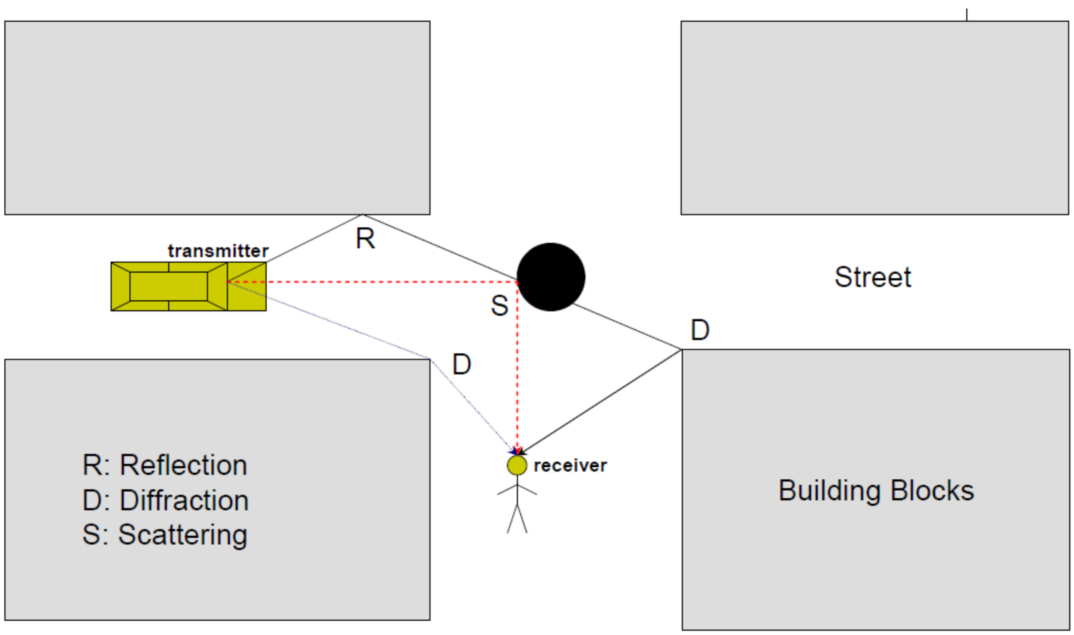
3- Scattering

l Occurs when the radio channel contains objects whose sizes are on the order of the wavelength or less of the propagating wave and also when the number of obstacles are quite large.

- They are produced by small objects, rough surfaces and other irregularities on the channel
- Follows same principles with diffraction
- Causes the transmitter energy to be radiated in many directions
- Lamp posts and street signs may cause scattering

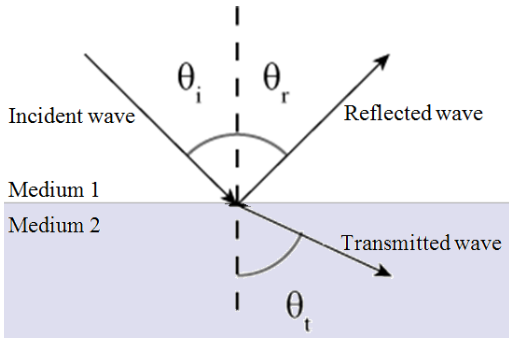


4.3.1 Reflection

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.

- Interaction of electromagnetic (EM) waves with materials having different electrical properties than the material through which the wave is traveling leads to transmitting of energy.

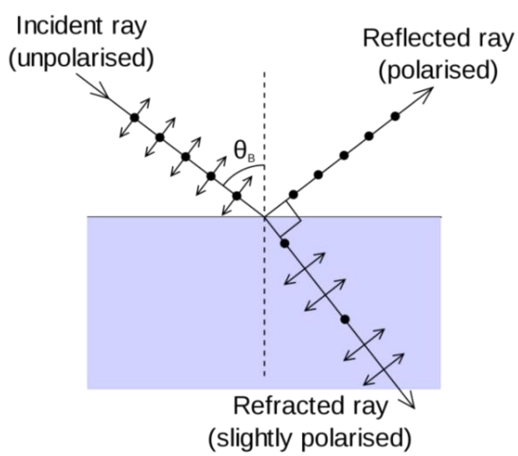
- When a radio wave falls on another medium having different electrical properties, a part of it is transmitted into it, while some energy is reflected back.



If the medium is a **dielectric**, some energy is reflected back and some energy is transmitted.

If the medium is a perfect **conductor**, all energy is reflected back to the first medium.

The amount of energy that is reflected back depends on the polarization of the EM wave.



<u>Brewster's angle</u> (also known as the polarization angle) is an angle of incidence at which wave with a particular polarization is perfectly transmitted through a dielectric surface, with no reflection (reflection coefficient is equal to zero).

- By applying laws of electro-magnetics, it is found to be

$$\sin\theta_B = \sqrt{\frac{\varepsilon_1}{\varepsilon_1+\varepsilon_2}}$$

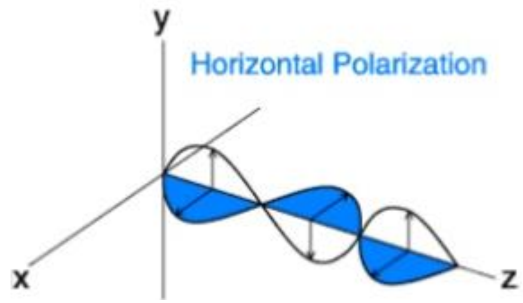
- For the case when the first medium is free space and the second medium has a relative permittivity ε_r, Brewster's angle can be expressed as

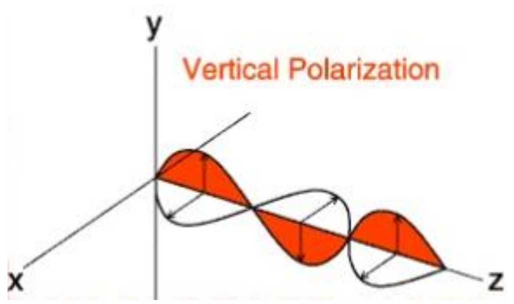
$$\sin\theta_B = \frac{\sqrt{\varepsilon_r - 1}}{\sqrt{\varepsilon_r^2 - 1}}$$

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

- The reflection coefficient depends on:
  - (a) Wave polarization
  - (b) Angle of incidence,
  - (c) Frequency of the propagating wave.

- For example, as the EM waves cannot pass through conductors, all the energy is reflected back with angle of incidence equal to the angle of reflection and reflection coefficient $\Gamma = -1$.
- In general, EM waves are polarized, meaning they have instantaneous electric field components in orthogonal directions in space.





Example 4

Calculate the Brewster angle for a wave impinging on ground having a permittivity of $\varepsilon_r = 4$.

Solution:

$$\sin\theta_B = \frac{\sqrt{\varepsilon_r - 1}}{\sqrt{\varepsilon_r^2 - 1}} = \frac{\sqrt{4-1}}{\sqrt{4^2 - 1}} = \frac{\sqrt{3}}{\sqrt{15}} = \sqrt{\frac{1}{5}}$$

$$\theta_B = \sin^{-1}\sqrt{\frac{1}{5}} = 26.56^o$$

Reflection from perfect conductor

- The electric field inside the perfect conductor is always zero. Hence all energy is reflected back. Therefore

$$\theta_i = \theta_r$$

a. For vertical polarization, and

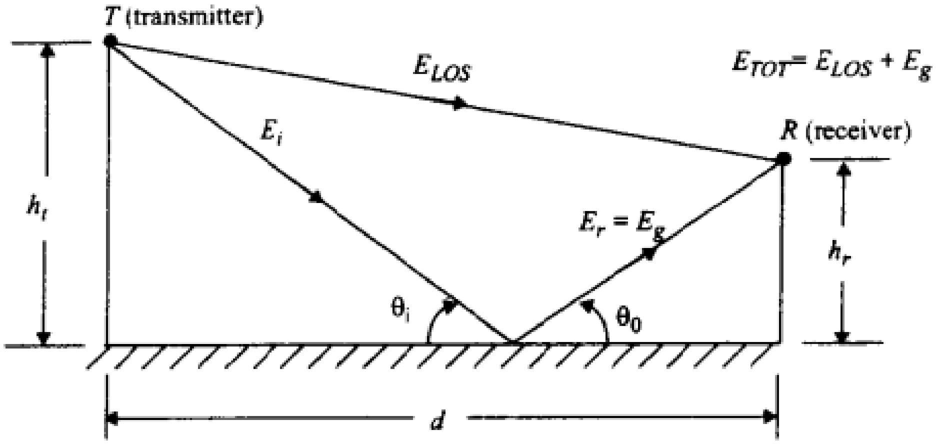
$$E_i = E_r$$

b. For horizontal polarization.

$$E_i = -E_r$$

Ground Reflection (2-ray) Model

- A single direct path between the base station and a mobile is seldom.
- The 2-ray ground reflection model (shown in Figure below) is a useful propagation model that is based on geometric optics, and considers both the direct path and a ground reflected propagation path between transmitter and receiver.
- This model is reasonably accurate for predicting the large-scale signal strength over distances of several kilometers for mobile radio systems that use tall towers (heights which exceed 50*m*), as well as for LOS microcell channels in urban areas.
- In most mobile communication systems, the maximum T-R separation distance is only a few tens of kilometers, and the earth may be assumed to be flat.
- The total received E-field (E_{TOT}) is a result of the direct LOS component (E_{LOS}), and the ground reflected component (E_g).



- Referring to Figure, h_t is the height of the transmitter and h_r is the height of the receiver.
- Two propagating waves arrive at the receiver:
    - The **direct wave** (LOS) that travels a distance *d'*
    - The **reflected wave** that travels a distance *d''*.

- The received E-field at a distance *d* from the transmitter can be approximated as

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

where

d is the distance over a flat earth between the bases of the transmitter and receiver antennas

k is a constant related to E_0, the antenna heights, and the wavelength.

- The power received power at a distance *d* from the transmitter can be expressed as

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

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As seen from equation above at large distances $d >> \sqrt{h_t h_r}$, the received power falls off with distance raised to the fourth power, or at a rate of 40 dB/decade. This is a much more rapid path loss than is experienced in free space.

Note also that at large values of *d*, the received power and path loss become independent of frequency.

***Example** 5*

A mobile is located 5 *km* away from a base station and uses a vertical *λ/4* monopole antenna with a gain of 2.55 *dB* to receive cellular radio signals. The E-field at 1*km* from the transmitter is measured to be 10^{-3} *V/m*. The carrier frequency used for this system is 900 *MHz*.

a) Find the length and the gain of the receiving antenna.
b) Find the received power at the mobile using the 2-ray ground reflection model assuming the height of the transmitting antenna is 50*m* and the receiving antenna is 1.5*m* above ground.

Solution

Given:

T-R separation distance = 5 *km*

E-field at a distance of 1*km*

Frequency of operation, *f* = 900 *MHz*

a)

$$\lambda = \frac{c}{f} = \frac{3\times 10^8}{900\times 10^6} = 0.333m$$

Length of the antenna, *L* = *λ/4* = 0.333/4 = 0.0833*m* = 8.33*cm*.

Gain of *λ/4* monopole antenna can be obtained using

$$G = \frac{4\pi A_e}{\lambda^2} = 1.8 = 2.55\ dB.$$

b) Since $d >> \sqrt{h_t h_r}$, the electric field is given by

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

$$= \frac{2\times10^{-3}\times1\times10^{3}}{5\times10^{3}}\left[\frac{2\pi\times50\times1.5}{0.333\times5\times10^{3}}\right] = 113.1\times10^{-6}\ V/m$$

The received power at a distance *d* can be obtained using

$$P_r(d) = \frac{|E|^2}{120\pi}A_e = \frac{|E|^2}{120\pi}\left(\frac{G\lambda^2}{4\pi}\right)$$

$$P_r(d) = \frac{(113.1\times10^{-6})^2}{377}\left(\frac{1.8\times(0.333)^2}{4\pi}\right)$$

$$= 5.4\times10^{-13}\ W = -122.68\,dBW\ or\ -92.68\,dBm$$

4.3.2 Scattering

- The actual received power at the receiver is stronger than claimed by the models of reflection and diffraction.
- The cause of scattering is that the trees, buildings and lamp-posts scatter energy in all directions. This provides extra energy at the receiver.
- Roughness is tested by a Rayleigh criterion, which defines a critical height h_c of surface protuberances for a given angle of incidence θ_i , given by,

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