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Resonant Excitation of a Truncated Metamaterial Cylindrical Shell by a Thin Wire Monopole

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***Abstract*—A truncated metamaterial cylindrical shell excited by a thin wire monopole is investigated using the integral equation technique as well as the finite element method. Simulations reveal a strong field singularity at the edge of the truncated cylindrical shell, which critically affects the matching characteristics of the monopole.**

***Index Terms*—metamaterials, electrically small antennas, computational electromagnetics**

I. Introduction

Materials with negative permittivity (ENG) and/or permeability (MNG) are known to be able to sustain resonances in arbitrary small volumes. Being considered as an opportunity for creation of electrically small antennas this extraordinary property has been investigated for various two- and three-dimensional structures. Particular attention has been paid to canonical structures including infinite solid and layered cylinders as well as hemispherical solids and shells [1], [2], [3]. In [4], it was shown that an electric source located at the axis of a truncated ENG cylindrical shell does excite a resonance, while it is well known that an infinite metamaterial cylinder/cylindrical shell does not sustain a resonance if excited by an infinite line source placed at its axis [5], [1].

In this paper a truncated ENG cylindrical shell excited by a thin wire monopole is further investigated using the volume and surface integral equation (VIE and SIE) techniques as well as the finite element method (FEM). For the integral equation simulations an in-house developed method of moments package Higher-Order Parallel Electromagnetic Simulator (HOPES) [6] is used, while the FEM analysis is performed by the commercial package COMSOL 3.4 [7].

II. Geometry of the Problem and Numerical Techniques

Figure 1 shows a truncated ENG cylindrical shell residing on an infinite perfectly conducting (PEC) ground plane and an on-axis excitation monopole. In all simulations the relative permittivity of the shell is set to $\varepsilon_r = -3$ and the operating frequency is $f_0 = 300$ MHz. The radius of the monopole is 0.5 mm and its height is equal to the height of the cylindrical shell $h = 10$ mm. The antenna is fed by a delta-gap voltage generator and a coaxial wave port in HOPES and COMSOL, respectively. HOPES utilizes higher-order basis functions and solves the problem in 3D; COMSOL employs the rotational symmetry and models the structure in 2D, thus providing a very accurate solution to the highly resonant configuration.

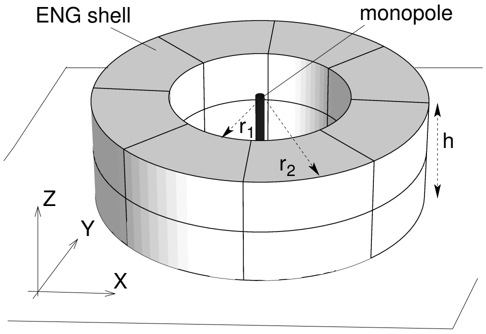
III. Edge Singularity Effects

Rounding of edges is a common way to avoid edge field singularities and ensure convergence of numerical techniques. However, in the case of a truncated ENG shell this should be done with special care, since the rounding strongly affects the electromagnetic response of the structure. Both SIE and FEM techniques predict highly resonant behavior of the input impedance of the antenna even for relatively small changes in the rounding radius r_c. The effect is illustrated in Fig. 2 for the structure with $r_1 = 10.0$ mm and $r_2 = 18.5$ mm.

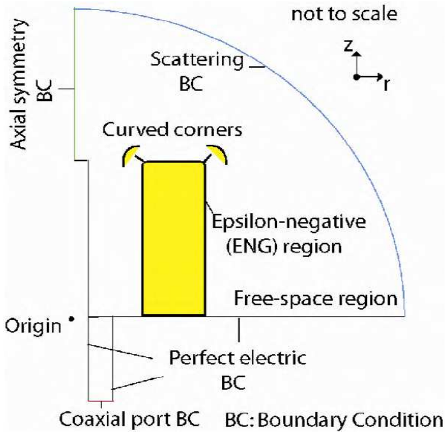
For a fixed rounding radius the ratio between external r_2 and internal r_1 radii defines the resonance frequency of the antenna in a way similar to the case of the shell with a capped top face [4]. Similarly, for a fixed frequency the resonant external radius r_2 can be plotted as a function of the internal radius r_1 as shown in Fig. 3a for various rounding radii r_c. This figure along with Fig. 3b, where the corresponding input resistance of the antenna is presented, can be used as guidelines to design a truncated ENG shell antenna excited by a wire monopole.

A. Note on Edge Singularity Treatment in VIE

As shown above, the rounding of edges can be used to avoid the edge singularities in both SIE and FEM. The corresponding procedure in the 3D VIE would lead to a very fine discretization yielding an inefficient solution. Alternatively, VIE requires a development of special singular basis functions, similar to those formulated for the surface integral equation in [8]. In the absence of singular basis functions, the employed higher-order basis functions are not able to reproduce the singularity on the sharp edge accurately enough. These functions applied on a mesh with the sharp edges reproduce the field behavior as it would be on the rounded edges. Figure 3 demonstrates that the third-order basis functions, which are used in the VIE simulations, yield the result that is very close to the result

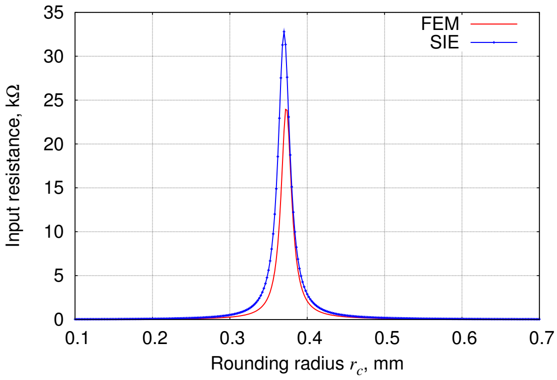


(a) Geometry

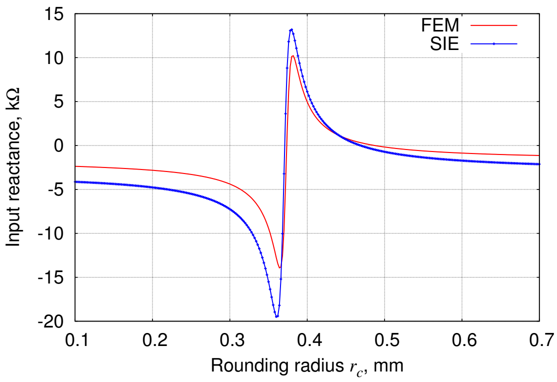


(b) COMSOL simulation set up

Fig. 1: Truncated ENG cylindrical shell excited by a monopole on a PEC ground plane

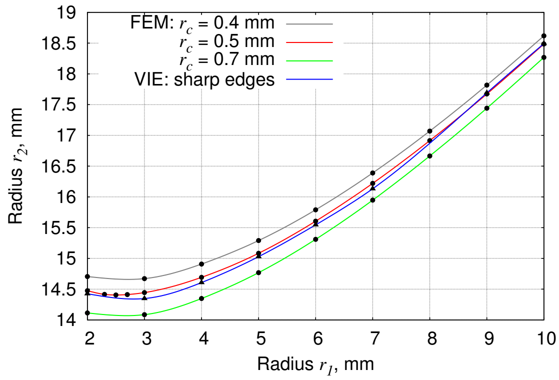


(a) Input resistance

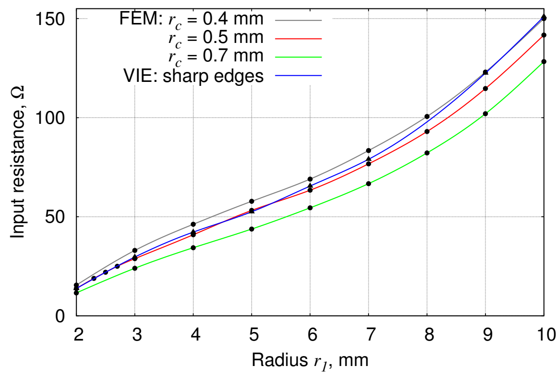


(b) Input reactance

Fig. 2: Input impedance of the truncated ENG shell antenna as a function of the edge rounding radius r_c



(a)



(b)

Fig. 3: Dependence of the resonant external radius r_2 and the corresponding input resistance on the internal radius r_1

obtained with FEM for the edges rounded with the radius $r_c = 0.5$ mm.

IV. Conclusions

Results of the presented investigation show that the singularity at the edge of the truncated ENG cylindrical shell critically affects the matching characteristics of the monopole. Moreover, for the rounded edge the input impedance strongly depends on the radius of the rounding. Thus, if an artificial ENG material is used to build the shell, careful investigations similar to those given in this paper should be carried out taking into account actual dimensions of the material unit cells, since this places a limitation on the minimum radius of the edge rounding.

Acknowledgment

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