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Wideband High Gain Fractal Antenna for Wireless Applications

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Abstract—The paper focuses on design and analysis of hexagon inspired fractal geometry and defected ground plane to evaluate the performance of patch antenna for wireless applications. It also emphasizes increasing the antenna bandwidth by incorporating novel rectangular Defected Ground Surface (DGS) structure with CPW feed. In the proposed work, antenna is simulated and fabricated for wireless applications using FR4 as the substrate, and it covers wide band with high gain. The antenna resonates at frequencies of 3.79 GHz and 5.5 GHz with measured return losses of −25.02 dB and −26.03 dB, respectively, making the proposed antenna suitable for Wi-Fi, cordless phone, wireless devices and wireless sensor networks applications.

1. INTRODUCTION

Antennas are most important part of any communication systems. In modern wireless communication, it is required to have small size, high gain, high directivity, wide/multi-band and low cost antennas. This research focuses on the design of ultra-wide and multi-band antennas with high values of gain. A wide-band antenna has its own advantages such as low transmission power, high data rate, high performance in multipath channel, and resistance to jamming which can be satisfied using fractal antenna geometry [1]. Antenna is a transducer employed to transmit or receive electromagnetic waves and is a transitional structure used between free space and energy guiding device. Modern technology has put special importance on small size and reliability, internetworking across the globe making technology to be more intelligent and sophisticated to provide all time communication which should be cost effective, noise free and robust. Compact microstrip patch antennas are increasing in popularity for use in communication systems due to their miniaturized size and cost effectiveness [2–4]. They offer good compatibility for embedded antennas in hand-held devices. The basic form of a patch antenna consists of a conducting patch printed on a ground plane which radiates only at the desired frequency band. Microstrip patch antennas have some disadvantages such as inherently narrow impedance bandwidth, low gain and poor radiation efficiency [5]. Some design techniques have been developed to overcome the disadvantages and design antennas with different properties that can fulfill the requirements in different applications. Wideband technology has attracted much attention recently because the communication systems promise high bandwidth, reduced fading from multipath propagation and low power requirements. Fractals were first introduced by Mandelbrot in 1977 as a way of ordering structures whose sizes were not whole numbers. Fractal has unique geometrical features in nature [6]. To overcome the disadvantage of microstrip patch antenna and for multiband applications, fractal antenna geometry is useful [7, 8]. Main advantage of fractal is compact size, multiband, and high gain [9, 10]. It can be used in the form of branching of tree leaves, plants, rough terrain, jaggedness of coastline, and many more examples in nature [11, 12]. Fractals have been applied in various fields such as image compression, study of high altitude lightning phenomena, and

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studies are carried out to create new types of antennas [13–15]. Fractals are geometric forms that can be found in natural surroundings. The use of fractal geometries has significantly impacted many areas of science and engineering [16, 17]. Antennas using some of these geometries for various telecommunications applications are already available commercially [18, 19]. The use of fractal geometries helps in improving several antenna features. Many DGS (Defected Ground Structure) structures have been proposed for improving parameters of antennas by incorporating DGS in the form of slots with dumbbell-shape, I-shape, U-shape and elliptic shape [20, 21]. Tuning of DGS structure is most important part of antenna design for achieving wideband applications. Here CPW feeding is used which is impedance matched at 50 Ω to achieve wide bandwidth. The proposed fractal antenna which is inspired from [22] with addition of defected ground plane structure is simulated and fabricated for achieving multiband characteristics with wide bandwidth and high gain for various wireless applications.

2. ANTENNA DESIGN

The hexagon shape fractal antenna is shown in Figure 1(a). The antenna is etched on an FR-4 substrate having relative permittivity of 4.4, loss tangent ($\tan\delta$) of 0.02 and thickness of 1.6 mm. The overall dimension of substrate is $45 \times 40 \times 1.6\,\text{mm}^3$. Here hexagonal shape is used on the top side with DGS at the bottom of the antenna to achieve multiband characteristics with high gain. Addition of small fractals near the edges of central hexagon leads to increase in the total electrical length of patch. It also leads to improved return loss while shifting the bandwidth at lower side. For bandwidth enhancement slotted rectangular DGS is introduced on the ground plane as shown in Figure 1(b). Fabricated prototype of the proposed antenna is illustrated in Figure 1(c). Design parameters of antenna are shown in Table 1. DGS structure helps in improving bandwidth of the antenna. Return losses of simulated and measured antennas are shown in Figure 2. Tuning of ground plane is useful to improve the bandwidth of antenna, which helps to achieve bandwidth up to 135.47% (1.31 GHz–6.81 GHz) covering two resonance frequencies at 3.79 GHz and 5.5 GHz.

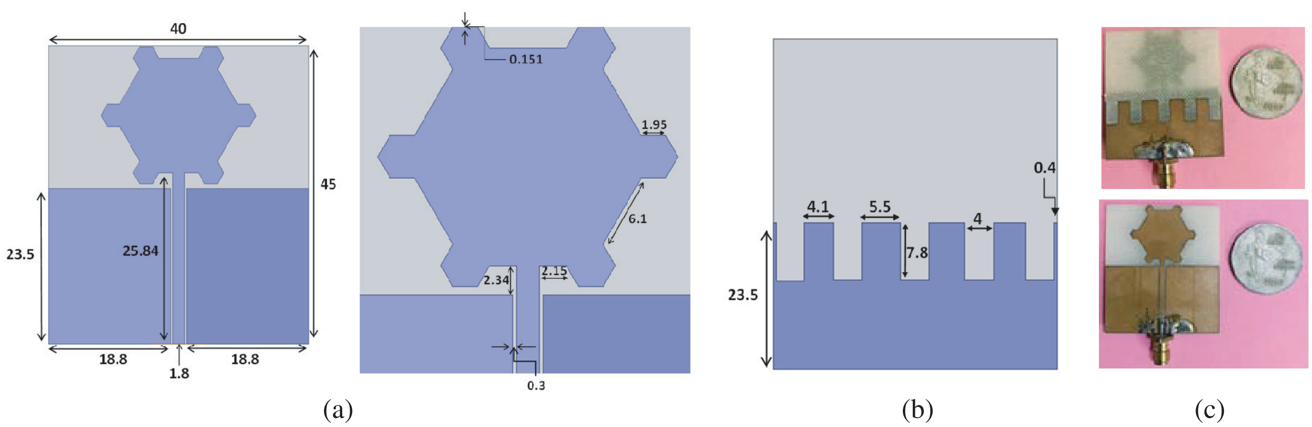


Figure 1. Proposed antenna geometry. (a) Front view. (b) Back view. (c) Fabricated antenna.

Table 1. Optimized parameters of the proposed antenna.

Dielectric constant (FR 4)	Thickness of substrate	Substrate Width	Substrate Length	Width of Feed line	Length of Feed line	Fractal Edge Length	Length of Ground	Gap between GND and CPW feed
4.4	1.6 mm	40 mm	45 mm	1.8	25.84 mm	1.95 mm	23.5 mm	0.3 mm

The gap between patch and coplanar ground plane also plays an important role for wideband. As the gap between coplanar ground and patch increases, the bandwidth of antenna is reduced, mainly due to the increased coupling capacitance which leads to narrowing of the impedance bandwidth. For

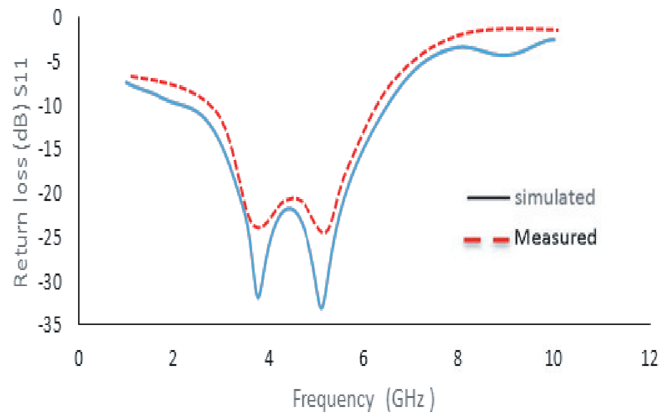


Figure 2. Simulated and measured return loss (dB).

the best value of impedance matching, the gap size of 0.3 mm is selected. Tuning of DGS is the most important part for wideband application which is shown in parametric studies. As the ground plane becomes more defected through implementation of slots, the bandwidth of the antenna increases significantly. Implementation of DGS contributes to back radiation which is the disadvantage of DGS. A novel rectangle DGS structure is proposed for achieving wide-band operation.

3. RESULTS AND DISCUSSIONS

The simulated and measured plots of return loss are shown in Figure 2. The return loss of -10 dB and gain above 3 dB are adequate to radiate from particular antenna. It is desired that maximum amount of power should be transferred to patch through feed line. As shown in Figure 2, the proposed antenna covers wide impedance bandwidth of 135% (1.31 GHz–6.81 GHz) with good return loss at both resonance frequencies. The measured value of return loss matches well with the simulated design. The antenna resonates at frequencies of 3.79 GHZ and 5.5 GHz having simulated return losses of 32.25 dB and 33.10 dB, respectively. The modifications in CPW width dimensions significantly affect the impedance matching and consequently the impedance bandwidth as illustrated in Figure 3(a). The variations in gap between CPW and microstrip feed-line creates major shift in antenna impedance matching. It creates major shift in antenna resonance mode as seen in Figure 3(b). Effect of variation in ground plane creates multiple resonances of nearby frequencies, hence antenna bandwidth significantly varies. By incorporating slots in Defected Ground Plane structure of antenna, it is observed that bandwidth is

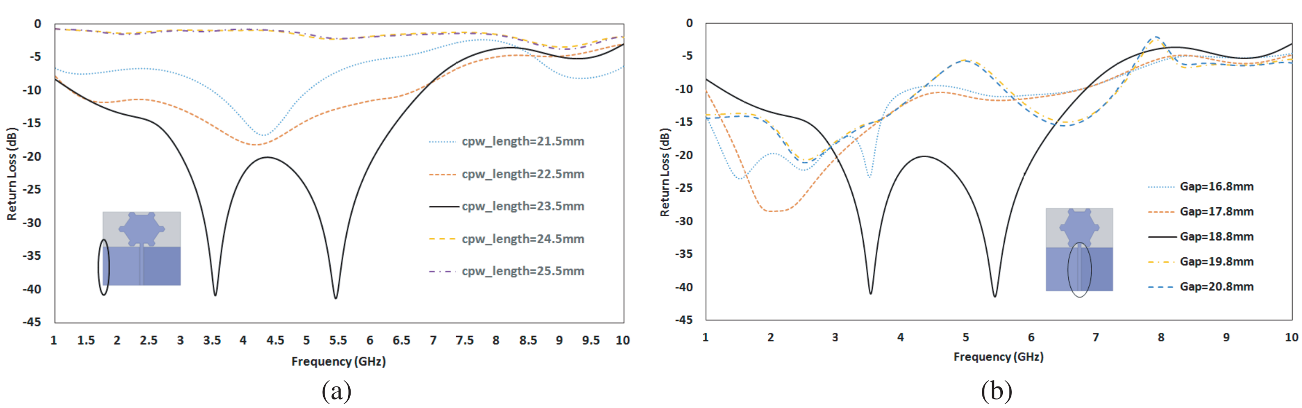
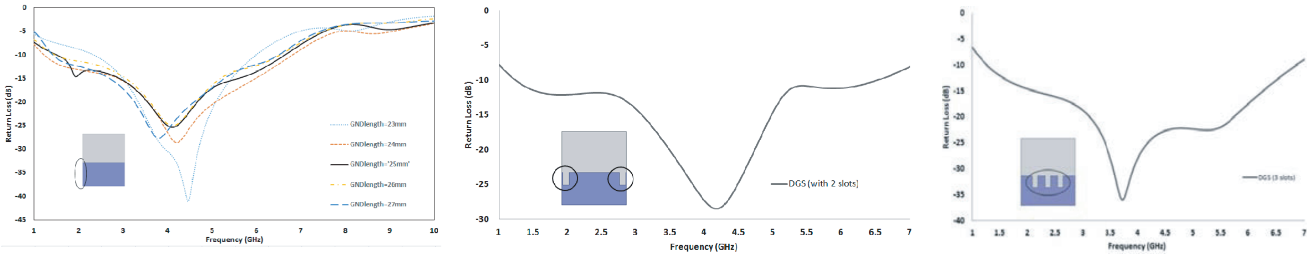
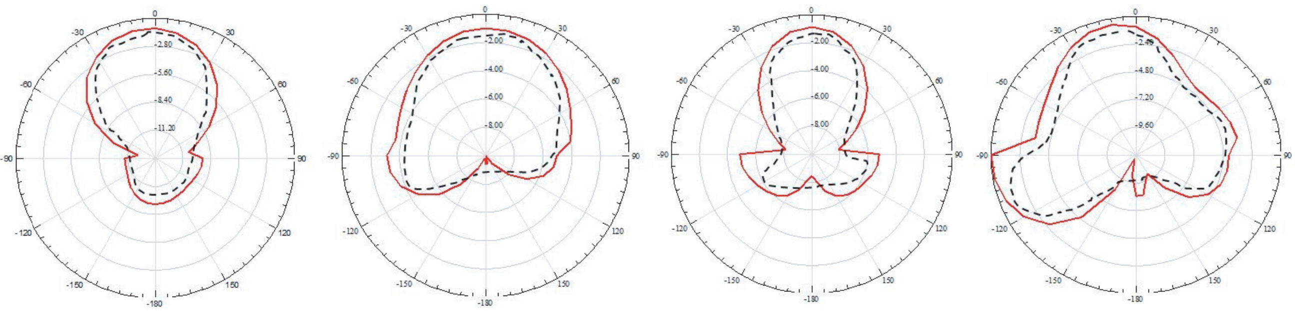


Figure 3. Effect of variation of CPW feed on return loss. (a) CPW feed length. (b) Gap between CPW and feedline.



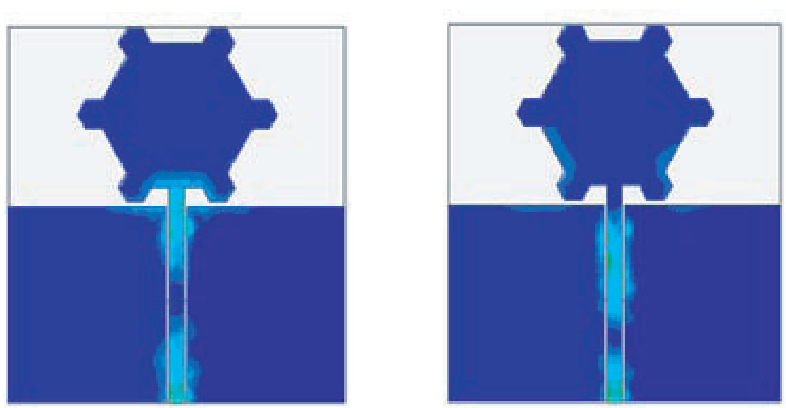
(a) (b) (c)

Figure 4. Effect of variation in ground plane on impedance bandwidth. (a) Length. (b) 2 slots. (c) 3 slots.



E Plane *H* Plane *E* Plane *H* Plane
(a) (b)

Figure 5. Simulated (solid) and measured (dashed) radiation pattern (*E* plane and *H* plane). (a) 3.79 GHz. (b) 5.5 GHz.



(a) (b)

Figure 6. Current distribution pattern (*E* plane and *H* plane). (a) 3.54 GHz. (b) 5.54 GHz.

enhanced significantly as illustrated in Figure 4. Figures 5(a) and (b) show the simulated and measured radiation patterns of antenna at 3.79 GHz and 5.5 GHz. *E*-*H* plane radiation pattern show gains of 6.2 dBi and 6.8 dBi, respectively at lower and higher frequency bands with bidirectional patterns.

As shown in Figure 6(a), surface current is uniformly distributed at middle of antenna at lower frequency, so patch is well matched and radiates at this frequency. As shown in Figure 6(b), at higher frequency 5.5 GHz current is concentrated on the lower edge of radiator which means that the antenna affects impedance characteristics at higher frequencies. We measure return loss using Keysight VNA N9912A. Comparison of measured and simulated return loss results is shown in Figure 2 which indicates that measured and simulated results are similar with slight variation which is mainly due to fabrication and connector losses. Another reason for variation is due to SMA connector loss, soldering effect at the feed and non-consideration of the actual SMA connector dimension during simulation. This proposed antenna design is suitable for WPAN's, Cordless telephone, WLAN, Wi-MAX, Wireless sensor networks and Unmanned Air Vehicle applications.

The comparisons of presented design in this paper inspired by [22], along with two closely relevant antennas presented in [13] and [1] are tabulated in Table 2. It is observed that our proposed antenna has enhanced bandwidth compared to other antennas presented in literature, while antenna gain is at par with other presented designs.

Table 2. Parameters comparison of the antennas.

Antenna Design	Dimensions (mm)	Bandwidth (%)	Gain (dBi)
Proposed antenna	$45 \times 40 \times 1.6$	1.31–6.81 GHz (135 %)	6.8
[22]	$25 \times 25 \times 1$	3–10.85 GHz (113.35 %)	3.4
[13]	$50 \times 40 \times 1.6$	2.7–9.3 GHz (110 %)	8.2
[1]	$31 \times 28 \times 1.6$	3–12.8 GHz (122 %)	6.2

4. CONCLUSION

The design of a compact CPW-fed hexagonal patch with a small hexagonal fractal element and rectangular DGS structure on bottom ground plane has been studied for designing a wideband antenna with high gain. The fabricated antenna dimension is $45 \times 40 \times 1.6\,\text{mm}^3$ which is suitable for integration with electric circuits. Simulated and measured results show good agreement. The antenna covers wide band of 135% (1.31 GHz–6.81 GHz) with two resonance frequencies at 3.79 GHZ and 5.5 GHz, respectively, with acceptable VSWR. The antenna has a high gain of above 6.5 dBi for proposed applications making it suitable for various wireless applications including WPAN, cordless telephone, WLAN, Wi-MAX, and unmanned air vehicle applications.

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