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Performance Measures of Mimo System Using Csrr Loaded Miniaturized Microstrip Patch Antenna

B. Jyothsna, Shaik Mastan Vali, V.N. Lakshmana Kumar

Abstract: MIMO technology has been used to increase the capacity rates and become an essential part in wireless communication systems. The challenging task in a wireless system is to design a compact size antennas. In this paper, a 4-Element metamaterial loaded microstrip patch antenna was designed. By using a CSRR loaded metamaterial DGS structure on the ground plane 50% of miniaturization was achieved. For the designed MIMO system the mutual coupling and the envelope correlation coefficient is less than -34 dB and 0.0.3. The other performance measures of MIMO system such as the TARC, Directive Gain and Return loss of the 4-element MIMO system are obtained to meet the MIMO system demands in real- time environment. The design was simulated using HFSS simulator software.

Key words**:** ***CSRR, ECC, Microstrip patch, MIMO system, TARC.***

I. INTRODUCTION

The advancement in wireless communication technology made a breakthrough to transmit and receive the signals to longer distances in terms of electromagnetic waves. Moreover, the main importance of this introduction is to focus on MIMO wireless communication systems which become an essential technology in mobile communication. MIMO technology was implemented to achieve higher data rates, high transmission speed and better channel capacity [1]. The data rates for mobile users can be improved by increasing the transmitted power to increase the Signal-to-Noise ratio or by providing wider bandwidth [2]. Both of these parameters are difficult to obtain because of the limitations of power and bandwidth. The possible solution to overcome the limit on power and bandwidth is to use multiple antenna system for a wireless communication environment. MIMO system requires more number of antennas that needs to integrate into communication devices. So compact structure is required to place the MIMO system in a limited space. But when antennas are placed very closely, electromagnetic interactions makes a large mutual coupling which results in the impedance mismatch, reduction in radiation and increases the antenna correlation. The big challenge in the MIMO system in spite of its benefits is the large mutual coupling. The performance of the MIMO system will degrade when the mutual coupling between the antenna elements is increased. To reduce the mutual coupling there were many methods that are used such as, in [3], [4] it was shown that the mutual coupling is reduced with the use of F-shaped slots between the radiating patch elements. In [5], the neutralized line technique is used to achieve the lowest mutual coupling between the antenna elements

In this paper using the miniaturization technique, a 4-Element CSRR loaded microstrip patch MIMO Antenna was designed. The geometrical parameter value for dielectric constant ε_r=4.4 is used for FR4 substrate material and the height of the substrate is 0.8 mm. The performance measures of MIMO system such as Return loss, ECC, TARC and Directive gain obtained are well suitable for wireless communication applications. The remaining sections of the paper are arranged as follows. In section 2, the antenna model and design methodology of single CSRR loaded microstrip patch antenna and its results are discussed. In section 3 the proposed 4-Element MIMO antenna design, MIMO performance metrics, and their results are discussed. Section 4 gives the conclusions.

2. Antenna Model and Design Methodology:

CSRR (Complementary Split Ring Resonator) metamaterials is an engineered material which has a great property that usually not available in naturally occurring materials. Metamaterials acquire their properties from their modified structures only, not from the material used. In electromagnetic wave propagation, the permittivity (Ɛ) and the permeability (µ) is determined by the material characteristics. The permittivity gives the information about the response of the material to the applied electric field and the permeability is a result of the induced magnetic fields to the materials. In naturally occurring materials both Ɛ and µ are positive known as Double Positive Substance (DPS) materials. To design and fabricate the metamaterial structure negative refractive index is one of the essential property. Generally, in negative refractive index metamaterials, both Ɛ and µ are negative resulting in the negative index of refraction.

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The negative index of refraction causes the group velocity and phase velocity of an electromagnetic wave to travel in the opposite direction to the direction of energy flow [6], [7]. Materials which exhibits reversed physical characteristics were first described theoretically by Victor Veselago in 1967.

In this section, the antenna design was divided into 2 different parts. In the first part, the conventional patch antenna was designed and later CSRR loaded structure was designed for the microstrip patch antenna for antenna miniaturization and the results for the two structures were shown. In section 3, four identical antenna elements are used to form a 2x2 MIMO system and the results obtained from HFSS are presented.

2.1 Design of conventional and single element CSRR loaded microstrip patch antenna.

In this part, the microstrip patch antenna (MPA) is designed using the FR4 substrate material with a dielectric constant of 4.4 and height of the substrate as 0.8 mm. The frequency of operation is used to design this is 5.04 GHz. The patch length l=14mm and width w=18mm are calculated using standard formulas [8]. The asymmetrical inset fed MPA is used to improve the return loss and bandwidth. Figure (2.1.1 (a)) depicts the geometry of the MPA with the above dimensions. To reduce the size of the MPA CSRR was etched underneath the patch with the outer radius R=6mm and inner radius r=5mm, slit width w=0.5 and the space between the rings g=0.5. Figure (2.1.1 (b)) depicts the geometry of the CSRR loaded MPA. The result comparison between these two designs shows that miniaturization of 50% of size reduction was done after using the CSRR metamaterial DGS structure compared with the conventional microstrip patch antenna.

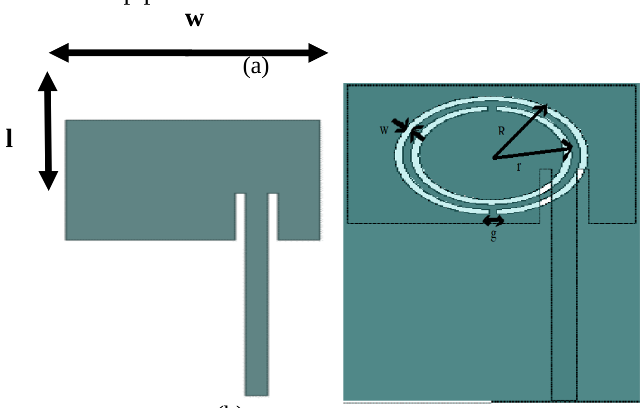
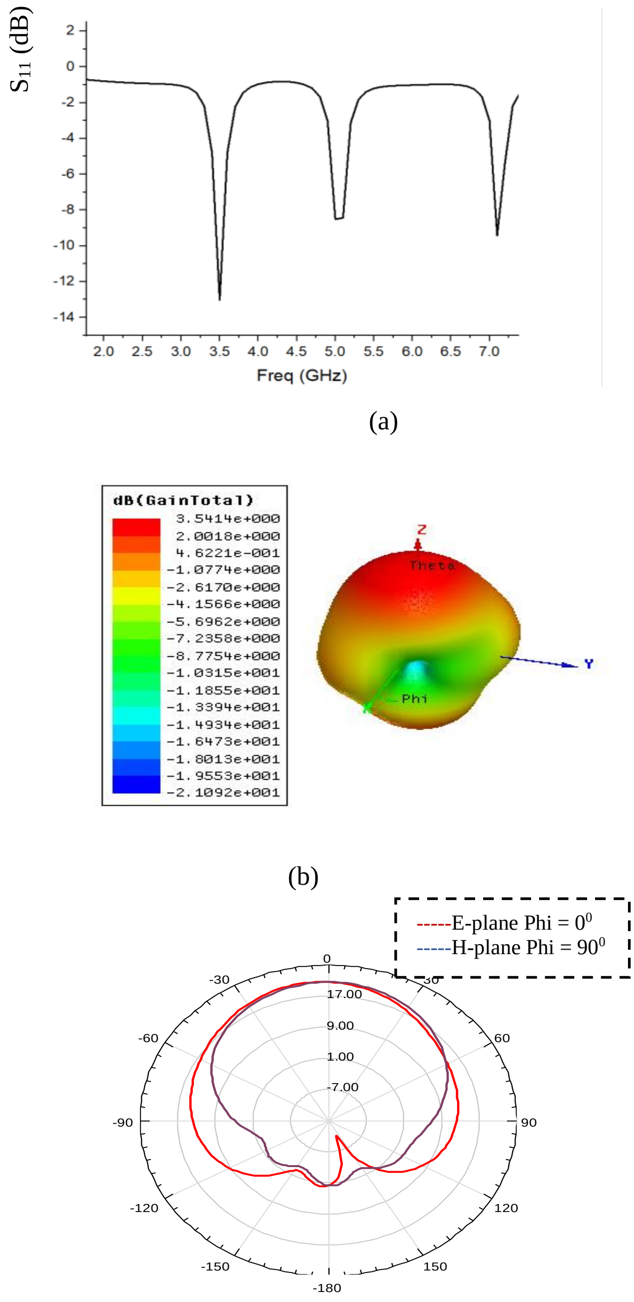


Figure 2.1.1: (a) Geometry of Conventional microstrip patch antenna (b) CSRR loaded microstrip patch antenna.

In the conventional microstrip patch antenna, different return loss values were obtained at different frequencies. At the frequency of 3.6 GHz, even though the return loss is good but the gain obtained is not suitable for the antenna to be operated. At 5.04GHz operating frequency, all the antenna parameters obtained are good for antenna applications and the results are shown in Figure 2.1.2.



(c)

Figure 2.1.2: Simulated results of Conventional microstrip patch antenna. (a) S_{11} plot (b) 3D Gain plot (c) 2D Radiation plot (E-plane and H-plane patterns).

When CSRR rings were removed from the ground plane of the conventional microstrip patch antenna the return loss was obtained is -22.78 at 2.52 GHz. The change in resonant frequency from 5.04 GHz to 2.52 GHz clearly shows that 51% of miniaturization was done when the conventional antenna is loaded with CSRR material. The gain and radiation pattern of the antenna obtained at 2.52 GHz and 3.6 GHz are also shown in Figure 2.1.3.

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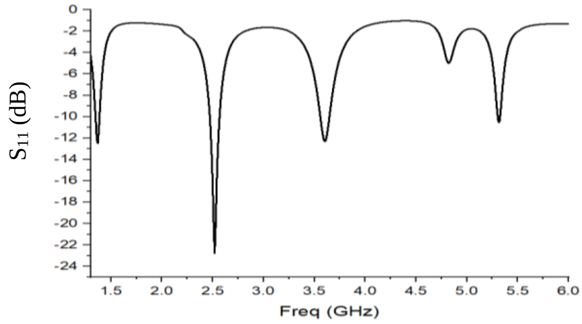
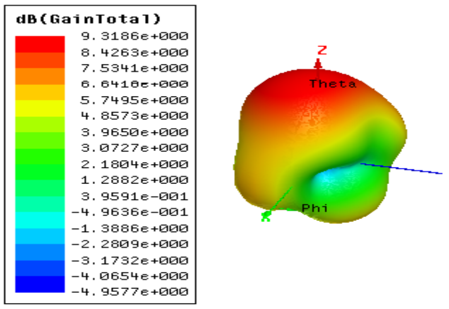


(a)



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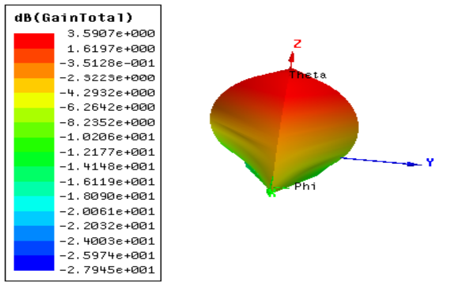

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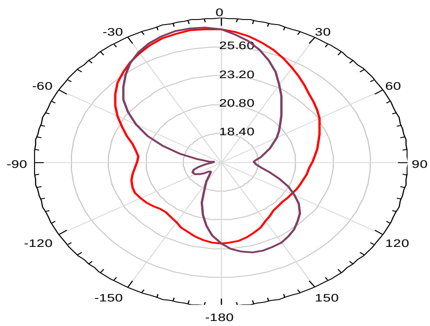
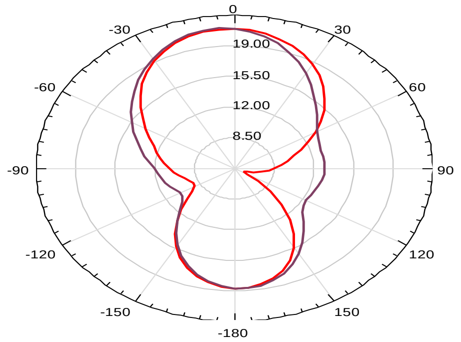


(d)

-----E-plane Phi = 0⁰
-----H-plane Phi = 90⁰



(e)

-----E-plane Phi = 0⁰
-----H-plane Phi = 90⁰

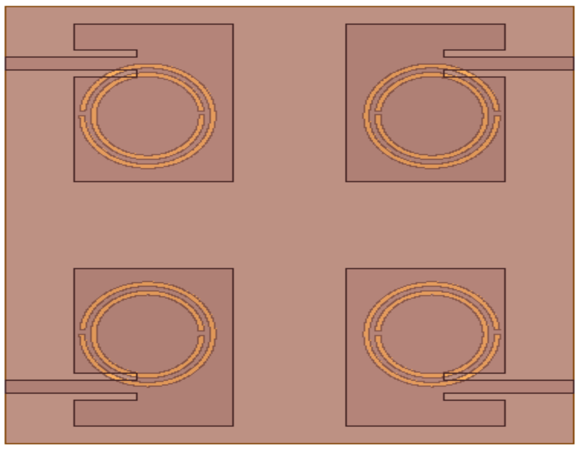
Figure 2.1.3: Simulation Results of C patch antenna. (a) S_{11} plot (b) 3D Gain plot at 2.52 GHz (c) 3D Gain plot at 3.6 GHz (d) 2D radiation plot at 2.52 GHz (e) 2D radiation plot at 3.6 GHz.

3. Design of 4-Element CSRR loaded MIMO antenna:

In this section, the CSRR loaded miniaturized MPA was designed on FR4 substrate with the patch dimensions of 14x18 mm^2. The design was tuned to the resonant at 2.7 GHz frequency. Later four individual CSRR miniaturized MPA elements are arranged in an area of 50x50 mm^2 to design a MIMO antenna system. The antenna elements are arranged to provide a spacing of 10mm between two antenna elements. The designed 4-Element MIMO system was simulated using HFSS simulator software.

Figure 3.1: Design geometry of the 4-Element CSRR loaded MIMO.

Here the 4 individual patch antenna elements were arranged on the substrate. The ground plane was etched with the CSRR rings with the outer ring radius R=6mm and the inner ring radius r=5mm. The spacing between the rings is 0.5 mm and the slit gap is 0.5mm.



Results Discussion for 4-Element CSRR loaded MIMO antenna:

The 4 element patch antennas with CSRR structure was exited with 4 port excitation. The HFSS results for basic antenna parameters are shown in Figure 3.1.1. In 3.2 it was discussed about the different MIMO antenna measures such as ECC, Mutual Coupling,

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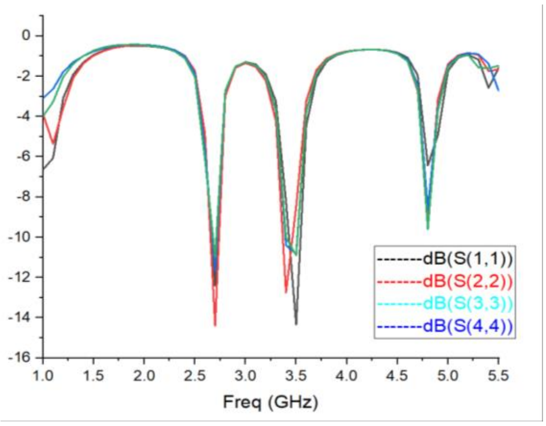
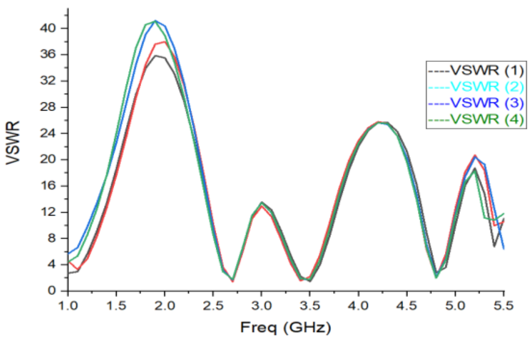
TARC and Directive gain for the resonant frequency. The HFSS results for all the above MIMO performance measures are shown.



(a)



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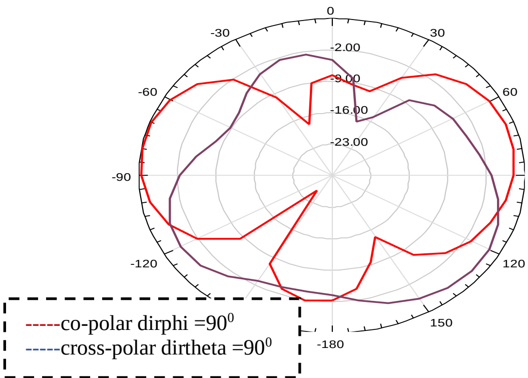
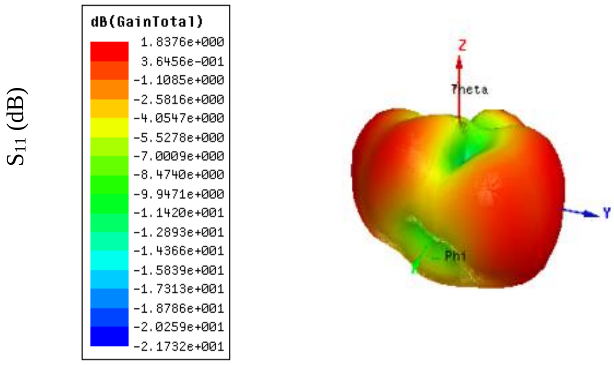


(c)

Figure 3.1.1: (a) Simulated S-parameters plot (b) Simulated VSWR plot (c) Simulated Co and Cross polar plot at 2.7 GHz (d) Simulated 3D Gain polar plot at 2.7 GHz.



(d)

3.2 MIMO Performance Measures or Characteristics:

Additional performance metrics to those of regular single antenna systems are essential to determine the MIMO system characteristics. While single antenna element metrics such as return loss, radiation patterns, and operating bandwidths are also required for MIMO antennas, other performance metrics such as envelope correlation coefficient (ECC), total active reflection coefficient (TARC), mutual coupling and directive gain are required for multi-antenna system characterization. These performance metrics take into account the effect of adjacent antennas on the overall system performance. All these are discussed and the simulated results are shown below separately.

Envelope Correlation Coefficient (ECC):

The characterization of the MIMO system is important in terms of its diversity performance. In the MIMO antenna system, the correlation between the two antenna elements is directly depends on how much distance is placed between the antenna elements. The parameter that tells about "how independent the two antenna radiation patterns are" known as ECC. Normally the radiation patterns of the one antenna should be different from the radiation pattern of the other antenna which results in the lower ECC value. Otherwise, the same patterns of these antennas will exhibit the larger value of ECC. From the scattering (S) parameters the ECC could be calculated as,

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

Mutual Coupling:

Mutual coupling became a challenging issue in MIMO system design. It is a result when a nearby antenna is absorbing the energy from the source antenna which is intended to transmit the energy to the destination antenna. Moreover, mutual coupling reduces the antenna radiation efficiency and reduces the performance of the transmitting and receiving antennas. Because of this reason, mutual coupling became an important issue and to be reduced the effect of absorbing energy to a far extent from the nearby antenna. Antenna isolation can be used to quantify the mutual coupling effect [10].

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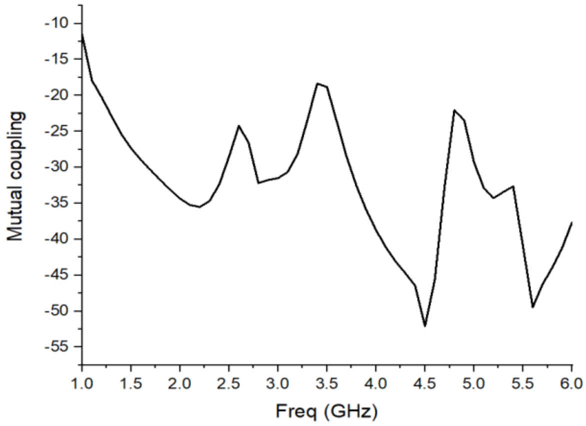


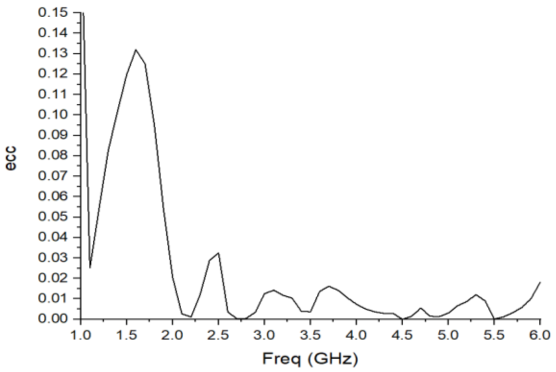
Total Active Reflection coefficient (TARC):

Multiple antenna system has to be operated with signals of different phases at the same time. TARC is used to relate the effect of antenna port when the signal is excited with incident power. Because in the MIMO antenna system all the delivered power at the port should be accepted by the antenna without any reflections to the other ports. It is simply defined as the square root of available power minus radiated power to the total available power at the N port antenna. The value of TARC can be calculated in decibel (dB) and it is a function of frequency. If the TARC value is zero all the delivered power is accepted by the antenna and if it is equal to one then the total power is radiated back as an outgoing power.

$$\Gamma_a^t = \sqrt{\frac{available\ power - radiated\ power}{available\ power}}$$

Directive Gain (D_G):

In (Electromagnetics) EM antenna system a simple gain or the antenna power gain is a key parameter for antennas directivity and efficiency. If the antenna is designed to work for a transmitting antenna, the gain describes how well the antenna is capable to convert its input power into the EM waves in a particular direction. Similarly, if it is a receiving antenna the gain describes the how well it is converting the incoming EM waves into electrical power. By knowing the definition of gain the directive gain is defined as the ratio of radiation intensity in a specified direction to the total radiated power.



$$D_G = \frac{U}{U_0} = \frac{4\Pi U}{P_{rad}}$$

Where,

U = radiation intensity of the test antenna, in watts per unit solid angle

U_0 = radiation intensity of the isotropic antenna, in watts per unit solid angle

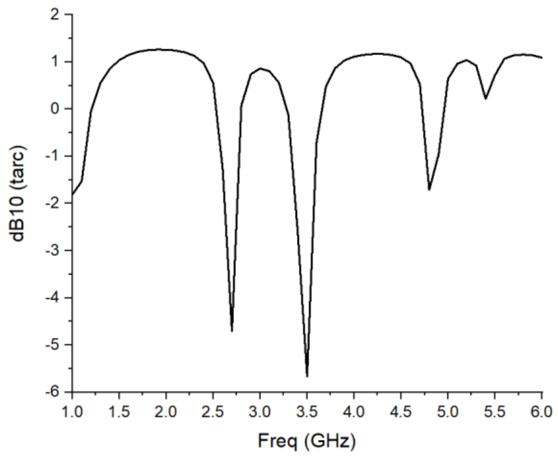
P_{rad} =Radiated power in watts

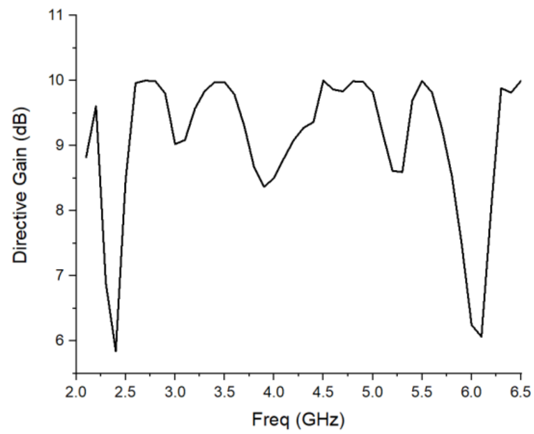
Simulated Results of MIMO performance metrics:

(a)

(b)

(c)





(d)

Figure 3.2: Simulated results for performance metrics of MIMO system. (a) ECC plot. (b) Mutual Coupling plot. (c) TARC plot. (d) Directive Gain plot.

From figure 3.2 (a) it was observed that the value of ECC is 0.024 at 2.7 GHz resonant Frequency. Ideally, the value of ECC should be 0 for best performance. To take advantage of diversity gain, the value of ρ should be below 0.03. The value of mutual coupling was -33 dB at 2.7 GHz frequency shown in figure 3.2 (b).

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The low mutual coupling indicated the less correlation exists between antenna elements. From figure 3.2 (c) the TARC values are obtained as -47 dB at 2.7 GHz frequency. It was observed that higher mutual coupling results in higher ECC and TARC.

4. Conclusion:

Microstrip patch antenna loaded with CSRR for miniaturization of antenna and Multiple Input Multiple Output (MIMO) antenna system loaded with CSRR on the ground plane was designed in this paper. The antenna size has been miniaturized by 50% through a metamaterial approach. Different performance measures of the MIMO system are calculated for the designed 4 element CSRR loaded MIMO system. The directive gain obtained at the resonant frequency is 9.9 dB and other values obtained were also shown. All the MIMO performance measures are suitable for wireless communication systems applications.

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