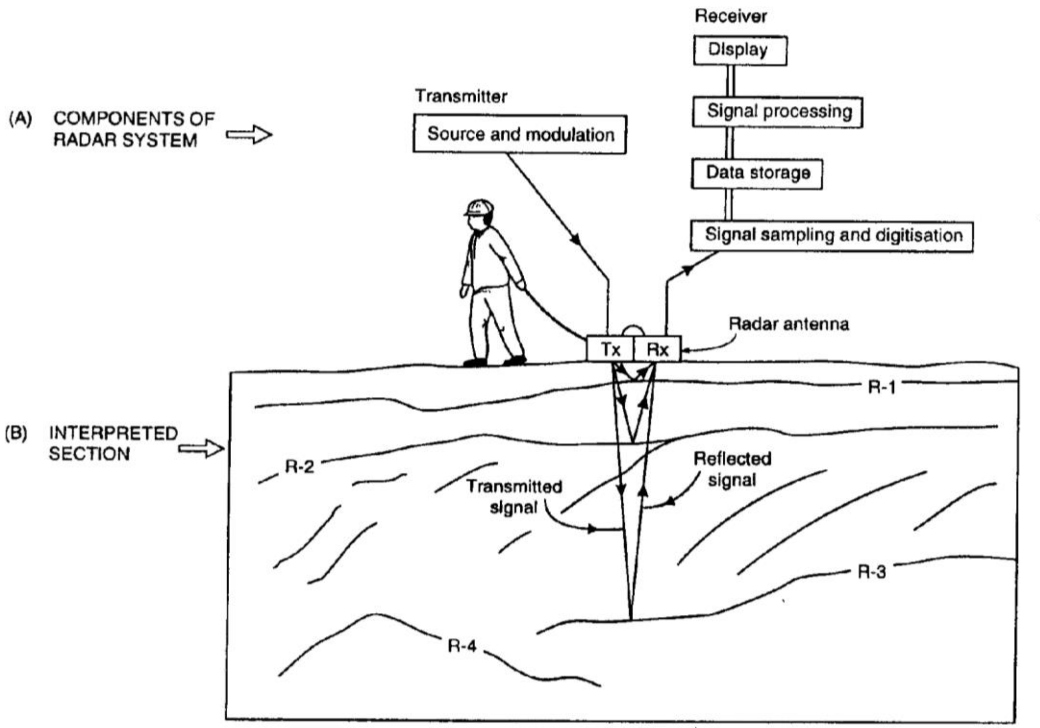
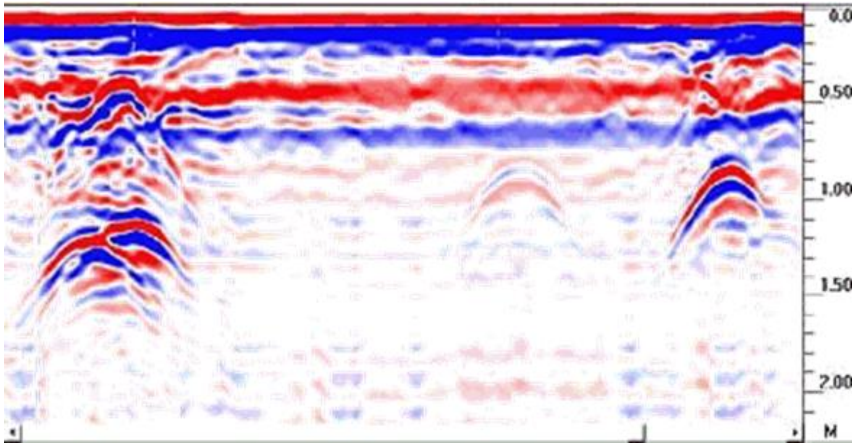
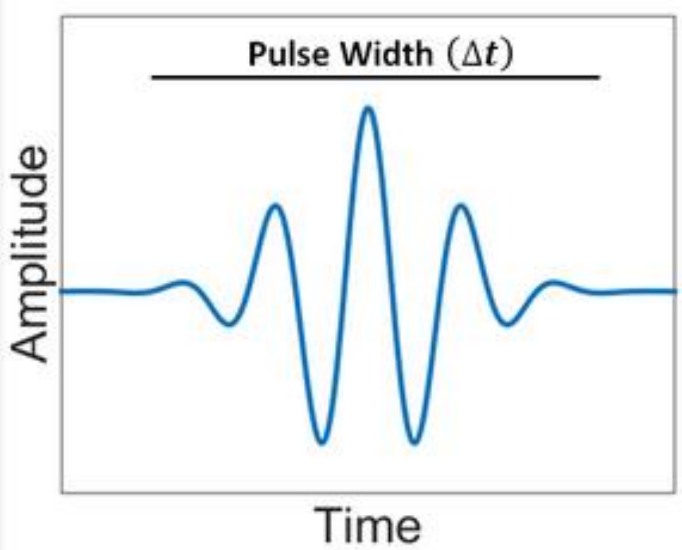
Ground Penetrating Radar (day 2)







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From Last Time

- Permittivity (ε) is the diagnostic physical property but electrical conductivity (σ) plays an important role.

- Radiowaves propagate at different speeds in different materials:

$$v = \frac{c}{\sqrt{\epsilon_r}}$$

- Radiowaves attenuate (lose amplitude) while they propagate:

<u>Skin depth:</u>

$$\delta \approx \begin{cases} 503\sqrt{\dfrac{1}{\sigma f}} & \text{for } \omega\varepsilon \ll \sigma \\ 0.0053\dfrac{\sqrt{\varepsilon_r}}{\sigma} & \text{for } \sigma \ll \omega\varepsilon \end{cases}$$

From Last Time

- Radiowaves reflect at boundaries where the velocity/dielectric permittivity changes:

$$R = \frac{\text{Reflected Amplitude}}{\text{Incident Amplitude}} = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}}$$

- Conductors are large reflectors of radiowaves

- Snell's law applies to GPR:

$$\frac{\sin\theta_1}{V_1} = \frac{\sin\theta_2}{V_2}$$

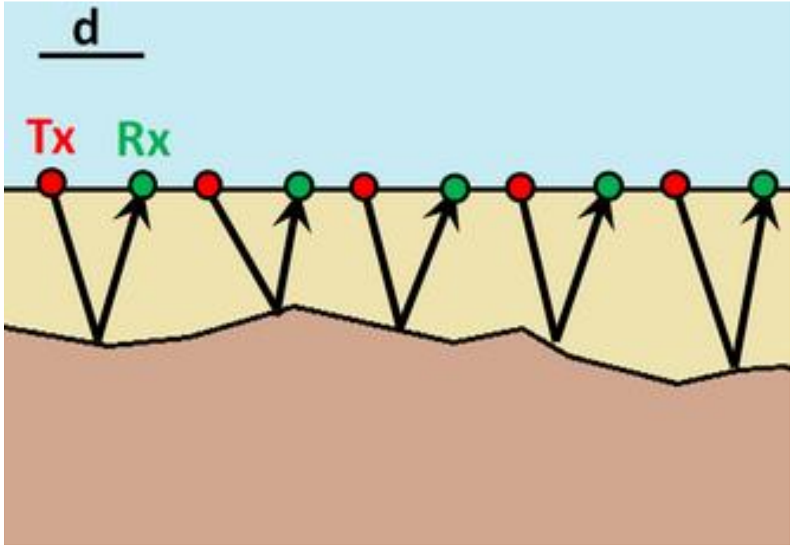
$$\sqrt{\varepsilon_1}\,\sin\theta_1 = \sqrt{\varepsilon_2}\,\sin\theta_2$$

Today's Topics

- Common survey configurations and some applications
- The source wavelet signal
- Resolution
- GPR App
- Probing distance
- Sources of Noise
- Processing

Common Offset Survey

- Tx-Rx distance is fixed
- Tx-Rx is moved for every shot
- Most common GPR survey
- Good for:
  - Finding horizontal interfaces
  - Locating discrete objects
- **Zero offset** survey has Tx-Rx coincident (same location)



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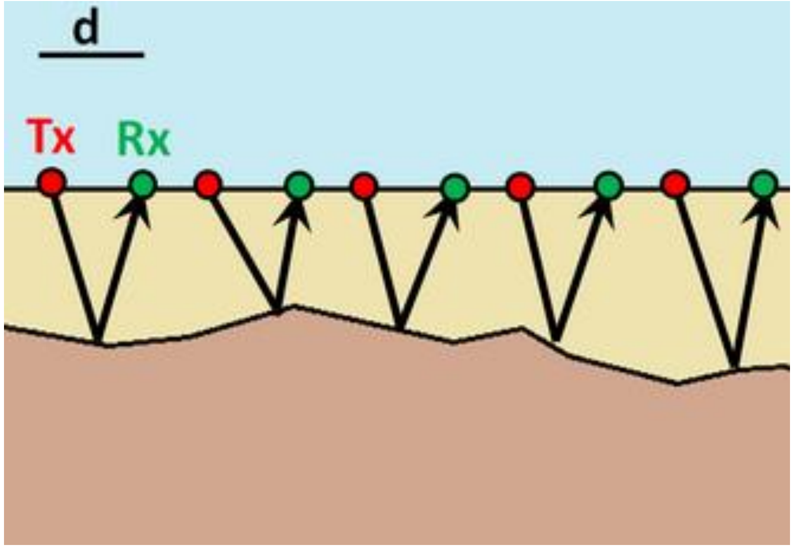
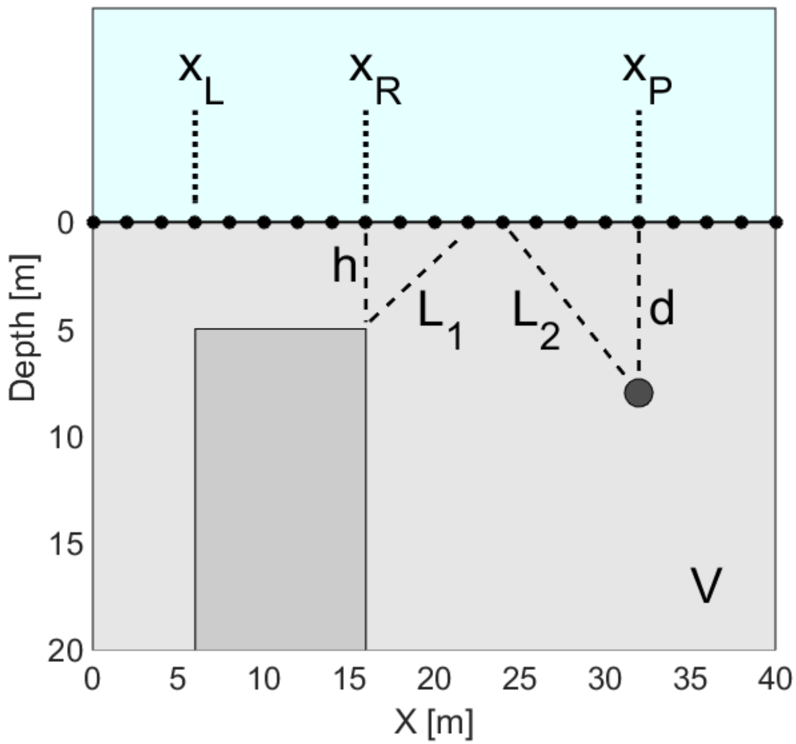
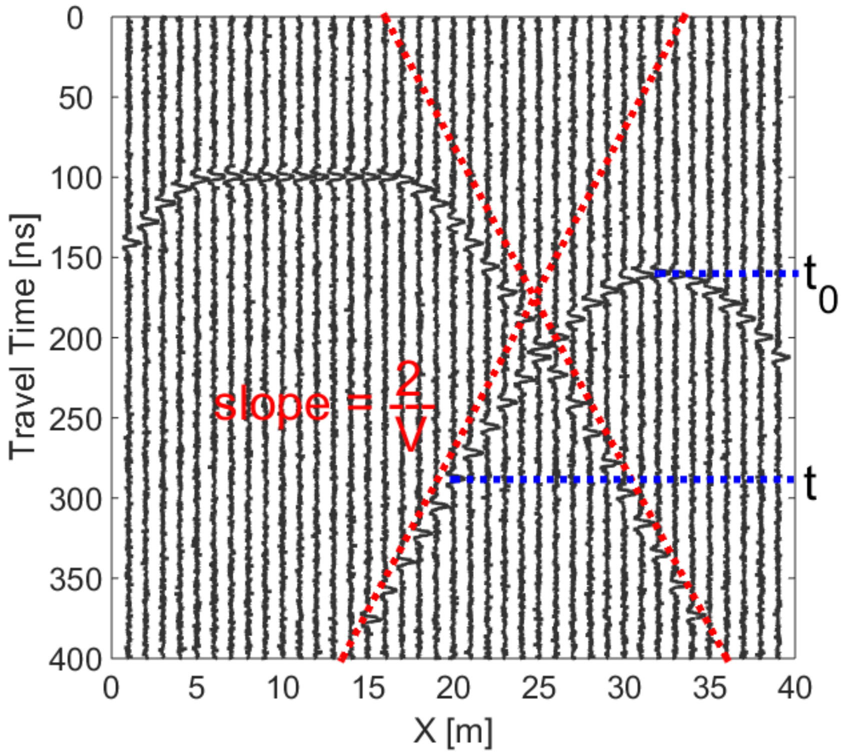


Zero Offset Survey: Finding Objects





- A thin pipe at x = 32 m and depth 8 m
- A block between xL and xR at 5 m depth

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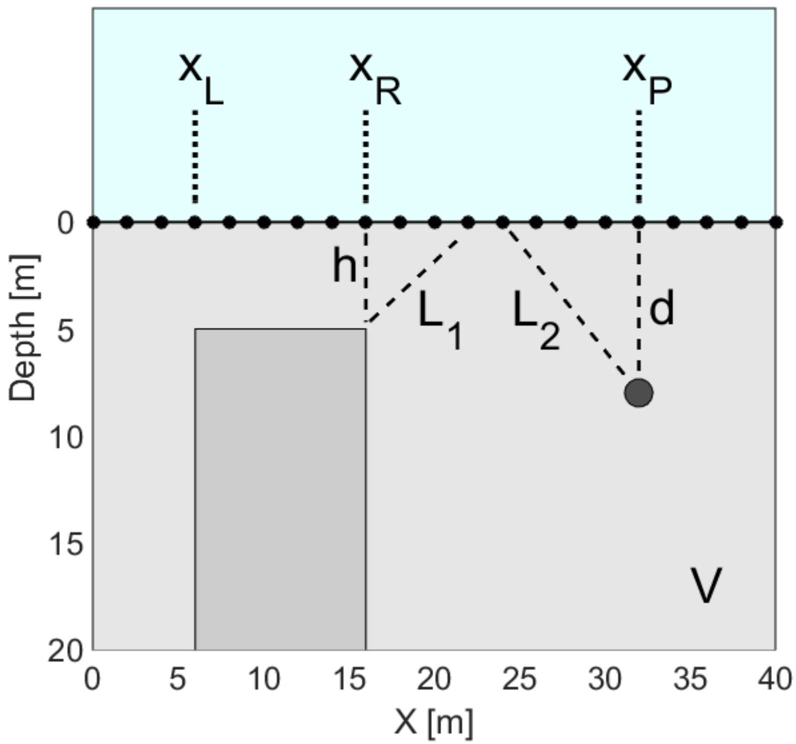
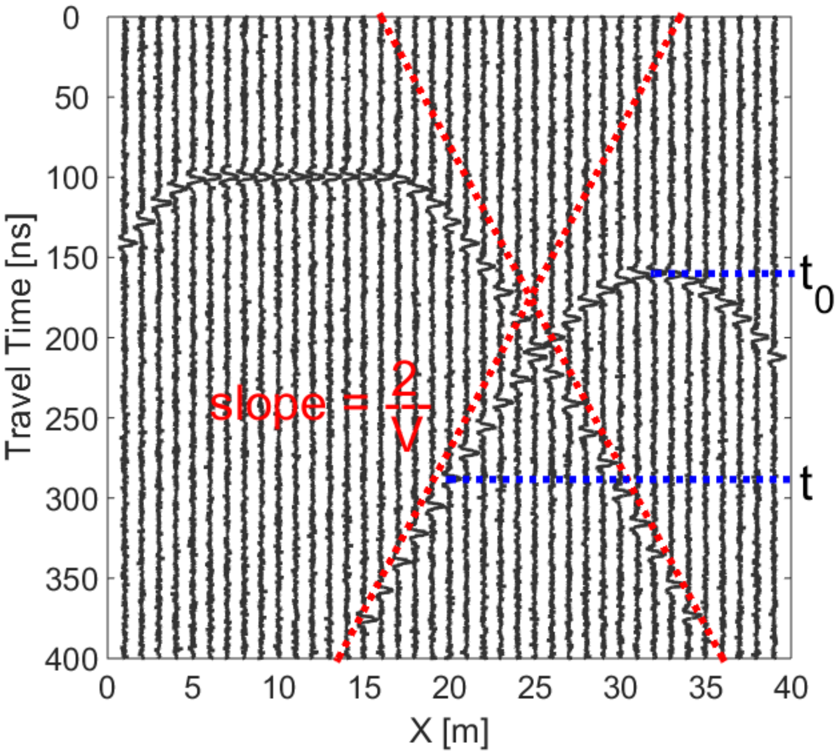
Zero Offset Survey: Finding Objects





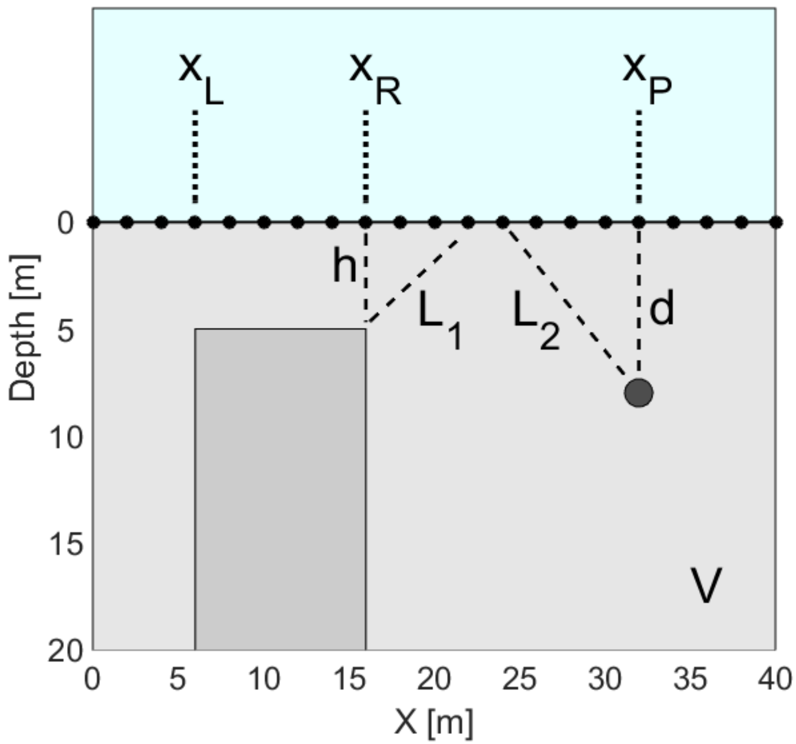
Travel time for the pipe:

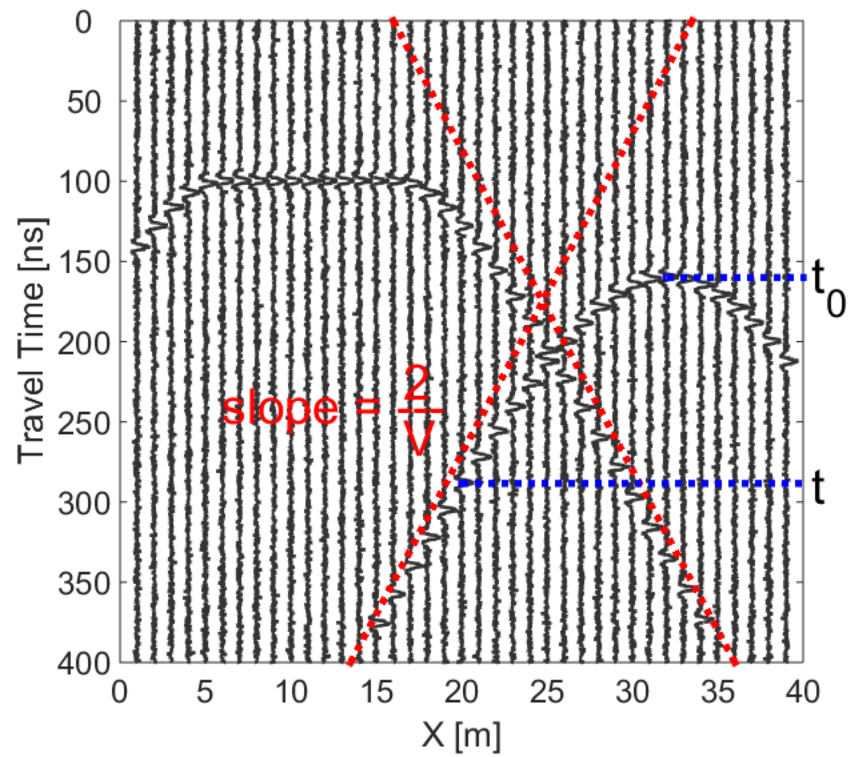
$$t_p = \frac{2L_2}{V} = \frac{2\sqrt{(x - x_p)^2 + d^2}}{V}$$

where

$$t_p(x_p) = \frac{2d}{V}$$

Zero Offset Survey: Finding Objects

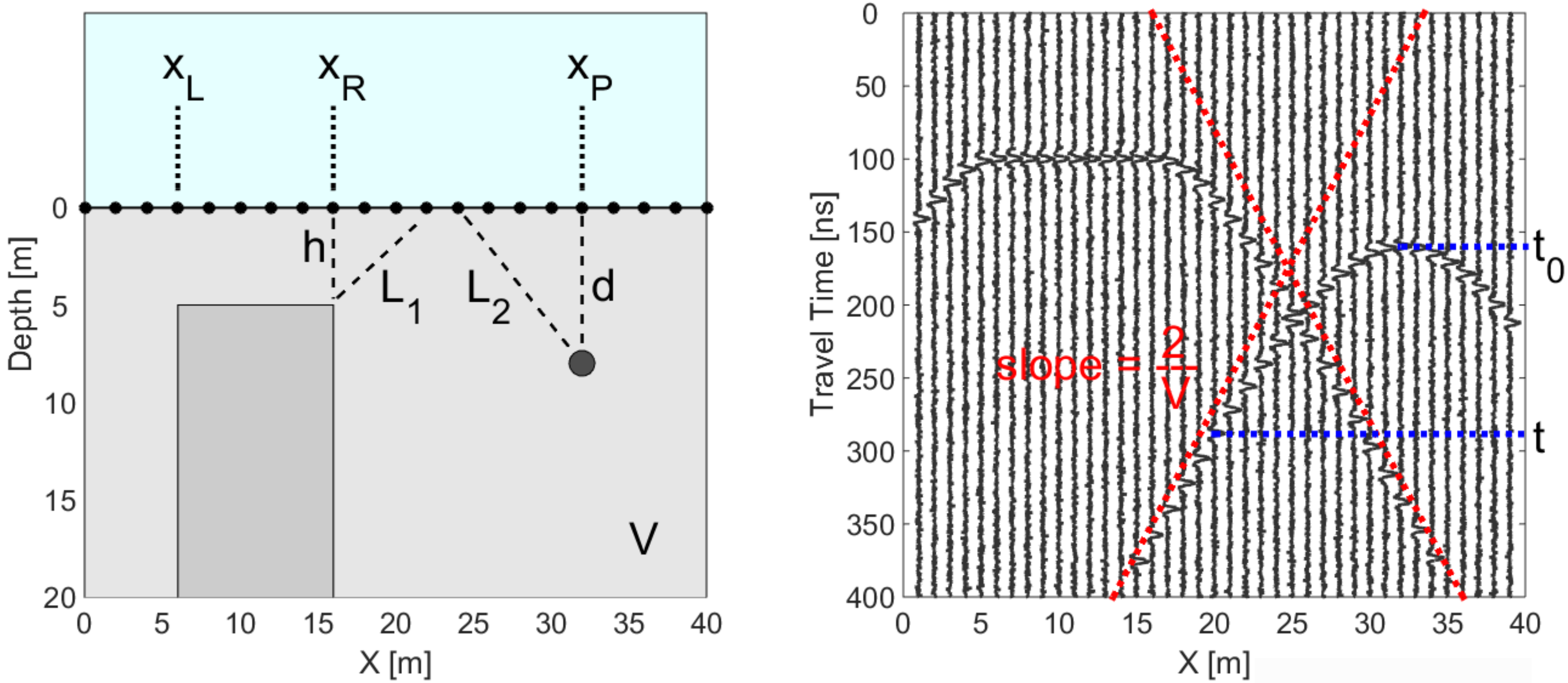




For the block:

$$t_b = \begin{cases} \dfrac{2\sqrt{(x-x_L)^2+h^2}}{V} & \text{for} \quad x < x_L \\ \dfrac{2h}{V} & \text{for} \quad x_L \le x \le x_R \\ \dfrac{2\sqrt{(x-x_R)^2+h^2}}{V} & \text{for} \quad x > x_R \end{cases}$$

Finding Objects (Method 1)



Slope (red dashed): $m = \pm 2/V$ where $t_0 = \dfrac{2d}{V}$

1) Get velocity from slope
2) Get depth to object

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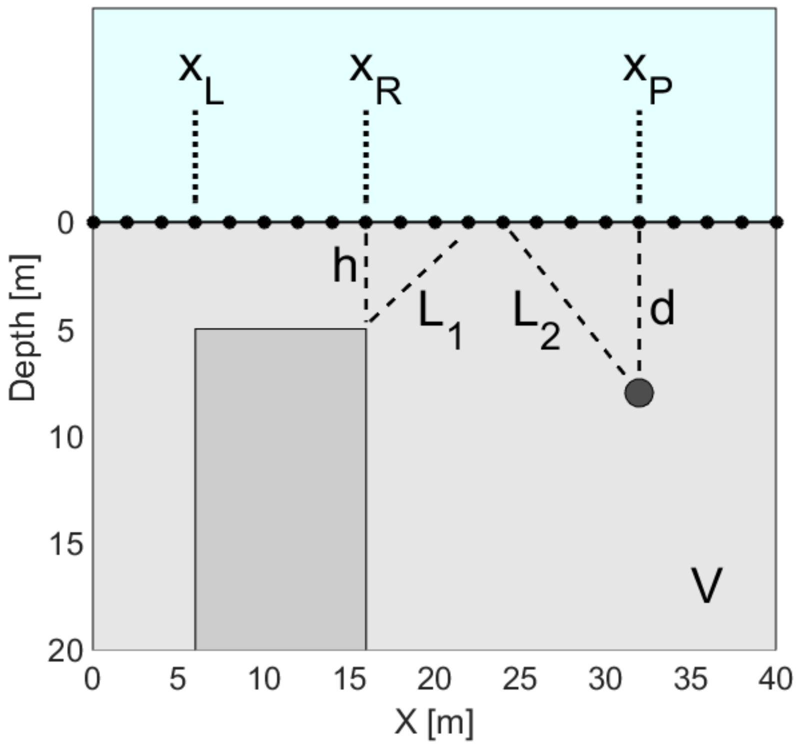
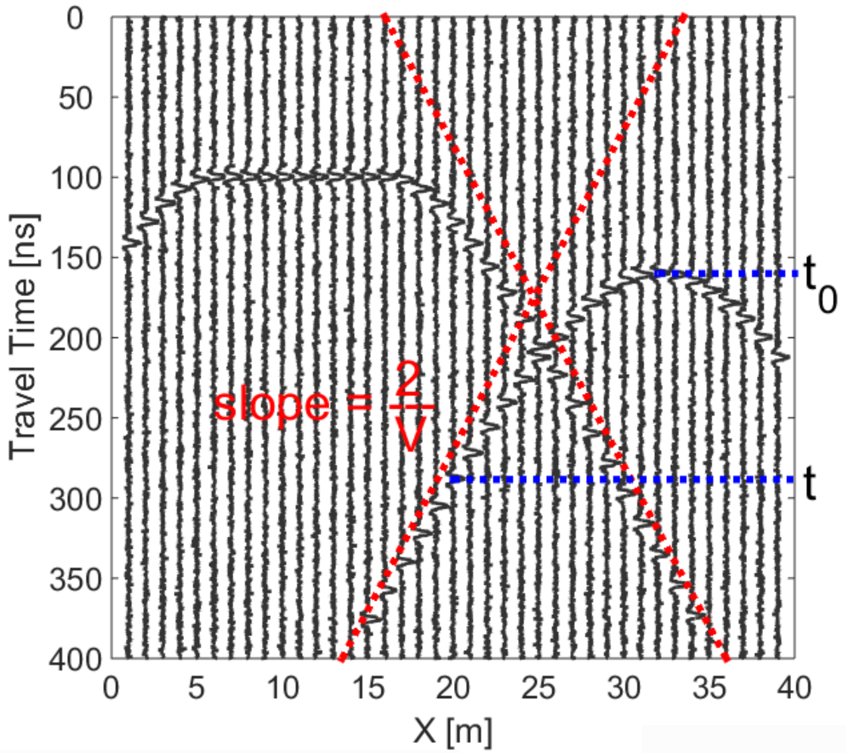
Finding Objects (Method 2)





Using a point (blue dashed): $V = 2\sqrt{\dfrac{(x - x_p)^2}{t^2 - t_0^2}}$ where $t_0 = \dfrac{2d}{V}$

1) Get velocity from a point on the curve
2) Get depth to object

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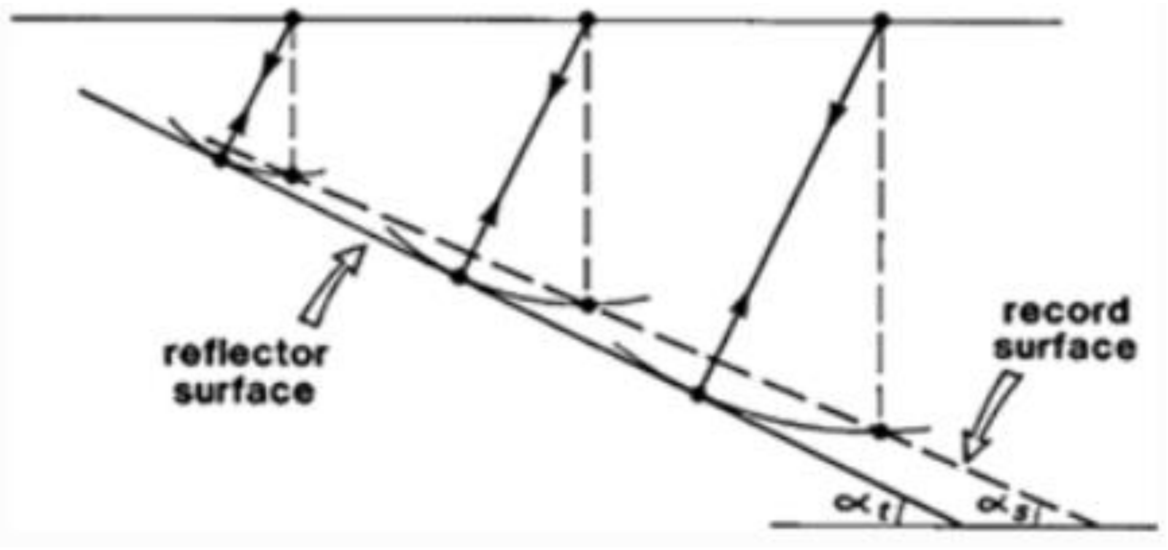
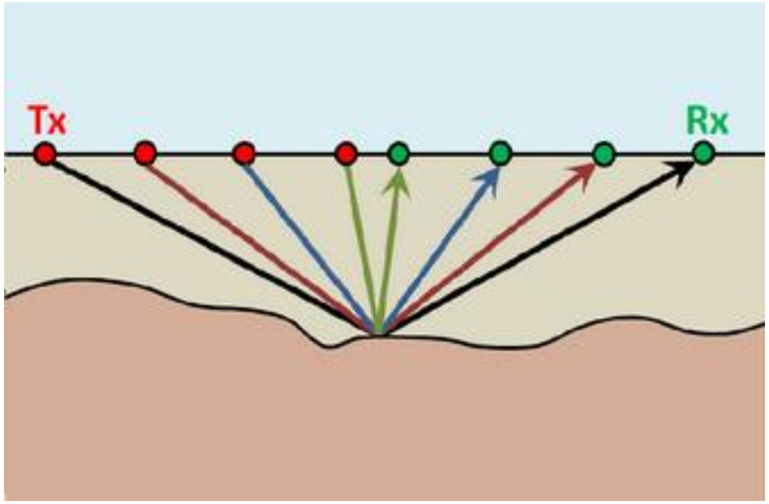
Zero Offset Survey: Dipping Layers



- Zero offset reflection is perpendicular to surface
- Can lead to underestimate of depth and slope of layer
- Can be corrected using **migration correction (GPG)**

Common Midpoint Survey

- Tx-Rx distance varies
- Midpoint between Tx-Rx is left constant
- Good for:
  - Finding horizontal interfaces



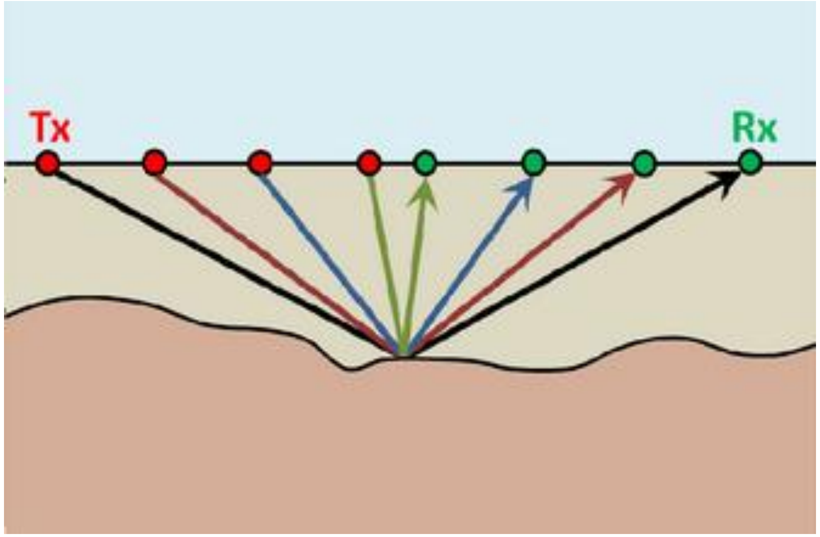
Common Midpoint Survey

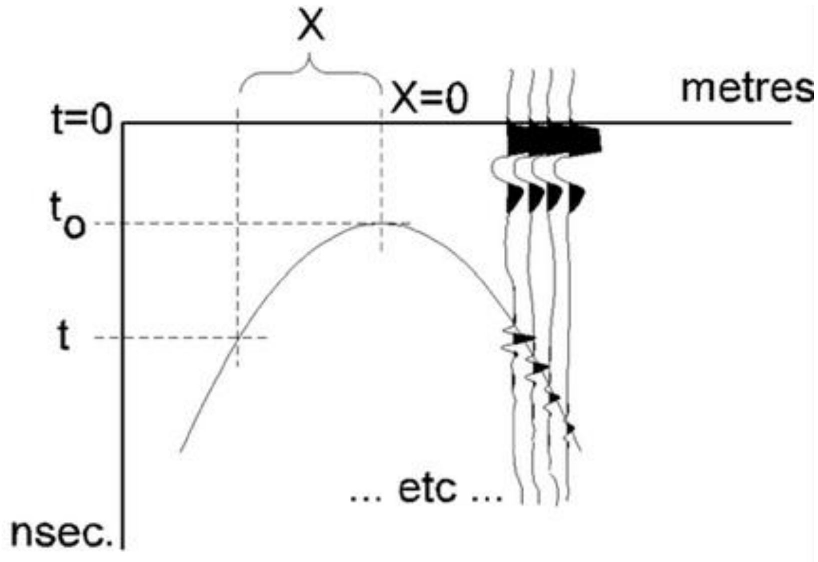
- Travel time off same reflection point make a hyperbola:

$$t = \frac{2\left(x^2 + d^2\right)^{1/2}}{V}$$

- Can use hyperbola to get velocity and layer depth

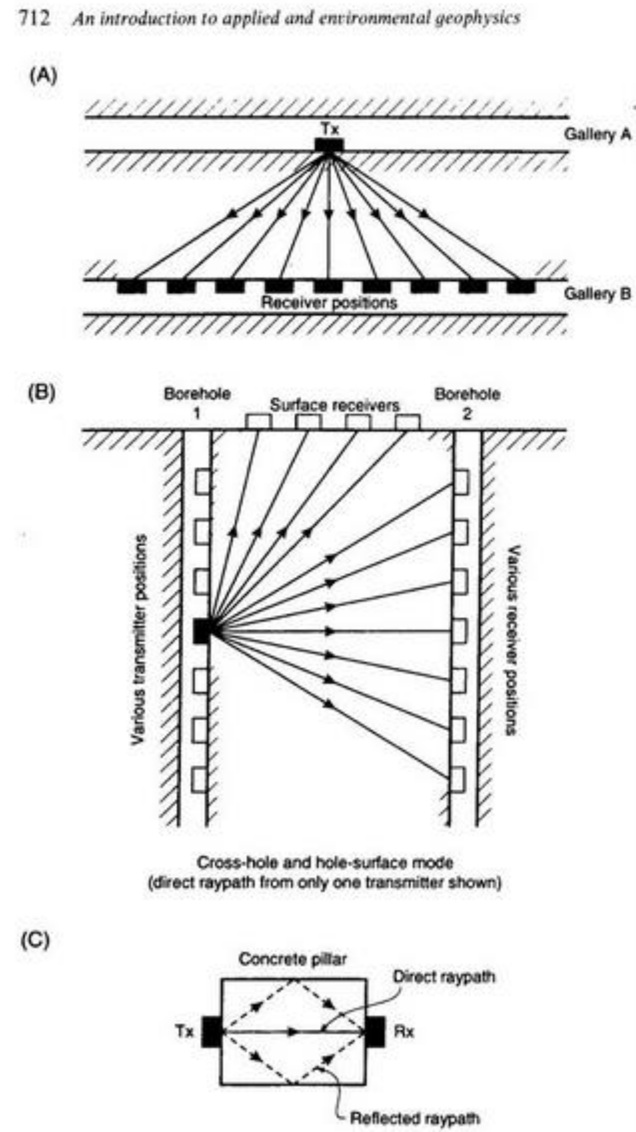
- Reading not hyperbola:
  - Indicates uneven/dipping interface





Transillumination Survey

- Tx and Rx are placed on opposing sides of a target.
- Sometimes many Tx and Rx
- Used for:
  - Structural integrity of mine shafts
  - Borehole surveys
  - Finding internal stuctures within objects

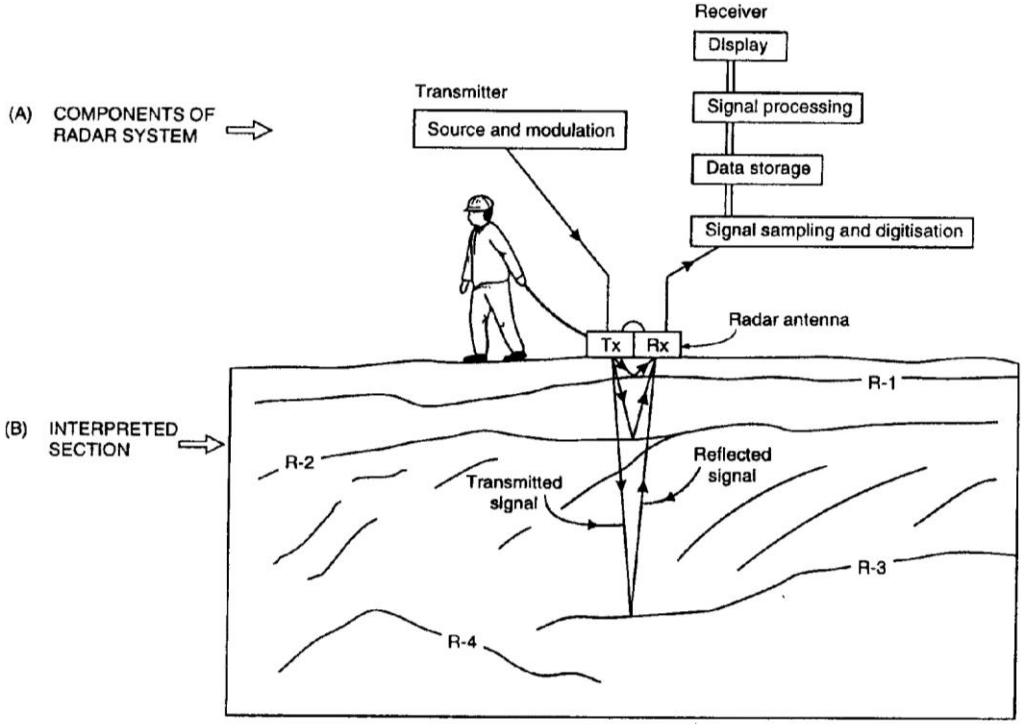


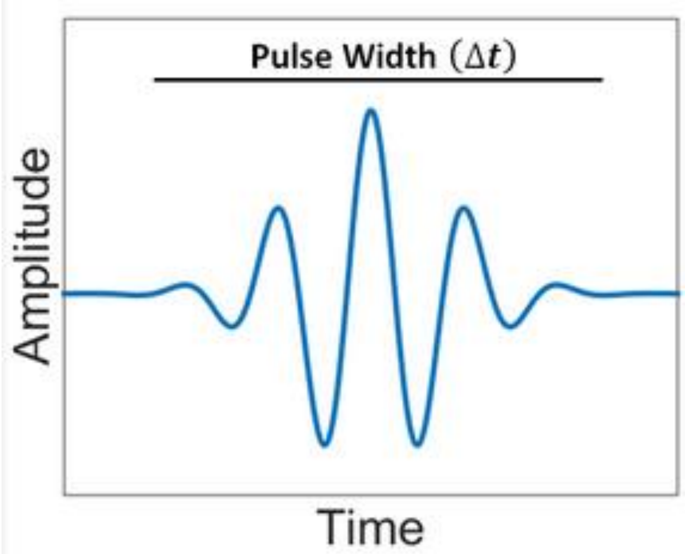
Recap Questions

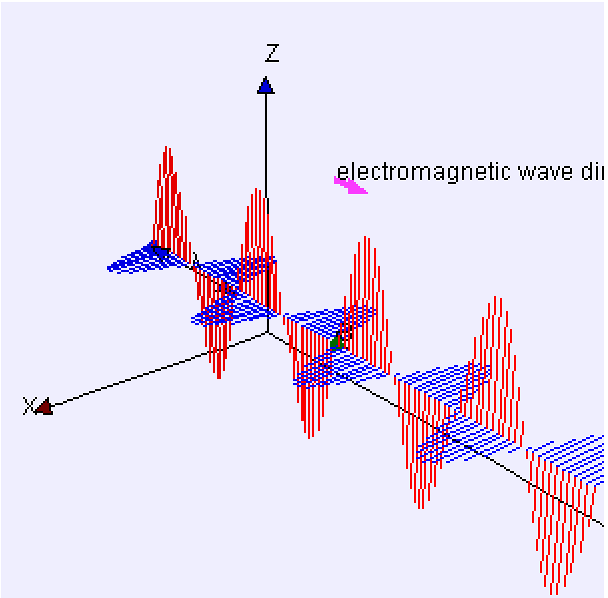
Q: What is the most commonly used survey configuation?

Q: What kind of signatures do objects make in radargrams?

GPR Source Signal







Examine properties of the source pulse

GPR Source Signal: Wavelet

- **Wavelet:** A wave-like oscillation of short duration
- **Bandwidth:** Range of frequencies in the wavelet
- **Pulse Width:** Time-duration of wavelet
- **Spatial Length:** Wavelength of the wavelet
- **Central Frequency:** Operating frequency of GPR survey

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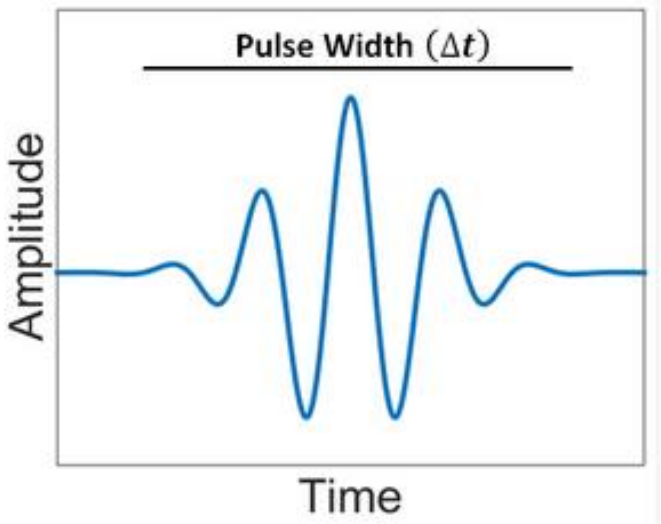
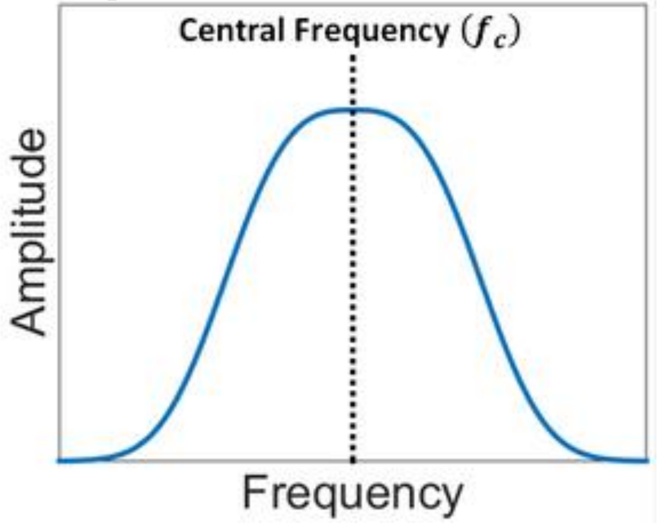
Wavelet



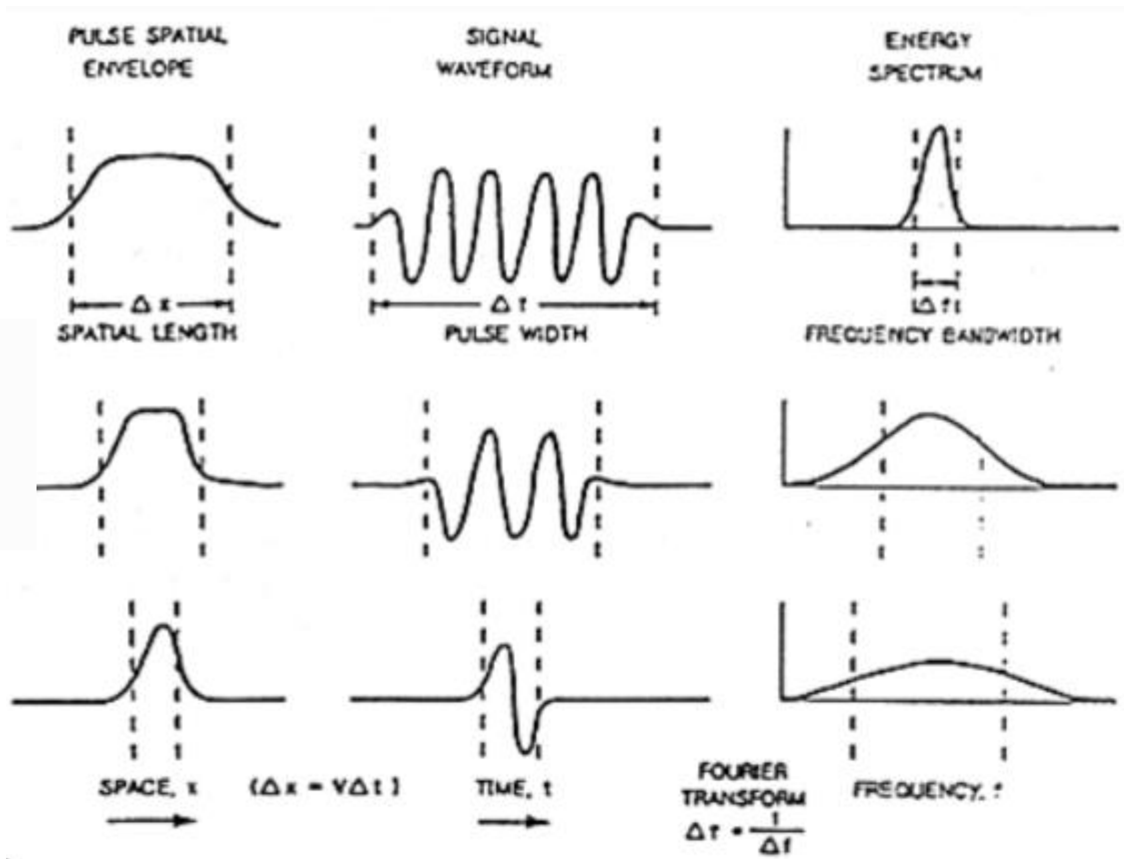
Frequencies in Wavelet



GPR Source Signal: Wavelet

- Shorter pulse overall contain higher frequencies
- Spatial length increases as pulse length increases
- Shorter pulses contain a wider range of frequencies

$$f_c = \frac{1}{\Delta t}$$



GPR Source Signal: Spatial Length

- The spatial length (wavelength) of the GPR pulse is dependent on the **central frequency** and **velocity**

$$\lambda = \frac{V}{f_c} = \frac{c}{f_c\sqrt{\varepsilon_r}}$$

- When the GPR signal at some frequency is transmitted across an interface, it can be stretched or contracted

- Lower velocity $\Rightarrow$ Shorter spatial length
- Lower frequency $\Rightarrow$ Larger spatial length

GPR Source Signal: Spatial Length

- Since $f_c = 1/\Delta t$, the spatial width is given by:

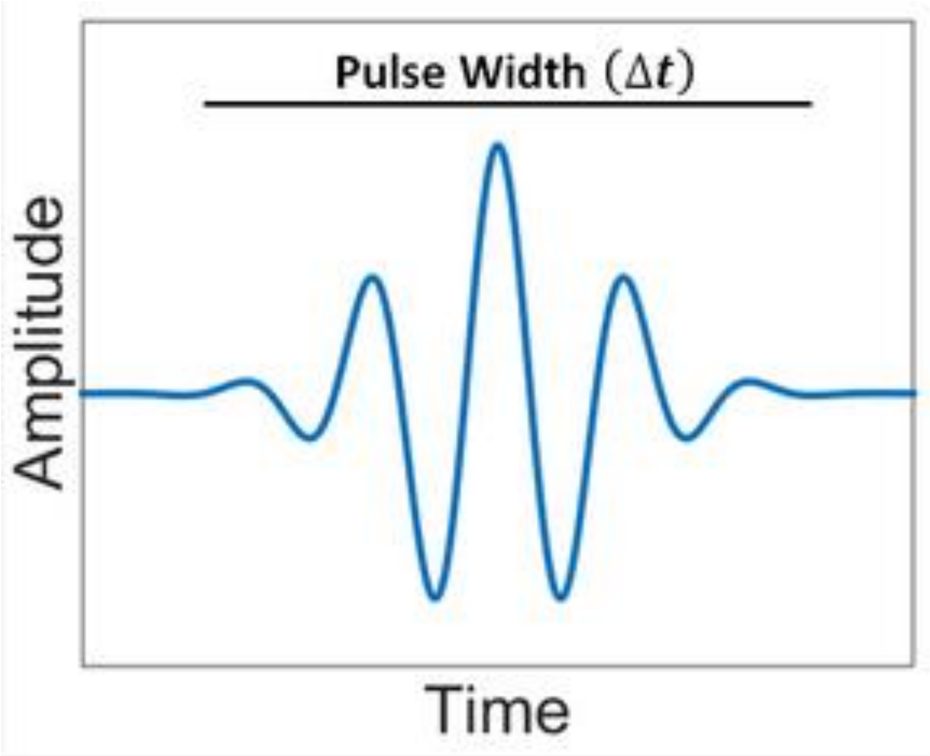
$$\lambda = V\,\Delta t = \frac{c\,\Delta t}{\sqrt{\varepsilon_r}}$$

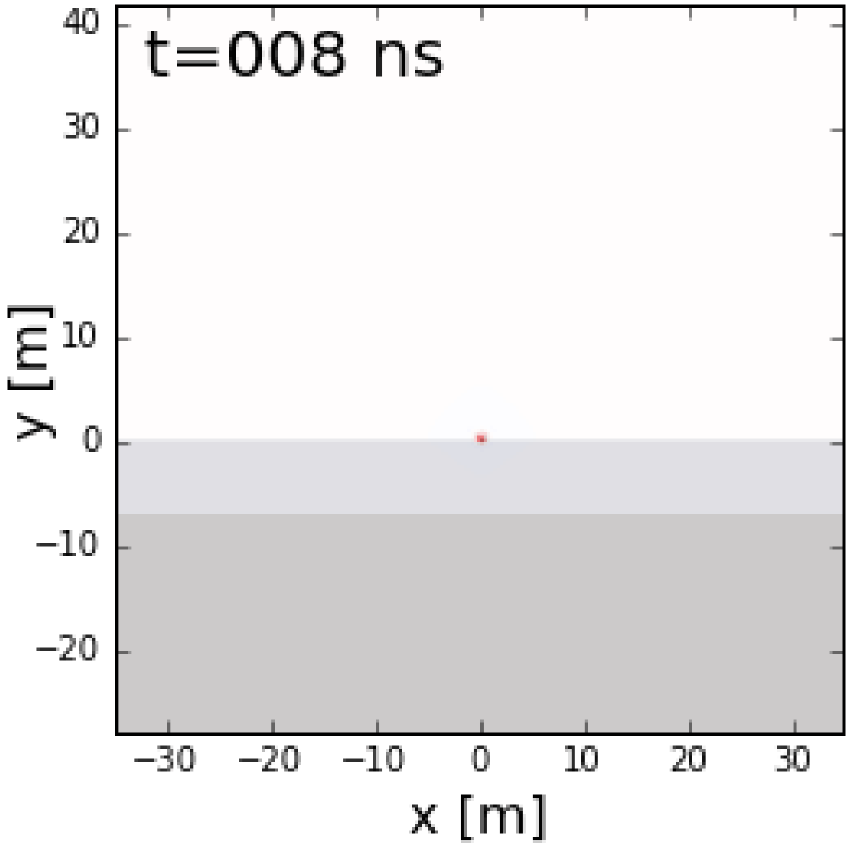
- Shorter pulse width $\Rightarrow$ Higher frequencies

  $\Rightarrow$ Shorter wavelength

Spatial Length: 2D Example

- Does the reflected signal coming up to the surface becomes stretched or contracted?
- Why is this?





Resolution of GPR Surveys

- **Resolution:** Smallest features which can be distinguished using the survey.

- Resolution depends on:
  - The frequency of the GPR signal
  - The physical properties of the ground
  - The dimensions and separations of features

Resolution of GPR Surveys: Layers

¼ wavelength rule:

The thickness of a layer must be at least ¼ the wavelength of the GPR signal.

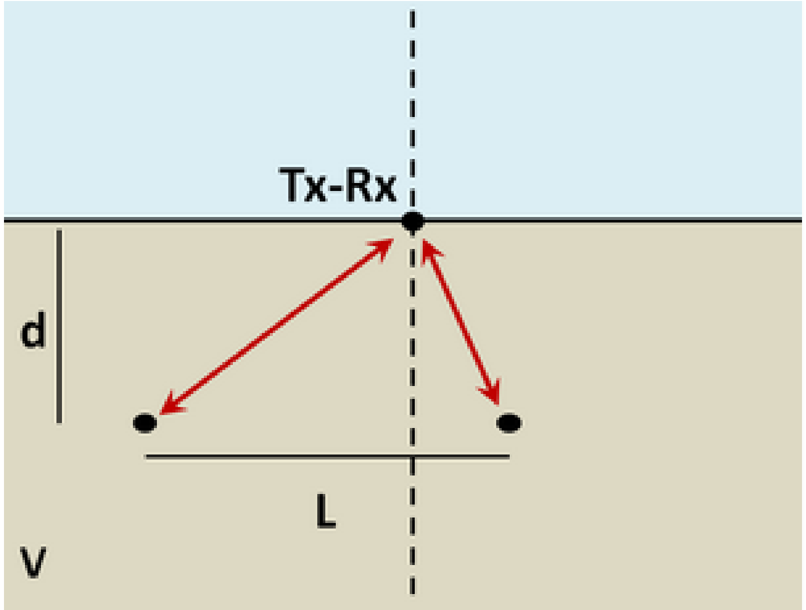
$$L > \frac{c}{4 f_c \sqrt{\varepsilon_r}} = \frac{c \Delta t}{4 \sqrt{\varepsilon_r}}$$

Resolution of GPR Surveys: Separation

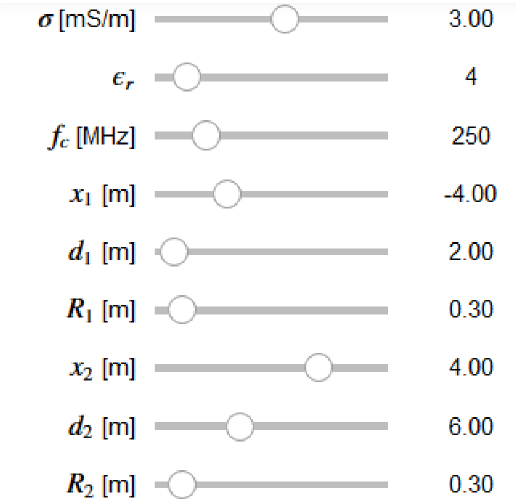
- If objects are too close to one another:
  - The two way travel time is almost the same
  - The two returning wavelet signals will overlap
  - They will appear to be one object

- **For zero offset survey**

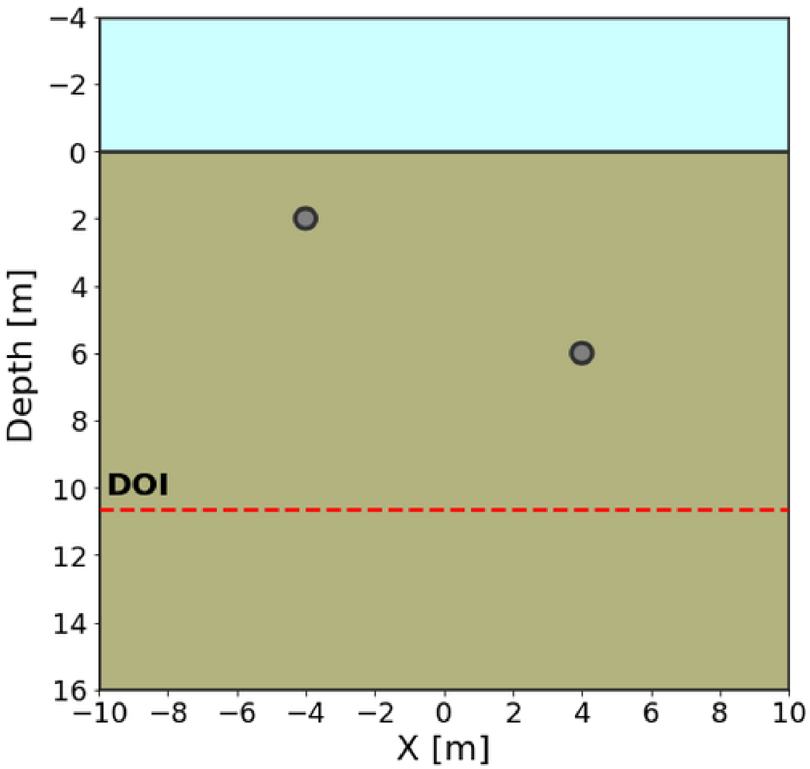
$$L > \sqrt{\frac{V\,d}{2 f_c}}$$

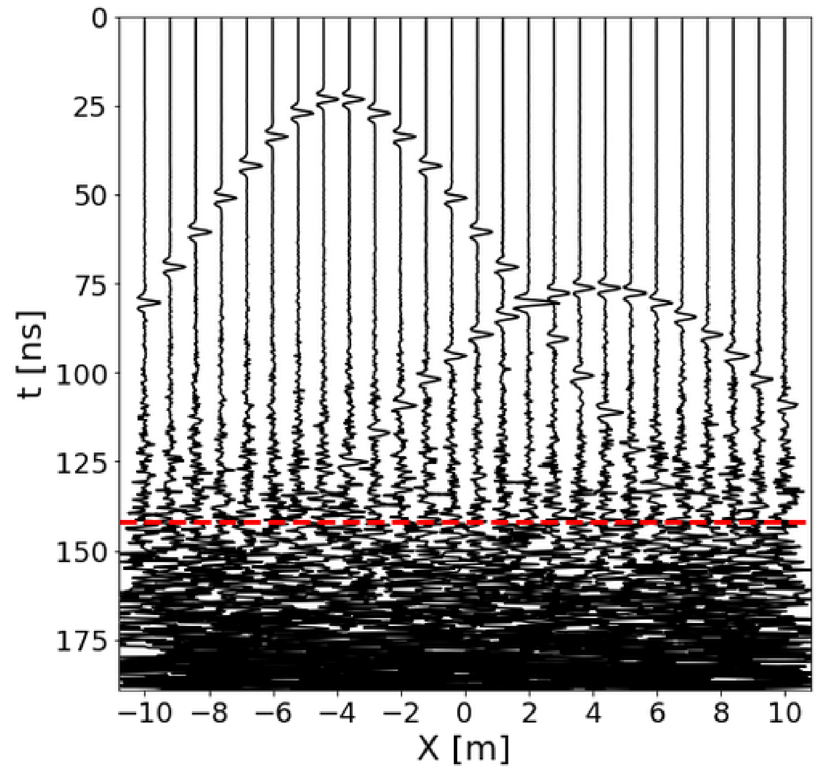


GPR Wave Regime App



- **Zero offset survey**
- **Two buried reflectors**





Probing Distance (Depth of Investigation)

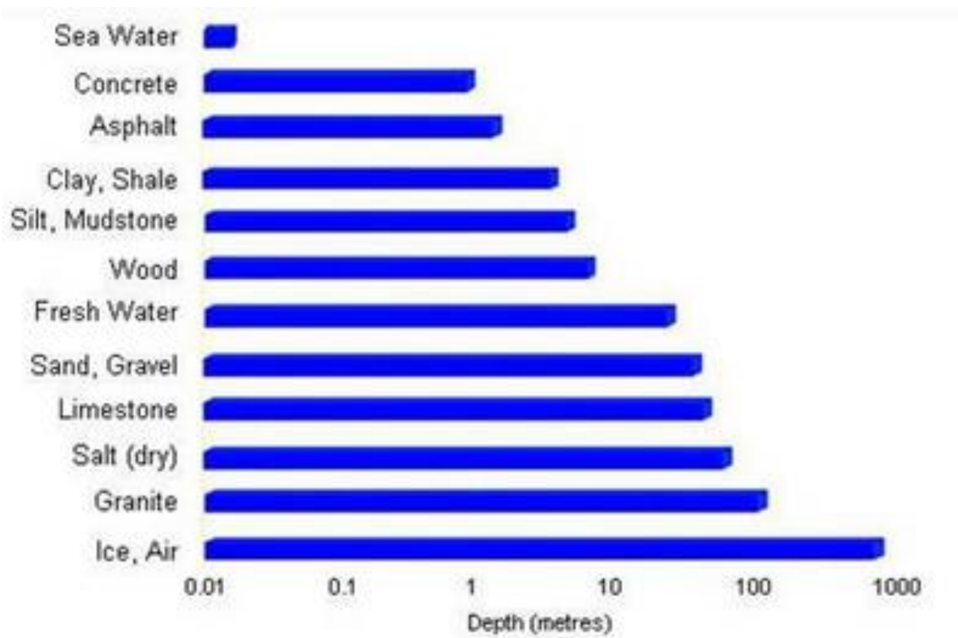
- Maximum depth at which GPR can be used to get information about subsurface

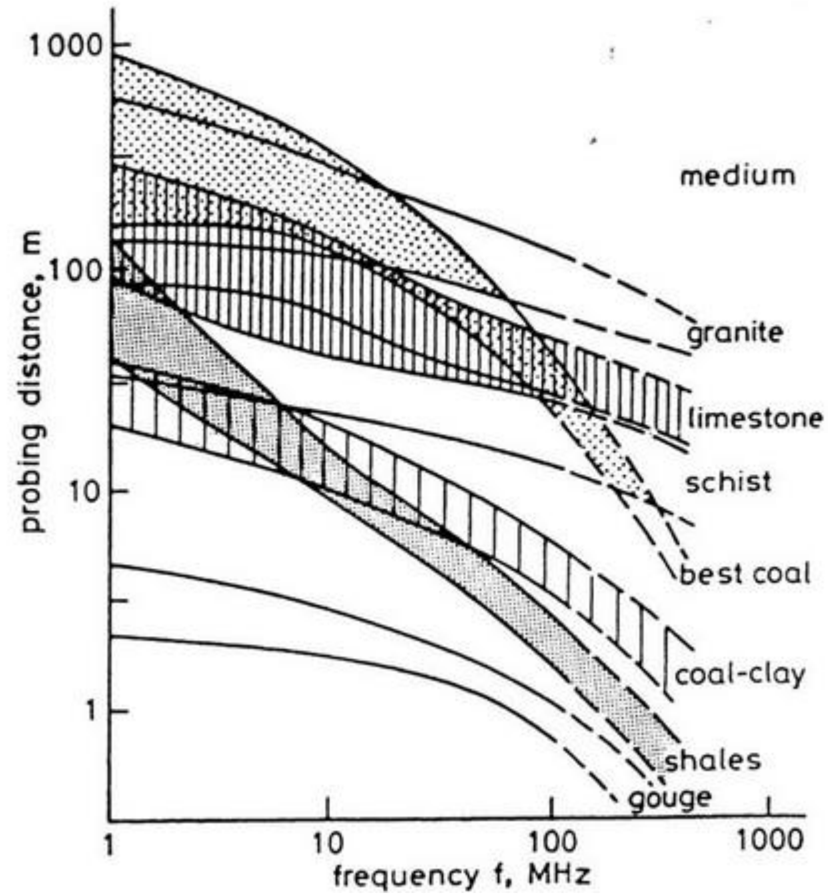
- Probing distance is approximation **3 skin depths:**

$$D = 3\delta \approx \begin{cases} 1510\sqrt{\dfrac{1}{\sigma f}} & \text{for } \omega\varepsilon \ll \sigma \\ 0.0159\dfrac{\sqrt{\varepsilon_r}}{\sigma} & \text{for } \omega\varepsilon \gg \sigma \end{cases}$$

Probing Distance (Depth of Investigation)

- Generally decreases as frequency increases
- Is lower for more conductive materials and non-dielectric materials





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Recap Questions

Q: If a GPR signal contains more high frequency waves, is its pulse length longer or shorter?

$$f_c = \frac{1}{\Delta t}$$

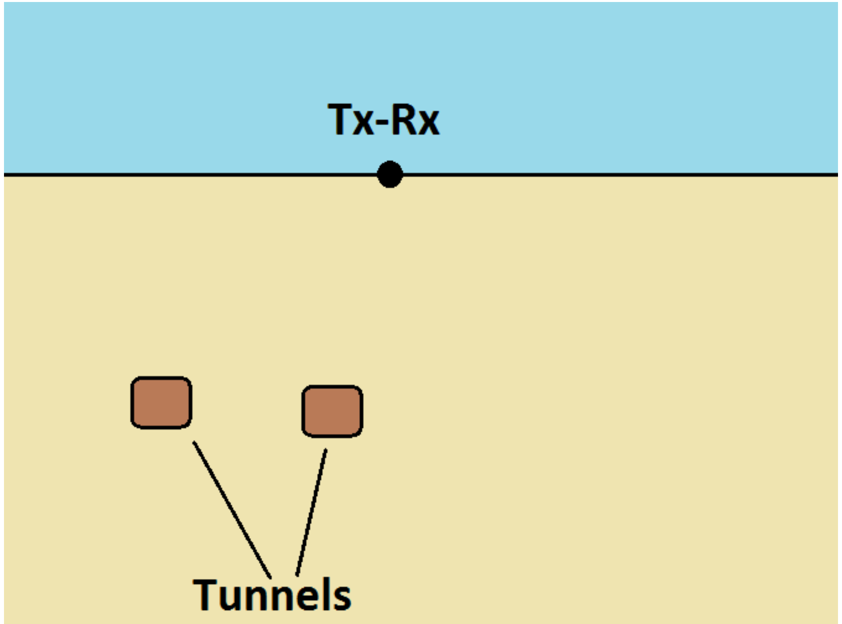
Q: How thick does a layer need to be for us to see it?

Q: What happens when objects are too close together?

Q: Does probing distance increase/decrease as frequency increases?

Probing Distance vs. Resolution

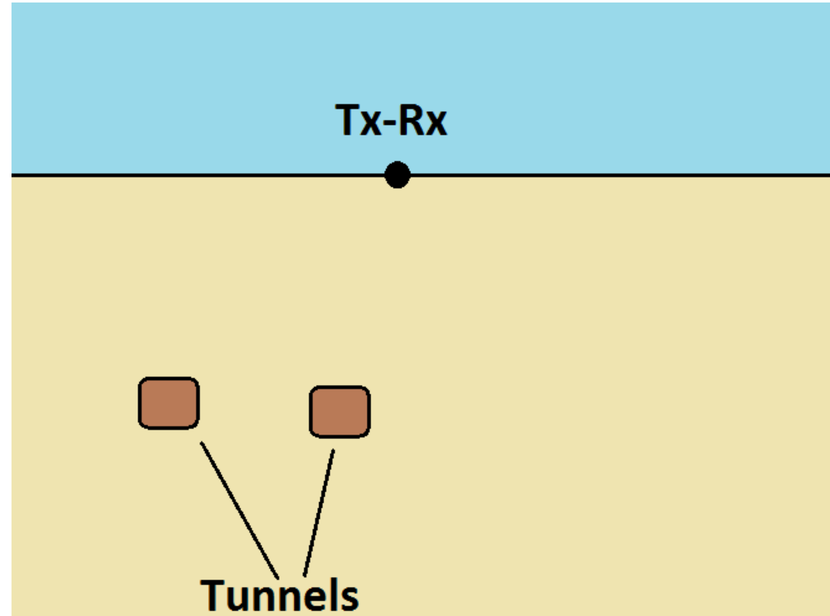
- Want to find two burried tunnels.
- Using a **zero offset** survey configuration.
- Higher frequencies give better resolution
- Lower frequencies give larger probing distance

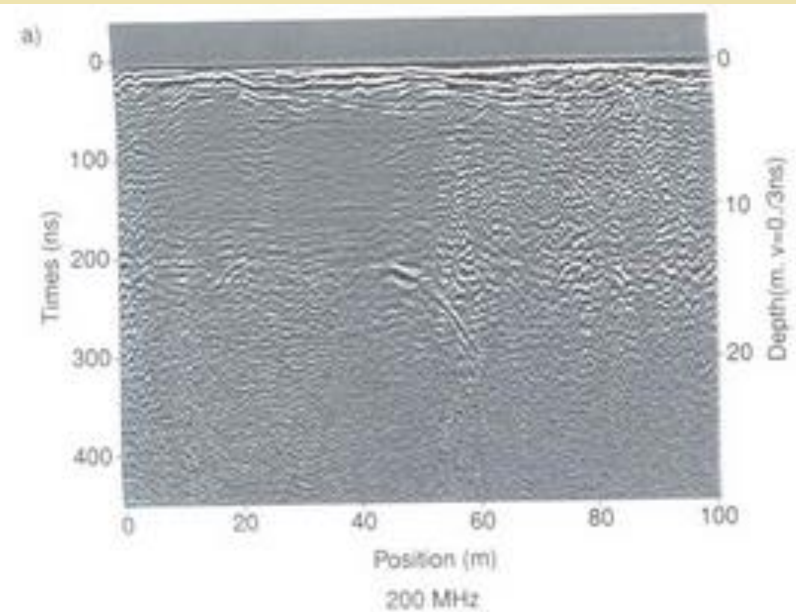


Radargram 200 MHz

- Little to no useful signal after 200 ns
- Can't see features from the tunnels

- Too much attenuation of signal
- Probing distance insufficient

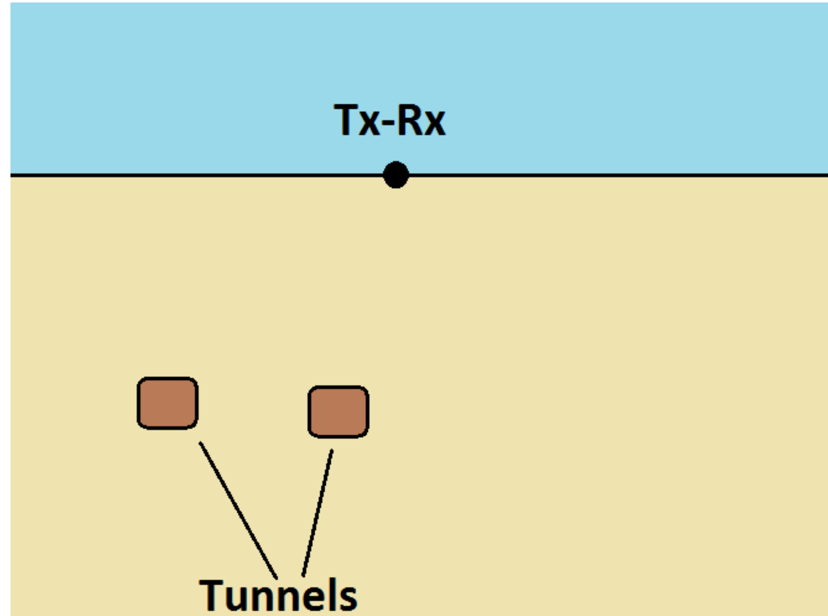


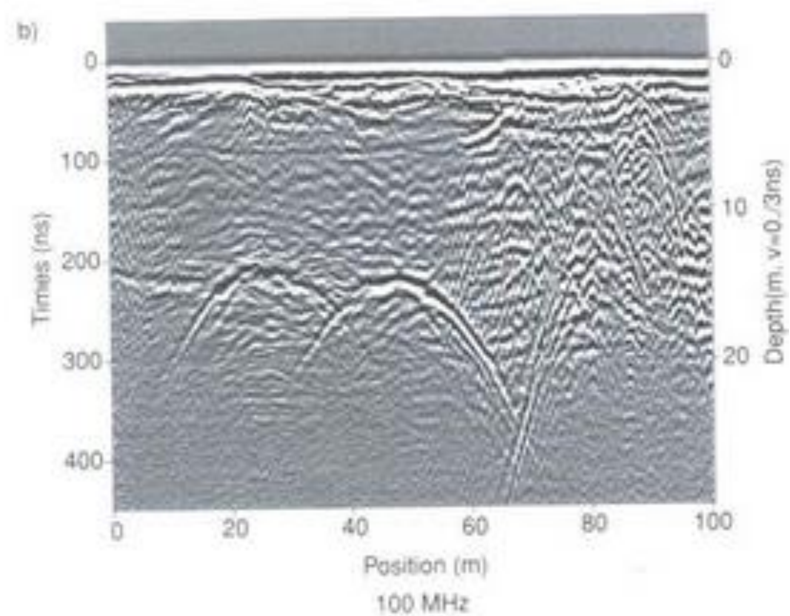


Radargram 100 MHz

- Useful signals up to 300 ns
- See top of hyperbolas from tunnels

- Lower resolution
- Can see tunnels

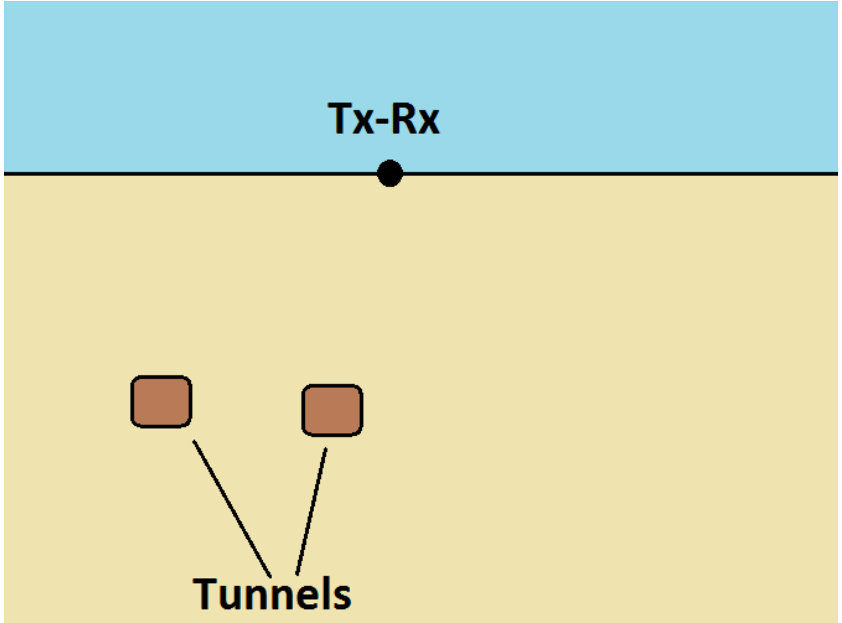


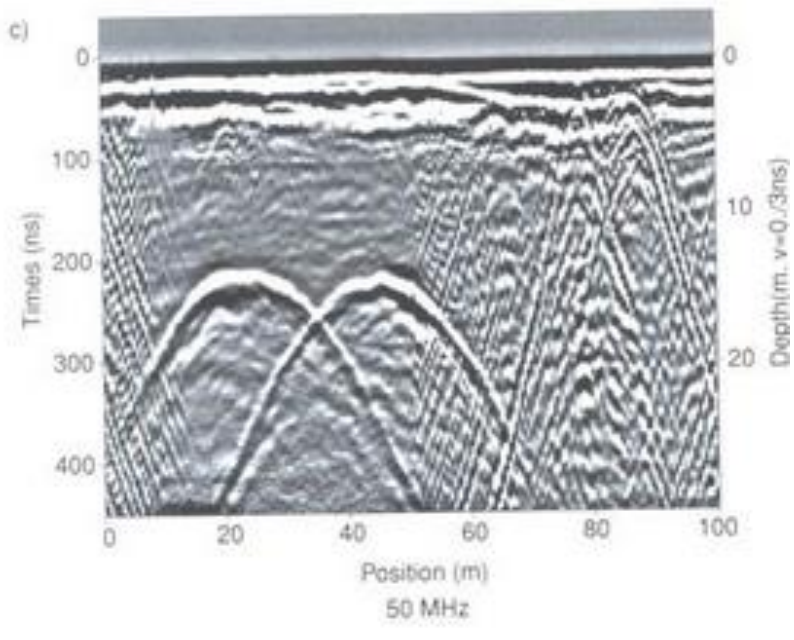


Radargram 50 MHz

- Useful signals through 400 ns
- Well-defined hyperbolas from tunnels

- Lower resolution image
- Best frequency for what we want to observe





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Recap of Material

- There is a compromise between resolution and probing distance:

Higher frequencies → Better resolution

Layers: $$L > \frac{c}{4 f_c \sqrt{\varepsilon_r}} = \frac{c\Delta t}{4\sqrt{\varepsilon_r}}$$

Objects: $$L > \sqrt{\frac{V\,d}{2 f_c}}$$

Higher frequencies → Lower probing distance

$$D = 3\delta \approx \begin{cases} 1510\sqrt{\dfrac{1}{\sigma f}} & \text{for } \omega\varepsilon \ll \sigma \\ 0.0159\dfrac{\sqrt{\varepsilon_r}}{\sigma} & \text{for } \omega\varepsilon \gg \sigma \end{cases}$$

Recap Questions:

Q: If higher frequencies give better resolution, what does that say about pulse width?

$$f_c = \frac{1}{\Delta t}$$

Q: What are some things you want to know before chosing an operating frequency?

Noise and GPR

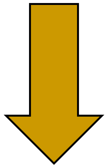
- **Any** signal which interfers from useful signals from GPR targets.

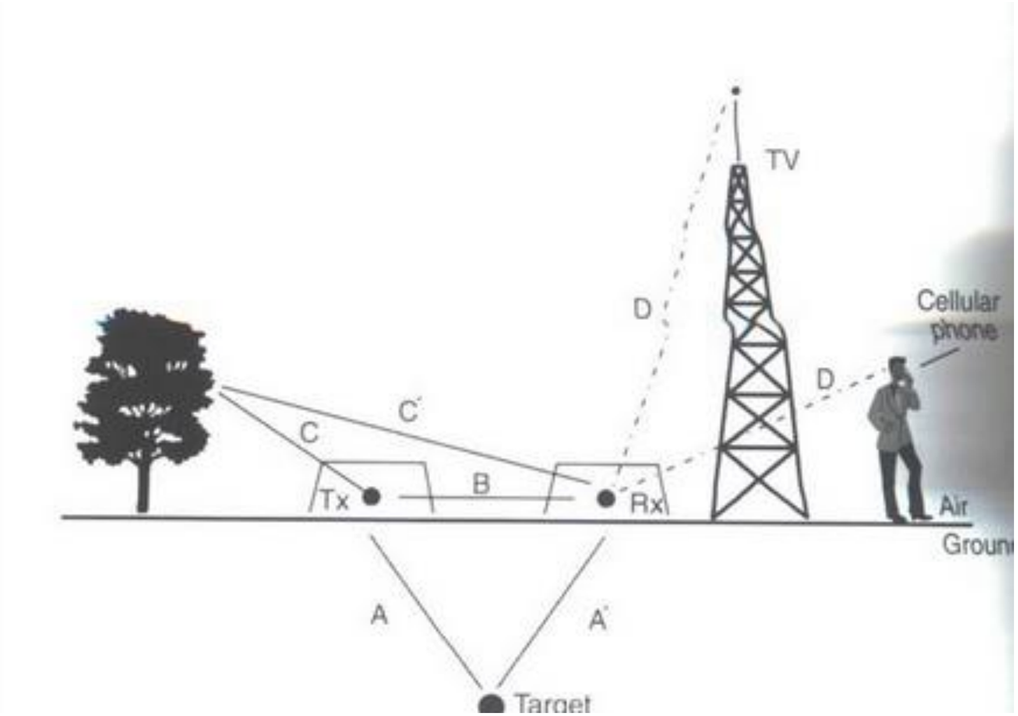
Examples:

- External radiowave sources
- Above ground objects
- Ringing
- Scattering

Interference from other Radiowave Sources

- Radio towers
- Cell phones
- Power Lines





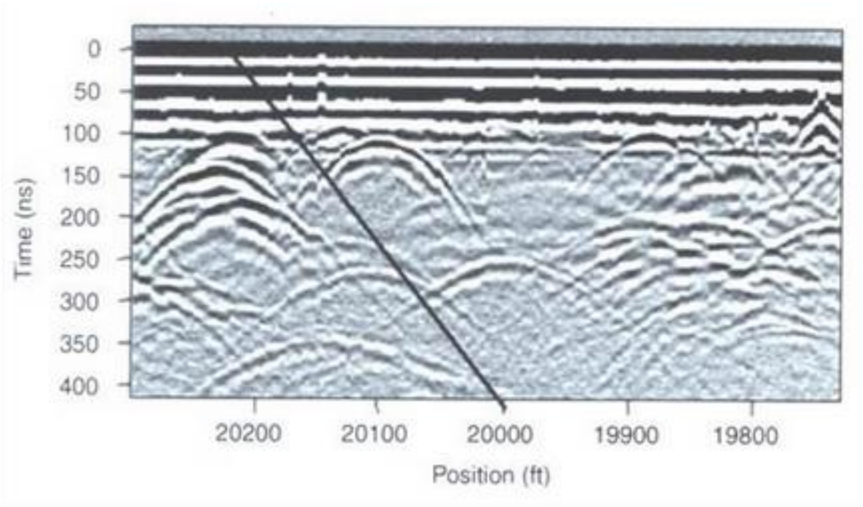
- Tx and Rx usually shielded to avoid these signals

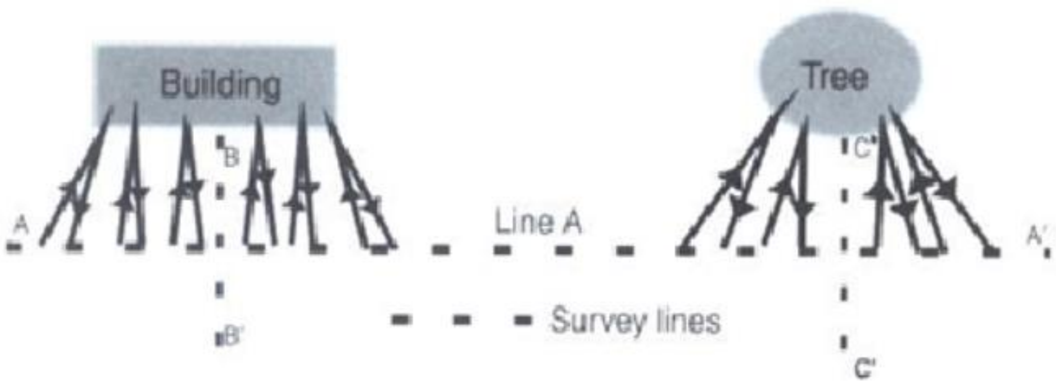
Noise from Above Ground Objects

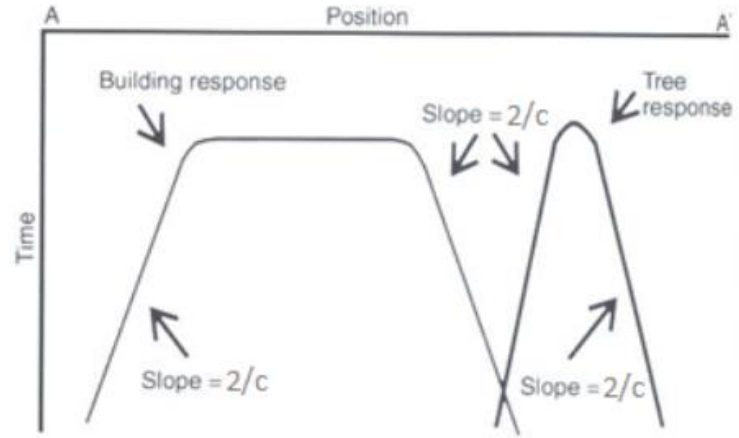
- Signals can reflect off neaby building and trees.
- Two-way travel time:

$$t = \frac{2\left(x^2 + d^2\right)^{1/2}}{V}$$

- Makes hyperbolas in zero offset surveys

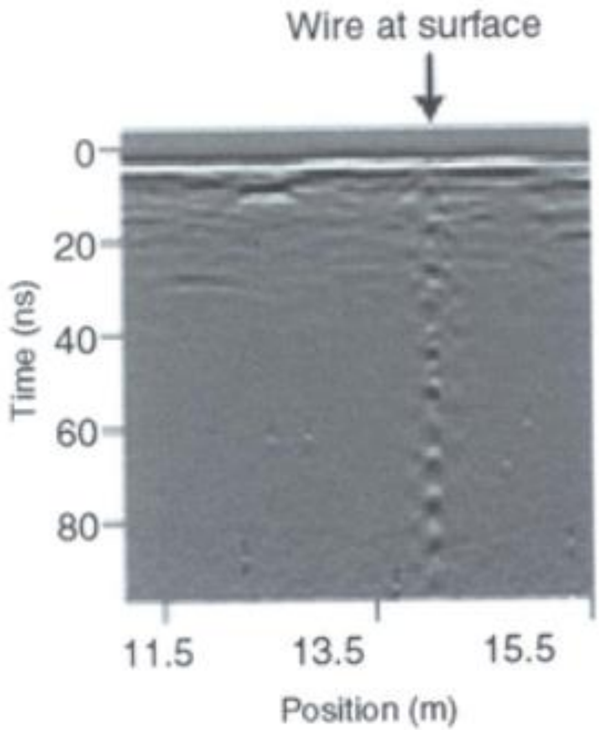






Noise from “Ringing”

- Caused when signals reverberate in regular fashion
- Signal repeatedly bounces within a layer or between objects.

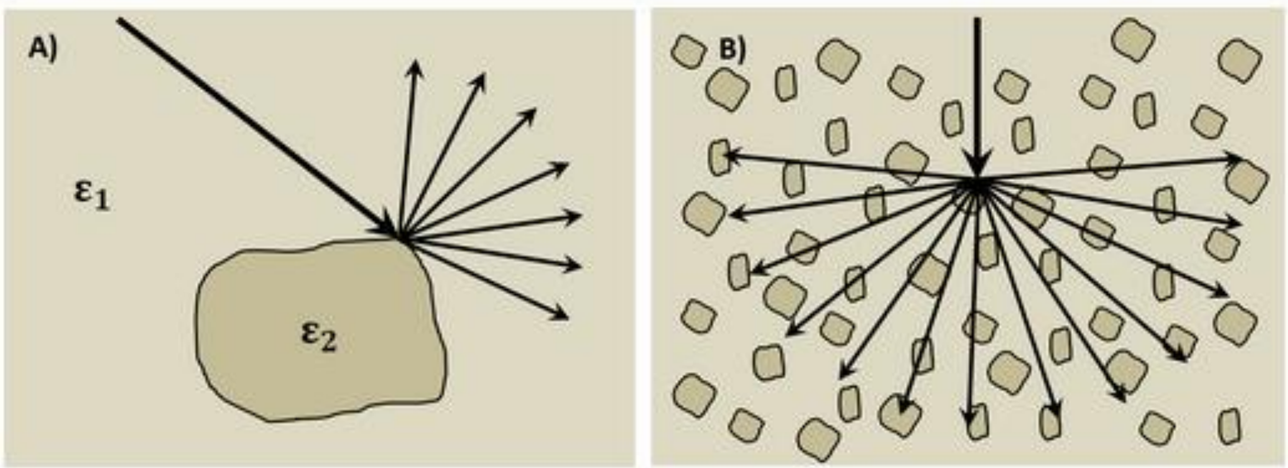


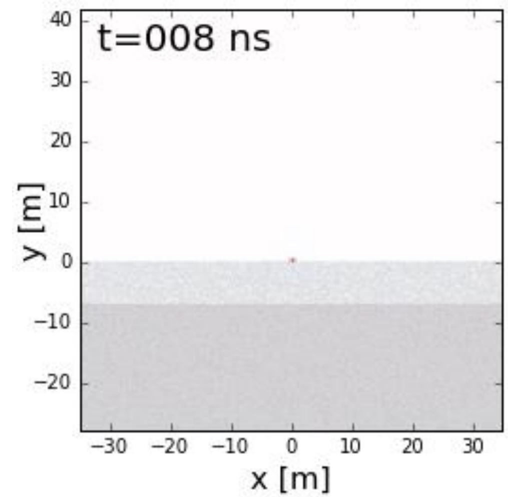
Wire below surface

2 nearby objects

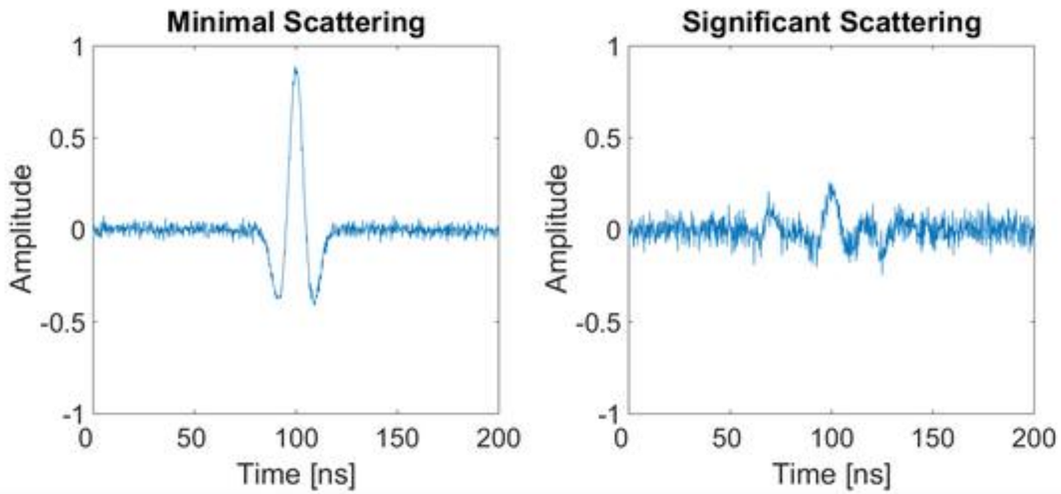
Noise from Scattering

- Deviations in signal path due to localized non-uniformities.





- Reduces amplitude of usable signal and increases noise.



Processing

Examples:

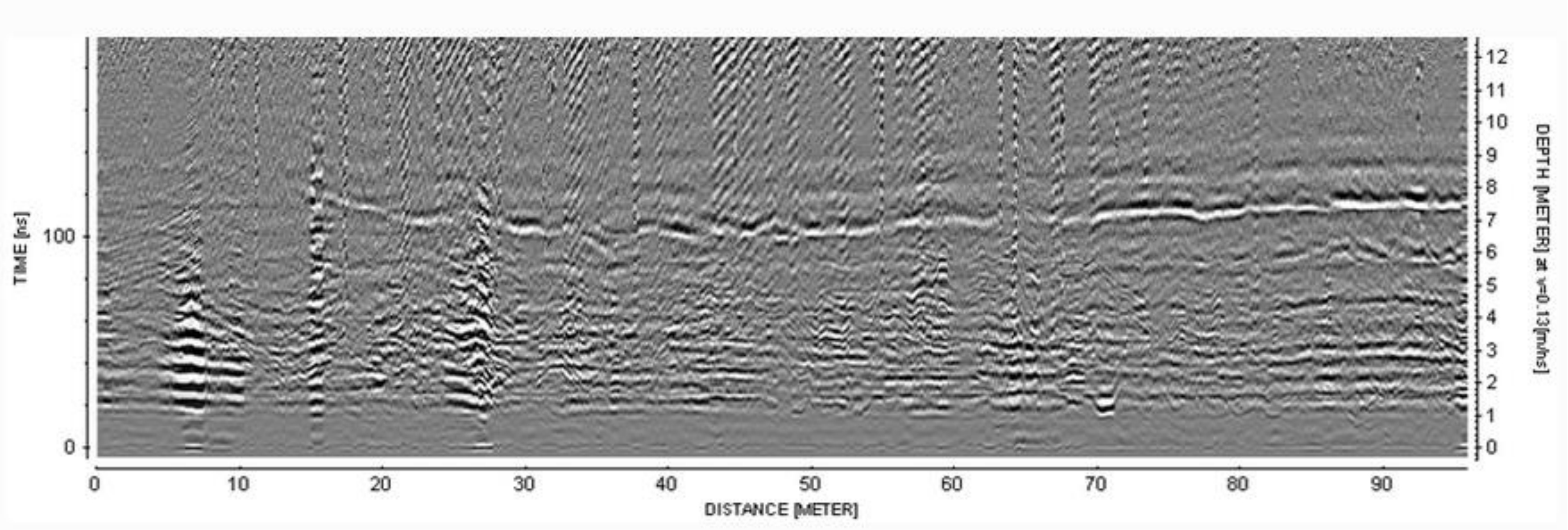
- Arrival time to depth conversion
- Gain correction
- Stackings
- Smoothing

Arrival Time to Depth Convesion

- Vertical axis usual 2-way travel time [ns]

- If you can get velocity, you can get an apparent depth:

$$d_a = \frac{Vt}{2}$$



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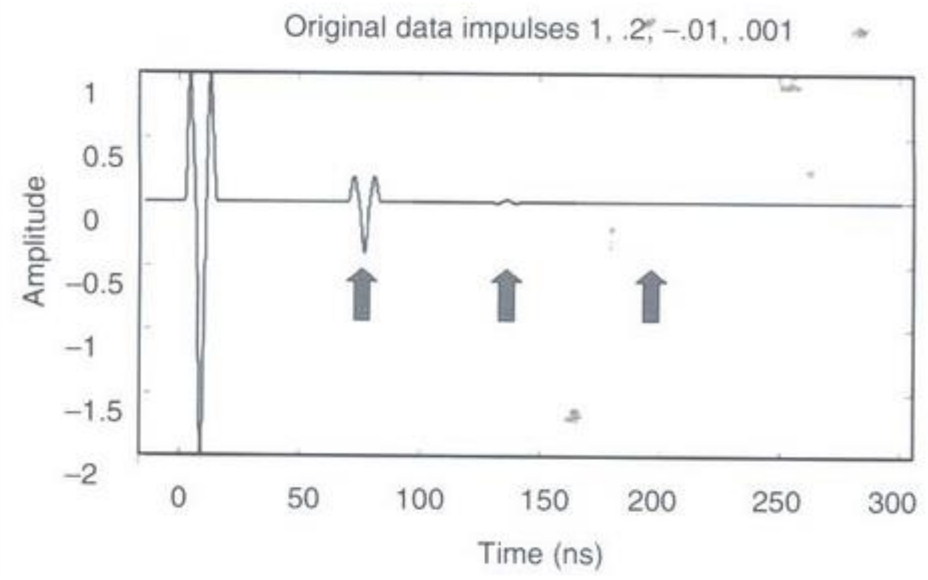
Gain Correction

- GPR signal strength decreases exponentially travel distance

→ Measured signal strength decreases over time

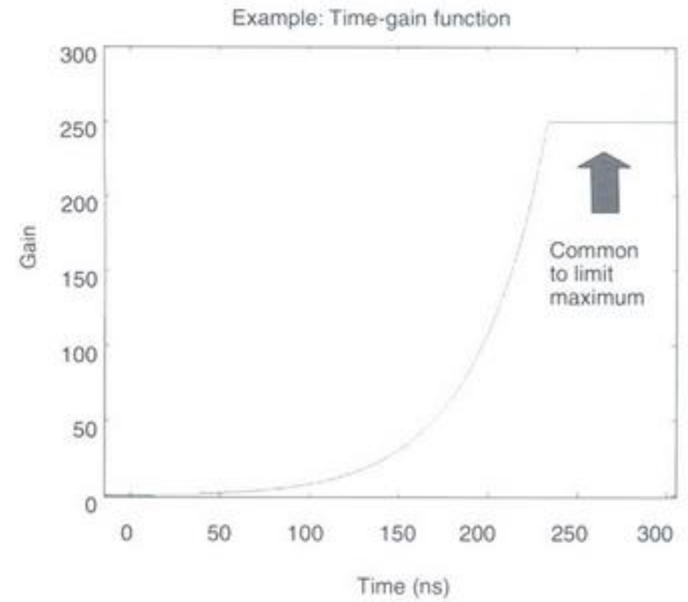


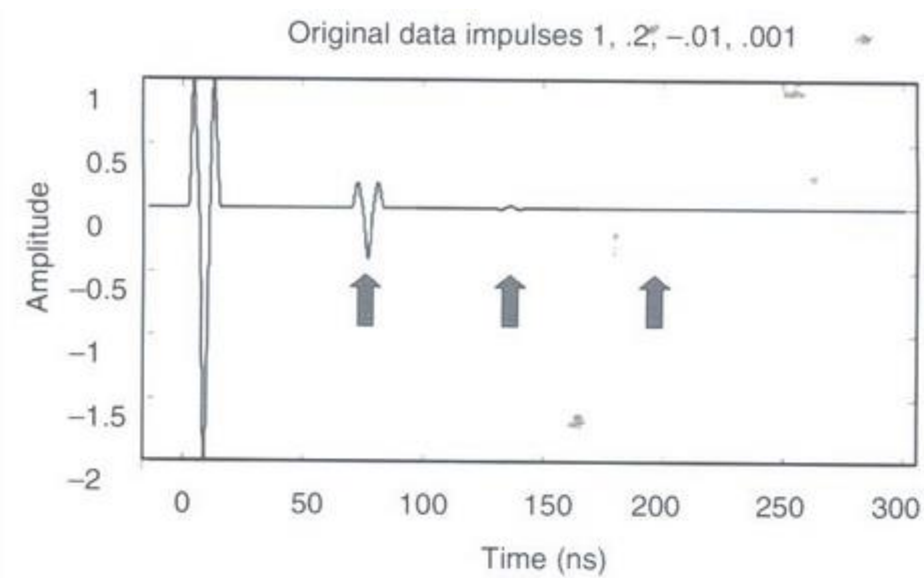
Gain Correction

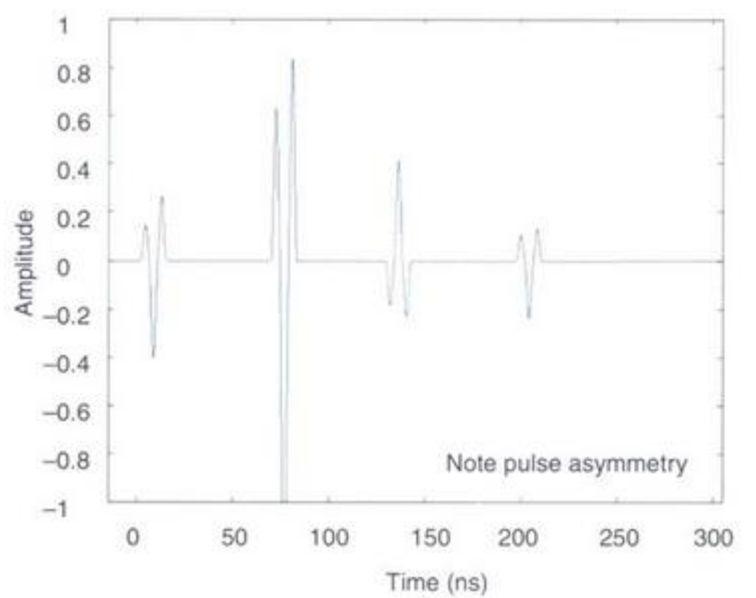
- Multiply raw data by a **gain factor** so that late signals can be recognized.

$$d(t) = g(t) \times d_{raw}(t)$$

- Gain factor generally counteracts exponential decay in amplitude







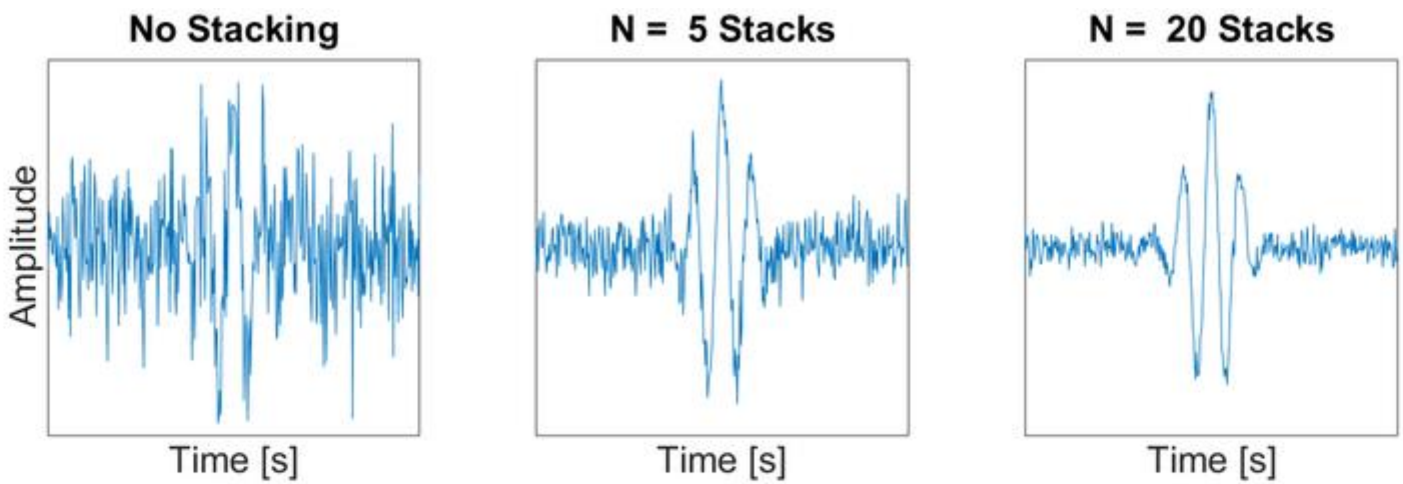
Stacking to Reduce Noise

- 2-way travel times for GPR are 100s of nanoseconds

  → The same GPR shot can be repeated many times within a short period of time

- Data from repeated shots are averaged (stacked)

- Stacking reduces the amplitude of incoherent noise



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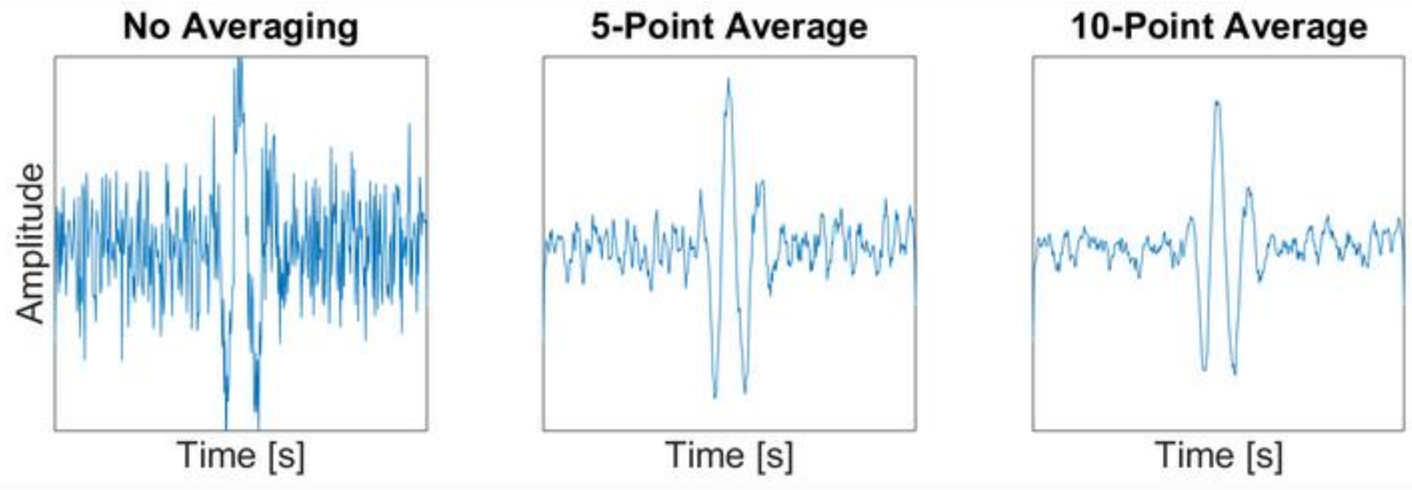
Smoothing to Reduce Noise

- Data sampling rate is very high relative to returning wavelet signal.

Wavelet signal is smooth whereas incoherent noise is random

- Smoothing decreases amplitude of random noise relative to returning signals.



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Processing Recap

- Gain correction is need so late time signals are as visible as early time signals.
- Stacking is used to reduce the noise to signal ratio.
- Smoothing can be used to reduce the amplitude of incoherent noise.

Recap Questions

Q: Why would we do a time to depth conversion?

Q: What's a way we can reduce incoherent noise?

Questions About Material?

Unit Activities

- **Labs (GPR)**
  - Monday, October 21^{st}
  - Tuesday, October 22^{nd}
- **TBL:**
  - Friday, October 18^{th}
- **Quiz:**
  - Friday, October 18^{th}