IUG Journal of Natural and Engineering Studies
Vol.20, No.2, pp 117-125 **2012**, ISSN 1726-6807, http://www.iugaza.edu.ps/ar/periodical/

A Novel Infinity Shaped Split Ring Resonator to Form a New Metamaterial

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Abstract: This paper proposes a new planner metamaterial whose unit cell is infinity-shaped split ring resonator. The cell is composed of two identical infinity-shaped copper patterns etched parallel on both sides of dielectric laminate. The metamaterial is very thin and easy to fabricate. The High Frequency Structure Simulator (HFSS) software was used to design, optimize and simulate the metamaterial unit cell. The effective material properties were retrieved from the calculated transmission and reflection characteristics of the structure. The characteristics and properties of the new metamaterial were plotted to show the material behavior. The new structure has very wide band frequencies, about 11.35 GHz, with negative refractive index.

Keywords: Negative refractive index (NRI), metamaterial, Left-handed material, effective medium parameters.

نوع جديد من المرنانات الحلقية المجزأة علي شكل رمز اللانهاية لتكوين مادة ميتاماتيريال

الملخص: تقترح هذه الدراسة نوعاً جديداً من الميتاماتيريال, حيث أن الوحدة الواحدة منه هي مرنان حلقي مجزأ علي شكل رمز اللانهاية. ويتكون المرنان من طبقتين متماثلتين ومتوازيتين من النحاس علي شكل رمز اللانهاية مطبوعتين علي سطحي طبقة من العازل الرفيع جداً وسهل التصنيع. وقد تم استخدام برنامج HFSS للحصول علي صفات النقل والانعكاس الموجي ومن ثم تمت معالجتهم للحصول علي الخواص الفعالة للمادة. جميع هذه الصفات والخواص تم رسمها وتوضيحها لتبيين سلوك هذه المادة. البنية الجديدة توفر مدى عريض جدا من الترددات بما مقداره 11.35 جيجا هيرتز مع وجود قيم سالبة لمعامل الانكسار الموجي.

1. INTRODUCTION

Metamaterials, which were proposed by Veselago in 1968 [1], are artificial structures composed of normal metals and dielectric materials arranged in a periodic way. This material possesses unusual properties such as negative permittivity ($\varepsilon < 0$), negative permeability ($\mu < 0$), and negative index of refraction. Furthermore, metamaterials is geometrically scalable which enables its realization over a significant range of the electromagnetic spectrum from radio frequency to the optical region. The unusual properties of metamaterials attracted much attention over the past several years to its design and application. Shelby *et. al*. [2, 3] achieved the first practical realization of the metamaterials. They demonstrated negative refraction at microwave frequencies using a volume distribution of a composite medium with split ring resonators (SRRs) and wires. Shelby *et. al*. used periodic arrays of SRRs to achieve negative permeability and periodic arrays of wires to achieve negative permittivity [4, 5]. Researchers have studied extensively the potential applications of metamaterials both theoretically and experimentally [6−12]. Designing of metamaterials is based mainly on shape and geometry of the conducting materials. Split rings resonators are very important in the construction of new types of metamaterials. Various types of ring and ring-like structures such as circular, square, V-shaped, Ω-shaped, U-shaped, and S-shaped are used to create new metamaterials [13−17].

In this paper, we propose a novel design of infinity-shaped split ring resonator structure consisting of two conducting strips over both faces of a substrate. Open, electric, magnetic and periodic boundary conditions were used in the simulation using ANSOFT's High Frequency Structure Simulator (HFSS), which is based on finite-element method (FEM). The S parameters and the retrieved effective material parameters (wave impedance, refractive index, permittivity, and permeability) were computed and presented. The robust method presented by Chen *et. al*. [7] was used to retrieve the constitutive effective parameters of metamaterials over the excitation frequency band. All simulations show that the new metamaterial 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

Figure 1 shows the unit cell structure proposed in this paper. It is constructed of two parallel infinity-shaped copper strips printed over both faces of a dielectric substrate. The copper strip thickness is 0.01 mm. The dielectric substrate is the FR4-epoxy with relative permittivity, dielectric loss tangent and thickness of ε_r = 4.4, tan δ_ε = 0.02 and t = 1.5 mm respectively.

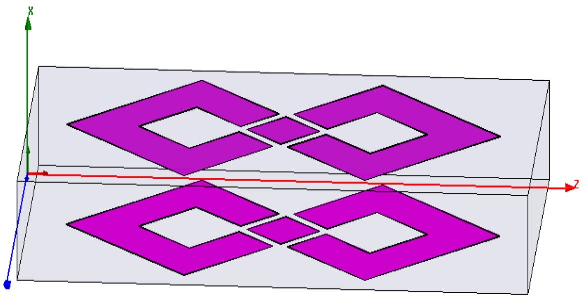


Figure 1: Side view of the unit cell.

Figure 2 shows the top view and the dimensions of the unit cell. The total dimensions of the conducting strips are 4.95 mm and 8.48 mm along the y and z directions, respectively.

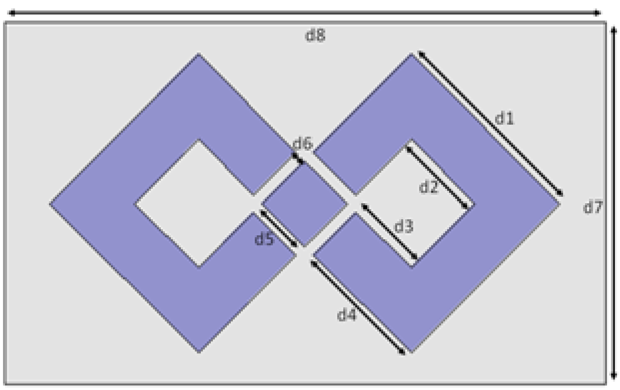


Figure 2: Top view of Infinity-shaped resonator showing the dimensions; d1 = 3.5 mm, d2 = 1.5 mm, d3 = 1.3 mm, d4 = 2.3 mm, d5 = 1 mm, d6 = 0.2 mm, d7 = 6 mm and d8 = 10 mm.

The metamaterial unit cell was designed, optimized and simulated using HFSS software. In the simulation setup, the unit cell was placed inside an air box with dimensions of 3 mm × 10 mm × 6 mm, figure 3. The air box was excited with a time varying electromagnetic field propagating along the z-axis with the electric field directed along the y-axis and the magnetic field intensity directed along the x-axis. Perfect electric conductor (PEC) boundary conditions were applied along the boundaries that are perpendicular to y-axis. Perfect magnetic conductor (PMC) boundary conditions were applied along the boundaries that are perpendicular to the x-axis. Open boundary conditions were applied to the remaining two boundaries [18]. Simulation was performed over the frequency band from 4 to 18 GHz with 0.05 GHz increments.

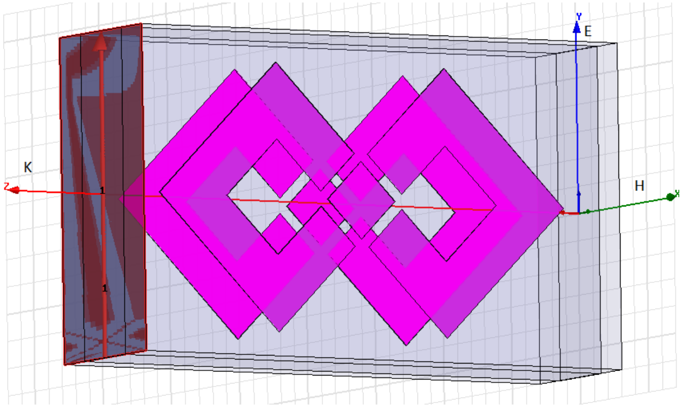


Figure 3: Side view of the unit cell showing the excitation and propagation directions.

The parameters of the effective medium were extracted from the S-parameters using the method given in [7] and [9]. The electric permittivity and magnetic permeability were computed from the equations ε = n / z and μ = n z; where z and n indicate the wave impedance and refractive index respectively.

3. RESULTS AND DISCUSSIONS

The magnitude and phase of transmission and reflection coefficients of the infinity shaped resonator were computed using simulated S_{21} and S_{11} parameters, respectively and are shown in figures 4 and 5.

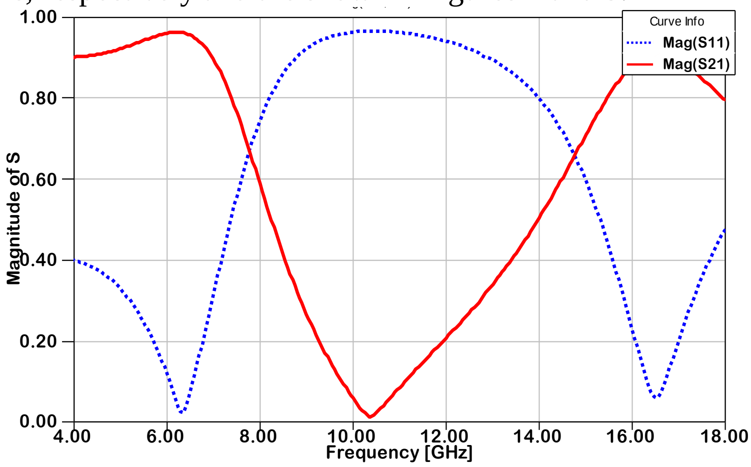


Figure 4: Magnitude of S_{11} and S_{21} as a function of frequency.

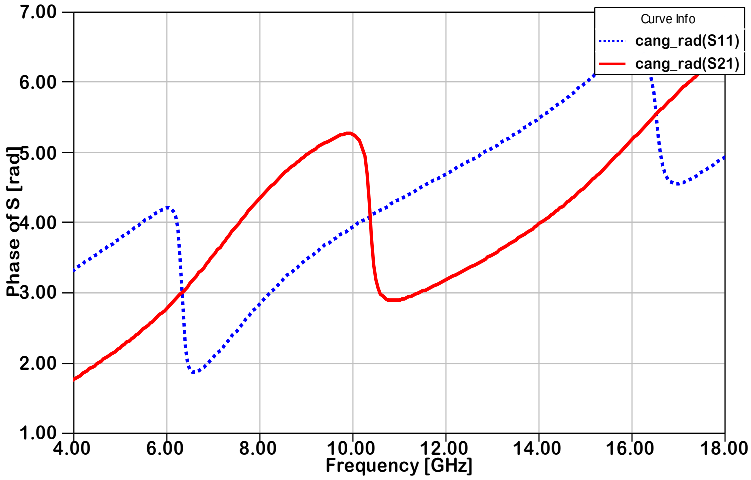
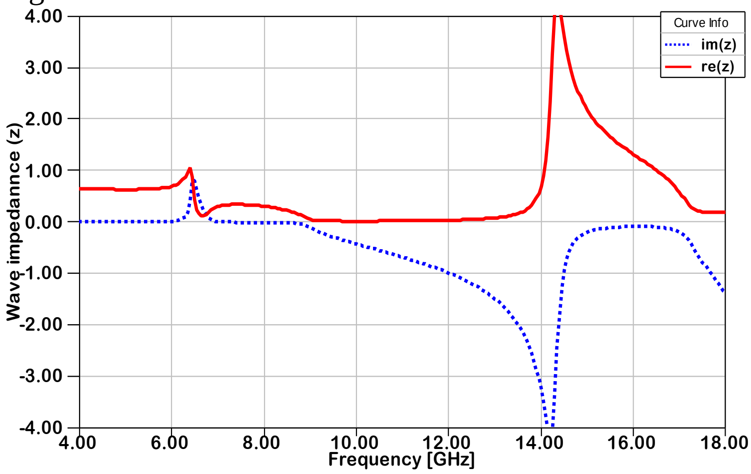
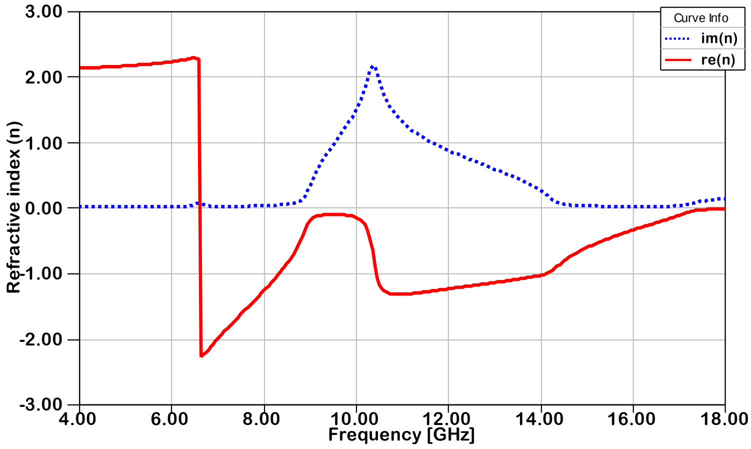


Figure 5: Cumulative angle Phase of S_{11} and S_{21} as a function of frequency.

The transmission peaks and the reflection dips appear at 6.35 GHz and 16.5 GHz. The transmission dip and the reflection peak appear at 10.35 GHz. This is considered as indication that there are resonant frequencies at those regions; also, the refractive index (n) will have negative values. The other electromagnetic characteristics such as wave impedance (z), refractive index (n), permeability (μ) and permittivity (ε) of the infinity-shaped resonator are shown in figure 6.

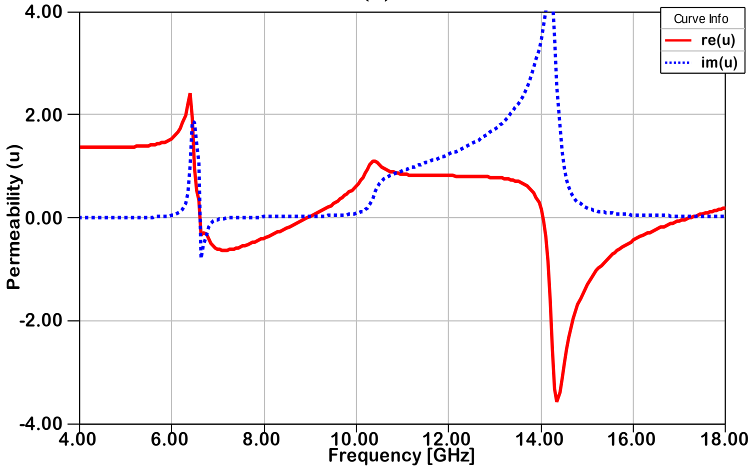


(a)



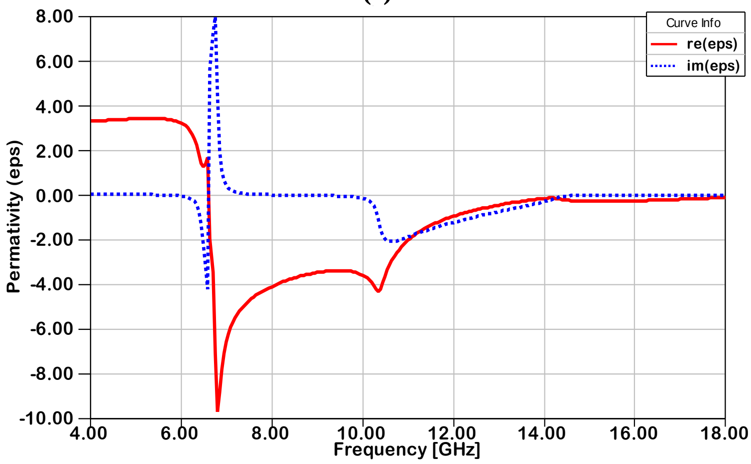
Curve Info
im(n)
re(n)
Refractive index (n)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
Frequency [GHz]

(b)



Curve Info
re(u)
im(u)
Permeability (u)
4.00
2.00
0.00
-2.00
-4.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
Frequency [GHz]

(c)



Curve Info
re(eps)
im(eps)
Permativity (eps)
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
Frequency [GHz]

(d)

Figure 6: Real and imaginary parts of (a) normalized wave impedance, (b) refractive index, (c) permeability and (d) permittivity as a function of frequency for the designed MTM.

The real part of the refractive index has negative values over a wide band of frequencies extending from 6.65 to 18 GHz, as shown in figure 6(b). That is due to the cascaded resonant frequencies at 6.35 GHz, 10.35 GHz and 16. 5 GHz. In the same region, the real part of permittivity is negative, and the real part of the permeability has negative values at two bands, from 6.65 GHz to 8.9 GHz and from 14.05 GHz to 17.15 GHz. Thus, it can be said that negative permittivity has wider frequency band than the permeability. But it can be noticed that n has negative values at some regions where the real part of permeability μ' is positive and the real part of permittivity ε' is negative, at this case n is called single negative refractive index. The refractive index n can have negative values without the simultaneous negative values of μ' and ε' if the condition $\mu'\varepsilon'' + \mu''\varepsilon' < 0$ is satisfied, [12]. This condition is plotted and is shown in figure 7. We can see that it is applied well to the infinity-shaped split ring resonator. Therefore, it is acceptable for n to have negative values at these regions.

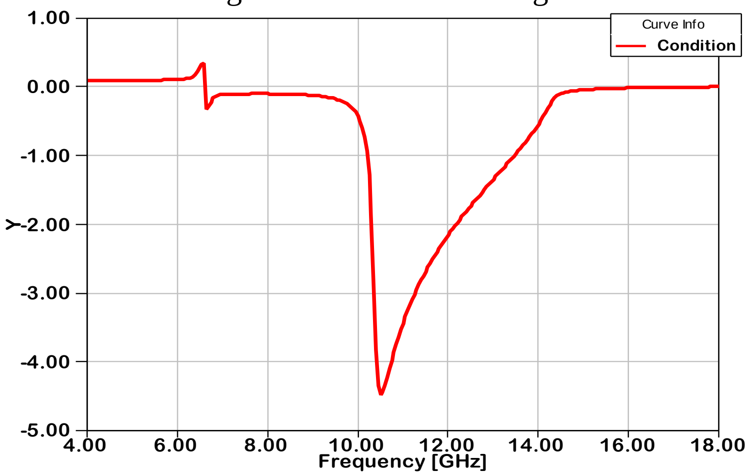


Figure 7: Plot of μ'ε'' + μ''ε' as a function of frequency..

The impedance of the metamaterials will be equal to that of free space if the real parts of ε and μ are equal [19]. For the infinity-shaped resonator, impedance matching, z = 1, occurred at two regions where the reflection coefficient is minimum. That is at 6.35 GHz where μ' = ε' = 2.2, and at 16.5 GHz, where μ' = ε' = -0.21.

4. CONCLUSION:

A novel metamaterial called Infinity-shaped split ring resonator is proposed, designed and modeled in this paper. The S- parameters for the new metamaterial are computed. Then, retrieved effective parameters (z, n, μ, ε) are computed using S- parameters and plotted to show the new metamaterial behavior. The infinity-shaped split ring resonator supports negative refractive index values over a very wide band of frequencies, about 11.35 GHz.

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