Team TBL #4: Understanding GPR signals and Survey Design

DUE: October 30, 2015

Overview

Ground penetrating radar (GPR) sends a pulse of radiowaves into the Earth. As GPR signals propagate through the Earth, they reflect, transmit and refract at interfaces. The propagation of the GPR signal depends on the frequencies contained in the source wavelet and the electromagnetic properties of the Earth; most importantly the dielectric permittivity and electrical conductivity. Because of the high frequencies used, GPR has high resolution, enabling us to image various buried objects such as pipes, historical remains, and geologic interfaces.

In your individual TBL you looked at GPR waves in a layered earth and also the application of a GPR survey to find a buried airplane. In the Team TBL you will: (a) revisit the movie and answer questions collectively (b) generate your own GPR survey to find some buried utilities (c) look at aspects of resolution and probing distance.

Instructions

Team exercise:

- Discuss the movie amongst yourselves
- As a team, answer the following questions
- You will hand this in at the end of the class

Resources

- GPG - Ground Penetrating Radar
- GPR Movie
- AttenuationApp Ipython Notebook for EM wave attenuation

Part I: GPR Movie

Q1. Watch the GPR Movie and look for the waves. Note that you can step through frame-by-frame using the arrows at the bottom (second and sixth buttons), or slow the frame rate using the minus-sign button on the left. In the GPR movie, Tx indicates the source location, and Rx locations are represented by the red line. No specific distances are provided and none are needed to answer the following questions.

a. Consider the screen shot at 96ns shown below: Label the following wavefronts: (A) Direct air wave; (B) Direct ground wave; (C) Reflected wave off the lower interface.

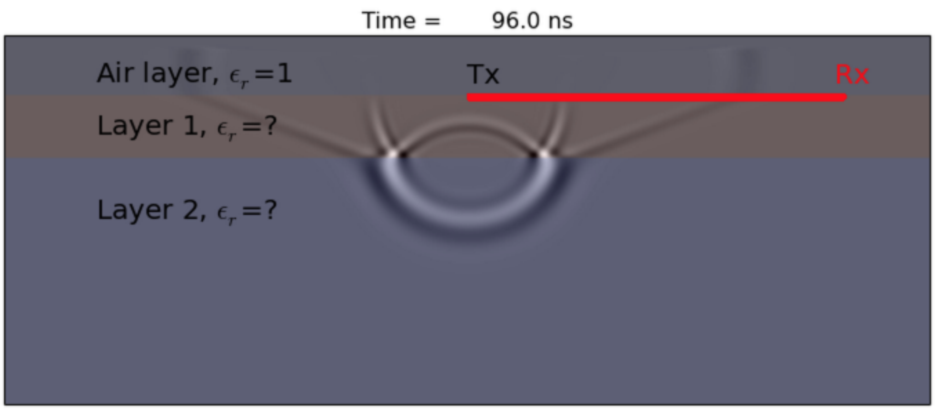

Figure 1: At 96 ns

b. Examine the thickness of the wavefronts in layer 1 and layer 2. (i) Is the spatial length of the wavelet signal larger in layer 1 or layer 2? (ii) Based on the information provided, rank the propagation velocity of all three mediums from highest to lowest.

c. In the GPG, examine the expression for resolution for two nearby objects. Based on the variables in this equation, provide **two** reasons why it would be harder to differentiate two nearby object in layer 2 as opposed to layer 1.

Q2. Consider the screen shot at 144ns shown below.

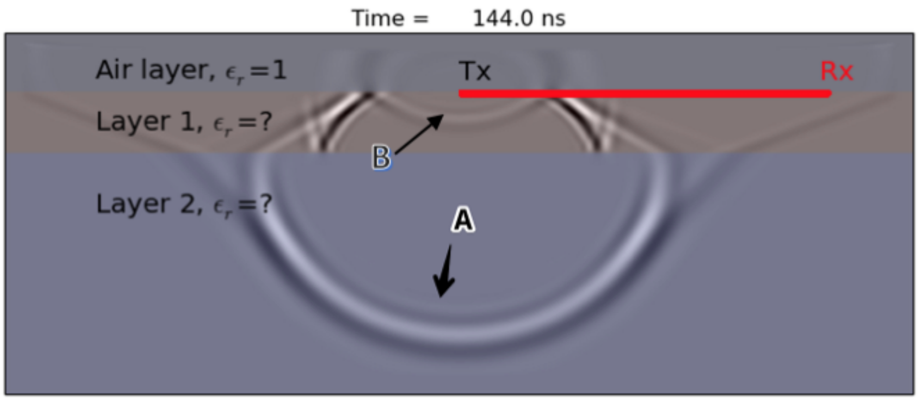

Figure 2: At 144 ns

a. What is the physical understanding of the wavefront labeled A?

b. What is the physical understanding of the wavefront labeled B?

c. Provide two reasons for how you can be certain $\varepsilon_{r,2} < \varepsilon_{r,1}$.

Part II: Survey design

Setup

In order to maintain a water service pipe network in town, pipes under roads must be periodically dug up and replaced. Unfortunately, utility maps for the area are old and out of date. Knowing the precise location and depth of each pipe is important, as buried gas lines and electrical wires can pose as serious hazards.

Fortunately, you have access to several GPR systems. The central operating frequencies for these systems are 25 MHz, 100 MHz and 1000 MHz, respectively. Each GPR system is contained within a single box. As a result, each system uses a **zero offset** configuration. Your objective is to design surveys which 1) have a sufficient probing distance and 2) provide sufficient resolution for the objects you want to find. These objects are:

(a) Utilities such as main domestic gas pipes and/or electrical utility wires. These objects are typically buried between 20cm and 50cm and have diameters of 5 cm or more.

(b) A water pipe. The top of the pipe is known to be between 1 and 2 metres below the surface. We also know the pipe has a 1 metre diameter.

Some additional information:

(a) The pipes and cables run parallel to the road.

(b) The conductivity of the earth is uniform and has a value $\sigma = 31.6$ mS/m; note $\log(\sigma) = -1.5$.

(c) The background Earth material is compact and moist. A good estimate for its relative permittivity is $\varepsilon_r = 9$.

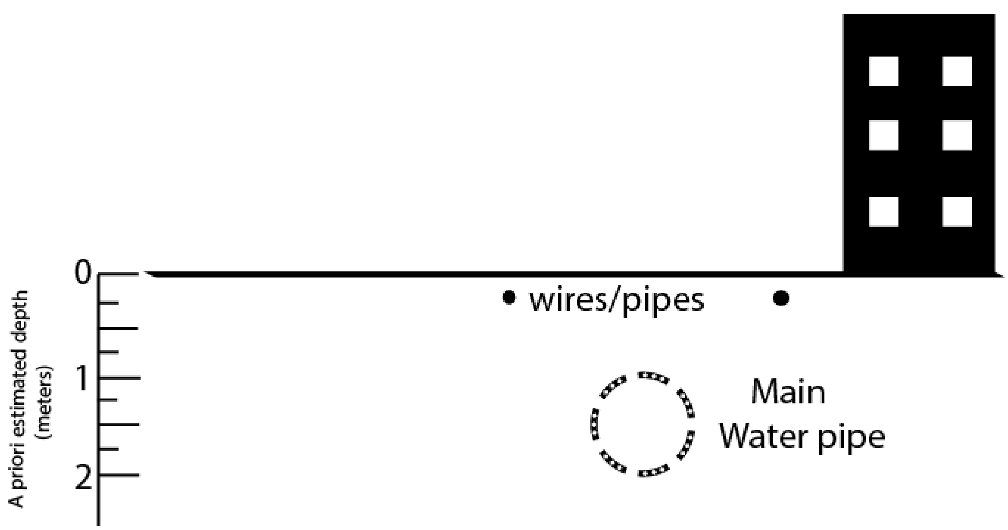

Figure 3: Sketch of the area to survey

Q3. If you forgot to shield the transmitter and receiver, what sources of noise may contaminate your data? (name two)

Q4. Given the pipe orientation, how would you orientate your acquisitions line?

Sketch

Q5. In order to consider the expected GPR signature from the pipe, we consider the model below.

a. First, sketch the reflected ray paths for the pipe model given below at figure 4.

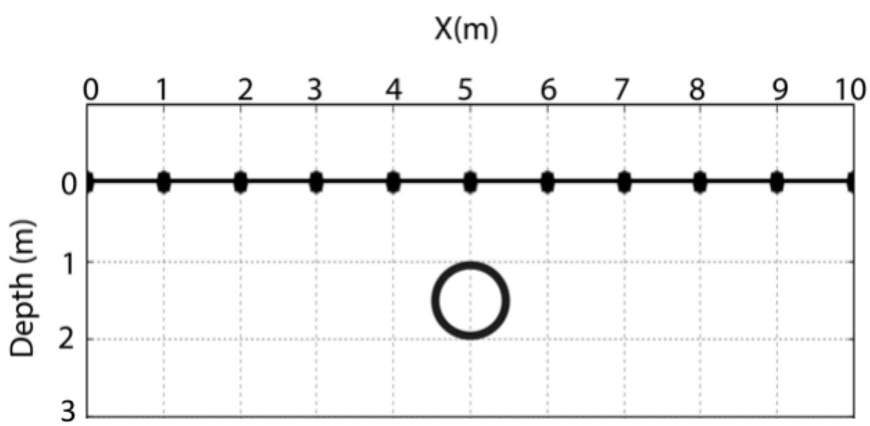

Figure 4: Ray paths for the pipe model for a zero-offset transmitter and receiver

b. Based on your a-priori knowledge, (i) what is the propagation velocity in the Earth? (ii) What is the minimum travel time? (iii) Based on the ray paths you drew, sketch the arrival time of those rays at receiver locations on figure 5. Make sure the slopes on the outsides of the signature correspond to the reciprocal of the propagation velocity.

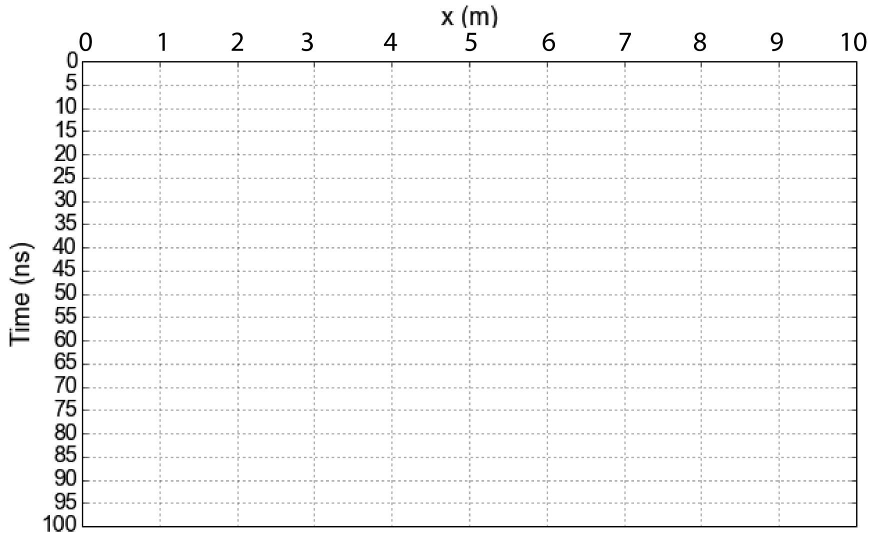

Figure 5: Arrival times for the pipe model

Q6. At x = 10m, the survey line ends because we hit the wall and foundation of a building. The wall and foundation are perpendicular to the survey line. There are two reflected signals from the building. What are they? Sketch the radargram signature of both these signals on the radargram above.

Q7. Provide a mathematical expression for the slope of each reflected signal in the radargram.

Properties

Q8. Here, we are going to investigate the effects of frequency and conductivity on skin depth. Using the AttenuationApp , we will fill in the table below. Assume the relative permittivity of the Earth is $\varepsilon_r = 9$.

- The probing distance is roughly equal to 3 skin depths.
- A good estimate for the resolution is given by the quarter wavelength formula $L = \frac{v}{4f}$.

- Note: $\log(0.0316 \text{ S/m}) = -1.5$

f (MHz)	**Conductivity σ (mS/m)**	**Probing Distance 3δ (m)**	**Resolution (m)**
25	31.6		
100	31.6		
1000	31.6		
25	1		
100	1		
1000	1		
25	1000		
100	1000		
1000	1000		

Survey

As a general set of rules: :

(a) our resolution length must be equal or smaller than the size of the feature.

(b) the feature must be within the probing distance for the GPR unit.

Q9. If the background conductivity is very high (eg. 1000 mS/m), why might the GPR survey be unsuccessful? Justify your answer.

Back to our case. We need to select a GPR system that has an appropriate probing distance and also provides the necessary resolution.

Q10. First consider the utilities (electric wires and gas pipes). Which frequency for the radar unit is needed to get good penetration and resolution? Base your answer on the previous table.

Q11. Now consider the main water pipe.

a. Would you be able to accurately image the pipe using the frequency you chose in the previous question? Justify your answer in term of probing distance and resolution.

b. Which frequency would you use if you were trying to image the water pipe? Base your answer on values in the table you completed.

Q12. In environments where the probing distance is small, why is it disadvantageous to use a large separation distance for a common offset survey?