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Truncated patch with circular ring metamaterial for enhanced MIMO performance

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Abstract – In this paper, a new wideband metamaterial truncated structure unit cell is introduced, comprising a novel unit cell design aimed at enhancing 5G applications. The unit cell features a truncated structure with a decagon ring slotted in a patch with three slits and is designed on a low-cost FR-4 lossy substrate. With dimensions of 13.8×13.8 mm² and a thickness of 1.6 mm (εr = 4.4, tanδ = 0.02), the proposed metamaterial unit cell covers a wideband frequency range from 7.5 GHz to 9.2 GHz. Notably, it spans segments of the S-band and extends into the C-band within the microwave regime. Simulation results highlight the unit cell's intriguing performance features, particularly its wideband capabilities. These characteristics position the proposed metamaterial unit cell as a promising solution for enhancing Multiple Input Multiple Output (MIMO) performance in 5G communication systems. Through comprehensive analysis, this study underscores the potential of the proposed metamaterial design to address the evolving demands of high-speed data transmission and reliable connectivity in modern wireless communication networks.

Keywords – Circular Ring, 5G, Metamaterial, MIMO, Truncated Patch and Wideband

I. INTRODUCTION

Metamaterials are composite materials designed to possess qualities not yet found in the natural world. Composite materials, like metals, can be assembled into assemblies of many elements to create engineers [1]. At sizes smaller than the wavelengths of the phenomena they effect metamaterials are typically structured in repeating patterns. For a device to be more compact, highly effective, inexpensive, and vigorously multiband designed for a range of frequency ranges, it is crucial to combine diverse components [2]. Implementing multiband design is mostly about achieving the multifunctional performance of the design at a reduced dimension and cost. There is nothing like this in material found in nature.

According to the specification, a metamaterial is a composite medium consisting of a periodic array of interspaced conducting nonmagnetic split ring resonators and continuous wires.

In 1999, demonstrated that metallic wires combined with split ring resonators could display a refraction index that is lower than zero at a particular frequency [3]. Since 2005, a configuration of synthetic structural elements that offers special and beneficial electromagnetic characteristics has been included in the definition of metamaterial [4]. The most common application of metamaterial in 2010 was in synthetic media that is arranged on a scale lower than the external wavelength influences [5]. 2015 saw the introduction of metamaterials, a man-made material with programmable electromagnetic properties [6]. Due to the rapid advancement of electromagnetics today, metamaterials are widely acknowledged as created materials for unique wave phenomena. By optimizing the metamaterial, many opportunities can be presented to new research areas, including absorber [7,8], antenna [9], gain enhancement [10], microwave application device - Wi-Fi, GPS [11,12], super-resolution [[13], [14], [15]], cloaking [16], radar cross-section (RCS) [17], reduction of specific absorption rate (SAR) [18], sensor [19], filter [20], perfect tunneling [21], radar and satellite [22,23], information metamaterial [24], and terahertz metamaterial [25,26]. It is crucial to build the optimal system across multiple application domains in order to achieve enhanced performance, including increased unit miniaturization and data measurement capacity.

The most current studies on metamaterial with superior polarization that spans the frequency bands S, C, or both. As an example, in 2017 Faruque et al. [27] created two C-shaped metamaterial designs that covered the S-band and X-bands. The device unit cell's dimensions were 14 × 14 mm². In the same year, [28] succeeded in creating a miniature unconventional material unit cell. The device had linear polarization and measured 6 x 6 mm2. Under the C-band, the lower frequency was discovered at 4.3 GHz. A double L-shaped metamaterial [29] with a 10 × 10 mm² unit cell structure was introduced in 2019 and achieved multiband. In 2020 saw the development of an inverse-epsilon-shaped KU band metamaterial [30] with a diameter of 10 × 10 mm² and low polarization, which had the same dimensions as the unit cell that was previously described. Multiband circular polarizers with distinct designs are also documented in the literature [26–31]. A significant issue in the research effort is designing a compact-sized structure to produce wideband circular polarized metamaterial resonance.

In order to create a wideband metamaterial, a new compressed unit cell made up of a circular decagon ring and a truncated patch has been developed in this work. Using the electromagnetic simulation tool CST software, the suggested truncated unit cell is designed to function in the frequency range of 7.5 GHz to 9.2 GHz. Within the microwave regime, it extends into the C-band and covers portions of the S-band. The structure of the proposed metamaterial unit cell is shown for applications in microwave wideband.

II. METHODOLOGY

A. Geometry of metamaterial unit cell

The structural view and geometrical configuration of the proposed metamaterial unit cell, shown in Figure 1, have been developed in this research to address the interaction issue among MIMO antenna performance in order to get a wideband response. The metallic truncated square patch circular ring slotted in patch with one, two, or three slots, respectively, makes up the suggested metamaterial unit cell. The unit cell is constructed on an inexpensive FR-4 lossy substrate, measuring 13.8 x 13.8 mm² overall, with a thickness of 1.6 mm, $\varepsilon r = 4.4$, and $\tan\delta = 0.02$. Through CST in the frequency domain, unit cell design and simulation are carried out.

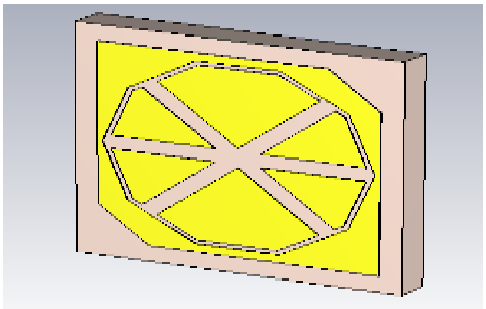

Fig. 1 Geometry of multiband metamaterial top view

In this work, we examine this setup where an electric field is oriented along the y-axis and an incoming electromagnetic wave propagates along the positive z-axis. The finite-difference time-domain approach is the foundation of the commercial tool CST Microwave Studio.

Boundaries for perfect electric and magnetic conductors are imposed along the x- and y-axes, respectively. Two waveguide ports are also positioned along the z-axis. The transmission and reflection coefficients are found using a frequency domain solver. The metamaterial configuration is simulated using a frequency range of 2-10 GHz with impedance matching set to fifty ohms.

B. Effective S-parameters Calculation

The transmission coefficient (S12) and reflection coefficient (S11) are required to ascertain the properties of the metamaterials, such as their relative permeability and permittivity. This outline's high prevalence geometrical estimation can be achieved by using a meshing scheme based on the FDTD technique. In order to achieve convergence, the meshing approach must take into account the simulation period. S-parameters of the described unit-cell and exhibit were computed using CST Microwave Studio. The Nicolson Rose Weir (NRW) technique was used to extract the compelling permeability (μ) and permittivity (ε) from the recreated complex S-parameters [13]. Effective refractive index (j) was extracted from the simulated complicated S-parameters using the direct refractive index approach.

III. Results and Discussions

In this section, the simulation results of the truncated unit cell metamaterial design are presented. The scattering parameters and characteristics of the unit cell's geometrical parameters are also analysed. The final metamaterial unit cell design shown in fig 1. Is approached using CST. The optimized physical dimensions are, in millimetres: W = 13.8, L = 13.8, S = 1, P = 11.9, r1=5.57, r2=5.5, c=3.1 and h = 1.6. The dielectric used is FR4 with relative permittivity 4.4 and loss tangent 0.02. fig 2 shows the unit-cell structure, reflection coefficient (S11) and transmission coefficient (S12) which operates frequency from 7.5GHz to 9.2Ghz. It can be observed that the metamaterial is covering wideband which covers the portion of C band and S band. fig 3 shows the extracted permeability of the proposed meta material. The curve generally shows typical behaviour of a meta-material. It can be seen the permeability of the proposed meta-material reaches almost zero in the range of 7GHz to 9GHz. And Surface current density of the unit cell is shown in fig 4. It can be seen that the current density is higher at the places where slot distance between patch and the slot is small. fig 5(a)and(b) shows Comparison between the proposed and modified metamaterial unit cells indicates that the proposed design offers superior resonance frequencies.

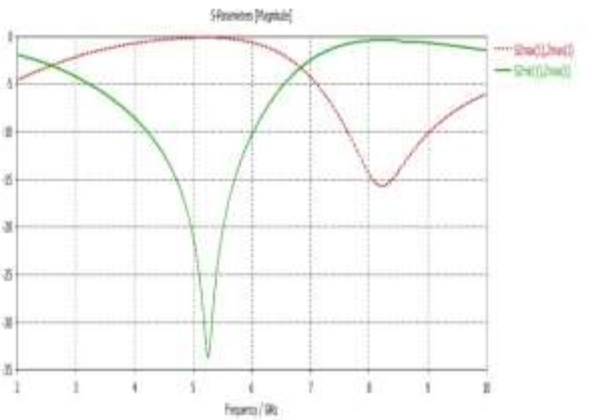

Fig. 2 Simulated scattering parameters of (S11) and (S12) of the proposed unit cell

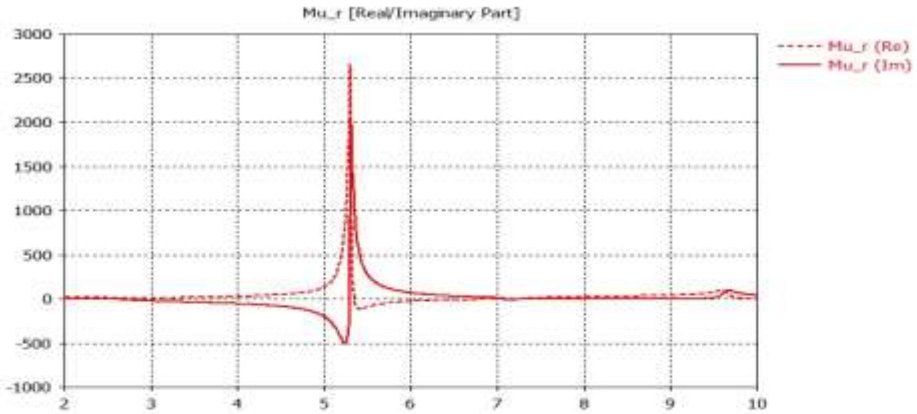

Fig .3 Effective extracted parameters permittivity and, permeability plot

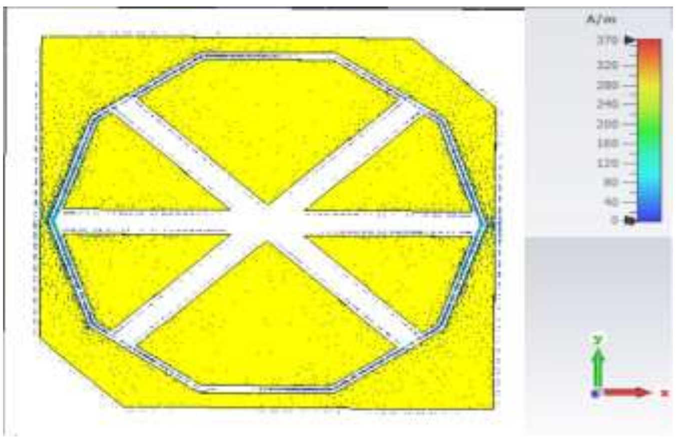

Fig. 4 Effective extracted parameters permittivity and, permeability plot

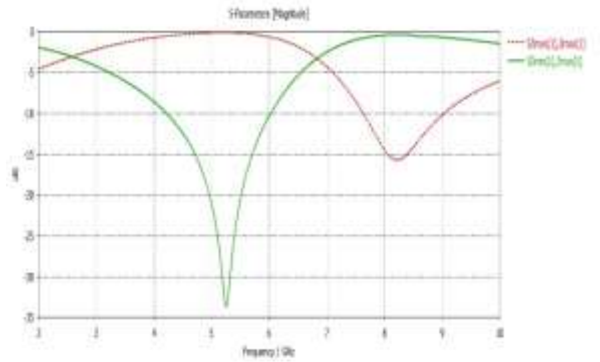

Fig. 5(a) reflection coefficient (S11) and transmission coefficient (S12) truncated proposed unit cell

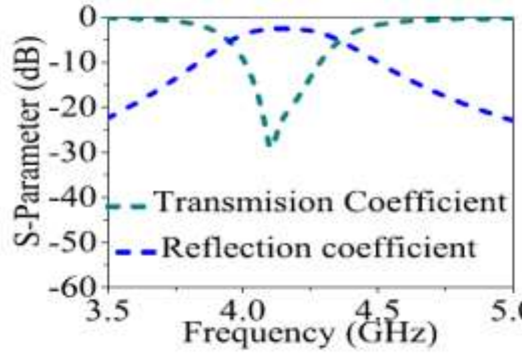

Fig. 5(b) (S11)and S(12) of modified unit cell.

The newly designed unit cell not only boasts a significantly broader frequency coverage, spanning from 7.5 GHz to 9.2 GHz, effectively encompassing essential segments of both the S-band and C-band spectra but also holds promise for enhancing MIMO antenna performance. In stark contrast, the previously modified unit cell offers a more limited operational range, extending merely from 4 to 4.4 GHz. This pronounced disparity underscores the substantial advancement achieved in frequency coverage with the proposed design, thereby enhancing its applicability across a diverse range of 5G applications.

IV. CONCLUSION

This paper presents, a compact size truncated patch circular ring unit cell metamaterial designed to cover a portion of the C band and S band frequencies while offering a wideband range from 7.5 to 9.2 GHz. unit cell measuring 13.8 x 13.8 mm², metamaterial demonstrates remarkable potential for improving Multiple Input Multiple Output (MIMO) performance. This innovative approach holds promise for enhancing data throughput, increasing spectral efficiency, and bolstering reliability in MIMO communication systems.

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