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.

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.*

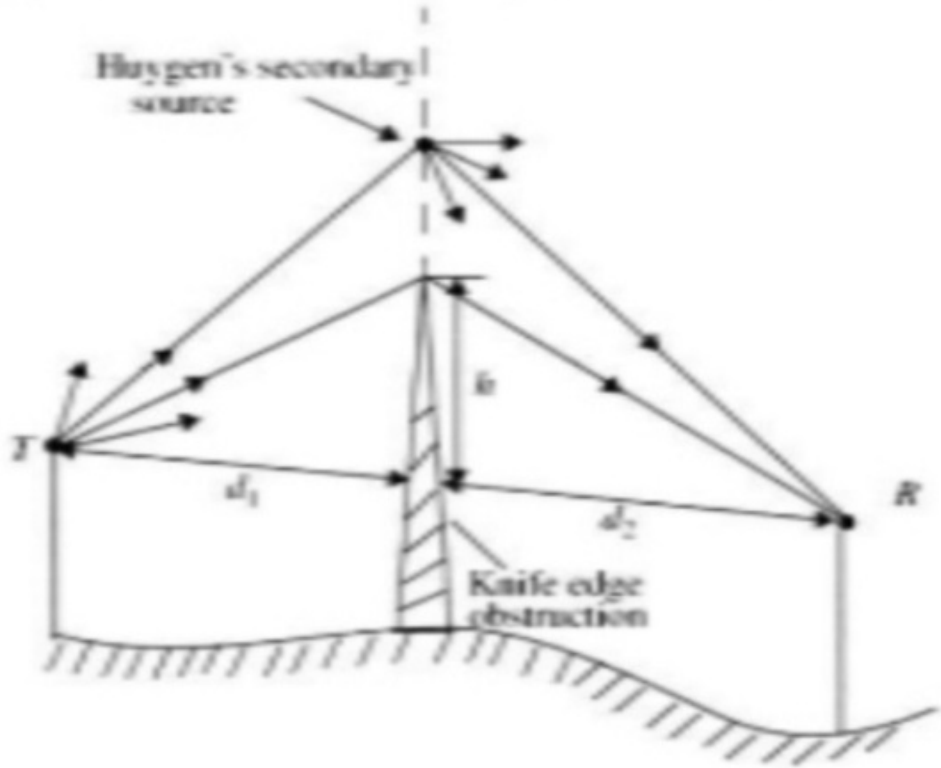
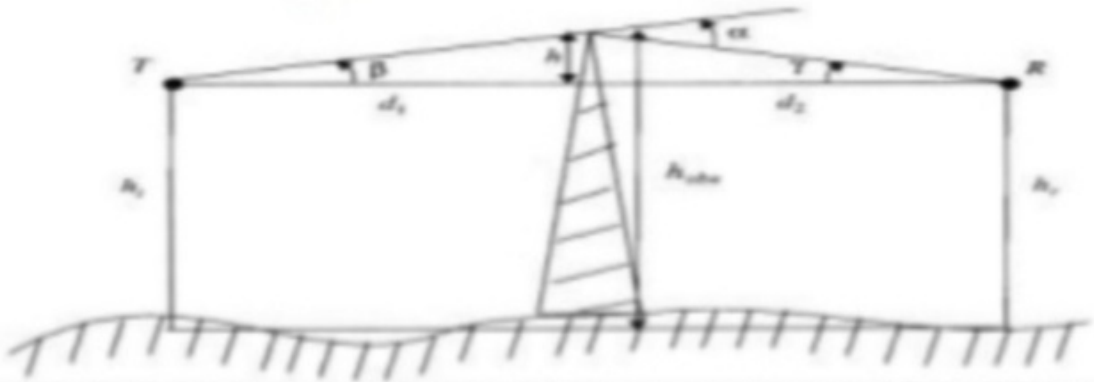
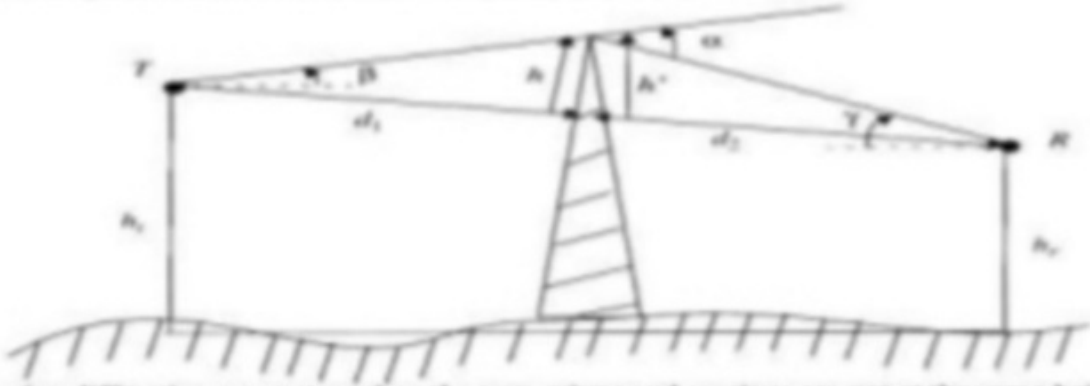


Figure 4.13 Illustration of knife-edge diffraction geometry. The receiver *R* is located in the shadow region.

Knife-edge Diffraction Model



(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.

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

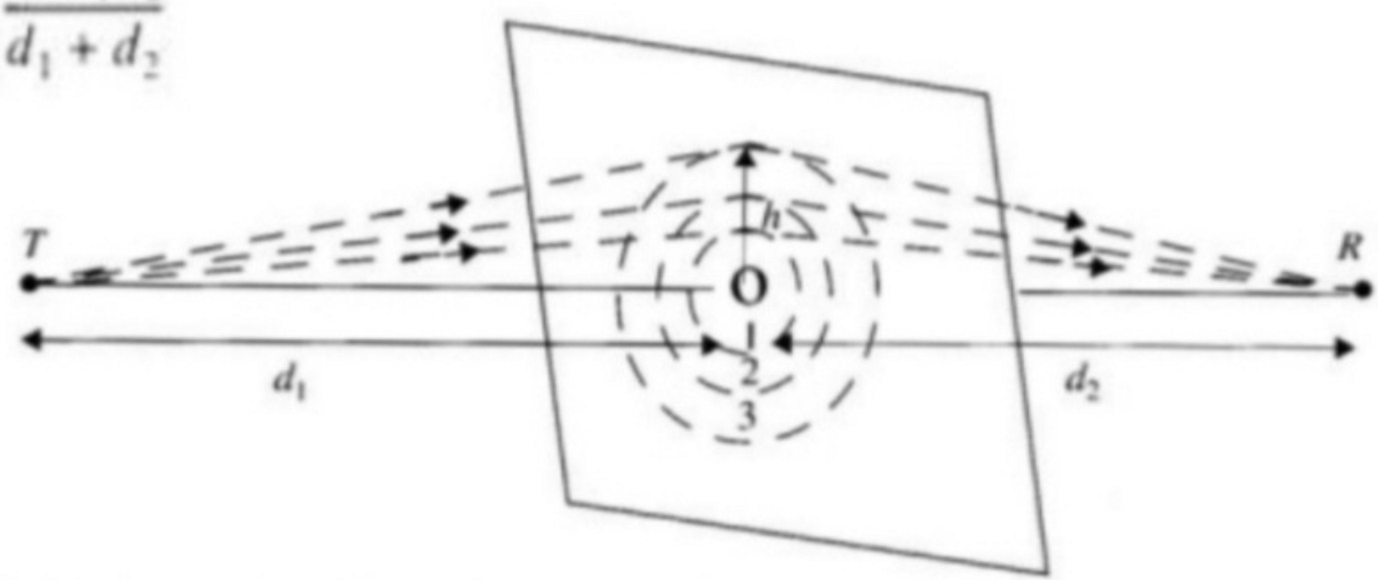
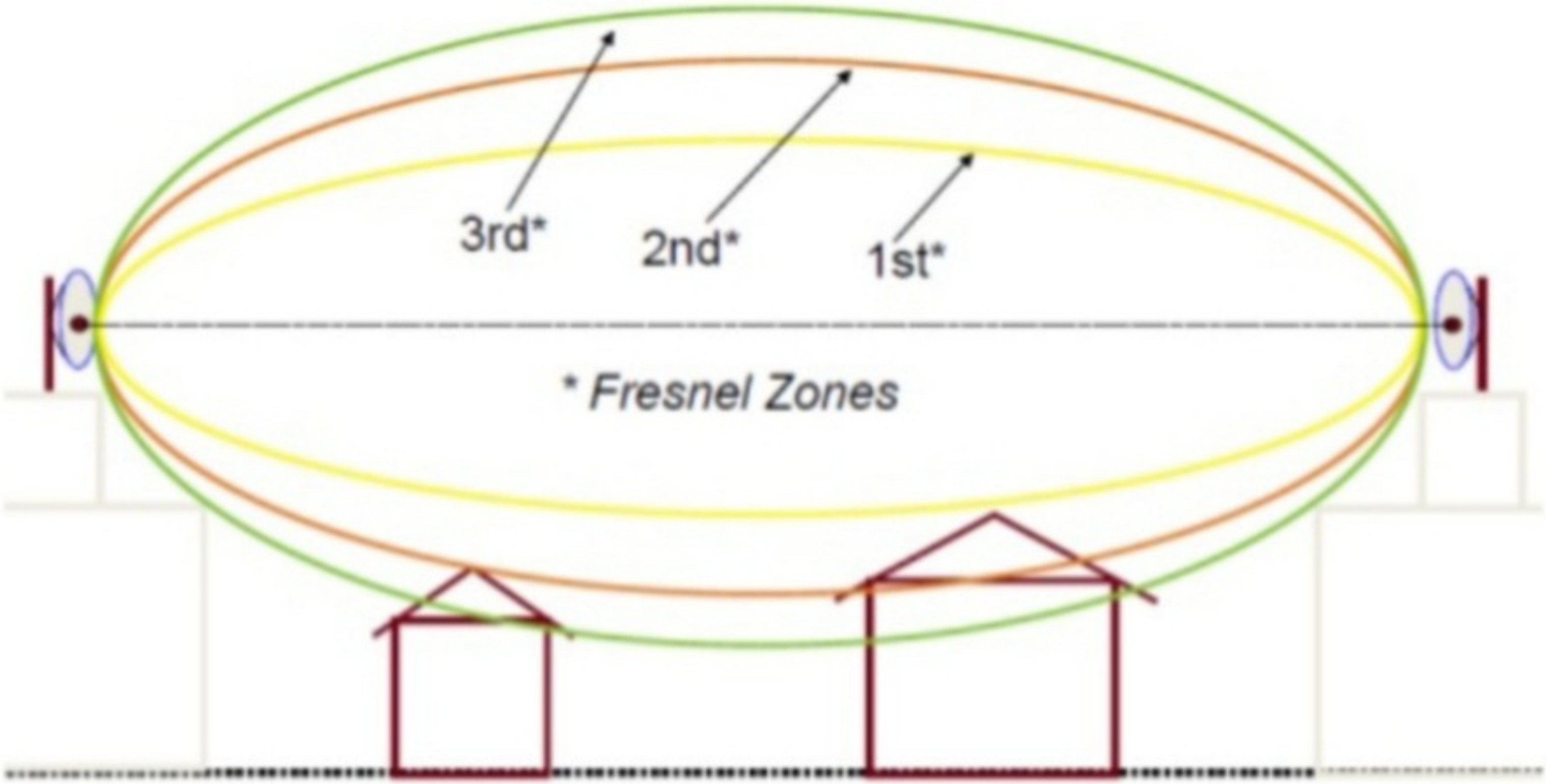


Figure 4.11 Concentric circles which define the boundaries of successive Fresnel zones.

Fresnel zones



Diffraction gain

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

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

- 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*

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

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

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.

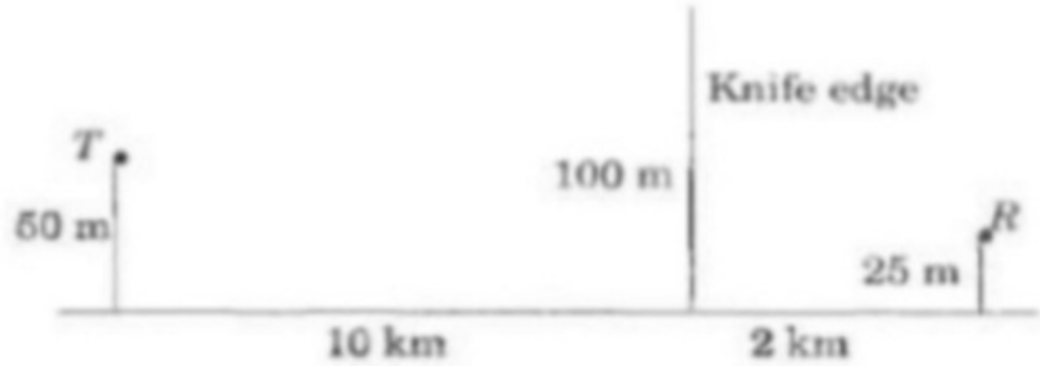
From Figure 4.14, the diffraction loss is approximately equal to 1 dB.

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

Example

Example 4.8

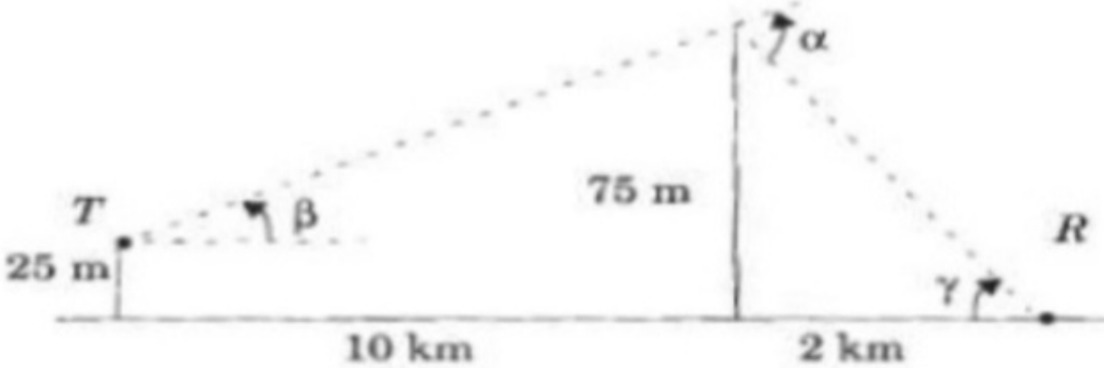
Given the following geometry, determine (a) the loss due to knife-edge diffraction, and (b) the height of the obstacle required to induce 6 dB diffraction loss. Assume $f = 900$ MHz.



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

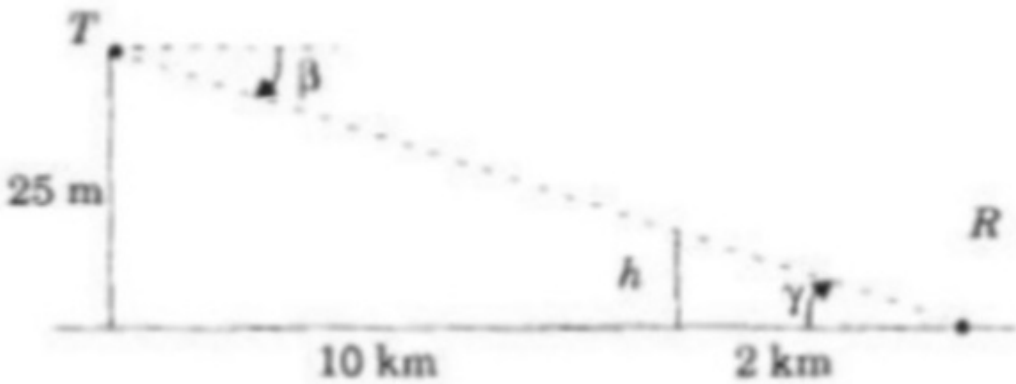
$$\alpha = \beta + \gamma = 2.434^\circ = 0.0424 \text{ rad}$$

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 (β = γ), as shown below.



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

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

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