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THE INFLUENCE OF THE SOIL ON REFLECTIONS FROM ABOVE SURFACE OBJECTS IN GPR DATA

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ABSTRACT

During a ground penetrating radar (gpr) survey special attention must be paid to objects which are present above the earth surface. These objects can result in unwanted reflections in the measured data. Due to the low losses in air and the high velocity, these reflected waves can obscure the data and can make the interpretation of gpr data a difficult task. Especially in an urban area it is important to know the origin of these reflections and how to reduce the influence of these unwanted reflections. The radiation characteristics of a horizontal dipole are investigated to determine the sensitivity for reflections coming from an object which is present above the surface. Both the amplitude and polarisation of the electric field play an important role. It is shown that the presence of the soil enables relatively strong reflections from vertical objects, which are present in a specific plane relative to the antennas. This analysis indicates that a reduction of the amplitude of unwanted reflections is possible by changing the acquisition parameters. A validation of these expectations is carried out by numerical modeling using a 3D modeling package for different objects present above the surface, which confirms the former expectations that the amplitude of unwanted reflections can be reduced by choosing a proper orientation of the source and receiver .

Key words: above surface reflections, radiation pattern, halfspace response, numerical modeling, acquisition setup

INTRODUCTION

The ground penetrating radar is used to obtain an image of the subsurface. However, gpr antennas emit also electromagnetic waves into the air. This is especially the case for unshielded antennas. When an electrical contrast is present in the subsurface or in the air, a reflected wave occurs and can be recorded by the receiver antenna. The unwanted reflections from above the surface obscure the reflections coming from the subsurface. Several publications show how to deal with these unwanted reflections and how to remove them from the data. However, erroneous interpretations are still made which show that the recognition of these unwanted reflections is mainly based on experience.

A distinction between reflections coming from the subsurface and coming from objects from above the surface can be made using techniques based on the difference in velocity of the waves coming from above the surface and waves coming from the subsurface. To identify a diffractor present above the surface, like a tree, is quite easy; the reflections will result in a hyperbolic event with a much smaller slope compared with reflections coming from the subsurface. Migration with a velocity of $c_0 = 0.3$ m/ns will result in a collapsing of the hyperbolic event showing that this event was travelling with the velocity of c_0. Bano et al., (1999) applied a filter in amplitude (treshold) to the migrated data to preserve only the large amplitudes of the focused hyperbola. In this way synthetic air diffractions are obtained by diffraction of the result with the velocity of free space, which can be used as a mask to remove the diffractions. Another option to remove reflections of above surface events is to flatten the scattered event, followed by a spatial low-pass filtering, subtraction and undoing the flattening (Sun and Young, 1995). This algorithm is successfully used by Dunbar et al. (1997) to remove unwanted diffractions from gpr data.

More difficult to recognize are reflections coming from larger objects present above the surface parallel to the survey line. These reflections will result in subhorizontal events, which are difficult to identify. For these type of reflections a combined common offset and common mid point analysis has to be carried out. Analysing the move-out in the common mid point measurement a distinguishing between a horizontal reflector of which the reflection has traveled through the air or through the subsurface can be made.

To prevent the erroneous interpretations it is better to alter the acquisition parameters of a field survey and prevent the measurement of unwanted reflections then to remove these unwanted reflections by some filter technique afterwards.

First the results of a field survey are discussed in which also reflections from above the surface are present. Subhorizontal events are identified as reflections from above surface objects using a combined common mid point and common offset measurement. Next, the radiation characteristics in a homogeneous space and in the presence of a homogeneous halfspace (the soil) are investigated by exact evaluating of the electric field, which enables a quantitative analysis of the influence of the polarisation of the electric field on the amplitude of the measured reflections from above surface objects. Finally some numerical modelling is carried out to investigate the sensitivity for reflections from above surface objects for different acquisition parameters.

FIELD SURVEY IN DELFT

Measurements were carried out in Delft using unshielded (pE100) antennas with a specified center frequency of 200 MHz. The top view of the location is depicted in Figure 1.

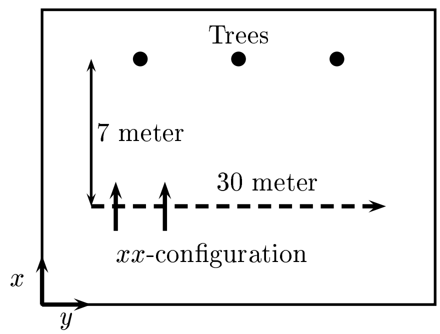

Figure 1. Topview of the survey line in Delft

The velocity of the electromagnetic waves in the subsurface is $c = 0.08$ m/ns. Several pipes were present in the subsurface, but also some trees were located near the survey line. The measured reflections are depicted in the common offset section on the left side in Figure 2. Clear hyperbolic features are present in the data. It can be seen that two different hyperbolas are present.

The tails of the hyperbolas of which the apex is present at 15 and 30 m, are slowly dipping. These small slopes of the tails indicate that the reflected waves have traveled with a high velocity. Migration with a velocity of $c_0 = 0.3$ m/ns resulted in a collapsing of the large hyperbolas (the result is not shown). The tails of the small hyperbolas of which the apex is present at 22, 29, 33 and 35 m are steeply dipping. These steep slopes indicate that the reflected waves have traveled with a small velocity. Hence, looking at the slope of the tails of the hyperbolas the reflection can be identified as coming from the subsurface or coming from above the surface.

However, also (sub)-horizontal events are present in the data. To determine the velocity with which these reflections have travelled a combined common offset and common mid point (cmp) analysis must be carried out. In the right side of Figure 2 the cmp results are depicted. The air and ground wave can be recognised (Event 1 and 2). The small move-out of events 3 and 4 shows that these reflections have traveled with a high velocity and are coming from above the surface. In this way the subhorizontal events from a common offset measurement can be identified as coming from the subsurface or coming from above the surface. Hence, subhorizontal reflections from above surface objects can be identified in a common offset result by analysing a cmp measurement which facilitates a velocity analysis and can be correlated with the common offset measurement.

RADIATION PATTERN

To determine the sensitivity of the measurement to reflections coming from above the surface we investigated the radiation pattern of a horizontal electric dipole.

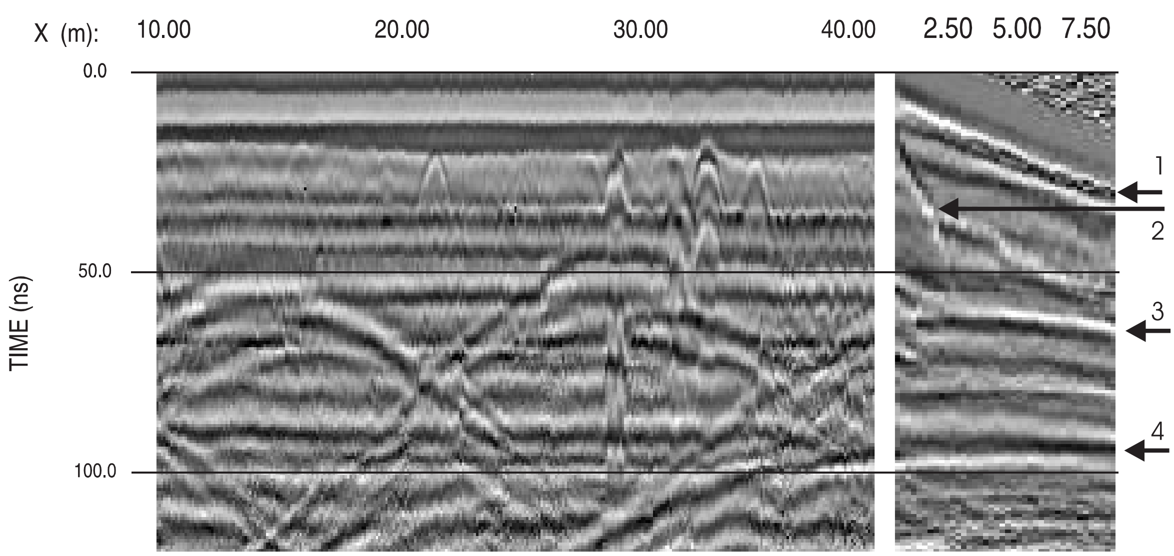

Figure 2. Combined common offset (left) and common mid point measurement (right).

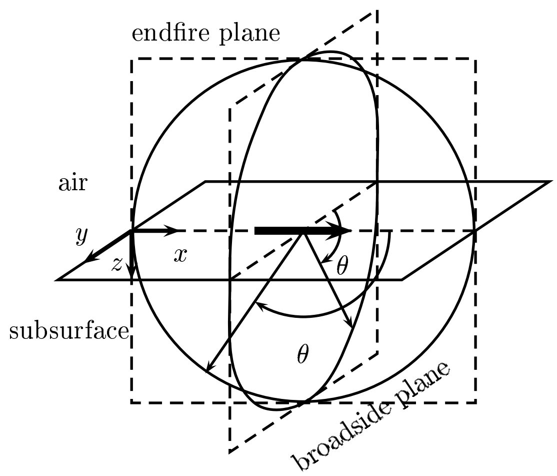

Figure 3. The different planes in which the radiation characteristics are analysed.

The radiation pattern is investigated in two different planes, the endfire plane and the broadside plane (See Figure 3). To determine the influence of the soil on the emitted electric field we investigated the radiation patterns of a horizontal dipole in a homogeneous space and in the presence of a halfspace. Far field expressions for a horizontal dipole present on a dielectric medium are given by Engheta and Papas (1982). However, usually objects are present in the intermediate range. Therefore we evaluated exact amplitudes of the electric field for a horizontal dipole using the analytical expressions for a homogeneous space (de Hoop, 1995) and a numerical evaluation of the exact integral representations for a homogeneous halfspace (See also Smith, 1984). the conductivity of the homogeneous space and the lower halfspace is $\sigma = 0.01$ S/m, and the relative permittivity equals $\varepsilon_r = 16$.

The amplitude and polarisation of the electric field in a homogeneous space at a distance of 2.5 meter are plotted in Figure 4 for the endfire and broadside plane, respectively. The dashed line indicates the amplitude and the arrows and circles indicate the polarisation of the electric field. The circle indicates that the direction of the electric field is normal to the plane of reference. In a homogeneous space a horizontal electric dipole generates a horizontal electric field at the (artificial) interface in the broadside plane. The amplitude of the electric field in the endfire plane is zero at the (artificial) interface. The only component of the electric field in the broadside plane is in the x-direction, while the components in the endfire plane are in the x- and z-direction. Note that only the electric field components which are parallel to the sphere of radius 2.5 meter are shown, because these components contribute to the radiated power.

In Figure 5 the amplitude and polarisation of the electric field in two homogeneous halfspaces at a distance of 2.5 m. are plotted for different frequencies. The amplitudes are normalized and the dipole is present at the interface.

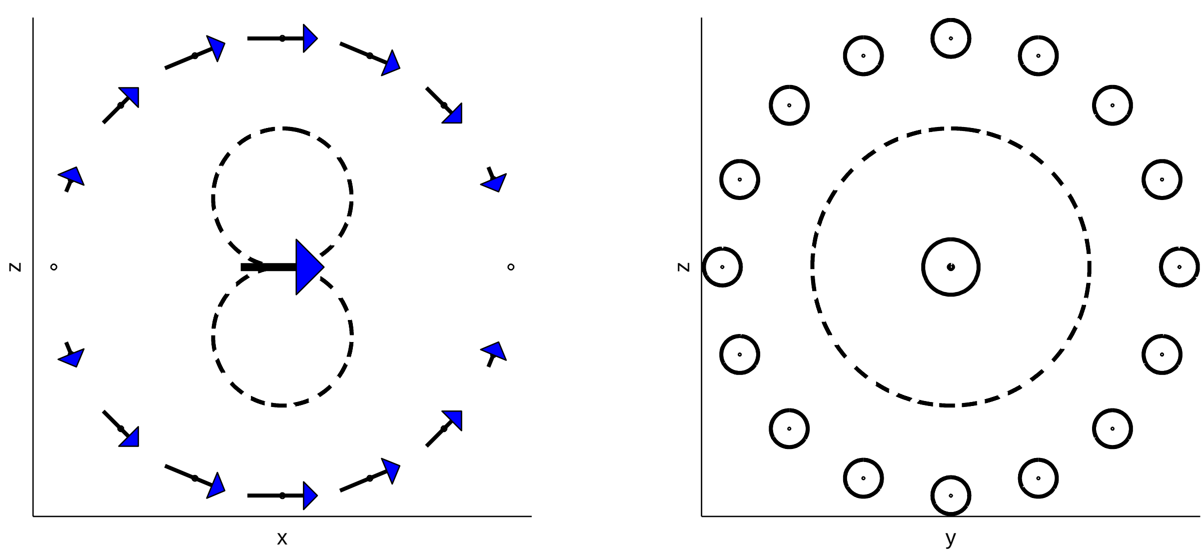

Figure 4. The exact evaluation of the amplitudes (lines) of the radiation pattern for a horizontal electric dipole (x-direction) at a radius of 2.5 m. in the endfire (left) and broadside plane (right) with corresponding directional characteristics (arrow or circle) of the electric wavefield in a homogeneous space.

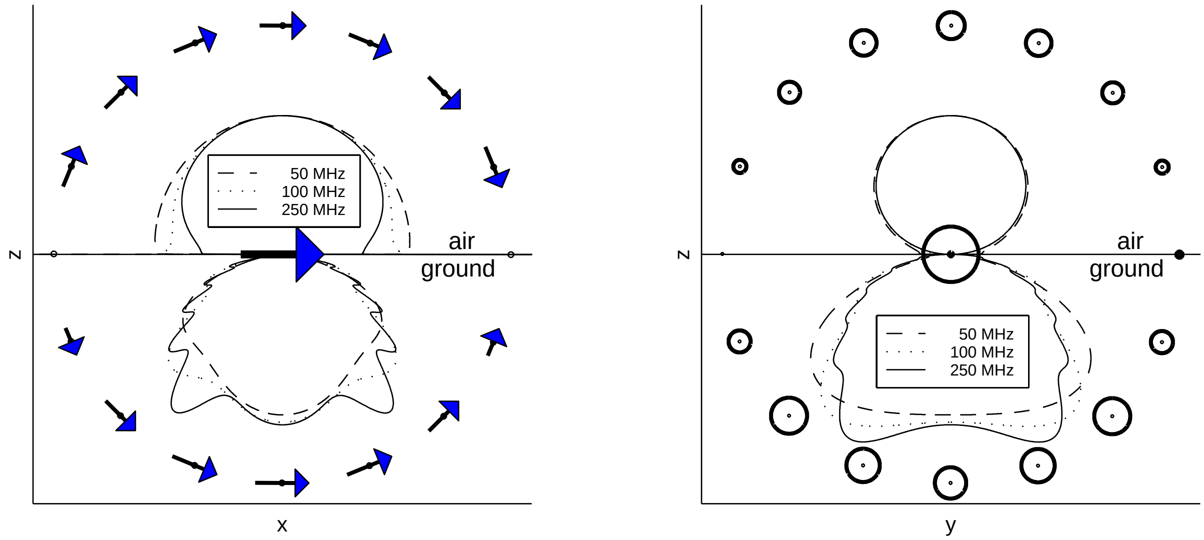

Figure 5. The exact evaluation of the amplitudes (lines) of the radiation pattern for a horizontal electric dipole present on an interface (x-direction) at a radius of 2.5 m. in the endfire (left) and broadside plane (right) for different frequencies with corresponding directional characteristics of the electric wavefield.

Note that in the broadside plane a relative null is present at the interface and that in the endfire plane near the interface in the upper halfspace (air) a relatively large vertical electric field component is present. Note that for 50 MHz the amplitude of the vertical electric field is relatively larger compared with the amplitude for 250 MHz. For the broadside plane a horizontal electric field is present near the interface, which is smaller than the vertical electric field in the endfire plane. It can be observed that the presence of the soil enables a large vertical polarised electric field close to the interface in the endfire plane. When the height of the antennas is increased it can be expected that the amplitude of the vertical polarised electric field close to the interface in the endfire plane will decrease and that the amplitude of the horizontal polarised electric field in the broadside plane will increase. The largest reflections occur when the polarisation of the electric field is parallel to the object causing the reflection, so it can be expected that a vertical object present above the surface, like a tree, will result in a larger unwanted reflection in the endfire plane than in the broadside plane. Conversely, a horizontal object will result in a larger unwanted reflection in the broadside plane than in the endfire plane.

In conclusion, the radiation patterns indicate the orientation and location relative to the antenna orientation of possible unwanted reflections coming from above the surface. This knowledge can be used to identify unwanted reflectors during the acquisition and to adapt the acquisition parameters to prevent these unwanted reflections.

NUMERICAL RESULTS

A validation of these expectations is carried out by numerical modeling using a 3D modeling package (Remis, 1998). The relative permittivity of the lower halfspace was $\varepsilon_r = 6$, the conductivity equals 0.001 S/m and the center frequency of the wavelet is $f_c = 50$ MHz. The spatial discretization in the 3D model is 0.25 m.

Three different objects were modeled (See Figure 6), a vertical plane with a relative permittivity of $\varepsilon_r = 40$, representing a wall (a), a horizontal object with a conductivity of $\sigma = 1000$ S/m, representing a wire (b) and a vertical object with a relative permittivity of $\varepsilon_r = 40$, representing a tree (c). The measured field is calculated for two different source-receiver configurations; the xx-configuration, where the objects are present in the endfire plane of the antennas and the yy-configuration, where the objects are present in the broadside plane of the antennas. The source and receiver are present on the interface. At the location of the object the electric field is vertical polarised for the xx-configuration and horizontal polarised for the yy-configuration. When the object is parallel to the polarisation of the electric field, it is expected that the amplitude of the reflection is larger compared with the reflection when the object is perpendicular to the polarisation of the electric field. We can expect that the wire will give the largest reflection for the yy-configuration, the tree will give the largest reflection for the xx-configuration and the wall will give the largest reflection for the xx-configuration.

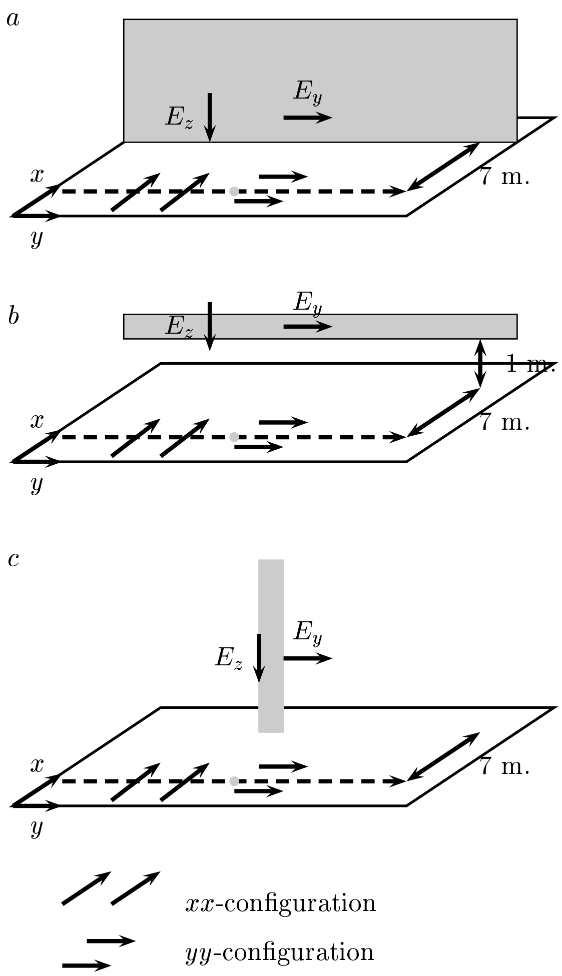

Figure 6. The configuration of the 3D model where three different objects are present above the surface.

The latter can be expected because the amplitude near the interface in the endfire plane is larger compared with the amplitude in the broadside plane (See Figure 5). In Figure 7 the reflections from a wall are depicted for the xx- and yy-configuration. For the xx-configuration the measured reflection was 2.7 times larger compared with the reflection for the yy-configuration. In Figure 8 the reflections from a wire are depicted for the xx- and yy-configuration. For the yy-configuration the measured reflection was 5 times larger compared with the reflection for the xx-configuration. In Figure 9 the reflections from a wall are depicted for the xx- and yy-configuration. For the xx-configuration the measured reflection was 21 times larger compared with the reflection for the yy-configuration. When the height of the antennas above the interface is increased, the measured amplitude for the yy-configuration increases, while the measured amplitude for the xx-configuration decreases. This indicates that the presence of the soil results in a relatively large vertical polarised vertical electric field close to the interface in the endfire plane.

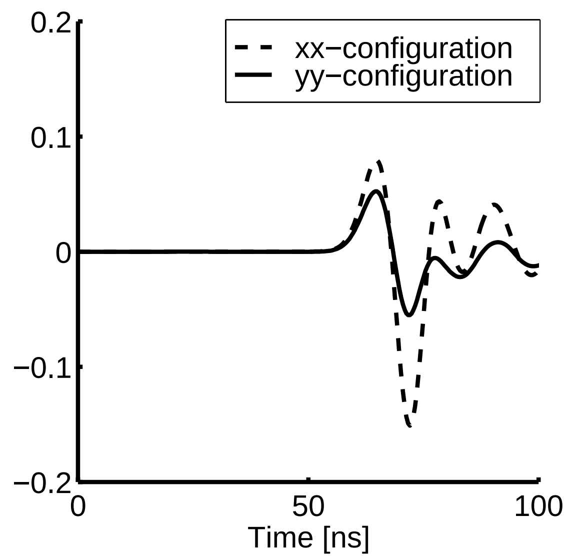

Figure 7. The reflection from a wall ($\varepsilon_r = 40$) for the xx- and yy-configuration.

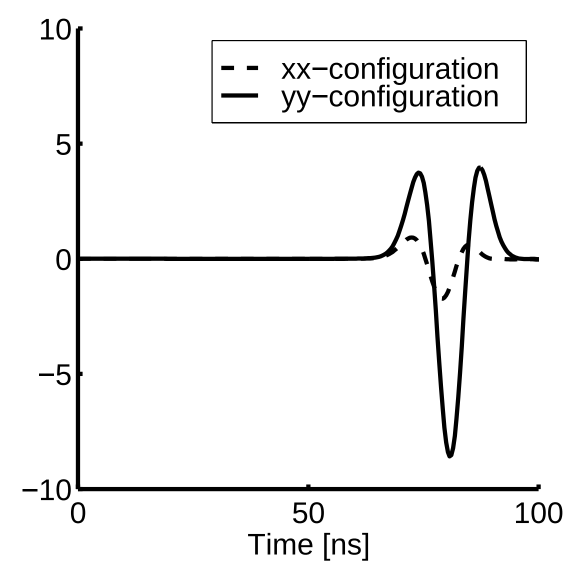

Figure 8. The reflection from a wire ($\sigma = 1000$ S/m) for the xx- and the yy-configuration

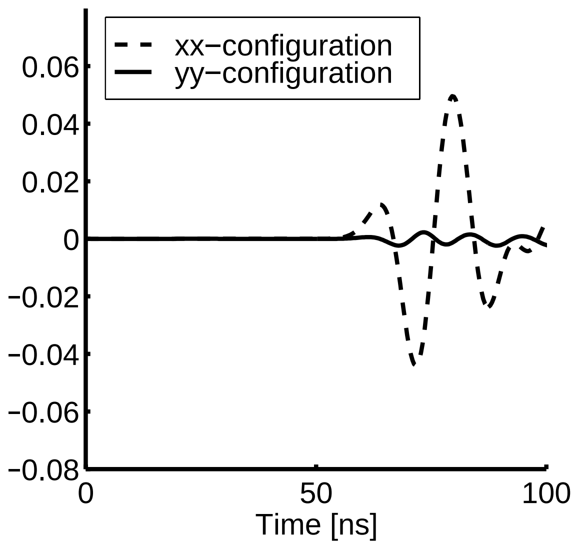

Figure 9. The reflection from a tree ($\varepsilon_r = 40$) for the xx- and the yy-configuration.

CONCLUSIONS

The interpreter of ground penetrating radar (gpr) data should keep in mind that reflections coming from objects from above the surface can be present in the data. Horizontal events in gpr data coming from above the surface can be identified using a combined common offset common mid point measurement by analysing the velocity of the reflection in the common mid point measurement.

The radiation characteristic of a horizontal dipole present on a dielectric medium shows the amplitude and the polarisation of the emitted and received electric field and is indispensible for the analysis of the origin of reflections from above surface objects. The largest reflections occur when the polarisation of the electric field is parallel to the object causing the reflection. To reduce the unwanted above surface reflections the antenna configuration must be choosen such that the emitted electric field is polarised prependicular to the objects which are present along the survey line; Vertical objects must be present in the broadside plane and horizontal objects must be present in the endfire plane of the source and receiver antennas to minimize the effect of unwanted reflections in gpr data. 3D Numerical modelling show that the unwanted reflections from a vertical object (tree) can be reduced by a factor 21 by choosing a proper orientation of the source and receiver antennas.

In reality the top soil is often different from the soil which is present deeper in the subsurface due to e.g. precipitation. It can be expected that the presence of a thin top soil will result in different amplitudes of the unwanted reflections.

ACKNOWLEDGEMENTS

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