SPM Simulations of One-Dimensional Two-Layer Rough Surfaces: Accuracy and Validity

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Methods for analyzing electromagnetic scattering from layered rough surfaces are key to the remote characterization of many naturally occurring structures including layered soil, layered ice, lakes, and rivers. These methods can also be used to model optical instruments that use surface plasmon resonance techniques to measure refractive indices of rough and thin material layers adsorbed on metallic films. In the past, numerous analytical and numerical techniques for analyzing electromagnetic scattering by 1D or 2D rough surfaces have been developed. The most prevalent analytical method is the small perturbation method (SPM), which assumes a rough surface with a height standard deviation that is small compared to the wavelength. This method was recently used successfully, up to the first order, to calculate scattering coefficients of two-layer rough surfaces (A. Tabatabaeenejad and M. Moghaddam, IEEE Trans. Geoscience Remote Sensing, submitted). The assumption of slight roughness is often valid when probing layered structures using low-frequency radars. Indeed, at low frequencies, most surfaces of interest are only slightly rough such that even if the structure is analyzed by an exact method without making this assumption, gains in accuracy are expected to be minimal. Therefore, it is imperative to investigate the conditions on surface roughness, slope, and subsurface permittivities for which the first-order SPM is accurate within a specified error bound. To achieve this, the SPM solution needs to be compared to one derived using a first principle solver that does not impose roughness restrictions. Since no exact analytical solutions exist for analyzing rough surface structures, in this work we numerically investigate the region of validity of SPM applied to scattering from 2D, two-layer rough surface structures.

In the past, a variety of integral equation and finite difference methods for analyzing scattering from rough surfaces have been proposed. Here, a fast PMCHWT-based integral equation solver is used to analyze scattering from a large ensemble of two-layer structures, including air-water-soil and air-soil-water configurations. All interfaces are assumed band-limited; both their height profiles as well as the electric and magnetic currents they support are modeled in terms of approximate prolate spheroidal functions. The solver is accelerated by approximating off-diagonal blocks in the method of moment interaction matrix in terms of low-rank products using skeleton notions. Simulations will be performed for 1D rough surfaces represented by zero-mean stationary random processes, separating homogeneous dielectric layers. The results of these simulations will be compared to those of the analytical first-order SPM over a wide range of surface parameters and dielectric constants to determine the SPM validity conditions.