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Design of a negative refractive index material based on numerical simulation

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ABSTRACT

Numerical simulation analysis of a new kind of resonator is presented. The proposed structure operates as a magnetic resonator that provides dual band negative permeability behavior as a result of magnetic resonance produced due to self and mutual coupling of the inclusions. It also shows negative permittivity for a broad frequency band. The proposed structure is capable of achieving negative refractive index at the frequency where both negative permittivity and negative permeability overlapping each other. The design of the resonator is simple and, thus, it allows playing with geometric contents for potential applications.

1. Introduction

The breakthroughs in different areas of science and technology, especially in micro-systems and nanotechnology, enabled structures for electromagnetic and optical applications in such a way previously unimaginable. A class of novel material structures, that is capable of showing such electromagnetic properties beyond the natural ones, consist of engineered materials which include photonic crystals [1] and left hand materials [2,3]. The left-hand materials are further classified into three sub-categories namely (i) negative permittivity materials (ii) negative permeability materials and (iii) negative refractive index materials.

Left-hand materials, due to their fascinating applications in various fields like invisibility cloaks, perfect lens, waveguides and resonators, gain a considerable attention in recent years. These are artificially designed materials, capable of achieving negative permittivity, permeability and negative index of refraction and do not exist naturally. The idea of negative permittivity and negative permeability and thus negative refractive index was first presented in 1967 by a Russian Physicist Veselago [4], who analyzed plane-wave propagation in the left-handed medium. The successful validation of left-hand

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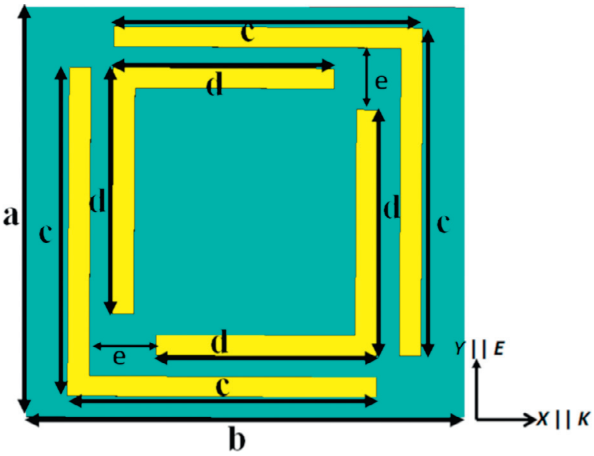

Fig. 1. Unit cell structure.

materials were reported by Smith et al. [5] and Shelby et al. [6] by proposing two-dimensional periodic structure unit cells of SRRs with copper strips. Since the first success, number of left-hand materials have been designed and experimental validation are reported, such as S-shaped resonators [7–10], Jerusalem cross conductor pairs [11,12] and cutwire pair (CWP) resonators [13]. The important restriction faced by the researchers is the narrow DNG frequency band. The magnetic resonance frequency bands are usually narrow whereas permittivity bands are wide in range in most of the SRR-based left-hand materials due to their wire resonance behavior.

In this paper, a new kind of split-ring resonator is designed and simulated. The inclusion is designed to obtain negative permeability, negative permittivity and thus negative refractive index. Geometry of the proposed structure is simple thus it allows controlling the geometric parameters in order to realize the desired features of the negative refractive index according to the potential application. The negative refractive index can easily change by varying the space between the inner and the outer rings of presented resonator. It's simple geometry make this resonator more effective.

2. Unit cell structure

The proposed resonator, shown in Fig. 1, is embedded on a host dielectric substrate. The thickness of host material is 0.25 mm, of which dielectric constant ($\varepsilon^{/}$) is set to 3.8 and the loss tangent factor (tg δ) is 0.0015. The length and width of the host dielectric material is $a = b = 2.0$ mm. The structure is made of copper with thickness of 0.017 mm and width 0.1 mm. The geometric parameters of given structure are $c = 1.6$ mm, $d = 1.4$ mm, $e = 0.3$ mm. The gap between the outer and the inner ring is 0.1 mm.

The sample is illuminated by a plane wave at normal incidence with the electric field parallel to the y-axis ($\boldsymbol{E}\,||\boldsymbol{Y}$) and the magnetic field parallel to the z-axis ($\boldsymbol{H}\ ||\ \boldsymbol{Z}$). The resulting propagation direction is along the x-axis ($\boldsymbol{k}\ ||\ \boldsymbol{X}$). Perfect electric conductor (PEC) boundary conditions were assigned for the side walls (X-Y planes) of the unit cell a horizontally polarized electric field. Perfect magnetic conductor (PMC) boundary conditions were employed for the top and bottom walls (Z-X planes) for a vertically polarized magnetic field. This corresponds to normal incidence (x) of a TEM plane wave.

3. Numerical results and discussion

Mu-negative behavior is difficult to obtain due to less magnetic charges. A diamagnetic response must be produced, which creates a magnetic field opposite to the one externally applied, to overcome this problem. Introducing resonant impurities is another way to create diamagnetism and thus negative permeability near the resonant frequency. Pendry et al. [14] proposed a nested split ring resonator (SRR) to create diamagnetism and thus achieved negative permeability. To obtain a very large negative permeability, a periodic array is needed in order to couple all split-ring resonator elements with each other that increases the magnetic response because diamagnetic effect, associated with single element, is not strong enough to produce large value of permeability. In this light, the geometry dependent capacitive elements such as gaps and splits are responsible to achieve resonant behavior. It means, by playing with the geometric elements such as unit cell size and the shape, the magnetic response and other physical features can be determined.

Geometry plays an important role in order to achieve negative refractive index. The new simpler geometric structures offer more flexibility and reliability on the control over electromagnetic properties and manufacturing processes. *S* parameter's retrieval method, in literature has been demonstrated to be a valid method [15–21]. Robust method [19], which is one of the valid methods, was used to calculate effective parameters of proposed structure in Fig. 1. The Finite Difference time Domain (FDTD) simulations were carried out to calculate the parameters under the frequency band ranges from 10.0 GHz