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Antenna Array with Reduced Inter-Element Displacement for Wireless Communication

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ABSTRACT
The paper proposes a novel antenna array design of patch antenna loaded with split ring structure, in the frequency band 2.7GHz. First, single structure was designed and analyzed then an array was constructed to increase the Directivity & Gain. Correlation co-efficient of array was calculated to find its suitability in MIMO specific applications. Three arrays were designed by varying inter-element displacement then a comparison was made to deduce the suitability of antenna in MIMO specific applications. Purpose of reducing inter-element displacement is to reduce the size of array

The performance of the array was investigated in terms of relevant parameters viz. impedance bandwidth, gain, axial ratio and efficiency.

The proposed antenna with reduced inter-element displacement exhibits good performance in terms of radiation efficiency and impedance bandwidth. Hence could be suitable candidate for wireless communication.

General Terms
Antenna Design, Simulation, study of results, MATLAB software.

Keywords
Array Antenna, Split Ring Resonator, MIMO, wireless communications, correlation coefficient.

1. INTRODUCTION
Today is the communication age, several wireless communication techniques like WiMAX, 3G, 4G and 5G has been introduce to increase capacity, range and reliability of communication. Multiple antenna techniques are the technique to enhance these parameters. MIMO is one of the technique by which both coverage and capacity of wireless mobile communication be enhanced.

MIMO is a multiple input multiple output antenna technique. MIMO is a technology which is used at both transmission and receiver equipment for wireless radio communication. It uses multiple antennas to send multiple parallel signals from transmitter. At the receiver, signal can be processed by relevant algorithm and special signal processing to sort out the multiple signals to produce single originally transmitted data. At the receiver end signal can be received and combined by using diversity techniques. [1-4,7,8]

Correlation coefficient is one of the parameter through which the capability of antenna in MIMO application can be identified. It is evaluated by the help of S parameters through the following equation.[6]

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

Where,

S_{11}* - Complex conjugate of S_{11}
S_{21}* - Complex conjugate of S_{21}
$|S_{11}|$ -Modulus of S_{11}
$|S_{12}|$ -Modulus of S_{12}
$|S_{21}|$ -Modulus of S_{21}
$|S_{22}|$ -Modulus of S_{22}

In the present paper, a multiple element antenna formed with Square Split Ring (SR) Array has been proposed. Proximity coupled feed is used to magnetically couple the SR array of two elements. For each array correlation coefficient was calculated and a relation between inter-element displacement and correlation coefficient is investigated. The designed antenna is aimed to give qualitatively better performance as compared to patch antenna and could be employed for MIMO applications.

2. DESIGN OF PROPOSED ANTENNA
Proposed antenna is designed using standard formula for patch antenna design. The effective length and width of the antenna can be calculated by the following formula.[5]

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} = \frac{\upsilon_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}}$$

The actual length and effective length of patch antenna is found as equation above.

$$L = \frac{1}{2f_r\sqrt{\epsilon_{\text{reff}}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L$$

$$L_{\text{eff}} = L + 2\Delta L$$

Where,

Fr	=	resonant Frequency.
μ_0,μ_r	=	Free Space & Relative Permeability
ε_0,ε_r	=	Free Space & Relative Permittivity
v_0	=	Speed of light.
L_{eff}	=	Length of patch antenna
W	=	Width of patch antenna.

Length L of antenna is 56mm and width of antenna is evaluated to be 25mm for frequency 2.7GHz. Two square split ring resonators (SRR) are designed with 25mm X 25 mm dimension. SRR is placed on the ground plane. Design parameters for this structure are chosen to be FR4 substrate with the height of 1.588mm, relative dielectric constant of 4.4 and a loss tangent of 0.0002.

A uniform linear array of this antenna element is then formed. Inter-element displacement (d) was kept of the order of λ/2, λ/4, λ/8 which is approximate equal to 57mm, 28.205mm, 12.05mm respectively for the resonant frequency of 2.7 GHz. Fig. 1 shows the array of antenna design in software which consists of two antenna elements having inter-element displacement 57mm.

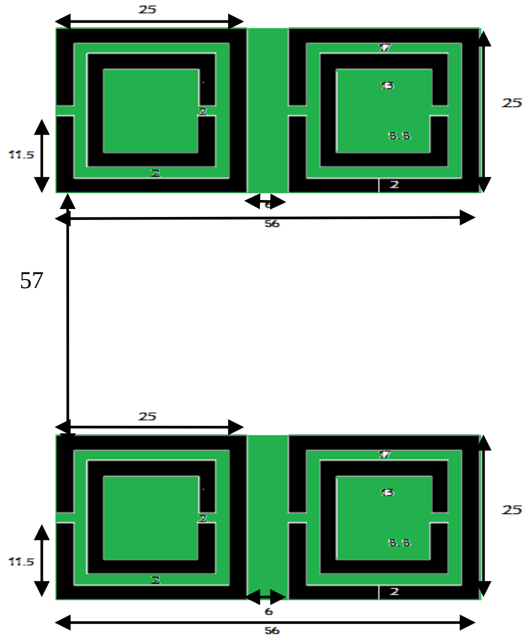

Fig. 1: Antenn array with element spacing of 57 mm. (All Dimensions in mm)

Over all structure of designed antenna is as shown in Fig 2.

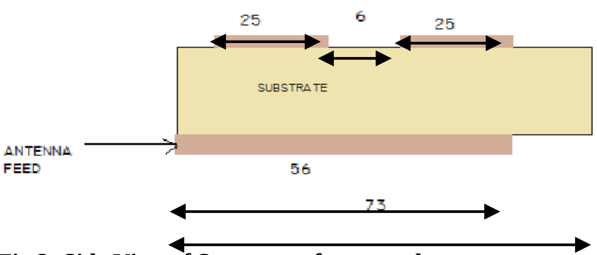

Fig 2: Side View of Structure of proposed antenna array. (All dimensions in mm)

Three different design were made in IE3D software and simulated. The structure of all the three design was same but the inter-elements displacements were varied.

DESIGN 1- In this antenna array design the inter-element displacement was kept λ/2 which is equal to 57mm for the resonator frequency of 2.7GHz.

DESIGN 2- In this antenna array design the intre-element displacement was kept λ/4 which is equal to 28.205mm for the resonator frequency 2.7GHz.

DESIGN 3- In this antenna array the inter-element displacement kept λ/8 which is equal to 12.05mm for resonator frequency of 2.7GHz.

3. RESULTS AND DISCUSSIONS

Proposed array of antenna was design in IE3D and simulate using MODUA engine. Simulation of the rectangular patch loaded with SRR was done and various parameters have been investigated.

The S parameter was observed for each design as shown in Fig 6 and was found to be same for all. With the help of equation 1 correlation coefficient was calculated by using MATLAB code which was developed by us.

3.1 Correlation coefficient calculation

In the expression, equation 1, of correlation coefficient S_{11}, S_{12}, S_{21}, S_{22} are the complex numbers. The magnitude and conjugate of these complex numbers can be taken in excel sheet. This excel sheet can be read by MATLAB thereby calculating the correlation coefficient of antenna array.

The correlation coefficient was calculated for all three designs as shown in the Table I. Graphs between frequency vs correlation coefficient were plotted as shown in Fig. 3 to Fig. 5 for three designs respectively.

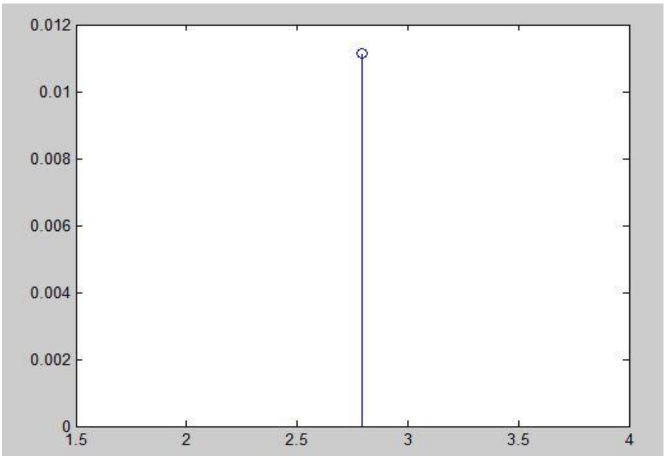

Fig 3: correlation coefficient versus freq. for d= 12.05mm

The correlation coefficient versus frequency curve at resonant frequency of design 2 is shown below.

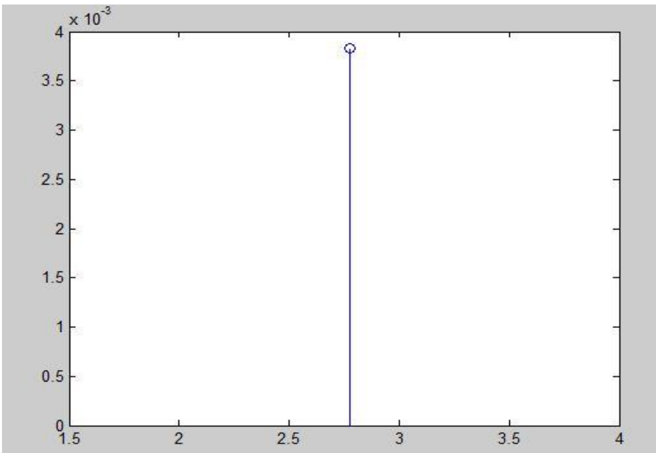

Fig 4: correlation coefficient versus freq. for d= 28.205mm

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The correlation coefficient versus frequency curve of design 1 is shown below.

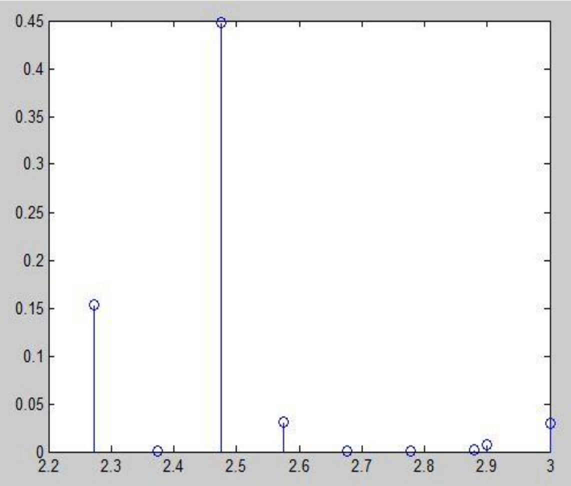

Fig 5: correlation coefficient versus freq for d=57mm

The correlation coefficient is not a function of frequency as it can be seen from the expression of correlation coefficient. But S parameters are the function of frequency, so correlation coefficient becomes an indirect function of frequency. The curve between frequencies versus correlation coefficient can be drawn using MATLAB.

The value of correlation coefficient for different inter-element displacements at frequency 2.7Hz which was obtained from MATLAB codes is shown below in form of Table 1.

Table ICorrelation Coefficient at different distances

S. No.	Frequency in GHz	Inter-element displacement (d in mm)	Correlation coefficient (ρ)
1	2.793	12.05	0.0111
2	2.778	28.205	0.0038
3	2.773	57	0.0012

Above table shows the values of three designs with different inter-element displacements of an antenna array and dependency of correlation coefficient on it. By the analysis of the above table it was deduced that correlation coefficient is decreases with increase in distance. All three designs were resonating at same frequency which is equal to 2.7GHz which indicate that by changing the inter-element displacement of array, its resonant frequency do not change. Return loss with minimum inter-element displacement was found to be below -20db and with maximum inter-element displacement was below -15db as shown in Fig 6. Similarly Radiation & Antenna Efficiency also remains unchanged i.e. 100% for all three designs as shown in Fig 7.

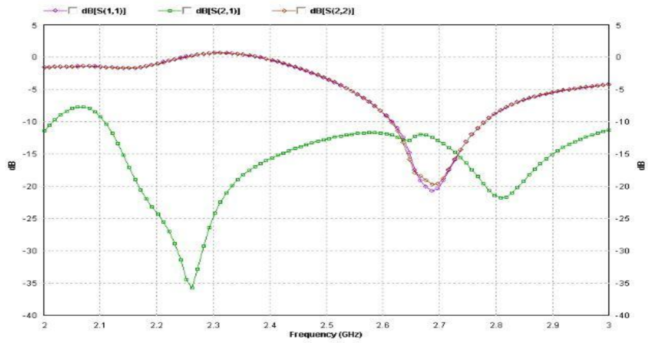

Fig 6:- Return loss versus frequency for design 3

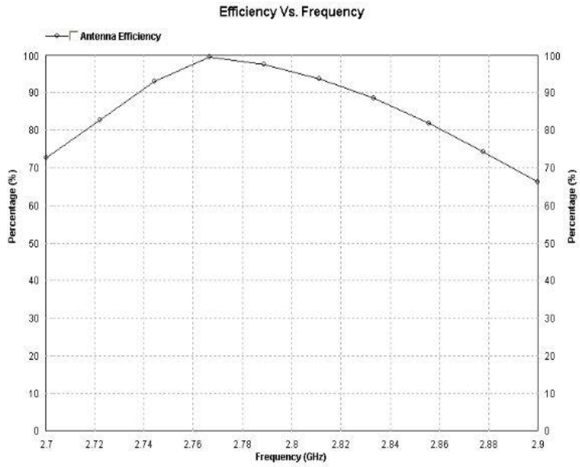

Fig 7:- Efficiency versus frequency for design 3

4. CONCLUSION

In this paper, advance antenna technique for MIMO application with two antenna element in an array is presented. The inter-element displacement of an antenna array was reduced and correlation coefficient was calculated in each cases. Thus it has been investigated that correlation coefficient is inversely proportional to the inter-element displacement. It was also found that practically inter-element displacement, in an array should be λ/4, but in the design proposed here, it is further reduced without effecting the performance of the array. The structure is therefore reduced in size. For the inter-element distance of array as 12.05mm (λ/8), 28.205mm (λ/4) and 57mm (λ/2), the correlation coefficients are calculated to be 0.0111, 0.0038, and 0.0012 respectively.

The proposed antenna design 3 therefore exhibits better performance in terms of correlation coefficient and could be suitable candidate for wireless communication using MIMO technique.

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