Team TBL #4: Survey Design, Probing Distance and Resolution

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. 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.

This exercise is split into 3 parts. In part 1, you will consider several practical aspects of survey design for an example problem. In part 2, probing distance and resolution are considered in the wave regime using the **GPR zero offset app**. In part 3, the AttenuationApp is used to investigate optimum survey parameters for the example problem. The AttenuationApp does not use an approximation for the propagation velocity or skin depth.

Instructions

With help from the **GPR zero offset** and **Attenuation** apps, answer the following multiple choice questions. This assignment is to be completed by the end of class.

Resources

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

Prelude

In order to maintain a water service pipe network in town, pipes under roads must be periodically dug up and replaced. Unfortunately, utility maps are frequently out of date.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. You are tasked with using GPR to locate a set of buried utilities (Figure 1), including:

- a pair of electrical utility wires/pipes, thought to be buried between a depth of 20cm and 50cm.
- a water pipe. The top of the pipe is known to be between 1 and 2 metres below the surface. The pipe has a known diameter of 1 m.

Your objective is to design a survey which 1) has a sufficient probing distance, 2) provides a sufficient resolution for the objects you want to find and 3) produces GPR signatures which are easy to interpret.

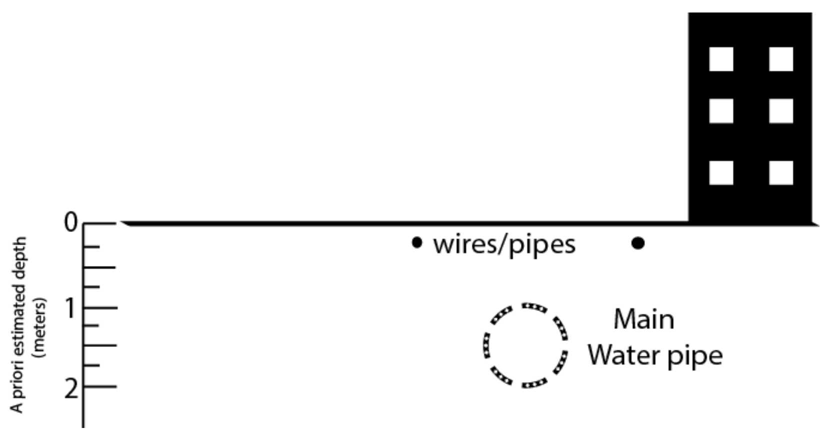

Figure 1: Sketch of the area to survey

Part 1: Survey design

Here, we will consider the transmitter-receiver configuration, orientation and other aspects of survey design for the problem illustrated in Figure 1. Decisions made here will ultimately determine the types of signatures which present in the resulting radargram data.

1. Which suvey configuration would work best for the problem illustrated in Figure 1?
   (a) Zero offset
   (b) Common Midpoint
   (c) Transillumination
   (d) Other

2. There are sources of noise which could contaminate the data if the transmitter and receiver are not shielded. Which of the following sources of noise is **not** eradicated by shielding the transmitter and receiver?
   (a) Ringing
   (b) Radiowave signals from power lines
   (c) Reflections from above ground infrastructure
   (d) Cell phones

3. Given the known orientation of the pipes and wires in Figure 1, how would you orient your acquisition line?
   (a) Parallel to the pipe/wires
   (b) Perpendicular to the pipe/wires
   (c) Either way is fine

4. Assume the GPR system you are using is not shielded, and that the reflection off a nearby building is observed (see Figure 1). What shape would the corresponding radargram signature have if the acquisition line were perpendicular to the building? (assume a zero offset survey is being used)
   (a) Linear
   (b) Hyperbolic
   (c) Flat middle with hyperbolic edges
   (d) None of the above

5. Which of the following is **not** useful information to be considered when choosing an operating frequency?
   (a) An estimate of the depth to your target.
   (b) The physical properties of the host media.
   (c) The dimensions of the target.
   (d) All of the above must be considered.

Part 2: Probing Distance and Resolution (wave regime)

GPR uses radiowave signals which are very high frequency. As a result, many characteristics of GPR signals, such as propagation velocity and skin depth, may be approximated by the "wave regime". Here, the **GPR zero offset app** is used to investigate how probing distance (depth of investigation) and resolution depend on electrical conductivity, relative permittivity and operating frequency. The fundamentals learned here will assist in determining optimum survey parameters for the problem illustrated in Figure 1 (part 3).

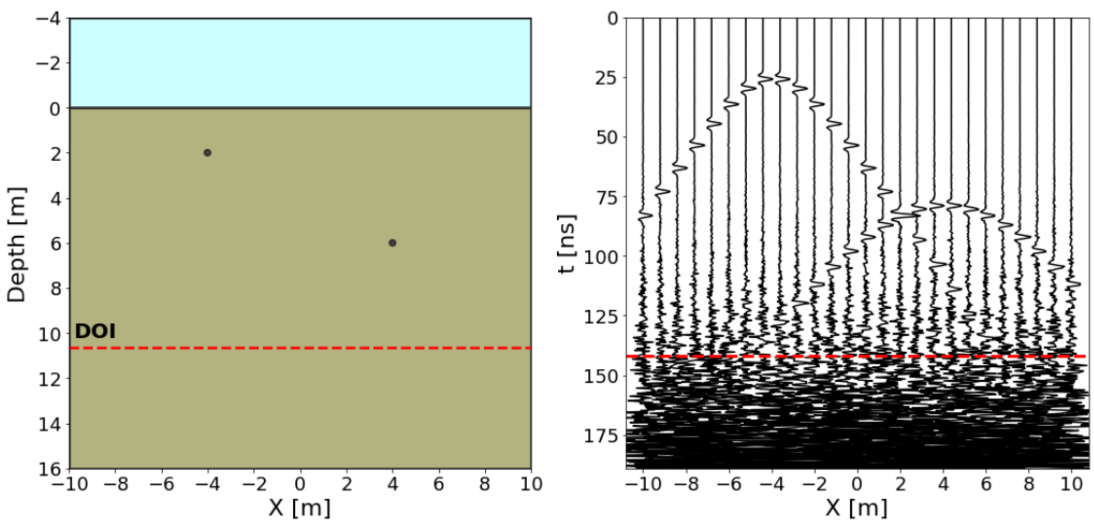

Figure 2: Screen shot of the GPR zero offset app.

Using the **GPR zero offset app**, answer the questions below regarding probing distance (DOI) and resolution in the wave regime. The following information may be useful:

- In the wave regime, the propagation velocity is equal to $v = \dfrac{c}{\sqrt{\varepsilon_r}}$
- The probing distance (depth of investigation) is equal to 3 skin depths ($DOI = 3\delta$)
- The horizontal resolution is approximately equal to $L = \sqrt{\dfrac{vd}{2f_c}}$

6. Using the default settings on the GPR zero offset app, what is the skin depth for the Earth?
   (a) 16 m
   (b) 10.8 m
   (c) 3.6 m
   (d) 1.8 m

7. Change the location of object 1 to (x_1, d_1)=(0m, 6m). Now slowly decrease the value of x_2. At what distance can object 1 and object 2 no longer be differentiated? (Confirm your answer by calculating the horizontal resolution).
   (a) 0.5 m
   (b) 1.25 m
   (c) 1.75 m
   (d) 2.5 m

8. Slowly increase the relative permittivity of the Earth from 4 to 9. Which of the following occurs?
   (a) The probing distance increases.
   (b) The horizontal resolution improves.
   (c) The wavelength of the GPR signal decreases.
   (d) All of the above

9. Reset the widget to default parameters (select cell and press Shift+Enter). Slowly increase the electrical conductivity from 3 mS/m to 5 mS/m. Why is the hyperbolic signature from object 2 no longer visible?
   (a) The object is at the limit of the probing distance.
   (b) The signal to noise ratio is too small.
   (c) a) and b) are correct.
   (d) a) and b) are incorrect.

10. Gradually increase the central operating frequency beginning from 250 MHz. Does the probing distance change? Why/why not?
   (a) No, because probing distance is independent of frequency in the wave regime.
   (b) No, because the relative permittivity of the Earth is small.
   (c) No, because the electrical conductivity of the Earth is large.
   (d) No, because the probing distance is less than 16 m

11. From all that you have learned from the app, which of the following statements are true?
    (a) Probing distance is bigger if the conductivity is small and the dielectric permittivity is large.
    (b) Probing distance is bigger if the conductivity is large and the dielectric permittivity is large.
    (c) Horizontal resolution is better for objects at depth and better if the Earth's dielectric permittivity is large.
    (d) Horizontal resolution is better for objects at depth and better if the operating frequency is large.

Part 3: Probing Distance and Resolution (general)

Here, we will use the AttenuationApp to consider an appropriate operating frequency for the survey illustrated in Figure 1. Unlike in part 2, we will **not** be using the wave regime approximation for skin depth and propagation velocity; these quantities are computed by the app at $f_c = 25$, 100 and 1000 MHz. The following information may be useful:

- The probing distance (depth of investigation) is equal to 3 skin depths ($DOI = 3\delta$)
- A good estimate for the vertical layer resolution is $L = \sqrt{\dfrac{vd}{4f}}$.
- $\log(0.0316 \text{ S/m}) = -1.5$

12. Using a transmitting frequency of 25 MHz, if the background conductivity is 0.0316 S/m (note that $\log(0.0316) = -1.5\text{S/m}$) and the relative permittivity is $\varepsilon_r = 9$, what is the probing distance?
    (a) 0.58 m
    (b) 0.88 m
    (c) 1.74 m
    (d) 2.68 m

13. Based on your previous answer, is the probing distance large enough to image both the electrical utility wires/pipes and the water pipe as shown in Figure 1?
    (a) No
    (b) Yes

14. Assume the electrical wires/pipes are buried at a depth of 50 cm and that the operating frequency is 25 MHz. At what conductivity would the wires no longer be visible? (Use the app to find the approximate conductivity)
    (a) 0.316 S/m
    (b) 1 S/m
    (c) 3.16 S/m
    (d) 10 S/m

15. Using an operating frequency of 100 MHz, if the background conductivity is 0.1 S/m and the relative permittivity is $\varepsilon_r = 9$, what is the vertical layer resolution?
    (a) 0.10 m
    (b) 0.16 m
    (c) 0.25 m
    (d) 0.32 m

16. Using the parameters from the previous equation, compute the vertical layer resolution assuming you are in the wave regime (i.e. neglect the electrical conductivity when compute the velocity). Does the wave regime approximation overestimate/underestimate the true vertical layer resolution?
    (a) 0.10 m. The wave regime approximation overestimates the vertical layer resolution.
    (b) 0.16 m. Both estimates would have been approximate.
    (c) 0.25 m. The wave regime approximation underestimates the vertical layer resolution.
    (d) 0.32 m. The wave regime approximation underestimates. the vertical layer resolution.

17. The app demonstrates how propagation velocity and skin depth depend on operating frequency. By examining the curves, which of the following is true?
    (a) In general, the propagation velocity and probing distance increase as a function of frequency.
    (b) Propagation velocity and probing distance are independent of frequency in the wave regime.
    (c) a) and b) are correct
    (d) a) and b) are incorrect