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Scattering by Dielectric or Conducting Cylinders above a Lossy Medium and Relevant Focusing Effects

Ludovica Tognolatti [(1)], Cristina Ponti[(1)], and Giuseppe Schettini[(1)]
(1) Roma Tre University, Department of Engineering, Via Vito Volterra 62, 00146, Rome, Italy

Abstract

In this paper, we present an analytical solution based on the Cylindrical Wave Approach to study the interaction of a plane-wave with cylindrical objects, either dielectric or conducting, placed above a semi-infinite lossy medium. The effects of focusing of the electromagnetic field by the array of scatterers is investigated. The analytical approach is validated by a comparison with a commercial software. Some numerical examples are presented, considering both TM and TE polarization of the incident wave in the millimeter frequency range at 24 GHz. Interesting applications are in the modelling of the scattered field by objects above a biological tissues, in the presence of wereable or implantable antennas sources.

1 Introduction

The Cylindrical Wave Approach is a numerical-analytical technique for the simulation of direct scattering by cylindrical targets. This method was used initially in a configuration similar to the one in this study, with the cylindrical targets positioned in the same medium as the source and the electromagnetic field evaluated only in the medium where cylinders are located [1], [2]. In this contribution, the analytical method is been extended to evaluate the scattered transmitted field in the medium below the dielectric or conducting cylinders, which is a lossy medium, in order to investigate electromagnetic field intensification effects. In the area of devices for health monitoring and recovery of right physiological behaviour of human organs, research is increasingly focusing on implantable or wearable devices at millimeter-wave frequencies [3], [4]. It is of interest to investigate the effect of objects placed in the vicinity of wearable or implantable antennas.
The paper is structured as follows: in Section 2, we present the theoretical framework; in Section 3, we present some numerical results. Conclusions are reported in Section 4.

2 Theoretical framework

We consider the geometry of the scattering problem illustrated in Fig.1. N circular cross-section cylinders, that may be either perfectly conducting or dielectric, are placed above a flat interface separating two half-spaces. The medium in which the targets are located is filled with air,

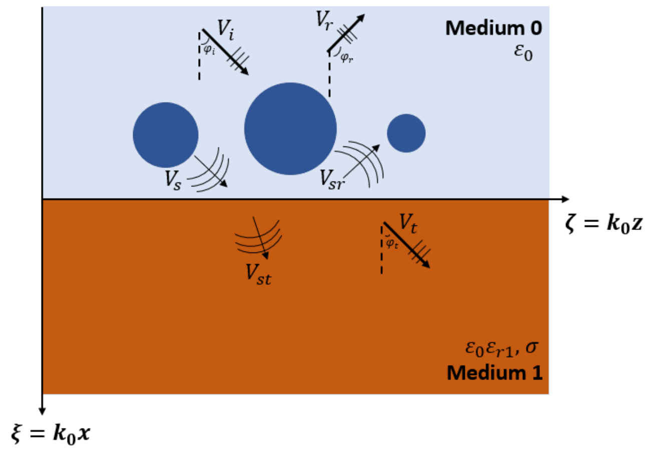

Figure 1. Geometry of the scattering problem and decomposition of the total field.

while the underlying medium is a lossy medium with real permittivity $\varepsilon_1 = \varepsilon_0\varepsilon_{r1}$ and conductivity σ, which is linear, homogeneous and isotropic. A scalar function $V(\xi,\zeta)$ is used to describe the y-directed electric field E, in case of TM^y polarization of the incident plane-wave propagating in the medium 0, or the y-directed magnetic field H, in the TE^y one. The total field is decomposed into several terms, as shown in Fig.1. In medium 0 the total field is decomposed into the following contributions: $V_i(\xi,\zeta)$ incident field, $V_r(\xi,\zeta)$ reflected field, $V_s(\xi,\zeta)$ scattered field by the cylinders, $V_{sr}(\xi,\zeta)$ scattered-reflected field, excited by the reflection of the scattered field V_s at the interface; in medium 1 we have: $V_t(\xi,\zeta)$ transmitted filed, excited by the transmission of the incident field through the interface, $V_{st}(\xi,\zeta)$ scattered-transmitted field excited by transmission of the scattered field through the interface.
The scattered transmitted field $V_{st}(\xi,\zeta)$ is derived with the Cylindrical Wave Approach through an expansion into cylindrical waves of the m-th order. The final definition of the m-th order transmitted cylindrical wave is:

$$TW_m(\xi,\zeta;\chi_q) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} T_{01}(n_\parallel)F_m(\chi_q,n_\parallel) \times e^{i\sqrt{1-(\frac{n_\parallel}{n_1})^2}\xi} e^{in_\parallel(\zeta-\eta_q)} dn_\parallel \quad (1)$$

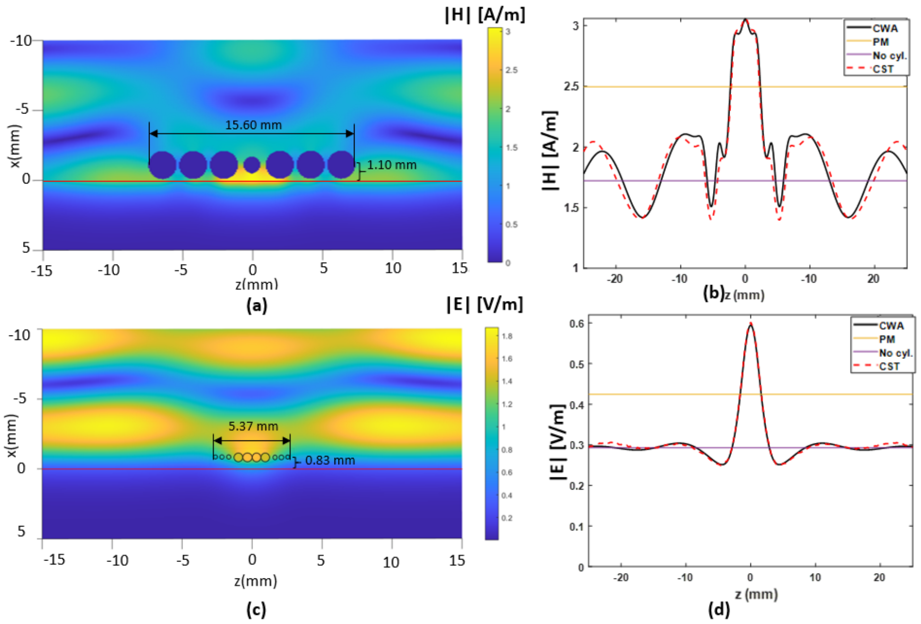

Figure 2. Focusing effects of PEC or dielectric cylinders over an half-space of muscle tissue ($\varepsilon_r = 27.4$ and $\sigma = 29.4$ S/m) at $f = 24$ GHz: (a) magnitude of the total H-field on xz plane for TE polarization and normal incidence ($\varphi_i = 0$) and PEC cylinders; (b) for the same setup as in (a), magnitude of the total H-field along x=0 mm line; (c) magnitude of the total E-field on xz plane, for TM polarization, normal incidence and dielectric cylinders ($\varepsilon_r = 10$); (d) for the same setup as in (c), magnitude of the total E-field along x=0 mm line. In (b) and in (d), the case without cylinders (No cyl.) and adopting a layer that achieves a perfect match (PM) are also reported.

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where $n_1 = \sqrt{\varepsilon_{r1} + \frac{i\sigma}{\omega\varepsilon_0}}$ and the normalized transmitted wavevector $\mathbf{k}^t/k_1 = \mathbf{n}^t = n^t_\perp \widehat{\mathbf{x}} + n^t_\parallel \widehat{\mathbf{z}}$, with $n^t_\parallel = \frac{n_\parallel}{n_1}$

Considering the contribution of N cylinders above the interface and taking into account all mutual interactions, the transmitted scattered field is expressed through expansions coefficient c_{qm} in the following form:

$$V_{st}(\xi,\zeta) = V_0 \sum_{q=1}^{N} \sum_{m=-\infty}^{+\infty} c_{qm} TW_m(\xi,\zeta;\chi_q) \qquad (2)$$

Depending on the polarization of the incident wave considered and the material of the targets (conductor or dielectric) different boundary conditions are imposed at the interface with the cylinders in order to compute c_{qm} [1], [2].

3 Numerical results

The analytical method has been numerically implemented in a Matlab code. As regards the truncation of the series concerning the order of the cylindrical waves, the criterion is to sum over $-M_q \le m \le M_q$ where M_q is the nearest integer to $3\alpha_q$ and α_q is the normalized radius of cylinder. [5]. The spectral integral in (1) and in the expression of the reflected cylindrical waves of m-th order RW_m are solved in MATLAB using the function `integral` that performs global adaptive quadrature [6]. A first example is shown in Fig.2 (a), for the case of an array of N=7 perfectly conducting cylinders placed above a biological tissue (muscle) with permittivity $\varepsilon_{r1} = 27.4$ and electric conductivity $\sigma = 29.4$ S/m at $f = 24$ GHz [7]. The dimensions and positions of the cylinders are chosen to achieve an intensification of the electromagnetic field in the region below the alignment of cylinders, as can be seen also in Fig.2 (b) where the magnitude of the total H-field on the surface of the muscle is shown (x=0 line) for TE polarization of the incident wave. It is worth to note that the central cylinder of the array has reduced radius in order to increase the intensification of the field.
A second example is shown in Fig.2(c), where we consider a configuration of N=10 very thin dielectric cylinders with permittivity $\varepsilon_r = 10$ and TM polarization of the incident plane-wave. With reference to Fig. 2 (c), the focusing effect of the electric field is shown also in Fig.2 (d). Also in this case, a significant intensification of the electromagnetic field is observed on the surface of the muscle. In both cases, results are compared to the case of absence of cylinders and to the case of the adoption of a layer that achieves a conjugate impedance matching (a layer on top of the muscle having the property of transmitting to the biological tissue all the incident power, acting as a quarter-wave transformer plus a reactive sheet that compensate the intrinsic inductance of the tissue). The validation of the analytical approach is shown by the comparison with results obtained in CST Microwave Studio (see Fig.2 (b),(d)) [8].

4 Conclusion

The effect of embellishemt objects to be possibly inserted in dresses weared by people, or patients, that should bring implantable or wereable devices to be powered by external wireless power transfer systems, is considered in this study. Some configurations that can improve the focusing and transmission to a receiving antenna are analyzed in detail.

5 Acknowledgments

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