AN ULTRA WIDEBAND MONOPOLE ANTENNA WITH MULTIPLE FRACTAL SLOTS WITH DUAL BAND REJECTION CHARACTERISTICS

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Abstract—A compact dual band notched Ultra-wideband (UWB) antenna with multiple Hilbert curve slots is proposed that exhibits an impedance bandwidth from 2.5 GHz to 12 GHz Hilbert curve slots result in band notch in the frequency range 5.15–5.85 GHz assigned to IEEE 802.11a and HYPERLAN/2 as well as 7.9–8.4 GHz band assigned to X-band uplink satellite communication systems. The antenna gain varies from 3 dBi to 5 dBi over the operating frequency. Stable radiation patterns throughout its operating frequency are obtained Over all antenna size is 25 mm by 45.75 mm including the ground plane. Simulation and measured result of the proposed antenna are in good agreement.

1. INTRODUCTION

In recent years, research in the area of ultra wideband (UWB) systems has generated a lot of interest among microwave engineers. Feb. 2002 witnessed the allocation of frequency range 3.1 to 10.6 GHz as the UWB application band by Federal Communication Commission (FCC), USA [1]. UWB system has attracted much attention for short-range communication technology because of its numerous advantages, such as extremely high data rates, low power consumption, low

cost and simple hardware configuration. During the past few years, various types of UWB antennas have been proposed to meet the requirement for different applications. However, there are some narrowband communication systems that coexist with the UWB communication system, which severely interferes with the functioning of the UWB systems. The most notable among them is 5.15–5.825 GHz band assigned for IEEE802.11a, HIPERLAN/2 and 7.9–8.4 GHz band assigned for X-band systems. To avoid possible interference between the UWB system and the existing WLAN and X-band systems, it is required that additional filtering circuits which rejects WLAN and X-band frequencies may be incorporated. However, the use of the independent filter results in increase of complexity, size, cost and insertion loss of the UWB system. A simpler way by which we can solve the problem is by cutting slots on the patch or ground plane [2–10], putting parasitic elements close to the radiator [11–16], using a tuning stub [17], embedding quarter-wavelength tuning stub [18], embedding resonant cell in the microstrip feed line [19] and utilizing a small resonant patch [20].

In this work, a novel CPW fed Ultra Wideband monopole antenna with space filling fractal slots based on Hilbert curve geometry [21] is proposed to achieve band notch characteristics centred around 5.5 GHz and 8.1 GHz. Hilbert fractal geometry provides sufficient miniaturization of the notch structure without affecting the radiation characteristics. The rejection band covers the IEEE802.11a as well as HIPERLAN/2 and X-band frequencies. Rest of the paper is organized as follows. In Section 2, detailed design as well as parametric study is presented. This is followed by results and discussion and conclusion in Sections 3 and 4, respectively.

2. ANTENNA DESIGN AND PARAMETRIC STUDY

Hilbert curve fractal geometry was first proposed in the year 1891 as space filling curve [22, 23]. Hilbert curve geometry in antenna design has been configured to reduce the size of antenna as well as to get multiple resonances [24–26]. Recently, circular polarized antennas [27] and high impedance structures [28] have been implemented using Hilbert curve. It can be seen from Fig. 1 that the total length of the Hilbert curve increases when increasing the iteration stage, while keeping the overall space of the entire geometry fixed. This phenomenon mainly stems from electrical miniaturization of the geometry. Taking this property into account, Hilbert curve is used in this work for designing a miniaturized band notch element in the UWB antenna as slots. To gain some insight about the Hilbert curves,

the first few iterations of this fractal geometry is illustrated in Fig. 1.

The sum S of all the line segments is given by (1).

$$S = \left(2^{2n} - 1\right) d = (2^n + 1) L \tag{1}$$

$$d = \frac{L}{2^{n-1}} \tag{2}$$

Here L is the side dimension of the Hilbert-curve, d is the length of each line segment, and n indicates the order of iteration. In this article, the Hilbert-curve with the second order $(n = 2)$ is used as the band notch element. The proposed wideband antenna consists of an ice-cream cone shaped CPW fed monopole with Hilbert curve shaped slots in the main patch as well as ground planes as shown in Fig. 2.

The antenna is constructed on Taconic substrate with a thickness 0.795 mm and relative dielectric constant (ε_r) of 2.2 and a loss tangent of 0.002 having dimensions of $25 \times 45.75\,\text{mm}^2$ $(W \times L)$. The radiator patch consist of a triangular, rectangular and semi elliptical sections. Two symmetrical Hilbert shaped slots are etched on the ground plane to obtain the notched band from 7.9 to 8.4 GHz, and another is etched from the radiator to notch the band from 5.15 to 5.85 GHz. The antenna shape and its dimensions were optimized by numerical analysis using commercial software CST Microwave Studio$^{\text{TM}}$.

The total length S_1 of the second order Hilbert slot etched from the main patch and the other one S_2 which is etched on the ground plane nearby the feed line can be deduced using (3) and (4) respectively. Moreover, the width and location of the slots can also be adjusted to
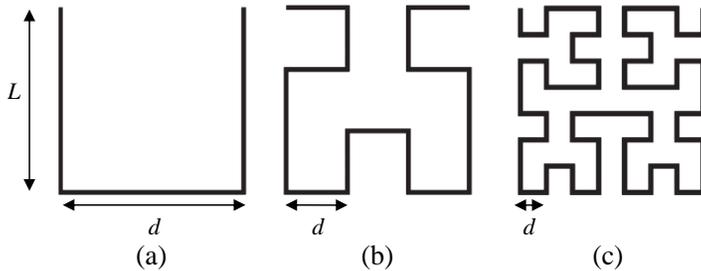

Figure 1. Hilbert-curves with increasing iteration order number n: (a) first order, (b) second order, and (c) third order.

fine tune the rejection bands.

$$S_1 = 15L_1 - 12T_1 \tag{3}$$

$$S_2 = 15L_2 - 12T_2 \tag{4}$$

$$S_1 \approx \frac{c}{2f_1\sqrt{\varepsilon_{eff}}} \tag{5}$$

$$S_1 \approx \frac{c}{2f_2\sqrt{\varepsilon_{eff}}} \tag{6}$$

The total length of the slots is found to be nearly equal to half of the guided wavelength at corresponding notch frequencies as depicted
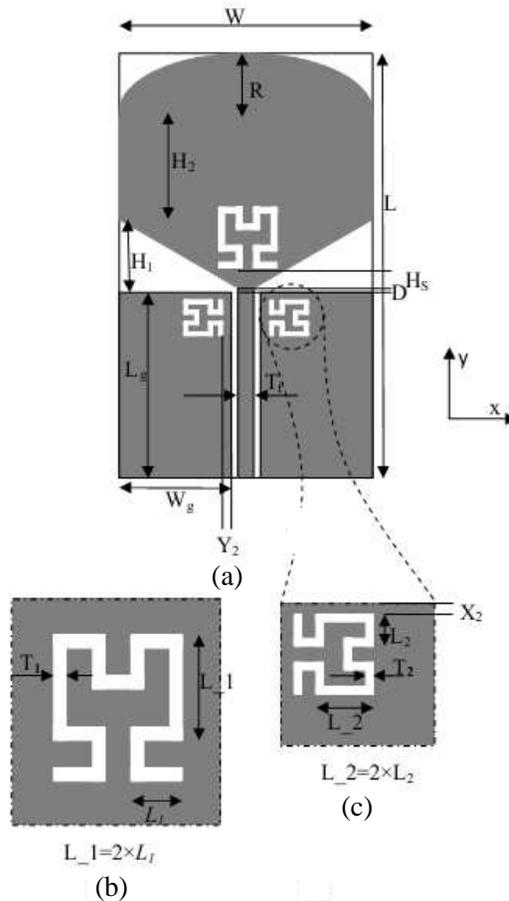

Figure 2. Geometry of proposed antenna. (b) Parameters of slot 1. (c) Parameters of slot 2.

in (5) and (6). Here f_1 stands for the centre frequency of WLAN systems that is 5.5 GHz and the X-band satellite communication systems centred around f_2 is 8.1 GHz. The Hilbert slot in the antenna consists of fifteen identical segments each of length L_1 and thickness T_1. The resonant frequency of the notch band depends on the length and width of the slot. Parametric studies on length and width of this slot is considered in Fig. 3 and Fig. 4 respectively. As the length of each segment L_1 is changed from 1.76 mm to 1.88 mm the resonant frequency of the corresponding notch band shifts to lower end frequency without affecting the second notch as shown in Fig. 3. An optimum segment length of 1.82 mm is chosen for which the desired notch frequency of 5.5 GHz is achieved.

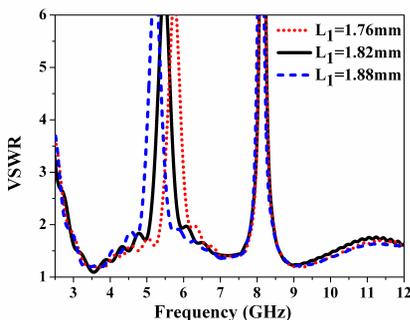As the slot width T_1 increases, the notched band is shifted towards
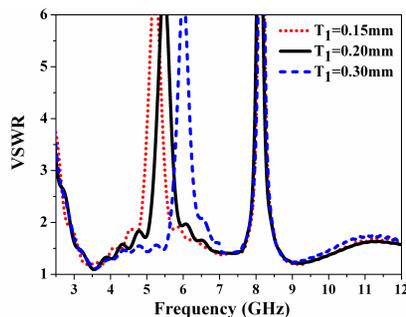

Figure 3. Simulated VSWR for different values of L_1.
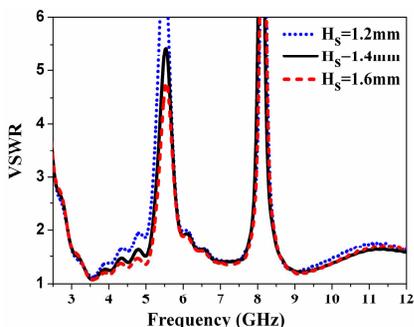

Figure 4. Simulated VSWR for different values of T_1.

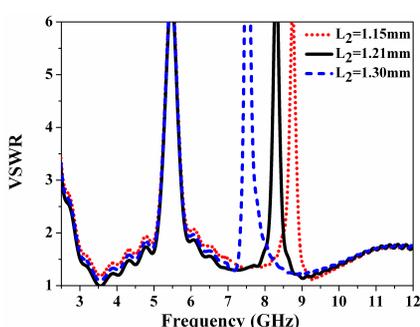**Figure 5.** Simulated VSWR for different values of H_S.

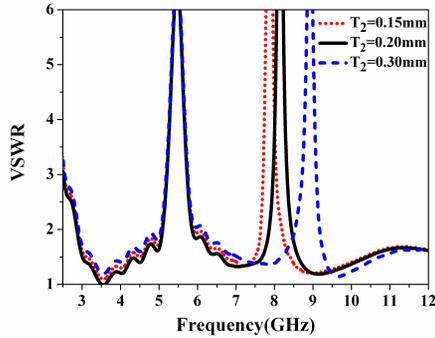**Figure 6.** Simulated VSWR for different values of L_2.

Figure 7. Simulated VSWR for different values of T_2.

higher frequency as shown in Fig. 4. Here, the slot width of 0.2 mm is selected as it suits the desired notch frequency.

The position of the slot on main patch is H_s, as depicted in Fig. 2, which is the distance between base of slot and point of connection of the feed line with antenna. Fig. 5 shows the variation in peak value of VSWR with changing H_S with other parameters remaining constant. It can be seen from the figure that higher the value of H_S the lower is the value of peak VSWR achieved. An optimum H_S is chosen to be 1.2 mm.

The effect of the parameters of the second slot, etched from either side of the ground plane is considered next. The length of each segment of this slot is L_2 and thickness is T_2. As the segment length is varied from 1.15 mm to 1.3 mm it is observed that the resonant frequency of band notch is shifted to lower frequency side without affecting the first one as demonstrated by Fig. 6. An optimum segment length of 1.21 mm is obtained for which the desired notch frequency of 8.1 GHz is achieved.

As the slot width T_2 increases, the notched band is shifted towards higher frequency as shown in Fig. 7. The slot width of 0.2 mm is found suitable for obtaining the desired notch around 8.1 GHz.

The gap between the radiation patch and the ground plane is D. An optimised value of gap D is found to be 0.25 mm. The CPW centre strip is of length 20.25 mm ($L_s = L_g + D$) and central strip width of CPW feed is 1.5 mm (T_f). Spacing between CPW plane and central conductor is 0.6 mm. This results in a 50 Ω CPW feed line. The final dimensions of the proposed antenna are tabulated in Table 1.

Table 1. Dimensions of the proposed UWB monopole antenna with multiple Hilbert curve fractal slots.

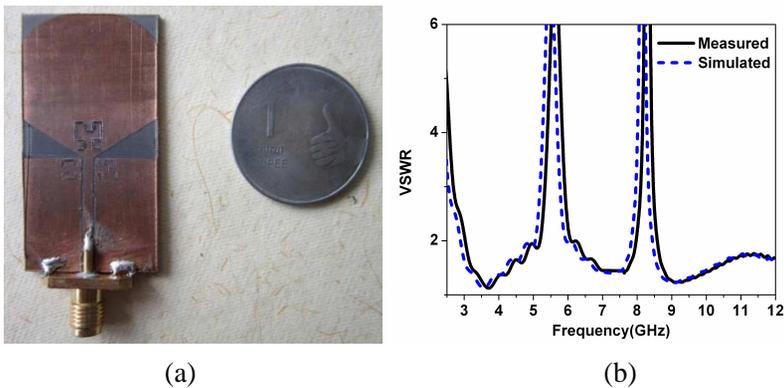| Antenna parameters	Value (mm)	Slot Parameters	Value (mm)
L	45.75	T_1	0.2
W	25.0	L_1	1.82
L_g	20.0	L_2	1.21
D	0.25	T_2	0.2
H_1	7.1	H_s	1.2
H_2	10.4	X_2	1.0
R	8.0	Y_2	1.0
T_f	1.5		
W_g	11.15		

(a) (b)

Figure 8. (a) Fabricated prototype of the proposed antenna. (b) Simulated and measured VSWR characteristics.

3. RESULTS AND DISCUSSION

All simulations in this work are carried out with CST Microwave Studio$^{\text{TM}}$. The fabricated prototype of the proposed antenna is shown in the Fig. 8(a). The overall antenna size is 25 mm by 45.75 mm. The corresponding electrical dimension of the proposed antenna is $0.57\lambda_0$ by $1.0\lambda_0$, where λ_0 is the free space wavelength corresponding to the centre frequency of the UWB band which is 6.85 GHz. The dimension of the antenna presented in this work is comparable in size to that
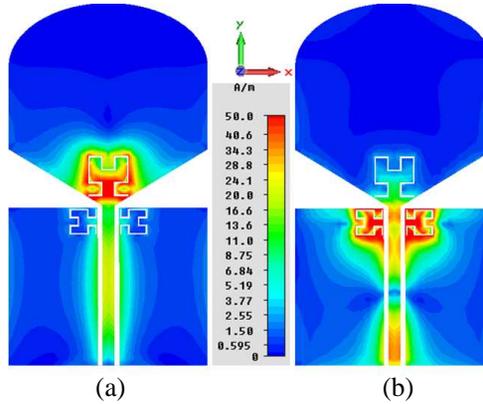
Figure 9. Current distribution on the antenna at (a) 5.5 GHz, (b) 8.1 GHz.

presented in [3, 7, 8, 14, 19]. It is observed that the size is more compact when compared to antennas reported in [2, 4, 5]. When compared to the UWB antenna reported in [10–12, 15, 16, 20], the present design is slightly larger. However the novelty of the design lies in achieving band notch characteristics by the use of Hilbert curve fractal slots that renders compact band notch elements. The simulated and measured resonance characteristics of the antenna are shown in Fig. 8(b). The measurement is performed using HP 8722C VNA. It is seen that the simulated and measured VSWR are in good agreement but slight disagreement is caused due to fabrication tolerance and connector losses. The characteristics reveal wideband behaviour with band width extending from 2.5–12 GHz for VSWR less than 2. The measured notch bands extend from 5.15 GHz to 5.85 GHz centred around 5.5 GHz and the other range from 7.8 GHz to 8.5 GHz with the band centred at 8.1 GHz. The effect of Hilbert fractal slots in generating the notch bands is illustrated in Fig. 9. It is observed that current is concentrated near the larger Hilbert slot in the patch at 5.5 GHz and near the smaller slots in the ground plane at 8.1 GHz.

For UWB applications, the antenna is usually required to have omnidirectional radiation pattern. The measured co-polar and cross-polar patterns of the proposed antenna at 3.1, 7 and 10.6 GHz are depicted in Fig. 10. At lower frequencies, the yz patterns are like a conventional monopole antenna. At higher frequencies, some ripples are observed in the pattern that is due to higher order modes. At upper frequency, a discrepancy is observed between simulated and measured cross-pol patterns. This is due to measurement set up. Results suggest that the proposed antenna show satisfactory omnidirectional radiation
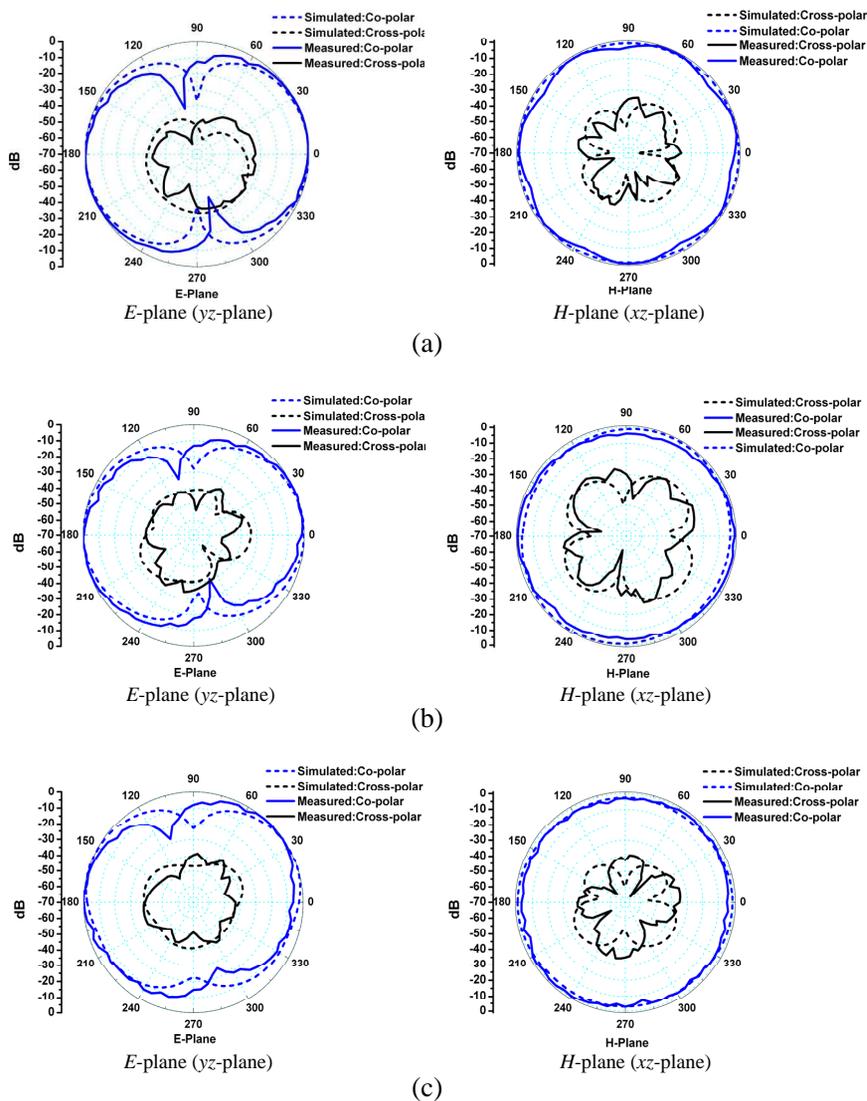
Figure 10. Co-pol and cross-pol patterns of the proposed antenna at (a) 3.1 GHz, (b) 7 GHz, (c) 10.6 GHz.

characteristics as co and cross polar levels have 25 dB to 30 dB isolation throughout its operating band.

Current distribution shows formation of standing waves of the notch frequencies. At higher frequencies the antenna behaves as a
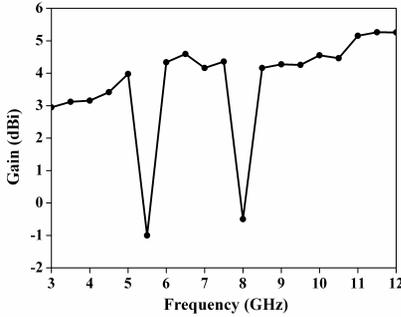
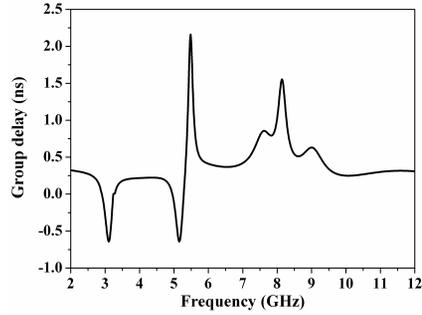**Figure 11.** Measured gain of the   **Figure 12.** Measured Group
band notch UWB antenna.   delay of the antenna.

travelling wave antenna. This can be observed from Figs. 10(a), (b) and (c) respectively.

The measured antenna gain from 3 to 12 GHz is shown in Fig. 11. The figure indicates that, the proposed antenna has almost flat gain except that in the notched band where the gain decreases sharply.

Wideband antenna system should be distortion free and to ensure this, temporal characterization is desirable. Fig. 12 shows the measured group delay of the antenna systems. The antenna shows a nearly flat response in 3 to 12 GHz band where the variation of group delay is less than 1 ns in the operating band except at the notch frequencies. This ensures satisfactory time domain characteristics and distortion free transmission.

To determine the 'correlation coefficient' between signals at the terminals of the receiving antenna denoted as $s_2(t)$ and the signal of the input antenna $s_1(t)$ the following relation as given in (7) is used

$$\rho = \max_\tau \left[\frac{\int s_1(t)s_2(t-\tau)}{\sqrt{s_1^2(t)dt}\sqrt{s_2^2(t)dt}} \right] \tag{7}$$

In (7), τ is the delay which is varied to make the numerator in the equation a maximum [29]. It determines the correlation between the electric field signals $s_1(t)$ and $s_2(t)$. The excited pulses are chosen as the reference signal $s_1(t)$, while the received pulse as signal $s_2(t)$. Indeed, it reflects the similarity between the source pulse and the received pulse. When the two signal waveforms are identical to each other, the fidelity reaches its peak, i.e., unity, which means the antenna system does not distort the input signal. The values of 'correlation coefficient' obtained for the entire band from 2.5–12 GHz which is 0.802.

4. CONCLUSION

The paper proposes and analyzes a novel dual band rejection ultra wideband monopole antenna where Hilbert fractal shaped slots on antenna and ground plane are adopted for producing interference suppression at WLAN and X-band. The impedance bandwidth ranges from 2.5 GHz to 12 GHz for S_{11} dB better than 10 dB. The notch bands extend from 5.15 GHz to 5.85 GHz and for 7.9 GHz to 8.4 GHz. The antenna gain varies from 3 dBi to 5 dBi over the band with dips at the rejection frequencies. The group delay excursion remains within 1 ns over the UWB region except at the rejection bands. The radiation characteristics are suitable for wireless communication considering wideband operations. This antenna is suitable for UWB short range communication system.

ACKNOWLEDGMENT

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