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Dual Band CSRR Loaded Crescent Slotted Circular Patch MIMO Antenna

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The analysis of the 4 element MIMO configuration of a dual band CSRR loaded crescent slotted circular patch antenna is presented in this paper. The primary radiator of the proposed antenna is the logo of the author's institute. The design of primary radiator follows a fixed geometry, which includes the crescent slot, star shaped slots and a spline split. The undefined structures in the logo are the main challenge to obtain the desired resonance frequency. The CSRR etched at the ground plane of the antenna helps to attain the desired resonance at 2.15 GHz and 2.4 GHz. The 4 element MIMO configuration is proposed to serve the high data rate applications. When four similar antenna elements are placed on the single substrate, the CSRR provides high isolation too. To design the compact MIMO, the distance between the antenna elements is kept as minimum. Hence the distance between the antenna elements is maintained as $\lambda/4$ to mitigate the effects of multipath propagation as well as to minimize the interferences between the antenna elements. The complete antenna is designed on the FR4 substrate ($\varepsilon_r = 4.4$). The simulations are carried out using Ansys HFSS 2023 R_2. The prototype of the designed antenna is developed and tested. The measured return loss is well below the 10 dB and the gain is 6.28 dB at 2.4 GHz resonance. The MIMO analysis of the antenna shows high isolation between the elements (< – 13 dB), low envelope correlation co-efficient (0.00008) and high directive gain (> 9.995). The obtained results ensured that the proposed antenna is well suited for Wi-Fi, bluetooth and Zigbee applications.

Keywords: Antenna, CSRR. MIMO, Diversity gain, Logo antenna, Miniaturization.

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1. INTRODUCTION

In today's scenario, high data-rate communications are preferred. MIMO (multiple inputs and multiple outputs) is one of the methods to achieve high data rates [1]. The challenge in the design of the MIMO antenna is achieving isolation between the antenna elements. To accomplish the high isolation between the antenna elements, protruding ground structures [2], decoupling structures [3-4], orthogonal polarization [5] and defected ground structures [6] can be employed in MIMO antenna. Reception of multiple channels without destructive interference is one of the major challenges in receiver design. This can be facilitated by multiband antennas [7]. In today's era of communication, high speed wireless applications are high in-demand. Most of the corporates present their logo within the buildings or their surroundings. When the displayed logo acts as the access point or node of their dedicated wireless network, it serves the dual purpose of branding as well as data transfer.

The objective of the authors is to design a multiband MIMO antenna for a predefined shape such as logo, emblem, etc. The proposed antenna element replicates the logo of the author's institution [8]. The challenge in the design of the logo antenna is the fixed dimensions of the patch. The patch or slots cannot be tuned for the desired resonance. This is achieved by employing CSRR at the ground plane of the proposed antenna. The dual resonance is also induced by CSRR in the ground plane and the 4 element MIMO of the dual band crescent slotted circular patch antenna (CSCPA) is designed and the parameters [9] of the MIMO antenna are also presented.

2. DESIGN OF DUAL BAND CRESCENT SLOTTED CIRCULAR PATCH ANTENNA (CSCPA)

The complementary split ring resonator (CSRR) loaded crescent slot circular antenna is presented in [8]. The proposed antenna has a gain of 2.38 dB and resonates at 2.4 GHz. The antenna is made to fit a predetermined shape that includes a circle-splined spline split, a small slot in the shape of a star, and a crescent slot. The CSRR is etched into the antenna's ground surface to obtain the resonance at 2.4 GHz and the many resonances caused by various slots are removed. The miniaturization is accomplished by the CSRR by moving the resonance from 2.59 GHz to 2.4 GHz.

Dual band resonance can be obtained by adding slots or parasitic elements to the radiator. But the structural changes of the antenna are restricted, since the antenna duplicates the logo. An additional CSRR is etched on the ground plane of the antenna to introduce the dual band behavior as well as to provide miniaturization. The top view and bottom view of the proposed antenna is shown in Fig. 1.

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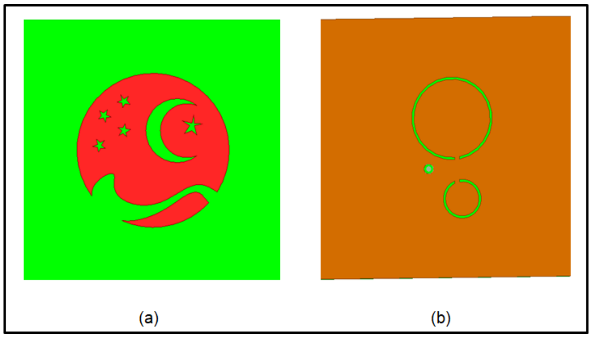


Fig. 1 – Dual band antenna (a) Top View (b) Bottom view

The placement of CSRRs is optimized to get the perfect impedance matching at the desired resonance frequency. The dimensions of the two CSRRs are different. Hence, they act as different resonators. The parallel combination of the three resonators including CSCPA results the dual resonance at 2.15 GHz and 2.4 GHz.

Table 1 – Dimensions of the proposed antenna

Parameters	Dimension (mm)
Length of the ground plane (L)	88.2
Width of the ground plane (W)	88.2
Thickness of the substrate (t)	1.6
Radius of the patch (r)	15.5
Width of crescent slot (S_w)	2
Width of CSRR gap (g)	1
Radius of Outer circle in CSRR (R)	5.1
Thickness of CSRR	0.6
Thickness of Cu foil	0.02

3. MIMO ANTENNA DESIGN

MIMO antenna can be designed using multiple, similar or different antenna elements. Mostly similar antennas are spaced g/4 apart. The distance between the elements is maintained at g/4, to receive all multipath components. Even though large distance between the antenna elements provides better isolation, the size of the antenna will increase.

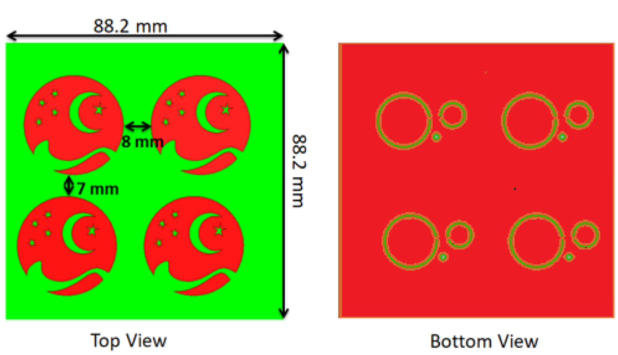


Fig. 2 – Proposed MIMO Antenna

Fig. 2 shows the proposed MIMO antenna. The antenna described in the section 2 is used as main radiating element. To combat the multipath fading, the spacing between the antenna elements should be in the order of g/4. Lesser distance between the antenna elements causes the reactive coupling between them and results poor isolation. Hence, the distance between the antenna elements is an important factor in MIMO antenna.

4. ANTENNA PROTOTYPE

The prototype of the MIMO antenna is shown in Fig. 3. The antenna is fabricated on the low cost FR4 substrate. The loss tangent of the substrate is 0.02 and the relative permittivity is 4.4. The overall dimension of the MIMO antenna is 88.2 × 88.2 × 1.6 mm^3.

The feed of the antenna is connected through the SMA connectors. The edge mount type SMA connectors are used in this prototype to avoid the metal contact with the CSRR. The ground pins of the SMA connector are shortened and placed as such it avoids the capacitive effect with the CSRR.

a b

Fig. 3 – Prototype (a) Top View (b) Bottom View

The capacitive effect near the feed may imbalance the impedance of the port and shifts the resonance frequency. So the care is taken to solder the SMA connectors with the feed point.

5. RESULTS AND DISCUSSION

Return Loss and Radiation pattern are the two important parameters to verify the resonant characteristics of the antenna. The simulated and measured return loss of single antenna element and MIMO antenna as well as the radiation pattern at both frequencies are presented and discussed in this section.

5.1 Return loss

The impedance matching at the resonance frequency is clearly depicted by the 'Return loss' curve of the antenna.

In MIMO antenna, all the elements share the common ground, which may create the impedance mismatch and shifts the resonance. The return loss of the MIMO antenna is measured using Agilent VNA N9925A in the Microwave laboratory. The simulated and measured results are well agreed. Fig. 4 shows the simulated and measured return loss of the proposed

MIMO antenna. Due to the cable and connector loss, a minimum deviation from the simulation results is present in the measured values.

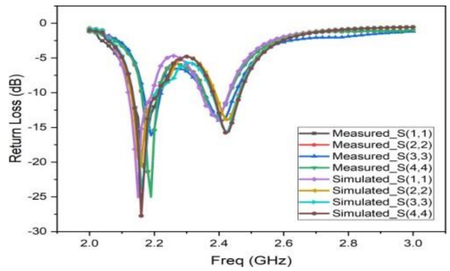
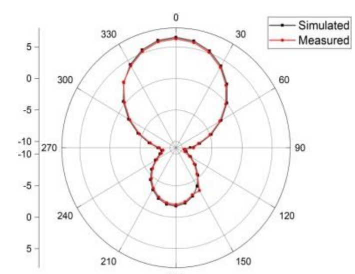


Fig. 4 – Simulated and Measured Return loss of all Ports

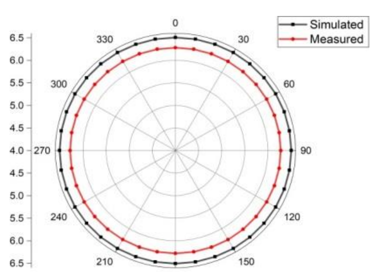
5.2 Radiation Pattern

The radiation pattern is presented for both the elevation and azimuth plane. In H plane, the monopole acts as an isotropic radiator and the constant gain is obtained in both the frequency. The radiation pattern is measured in a sealed anechoic chamber at VIT University, Chennai. The receiver side is where the MIMO antenna is installed, and the radiation pattern is measured. The transmitter is the conventional Horn antenna. The obtained S_{21} readings and peak gain are used to calculate the radiation pattern.

The gain of the proposed antenna is calculated using the Friis's Communication formula. Fig. 5 shows the measured and simulated results of the antenna gain. The small deviation obtained in the measured value of gain is within the permissible range. This deviation may occur due to the reflections from the cables in the receiver side. The measured peak gain at 2.4 GHz is 6.28 dB.



a



b

Fig. 5 – Simulated & Measured RP (a) E plane (b) H Plane

6. ANALYSIS OF MIMO ANTENNA

The return loss and the radiation pattern are the important performance metrics of any antenna. For MIMO antenna, the following additional measures are also analyzed to evaluate the performance.

6.1 Isolation

When the number of antenna elements is increased, the space between the elements is reduced, that induces mutual coupling. Hence, the main challenge of the MIMO antenna is to achieve a compact MIMO system with a high degree of isolation. Defective ground structures, neutralization line and isolators are used to increase the isolation. In the proposed work, no specific structures are employed for isolation. The CSCPA has two CSRRs on its ground plane. These CSRRs act as a defective ground structure and reduces the mutual coupling between them. Thus the proposed antenna acts as a self-isolating MIMO antenna. Fig. 6 shows the Isolation between the antenna elements in the proposed MIMO.

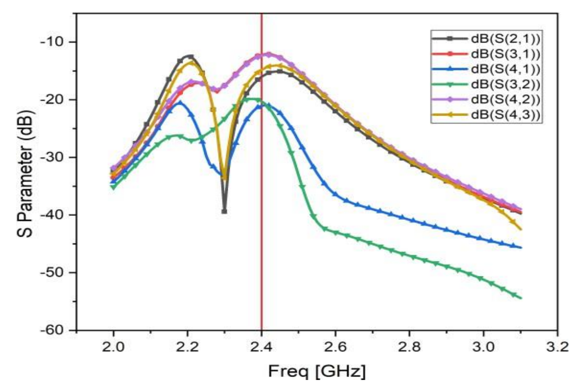


Fig. 6 – Isolation Vs Frequency

6.2 Envelope Correlation Co-efficient (ECC)

Envelope correlation coefficient is a measure of the correlation between the radiation patterns of the two antennas. If there is no correlation, the ECC is zero. In MIMO antenna, the radiation pattern correlation should be less to receive or transmit the EM waves in all direction. The correlation between the radiation patterns may cause interference, when the antenna elements are used for different purpose. Even though ECC is a measure related to the radiation pattern, it can also be obtained from the scattering parameters 10.

$$\rho_e(i,j,N) = \frac{\left|\sum_{n=1}^{N} S_{i,n}^{*} S_{n,j}\right|^2}{\prod_{k=(i,j)}\left|1 - \sum_{n=1}^{N} S_{i,n}^{*} S_{n,k}\right|} \quad (1)$$

The obtained ECC is 0.00008 for the proposed MIMO antenna. It is well below the threshold 0.02, in the desired resonance band. The graphical representation of ECC and DG is shown in Fig-7.

6.3 Diversity Gain (DG)

Diversity Gain (DG) is defined as the gain obtained, when the diversity schemes are applied. Multiple antennas offer a spatial diversity. With respect to the diversity, the expected power gain is represented in terms of DG. High DG increases the SIR. (Signal to Interference Ratio). DG is expressed as the relative measurement, results from isolation between the antennas. If the isolation between the antennas is high, the radiation patterns are diversified and the diversity gain is also high. This can also be achieved from employing the diversity schemes in the receiver.

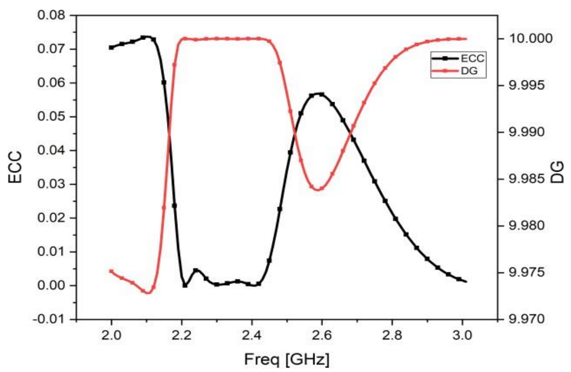


Fig. 7 – Envelope Correlation Coefficient & Diversity Gain of the proposed MIMO antenna

DG is also known as the reverse parameter of the ECC. When the ECC is low DG is comparatively high and vice versa. The theoretical limit of DG should be above 9.5. The formula to calculate DG is,

$$DG = 10\sqrt{(1 - ECC^2}\qquad (2)$$

Since the proposed MIMO has very good isolation between the ports, the ECC and DG are obtained above the theoretical limit.

7. COMPARATIVE ANALYSIS

The performance measures of the proposed antenna are compared with the results of recent literature and presented in Table 2. Mostly, the MIMO antennas are designed using the microstrip line feed. The microstrip line feed gives the flexibility in the design, such that the radiators can be placed orthogonal to each other and improves isolation between them. The proposed antenna is fed with co-axial probe where the feed of all radiators lie in the same plane with same pattern. Hence the isolation is achieved due to the CSRRs placed at the ground plane.

Table 2 – Comparative analysis of existing antenna with the proposed antenna

Ref	Antenna Size (mm x mm x mm)	No.of ports	Operating Frequency	Gain (dBi)	Isolation (dB)	ECC	Substrate
[11]	60 x 60 x 0.79	4	2.4 5.2 8.1	4.25 5 5.5	30	0.0001	Rogers 5880
[12]	120 x 50 x 1.8	2	2.4 5	6.7	15	< 0.12	FR4
[13]	45.5 x 45.5 x 1.96	4	2.4	2.84	58	0.0054	FR4
Proposed work	88.2 x 88.2 x 1.6	4	2.15 2.4	6.28	13	0.00008	FR4

In [11] the spacing between antenna elements are 20 mm, which is greater than g/4. PEC and PMC structures are employed in [12] to increase the gain and EBG improves the isolation. The proposed antenna has comparative dimension with minimum distance between all the radiators. There is no isolation structures employed and offers high gain with loss substrate.

8. CONCLUSION

MIMO antenna is preferred for the high data rate applications and multipath transmission. The logo antenna which is designed for 2.4GHz resonance will be suitable for MIMO antenna, due to the presence of CSRR on the ground plane. The CSRR can diversify the current distribution in the ground plane and reduce the effects of mutual coupling. The anaysis of MIMO parameters proved the suitability of the proposed antenna in MIMO configuration.

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Двохдіапазонна CSRR навантажена півмісяцева прорізна кругла патч-антена типу MIMO

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У цьому документі представлено аналіз 4-елементної конфігурації MIMO дводіапазонної CSRR-навантаженої круглої щілинної антени з півмісяцем. Основним випромінювачем пропонованої антени є логотип інституту автора. Конструкція первинного радіатора відповідає фіксованій геометрії, яка включає півмісяць, щілини у формі зірки та шлицевий розріз. Невизначені структури в логотипі є основною проблемою для отримання бажаної резонансної частоти. CSRR, вигравіруваний на площині заземлення антени, допомагає досягти бажаного резонансу на 2,15 ГГц і 2,4 ГГц. 4-елементна конфігурація MIMO пропонується для обслуговування програм з високою швидкістю передачі даних. Коли чотири подібні елементи антени розміщені на одній підкладці, CSRR також забезпечує високу ізоляцію. Для розробки компактного MIMO відстань між елементами антени зберігається мінімальною. Таким чином, відстань між елементами антени підтримується рівною $\lambda/4$, щоб пом'якшити вплив багатопроменевого поширення, а також мінімізувати перешкоди між елементами антени. Повна антена розроблена на підкладці FR4 (ε_r = 4,4). Моделювання виконується за допомогою Ansys HFSS 2023 R_2. Розроблено та випробувано дослідний зразок розробленої антени. Виміряні зворотні втрати значно нижчі за 10 дБ, а посилення становить 6,28 дБ при резонансі 2,4 ГГц. Аналіз MIMO антени показує високу ізоляцію між елементами (< – 13 дБ), низький коефіцієнт кореляції огинаючої (0,00008) і високе підсилення спрямованості (> 9,995). Отримані результати підтвердили, що запропонована антена добре підходить для додатків Wi-Fi, bluetooth і Zigbee.

Ключові слова: Антена, CSRR, MIMO, Посилення, Мініатюризація.