Progress In Electromagnetics Research C, Vol. 11, 39–49, 2009

A NOVEL MAPLE-LEAF SHAPED UWB ANTENNA WITH A 5.0–6.0 GHz BAND-NOTCH CHARACTERISTIC

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Abstract—A novel microstrip fed ultra-wideband (UWB) antenna with different band rejection techniques is presented in this paper. The antenna consists of a maple-leaf shaped radiator fed by a microstrip line with a finite ground plane on the other side of the substrate. The size of the UWB antenna is $30.5 \times 35.5\,\mathrm{mm}^2$ which is only about $0.3 \times 0.35\lambda^2$ at 3 GHz. The calculated impedance bandwidth of the proposed antenna ranges from 3 GHz to 14 GHz with relatively stable radiation patterns. Two different techniques have been implemented to achieve band-notch characteristic in the 5.0–6.0 GHz WLAN frequency band. The first one uses an H-shaped slot cut away from the radiating patch while the other one uses two rectangular slits in the ground plane creating defected ground structure (DGS).

1. INTRODUCTION

Recently, ultra-wideband (UWB) antennas as part of the UWB systems have drawn a great attention since Federal Communication Commission (FCC) released its report in 2002 [1] to allow using UWB frequency band for commercial applications. It requires an antenna of small size, wide impedance bandwidth of 3.1–10.6 GHz, omni-directional radiation patterns, and stable gain. Various types of planar UWB antennas have been developed for UWB applications [2–10]. However, there are several narrowband communication systems operating below 10 GHz and may cause interference with UWB systems such as wireless local area network (WLAN) systems operating at 5.15–5.825 GHz frequency band. To solve this problem, many

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UWB antennas have been proposed for achieving band-notched characteristic [8–11]. Some techniques are based on embedding a thin slot in the radiating patch, i.e., π-shaped slot [8], or using parasitic strips, i.e., inverted C-shaped parasitic strip [9]. Other techniques are based on embedding a stub inside a slot cut in the radiating patch [10], or even using a slot defected ground structure (DGS) in the ground plane, i.e., H-shaped slot DGS [11].

In this paper, we present a novel maple-leaf shaped microstrip-line fed planar monopole antenna for UWB operation. The proposed antenna consists of an optimized maple-leaf shaped radiating element and is fed by a microstrip line. The calculated results show that the proposed antenna can achieve a bandwidth of more than 10 GHz, from 3.1 GHz to 13.15 GHz for a reflection coefficient (S_{11}) less than -10 dB [14]. Band-stop performance is obtained by embedding an H-shaped slot into the radiating patch. Using two cutting strips in the ground plane is also used as an alternative technique to achieve band-rejection capability for the proposed antenna. The band-notched resonance frequency and the bandwidth can be easily controlled by adjusting the dimensions of the slots. Section 2 introduces the configuration of the proposed antennas and simulated and experimental results. Finally, the conclusions of this work are given in Section 3.

2. ANTENNA DESIGN AND EXPERIMENTAL RESULTS

The proposed structures are simulated using two independent commercial software packages, i.e., Ansoft HFSS software [12] which utilizes the finite element method (FEM) in frequency domain and CST MWS [13] that is based on the finite integration technique (FIT) in time domain. The design goals are to achieve impedance bandwidth cover the whole UWB frequency spectrum with good gain, stable radiation patterns, phase linearity, constant group delay characteristics across the whole desired band.

2.1. Design of a Maple-leaf Shaped Monopole Antenna

Figure 1(a) shows the geometry and configuration of the proposed UWB antenna fed by a $50\,\Omega$ microstrip line. The radiating element consists of a maple-leaf shaped patch which represents the Canada flag symbol etched on a Rogers RT Duroid 5880 substrate with dielectric constant $\varepsilon_r = 2.2$ and dielectric loss tangent $\tan\delta = 0.0009$, and thickness $h = 1.575$ mm.

By examining the current distribution of monopole antennas with regular shapes, i.e., circular, rectangular, etc., the proposed cuttings in the maple-leaf shaped monopole antenna are used to increase the antenna perimeter which affects the lower resonant frequency and then increasing the maximum achieved impedance bandwidth. It is well known that the current distribution is mainly concentrated in the edges rather than in the center of the printed monopole antenna. So, by increasing the antenna perimeter p, the surface current will take longer path and this will be equivalent to a longer length monopole and in turn will decrease the lowest resonance frequency f_L according to [5]

$$\varepsilon_{eff} \approx (\varepsilon_r + 1)/2 \tag{1}$$

$$f_L \text{ (GHz)} = 300/p\sqrt{\varepsilon_{eff}} \tag{2}$$

Details of the generated optimized parameters are summarized in Table 1. The parameters of $L_1 \sim L_{10}$ are determined using optimization in the commercial software programs and their effects on the overall antenna impedance bandwidth are studied using parametric study. A photograph of the proposed UWB antenna prototype is shown in Figure 1(b).

The calculated and measured reflection coefficient curves against the frequency for the designed UWB antenna is plotted in Figure 2. It is observed from the calculated results that the designed antenna exhibits an impedance bandwidth of more than 10 GHz starts from 3 GHz to 14 GHz. The measured results show that the impedance bandwidth is dual band, i.e., 4.1–7 GHz and 8.7–13.3 GHz. The difference between the measured and calculated results may be due to the manufacturing tolerance especially the simulated results are already very close to −10 dB in the region 7.0–9.0 GHz frequency band. The manufacturing tolerance has been simulated and the obtained results confirm the above explanation.

Table 1. Antenna dimensions.

W	30.48 mm	L_3	2.65 mm
L	35.56 mm	L_4	4.10 mm
L_G	12.95 mm	L_5	4.34 mm
W_1	5.59 mm	L_6	3.05 mm
W_f	4.06 mm	L_7	5.39 mm
d	0.84 mm	L_8	7.73 mm
L_1	2.27 mm	L_9	4.02 mm
L_2	7.47 mm	L_{10}	5.24 mm

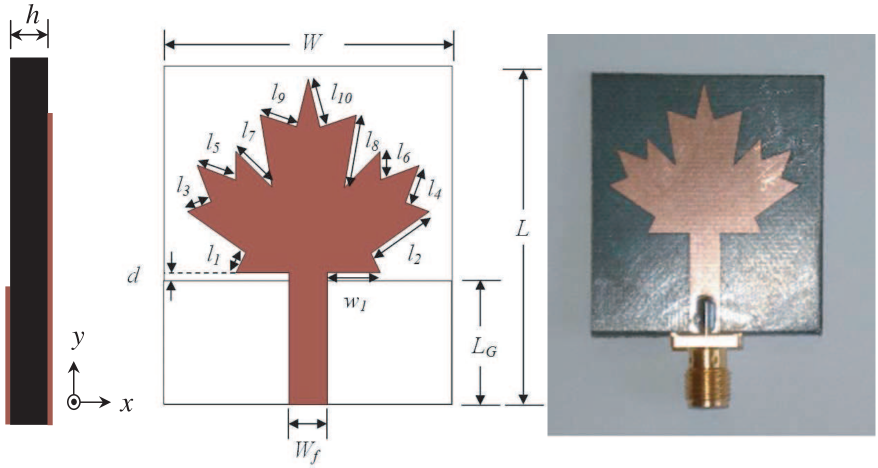


Figure 1. (a) Geometry of the proposed maple-leaf shaped printed monopole antenna. (b) Photograph of the proposed antenna prototype.

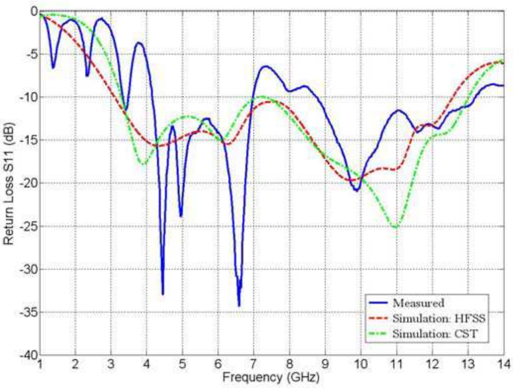


Figure 2. Measured and simulated reflection coefficient curves versus frequency of the proposed maple-leaf shaped printed monopole antenna.

Figure 3 shows the calculated and measured E-plane and H-plane radiation patterns at frequencies 3 GHz, 5 GHz, 7 GHz, and 9 GHz respectively. As expected, the proposed antenna exhibits a dipole-like radiation patterns. The E-plane (y-z plane) radiation pattern is almost like a daunt shape while a good omni-directional radiation pattern in H-plane (x-z plane) is achieved with stable radiation patterns with frequency.

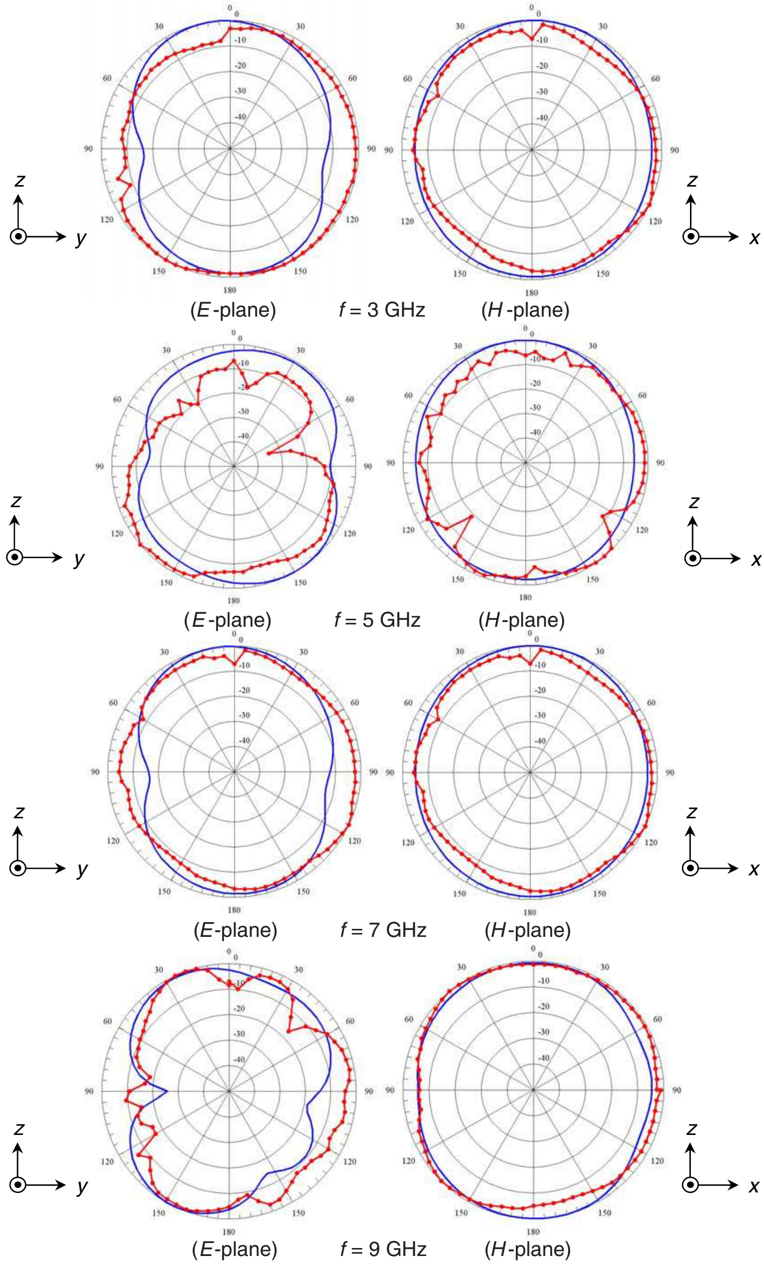
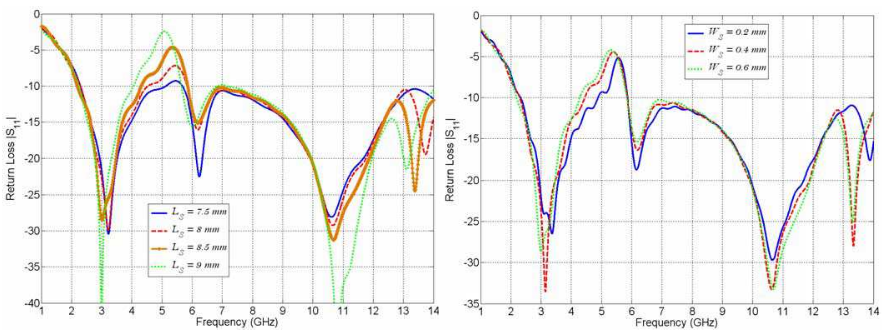


Figure 3. Measured (marker line) and calculated (solid line) radiation patterns of the proposed maple-leaf shaped printed monopole antenna.

Figure 4. Geometry and photograph of the proposed bandstop antenna using an H-slot.



(a) (b)

Figure 5. Simulated reflection coefficient curves for different (a) slot lengths L_S with $W_S = 0.65$ mm and $D_S = 18.6$ mm, (b) slot widths W_S with $L_S = 8.6$ mm and $D_S = 18.6$.

2.2. Design of Bandstop Antennas

Band-notched characteristic is obtained by modifying the above UWB antenna using two different techniques. The first proposed technique is based on cutting an H-shaped slot away from the radiating patch as shown in Figure 4. The slot resonating element dimensions control the rejection band of the band-notched filter. By adjusting the dimensions of the slot, both the notch center frequency and the bandwidth can be easily controlled. A parametric study has been carried out to address the effect of slot parameters on the frequency response of the proposed bandstop antenna. It is found that the reflection coefficient is very sensitive to the length of the slot (L_S), and its width (W_S) for a fixed location (D_S). Figure 5(a) presents the simulated reflection coefficients for different slot lengths with fixed W_S and D_S to 0.65 mm and 18.6 mm, respectively.

It can be noticed that the simulated resonant frequency of the bandstop filter is dependent on the slot length. By increasing the slot length, the resonant frequency of the bandstop filters decreases and vice versa. The variation of reflection coefficients with the slot width for fixed $L_S = 8.6$ mm and $D_S = 18.6$ mm are introduced in Figure 5(b).

By increasing the slot width, the bandwidth is increased as well and vice versa. The optimized slot parameters are found to be: $W_S = 0.65$ mm, $L_S = 8.6$ mm, and $D_S = 18.6$ mm. It can be concluded that adjusting the mean length of the slot to be about one half-wavelength

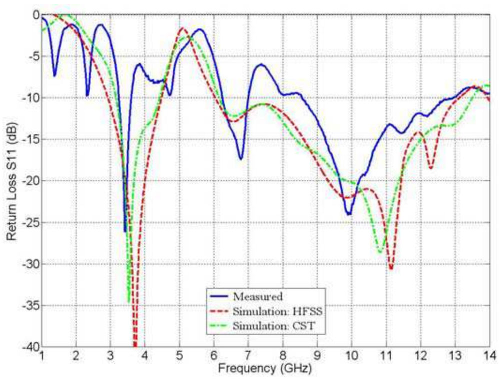


Figure 6. Measured and simulated reflection coefficient curves for the proposed bandstop antenna using an H-slot.

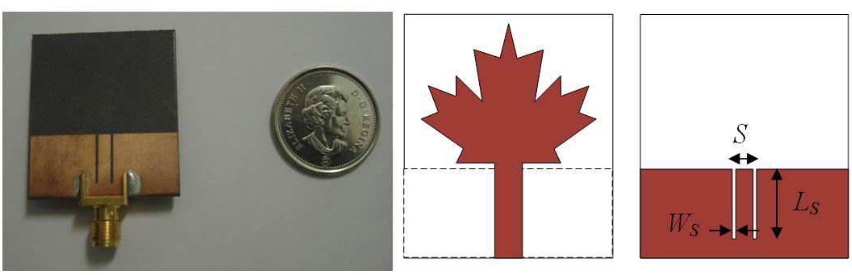
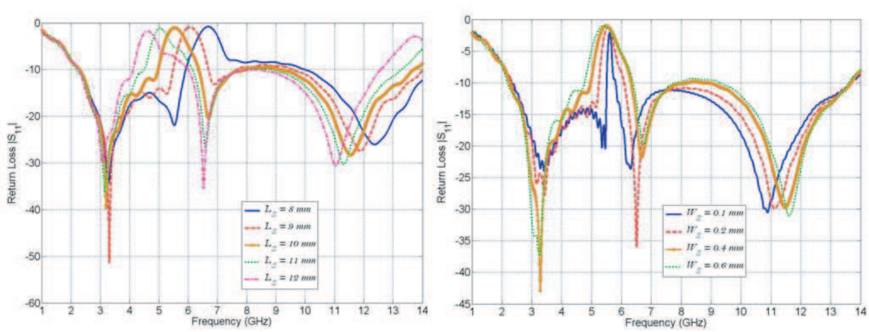


Figure 7. Geometry and photograph of the proposed bandstop antenna using two slits.

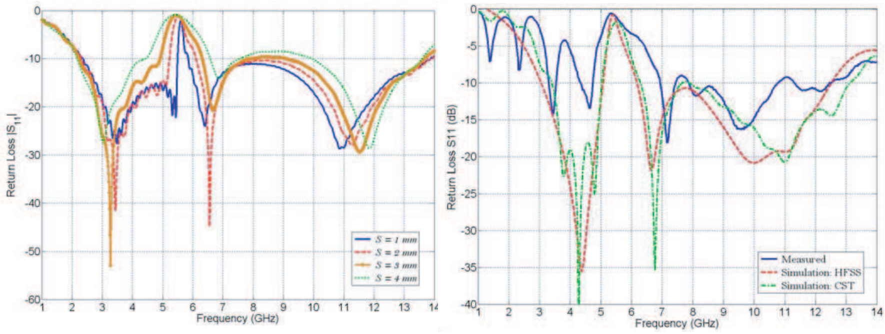
at the desired notched frequency, a destructive interference can take place, thus causing the antenna to be nonresponsive at that frequency. The calculated mean length of the slot is about $3L_S = 26\,\mathrm{mm}$ and the calculated half-wavelength at the notch frequency $f = 5.5\,\mathrm{GHz}$ is $\lambda/2 = 27.7\,\mathrm{mm}$. The measured and calculated reflection coefficients of the proposed bandstop antenna with H-slot are illustrated in Figure 6. Compared with the simulated results, there is a good agreement between measured and simulated results and the performance in the band-notched range from 5.0 GHz to 6.0 GHz is achieved.

Another proposed band rejection technique is based on cutting two narrow slits in the ground plane making a defected ground structure (DGS) as shown in Figure 7. By adjusting the dimensions of the length (L_S), the width (W_S) of the two slits, and the separation distance between them (S), the bandstop characteristic can be easily controlled. A parametric study has been carried out to address the effect of different filtering element parameters on the frequency response of the proposed bandstop antenna. Figure 8(a) presents the simulated reflection coefficients for different slit lengths with fixed W_S and S to 0.5 mm and 3 mm, respectively. It can be noticed that the simulated resonant frequency of the bandstop filter is dependent on the slit length. By increasing the slit length, the resonant frequency of the bandstop filters decreases and vice versa. The variations of reflection coefficients with the slit width for fixed $L_S = 10.2\,\mathrm{mm}$ and $S = 3\,\mathrm{mm}$ are reported in Figure 8(b). Also, the effect of varying the separation distance between slits on the bandstop antenna response has been plotted in Figure 9(a). It can be noticed that both slit



(a) (b)

Figure 8. Simulated reflection coefficient curves for different (a) slit lengths L_S with $W_S = 0.5\,\mathrm{mm}$ and $S = 3\,\mathrm{mm}$, (b) slit widths W_S with $L_S = 10.2\,\mathrm{mm}$ and $S = 3\,\mathrm{mm}$.



(a) (b)

Figure 9. (a) Simulated reflection coefficient curves for different separation distance between slits S with $L_S = 10.2$ mm and $W_S = 0.5$ mm, (b) measured and simulated reflection coefficient curves for the proposed bandstop antenna using two slits.

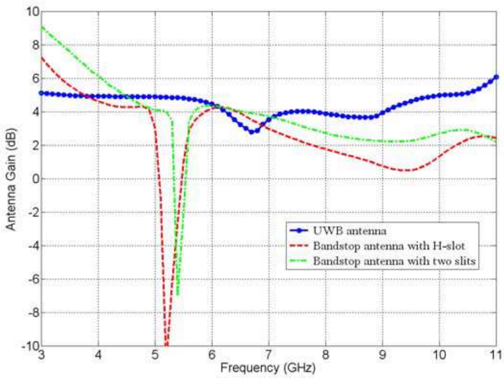


Figure 10. Gain curves versus frequency for the proposed antennas.

width and separation distance between slits affect the bandwidth of the frequency response of the proposed bandstop antenna. The DGS optimized parameters are found to be: $W_S = 0.5$ mm, $L_S = 10.2$ mm, and $S = 3$ mm.

Figure 9(b) presents the measured and calculated reflection coefficients of the proposed bandstop antenna with two slits. There is a good agreement between the measured and simulated results and the performance in the band-notched range from 5.0 GHz to 6.0 GHz is successfully achieved. The HFSS calculated antenna gains in the entire operating frequency band for the UWB antenna, bandstop antenna with H-slot and with two slits are presented in Figure 10. It can be noticed that the UWB antenna gain is almost stable over the whole frequency band. For bandstop antennas with H-slot and with two slits, a sharp gain decrease is shown between 5.0 GHz and 6.0 GHz.

3. CONCLUSION

In this paper, a novel maple-leaf shaped printed monopole antenna for UWB applications has been designed and presented. The antenna impedance bandwidth with reflection coefficient less than −10 dB is more than 10 GHz from 3.1 GHz to 13.15 GHz covering the UWB frequency band for communication systems. The proposed antenna exhibits a reasonable H-plane omni-directional radiation and a donut-shaped radiation in E-plane. Two different techniques have been implemented to achieve band-notch characteristic in the 5.0–6.0 GHz WLAN frequency band. By embedding an H-shaped slot cut away from the radiating patch, a frequency band notch is created which enables avoiding the interference with existing WLAN systems. Using two rectangular slits in the ground plane can also achieve band-notch characteristic in the 5.0–6.0 GHz WLAN band.

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