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Rigorous and asymptotic models of coherent scattering from random rough layers with applications to roadways and geoscience

Nicolas Pinel (1), Christophe Bourlier (2), Cédric Le Bastard (3,2)

(1) Alyotech, Alyotech TS&I, Nantes, France (nicolas.pinel@alyotech.fr, (+33) 251 896 455), (2) IETR Laboratory, LUNAM University, University of Nantes, Nantes, France (christophe.bourlier@univ-nantes.fr), (3) CEREMA, Les Ponts de Cé, France (cedric.lebastard@developpement-durable.gouv.fr)

This paper presents the rigorous efficient PILE (Propagation-Inside-Layer Expansion) numerical method [1] and an extension of the Ament model [2] to calculate the field scattered by three homogeneous media separated by two random rough surfaces. Here, the study is applied to ground penetrating radar (GPR) (nadir angle, wide band) for nondestructive survey by taking the roughness of the surfaces into account and by calculating the contribution of each echo coming from the multiple scattering inside the layer. Applications to roadways and geoscience are investigated.

The PILE method starts from the Method of Moments (MoM), and the impedance matrix is inverted by blocks from the Taylor series expansion of the inverse of the Schur complement. Its great advantage is that it is rigorous, with a simple formulation and has a straightforward physical interpretation. Actually, this last property relies on the fact that each block of the impedance matrix is linked to a particular and quasi-independent physical process occurring during the multiple scattering between the two rough surfaces. Furthermore, the PILE method allows us to use any acceleration algorithm (MLFMM, BMIA/CAG, Forward-Backward with or without Spectral Acceleration, etc.) developed for a single interface.

In addition, an asymptotic approach is extended to rough layered media: the scalar Kirchhoff-tangent plane approximation (SKA), for calculating the coherent scattering from the rough layer. The numerical rigorous PILE method is used as a reference to validate this asymptotic model. The study focuses on 2D problems with so-called 1D surfaces, for computational ease of the reference numerical method. Nevertheless, it must be highlighted that the SKA approach can readily be applied to 3D problems. This approach is applied to rough layers with two slightly rough surfaces characterized by either Gaussian or exponential correlation functions. The height probability density function (PDF) is assumed to be Gaussian.

The SKA model was shown to correctly predict the coherent scattered field for typical configurations in pavement survey by GPR at nadir, in the whole frequency band [0.5; 10] GHz [2]. This analysis will then be extended to geoscience applications. By taking into account the time delay of each echo in this new model, this direct simple EM model can be a good candidate for its use in signal processing algorithms for the estimation of physical parameters of the layer like its thickness H and also and more important, for the estimation of the RMS (root mean square) heights of two the rough interfaces simultaneously.

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[2] N. Pinel, C. Le Bastard, C. Bourlier, M. Sun, “Asymptotic Modeling of Coherent Scattering from Random Rough Layers: Application to Road Survey by GPR at Nadir”, International Journal of Antennas and Propagation, vol. 2012, Article ID 874840, 9 pages, 2012