Coherent Scattering of Electromagnetic Waves from Layered Rough Surfaces Within the Kirchhoff Regime

Alireza Tabatabaeenejad and Mahta Moghaddam
Department of Electrical Engineering—Electrophysics
University of Southern California
Los Angeles, CA 90089-0271

Scattering of electromagnetic waves from layered rough surfaces with an arbitrary number of layers finds applications in diverse environmental sensing scenarios, such as characterizing layering properties of terrestrial soil. While many of these applications rely on backscattering predictions using incoherent analyses, there is a need for prediction of the coherently scattered wave from layered rough surfaces. The primary application of the model presented in this work is remote sensing of subsurface soil moisture in forested regions. This model is intended for use in the NASA Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) mission, which uses a P-band synthetic aperture radar currently collecting data over key (vegetated) biomes of north America. Retrieval of soil moisture from radar measurements requires accurate and efficient forward scattering models. Several such radar scattering models exist for vegetated areas. These models identify scattering mechanisms including scattering from the crown layer, scattering from trunks, double-bounce scattering between the crown layer and ground, double-bounce scattering between trunks and ground, and backscattering from ground. It has been shown that at P- and L-bands, the trunk-ground mechanism becomes dominant, especially for tall stands. Moreover, as we will show, at P-band and in a layered structure, a subsurface layer can have a significant contribution to the total reflection of the incident wave. Therefore, it is important that a forest scattering model consider the coherent processes between soil layers in the modeling of the double-bounce mechanisms. To this end, not only a coherent scattering model is necessary but also subsurface layers should be taken into account. This work calculates the coherent component of the wave scattered by a layered rough surface structure within the Kirchhoff regime, where it is assumed that the scatterer surface at each point has a radius of curvature much larger than the wavelength. Application of the Kirchhoff approximation for electromagnetic scattering from single rough surfaces dates back to the 1970s. Several newer studies have applied this approximation to the problem of scattering from two-layer rough surfaces where calculation of the scattered wave involves numerical integration. While in this work we do not make any assumption about the layer thickness, except we implicitly assume it is large enough to avoid spatial overlaps between the boundaries, we make a few assumptions about the surfaces. We assume the surfaces not only have large radii of curvature to allow the use of the Kirchhoff approximation but also have small slopes so that the partial derivatives of surface profiles would be very small. Moreover, we assume roughness height is small so that the coherent component of the scattered wave would be dominant. We expect that at low frequencies such as P-band, many surfaces of interest satisfy these conditions. The boundary profiles of layers are also assumed to be uncorrelated. These assumptions will allow us to derive a succinct solution for the scattered wave with an algebraic expression that can readily be evaluated.