TRIANGULAR SPLIT RING RESONATOR AND WIRE STRIP TO FORM NEW METAMATERIAL

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Abstract

In this work, a new metamaterial whose unit cell has triangular split ring resonator and wire strip is studied. This new metamaterial is designed and investigated in base of the shape of the ring resonator. S parameters and retrieved effective material parameters are computed to show the properties of the new metamaterial. In addition, electric field distribution and induced surface current density on the split rings and wire strip are illustrated. It is shown that the designed new metamaterial exhibits double negative properties in the frequency region of interest and it can be manufactured for the potential applications of metamaterials.

1. Introduction

The idea of metamaterial (MTM) started with the Veselago's proposal in 1967 [1]. Veselago proposed a new type of material which has simultaneously negative permittivity and permeability and he showed the general electromagnetic properties of such material. He theoretically formed a lossless MTM and presented the extraordinary properties of this material which is not found in nature. Then, Pendry and his coworkers illustrated their studies about the negative permittivity and the negative permeability as in [2] and [3]. They declared that an array of metallic wires can be constructed to obtain negative permittivity in 1996 [2] and a metallization of split rings can be manufactured for negative permeability in 1999 [3]. Later than, Smith and his colleagues demonstrated a new MTM that shows simultaneously negative permittivity and permeability and carried out microwave experiments to test its unusual properties in 2000 [4]. The first experiment showing negative refraction was performed using a metamaterial consisting of a two-dimensional array of repeated unit cells of copper strips and split ring resonators in 2001 by Shelby et. al. [5]. Several theoretical and experimental works have been studied by researchers on MTMs and their potential applications [6−17]. The design of MTM based on shape and geometry is the most interesting work among the others [8−17]. Especially, the design of split rings is very important to construct a new type of MTMs. Numerous types of different ring and ring-like structures such as circular, square, Ω-shaped, U-shaped, S-shaped and others are used to create new MTMs (see [13] for a brief history). In the light of the known structures, we decided to build a new MTM using triangular shaped ring which has not been studied yet. Thus, we construct and analyze a new MTM that contains triangular split ring resonator (TSRR) and wire strip (WS). In the analysis, S parameters and retrieved effective material parameters (wave impedance, refractive index, permittivity, and permeability) are computed and presented. From the simulation results, the real part of the refractive index is found to be negative at frequencies where both real parts of the permittivity and permeability are negative. All simulations show that new MTM is well designed and it can be manufactured for several potential applications in the microwave, millimeter-wave and optical frequency bands.

2. Design and Simulation

The combination of SRR and WS structures are commonly used to fabricate artificial MTMs showing unconventional properties not found in nature. In literature, several types of SRR are recommended for the construction purposes. TSRR is one of them and it is first studied in this work. Figure 1 illustrates the geometry of the unit cells comprised of TSRR and WS. An FR4 of 0.25 mm thickness (with relative permittivity $\varepsilon_r = 4.4$ and loss tangent $\delta = 0.02$) is used as a substrate for each configuration. TSRR and WS are made of copper with conductivity of $5.8\text{x}10^7$ S/m and thickness of 0.017 mm. The width of all TSRR is 0.4 mm. TSRR is located on one face of FR4 and WS is etched on its opposite face. WS is continuous along the whole of FR4 substrate in all structures, as shown in Figure 1. Metamaterial unit cells are designed and simulated using the commercial software package, ANSOFT's High Frequency Structure Simulator

(HFSS), based on finite-element method (FEM). Open, electric, magnetic and periodic boundary conditions are used in the simulation. Each configuration is placed in a two-port waveguide formed by a pair of both perfect electric conductor (PEC) and perfect magnetic conductor (PMC) walls. All FR4 substrates with TSRR and WS are centered in the waveguide.

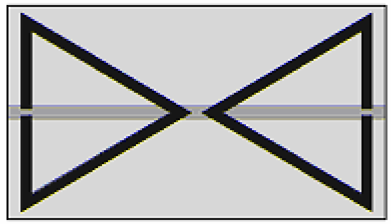

Figure 1: Unit cell of new metamaterial

To show the physical properties of the designed structures, S parameters for a single unit cell is calculated with the mentioned boundaries along the wave propagation. Next, the effective material parameters can be extracted from the S parameters as in [8], [9], and [11]. Then, the electric permittivity and magnetic permeability can be computed from the equations of $\varepsilon = n / z$ and $\mu = n z$ where z and n indicate the wave impedance and refractive index, respectively.

The width of WS is 0.5 mm. The base and the height of TSRR are 7.794 mm and 6.75 mm, respectively. The gap in each TSRR is 0.3 mm and the separation between TSRR is 0.4 mm. The S parameters for the given MTM are computed and the effective material parameters are extracted by means of S parameters using HFSS which are given in Figure 2. In this figure, the magnitude and the phase of S parameters, real and imaginary parts of wave impedance, refractive index, permittivity and permeability are illustrated. S parameters and wave impedance are plotted in the range of 0−8 GHz. But, the refractive index, permittivity and permeability are plotted between 2.5 GHz and 5.5 GHz to see the negative region easily (for the zooming purpose). As it is seen, all parameters are frequency dependent complex functions which satisfy certain requirements of causality. The dip in the phase of S_{21} indicates the presence of negative region which is observed at 4.33 GHz. For passive materials, real part of the wave impedance and imaginary part of the refractive index must be greater than zero. The wave impedance and refractive index satisfy this condition for our configuration. According to the refractive index, the negative band approximately lies between 3.5 GHz and 5 GHz. In the theory of metamaterials, the real parts of the permittivity and permeability must be negative. Negative real parts of the permittivity and permeability lies in the negative band (3.5−5 GHz). Also, the permittivity and permeability show Drude and Lorentz response behavior in the studied frequency region, respectively. While negative permittivity occurs between the region of 2.5 GHz and 5.5 GHz, negative permeability occurs over the range of ~ 4.4 GHz to ~ 5 GHz. Thus, it can be said that negative permittivity has wider frequency band than the permeability.

In Figure 3, we present the electric field and surface current density for the designed MTM. The color map shows the electric field amplitude, and the arrows indicate the direction and size of the surface current density. The electric field is strong at the apex and at the gaps as it is desired. The induced surface current density is in the circular form and it is weak at the gaps. Thus, around the apex and the gaps of TSRR and around the center and ends of WS, the electric field is resonantly enhanced. In addition, the contribution of WS to the induced surface current density is very weak in this type of metamaterial.

3. Conclusion

We have studied the new MTM consisting of FR4 substrate, TSRR, and WS. A new geometry for the ring resonator, TSRR, was introduced, designed and modeled. S parameters are computed for the designed MTM. Then, retrieved effective material parameters are computed using S parameters. The dip in the phase of S_{21} is observed for the designed MTM and the negative region is indicated. The refractive index confirms the indicated negative region and the negative real part of the refractive index occurs around this frequency region. It can be said that from the simulation results, the permittivity and permeability show Drude and Lorentz response behavior respectively in the studied frequency region as it is desired. In addition, the real part of the refractive index is negative at frequencies where both the real parts of the permittivity and permeability are negative. It can be concluded that the designed MTMs exhibit double negative properties in the frequency band of interest. It means that the modeled structures are well designed and successfully work around the operation frequency. Furthermore, the electric field distribution and induced current density on the TSRR and WS are also presented. The contribution of TSRR and WS to the electric field and the surface current density is also indicated. As a result, our novel MTMs can provide new ways to design, characterize, and manufacture new MTMs in the microwave, millimeter wave, and optical frequency regions. All these structures can be used to construct new functional devices such as electromagnetic filters, antennas, and etc.

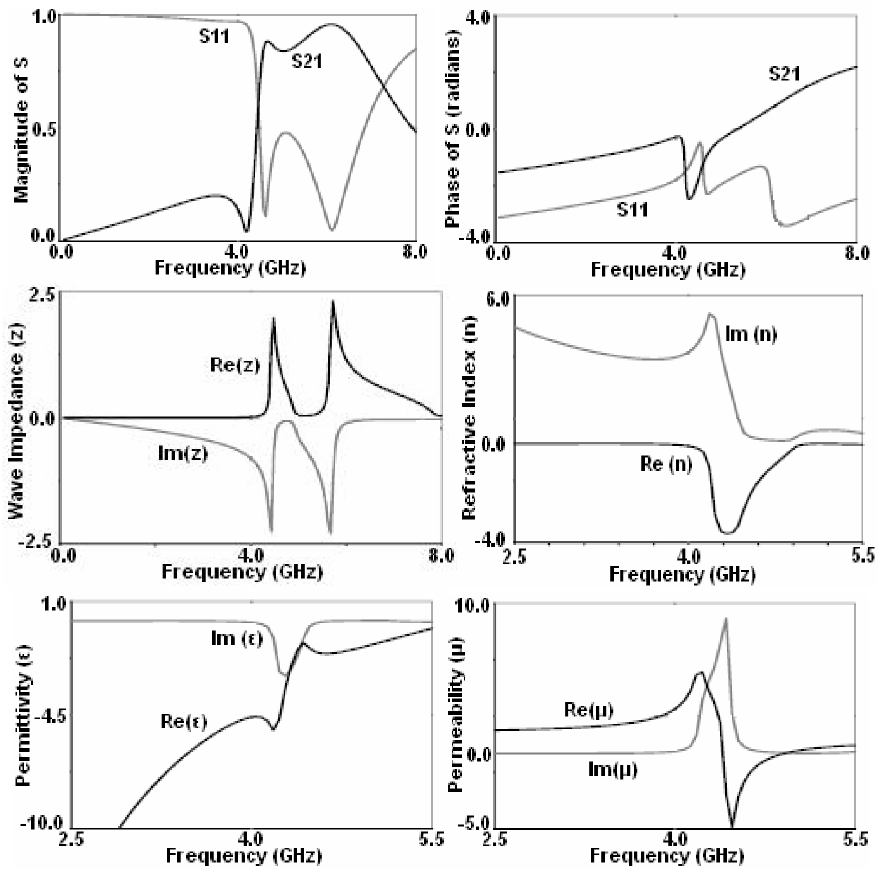

Figure 2: Magnitude and phase of S parameters, real and imaginary parts of the wave impedance, refractive index, permittivity and permeability for the designed MTM.

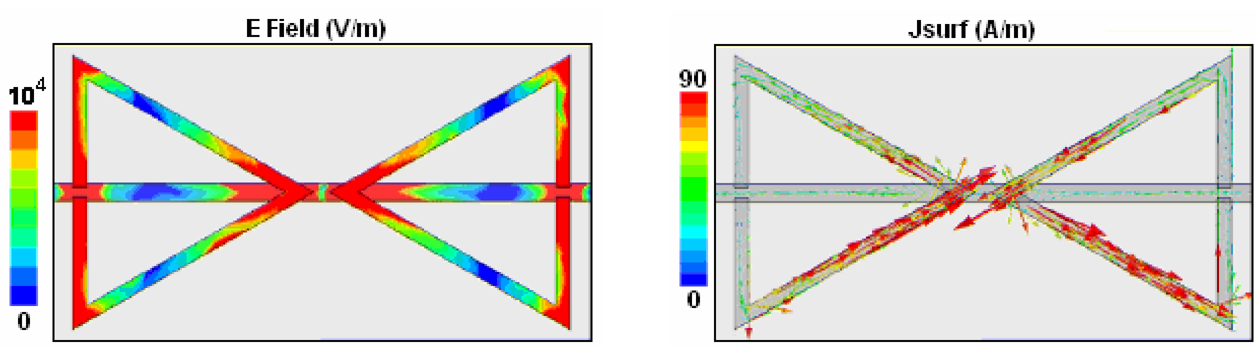

Figure 3: Electric field and surface current density.

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