# Mutual coupling reduction in a two element patch antenna array using complementary split ring resonator metamaterial structure

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In an antenna array the far field radiation pattern is affected by the mutual coupling between the array elements. This paper presents a solution to reduce the mutual coupling between two element patch antenna array by incorporating Complementary Split Ring Resonator (CSRR) metamaterial structure on the ground plane. The proposed antenna is designed consisting of two hexagonal patch elements with CSRR structure. By incorporating the CSRR structure mutual coupling has been reduced from -10dB to -24 dB. The two-element patch antenna array is fabricated and S parameters of the prototype are measured and compared with the simulation results. The measured and simulation results are in good agreement with S11<-10dB, S12<-24 dB.

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*Keywords*: Array, CSRR, Mutual coupling, Radiation pattern, S parameters

## 1. Introduction

Mutual coupling is an electromagnetic phenomenon that is noticed in antenna arrays due to the field interaction between the patch elements [1]. Reduction in mutual coupling poses a strong challenge in array antenna applications. Over the years the mutual coupling effect has become more predominant with the development of miniaturized radio transceivers [2]. When the spacing between the patch elements is very close, the power radiated by an antenna will be engrossed by the adjacent element of the array [3]. This will affect the discrete element pattern and there by amends the overall radiation pattern of the array [4]. Apart from near field interaction surface waves also leads to the coupling between the patch antennas [5]- [6]. In a situation where the antennas are printed on a very low permittivity substrate material the near field coupling appears to be very strong which in turn degrades the antenna radiation characteristics [7].

Since early days, mutual coupling reduction is one of the most engaging domains for antenna architects. By and large, analysis of mutual coupling is done through two distinctive ways; cavity model [8, 9] and transmission line model [10]. Recently, a portion of the philosophies were utilized to decrease the Mutual Coupling by utilizing a few structures like Defective Ground Structure (DGS) [11], EBG structure, diverse shape resonator [12] and so on. In few of the writings [13-14] EBG structures are proposed to be appropriate one to beat the mutual coupling since they suppress the surface currents. However, incorporating such kind of periodic structures in between the antenna elements, the separation should be large in between the elements, greater than one-third of the free space wavelength is essential. In [15], to diminish the Mutual Coupling in-between the two elements a slot was used on the ground plane, even though the setup utilised is a straightforward structure the radiation pattern is influenced mainly on the back side. In literature [16-19], configurations like multiple dielectric substrates, DGS and UC-EBG (uniplanar compact electromagnetic band-gap) Superstrate have been investigated to overcome the mutual coupling effects between antenna elements. A wideband asymmetric loop resonator is proposed in [20] and differential feeding in [21] for isolation enhancement in antenna arrays. In [22] to achieve mutual coupling and cross-polarisation reduction, a string of H- shaped defected ground structure is inserted underneath the two patches which has a limitation of maximum peak gain of just 2 dBi. Besides, numerous different solutions to diminish the mutual coupling have been presented including 3-D metamaterial structure [23], fractal defected ground structures [24] artificial magnetic conductor (AMC) [25], Meander line [26], Multi-Layered Electromagnetic Band Gap Structures [27] and Embedded Periphery Slot [28]. In [29-30] metamaterial fractal electromagnetic band-gap structures are used between the closely packed patches to enhance the isolation.

In this paper a two element array antenna is demonstrated which are placed very close to each other. A new terminology is discussed to reduce the mutual coupling between two elements by incorporating metamaterial CSRR structures on the ground plane. With the proposed technique a parametric study is done on mutual coupling variation with the change of distance in between the two CSRR structures on the ground plane.

## 2. Working principle of the resonator

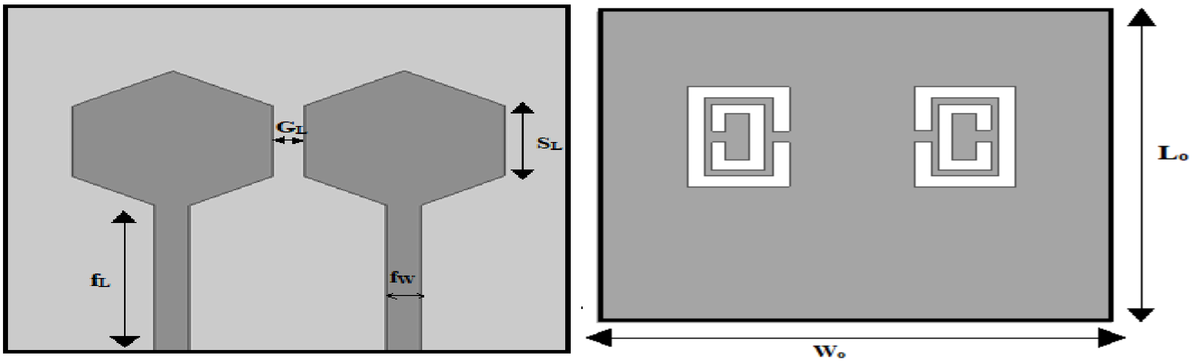
To diminish the Mutual Coupling in-between the two elements, the CSRR is structured so that the resonant frequency of the antenna falls under the split ring resonator's stop band. From a detailed parametric study [10] it is found that the resonant frequency of a CSRR is reliant on the split width (g), gap width (b), slot length (L) as,

$$f = \frac{v}{(4*(L-g)-b)\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

where, 'v' represents velocity of light of in vacuum and $\varepsilon_r$ is the relative permittivity of the substrate material. The CSRR at the magnetic resonance has the vertical electric field over the ground plane that emerges because of thin (1.6 mm) substrate. The resonator at that point acts as a left-handed material indicating negative permeability and totally suppresses the prevailing surface waves from reaching the other elements within the near field of the antenna.

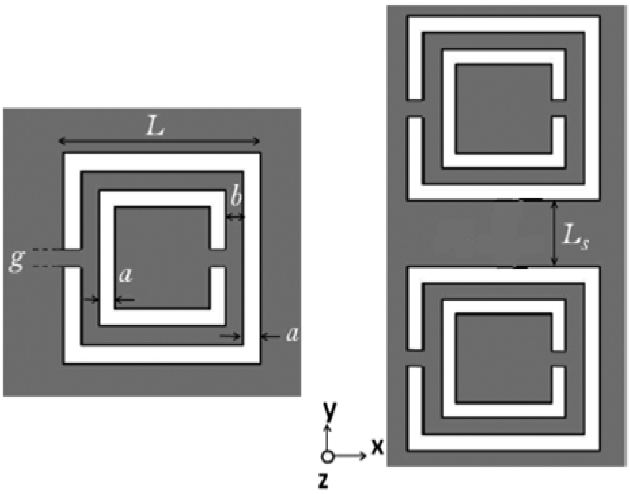
## 3. Antenna design

Shown in Fig. 1 is the geometry of proposed design, 1(a) top layer and 1(b) ground layer. This design uses two hexagonal radiating elements which are closely spaced at 2mm apart from each other on a 32 mm × 32 mm FR4 substrate material. The loss tangent, permittivity and thickness of the substrate are 0.02, 4.4, and 1.6 mm, respectively.




*(a)* *(b)*

*Fig.1 (a) Radiating layer configuration, (b) Ground plane configuration*




*(a)* *(b)*

*Fig. 2. (a) CSRR unit cell. (b) Layout of proposed CSRRs unit cell*

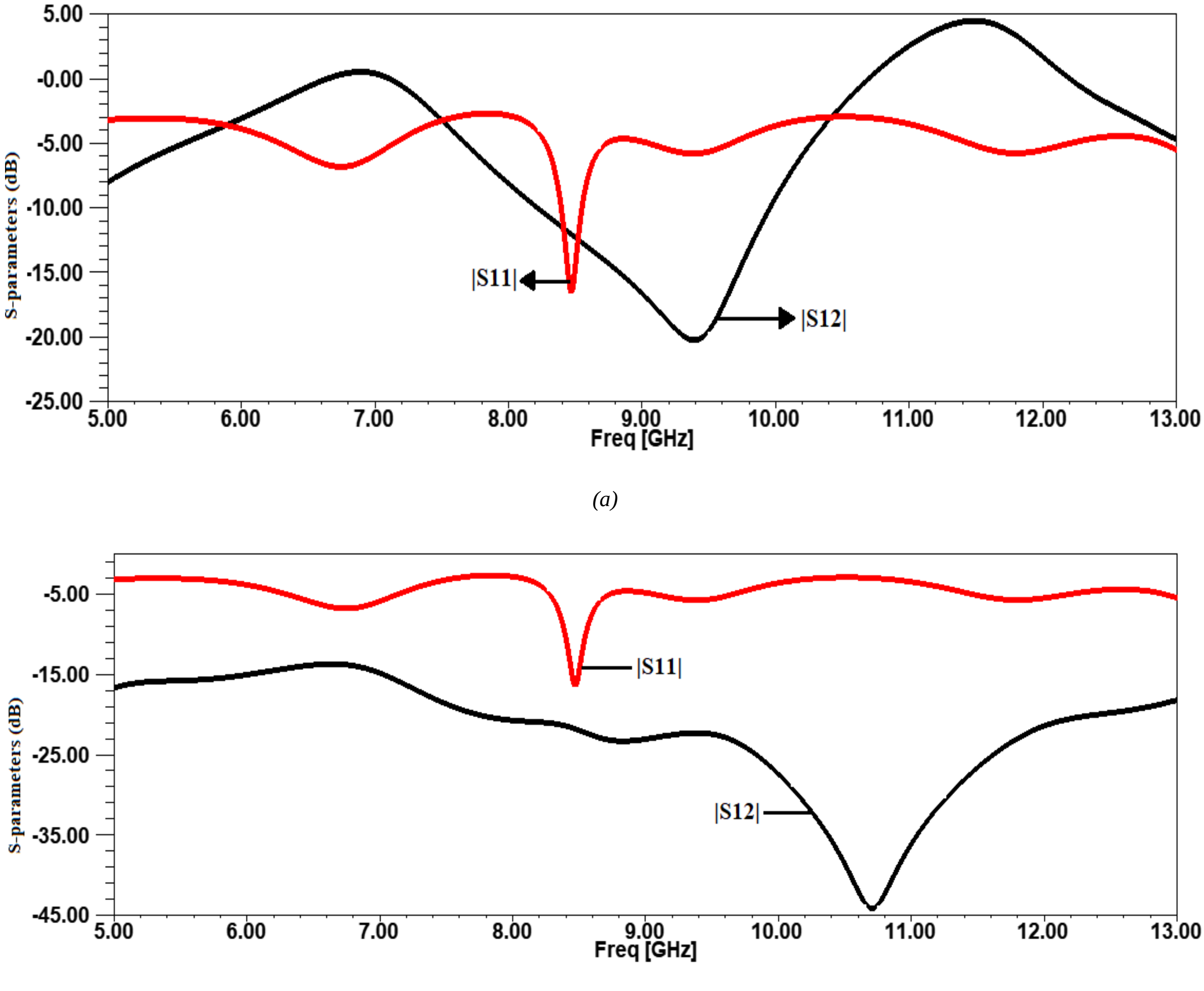
The structure as shown in Fig. 1 (b) consists of two cells of CSRRs loaded on the ground plane of the array antenna with a space of Ls in between. Over all specifications of the proposed design are listed in Table 1. Fig 2 (a) shows the basic CSRR unit cell and 2 (b) shows its layout in the ground plane. Maintaining a constant distance 2 mm in between the two patch elements the mutual coupling effect is studied by varying the distance ($L_S$) between the two CSSRs which are loaded on the ground plane.

*Table 1. Dimensions of proposed design*

| Parameter | $G_L$ | $f_L$ | $f_W$ | $S_L$ | $W_o$ | $L_o$ | a | b | L | g | $L_S$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Unit(mm) | 1 | 13 | 2 | 6.5 | 32 | 32 | 1 | 0.5 | 6 | 1 | 7.5 |

## 4. Results and discussions (simulated and measured)

The results for different cases are discussed in this section. The proposed design is developed and optimised using HFSS simulator. For the regular antenna array structure, the simulated result is shown in Fig 3a where CSRR is not realized on the ground plane. Fig 3(b) shows the S parameters of the antenna when CSRR is deployed, where the resonance frequency is observed to be 8.5 GHz. On comparing the both the plots, the depth of S21 reduces by -14 dB at the antennas operating frequency for a CSRR model. Fig 4 shows the comparison of S21 parameter when loaded with and without CSRR model on the ground plane. It can also be noticed from the same that a drastic reduction in the mutual coupling has been achieved when CSRR model is realized.




(b)

*Fig.3. Scattering parameters (a) without CSRR (b) with CSRR, (S11=S22 and S21=S12) (color online)*

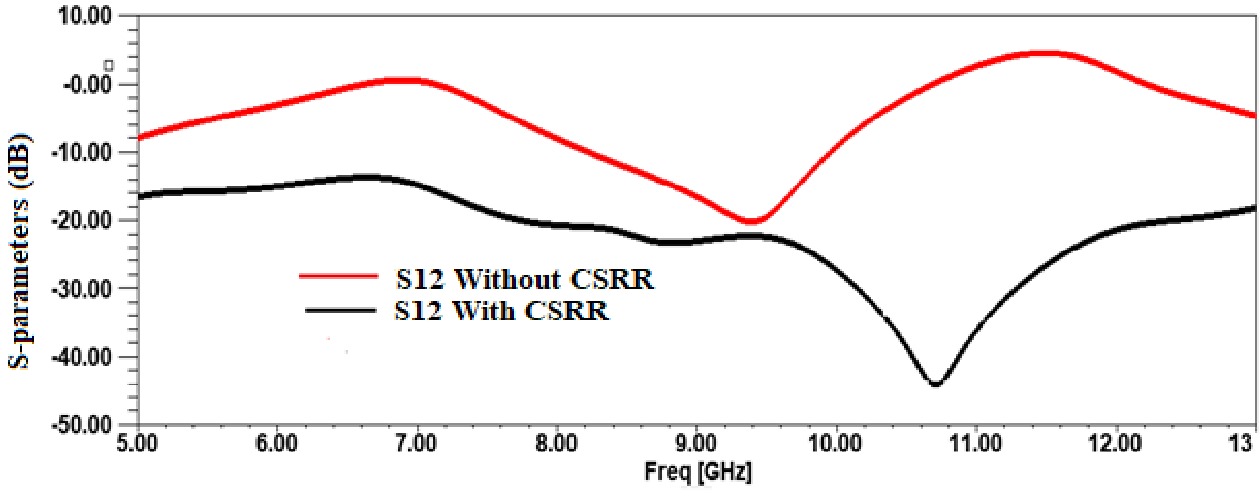



*Fig. 4. Mutual coupling characteristics with and without CSRR*

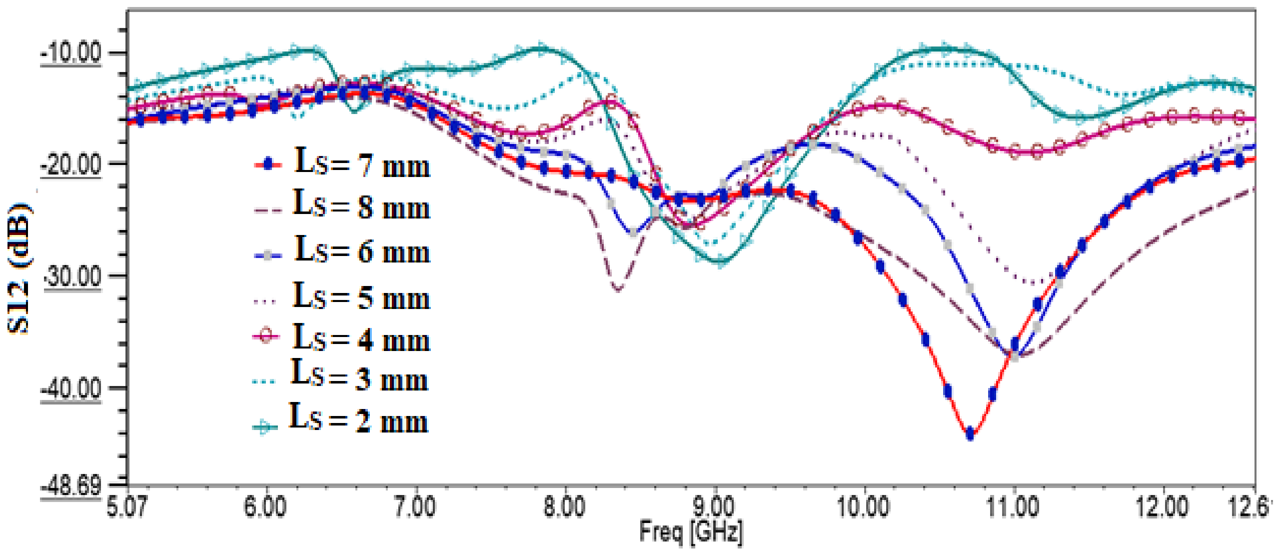



*Fig. 5. Mutual coupling characteristics with various $L_S$ in between two CSRR cells (color online)*

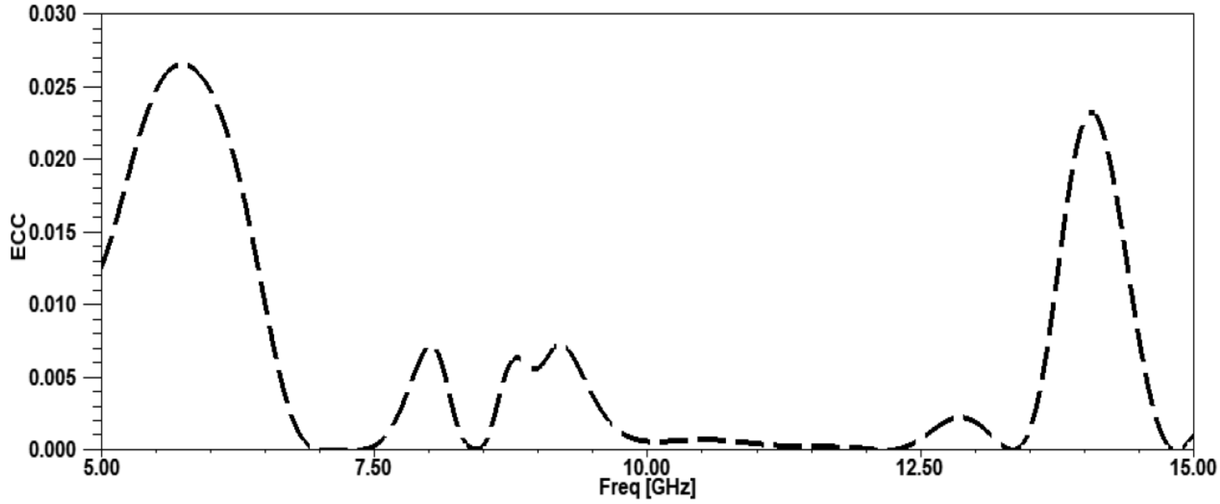



*Fig. 6. Envelope correlation coefficient*

Fig. 5 shows the S21 comparison of the proposed design for various distances (LS) maintained in between the two CSRR cells which are on the ground plane. The proposed design is analysed by maintaining various distances (2, 3, 4, 5, 6, 7,8mm) in-between the two CSRR cells and observed that when a distance of 7mm is maintained in between them the depth of S21 is reduced drastically. It can also be noticed that as the distance between the two CSRR cells is increased the depth of S21 is also reduced and when the distance is increased beyond 7mm the S21 is increased.

Envelope correlation coefficient (ECC) is one important parameter that indicates the correlation between radiating elements. It can be calculated using S-parameters based on the Eq. 2, the allowable practical limit should be <0.5 and the Fig. 6 illustrates that the ECC at resonance frequency is <0.005.

$$\text{ECC} = \frac{a}{b} \qquad (2)$$

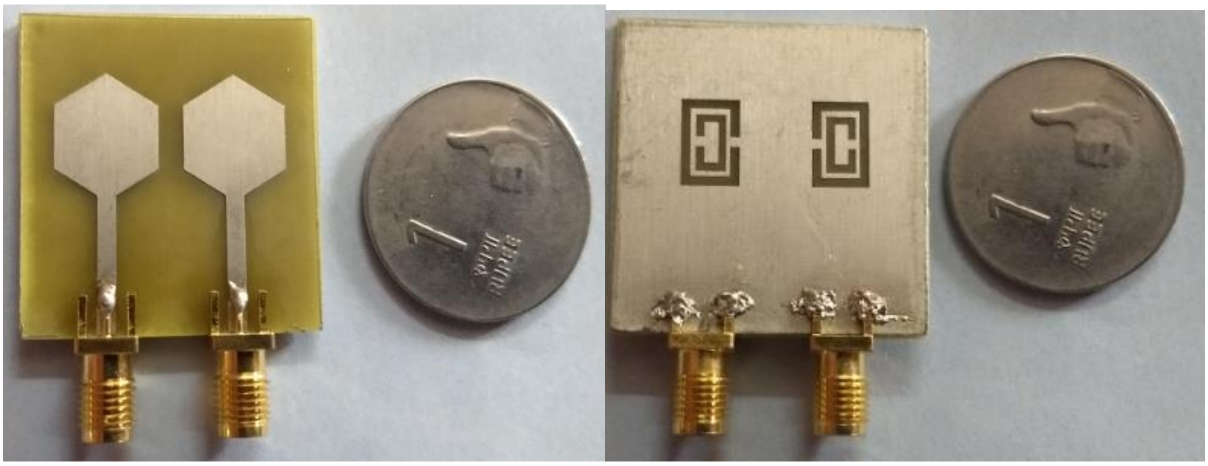
where

$$\text{'a'} = |S_{11} * S_{21} + S_{12} * S_{22}|^2$$

and

$$\text{'b'} = |(1 - |S_{11}|^2 - |S_{21}|^2)\,(1 - |S_{22}|^2 - |S_{12}|^2)|$$

To validate the simulation results the antenna is fabricated on a FR4 substrate material and measured using network analyzer. Fig. 7 represents the proposed antenna's fabricated prototype. Fig 7(a) shows the top view of the antenna array with a 2 mm distance separation between the two patches. In Fig 7 (b) CSRR can be seen etched on the ground plane with a 7 mm distance separation between two CSRR cells. The position of placement of CSRR cells on the ground plane has a significant effect on the mutual coupling characteristics. Reflection coefficient and mutual coupling characteristics of the proposed antenna array is plotted in Fig. 8. The measured and simulated results are in good agreement with a reduction of -24 dB mutual coupling. The simulated peak gain of the proposed design is shown in Fig. 9 and is observed to be 5.62 dB.



*(a)* *(b)*

*Fig. 7. Fabricated prototype (a). Top view (b). Bottom view (color online)*

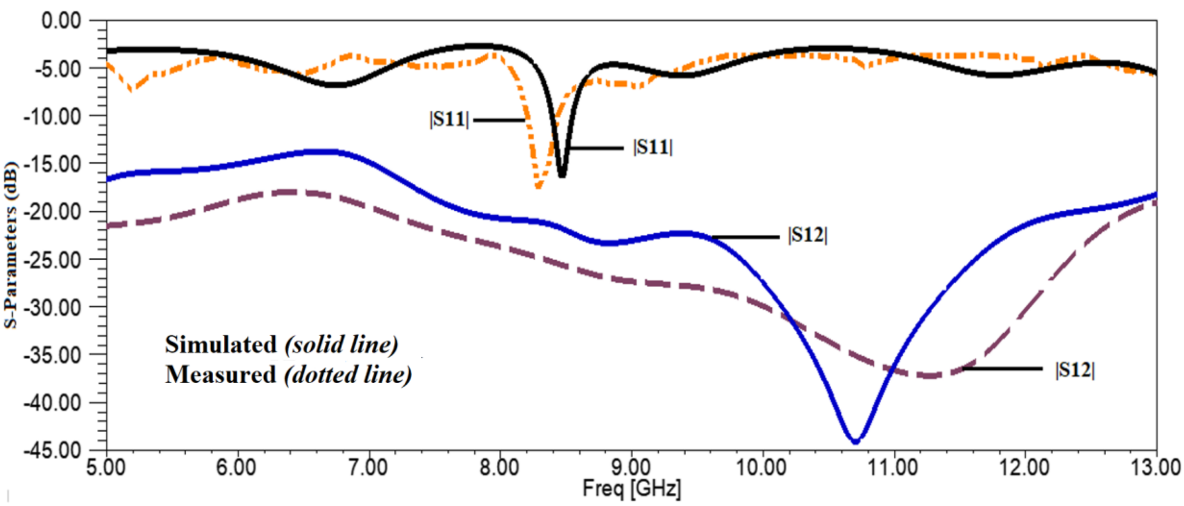



*Fig. 8. Simulated and Measured reflection coefficient and mutual coupling characteristics (color online)*

Fig. 10 represents the simulated radiation characteristics of antenna array with and without CSRR at the operating frequency in boresight direction (Phi= 0 and 90 degrees). It can be observed that there a slight variation in the radiation characteristics of antenna array with and without CSRR at the resonant frequency, which says that the CSRR structure used in the design can diminish the mutual coupling without affecting the characteristics of radiation. Fig 11 illustrates the measured radiation characteristics at the boresight, which explains that at Phi=$0^0$ there is an omnidirectional pattern and at Phi= $90^0$ there is bidirectional pattern.

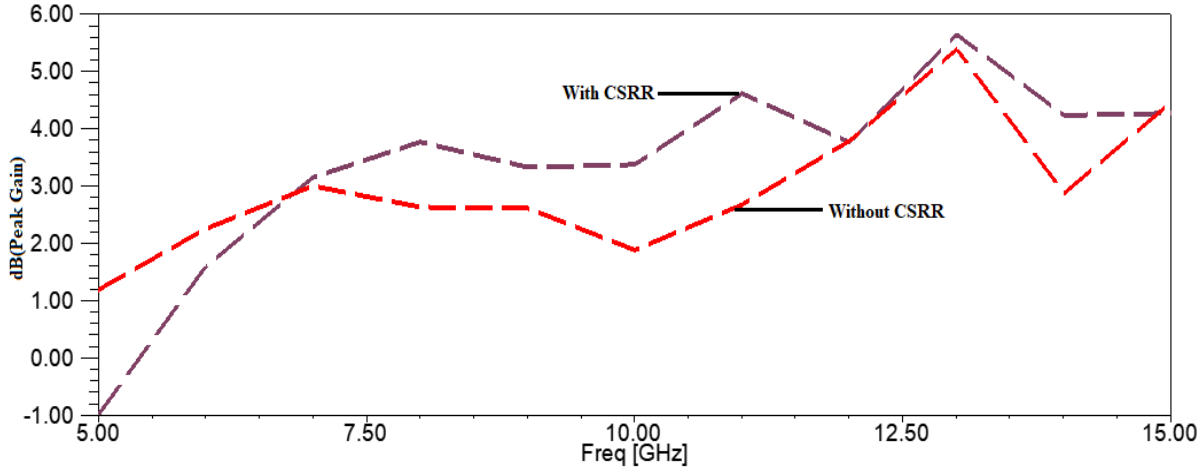
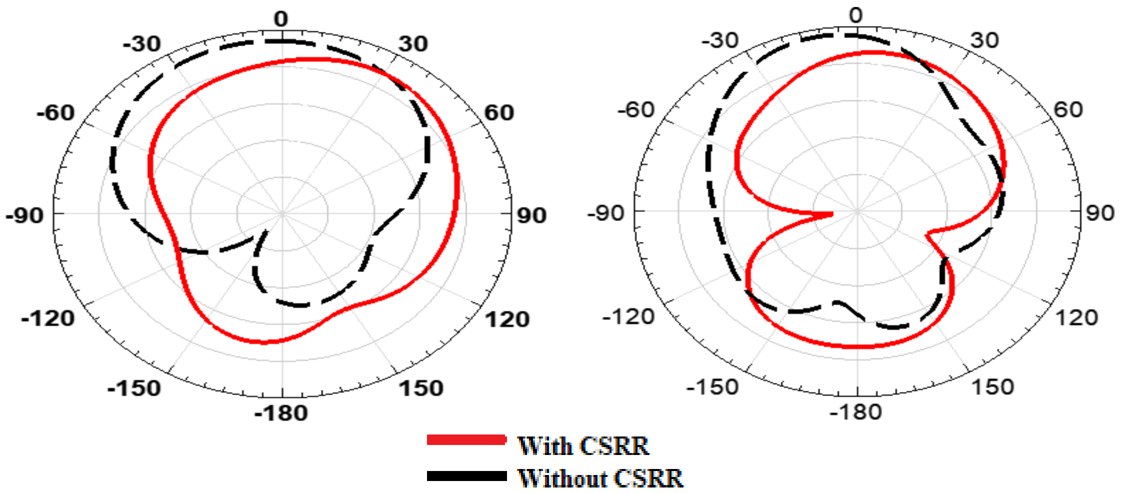



*Fig. 9. Simulated Peak Gain of the proposed design (color online)*




*(a)* *(b)*

*Fig.10. Simulated radiation characteristics of antenna array with and without CSRR at the boresight (a) Phi=0 (b) Phi=90 (color online)*

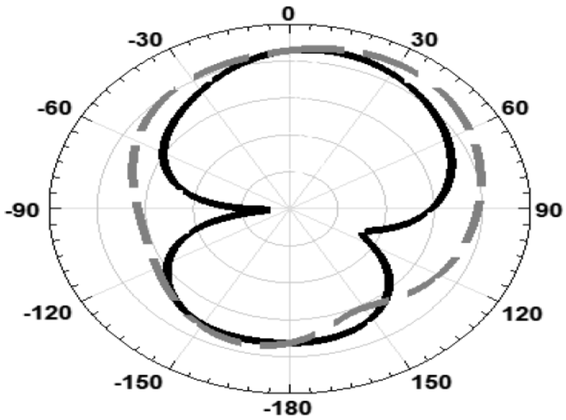



*Fig 11. Measured radiation characteristics at the boresight, Phi= $0^0$ (dotted line) and Phi= $90^0$ (solid line)*

*Table 2. Comparison of proposed work and existing work*

| S.No. | Ref. No. | Approach | Size of the array in $mm^2$ | Frequency ($f_0$) In GHz | Edge to Edge spacing | ECC | Improvement in S12 (dB) |
|---|---|---|---|---|---|---|---|
| 1 | 16 | Multilayer Dielectric + EBG | 130 x 130 | 3.0 | 40 mm | <0.5 | 10 |
| 2 | 17 | Uniplanar EBG over Superstrate | 78.3 x 78.3 | 5.75 | 26 mm | <0.5 | 10 |
| 3 | 18 | DGS | 63.5 x 40.0 | 9.2 | 8.6 mm | <0.3 | 16.50 |
| 4 | 19 | PCI | 54 x 60 | 5.8 | 20.5 mm | <0.1 | 19.6 |
| 5 | 20 | Asymmetric Loop Resonator | 100 x 60 | 4.2 | 5 mm | <0.1 | 18.6 |
| 6 | 21 | Differential Feeding | 43 x 20 | 16 | 3.5 | <0.4 | 17 |
| 7 | Proposed work | CSRR | 32 x 32 | 8.5 | 2 mm | <0.005 | 24 |

A comparative study of mutual coupling reduction using various design techniques is shown in Table 2. It can be concluded from the comparative study that; a lower profile is occupied by the proposed antenna with a very low ECC and edge to edge spacing maintained between radiating elements is also very minimum.

## 5. Conclusion

A compact two element antenna array loaded with CSRR on the ground plane is demonstrated to supress the coupling between closely spaced patch elements. With an edge to edge spacing of 2 mm, -24 dB reduction in coupling is achieved at the operating frequency. With the ejection of CSRR on the ground plane enhancement of coupling reduction took place from -10 dB to -24 dB. When compared with the simulated results the measured results are observed to be in good agreement. It is interesting to be noticed that when compared with the existing works the edge to edge spacing maintained between patch elements is just 2 mm and the ECC is very minimum. The proposed antenna can be used in X- band applications.

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