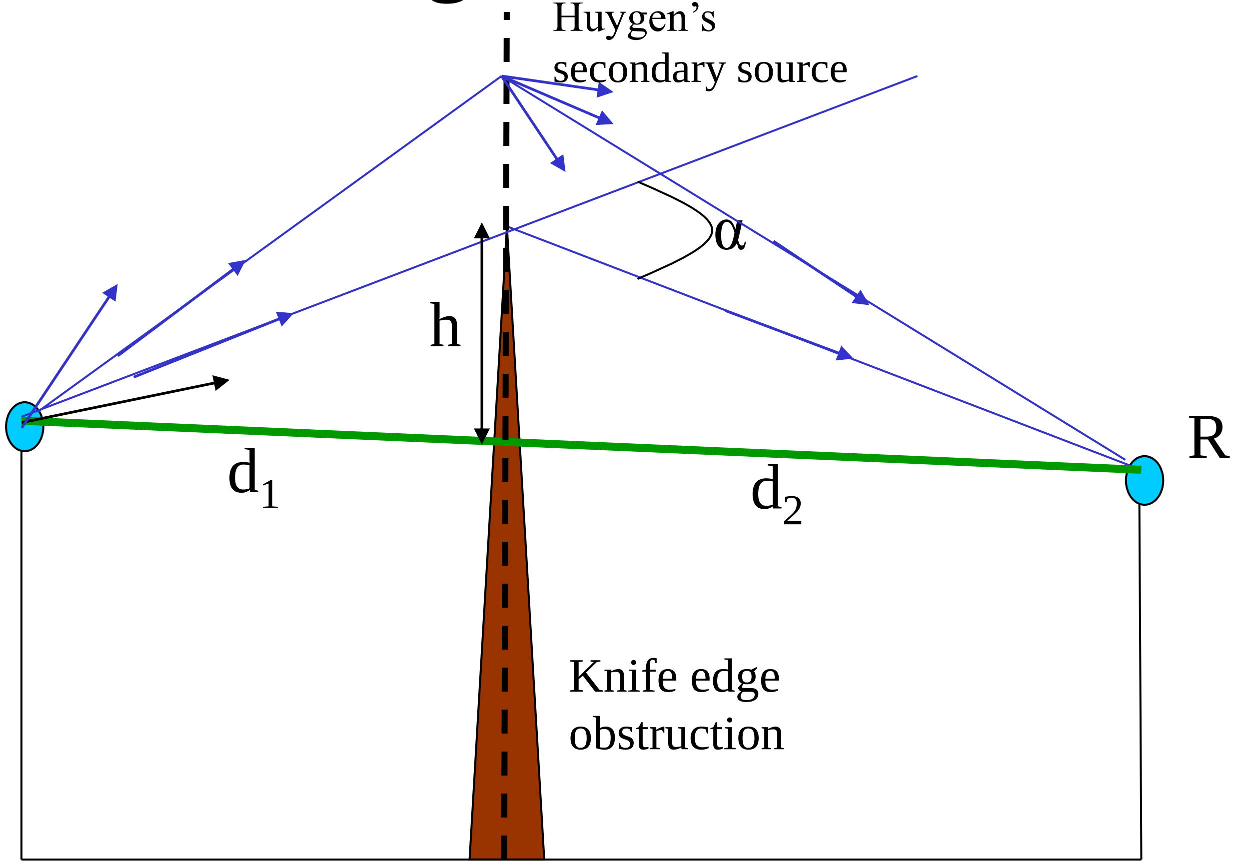
Fresnel-Kirchoff diffraction parameter,

$$\nu = h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}} = \alpha\sqrt{\frac{2 d_1 d_2}{\lambda(d_1+d_2)}}$$

Therefore $\phi = \frac{\pi}{2}\nu^2$

Which Depends on h, position of obstacle and location transmitter and receiver

Knife-edge Diffraction Model



When shadowing is caused by a single object such as a hill or mountain, the attenuation caused by diffraction can be estimated by treating the obstruction as a diffracting knife edge. This is the simplest of diffraction models and the diffraction loss in this case can be readily estimated using the classical Fresnel solution for the filed behind a knife edge.

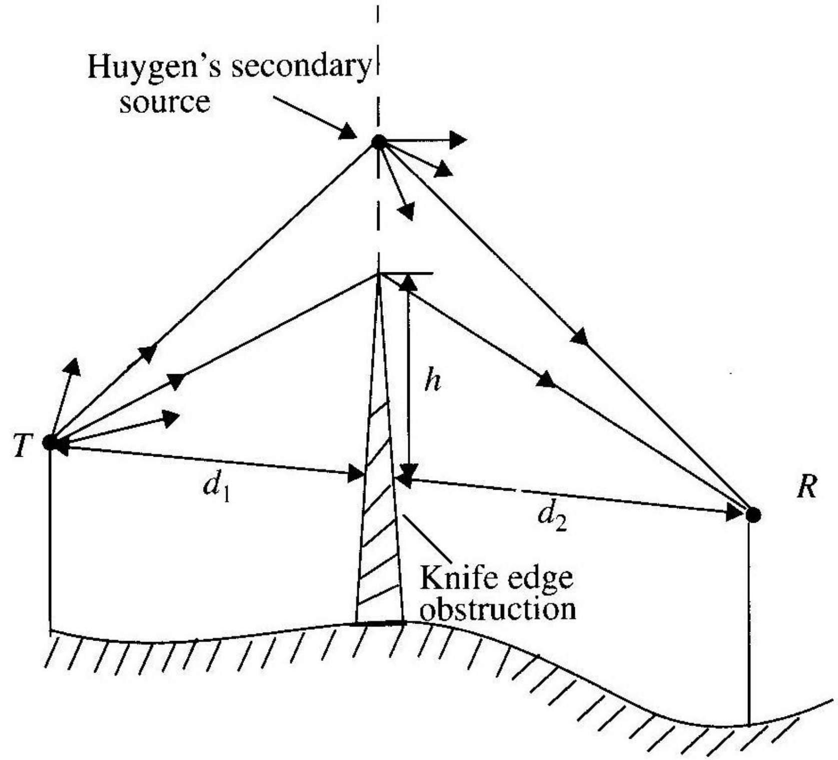


Figure 4.13 Illustration of knife-edge diffraction geometry. The receiver *R* is located in the shadow region.

Consider a receiver at point R in the shadow region (also called the diffraction zone). The field strength a point R in above fig is a vector sum of the fields due to all of the secondary Huygen's sources in the plane above the knife edge.

The electric field strength, E_d of a knife edge diffraction wave is,

$$\frac{E_d}{E_0} = F(v) = \frac{1+j}{2}\int_v^{\infty} \exp\left(-\frac{j\pi t^2}{2}\right)dt$$

Where E_0 is the free space field strength in the absence of both the ground and the knife edge and F(v) is the complex Fresnel integral. The Fresnel integral F(v) is a function of the Fresnel-Kirchoff diffraction parameter v.

$$v = h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}} = \alpha\sqrt{\frac{2d_1d_2}{\lambda(d_1+d_2)}}$$

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

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

An approximate solution of above equation is,

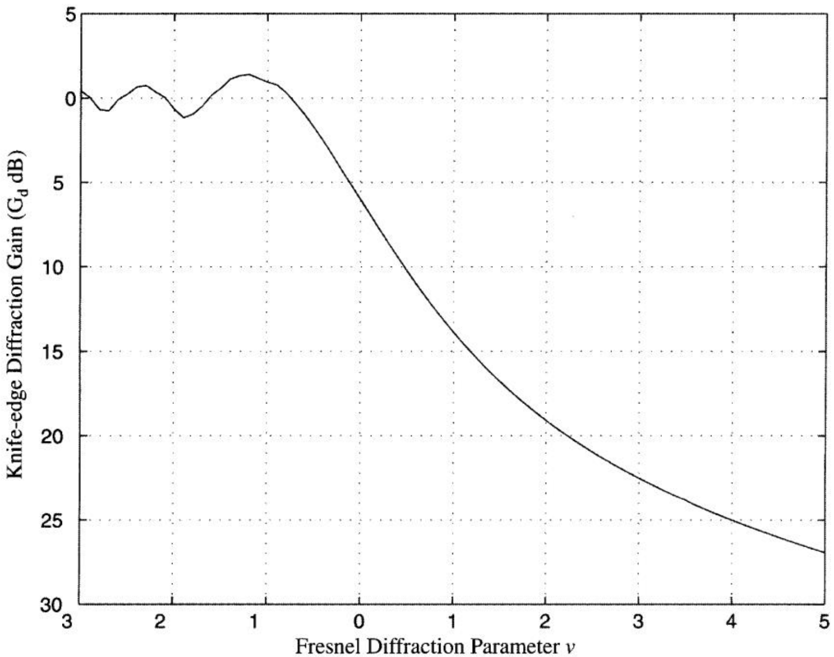


Figure 4.14 Knife-edge diffraction gain as a function of Fresnel diffraction parameter v.

$$G_d(dB) = 0 \qquad v \le -1$$

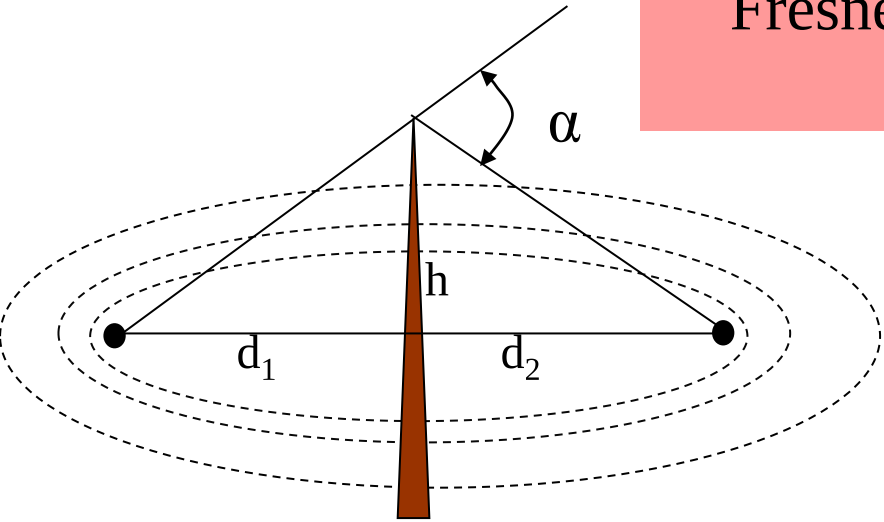
$$G_d(\text{dB}) = 20\log(0.5 - 0.62v) \qquad -1 \le v \le 0$$

$$G_d(\text{dB}) = 20\log(0.5\exp(-0.95v)) \qquad 0 \le v \le 1$$

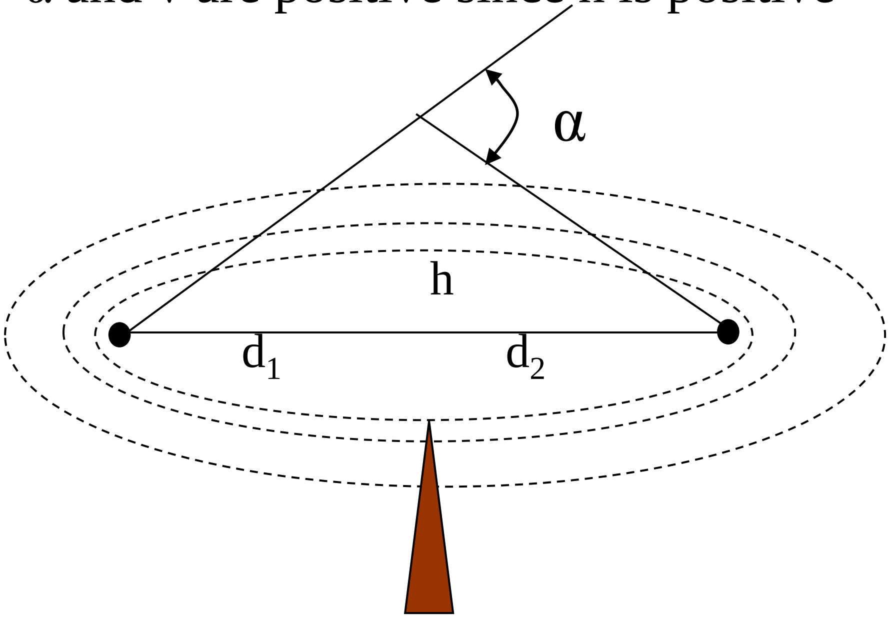
$$G_d(\text{dB}) = 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1v)^2}\right) \qquad 1 \le v \le 2.4$$

$$G_d(\text{dB}) = 20\log\left(\frac{0.225}{v}\right) \qquad v > 2.4$$

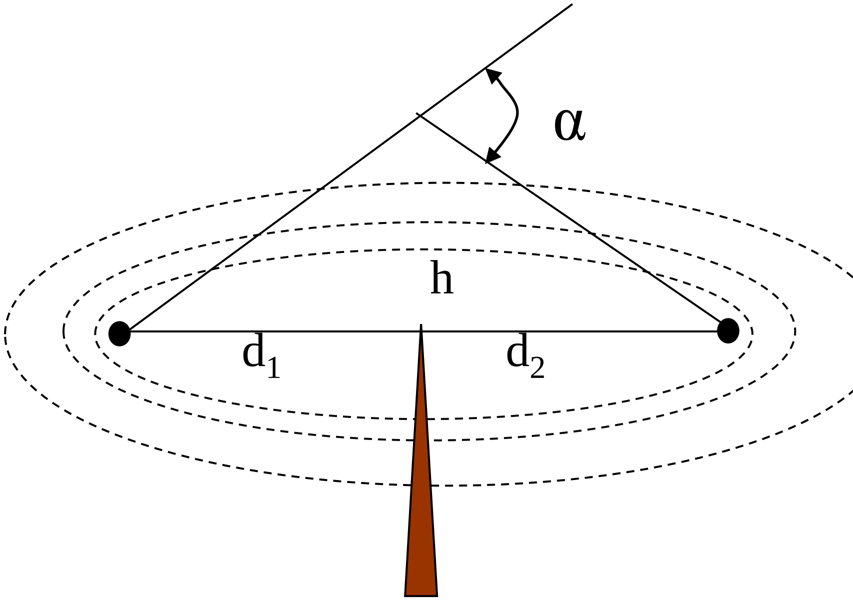
Fresnel zones under different knife-edge diffraction scenarios



α and v are positive since h is positive



α and v are negative since h is negative



α and v are 0 since h is 0

A family of ellipsoids can be constructed between transmitter and receiver by joining all points for which the excess path delay is an integral multiple of λ/2. The ellipsoids represent Fresnel zones.

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

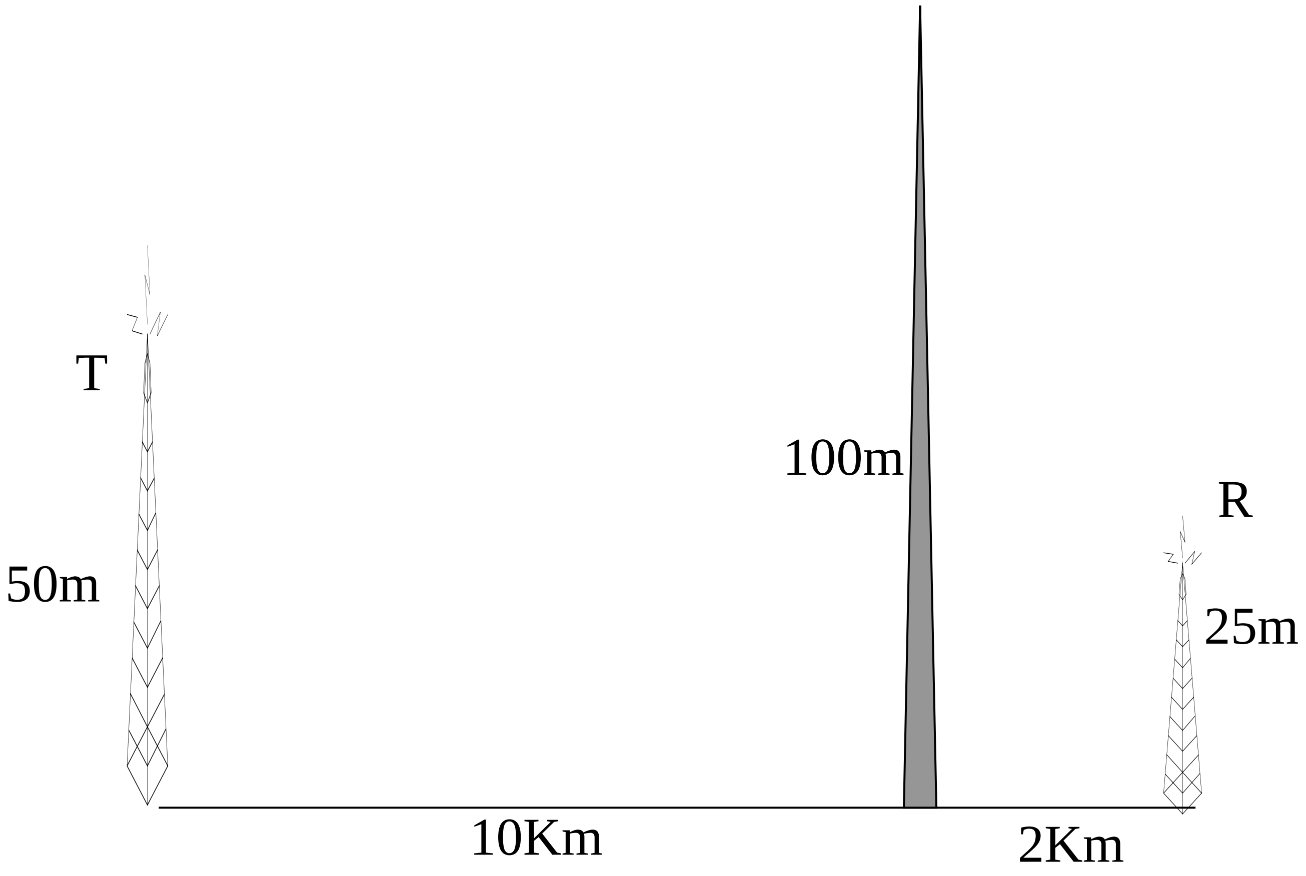
Using Equation (4.56), the Fresnel diffraction parameter is obtained as −2.74.

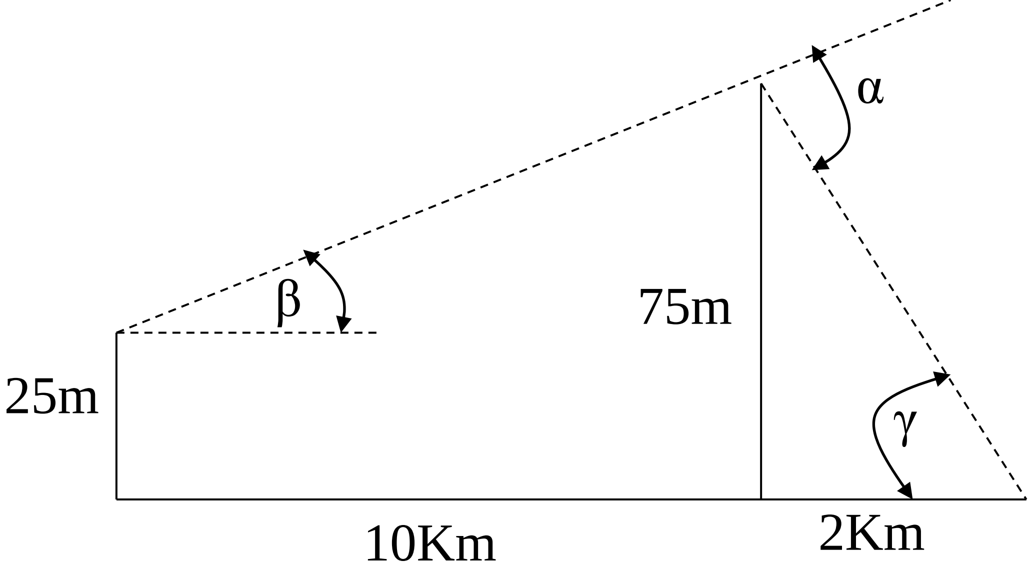
From Figure 4.14, the diffraction loss is approximately equal to 1 dB.

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

Example-1

For the following geometry determine (i) loss due to knife edge diffraction and (ii) height of the obstruction due to 6dB diffraction loss where f = 900MHz.





Redrawing the geometry subtracting the height of the smallest structure

The wavelength,

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}}{900\times10^{6}} = \frac{1}{3}m$$

$$\beta = \tan^{-1}\left(\frac{75-25}{10000}\right) = 0.2865^{0} \quad \gamma = \tan^{-1}\left(\frac{75}{2000}\right) = 2.15^{0}$$

$$\alpha = \beta + \gamma = 2.434^{0} = 0.0424\,rad$$

Now *Fresnel-Kirchoff* diffraction parameter,

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

The diffraction gain due to the presence of a knife edge,

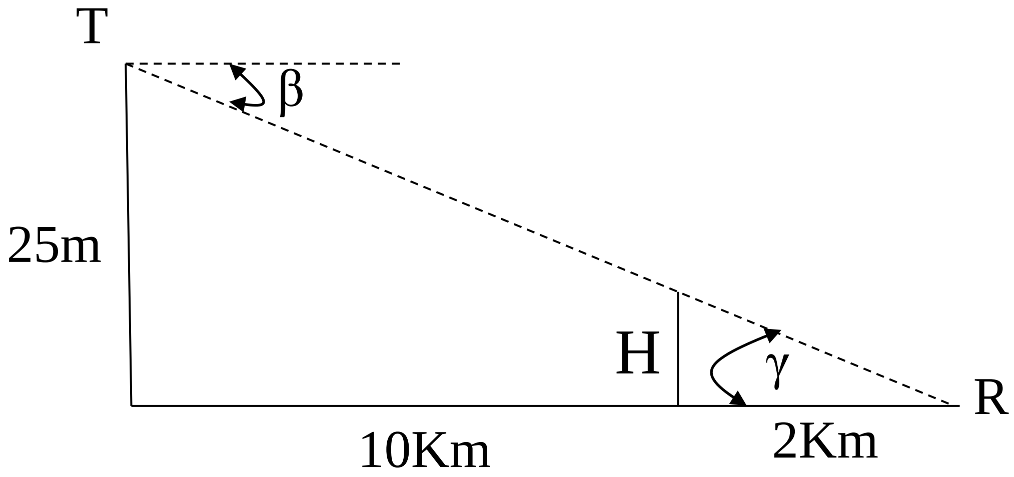
$$G_d(dB) = 20\log\left(\frac{0.225}{v}\right) = 20\log\left(\frac{0.225}{4.24}\right) = -25.5dB$$

ii) For 6dB diffraction loss, v = 0,

$$v = h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}} = 0$$

$$\Rightarrow h = 0$$

Therefore the knife edge obstruction just touch the LOS. The geometry will take the form,



$$\frac{H}{2000} = \frac{25}{12000}$$

$$\Rightarrow H = 4.16m$$

Scattering

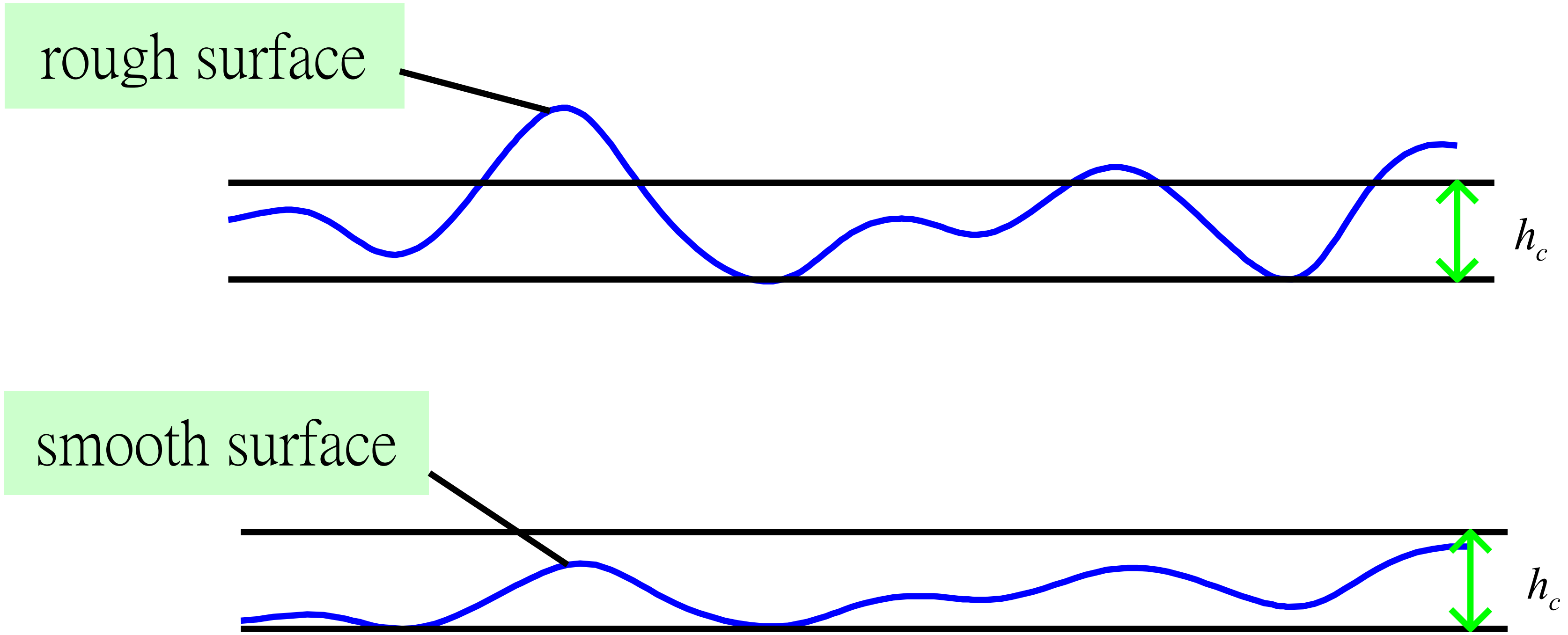
- Received signal strength is often stronger than that predicted by reflection/diffraction models alone
- The EM wave incident upon a rough or complex surface is **scattered** in **many** directions and provides more energy at a receiver
  - energy that would have been absorbed is instead reflected to the Rx.
- Scattering is caused by trees, lamp posts, towers, etc.
- flat surface → EM reflection (one direction)
- rough surface → EM scattering (many directions)

Scattering

When a radio wave impinges on a rough surface, the reflected energy is spread out (diffused) in all directions due to scattering. Flat surfaces that have much larger dimension than a wavelength may be modeled as reflective surfaces. However the roughness of such surfaces often induces propagation effects different from the specular reflection. Surface roughness is often tested using the Rayleigh criterion which defines a critical height (h_c) of surface protuberances for a given angle of incidence θi given by,

$$h_c=\lambda/8\sin(\theta_i)$$

A surface is considered smooth if its minimum to maximum protuberance h is less than h_c and is considered rough if the protuberance is greater than h_c.


rough surface
h_c
smooth surface
h_c