Design and Performance Analysis of Compact MIMO Antenna by Mutual Coupling Suppression between Elements

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***Abstract*— Modern wireless communication systems require low profile, light weight, high gain, and simple structure antennas to assure reliability, mobility, and high efficiency characteristics. Microstrip antennas provide such requirements. This paper presents a compact microstrip antenna array designed for WLAN application. The designed antenna array works in the frequency range of 5.3143 to 5.6291 GHz by using FR4 dielectric substrate with permittivity ε_r= 4.4 and height, h =1.588 mm. The small spacing between the array elements results in strong mutual coupling, which has been shown to affect the performance by changing the antenna pattern and reducing the antenna efficiency. To mitigate the aforesaid coupling effects, a novel Ring Resonator (RR) Structure was employed in the microstrip antenna array. The proposed structure reduces mutual coupling by 10dB at λ/8 element spacing. The simulation has been performed by using HFSS simulator. The designed antenna arrays were fabricated and tested using National Instrument's NI-PXIe-1075 Spectrum Analyzer.**

***Keywords*— array antenna, metamaterials, microstrip antenna, mutual coupling**

I. INTRODUCTION

Present communication devices employ MIMO antennas to achieve high speed and high quality transmission to transmit large user data. Also, modern wireless communication system requires low profile, light weight, high gain and simple structure antennas to assure reliability, mobility, and high efficiency characteristics. Microstrip antennas satisfy such requirements [1]. The advantages of microstrip antenna over others is the ease of construction, light weight, low cost and conformability to mounting surface which makes them suitable for use in modern communication equipments. The design of compact MIMO antennas for several applications was discussed in [2-5]. The major issues addressed in these literatures were mutual coupling that arise due to small antenna separation. Techniques to reduce the coupling between antennas include a dielectric slab EBG [6], inclusion of parasitic elements in the spacing [7], modified ground planes such as UC-PBG defects with diagonal slots on patch [8], concave rectangular patches [9]. Engineered structures such as metamaterials were also used for coupling reduction. The most popular among them are the split ring resonators (SRR) and their variants [10-13]. The reference [14] discusses a mathematical approach to reduce mutual coupling that includes impedance matching technique and [15] derive the expressions for mutual coupling between the rectangular patch elements. The expression emphasizes the effect of element spacing on the mutual coupling. Also, an expression for far field radiation pattern for microstrip antenna arrays taking into account the mutual coupling was derived.

In this paper, we investigate the design and performance of a microstrip antenna array with a novel Ring Resonator structure that is included between the antenna elements for mutual coupling reduction. The effects of the inclusion of this structure on antenna performances are also studied. The paper is organized as follows: Section II gives antenna design; sections III and IV provide simulation results and effects of mutual coupling on antenna performance.

II. ANTENNA DESIGN

A. Microstrip Array Design

A rectangular patch antenna array with two elements, as shown in Fig.1, is etched on a common ground plane with each element resonating at 5.5GHz. An FR4 substrate with ε_r =4.4 used for the simulations.

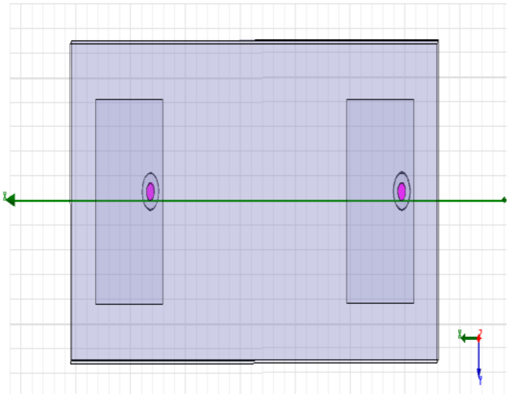

Fig.1. Rectangular Patch Antenna array simulated on FR4 substrate using HFSS tool.

The antenna array dimensions, material properties and operating frequency details are shown in Table.1.

TABLE 1: ANTENNA ARRAY SPECIFICATIONS

Parameters	Specifications
Frequency of Operation	5.31 GHz to 5.62 GHz
Resonant Frequency	5.5GHz
Substrate	FR4 epoxy
Height of the Substrate	1.58mm
Length of the Patches	16.598 mm
Widht of the Patches	12.219 mm
Dielectric constant	4.4
Distance between antennas	30mm

The width of the radiating edge is predicted by the following formula [1]

$$w = \frac{V_0}{2f_r}\left(\sqrt{\frac{2}{\varepsilon_r + 1}}\right) \qquad (1)$$

Where, f_r is the resonant frequency (5.5GHz), ε_r is the dielectric constant of the substrate and V_o is the velocity of light in free space = 3e8 m/s. The width obtained from (1) is 16.598 mm. A separation of 30 mm was maintained between the antennas. The photograph of the fabricated antennas is shown in Fig.2.

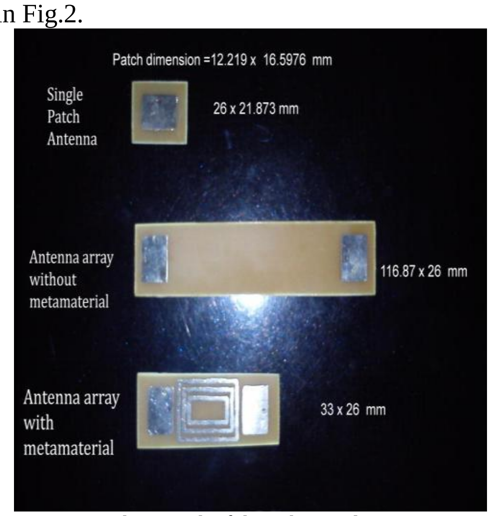

Fig.2. Photograph of the Fabricated Antennas

B. Ring Resonator and its Design

The developments in wireless devices increased the need for more compact antenna designs. But this compactness leads to severe degradation in gain and directivity due to near field interactions and strong mutual coupling between the antenna elements. Therefore, suppressing this coupling in the array is essential for better performance in MIMO systems.

Ring resonators were used for the purpose of reducing the mutual coupling between antenna elements. Four rings employed between the antennas with $\lambda/2$ spacing between them are shown in Fig.3. Each ring is of 1.7mm width and 0.1 mm height with spacing between the rings equal to 0.8 mm in x-direction and 1.3mm in y-direction. The rings are made of low cost copper material with relative permittivity ε_r =1. The rings are supported by FR4 substrate with ε_r =4.4.

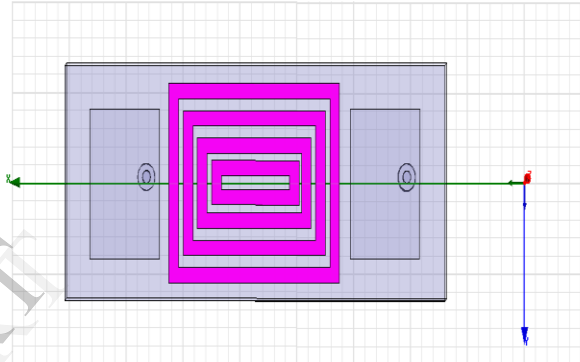

Fig.3. Ring Resonator Structure employed between antenna elements with λ /2 spacings between them

The ring dimension and spacing are optimized to get lowest mutual coupling. The surface current plot of the RR based array designed using HFSS tool is shown in Fig.4.

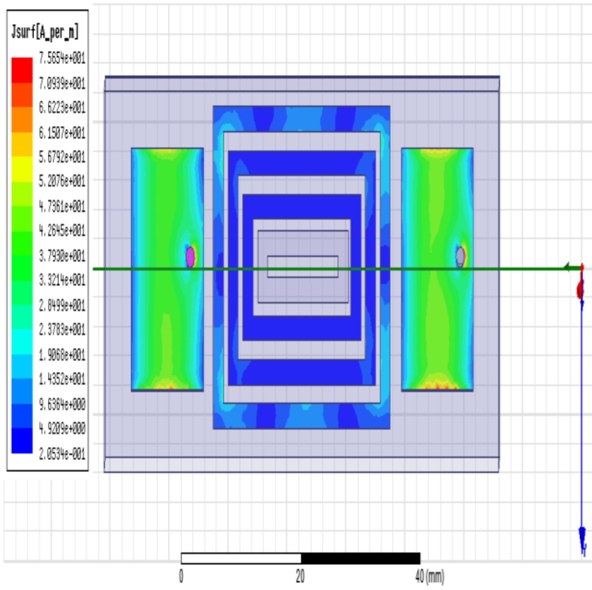

Fig.4. Surface Current Plot for Antenna Array with RR for mutual coupling reduction between elements simulated using HFSS.

The RR localizes the currents within the antenna (green colour) and thereby contributes in the reduction of mutual coupling.

III. Simulation Results and Testing

The mutual coupling between the antennas was analyzed in terms of electrical isolation (S_{21}) between the two ports for different element spacing in wavelengths. The result of this analysis is shown in Table.2.

TABLE 2: MUTUAL COUPLING AND ARRAY SIZE FOR DIFFERENT SPACINGS BETWEEN ANTENNA ELEMENTS

Distance Between Antennas In Wavelengths	**Array Size In mm**	**Mutual Coupling Without Ring Structure In dB**	**Mutual Coupling With Ring Structure In dB**
λ/2	66.873 x 26	-31.562	-45.9076
λ/4	46.873 x 26	-24.9963	-31.6265
λ/8	39.873 x 26	-23.319	-33.54

It can be observed that there is around 10 dB mutual coupling reduction in all the cases and array experiences 59% reduction in size to obtain same amount of mutual coupling as obtained in λ/2 without Ring Structure. The HFSS plot for mutual coupling reduction in λ/8 case is shown in Fig.5.

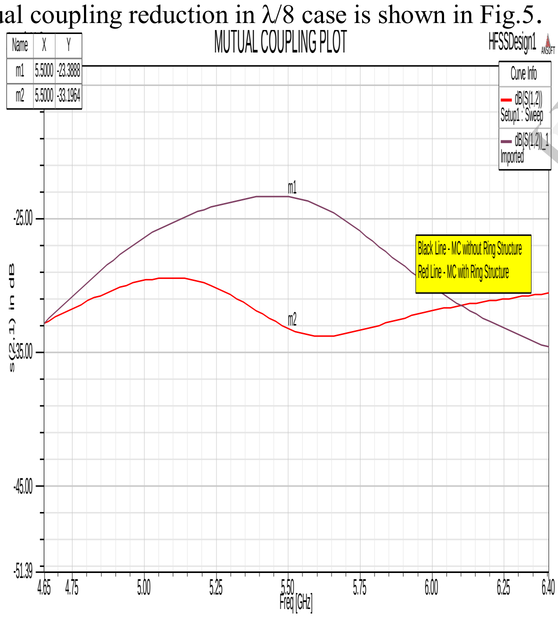

Fig.5. Mutual Coupling Plot for λ/8 element spacing between antennas

The fabricated antennas were tested using National Instrument's Spectrum Analyzer, NI-PXIe-1075. The Antenna Under Test (AUT) is connected to RF cable with the help of SMA connector on the receiving side. The experimental setup is shown in Fig.6.

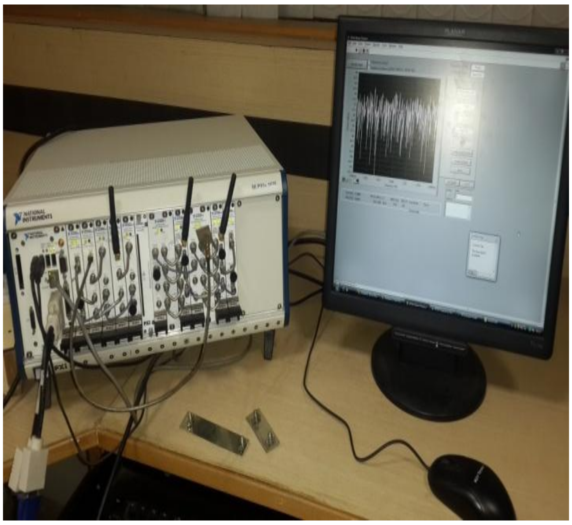

Fig.6. Experimental set-up with spectrum analyzer

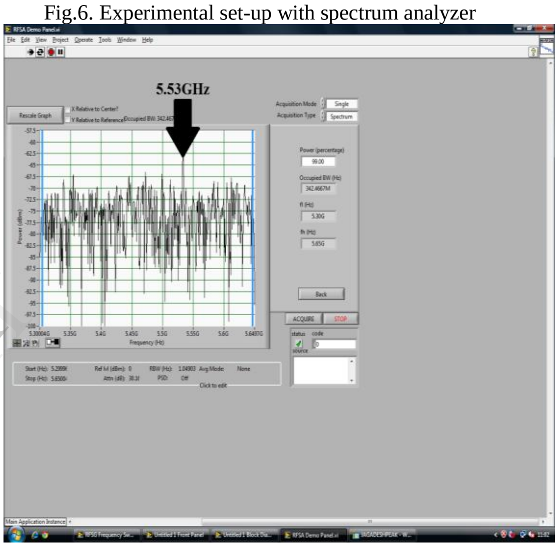

Fig.7. Spectrum Analyzer output for Patch Antenna

The spectrum analyzer output for single patch is shown in Fig.7. It shows that the peak received power is -62.5dBm at 5.53GHz indicating that it is the resonant frequency. The bandwidth obtained is 342MHz. The antenna is having an attenuation of 30dB. The distortions are a function of amount of metal used and location of soldering.

TABLE 3: COMPARISON OF SIMULATED AND MEASURED PATCH ANTENNA RESULTS

Parameters	**Simulation Results P1**	**Testing/Measured P2**	**Percentage Deviation from simulation (P1~P2)/P1 %**
Resonant frequency	5.5GHz	5.53GHz	5.4 (300MHz)
Bandwidth	300MHz	342MHz	14 (42MHz)
Resonant frequency	5.5GHz	5.53GHz	5.4 (300MHz)

Comparison between simulated and measured patch antenna result is shown in Table 3. There is a 300MHz shift in resonant frequency of AUT compared to the simulated one. This shift will not create a problem as the AUT's resonating frequency is within the frequency range (5.31-5.62 GHz) for which the antenna was designed. There is an increase in the bandwidth of AUT by 42 MHz compared to simulated one which is 14% shift. Both the parameters measured deviate by less than 15% compared to simulation owing to the accuracy of simulator. The deviation of measured patch antenna performance from the simulated results can be accounted for fabrication and human errors (setup arrangement /variation) during antenna testing.

IV. Effect of Mutual Coupling on Antenna Performance of λ /8 Element Spacings Between the Antennas

The analysis on the impact of mutual coupling is made for λ/8 element spacing between the elements and assumes similar effects on other element spacing.

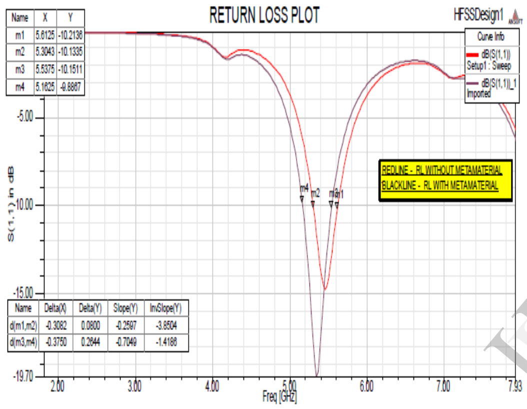

Fig.8. Return Loss Plot in dB for λ/8 Element Spacing Between the Elements

From Fig.8 we see that almost the same bandwidth is achieved in with and without RR cases. (0.3GHz). Return loss in with RR case is more compared to without RR case but is slightly shifted in resonant frequency which can be overcome by adjusting antenna dimensions.

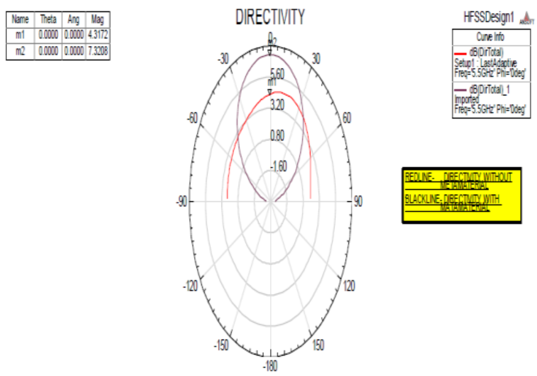

Fig.9. Directivity Plot dB for λ/8 Element Spacing Between the Elements

From Fig.9 we see that the directivity in with RR case is more than without RR case by 3dB. The directivities are measured at Phi=0 deg. The ring resonator reduces the radiation of the antenna in undesired direction and increases the radiation only in the desired direction.

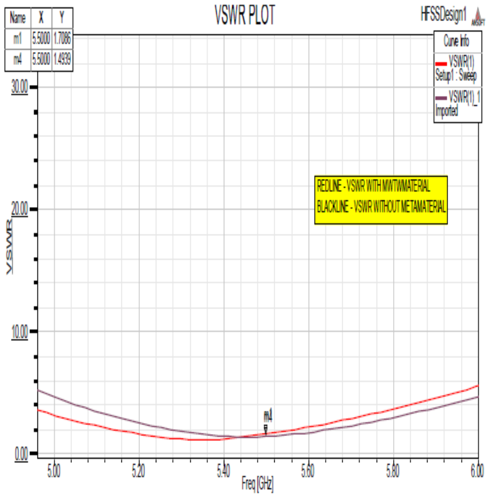

Fig.10. VSWR Plot for λ/8 Element Spacing Between the Elements

The VSWR with RR is 1.7 and without RR it is 1.47. In both the cases VSWR is maintained below 2. The VSWR in RR case is more because of current flowing between the antenna elements resulting in standing wave pattern.

V. Conclusion

In this paper, bulkiness of the designed antenna array system was treated for miniaturization by reducing the mutual coupling between the elements. The proposed ring resonator structure reduces mutual coupling by 16dB at λ/2 element spacing, and 10dB at λ/8 element spacing. Also the array size was reduced to 59% to obtain same amount of mutual coupling as obtained in λ/2 without Ring Resonator Structure. The simulation has been performed by using HFSS simulator which is a commercially available antenna simulator. The designed antenna arrays were fabricated and tested using National Instrument's NI-PXIe-1075 Spectrum Analyzer. The simulated and measured patch antenna performances such as Bandwidth and Resonant Frequency showed less than 15% deviation which also depicts the efficiency of the simulator.

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