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# A Crescent Shaped Split Ring Resonator to Form a New Metamaterial

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## ABSTRACT

This paper proposes a new planner metamaterial consisting of crescent shaped split ring resonator unit cells. The cell is composed of a crescent shaped strip over one face of a dielectric substrate, and an oblong over the second face. The cell is very thin and easy to fabricate. The transmission characteristics of the structure were obtained using High Frequency Structure Simulator (HFSS) commercial software by ANSOFT. Then the effective material properties were retrieved. All the transmission characteristics and material properties were plotted to show the material behavior with frequency. The new metamaterial provides a double negative refractive index over a specific frequency band.

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

## 1. INTRODUCTION

Metamaterials, which are proposed by Veselago in 1968 [1], exhibit characteristics that are not available in ordinary materials found in nature such as negative permittivity ($\varepsilon < 0$), permeability ($\mu < 0$), refractive index and group velocity. Shelby et al. used split ring resonators (SRRs), wires and dielectric material to compose a new metamaterial in order to demonstrated the negative refraction index at microwave frequencies [2, 3]. They achieved negative permeability using periodic arrays of SRRs and negative permittivity using periodic arrays of wires [4, 5]. Metamaterials and their potential applications had been studied extensively by researchers both theoretically and experimentally [6−12]. Designing of MTM is based mainly on shape and geometry of the conducting materials. Split rings resonators are very important to construct a new type of metamaterials. Various types of ring and ring-like structures such as circular, square, V-shaped Ω-shaped, U-shaped, S-shaped, infinity shape, etc. are used to create new metamaterials [13−17].

The crescent shape resonator has been manufactured before for some applications in nanometers such as visible resonances [18] and plasmonic resonances [19]. In this paper, a simple easy to fabricate crescent shape split ring resonator is studied as a metamaterial in millimeters to create negative refractive index media. The unit cell consists of a crescent shape copper strip over the top side of a dielectric substrate and an oblong copper in the bottom side. The commercial software High Frequency Structure Simulator (HFSS) with open, electric, magnetic and periodic boundary conditions was used for the simulation. The S parameters and the effective material parameters (wave impedance, refractive index, permittivity, and permeability) are computed and presented to show the behavior of the new metamaterial. The constitutive effective parameters of the new metamaterial over the excitation frequency band were retrieved using the robust method presented by Chen et.al. [6]. All simulations show that new MTM is well designed and suitable for manufacturing for many applications in the microwave and millimeter-wave bands.

## 2. DESIGN AND SIMULATION

Crescent shape split ring resonator is proposed. The unit cell consists of a crescent shape copper strip over one face of a dielectric substrate and an oblong copper on the other face. Figure 1 shows the structure of a unit cell of the new metamaterial proposed which is consisting of copper and dielectric material. The dielectric substrate used is the FR4-epoxy with relative permittivity $\varepsilon_r$ = 4.4, dielectric loss tangent $\tan\delta_\varepsilon$ = 0.02 and thickness of 0.25 mm. The crescent shape is copper with 0.017 mm thickness on one face of the substrate and an oblong of copper material with 0.017 mm thickness on the other face. The optimized dimensions of the unit cell are shown in figure 2.

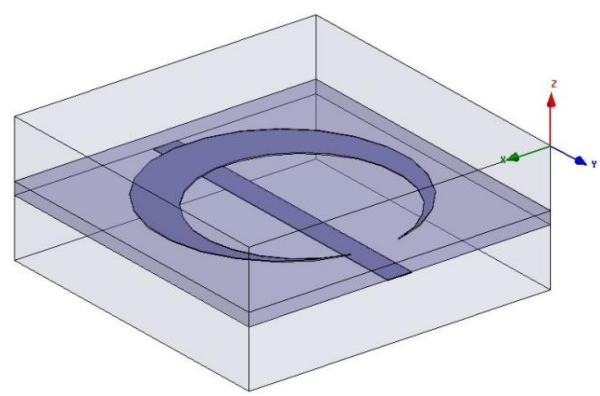



**Figure 1:- The crescent shaped unit cell showing the excitation and propagation directions**

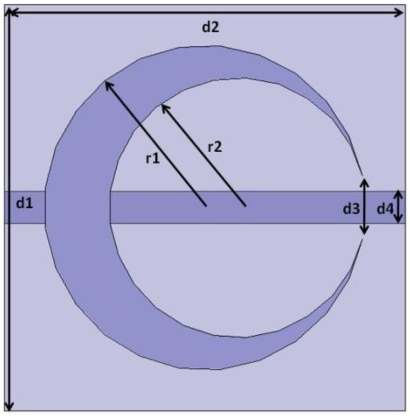



**Figure 2:- The crescent shaped unit cell dimensions; d1 = d2 = 6 mm, d3 = 0.942 mm, d4 = 0.48 mm, r1 = 2.4 mm, r2 = 1.914 mm.**

The Metamaterial unit cell is designed, optimized and simulated using the commercial software package High Frequency Structure Simulator (HFSS). For the simulation, the unit cell is placed inside an air box with dimensions of 6 mm × 6 mm × 2.5 mm, Time varying electromagnetic field having ***E*** vector along y axis, ***H*** vector along z axis, propagating along x axis is used to excite the cell. Perfect Electric Conductor (PEC) was applied at the surfaces of constant y. Perfect magnetic conductor (PMC) boundary condition was applied at the surfaces of constant z. At the remaining two boundaries, open boundary condition was applied [20]. The simulation was done in the frequency band 5 GHz – 18 GHz with 0.05 GHz incremental step. The method given in [6, 8] was used to calculate the effective parameters of the medium from the calculated S parameters. Then, the relative permittivity and permeability were computed from the equations of $\varepsilon = n / z$ and $\mu = n \times z$ where n and z are the refractive index and the wave impedance, respectively.

## 3. RESULTS AND DISCUSSION

The magnitude and phase of reflection coefficient, transmission coefficient and characteristics of the metamaterial cell were computed and are shown in figures 3 and 4. One can notice that the dip of $S_{21}$ phase and the minimum transmission, magnitude of $S_{21}$, occurred at 7.55 GHz. This is an indication that a resonant frequency and a negative refractive index occurring at this frequency.

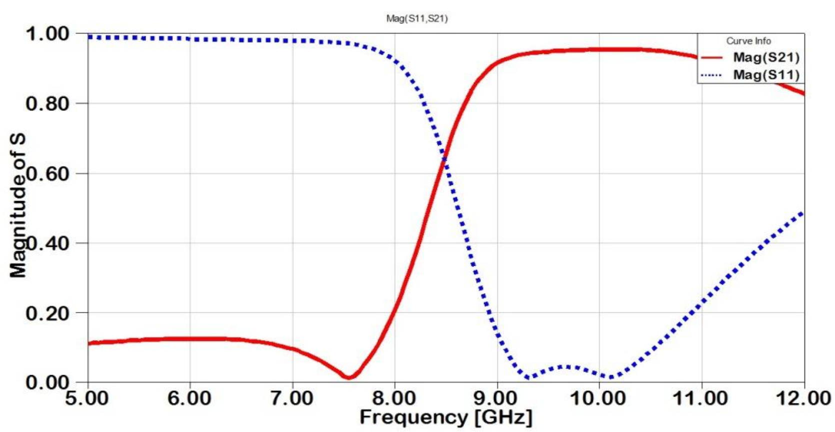



**Figure 3:- Magnitude of $S_{11}$ and $S_{21}$**

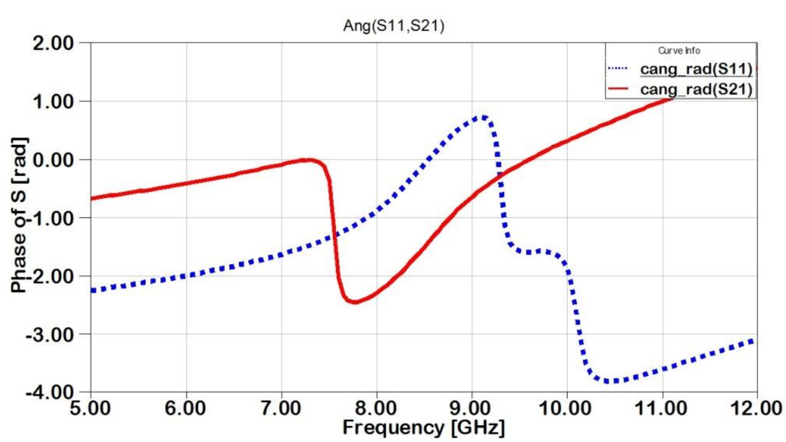
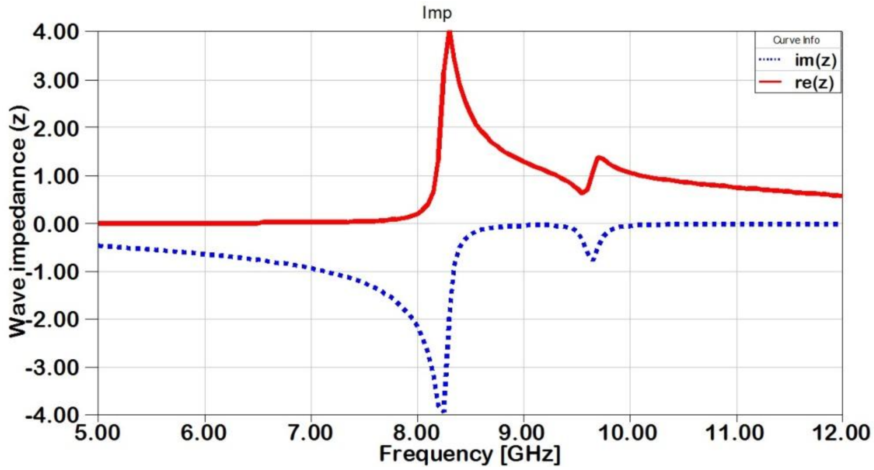
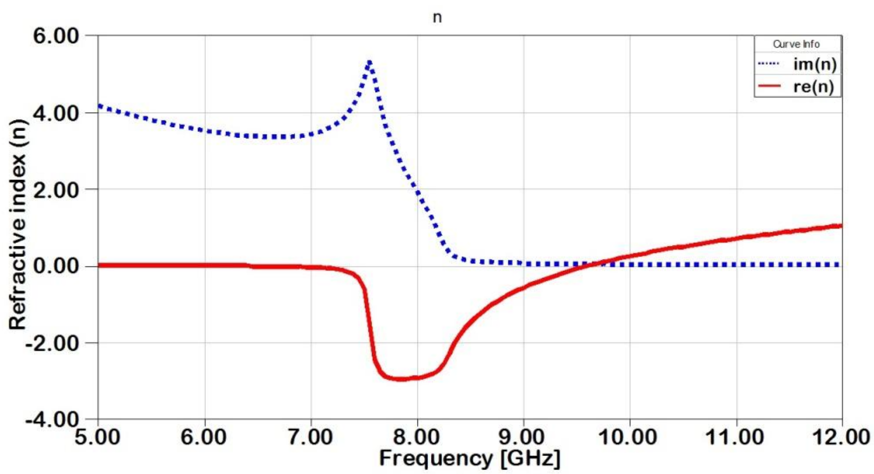



**Figure 4:- Cumulative angle of $S_{11}$ and $S_{21}$**

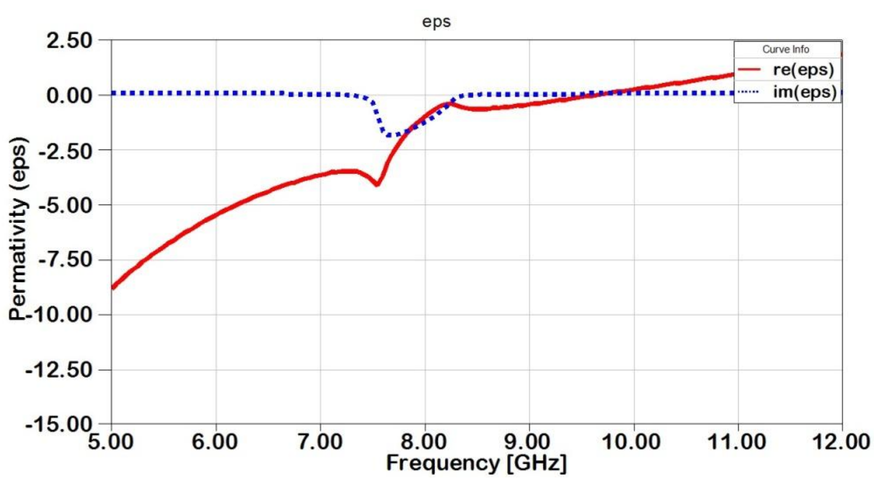
The real and imaginary parts of the remaining electromagnetic properties of the metamaterial cell such as: the wave impedance (z), the refractive index (n), the relative permeability (μ) and the relative permittivity (ε) were plotted by in figure 5.



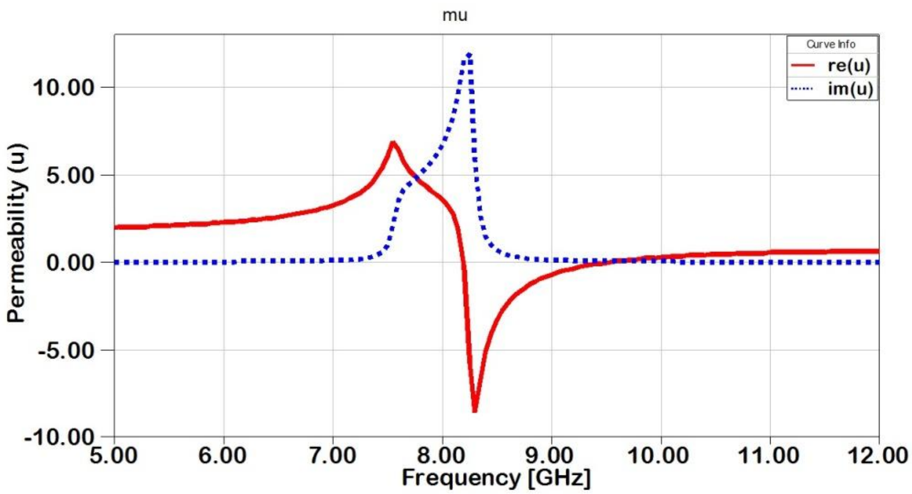

(a)




(b)




(c)




(d)

**Figure 5:- Real and imaginary parts of (a) wave impedance, (b) refractive index, (c) permittivity and (d) permeability.**

One can see from figure 5 that real part of the refractive index n has negative values from 7 GHz to 9.6 GHz, which is the same region of the resonant frequency. In the same region, the real part of permittivity is negative and the real part of the permeability has a positive and negative values. Hence, it can be said that negative permittivity has wider frequency band than the permeability. The wide bandwidth of negative refraction, about 2.6 GHz, is a good characteristic of the crescent shaped resonator. When a medium has negative refraction, left hand medium, phase velocity and group velocity will be antiparallel, amplification of evanescent waves can be realized, Doppler effect and Cherenkov radiation will be reversed and reversal of Snell's law will occur at the interface with another medium having positive refraction, right hand medium.

A parametric study of the substrate thickness was performed on the resonator. Increasing and decreasing the substrate thickness affect on the resonator behavior, and figure 6 shows the effects on the real part of refractive index n. thicker substrate gives lower frequencies range with negative refraction and bigger negative refracive index values.

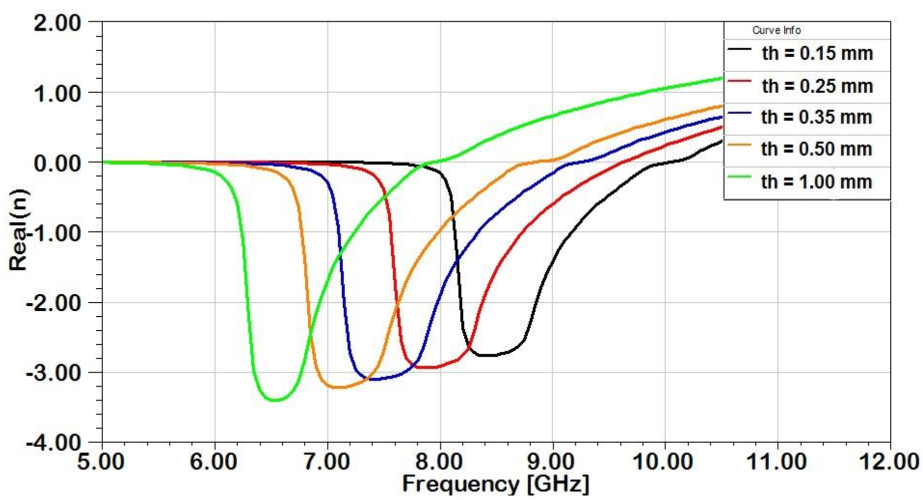



**Figure 6:- Real part of refractive index n with different substrate thicknesses**

## 4. CONCLUSION

A new metamaterial structure, Crescent shape split ring resonator, was proposed and discussed in this paper. S parameters and electromagnetic chrachteristics (z, n, μ, ε) were plotted to show the new metamaterial behavior. Aslo, a parametric study was performed to show the effect of changing the substrate thickness. The easy fabricated crescent shape resonator provides a negative refractive index (n) over a wide bandwidth, about 2.6 GHz.

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