

WIRELESS AND MOBILE
COMMUNICATION I
ET 3202

The modules to be covered

1. **Radio propagation (6 hrs)**

Basic propagation Mechanisms, Large Scale fading, Small scale fading

2. **Propagation Models (8 hrs)**

Link budget model, Free space path loss model, Outdoor Propagation Models, Indoor Propagation Models

3. **Cellular Concepts and Access Techniques (6 hrs)**

Cell concept, Frequency reuse, channel assignment, handoffs, interference, Grade of Service, Improving Coverage, FDMA, TDMA, SDMA

4. **Spread Spectrum Techniques (5 hrs)**

FHMA, CDMA, WCDMA, Hybrid spread spectrum techniques

5. **Capacity of cellular system (5 hrs)**

TDMA, FDMA, CDMA

Method of Assessment

1. Continuous Assessment : 30%
2. End Semester Examination : 70%

Important Points

- Total Credits : 2
- Total Number of hours : 30
- Number of Lecture Hours : 26
- Number of practical hrs : 8

References

1. Theodore S. Rappaport, (2002). Wireless Communication. Prentice Hall.
2. Andrea Goldsmith, (2005). Wireless Communication. Cambridge University Press.

Module 0: Overview

Telecommunication

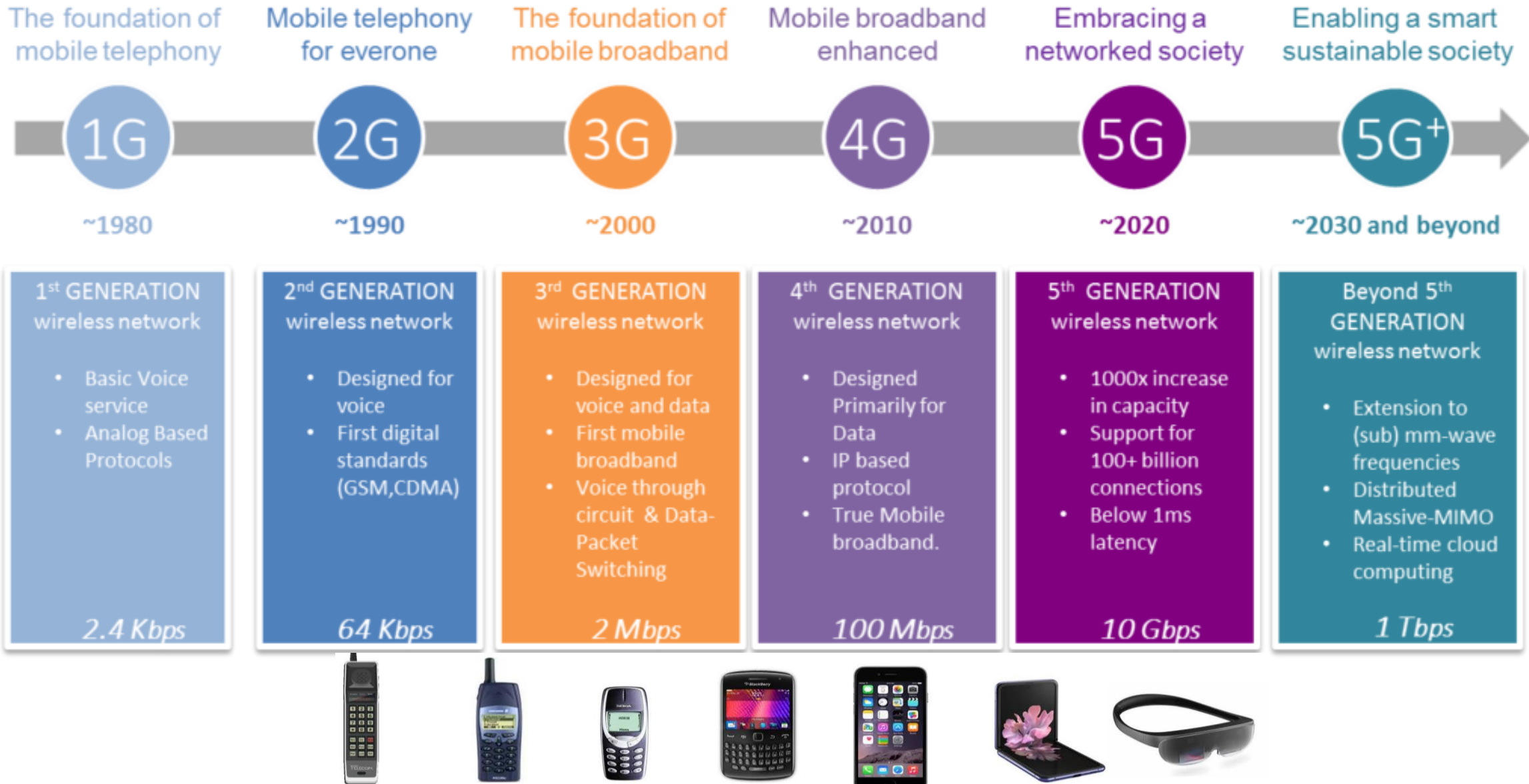
1. Communications is concerned with the transmission of information, or messages, from one point to another.
2. Evolution of the subject.
3. Faster progress over last 150 years than that of any other human activity (bigger, faster, cheaper, smaller).
4. Tremendous impact on the way we live our lives.

Introduction to Wireless Communication

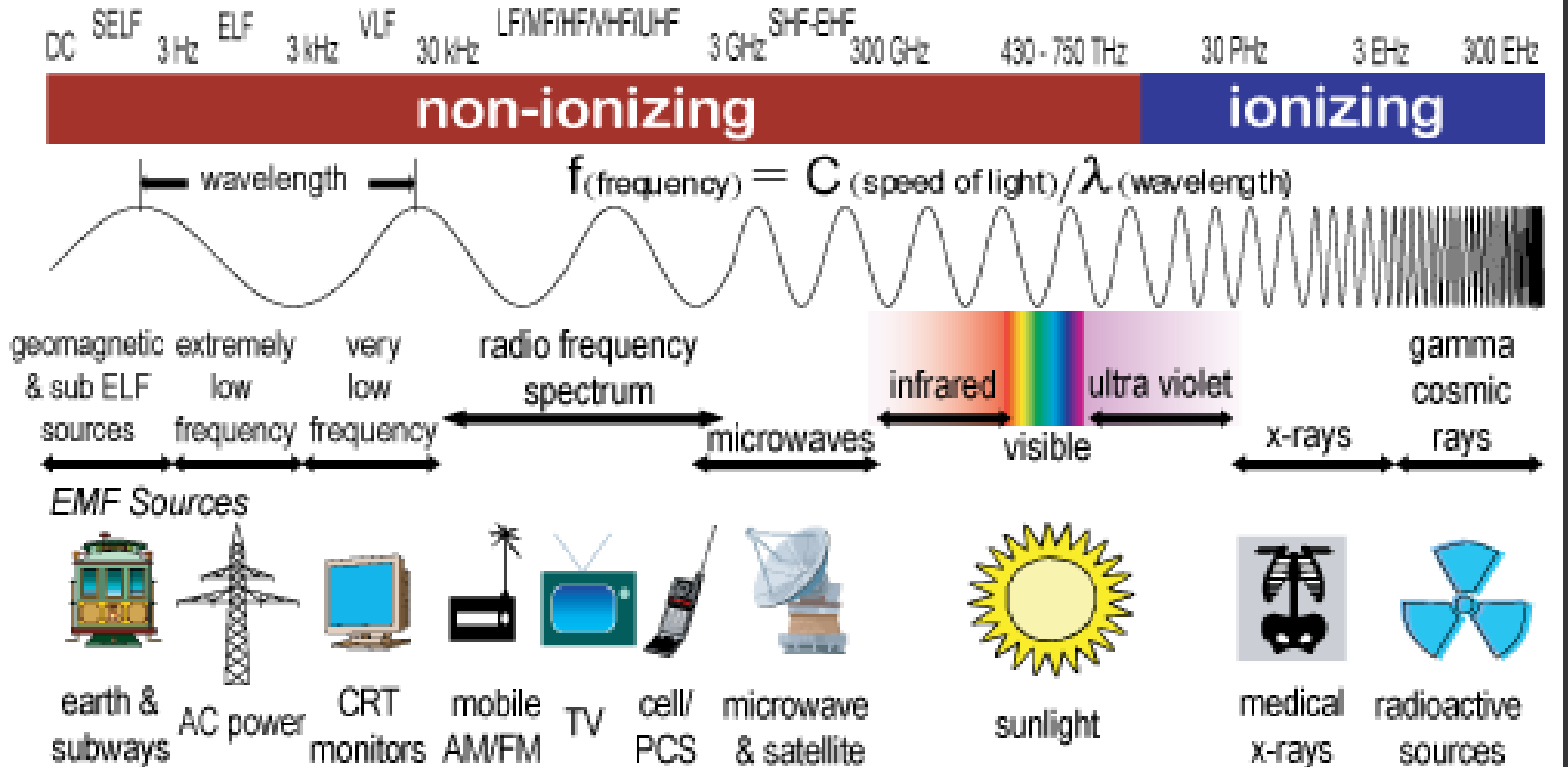
- Wireless communication involves the transmission of information over a distance without the help of wires, cables or any other forms of electrical conductors.
- Wireless communication is a broad term that incorporates all procedures and forms of connecting and **communicating between two or more devices using a wireless signal** through wireless communication technologies and devices.



Evolution of Wireless Communication



Electromagnetic Spectrum



Gigahertz (GHz) 10⁻⁹ Terahertz (THz) 10⁻¹² Petahertz (PHz) 10⁻¹⁵ Exahertz (EHx) 10⁻¹⁸ Zettahertz (ZHx) 10⁻²¹ Yottahertz (YHz) 10⁻²⁴

Features of Wireless Communication

- The **evolution of wireless technology** has brought many advancements with its effective features.
- The transmitted distance can be **anywhere between a few meters** (for example, a television's remote control) and **thousands of kilometers** (for example, radio communication)
- Wireless communication can be used for **cellular telephony, wireless access to the internet, wireless home networking**, and so on.
- Other **examples of applications** of radio wireless technology include GPS units, garage door openers, wireless computer mice, keyboards and headsets, headphones, radio receivers, satellite television, broadcast television and cordless telephones.



Wireless – Advantages

- **Wireless communication** involves transfer of information **without any physical connection** between two or more points. Because of this absence of any 'physical infrastructure', wireless communication has certain advantages. This would often include collapsing distance or space.
- Wireless communication has **several advantages**; the most important ones are discussed below:

Cost effectiveness

- Wired communication entails the use of connection wires. In wireless networks, communication **does not require elaborate physical infrastructure or maintenance practices**. Hence the **cost is reduced**.
- **Example** - Any company providing wireless communication services does not incur a lot of costs, and as a result, **it is able to charge cheaply** with regard to its customer fees.

Flexibility

- Wireless communication enables people to communicate regardless of their **location**. It is **not necessary** to be in an office or some telephone booth in order to pass and receive messages.

Convenience

- Wireless communication devices like mobile phones are quite simple and therefore **allow anyone to use them**, wherever they may be. There is no need to **physically connect** anything in order to receive or pass messages.
- **Example** - Wireless communications services can also be seen in Internet technologies such as Wi-Fi. With no network cables hampering movement, we can now **connect with almost anyone, anywhere, anytime**.

Speed

- Improvements can also be seen in speed. The network connectivity or the accessibility were **much improved in accuracy and speed**.
- **Example** – A wireless remote can operate a system faster than a wired one. The wireless control of a machine can easily stop its working if something goes wrong, whereas direct operation can't act so fast.

Accessibility

- The wireless technology helps **easy accessibility as the remote areas** where ground lines can't be properly laid, are being easily connected to the network.
- **Example** - In rural regions, **online education is now possible**. Educators no longer need to travel to far-flung areas to teach their lessons. Thanks to live streaming of their educational modules.

Constant connectivity

- Constant connectivity also ensures that people can respond to emergencies relatively quickly.
- **Example** – A wireless mobile can ensure you a constant connectivity though you move from place to place or while you travel, **whereas a wired land line can't.**

Module 1: Radio Propagation

- In mobile radio channel there is certain **fundamental limitations** on the performance of wireless communication system.
- There are **many obstructions between transmitter to receiver** like buildings, mountains, trees etc.
- When mobile terminal moves from one place to another, speed of motion impacts on signal level and performance of channel.
- When **line of sight (LoS)** is present between transmitter and receiver the **performance get improves**.

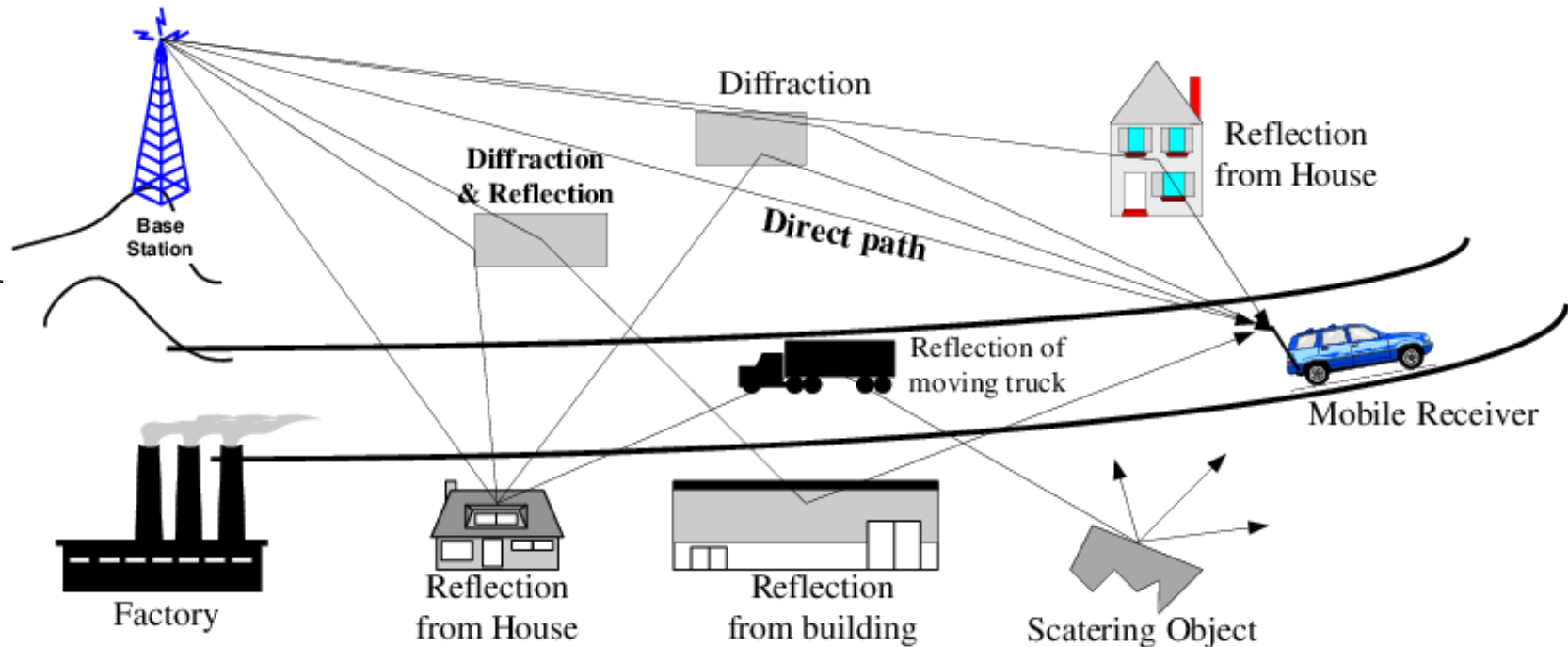
The Three Basic Propagation Mechanisms

- Radio signals in wireless systems propagate according to three phenomena:

- **Reflection**

- **Diffraction**

- **Scattering**

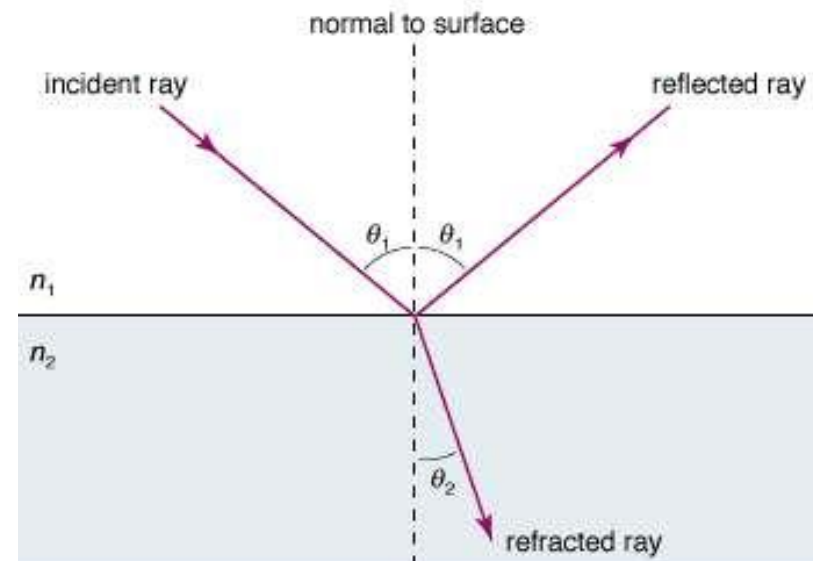


- The **amplitude and the phase angle** of the reflected wave depend on the **surface characteristics**.

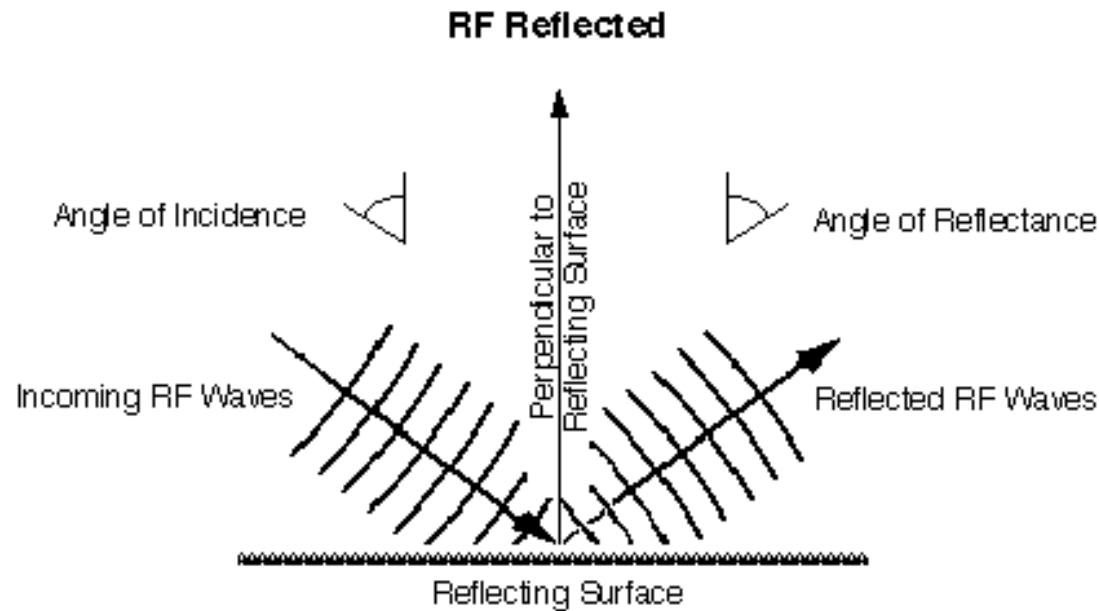
Reflection

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

- When a radio wave propagating in one medium impinges upon another medium having different electrical properties, the wave is **partially reflected and partially transmitted (refracted)**.
- If the plane wave is incident on a **perfect dielectric**, part of the energy is **transmitted** into the second medium and part of the energy is **reflected** back into the first medium, and **there is no loss of energy in absorption**.

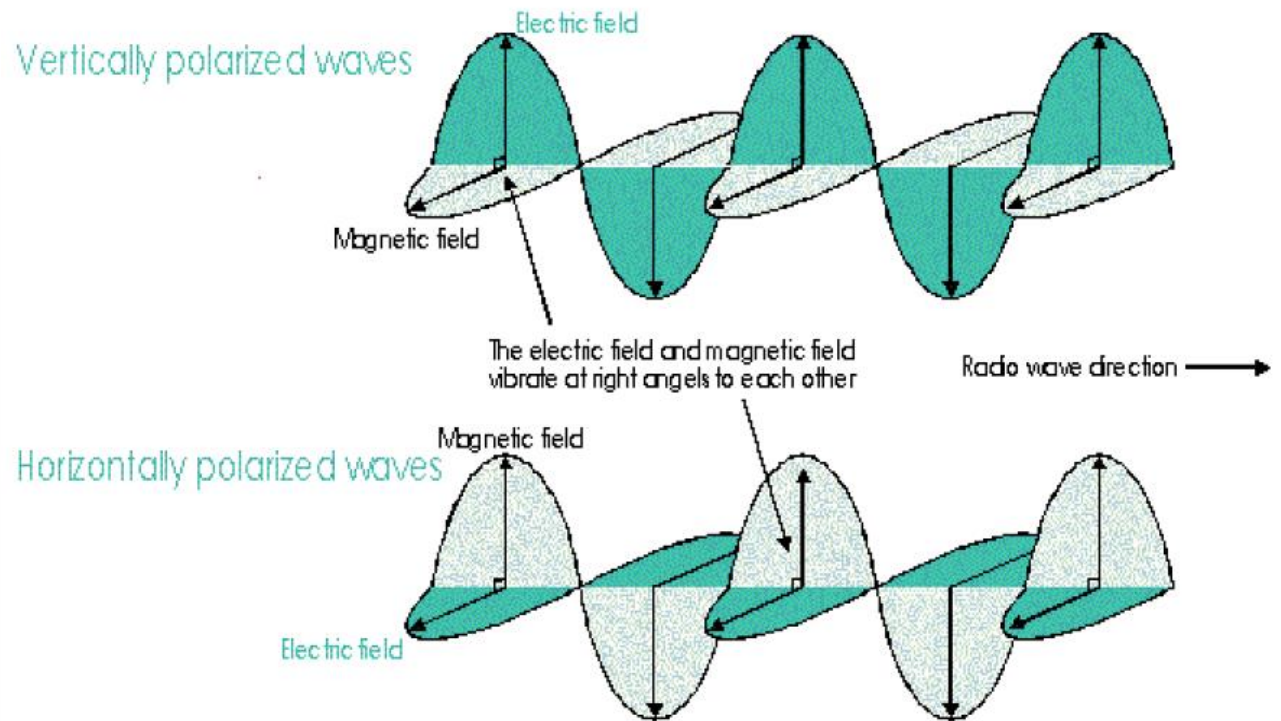
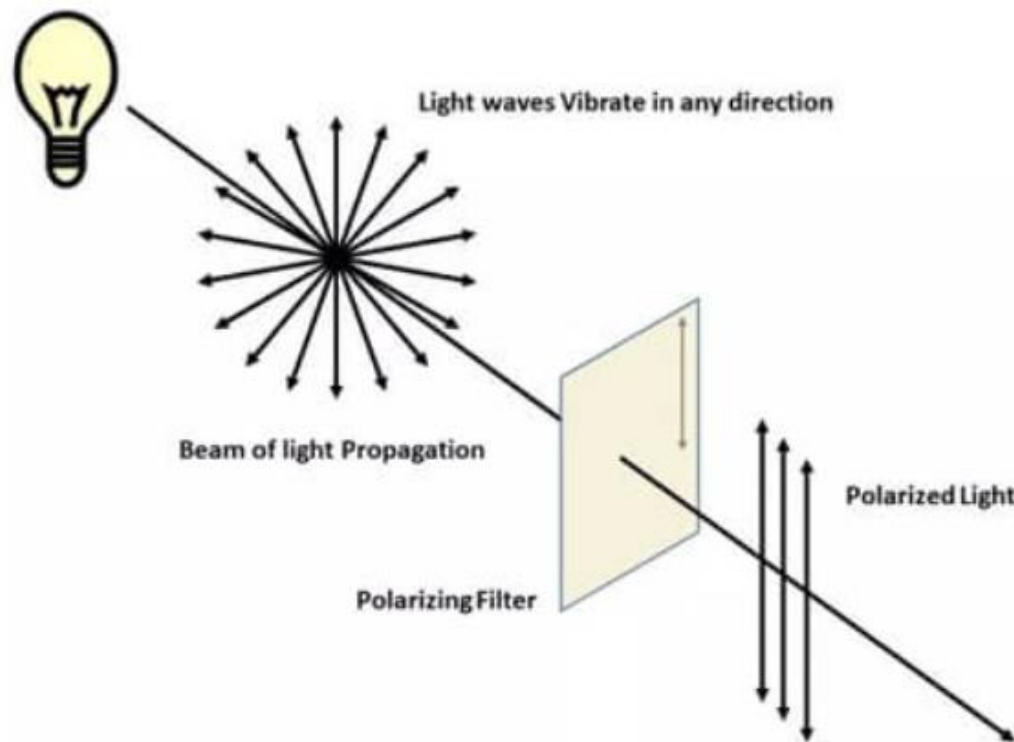


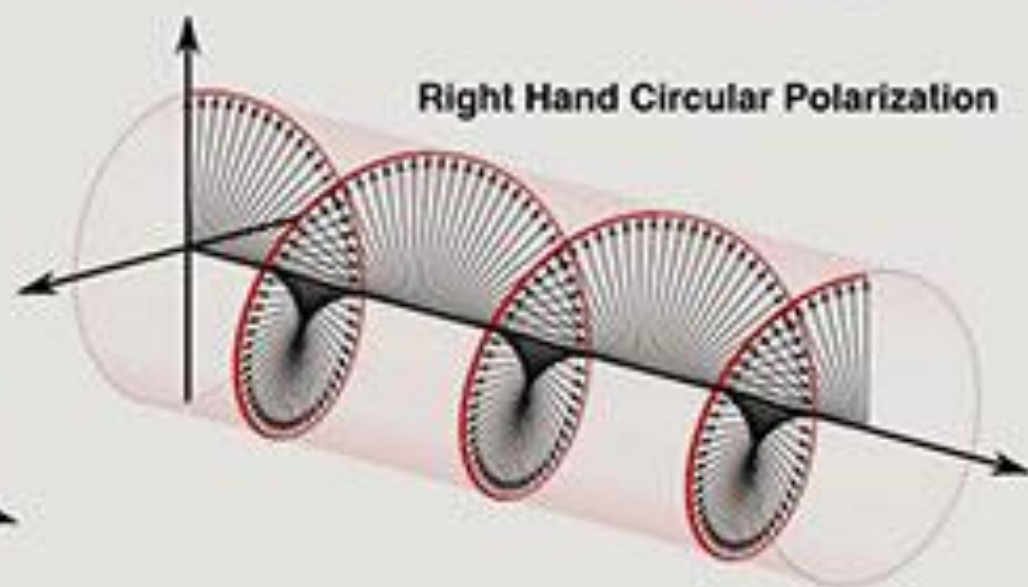
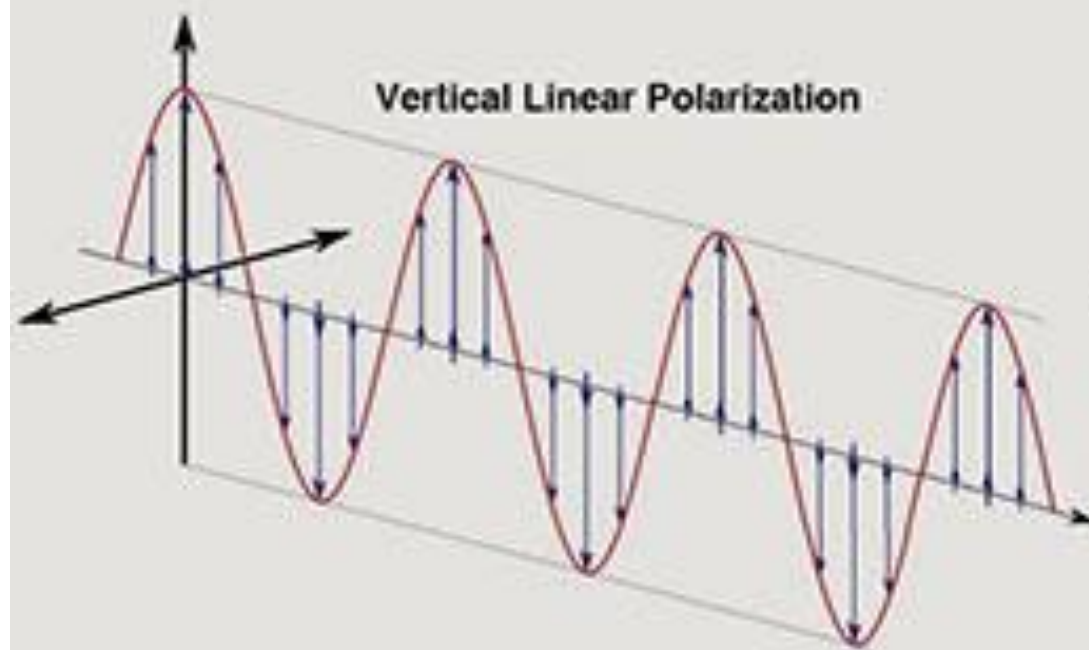
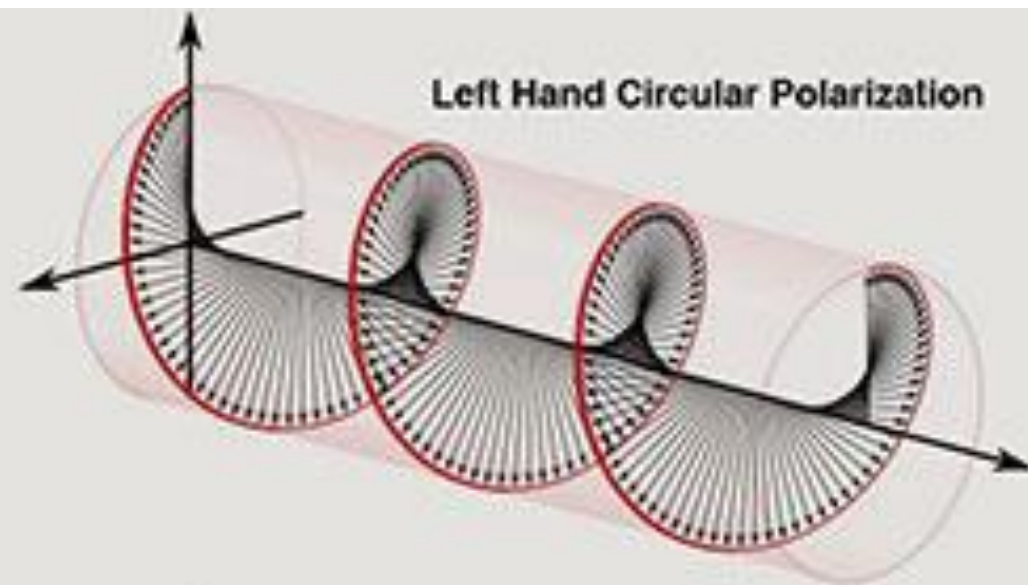
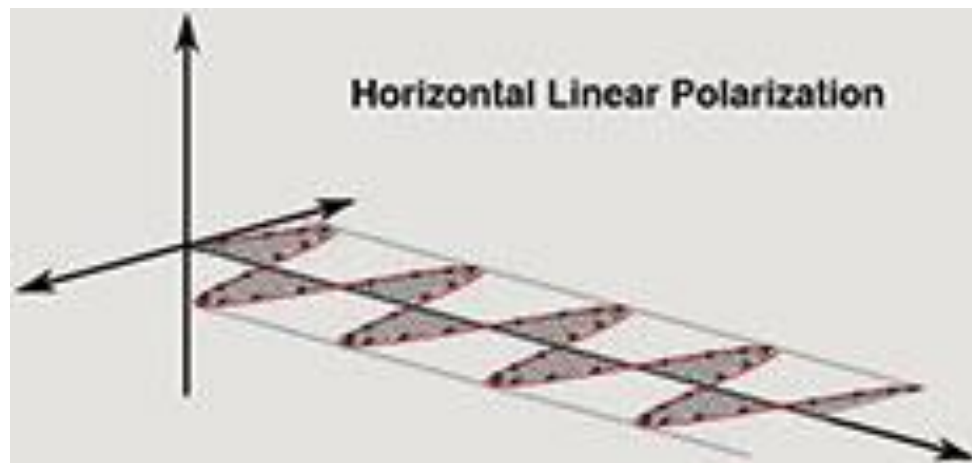
- If the second medium is a **perfect conductor**, then **all incident energy is reflected back** into the first medium **without loss of energy**.



- The **electric field intensity of the reflected and transmitted waves** may be related to the incident wave in the medium of origin through the **Fresnel reflection coefficient (Γ)**.
- The **reflection coefficient** is a function of the **material properties**, and generally **depends on the wave polarization, angle of incidence**, and the **frequency of the propagating wave**.
- In general, **electromagnetic waves are not polarized**, But, we need to make them polarized, as per the requirements.

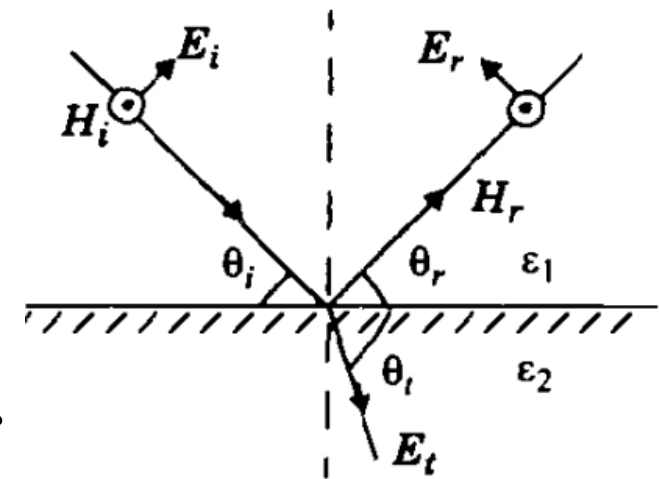
- A polarized wave may be mathematically represented as the sum of two spatially orthogonal components, such as **vertical and horizontal**, or **left-hand or right-hand circularly polarized** components.





Reflection from Dielectrics [E-field polarization is parallel with the plane of incidence]

- Electromagnetic wave **incident** at an angle θ_i with the plane of the boundary between two dielectric media.
- As shown in the figure, part of the energy is **reflected back to the first media at an angle θ_r** and part of the energy is **transmitted (refracted) into the second media at an angle θ_t** . The nature of reflection varies with the **direction of polarization of the E-field**.
- The E-field polarization is parallel with the plane of incidence (on the Same plane of incidence).



- The **plane of incidence** is defined as the plane containing the **incident, reflected, and transmitted** rays.
- In above Figure , the E—field polarization is **parallel with the plane of incidence** (that is, the E-field has a vertical polarization, or **normal component, with respect to the reflecting surface**)
- In Figure, the subscripts **i, r, t** refer to the **incident, reflected, and transmitted fields**, respectively
- Parameters **$\epsilon_1, \mu_1, \sigma_1$ and $\epsilon_2, \mu_2, \sigma_2$** , represent the **permittivity, permeability, and conductance** of the two media, respectively.
- Often, the dielectric constant of a **perfect (lossless) dielectric** is related to a relative value of permittivity, such that **$\epsilon = \epsilon_0 \epsilon_r$** , where is **$\epsilon_0$** constant given by 8.85×10^{-12} F/m.

- If a **dielectric material** is **lossy**, it will **absorb power** and may be described by a **complex dielectric constant** given by.

$$\epsilon = \epsilon_0 \epsilon_r - j\epsilon'$$

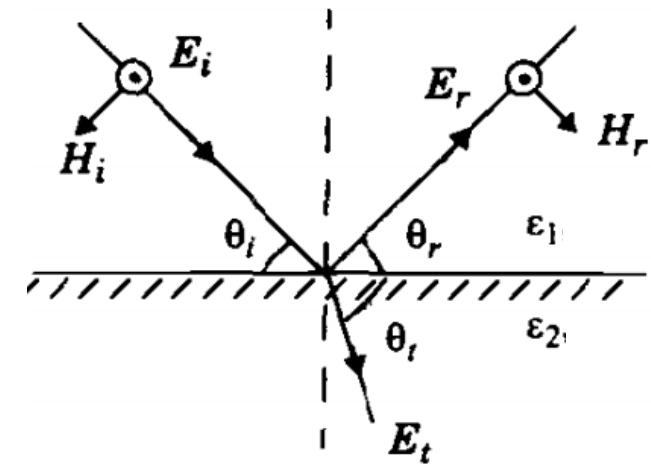
- Where: $\epsilon' = \frac{\sigma}{2\pi f}$
- and **σ** is the **conductivity** of the material measured in **Siemens/meter**.
- For lossy dielectrics, **ϵ_0** and **ϵ_r** are **generally constant with frequency**, but **σ** may be **sensitive to the operating frequency**, as shown in Table. Electrical properties of a wide range of materials were characterized over a **large frequency range**.

Table 3.1 Material Parameters at Various Frequencies

Material	Relative Permittivity ϵ_r	Conductivity σ (s/m)	Frequency (MHz)
Poor Ground	4	0.001	100
Typical Ground	15	0.005	100
Good Ground	25	0.02	100
Sea Water	81	5.0	100
Fresh Water	81	0.001	100
Brick	4.44	0.001	4000
Limestone	7.51	0.028	4000
Glass, Corning 707	4	0.00000018	1
Glass, Corning 707	4	0.000027	100
Glass, Corning 707	4	0.005	10000

Reflection from Dielectrics [E- Field normal/Perpendicular to the plane of incidence]

- The Figure shows the **E-field polarization is perpendicular** to the plane of incidence (that is, the incident E-field is **pointing out of the page** towards the reader, and is **perpendicular to page** and **parallel** to the reflecting surface)



E-field normal to the plane of incidence

Reflection from Dielectrics

- The reflection coefficients for the two cases of parallel and perpendicular E-field polarization at the boundary of two dielectrics are

$$\Gamma_{\parallel} = \frac{E_r}{E_i} = \frac{\eta_2 \sin \theta_t - \eta_1 \sin \theta_i}{\eta_2 \sin \theta_t + \eta_1 \sin \theta_i} \quad (\text{E-field in plane of incidence})$$

$$\Gamma_{\perp} = \frac{E_r}{E_i} = \frac{\eta_2 \sin \theta_i - \eta_1 \sin \theta_t}{\eta_2 \sin \theta_i + \eta_1 \sin \theta_t} \quad (\text{E-field not in plane of incidence})$$

- Where ϵ is the permittivity of the respective medium
- η_i - is the intrinsic impedance of the i th medium ($i = 1, 2$), and is given by $\sqrt{\mu_i / \epsilon_i}$, the ratio of electric to magnetic field for a uniform plane wave in the particular medium.

Reflection from Dielectrics

- **The velocity** of an electromagnetic wave is given by $1 / \sqrt{\mu \cdot \epsilon}$ and the boundary conditions at the surface of incidence obey **Snell's Law** which, referring to Figure , is given by.

$$\sqrt{\mu_1 \epsilon_1} \sin (90 - \theta_i) = \sqrt{\mu_2 \epsilon_2} \sin (90 - \theta_t)$$

- The boundary conditions from **Maxwell's equations** are used to derive equations:

$$\theta_i = \theta_r$$

$$E_r = \Gamma E_i$$

$$E_t = (1 + \Gamma) E_i$$

where Γ is either Γ_1 or Γ_L , depending on polarization. For the case when the first medium is free space and $\mu_1 = \mu_2$, the reflection coefficients for the two cases of vertical and horizontal polarization can be simplified to :

$$\Gamma_{\parallel} = \frac{-\epsilon_r \sin \theta_i + \sqrt{\epsilon_r - \cos^2 \theta_i}}{\epsilon_r \sin \theta_i + \sqrt{\epsilon_r - \cos^2 \theta_i}}$$

$$\Gamma_{\perp} = \frac{\sin \theta_i - \sqrt{\epsilon_r - \cos^2 \theta_i}}{\sin \theta_i + \sqrt{\epsilon_r - \cos^2 \theta_i}}$$

Brewster Angle:

- The Brewster angle is the angle at which **no reflection** occurs in the medium of origin. It occurs when the incident angle θ_B is such that the **reflection coefficient $\Gamma_{||}$ is equal to zero**. The Brewster angle is given by the value of θ_B which satisfies:

$$\sin(\theta_B) = \sqrt{\epsilon_1} / \sqrt{\epsilon_1 + \epsilon_2}$$

- For the case when the **first medium is free space** and the second medium has a **relative permittivity ϵ_r** , above equation can be expressed as

$$\sin(\theta_B) = \frac{\sqrt{\epsilon_r - 1}}{\sqrt{\epsilon_r}}$$

- Note that the **Brewster angle occurs only for vertical (i.e. parallel) polarization.**

Example :

- ❖ Calculate the Brewster angle for a wave impinging on ground having a permittivity of $\epsilon_r = 4$

Figure shows a **plot of the reflection coefficient for vertical (parallel) polarization** as a function of the incident angle for the case when a wave propagates in free space and the reflection surface has **(a) $\epsilon_r = 4$, and (b) $\epsilon_r = 12$.**

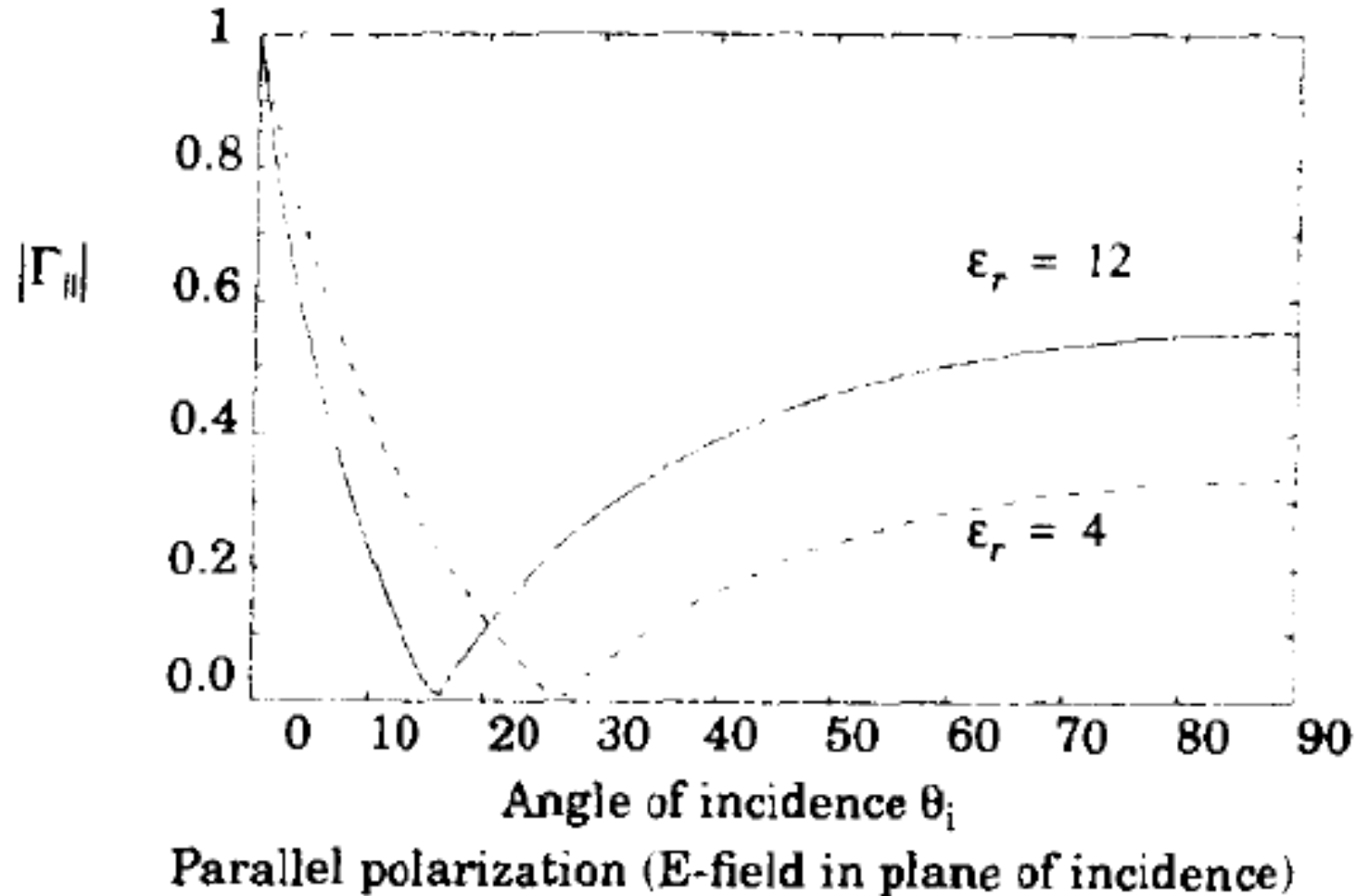
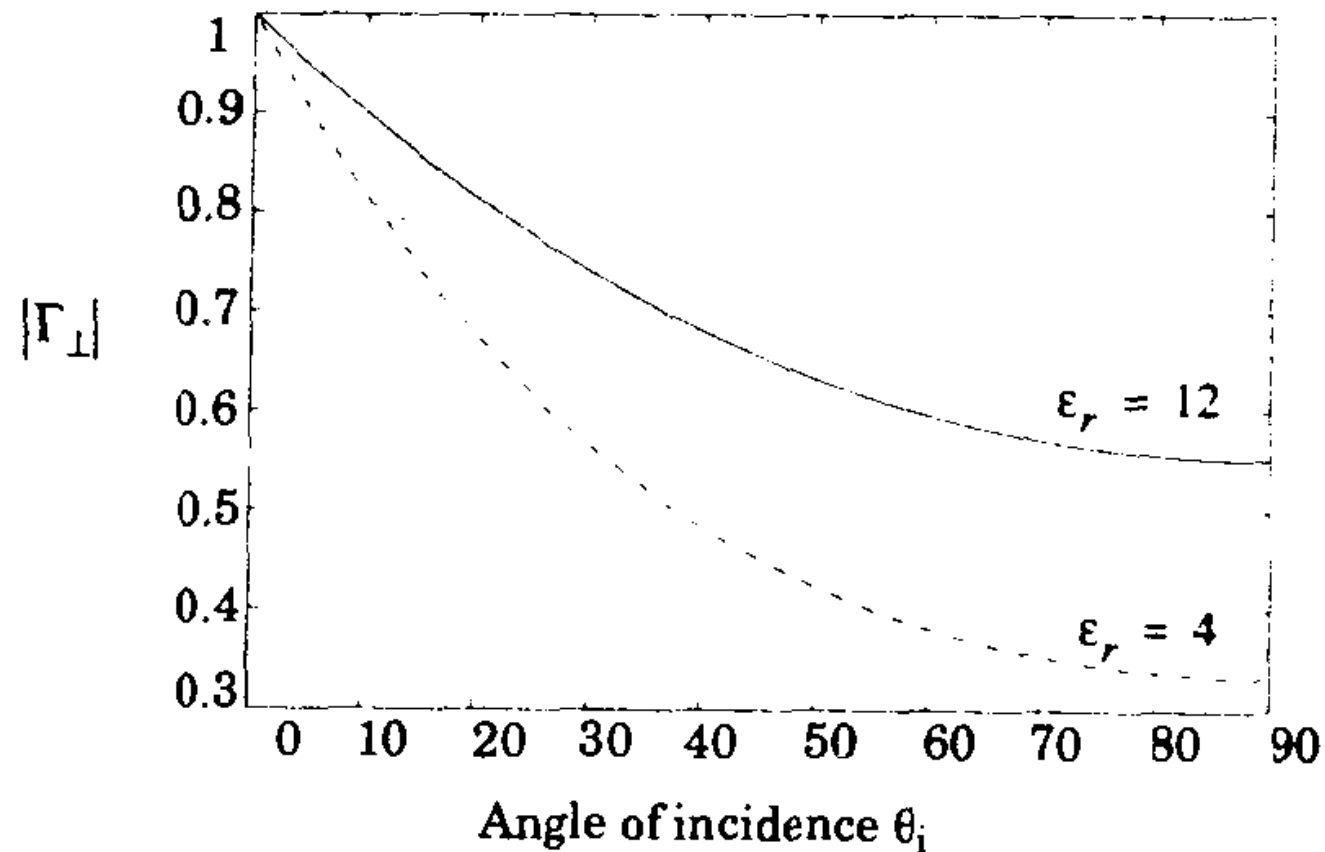


Figure shows a plot of the reflection coefficient for **Horizontal(perpendicular) polarization** as a function of the incident angle for the case when a wave propagates in free space and the reflection surface has **(a) $\epsilon_r = 4$, and (b) $\epsilon_r = 12$.**



Perpendicular polarization (E-field not in plane of incidence)

Example 3.4

Demonstrate that if medium 1 is free space and medium 2 is a dielectric, both $|\Gamma_{\parallel}|$ and $|\Gamma_{\perp}|$ approach 1 as θ_i approaches 0° regardless of ϵ_r .

Reflection from Perfect Conductors:

- Since electromagnetic **energy cannot pass through a perfect conductor** a plane wave incident on a conductor has all of its energy reflected.
- As the electric field at the surface of the conductor **must be equal to zero at all times in order to obey Maxwell's equations**, the reflected wave **must be equal in magnitude** to the incident wave.
- For the case when E-field polarization is in the plane of incidence, the boundary conditions require that:

$$\theta_r = \theta_i$$

And $E_i = E_r$ (E-field in plane of incidence : **No phase change**)

- Similarly, for the case when the E-field is **horizontally polarized**, the boundary conditions require that
- **$E_i = -E_r$** (E field normal to plane of incidence – There is a **phase reversal of a 180 degree**)

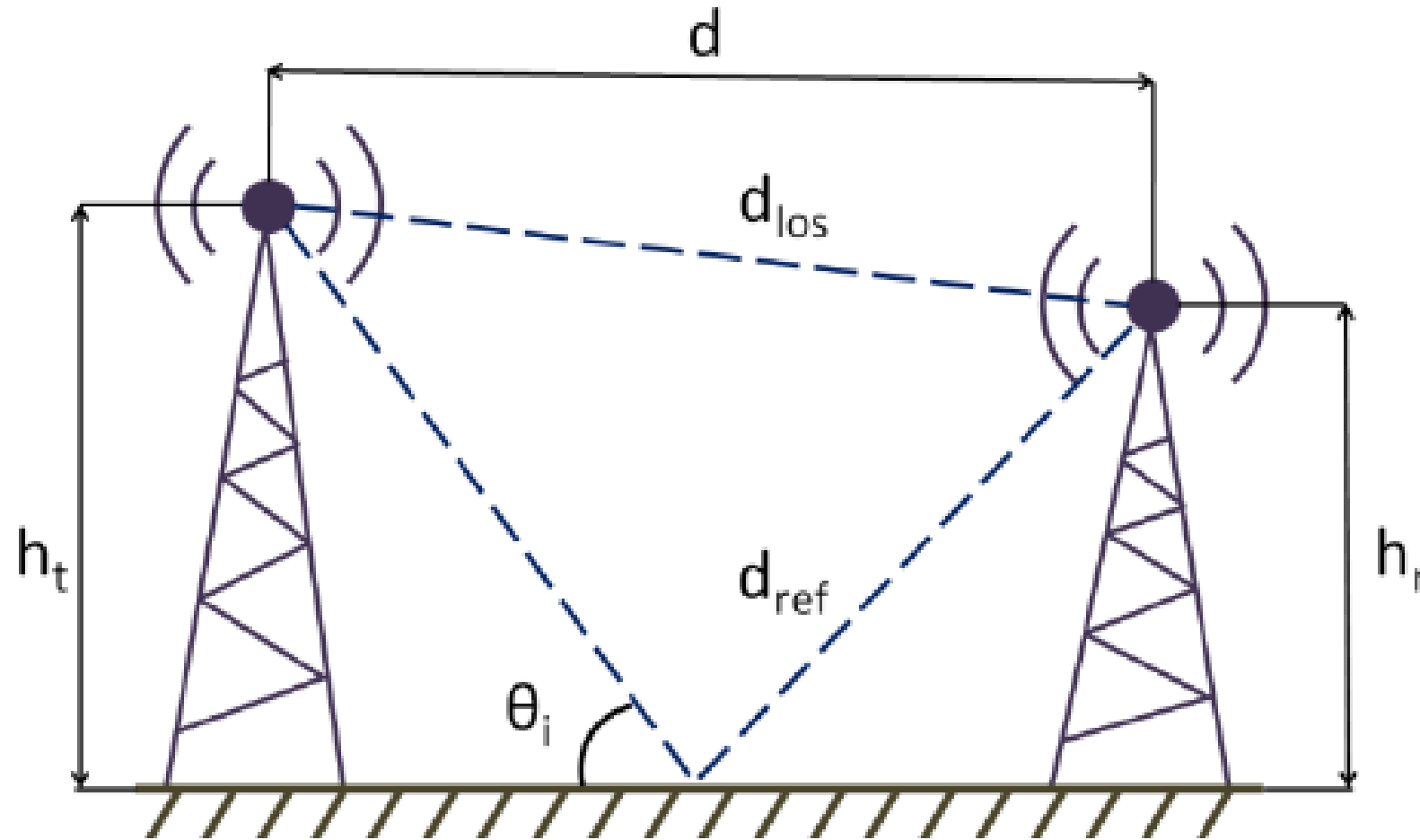
Reflection coefficient values as follows :

- $\Gamma(\text{parallel or vertical}) = 1$
- $\Gamma(\text{perpendicular or horizontal}) = -1$

Ground Reflection (Two Ray) Model:

- In mobile radio channel, **single direct path between base station and mobile is seldom**, and hence the **free space propagation model** is in most **cases inaccurate** when used alone.
- Two ray ground reflection model is useful
 - Based on **geometric optics**
 - considers **both the direct path and a ground reflected propagation path** between transmitter and receiver
- 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:



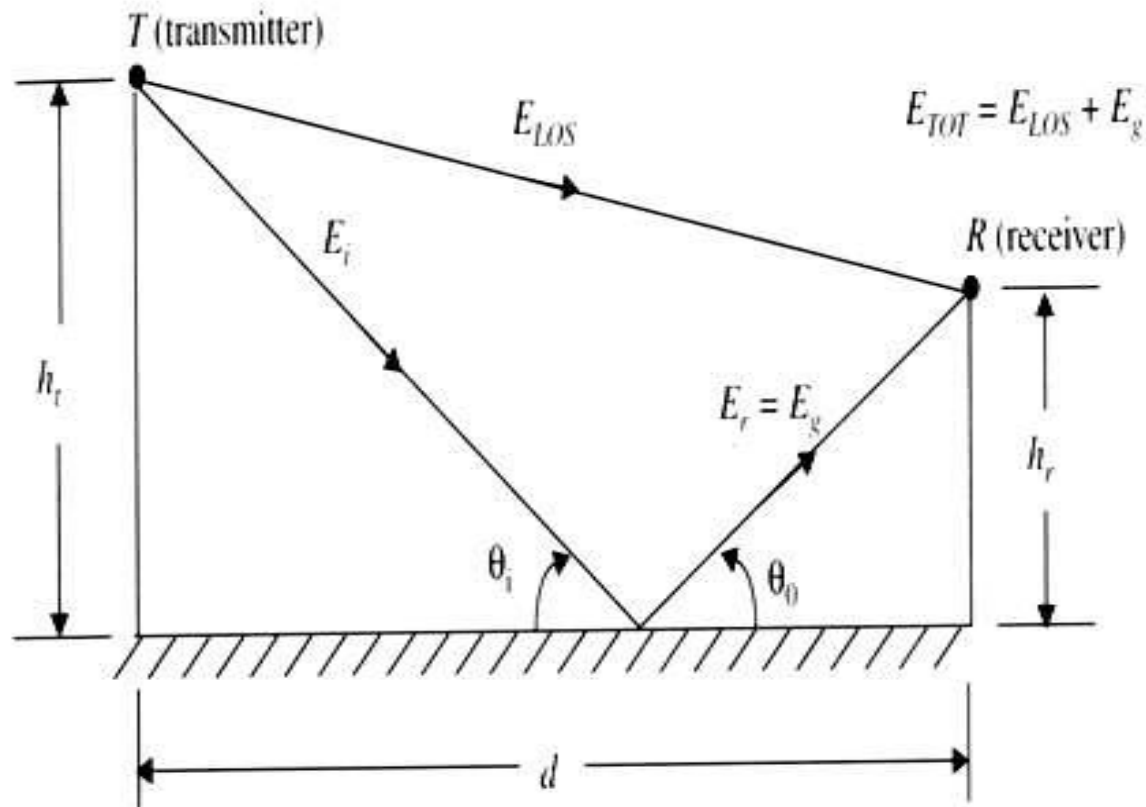


Figure 4.7 Two-ray ground reflection model.

Where;

ht – height of Tx Antenna

hr – height of Rx Antenna

E_{LOS} – E field of LOS Signal

E_g – E field of Reflected Signal

E_i - E field of incident Signal

d- (T-R) Separation

Assumptions:

1. **Height of the antennas are larger** than the wavelength of propagating wave.
2. Height of the antennas are lesser than the **T-R separation**.
3. Earth as a **perfect conductor**.
4. **Lack of curvature** of earth.

- Parameters to be Estimated

- E field of both rays (**E_{LOS} & E_g**)
- Path Difference (**▲**)
- Phase difference (**θ▲**)
- Time Delay (**T_d**)
- If **E₀** is the free space E-field (in units of V/m) at a reference distance **d₀** from the transmitter, then for $d > d_0$: , the free space propagating E—field is given by:

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

Above equation is derived by an Equation related to **Fields of the Electromagnetic theory**.

$$E(Z, t) = E_0 \cdot e^{-\alpha Z} \cdot \cos(\omega t - \beta Z) \cdot \hat{ax}$$

ax – Direction of E field variation

Z - direction of propagation

β - Phase constant

W - Frequency

α - Attenuation constant

E₀ - Amplitude of wave

- Two propagating waves arrive at the receiver:
 - The **direct wave** that travels a distance **d'**; and
 - The **reflected wave** that travels a distance **d''**.
- The **E-field due to the line-of-sight component at the receiver** can be expressed as:

$$E_{los}(d', t) = \frac{E_o d_o}{d'} \cdot \cos \left(\omega_c \left(t - \frac{d'}{c} \right) \right)$$

- **E-field for the ground reflected wave**, which has a propagation distance of **d''**, can be expressed as

$$E_g(d'', t) = \textcolor{red}{\Gamma} \frac{E_o d_o}{d''} \cdot \cos \left(\omega_c \left(t - \frac{d''}{c} \right) \right)$$

- According to **laws of reflection** in dielectrics

$$\theta_i = \theta_o$$

- E-field for the ground reflected wave, which has a propagation distance of d'' , can be expressed as **Total E field equation** is given by:

and

$$\mathbf{E}_g = \Gamma \mathbf{E}_i$$

$$\mathbf{E}_t = (1 + \Gamma) \mathbf{E}_i$$

- Where Γ is the **reflection coefficient** for ground. **For small values of θ_i** (i.e., grazing incidence), the **reflected wave is equal in magnitude and 180° out of phase** with the incident wave.
- The resultant E-field, assuming **perfect ground reflection** (i.e., $\Gamma = -1$ and $\mathbf{E}_t = \mathbf{0}$) is the vector sum of **\mathbf{E}_{LOS} and \mathbf{E}_g** the resultant total E-field envelope is given by:

$$|\mathbf{E}_{tot}| = |\mathbf{E}_{los}| + |\mathbf{E}_g|$$

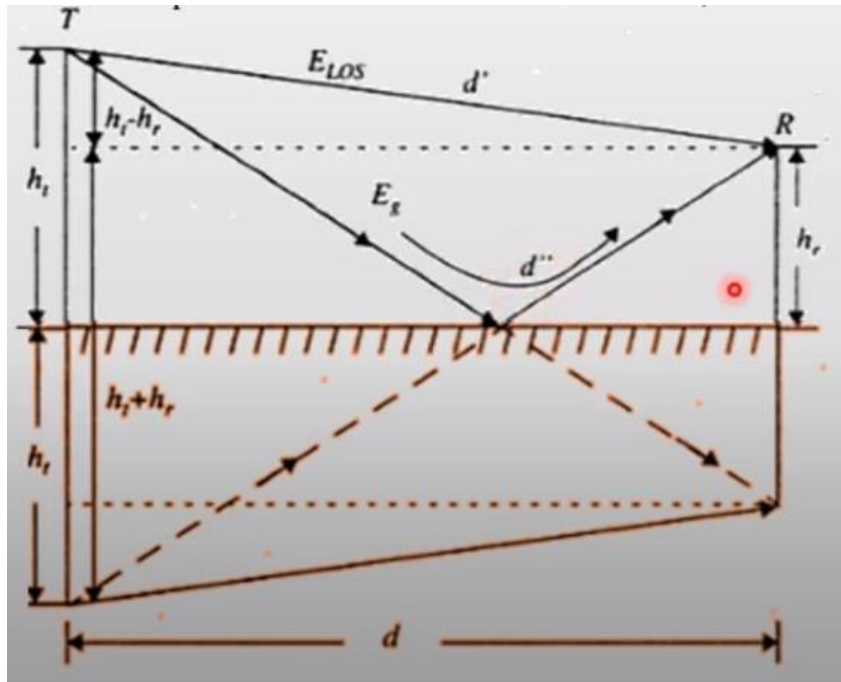
$$|E_{tot}| = \frac{E_o d_o}{d'} \cdot \cos\left(\omega_c(t - \frac{d'}{c})\right) + \textcolor{red}{\Gamma} \frac{E_o d_o}{d''} \cdot \cos\left(\omega_c(t - \frac{d''}{c})\right)$$

- Assuming the ground is a perfect conductor, we get reflection

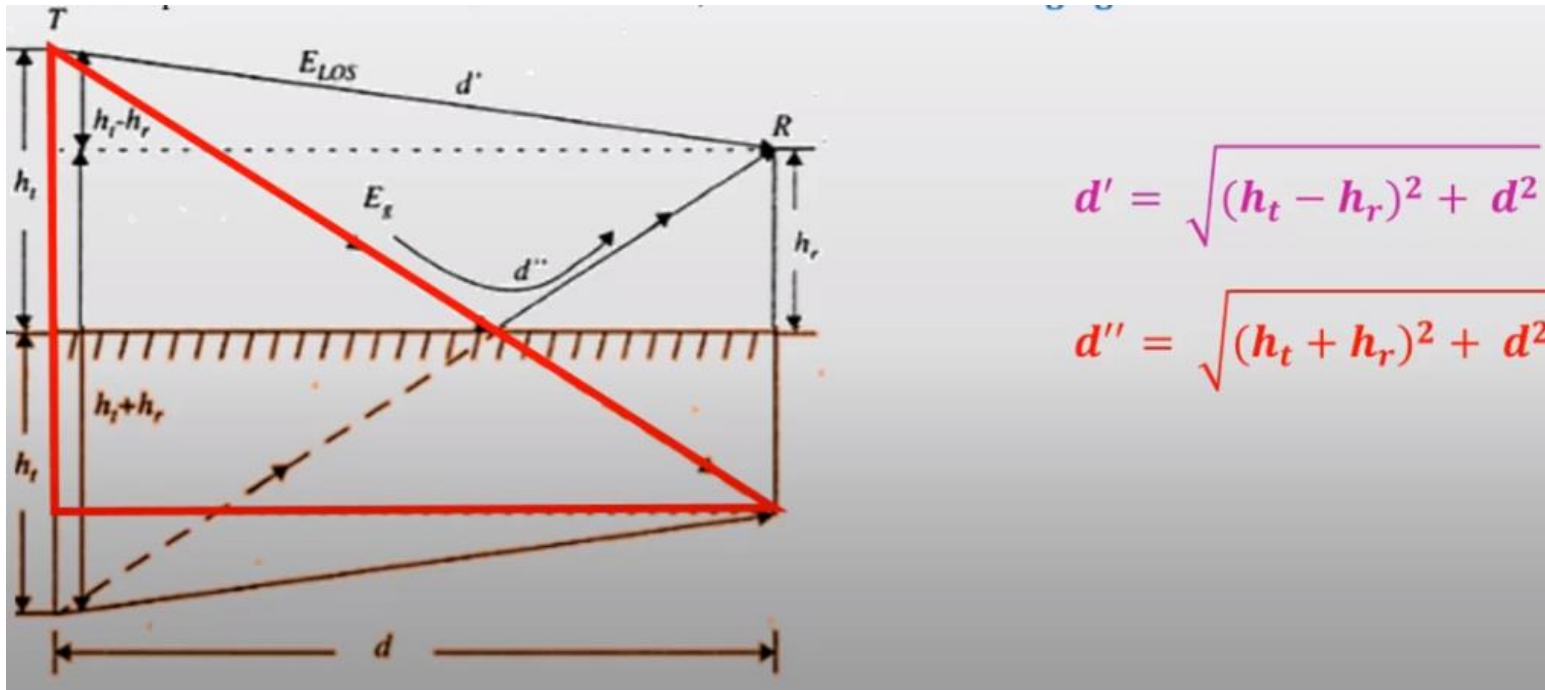
$$E_{TOT}(d, t) = \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + (-1) \frac{E_0 d_0}{d''} \cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

Calculate the Path difference (▲)

- Since the path taken by two rays are different and they travel different distances. We use **method of imaging** to find the path difference.



➤ We can get the values for the d' and d''



$$d' = \sqrt{(h_t - h_r)^2 + d^2}$$

$$d'' = \sqrt{(h_t + h_r)^2 + d^2}$$

Path difference can be taken as: $\Delta = d'' - d' = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$

When the T-R separation distance d is very large compared $h_t + h_r$, Equation can be simplified using a **Taylor series approximation**

$$\Delta = d'' - d' \approx \frac{2h_t h_r}{d}$$

- When we know the phase difference and time delay between the two E field components,
- we can calculate **phase difference** as:

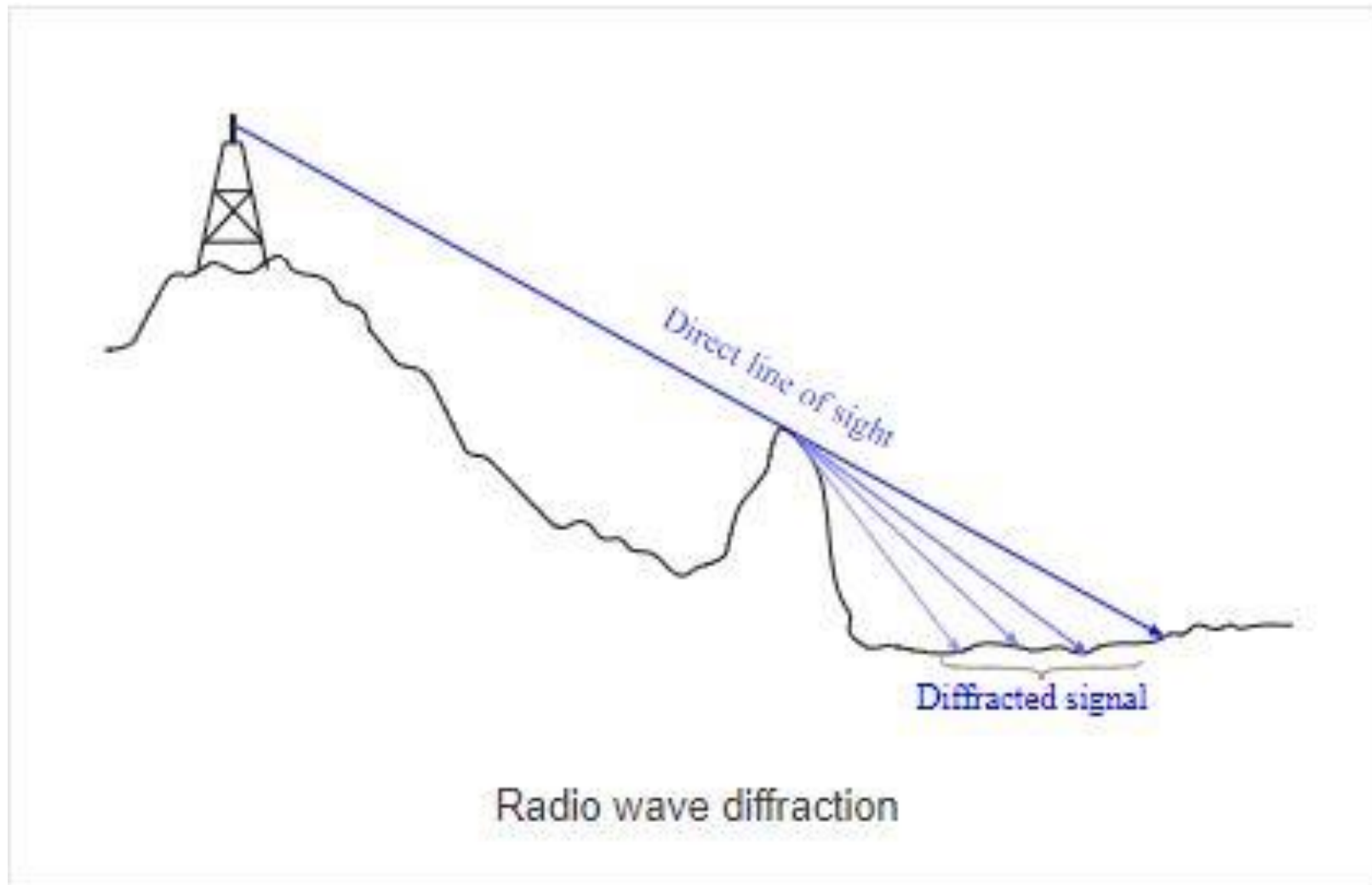
$$\theta_{\Delta} = \frac{2\pi\Delta}{\lambda} = \frac{\Delta\omega_c}{c}$$

- Time delay as:

$$\tau_d = \frac{\Delta}{c} = \frac{\theta_{\Delta}}{2\pi f_c}$$

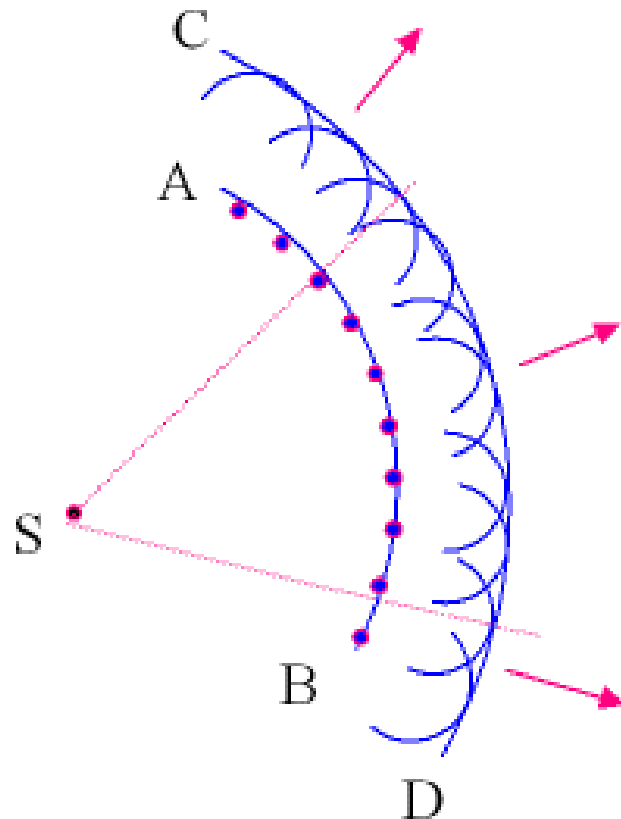
Diffraction:

- 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 is a phenomena which demonstrates the **wave property** of the light or EM waves.

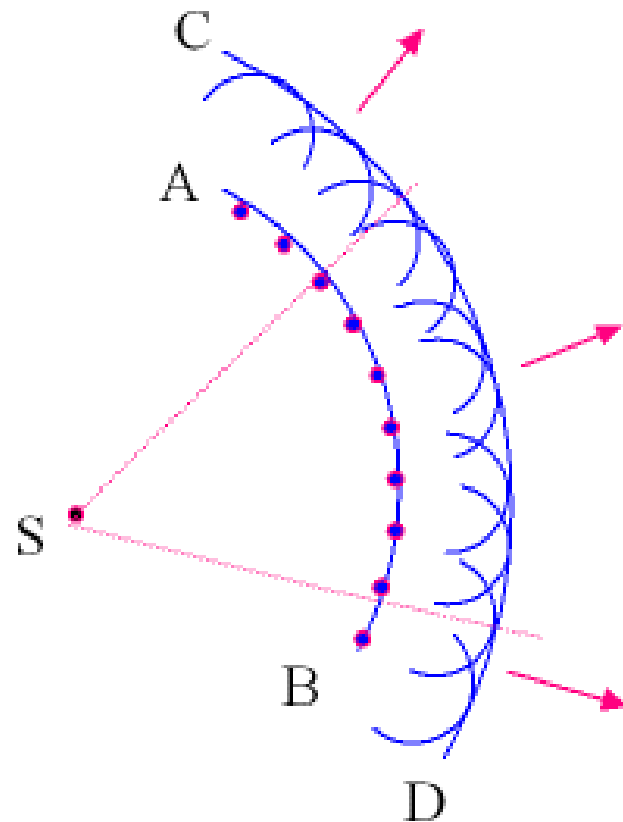
- The phenomenon of diffraction can be explained by **Huygen's principle**, which states that **all points on a wave front can be considered as point sources for the production of secondary wavelets**, and that these **wavelets combine to produce a new wave front** in the direction of propagation.



Huygens' Principle:

Each wavefront is the envelope of the wavelets. Each point on a wavefront acts as an independent source to generate wavelets for the next wavefront. AB and CD are two wavefronts.

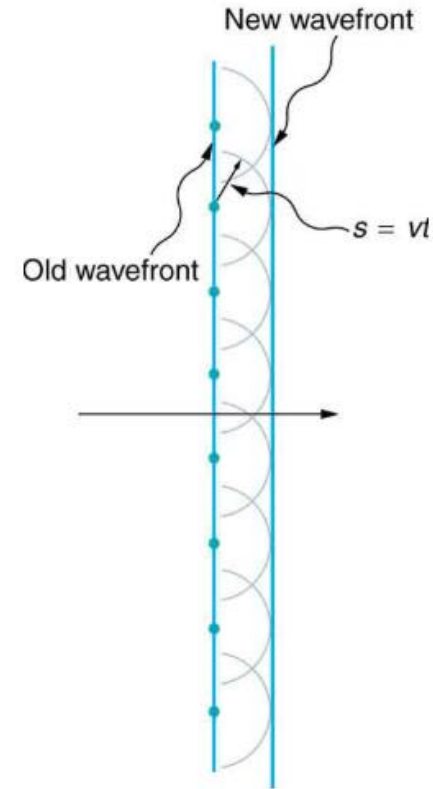
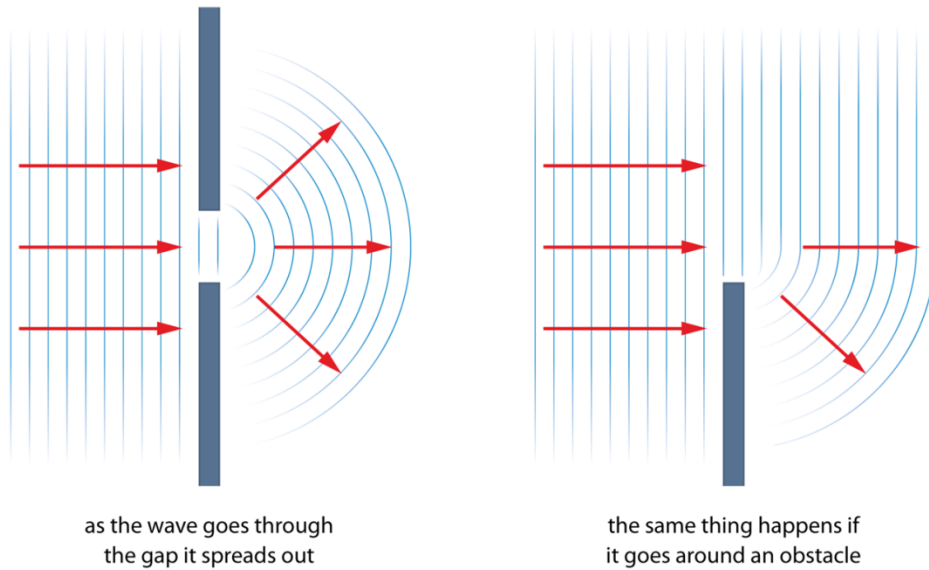
- Diffraction is caused by the **propagation of secondary wavelets** into a **shadowed region**.
- The **field strength of a diffracted wave in the shadowed region is the vector sum** of the electric field components of all the secondary wavelets in the space around the obstacle.



Huygens' Principle:

Each wavefront is the envelope of the wavelets. Each point on a wavefront acts as an independent source to generate wavelets for the next wavefront. AB and CD are two wavefronts.

- Suppose wave fronts are travelling and hit an obstacle with an opening : **Assume the opening is much smaller than the wavelength of the wave itself.**



- Huygen's principle **predicts that the wave will partially** move through the opening. This ability is called **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 insight 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**.
- 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 field behind a knife edge**.

- 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.

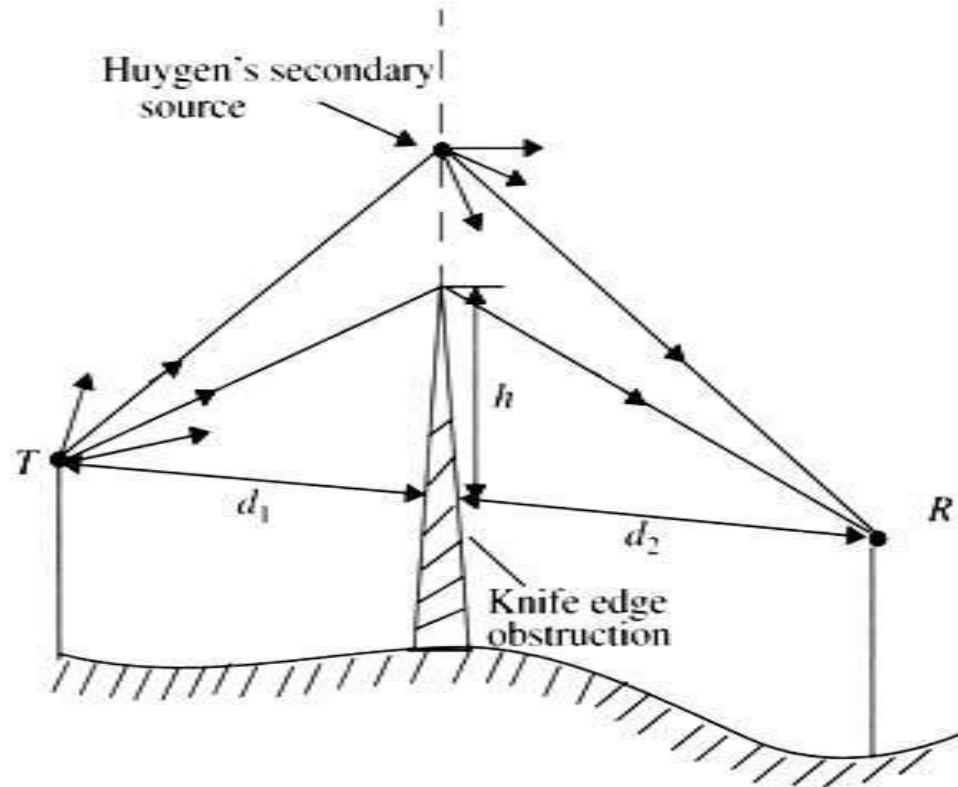
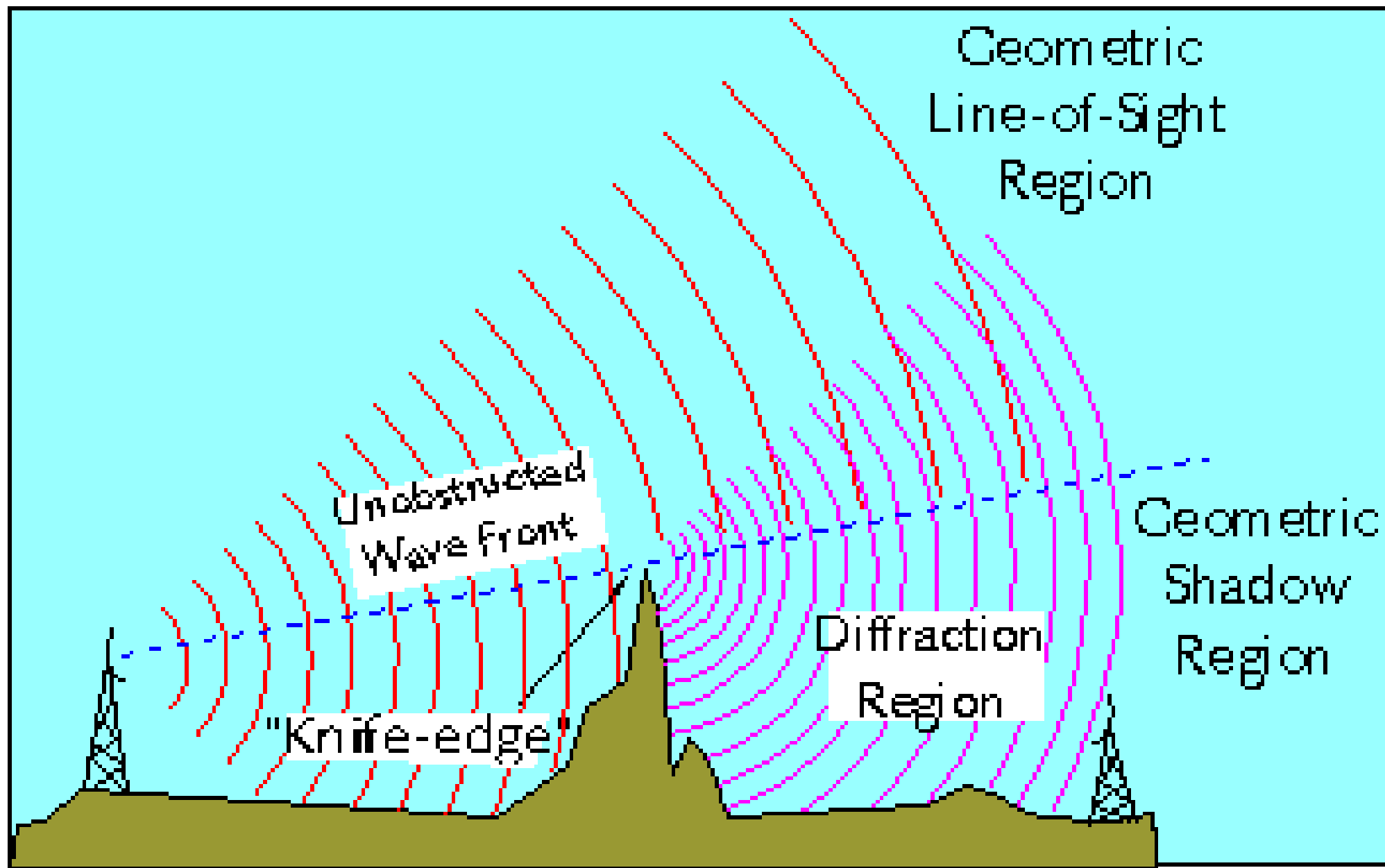
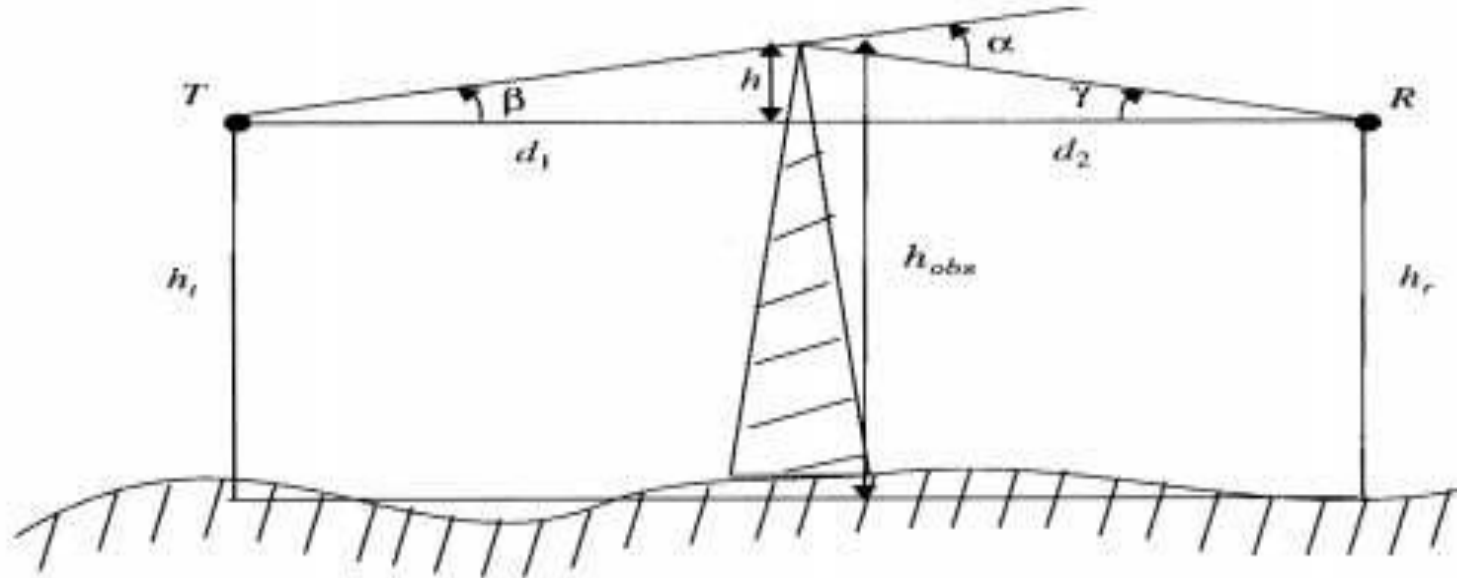


Figure 4.13 Illustration of knife-edge diffraction geometry. The receiver R is located in the shadow region.



knife-edge effect

Knife Edge Geometry when $h_t = h_r$

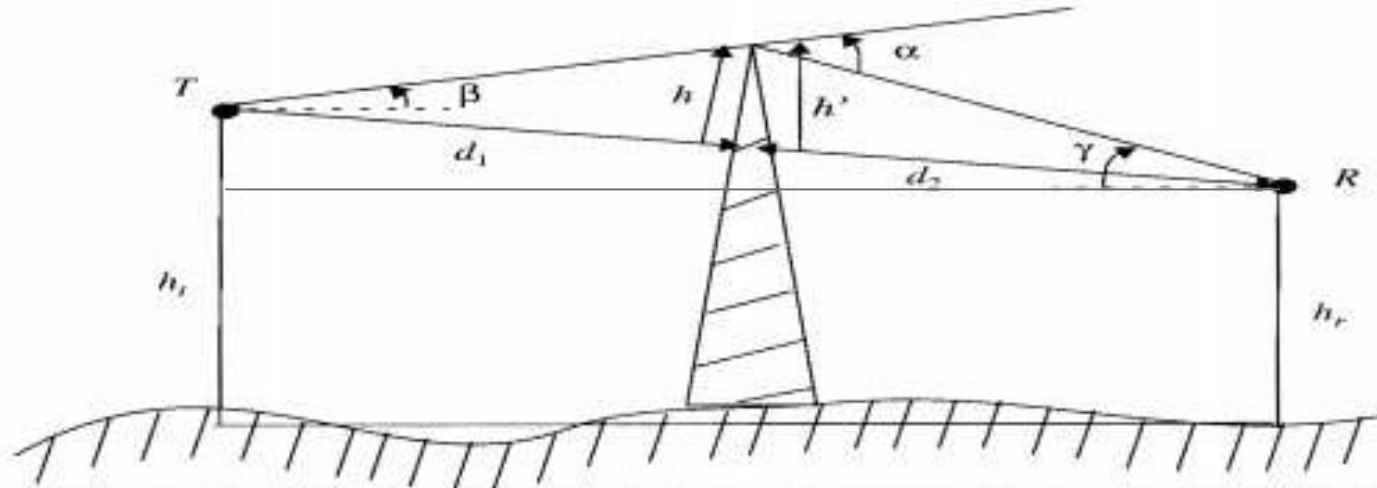


(a) Knife-edge diffraction geometry. The point T denotes the transmitter and R denotes the receiver, with an infinite knife-edge obstruction blocking the line-of-sight path.

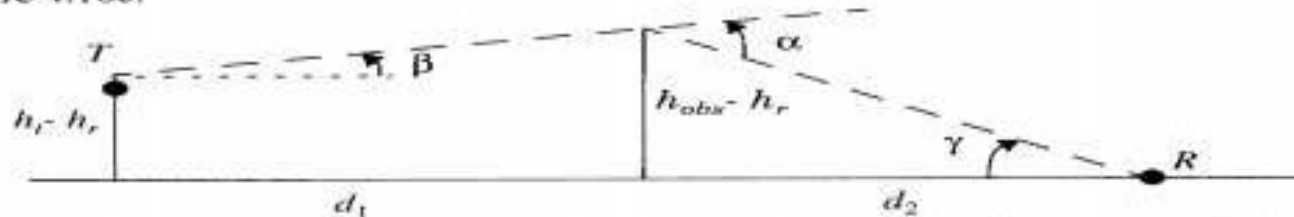
- Here **h is the effective height** of the Obstacle, which is affected for the diffraction/or can be considered as the **sharp edge**.

We can consider the $h = h_{obs} - h_t$

Knife Edge Geometry when $h_t > h_r$



(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 $h \ll d_1$ 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.

- When the α and β are very small, then h and h' can be approximated to be same.
- Above first diagram is the **most practical diagram** and we have derived second diagram from it.

Assuming $h \ll d_1, d_2$ and $h \gg \text{Wave Length}$, We can obtain the difference between the direct path and the diffracted path, called the **excess path delay** from above figure a as:

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

Phase difference can be written as: $\phi = \frac{2\pi\Delta}{\lambda} \approx \frac{2\pi}{\lambda} \frac{h^2}{2} \frac{(d_1 + d_2)}{d_1 d_2}$

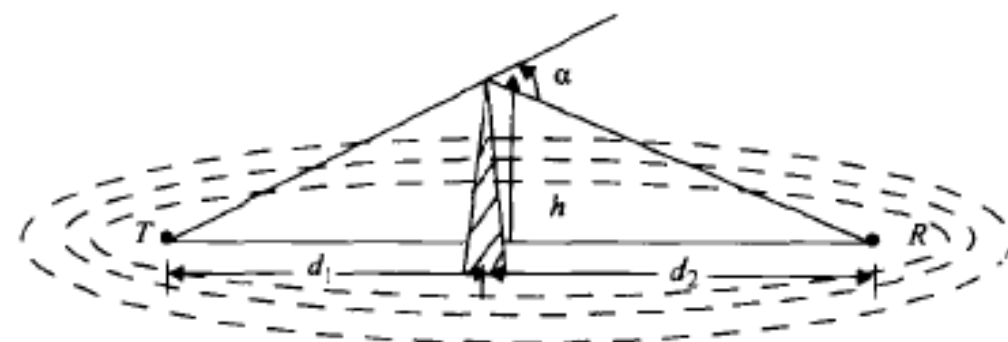
Fresnel-Kirchoff diffraction parameter v which is given by;

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

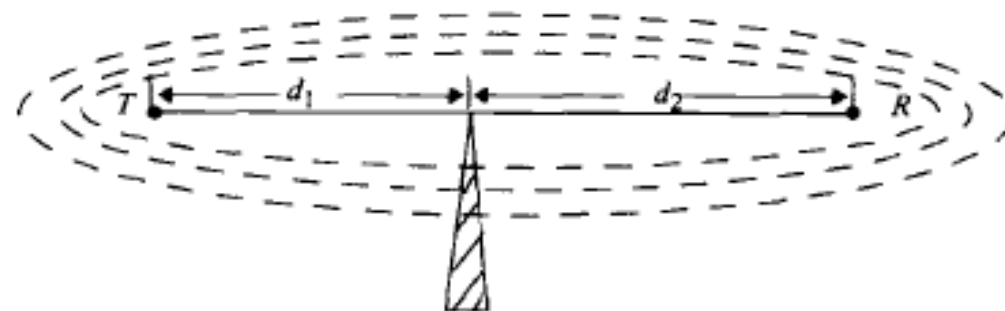
where α has units of radians.

Phase Difference can be written as: $\phi = \frac{\pi}{2} v^2$

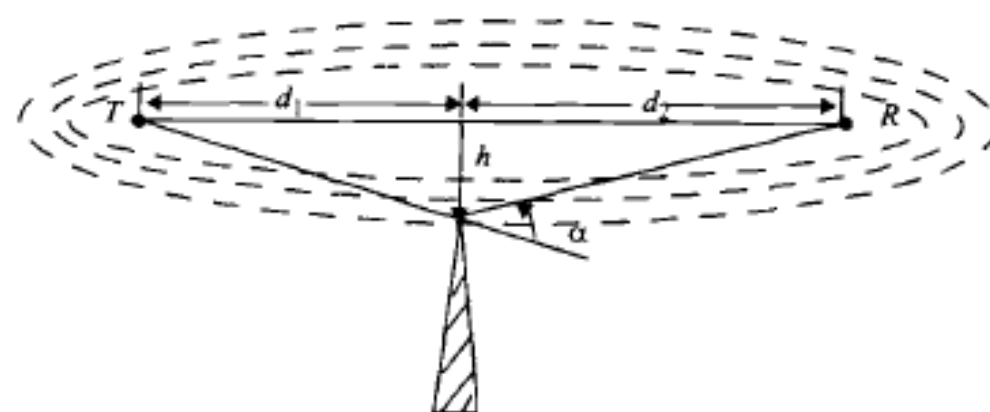
α can be calculated from **figure c** ; $\alpha \approx h \left(\frac{d_1 + d_2}{d_1 d_2} \right)$



(a) α and v are positive, since h is positive



(b) α and v are equal to zero, since h is equal to zero



(c) α and v are negative, since h is negative

Figure 3.12
Illustration of Fresnel zones for different knife-edge diffraction scenarios.

Fresnel-Kirchoff diffraction parameter

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

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

- where **E(o)** 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 **diffraction gain due to the presence of a knife edge**, as compared to the free space E-field, is given by

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

An approximate solution for equation provided as:

$G_d(\text{dB}) = 0$	$v \leq -1$
$G_d(\text{dB}) = 20\log(0.5 - 0.62v)$	$-1 \leq v \leq 0$
$G_d(\text{dB}) = 20\log(0.5 \exp(-0.95v))$	$0 \leq v \leq 1$
$G_d(\text{dB}) = 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1v)^2}\right)$	$1 \leq v \leq 2.4$
$G_d(\text{dB}) = 20\log\left(\frac{0.225}{v}\right)$	$v > 2.4$

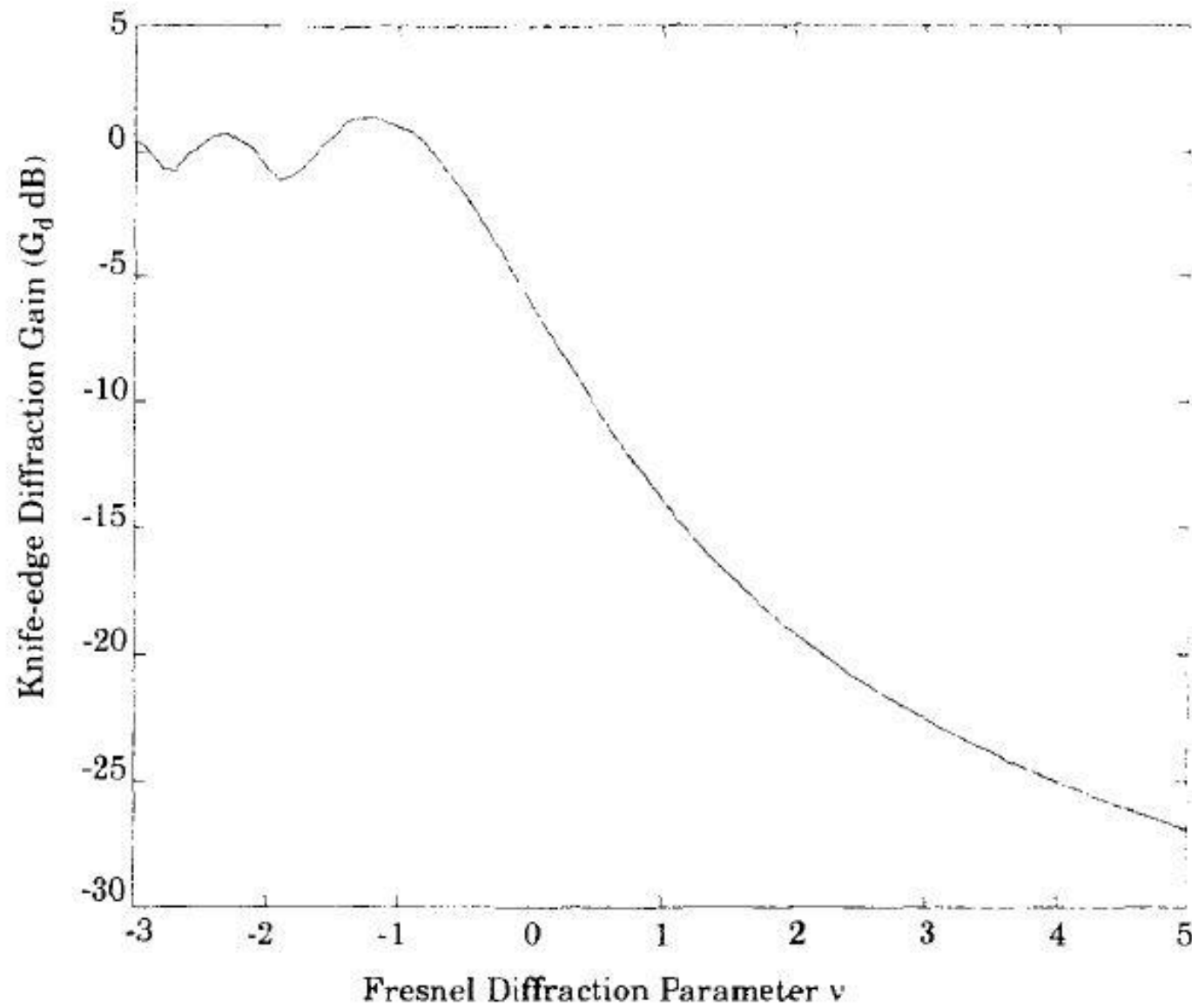
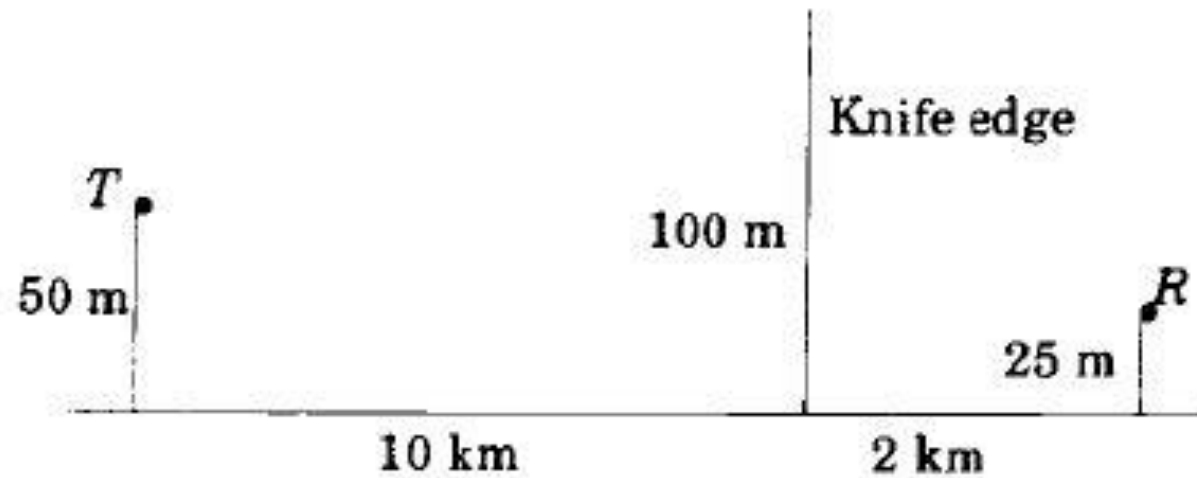


Figure 3.14
Knife-edge diffraction gain as a function of Fresnel diffraction parameter v

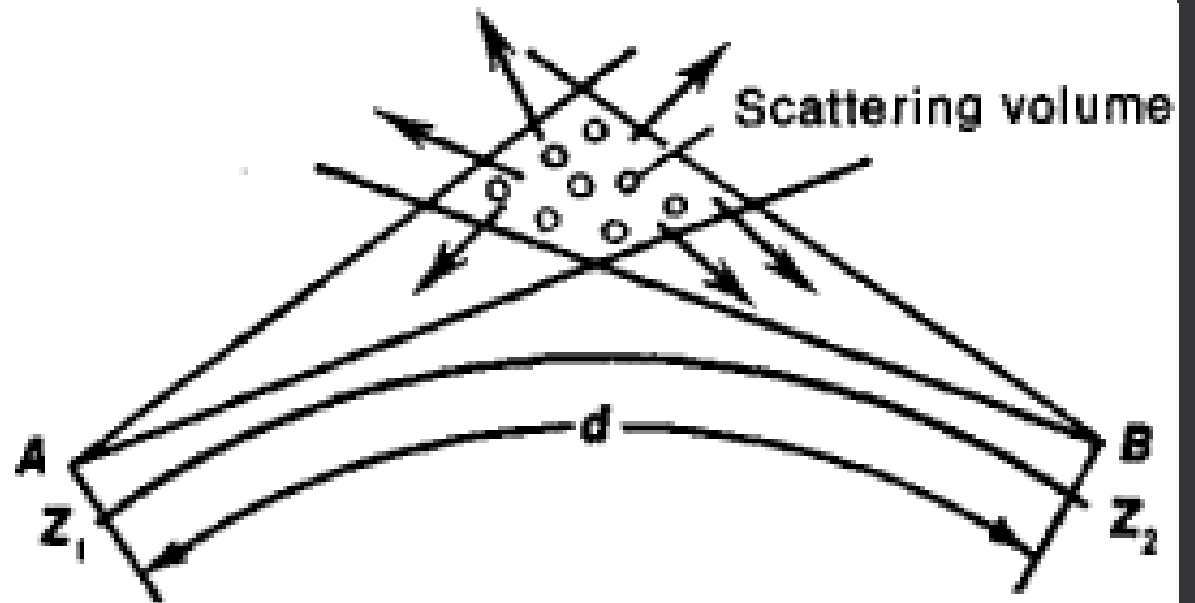
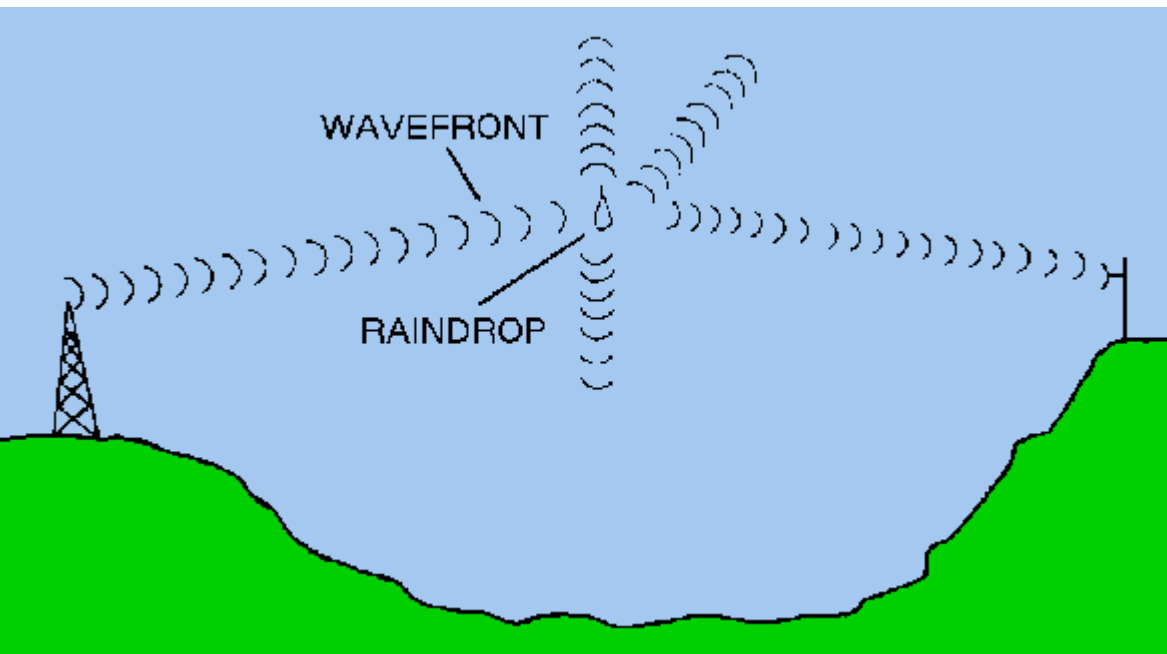
• Q-1

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.

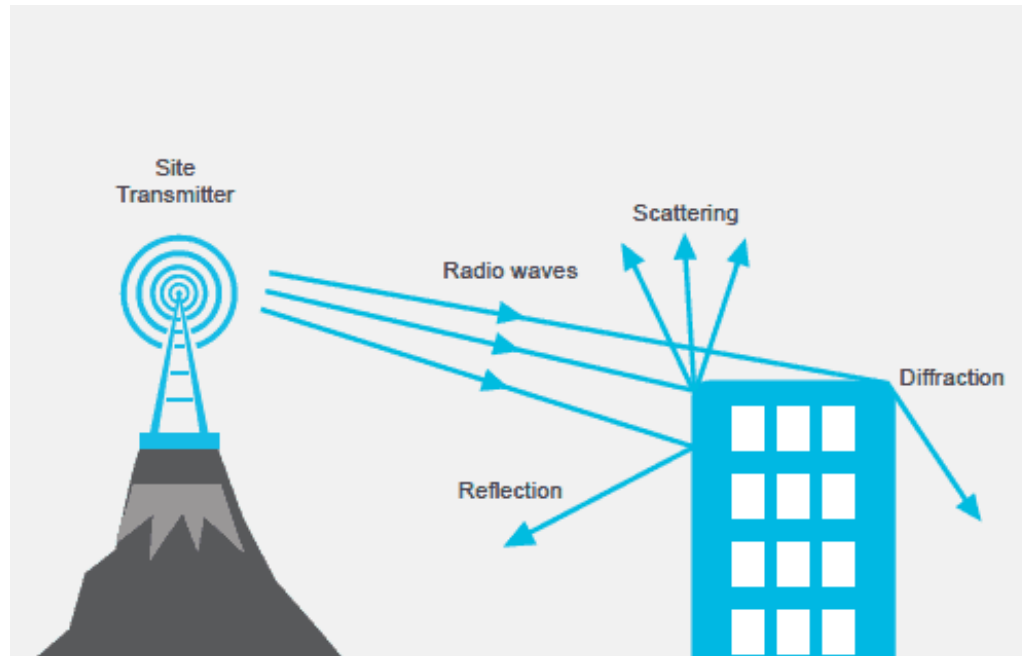


Scattering:

- 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.



- The **actual received signal** in a mobile radio environment is **often stronger** than what is **predicted by reflection and diffraction** models alone.
- This is because when a radio wave impinges on a rough surface, the **reflected energy is spread out (diffused)** in all **directions due to scattering**.
- Objects such as **lamp posts and trees** tend to scatter energy in all directions, thereby **providing additional radio energy at a receiver**.



Scattering:

- Rough surfaces induces specular reflections:

Surface roughness is often tested using the **Rayleigh criterion** which defines a **critical height (hc)** of surface protuberances for a given **angle of incidence θ_i** is given by:

$$h_c = \frac{\lambda}{8 \sin \theta_i}$$

- Roughness is depend on: **Surface height range, Angle of incidence and Wavelength**

Let **h** = maximum protuberance – minimum protuberance

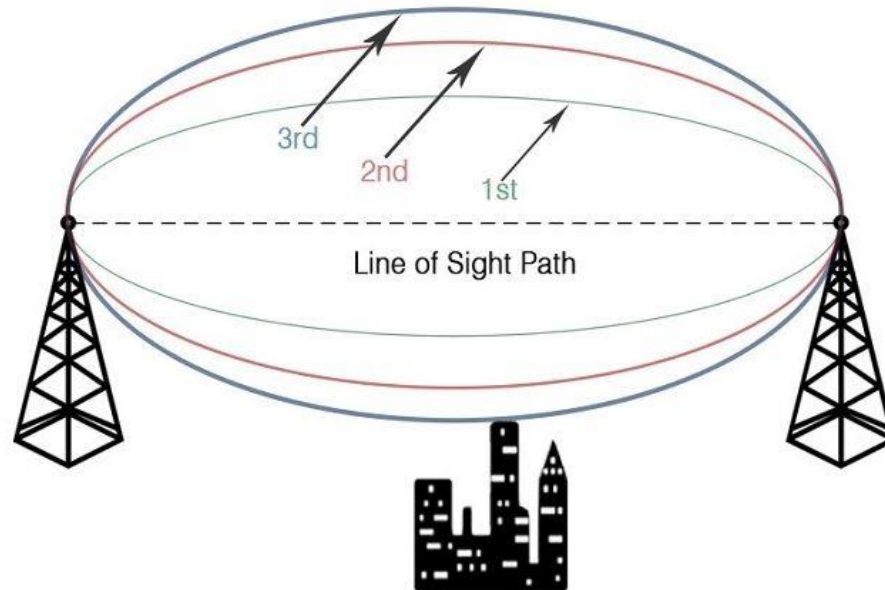
if **h** < **hc** ; surface is **considered smooth**

if **h** > **hc** ; surface is **considered rough**

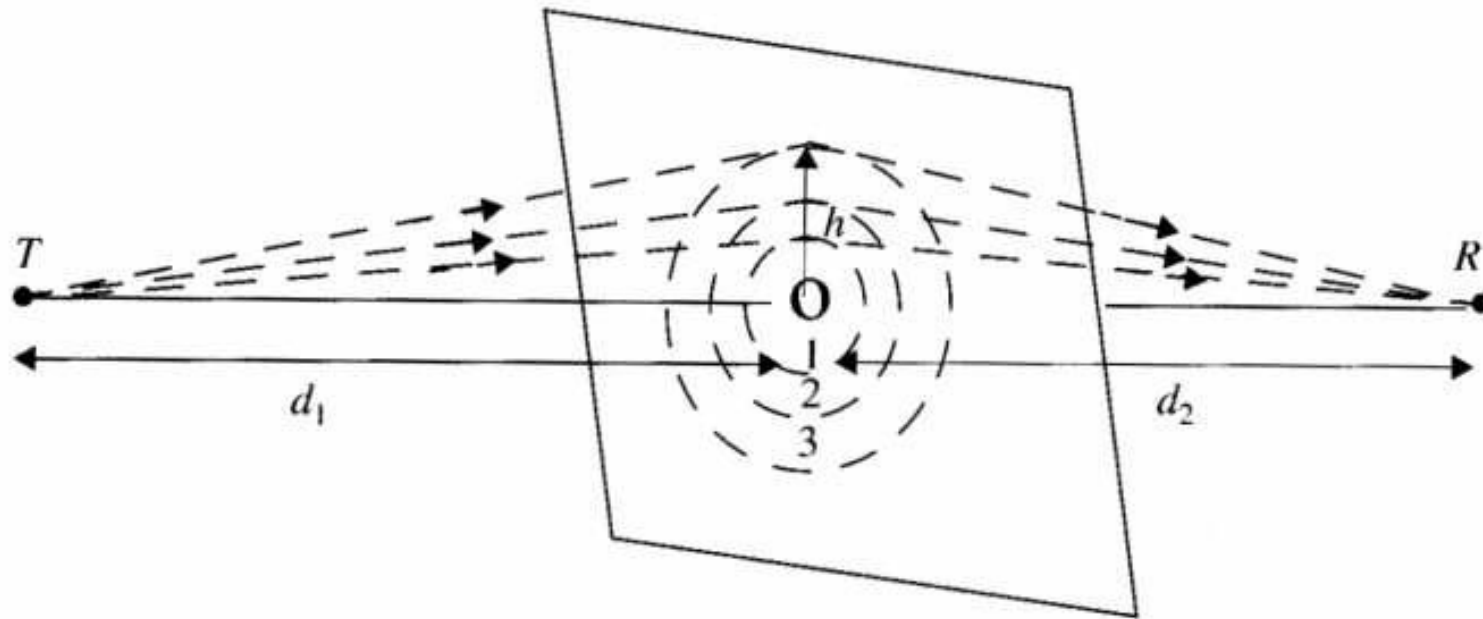


Fresnel Zone Geometry

- It is important to keep an **elliptical region** between **the transmit antenna and the receive antenna free** from any obstruction for the proper functioning of the system.
- This **3D elliptical region** between the transmit antenna and the receive antenna **is called the Fresnel Zone**.
- The size of the ellipse is determined by the **frequency** of operation and the **distance** between the two sites.

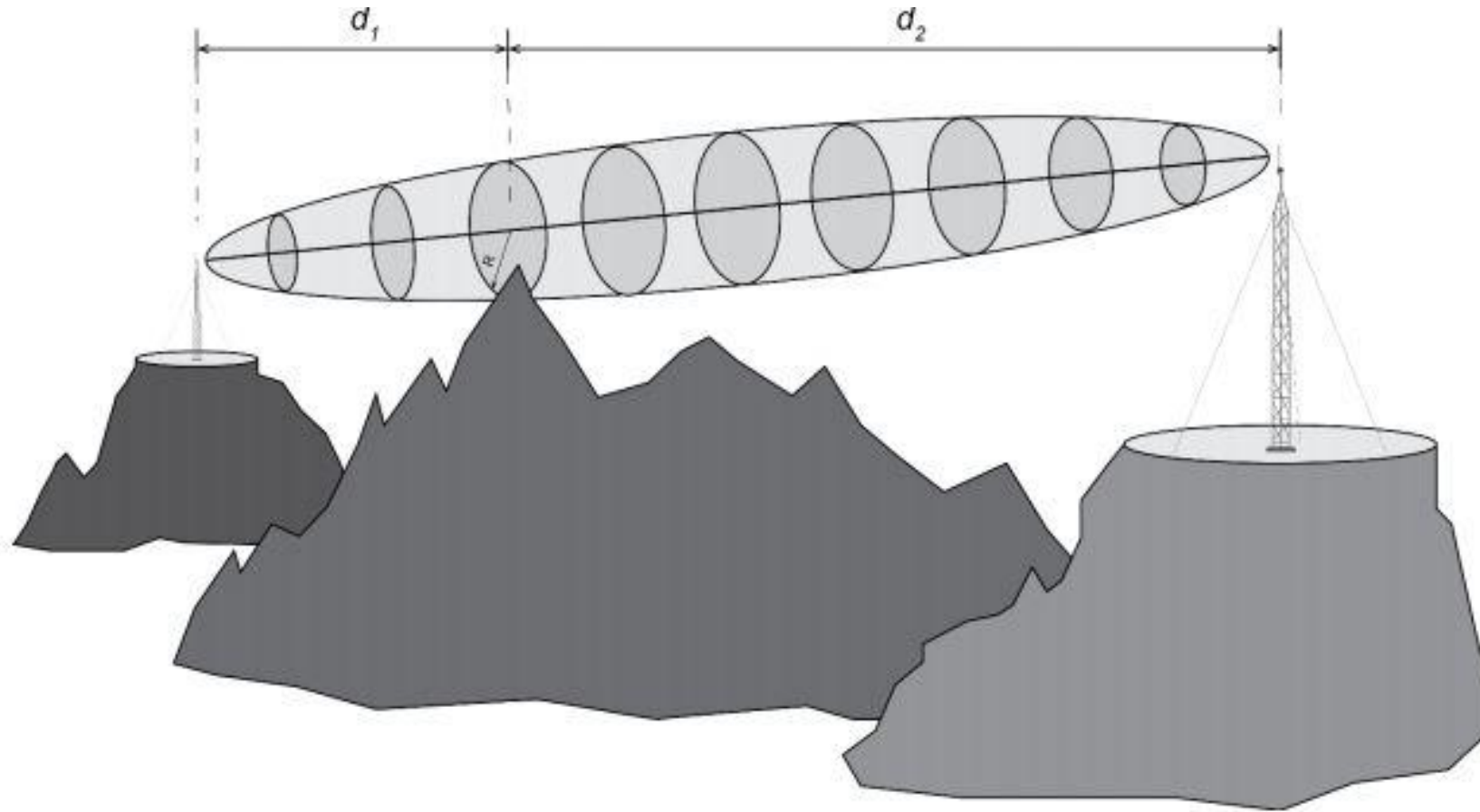


- Fresnel zones represent successive regions where secondary waves have a path length from the TX to the RX **which are $n\lambda/2$ greater in path length than of the LOS path**. The plane below illustrates successive Fresnel zones.

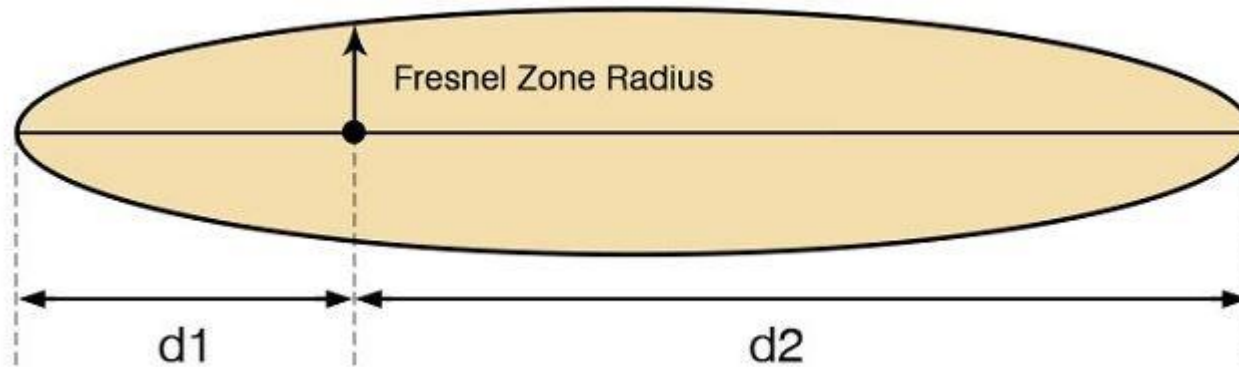


Concentric circles which define the boundaries of successive Fresnel zones.

- The **primary Fresnel zone** is required to be at least **60% clear of any obstruction** to ensure the highest performance of wireless link.



- The Fresnel zone is made up of multiple zones, with **zone 1 having the strongest signal** and following zones (Zone 2, and Zone 3) having **weaker signals**.



$$\text{Fresnel Zone radius, } R = \sqrt{\frac{n d_1 d_2 \lambda}{d_1 + d_2}}$$

Where,

n = Fresnel Zone number (Should be greater than zero)

λ = Frequency

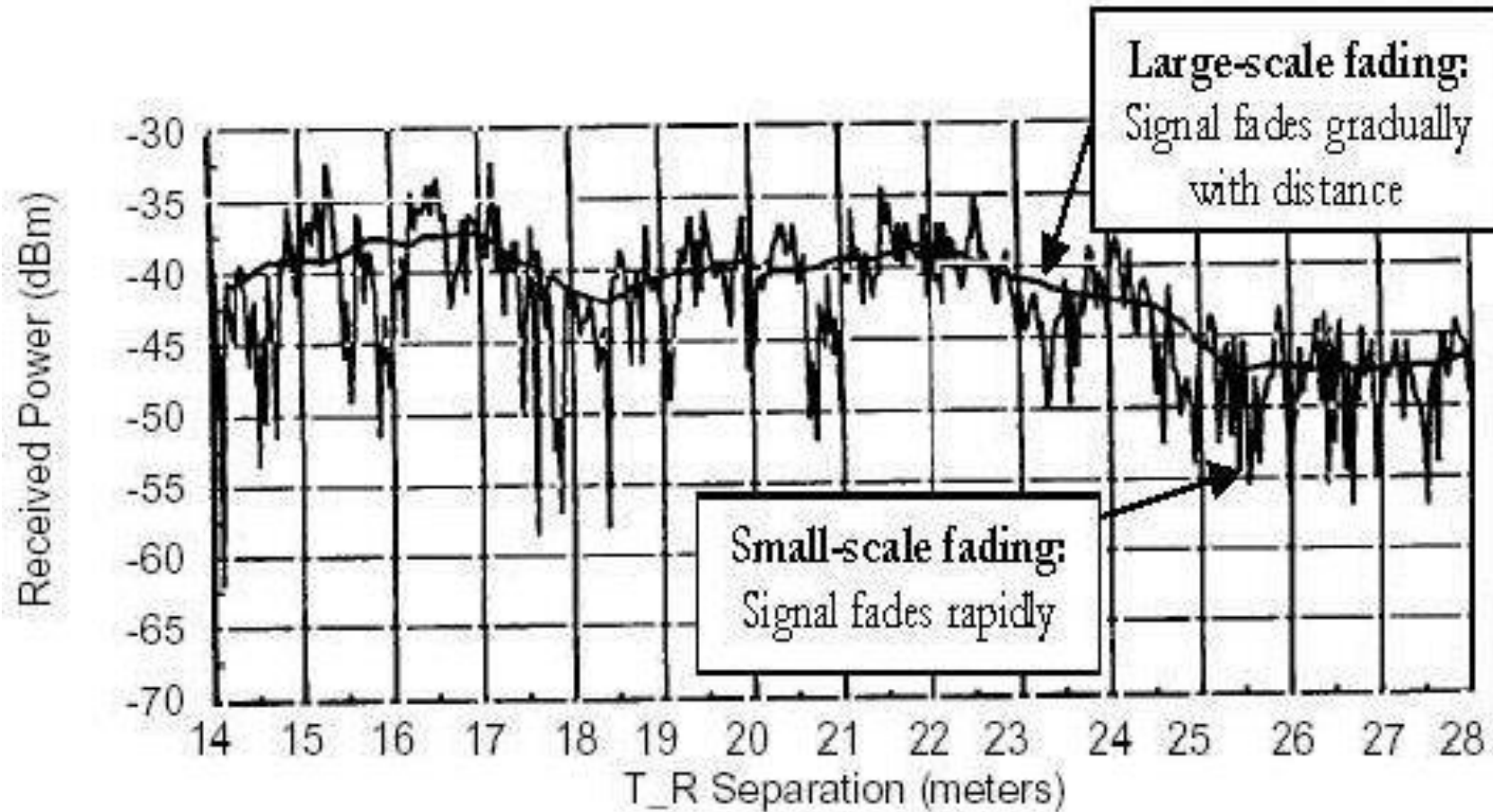
Fading

- Fading refers to the **variation of the signal strength (Fluctuation of the Amplitude of a Radio Signal)** with respect to **time period or Travel distance** and is widely prevalent in wireless transmissions.
- The most common causes of fading in the wireless environment are **multipath propagation and mobility** (of objects as well as the communicating devices)
- The fading phenomena results as a result of **constructive interference or Destructive interference** at the receiver side.
- Caused by interference from **multiple copies of Tx signal** arriving at Rx at **slightly different times**.

Large Scale Fading

- Large scale-fading represents the average signal-power attenuation or path loss **due to motion over large areas. (In the scale of cell size)**
- It is impacted by terrain configuration between the transmitter and receiver, and over a very long distance (**several hundreds or thousands of meters**), there is a steady decrease in power.

Large Scale fading vs Small Scale Fading



Small Scale Fading

- **Small-scale fading**, or simply fading describes the **rapid fluctuation of the amplitude (some times phase)** of a radio signal **over a short period of time or travel distance**.
- It is **caused by interference** between two or more versions of the transmitted signal which arrive at the receiver at different times.
- This interference can vary widely in **amplitude and phase over time**.

Small-Scale Fading effects

- The three most **important fading effects** are:
 1. **Rapid changes in signal strength** over a small travel distance or time interval.
 2. **Random frequency modulation** due to varying Doppler shifts (described later) on different multi-path signals.
 3. **Time dispersions (echos)** caused by multi-path propagation delays.

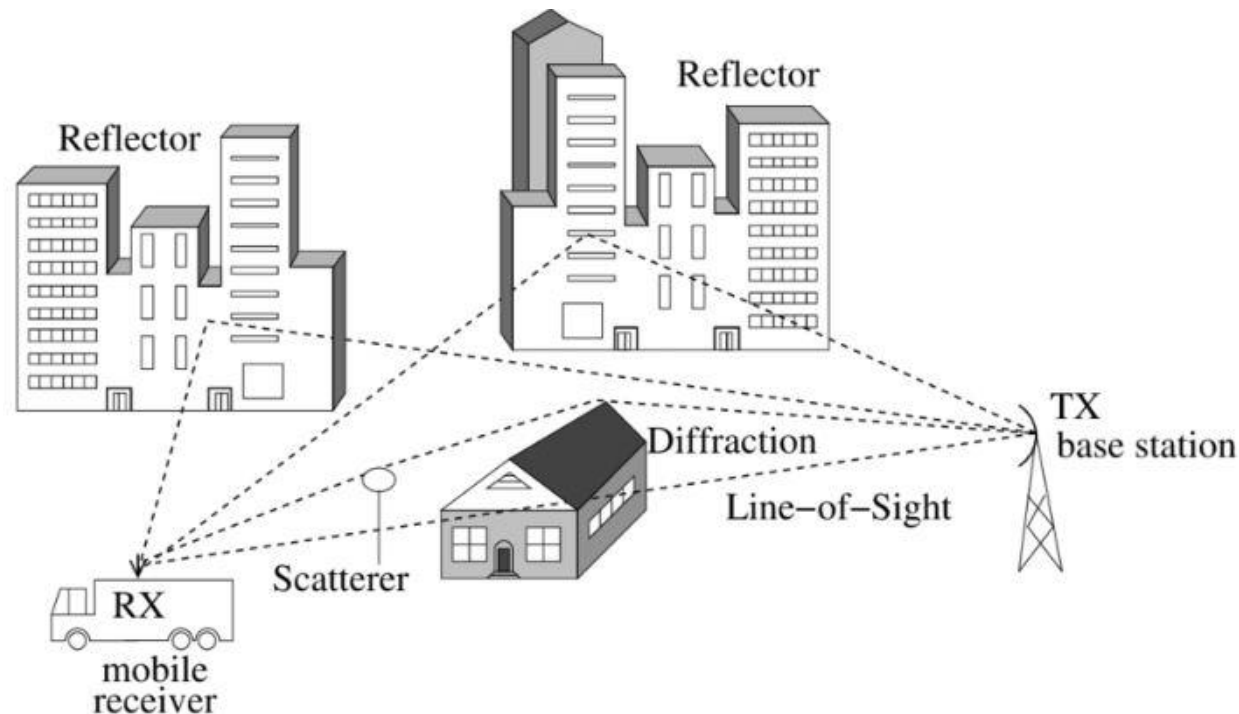
Factors Influencing Small-scale Fading

The following physical factors in the radio propagation channel influence small-scale fading:

- **Multi-path propagation**
- **Speed of the mobile**
- **Speed of the surrounding objects**
- **The transmission bandwidth of the signal**

Multi-path propagation

- The presence of **reflecting objects and scatters** in the channel creates a **constantly changing environment**.
- This results in multiple versions of the transmitted signal that arrive at the receiving antenna, **displaced with respect to one another in time and spatial orientation**.



Multi-path propagation

- The random phase and amplitudes of the different multipath components cause fluctuations in signal **strength(cause constructive and destructive interferences)**, thereby inducing *small-scale fading*, signal distortion, or both.
- Multipath propagation **often lengthens the time required for the baseband portion of the signal to reach the receiver** which can cause signal smearing due to inter-symbol interference.

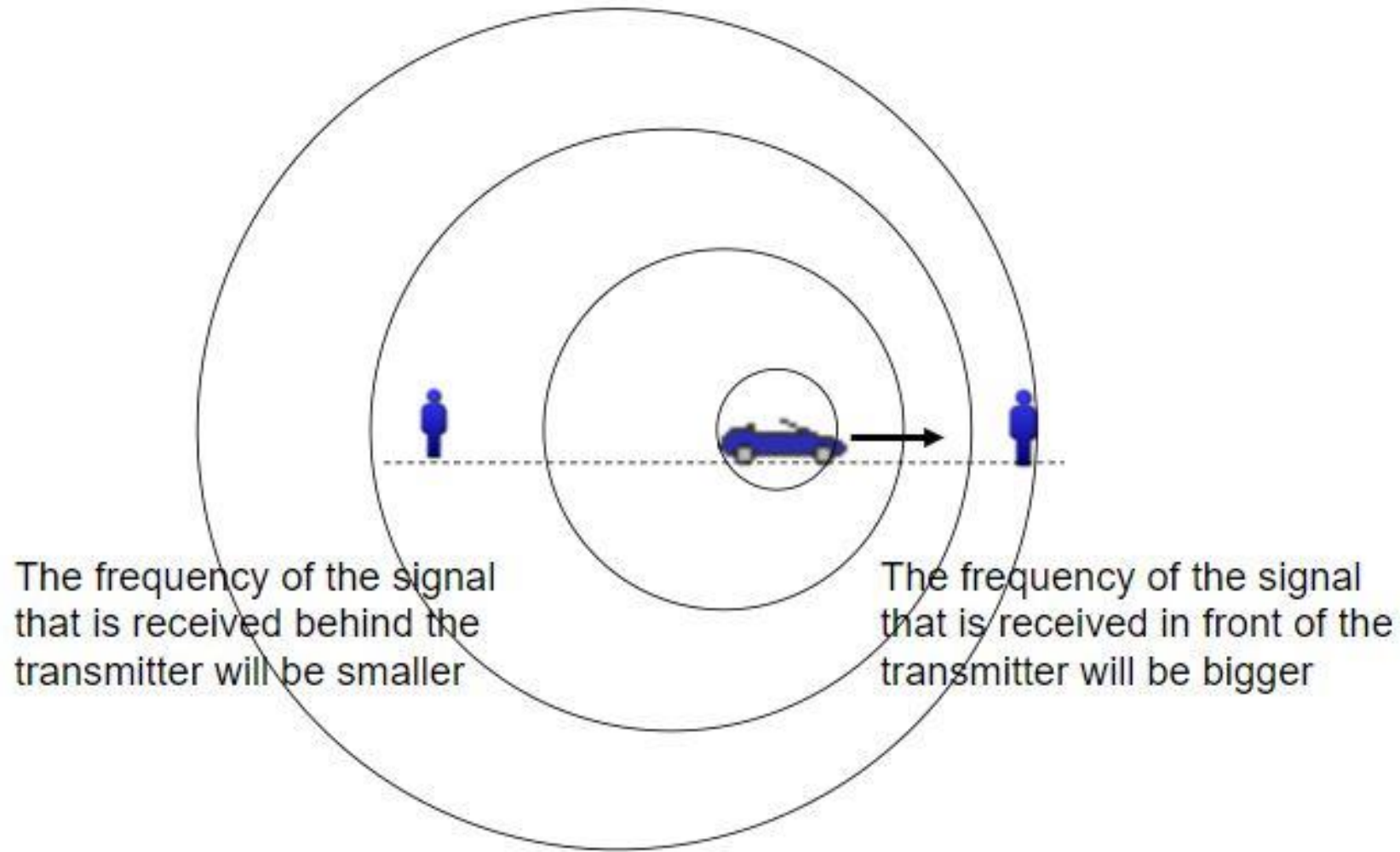
Speed of the Mobile

- The **relative motion between the base station and the mobile**, results in **random frequency modulation** due to different Doppler shifts on each of the multipath components.
- **Doppler shift will be positive or negative** depending on whether the **mobile receiver is moving toward or away** from the base station.

Doppler Shift

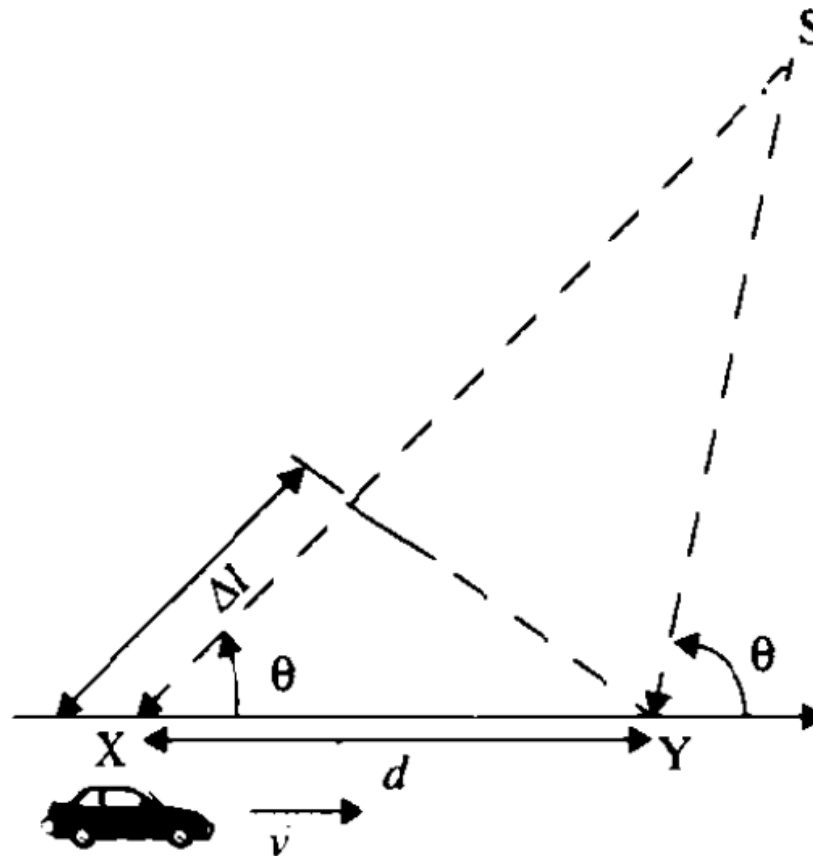
- The **Doppler effect (or the Doppler shift)** is the **change in frequency of a wave** in relation to an observer who is moving relative to the wave source.
- When a Transmitter or Receiver moving, the **frequency of the received signal** changes. It is **different than the frequency of transmission**. This is **called Doppler effect**.
- **Depends on;**
 - Relative Velocity of the Receiver with respect to Transmitter.
 - The Frequency of the transmitted wave.
 - Direction of travelling with respect to the direction of the arriving signal.

When Transmitter is moving



Doppler Shift – When receiver is moving

- Consider a **mobile moving at a constant velocity v** , along a path segment having **length d** between points **X** and **Y**, while it receives signals from a **remote source S** , as illustrated as figure below:



- The **difference in path lengths traveled by the wave** from source S to the mobile at points X and Y

$$\Delta l = d \cos \theta = v \Delta t \cos \theta.$$

- where Δt is the time required for the mobile to travel from X to Y, and θ is assumed to be the same at points X and Y **since the source is assumed to be very far away**
- The phase change in the received signal due to the difference in path lengths is therefore;

$$\Delta \phi = \frac{2\pi \Delta l}{\lambda} = \frac{2\pi v \Delta t}{\lambda} \cos \theta$$

- The **apparent change in frequency**, or **Doppler shift**, is given by f_d where:

$$f_d = \frac{1}{2\pi} \cdot \frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda} \cdot \cos\theta$$

- Above Equation relates the **Doppler shift** to the **mobile velocity** and the **spatial angle** between the **direction of motion of the mobile** and the **direction of arrival** of the wave.
- It can be seen from above equation that if the **mobile is moving toward** the direction of arrival of the wave, the Doppler shift is positive (i.e., the apparent received frequency is increased).
- If the **mobile is moving away from** the direction of arrival of the wave, the Doppler shift is negative apparent received frequency is decreased.

Example:

Consider a transmitter which radiates a Sinusoidal $f_c = 1850$ MHz. For a Vehicle moving 60 mph, compute the Rx carrier frequency if the mobile is moving (a) Directly towards the Tx (b) Away from the Tx (c) In a direction perpendicular to the direction of Tx signal. Given 1 mile = 1.6 km

Speed of surrounding objects

- If objects in the radio channel are in motion, **they induce a time varying Doppler shift** on multipath components.
- If the **surrounding objects move at a greater rate than the mobile**, then this effect dominates the **small-scale fading**.
- Otherwise, **motion of surrounding objects may be ignored**, and only the speed of the mobile need to be considered.

The transmission bandwidth of the signal

- If the transmitted radio signal **bandwidth is greater than the "bandwidth" of the multi-path channel**, the received signal will be **distorted**.
- If the transmitted signal has a **narrow bandwidth as compared to the channel**, the amplitude of the signal will **change rapidly**, but **the signal will not be distorted in time**
- Thus, the statistics of small-scale signal strength and the likelihood of signal smearing appearing over small-scale distances are very much related to the specific amplitudes and delays of the multipath channel, as well as the bandwidth of the transmitted signal