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A CPW-FED PROPELLER SHAPED MONOPOLE ANTENNA WITH SUPER WIDEBAND CHARACTERISTICS

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Abstract—A super-wideband antenna based on a propeller shaped printed monopole with a CPW feed is presented in this paper. The enhanced bandwidth is obtained by modifying the disk of a conventional circular disk monopole to resemble a propeller. This design produces an extremely wide impedance bandwidth from 3 to 35 GHz with an impedance bandwidth ratio of 11.6 : 1. The gain of the proposed antenna varies from 4 dBi to 5.2 dBi. The antenna has fairly stable radiation characteristics throughout its operating band. The developed prototype is fabricated and measured. Simulation and experimental results are in good agreement.

1. INTRODUCTION

With the development of ultra wideband (UWB) technology for short range and high data rate communications [1], many UWB antennas [2–7] have been designed to work on the frequency band ranging from 3.1 GHz to 10.6 GHz. Besides exploiting the UWB operating band from 3.1 to 10.6 GHz for wireless personal area network

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(WPAN) applications, the current users of WPAN are also eagerly demanding a super wideband (SWB) to cover both short- and long-range transmission for future UWB communications. In the open literature, few SWB antennas have been reported in the planar domain [8–15]. However, challenges remain in the design of such antennas so far as suitable matching over this wide range is concerned. Another design constraint is the pattern stability over a wide range. These issues need to be addressed in such antenna designs.

In this work, a novel propeller shaped SWB antenna with an operating bandwidth of 32 GHz (3 GHz–35 GHz) is proposed. By shaping the radiator like a propeller, the effective electrical path traversed by the surface current is increased and the proposed antenna is able to provide an extremely large impedance matching from 3 to 35 GHz in comparison to a conventional circular monopole, designed using [3], which provides an impedance bandwidth up to 11 GHz only. The paper is organized as follows. The design details and a parametric study are discussed in Section 2. Section 3 describes the results and discussion followed by conclusion in Section 4.

2. ANTENNA DESIGN AND PARAMETRIC STUDY

The geometry of the proposed CPW feed propeller shaped monopole antenna starting its evolution from a conventional circular monopole is shown in Fig. 1. The evolution of the propeller shaped antenna begins with a conventional circular monopole of radius R_1 as shown in Fig. 1(a). Creation of the propeller shape involves use of coordinate geometry and trigonometry. Referring to Fig. 1(b) a circle of radius R_1 with centre $O(0,0)$ is drawn to represent the radiator portion of the circular monopole. A concentric circle C_1 with centre $O(0,0)$ and radius R is also drawn, and a point $P_1(R,0)$ is chosen on the circle C_1. Now with P_1 as centre and R as radius, a circle C_2 is drawn. Another point $P_2(x_o,y_o)$ is chosen on the circle C_1. Now with P_2 as centre and R as radius, another circle C_3 is constructed. Now the intersecting point of the circles C_1 and C_2 which is $B(x_2,y_2)$ can be found by solving the equations of the circles C_1 and C_2. Similarly $A(x_1,y_1)$ which is the point of intersection of C_1 and C_3 can be obtained by solving the equations of the circles C_1 and C_3. The optimum value of R is taken to be 20 mm as it supports smooth transition of current and hence exhibit good impedance matching. The circumferential distance or the arc length s is calculated via Fig. 1(b) using subsequent steps. From the isosceles triangle AOB, the length of the chord 'AB' indicated by a, joining the edges of the two blades which are $A(x_1,y_1)$ and $B(x_2,y_2)$, is calculated using.

$$a = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{1}$$

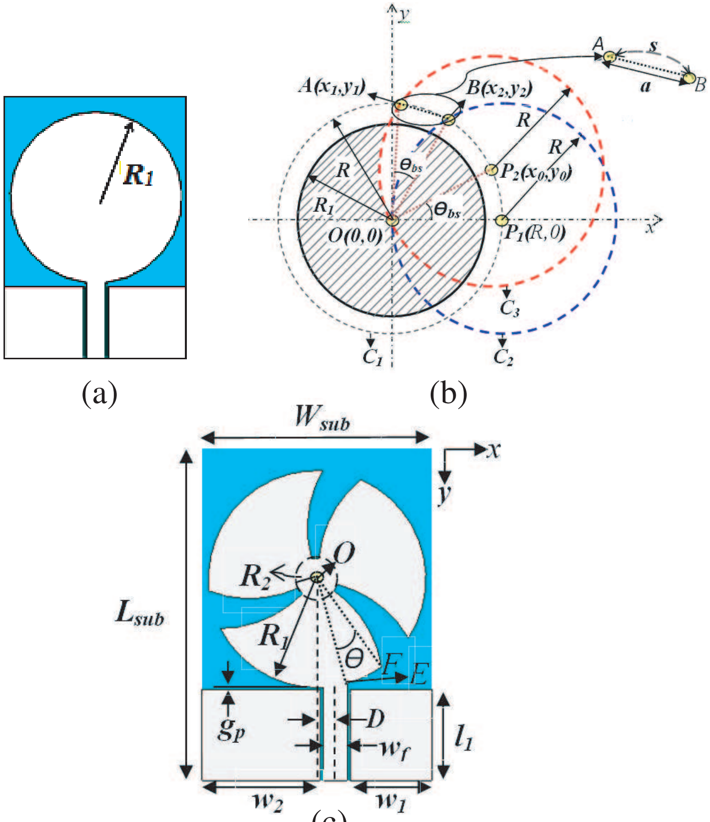
The angular distance θ_{bs} is then calculated using.

$$\theta_{bs} = 2 \times \sin^{-1}\left(\frac{a}{2 \times R_1}\right) \tag{2}$$

After the value of θ_{bs} is obtained, the radial distance 's' is obtained using.

$$s = R_1 \times \theta_{bs} \tag{3}$$

Referring to Fig. 1(c), angle θ is the radial angle formed by the isosceles triangle OEF, where E and F are the points on edge of the



(a) (b) (c)

Figure 1. (a) Initial circular monopole. (b) Construction of blades of propeller shaped monopole. (c) Design layout of propeller shaped monopole antenna.

feed and blade respectively, as shown in Fig. 1(c). D in Fig. 1(c) denotes the offset distance of the feed from the centre of the propeller.

For the initial circular monopole, the radius R_1 is chosen to be 19 mm and it is seen that it covers the bandwidth of 1–11 GHz (166%) in accordance with a $\lambda/4$ monopole [3]. Due to shaping the disk like a propeller, lower end frequency is shifted to 3 GHz but matching is improved upto 35 GHz, hence covering a bandwidth of 3–35 GHz (168%) that covers UWB and other super-wideband applications. Shifting in lower end frequency is observed due to perturbation of the original circular monopole. The outer circle radius R_1 which is 19 mm is the radius of the main radiator as shown in Fig. 1(c) and the optimum radius R_2 of centre base circle is chosen to be 2.4 mm.

The antenna is realized on a low cost FR4 substrate with a dielectric constant of 4.4, loss tangent of 0.002 and a height of 1.6 mm with an overall substrate area of $38 \times 55\,\text{mm}^2$ ($W_{sub} \times L_{sub}$). The central conductor of the 50 Ohm CPW feed has a length l_1 and a width w_f of 15.4 mm and 4 mm respectively. The separation between the radiator and the ground plane g_p is 0.3 mm. The proposed antenna is analyzed by the finite integration method using the time domain solver of the CST Microwave Studio$^{\text{TM}}$ [16]. Moreover parameter sweep is used to obtain the best values of the parameters listed in Table 1.

To understand the dependence of various parameters on impedance bandwidth (frequency range over which $|S_{11}|$ dB is better

Table 1. Dimensions of the proposed propeller shaped monopole antenna.

Parameters	**Value (mm)**
W_{sub}	38
L_{sub}	55
R_1	19
R_2	2.4
w_1	13.5
w_2	19.5
l_1	15.12
w_f	4
g_f	0.5
g_p	0.3
D	3.5
s	6.3

than 10 dB), various parametric studies have been performed. The dependence of return loss on spacing between ground plane and radiator g_p is shown in Fig. 2. It is seen that impedance matching at lower frequencies is largely affected than its higher frequencies which is clarified by current distribution in later part of this paper. An optimized value of g_p is taken as 0.3 mm which suits better matching. Dependence of return loss on outer radius R_1 is depicted in Fig. 3. It is observed that, as outer radius increases, matching at lower frequencies is improved which is due to the increment of effective electrical path on the surface of the antenna.

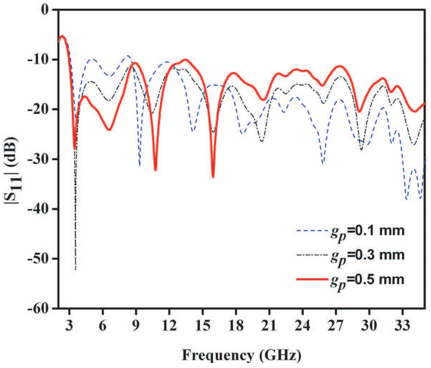


Figure 2. Effect of gap g_p between patch and ground plane on $|S_{11}|$.

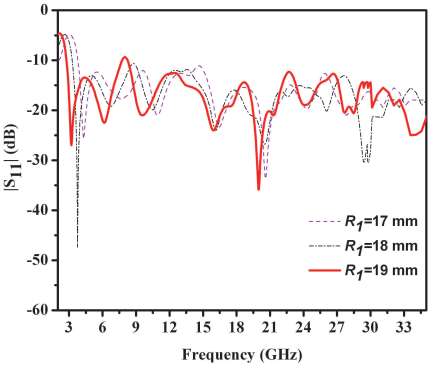


Figure 3. Effect of radius R_1 on $|S_{11}|$ characteristics.

The inter blade spacing of the antenna largely affects the impedance bandwidth. Inter blade spacing depends on the circumferential distance which is s, as indicated in Fig. 1(b). As s increases, inter blade spacing also increases which in turn shows mismatching at frequencies around 6 GHz which is due to the decrement of effective electrical path. Also if the inter blade spacing reduces, impedance matching at frequencies around 9 GHz deteriorates due to destructive interference from opposite current path in edges of the adjacent blades as depicted in Fig. 4. An optimized value of s is taken as 6.3 mm. By shifting the offset feeding position, i.e., by changing the value of D, some notable variations on impedance matching are observed as depicted in Fig. 5. The optimum value of D is chosen as 3.5 mm.

The effect of variation of inner circle radius R_2 is studied as shown in Fig. 6 and is observed that as R_2 decreases impedance matching at lower frequencies gets affected while an increase in R_2 affects the

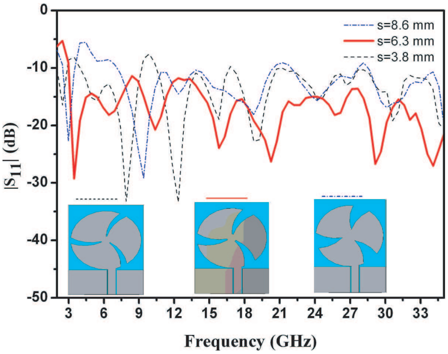


Figure 4. Effect of inter blade radial spacing s on $|S_{11}|$ characteristics.

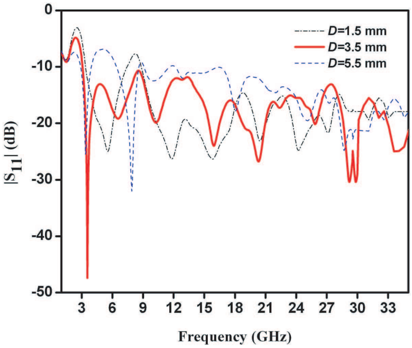


Figure 5. Effect of offset feed distance D on $|S_{11}|$ characteristics.

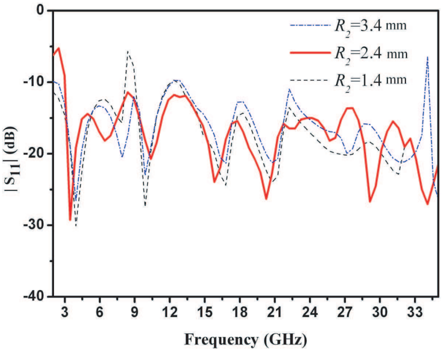


Figure 6. Effect of radius R_2 on $|S_{11}|$ characteristics.

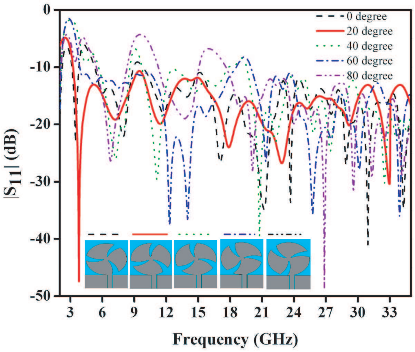


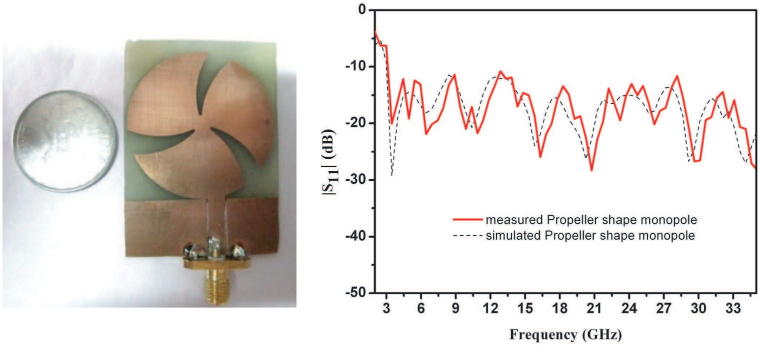
Figure 7. Effect of angle θ on $|S_{11}|$ characteristics.

impedance matching at higher frequencies. So the optimum value of R_2 is chosen to be 2.4 mm. Finally, the effect of radial angle θ as shown in Fig. 1(c) on impedance bandwidth has been studied and is depicted in Fig. 7. The parametric study has been performed by taking various values of θ covering the entire blade. It has been found from the parametric study that the optimum value of θ is 20 degrees.

3. RESULTS AND DISCUSSION

The optimized dimensions of the super wideband propeller shaped monopole as obtained from parametric studies are tabulated in Table 1.

Using these dimensions a prototype was developed as illustrated in



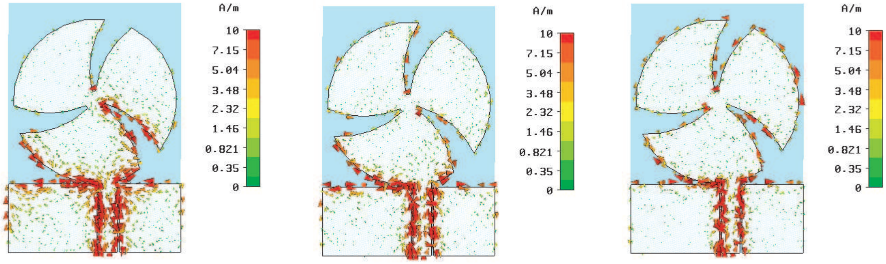
(a) (b)

Figure 8. (a) Fabricated prototype of the proposed antenna. (b) Measured and simulated $|S_{11}|$ characteristics.

the Fig. 8(a). The simulated and measured resonance characteristics of the antenna are shown in Fig. 8(b). The S-parameters were measured using a Rhode and Schwarz ZVA40VNA in its full operational span. Simulated and measured return loss characteristics are found to be in good agreement, though some mismatch is observed due to losses in the connector, fabrication tolerance, and substrate losses.

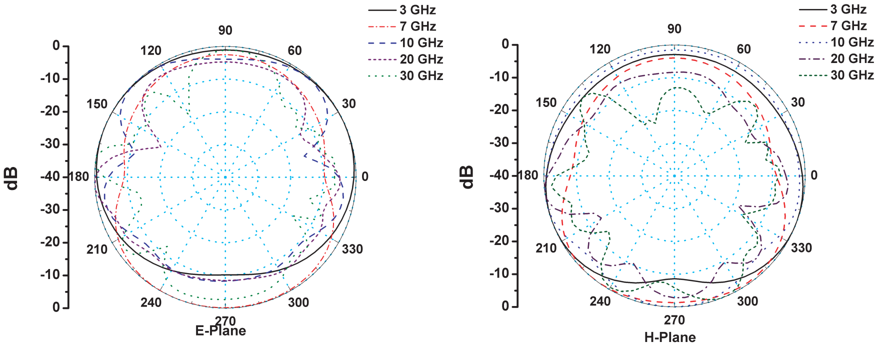
When compared with a conventional circular disk monopole antenna of radius 19 mm [3] which provides an impedance bandwidth of only up to 11 GHz, the impedance bandwidth of the proposed propeller shaped monopole extends upto 35 GHz, providing extreme super wideband characteristics. The designed antenna is larger in size in comparison to those in [13] and [14] but provides better impedance matching throughout its operating band. But when compared to that in [15], the proposed antenna is smaller in size and exhibit improved impedance matching throughout its bandwidth.

To have an insight into the functionality of the proposed propeller shaped monopole, simulated surface current distributions at different operating frequencies are shown in Fig. 9. It is seen that at lower frequencies like 5 GHz, current is mainly distributed along the feed, upper part of the ground plane, and lower part of the radiator. That is why, the gap (g_p) between the patch and radiator greatly affects the impedance matching at lower frequencies than at higher frequencies counterpart. It is also prominent that the upper two sections of the radiator don't have much significance at this lower frequency of operation. An offset feeding technique is used here to get proper impedance matching from feeding strip to radiator. Also the number of blades in the radiator is limited up to three to get a bigger surface area



(a) (b) (c)

Figure 9. Simulated current distribution on the antenna at (a) 5 GHz, (b) 15 GHz, (c) 30 GHz.



(a) (b)

Figure 10. Normalized measured radiation patterns in the (a) E-plane, (b) H-plane.

per blade which causes smooth transition of current from the feeding strip to the lower part of the radiator. At the next higher frequency of 15 GHz, it is observed that the current slightly spreads to the upper parts of the radiator. At 30 GHz, the current gets well distributed and travels towards the edges of the radiator.

The measured far-field normalized radiation patterns of the proposed antenna at 3, 7, 10, 20 and 30 GHz are depicted in Fig. 10. At lower frequencies, near omnidirectional radiation characteristics are observed. For the upper band, ripples arise with increasing frequency, whereby this phenomenon is due to the diversified electric current distribution on the proposed antenna and also because the antenna operates at higher order modes instead of the typical monopole mode. The antenna shows satisfactory omnidirectional radiation characteristics throughout its whole operating span.

The gain of the antenna is measured and it is found that the antenna gain varies from 4 dBi at 3 GHz to 6 dBi at 13 GHz. After that, the gain gradually decreases to 3.9 dBi at 25 GHz due to dielectric loss of the substrate at higher frequencies. The measured gain variations of the proposed antenna are depicted in Table 2. The group delay profile is almost linear throughout the operating band as depicted in Fig. 11. This ensures the distortionless characteristics of the proposed antenna.

Table 2. Measured gain of the proposed antenna.

Frequency (GHz)	3	8	13	18	25
Gain (dBi)	4	4.5	6	5.2	3.9

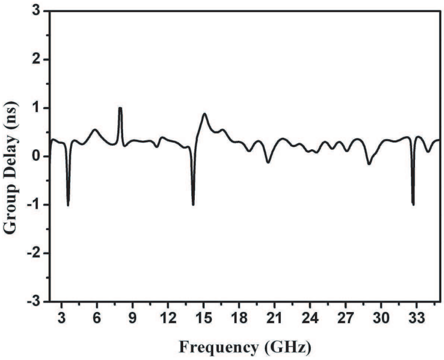


Figure 11. Group delay variation over the band of the proposed super wideband antenna.

4. CONCLUSION

An extremely super-wideband propeller shaped printed monopole antenna has been proposed. By shaping the radiator like a propeller, effective electrical path of the surface current has been increased and very wide impedance has been obtained. The impedance bandwidth of the proposed propeller shaped monopole antenna reaches is 168% and satisfactory omni-directional radiation patterns are also obtained. Moreover the proposed antenna is found to be distortionless as studied from the group delay profile. Very ultra wide impedance bandwidth with a simple structure makes the antenna suitable for future UWB communications as well as UWB imaging systems.

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