Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 6, April : 2024

INVESTIGATING THE ELECTROMAGNETIC RESPONSE OF NOVEL METAMATERIALS AT 7.6 GIGAHERTZ

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ABSTRACT:
This paper presents a detailed investigation into the electromagnetic properties of metamaterials operating at 7.6 GHz, focusing on negative permittivity and permeability phenomena. Specifically, the research examines the design, simulation, and performance analysis of Split Ring Resonator (SRR) metamaterials. Emphasizing the significance of accurate electromagnetic simulations, the study incorporates the application of port boundary conditions to enhance simulation fidelity. Through rigorous analysis, the paper elucidates the role of port boundary conditions in accurately characterizing the electromagnetic response of metamaterial structures.

Keywords:-
Microwave, resonance, transmission line, split ring, dielectric, coupling, metamaterial, miniaturization, frequency selective surface, high Q factor.

1. INTRODUCTION:-
This paper presents a detailed investigation into the electromagnetic properties of metamaterials operating at 7.6 GHz, focusing on negative permittivity and permeability phenomena. Specifically, the research examines the design, simulation, and performance analysis of Split Ring Resonator (SRR) metamaterials. A Split Ring Resonator is an imitation created Construction commonly found in metamaterials. Its aim is to manipulate the magnetic susceptibility in numerous types of metamaterials especially in frequency range up to 200 terahertz.

2. DESIGN AND STRUCTURE:-
The design process of the SRR metamaterial involves optimizing geometrical parameters to achieve resonance at 7.6 GHz. SRRs contain a pair of coordinated metallic rings carved on a non conductor substrate. The rings have splits or gaps on opposite sides; the structural inhomogeneities allow SRRs to hold up resonant wavelengths much greater than the diameter of the rings. The curves can be either concentric or square and the gaps can be adjusted as needed. Dimensions of square split ring resonator are given below:-

S. No.	Parameters	Values
a.	length of substrate	2.78 mm
b.	width of substrate	2.78 mm
c.	length of outer ring	2.60 mm
d.	width of outer ring	0.2 mm
e.	distance between two rings	0.25 mm
f.	length of inner ring	1.70 mm

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g.	width of inner ring	0.2 mm
h.	length of strip	2.78 mm
i.	width of strip	1.228 mm
j.	width of rectangular cut	0.3 mm

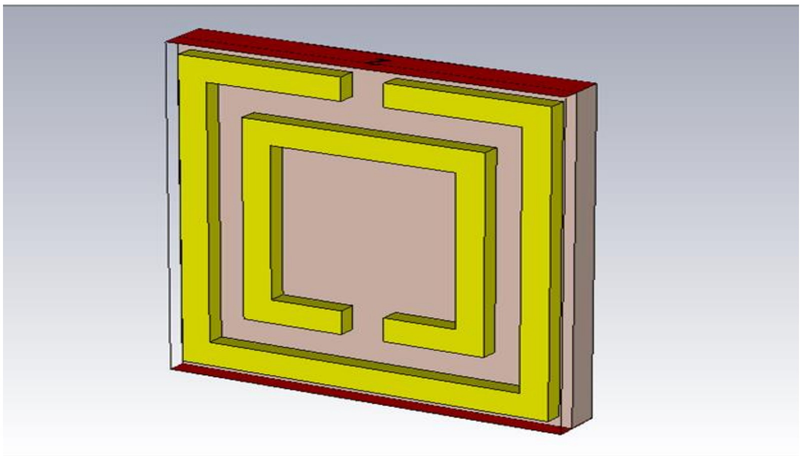
Figure 1. Square split ring resonator

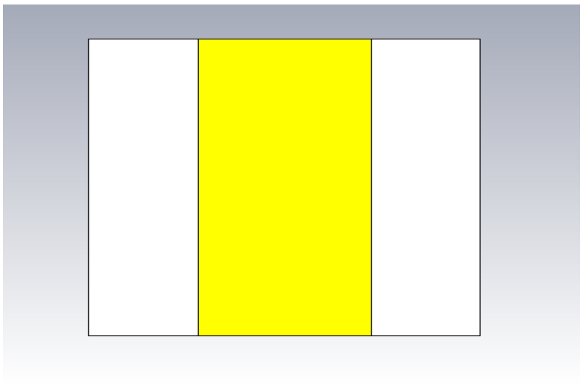
Figure 2. Rare view of square split ring resonator.

3. BOUNDARY CONDITIONS:-

Boundary conditions play a crucial role in modeling and understanding the behavior of SRRs. Here are the key aspects:-

perfect electric conductor boundaries are chosen such that the electric field is across the space of SRR. Essentially this means that the electric field lines run perpendicular to the gap, connecting the two halves of the split ring. By enforcing PEC boundaries, we ensure that the electric field interacts with the SRR in the desired manner. perfect **magnetic conductor boundaries** are selected such that the magnetic field passes through the SRR. These boundaries help define the behavior of the magnetic field within the SRR structure. **Edge singularities and concentric boundaries** when dealing with SRRs we often assume that the concentric boundaries (the inner and outer age of the rings) are hard. In this paper, we applied PEC and PMC boundary conditions. In this presented paper the electric tangential field (Et) is equal to zero along the y axis. The magnetic tangential field (Ht) is equal to zero along the Z axis and the boundaries open along the x axis, open boundary in x axis, this means that the boundary does not constrain the electromagnetic fields in the x-axis direction, allowing waves to propagate freely through the boundary. Et is equal to zero in y -axis, this indicates that the electric field components tangential to the boundary are zero along the y-axis. It implies that there are no electric field components parallel to the boundary in the y-axis direction. Mt is equal to zero, this specifies that the magnetic field components tangential to the boundary are zero along the z axis. It means that there are no magnetic field components parallel to the boundary in the Z axis direction.

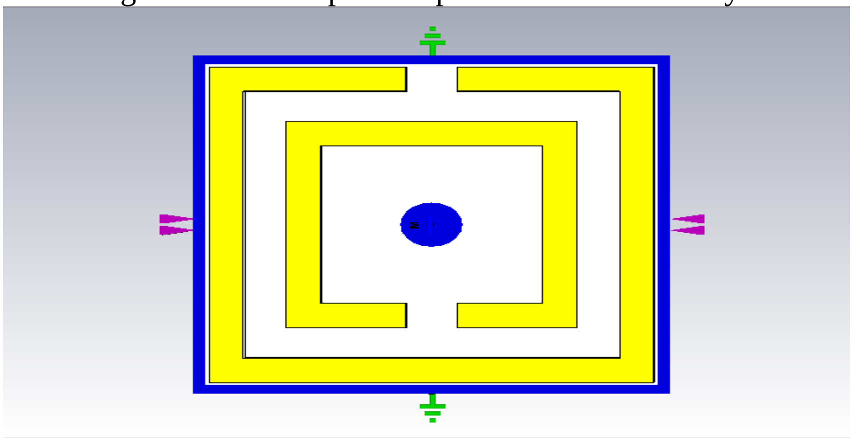

Figure 3. Front view of Boundary condition for the Introduced square ring resonator.

4. PORTS AT SRR:-

In the context of electromagnetic simulation and analysis ports are used to define the input and output connections to a device or structure. For SRRs, ports are typically placed at specific locations on the structure.

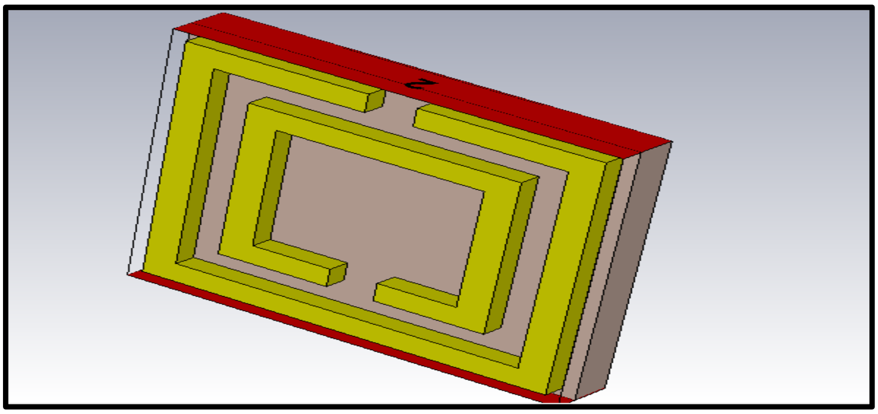

Figure 4. Ports at y axis of square split ring resonator.

5. PERMITTIVITY AND PERMEABILITY OF SRR METAMATERIAL:-

SRR (split ring resonator) metamaterials exhibit properties that are different from conventional materials. In general SRR metamaterials are engineered to have negative permittivity and permeability at 7.6 Ghz frequencies, enabling unique electromagnetic properties such as negative refractive index or some wavelength imaging.Figure 5 and figure 6 show the negative permittivity and permeability, which shows that the SRR mathematician is working perfectly at 7.6Ghz frequency.

Metamaterials are engineered materials designed to exhibit properties not found in naturally occurring substances. They often have unique permittivity (ε) and permeability (μ) values, which are crucial for manipulating electromagnetic waves.The permittivity (ε) of a metamaterial refers to its ability to store electrical energy in an electric field. It is defined *as:*

$$\varepsilon = \varepsilon_0 * \varepsilon_r$$

Where,

ε_0 is the vacuum permittivity (8.854 x 10^(-12) F/m)

ε_r is the relative permittivity of the material

The permeability (μ) of a metamaterial refers to its ability to support magnetic fields. It is defined as:

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$$\mu = \mu_0 * \mu_r$$

Where,
μ_0 is the vacuum permeability (4π x 10^(-7) H/m)
μ_r is the relative permeability of the material
Metamaterials can have negative or near-zero values for both permittivity and permeability, allowing for unique manipulation of electromagnetic waves, such as cloaking or superlensing effects. These properties are often exploited in applications like antenna design, imaging systems, and waveguides.

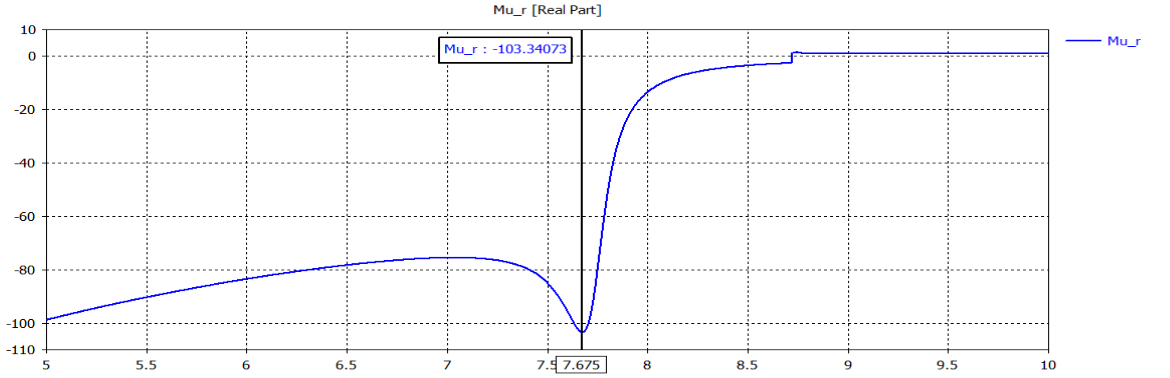

Figure 5. Negative permeability of 7.6 Ghz frequency.

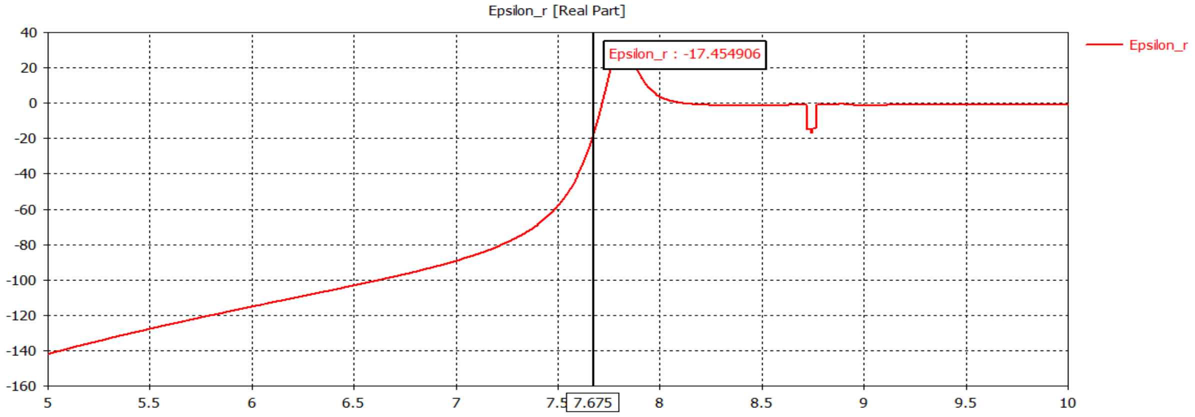

Figure 6. Negative permittivity of 7.6 Ghz frequency.

6. APPLICATIONS:-

The accurate characterization of SRR metamaterials facilitated by port boundary conditions has significant implications for various applications, including antenna design, sensing, and electromagnetic wave manipulation. The enhanced simulation accuracy enables more precise optimization of metamaterial structures for specific application requirements.

7. LIMITATIONS:-

One limitation of this study is the Reliance on simulation techniques which might fully catch the complexities of actual world environments. In addition, the accuracy of simulation depends on the fidelity of the material models and boundary conditions used.

8. PERFORMANCE EVALUATION:-

The performance evaluation of the SRR metamaterial focuses on its resonance behavior and electromagnetic properties at 7.6 GHz. By incorporating port boundary conditions into the simulations, the accuracy of the performance evaluation is enhanced, providing insights into the metamaterial's response to external excitation.

Ongoing research continues to explore novel applications of SRRs, including miniaturized antennas, beamforming, and reconfigurable antennas.Understanding the electromagnetic behavior of SRRs and optimizing their design remains a key area of interest for researchers.

9. CONCLUSION:-

In conclusion, this paper demonstrates the importance of port boundary conditions, particularly Perfectly Matched Layer (PML) boundary conditions and lumped ports, in accurately characterizing the electromagnetic response of SRR metamaterials operating at 7.6 GHz. By incorporating these boundary conditions into electromagnetic simulations, the accuracy of performance evaluation is significantly improved, enabling more informed design decisions and advancing the potential applications of metamaterials in various fields.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to Sunil Kumar Singh , Associate professor, for their invaluable guidance, support, and insightful feedback throughout the course of this research. Their expertise has greatly enriched the quality of our work. We are also thankful to my family and friends for providing access to the necessary resources and facilities. Additionally, we extend our appreciation to all participants who generously contributed their time and insights, without whom this study would not have been possible.

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