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The Cylindrical Wave Approach for the full-wave solution of the electromagnetic scattering problem by subsurface dielectric and metallic two-dimensional arbitrary-section targets: A review of the method and applications

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In the Ground Penetrating Radar (GPR) context, the development of analytical-numerical approaches for the full-wave solution of electromagnetic scattering problems by subsurface targets is a topic of great interest. GPR radargrams often have no resemblance to the subsurface or structure over which they were acquired; various factors, including the innate design of the survey equipment and the complexity of electromagnetic propagation in composite scenarios, can disguise complex structures recorded on reflection profiles. By using an electromagnetic simulator it is possible to better understand the limitations and capabilities of the GPR technique, investigate how target structures get translated into radargrams, and interpret complex datasets. Electromagnetic modelling and simulation can aid the choice of the most proper equipment for a specific survey and are crucial for the design of new antennas. An electromagnetic simulator can be employed to produce synthetic radargrams with the purposes of testing new processing, imaging and inversion algorithms. Furthermore, a fast and accurate forward solver can be embedded in an inverse solver.

In utility detection, assessment of reinforced concrete structures, and many other civil-engineering applications of GPR, the sought targets are long and thin. In these cases, two-dimensional (2D) scattering methods can be effectively used, being easier to implement and computationally cheaper than three-dimensional (3D) ones; in fact, nowadays running 3D realistic models of GPR scenarios is still a challenging task, notwithstanding computing power is increasing and becoming more accessible.

This contribution is a review on the basic principles, potential and limits of the Cylindrical Wave Approach (CWA) for GPR applications, including a description of the most recent advancements and ideas for future development. The CWA is an efficient spectral-domain technique for the rigorous solution of the 2D scattering problem by circular-section dielectric and metallic objects buried in a dielectric half-space or embedded in a multilayer. In this method, the field scattered by the targets is represented in terms of a superposition of cylindrical waves; use is made of the plane wave spectrum to deal with the interaction of such waves with the planar interfaces between air and soil, and between different layers in the ground. All the multiple-reflection and -scattering phenomena are taken into account. The CWA can be applied for arbitrary values of the permittivity, size and position of the targets, and for arbitrary values of the permittivity of the host media (which can be lossy or unlossy). Because the method is implemented in the spectral domain, dispersive soils can be easily modelled. Obstacles of general shape can be simulated with excellent results, by approximating them with a suitable set of small circular-section cylinders. The technique can be used to study the scattering of an incident pulsed wave with a general time-domain shape. An extended version of the CWA can take into account the presence of roughness in the interface between air and soil. Overall, the CWA allows an advanced electromagnetic modelling of the environment, it has a high and not yet fully-exploited potential in the GPR field, and is definitely worth being further studied and developed.