ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 5, Issue 7, July 2016

Design of MIMO Antenna with High Isolation for UWB Applications

D. Thiripurasundari, S. Sameer,

Abstract — **Dual element multiple input-multiple output (MIMO) antenna for Personal Area Network (PAN) is presented in this paper. The antenna is fabricated on FR4 substrate with dielectric constant ε_r= 4.3 and thickness '*t*' of 1.6 mm and dimension of 50 × 50 mm^2 fed by a 50 Ω microstrip lines. MIMO performance parameters such as diversity gain and envelope correlation coefficient are obtained to find the suitability of this structure for MIMO application. The designed antenna exhibits ultra wide bandwidth ranging from 3.1 GHz to 10.6 GHz with isolation ≤ -15 dB. The average gain of the antenna is 4 dB.**

Index Terms **— Diversity antenna, isolation, multiple-input multiple-output, Ultra-wideband antenna.**

I. INTRODUCTION

MIMO technology can improve the performance of wireless communication systems by increasing the channel capacity as well reducing the adverse effect due to of multipath fading. MIMO technology makes use of multipath to increase the throughput of the channel with every pair of antennas added to the system design. Due to strong mutual coupling among the antenna elements it is difficult to place multiple antennas together within the substrate while maintaining high isolation. Due to this reason researchers have turned their attention to the design of UWB MIMO antenna with increased isolation between the elements.

In [1] a staircase shaped antenna element is proposed for portable UWB MIMO application. Two symmetrical antenna elements fed by coplanar stripline are connected back to back to improve isolation. In addition to back to back configuration a conducting strip is placed between the elements to act as a reflector to cancel out the fields between the two elements enhancing the isolation. This configuration provides isolation of 20 dB throughout the band. A 2 × 2 (4 element) slot antenna for UWB portable wireless application is presented in [2]. Ultra wide bandwidth is achieved by creating steps in the slot. The length of the steps in the slots determines the resonant frequency of the UWB antenna. All the elements are fed using microstrip line on one side of the substrate and the ground plane is on the other side of the substrate. Higher isolation of 22 dB is achieved by maintaining proper gap between the antenna elements without the need for any additional design. A compact UWB MIMO antenna for portable application is proposed [3]. Two square monopoles form the antenna elements. Mutual coupling reduction is achieved by placing a T shaped stub in the ground plane. In addition to the stub, a vertical slot is also etched on the T shaped stub to improve the isolation. Band notched characteristics is obtained by placing vertical strips in the ground plane.

A compact MIMO antenna with band notched characteristic is reported for UWB application [4]. Rhombic shaped slot is excited by two orthogonal microstripline. T shaped parasitic strips improve the isolation. In addition, two L shaped slits are also introduced in the ground plane to provide notched band. The designed antenna is suitable for MIMO diversity systems. Two semicircular patches fed with microstrip feed line for UWB application is proposed [5]. These patches are placed perpendicularly to provide low correlation between the antenna elements and high diversity. The ground plane beneath the patch is truncated to obtain ultra wide bandwidth.

A circular monopole MIMO antenna for low UWB band (3.1-5 GHz) is reported [6]. The antenna is fed with a microstrip feed line and circular disc with two metal strips each one of it connecting the circular patch nearer is placed nearer to feed line to reduce mutual coupling. The structure provides isolation of 22 dB. The decoupling mechanism is analyzed through parametric study and current distribution plot. A compact UWB 2×2 MIMO antenna is presented [7]. The antenna structure is in the shape of U with broader horizontal section. The final structure has been arrived by etching out the low current region of the basic rectangular patch. Ground part is protruded from bottom to top to improve the impedance matching. In addition to matching they also help in reducing interaction between the feeds. A metal strip is placed on top part of the patch to notch out the WLAN 5.15-5.85 band. In addition to the metal strip a slot is also introduced on the patch to reject the WiMax 3.3 -3.7 GHz band. Another metal strip is introduced between the protruded ground planes to reduce the mutual coupling. It was also observed that the effect of metal strips and slots on the patch antenna has negligible effect in isolation.

A compact MIMO slot antenna with DGS for isolation enhancement is proposed [8]. The rectangular stepped slot is fed with the micro strip feed line on the rear side. A T shaped defected structure is etched on the ground plane. Firstly, it reduces the first resonant frequency by increasing the current path length. Secondly, it provides isolation between the two structures by suppressing surface current between the two. A open ended line slot is also introduced to reduce the coupling. A UWB MIMO antenna for automotive UWB application with modified ground plane is presented [9]. The structure is a hybrid of both circular and square ring. The impedance bandwidth of the antenna is improved by modifying the shape of the ground plane. A semi circular slot is etched on the

Manuscript received *July. 2016.*

D. Thiripurasundari*, Communication Engineering Department, VIT University, Vellore, India.*

S. Sameer*, Communication Engineering Department, VIT University, Vellore, India.*

ground plane beneath the feed line. The ground is extended in the form of the L shaped stub to further improve the bandwidth. Different antenna configurations such as parallel and perpendicular antenna placement are analyzed for diversity performance.

In this paper UWB MIMO antenna with high isolation without the need for decoupling network is proposed. In addition to return loss and radiation pattern MIMO performance parameters such as envelope correlation coefficient and diversity gain are also determined to check the suitability of the designed antenna for MIMO application.

II. ANTENNA DESIGN

The geometry and dimension of single element rectangular antenna is shown in Figure 1. The antenna is designed using standard equation given in [10]. The width '*W*' of antenna is critical in terms of power, efficiency

The width of the patch is given by:

$$W = \frac{c}{2f_c\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (1)$$

where,

c - velocity light 3×10^8 m/s

f_c - centre frequency 6.85 GHz

ε_r - permittivity of the substrate

The width mainly depends on the operating frequency and substrate dielectric constant ε_r. By substituting these values the width, W = 13.4517 mm. The length of patch determines the resonant frequency which is also a critical factor. For all UWB antennas the lower resonant frequency determines the length of the antenna as against the center frequency of conventional narrowband antenna. The length of the patch is given by [11].

$$L = \frac{7.2}{k \times f_l(GHz)} - r(cm) - p(cm) \qquad (2)$$

where,

k – Empirical value of 1.15

f_l – lower frequency , GHz

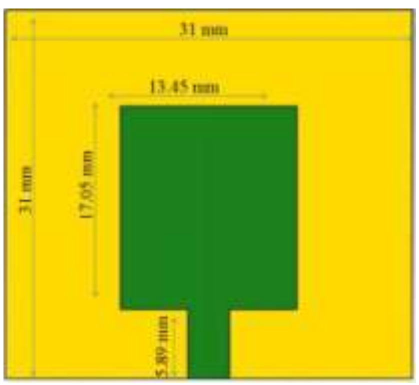
W- Patch width

r – equivalent radius of the circular patch and is given by

$$r = \frac{W}{2\pi} = 0.2140 \text{ cm}$$

P = gap between patch and ground

By substituting these values we get length, *L* = 17.0563mm.



(a)

(b)

Fig.1.Geometry of rectangular UWB patch antenna (a) Front view (b) back view

III. RESULT AND DISCUSSION

The gap 'p' between the patch and ground plane is an important factor in determining the amount of impedance matching. The frequency vs reflection coefficient characteristic of the antenna for various value of 'p' is shown in Fig.2. The gap is varied in steps of 0.25mm from 0.25 mm to 1.75 mm. As gap is varied from 0.25 mm to 1.75 mm the mid band matching is achieved, where as upper band matching reduces except for 1mm. Hence, the gap distance is chosen as 1 mm. It is also observed that the single antenna element exhibits wide bandwidth of 7.2 GHz from 3.39 GHz to10.59 GHz.

To find the suitability of this antenna for MIMO application, the antenna placement is varied by placing the two antennas in parallel configuration and in perpendicular configuration. The two antenna geometry for parallel orientation is shown in Fig.3. As rule of thumb the two antenna elements are placed side by side at a distance of $\lambda_g/2$. The dimensions are calculated from equation (3) and (4).

$$\lambda_o = \frac{c_o}{fr} = \frac{3\times10^8}{6.85\times10^9} = 0.0437 \text{ m} \qquad (3)$$

$$\frac{\lambda g}{2} = \frac{\lambda_o}{2\times\sqrt{\varepsilon eff}} = \frac{0.04}{2\times\sqrt{3.5}} = 11.78\ mm \qquad (4)$$

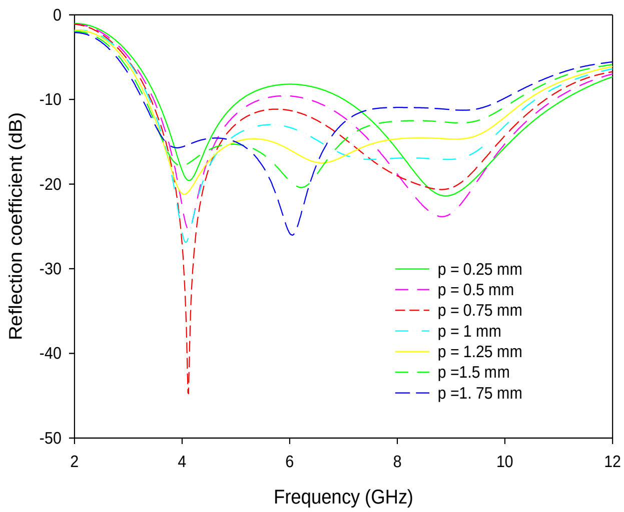


Fig.2. Variation of reflection coefficient with gap distance p

ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
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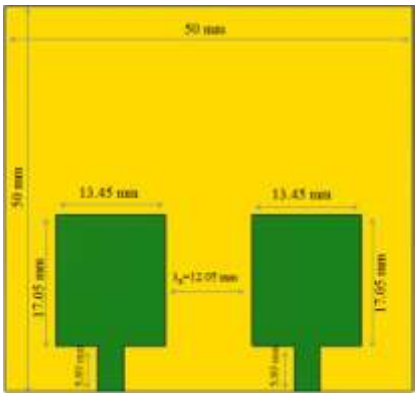
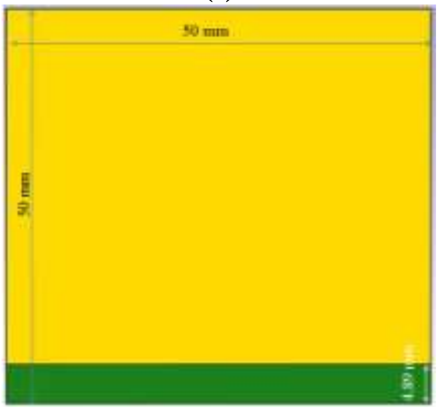


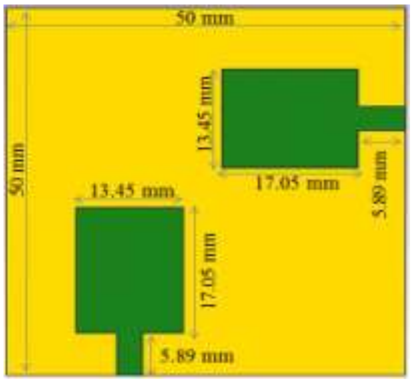
(a)



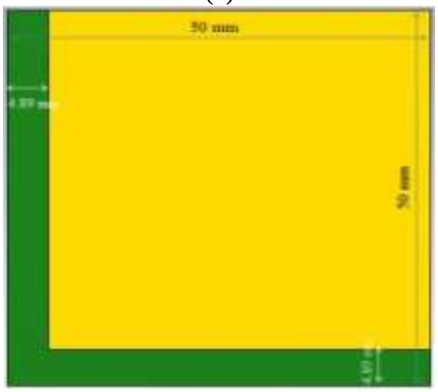
(b)

Fig.3. Antennas placed in parallel (a) front view (b) back view

The frequency vs refection coefficient of the antenna at the two antenna ports is shown in Fig.4. It can be seen that the antenna has reflection coefficient greater than 10 dB. Also, the isolation of the antenna is poor at 5 GHz. This is due to the induced current from one antenna affecting the performance of the other antenna, thereby increasing the coupling between the antennas, reducing isolation between the elements.



(a)



(b)

Fig.5. Antennas placed perpendicularly (a) front view (b) back view

The antenna elements are placed perpendicularly as shown in Fig.5. The performance of the antenna is analyzed through simulation. The simulated characteristic of the antenna is shown Fig. 6. It can be observed that the antenna exhibits very wide bandwidth from 3.414 GHz to 10.898 GHz. The isolation between the ports is less than -15 dB throughout the band. This isolation is achieved without the need for additional decoupling network. Hence the perpendicular placement is best suitable for MIMO configuration.

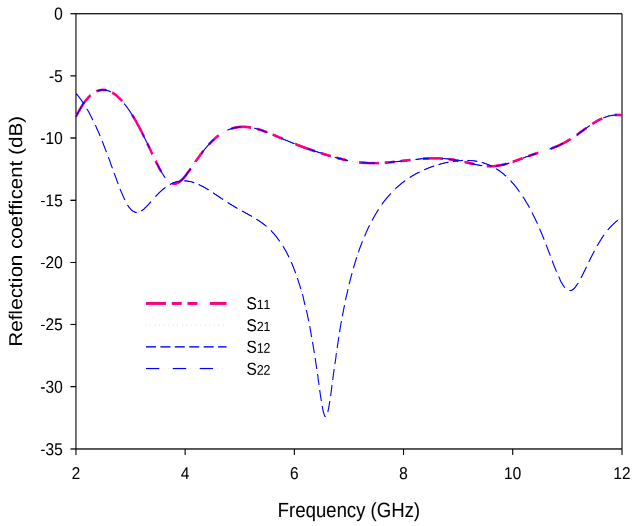


Fig.4. Simulated reflection coefficient characteristics of the antenna for parallel arrangement

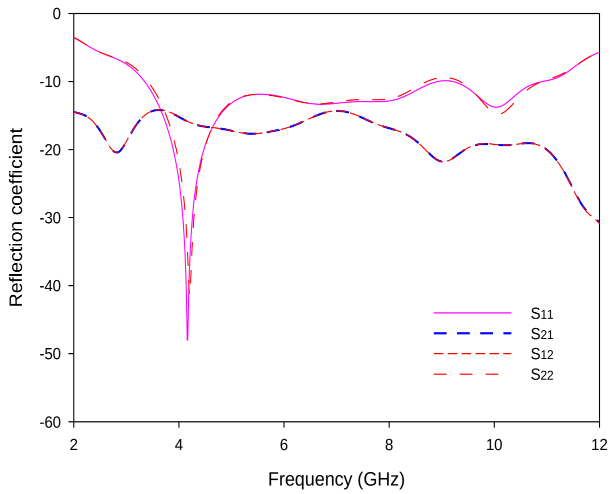


Fig. 6. Simulated reflection coefficient characteristics of the antenna for perpendicular arrangement

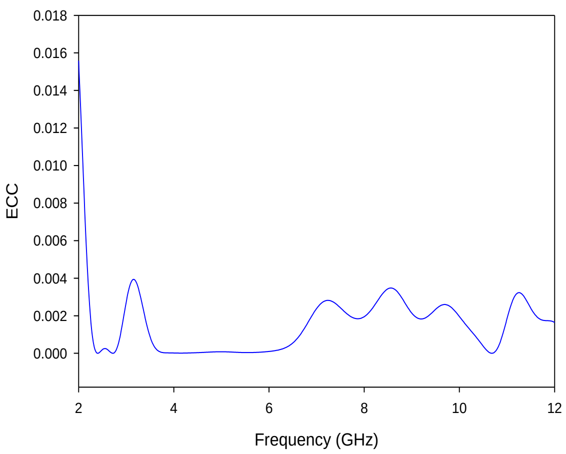


Fig. 7 Frequency vs envelope correlation coefficient

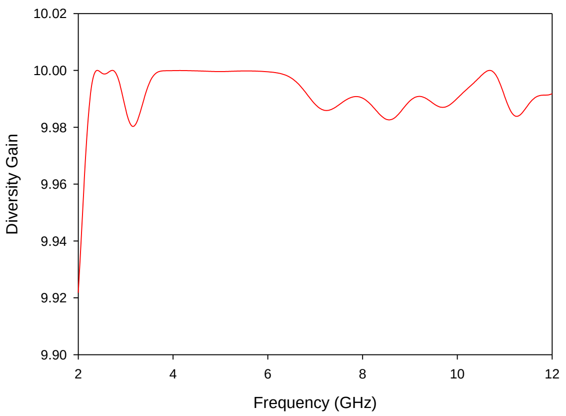


Fig.8. Frequency vs diversity Gain

In addition to the return loss characteristic of the antenna, additional performance parameters such as envelope correlation coefficient (ECC) and diversity gain (DG) are required to evaluate the diversity performance of the MIMO antenna configuration. Envelope correlation coefficient gives the measure of how much the ports are isolated or correlated. The ECC can be determined from the radiation pattern of the antenna. Acceptable level of envelope correlation coefficient is less than 0.3. The frequency vs ECC graph is shown in Fig. 7. It can be seen that the value of ECC is well below the acceptable value of 0.3. This indicates that there is very less coupling between the antenna elements.

The diversity gain of the antenna is determined using S parameter as given in equation (5).

$$\text{Diversity Gain} = \sqrt{1 - |\rho_e|^2} \quad (5)$$

The ideal value of diversity gain should be 10 which is the maximum possible value which can be obtained. The frequency vs diversity gain of the antenna is shown in Fig 8. It can be seen that diversity gain of 10 is maintained throughout the band.

The radiation pattern characteristic of the antenna is shown Fig. 9 (a-d). The pattern is obtained at 4 GHz, 6 GHz , 8 GHz and 10 GHz respectively. It can be seen that the pattern is almost same throughout the band and provides a gain of 4 dB.

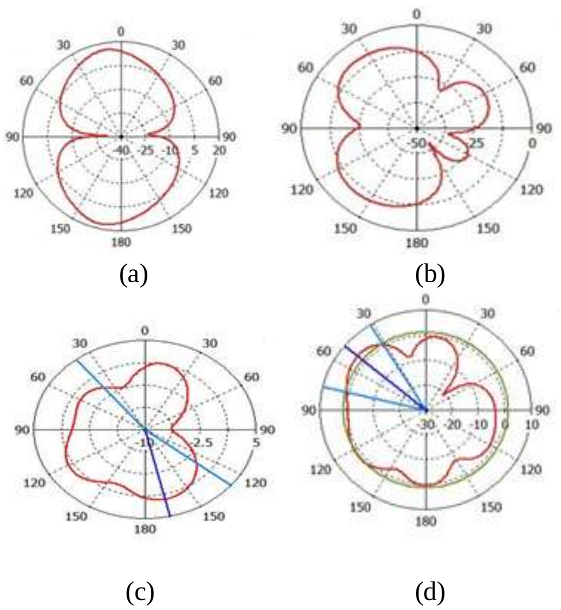


Fig. 9 Radiation pattern at (a) 4 GHz (b) 6 GHz (c) 8 GHz (d) 10 GHz

IV. Conclusion

A UWB MIMO antenna is designed and its characteristics are analyzed. The designed antenna covers wide band of 3.414 GHz to 10.898 GHz and isolation of over 15 dB without the need for additional decoupling network. The decoupling between the antenna elements is analyzed through different orientation of antenna elements. The MIMO performance parameters ECC and diversity gain are determined to find the suitability of this antenna for MIMO application.

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D. Thiripurasundari has completed BE, ME and PhD degree from Bharathiyar University, Anna University and VIT University respectively. She has 23 years of teaching experience and currently working as professor in VIT University. Her research interest includes design and modeling of ultra wide band antenna, fractal antenna, MIMO antenna and design of passive microwave components. She has contributed papers in both National and International conference and journal. She is senior member of IEEE. She was the co investigator of Design and Development of Multiband Wearable Antenna funded by DRDO, Government of India.

S. Sameer is currently pursuing M. Tech (Communication Engineering) in VIT University. He is interested in the design of wearable antenna and MIMO antenna. He has also published few papers in International journal and National conference.