Novel dual-band B-shaped printed monopole antenna for MIMO application

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A novel dual-band B-shaped printed monopole antenna for MIMO wireless application is presented in this paper. The proposed antenna consists of B-shaped element which operates at dual-band frequencies (2.45 and 5.8 GHz). The antenna has been simulated using CST software and the prototype has been fabricated on FR4 substrate. The impedance bandwidths (BWs) that have been achieved are 29.9% and 33.8% for 2.45GHz and 5.8GHz bands respectively. The mutual coupling and correlation coefficient have also been investigated in which the antenna provides -22dB of mutual coupling and 0.02 of correlation coefficient. The proposed design achieves low mutual coupling and correlation coefficient at a separation distance of $\lambda/12$ between antenna arrays. There is good agreement between the measurement and simulation results in terms of return loss and radiation pattern.

1. Introduction

The use of multiple inputs multiple output (MIMO) systems in the wireless communications are becoming increasingly popular in the current research trends due to increased traffic capacity without increasing the bandwidth and transmit power. The use of MIMO can enhance performances of the traditional wireless communication as it takes the advantage of the rich multipath environment to increase the capacity [1].

In MIMO systems, the challenge in antenna design is due to the effect of radiation pattern, mutual coupling, antenna configuration and array size in the MIMO performance [2]. One of the critical issues in MIMO antenna design is to reduce the correlation between the received signals and the mutual coupling between the antenna elements. Mutual coupling is an important parameter which affects the correlation coefficient; and the former is also affected by the spacing and orientation of the antenna arrays. The separation between two antennas is very limited in modern compact mobile devices, thus requiring the two antennas to be placed as close as possible; but the cost of which is the increase in mutual coupling. In [3] it has been shown that for good mutual coupling to be attained, the minimum distance between the antenna array should be at least half of the wavelength, $\lambda/2$. However, $\lambda/2$ separation is still considered as being very large in small devices due to very limited space. A number of antenna designs for multi-band and MIMO applications have been reported in the literature [4-8]. In [4] tri-band E-shaped printed monopole antenna for MIMO application has been reported. The mutual coupling and correlation coefficient are -15dB and < 0.002, respectively, while the spacing between the antenna elements is $\lambda/10$. Two element Planar Inverted-F Antenna (PIFA) array antenna operating at 5.2GHz has be reported in [5]. The bandwidth was 310MHz, the isolation was better than 20dB and the separation between the two antenna elements was 20 mm, which is less than half the wavelength. In [6] compact C-shaped monopole array antenna operating at 2.4GHz was reported, with an isolation of less than -12dB at a separation distance of $\lambda/10$ between antenna array element. However, most of these designs are still large in size, which therefore motivates the need to come up with new designs that have the capabilities of improving such antenna characteristics as mutual coupling, radiation pattern and correlation coefficient. Different types of feeding techniques which are commonly used in antenna designs include microstrip feeding and Coplanar Waveguide (CPW) feeding.

A lot of techniques have been researched on CPW-fed antenna for wireless communications due to its simple structure and ease of integration with the active devices[9]. Nowadays, the printed monopole antennas are most widely used because of compact size and ease of integration with the portable communication devices. The antennas also have wideband characteristic, omni-directional radiation pattern, high radiation efficiency [9-11].

In this paper, a novel B-shaped printed monopole antenna with dual band for MIMO wireless communication is presented. The proposed antenna satisfies the 2.45 GHz and 5.8 GHz bandwidth requirements. The antenna consists

of B-shaped structure fed by a CPW and rectangular ground plane placed behind the antenna. The antenna provides 10dB impedance bandwidth of 564 MHz and 719 MHz for 2.45 GHz and 5.8 GHz respectively. The antenna can be applied in MIMO wireless communication. In the proposed antenna, orthogonal configuration of the antenna array has been used in all the analyses as they give low mutual coupling, low correlation and better radiation pattern. The simulations were done using CST Microwave studio 2010 and simulated and measured results have been compared.

The paper is organized in section as follows. In section 2, the antenna design fed by CPW is presented. Section 3 describes the B-shaped monopole antenna with parametric studies which shows the effects of different parameters on the proposed antenna. In section 4, the reflection coefficient and radiation characteristics of the proposed antenna and MIMO characteristics of the antenna has been presented and discussed. Lastly, in section 5 concludes the paper with the proposed antenna with good characteristics which have been achieved in MIMO applications.

2. Antenna Design

The geometry and parameters of proposed B-shaped Dual-Band printed monopole antenna is shown in Fig. 1. An inexpensive FR4 substrate, having a permittivity of 4.4, a thickness of 1.6 mm and loss tangent of 0.019, has been used for the antenna fabrication. The structure comprises of two semi-circular patches with semi-circular slots and rectangular shape with rectangular slots which are connected to the semi-circular slot of the semi-circular shape to form the B-shaped. The B-shaped creates changes in the current flow in order to achieve dual band frequencies which are due to the two semi-circular slots. At lower frequency band (2.45GHz) the current flows in the lower part of the B-shape while at upper frequency (5.8GHz) the current flows in the upper part. The rectangular shape without the semi-circular shape provides single frequency. When the semicircular shape is introduced, a new resonance is created to provide the dual frequency band. The semi-circular slots introduced in the structure improve the radiation pattern of the proposed antenna.

The proposed antenna uses CPW-feed with a loaded rectangular patch at lower side of the substrate. The rectangular ground plane has a length of L_{gnd2} and its width is equal to the substrate's width. The loaded patch at the ground is used to improve the impedance bandwidth and lower the operating frequency of the proposed antenna.

The optimum design was obtained after several optimization processes. The final dimension of $20 \times 37 \times 1.6\ mm^3$ has been obtained. The parameters of the optimized design are shown in Table 1. The antenna prototype is shown in Fig. 2. In this article, a two elements antenna array has been proposed as shown in Fig. 3 (a) and (b). Full detailed explanations were presented in Subsection 4.2.
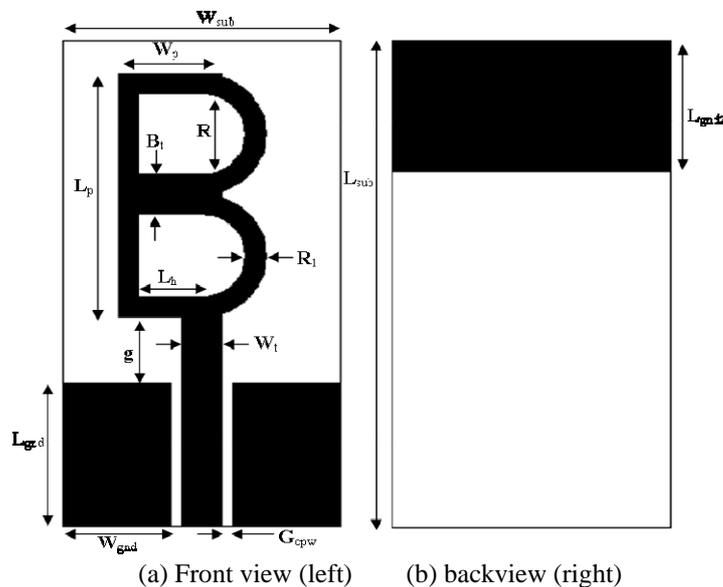

(a) Front view (left)   (b) backview (right)

Fig. 1. Geometry of the B-shaped monopole antenna (a) Front view (left) and (b) backview (right).

Fig.2. Prototype of the proposed antenna

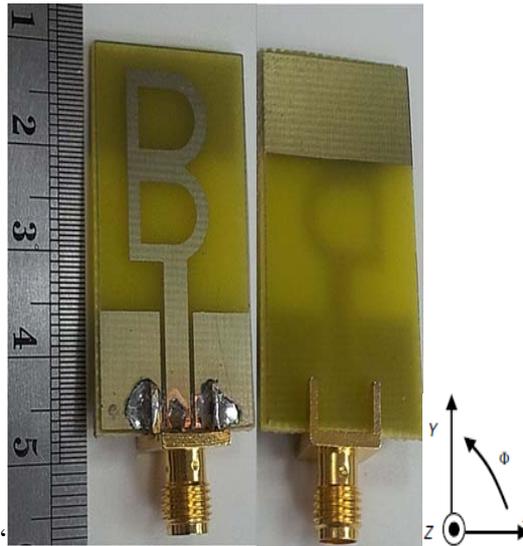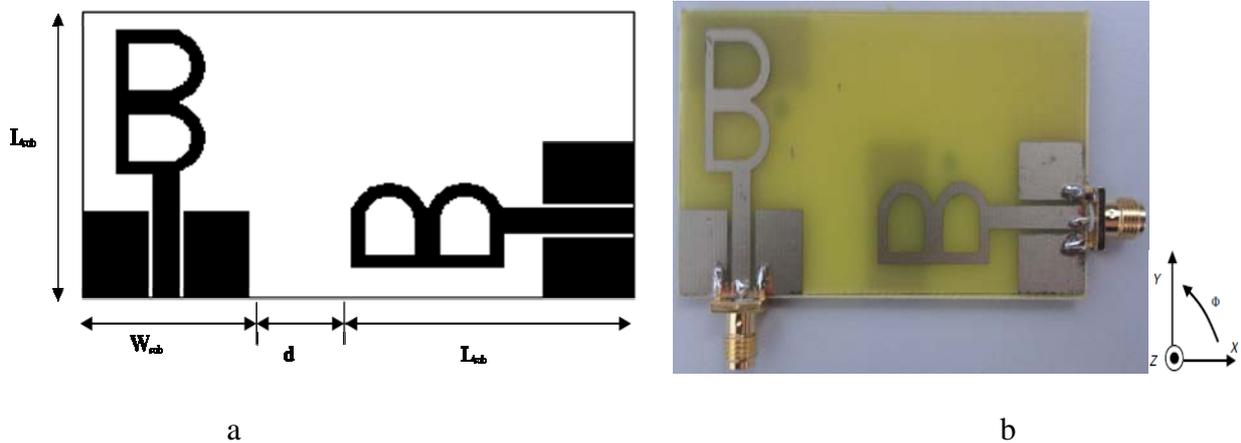a   b

Fig. 3. B-shaped monopole antenna array (a) Geometry and (b) Prototype.

Table 1. Optimum antenna parameters

Notation	L_{gnd}	L_{gnd2}	L_h	L_p	W_f	W_p	W_{sub}	G_{cpw}	g	L_{sub}	R	R_1	B_t	W_{gnd}
Value (mm)	11	10	4.6	18.5	3	12	20	0.8	5	37	4.6	1.5	3	7.7

3. The parametric studies of the b-shaped monopole antenna structure

In this section the parametric studies of the B-shaped monopole antenna have been done to investigate the effect of different parameters in the antenna performance. The effect of varying the B-slot, L_h, feed gap, g and length of the second ground plane, L_{gnd2} .was studied. The performance of B-shaped monopole antenna with different lengths L_h of B-shape slot and length of second ground plane length were

analyzed in terms of the reflection coefficient and radiation pattern while keeping the other parameters of the proposed antenna the same. The value of L_h was varied from 3mm to 5mm. Fig. 4(a) shows the results of simulated return loss for different values of B-slot. It is observed that the variation of B-slot has significant influence on the upper resonant frequency F_H, but the lower resonance frequency F_L remain unaffected. Increasing the value of L_h causes the frequency to increase to higher value from F_H, while decreasing L_h causes the frequency to decrease to lower value from F_L. It has been observed from this

analysis that F_L is almost independent of increasing or decreasing the value of L_h. The optimum value of L_h used in analyzing the proposed antenna is $L_h = 4.6\,mm$ which gives lower and upper resonant frequencies.

It can be seen from Fig. 4(b) that the length of the ground plane is increased from zero to 14mm. The value of zero which is equivalent to the proposed antenna without second ground plane gives $F_H = 6.1 GHz$. When 14 mm is used as the length of ground plane, the value of F_H was reduced to $4.87\ GHz$. It has been observed that value of F_H decreases very significantly from $6.1\ GHz\ to\ 4.87\ GHz$, compared to the value of F_L which is constant at roughly $2.45\ GHz$. Investigations have shown that the second ground plane, introduced in this proposed antenna, helps to reduce the value of F_H and improve the radiation pattern. The parametric studies yield a value of 10 mm as the optimum the length of the second ground, which gives the required value of $F_H = 5.8\ GHz$.
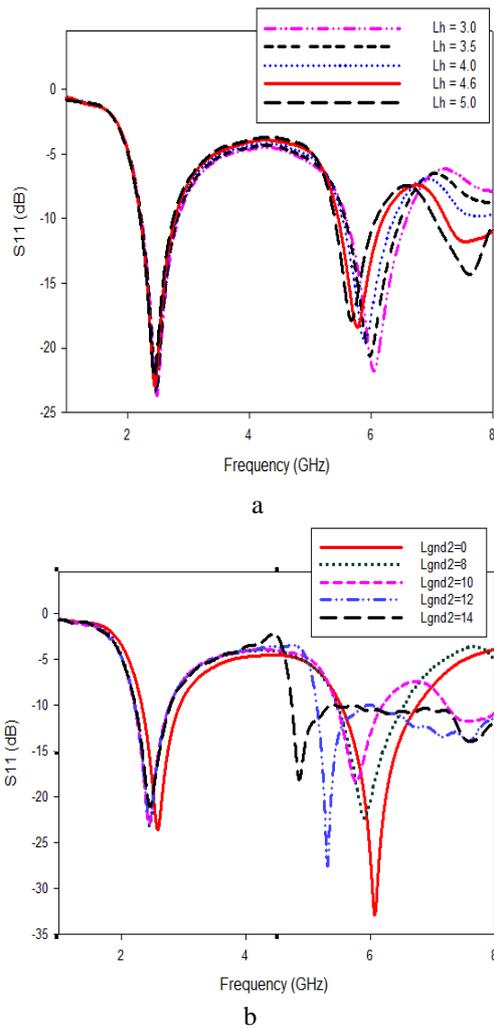

a

b

Fig. 4. Simulated return loss of the proposed antenna with different values of (a) slot length (b) length of second ground plane.

Fig. 5(a) shows results of the simulated return loss for different values of the gap g between the CPW ground and the radiating element. It has been observed that varying the values of g affects both the lower and upper frequency bands, with the effect being more significant at latter band.
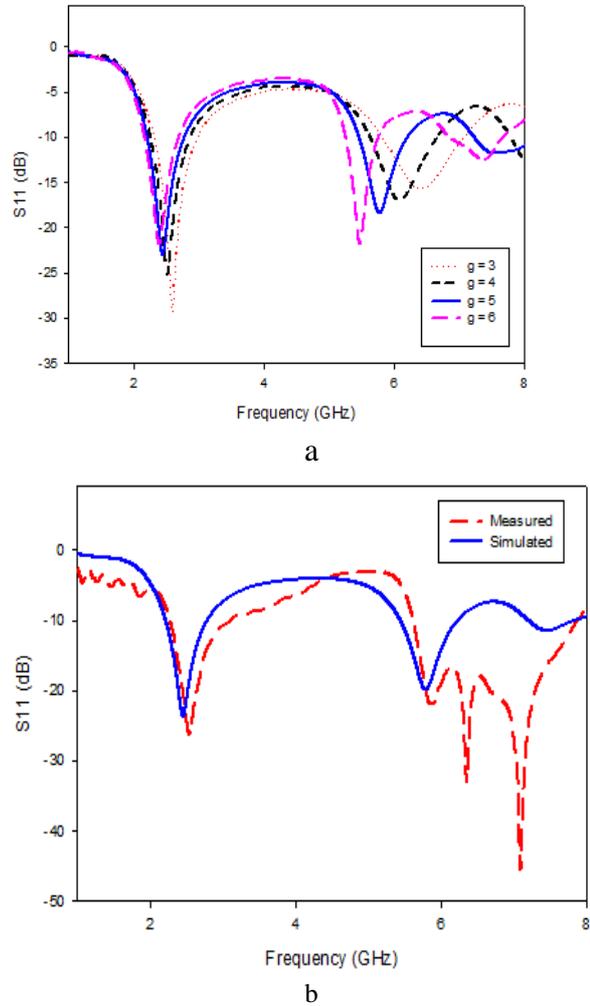

a

b

Fig. 5. (a) Simulated return loss with different gap lengths and (b) Simulated and measured return losses of the proposed antenna.

4. Results and Discussion

The main characteristics of the dual-band B-shaped printed monopole antenna, configured as antenna array for MIMO application, is discussed in this section. Both the antenna's parallel and orthogonal configurations are also presented.

4.1. B-shaped printed monopole antenna

The prototype based on the design was fabricated and measured the return loss using Agilent E5071C Vector Network Analyzer. This Fig. 5(b) shows the simulated and measured reflection coefficients, which clearly shows that

there seems to be close agreement between the measurement and simulation of the reflection coefficient (S11) in the lower resonant frequency. However, slight deviation was observed in the upper resonant frequency; nevertheless the measured bandwidth is still better than that of simulation. It can also be observed in the measurement results presented in Fig. 5(b) that at lower resonant frequency band, 2.45GHz, the reflection coefficient is -23dB and the bandwidth is 29.9% which is higher compared to the simulated reflection coefficient. The upper resonate frequency occurs at 5.8GHz with the reflection coefficient of -20dB and bandwidth is 33.8% which is greater than the simulation. The discrepancies in

the measured and simulated results are due to some imperfection in the fabrication of the antenna prototype. From the measurement it is clear that the proposed antenna can be used for dual-band frequency of 2.45GHz and 5.8GHz wireless communication application.

The far-field radiation pattern was also measured at 2.45GHz and 5.8GHz. Fig. 6 shows the measured and simulated E- and H-plane radiation pattern at 2.45GHz and 5.8GHz. It can be seen that the simulated and measured radiation pattern results shows the similar shape. In general the measured and simulated results for both frequency band gives close to omnidirectional radiation pattern.
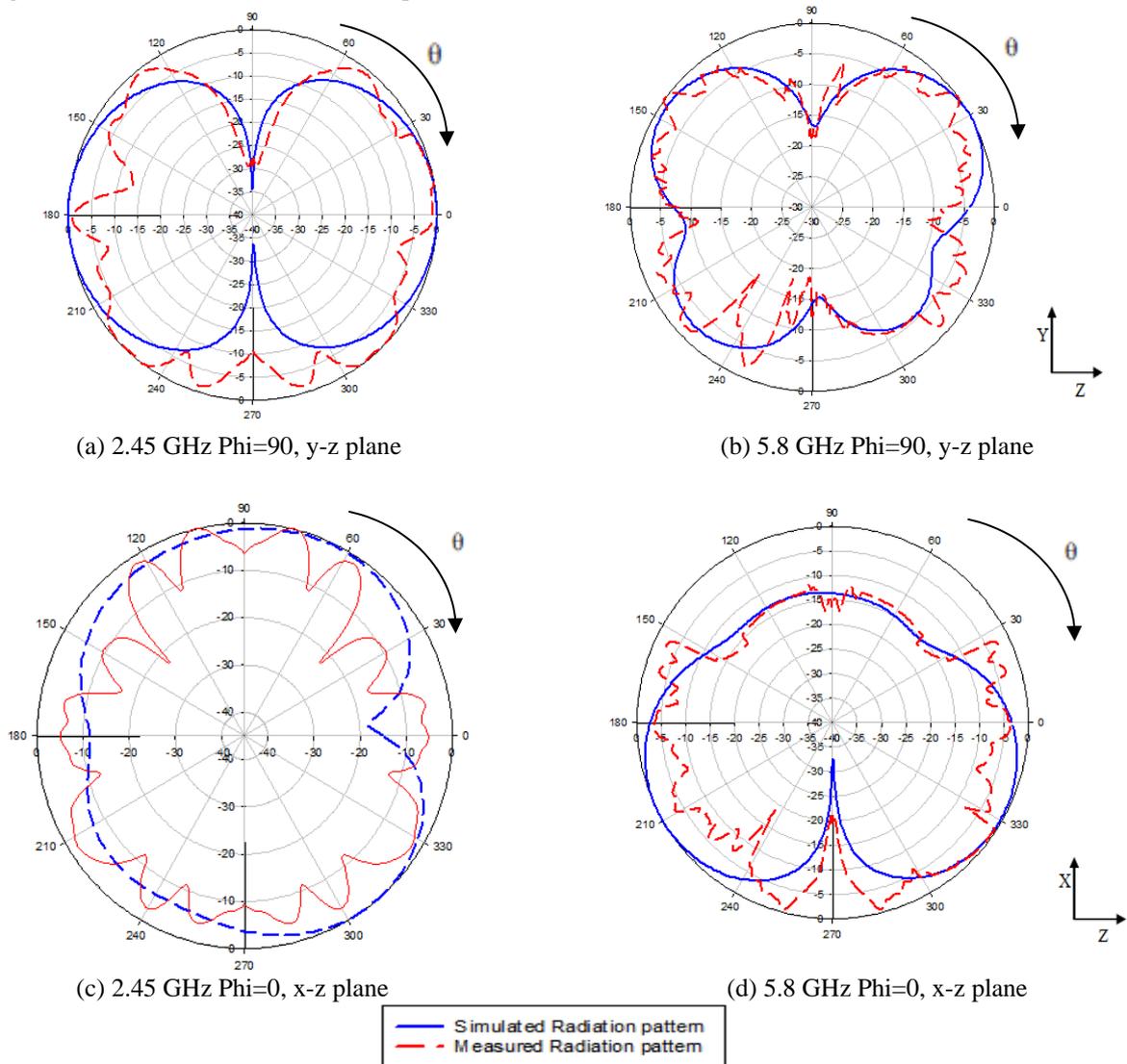

(a) 2.45 GHz Phi=90, y-z plane

(b) 5.8 GHz Phi=90, y-z plane

(c) 2.45 GHz Phi=0, x-z plane

(d) 5.8 GHz Phi=0, x-z plane

Fig. 6. (a)-(d) Simulated and Measured radiation pattern for the B-shaped monopole antenna

4.2. B-shaped monopole antenna for MIMO applications

Two elements antenna array has been proposed in Figs 3 (a) and (b). The antenna array comprises of two antenna elements, as shown in Fig. 1. The proposed antenna uses correlation coefficient and mutual coupling

to measure the performance of antenna array for MIMO application. The investigation which has been done in [4] shows that parallel has higher mutual coupling than orthogonal configuration for the same distance between the antenna arrays; therefore in the MIMO analysis in this paper orthogonal configuration has been used (Fig. 3(a)). Fig. 7 shows the parametric studies which have been done on

mutual coupling for different separation distance between the antenna arrays in orthogonal configuration. From Fig. 7, it can be seen that the mutual coupling decreases with increasing the distance between the antenna arrays of the proposed antenna. The separation distance between the antenna arrays is taken as 10mm which is $\lambda/12$ of lower frequency (2.45GHz). The distance smaller than 10mm gives greater values of the mutual coupling and distance greater than 10mm gives better value of the mutual coupling however the optimum distance has been used which gives better values of the mutual coupling. Figs 8 and 9 shows the simulated and measured S-parameters which shows that there seems to be close agreement between the measurement and simulation. It can be seen that low mutual coupling of nearly -20dB and 30dB for 2.45GHz and 5.8GHz band respectively.
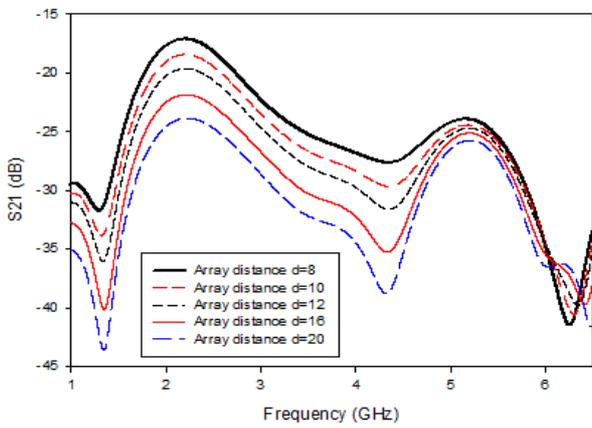

Fig. 7. Simulated Mutual Coupling for different array distances of B-shape Antenna array
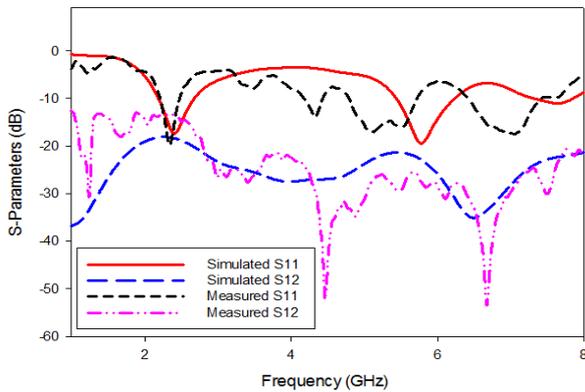

Fig. 8. Measured and simulated S-parameters (S11, S12) of proposed Antenna array
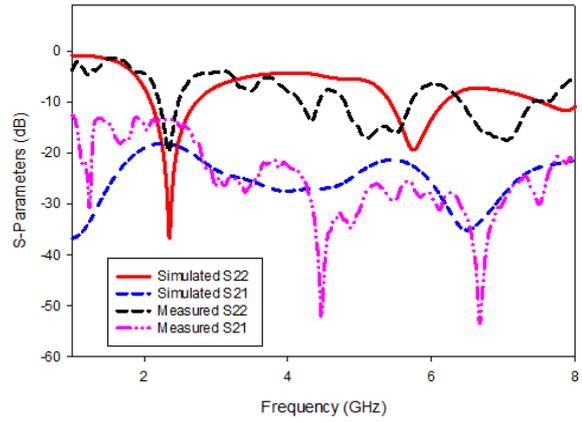

Fig. 9. Measured and simulated S-parameters (S22, S21) of proposed Antenna array

The correlation coefficient determines the quality of the multichannel in the diversity and MIMO systems. It can be calculated from either far field radiation pattern or S-parameters [12]. Using the far field radiation pattern accurate results can be obtained but the calculation is very complex. In this analysis the S-parameter has been used to calculate the correlation coefficient. The calculated value of the correlation coefficient between two ports [4, 13, 14] is 0.02, as shown in Equation (1). The correlation coefficient of 0.02 has been achieved.

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

where S_{11}^* and S_{12}^* are the conjugates of S_{11} and S_{12} respectively.

Figs. 10 and 11 show the simulated and measured radiation patterns of the proposed B-shaped antenna array for 2.45 GHz and 5.8 GHz for port 1. It can be seen that the simulated and measured results are in close agreement.
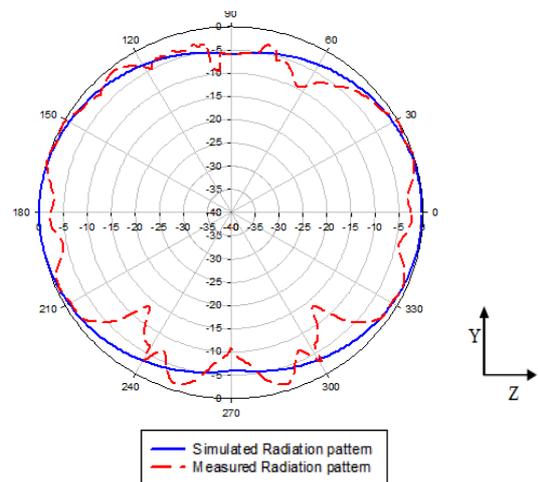

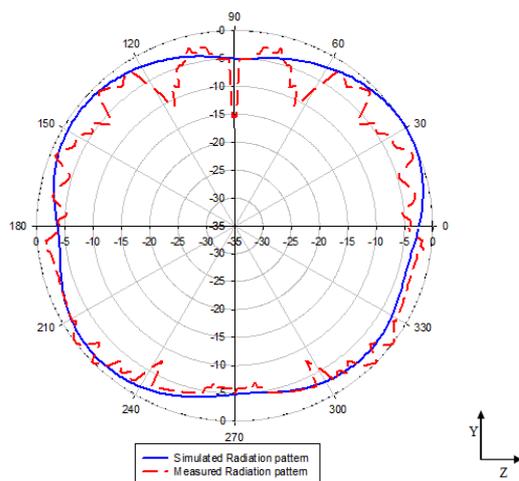*Fig. 10. Simulated and Measured E-Plane radiation pattern of the proposed antenna array at 2.45 GHz*

Fig. 11. Simulated and Measured E-Plane radiation patterns of the proposed antenna array at 5.8 GHz

5. Conclusions

A novel dual-band B-shape monopole antenna has been proposed and fabricated for MIMO wireless communication in this paper. The proposed B-shaped antenna was investigated in details, and the simulated results of the parametric studies were also presented. The final optimized design has been fabricated and measured. The antenna reflection coefficient, correlation coefficient, mutual coupling and radiation pattern were analyzed and discussed. % impedance BWs of 29.9% and 33.8% have been achieved for the 2.45 and 5.8GHz bands respectively. Low antenna mutual coupling (22.95 dB) and correlation coefficient (0.02) have been achieved at separation distance of $\lambda/12$ (the antenna's lower frequency band) in the proposed design. Moreover, the proposed B-shaped antenna is low profile and cheap.

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