Journal of Electrical Engineering and Automation (ISSN: 2582-3051)
www.irojournals.com/iroeea/

MIMO Two Dimensional Metamaterial Antenna for Wireless Communication and Radar Applications

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Abstract

The current research, aims in minimizing the mutual coupling between the antennas. An unique wideband square split ring metamaterial structure is proposed and positioned in the same plane of antenna. At frequencies between 4.2 GHz and 8 GHz, isolation of -20 dB is achieved due to the ENG features present in metamaterial structure. The metamaterial structure proposed has a permittivity of 4.3, it is made on FR-4 Substrate with 1.6 mm thickness. The proposed MIMO antenna operates in the C band (4.2 GHz-8 GHz) and has an isolation of -20 dB after applying a decoupling method in the entire C band. Gain, ECC, and DG among other performance and diversity factors, are computed and found within the allowed operating range for MIMO, further demonstrating that the design is a good substitution for the other existing design.

Keywords: Diversity Gain (DG), Envelope correlation coefficient (ECC), Ultra-Wideband (UWB), Multi-Input-Multi-Output (MIMO).

1. Introduction

Today, wireless devices are considered to be a basic necessity for people. However, traditional Single-Input Single-Output (SISO) systems fail to keep up with the need for better

DOI: https://doi.org/10.36548/jeea.2023.3.005
Received: 02.09.2023, received in revised form: 20.09.2023, accepted: 09.10.2023, published: 25.10.2023

coverage and faster data rates due to their lesser channel capacity for transmitting and receiving information. The introduction of MIMO technology transforms wireless communication by using array of antennas in transmitter as well as receiver ends to maximize the capacity of the channel and data transmission rate [1]. In MIMO when an array of antennas is placed to transfer the information several problems occur; one of the major problems is mutual coupling that arises due to the impact of the performance of one antenna over the other that are placed side by side. This mutual coupling results in parameter degradation as well as in the gain and the efficiency of the antenna operation [2]. Multiple designs and strategies have been used in the research studies mentioned to primarily lessen the mutual coupling in MIMO systems e.g., Defected Ground Structure (DGS) [3-5], Split ring resonator [6-7], Complement split ring resonator (CSRR) [8], Electromagnetic Bandgap structure (EBG) [9], Neutralization lines [10], Different geometric elements [11], orthogonal ports and orthogonal placement of antenna [12-14], parallel coupled line resonator [15], a slot cut in antenna [16], stub resistance loaded [17-18], Complementary Minkowski fractal [19], Metamaterial is one of the effective solutions[20] Metamaterials are artificially created materials with electromagnetic wave manipulation capabilities, simultaneously negative permittivity and permeability was investigated in 1968 [21] and later experimentally presented the same characteristics in the year 2000 [22]. The study has proposed a design-based metamaterial (MTM) for MIMO system to improvise the isolation in it. The Metamaterial structures can be used in many ways to get desired results, it can be used as a superstrate by placing the MTM structure above the antenna and can be placed on the same plane in which the antenna is placed. The suggested metamaterial structure improves antenna isolation with a small space (11 mm) between the edges and no modifications to the original antenna, the proposed design is notably reported to provide a -20dB isolation in the entire C band.

1.1 Material and Method

The design of the proposed crescent MIMO antenna with metamaterial is shown in Fig. 1. The antenna is designed using “CST software, low-cost FR4 substrate (εr=4.4, $\tan\delta$=0.02) with dimensions of 40mm×20mm×1.6 mm”.

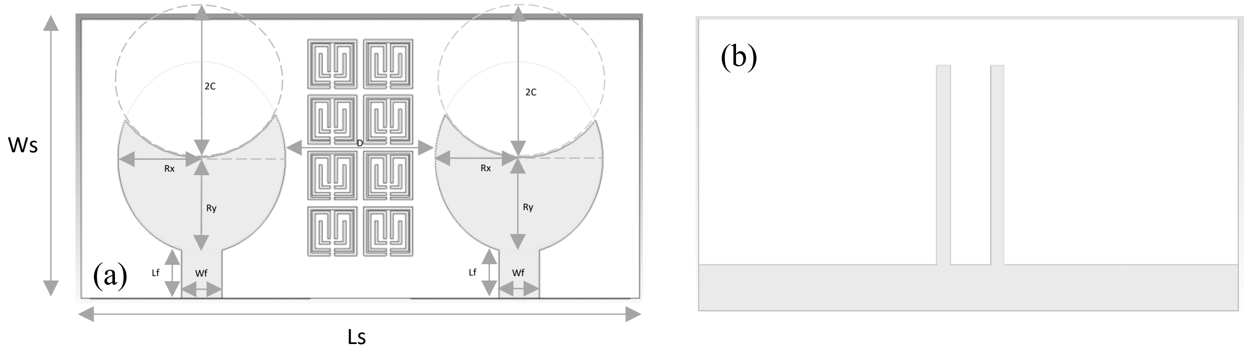


Figure 1. Proposed Structure **(a)** Front View (**b)** Bottom View

The optimized dimensions are Ws=20mm, Ls=40mm, Rx=6, Ry=6.75mm, G0=3.25mm, Wf=2.9mm, Lf=3.25 mm, C=6.5mm, D=11 mm. Rx=6, Ry=6.75mm, G0=3.25mm, Wf=2.9mm, Lf=3.25 mm, C=6.5mm, D=11 mm.

2. Structure of the Antenna

The proposed work begins with two element crescent shaped "MIMO antenna" as shown in Fig 2a. With a microstrip feed line, two identically sized elliptical patch antennas are employed The rear portion of the antenna is a reduced ground structure. For the optimal performance of the design, it is printed on a "40x20x1.57 mm3 FR-4 substrate with Er = 4.3, maintaining an 11 mm edge-to-edge spacing between two patches".

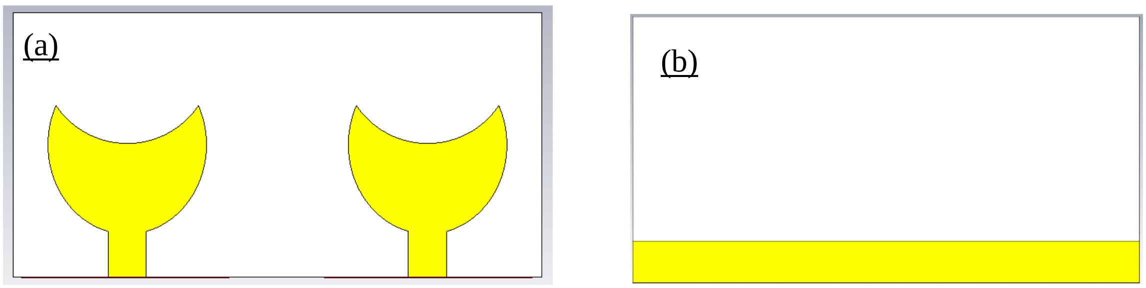
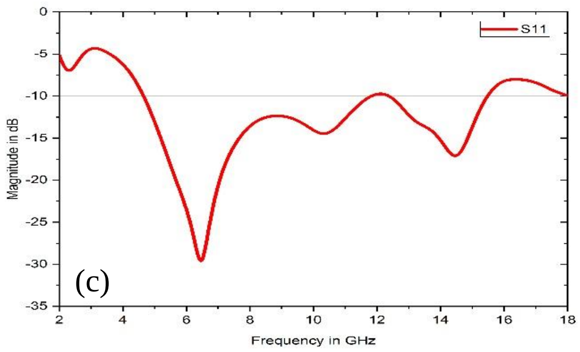


Figure 2. (a) Front View of Crescent Elliptical Patch

(b) Bottom View of Crescent Elliptical Patch



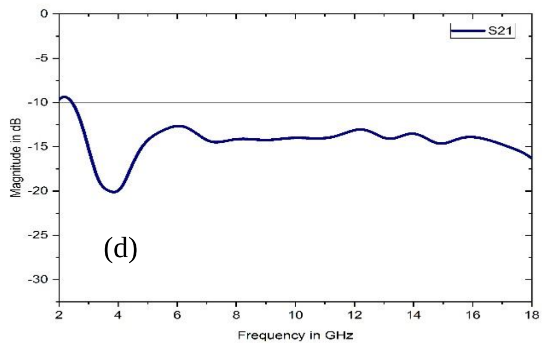


Figure 2. (c) Extracted S_{11} Parameter **(d)** Extracted S_{21} Parameter

3. Designing of Metamaterial Unit Cell (MUC)

The 4x4 mm2 MUC is made up of a square split ring with a relative permittivity of 4.3 on a “1.6 mm thick FR-4 substrate”, as shown in Figure 3a. The space across the split ring produces the capacitance. Due to the simplicity of its structure, square split rings' symmetrical design also provides a way where currents connected to each square split ring can go in the opposite direction, negating the effect of near-field coupling. It was assumed that the magneto-electric coupling is minimal and that the material response is isotropic at least over a specific range of frequencies and polarisation of the fields.:

$$\nabla \times E = -j\omega\mu H$$

$$\nabla \times H = j\omega\varepsilon E$$

where $\varepsilon,$=local electric permittivity and $\mu =$ magnetic permeability. Most natural materials exhibit these two characteristics from their electromagnetic wave interactions, producing values that are in accordance with the constraints $\text{Re}[\varepsilon] \geq \varepsilon_0$, $\text{Re}[\mu] \geq \mu_0$, $\text{Im}[\varepsilon] < 0$, $\text{Im}[\mu] < 0$ that implies the material is passive and has an index of refraction greater than or equal to the free-space value. However, if a reasonable temporal dispersion complies with the limitations imposed by causality, the real components of a passive material's permittivity and permeability at a particular frequency may theoretically provide any actual value. (i.e., Kramers Kronig relation) [23]. In contrast, if both of these numbers are negative, the corresponding materials may be referred to as double-negative (DNG). Materials having both positive real parts for permittivity and permeability, as most natural materials do, are referred to as double-positive materials (DPS). The negative material (ENG) with uniform electromagnetic wave is applied over the MUC in the negative as well as positive X-direction preserving electric as well as the walls of the magnetic boundary across the axis Y, Z correspondingly, to get (S11) and (S21) coefficient that denote the reflection and the transmitting correspondingly by means of "CST Microwave Studio". Media with a negative real part of the permeability but a positive permittivity are known as Mu-negative media.

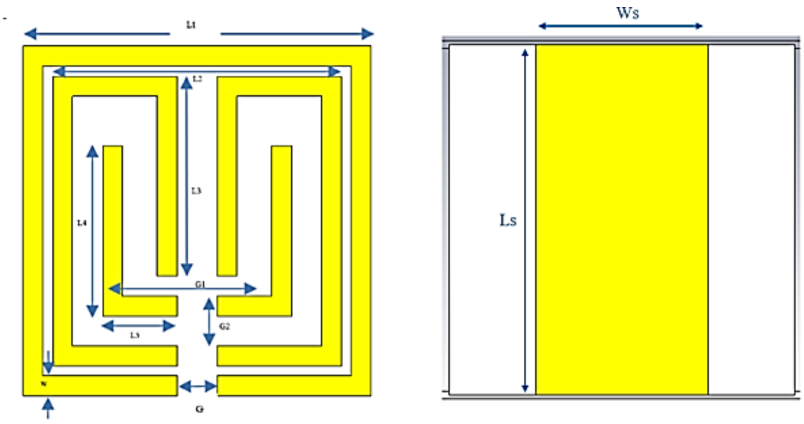


Figure 3. MUC **(a)** Top view **(b)** Bottom View

The optimized dimensions are L1= 3.5mm, L2=2.9 mm, L3=2 mm, L4 = 0.75 mm, L5 = 3.95 mm, G=0.4 mm, G1 = 0.5 mm, G2 = 1.5 mm, Ls = 4mm, Ws= 2mm

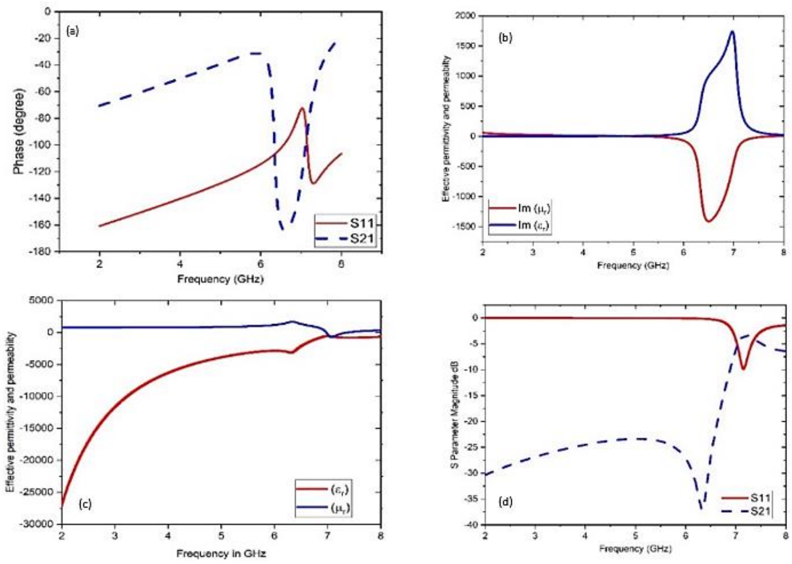


Figure 4(a) Extracted Real Effective Parameters **(b)** Extracted Imaginary Effective Parameters **(c)** Reflection and Transmission Coefficients Phase Plot **(d)** Magnitude Plot of Reflection and Transmission

Above Figure 4a shows the value of extracted permittivity and permeability, extracted Permittivity is completely negative in the range of 2-8 GHz which denotes ENG metamaterial type. The actual material parameters are evaluated applying the algorithm of the study conducted in [24]. The mathematical relationships among the permittivity, permeability and scattering parameters, of the material are specified in Eqs. (1)-(4) as described in [24-26]:

$$Z = \pm\sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \quad (1)$$

$$e^{jk_0 d} = \frac{S_{21}}{1 - S_{11}\frac{z-1}{z+1}} \quad (2)$$

$$\varepsilon = \frac{\eta}{Z} \quad (3)$$

$$\mu = \eta * z \quad (4)$$

Where, k_0 = "wave number", Z = "normalized impedance", d = "material thickness" , ε = "effective permeability", η = "refractive index".

4. MUC Integrated MIMO

The "two-element crescent-shaped elliptical patch MIMO antenna" is shown in Fig. 2a with a dimension of 40x20x1.57 mm3 FR-4 substrate with Er = 4.3, keeping edge-to-edge separation of 11 mm is used with metamaterial unit cell structure placed on the same plane of the antenna, with 8-unit cells (4x2) printed with a copper strip on the backside. The unit cell is placed apart at a distance of 0.5 mm by all sides and is optimized for better isolation by vertically shifting the metamaterial unit cell in the downward direction to achieve isolation better than -20 dB in the range of 4.2 GHz to 8 GHz frequency band isolation for greater than -20dB in the entire range of wireless application. Below shown Figure 5a depicts the antenna with a metamaterial structure to improve the isolation of the antenna below greater than -20 dB in the entire range of wireless applications.

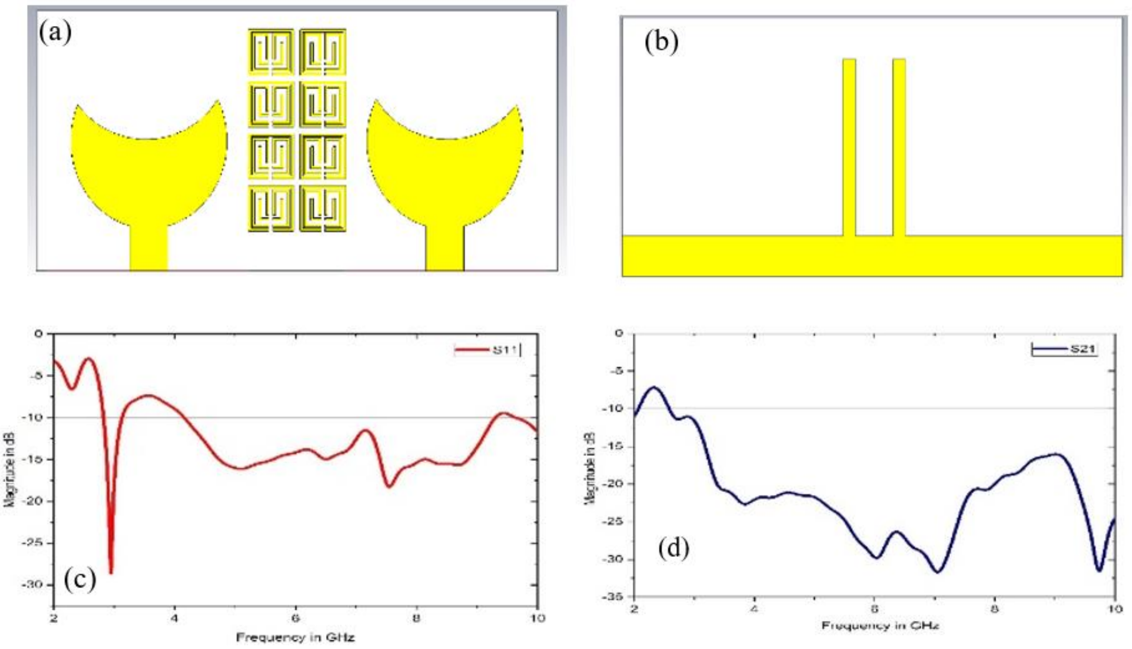


Figure 5. Proposed Design **(a)** Front View (**b)** Bottom View **(c)** Extracted S_{11} Parameter **(d)** Extracted S_{21} Parameter

5. Result and Discussion

The parameters ECC and DG are used in understanding and verifying the mutual coupling The parameter Envelop correlation coefficient (ECC) describes the correlation as well as isolation among various antenna and level of interference caused radiation pattern in one antenna influences the other as every port is engaged concurrently.

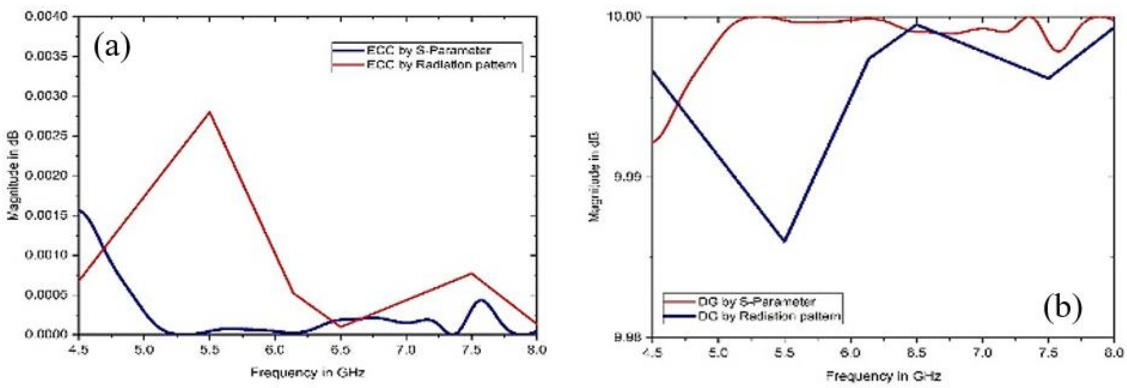


Figure 6. (a) Envelop Correlation Coefficient **(b)** Diversity Gain

ECC is estimated either by S parameter or the radiation characteristics as depicted in Equation (1) and (2) correspondingly [27-28]:

$$ECC = \frac{|S_{11}^{*}S_{12}+S_{21}^{*}S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} \quad (1)$$

$$ECC = \frac{|\int\int_{4\pi}(\mathbf{B}_i(\theta,\phi)) \times \mathbf{B}_j(\theta,\phi))d\Omega|^2}{\int\int_{4\pi}|\mathbf{B}_i(\theta,\phi))|^2 d\Omega \int\int_{4\pi}|\mathbf{B}_j(\theta,\phi))|^2 d\Omega} \quad (2)$$

The extracted ECC using simulated S parameters is shown in Figure 6a. In the proposed study, S-parameters is used to obtain ECC i.e.; “ECC is <0.0025” in the entire WLAN frequency range. The gained ECC = 0.0025, this is less compared to the normal value (<0.5). The low ECC results in low correlation among the antenna radiator.

DG, offers the knowledge of the average SNR of signals transmitted through MIMO single antennas and received at the receiver’s end through multiple paths, DG is determined on ECC value applying the mathematical expression in [27] and by using radiation pattern given below in equations (3) and (4) respectively shown below:

$$Diversity\ Gain = 10\sqrt{1-|ECC^2|} \quad (3)$$

$$Diversity\ Gain = \left[\frac{\gamma_c}{SNR_c} - \frac{\gamma_1}{SNR_1}\right]_{P(\gamma_c<\gamma_s/SNR)} \quad (4)$$

The MIMO structure DG is shown in Figure 6b. DG obtained in the total WLAN range for a specific MIMO is >9.98. MIMO design DG has to be nearly 10 dB for the complete UWB Range to have a reliable and high quality wireless communication system.

An ENG Metamaterial unit cell proves its effect in C band application and decouples the antenna below -20dB in the C band range. The below graph represents the comparison of S11 and S21 with and without material with positive stable gain over all frequency ranges.

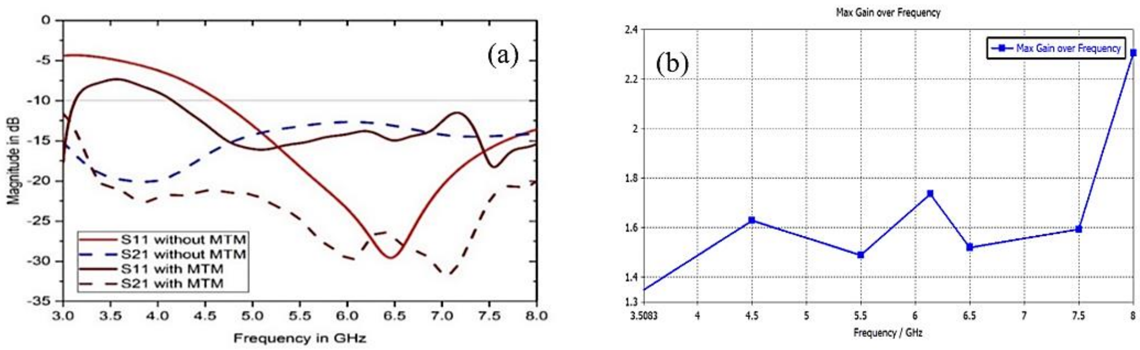


Figure 7. (a) Assessment S Parameter of with and without Metamaterial **(b)** Gain of the Crescent-Shaped Antenna with Metamaterial

The designed metamaterial unit cell and its implementation demonstrate promising characteristics for C band applications. Further studies could explore its behavior in real-world scenarios and investigate methods for enhancing its performance under adverse conditions.

6. Conclusion

To improvise the isolation of a two-port MIMO antenna, an efficient method has been proposed for the C band applications range. In this method, the metamaterial structure is positioned on the same plane of antennas. In order to reduce coupling across two antennas by absorbing the near magnetic field, a 4x2 array unit cell ENG metamaterial structure with a gap of 0.5 mm is placed on the plane of an antenna. This isolation is reached below -20dB in the region of WiFi and radar system use. ECC, DG and gain of proposed design is also evaluated by using S-parameters and radiation field which is found to be well below acceptable range for MIMO antenna system. The proposed work and the other existing methods are compared in terms of antenna size, the material used, resonating frequency band, ECC, and DG. The comparison clearly shows that the design put forth could perform better in applications of C band.

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