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Applications of Fourth-Layered Rectangular Split Ring Resonator of Swastika-Shaped Metamaterial Unit Cell

Rahul Ateriya
M.E. (Microwave Engineering), Dept of ECE
Jabalpur Engineering College,
Jabalpur, India

Garima Tiwari
Assistant Professor, Dept of ECE Jabalpur
Engineering College,
Jabalpur, India

***Abstract*: In this paper, we design the structures for microwave containing 'left-handed' metamaterials – artificial composites with simultaneously negative effective permittivity and permeability which achieve negative values of refractive index. Attention has been given to the fundamentals of negative index materials, the main design strategies and proposed applications which include Absorber, subwavelength resonant cavities, sub-diffraction limited near-field lenses (superlenses) and phase compensators, which shows a single negative permeability and Refractive Index characteristics at 1-15 GHz frequency ranges. The Absorber is made of Fourth layered Swastika-shaped conductors as a patch and the dielectric substrate, which shows the characteristic of single negative properties of light at different frequency ranges. The permeability has -91dB negative properties in the 1.06 to 1.21 GHz frequency and -16.5 dB in 9.16 to 9.23 GHz frequency ranges. The permittivity of fourth-layered rectangular SRR Swastika-shaped metamaterial has -212 dB negative properties of metamaterial in 1.97 to 2 GHz, -196 dB in 2.5 to 2.8 GHz, -16 dB in 4.6 to 5.29 GHz and -90 dB in 10.23 to 10.25 GHz frequency ranges, which shows the characteristics of Absorber, subwavelength resonant cavities, sub-diffraction limited near-field lenses (superlenses) and phase compensators of the electromagnetic waves of proposed structure.**

Index Terms — Metamaterial, FSS, Swastika-shaped metamaterial, CST and Rectangular SRR.

I. INTRODUCTION

The advent of microsystem technologies and nanotechnologies enabled breakthroughs in many different areas of science and technology, offering functionalities well beyond the natural ones. It enabled structuring of materials for electromagnetic and optical applications in manners previ-ously unimaginable. Among probably the best known examples of novel electromagnetic structures are photonic crystals [1] and the negative refractive index metamaterials, popularly known as 'left-handed' materials [2], [3]. These enabled extension of the operation of passive and active elements for microwave and optical applications beyond the limits previously deemed possible. Another result was an extreme miniaturization of components, sometimes even three to four orders of magnitude.

Negative refractive index metamaterials (NRM) are artificial composites, characterized by sub-wavelength features and negative effective value of refractive index [2], [3]. These materials were theoretically predicted in 1967 by Veselago [4] (in English translation of his text it is erroneously stated that the first results on this topic were published in 1964). However, most of the ideas connected with negative refraction appeared even earlier. L.I. Mandelshtam described negative refraction and backward propagation of waves in his textbook published in 1944 [5]. Backward-wave transmission lines were described by Malyuzhinets in 1951 [6]. The early history of the field is described in some detail in [7]. With the arrival of micro- and nanofabrication, new possibilities opened for practical implementation of different metamaterials and the field became intensely studied by a number of research teams. Extremely influential were seminal texts by Pendry [8]. Today the number of the teams studying NRM and the number of published treatises on this topic are both increasing exponentially We use CST High Frequency Structure Simulator (CST 16.0) which uses Finite-Difference Time- Domain (FDTD) method for the extraction of S parameter. MATLAB scripts are used for the calculation of permittivity, permeability and refractive index curves In view of this, a fourth-layered Rectangular SRR Swastika-shaped metamaterial structure (Fig. 1) is proposed in this paper implying the same principle of Resonators, which show μ- negative and ε-negative characteristics at distinct microwave frequency ranges. The proposed MTM structure is further tailored geometrically and conceptually to achieve FSS-like selective EM characteristics applications in microwave and millimeter wave frequency ranges.

II. DESIGN THE STRUCTURE OF FOURTH-LAYERED RECTANGULAR SRR SWASTIKA-SHAPED METAMATERIAL UNIT CELL

The metamaterial structure proposed in this paper consists of Fourth-layered rectangular SRR Swastika-shaped structures, which are used as a patch which is made up of a copper conductor on either side of the substrate shown in Fig. 1. The structure is made of a Rogers RT5880LZ lossy material as a dielectric slab with the height of 1.8 mm, which can be changed according to the requirement of bandwidth. To design the proposed structure, we used symmetry structure of swastika-shaped to get more appropriate simulation of the metamaterial structure. We designed the structure with 20 mm distance of length and

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width of the Fourth Layered Rectangular SRR of swastika shaped metamaterial.

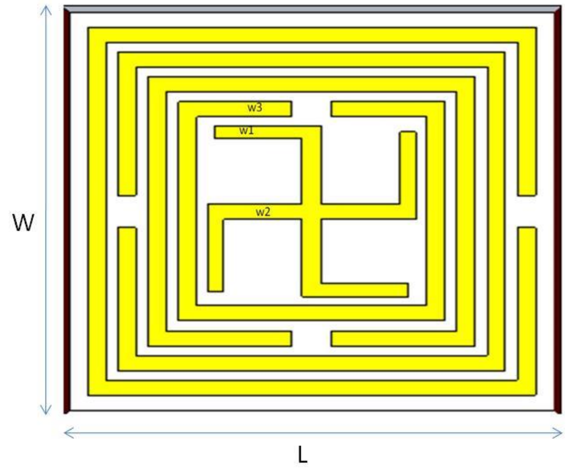

Fig.1. Schematic Diagram of Fourth Layered Rectangular SRR of Swastika-shaped FSS Metamaterial unit cell

The wave port is used to excite the EM wave inside the proposed structure, which can be used to analyze the characteristics of wave of light. The fourth-Layered rectangular SRR swastika-shaped FSS metamaterial structure with applied wave port is shown in Fig. no.2. The electromagnetic (EM) Wave ports is used here to analysis of fourth-Layered rectangular SRR swastika-shaped FSS metamaterial structure is carried out using the full-wave Simulation method based on CST software package and then validated with the experimental results, which shows the characteristics of Absorber of the electromagnetic waves of proposed structure. To obtain S parameters of the proposed structure by the use of post processing in CST, the Refractive index and permeability curves are calculated. Perfect electric and perfect magnetic (PE-PM) boundary conditions are used here in CST to extract the S parameters. To excite the proposed structure, wave ports are used.

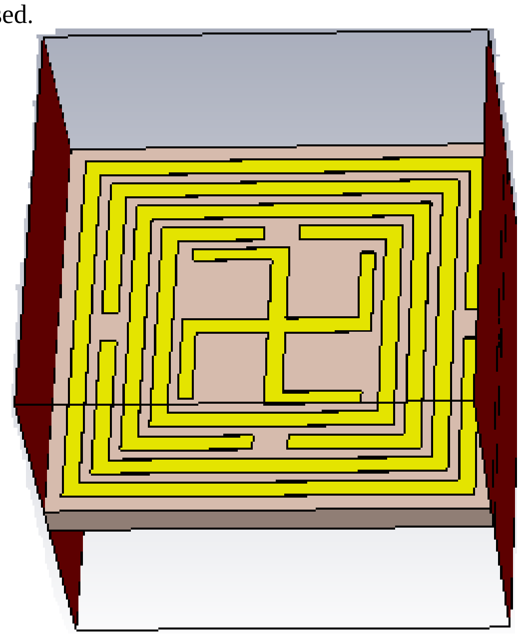

Fig.2. Schematic Diagram of Fourth Layered Rect. SRR of Swastika-shaped FSS Metamaterial unit cell with wave ports

The proposed structure is designed on Rogers RT5880LZ (lossy) substrate with relative permittivity $\mathcal{E}r$ = 4.3, a loss tangent 0.002 and a thickness of 1.8 mm. The conducting layer is of copper with a thickness of 0.0175 mm. The design parameters of the Fourth layered Rectangular SRR Swastika-shaped metamaterial unit cell are given in Table I.

Table no. I - Description of parameters of Fourth-layered rectangular SRR Swastika-shaped FSS metamaterial

S.N.	parameters	Values (mm)	Description
1	L	20	length
2	W	20	width
3	Ts	1.8	Thickness of substrate
4	Tc	0.017	Thickness of copper
5	W1	0.65	width of outer lines
6	W2	1	Width of plus
7	W3	0.75	Width of rectangular SRR

III. NUMERICAL FORMULATION AND EVUALATION OF FOURTH-LAYERED RECTANGULAR SRR SWASTIKA-SHAPED FSS METAMATERIAL

A Fourth Layered Rectangular SRR of Swastika-shaped metamaterial structure has been presented in this paper, which shows μ-negative, ε-negative and refractive index characteristics in different frequency ranges. It has been demonstrated that the metamaterial properties of Fourth -layered Swastika-shaped structure depend on its electric (symmetric distribution) and magnetic (asymmetric distribution) resonances. This concept has been verified by numerical simulations and demonstrated experimentally. In electromagnetic, the material's characteristics are defined by the permittivity, permeability, and Conductivity. The propagation profile of the material at a different frequency is defined by the extraction of permittivity, permeability at that frequency.

To extract the permittivity, permeability, refractive index, current surface and impedance of the material of the fourth-layered Rectangular SRR Metamaterial unit with lattice vectors in all three dimensions. For the simulation of the periodic metamaterial and excitation of this metamaterial in order to extract the *S* parameters, appropriate boundary conditions and excitations are assigned to the different surface of the three-dimensional unit element. Fig.no3. Shows the reflection coefficient (S11) of s parameter and the transmission coefficient (S21) of s parameters, which is shown in fig.no.4.. The relationship between the permittivity (ε), permeability (μ) and refractive index, impedance is shown by the following expressions.

$$S_{11} = \frac{R_{01}(1-e^{i2nk_0d})}{1-R_{01}^2 e^{i2nk_0d}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$S_{21} = \frac{(1-R_{01}^2)e^{i2nk_0d})}{1-R_{01}^2 e^{i2nk_0d}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

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$$\mu = nz \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3$$

$$\mu_r \sim \frac{(1-V_2)}{(1+V_2)} \frac{2}{jk_0 d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \; 4$$

$$n = \frac{k}{k_0} = \sqrt{\varepsilon_r \mu_r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 5$$

$$\varepsilon_r = \left(\frac{k}{k_0}\right)^2 \frac{1}{\mu_r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

$$z = \pm\sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \quad \ldots\ldots\ldots\ldots\ldots 7$$

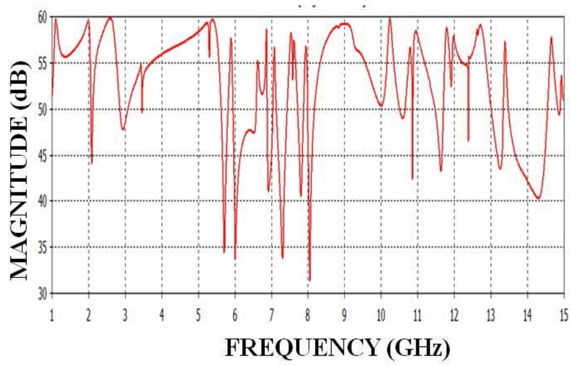

Fig.3. Reflection coefficient (S11) of Fourth Layered Rect SRR Swastika-shaped FSS Metamaterial structure

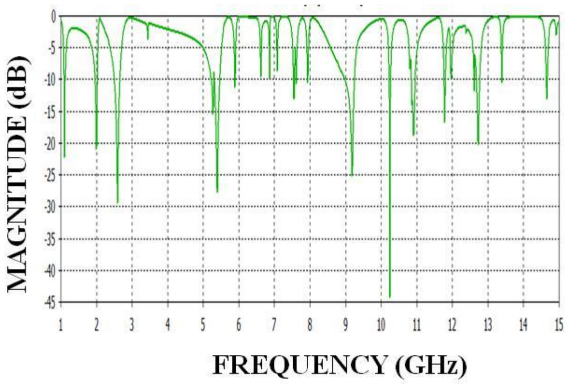

Fig.4. Transmission coefficient (S21) of Fourth Layered Rect SRR Swastika-shaped FSS Metamaterial structure

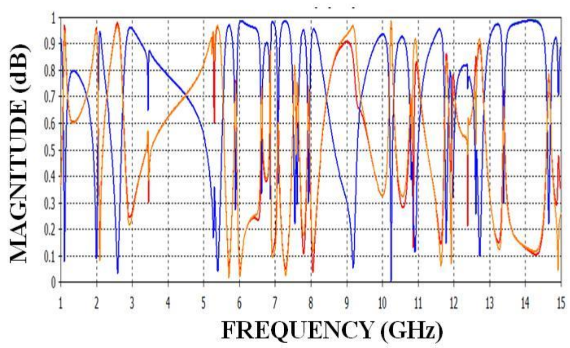

Fig.5. S-Parameters of Fourth Layered Rect SRR Swastika-shaped FSS Metamaterial structure

IV. RESULTS OF FOURTH-LAYERED RECTANGULAR SRR SWASTIKA-SHAPED FSS METAMATERIAL

Using CST software, S parameters are extracted from the simulation of Fourth-Layered Rectangular SRR Swastika-shaped metamaterial unit cell. The permeability, permittivity, refractive index, and impedance are extracted from magnitude of S11 and S21 parameters. The permeability is shown in fig no.6, which showing -91dB negative properties in the 1.06 to 1.21 GHz frequency and -16.5 dB in 9.16 to 9.23 GHz frequency ranges. The permittivity of fourth-layered rectangular SRR Swastika-shaped metamaterial is shown in fig no.7, which has -212 dB negative properties of metamaterial in 1.97 to 2 GHz, -196 dB in 2.5 to 2.8 GHz, -16 dB in 4.6 to 5.29 GHz and -90 dB in 10.23 to 10.25 GHz frequency ranges. The impedance of the proposed structure is shown in fig no. 8, which has minimum impedance at that frequency range. The refractive index of the Fourth-layered rectangular SRR Swastika-shaped metamaterial is shown in fig no. 9, which has negative properties of metamaterial.

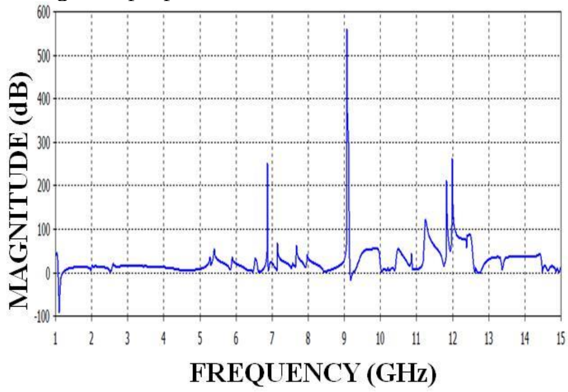

Fig.6. Permeability of fourth-Layered rectangular SRR swastika-shaped FSS Metamaterial

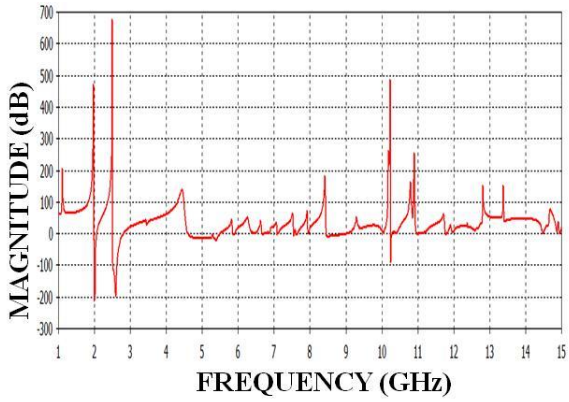

Fig.7. Permittivity of fourth-Layered rectangular SRR swastika-shaped FSS Metamaterial

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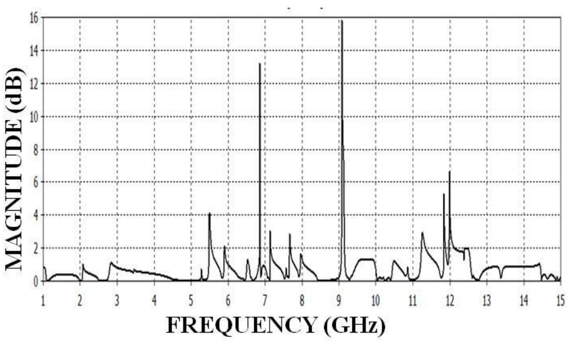

Fig.8. Impedance of fourth-Layered rectangular SRR swastika-shaped FSS Metamaterial

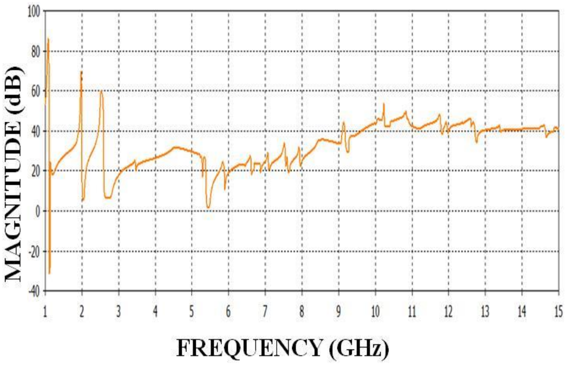

Fig.9. Refractive Index fourth-Layered rectangular SRR swastika-shaped FSS Metamaterial

The distribution of charge is the maximum on the surface of rectangular SRR, which is shown in fig no. 10. The maximum charge is 619.5A/m at 1.12 GHz with different phase angle.

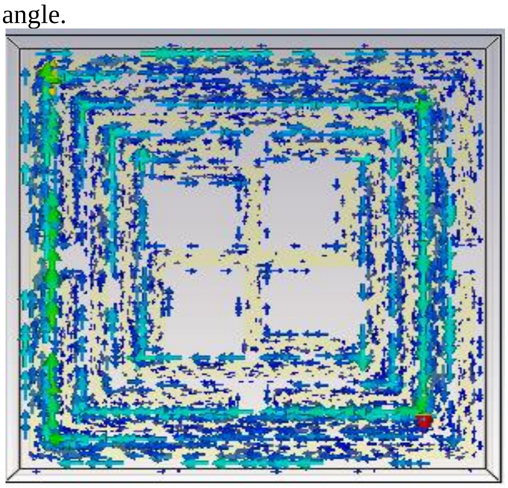
Fig.10. Current Surface of Fourth Layered of swastika-shaped FSS Metamaterial at 1.12 GHz

TABLE NO.II - DISCRIPTION OF PREMEABILITY AND REFRACTIVE INDEX OF SWASTIK-SHAPED FSS METAMATERIAL

S.N.	PARAMETERS	VALUE (GHz)	RANGE (GHz)
1.	PERMEABILITY	-91 -16.5	1.06 - 1.21 9.16 - 9.23
2	PERMITTIVITY	-212 -196 -16 -90	1.97 – 2.0 2.5 – 2.8 4.6 – 5.29 10.23 -10.25
3	REFRACTIVE INDEX	-31	1.10 - 1.13

V. CONCLUSION

A Fourth Layered Swastika-shaped Frequency selective surface metamaterial is designed and analyzed for applications which include Absorber, subwavelength resonant cavities, sub-diffraction limited near-field lenses (superlenses) and phase compensators in 1-15 GHz frequency range and it can be used as a single negative materials, these characteristics of light the proposed structure is useful in this frequency range. The permeability has -91dB negative properties in the 1.06 to 1.21 GHz frequency and -16.5 dB in 9.16 to 9.23 GHz frequency ranges. The permittivity of fourth-layered rectangular SRR Swastika-shaped metamaterial has -212 dB negative properties of metamaterial in 1.97 to 2 GHz, -196 dB in 2.5 to 2.8 GHz, -16 dB in 4.6 to 5.29 GHz and -90 dB in 10.23 to 10.25 GHz frequency ranges. Perfect electric and perfect magnetic (PE-PM) boundary conditions applied to get better simulation of the proposed structure in this frequency ranges. In addition to the periodic boundary conditions, wave ports are used for the excitation of Fourth-Layered rectangular SRR Swastika-shaped FSS Metamaterial.

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