DESIGN OF NOVEL SSR BASED OCTAGONAL SHAPE RADIATOR FOR TERAHERTZ APPLICATION

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ABSTRACT

Antennas that possess a larger gain and efficient across a wider frequency range are more beneficial. Reaching these qualities at greater frequencies while preserving a compact size makes the design more complex. A novel square split ring (SSR) octagonal shaped radiator suitable for metamaterial structure is proposed. The Rogers substrate with dielectric constant of 2.2, 0.8mm thickness and 0.00009 loss tangent is used in the design. The size of the SSR is 2.0 by 2.0mm^2 and the total size of the unit cell is 2.4 by 2.4 mm^2. The electromagnetic characteristics of this antenna in terms of S11 and S12 are compared. The CST MICROWAVE STUDIO which is commercially available software (electromagnetic simulator) that operate on Finite-Difference Time-Domain (FDTD) method was used to simulate the unit cell. The antenna's performance is visualise from reflection coefficient (S11 and S12), permittivity and permeability. The simulation results shows that the unit cell have reflection coefficient between -10dB and -35dB at 190GHz to 300GHz, at 210 GHz and 255 GHz for x-direction and for y direction at 219 GHz and 290 GHz resonator creates an effective stop-band, also the designed radiator has a near zero permeability and permittivity. These results make it suitable for design of metamaterial antenna for Terahertz application.

Keywords: *Antenna, Terahertz, Metamaterials, Square Split Ring, CST, 6G.*

1. INTRODUCTION

Over the past several years, there has been a notable increase in the demand for wireless data traffic (Akyildiz *et al.,* 2022; Salahdine *et al.,* 2023) due to the rapid expansion of mobile devices and multimedia applications. Industry and academics have expressed a significant deal of interest in the potential use of the terahertz (THz) spectrum to meet these objectives (Ning *et al*., 2023; Chen *et al.,* 2022; Allanki *et al*., 2023). Against the millimeter-wave (mmWave) band, the THz band can offer more plentiful bandwidth (from 0.1 THz to 10 THz) and greater data rates (from micro-seconds (Akyildiz *et al*., 2022)).

Thus, the creation of high-performance systems, including antennas is the primary obstacle for wireless communications. Furthermore, it is challenging for conventional communication frequency bands to deliver anticipated future data speeds due to their overload and constraints. Higher frequency communication technologies, including millimeter wave (MMW) and THz band are therefore necessary (Hong *et al.,* 2021). It is thought that the THz band is a potential option for facilitating communications beyond 5G and 6G. Despite the THz band's many alluring benefits, creating a dependable communication connection at THz frequencies is a challenging undertaking. This is due to two factors: (i) the THz band has very high free-space losses and substantial atmospheric attenuation; and (ii) the line-of-sight (LoS) connection is very susceptible to blockage effects in the THz range, resulting in often intermittent communications. These drawbacks might seriously impair THz communication systems' service coverage and negatively impact their communication range. Another limiting factor is the transmitter and receiver, where antennas are essential components.

Antennas with wide input-impedance bandwidths and strong directivity are necessary to offset free space attenuation for communication in the MMW bands while maintaining good radiation efficiency and reliable radiation patterns.

For the improvement of the future communication systems, the International Telecommunication Union (ITU)-R approved frequency bands for the development of 6G at the World Radio Conference (WRC) 2023. Frequencies between 4.400 GHz and 14.8 GHz have been allocated for 6G mobile communication, while 102GHz to 278GHz have been earmarked for advanced use cases in 6G (Castro, 2023). Wireless devices and equipment for the next generation communication are expected to be tiny, operate at large bandwidth, and be highly reliable. The most critical component of these emerging wireless devices and equipment is the antenna device. Consequently, there is a need for the development of new antenna structures.

Antennas are essential components of wireless telephony systems. A variety of antenna types have been designed and studied for a range of uses. End customers are currently demanding smaller, lighter gadgets with improved performance, which is a current trend. They take up extremely little room in systems because of their tiny size. The need for compact antennas that can perform well in a variety of applications has grown dramatically in the last several years. L, S, C, and X band are used by applications including GSM, WiMAX, IMT-2000, Wireless Area Networks, and computer networks. Kurz-under (Ku) bands are used by cloud computing equipment, direct broadcast satellite services, and Multi-Protocol Label Switching (MPLS). Airport Surface Detection Equipment (ASDE) use Kurz (K) band radars as they provide high resolution and are suitable for short range communication.

Researchers are currently focusing on the W (75-110 GHz), D (110-170 GHz), and G (100-300 GHz) bands. The sub-THz mmWave band is the name given to the W and D bands. It is anticipated that antennas functioning at these elevated frequencies will be minuscule, focused, and adaptable (Rasilainen *et al.,* 2023). One of the main concerns is designing an antenna for such a high frequency. substrate-integrated waveguides have gotten attraction for application in manufacturing low cost and profile antennas. In the literature there are various techniques for expanding antenna bandwidth; researchers and academics frequently employ stub insertions, parasitic patch loading, slot etching, band gap designs, and inserting via ports. With increased data speeds and network capacity, the switch to Sub-6G mmWave frequencies signifies a paradigm change in wireless communication.

Recently, the drawbacks of antenna operating at higher frequencies have motivated researchers and designers to the development of metamaterial antennas in order to overcome these constraints and enhance antenna performance for a variety of applications (Dixit and Kumar, 2022). Actually, this is a type of antenna that uses specifically created metamaterials to outperform conventional antenna designs in terms of performance (Ahmed *et al.,* 2023). Metamaterials are artificial materials with distinct properties not present in naturally occurring materials, consisting of building blocks. The creation of a metamaterial unit cell varies based on desired properties. In designing metamaterial antenna, the following steps are to be follow:

• Identification of the desired properties of the final metamaterial. This might include characteristics like a high electromagnetic absorption rate, a negative refractive index, or acoustic insulation.

• Selection of unit cell geometry. This is a crucial stage since the final metamaterial's characteristics will be greatly influenced by the shape of the unit cell. Mushroom structures, split ring resonators, or fishnet structures are examples of such shape.

• Determination of material properties of the unit cell. The final metamaterial's characteristics will also be influenced by these attributes. The necessary qualities and the relevant frequency range will determine which materials are used.

• Design of the meta cell on CST MWS.

As it can be seen from above, designing a unit cell radiator is crucial when designing a metamaterial antenna for high performance application. The square split ring (SSR) resonator has been widely adopted for the design of 6G antennas. However, in this work, an SSR-octagonal shaped unit cell operating at the sub-THz band is proposed. Table 1 shows the comparism of related work with the proposed work

Table 1: Comparism of related works with proposed work

Autor(s)	Geometry	Substrate	Frequency	Bandwidth
(Appasani, 2022)	CHRR	indium antimonide	1 to 2 THz	1 THz
(Chen *et al.*, 2020)	Centrosymmetric nested SSR	silicon	0.1 to 1.9 THz	1 THz
(Orazbayev *et al.*, 2015)	closed ring resonators (CRR)	silicon	75 to 85 GHz	10 GHz
(EL Ghzaoui *et al.*, 2023)	SSR with hexagonal shaped structure.	Rogers	160 to 280 GHz	120 GHz
(Muqdad *et al.*, 2023)	Square framed rhombus ring shaped	FR4	0.2 to 2 GHz	1.8 GHz
Proposed work	SSR octagonal shaped radiator	Rogers	0.19 to 0.30 THz	210 GHz

2. Antenna geometry and configuration

Antenna performance is largely dependent on its design, with many formulas being used to compute the design parameters (Colaco and Lohani, 2020; Merlin and Umamaheswari, 2022). In this work, the unit cell structure is designed using an inexpensive Rogers substrate with a relative permittivity of 2.2, 0.08 mm of thickness, and copper cladding. The unit cell was simulated using the computer simulation tool (CST) Microwave software (MWS), which is available for purchase. The metamaterial (MTM) unit cell consists of SSR unit cell combined with octagonal shape structure with 0.2 mm slab operating at 190 GHz to 300 GHz (0.19 THZ - 0.30 THZ). The geometry of the proposed unit cell is shown in Figure 1, and Table 2 shows the unit cell parameters.

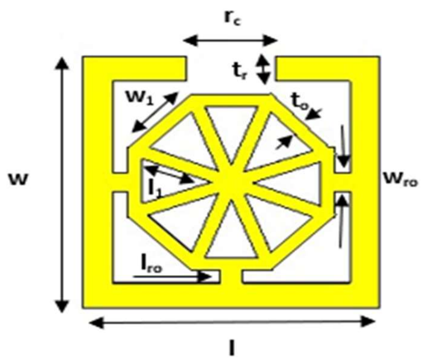

Figure 1. Geometry of the proposed unit cell

Table 2: Unit cell parameters

Parameter	(mm)	Description
l	2.0	Length of the patch
w	1.5	Width of the patch
t_s	0.08	Substrate thickness
t_p	0.03	Patch thickness
t_g	0.05	Ground thickness
r_c	0.1	Square ring cut
c_g	0.1	Circular ring cut
c_t	0.1	Thickness of circular ring
r	0.6	Radius of circular ring

A frequent example for the metamaterial structure is the Inductive-capacitive (LC) resonator, in which the metallic rings and stubs create the inductive effect, while the gaps and splits cause the capacitive effect. The configuration of metallic rings, stubs, and gaps often controls the metamaterial structure's resonance characteristics. The metamaterial structure with meander lines is positioned between two wave ports, one on the negative z-axis and one on the positive z-axis. Two simulation sets were used to validate the unit cell's operating principle. Figure 2 shows the simulation set ups for x and y direction. Figure 3 shows the evolution of the proposed meta cell.

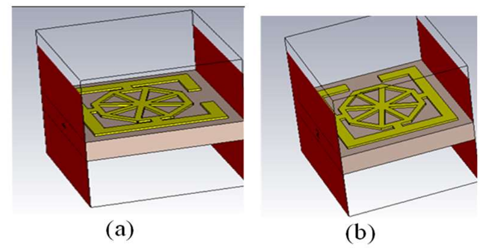

Figure 2: simulation set up (a) x direction, (b) y direction

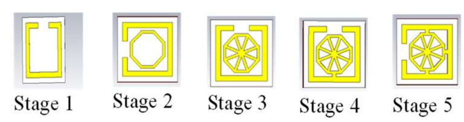

Figure 3: Evolution of proposed unit cell

Selecting the right unit cell for an antenna system typically requires performing simulations on several parameters such as S11 and S12, to carry out the performance of the meta cell. S11 is a plot that shows the reflection coefficient of the meta cell, and S12 metric that shows the power transferred from one meta cell port to another, is frequently used to assess how well the various meta cell components are coupled. In this work, CST MWS software was used to model the unit cell and display its performance regarding S11 parameters for both the x-direction and y-direction. The suitability of a unit cell for metamaterial is also determined by permeability and permittivity of the unit cell, the permittivity and permeability of the designed unit cell is shown using CST MWS software.

3. Simulation Results and discussion

CST MWS is used to model the meta cell in this work and its performance under different conditions is simulated. Figure 4 and 5 display the performance of the unit cell regarding S11 parameter for the x-direction and y-direction, respectively. The reflection coefficient, which is represented by (S11), is also known as return loss. Because return loss in an antenna is a ratio of incoming power to reflected power, an antenna's performance typically depends upon a good reflection coefficient of at least -10 dB or better than -15 dB. If the reflection coefficient is 0 dB, then the antenna has reflected all of the power, meaning no radiation has occurred. Also, it is noticed from the Figures 4 and 5 that the resonance shift towards the lower frequency band is indicated by the transmission coefficients. Conclusion can be drawn from the results in Figures 4 and 5 that the proposed unit cell is the most suitable meta cell for the metamaterial Antenna. S11 and S12 parameters were simulated and compared in order to established clear picture on the unit cell, this is done to determine the stop band of the meta cell. It can be seen from Figures 4 and 5 that at 210 GHz and 300 GHz for x-direction and for y direction at 219 GHz and 290 GHz the square split ring resonator creates an effective stop-band. These results make it suitable for metamaterial antenna. Stage 5 was chosen for both x and y because of its wider range over others.

Permittivity, permeability, and refractive index characteristics of the metamaterial structure are ascertained using the simulated reflection and transmission parameters of the unit cell displayed in Figures 6 and 7. In the suggested metamaterial construction, the frequency ranges of 190–300 and 195–288 GHz, for x- and y-direction, respectively,

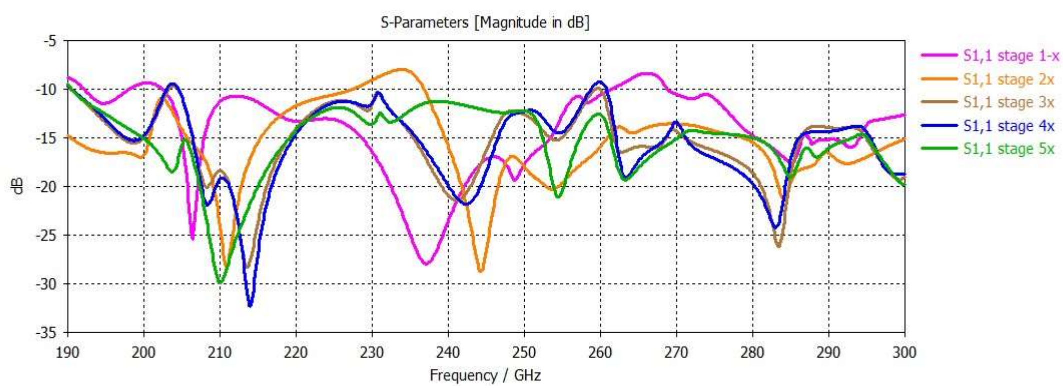

Figure 4. S11 parameter for the x-direction

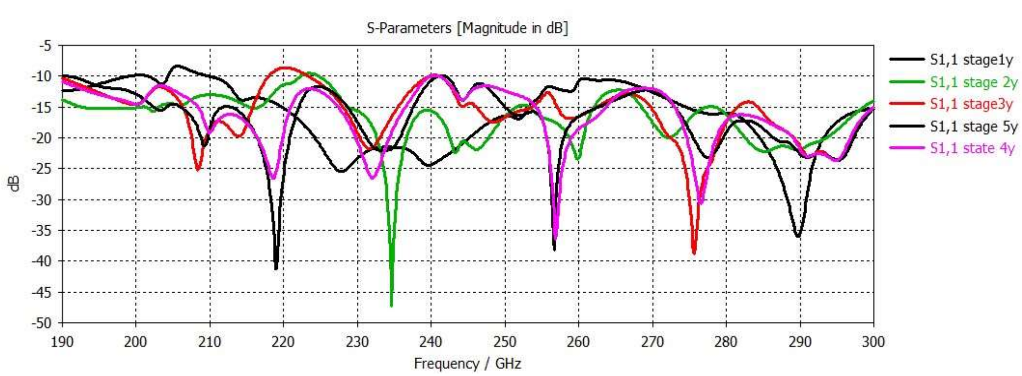

Figure 5. S11 parameter for the y-direction

exhibit Near Zero Rifractive index and Episilon Negative (NZR-ENG) metamaterial characteristics. The metamaterial exhibits near zero refractive index and negative permeability within these frequency ranges. When light enters a conventional material, its propagation through the refractive index of the suggested unit cell, as shown in Figure. 6 and 7, is almost zero, indicating that it performs well and may be utilized to create a high-performance radiator for wireless systems. Furthermore, the negative permeability achieved in

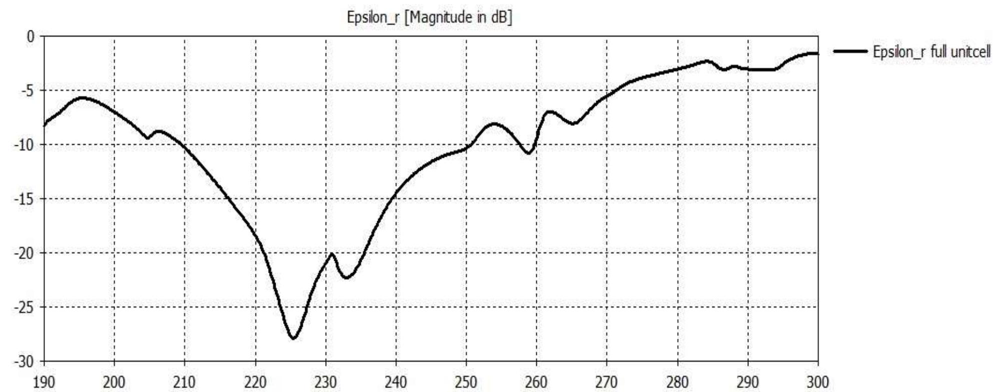

Figure 6. Permittivity of the unit cell

Figure 7. Permeability of the unit cell

material is determined by its refractive index; a positive index means that light bends toward the normal. Nevertheless, it is possible to build a metamaterial structure so that the refractive index is negative, causing light to bend away from the normal when it enters the material. This may result in some unusual optical characteristics including cloaking, superlensing, and negative refraction. For these characteristics to manifest, a metamaterial cell must have a near-zero refractive index (NZRI). The this study is required for metamaterial radiators to function better and have better radiative qualities.

In traditional antennas, the materials and geometry utilized in their construction define their radiative qualities. On the other hand, the metamaterial's effective permeability and permittivity govern the radiative characteristics of a metamaterial antenna. Furthermore, the necessary negative permittivity response may be obtained by carefully planning the configuration and placement of these radiating element within the metamaterial cell. This makes it possible to produce the special optical qualities of metamaterials, such as cloaking and negative refraction.

4. Conclusion

A unit cell suitable for metamaterial structure was designed and analyzed in this work using CST 2019. Simulation results shows that the SSR resonator creates an effective stop-band at the 210 GHz and 300 GHz for x-direction while for y direction it creates an effective stop band at 219 GHz and 290 GHz, and exhibits NZRI. These results make it suitable for metamaterial antenna. By introducing subwavelength resonant structures, such as split-ring resonators, we create an artificial electromagnetic medium with negative refractive index (negative permeability and negative permittivity), also known as a metamaterial.
These subwavelength resonant structures are made to have resonance frequencies that coincide with the frequency of the incident radiation, and they are usually considerably smaller than the wavelength of the electromagnetic radiation they interact with. Researchers are interested in metamaterials because of their negative refractive index, which has several intriguing and practical features. They may be utilized to make incredibly small and effective antennas. This is due to the fact that the antenna may be made far smaller than conventional antennas by using the negative permeability to produce a refractive index that is almost zero.
Overall, the study of negative permeability antennas is an intriguing discipline that might completely transform the electromagnetics community. Numerous applications, such as cloaking devices, radar systems, and wireless communication systems, have previously made use of them. This type of antenna was suggested in this paper for sub-THz frequencies in 6G applications.

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