

A NOVEL UWB OCTAGONAL SEMI-RING MONOPOLE ANTENNA WITH WING-SHAPED CPW FEEDING STRUCTURE

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Abstract—In this paper, an ultra-wideband (UWB) monopole printed antenna with wing-shaped coplanar waveguides (CPW) feeder is proposed, in which the wing-shaped CPW feeder is used to increase the impedance bandwidth. A CPW-fed antenna is used in this design for its simple structure, compact size and ease of integration with microwave circuits. The proposed antenna is fabricated on Durion Roger R4003c, $22 \times 41 \text{ mm}^2$ substrate and measured. The simulated and measured results show that the antenna operates between 2.04 to 11.67 GHz. The unique wing-shaped CPW feeding structure causes a significant increase on the bandwidth of the proposed antenna compared to the present patch antennas. Also it removes unwanted ripples from the return loss and improves antenna's pattern.

1. INTRODUCTION

The Federal Communication Commission (FCC) in the United States of America has determined a frequency range of 3.1 to 10.6 GHz as an Ultra Wideband. The UWB antennas are one of the important part of those researches for developing of UWB communication systems. Nevertheless, some limitations, such as size, pattern and time-domain characteristics, must be considered in many commercial ultra wideband units.

First of all, they have to be small enough to be compatible with UWB terminals. Also they usually need to have an omnidirectional pattern to cover a large area. Finally, they need a good impulse response with minimum distortion for both transmission and reception [1–3].

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Signal transmission and reception need minimized distortion, spreading and ringing since UWB antennas transmit narrow pulses instead of continuous wave for sending information [4]. Microstrip patch antennas are small enough to be located in commercial UWB terminals, so they are very popular in UWB systems. In spite of their small size, they have some serious limitations to be used in UWB systems. One of those limitations refers to their bandwidth. They have a very narrow bandwidth, less than 5%. However, there have been many techniques to increase their bandwidth [2]. Creating some slots in patch and ground plane, using finite and modified ground plane, thicker substrate with lower permittivity are some of those techniques employed in this paper to achieve ultra-wide bandwidth. The slots may produce wider bandwidth as it makes irregular current surface on patch and ground plane [5]. Many research efforts have been devoted to ultra-wide band systems and signals [5–23].

In this paper, a monopole printed antenna with a wing-shaped CPW feeding structure for UWB applications is presented and discussed. This antenna operates from 2.04 GHz up to 11.67 GHz (140% of the impedance bandwidth). The design of the antenna was simulated using the CST Studio Suite and good agreement achieved between measurement and simulation after fabrication of prototype.

2. ANTENNA STRUCTURE

2.1. Resonance Frequency

By using some numerical methods to calculate the resonant frequencies of a polygonal patch antenna, a good approximate equation for resonant frequency of polygonal ring patch is obtained:

$$f_r = \frac{\chi_{nm}c}{16r \sin\left(\frac{\theta}{2}\right) \sqrt{\epsilon_r}} \quad (1)$$

where c is the velocity of light in free space, $\chi_{nm} = k_{nm}r$, and θ is shown in Figure 1.

And

$$k = \frac{2\pi\sqrt{\epsilon_r}}{\lambda_0} \quad (2)$$

By solving Eq. (1) for the first TM_{nm} modes of an octagonal ring patch antenna ($\theta = 45^\circ$), a good approximation of resonant frequency can be achieved:

$$f_r = \frac{90.24}{r\sqrt{\epsilon_r}} \quad (3)$$

where f_r is the resonance frequency in GHz, r the radius in mm, and ϵ_r the dielectric permittivity. The field dose not vary in the ϕ direction since TM_{0m} modes only vary through the width of patch antenna, where m is even. Also TM_{11} is called as *dominant mode* since it has the minimum mean radius of ring for any given frequency [1–3].

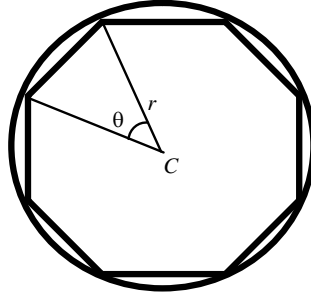


Figure 1. θ in a polygon.

2.2. Antenna Design

Figure 2 shows the octagonal semi-ring monopole printed antenna with a wing-shaped CPW-fed. r_1 and r_2 are the outer and inner radii of the proposed octagonal semi-ring patch antenna, respectively. To achieve 50Ω input impedance, W_f , h_f and h_4 were chosen at 2.6, 20.4 and 3 mm, respectively. Also Duroid Roger4003c was used as a dielectric substrate with a thickness of $h = 0.87$ mm and relative permittivity of $\epsilon_r = 3.8$.

According to [3], wide bandwidth can be achieved by overlapping some close resonant frequencies. Hence, three close resonant frequencies were assumed for first stage of antenna design at 4.5, 7.5 and 9.5 GHz. Regarding to Eq. (3), we can calculate the radius of octagonal ring monopole antenna:

$$r = \frac{90.24}{f_r \sqrt{\epsilon_r}} \tag{4}$$

Also considering Eq. (4), the inner and outer radii of octagonal ring monopole antenna at 4.5 and 9.5 GHz were chosen as follows:

$$r_1 \approx 5 \text{ mm} \tag{5}$$

$$r_2 \approx 10 \text{ mm} \tag{6}$$

The separation resonant modes can be controlled by the ration of outer to inner radius [2, 3]. To achieve another desired resonant frequency at

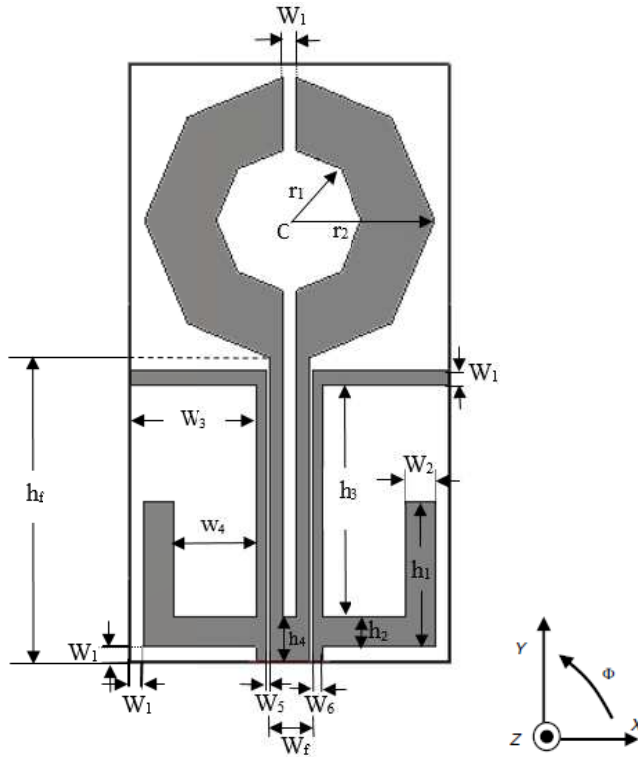


Figure 2. The geometry of the proposed antenna.

7.5 GHz, we used two rectangular slots on the CPW feeding structure. They can be calculated using Eq. (7) :

$$h_1 = \frac{C}{2f_r \sqrt{\epsilon_r}} \tag{7}$$

where C (velocity of light) equals 3×10^8 m/s, and f_r is the resonant frequency in Hz and h_1 the length of patch in m. The slots are symmetrical and will be achieved as follow:

$$h_1 \approx 10 \text{ mm} \tag{8}$$

Figure 3 illustrates how the dimensions of wing-shaped CPW feeding are determined by steps. After calculating the radiuses of the octagonal antenna (with assumption of microstrip line feeder and an infinite ground plane at the other side of substrate), the wing-shaped CPW-feeding structure is designed. Figure 3(a) is the basic shape of CPW-fed structure, then four slots are designed in Figures 3(b) and (c)

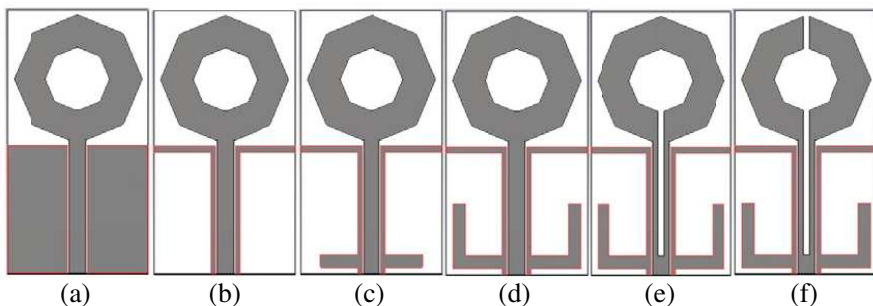


Figure 3. Design procedure of wing-shaped CPW feeding structure.

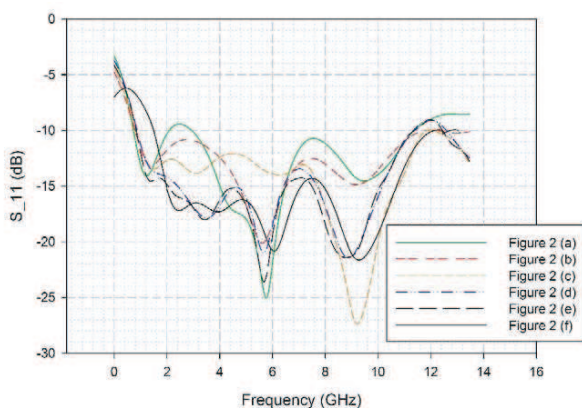


Figure 4. Simulated return loss for each design steps of wing-shaped CPW feeding structure.

to increase the impedance bandwidth of antenna. Also, Figure 3(d) shows how a new slot with height of h_1 , which is calculated in this section, is located. Finally, two narrow rectangular slots are designed in the patch to intensify the current distribution on the patch shown in Figures 3(e) and (f). In addition, Figure 4 depicts the simulated return loss results of aforementioned design steps for the wing-shaped CPW feeding structure.

Any intentional changes on the CPW feeding structure leads to new changes on current surface distribution. If these changes can be selected carefully, they can achieve wider bandwidth. The optimized values of antenna’s parameters are summarized in Table 1.

Table 1. Dimensions of the proposed antenna.

Parameter	W_1	W_2	W_3	W_4	W_5	W_6	W_f
Size (mm)	1	2	8.7	5.7	0.3	0.7	2.6
Parameter	h_f	h_1	h_2	h_3	h_4	r_1	r_2
Size (mm)	20.8	10	2	16	3	5	10

3. RESULTS AND DISCUSSION

Figure 5 shows the prototype of the proposed antenna which is measured, and good agreement can also be observed between simulation and measurement. Also the simulated and measured return losses shown in Figure 6 demonstrate that the antenna operates between 2.04 to 11.67 GHz which can cover the UWB frequency range.

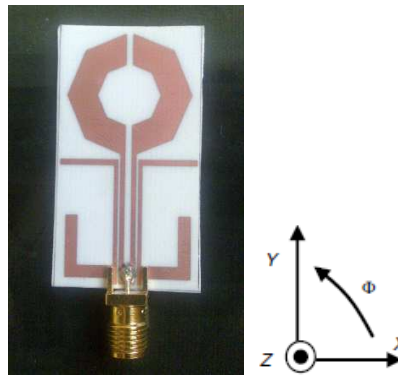
**Figure 5.** Prototype of the proposed antenna.

Figure 6 depicts comparison among simulated return loss results in various feeding approaches with different ground plane types. The measured return loss of the proposed antenna is also illustrated in Figure 6. The pink color shows three resonant frequencies calculated for normal octagonal ring antenna although they do not provide enough impedance bandwidth. Hence the wing-shaped structure is designed to achieve the adequate bandwidth for proposed antenna. As can be noted from return loss results, the overlapping of closely distributed resonance modes across the spectrum results in an ultra-wide bandwidth. The insignificant inconsistency observed between measured and calculated resonances may have many reasons. If we use effective dielectric constant, ϵ_{re} , instead of dielectric constant ϵ_r in Eq. (1), we may get more coordination between calculated and

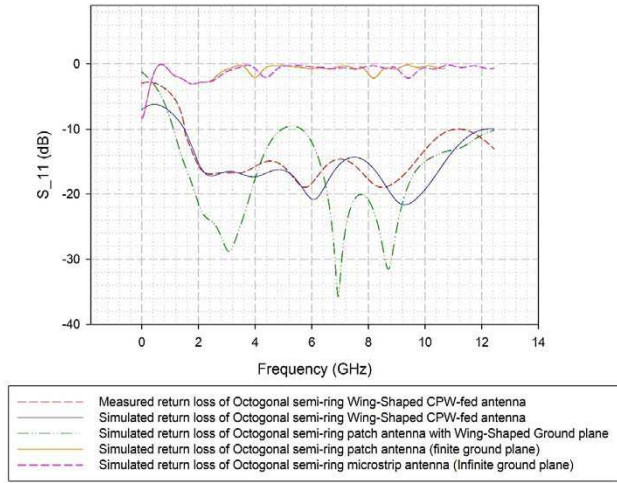


Figure 6. Simulated and measured return losses for proposed antenna.

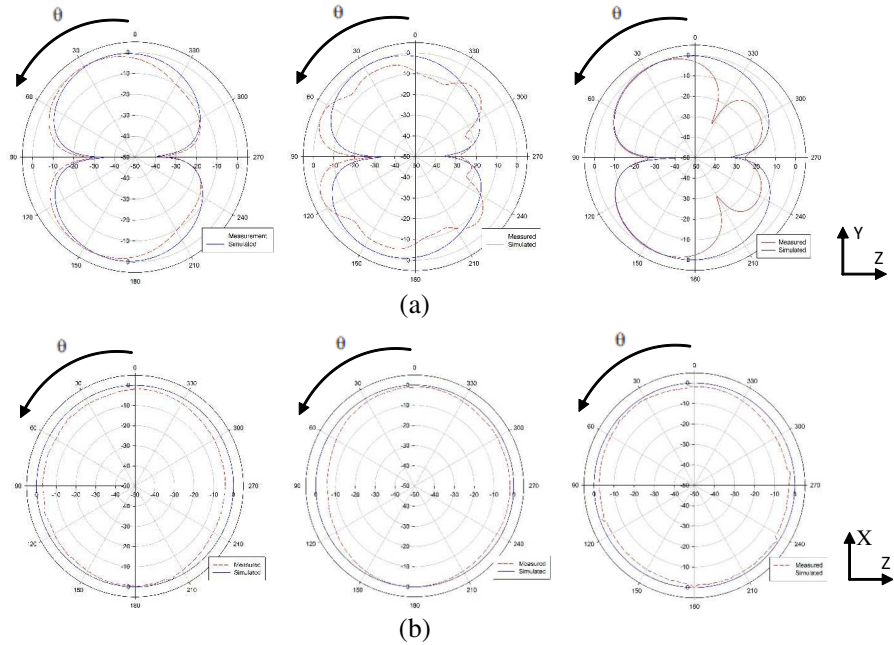


Figure 7. Simulated and measured radiation patterns for proposed antenna for (a) *E*-Plane and (b) *H*-Plane at 4.7, 7.6 and 9.3 GHz.

measured results.

$$f_r = \frac{\chi_{nm}c}{16r \sin\left(\frac{\theta}{2}\right) \sqrt{\epsilon_r}} \tag{9}$$

To get the value of ϵ_{re} , the modified outer and inner radii, r_{1e} and r_{2e} , should be used. The empirical formulas for r_{1e} and r_{2e} are:

$$r_{1e} = r_1 + \frac{3h}{4} \tag{10}$$

$$r_{2e} = r_2 - \frac{3h}{4} \tag{11}$$

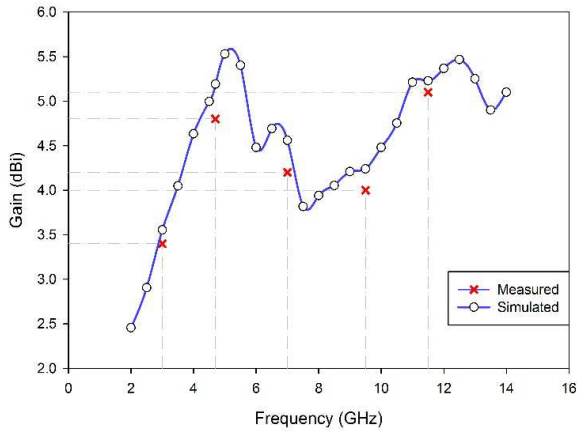


Figure 8. Simulated and measured gains of proposed antenna.

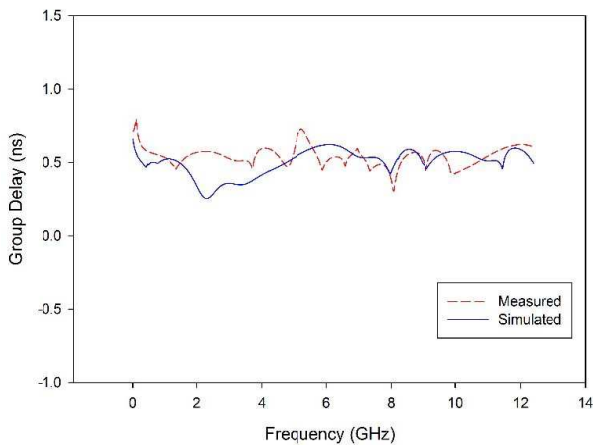


Figure 9. Simulated and measured group delays of proposed antenna

The radiation patterns for both E - and H -planes of the proposed antenna is shown in Figure 7. As can be observed, the radiation pattern can be said normal to the radiating patch. The inconsistency between simulated and measured results may occur due to the alignment factor between the reference and test antennas.

Figure 8 indicates the simulated and measured gains for the proposed antenna within the frequency band. As it represents, the antenna gain ranges between 2.4 to 5.5 dBi along 2.55 to 11.6 GHz. Also the maximum gain variation is about 3.1 dBi, and the maximum gain peak yielded from measurement is almost 5.1 dBi. In addition, Figure 9 depicts the measured group delay of the proposed antenna which looks almost flat in desired bandwidth.

Figure 10 indicates the current distribution of proposed antenna. As it is obvious, the current has higher density on the wing-shaped CPW-feeding. These current distributions show the effect of slots on the antenna. As it is clearly obvious, majority of the current surface incline at the edge of slots which leads to have more resonant frequencies. If these slots are created by calculations, they can create close resonant frequencies which result in wider bandwidth.

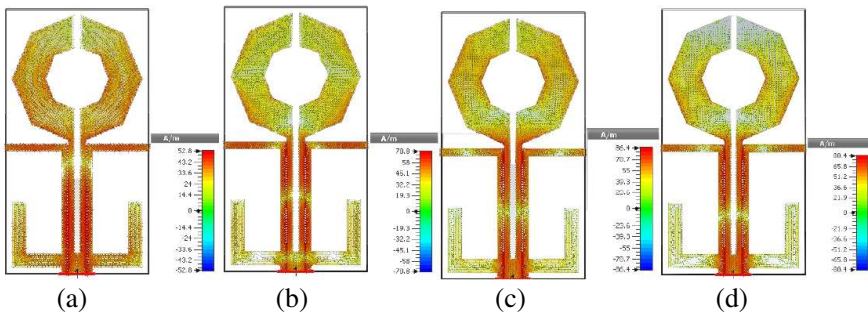


Figure 10. Current distribution of proposed antenna. (a) 2.5 GHz. (b) 4 GHz. (c) 7 GHz. (d) 10 GHz.

4. CONCLUSION

The realized antenna designed for ultra-wideband applications has a -10 dB impedance bandwidth from 2.04 GHz to 11.67 GHz (140% fractional bandwidth), and the gain is about 2.4 dBi to 5.5 dBi. The measured antenna performance agrees well with those predicted by the numerical models. The antenna has small group delay variations in frequency domain and is studied in terms of return loss, radiation pattern, gain, group delay and current distributions in this paper.

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