ELECTROMAGNETIC SCATTERING FROM ARBITRARY RANDOM ROUGH SURFACES USING STABILIZED EXTENDED BOUNDARY CONDITION METHOD (SEBCM) FOR REMOTE SENSING OF SOIL MOISTURE

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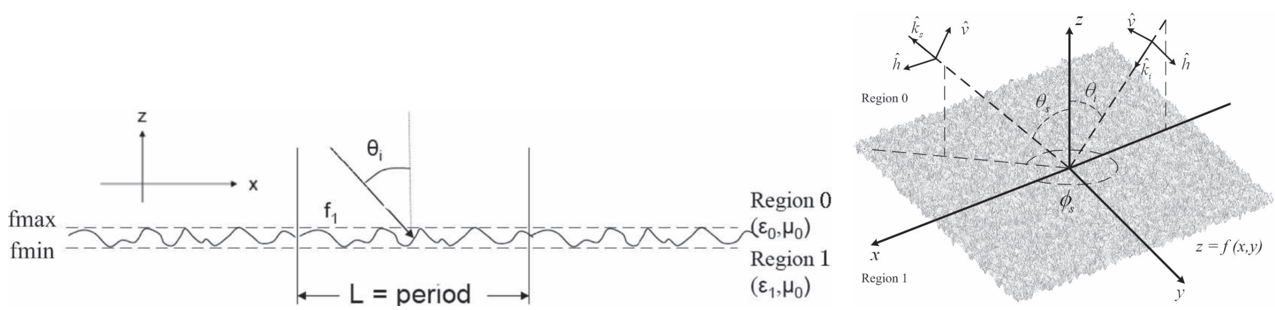
1. INTRODUCTION

The global soil moisture distribution has been a subject of great interest for its temporal and spatial variations being critical parameters in climatic and hydrologic models. To provide global measurements of soil moisture, NASA is developing the Soil Moisture Active/Passive (SMAP) mission, which will map the global soil moisture with unprecedented resolution, sensitivity, and area coverage. As one of the main SMAP instruments, a synthetic aperture radar (SAR) operating at L-band will provide measurements with ground resolutions of 1-3 km, sensing the soil conditions through moderate vegetation cover. To retrieve the soil properties from the radar measurements, accurate and highly efficient inverse algorithms are necessary, which in turn require accurate and efficient radar forward scattering models. Since soil can be modeled as a random rough surface (or layered rough surfaces if its subsurface structure is also of interest), high-performance electromagnetic scattering models in 2 and 3 dimensions are of high interest and have been the subject of many recent investigations.

To solve the forward scattering problem for rough surfaces, many approaches have been used, including analytical, numerical, and empirical. The analytical methods are based on approximation techniques [2]. Though they have the highest computational efficiency, their solutions are only valid within small roughness regimes and cannot cover the entire range of practical problems. The numerical solutions typically use differential equation formulations for time-domain approaches and surface integral equation formulations for frequency-domain approaches, including method of moments (MoM), Integral Equation Method (IEM), and Advanced Integral Equation Method (AIEM). These numerical methods are capable of simulating surfaces with arbitrary roughness, however, their computational cost is typically high, especially for the three-dimensional problem, which is more realistic. Besides methods mentioned above, the empirical formulas are used as well which are based on curve-fitting of experimental data. They are accurate for the particular location used, but usually not elsewhere, and lack physical insight.

Having features of both analytical and numerical methods, the extended boundary condition method (EBCM) is an attractive approach for its expected accuracy and computational efficiency. It gives accurate full wave solutions including co-pol and cross-pol components in a fraction of the time needed by numerical methods such as MoM. However, classical EBCM [2] has not been practically used as a main approach to solve the rough surface scattering problem due to its much smaller validity domain than that being theoretically predicted. The EBCM matrix system tends to be unstable and ill conditioned when applied to surfaces with large roughnesses or highly lossy media. This limits the classical EBCM to the validity domain only slightly larger than that of approximate techniques, which give faster analytical solutions. In this work, we not only amend the formulation to solve the system instability problem, we also develop a significantly enhanced numerical solution for the resulting system to effectively eliminate the ill conditioning problem. Results of the stabilized EBCM, hereafter named as SEBCM, are compared with solutions given by the method of moments (MoM). We show that the SEBCM can now be applied to surface scattering problems with realistic roughnesses and conductive losses that meet the soil moisture application needs.

2. PROBLEM GEOMETRY AND APPROACH DESCRIPTION



(a) 2D geometry (b) 3D geometry

Figure 1. Problem geometries.

Problem geometries of both 2D and 3D bistatic scattering from an arbitrary random rough surface are shown in Figure 1. The 1D or 2D rough surface f separates the free space (region 0, ϵ_0, μ_0) from a homogenous medium (region 1, ϵ_1, $\mu_1 = \mu_0$). Based on EBCM [2], SEBCM expands the fields in terms of a superposition of Floquet modes and matches the extended boundary conditions (EBC) at test surfaces away from the actual rough surface to retrieve the surface currents, thereby to obtain the scattered fields. SEBCM further use a z-coordinate transformation to restrict and control the test surface locations explicitly, which solves the instability of the classical EBCM. On the other hand, Floquet modes are reordered to have balanced k-chart in k-space and a so-called k-boundary is introduced to control the number of modes involved in the computation to exclude the modes at large transmitting angles that are not able to reach the test surfaces due to the lossy medium in region 1. This effectively stabilizes the system for lossy cases. Moreover, some angle tolerance for the back-scattering calculation is allowed to have variable total number of Floquet modes in the computation so that if desired, solutions with larger error can be obtained with relatively small computational resources.

3. RESULTS AND FUTURE WORK

Extensive simulations have been performed for scattering from both lossless and lossy medium. For scattering from a lossy medium, solutions are simulated using SMAP parameters at L-band as a function of soil moisture content for various surface statistic properties. The comparison with MoM shows very good performance of the SEBCM even for large roughnesses. The 3D EBCM [3] is also stabilized in the similar way and being applied to cases of variant surface properties.

Current ongoing work includes testing the 3D SEBCM against other techniques beyond the small roughness regime, e.g., MoM., as well as further optimization of the computational aspects. Future works includes applying this method to analyze scattering from multi-layered media with or without buried objects in three dimensions. This forward model is intended as a candidate for the development of the inverse problem for soil moisture retrieval from radar systems such as SMAP.

4. REFERENCES

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