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ULTRA-WIDEBAND CO-LOCATED DIVERSITY ANTENNA FOR ENHANCING CHANNEL CAPACITY

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Abstract

In this paper, we have presented a novel approach of diversity antenna with high isolation which improves the channel capacity in wireless communication application. We have proposed diversity antenna which consists of two billhook shaped patch elements along with rectangular slot inserted in it and a narrow semi-circular shape on the ground plane. Ultra-wideband (UWB) diversity antenna elements are placed orthogonal to each other to obtain high isolation, also achieve the polarization and pattern diversity. We have calculated the patch size of diversity antenna is 33×18mm in compactness condition. In this paper, the diversity antenna is implemented, fabricated and its parameters are evaluated by CST Studio. The proposed technique of UWB MIMO (Multiple Input Multiple Output) antenna achieved larger bandwidth, low mutual coupling and envelope correlation coefficient (ECC) over the UWB frequency band. For diversity antenna, we have observed diversity performance factors like diversity gain, capacity loss, and ECC. With the help of these parameters, we have shown improvement in the channel capacity. Through our simulation and experimental results, it is observed that our new proposed technique is better than existing methods.

Keywords:

MIMO Antenna, UWB, Diversity Antenna, Channel Capacity, ECC

1. INTRODUCTION

In recent years, tremendous growth is observed in wireless communication technology. In last few years, a lot of research has been done in the wireless domain. In those years demand of high data rate and channel capacity has increased and are fulfilled by both UWB and MIMO technology [1]. Particularly UWB technology is a promising solution for high data rate where MIMO system is excellent in enhancing channel capacity [2]. Ultra-Wideband (UWB) technology gives high-speeddata but suffers from multipath signal fading thus a combination of UWB and MIMO technology gives very good performance [3]. This technology provides high diversity gain, multiplexing gain, and capacity enhancement. To design the UWB MIMO antenna, there are different diversity techniques like adaptive antenna systems, spatial multiplexing diversity, and antenna diversity [4]. Antenna diversity is well-known technique at mitigating multipath signal fading. This diversity scheme uses two or more antennas to improve the reliability and quality of the wireless link. Antenna diversity can be realized in several ways based on the signal interference, environment. The wireless system designer can employ some methods of antenna diversity to improve the signal quality and these methods are pattern diversity, polarization diversity, and spatial diversity [6]. For the practical implementation of diversity antenna, some of the methods explained above are used. In this paper, polarization diversity of proposed antenna is achieved. When multiple antennas are placed closely to each other on a mobile platform, the problem of mutual coupling or isolation arises which is of prime importance in any antenna design. Hence, it is a challenge to design a compact UWB diversity antenna with low mutual coupling.

2. RELATED WORK

Some of the antenna related work i.e. literature survey in UWB MIMO domain have been studied and made some changes in the existing geometry, different techniques to be used to improve the results and concept. In the papers [7]-[8] distance criteria are explained for maximum isolation. Later that size was a very vital in the wireless communication. Thus to overcome size problem number of other solutions were invented. [9][10] explains inserting stub to reduce mutual coupling having antenna size of 40mm×68mm. In paper [11] is reference paper having antenna size 58mm×58mm used angular variation technique to reduce coupling. In [13] vector antenna uses heterogeneous structure method with antenna size of 50mm×38mm for enhancing channel capacity. Different techniques are used to reduce the mutual coupling and enhance the channel capacity. Some techniques like Decoupling and Matching Network (DMN), Electronic Band Gap structure (EBG) are used in lower ultra-wideband and other some are used in the upper ultra-wideband frequency band.

In the paper, Planar Ultra-Wideband Antennas in Ku- and K-Band for Pattern or Polarization Diversity Application, [9] Tatsuo Itohv explained two planar diversity antennas operating in Ku- (12.4-18GHz) and K-band (18-26.5GHz) are proposed for UWB applications. Both of them consist of a monopole radiating element and two orthogonal feeding ports. Their ground planes are modified and optimized to improve the isolation as well as to control the radiation. The first one is a pattern diversity antenna with a disc monopole patch. The second one is a polarization diversity antenna based on a square patch which is able to provide both linear and circular polarizations. Different feeding approaches are adopted to obtain a broadband impedance matching. Two wideband couplers are designed to provide the required feeding circuit. Both the simulated and measured results are presented to verify the proposed idea. Good radiation efficiency and isolation between the two ports are achieved. Consistent diversity performance is observed across the whole UWB bandwidth which is demonstrated by their radiation patterns.

Lihong Wang et al. proposed the antenna which consists of an annular slot and orthogonal feeding mechanisms to achieve polarization diversity performance across the UWB from 2.8-11GHz. By introducing a cross-shaped strip diagonally between the two U-shaped stubs, andinterpret isolation better than 14dB is accomplished except at the lower and higher frequency end. The notch band from 5.0-6.3GHz is realized by embedding arc-shaped slot resonators on the feeding structures. The proposed antenna facilitates nearly Omni directional radiation pattern, low envelope correction coefficient, moderate gain, and efficiency. Moreover, the time-domain analysis displays minimum dispersion to the radiated pulse. All these features make the proposed antenna a good candidate for future wireless communication systems with the polarization-diversity operation, where the challenge such as multipath fading is a major concern.

2.1 MAIN CONTRIBUTION

Reduction in mutual coupling between neighboring antenna elements along with the compact size is a very complex task in antenna design. A lot of research is still going on in antenna design specifically in isolation enhancement. In this paper we have developed heterogeneous structure and maximum capacity will be achieved by data transfer without interference which is possible due to less mutual coupling. Thus higher isolation and enhancement in channel capacity observed than the existing system.

2.2 ORGANIZATION OF PAPER

The rest of this paper is organized as follows. Section 3 describes the antenna design in this paper, including antenna configurations, dimensions, effect of the ground structure. The antenna's simulated and practical results of the parameters are explained in section 4, diversity parameters are discussed in section 5, effects on antenna parameters due to parametric variations is observed in section 6; section 7 suggested improvement in channel capacity followed by a conclusion.

3. PROPOSED ANTENNA

The geometry of the proposed UWB MIMO antenna, having a compact size of 16mm×18mm×1.6mm (one element antenna), is shown in Fig.1. It is designed on the substrate known as FR4; its thickness is 1.6mm, a dielectric constant of 4.4, and a loss tangent of 0.002. The antenna structure consists of two billhook shaped planar monopole antenna elements, having orthogonal ports along with microstrip feeding technique. This feed line uses 50Ω SMA connector for impedance matching purpose.

The two billhook shaped radiating elements are homogeneous and placed orthogonal to each other i.e. one element placed in X-axis where other is along the Y-axis having 17.6mm distance between them. Antenna elements are placed less than or equal to λ/2 distance apart from its adjacent element. As proposed antenna having planar geometry, radiating element is placed the upper side of substrate and ground plane is on the lower side. Starting edge of the microstrip line in the radiating patch is blended for improving return loss i.e. increasing the flow of current in the antenna element over the ultra-wideband frequency range, particularly at the center frequency. The separation between the ground and the radiating patch is optimized for the maximum impedance matching.

To reduce the mutual coupling between the two radiating patches, inverted C-shaped structure is printed in the ground plane and an additional U shape is added between the two ground planes. The U-shaped slit shows dimensions L5, L7, and W9. Rectangular slot with dimensions L3×W5 is inserted in the ground plane. This additional structure is act as a reflector and hence it enhances the isolation between adjacent radiating elements. Finally, the antenna dimensions are optimized for matching maximum impedance and isolation. The optimized dimensions are as shown in Table.1. The Fig.2 indicates geometry of the two ports proposed antenna. The two antenna elements have individual ground planes. Ground structure is modeled according to the radiating patch elements to avoid the interference. Only that antenna will be active which receive the signal and other should be inactive due to the particular ground structure thus reduction in the interference and correlation should be minimum.

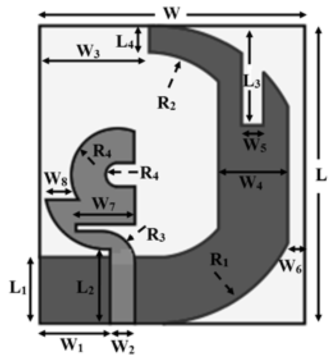


Fig.1. Basic geometry of proposed antenna

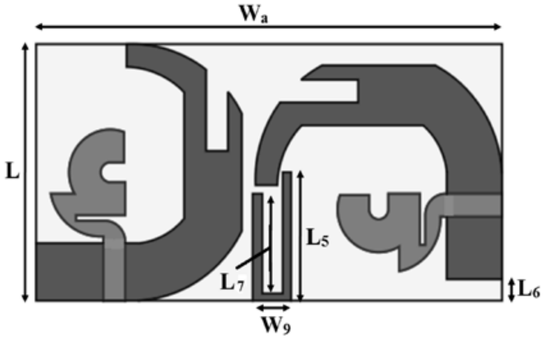


Fig.2. Two port geometry of proposed antenna

3.1 COMPACT UWB MIMO ANTENNA DESIGN

The geometry of the proposed UWB MIMO antenna, (two elements) having compact size of only 33mm×18mm×1.6mm is shown in Fig.2. The Proposed antenna structure is microstrip patch antenna thus design steps are as follows.

Step 1: Calculation of Width (*W*):

The width of microstrip patch antenna is given as,

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

where,

C = Free space velocity of light, 3×10^8m/s

f_r = Operating frequency

ε_r = Dielectric constant

Step 2: Calculation of effective dielectric constant (ε_{reff}):

The effective dielectric constant is given in Eq.(2)

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left\{1 + 12\frac{h}{w}\right\}^{0.5} \tag{2}$$

where,

h = height of dielectric substrate

w = width of patch

Step 3: Calculation of effective length (L_{eff}):

The effective length is shown in Eq.(3)

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} \tag{3}$$

Step 4: Calculation of actual length of patch (L):

Actual length is obtained by Eq.(4)

$$L = L_{eff} - 2\Delta L \tag{4}$$

where,

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)}$$

With the help of above formulae diversity antenna dimensions are obtained and optimized dimensions are given in Table.1.

Table.1. Dimensions of Proposed Antenna

Parameter	**L**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**
Values	18	4.03	4.5	6	1.6	9	2.5	7.5
Parameter	W	W1	W2	W3	W4	W5	W6	W7
Values	16	4.25	1.5	6.6	4.3	1.3	1	3.55
Parameter	W8	W9	Wa	Wb	Lb	R3	R1	R2
Values	2	2.3	34	34	36	3	0.8	1.5

4. RESULTS AND DISCUSSION

While testing any type of antenna, some parameters need to be verified like reflection coefficient, isolation, VSWR etc. Implemented design is verified by CST Studio software and practical results by Vector Network Analyzer (VNA). Improvement in the antenna parameters can be achieved by the various ground structure and is as shown in the following section.

4.1 S PARAMETERS

The Fig.3 shows the return loss performance of proposed antenna with and without reflectors. As shown in graph performance level is quite better in an antenna with reflectors. Thus, return loss i.e. S11 as well as isolation S21 is good in the working band. With a return loss is 13dB over frequency range start from 3.3GHz and extends above 11GHz. The U-shaped reflector is added to the ground to achieve isolation less than 15dB over upper ultra-wideband i.e. from 5.3-11.2GHz. Mutual coupling of proposed antenna is shown in Fig.4. We have measured the result for return loss with the optimized ground plane which is about 12dB over UWB range. The improvement in the return loss at lower UWB frequencies is obtained by inserting the rectangular slot and U-shaped slot in the ground plane, blending the edges of the inverted C-shaped ground structure.

4.2 RADIATION PATTERN

The radiation pattern of the antenna is the strength of the radio waves from the antenna or another source in the field of antenna design. The simulated results of radiation patterns in H(XZ) and E(YZ) planes for port-1 and port-2 at three different frequencies of 6GHz, 8GHz, and 11GHz are shown in Fig.5(a), Fig.5(b) and Fig.5(c), respectively. Due to the homogeneous structure of antenna elements, radiation pattern for both the antenna is linear. Both the antennas are showing linear polarization, vertically placed antenna shows vertical polarization and horizontally placed antenna shows horizontal polarization such behavior accomplishes polarization diversity.

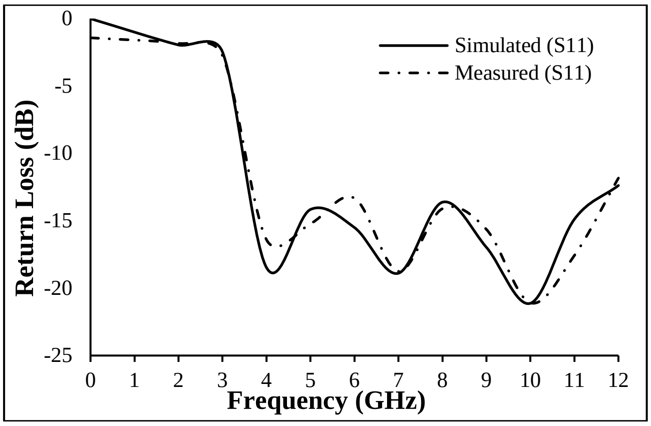


Fig.3. Result of S11 parameter

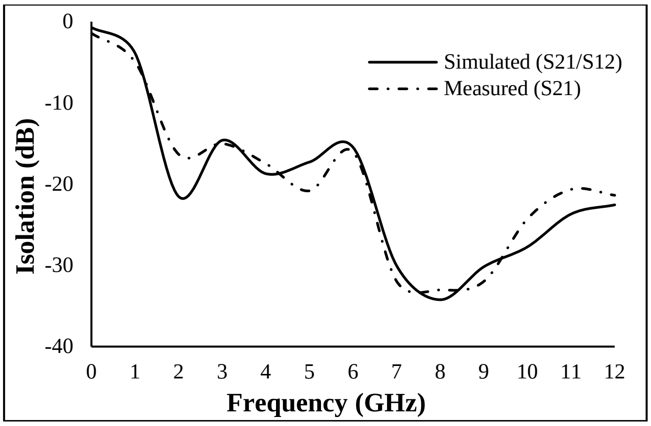


Fig.4. Result of S21 parameter

The experimental radiation pattern is observed in the anechoic chamber. The E-plane shows the figure of eight like structure, whereas the H-plane shows the omnidirectional nature.

The Fig.6.(a) and Fig.6.(b) show the simulated 3D radiation patterns of the two antenna elements at 8GHz and 11GHz respectively. It can be seen that the two antenna elements have orthogonal polarizations and radiation patterns. In proposed design, we have obtained polarization diversity. Vertically placed patch antenna is vertically polarized and horizontally placed shows horizontal polarization. In short, we get linear polarization from this proposed antenna.

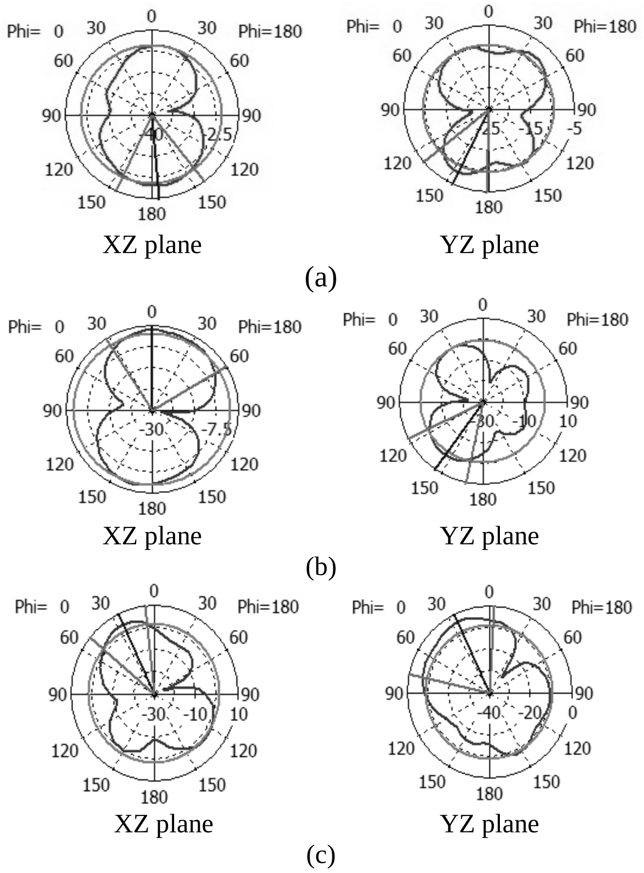


Fig.5. Radiation pattern at (a) 6GHz (b) 8GHz (c) 11GHz

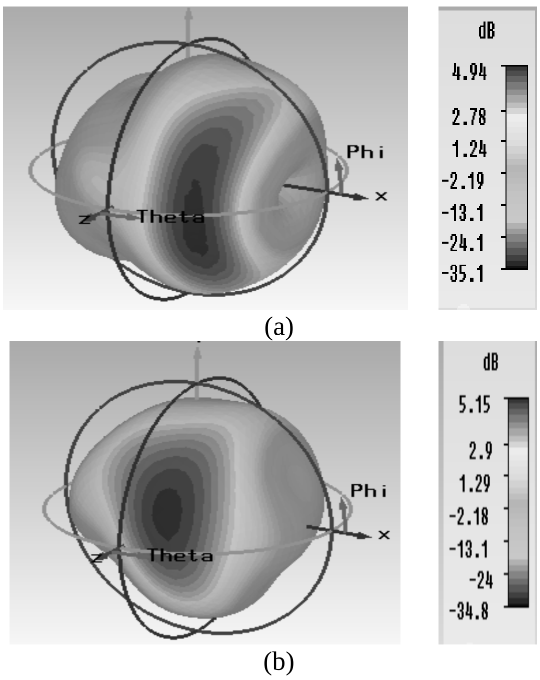


Fig.6. 3D view of radiation pattern (a) at 8GHz (b) at 11GHz

5. DIVERSITY PERFORMANCE

Parameters like diversity gain, capacity loss, envelope correlation coefficient (ECC) are responsible for diversity performance of the antenna discussed in this section.

5.1 ENVELOPE CORRELATION COEFFICIENTS (ECC)

This parameter tells us how independent two antennas' radiation patterns, polarizations are. For better performance of diversity antenna correlation between neighboring antenna elements should be zero. This is accomplished by placing the antenna elements orthogonal to each other. The practical value of ECC should be less than one which is supposed to be good enough for diversity performance. ECC of proposed antenna is calculated by S-parameters using Eq.(5).

The simulated ECC curve is plotted in Fig.7. It shows that simulated ECC is below 0.006 in 2.1-3.5GHz, and is good enough to express diversity parameter and above 3.5GHz it is almost zero. ECC is calculated by S parameters. Return loss and isolation both are responsible for excellent ECC performance. The relation between them is given in Eq.(5).

$$\rho = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^{2}}{\left(1-\left|S_{22}\right|^{2}-\left|S_{12}\right|^{2}\right)\left(1-\left|S_{11}\right|^{2}-\left|S_{21}\right|^{2}\right)} \tag{5}$$

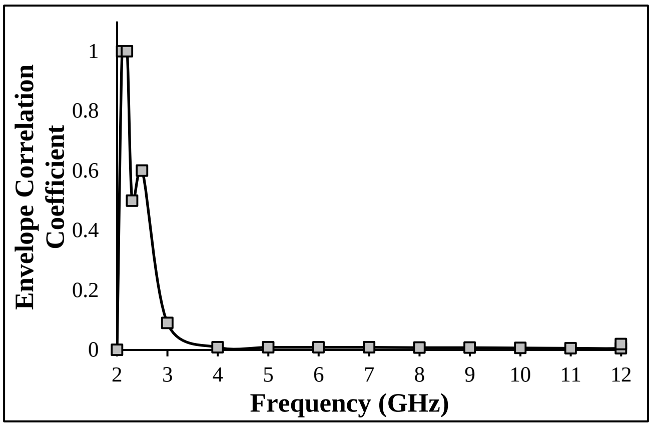


Fig.7. Envelope Correlation Coefficient (ECC)

5.2 DIVERSITY GAIN

The antenna absolute gain according to [2] is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. The Fig.8 shows the simulated results for the antenna (diversity gain) and is 10dB. Diversity Gain (DG) is calculated for proposed antenna as it is diversity antenna and is defined as an enhancement in the performance of diversity techniques proposed for antenna design. This paper tells us about the antenna diversity techniques. The increment in signal to noise ratio at given probability error is also called as diversity gain. Diversity gain is also related to envelope correlation coefficient and is given by Eq.(6).

$$DG = 10\sqrt{1-|E|^{2}} \tag{6}$$

where,

DG = Diversity Gain

E = Envelope Correlation Coefficient

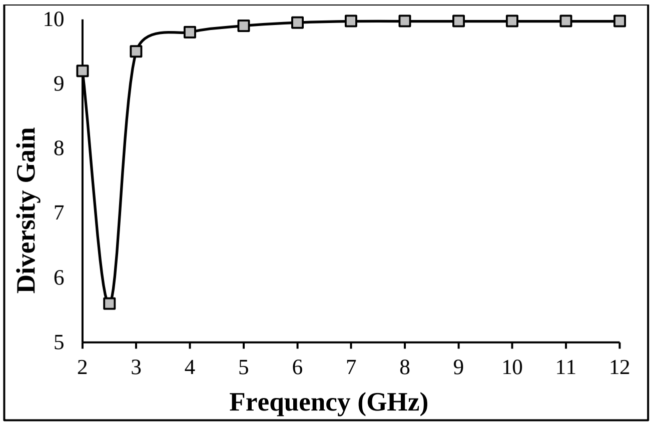


Fig.8. Diversity Gain

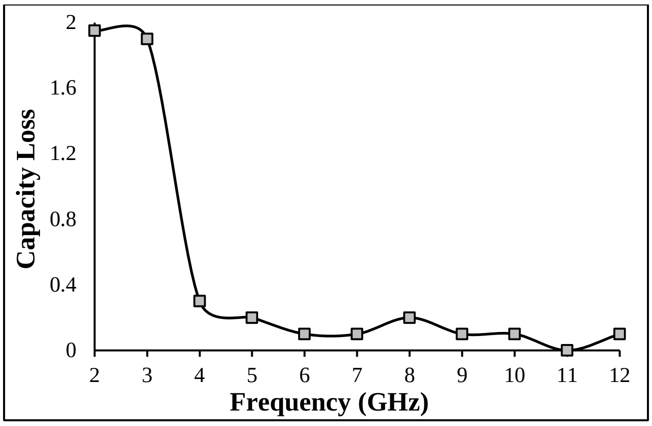


Fig.9. Capacity Loss

5.3 CAPACITY LOSS

The correlation coefficient and diversity gain describe the diversity performance along with the capacity loss parameter in the MIMO antenna. Channel capacity grows linearly with the number of antennas without increasing premium bandwidth or transmitted power. The amount of system performance degradation is given by capacity loss [14]. The correlation in the MIMO channel induces a loss of capacity. For a high Signal to Noise Ratio (SNR), the capacity loss is obtained using Eq.(7) and its required correlation matrix is given by Eq.(8).

$$C(Loss) = -\log_2 \det(\eta) \tag{7}$$

where, (η) = 2×2 correlation matrix

$$\eta = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix} \tag{8}$$

Capacity loss depends on the S-parameters and is calculated by using Eq.(9) and Eq.(10). For proposed diversity antenna capacity loss is 0.37 bits/sec/Hz.

$$\sigma_{ii} = 1 - \left(\left| S_{ii} \right|^2 - \left| S_{ij} \right|^2 \right) \tag{9}$$

$$\sigma_{ij} = -\left(S_{ii}^{*} S_{ij} + S_{ji} S_{jj}^{*} \right) \tag{10}$$

The Fig.9 shows the simulated graph of capacity loss. The curve shows the capacity loss is below 0.4 bits/sec/Hz.

6. PARAMETRIC STUDY

6.1 VARIATION OF THE DIFFERENCE BETWEEN PATCH ELEMENT AND GROUND

Proposed antenna has planar geometry i.e. the ground and the patch which are on opposite sides of the substrate. The gap between them is an important factor in the antenna design to obtain 50Ω impedance matches.

The gap is nothing but the difference between L2 & L1 and is indicated by g = L2-L1. As the gap decreases, the isolation (|S21|) increases within the frequency range of 3.5GHz-10GHz, whereas an increase in gap decreases the isolation |S21| at the higher frequencies which is shown in Fig.10. The Table.2 shows exact value of isolation due to variations in the gap and there is no effect on return loss.

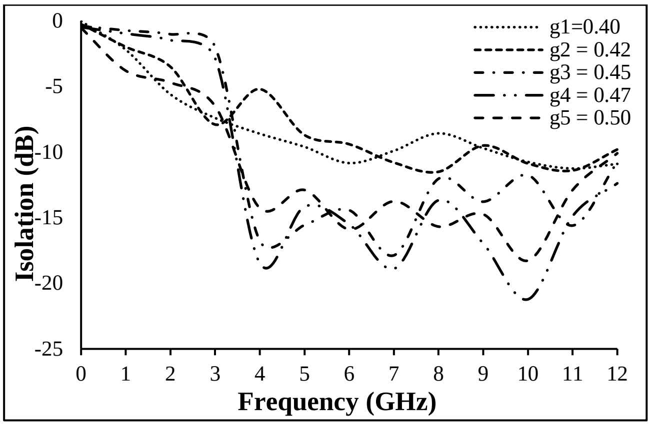
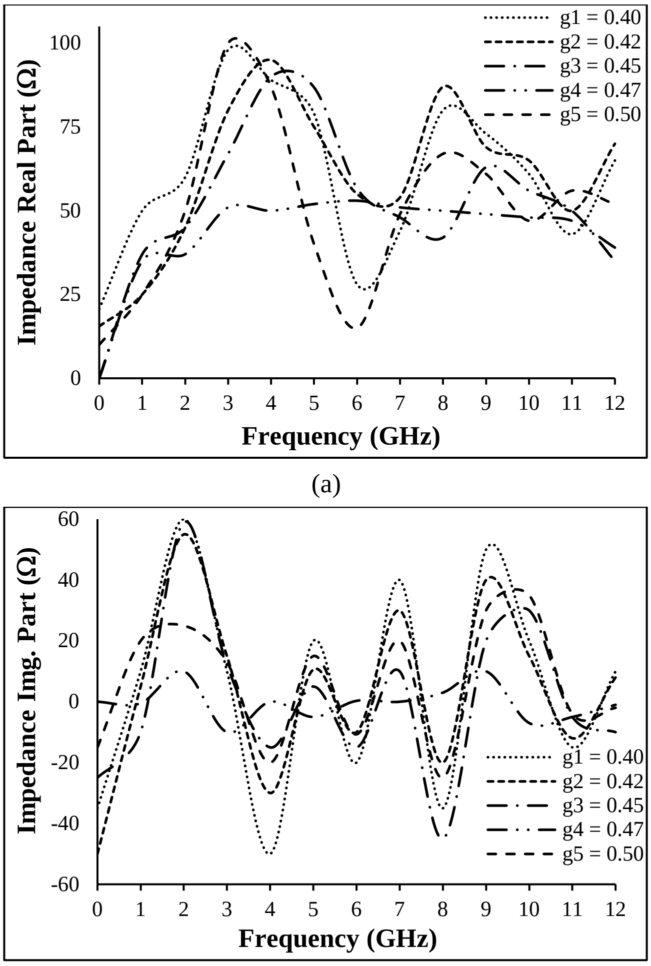


Fig.10. Effect of isolation due to variation in '*g*'

There is the effect of variation of '*g*' on impedance too. When the gap is 0.47, impedance matching is almost done at 50Ω. But for other difference in the gap, impedance is varying from negative imaginary part to positive along with different real part of the impedance. At $g1$ = 0.40, $g5$ = 0.50 i.e. for both extreme points imaginary part is negative whereas for other gap variation it is positive as shown in Fig.11(a) and Fig.11(b). The Table.3 shows parametric variations.

Table.2. Variation in parameter *g*

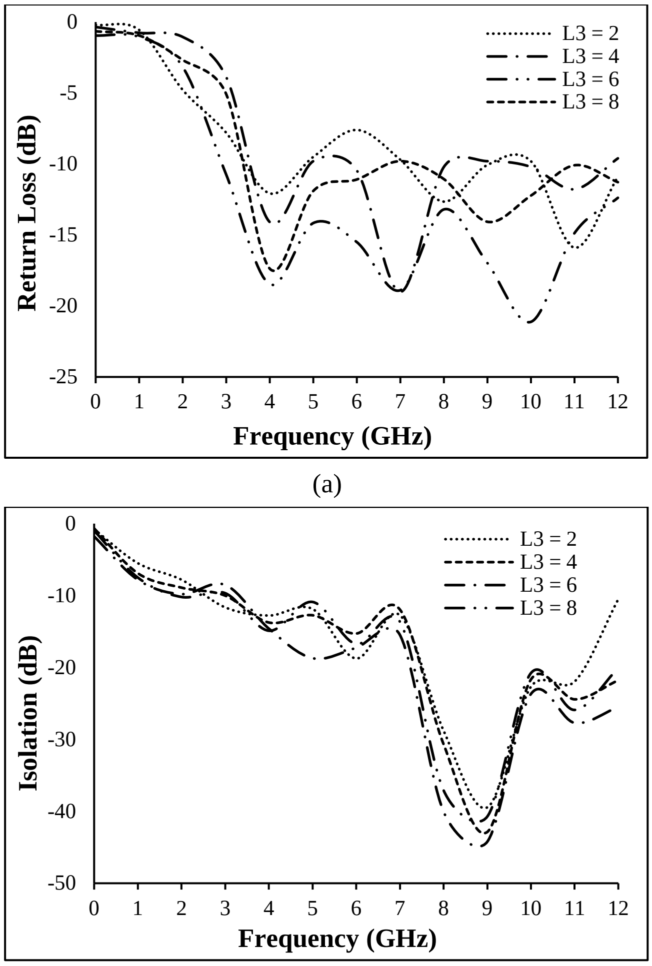
Parametric Variation *g*	Isolation(dB)
$g1$ = 0.40	9.8
$g2$ = 0.42	10
$g3$ = 0.45	13
$g4$ = 0.47	15
$g5$ = 0.50	14



(a)

(b)

Fig.11. Effect on impedance due to variation in ‘*g*’ on (a) Real Part (b) Imaginary Part



(a)

(b)

Fig.12. Effect on S-parameter due to variation in ‘L3’ (a) S11 (b) S21

Table.3.Variation in parameter *g*

Parametric Variation of *g*	Impedance (ohm)
*g*1 = 0.40	100 + 60j
*g*2 = 0.42	90 + 55j
*g*3 = 0.45	75 + 30j
*g*4 = 0.47	50 + 0.07j
*g*5 = 0.50	55 + 65j

6.2 VARIATION IN L3

Due to the variation of L3, S parameters are affected. There is the effect on return loss as well as mutual coupling between antenna elements which is shown in the Fig.12(a) and Fig.12(b) respectively. As the length of L3 increases from 2 to 8mm isolation increases and return loss decreases towards negative scale. This exact parametric response is shown in Table.4.

Table.4. Variation in parameter L3

Parametric Variation of L3	Return Loss (dB)	Isolation (dB)
L3 = 2	10	9.7
L3= 4	8.7	10.5
L3 = 6	10	18
L3 = 8	9.29	11

6.3 VARIATION IN BLEND R3

Blending up to 3mm does not affect the isolation, but over blending distorts the return loss over the higher frequency band. Variation in blend R3, affect the isolation parameter i.e. S21 and is shown in Fig.13. Performance parameter variation is shown in Table.5.

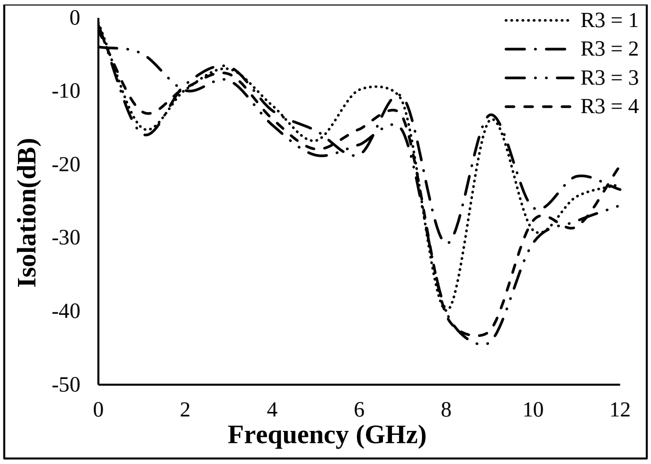


Fig.13. Effect on isolation due to variation in 'R3'

Table.5. Variation in parameter R3

Parametric Variation of R3	Isolation(dB)
R3 = 1	9.9
R3 = 2	10
R3 = 3	17
R3 = 4	15

7. CHANNEL CAPACITY

Channel capacity is studied by a different researcher in different environment system or model. For the different environment, we get different channel capacity depending on the degree of fading. Shannon has given the exact idea about the channel capacity. According to the Shannon, capacity is defined as the highest rate of information can be traveled over a communications channel without any interference.

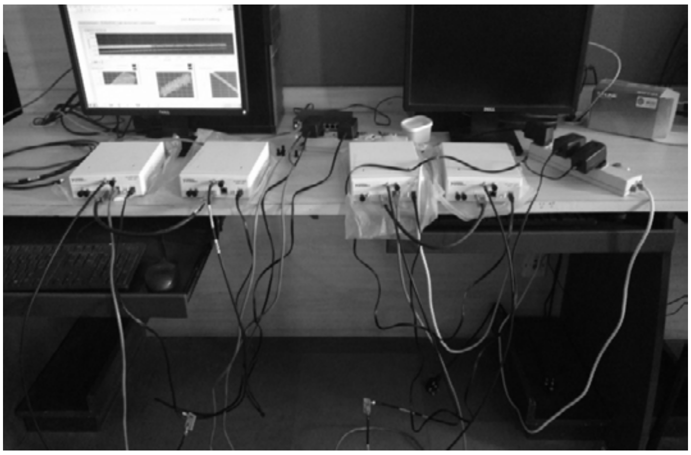
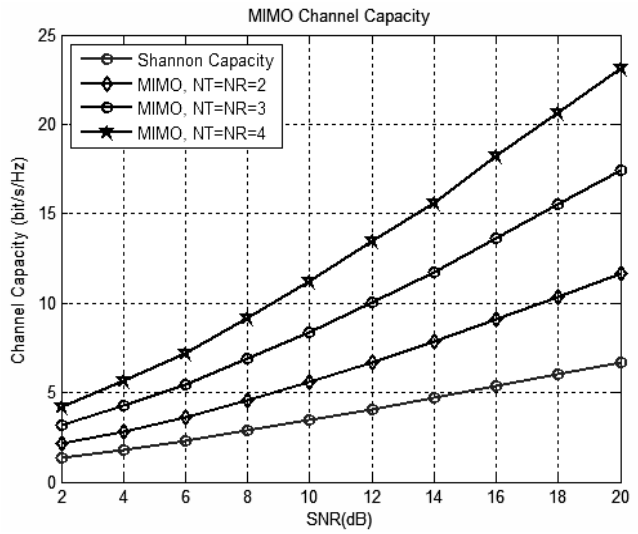


Fig.14. USRP Setup

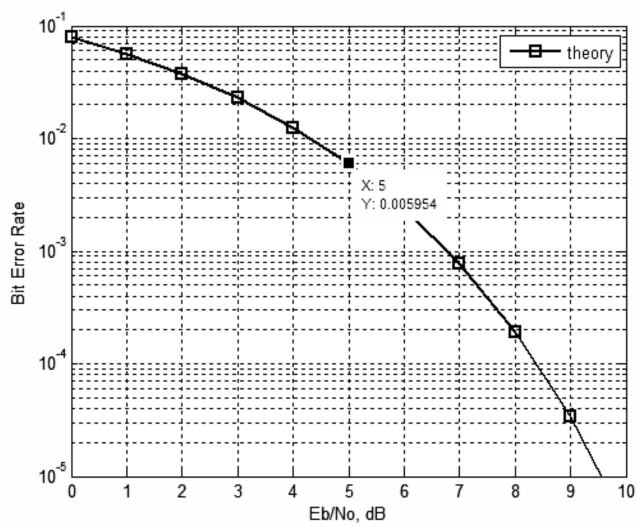
Channel capacity is influenced by the performance of diversity parameters as discussed in section 5. Moreover, these factors are responsible for enhancing channel capacity. For least value of diversity factors channel capacity is more or we see enhancement in capacity, except diversity gain. Practically for this UWB MIMO antenna capacity is verified by using USRP set up. For channel capacity calculation Rayleigh environment is developed. Two antennas are connected to two different USRP kit where one acts as a transmitter and other is a receiver. Set up of USRP is shown above in Fig.14. Here the distance between transmitter and receiver is 0.5m. As antenna size is very much small thus power required for reliable transmission is very high. With the help of proposed antenna, we have measured direct SNR or BER (bit error rate).

We have calculated BER value with the help of USRP kit and measure the capacity by channel capacity graph which is obtained from the MATLAB programming. The Fig.15 shares some information about the channel capacity. In Fig.15(a) information of channel capacity is explained. It tells us that in MIMO system as a number of antenna increases channel capacity also goes on increasing. The Fig.15(b) shows bit error rate.

The Table.6 shows the performance comparison with existing techniques. We have compared our proposed technique with [10] [13]. It is found that proposed technique provides better results in terms of antenna parameters like size, return loss, isolation, ECC, bandwidth, diversity gain.



(a)



(b)

Fig.15. Channel capacity (a) Shannon capacity (b) Bit Error Rate

8. CONCLUSION

A printed, compact, planar UWB MIMO Diversity antenna for enhancing isolation and channel capacity has been investigated in this paper. The measured and simulated impedance bandwidth for $|S11| < -12$dB is shown over the ultra-wideband range. Also, the isolation achieved for proposed antenna is -18dB, in a uniform environment. About radiation pattern H-plane gives Omni directional behavior whereas bidirectional behavior in the E-plane. Envelope correlation coefficient is 0.6 for the non-uniform environment and in upper UWB frequency band, it is almost zero. Diversity gain is approximately close to 10dB. The relation between DG and ECC tell us that as gain increases correlation goes on decreasing and thus there is an enhancement in capacity. These results show that the proposed antenna system is suitable for portable MIMO/Diversity applications. Channel capacity achieved for 10dB SNR is 5.3 bits/sec/Hz. Thus, according to all the practical and simulated results proposed UWB diversity antenna achieves low mutual coupling/high isolation, good return loss, enhanced channel capacity, low envelope correlation coefficients and hence applicable for wireless communication.

Table.6. Performance Comparison with Existing Methods

Parameters	**[10]**	**[13]**	**Proposed Antenna**
Size	$25.7\times14.4mm^2$	$58\times58mm^2$	$33\times18mm^2$
Return loss (S11)	10dB	10dB	12dB
Isolation (S21)	13dB	11.24dB	18dB
Bandwidth (GHz)	2.9-9.76	3.1-11.3	3.5-12.2
ECC	-	0.12	0.006
Diversity Gain	-	-	9.97

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