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Novel Elliptical Branched Ultra-Wideband Microstrip Antenna Using Fractal Methods for MIMO Systems

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ABSTRACT: A novel elliptical branched shape patch as a radiating part of an antenna is proposed for Ultra-Wideband (UWB) and Multi-Input-Multi-Output (MIMO) applications. The antenna has been designed on the basis of the elliptical geometry and space-filling property of the fractals. The proposed antenna is compact with the size of 30×30×1 mm3 which is fabricated on a substrate of FR-4. The parameters of the antenna were optimized by means of numerical simulations in ANSYS Electronics software. The measurement and simulation results show that the antenna has a -10 dB return loss bandwidth from 2.86 GHz to 12 GHz for UWB applications, moreover, the group delay variation is less than 10 ns over the frequency band. All the steps of simulation and measurement of the proposed antenna are compared and discussed.

Keywords**:** Fractal, Microstrip Antenna, Ultra-wideband, Multi-Input-Multi-Output, Branch Antenna.

INTRODUCTION

After allocation of the frequency band of 3.1-10.6 GHz (UWB) for commercial use by the FCC (Federal Communication Commission) [1] Ultra-wideband and Super-wideband systems have received huge attraction in wireless communication. Microstrip antennas are popular because of offering antennas with low cost, low profile, lightweight, and ease of fabrication [2].

Moreover, it is worth noting that the maximum operating frequency range of an indoor UWB antenna in the provision of FCC-sanctioned UWB technology is from3.1 to 10.6 GHz with a ratio bandwidth of 3.4:1 [2].

In recent years, wireless communication systems have increased rapidly. In high-bit-rate wireless communication for reduced multipath fading and increased capacity, multiple-input-multiple-output (MIMO) systems are suitable [2]. The MIMO antenna array should have a compact structure and high isolation between the signal ports [2]. To achieve maximum channel capacity the array is also required to have a high gain [2].

The main parameters expected from ultra-wideband or super-wideband monopole antennas are structures that have a good return-loss response and exhibit desirable radiation characteristics that are essentially Omni-directional [3-6].

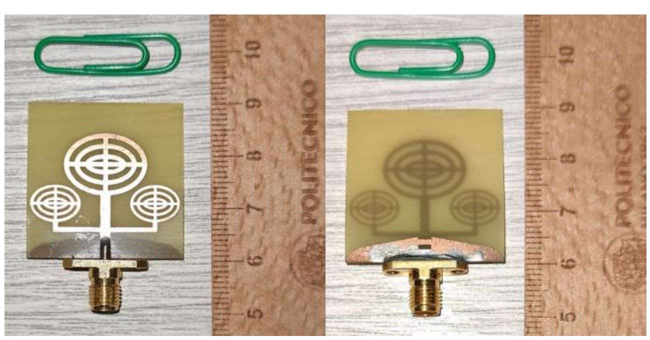


Figure 1. front view, and back view of the proposed realized antenna.

There are various techniques to realize a specific bandwidth [7]. In the case of fractal antennas, one of the considerable and substantial methods is keeping up iterations to achieve desirable and agreeable impedance bandwidth. In the design of ultra-wideband antennas, the geometry of the antenna's radiating patch and its ground plane plays a significant role [8]. Examples of various techniques of designing monopole antennas include rectangular, triangular, circular, and elliptical [9]. Because of the self-similarity and space-filling characteristics [10-13], fractal concepts and methods have emerged as a viable and reliable method for designing compact UWB, SWB, and multiband antennas [8].

In this paper, our main goal is to present a novel patch structure with enhanced ground structure in which by using fractal's properties we can achieve the aforementioned applications.
The front and the back view of the proposed antenna is depicted in Figure 1.

ANTENNA CONFIGURATION

We prefer to divide the structure of the antenna into two sub-categories: Patch Structure and Ground Structure.

Patch Structure

The patch structure of the proposed antenna and its geometry is shown in Figure 2.

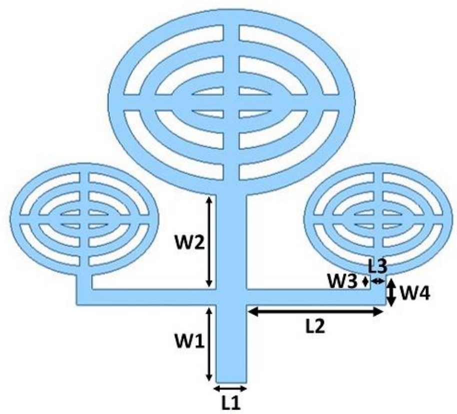


Figure 2. Patch structure of the proposed antenna and its geometry.
L1=2mm, L2=9mm, L3=1mm, W1=5mm, W2=6mm, W3=1mm, W4=2mm.

First, we have 1 horizontal ellipse with the major axis of 16 mm and the minor axis of 12 mm in which the other 5 ellipses nested inside it with the following geometry (major axis, minor axis): (14, 10), (12, 8), (10, 6), (8, 4), (6, 2). The width of the cross shape inside the ellipses is 1 mm. Then in the second step, we reduce the dimension of the whole first structure by the factor of 0.6 to decrease the dimension to fulfill the desired application. Moreover, due to symmetrical and better radiation and, we put 2 of them beside the main structure as is shown in Figure 2.

Ground Structure

Figure 3 shows the structure and dimension of the antenna's ground plane.

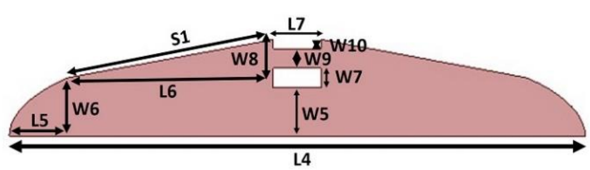


Figure 3. Patch structure of the proposed antenna and its geometry.
L4=30mm, L5= 3mm, L6=10.74mm, L7=2.5mm, W5=2.5mm, W6=3mm, W7=1mm, W8=2mm, W9=1mm, W10=0.48mm, S1=10.91mm.

First, we have a half ellipse as a ground plane with the size of the major axis equals 30mm and the minor axis equals 10mm of the complete ellipse. We also subtract 2 more tiny rectangles from the first half ellipse as depicted in Figure 3. Then, as it is shown we eliminate the curved shape of the 2 parts of the half ellipse and flatten it which is shown as S1.

Simulation and Experimental results and discussions

The prototype antenna was fabricated on FR4 substrate with a thickness of 1 mm, the permittivity of 4.4, and loss tangent of 0.024 using conventional printed circuit board (PCB) technique. We use a 50Ω SMA connector to feed the antenna. The width and height of the microstrip feedline are shown in figure 2, to achieve a 50Ω characteristic impedance.

The performance of the proposed antenna was researched using ANSYS Electronics (Electromagnetics) Suite (ver. 18.2). we measured the impedance bandwidth of the antenna by using the Agilent 8722ES Vector Network Analyzer [7].

Design

As it is stated, we obtain the optimal structure with the aforementioned steps.

The impedance bandwidth of the proposed antenna was measured by the use of the Agilent 8722ES Vector Network Analyzer. The comparison between simulated and measured return loss is shown in Figure 4.

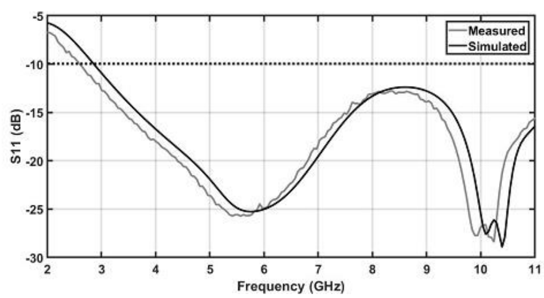
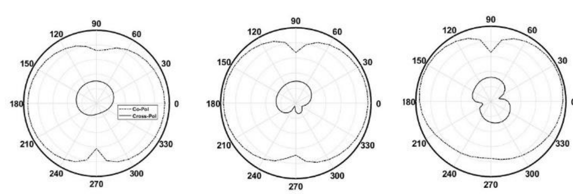


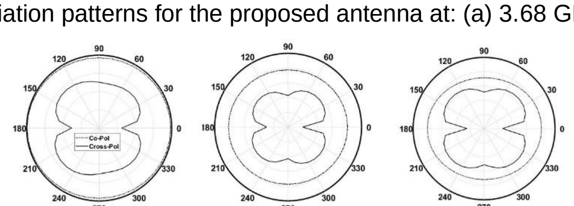
Figure 4. Simulated and measured return-loss of the antenna.

The simulated radiation characteristics of the antenna are shown in Figure 4 and Figure 5. The antenna exhibits a stable radiation pattern over the operating band. Both, its E-plane and H-plane radiation patterns are Omni-directional across its operational bandwidth since the proposed antenna's structure is symmetrical [7]. In the E-plane, the radiation patterns remain a dumbbell shape over the frequency band. the cross-polarization levels are generally lower than the co-polarization ones [7].



(a) (b) (c)

Figure 4. Simulated E-plane radiation patterns for the proposed antenna at: (a) 3.68 GHz, (b) 5.75 GHz, (c) 7.34 GHz.



(a) (b) (c)

Figure 5. Simulated H-plane radiation patterns for the proposed antenna at: (a) 3.68 GHz, (b) 5.75 GHz, (c) 7.34 GHz.

Figure 6.shows the 3D radiation pattern of the proposed antenna.

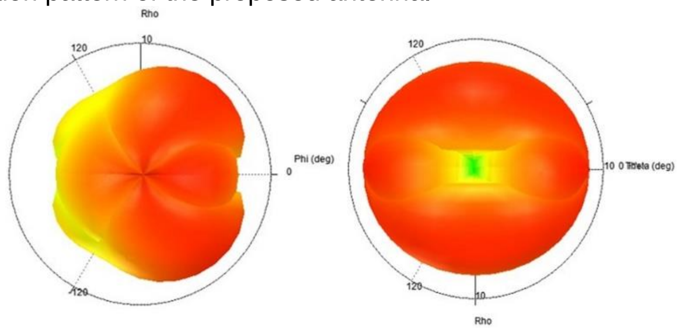


Figure 6. 3D radiation pattern of the proposed antenna at 7 GHz.

The measured gain of the antenna is exhibited in Figure 7. The minimum gain is at the initial frequencies due to the compact size of the antenna.

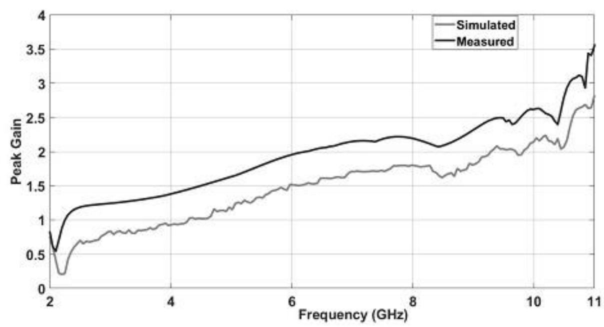


Figure 7. Measurement peak gain of the proposed antenna.

This antenna can be used in MIMO applications. The performance of a proper antenna array for MIMO applications is based on different parameters and features such as mutual coupling and radiation pattern. Based on the two configurations, any two such antennas can be arranged beside each other. These configurations are side-by-side (SBS) and face-to-face (FTF). Figure 8 illustrates the simulated S12 parameter of these two configurations. In each case, the spacing between array elements is set at 500mm.

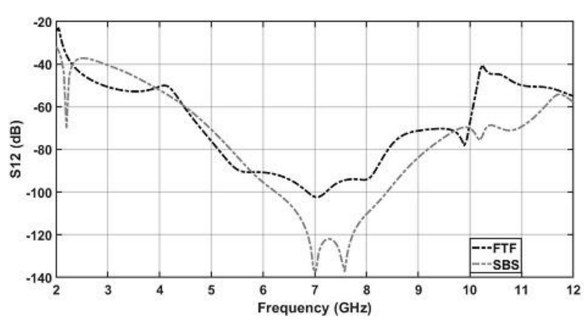


Figure 8. Simulated S-parameters of the MIMO configuration of the proposed antenna for a different arrangement of two elements beside each other.

As can be seen from Figure 8, It is obvious that S21 or mutual coupling in the entire frequency band is under -40 dB for both SBS and FTF configurations in the entire UWB frequency band.

The key in the UWB antenna design is to obtain good linearity of the phase of the radiated field because the antenna should have the capability of transmitting the electrical pulse with minimal distortion. Usually, the group delay is used to evaluate the phase response of the transfer function because it is defined as the rate of change of the total phase shift with respect to angular frequency. Ideally, when the phase response is strictly linear, the group delay is constant [14].

$$\tau_f = -\frac{d\varphi}{d\omega} \qquad [14]$$

Measurement of group delay was performed by exciting two identical prototype antennas, which were located in their far-field, in two orientations: side-by-side and face-to-face. The system's transfer function was measured in an anechoic chamber. The separation between the identical monopole antenna pair was 0.5 m [2].

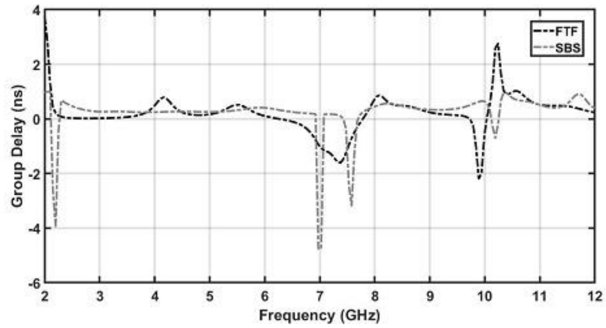


Figure 9.Simulated group delay of the antenna

As depicted from Figure 9, the group delay variation of the proposed antennas is less than 8 ns over the frequency band from 2 up to 12 GHz which certifies us that transmitted or received pulse will not distort and will maintain its shape. Therefore, the proposed antenna is proper for modern UWB communication and MIMO systems.

Conclusion

In this paper, a novel microstrip antenna with compact size for UWB and MIMO applications was presented. By using the Elliptical shapes, branch techniques, and the proper ground-plane good results were achieved. Moreover, by applying space-filling methods of fractal concept, a very nice impedance bandwidth was acquired. Moreover, The Measured return loss and simulated radiation patterns of the antenna at 3 frequencies were presented. Then, the proposed antenna was investigated in MIMO systems and the simulated group delay was depicted. Finally, the results revealed that the proposed antenna could be an appropriate candidate for UWB and MIMO applications.

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