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Tilted GPR beam in the ground

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Summary

In this presentation, I introduce the idea of a tilted beam in GPR. Tilting is now possible due to the relatively narrow beam of my Gopher antenna. The use of a neoprene filling allows for a smooth coupling between the antenna and the ground.

Introduction

Normally, the GPR antenna is positioned flat against the ground or on some other surface, and the beam is aimed vertically downwards or perpendicular to the surface. However, in many radar applications the radar beam is tilted. Some GPR applications use a tilted antenna high above the ground (Camilo et al. 2017). The next logical step is to ask whether the same principle could be used in the GPR directly coupled to the ground. A GPR antenna with a narrow beam could do it.

I presented my Gopher antenna design at the IWAGPR2019 conference in The Hague (Voipio 2019). I am currently developing a method to visualize the radiation within the ground and will publish the results in a forthcoming paper. The current simulation results indicate that the Gopher antenna beam is approximately 50° wide both in the E-plane and in the H-plane within the ground. That would allow tilting the antenna box 60° upwards from the horizontal position.

I am using neoprene to fill the gap between the ground and the antenna box when the radar is tilted. My simulations using FDTD and using a relative permittivity of 6.7 for the neoprene and for the ground indicate that the tilting would work. In the simulations, when I tilt the antenna box 60° upwards from the horizontal position, the resulting beam maximum is 44° downwards from the horizontal plane and has a 24° wide vertical beam in the ground. In the perpendicular direction, the beam is 40° wide. The narrow beams allow the radar to reveal vertical structures underground by rotating the radar on the ground and varying the tilt.

It could also be possible to use the GPR on horizontal ground in the manner of the side-looking airborne radar with SAR processing. Or one could use the GPR on a sloping hill so that the GPR beam is vertically oriented.

The beam shape information about the existing commercial antennas is not commonly available. There are some academic works available (Warren et al. 2012 and 2017,

Daniels 1996). With the pulse radar, the beam shape depends on the pulse width, but to my knowledge the pulse width is not optimized to achieve a narrow beam. The measured information is normally used for SAR processing where a wide beamwidth is beneficial. Thus, it is common understanding that the GPR antenna beams are wide.

Simulation of the tilted beam

FDTD simulation indicates that tilting the antenna box 60° upwards produces a beam tilted 46° from the vertical upwards (44° from the horizontal downwards), as in Figure 1. The simulation utilizes square cubes as in Figure 2. After the simulation, the picture was rotated so that it represents the actual measurement setup as in Figure 1 – see also Figures 3 and 5.

Figure 1: Simulation result of the beam rotated so that it corresponds to the experiment at the 60° tilt of the antenna.

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Figure 2: The FDTD simulation space. Brown is ground (earth and neoprene fill), gray is neoprene around the antenna and white is air. In this picture, the antenna beam is downwards. After the simulation, the resulting picture is rotated 60° as in Figure 1.

Field tests overview

The neoprene roll is inside a plastic package. The roll is loosely bound, so it will adjust between the antenna bottom and the earth to fill the gap. Tilting was done manually. It is not accurate, but it was sufficient to prove that the concept works. The measured profile does not have location markers, thus the angle had to be estimated. Then the file was imported to Matlab and filtered using similar procedures as in (Conyers 2012), with Matlab code written by me.

Figure 3: The general experiment arrangement, with the neoprene roll inside a plastic package. The roll is not tight, so it will adjust between the antenna bottom and the earth to fill the gap.

Field test: a tilting example

The measured profile is shown in Figure 4. It displays a number of reflections, but one can discern one continuous reflection feature moving upward from the left at 0.5 m and another continuous reflection feature moving downward from the left at 1.4 m.

Figure 4: Measured profile (B-scan) after filtering.

The drawing in Figure 5 shows the antenna positioning and the estimated distances from the profile and the calculated structure locations. The profile interpretation combined with this calculation indicate that the antenna tilting reveals vertical structures.

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Figure 5: Drawing of the inferred geometry. GPR is tilted 60° . The tilted beam 0.3 m long corresponds to the 45° angle in Figure 4, the 1.5 m and the 0.5 m beam correspond to the 20° angle and the 1.4 m beam to the 0° angle.

Field test: a panning example

The antenna is tilted 60° and is near the wall. Panning around from -45° to 0° (perpendicular to the wall) to $+45^\circ$. The B-scan in Figure 6 shows an arc as expected: the distance becomes shorter and then longer again.

The visually estimated distance from the wall is 0.25 m, allowing some compression for the neoprene roll. With a

ground beam angle of 45° and a panning angle of 0° , the measured distance would be 0.35 m. With a tilt angle of 45° and a panning of angle 45° , the measured distance would be 0.5 m.

Figure 6: Measured profile (B-scan) after filtering.

Evaluation of the velocity in the ground

I used a relative permittivity 4 (electromagnetic wave velocity 0.15 m/ns) in the field test profiles, because the ground is gravel. It corresponds to the visible horizontal distance between the radar and the foundation.

It is possible to calculate the velocity with the tilted beam if there is a vertical target partially visible on the ground. This allows a reference measurement along the ground. Then the velocity can be calculated using the information of the tilt angle and the received pulse time.

Furthermore, I expect that this method could be used to determine the velocities in a layered earth medium. The calculation would be complex, but still mathematically deterministic. The current simulations indicate that the tilted beam angle varies only a few degrees in the top layer when the relative permittivity varies between 4 and 9. The subsequent layers refract the beam normally according to Snell's law, adding some complexity to the calculation.

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Conclusions

The simulations and these early tests demonstrate that the GPR tilting concept works. These experiments also demonstrate that the beam of the Gopher antenna is sufficiently narrow for tilting.

A tilted radar beam in the ground provides additional information in GPR surveys: it can reveal the existence of vertical structures in the ground and helps evaluate sloping layer features. In archaeology the tilted beam may disclose buried remains close to the edge of a demolition rubble layer.

As an additional bonus, the tilted beam can be used to determine the velocity in the ground. Further improvements of the test arrangement and additional practical use cases will reveal more about the feasibility of the concept.

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