THE ROLE OF GEOMETRY OF INCLUSIONS IN FORMING METAMATERIALS WITH NEGATIVE PERMITTIVITY AND PERMEABILITY

Nader Engheta(1) , Sudarshan R. Nelatury(2) , Ahmad Hoorfar(3)

(1) University of Pennsylvania, Department of Electrical and Systems Engineering, Philadelphia, PA 19104, U.S.A
E-mail: engheta@ee.upenn.edu.

(2) Villanova University, Department of Electrical and Computer Engineering, Villanova, PA 19085, U.S.A,
E-mail: nelatury@ece.vill.edu

(3) As (2) above, E-mail: hoorfar@ece.villanova.edu,

ABSTRACT

With recent interest in metamaterials with negative permittivity and permeability, we explore, using analytical/numerical tools, electromagnetic wave interaction with certain metallic inclusions with various shapes, which when embedded in a host medium, may lead to composite media with negative material parameters. These geometries include omega and nonlocal omega inclusions, dovetail and extended dovetail inclusions, and some related geometries. We analyze the electric and magnetic polarizability tensors for these inclusions and we then apply the Maxwell-Garnett analytic formulation to obtain approximate values for the effective permittivity and permeability of the bulk media. We present how some of these geometries can lead to media with double negative parameters.

STATEMENT OF THE PROBLEM

The topic of complex materials in which both permittivity *and* permeability possess negative values at some frequencies has recently gained considerable attention [1]-[11]. This idea was originally initiated by Veselago in 1967, who theoretically studied plane wave propagation in a material whose permittivity and permeability were assumed to be simultaneously negative [6]. Recently Shelby, Smith, and Schultz constructed such a composite medium for the microwave regime, and experimentally showed the presence of anomalous refraction in this medium [5]. As a potential application of this material, the idea of compact cavity resonators in which a combination of a slab of conventional material and a slab of metamaterial with negative permittivity and permeability was recently introduced by Engheta [11]

In the first experimental demonstration of such a medium, Smith *et al*. constructed a "composite medium" made of a periodic lattice array of conducting wires interlaced with a lattice array of conducting dual split-ring resonators. They showed that in a certain range of frequencies, the constructed metamaterial exhibits anomalous refraction, which is the indication of having the direction of Poynting vector of a time-harmonic monochromatic plane wave being antiparallel with the direction of its phase flow. The interaction of electromagnetic wave with the resonant "unit cell" of such a composite medium is a key point to understanding the electromagnetic properties of the bulk medium. To that end, we have initiated a series of analytical/numerical studies of electromagnetic waves with a variety of metallic inclusions of various geometries/shapes. One of our goals has been to find single-part inclusions (instead of inclusions with two separate parts such as conducting wires and separate double split-ring resonators), which when embedded in a host medium, lead to bulk composite medium with negative effective permittivity and permeability.

We begin our study with numerical analysis of electric and magnetic polarizability tensors of a metallic object of the form of "Omega" structure. As is well known, the induced electric dipole moment $\boldsymbol{p}$ and magnetic dipole moment $\boldsymbol{m}$ on small inclusions can be expressed in terms of local electric and magnetic fields $\boldsymbol{E}$ and $\boldsymbol{H}$ as

$$\begin{aligned} \boldsymbol{p} &= \underline{\underline{\boldsymbol{a}}}_{ee} \cdot \boldsymbol{E} + \underline{\underline{\boldsymbol{a}}}_{em} \cdot \boldsymbol{H} \\ \boldsymbol{m} &= \underline{\underline{\boldsymbol{a}}}_{me} \cdot \boldsymbol{E} + \underline{\underline{\boldsymbol{a}}}_{mm} \cdot \boldsymbol{H} \end{aligned} \qquad (1)$$

where $\underline{\underline{\boldsymbol{a}}}_{ee}$, $\underline{\underline{\boldsymbol{a}}}_{em}$, $\underline{\underline{\boldsymbol{a}}}_{me}$, and $\underline{\underline{\boldsymbol{a}}}_{mm}$ are the polarizability tensors that depend on the geometry of the inclusion (scatterer). We were motivated by an earlier study by Saadoun and Engheta in which theoretical study of electromagnetic wave interaction with omega media using the circuit-model approach had also conceptually revealed the possibility of having negative permittivity and permeability in omega media for certain range of frequencies [7]. From the omega structure, we expand our analysis to various other shapes, such as extended ("nonlocal") omega structures, dovetail structures, and the extended dovetail structures, and some other related geometries. Figure 1 presents some of these inclusions.

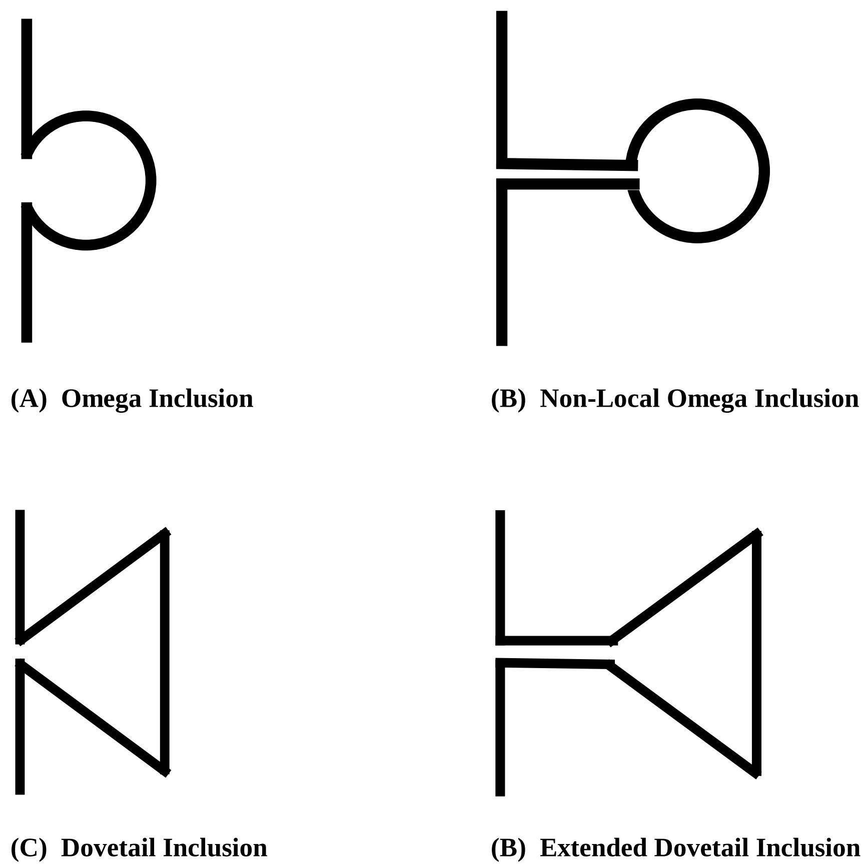

Fig. 1. Sketch of some selected inclusions with various geometries used in our analysis. All these inclusions are single-part inclusions

From the knowledge of the electric and magnetic polarizability tensors, which we gather using the moment-method numerical codes, we then apply an appropriate form of the Maxwell-Garnett analytic formulation [12] to obtain approximate values for the effective permittivity and permeability of the bulk media. Our study reveals the interesting role of geometry of inclusions in achieving the bulk metamaterials with negative permittivity and permeability. In our poster, we present how and why some of these geometries lead to composite media with negative effective permittivity and permeability. The roles of relative segment size in each class of these inclusions will be discussed and will be shown how such relative size can provide possibility of negative parameters for the bulk media. This provides us with useful physical pictures and intuitive understanding of the concept of negative ε and negative μ. The results, physical insights, and intuitive remarks will be presented in our poster.

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