NUMERICAL AND EXPERIMENTAL INVESTIGATION OF A NOVEL ULTRAWIDEBAND BUTTERFLY SHAPED PRINTED MONOPOLE ANTENNA WITH BANDSTOP FUNCTION

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Abstract—In this paper, a novel compact butterfly shaped printed monopole antenna for ultra-wideband (UWB) applications is presented. The proposed antenna is designed with a standard printed circuit board (PCB) process for suitable integration with other microwave components. The antenna prototype is designed then fabricated and tested experimentally. The calculated impedance bandwidth of the proposed antenna ranges from 3 GHz to 13 GHz for a 10 dB reflection coefficient (S_{11}) while the measured impedance bandwidth ranges from 3 GHz to 10.8 GHz covering the whole UWB frequency range. The measured antenna radiation patterns show relatively stable radiation patterns with almost constant gain over the whole frequency band of interest. By introducing a slit ring resonator (SRR) in the feedline, a bandstop of 830 MHz from 5.0 to 5.83 GHz for band rejection of wireless local area network (WLAN) can be achieved. So, the proposed antenna is considered a good candidate for future UWB communication systems.

1. INTRODUCTION

Since Federal Communication Commission (FCC) released its report in 2002, Ultra-wideband (UWB) system design and its application in commercial wireless communications have drawn a great attention [1]. Because the antenna is considered as an essential part of the UWB system and it affects the overall performance of the UWB system,

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many different antenna designs have been developed recently [2–9]. But the designed antenna for UWB applications should meet the design requirements for UWB operation such as wide impedance bandwidth, i.e., 3.1–10.6 GHz, low profile, compact size, with both good omni-directional radiation patterns and gain flatness. Among those different antenna designs, printed monopole antennas are promising for applications in UWB communications [2–7].

However, there are several narrowband communication systems operating in the 5.15–5.825 GHz which overlap with UWB frequency band such as IEEE 802.11a wireless local area network (WLAN) system or HIPERLAN/2 wireless system. This frequency overlap among the existing wireless systems and UWB systems may cause interference. At the interfering frequency band, a filter with bandstop characteristics is to be connected to the UWB antenna to achieve a notch function and hence avoid the interference. Several UWB antennas with different bandstop filter designs have been widely discussed in recent years [8–12].

In this paper, a novel compact butterfly shaped printed monopole antenna for UWB applications is proposed. The antenna radiating patch consists of a two overlapped elliptical discs forming the two wings of the butterfly with two annular slot rings. The calculated results show that the proposed antenna can achieve a calculated reflection coefficient (S_{11}) better than -10 dB over a bandwidth of 10 GHz, from 3 GHz to 13 GHz. The measured results show that the antenna can achieve a bandwidth of 7.8 GHz from 3 GHz to 10.8 GHz covering the whole UWB frequency band. Bandstop function can be obtained by modifying the proposed antenna by using a slit ring resonator (SRR) element. The configuration of the proposed antenna and parametric optimization is described in Section 2. The calculated and experimental results are presented and discussed in Section 3. Section 4 presents the proposed bandstop antenna. Finally, the conclusions of this work are given in Section 5.

2. ANTENNA CONFIGURATION AND PARAMETRIC OPTIMIZATION

The geometry of the proposed antenna is shown in Figure 1. The radiating element consists of two overlapped elliptical discs of major and minor radii a and b (elliptically ratio a/b) forming the two wings of the butterfly. This radiating patch is fed by a 50 Ω microstrip line of width $W_{feed} = 4.8$ mm and it can be connected directly to a 50 Ω SMA connector. The proposed antenna is etched on 1.575 mm-thick Rogers RT Duroid 5880 substrate with relative permittivity $\varepsilon_r = 2.2$ and loss

factor $\tan \delta = 0.0009$. The length and the width of the dielectric substrate are $L = 35$ mm and $W = 30$ mm, respectively. On the other side of the substrate, there is a finite length ground plane with dimensions of $W \times L_G$. The width of the feed gap between the feeding point and the ground plane is d. Two annular slot rings of an outer and inner radii r_1 and r_2 have been cut out from the radiating patch. These slots are located at distance c and e from the two ellipses' edges. The use of two annular slot rings minimizes the copper area and hence reduces the copper losses and increases the antenna radiation efficiency.

An extensive parametric study was carried out to investigate the effect of different design parameters on the antenna performance. A parametric study in Figure 2 shows how the elliptical disc major radius a and the elliptically ratio a/b strongly affects the antenna operating bandwidth. The parametric study is performed where other parameters are fixed, i.e., $b = 16$ mm, $c = e = 5.2$ mm, $d = 1.1$ mm, $L_G = 12.8$ mm, $r_1 = 3$ mm and $r_2 = 2$ mm. It has been found that the optimum values for the elliptical disc major radius and the elliptically ratio to achieve the maximum available bandwidth are $a = 20$ mm and $a/b = 1.6$. For further understanding the effect of antenna parameters on its performance, parametric studies have been numerically calculated for annular slot rings inner and outer radii r_1 and r_2 as shown in Figures 3(a) & (b), respectively. Also, the effect of annular slot rings locations c and e has been studied and presented in Figures 4(a) & (b). It can be noticed that the annular
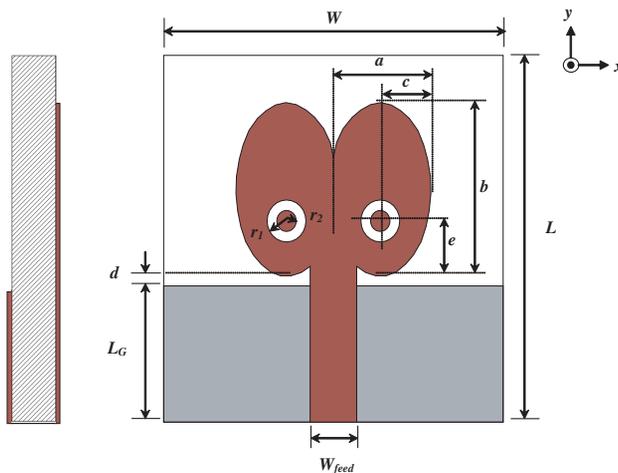
Figure 1. Geometry of the proposed butterfly antenna: side and top views.
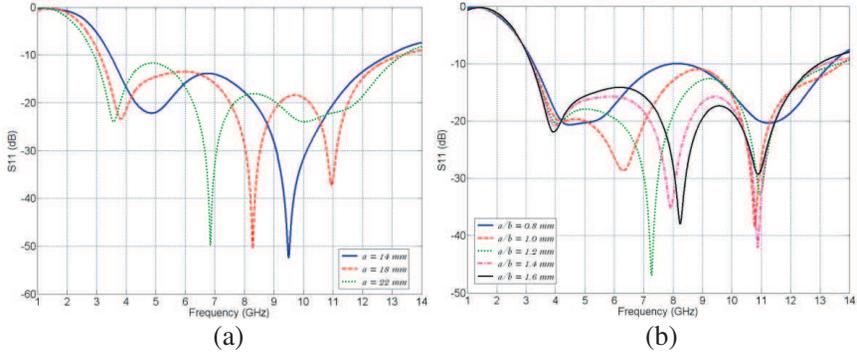
Figure 2. Reflection coefficient curves for different values of (a) elliptical disc major radius a, (b) elliptically ratio a/b for $a = 20$ mm.
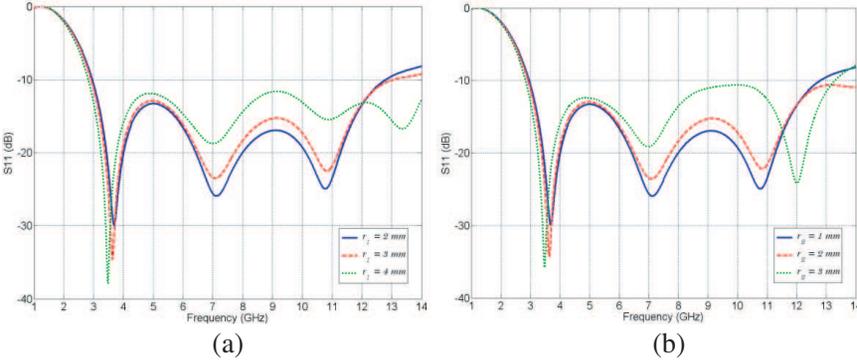
Figure 3. Reflection coefficient curves for different values of annular slot rings (a) outer radius r_1 with $r_2 = 1$ mm, (b) inner radius r_2 with $r_1 - r_2 = 1$ mm.

slot rings dimensions and locations have a small effect on the antenna performance. Figures 5(a) & (b) present the reflection coefficient curves versus frequency for different values of ground length L_G and feeding gap d, respectively. The length of the ground plane L_G has no much effect on the antenna impedance characteristic. On contrary, the feeding gap d strongly affects the antenna impedance matching and the antenna bandwidth as well.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The optimized antenna parameters are summarized and shown in Table 1. The photo of the fabricated antenna prototype is shown in Figure 6. The designed antenna is simulated and optimized using
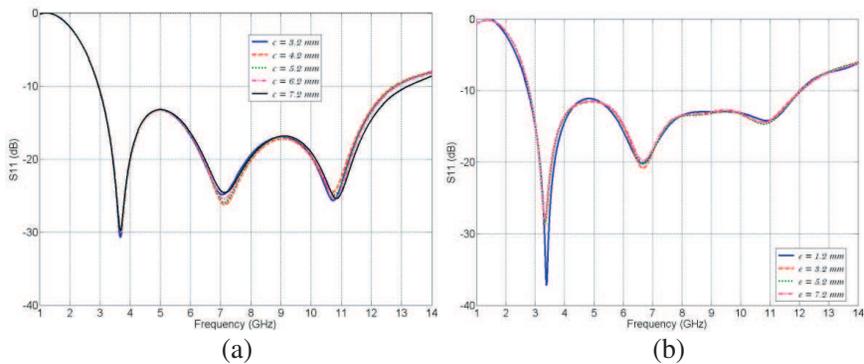
Figure 4. Reflection coefficient curves for different values of annular slot rings location (a) c, (b) e.
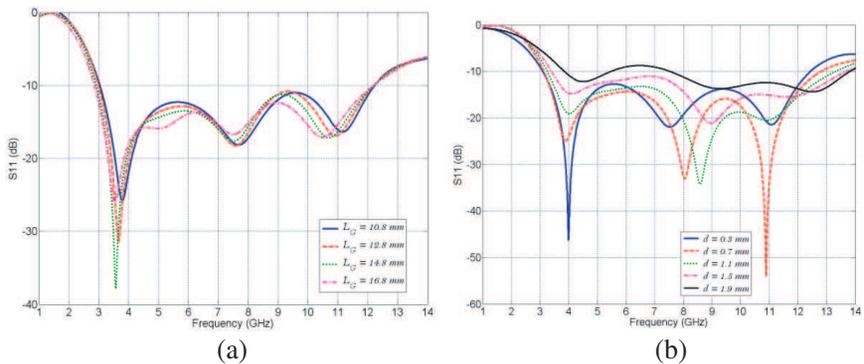
Figure 5. Reflection coefficient curves for different values of (a) ground length L_G, (b) feeding gap d.

Table 1. Optimized parameters dimensions for the proposed antenna (Units: mm).

W	L	a	a/b	c	d	e	r_1	r_2	L_G	h
30	35	20	1.6	5.2	1.1	5.2	3	2	12.8	1.575

two commercial electromagnetic simulators: Ansoft HFSS [13], which utilizes Finite Element Method (FEM) in frequency domain, and CST Microwave Studio [14] that is based on Finite Integration Technique (FIT) in time domain.

The calculated and measured reflection coefficient against the frequency of the proposed antenna is plotted in Figure 7. It is
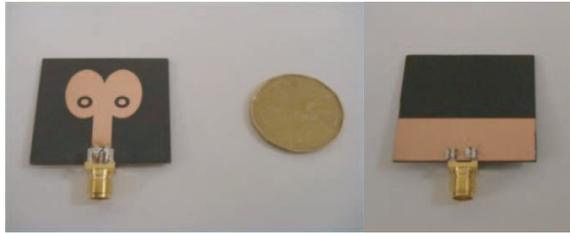
Figure 6. Photograph of the fabricated antenna prototype: top and bottom views.
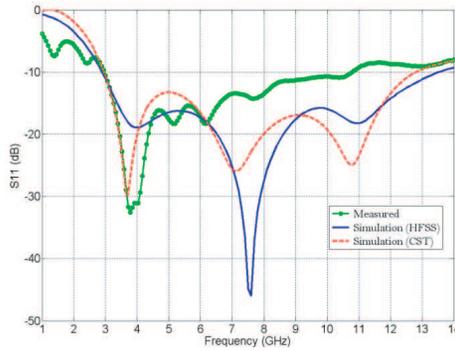
Figure 7. Measured and calculated reflection coefficient curves of the proposed antenna.
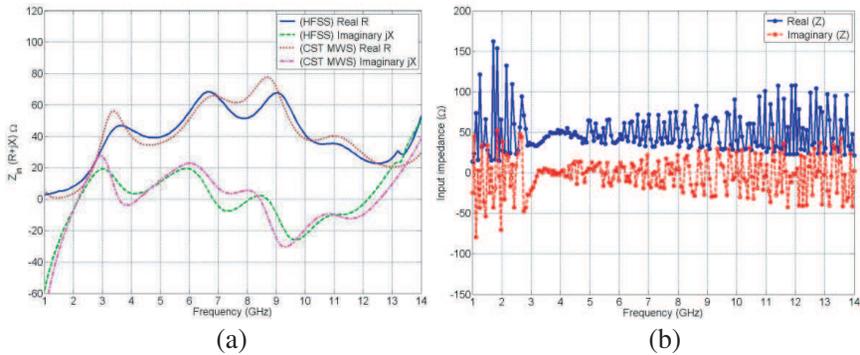
Figure 8. (a) Calculated and (b) measured input impedance curves of the proposed antenna.
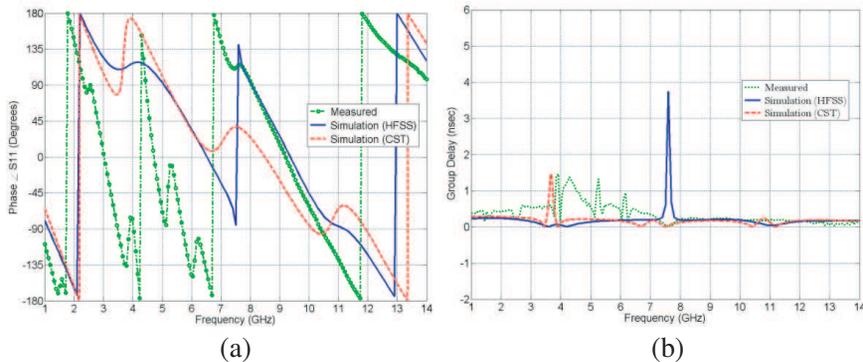
Figure 9. Measured and calculated antenna (a) phase and (b) group delay.

observed from the results that the antenna exhibits a simulated impedance bandwidth of about 10 GHz starting from 3.0 to 13.0 GHz and measured impedance bandwidth starts at 3.0 up to 10.8 GHz covering the whole UWB frequency band. Figures 8(a) & (b) present the calculated variation of the antenna input impedance with frequency and the measured real and imaginary parts of the antenna input impedance, respectively. The results show that the antenna input impedance $Z_{in} = R_{in} + jX_{in}$ has a real part R_{in} oscillating around 50Ω and an imaginary part jX_{in} oscillating around 0Ω over the whole UWB frequency band. The measured and calculated phase and antenna group delay is shown in Figures 9(a) & (b), respectively. The maximum measured group delay is less than 2 ns through the whole frequency band of interest. It can be seen from Figures 7 & 9 that the measured results agree well with CST simulated results especially at low frequency band (from 3 to 6 GHz). At the high frequency band (from 6 to 12 GHz), there is a disagreement with the simulated results. This is may be due to the fabrication tolerance and the loss effect of the substrate at high frequencies which is not taken into account in simulations.

Also, the measured and HFSS calculated antenna radiation patterns in both E- and H-planes at different frequencies, i.e., 3, 5, 7 and 9 GHz are plotted in Figure 10. It can be noticed that the proposed antenna exhibits stable radiation patterns across the whole frequency band better than the calculated results. Also, the E-plane (yz-plane) patterns are like dipole while the H-plane (xz-plane) patterns are nearly omni-directional.

4. PROPOSED BANDSTOP ANTENNA

Bandstop performance can be obtained by modifying the above UWB antenna. A slit ring resonator (SRR) element is cut away from the microstrip feedline as shown in Figure 11. The SRR element takes like C-shape and its dimensions will control the rejection band of the bandstop filter. The optimized SRR parameters are: $W_s = 2.4\,\text{mm}$, $L_s = 9\,\text{mm}$, $T = 0.2\,\text{mm}$, $W_g = 0.8\,\text{mm}$ and $D_s = 2.8\,\text{mm}$.

(E-plane) $f = 3\,\text{GHz}$ (H-plane)

(E-plane) $f = 5\,\text{GHz}$ (H-plane)

(E-plane) $f = 7\,\text{GHz}$ (H-plane)

(*E*-plane) $f = 9\,\text{GHz}$ (*H*-plane)
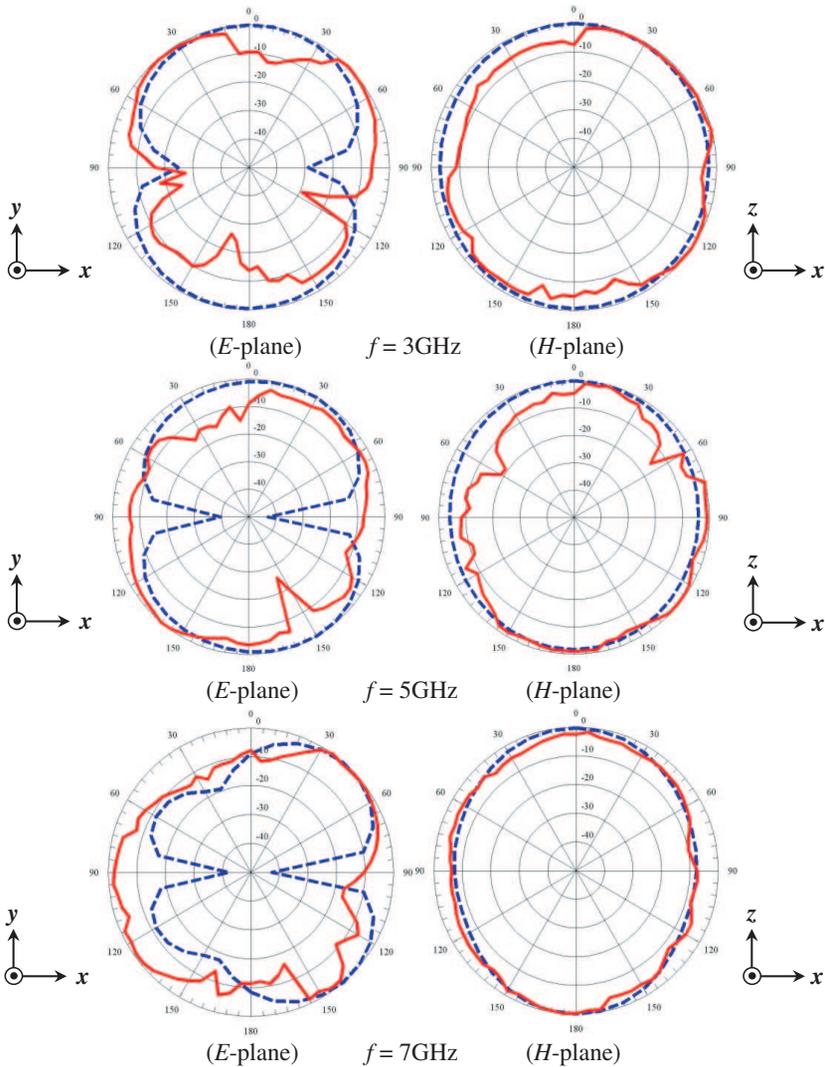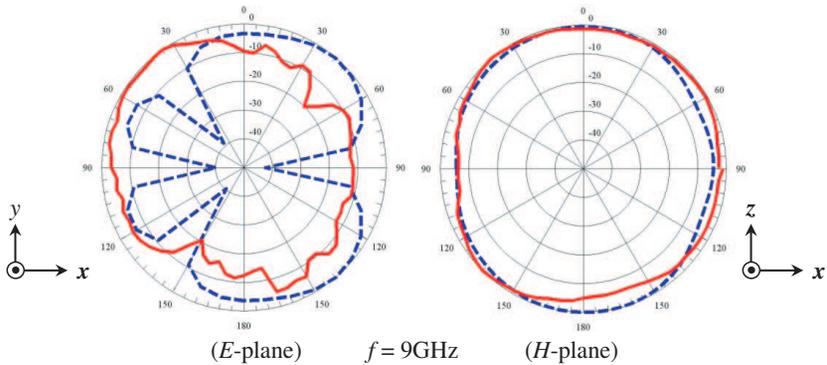
Figure 10. Radiation patterns of the proposed antenna. Solid lines for measured and dashed lines for calculated.
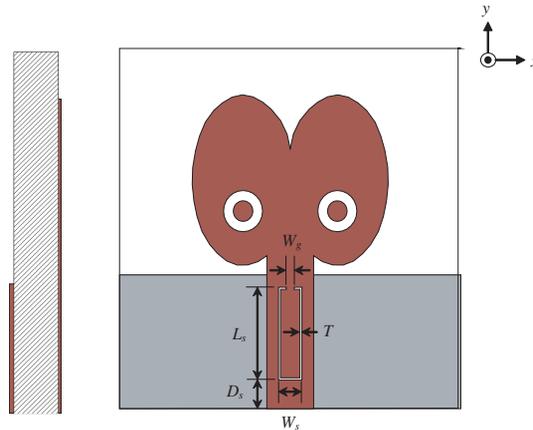
Figure 11. Geometry of the proposed bandstop antenna: side and top views.

The VSWR of the Bandstop antenna is shown in Figure 12. Compared with the reference antenna (without slot), only the performance in the band-notched range from 5.0 GHz to 5.88 GHz is noticeably different. The antenna gains against frequency for both bandstop antenna and the reference antenna (without slots) are presented in Figure 13.

It can be noticed that the UWB antenna gain is almost stable over the whole frequency band. The gain is between 4 dB and 6 dB for the UWB antenna. As expected, a sharp gain decrease is shown for the bandstop antenna between 5.0 GHz and 5.83 GHz.
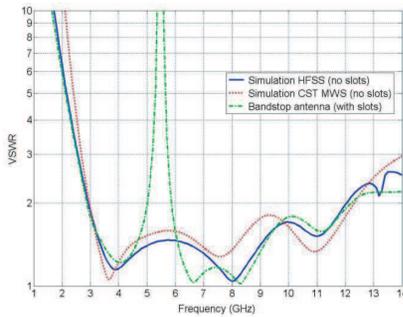
Figure 12. VSWR of the bandstop antenna and the UWB antenna without slots.
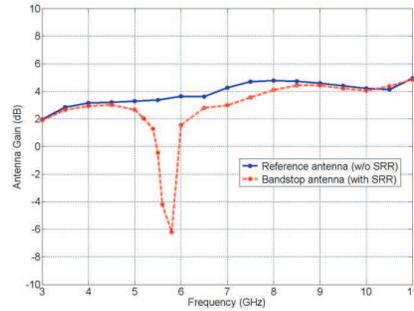
Figure 13. Antenna gains of the UWB antenna and the bandstop antenna.

5. CONCUSION

In this paper, a novel butterfly shaped printed monopole antenna for UWB short-range wireless communications has been presented. The proposed antenna prototype has been designed, fabricated and tested. Both calculated and measured results show that the proposed antenna has a broadband matched impedance band with almost constant gain. The proposed antenna has an impedance bandwidth of about 7.8 GHz from 3 GHz to 10.8 GHz covering the whole UWB frequency band. Also, the effect of antenna parameters on the antenna performance has been addressed. The antenna also has a good E- and H-plane radiation patterns through the entire UWB frequency band. By embedding a slit ring resonator (SRR) element in the feedline, a frequency band notch has been created which enables avoiding the interference with the existing WLAN systems. From these results, it is confirmed that the proposed antenna is a good candidate for UWB short-range wireless communication applications.

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