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A Novel Metamaterial Based on Concentric Circular Split Rings Mounted on Epoxy Substrate for Negative Permitivity and Permeability

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Abstract - The split ring resonator metamaterial is created in this article using HFSS. The planned structure consists of four concentric split rings and is capable of resonating at three different frequencies: 3GHz, 5.5GHz, and 6.8GHz. The suggested cell has a total size of 7mm x 7mm x 1mm and is constructed on a low-cost FR4 epoxy substrate. Computer simulations are used to determine the electromagnetic characteristics of the proposed construction. The new aspect of the suggested structure is its compact size and simple resonant structure. The structure is suited for use in wireless applications operating in the S, X, and C bands.

Keywords : *antenna, electromagnetic characteristics, metamaterials, split ring resonators, wireless applications.*

INTRODUCTION

One of the most advanced composite materials ever created is Metamaterial (MTM). Researchers from a wide range of areas have drawn inspiration from this structure's unique properties and used it to develop new approaches. Double negative structures have both negative permeability and permittivity. Veselago was the first to investigate metamaterials back in 1967. Through waveguides and in open space, the peculiar substance can observe light propagation. Electromagnetic wave manipulation has several uses, including holography, signal multiplexing, and so on as a consequence. With the MTM one can use it for anything from filters to cloaking to absorbers, and it can even be utilised for antenna design. Radar and satellite communications both make considerable use of MTM.

Spiral resonators and periodic array structures [1]–[4] are two more forms of metamaterials that have been suggested. Split ring resonators [5]–[8] are another. The SRR unit cell structure has been studied for antenna design downsizing, generating multi-band operation, and increasing bandwidth and gain [9]–[15]. The number of operational bands, the size, and the gain of multiband antennas loaded with metamaterials have been described in [16]–[23]. However, substrates with high permittivity or small-sized radiating components may reduce antenna size [24]. Several techniques exist for reducing the size of the antenna radiator, including the use of metamaterial, the creation of slots, the use of defective ground structure, and the addition of parasitic element strips.

STRUCTURE DESIGN

Metamaterial unit cells are shown in Figure 1 in a top-down perspective. To begin, the 7mm x 7mm FR4 epoxy dielectric substrate material with a 1mm thickness is the basis of the proposed construction. The material's dielectric constant is 4.4 and its dielectric tangent loss is 0.02. Concentric split rings provide the basic framework for the design under consideration. 0.1mm thick copper is used in these resonators. To put it another way, the diameter of circular rings is 0.01 millimetres. The rings have a 0.4mm space between them. In the circular rings, the split spaces are all exactly 0.4mm. Table 1 shows the complete dimensional specifications of the MTM unit cell.

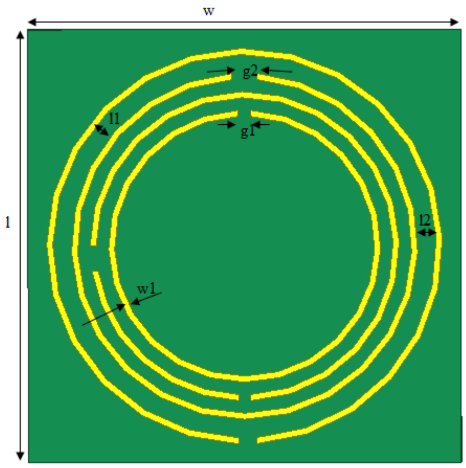

Figure 1: HFSS simulated top view of the metamaterial unit cell

Table 1: Summary of dimensions of proposed Metamaterial unit cell

Parameter	Dimension in mm
w	7
l	7
l1	0.4
l2	0.25
w1	0.1
g1	0.2
g2	0.4

Figure. 2 shows the border shape of the proposed metamaterial unit cell. HFSS software is used to analyse the electromagnetic response of the proposed unit cell. Ports on the negative and positive z-axes are used for waveguide ports, and the suggested structure is positioned in the centre, where the EM wave acts as the driving force. The ideal electric conductor is one with a zero tangential component electric field as its boundary condition (PEC). PEC boundary conditions are the magnetic equivalent of PEC borders. All modes receive EM wave sources from waveport 1. Ideal electric and ideal magnetic boundaries are allocated to the planes that are perpendicular to xz and yz. HFSS was used to model the proposed unit cell in the frequency range of 2 to 14GHz. We derived the complex scattering parameters S11 and S21 from simulations of unit cells in the appropriate frequency range.

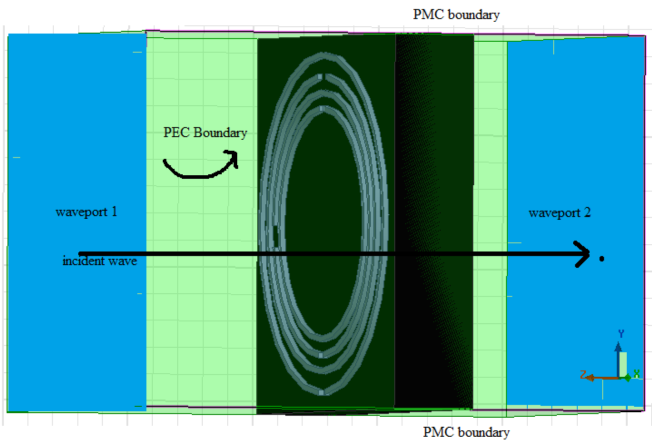

Figure 2: Boundary conditions of the proposed structure

Figure 3 depicts the comparable circuit for the HFSS simulated metamaterial unit cell. Inductances are created by the metal strip, while capacitances are created by the split gap of the specified unit cell. The inductances L1, L2, L3, and L4 are formed by the four concentric circular rings. C1, C2, C3, and C4 are capacitances generated by breaks in the rings 1, 2, 3, and 4. The space between the first and second rings forms C5. The space between the second and third rings forms C6. C7, on the other hand, is produced by the space between the third and fourth rings.

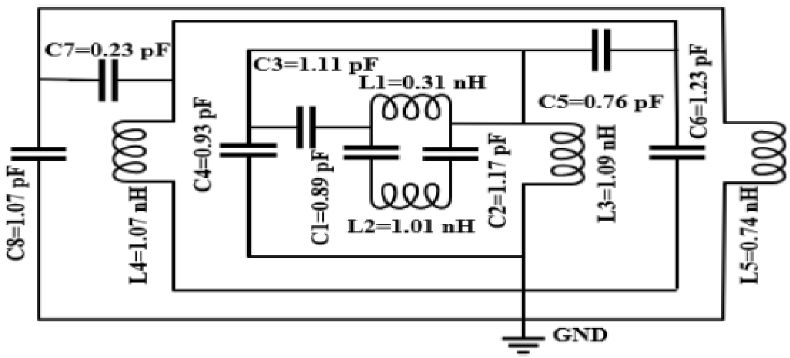

Figure 3 Comparable circuit of the suggested split ring resonator

Metamaterial unit cell surface currents for various transmission resonant frequencies are outlined below. There were three separate resonances that occurred at 3GHz, 5GHz, and 8GHz, as shown in Figure 4. The patch's surface distributes the current. The strength of current in the third and fourth rings is particularly strong at 3GHz, the first resonant frequency. The strength of current in the first, third, and fourth rings is particularly strong at 5.5GHz, the second resonant frequency. The strength of current in the first and third rings is strong on the bottom side at 6.5GHz, the third resonant frequency.

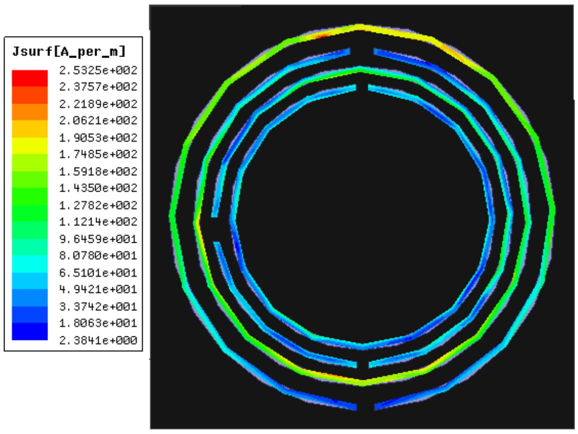

Figure 5a: at 3GHz

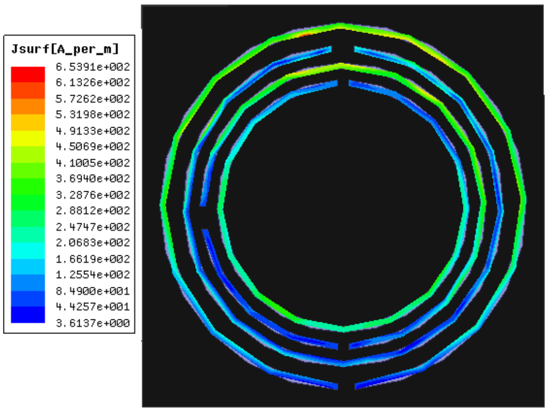

Figure 5b: at 5.5GHz

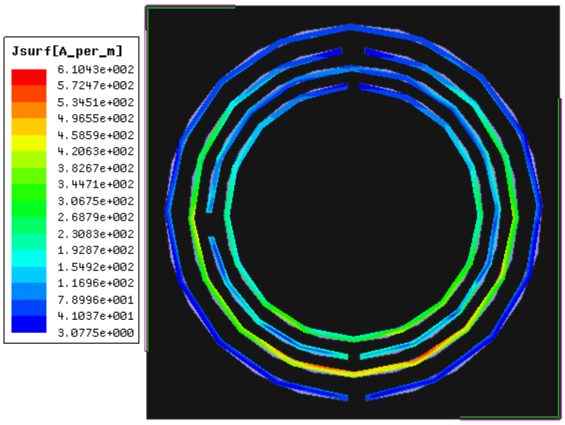

Figure 5c: at 6.5GHz

Figure 5: Analysis of surface current for the proposed structure

RESULTS AND DISCUSSIONS

Figure 6 shows the suggested unit cell's S-parameter. The three resonant frequencies are 3GHz, 5.5GHz and 6.8GHz. The -10dB bandwidth at these resonant frequencies are 0.2GHz, 0.35GHz and 0.2GHz respectively. The effective medium parameters ϵ_{r}, μ_r of the proposed metamaterial unit cell is derived from scattering parameters using the NRW approach. Figure 4 and 5 the extracted real and imaginary parts of the permittivity and permeability. It is seen that the derived metamaterial shows epsilon and mu negative in the desired frequency range i.e. double negative.

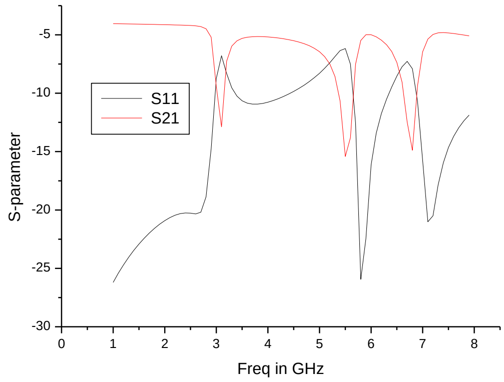

Figure 6: S-parameter plot for proposed metamaterial unit cell

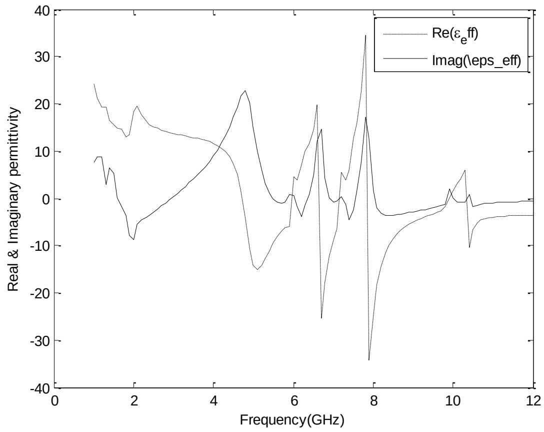

Figure 7: Frequency vs. relative permittivity plot

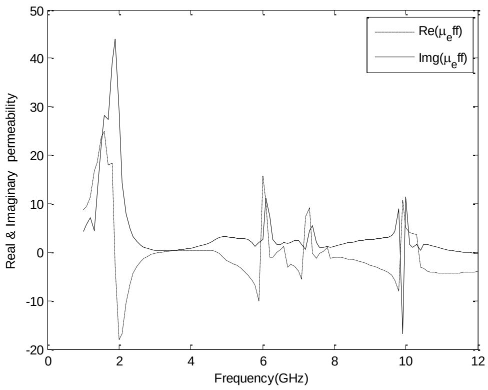

Figure 8: Frequency vs. relative permeability plot

Table 2 compares existing cell layouts with the proposed metamaterial unit cell structure. The suggested unit cell is capable of handling frequencies in three bands and having properties that are both positive and negative at the same time. The size and performance of the unit cell have been enhanced in comparison to the construction shown in Table 2.

TABLE 2: Analyzes of potential and already-created structure

References	**Metamaterial Structure**	**Size**	**Metamaterial type**
17	Concentric crossed line	10mm x 10mm	SNG
18	Circular CSRR shaped	9mm x 9mm	SNG
19	Inverse double V shaped	8mm x 8mm	DNG
Proposed work	Four concentric split rings	7mm x 7mm	DNG

The study proposes and quantitatively validates a four-concentric circular shaped split ring resonator metamaterial unit cell for Wi-Fi and satellite applications. The developed metamaterial unit cell operates at three resonant frequencies of 3GHz, 5.5GHz, and 6.8GHz and has a -10dB bandwidth of 0.2GHz, 0.35GHz, and 0.2GHz at these resonant frequencies, respectively. Additionally, at these resonant frequencies, the structure shows negative epsilon and negative mu properties. As a result, the suggested structures exhibit dual negative metamaterial properties. When the suggested structure is compared to existing structures, it is seen that the proposed structure is smaller (7mm x 7mm) and has increased metamaterial properties. The proposed metamaterial is well suited for usage in wireless S and C band applications.

CONCLUSION

The study proposes and quantitatively validates a four-concentric circular shaped split ring resonator metamaterial unit cell for Wi-Fi and satellite applications. The developed metamaterial unit cell operates at three resonant frequencies of 3GHz, 5.5GHz, and 6.8GHz and has a -10dB bandwidth of 0.2GHz, 0.35GHz, and 0.2GHz at these resonant frequencies, respectively. Additionally, at these resonant frequencies, the structure shows negative epsilon and negative mu properties. As a result, the suggested structures exhibit dual negative metamaterial properties. When the suggested structure is compared to existing structures, it is seen that the proposed structure is smaller (7mm x 7mm) and has increased metamaterial properties. The proposed metamaterial is well suited for usage in wireless S and C band applications.

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