A Multi Slot Patch Antenna for 4G MIMO Communications

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Abstract

A compact two element MIMO (Multiple Input Multiple Output) system is proposed using a multi slot patch antenna employing polarization diversity. The proposed MIMO system offers improved bandwidth, return loss and isolation characteristics. The system resonates at 5.35GHz and 5.81GHz frequencies for VSWR≤2, which can be used for 4G & WiMAX applications. The simulation results of return loss, mutual coupling, correlation coefficient and gain are presented. The channel capacities for the developed system are also estimated for indoor propagation.

Keywords: *Multi slot patch antenna, MIMO systems, Polarization diversity, impedance bandwidth, mutual coupling, channel capacity.*

1. Introduction

In the current 3G & 4G wireless communication systems, MIMO (Multiple Input Multiple Output) technology plays a key role for attaining improved data rates. These technologies require larger data rates with high speed, quality of transmission and accuracy. The technique of improving the channel capacity with increasing the no. of antennas at the transmitter and receiver was first predicted by Foschini in [1]. This technique has given an ample opportunity for the researchers and academicians to explore the ways of enhancing the data rates. The primary research emphasizes data encoding, DSP algorithms, channel characteristics, receiver design and antenna design [2].

However, when multiple antennas are involved at closer spacing the technical challenges are more pronounced compared to a SISO (Single Input Single Output) system. Hence, the basic aim of MIMO antenna design is to minimize the correlation between the multiple signals [3]. The parameter that describes the correlation between the received signals in highly diversified environments is mutual coupling, as it may affect the performance of the system. By calculating the mutual coupling, one can analyze the electromagnetic field interactions that exist between antenna elements of a MIMO system. Higher mutual coupling may result in higher correlation coefficients thus reducing the antenna efficiencies. The impact of mutual coupling on the capacity of MIMO systems is studied in [4].

The mutual coupling mainly depends on the distance between the elements of an antenna array. By increasing the distance between the elements of the antennas, the mutual coupling can be reduced. However, the distance between the antennas cannot be maintained too large, since MIMO systems have their major applications in Mobile terminals, laptops, MODEMs, WLAN Access Points etc., where miniaturization is the main concern. Not only the physical constraints but also the concerns on ergonomics and aesthetics are few other important aspects in the design of MIMO systems. The distance between antenna elements in practice cannot be extended beyond a certain level which limits the use of spatial diversity to achieve the desired spectral efficiencies and transmission qualities. As an alternative solution to achieve compactness in MIMO systems, the use of pattern diversity [5, 6], multimode diversity [7], and polarization diversity [8] techniques in conjunction with space diversity are discussed in the literature.

In the present letter, the orthogonal polarization concept is applied to the proposed multi slot patch antenna yielding better results in terms of return loss, mutual coupling and impedance bandwidth. The designed system resonates at 5.35GHz and 5.81GHz frequencies for VSWR≤2.The measured mutual coupling between the antenna elements is small and is less than -27dB. The antenna design is simulated using the FEKO EM simulator. In section 2, the proposed antenna geometry is presented and in Section 3 the two element MIMO array system is presented with simulation results. In section 4, the channel capacities are estimated for 1×1, 2×2 and 4×4 MIMO systems in the indoor propagation environment. The final conclusion of the paper is given in Section 5.

2. Antenna Design

The primary objective of the antennas used in MIMO systems is to improve the bandwidth of the patch antenna.The bandwidth of microstrip antenna can be increased by using air as the substrate. However, dielectric substrate is preferred, if compact antenna size is required . A few techniques can be applied to improve the microstrip antenna bandwidth. These include introducing parasitic element either in coplanar or stack configuration, increasing the substrate thickness and modifying the shape of a patch by inserting slots. The last approach is particularly attractive because it can provide excellent bandwidth improvement and maintain a single-layer radiating structure to preserve the antenna's thin profile characteristic. In the present work, incorporating extra slots in the patch is adopted for achieving higher bandwidths.

A normal E shaped patch antenna, which can be used for WLAN applications is shown in Fig. 1.The various parameters of the patch can be modified to get different resonant frequencies. This antenna was modified by taking two more slots at the edges of the patch as shown in Fig.2. The multi slot patch antenna is designed with the following dimensions on a ground plane of area 27×30 mm (all dimensions are taken in mm).

$$(L, W, h, Ls) = (17.2, 20, 3.2, 10) \qquad W_1=5.9,\ Wt=6.2,\ Ws=1.0$$

The dimensions d1 and d2 of the patch in the proposed multi slot patch antenna are taken as 2mm and 4mm respectively.

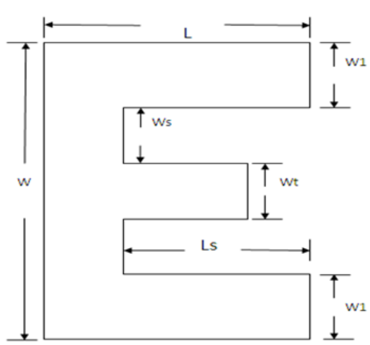

Fig. 1
(E Shaped Patch Antenna)

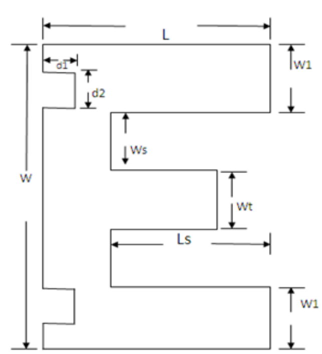

Fig. 2
(Modified Multi Slot Patch Antenna)

For the design of this antenna, the substrate RT/duroid® 5870 /5880 of thickness 3.175mm and with low permittivity (ε_r=2.2) value is selected. The proposed modified patch antenna gives an improved bandwidth from 7% to 16% and an improved return loss.The reason for the improvement in the bandwidth is due to the increase in the lengh of the current path, when extra slots are incorporated in the patch. The proposed antenna resonates at the two frequencies 5.35GHz and 5.81GHz as shown in Fig.3. This dual band operation with less mutual coupling is useful for Wimax(Wireless interoperability for microwave access) applications. Hence, this antenna was selected for the design of a two element MIMO array system employing polarization diversity, which is discussed in the following section.

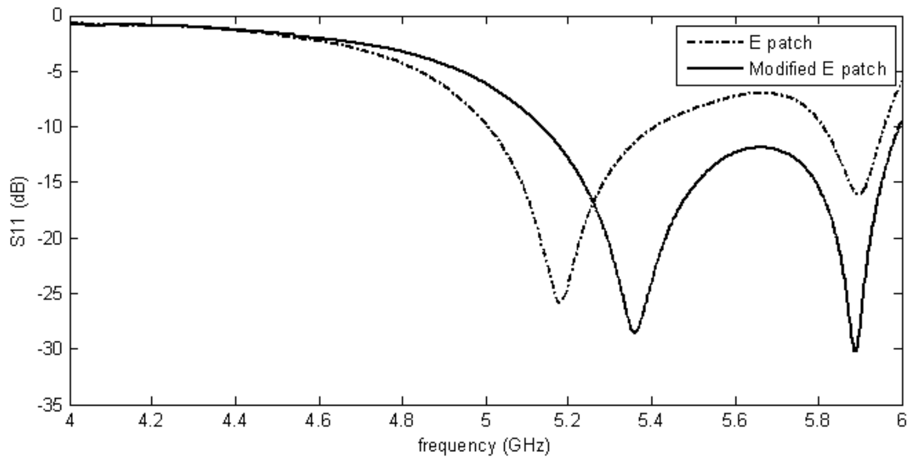

Fig 3. Comparison of Return Loss Between the Normal E Patch and Modified E Patch Antenna

3. Two Element MIMO Array with Polarization Diversity

The main design criteria for MIMO system engineers in developing small electronic modules is mutual coupling, which mainly arises due to the smaller spacing between the elements. However, when multiple antennas are involved at closer spacing the design issues are more complicated compared to a SISO (Single Input Single Output) system. The mutual coupling mainly depends on the distance between the elements of an antenna array. By increasing the distance between the elements of the antennas, the mutual coupling can be reduced. However, the distance between the antennas cannot be maintained too large, since MIMO systems have their major applications in Mobile terminals, laptops, MODEMs, WLAN Access Points etc., where miniaturization is the main task. Hence, another means of achieving lesser mutual coupling is employing the diversity concept.

In [9], the authors presented the concept of various diversity techniques like, spatial diversity, polarization diversity and pattern diversity for MIMO systems. In all these techniques, the mutual coupling can be mitigated more with the use of polarization diversity. In a typical case of linear polarization diversity, signals are transmitted and received via horizontally polarized as well as vertically polarized antennas. The orthogonality of two distinct polarizations constructs independent and uncorrelated signals on each antenna and thus, leads to potentially a full-rank MIMO channel and a full rank MIMO channel obviously gives improved channel capacity.

An E shaped patch antenna is an ideal candidate for MIMO systems as two nearby E shaped antennas have lesser mutual coupling. In this paper, two such antennas are taken (in this case, the modified E shaped patch antennas are considered) as shown in Fig 4. To achieve orthogonal polarization, one element is rotated to 90^0 with respect to its adjacent element as shown in the figure. Here polarization diversity is mainly considered as the results from [10], indicate that this technique improves the channel capacity with lesser spacing between the elements and also with lesser constraints on antenna configurations.

For the proposed MIMO system, the separation between the elements is 10 mm which is 0.17λ. This separation is much smaller compared to the conventional arrays which are separated by 0.5λ. For the proposed MIMO array the dimensions are taken same as that of the modified antenna mentioned in Section 2.The antennas are mounted on a substrate symmetrically with $\varepsilon_r = 2.2$, which in turn is mounted on a ground plane (PEC).

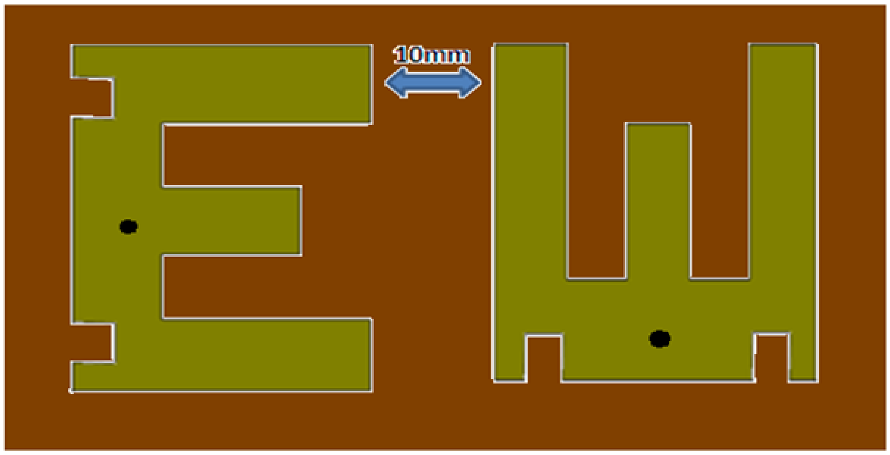

Fig 4. Two Element MIMO System with Orthogonal Polarization

The results are presented in the Fig 5. From the observed results it is evident that the proposed MIMO array exhibits improved return loss (s_{11}) and excellent isolation properties (S_{12}) at the resonant frequencies 5.35 GHz and 5.81GHz. The antenna gives the -10dB bandwidth of 16%. At the resonant frequencies the values of S_{11} are -27dB and -32dB respectively, which gives good impedance matching for the antenna.

The important parameter to be considered in the design is mutual coupling S_{12} which is < -27dB at both the resonant frequencies. This low value of mutual coupling suggests the proposed array system to be an efficient system in terms of isolation. Here, this value of mutual coupling is achieved only for a separation of 0.17λ. In the proposed model, the bandwidth obtained (16%) is far better than the bandwidth obtained for the two element MIMO system (5%) discussed in [11] for almost with same return loss, mutual coupling and size.

The VSWR plot of the proposed MIMO array is presented in the Fig 6.The plot gives the desired values of VSWR at the resonant frequencies which are less than 2. The VSWR value is observed as 1.14 and 1.34 at the resonant frequencies 5.35GHz and 5.81GHz respectively, indicating improved matching conditions. The gain plot is shown in the Fig. 7 which gives the peak gain of 7dBi. The radiation patterns of the proposed antenna at the two resonant frequencies are shown in Fig 8. At the 5.4 GHz resonant frequency the main lobe magnitude is 1.9dB with an angular width of 132.8 degrees and the main lobe is directed along 265^o direction. Similarly, at the second resonant frequency the main lobe magnitude is 0.9 dB with an angular width of 125.8 degrees and the main lobe is directed along 0^o direction.

Another important parameter to estimate the performance of a MIMO system is the correlation coefficient, which can be calculated using the below given formula. From the plot, it can be observed that the correlation coefficient is minimum at the resonant frequencies as shown in Fig. 9.

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

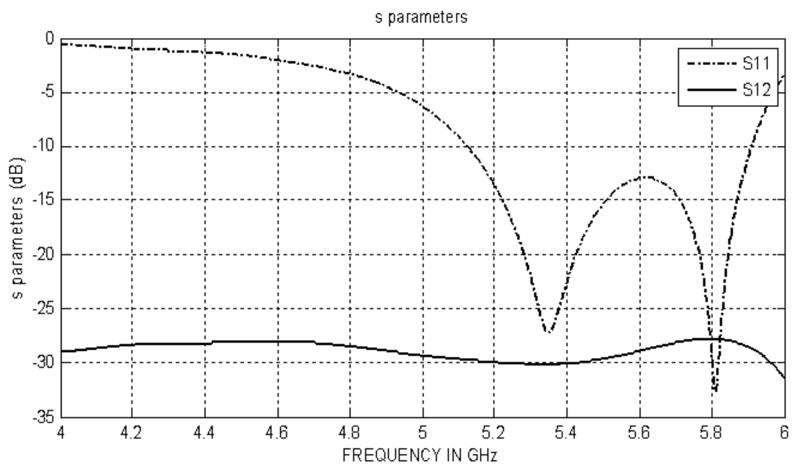

Fig 5. S Parameters of Proposed MIMO Array

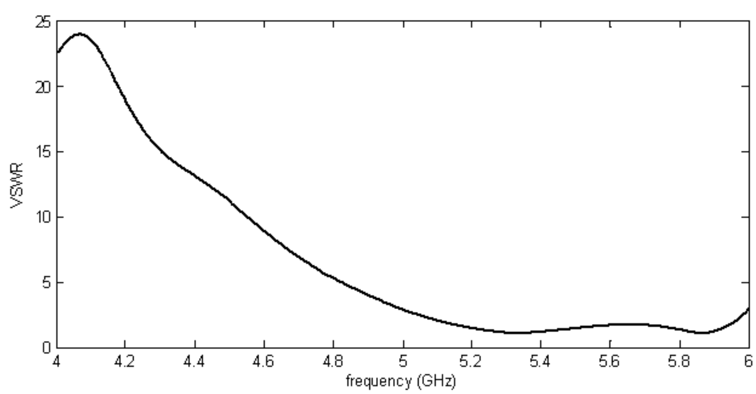

Fig 6. VSWR Plot

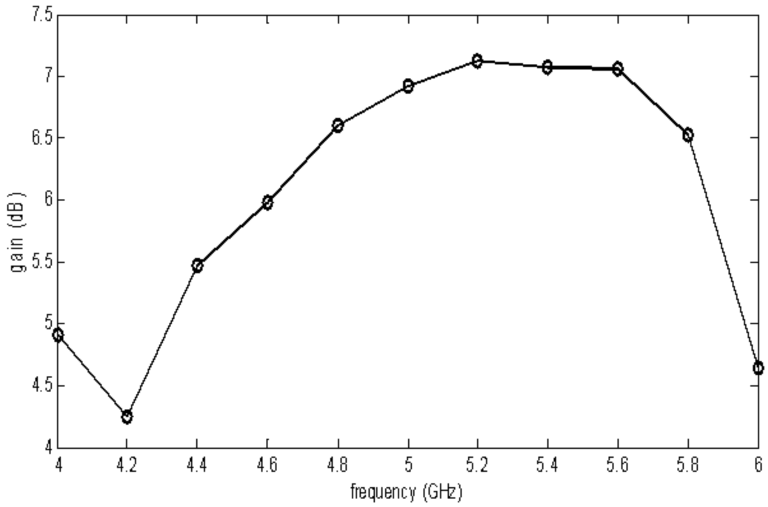

Fig 7. Gain Plot

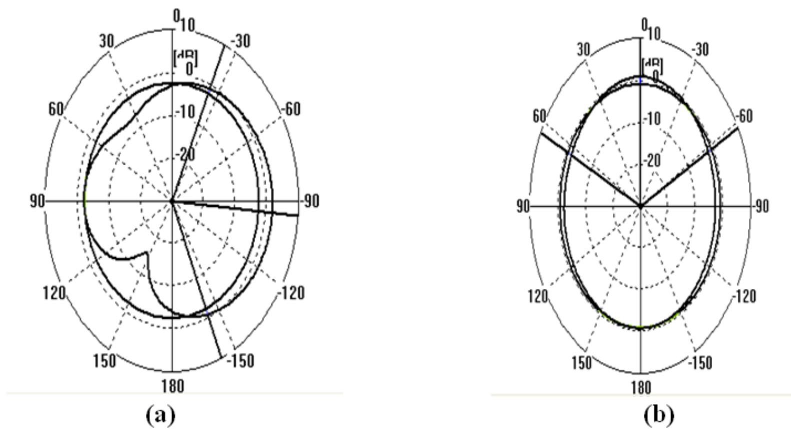

Fig 8. Radiation Patterns of the Proposed MIMO Array at 5.35 GHz (b) 5.81 GHz

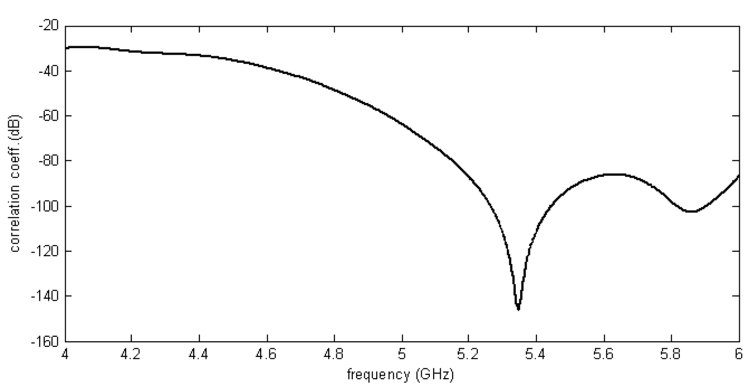

Fig. 9 Correlation Coefficient Plot of the Proposed MIMO Array

4. Channel Capacity Calculations

The main objective of the MIMO systems is to improve the channel capacity, by employing more no. of antennas at the transmitter and receiver side. In this section, 1×1, 2×2 and 4×4 MIMO systems are taken and their capacities are analyzed using ray tracing simulator, namely wireless Insite in the indoor propagation environment.
Then channel capacity of a MIMO system [1] can be calculated using the relation

$$c(\xi) = \log_2 \det\left[I_n + \frac{\xi}{n} HH^T \right] bits/s/Hz$$

Where,

ξ = Signal to Noise ratio,
I_n = Identity matrix of order n
$H^\dagger$ = Hermitian transpose of the H matrix (Channel Coefficient matrix),
n = no. of antennas.

Channel parameter matrix or the H-matrix is computed by using the formula

$$\mathbf{h_{ij}} = \sum_{\mathbf{k=1}}^{\mathbf{M}} \sqrt{\mathbf{p_k}} \bullet e^{i(2\pi/\lambda)l_k} \bullet e^{i2\pi f\tau_k}$$

Where,

M = number of rays between transmitter and receiver,
f_0 = carrier frequency,
P_k = received power from k^{th} ray,
l_k = path length of the k^{th} ray and
τ_k= time taken by the k^{th} ray to reach the receiver.
hij = complex path gain from j^{th} transmitter to i^{th} receiver.

The measurements have been carried out by using the ray tracing simulator in an indoor propagation environment, which is shown in Fig. 10. The transmitters and receivers have been placed at various locations and channel capacity for each of the MIMO configurations have been calculated for different values of Signal to Noise ratio. The measured channel capacity for different values of SNR is shown in Fig. 11. From the figure, we can observe that the channel is capacity is improved with increasing the no. of antennas at both the transmitter and receiver.

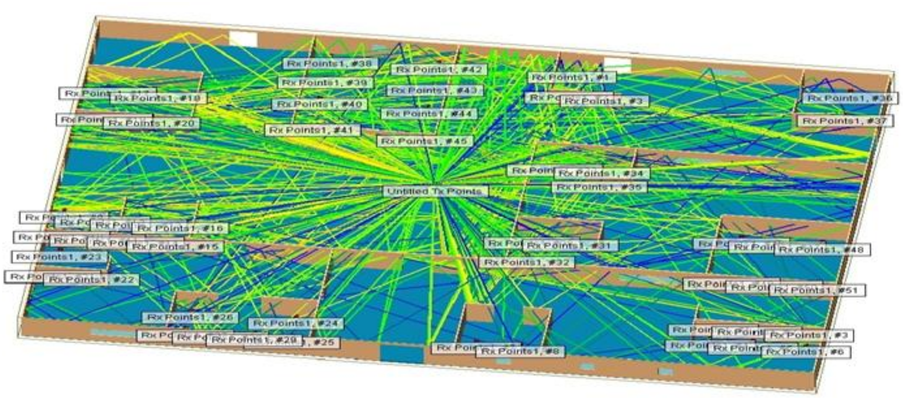

Fig 10. Indoor Propagation Environment

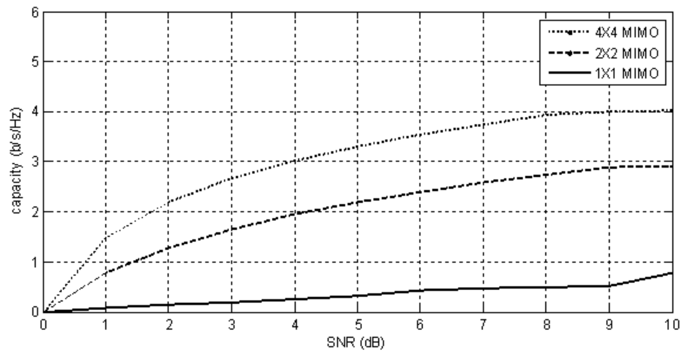

Fig. 11. Channel Capacity

5. Conclusion

In this paper, a two element MIMO system is proposed using a multi slot patch antenna employing orthogonal polarization diversity. The proposed antenna array resonates at dual band offering an improved bandwidth of 16% with return loss and mutual coupling < -27dB. These characteristics are well suited for all 4G MIMO applications. The channel capacity is calculated for various MIMO systems and it has been verified that, the channel capacity increases with increasing the no. of antennas at the transmitter and receiver. The proposed study can be extended by employing more no. of antennas in MIMO system for improving the channel capacity of the MIMO systems.

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