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Mitigating Mutual Coupling in Metamaterial Antenna with Circular Complimentary Ring Resonators via Giza Pyramids Construction Algorithm (GPCA)

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ABSTRACT

Metamaterial element simulation is a common use for Complementary Split Ring Resonators (CSRR). These components act as synthetic materials with peculiar characteristics and are uniformly organized in a periodic arrangement. It must be positioned transversally in the waveguide for the CSRR to interact with the electromagnetic fields in a proper manner. Here, the CSRR structure, which is positioned longitudinally in the waveguide, is the dual of the SRR. This paper proposes a Circular Complementary Split Ring Resonator (CSRR) to lessen mutual coupling between two closely spaced planar inverted antennas. Between the two pieces is a CSRR structure. A mutual coupling decrease of almost 6 dB was attained at the resonant frequency after the design model was examined and refined using the commercial software program HFSS 15.0. It is demonstrated that the process significantly affects the antenna's efficiency and performance, particularly its bandwidth, which is expanded for X-band. Additionally, the structure has reduced mutual coupling and low loss. The findings demonstrate that at the array's operating frequency, a decrease in mutual coupling between elements is achieved. The agreement between simulation findings and experimental data is fairly excellent. The development of this suggested complementary split ring resonator metamaterial antenna by enhancing its efficiency, reliability, and range is the ultimate objective of the Giza Pyramids Construction Algorithm (GPCA).

Keywords: Mutual Coupling Reduction, Metamaterial Structure, Circular Complementary Split Ring

Resonator, X-Band, Giza Pyramids Construction Algorithm

I. INTRODUCTION

Mutual coupling between array elements influences the element input impedance as well as the embedded element radiation pattern. The embedded element pattern is different from the isolated element pattern because radiation from one driven element causes currents to flow through nearby elements. Additionally, a nonzero voltage is induced at the terminals of additional components by the driven element. The antenna is extremely tiny in millimeter microstrip antennas. Because surface waves propagate over a distance of l/2 between two antennas, mutual coupling is essential. Additionally, it has been noted that a minor increase in bandwidth results from a rise in mutual coupling caused by both substrate thickness and permittivity. Therefore, it is crucial to use novel strategies to decrease mutual coupling in the situation of high permittivity.

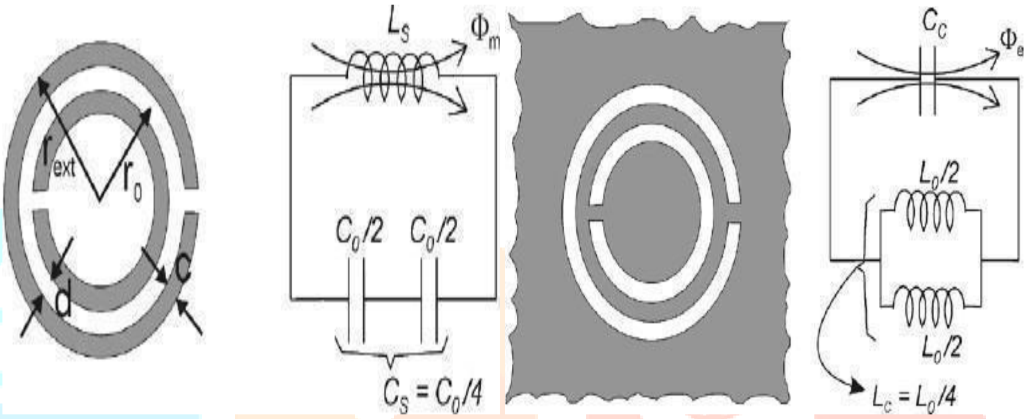

Figure.1: Complementary split-ring resonator (CSRR) Structures

When the electric field from one patch causes current to flow through the second patch, this is known as mutual coupling. There is more coupling between two patches the closer they are to one another. Since mutual coupling influences the array's input impedance, the patches should be aligned to reduce it in order to create the optimal array. To lessen the mutual coupling between two coplanar microstrip antennas, a novel structure based on Complimentary Split-Ring Resonators (CSRRs) is presented. It is possible for Complimentary Split Ring Resonators (CSRR) to achieve a high impedance surface. Harmonic rejection and filtering were achieved through the employment of complementary split-ring resonator (CSRR) structures. The duality principle applied to the magnetically resonant SRR structures provides the greatest understanding of the electromagnetic behavior of the CSRR. CSRR are complementary SRRs in which the substrate takes the place of the metallic layer and vice versa. They demonstrate a dual circuit property to one another. Figure 1 depicts complementary split ring resonator structures.

II GIZA PYRAMIDS CONSTRUCTION ALGORITHM (GPCA)

Many of the optimization issues we face today cannot be resolved in a reasonable amount of time or with precise methodologies. The application of metaheuristic algorithms is one method for resolving such issues. It now presents a novel population-based metaheuristic algorithm that draws inspiration from a fresh source. Inspired by the ancient past, this algorithm, known as the Construction of Pyramids of Giza (GPC), possesses the qualities of a good metaheuristic algorithm for a variety of issues. Observing and reflecting on the legacy of the ancient past in order to comprehend the best practices, strategies, and tactics of that time period is what inspired antiquity. The movement of laborers and the pushing of stone blocks on a ramp power the Construction of the Pyramids of Giza (GPC) algorithm. The introduction of a new ideology and inspiration comes from the ancient past. Numerous man-made structures demonstrate how the constraints and lack of hardware and software capabilities in the past led to some optimization, despite the fact that there were numerous limitations in the past. Three enormous pyramids that were constructed during the Fourth Dynasty of ancient Egypt are located within the Giza Pyramid Complex, sometimes referred to as the Giza Necropolis. The Pyramid of Khufu is the biggest pyramid and one of the Seven Wonders. Menkaure and Khafre are the names of the other two pyramids. Archaeologists claim that because the pyramids' construction changed over time, the methods used are different. The most crucial factor in the pyramids' construction was the workers' management. Its construction was optimized because of the scarcity of equipment, the comparatively short construction period, and the huge quantity of stone blocks utilized in the pyramids.

III PROPOSED CCSRR METAMATERIAL ANTENNA DESIGN

Circular Complimentary Ring Resonator design was taken into consideration in order to examine the reflection/transmission coefficient: radiation patterns, electric fields, directivity, and peak gain. It describes how the top and bottom sides seem in three dimensions. Every measurement was taken into account in millimeters. The design's overall measurements were. For the excitation, the lumped port was applied to the structure. The ground and patch layers were 0.35 mm thick. The height of the substrate was 1.5 mm. Rogers Substrate was selected as the substrate material due to its low cost and ease of fabrication. The dielectric constant of the Rogers Substrate is 3.55.

The structure of a circular complementary ring resonator is made to resonate at particular frequencies. It can prevent mutual coupling and change the way electromagnetic waves propagate by positioned strategically between antenna elements of an array. The Circular Complimentary Ring Resonator (CCSRR) metamaterial structure efficiently increases the isolation between antennas by decreasing mutual coupling between neighboring antennas. Because less signal energy is wasted to interference and reflections, this improves antenna performance in terms of return loss. The suggested circular complementary ring resonator metamaterial antenna is shown in Fig. 2 and was created with HFSS.

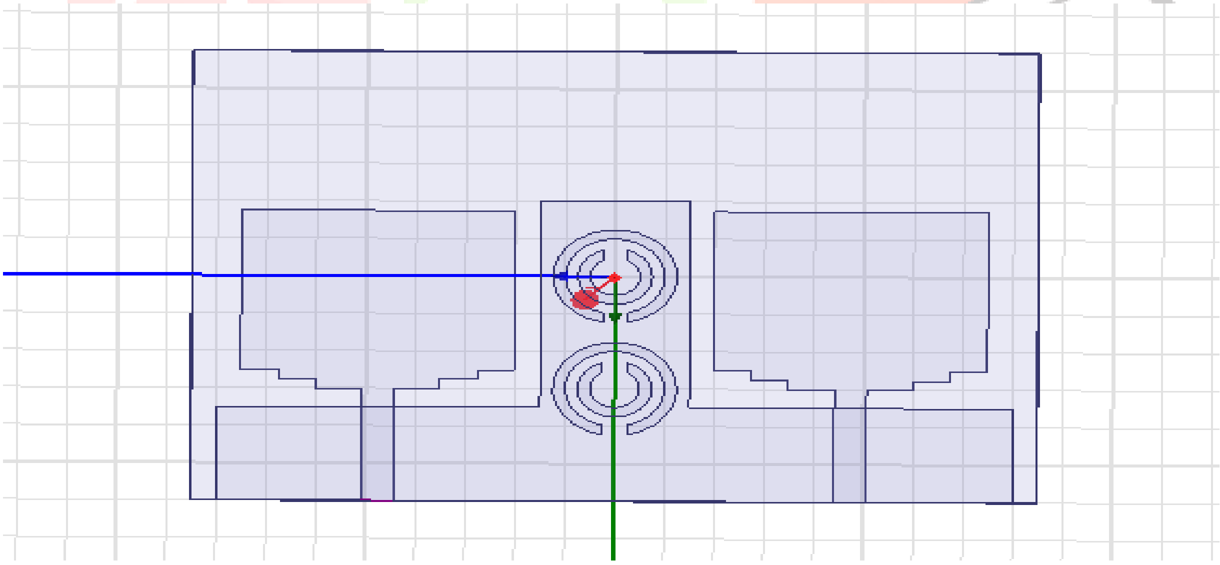

Figure.2: Proposed Circular Complimentary Split Ring Resonator Metamaterial Antenna

IV SIMULATION RESULTS

a) S11

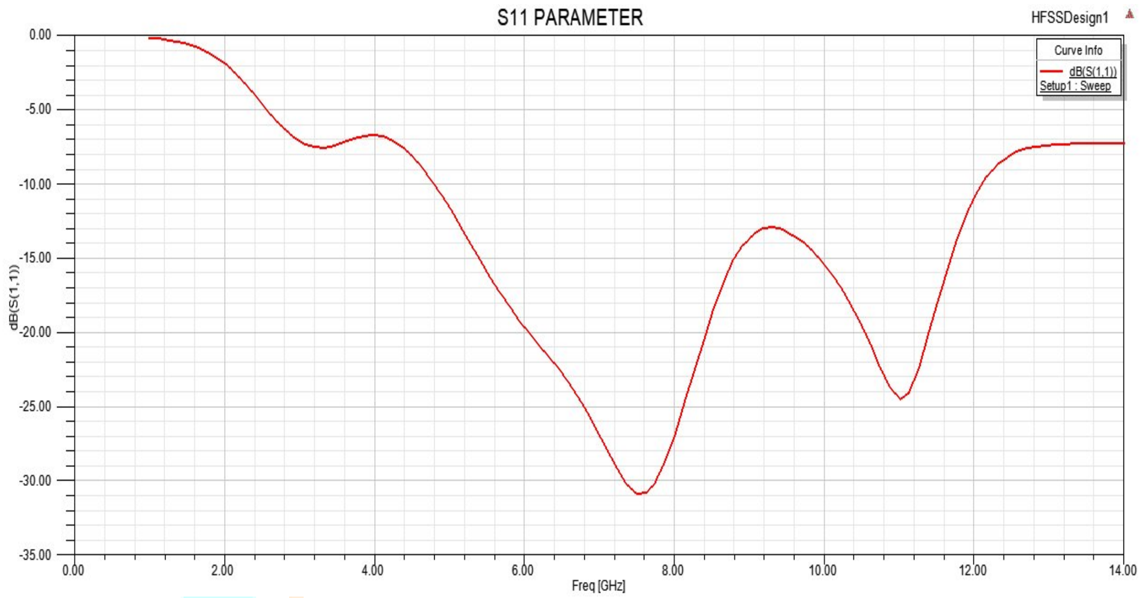

Figure.3: S11 of Proposed Circular Complimentary Split Ring Resonator Metamaterial Antenna

Figure 3 displays the return loss of the circular complementary split ring resonator metamaterial antenna on top in HFSS.Two notable resonant frequencies with return losses of **-30 dB and -22 dB** respectively, are visible at roughly 7.7 GHz and 11.2 GHz in the simulated return loss (S11) figure. 4.4 GHz is the total effective bandwidth of the antenna's two operational bands, which are 5.8–8.3 GHz and 10.3–12.2 GHz, where the S11 is below -10 dB. Radar and satellite communications are two examples of dual-band or wideband X-band applications that can benefit from these features.

b) S12

S12 of Circular Complimentary Split Ring Resonator Metamaterial Antenna on top in HFSS is shown in figure 4. In the working X-band, the proposed antenna shows low mutual coupling, with S12 values between 8 GHz and 12 GHz being less than -15 dB. Near 6.3 GHz, the lowest coupling reaches about **-27 dB**. This suggests superior port isolation, which qualifies the design for MIMO systems and densely packed antenna arrays.

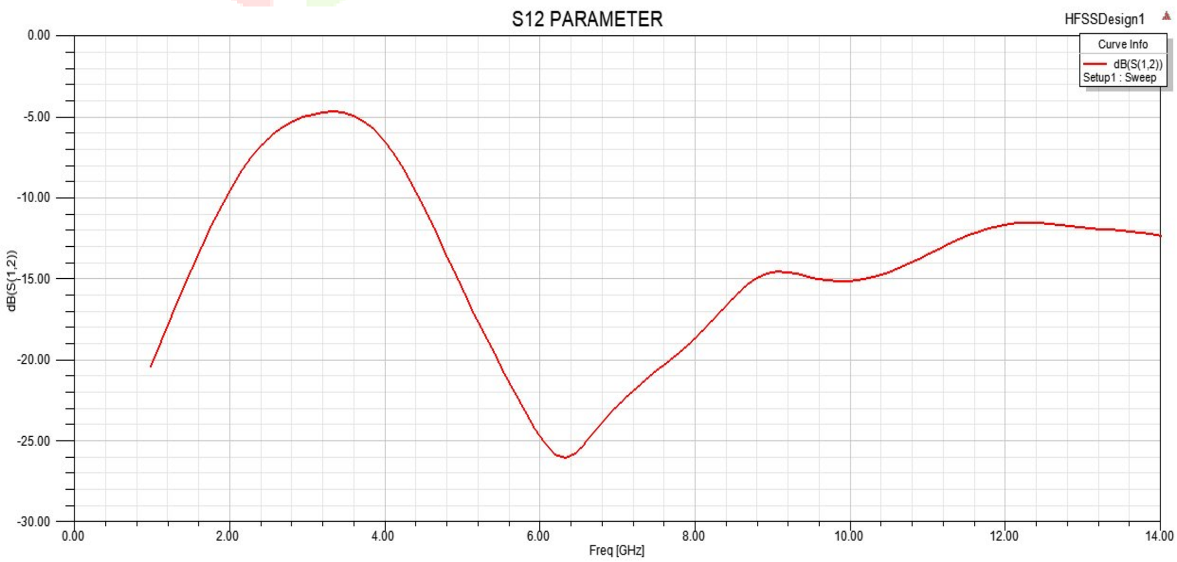

Figure.4: S12 of Proposed Circular Complimentary Split Ring Resonator Metamaterial Antenna

c) Frequency vs Gain

Antenna gain, which is commonly measured in decibels relative to isotropic (dBi), quantifies an antenna's capacity to focus and transmit or receive radio waves in a particular direction in comparison to a theoretical isotropic antenna (which radiates equally in all directions). The power transmitted per unit solid angle is the only definition of gain. The gain peaks at **6.46 dB** at 10 GHz after progressively increasing from about -1.5 dB at 6 GHz. One of the key resonant bands seen in the S11 figure is aligned with the antenna's comparatively high and steady gain throughout the 9–11 GHz range. This behavior shows that throughout the X-band frequency range, the antenna has efficient radiation characteristics in addition to good impedance matching.Frequency vs Gain Plot of Circular Complimentary Split Ring Resonator Metamaterial Antenna on top in HFSS is shown in figure.7.

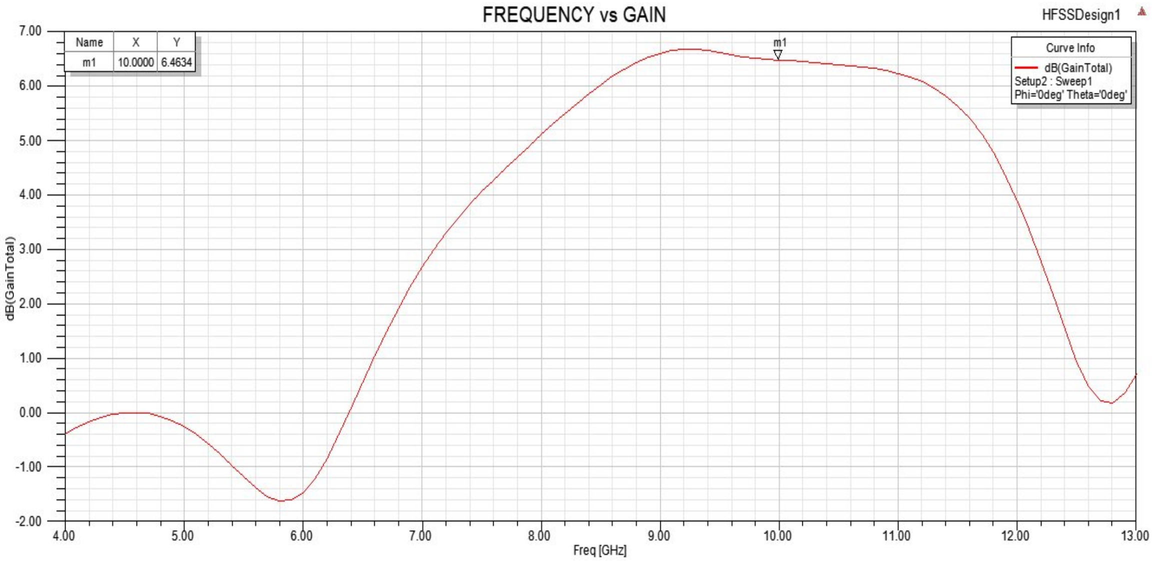

Figure.5: Freq vs Gain of Proposed Circular Complimentary Split Ring Resonator Metamaterial Antenna

d) Directivity

The ability of an antenna to concentrate its radiation in a particular direction is known as directivity. Regardless of distance from the antenna, it is a unit-less value. Directivity of Circular Complimentary Split Ring Resonator Metamaterial Antennaon top in HFSS is shown in figure 6. The antenna shows extremely directed radiation, with a peak directivity of about **6.6 dBi** close to 10 GHz. The antenna's remarkable efficiency of about 98% is confirmed by the directivity curve's tight alignment with the gain profile. This confirms that the design works well for X-band applications, especially those where low loss and good directivity are essential.

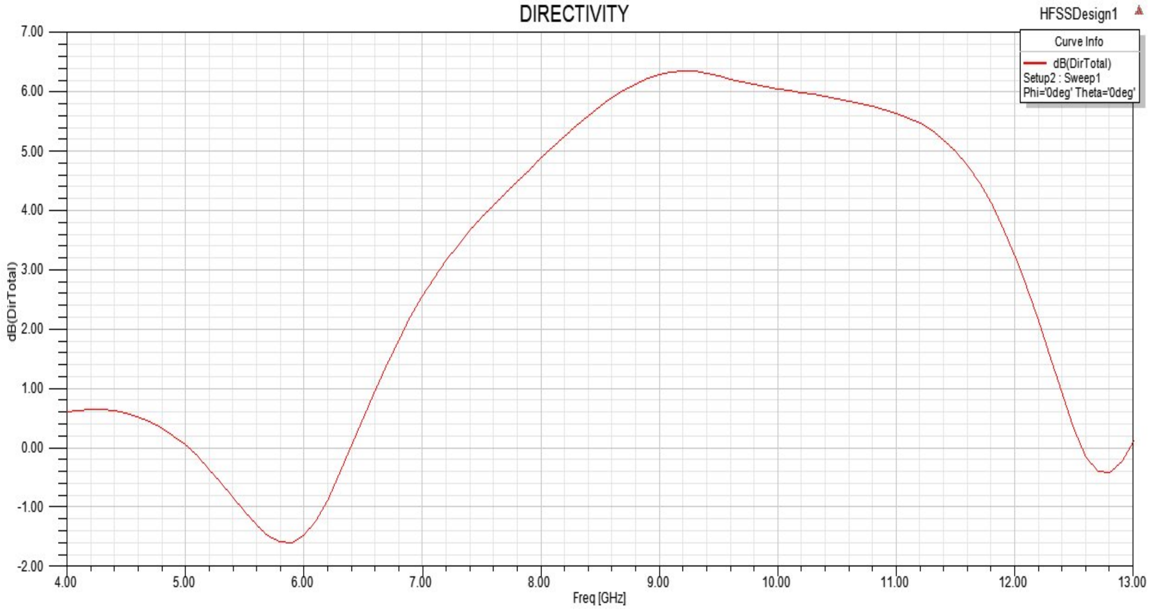

Figure.6: Directivity of Proposed Circular Complimentary Split Ring Resonator Metamaterial Antenna

e) Radiation Pattern

The change in power emitted by an antenna as a function of distance from the antenna is known as the radiation pattern. The far field of the antenna shows this power variation as a function of arrival angle. The Radiation Pattern of Circular Complimentary Split Ring Resonator Metamaterial Antennaon top in HFSS is shown in figure 7.

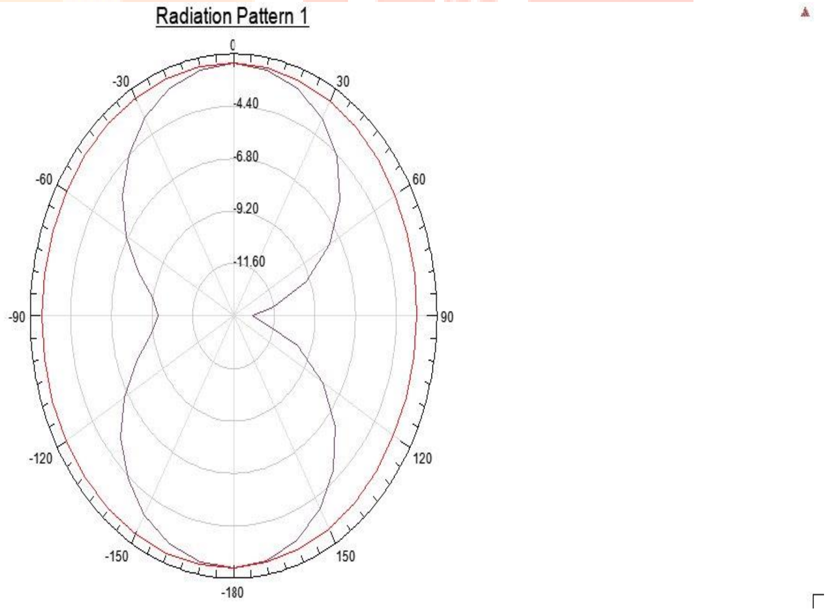

Figure.7: Radiation Pattern of Proposed Circular Complimentary Split Ring Resonator Metamaterial Antenna

V SUMMARY

Parameter	Value / Observation	Remarks
Operating Band	6.8 GHz to 11.8 GHz (from S11 plot)	Covers major portion of X-band (8–12 GHz)
Bandwidth	5 GHz	Wide bandwidth; suitable for wideband X-band communication
S11 (Return Loss)	Min: ~ -32 dB @ 7.8 GHz	Excellent impedance matching; < -10 dB throughout the band
S12 (Isolation)	Min: ~ -26 dB @ 6.3 GHz	Good isolation between ports (for MIMO or array configurations)
Peak Gain	6.46 dB @ 10 GHz	High gain; suitable for directional applications
Peak Directivity	~6.3 dB @ 9–10 GHz (from Directivity plot)	Matches with gain, indicating good radiation efficiency
Radiation Pattern	Radiation Pattern 2 is better – More directive, lower side lobes	Suitable for focused beam, point-to-point X-band communication
Beam Shape	Directive main lobe with suppressed side/back lobes	Indicates good antenna performance
Application Suitability	X-band (8–12 GHz) radar, satellite, or wireless communication systems	Based on gain, bandwidth, and directivity

Table 1: Summary of Proposed Circular Complimentary Split Ring Resonator Metamaterial Antenna

VI CONCLUSION

This Paper finally proposes a rectangular microstrip patch antenna array for X-band applications using complementary split ring resonator (CSRR) components. To drastically lower mutual coupling, the CSRR structures are thoughtfully incorporated in between the densely populated rectangular patches. The design provides a significant improvement in performance metrics in addition to having good resonance in the X-band frequency region. At 10 GHz, directivity is 6.32 dB and gain rises to 6.46 dB due to optimized antenna size and CSRR arrangement. Minimal mutual coupling is shown by the successful suppression of the return loss (S12 parameter) below -25 dB. Directional properties are highly efficiently confirmed by radiation patterns. The suggested architecture is therefore ideal for X-band wireless communication systems since the addition of CSRR between patch parts offers a dependable and efficient way to improve isolation and gain.

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