Compact CPW-fed Circular Patch Antenna for UWB Applications

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Abstract— **In this paper, a novel CPW-fed antenna is presented for UWB applications. The antenna mainly comprises of a simple circular patch and a modified ground plane. The inclusion of two novel symmetrical rectangular slots with inner area of 3×2.8 mm^2 to the top corners of the antenna creates a new path for the current and consequently leads to the bandwidth enhancement. A rectangular stub is also adopted to further broaden the antenna impedance bandwidth. The proposed antenna has a compact size of 20×20×1.6 mm^3 and covers the wide frequency band of 3-23.5 GHz (154%). Constant gain and suitable radiation patterns are observed for the presented antenna. Good agreement between the simulated and measured results clearly shows the validity of the proposed structure. The design steps and bandwidth enhancement process are discussed in detail.**

Index Terms— CPW feed line, UWB antenna, and Wide frequency band.

I. INTRODUCTION

Since the assignment of the frequency band of 3.1-10.6 GHz as UWB frequency range by Federal Communication Commission (FCC), antenna design has become a challenging topic among the communication experts. Antenna, as an important and vital part of every communication system, has experienced seachange during its development process. Nowadays, only the antennas with characteristics such as low cost, compact size, good radiation properties and wide operating bandwidth are worthy to be used in UWB applications. Many UWB antennas with suitable characteristics are available in the literature. Different bandwidth enhancement techniques such as Defected ground structures(DGS) and Derected microstrip structures(DMS) have been employed in the papers to reach the desirable characteristics.[1]-[2]. Among the existing antennas, CPW-fed antennas featured with the mentioned marvelous merits have attracted the attention of antenna designers. A vast variety of CPW-fed antennas with different radiating patch shapes, slots and ground plane structures have been introduced for UWB systems. For instance in the novel structure of antenna in [3], two rectangular slots are cut from the ground plane to widen the antenna impedance bandwidth. In [4], an elliptical monopole patch with trapeziform ground plane is introduced. Authors

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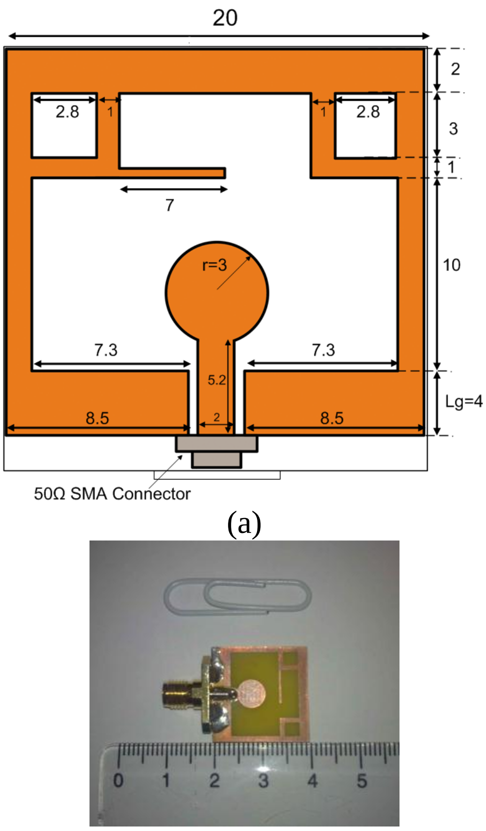


Fig.1. The geometry of the proposed antenna (a) the schematic structure, (b) The fabricated antenna.

in [5] offer an antenna with an arc shaped tuning stub. A simple design of a tapered slot antenna with UWB characteristics is proposed in [6]. An antenna with a U-shaped square patch combined with two parasitic tuning stubs, is the structure presented in [7] to obtain the UWB system requirements. The antenna with such a structure, produces an impedance bandwidth of 129%.

In [8], a monopole like slot antenna is presented for UWB applications. An antenna with circular and elliptical stubs is presented in [9] to operate over the UWB frequency range. A novel design of modified elliptical antenna is used in [10] as an UWB antenna. Using of a rectangular slot with cross type structure with CPW feed line is the geometry adopted in [11]. An antenna with rectangular aperture on a printed circuit board ground plane and a T-shaped exciting stub is presented in [12]. Two printed wide slot antennas with E-shaped patches and slots are designed in [13] for broadband applications. In [14] an antenna with annulus strip as a ground plane and an open crescent patch placed in the inner annulus as the radiating element is introduced, and provides an impedance bandwidth of 129%. In [15], by cutting some parts of the antenna with low level current distribution, the UWB characteristic is obtained. The antenna in [16] benefits from a novel shape of radiating patch, which strongly influences the antenna performance. The radiating element consists of two semi circles with different radii, connected to each other and produce a very wide operating band.

In this paper, a novel CPW-fed antenna is presented for UWB applications. By the addition of two rectangular- shaped slots to the antenna structure, a new path is made for the current. The flow of current through this path, excites a new resonance and the bandwidth is enhanced. By the inclusion of a rectangular stub to the antenna ground plane, higher impedance bandwidth is obtained. The antenna is printed on a 20×20 mm^2 FR4 substrate with permitivity of 4.4 and thickness of 1.6mm. The proposed antenna operates over the frequency range of 3-23.5 GHz. The simulation results are carried out using Ansoft High Frequency Structure Simulator (HFSS). The antenna has been fabricated and tested. Good similarity is obtained between the simulated and measured results which shows the validity of the proposed structure. The rest of the paper is organized as follows: Section II describes the antenna geometry and design process. The parametric study, simulation results, measured results and their comparison is presented in Section III, and finally section IV concludes the paper.

II. Antenna Configuration and Design

The schematic geometry of the proposed antenna is shown in Fig. 1(a). The fabricated antenna with the SMA connector connected to its extremity is also shown in Fig. 1(b). The antenna is printed on a FR4 substrate with permittivity of 4.4, loss tangent of 0.002 and thickness of 1.6mm. Both the circular radiating patch and the ground plane are printed on the same side of the substrate, so the fabrication is very easy and cost effective. As it is seen from Fig.1, a simple circular patch with radius of 3 mm is fed by a 50Ω CPW feed line. The length and width of the feed line are 5.2 mm and 2 mm respectively. The feed line width and the separation gap between the feed line and ground plane (s=0.5 mm) are selected to obtain the 50Ω input impedance. Two novel rectangular slots with inner areas of 3×2.8 mm^2 are added to the top corners of the ground plane. The addition of these slots creates a new path for current. The flow of current through this newly made path, leads to the excitement of a new resonance and bandwidth enhancement. Apart from the symmetrical square slots, an asymmetrical rectangular stub with dimensions of 7×0.5 mm^2 is also included in the antenna structure to further broaden the impedance bandwidth.

To provide a better understanding of the antenna design process, three antennas are presented in Fig. 2, which show the development process of the proposed antenna. In Fig. 2(a), the antenna with a simple circular patch is seen. In Fig. 2(b), two novel square slots are introduced at the top corners of the antenna and in Fig. 2(c), a rectangular stub is also added to the antenna structure and the final configuration is achieved.

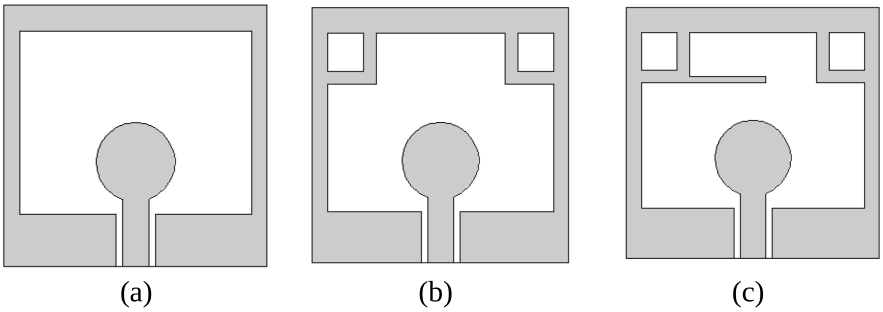


Fig. 2. (a) Antenna with only a circular patch, (b) Antenna with circular patch and square slots, (c) Proposed antenna.

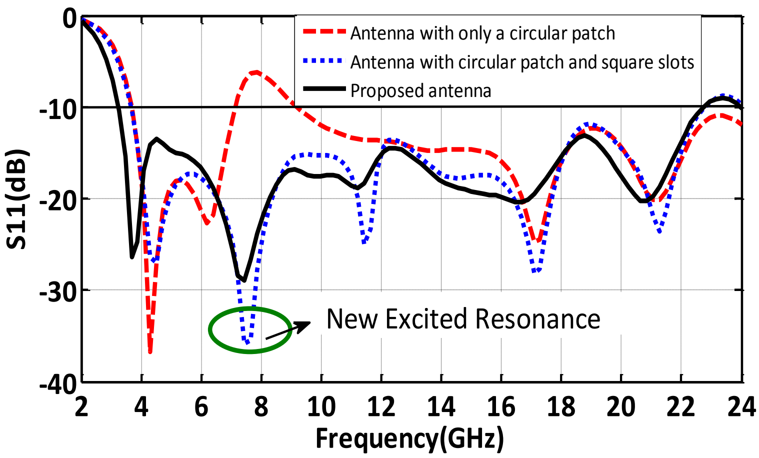
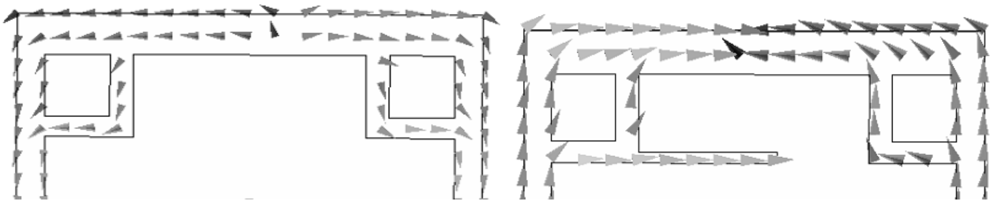


Fig. 3. Simulated S_{11} curves for the three mentioned antennas.

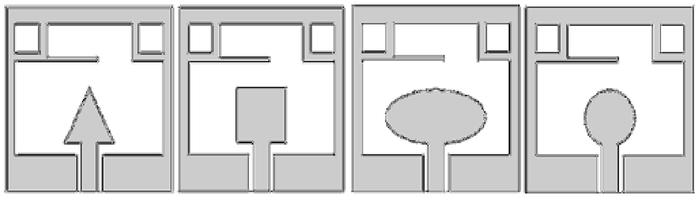
The three mentioned antennas are simulated and the resultant S_{11} results are plotted in Fig.3. As it is seen, when only a circular patch is included in the antenna structure, the antenna covers the frequency range of 3.8-7 GHz and does not satisfy the UWB requirements. In next step, when the rectangular slots are applied to the antenna, a new path is created for the current. By the creation of this new path, a new resonance is excited and the notch of 7-9 GHz which was made in the first step, is disappeared and a wide bandwidth is obtained. The new resonance is shown in Fig. 3. Finally, in the proposed antenna, the addition of the rectangular stub leads to the displacement of the first resonance toward lower frequencies which produces a wide impedance bandwidth.

To further analyze the bandwidth enhancement process, the surface current distribution on the antenna as shown in Fig. 4. From Fig. 4(a), it is clearly seen that by the inclusion of the square slots, a new path is created for the current. The current flow through this newly created rectangular path is obviously shown. Fig. 4(b) shows the flow of current in the rectangular stub. The creation of a new path for the current by this stub, leads to the displacement of the first resonance and wider bandwidth at lower frequencies.



(a) (b)

Fig. 4. Surface current distribution at (a) Square slots, (b) Square slots and rectangular stub.



(a) (b) (c) (d)

Fig. 5. The configuration of the antenna with different patch shapes: (a) Triangular patch, (b) Square patch, (c) Elliptical patch and (d) Circular patch.

III. RESULTS AND DISCUSSIONS

A. Radiating Patch Shape

As it was mentioned earlier, a circular radiating patch is adopted in this antenna. To show the superiority of the circular-shaped patch to the other radiating element shapes, four antennas with different patch shapes have been analyzed. The structures of the antennas with different patches are shown in Fig. 5. Antenna 1 has a triangular patch. In Antenna 2 a square patch with dimension of 3×3 mm^2 is introduced. Antenna 3 includes an elliptical patch with smaller diameter of 3 mm and finally antenna 4 is the proposed structure, which includes a circular patch with radius of 3 mm. The S_{11} curves of the four antennas are plotted in Fig. 6. Simulation results confirm that the circular patch has the widest bandwidth among the other patch shapes. The reason is laid in the inherent wide band property of circular patches. This shape provides wider area for the current and hence, inherently has wide bandwidth.

To have a deeper insight of the effect of different parameters' variations on the antenna performance, a parametric study is carried out. All the simulated results are obtained using Ansoft High Frequency Structure Simulator (HFSS). At each of the parametric studies, one parameter is changing and the others are kept constant at the given values at Fig. 1.

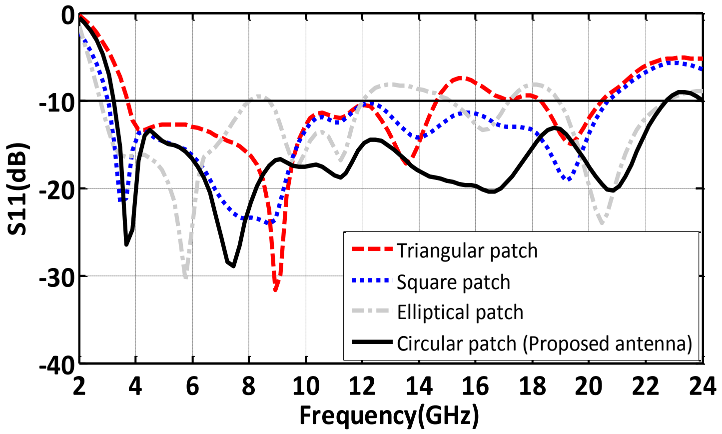


Fig. 6. Simulated S_{11} curves for triangular, square, elliptical and circular patch shapes.

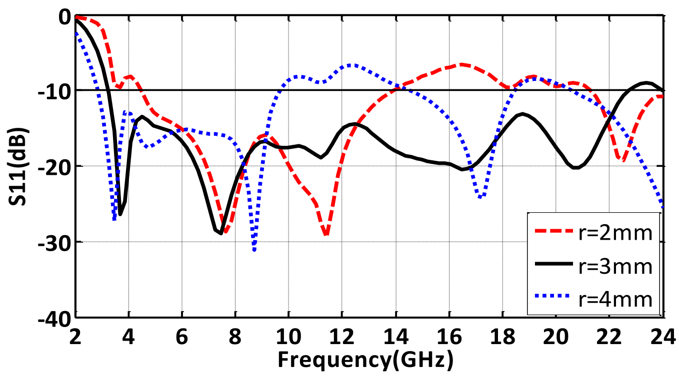


Fig.7. Simulated S_{11} curves for different values of circular patch radius 'r'.

B. The Radius of the Circular Patch

As it was shown earlier, circular patch provides wider bandwidth in comparison with the other antenna radiating patch shapes. The radius of the circle, is an important parameter in determining the antenna performance. The S_{11} curves for three values of the circular patch radius are plotted in Fig. 7. It is seen that both lower and upper frequencies are sensitive to the variation of r. For two values of r=2 mm and r=4 mm, the assigned UWB is not covered by the antenna. Simulation results show that when r=3 mm is selected, the antenna not only covers the whole UWB frequency range, but it operates over the very wide frequency band of 3-23.5 GHz.

C. The Ground Plane Length 'L_g'

The other parameter to be studied is the ground plane length named as L_g. The variation of this parameter influences the antenna performance. To analyze the effect of L_g on the antenna impedance bandwidth, S_{11} curve for different values of L_g are plotted in Fig. 8. By the increasing of L_g, the strong

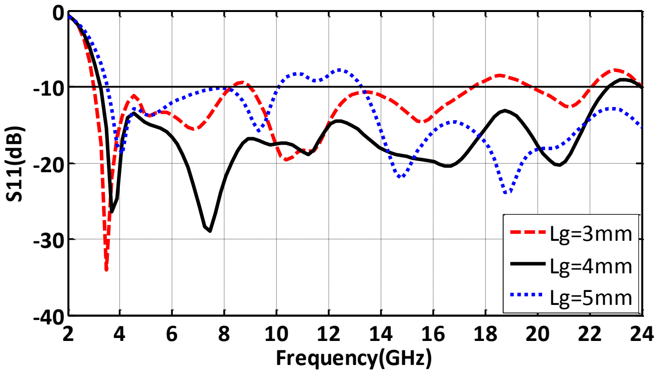


Fig. 8. Simulated S_{11} curves for different values of L_g.

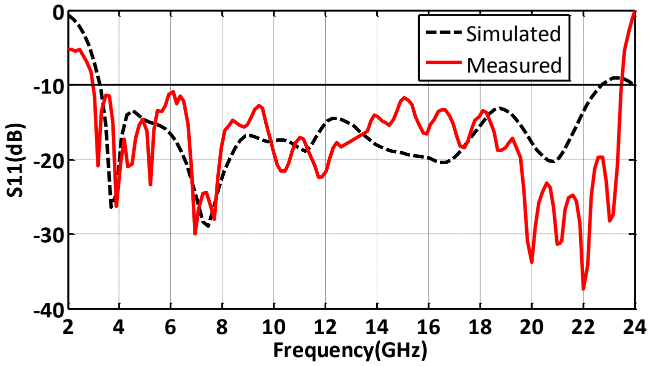


Fig. 9. Simulated and measured S_{11} curves for the proposed antenna.

coupling between the ground plane and radiating patch, leads to the bandwidth reduction. From Fig. 8 it is seen that both lower and upper frequencies are sensitive to this parameter. When L_g=4 mm, the widest bandwidth is obtained.

The antenna with the given values in Fig.1 has been fabricated and tested. Fig. 9 shows the simulated and measured S_{11} curves for the proposed antenna. It is seen that good agreement is obtained between simulated and measured results. It is seen that in the measurement process, the bandwidth of 3-23.5 GHz is covered by the antenna. The slight difference between the results may be due to the SMA connector that is used in measurement process but is not considered in simulation.

The proposed antenna has a compact size of 20 ×20×1.6 mm^3 and covers the frequency band of 3-23.5 GHz (154%). TABLE.I compares the performance of the proposed antenna and some of the recently published antennas. The antenna size, impedance bandwidth, and the bandwidth increment percentage are compared in this Table.

As it is seen from TABLE.I, the antenna presented in this work occupies smaller area than the antennas in [1],[4],[5], [11] and [13]. Although having smaller size, the present work covers 25.5%, 43%, 28%, 8% and 45% more bandwidth respect to the mentioned antennas, respectively.

TABLE. I : COMPARISON OF ANTENNA IN THIS WORK AND SOME OF THE RECENTLY PUBLISHED ANTENNAS.

Ant.	*Size(mm)*	*BW(GHz)*	*BW increment(%)*
Ant in this work	20×20×1.6	3-23.5	--------
Ant in [3]	20×18×1.6	3.04-20.22	7%
Ant in [6]	55.4×38.5×0.508	3.05-10.65	43%
Ant in [7]	24×28×0.787	2.81-12.58	28%
Ant in [8]	29×26×1.5	2.7-12.4	25.5%
Ant in [11]	20×19×1.6	4.8-12.8	63%
Ant in [13]	85×85×1	2.83-18.2	8%
Ant in [15]	30×13×1.6	3.1-10.6	45%

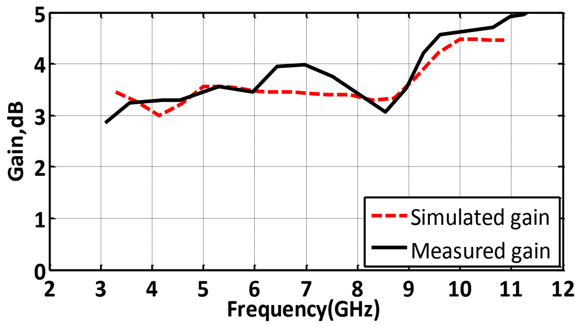


Fig. 10. Measured and simulated antenna peak gain.

The proposed antennas has 10% and 5% larger size in comparison with the antennas in [6] and [9], but it covers 7% and 64% wider bandwidth respectively. The proposed antenna with small size of 20×20×1.6 mm^3, covers the wide bandwidth of 3-23.5 GHz which is as high as 154%.

The peak gain of the proposed antenna is also measured. It is seen that over the frequency range of UWB, nearly flat and constant gain is obtained for the antenna. The measured and simulated peak gains are plotted in Fig. 10. The measured antenna gain varies between the maximum value of about 5 dBi at 11 GHz and the minimum value of about 2.9 dBi at 3 GHz. The simulated and measured results confirm each other. Group delay is the other important characteristic that is analyzed for this antenna. Fig. 11 shows the simulated group delay. It is seen that the peak to peak amplitude of the group delay is less that 2ns in the UWB frequency range which is acceptable within the UWB field requirements. Measured radiation patterns at yz-plane and xz-plane at the sample frequencies of 6 GHz and 10 GHz of the fabricated antenna are plotted in Fig. 12. Nearly omni-directional pattern with low level cross polarization is observed for the antenna. Also Co and Cross polarizations do not interfere with each other.

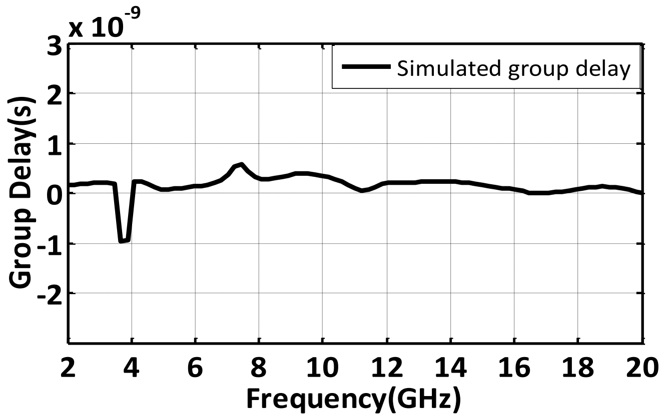


Fig.11. Simulated group delay of the proposed antenna.

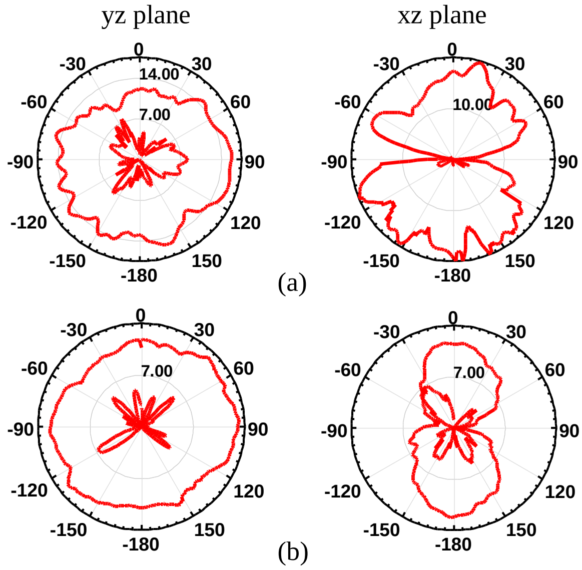


Fig. 12. Measured radiation patterns at yz and xz plane at (a) 6 GHz, (b) 10 GHz

IV. CONCLUSION

A novel CPW-fed antenna is presented for UWB applications. The basic structure of the proposed antenna consists of a simple circular-shaped radiating patch and a ground plane. By the addition of two novel rectangular slots at the top corners of the antenna, a new path is created for the current and a new resonance is excited which leads to the bandwidth enhancement. An asymmetrical rectangular stub is also added to further improve the bandwidth. The antenna has a small size of $20\times20\times1.6$ mm^3 and operates over the wide bandwidth of 3-23.5 GHz (154%), that is more compact than most of the previously designed CPW-fed antennas and covers wider bandwidth. For the fabricated prototype of the antenna, omni-directional pattern and nearly constant gain is observed over the UWB frequency range. Small size, easy fabrication process, light weight, wide impedance bandwidth, good radiation properties and low cross polarization, make this antenna a very beneficial candidate for UWB systems.

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