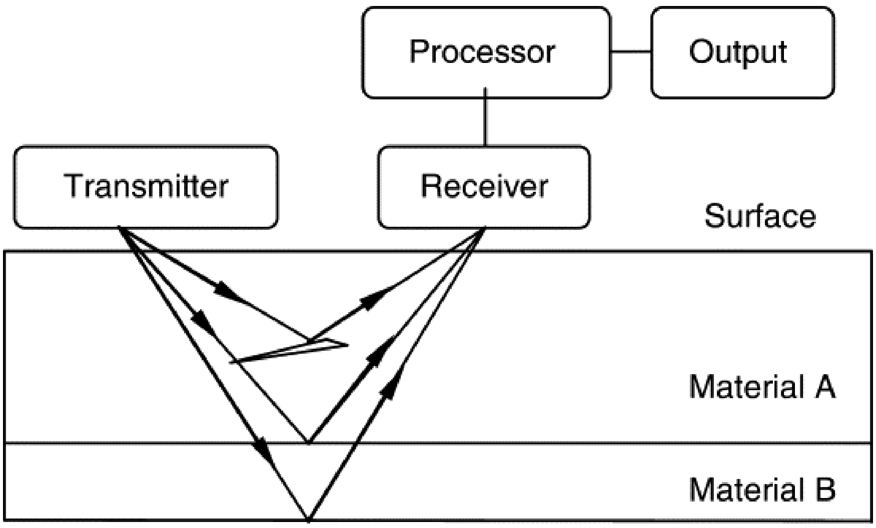
Modeling and simulating GPR with gprMax

Content:

1- Introduction and general background

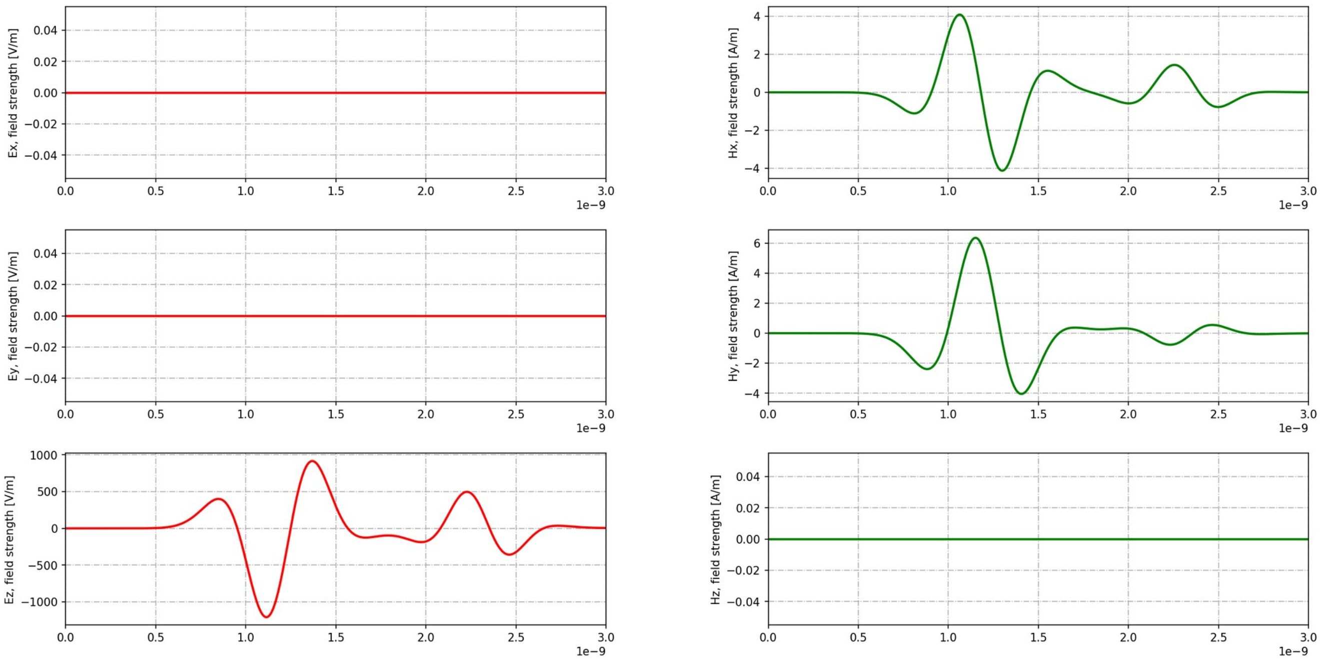
A- Working principle of GPR sensor:

GPR uses **electromagnetic radiation** in the **microwave band** of the **radio spectrum** (This is why it's called RADAR), and detects the reflected signals from subsurface structures.



GPR uses high-frequency (usually polarized) radio waves, usually in the range 10 MHz to 2.6 GHz. A GPR transmitter and antenna emits electromagnetic energy into the ground. When the energy encounters a buried object or a boundary between materials having different permittivities, it may be reflected or refracted or scattered back to the surface. A receiving antenna can then record the variations in the return signal.

The output signal from the receiver (Rx) based on this single transmit-receive cycle is called A-scan which is a plot of electromagnetic wave versus time of travel.

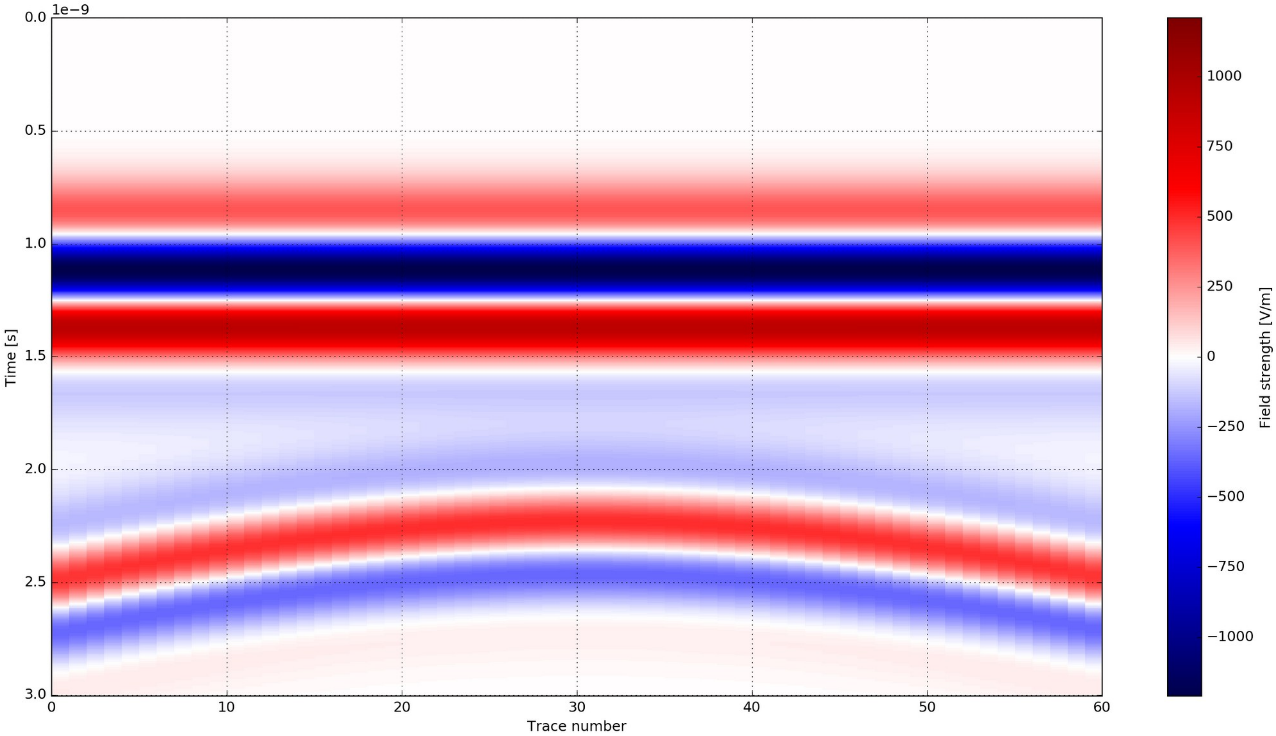


The time relates to the depth by the following equation:

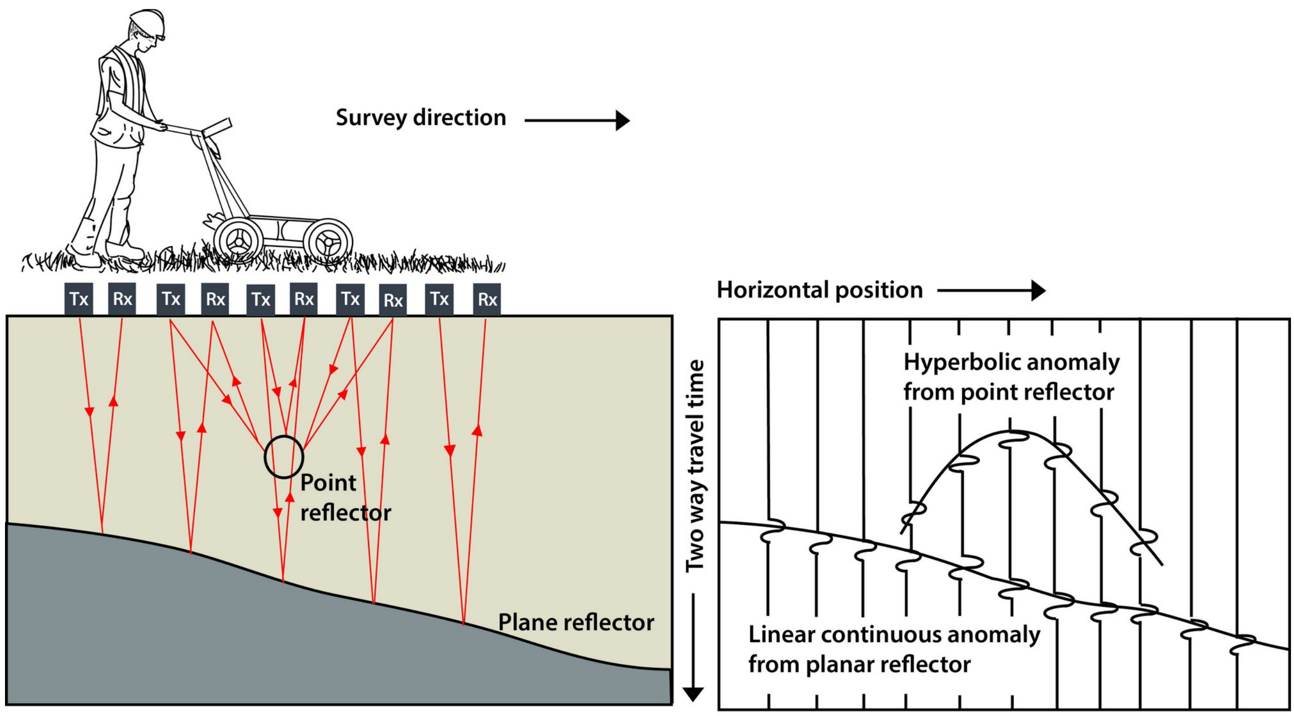
$$d = \frac{t_n \cdot c}{2\sqrt{\varepsilon_r}}$$

where c is the speed of light in air divided by sqrt(medium permittivity) .

B-scan is composed of multiple traces (A-scans) recorded as the source and receiver are moved over the target.



The image below shows in more details how the B-scan is formed.



B- gprMax modeling

Link: http://docs.gprmax.com/en/latest/gprmodelling.html

Use the above link to understand [Solving Maxwell equation in 3D, Space and time discretization, Absorbing boundary conditions, coordinate system conventions]

Command	Function
#domain:	Controls the physical size of the model
#dx_dy:	Defines the discretization steps
#time_window:	Defines the simulated time window for the GPR trace
#medium:	Introduces the electrical properties of different media in the model
#box:	Introduce a rectangle of specific properties into the models space
#cylinder:	Like the box: but introduces a cylinder into the model
#triangle:	Like the box: but introduces a triangular patch.
#tx:	Specifies the details of a transmitter (Tx)
#rx:	Specifies the details of a receiver (Rx)
#scan:	Can be used to automatically generate B-Scans

Some commands used in gprMax for simulation.

Look for complete examples:
http://docs.gprmax.com/en/latest/examples_simple_2D.html

2- How to choose simulation variables.

A- Spatial discretization (space step size for discretization):

selecting dx, dy, dz must be not violet the following inequality:

$$\Delta t \leq \frac{1}{c\sqrt{\frac{1}{(\Delta x)^2} + \frac{1}{(\Delta y)^2} + \frac{1}{(\Delta z)^2}}},$$

The first step, we determined the highest frequency (Maximum Frequency). In general, the highest frequency can be estimated three to four times of the center frequency or sometimes the gpr manufacturer specifies the maximum frequency explicit:

Fmax = 3 * Fc, then compute the wave length :

$$\lambda = \frac{c}{f_m\sqrt{\varepsilon_r}}$$

The discretization step should be at least ten times smaller than the smallest wavelength of the propagating electromagnetic fields.

$$\Delta l = \frac{\lambda}{10}$$

B- Time window (maximum time from transmission to reception):

The relationship between time step for discretization and the time windows is as follow:

$$t_w = \Delta t \times N_{it},$$

You could specify the time window directly using float number, or specify the total number of iterations and gprMax will automatically compute the time window given that it knows the time step from the previous computation of the space and time discretization.

Note: in GPR data sheet you may find the time window explicitly for your GPR model.

C- Material:

```
#material: f1 f2 f3 f4 str1<identifier>
```

- `f1` is the relative permittivity,
- `f2` is the conductivity (Siemens/metre),
- `f3` is the relative permeability,
- `f4` is the magnetic loss (Ohms/metre),

For example `#material: 3 0.01 1 0 my_sand` creates a material called `my_sand` which has sand properties.

3-Antenna modeling

1- Specifying the waveform, source, rx parameters

```
#waveform: ricker 1 1.5e9 my_ricker
#hertzian_dipole: z 0.040 0.170 0 my_ricker
#rx: 0.080 0.170 0
#src_steps: 0.002 0 0
#rx_steps: 0.002 0 0
```

Note: the rx and the hertzian dipole should differ in x-components only and make sure to position them inside the domain, also make sure that the steps for src and rx given the total number of iterations not exceeds the domain size.

2- Use off-the shelf models that is builtin the simulator.

```
#python:
from user_libs.antennas.GSSI import antenna_like_GSSI_1500
antenna_like_GSSI_1500(0.105 + current_model_run * 0.005, 0.074, 0.170, 0.001)
#end_python:
```

3- For more advanced modeling which requires advanced domain knowledge checkout this link: http://docs.gprmax.com/en/latest/examples_antennas.html

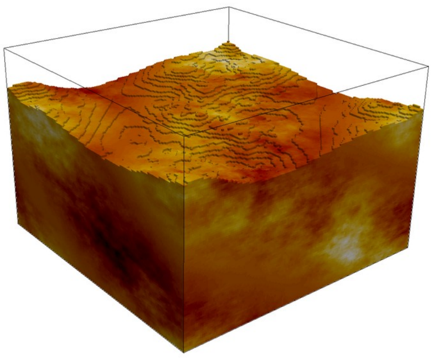
4- Complex environment modeling

For air-bone gpr we have to put the gpr in air material/medium at a certain distance to the floor, which would be another material (sand, soil, concrete).

#fractal_box instead of #box simulated a box with a series of dispersive materials.

For simulating anisotropic material based box:

```
#material: 40 5.41 1 0 cfrpX
#material: 7.5 0.016 1 0 cfrpYZ
#box: 0 0 0 0.1 0.1 0.05 cfrpX cfrpYZ
    cfrpYZ
```



For more info in this topic checkout this link:
http://docs.gprmax.com/en/latest/examples_advanced.html