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Compact planar ultrawideband MIMO antenna for wireless applications

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ABSTRACT

A compact microstrip fed printed monopole MIMO antenna with ultrawideband (UWB) frequency response (S_{11}< -10 dB for 3.1-10.6 GHz) is proposed in this paper. The proposed antenna is miniaturized and has a high isolation of > 23 dB between the ports compared to the existing UWB multi-input multi output (MIMO) antennas in the literature. The proposed antenna is built on FR4 substrate with thickness of 1.6 mm using all-digital single chip architecture and it is planar in geometry to be easily integrated with the other electronic components in the printed circuit board (PCB). The UWB-MIMO antenna is analyzed using simulation and measurements and its performance is investigated. The antenna is extremely useful for low power short range communications and it provides high multipath immunity due to diversity.

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1. INTRODUCTION

Ultra-wideband (UWB) technologies have widely drawn considerable attention due to the several advantages for communications and sensing applications due to the properties of low-power consumption, high data rate, robustness to the multipath environment, relatively low complexity and high time-domain resolution. UWB antennas cover the frequency range of 3.1 GHz to 10.6 GHz which is mainly assigned for the UWB indoor communication applications. Currently, there is a huge demand in increasing the channel capacity. Hence, the two or more, multiple antennas in a single terminal can provide higher data rate which increases the channel capacity without sacrificing the requirement of additional power and frequency bands.

MIMO, Multiple-Input Multiple-Output systems are enriched withmultiple antennas, which can be used as both in transmitter as well as in receiver mode. These multiple antennas have the advantages of higher data rate which in turn enhances the channelcapacity, greater reliability of the system without any extra power or bandwidth. Since, multiple antennas occupy the same arrayof antenna structure, less spacing would be placed between them, and hence mutual coupling isincreased. Hence, high port isolation is recommended to reduce the losses.

The combination of UWB technology with multi-input multi output (MIMO) is proposed in this paper. This system increases the channel capacity for several users to access several services at the same time. It also overcomes the disadvantage of multipath fading in which conventional UWB technologies are facing. This paper gives an effective solution for the limitation of short range communication which require low power consumption devices. But in MIMO technology, several factors of antenna are to be considered such as size, isolation and gain etc.

Several techniques have been introduced such as slits [1] to enhance the impedance matching. A2 × 1 UWB MIMO antenna is designed in [2] with only limited bandwidth (3–6 GHz) which does not meet the FCC specifications and there are many parameters that influence the isolation and VSWR. Whereas, some of the antennas have complex geometry [3] to achieve UWB response. In order to reduce mutual coupling between MIMO antennas ,many configurations and structures have been implemented.Protruded stubs with two element MIMO are introducedin [4] to reduce the wideband mutual coupling between the radiators, the space is not used effectivelywhich results in larger size of antenna.Although many neutralization lines are implemented in [5] to reduce the wideband mutual coupling between the radiators, theisolaton reported is veryless at higher frequencies.The UWB band is covered thoughwrench shaped structures with slots [6]. In [7], a diversity MIMO antenna has been desiged in which protrudedstubs that are employed for the port isolation between the antenna elements to cover theentire UWB spectrum. In [8], a 2–port compact MIMO antenna using asymmetric coplanarstrip feeding configuration has been design with the structure of slots between the monopole andthe ground plane for the achievement of high port isolation of 20 dB. The Isolation of < -15 dB hasbeen achievced by designing defected ground plane and the introduction of the slits in the patchof the antenna as in [9]. In [10], isolation is not very high even without decoupling structures. Though various slots have been introduced in [11], lower UWB range is not covered. A highly compact single element antenna is designed for UWB applications in [12] which cannot be used for MIMO applications. MIMO antennas in [13, 14] occupy a larger board space to radiate a particular frequency range of 2.41-2.46 GHz and 2.2-2.9 GHz respectively.

In summary, the size of the existing antennas is vey large when compared with proposed fourelement MIMO antenna. This paper addresses the issues of size, complexity and isolationof UWB MIMO antenna.

2. ATENNA DESIGN

2.1. Conventional single element UWB antenna design

The geometry of a single element UWB antenna and detailed design parameters are shown in Figure 1 and Table 1 respectively. The proposed monopole antenna is printed on the FR4 - epoxy substrate with the thickness of 1.6 mm and dielectric loss tangent of 0.02. The total volume of the antenna is 40 × 40 × 1.6 mm^3. A circular radiating patch is etched on the front side of the substrate and a partial ground plane is present on the back side.

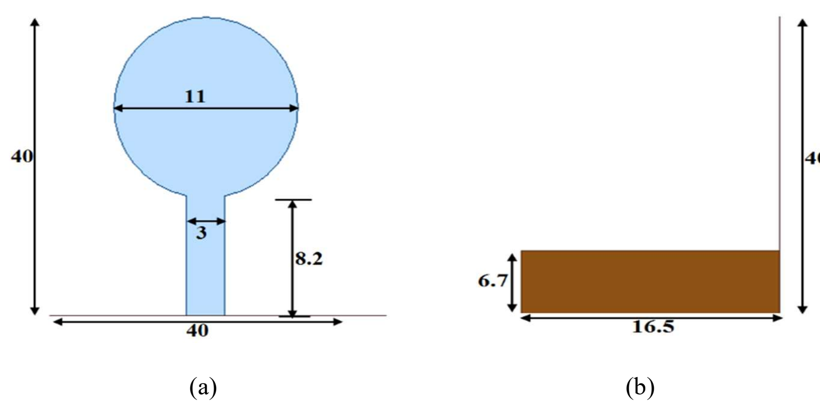


Figure 1. (a) Top layer of single element antenna and (b) Bottom layer of single element antenna (all dimensions are in mm)

Table 1. Dimensions of the single element UWB monopole antenna

Sl. No.	Structure	Material	Size (mm) X	Y	Z
1	Substrate	FR4 – epoxy	40	40	1.6
2	Patch	Copper	5.5(radius)	-	0.035
3	Feedline	Copper	8.2	3	0.035
4	Ground	Copper	16.5	6.7	0.035

2.2. Four element UWB MIMO antenna

Figure 2 depicts the geometry of the four element UWB MIMO antenna. The microstrip fed antenna is matched at 50Ω impedance which gives radiation with high reliability and impedance matching. The principle antenna element is considered as a circular quarter wave monopole with the edge to feed gap distance of 1.5 mm. This feed gap determines the impedance bandwidth of the antenna. The antenna elements are spatially constructed with high intrinsic isolation without any additional filtering requirements and that allows easy extension of number of elements in an array. The absence of decoupling circuit or isolating structures gives the compact size of 40 × 40 × 1.6 mm^3. This is the most compact four element MIMO antenna realized till date.

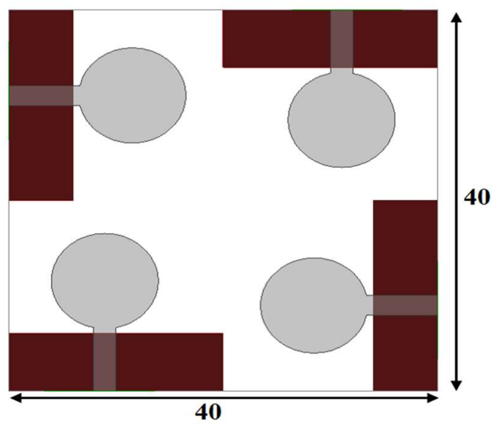


Figure 2. Four element UWB MIMO antenna (all dimensions are in mm)

3. RESULTS AND DISCUSSION

3.1. Return loss

Initially, single element UWB antenna is simulated and its performance in terms of return loss andgain are analyzed. Later, four element UWB MIMO antenna is implemented and the antenna's performances are re-analyzed. The simulated results of the antenna is illustrated by the excitation given at port 1 while the other ports are matched with 50 Ω load. The proposed antenna has < -10 dB impedance bandwidth over the operating band. The simulated result of return loss plot of single element UWB antenna and four element UWB MIMO antenna is compared in Figure 3.

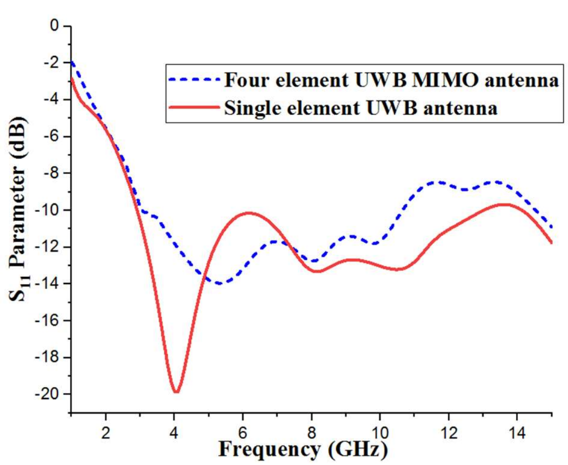


Figure 3. Simulated plot of return loss

3.2. Isolation

The main challenge in construction of UWB MIMO technology is to increase the number of elements in antenna array with high isolation and without introduction of any decoupling circuits. The isolation of the proposed antenna isgreater than 23 dB as observed over UWB band.

3.3. Fabricated antenna

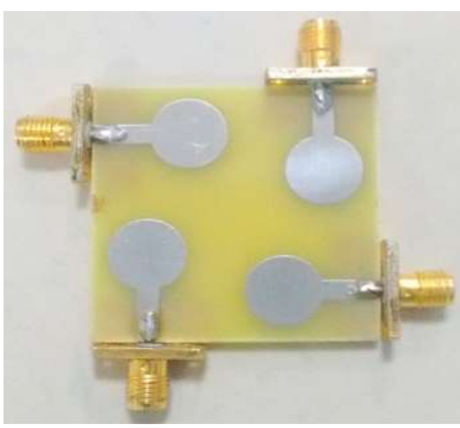
The proposed MIMO antenna is fabricated on a low cost FR4 substrate with the thickness of 1.6 mm which is shown in Figure 4. The fabricated antenna is testedforreturn loss and isolation parameters using Rohde and Schwarz vector network analyzer as shown in Figure 5. During measurement, one port is excited and other ports are matched with 50-Ω load impedance. Figure 6, depicts the comparison plot of simulated and measured results of return loss in which the antenna covers the UWB band of 3.1-10.6 GHz with S_{11}< -10 dB and it can be observed that the measured S-parameters are very well matching with the simulation results.

It can be observed from Figure 7, that the antenna has a high port isolation of > 23 dB over the entire UWB spectrum. The performance of proposed antenna in terms of gain and radiation pattern are tested using Anechoic chamber which is shown is Figure 8. The summary of the performance of the proposed antenna with the existing UWB MIMO antennas is tabulated in Table 2. It can be observed that the proposed antenna is better in terms of size, simplicity and isolation.

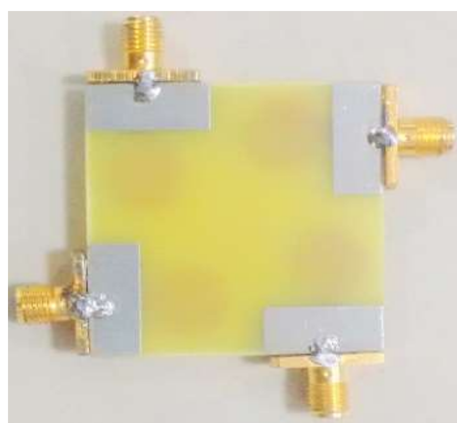
Table 2. Comparison of proposed MIMO antenna with existing structures

Ref.	No. of elements	Bandwidth (GHz)	Size (λ × λ)	Complexity (Yes/No)	Decouplers (Yes/No)	S_{ij}^{*} (dB)
[1]	2	3.1- 10.9	0.4 × 0.4	Yes	Yes	>15
[2]	2	3.1-5	0.34 × 0.16	Yes	Yes	>22
[3]	2	2.4- 9.2	0.32 × 0.32	Yes	Yes	>20
[4]	2	3.4-12	0.45 × 0.45	Yes	Yes	>15
[5]	2	2.87-10.4	0.28 × 0.25	Yes	Yes	>20
[6]	2	4.2-9	0.49 × 0.53	Yes	Yes	>16
[7]	2	3.1-10.6	0.22 × 0.26	Yes	Yes	>18
[8]	4	3-10.6	0.6 ×0.5	Yes	Yes	>20
[9]	2	2.83-10.18	0.5×0.3	Yes	Yes	>15
[10]	2	3-11.5	0.48×0.28	Yes	No	>15
[11]	1	4.5-11.8	1×0.7	No	No	Nil
[12]	1	3-14	0.3×0.3	Yes	No	Nil
[13]	2	2.41-2.46	0.96×1	Yes	Yes	>27
[14]	2	2.2-2.9	0.51×0.58	Yes	No	>20
Proposed	4	3.1-10.6	0.4 × 0.4	No	No	>23

*S_{ij} is the isolation between the i^{th} antenna element and j^{th} antenna



(a)



(b)

Figure 4. (a) Front view of proposed antenna and (b) Back view of proposed antenna

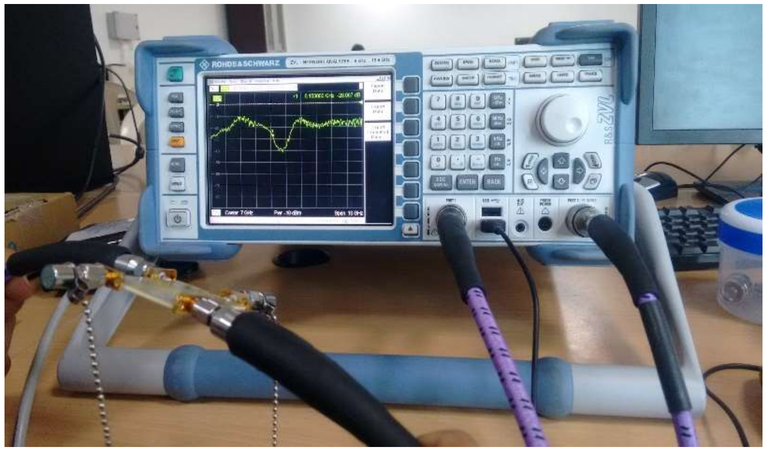


Figure 5. Measurement of isolation using vector network analyzer

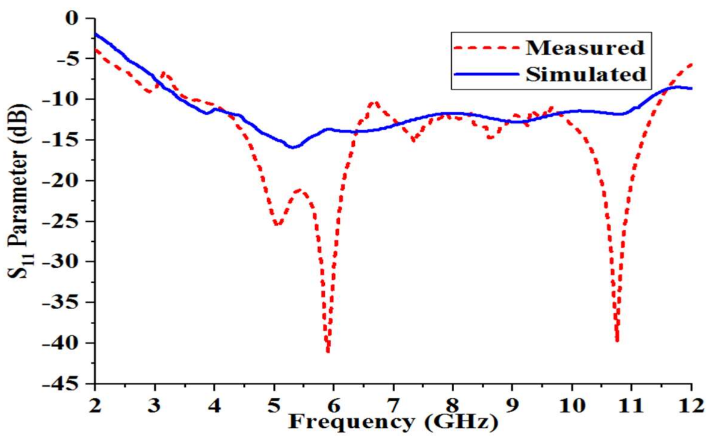


Figure 6. Simulated and measured results of return loss

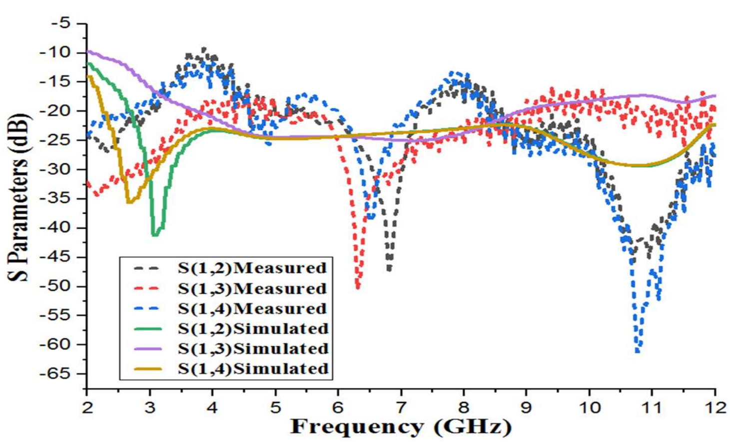


Figure 7 (a). Simulated and measured results of S(1,2), S(1,3) and S(1,4)

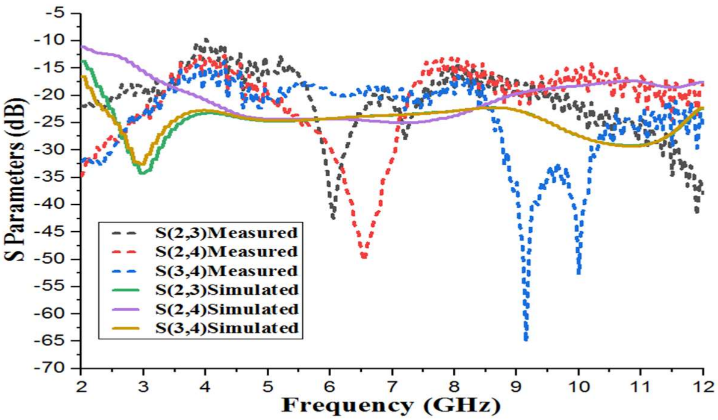


Figure 7 (b). Simulated and measured results of S(2,3), S(2,4) and S(3,4)

Figure 8. Measurement of gain and radiation pattern in ananechoic chamber

3.4. Peak gain

The peak gain of the proposed antenna is 3.1 dBiat 9.9 GHz and the gain varies from –2.3 dBi to 3.1 dBi over the UWB spectrum as shown in Figure 9.

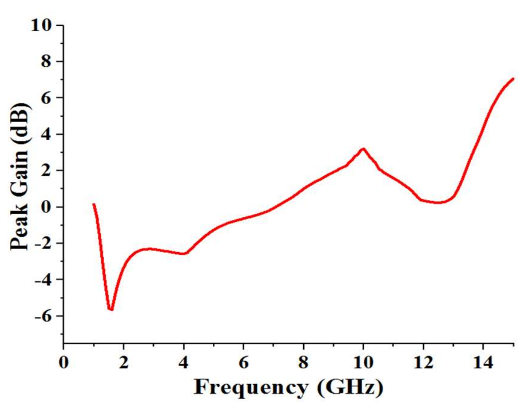


Figure 9. Peak gain plot

3.5. Radiation pattern

In Figure 10 (a) to Figure 10 (c), the radiation patterns of the proposed antenna at *xz* and *yz* planes are investigated at 3.3 GHz, 5.5 GHz and 7.5 GHz, respectively. It can be seen that the antenna exhibits omni directional radiation pattern at *xz* plane and a figure of eight pattern in the *yz* plane. The radiation patterns are stable at lower, middle and higher frequencies ensuring good UWB performance.

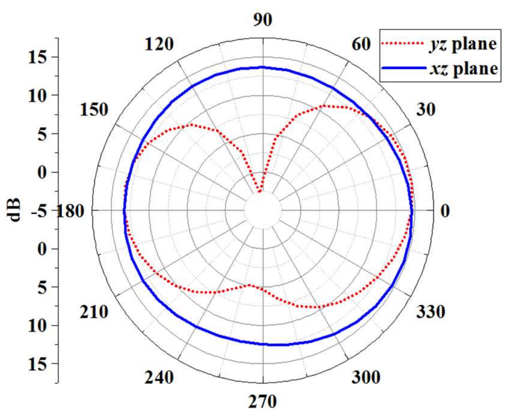


Figure 10 (a). Radiation Pattern at 3.3 GHz

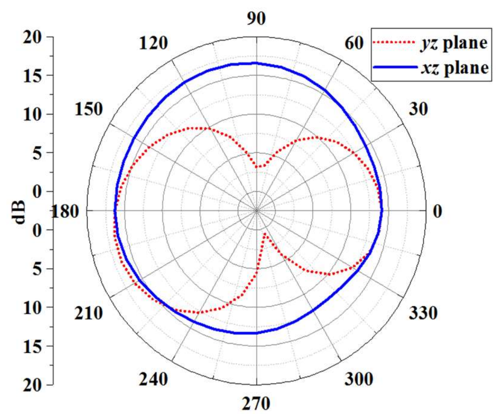


Figure 10 (b). Radiation Pattern at 5.5 GHz

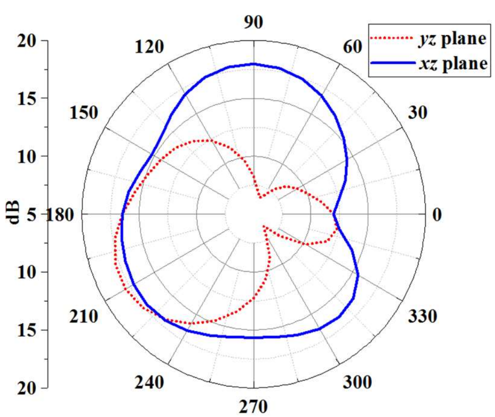


Figure 10 (c). Radiation Pattern at 7.5 GHz

4. CONCLUSION

A compact, cost – efficient UWB MIMO monopole antenna has been designed and investigated. The antenna has -10 dB impedance bandwidth from 3.1–10.6 GHz. The proposed antenna isdevoid of decoupling circuits and has high isolation of >23 dB with stable radiation patterns within the operating band. It has a very compact size of 40 × 40 mm and it can be scalable to many number of elements in an antenna array which would be utilized for future 5G communication systems.

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