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A New Coplanar Waveguide (CPW)-Fed Monopole Antenna Using Fractal Methods For Ultra-Wideband and Super-Wideband Applications

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ABSTRACT: By using fractal methods a novel coplanar waveguide (CPW)-fed monopole as a radiating part of an antenna is proposed for Super-wideband (SWB) and Ultra-wideband (UWB) applications. The antenna has been designed on the basis of the unique geometry in which every change in each step will be stated and explained. The proposed CPW slot antenna is compact with the size of 30×32×1 mm^3 which is printed on a substrate of FR-4. The parameters of this antenna were optimized by means of numerical simulations in ANSYS Electronics software, after which the antenna was fabricated. The measurement results show that the proposed antenna has a -10 dB return loss bandwidth from 2.63 GHz to 16 GHz for UWB applications and from 1.35 GHz to 28.92 GHz for SWB applications, which covers the entire required band for both applications, moreover, giving a ratio impedance bandwidth of more than 20:1 satisfies the SWB requirements. Every step of simulation and measurement results are compared and discussed.

***Keywords*:** Fractal, Coplanar Waveguide, Ultra-wideband, Super-Wideband, Monopole 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 wonderful attraction in wireless communication. Microstrip antennas are popular because of offering antennas with low cost, low profile, light weight, and ease of fabrication [2].

Moreover, it is worthy 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, while an antenna with a ratio bandwidth greater than or equal to 10:1 is generally called a super-wideband (SWB) antenna in the antenna literature [2].

The main parameters expected from ultra-wideband or super-wideband monopole antennas are structures that have good return-loss response and exhibit desirable radiation characteristics that are essentially Omni-directional [3-5].

There are various techniques to realize a specific bandwidth. 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 play a significant role [6]. Examples of various techniques of designing monopole antennas include: rectangular, triangular, circular and elliptical [7]. Because of the self-similarity and space-filling characteristics [8-11], fractal concepts and methods have emerged as a viable and reliable method for designing compact UWB, SWB, and multiband antennas.

In this paper, the main goal is to present a novel fractal structure with enhanced ground structure with step-by-step procedure.
It is worthy mentioning that the frequency range of the proposed antenna for SWB applications embrace frequency bands, such as: L bans, S band, C band, X band, Ku band, and K band.

ANTENNA CONFIGURATION

We divide the whole structure into two sub-categories: Patch Structure and Ground Structure.

Patch Structure

The sequence of steps showing the evolution of the proposed antenna geometry is shown in Fig. 1.

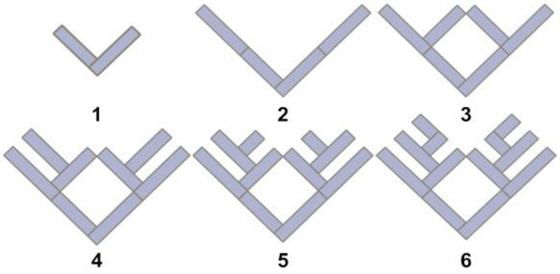

Figure 1. Steps showing evolution of the patch of the proposed antenna.

First, we have 2 similar rectangular shape elements that stick to each other in a way that the angle between them is 90 degree. Then in the second step, we continue to increase the length of the radiative element, so we add 2 more elements just like the previous one with the same size along the previous elements. In third step, in the middle of each element we put an element in a perpendicular way. In the fourth step another two elements with 90-degree angle will be put in the middle of the last elements that we put. In steps fifth and sixth we keep up with the same procedure to achieve the last structure, Furthermore, the reason behind this procedure will be explained in the Result and Discussion part. Dimension of the last structure is shown in the Fig. 2.

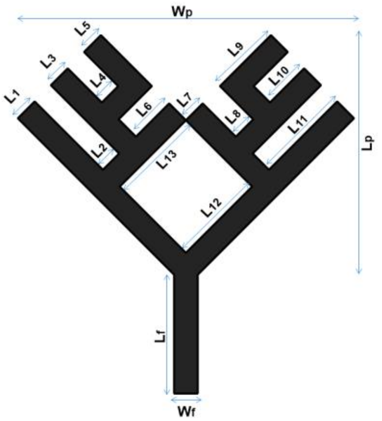

Figure 2. Dimension of the last structure of the proposed antenna.
L1=L2=L3=L4=L5=L7=L8=Wf=2mm, L6=L10=4mm, L9=6mm, L11=L12=L13=8mm, Lf=10mm, Wp=28.29mm, Lp=20.13mm.

Ground Structure

The sequence of steps showing the evolution of the proposed antenna geometry is shown in Fig. 3.

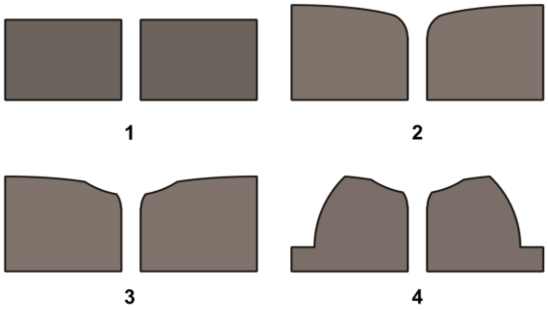

Figure 3. Steps showing evolution of the ground of the proposed antenna.

First, we have two exactly similar rectangular with size of 14.35×9.53 mm^2. In the second step we add two quarter-elliptical on the top of two rectangles. In the third step we subtract both a lunate shape and a quasi-isosceles trapezium from the top-middle of the previous structure. In the last step we deduct the two trapezoids with internal curvature from left and right side of the third structure. Finally, we achieve the desired shape for the antenna’s ground. Moreover, the reason behind this procedure will be explained in the Result and Discussion part. Dimension of the last structure is shown in the Fig. 4.1, 4.2, and 4.3.

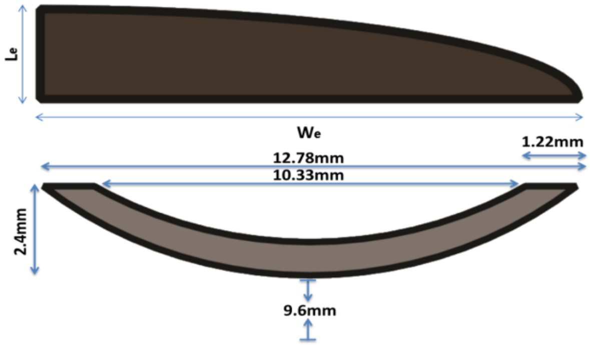

Figure 4.1. Quarter-elliptical and lunate shape. Le=2.64mm, We=13.8mm.

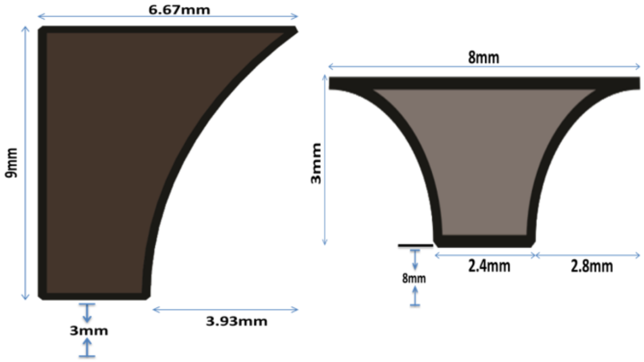

Figure 4.2. Quasi-isosceles trapezium and trapezoids with internal curvature.

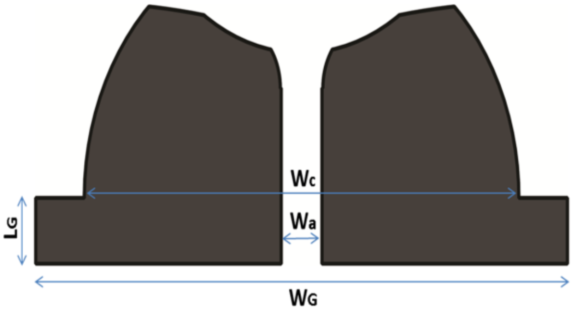

Figure 4.3. The ultimate structure. L_G=3mm, Wc=24.5mm, Wa=2.3mm, W_G=30mm.

Simulation and Experimental results and discussions

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

The performance of the antenna was investigated using ANSYS Electronics (Electromagnetics) Suite (ver. 18.2). The impedance bandwidth of the antenna was measured using the Agilent 8722ES Vector Network Analyzer.

Ground Design

As it is stated, in 4 steps we obtain the optimal structure. We started with 2 rectangles besides the feedline with the same size. Then, add the two quarter-elliptical on the top of two rectangles because of having the less consumption energy and uniform radiation as depicted in the Fig. 5.

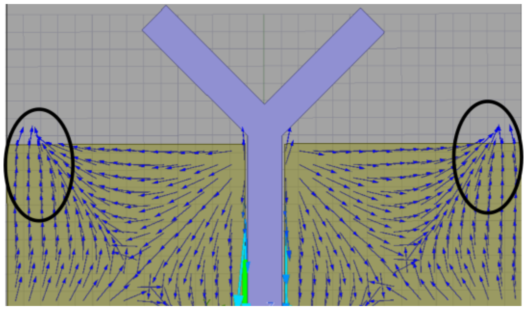

Figure 5. Simulated surface current distribution over the ground-plane

After adding the two quarter-elliptical, due to having energy consumption in the area that is shown in the Fig. 6 we subtract a lunate shape from top-middle of the ground structure.

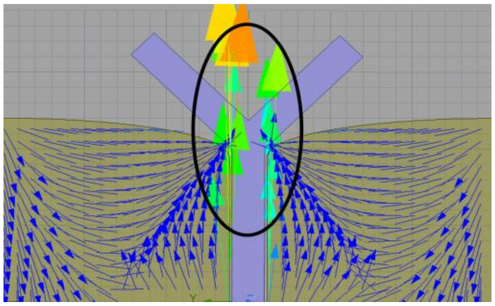

Figure 6. Simulated surface current distribution over the ground-plane

After applying the lunate shape as it can be observed in Fig. 7 the radiation become better, but it still needs some improvement. Therefore, we deduct a quasi-isosceles trapezium from the top middle.

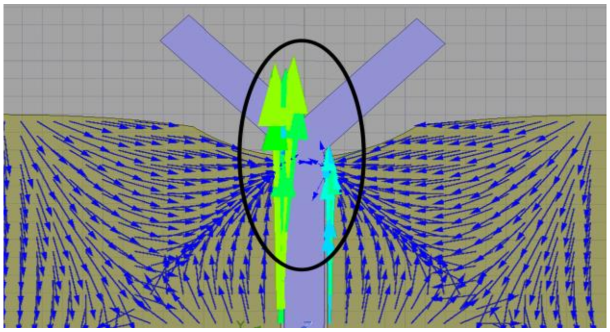

Figure 7. Simulated surface current distribution

As it is shown in the Fig. 8 by subtracting the quasi-isosceles trapezium from the top middle, we obtain a very good results in the middle part, whereas, as depicted there is the conflict and collision in the right and left part of the ground plane.

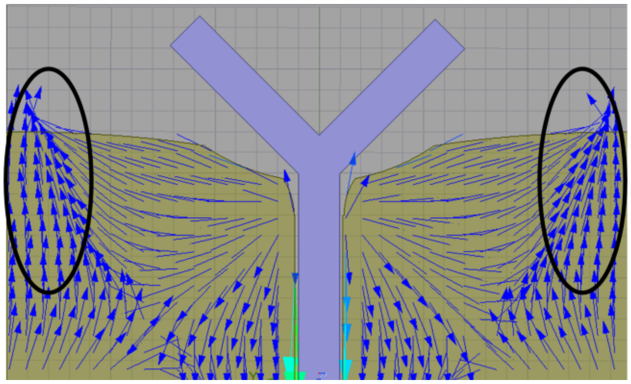

Figure 8. Simulated surface current distribution

Therefore, as a last step in designing the ground-plane, we subtract the two trapezoids with internal curvature from left and right side of the last structure as it is shown in the Fig. 4.3.

Simulated ground-plane return-loss for each step of construction is depicted in Fig. 9. It is important to consider that the antenna’s patch is maintained at first step.

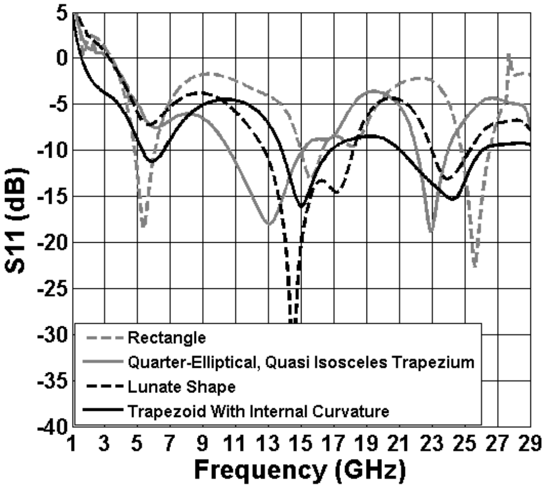

Figure 9. Simulated ground-plane return-loss for each step of designing.

Patch Design

As it is mentioned, in 6 steps we achieve the desired structure for the patch. We began with 2 perpendicular elements in a same dimension, and due to wanting to sketch the patch in a swastika-like shape but in 2 different branches for having better omni-directional radiation, we continued the steps and in every step, we put the same elements in the middle of the previous ones with 90-degree angle to obtain the observed structure.

After reaching the last step, due to the one of the important properties of fractal's concept that is space filling which helps the both, return-loss and radiation patterns, improve their characteristics and finally, acceptable results emerge.

In just 2 steps of scaling-down, in a way that in each iteration the scaled parts completely fit the inner part of the main structure, we got very unique and perfect return-loss, due to using the fractal's space filling feature.

Fig. 10 shows the simulated return-loss for all the 6 steps of the antenna patch.

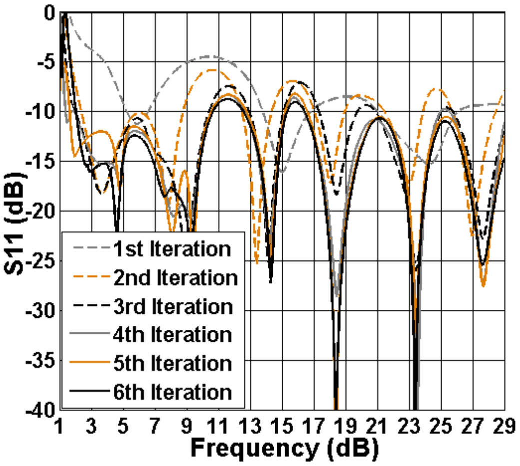

Figure 10. Simulated return-loss for the patch

Fig. 11 depicts the return-loss of all the iterations from the main part, alone, to applying each scaled part.

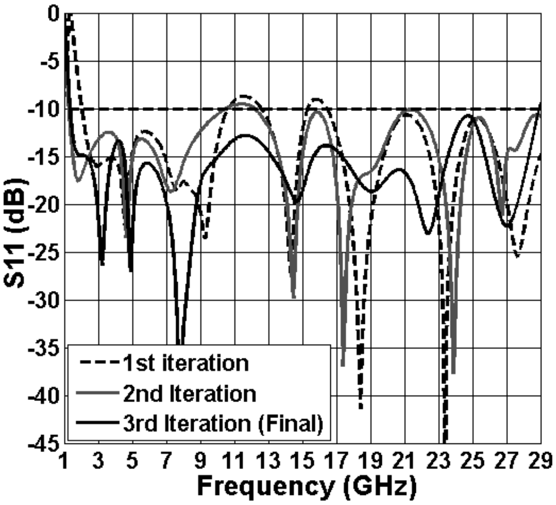

Figure 11. Simulated return-loss of all the scaled-down iterations.

The measured radiation characteristics of the antenna are shown in Fig. 12 and Fig. 13. 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. 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 [6].

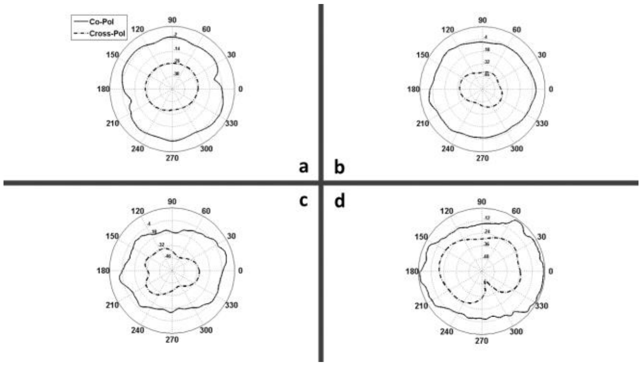

Figure 12. Measured E-plane radiation patterns for the proposed antenna at: (a) 3.86 GHz, (b) 5.71 GHz, (c) 7.32 GHz, (d) 9.53 GHz.

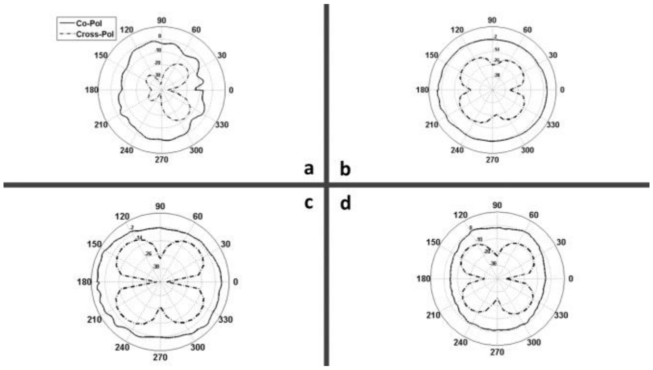

Figure 13. Measured H-plane radiation patterns for the proposed antenna at: (a) 3.86 GHz, (b) 5.71 GHz, (c) 7.32 GHz, (d) 9.53 GHz.

The key in the UWB antenna design is to obtain a 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 [2].

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 [2]. The separation distance between the two identical monopole antenna pairs is 0.5 m.
Fig. 14. Shows the group delay for side-by side and face-to-face orientations. It is realized that the group delay variation is less than 4 nano seconds over UWB and SWB.

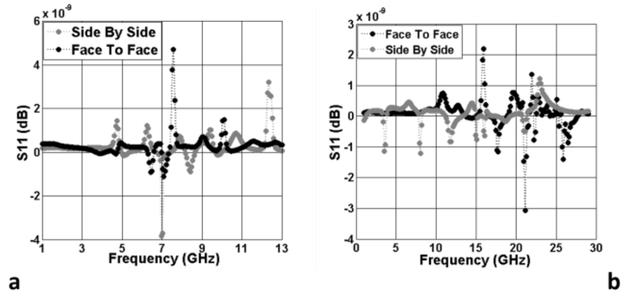

Figure 14. Measured group delay of the proposed antenna (a) UWB, (b) SWB

The impedance bandwidth of the antenna was measured using the Agilent 8722ES Vector Network Analyzer. The comparison between simulated and measured return-loss performance is shown in Fig. 15.

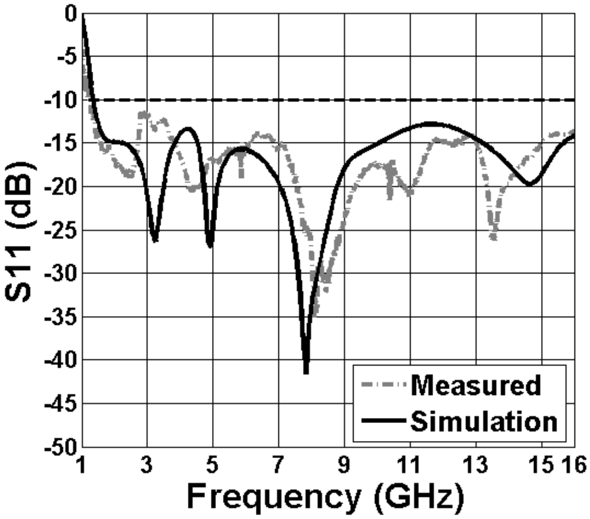

Figure 15. Simulated and measured return-loss of the antenna.

As depicted, there is a good agreement between measured and simulated return-loss.

Figure 16. The photograph of the proposed realized antenna.

Fig. 16 shows the proposed CPW-fed monopole antenna using fractal methods for Ultra-wideband and Super-wideband Applications.

conclusion

In this paper, a new CPW antenna with compact size for UWB and SWB applications was presented. By using the geometrical shapes, the proper ground-plane was achieved. Moreover, by applying space-filling properties of fractal concept, a very good impedance bandwidth was obtained. Then the measured radiation patterns of the antenna at four frequencies were presented. Finally, the results revealed that the proposed antenna could be an appropriate candidate for UWB and SWB applications.

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