Lect6: Medium & Wave Characteristics

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Medium & wave characteristics

❑Medium Constitutive Parameters:

- Permittivity denoted by ϵ in Farad per meter (F/m) $\varepsilon = \varepsilon_0 \varepsilon_r$
- Permeability denoted by μ in Henry per meter (H/m) $\mu = \mu_0 \mu_r$
- Conductivity denoted by σ in Siemens per meter (S/m).

μ_r, ε_r are the relative values (i.e. $\mu_r = \varepsilon_r = 1$ in free space).

In free space, values of the above parameters are:

$$\sigma = 0, \quad \epsilon_0 = 8.85 \times 10^{-12} (\text{F/m}), \mu_0 = 4\pi \times 10^{-7} \ (\text{H/m})$$

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- Typical constitutive parameters by ITU:

Surface	Conductivity, σ [S m^{-1}]	Relative dielectric constant, ε_r
Dry ground	0.001	4–7
Average ground	0.005	15
Wet ground	0.02	25–30
Sea water	5	81
Fresh water	0.01	81

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❑ **Medium Conductivity**

- *Either good dielectric or good conductor*:

Good dielectric (insulator)
$(\sigma/\omega\varepsilon)^2 \ll 1$

Good conductor
$(\sigma/\omega\varepsilon)^2 \gg 1$

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❑Medium Conductivity

Example. Calculate the conductivity of a piece of land specified by $\sigma = 5\,\text{mS/m}$, $\mu_r = 1$, and $\epsilon_r = 12$ for radiowaves of $f_1 = 10\,\text{KHz}$ and $f_2 = 10\,\text{GHz}$.

***Solution*:** For $f_1 = 10\,\text{KHz}$

$$\frac{\sigma}{\omega\epsilon_r\epsilon_0} = \frac{0.005}{2\pi \times 10^4 \times 8.85 \times 10^{-12} \times 12}$$

$$= 749.3 \gg 1.$$

Thus the land is of good conductivity at f_1, and for $f_2 = 10\,\text{GHz}$. The conductivity index is:

$$\frac{\sigma}{\omega\epsilon_r\epsilon_0} = 7.5 \times 10^{-4} \ll 1.$$

Therefore the land is a good dielectric at f_2. ■

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❑ **Wave Velocity:**

➢ For good dielectric: $\approx \frac{1}{\sqrt{\mu\varepsilon}}$

➢ In free space: $v = c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} \approx 3 \times 10^8 \text{ m s}^{-1}$

➢ For good conductor: $\approx \sqrt{\frac{2\omega}{\mu\sigma}}$

➢ Wave wavelength: $\lambda = \frac{v}{f}$

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❑Wave Velocity:

Example. Calculate the velocity of a radiowave propagating at 100 MHz in the following media:

1. Sea-water, $\mu_r = 1$ and $\epsilon_r = 81$
2. Air with $\epsilon_r = \mu_r = 1$

   Specify λ and V for $f_2 = 1$ GHz

***Solution*:**

1.

$$V_1 = \frac{1}{\sqrt{\mu\epsilon}} = \frac{C}{9} = 3.33 \times 10^7 \text{ m/s}$$

2.

$$V_2 = \frac{1}{\sqrt{\mu_0\epsilon_0}} = C = 3 \times 10^8 \text{ m/s}$$

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❑Wave Velocity:

$$f_1 = 100\text{ MHz} \quad \Rightarrow \quad \lambda_1 = \frac{v_1}{f_1} = 0.333\text{ m}$$

$$\lambda_2 = \frac{v_2}{f_1} = 3\text{ m}$$

$$f_2 = 1\text{GHz} \quad \Rightarrow \quad \lambda_1' = \frac{v_1}{f_2} = 0.33\text{ cm}$$

$$\lambda_2' = \frac{v_2}{f_2} = 30\text{ cm}$$

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- **Lossy Media:** *Medium with significant conductivity → the wave's amplitude diminishes with distance (attenuated).*
- **Attenuation Factor α :**
  - For good dielectric: $\approx \frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}}$
  - For good conductor (*significant attenuation*): $\approx \sqrt{\frac{\omega\mu\sigma}{2}}$
- **Penetration (Skin) depth:** a distance in the medium (like Earth) at which the wave amplitude of a radio wave incident at surface falls to 1/e (0.368) of its initial value.

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❑Wave optical characteristics:

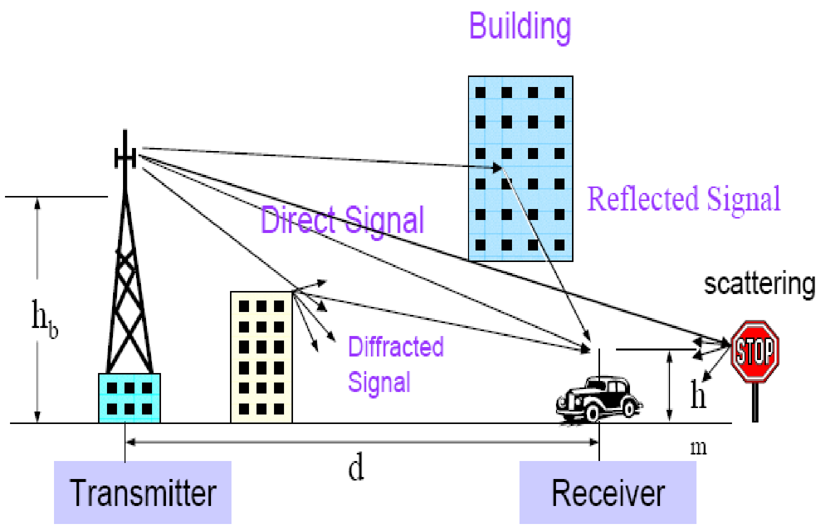
- In practice, boundaries between media exist (air and the ground, buildings and the air, from Earth to space, etc.).
- So, medium (like free space) constitutive parameters vary, which causes changes in amplitude, phase, & direction of propagating waves:

➢**Reflection.**

➢**Refraction.**

➢**Diffraction.**

➢**Scattering.**



Medium & wave characteristics

❑Both media lossless : Reflection & Refraction:

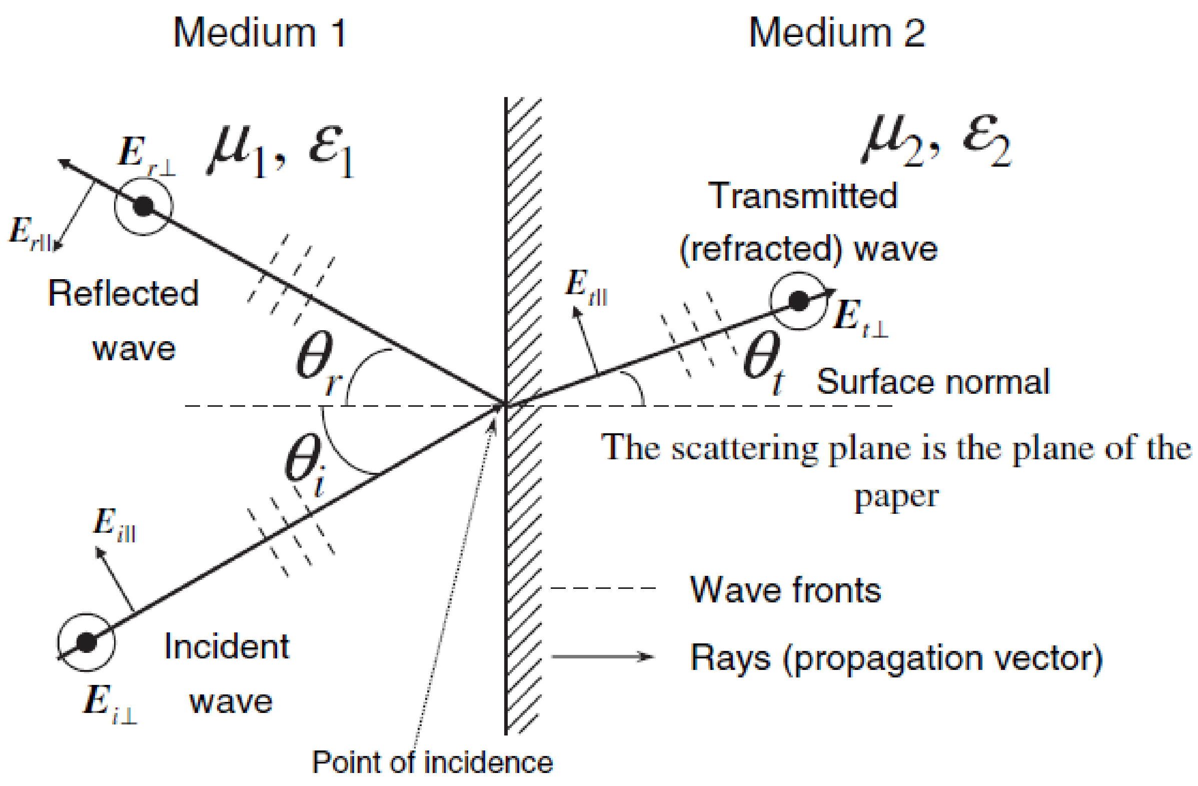
- **Snell's laws:**

1. 1st $\theta_i = \theta_r$

2. 2nd $\dfrac{\sin\theta_i}{\sin\theta_t} = \dfrac{n_2}{n_1}$

Note: refraction index $n = \dfrac{c}{v}$

Note: the ratio $v/\lambda = f$ **is maintained everywhere.**



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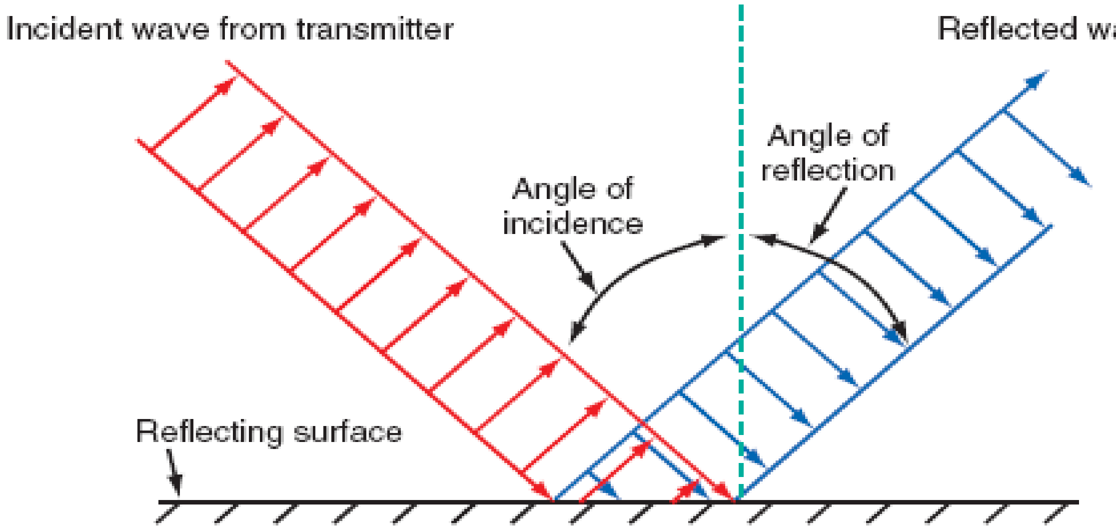
❑Lossless to lossy: only reflection

- Radio waves are reflected by any conducting surface.
- Reflection is also produced by other partially conductive surfaces, such as the earth and water.
- Reflection follows the principles of light wave reflection. That is, the angle of reflection is equal to the angle of incidence (1st snell's law).
- The reflection process reverses the polarity of a wave. This is equivalent to a 180° phase shift.



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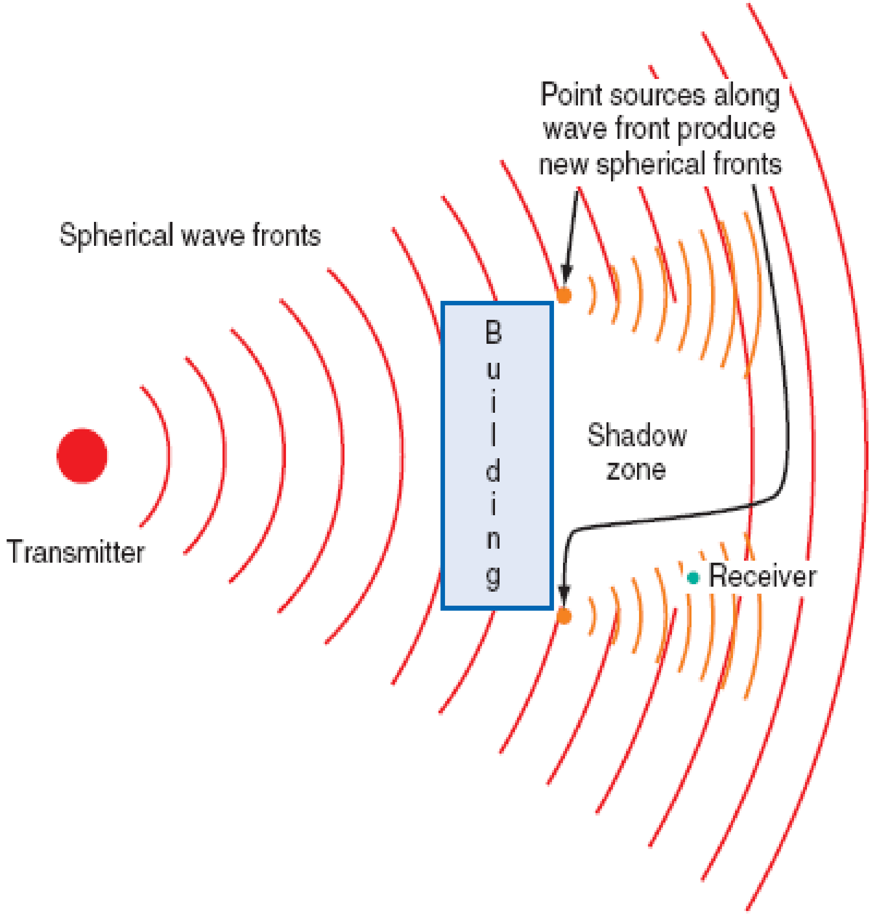
❑Diffraction:

<u>Huygens' principle</u> is based on the assumption that all electromagnetic waves, light as well as radio waves, radiate as spherical wave fronts from a source. Each point on a wave front at any given time can be considered as a point source for additional spherical waves. When the waves encounter an obstacle, they pass around it, above it, and on either side.



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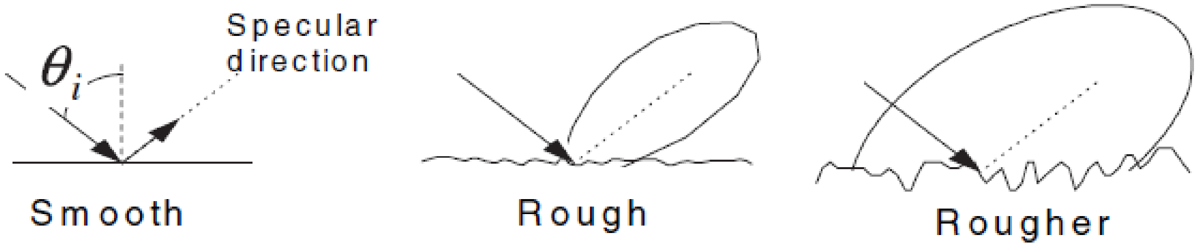
❑Scattering:

- Reflected wave from rough surface becomes scattered.



- Due to objects in the medium that are small compared to wavelength and the number of objects is many (e.g., foliage (tree leaves), street signs, lamp posts, rain, shower).

Thank you