Design and Analysis of Compact MIMO Antenna for UWB Applications

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***Abstract*— The need to produce light weight and cheap components and devices has been the driving force for macro-electronics. Electronics that can be stretched has recently attracted considerable attention. In this work a design of printed rectangular monopole antenna for Ultra-Wide Band (UWB) applications is presented. High-frequency structure simulator (HFSS) is used to design the printed antenna is to achieve the best reflection coefficient. Moreover, the stretching effect on the antenna response is studied along x-axis and y-axis. Also, compact UWB Multiple-Input Multiple-Output (MIMO) antennas are proposed. In order to enhance impedance matching and improve the isolation, each UWB MIMO antenna which consists of two comparable monopole elements is proposed with different stubs on the ground plane; the first one is a vertical slotted stub and the other is a ground slotted stub ended with a rectangular loop. The reflection coefficient, mutual coupling, peak gain and radiation patterns have been analysed. The obtained results show that the impedance bandwidth of the antenna is from 3–15 GHz, less than -25 dB mutual coupling between the two ports. The size of the designed antenna is 32 $\times$ 18 mm^2. As a result, it can be noticed that the proposed antenna is appropriate for UWB MIMO systems.**

Keywords*— *Monopole antenna, Ultra-Wide band Multiple-Input Multiple-Output antenna, stretchable material, Microstrip Antennas.

I. INTRODUCTION

In recent years, the significant attention has focused on wearable system for monitoring human health and detecting human motions [1,2]. By Using the wearable wireless communication, we can provide remote diagnosis and transmit the sensory data. For transmitting and receiving, the antenna is a critical component [3].

Rigid antenna fails to work properly when it is under mechanical deformation, so development of stretchable and flexible antenna leads for new device configurations. Silver nanowires (AgNWs) are a promising material for these antennas and other components including solar cells, and sensors [4].

In 2000, the Federal Communication Commission (FCC) issued a license for ultra-wideband communication system for bandwidth of (3.1-10.6) GHz. Since that time many microwave components have been implemented within the specified bandwidth, these components are: Microwave filters,

couplers and antennas [5]. The UWB antenna is used in many applications like ground penetrating radar (GPR), military applications, and medical imaging [6].

Applications such as target detection, and RFID readers need high gains and narrow beamwidths, but the existing UWB antennas have a small gains and omnidirectional radiation patterns [7,8]. The UWB array can be good choice to achieve good gains and directional radiation patterns.

In [9], an UWB MIMO antenna with compact size was presented. The antenna consists of 2 identical monopole antennas and the isolation was improved with a comb-line structure on the ground layer. In [10] the wide band isolation has been improved by a decoupling structure which has been inserted between two antenna elements. High isolation and dual reject bands can be achieved by the antenna presented in [11]. Using parasitic slots and strips on the radiator, A dual band-notched characteristic was created. In [12], the antenna with notch-band characteristic had the compact size of 22 × 36 mm^2, but |S21| was less than −15 dB for the wanted band.

In this paper, a design of printed rectangular monopole patch antenna for UWB applications using a stretchable and reversibly deformable material is presented. A stretchable and highly conductive material of AgNWs is used to design the radiating element and the AgNWs is embedded in the surface layer of an elastomeric substrate. It's effectiveness and efficiency are checked under stretching to use in wearable systems like wearable textile technologies, wearable health technologies, and wearable consumer electronics. The other geometry is a compact MIMO UWB antenna which is introduced using PDMS/AgNWs with different stubs to improve and minimize the mutual coupling between elements and achieving compact size.

II. ANTENNA DESIGN

The suggested paradigm of the monopole patch UWB antenna is shown in Fig. 1. One antenna element is printed on a 16 mm X 18 mm stretchable Polydimethylsiloxane (PDMS) substrate, with a thickness of 1mm and relative permittivity of nearly 2.8 and loss tangent ranging from 0.01

to 0.05. According we modelled the substrate material with loss tangent of 0.02. Conductivity of the AgNW/PDMS stretchable conductor is nearly 8130 Scm^{-1} before stretching as in [13]. AgNWs is used for the patch and the ground plates.

The UWB antenna consists of a monopole antenna. The radiating element has a rectangular shape, and there is a symmetrical staircase structure on the two bottom corners of the radiating element.

To get the desired frequency, the rectangular patch was designed to be 7 mm X 11 mm, backed with an 18 mm X 5.9 mm ground plane. A staircase structure was employed For matching the input impedance of a 2 mm X 6 mm 50 Ω microstrip feed line,. The dimensions of the antenna were optimized in ANSYS HFSS v.13 to get the best reflection coefficient and improve the coupling between the radiating element and the feed line. The optimized antenna's dimensions are listed in Table 1.

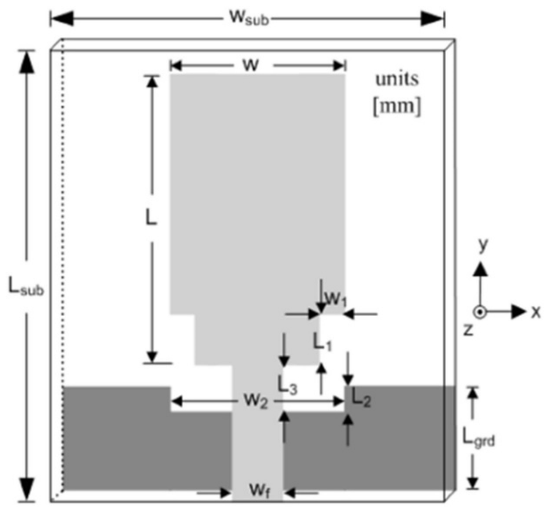


Fig. 1 Monopole UWB antenna

TABLE 1 Dimensions of the proposed UWB antenna (mm).

w_{sub}	l_{sub}	w	L	w_1	l_1	w_2	l_2	w_f	l_3	l_{gnd}	h
16	18	7	11	0.5	1	9	1	2	1.1	5.9	2

The other geometry is a compact UWB MIMO antenna which shown in Fig. 2. This antenna was designed with the same material parameters. Two identical patches with dimensions 7 mm X 11 mm were arranged in parallel. Set up more than one radiating elements on the close space, the mutual coupling between them can be very large. In this design, the edge-to-edge spacing between the patches is 9mm which is nearly equal to the half wavelength for the highest frequency (f_{max} = 15 GHz) which is equal to 20 mm. Each antenna is feed by a 50 Ω microstrip line. The dimensions of the ground plane are w_{gnd} X l_{gnd} mm^2 and for improving the impedance matching at high frequencies, a rectangular slot with dimensions of w_2 X l_2 mm^2 is cut on the ground plane underneath each feeding line. Finally, ground stubs were added on the ground plane of the antenna.

Diverse methods have been checked to merge MIMO techniques with UWB technology trying to slash the mutual coupling between elements and getting a compact size. The proposed structures can efficiently improve isolation and enhance the bandwidth of the antenna. The optimized dimensions for the substrate of the UWB MIMO antenna are 32 X 18 mm^2 and all other dimensions are the same like the previous antenna.

III. Results and Discussion

A. *Antenna Elements*

The designed UWB antenna consists of a rectangular patch element. The monopole patch antenna was designed using a stretchable material, PDMS for the substrate and AgNWs for the top and ground plates. The optimal dimensions for the structure of the UWB patch antenna were shown in the previous section.

The UWB rectangular monopole patch antenna has approximately a lower resonance frequency at [14]

$$f_{rl} = \frac{144}{l_{gnd} + L + g + \frac{w_{sub}}{\sqrt{1+\varepsilon r}} + \frac{w}{\sqrt{1+\varepsilon r}}} \text{ GHz} \quad (1)$$

Where $l_{gnd}, L, and\ g$ are the length of the ground, the length of the radiating element and the gap between them respectively. The calculated f_{rl} is about 7 GHz. Fig. 3 shows the simulated $|S_{11}|$ which is less than -10 dB for the UWB operation.

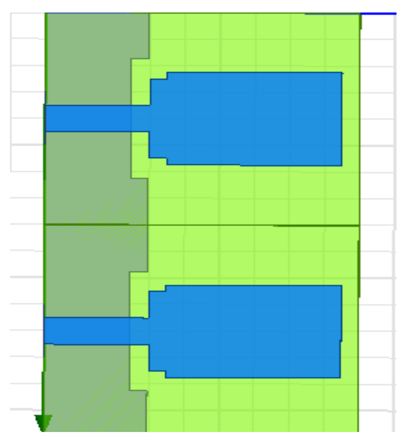


Fig. 2 The top view of the UWB MIMO antenna.

For input impedance matching improvement and enhancement the bandwidth of the antenna, a staircase structure was done for each patch and a rectangular slot was cut on the ground plane underneath each feeding line. By changing l_1 and w_1, the lower cut off frequency could be changed to reach 6 GHz and $|S_{11}|$ will be less than -10 dB from 3.37 GHz to 15.2 GHz which means that the staircase and the slot in the ground plate have a huge outcome by improving the input impedance matching as shown in Fig. 4.

After these improvements, the stretching was applied on the antenna along x-axis and y-axis, along its width and length respectively, the applied stretching was between (0-15) %. The value of S_{11} gives an indication about how the waves are reflected under stretching and how this affected antenna bandwidth. Fig. 5 represents the value of S_{11} under stretching along x-axis and Fig. 6 for S_{11} with stretching along y-axis. In UWB application, it is acceptable when its value is less than -10 dB continuously.

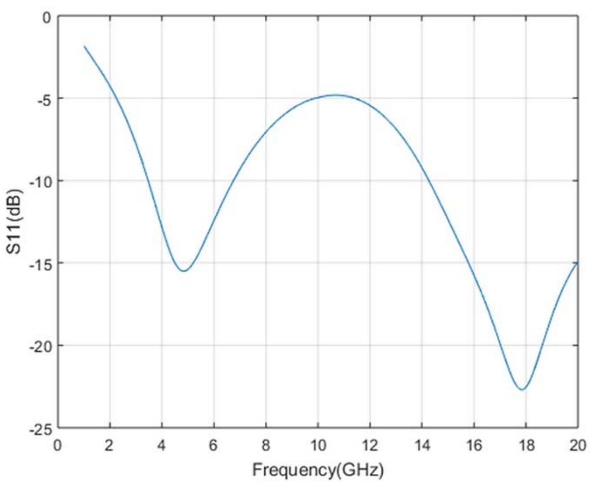


Fig. 3 Simulated $|S_{11}|$

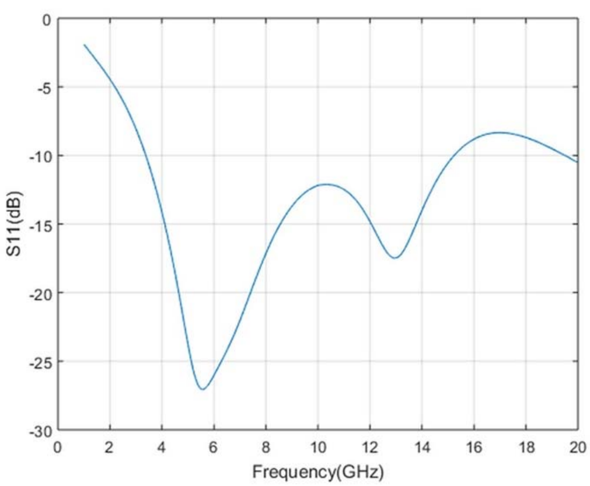


Fig. 4 Simulated $|S_{11}|$ after doing staircase and ground slot

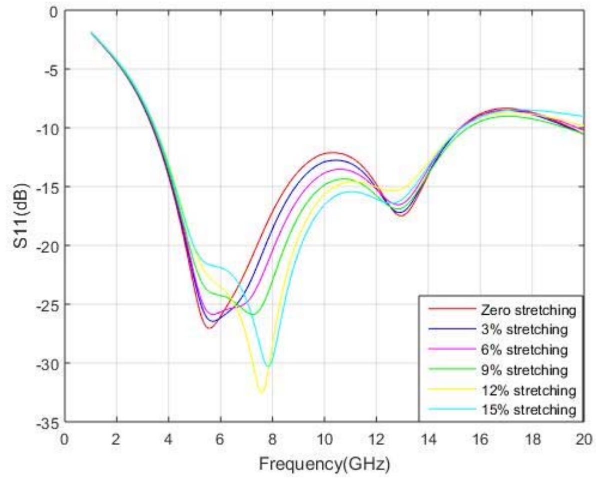


Fig. 5 Simulated $|S_{11}|$ with stretching along x-axis

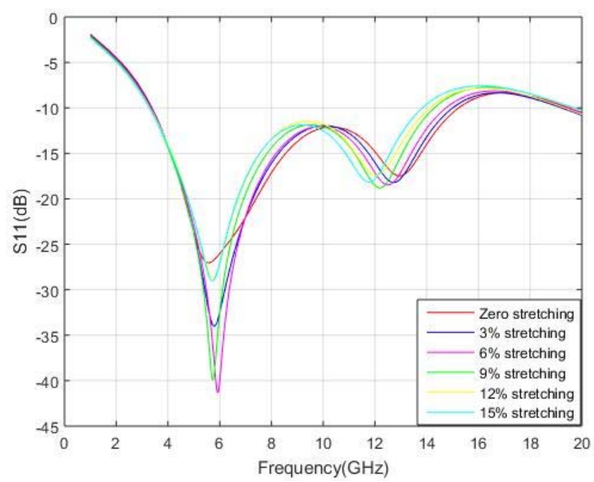


Fig. 6 Simulated $|S_{11}|$ with stretching along y-axis

Due to the applied strain, we have a shift at the resonance frequencies and this change is accounted by changing the dimensions of the antenna as a function of the applied strain. PDMS is a typical hyper-elastic material and under consideration of constant total volume during deformation [15]. The length and thickness of the antenna shrink proportionally, when it is stretched along its width and the lower resonance frequency f_{rl} is determined using equation 1. When a strain of s is applied along x-axis, the new dimensions of the antenna, width w, length L, thickness h as the function of s are [9]:

$$W = w_0 * (1 + s) \tag{2}$$

$$L = \frac{L_0}{\sqrt{1+s}} \tag{3}$$

$$h = \frac{h_0}{\sqrt{1+s}} \tag{4}$$

When a strain is applied along y-axis, the width and thickness shrink proportionally. As we can see in Fig. 5 and

Fig. 6, with stretching, the antenna bandwidth was nearly constant for each value of s.

As shown in Fig. 2, when placing the two antennas close to each other, the UWB frequency band is covered. Fig. 7 shows the S-parameters S_{11}, and S_{12}, in dB for the MIMO UWB antenna.

S_{11} is less than -10 dB and S_{12} is less than -15 dB for the desired frequencies, S_{11} is good and S_{12} is wanted to be less than -25 dB for UWB applications. So, we need to improve isolation between antenna elements.

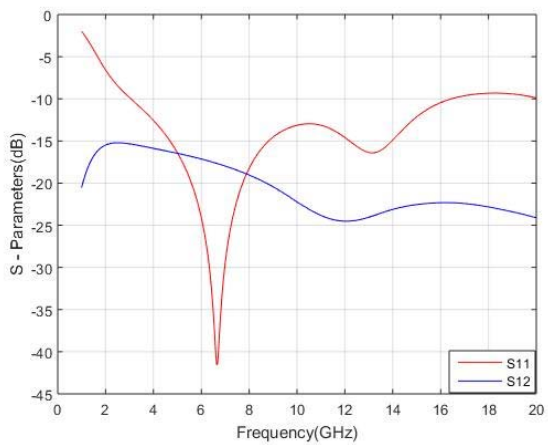


Fig. 7 S-Parameters for MIMO antenna.

B. *Improving of Isolation*

To maintain high efficiency, the mutual coupling between radiating elements should be minimized [9]. To reduce it in the UWB band, several structures are used in the presented MIMO antenna. These structures achieve high isolation because of different mechanisms. One of them, changing the current distribution in the ground plane using stubs, which will reduce the mutual coupling by capturing the current towards them. Also, an improvement in the impedance matching will happen.

One of these structures is an AgNWs stub which was introduced vertically between the radiating elements, between the substrate of each antenna. Using this stub, the mutual coupling was improved for the band of UWB and the isolation was less than -25 dB for the frequency band of 3.9 – 11.9 GHz, shown in Fig. 9. Due to the symmetry of the antenna and as S_{22} and $S_{12}$are identical to $S_{11}$and S_{21}, respectively, we have only presented S_{11} and S_{12}.

Initially, we introduced an AgNWs sheet between the substrates and then two slots were created to improve the mutual coupling, each slot has 7 mm length and 0.5 mm of thickness as shown in Figure 8 a and b.

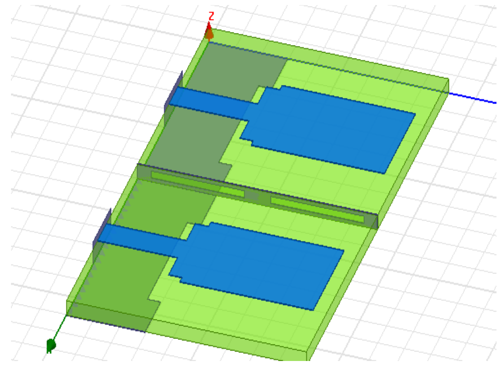


Fig. 8 (a) Geometries of MIMO antenna with vertical stub.

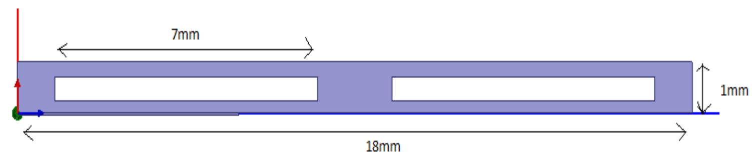


Fig. 8 (b) Geometries of the stub.

The other structure was a stub which made in the ground layer as shown in Fig. 10. The mutual coupling for the desired band was improved, and S_{12} was less than -25 dB for the band of 3.5-10.6 GHz. Shown in Fig. 11.

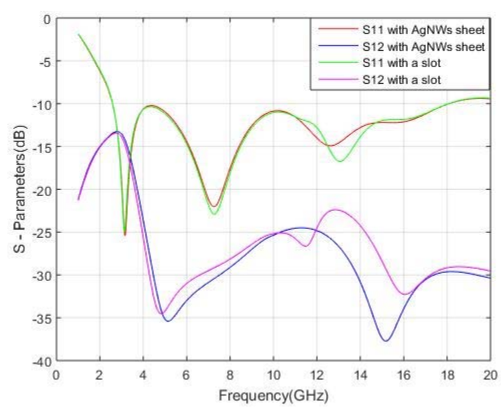


Fig. 9 S-Parameters for MIMO antenna with vertical stub.

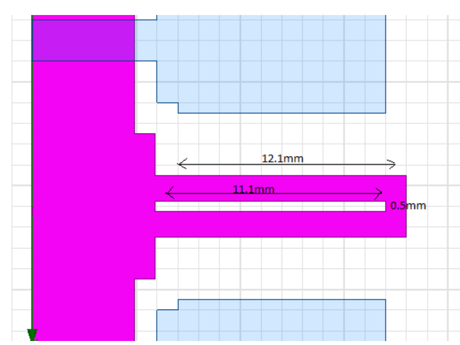


Fig. 10 Geometries of the ground stub.

Finally, a rectangular loop was added at the end of the ground sub, shown in Fig. 12. The proposed loop improves the mutual coupling and the isolation for the f band of 3-10.6 GHz as shown in Fig. 13.

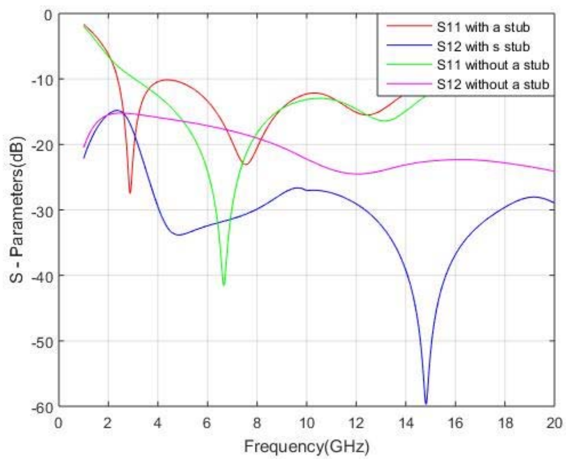


Fig. 11 S-Parameters for MIMO antenna with and without a ground stub.

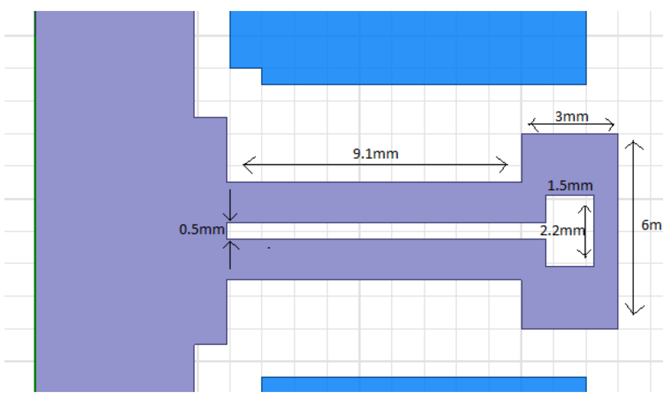


Fig. 12 Geometries of the ground stub with a loop.

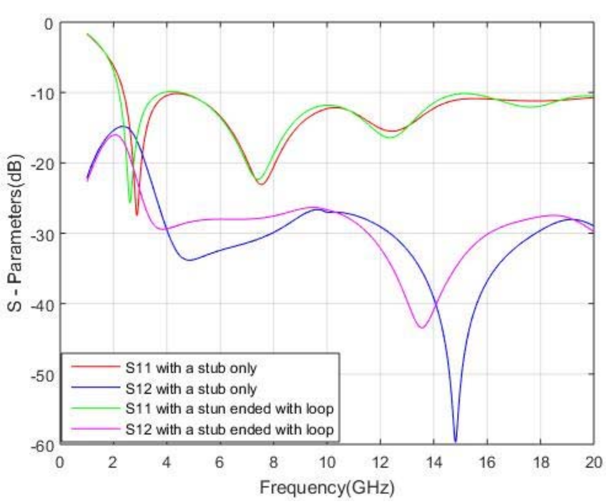


Fig. 13 S-Parameters for MIMO antenna with and without a rectangular loop.

C. Other antenna parameter

The paradigm of the UWB and UWB MIMO antennas described in previous sections have been simulated. The s parameters of the final design are presented. These results prove that this antenna specify the specifications of the UWB MIMO operation across the whole band.

- *Radiation Patterns*

The simulated radiation patterns of the UWB antenna at the frequencies of 4.5 GHz and 9 GHz in 3D polar plot are shown in Fig. 14 (a) and (b). The radiation pattern for the antenna is nearly omnidirectional for these frequencies. At 4.5 GHz frequency, we have less deviation in the radiation pattern but when the frequency is increased the similarity in the radiation pattern decreases.

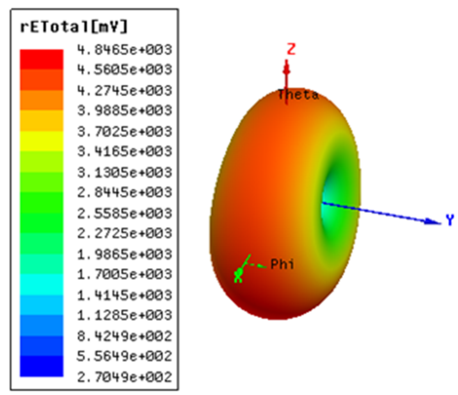
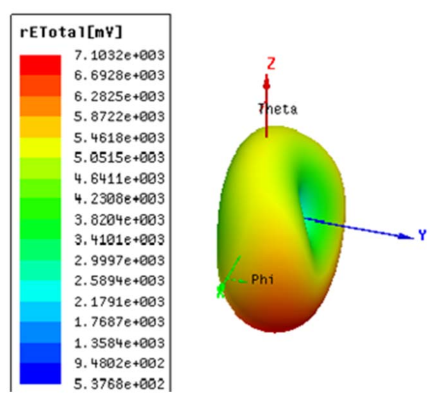


Fig. 14 3D radiation pattern for the UWB antenna at (a) 4.5 GHz.



(b) 3D radiation pattern for the UWB antenna at 9 GHz.

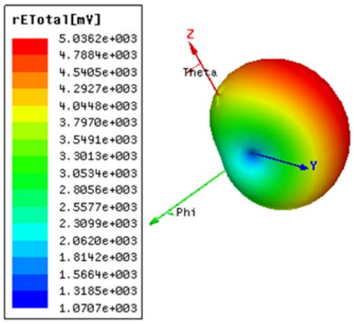
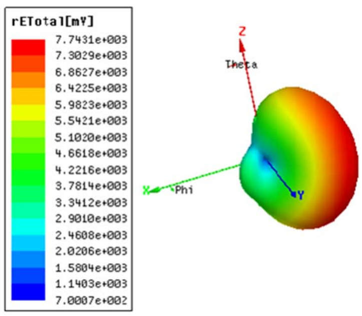


Fig. 15 3D radiation pattern for the MIMO UWB antenna with a rectangular loop at (a) 4.5 GHz



(b) 3D radiation pattern for the MIMO UWB antenna with a rectangular loop at 9 GHz.

3D radiation pattern results of the proposed MIMO UWB antenna with a ground stub ended with a rectangular loop at the frequencies of 4.5 GHz and 9 GHz in 3D polar plot are shown in Fig. 15 (a) and (b).

As we can see, when the MIMO UWB antenna was introduced, the radiation pattern became more directive especially when the stubs were added to the ground plane.

D. Performance Comparison

In this section, a quick comparison will be done between the proposed antenna and recently designed antennas in [9,10,11,12] on the size, isolation and bandwidth. Table 2 shows this comparison. Our antenna achieves good isolation performance with compact size. Therefore, we can conclude that it is a good choice for UWB MIMO system applications.

TABLE 2. Performance comparison of the proposed antenna and some referance antennas.

Reference	Size (mm^3)	Bandwidth (GHz)	Isolation (dB)
9	26 × 31 × 0.78	2.8 – 12	-25
10	35 × 40 × 0.8	3 – 11.6	-16
11	27 × 30 × 0.8	3 – 11	-20
12	22 × 36 × 1.6	3.1 – 11	-15
Our Work	32 × 18 × 1	3 – 15	-25

IV. Conclusion

We have presented a class of monopole patch UWB antennas which are stretchable. An UWB monopole antenna was simulated and the main antenna parameters were measured and analyzed such that S parameters, and radiation properties of the antenna were characterized under stretching along x-axis and y-axis. Also a tight UWB MIMO antenna was proposed and an isolation improvement was made for a UWB application. This improvement was presented by using different stubs to improve mutual coupling and impedance matching. It is noticed from results that the antenna can cover the UWB band of 3.1–10.6 GHz with good mutual coupling and isolation in the whole UWB band. Based on the simulated performance, the MIMO antenna is good choice for UWB applications.

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