

Split Ring Resonator based Metamaterial

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Abstract — Split ring resonator-based metamaterial simulation and design is the base of this study. In 5G wireless communication, at the resonance frequency of 3.5 GHz, optimization is achieved. For this frequency, there are many applications. The SRR unit cell was formed on the low loss dielectric substrate using copper due to its high electric conductivity. Besides, in order to get the sharp resonance behaviour, the geometry of metamaterial was modified using electromagnetic simulators like HFSS. At the resonance frequency of 3.5 GHz, this material has negative permeability and negative permittivity that is useful for electromagnetic shielding.

Keywords—*Split-Ring Resonator (SRR), Metamaterials, Negative permittivity, Transmission coefficient(S-parameters).*

I. INTRODUCTION

Split Ring Resonators (SRRs) are prominent for their strong magnetic resonance and compact design. Square, hexagonal, and tri-circle SRR configurations have shown high sensitivity, dual-band operation, and efficient liquid sensing, proving their effectiveness in advanced sensing and electromagnetic applications [1]-[3]. Split ring resonators (SRRs) are metamaterial structures consisting of concentric metallic rings with splits that function as LC resonators, providing negative permeability and enhanced electromagnetic control within compact geometries. When integrated with dielectric resonator antennas (DRAs), SRRs enable miniaturized multiband antennas that exhibit high gain, wide bandwidth, and improved radiation efficiency suitable for modern 4G, 5G, and emerging 6G wireless systems [4]-[6].

Also, SRR-based fractal metamaterial absorbers have demonstrated broadband and polarization-independent operation in the microwave K- and Ka-band. The fractal geometry can improve bandwidth and absorption efficiency, thus these structures are of interest for mitigated electromagnetic interference. This study investigates compact rectangular DRA's and fractal-based SRR metamaterial absorbers optimized for sub-for their respective applications, 5 GHz and 20–30 GHz, they provide efficient, low-cost solutions for next-generation communication technologies [7]-[8]. Among the most basic and often utilized building elements in the creation of metamaterials (MTMs) is

the Split-Ring Resonator (SRR). The SRR is typically made up of conductive rings with gaps; when illuminated with an incident electromagnetic wave, the rings act as a resonant LC circuit. This resonance can present remarkable magnetic responses, and thus can achieve negative permeability over a given frequency band [9]-[11]. The SRR is quite versatile, and different forms have been proposed, including square (SSRR), circular (CSRR), and oval-shaped rings, to achieve specific resonant characteristics operating at given frequencies and applications [12]-[13].

Metamaterials utilizing split-ring resonators (SRR) have attractive electromagnetic characteristics such as relatively high absorption, polarization insensitivity, and multiband characteristics for integrated energy harvesters, energy shields, and advanced communications applications.[14]-[15].

In this study, an intelligent reflecting surface unit cell based on split ring resonator (SRR) is analysed. The proposed unit cell is tuned to align with at 3.5 GHz. This frequency is one of the key frequencies used in the implementation of sub-6 GHz 5G communication systems. Moreover, the designed SRR unit cell tries to achieve stability with respect to azimuthal (ϕ) and elevation (θ) angles of incidence. This stability would lead to efficient signal manipulation capabilities, particularly in the case of complex urban areas. Therefore, the designed structure could increase the efficiency of IRS-based wireless communication networks and reduce their performance degradation due to the angle of incidence.

The rest of this paper is structured as follows. The geometric design of the proposed SRR unit cell is described in Section II. Section III discusses the simulation details, parametric analysis, magnitude response, phase response, and angular stability performance of the designed unit cell. Finally, Section IV contains the conclusion of this paper.

II. PROPOSED METHODOLOGY

The main aim of this study is the design and synthesis of a dual-square Split Ring Resonator (SRR)-based metamaterial structure tuned to 3.5 GHz for sub-6 GHz 5G communication as illustrated in table 1 . The main idea here is to develop a compact unit cell and an array of such cells to improve electromagnetic behavior, including resonance performance

coefficient is smaller than -25 dB. The resonant frequency and resonance depth have not been changed significantly at different azimuthal angles, which means no sensitivity to the azimuthal angle changes.

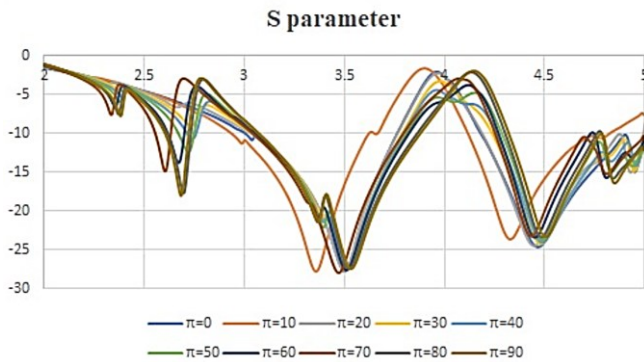


Fig. 4. Phi variation output

According to Fig. 5, the study of the θ -response of the designed metamaterial unit cell for different elevations angles ranging from 0° to 70° was conducted in order to analyse its behaviour under oblique incidence illumination. The obtained simulation result shows a clear resonant effect with the fact that the reflection coefficient does not surpass -20 dB for small θ angles, indicating the presence of impedance matching as well as resonant coupling effects. With increasing θ angle, it is observed that the resonant frequency shifts to higher frequency range while resonance magnitude reduces gradually due to the variation of electromagnetic field strength and electrical length of the resonator under oblique incidence condition. Nevertheless, the resonant effect magnitude remains smaller than -10 dB for any considered θ angles.

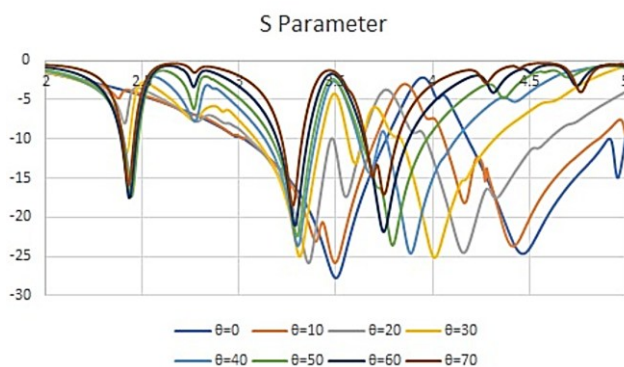


Fig. 5. Theta variation output

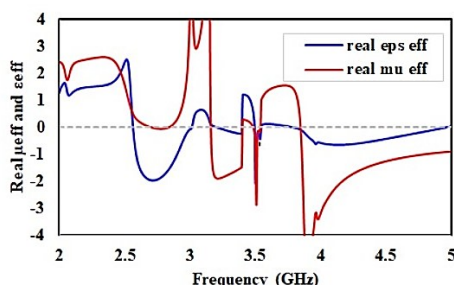


Fig. 6. Metamaterial simulation

The metamaterial parameters will be extracted using MATLAB, and for calculating the S_{21} and S_{11} parameters of the proposed design, using Ansys HFSS

Figure 6 demonstrates the retrieved material parameters between the frequencies of 2 to 5 GHz. It can be noticed that the real values of effective permittivity (ϵ_{eff}) and effective permeability (μ_{eff}) show the dispersion property and changing signs, proving that the proposed structure acts as a resonant metamaterial. In Figure 6, the curve marked in blue is that of permittivity, and the curve shown in red is of permeability. Negative nature of parameters can be seen in the range of 3-3.5 GHz. This is because these parameters demonstrate the metamaterial properties.

IV.CONCLUSION

The proposed dual-square Split Ring Resonator (SRR)-based metamaterial structure has been successfully designed, simulated, and analyzed for operation in the 3.5 GHz sub-6 GHz 5G band. The optimized dual-square configuration exhibits strong resonance characteristics, improved electromagnetic field confinement, enhanced impedance matching, and reduced reflection loss compared to conventional SRR geometries. The structure maintains stable resonance behavior under varying ϕ and θ angles of incidence, demonstrating excellent angular stability and polarization-independent performance. Furthermore, the implementation of a 5×5 SRR array enhances phase control and electromagnetic wave manipulation capabilities, making the design suitable for Intelligent Reflecting Surface (IRS) applications. The retrieved effective constitutive parameters confirm the metamaterial behavior of the proposed structure through the realization of negative electromagnetic properties within the operating frequency range. Owing to its compact size, stable resonance response, and favorable electromagnetic characteristics, the proposed metamaterial structure is a promising structure for next-generation sub-6 GHz 5G communication systems, compact microwave resonators, filters, absorbers, and other advanced electromagnetic devices.

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