EGM703 – Advanced Active and Passive Remote Sensing

Week 5, Part 1: Principles of Ground-Penetrating Radar

Week 5 Outline

1. Principles of GPR
2. GPR Application: Archaeology
3. GPR Application: Glaciology
4. Other GPR Applications

Recall: Electric permittivity

- As EM wave travels through dielectric medium, it loses energy (attenuation)

$$\varepsilon_r = \boxed{\varepsilon'_r} - \boxed{i\,\varepsilon''_r}$$

  - Real part: dielectric constant (lossless)
  - Imaginary part: absorption (energy loss)
- Attenuation is exponential (amplitude decays exponentially with depth)
- Propagation depth δ_p can be approximated:

$$\delta_p \approx \frac{\lambda\sqrt{\varepsilon'_r}}{2\pi\varepsilon''_r}$$

- Most materials have some penetration depth (except for liquid water, wet snow)
  - Spoiler alert: liquid water is <u>really</u> important in microwave remote sensing

Dielectric properties and propagation speed

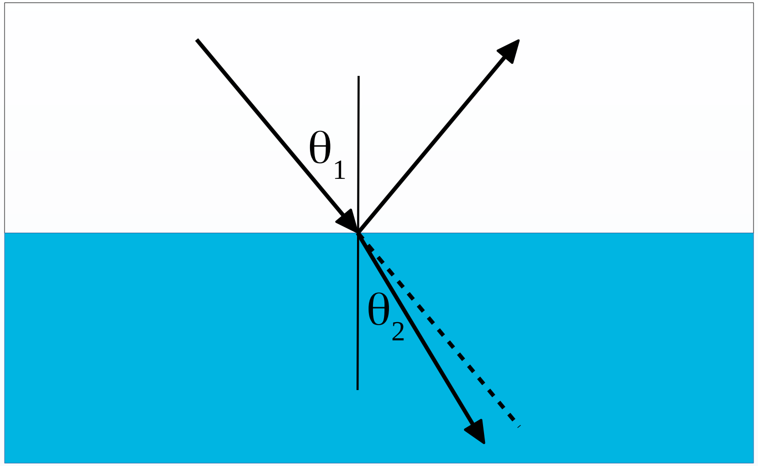
- Electric permittivity determines wave speed through medium
- For a low-loss, non-magnetic medium, can neglect μ_r, ε_r'':

$$c = \frac{c_0}{\sqrt{\varepsilon'_r}}$$

- As wave propagates through material, loses energy due to:
  - Scattering (reflection)
  - Attenuation (ε_r'')
  - Spreading

Reflection and refraction

- As permittivity changes:
  - Reflection (scattering)
  - Transmission
  - Wave speed changes
- Examples:
  - Scatterers within media
  - Two different media
- Larger contrast between materials: stronger reflection

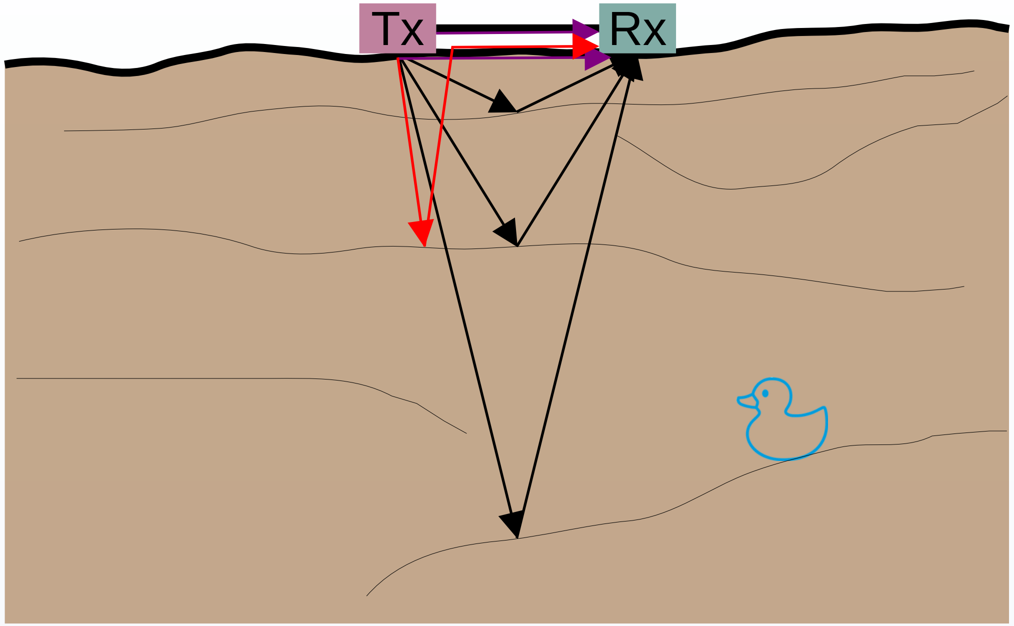


$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

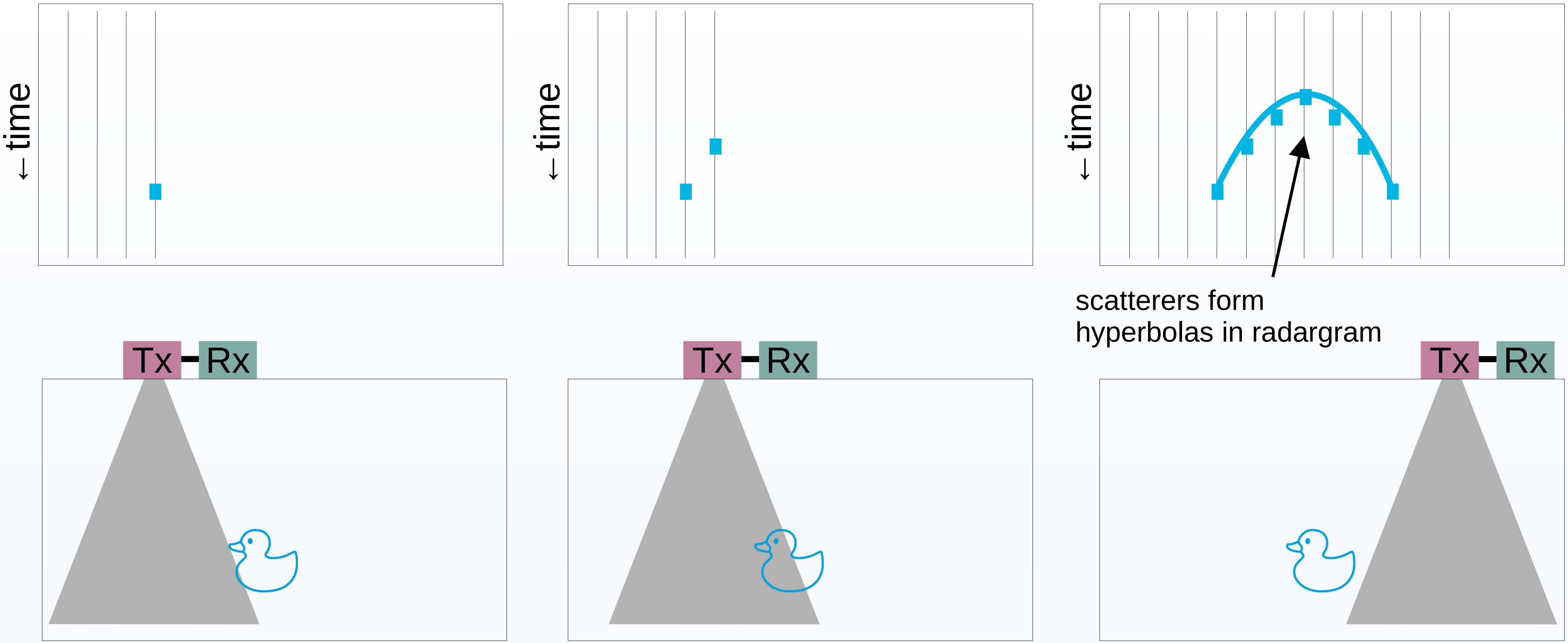
$$n = \sqrt{\frac{\varepsilon \mu}{\varepsilon_0 \mu_0}} = \sqrt{\varepsilon_r \mu_r}$$

Ground-penetrating radar: the basic setup

- Send out signal, measure time it takes to come back
- Components:
  - Transmitting antenna (Tx)
  - Receiving antenna (Rx)
- Signal reflects off of internal horizons/scatterers
  - Air waves, ground surface waves
  - Refracted reflection (lateral waves)
- Receiving antenna records amplitude, two-way travel time

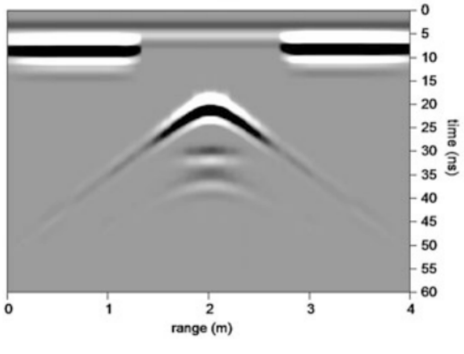


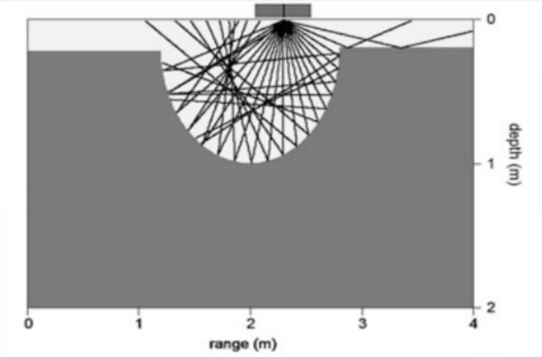
Radargram formation



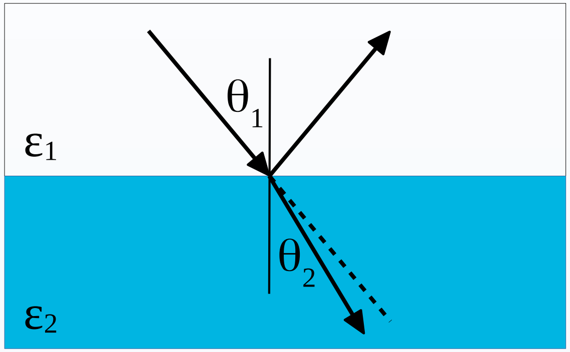
Scatterers

- (point) scatterers trace hyperbolic shape in radargram
  - Centered over scatterer
- Returns from surfaces can be complex
  - e.g., semi-circular trench
- Amount of reflection R depends on dielectric contrast
  - Similar dielectric properties: weaker return signal



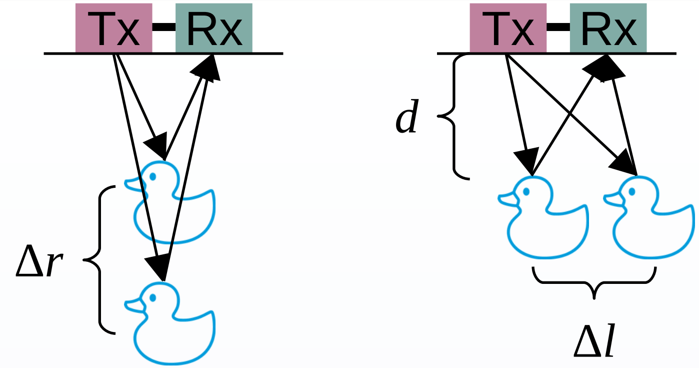


$$R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}$$



Resolution

- Resolution: ability to distinguish between objects
- Vertical resolution, Δr:
  - Function of pulse width *W*, velocity *c*
  - Similar to range resolution
- Horizontal resolution, Δl:
  - Decreases with depth
  - Sometimes related to elliptical sensor footprint

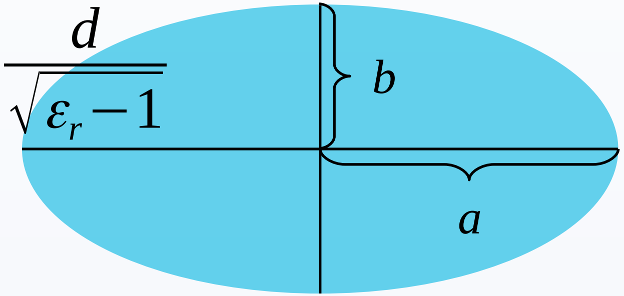


$$\Delta r \geq \frac{cW}{4}$$

$$\Delta l \geq \sqrt{\frac{cdW}{2}}$$

$$a = \frac{\lambda}{4} + \frac{d}{\sqrt{\varepsilon_r - 1}}$$

$$b = \frac{a}{2}$$



Limitations

- Due to attenuation, maximum depth depends on frequency:
  - Low frequency: deeper
  - High frequency: shallower
  - Tradeoff between resolution, penetration depth
- High conductivity: low signal penetration
  - i.e., clays, saltwater
- Grid spacing

Summary

- Depending on dielectric properties, electromagnetic waves can penetrate into materials (like the ground)
- We can use this to study:
  - Internal structures
  - Location of scattering objects
- Success depends largely on frequency, properties of materials

Additional resources

- Geophysics for Practicing Geoscientists [GeoSci]
- Robinson et al., 2013 [British Society for Geomorphology]
- Goodman, 1994 [Geophysics]
- Understanding the GPR radargram [Oerad Tech]
- A Ground Penetrating Radar Study [Jamestown Rediscovery]
- Archaeology of the "Dead Shed" Construction Site [Jamestown Rediscovery]