2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

On the forward scattering by targets below a multilayer

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Abstract

A method for solving forward scattering problems in through-the-wall applications with multilayered walls is presented. Targets are perfectly conducting cylindrical scatterers, with circular cross section, hidden by the wall. The technique is developed in the frequency domain, and it employs expansions of the scattered fields by the targets through cylindrical waves as basis functions. Numerical results allow to solve the scattering problem in large domains, with a semi-analytical technique.

1. Introduction

Solution to the electromagnetic scattering by targets below a multilayer has important applications in the field of the Through-the-Wall radar [1]. With an accurate modelling of the physical layout, the knowledge of the interaction of the electromagnetic radiation with the wall allows an improved radar detection. The most common models of wall, from an electromagnetic point of view, include homogeneous walls, layered walls, as drywall combined to wood or layers of different material, or periodic walls as cinder-blocks or reinforced concrete with metallic bars. An homogenization of walls with period structure into layered ones is also possible, as for the case of cinder-blocks, and the availability of a layered model in the scattering problem is useful to deal with many classes of walls. Possible techniques of analysis, with reference to homogenous or layered walls, include the presence of a target beyond, and are mainly numerical, as the FDTD [2]-[4]. To accelerate the computations in large domain, full-wave methods, as Green's function approaches, are combined to high-frequency asymptotic techniques [5].

In this paper we propose an analytical-numerical technique based on the Cylindrical Wave Approach (CWA) to solve the scattering by cylindrical targets hidden by a layered wall. The technique presented in [6]-[8] for targets placed in a semi-infinite medium, or below one homogeneous layer is here extended. The scattered fields by the cylinders are dealt with through an analytical approach, employing expansions into cylindrical waves. Their interaction with the multilayer, to evaluate the final transmission of the scattered fields in the initial medium, is solved through two sets of waves, a down-propagating scattered-reflected field, and an up-propagating scattered

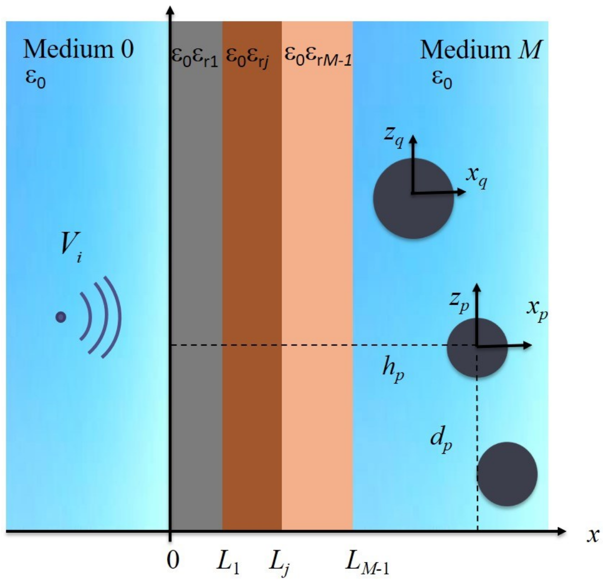

Figure 1. Geometry of the problem.

transmitted field. Solution is developed in the frequency domain, for a monochromatic line-source as incident field.

2. Layout

Geometry of the problem is depicted in Fig. 1: Medium 0 (vacuum), is followed by M-1 layers of permittivity $\varepsilon_0\varepsilon_{rj}$ (j = 1, …, M-1), and by a final half-space, i.e., Medium M (vacuum). The lowest boundary of the j-layer is at a depth $x = L_j$, and its thickness is $L_j - L_{j\text{-}1}$.

We assume that the source of the scattering problem is a line source, radiating a field:

$$V_i = -V_0 H_0^{(1)}(n_0\rho) \tag{1}$$

When the incident field is transmitted in the final medium (Medium M), a scattered field is excited by the cylinders:

$$V_s(\xi,\zeta) = V_0 \sum_{q=1}^{N}\sum_{m=-\infty}^{+\infty} c_{qm}\left[CW_{m-\ell}(n_M\xi_{qp}, n_M\zeta_{qp}) \times (1-\delta_{qp}) + \frac{H_\ell^{(1)}(n_M\rho_p)}{J_\ell(n_M\rho_p)}\delta_{qp}\delta_{\ell m}\right] \quad (2)$$

In (2), CW_m are the basis functions, that are proportional to first-kind Hankel functions times an angular term. The scattered field (2) interacts with the interfaces bounding the multilayer leading to reflected-scattered fields, and transmitted scattered fields, that form two sets of waves: an left-propagating, and a right-propagating one, respectively. In their definition, the multiple reflections experienced at the interfaces are taken into account, through suitable reflection and transmission coefficients. The expression of the cylindrical waves is obtained through spectral basis functions. Reflected cylindrical waves are used to define the scattered reflected fields:

$$RW_m(\xi,\zeta) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} T_{M,j}(n_{||})\Gamma_{j,j-1}(n_{||})\, F_m(\chi, n_{||}) e^{i n_j n_{\perp}^{tj}\xi} e^{i n_j n_{||}^{tj}\zeta} dn_{||} \quad (3)$$

As to the scattered-transmitted fields, they are obtained through transmitted cylindrical waves as basis functions:

$$T(\xi,\zeta,\chi) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} T_{M,j}(n_{||})T_{1,0}(n_{||})\, F_m(\chi, n_{||}) e^{i n_j n_{\perp}^{tj}\xi} e^{i n_j n_{||}^{tj}\zeta} dn_{||} \quad (4)$$

Solution to the scattering problem, i.e., the determination of the expansion coefficients of the involved scattered fields, is found by imposing boundary conditions at the cylinder's interface [7].

3. Results

The method described in Section 2 allows to evaluate the scattered field in the whole domain. As example of results, a 2D color map relevant to the scattered field in each medium is reported in Fig. 2. The target is a PEC circular cross-section cylinder of radius *a* = 5 cm. It is placed in air below a layered wall made by two identical external layers of thickness 4 cm and relative permittivity 4.52, embedding an internal layer of thickness 12 cm and relative permittivity 1.452. The proposed physical parameters of the wall are relevant to the homogenized model of a cinder-block wall [1]. Frequency of the source is 3GHz, which allows to detect interference effects in the layers of the wall, in particular in the two external layers.

4. Acknowledgements

The authors would like to acknowledge the Italian Ministry of Education (MIUR) for funding the Programma di Ricerca di Interesse Nazionale (PRIN) project: Ultra-wideband Virtual Imaging Extra Wall (U-View) for high-penetration high quality imagery of enclosed structures.

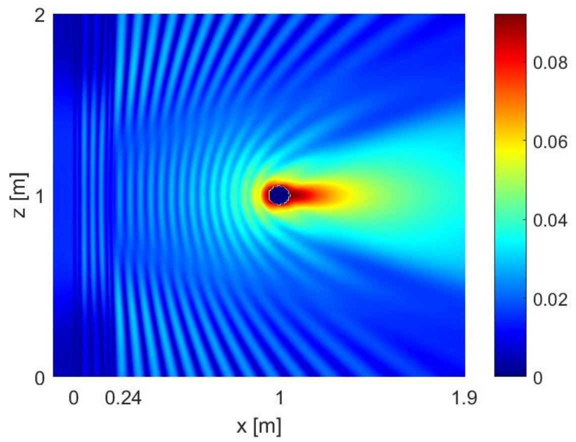

Figure 2. 2D color map of the scattered field by a target of radius 5 cm below a layered wall.

5. References

1. M. G. Amin, Through-the-Wall radar Imaging, CRC Press 2011.

2. F. Soldovieri, and R. Solimene,, «Through-Wall Imaging via a Linear Inverse Scattering Algorithm,» IEEE Trans. Geosc. Rem. Sens., **4**, pp. 513-517, October 2007.

3. X. Zhang, X. Xi, M. Li, and D. Wu, "Comparison of Impulse Radar and Spread-Spectrum Radar in Through-Wall Imaging," IEEE Trans. Micr. Th. Tech., **64**, pp. 669-706, March 2016.

4. B. Yektakhah, and K. Sarabandi, "All-Directions Through-the-Wall Radar Imaging Using a Small Number of Moving Transceivers," IEEE Trans. Geosc. Rem. Sens., **54**, pp. 6415-6428, November 2016.

5. Gennarelli, G. Vivone, P. Braca, F. Soldovieri, and M. G. Amin, "Multiple Extended Target Tracking for Through-Wall Radars," IEEE Trans. Geosc. Rem. Sens., **53**, pp. 6482-6494, December 2015.

6. F. Frezza, L. Pajewski, C. Ponti, and G. Schettini, "Through-wall electromagnetic scattering by N conducting cylinders," J. Opt. Soc. Am. A, **30**, pp. 1632-1639, August 2013.

7. C. Ponti, and S. Vellucci, "Scattering by conducting cylinders below a dielectric layer with a fast noniterative approach," IEEE Trans. Micr. Th. Tech., **63**, pp. 30-39, January 2015.

8. C. Ponti, M. Santarsiero, and G. Schettini, "Electromagnetic Scattering of a Pulsed Signal by Conducting Cylindrical Targets Embedded in a Half-Space Medium," IEEE Trans. Ant. Propag., **65**, pp. 3073-3083, June 2017.