Sounding and Signal Simulation of Complex Surface and Subsurface Structures for the WISDOM GPR

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Key in the interpretation and understanding of WISDOMs ground penetrating RADAR (GPR) measurements is the capability to correctly (and efficiently) simulate the instrument characteristics and the RADAR wave propagation in the Martian subsurface (the signal received by WISDOM), taking into account all relevant effects at large scale. In this contribution we present a ray tracing approach that can be applied to heterogeneous and inhomogeneous media and includes the antenna characteristics of the WISDOM instrument as well as rover structures.

The WISDOM GPR is part of the 2022 ESA-Roscosmos ExoMars "Rosalind Franklin" rover payload. It will probe the Martian surface and subface at centimetric resolution and a penetration depth of about 3m. WISDOMs primary scientific objective is the high-resolution characterization of the material distribution within the first few meters of the Martian subsurface as a contribution to the search for evidence of past life [1] and to support the drilling operations [2].

The simulation tool consists of two parts: The first part simulates the instrument at system level and generates the signal that is fed into the antenna as well as the receive-filter and discretization characteristic of the instrument (taking into account filters, RF effects and the ADC). The second part simulates the wave propagation of this signal in complex media (inhomogeneous or heterogeneous lossy media) taking into account polarization effects and the WISDOM antenna pattern [3]. This method is a hybrid between conventional raytracing (SBR), differential raytracing and physical optics. The simulation complexity can be granularly controlled and weighed against the level of approximation. It is capable of simulating electrically large domains with an acceptable accuracy yielding good predictions of the propagation properties in Martial soil while being significantly less computationally expensive than conventional full-wave solvers like FEM or the Finite-Differences in Time-Domain Method.
The results of the system-level-simulation and the propagation simulation for multiple measurement positions (along a rover track) are then combined (similar to the application of a filter) in order to generate a synthetic radargram. This radargram can be directly compared to the WISDOM measurements.

The proposed method is validated using measurements of the WISDOM instrument at analog sites and by reference simulations using the FDTD Method [4]. We present synthetic radargrams as simulation results for several sounding scenarios including the WISDOM antenna characteristics, an inhomogeneous subsurface and lossy materials.

The proposed approximation method yields accurate estimates of WISDOM soundings for a complex subsurface while being significantly faster than conventional (full wave) methods. The synthetic radargrams can easily be compared to actual measured data.

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