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A CIRCULAR SHAPED SIERPINSKI CARPET FRACTAL UWB MONOPOLE ANTENNA WITH BAND REJECTION CAPABILITY

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Abstract—A novel planar ultra wideband (UWB) antenna using a second iteration Sierpinski carpet fractal shape with circular boundary is presented in this paper. The antenna covers the frequency band from 3 GHz to 12 GHz (VSWR ≤ 2). The proposed antenna has a meander shaped slot that renders the capability to reject 5.15–5.825 GHz band assigned for IEEE802.11a and HIPERLAN/2. The gain is suppressed very well in the desired WLAN bands. The measured antenna peak gain varies from 1.85 dBi to 6 dBi within the band. The time domain characteristics show that the antenna is not dispersive. A fabricated prototype is developed with close agreement between simulated and measured resonance as well as radiation characteristics.

1. INTRODUCTION

In recent years, research in the area of ultra wideband system (UWB) has generated a lot of interest among microwave engineers. February 2002 witnessed the allocation of the frequency band between 3.1 GHz to 10.6 GHz as the UWB application band by the Federal Communication Commission (FCC), USA [1]. One of the major components in UWB system is the antenna, which is a challenging task to design due to a 110% impedance bandwidth. During the past few years, various types of UWB antennas have been proposed to

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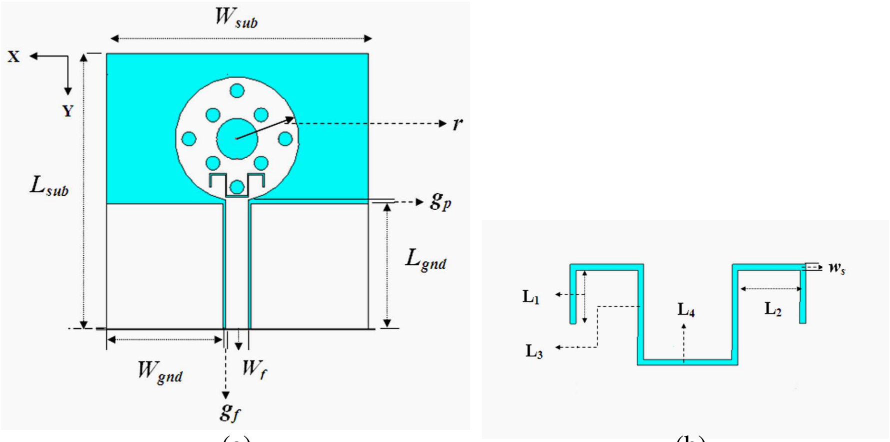
meet the requirement for different applications. The designs reported were mainly focused on achieving the frequency range as specified for UWB [2–4]. However, there are some narrowband communication systems that coexist with the UWB communication system, which severely interferes with the functioning of the UWB systems. The most notable among them is 5.15–5.825 GHz band assigned for IEEE802.11a and HIPERLAN/2. Band-stop filters connected to UWB antenna can be used to reject these bands. However, band-stop filter increases the circuit dimension. A simpler way by which we can solve the problem is by cutting slots on the patch or ground plane [5–9], putting parasitic elements close to the radiator [10–13], using a tuning stub [14], embedding quarter-wavelength tuning stub in a circular ring monopole [15], embedding resonant cell in the microstrip fed line [16] and utilizing a small resonant patch [17]. The designs of UWB antenna have been reported where sub wavelength structures as SRR [18] and electromagnetic band gap structures [19] are used to create notch bands. The CPW-fed circular disc fractal monopole, as reported in [20], has a simple structure and presents good performances in both the time and frequency domains.

In this work, a novel CPW fed planar Sierpinski carpet fractal shape with circular boundary as UWB antenna with band notch characteristics centered around 5.5 GHz is proposed. The sharp band notched characteristic is achieved by etching meandered slot from the fractal shaped radiating element. The meander geometry provides sufficient miniaturization and does not affect the radiation characteristics. The rejection band covers the IEEE802.11a as well as HIPERLAN/2 frequencies. Rest of the paper is 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

The proposed antenna is realized on FR4 substrate of $\varepsilon_r = 4.4$, $h = 1.59$ mm having loss tangent $\tan\delta = 0.002$. The initiator to realize circular boundary carpet fractal is a circular shaped antenna whose dimension is determined as $\lambda g/4$ of the lowest resonant frequency such that the UWB range is covered. The first iteration of this fractal antenna is constructed by etching out the center circle of radius 3 mm inside the patch and subtracting it from the patch. The next stage is achieved by subtracting additional eight circles of one third radius (1 mm) of the center circle that follows the same technique adopted to realize Sierpinski carpet geometry [21]. The second iteration fractal



(a) (b)

Figure 1. (a) Circular boundary Sierpinski carpet fractal shaped antenna of second iteration. (b) Dimension of the slot creating band rejection is illustrated.

antenna is considered for implementing the antenna shape.

The second iteration circular boundary Sierpinski carpet shaped monopole antenna is shown in Figure 1(a). The meandered slot as shown in Figure 1(b) that is embedded on the radiating element is close to half wavelength corresponding to center frequency of the notch band which is 5.5 GHz. The antenna is fed by a CPW. The CPW-feed is advantageous for less dispersion at higher frequency, broader matching, easy fabrication and integration with MIC/MMIC. The CPW-fed monopole antenna has the ease of installation, and the radiation pattern is near omnidirectional in the azimuthal plane. The proposed antenna is simulated, and parametric study is performed using CST Microwave Studio$^{\text{TM}}$.

The dimensions L_{sub} and W_{sub} denote the length and width of the substrate (40 mm $\times$ 38 mm), respectively. The 50 Ω impedance is achieved by adjusting the width W_f as 3.2 mm, and the gap between the ground plane and feed which is $g_f = 0.4$ mm. The length of the ground plane L_{gnd} and the width of the ground plane W_{gnd} are important design parameters. The length of the ground plane in turn governs the spacing between patch and ground plane gap (g_p). The fine tuning parameter in antenna geometry is the gap (g_p) between the antenna and ground plane. The gap between the radiation patch and ground plane has an important effect on the impedance matching of the proposed antenna, as shown in Figure 2. When the gap is increased

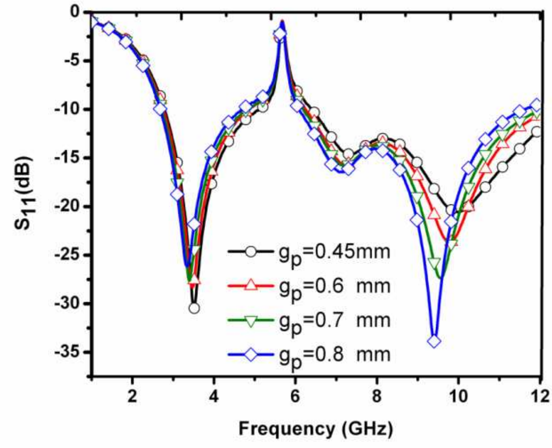


Figure 2. Effect of gap between patch and ground on resonance characteristics.

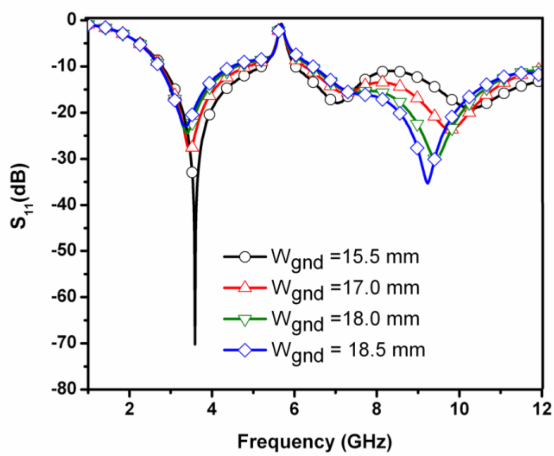


Figure 3. Effect of ground plane width on antenna resonance characteristics.

from 0.45 to 0.8 mm, in other words the length of the ground plane decreases, there is a shift in the higher band resonance with the rest remaining unaltered. It thus ensures matching at the higher band of the UWB frequencies. An optimized value of gap g_p is found to be 0.6 mm which is proper for impedance matching between feed and the antenna.

The width of the ground plane denoted by W_{gnd} has effect on matching characteristics over the band and hence influences the antenna gain. The current distribution on the ground plane affects antenna characteristics. The monopole antenna as well as the ground plane forms an equivalent dipole antenna. Figure 3 shows the effects of varying the ground plane width on the simulated return loss. In Figure 3, as the width of the ground plane increases, the matching over the band improves, indicating higher antenna gain. A compromise between antenna size and gain is achieved if a ground plane width of 17 mm is considered.

The antenna has a meandered slot of width w_s, and the slot is divided into four sections where the sections are denoted by lengths L_1, L_2, L_3 and L_4 from which the total length l_s is calculated. Parametric study on the length and width of the meandered slot is considered next. The resonant frequency of the notched-band depends on the length of the slot. As the length of slot increases from 17.2 mm to 19.6 mm, the resonant frequency of band-notched shifts to lower frequency side as shown in Figure 4. An optimum slot length of 18.4 mm is obtained for which the desired notch frequency of 5.5 GHz is achieved.

As the slot width increases, the notched band is shifted towards higher frequency as shown in Figure 5. The slot width of 0.2 mm suits the resonant need. It is observed from the parametric study that the resonant frequency of the notched-band depends on the length of the slot, and notched bandwidth depends upon width of the slot.

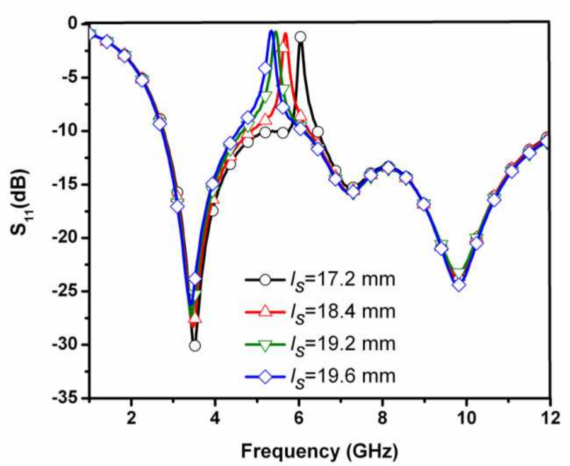


Figure 4. Effect of length of the slot on antenna resonance characteristics.

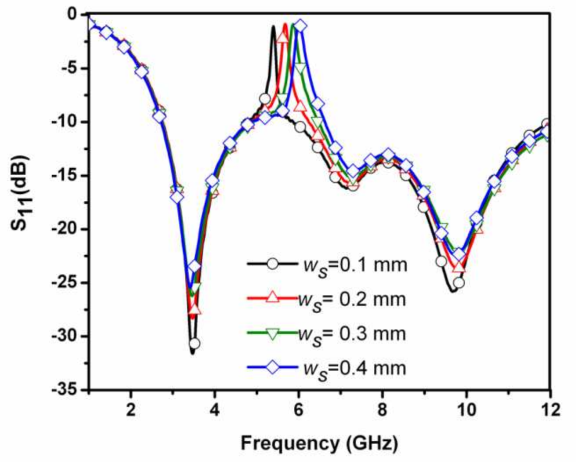


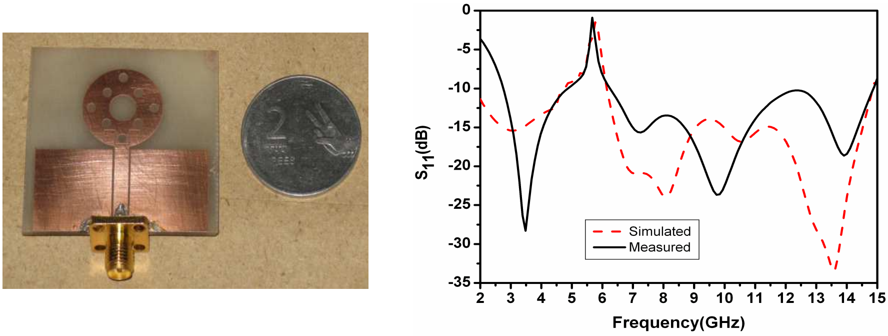
Figure 5. Influence of width of the slot on antenna resonance characteristics.

Table 1. Circular boundary shaped Carpet fractal UWB antenna design parameters.

Antenna Parameter	**Value (mm)**
W_{sub}	38
L_{sub}	40
L_{gnd}	18.14
W_{gnd}	17
r	9
g_f	0.4
W_f	3.2
g_p	0.6
Notch Parameter	**Value (mm)**
L_1	2
L_2	3.5
L_3	3.2
L_4	3
l_s	18.4
W_s	0.2

3. RESULTS AND DISCUSSION

From the parametric study, as discussed in Section 2, the final dimensions of the antenna and the notch are tabulated in Table 1. The fabricated prototype of the proposed antenna is shown in Figure 6(a). The simulated and measured resonance characteristics of the antenna are shown in Figure 6(b). The S_{11} (dB) of the antenna is measured using HP 8722C VNA. It is seen that the simulated and measured results are in close agreement. However, there is some discrepancy due to fabrication tolerance and the effect of the connectors. The resonance characteristics reveal UWB behavior with bandwidth extending from 2.7 GHz to 12 GHz for S_{11} better than 10 dB. It is also clear from Figure 6 that the undesired sub band from 5.15 to 5.825 GHz is



(a) (b)

Figure 6. (a) Fabricated prototype of the antenna. (b) Simulated and measured S_{11} characteristics of the proposed antenna.

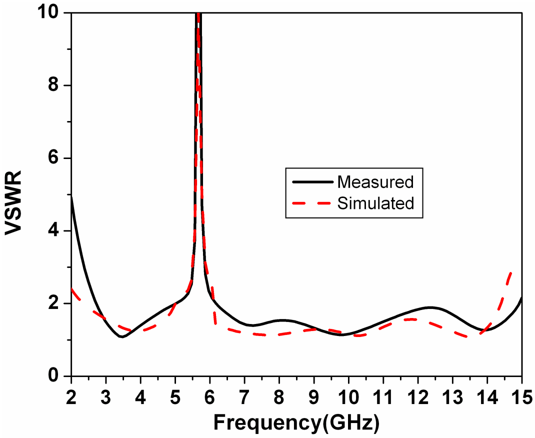


Figure 7. Simulated and measured VSWR characteristics of the proposed antenna.

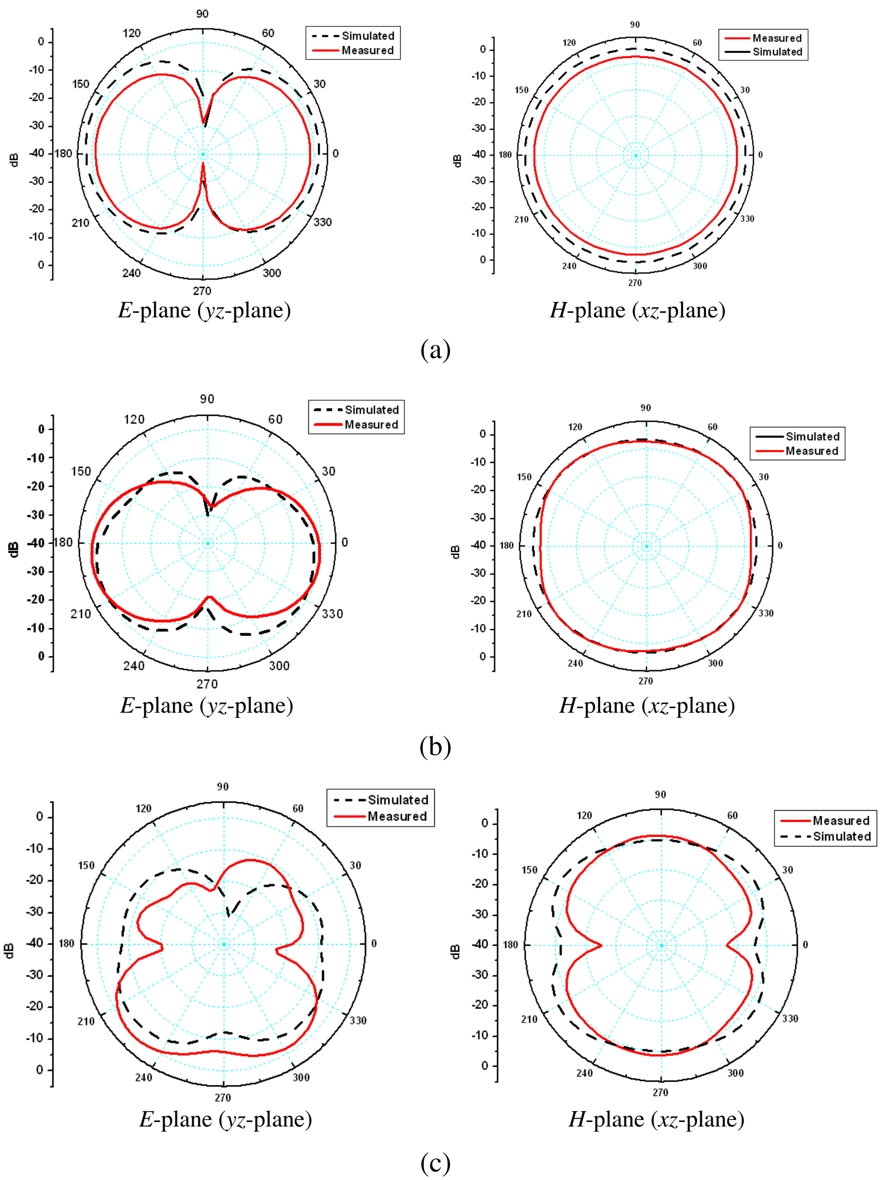


Figure 8. Measured (solid) and simulated (dotted) principal plane patterns of the CPW fed circular fractal monopole at (a) 3.1 GHz, (b) 6.85 GHz, and (c) 10 GHz.

rejected, while the wideband behavior of the antenna is maintained. Figure 7 shows the measured as well as simulated VSWR of the proposed fractal band notch antenna. It shows that the antenna provides a sharp band notch of 5–6 GHz (VSWR > 2), so the antenna inhibits interference with the existing WLAN frequencies.

From the UWB applications point of view, the antenna is usually required to have an omnidirectional radiation pattern. For the proposed antenna, this requirement is fulfilled over the whole bandwidth as shown in Figure 8. The radiation patterns of the antenna at three frequencies have been measured. The measured and simulated radiation patterns at 3.1 GHz, 6.85 GHz, and 10 GHz are

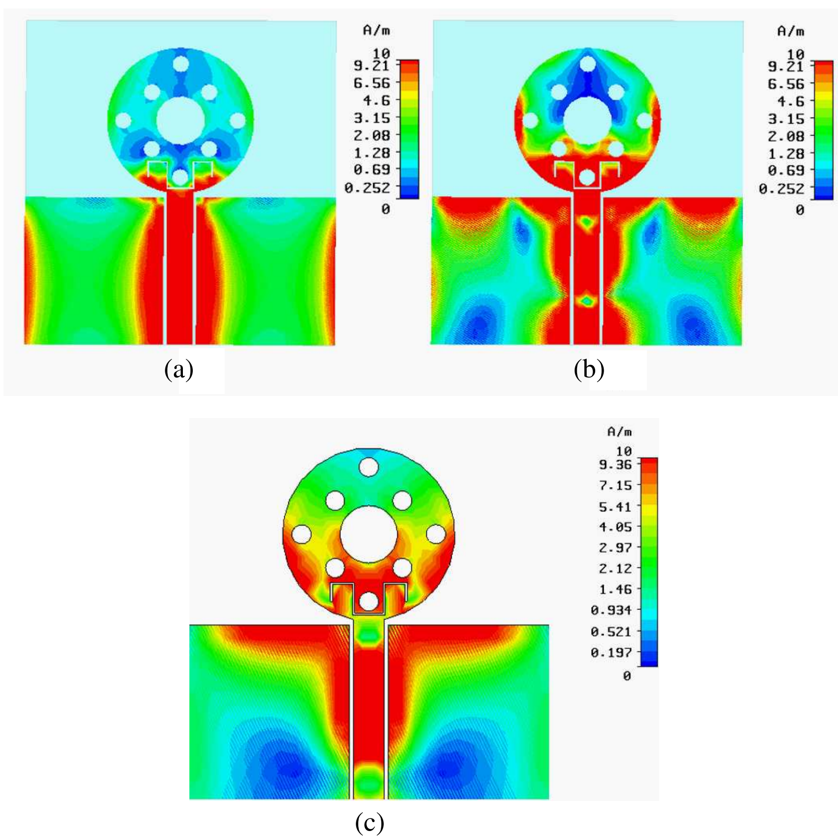


Figure 9. (a) Current distribution at 3.1 GHz. (b) Current distribution at 10 GHz. (c) Current distribution over slot at notched frequency 5.5 GHz.

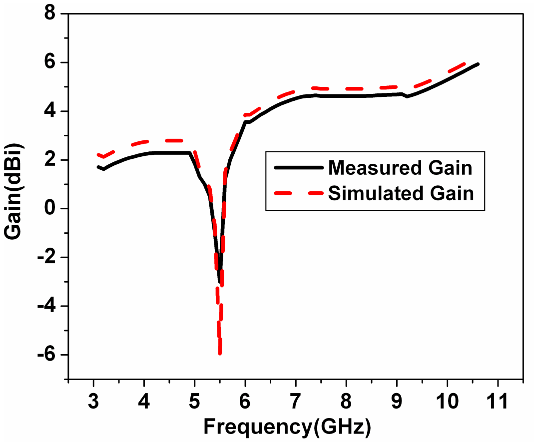


Figure 10. Simulated and measured peak gains plotted over the band.

plotted respectively in Figure 8.

The current distribution at three frequencies, namely 3.1 GHz, 10 GHz and 5.5 GHz, are shown in Figures 9(a), 9(b) and 9(c), respectively. It is shown that the antenna mainly behaves as a radiating slot formed between the antenna base and ground plane. The current distribution at 5.5 GHz is displayed in Figure 9(c) that shows the concentration of the current near slot resulting in a standing wave and thereby a rejection. The simulated and measured peak antenna gains of the proposed antenna are shown in Figure 10. It is observed that the measured gain varies from 1.85 dBi to 6 dBi within the band. At the notch region, there is a sharp fall in gain to about -3 dBi.

UWB antenna system should be distortion free, and to ensure this, temporal characterization is desirable. Figure 11 shows the measured group delay of the antenna systems. The antenna shows a nearly flat response in 3.1 to 10.6 GHz UWB band, and the variation of group delay is less than 1 ns except in the notched band, where the group delay makes large excursion. This ensures satisfactory time domain characteristics and distortion free transmission.

To determine the 'correlation coefficient' between signals at the terminals of the receiving antenna $s_2(t)$ and the input signal $s_1(t)$, the following relation in Equation (1) is used:

$$\rho = \max_{\tau}\left[\frac{\int s_1(t)s_2(t-\tau)}{\sqrt{s_1^2(t)dt}\sqrt{s_2^2(t)dt}}\right] \tag{1}$$

In (1), τ is the delay which is varied to make the numerator in the equation maximum [22]. It determines the correlation between

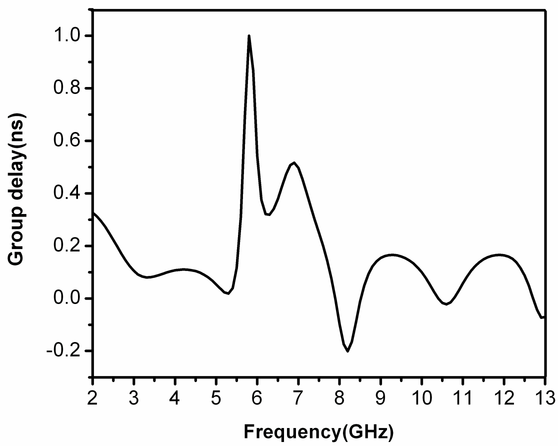


Figure 11. Measured group delay profile of the proposed UWB band notch antenna.

the electric field signals $s_1(t)$ and $s_2(t)$. The proposed antennas are assumed to be excited by the UWB signal to examine the time domain response of the proposed antennas. The input signal is a fifth derivative Gaussian pulse and its fifth derivative. 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, the fidelity reaches its peak, i.e., unity, which means that the antenna system does not distort the input signal at all. However, the distortion of the transmitted signal is expected due to the existence of the notch in the frequency response of the antenna. The fidelity factor of the band notched circular boundary carpet shaped fractal with meandered slot is slightly lower than the planar fractal antenna, and the rate of distortion is less. The correlation coefficient found from the slotted fractal antenna is 0.8342 and from the unslotted fractal shaped antenna is 0.8933.

4. CONCLUSION

In this work, a CPW-fed circular boundary Sierpinski carpet fractal shaped antenna with meandered shape slot to include a rejection band is proposed for UWB application. By etching a meandered shape slot, the interference to 5.15–5.825 GHz band assigned for IEEE802.11a and HIPERLAN/2 is reduced. Stable radiation patterns over the

UWB band are obtained. The measured antenna peak gain varies from 1.85 dBi to 6 dBi within the band. The group delay variation is within 1 ns. The simulated and measured resonance and radiation characteristics are in good agreement.

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