An Efficient Method of Retrieval of Parameters for Three-layer Nonsmooth-interface Media

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Many environmental, industrial, military, geological, and civil engineering applications require fast and accurate non-contact estimation of parameters of subsurface structures, possibly with multiple layers. These applications include estimating the depth of bodies of fresh water, through-the-wall imaging, detecting buried objects, and estimating root-zone soil moisture and composition. The penetrating abilities of low frequency radiation make it a good candidate for this group of applications, provided sufficient resolution can be achieved. Since the radar measures the scattered fields which are proportional to the radar cross section of the targets, an efficient inversion methodology is needed to obtain the sought-after parameters from the instrument measurements. Most inversion algorithms require multiple iterative evaluations of a forward scattering model. Therefore, an efficient forward model with a large region of validity is crucial for the success of the inversion. In this work, we use a recently developed forward model that satisfies these criteria, and is optimized for application to media where the top interface is approximated as a periodic surface of given profile, while the bottom is treated as a rough surface with given statistics and dielectric properties. This model would apply, for example, to bodies of fresh water, desert sand, and adobe walls. The forward scattering algorithm is based on the extended boundary condition method (EBCM) and scattering matrix technique, and has been reported previously. First, discrete Floquet modes are generated for the top periodic surface. Then, a period is assigned to the bottom random rough surface, which equals an integer multiple of the period of the top surface, and used to generate the Floquet modes for this lower interface. Finally, the modes are matched to obtain the overall transition matrix for the system and to calculate the scattering cross sections.

Even though the computational complexity of this model is significantly less than a fully numerical routine such as MOM, it is still too slow for use in an iterative inversion algorithm. To make the model more suitable for inversion, the full model is simulated for a range of parameters such as dielectric constant, surface statistics, and layer separation. Then, the dependence on each of these parameters is sequentially modeled using much simpler, analytically differentiable functions, such as multidimensional polynomials or simple transcendental functions. Once the simplified model is developed, the subsequent evaluations of the forward model are extremely fast and the forward model is suited for both local and global inversion techniques. The inversion process requires at least as many independent data points (measurements) as there are unknown model parameters. In practice, the initial overhead cost of simulating the function for a range of values of all of the unknowns may be too large to be practical. Therefore, a sequential layer characterization algorithm is applied. Assuming that the medium between the first and second interfaces is lossy, the problem is simulated at a sufficiently high frequency such that the effect of the 2nd interface is negligible. Since only the top layer affects the cross section coefficients the number of unknown parameters drops to two or three. After retrieving the parameters of the first interface, the procedure is repeated at a low frequency to recover the parameters of the lower interface. This algorithm allows the number of evaluations of the full EM model to be significantly reduced. While the direct method requires the number of forward model evaluations to be equal to the product of the number of simulation points for both layers, the new algorithm reduces the total number to just the sum of the two.