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Analysis of hyperbolic signatures from small discontinuities using an UWB ground-coupled radar: FDTD simulations and field experiments

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Ground penetrating radar (GPR) is a well-known non-destructive technique based on electromagnetic wave propagation that is able to detect by reflection or scattering of waves dielectric discontinuities in the underground. Our application is mainly concerned with civil engineering to perform supervision, inventory, and soil characterization. Because the air-coupled radar suffers from a significant reflection at the ground interface that reduces energy transfer of electromagnetic radiation in the sub-surface and penetration depth, we have developed an ultra-wide band (UWB) ground-coupled radar made of a pair of partially shielded compact planar bowtie slot antennas. As the antenna dimension (36*23 cm2) is close to the A4 sheet size, the maturity of the microstrip technology has allowed to design a particular geometry on the FR4 substrate (h=1.5 mm) which is able to operate at frequencies from 460 MHz to beyond 4 GHz in air. Contrary to a commercial GPR where details on antenna design are not available, it appears here possible to know and control the radiation characteristics and develop full-wave FDTD modeling that can represent field experiments for comparisons and analyses. The objective of this work is to improve, by means of a parametric study, the knowledge of physical phenomena involved in dielectric polarization when waves interact with buried discontinuities and particularly cracks, pipes, delaminations that can be distinguished by their shape, size, dielectric contrast with the surrounding medium, orientation relative to the electric field… Thus, we have first characterized by FDTD modeling and field measurements in a wet sand the radar link in two perpendicular polarizations (parallel and mirror) in the presence of a common soil (epsilon'=5.5, sigma=0.01 S/m) considering variable offsets. Afterwards, we have studied and analyzed the hyperbola signatures generated by the presence of buried canonical objects (pipes, strips) with several dielectric properties (dielectric and conductive) in a wet sand with a small lateral dimension (less than 20 mm) in both polarizations. Comparisons with FDTD simulations including the detailed structure of the antennas appear promising as they have allowed to interpret the measurements and take advantage of signal polarization to extract information associated with the discontinuities. After cluster removal using classical data processing (SVD, median value substraction…), the analytical model based on the ray theory and including the antenna size has allowed to first analyze the hyperbola responses. This study is supposed to prepare the development of data processing associated with B-scans to extract quantitative information from the electromagnetic probing of the subsurface in a very large frequency band.