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A CPW-Fed Hexagonal Antenna With Fractal Elements For UWB Applications

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Abstract: We propose a coplanar waveguide-fed hexagonal antenna design for ultra wideband applications. The size of the antenna is miniaturized to $25 \times 25 \times 1.588$ mm^3 and the impedance bandwidth is improved by adding fractal elements at the edges. Parametric analysis of the fractal elements and the impedance behavior is performed to realize the radiation characteristics and bandwidth coverage as required for microwave imaging. The addition of fractal elements introduces multi-resonance at different frequency and covers a large bandwidth of 1.7 GHz–11 GHz respectively. The effect of surface currents in the ground plane reduces the antennas operating bandwidth which is reduced by introducing defective ground structure. The proposed antenna has an average gain of 2.35dB, radiation efficiency of 93% to 96%.

Keywords: CPW-fed, hexagon patch antenna, fractal UWB antenna, impedance matching, defective ground structure.

1 Introduction

In recent times, ultra-wideband (UWB) antennas and its technology is one of the fastest emerging technology in the field of wireless communication, medical diagnosis and military applications. The UWB antennas have to be operating only from 3.1 GHz to 10.6 GHz as per the Federal Communication Commission (FCC) regulations. The transmitter and receiver antennas for such systems should be compact and light in weight for portability. The requirements such as compact size, gain stability, low distortion and delays over the frequency band must be considered. These applications are mainly categorized into the categories such as sensors, location tracking, and radar technology. A small microstrip patch slots antenna has a limited bandwidth [1]. The implementation of various slots in addition to main slot increases the bandwidth of the antenna [2].

The radiation characteristic of the antenna is one of the important parameter in required applications. The improvement in bandwidth is accomplished by lowering the radiation Q of the antenna. The method of minimizing the radiation Q of the antenna is achieved by adding resistance in the conductor element of the antenna. This minimizes the radiation efficiency of the antenna since the resistive loading is seldom used. The antennas required at various applications must be in small size, omnidirectional and directional radiation characteristics; constant gain is fulfilled by several structures [3].

A hexagonal tree-shaped fractal antenna is designed with much iteration to operate at UWB frequency range [4], where it is accomplished by increasing the length of the hexagon structure. A circular-shaped fractal antenna with multiple iterative orthogonal elliptical slots, CPW-fed line and tapered ground plane are introduced to enhance the bandwidth and omnidirectional radiation pattern is achieved [5]. A CPW–fed fractal antenna with an insertion of trapezoidal fractal structures and hexagonal slots makes the antenna to resonate at multiple frequencies over the UWB of 3.1 to 10.6 GHz. Several researches are made in the UWB antenna for bandwidth improvement by etching slots and the antenna radiates in omnidirectional pattern [6].

Several CPW-fed monopole antennas are developed and the bandwidth is improvement by introducing multiple slots and different fractal structures [7, 8]. A CPW–fed monopole antenna is investigated to achieve multi resonance technique at UWB frequency range [9]. A study of calculating the resonance frequency of the hexagonal microstrip patches equating to the area of the circular monopole antenna [10].

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A hexagonal patch antenna with two iterative steps of new fractal-shaped slot is added to increase the bandwidth of the antenna for UWB applications [11]. A comparative study of microstrip line fed and CPW-fed patch antennas is done for UWB applications. It is observed that the CPW-fed patch gives a better bandwidth improvement than the microstrip line fed patch antenna. The presence of patch and the feed line on the same side eliminates the alignment problem in the patch radiator and gives a better return loss characteristic with an increase in bandwidth [12].

To achieve the entire UWB frequency range with additional resonance Koch fractal geometry is introduced which results in a stable omnidirectional radiation pattern [13, 14]. A microstrip patch antennas were analyzed under the categories of multi-resonance antennas, multi-resonance combined with broadband techniques and patches with high directivity using fractal structures are reviewed [15]. An infinite ground plane antenna never gives a broad bandwidth of operation; a finite ground plane is preferred to cover larger bandwidth [16].

2 Antenna Geometry

The evolution of proposed hexagonal antenna with fractal elements is shown in Fig. 1. The size of the antenna is $25 \times 25 \times 1.588$ mm^3 and is etched on an FR4 substrate of dielectric constant 4.4. Initially a hexagon structure is developed with a side length of 8 mm. the hexagonal patch resonates at two-frequency ranges at 2 GHz to 3.7 GHz and 5 GHz to 10 GHz with a reflection coefficient of-30 dB and-19 dB respectively. The proposed antenna is based on the multi-resonance behavior of fractal antenna [6]. The fractional bandwidth of the hexagon patch antenna is greater than 500 MHz and it satisfy the FCC standard of ultra wide band (UWB) antenna.

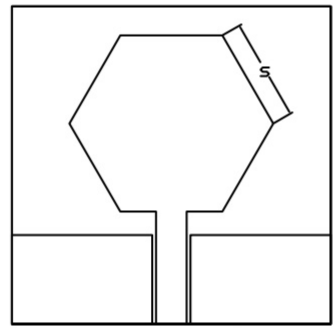
The dimension of the hexagonal patch is calculated using the following mathematical equations of a circular monopole antenna since these two antennas are related to each other. The resonant frequency of the circular monopole antenna is given by [17, 18]

$$f_r = \frac{X_{nm} c}{2\pi a_e \sqrt{\varepsilon_r}} \quad (1)$$

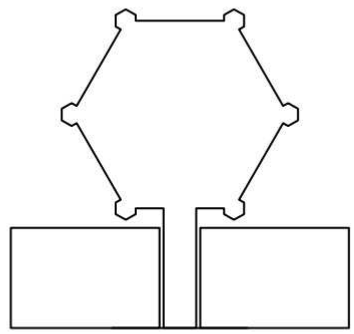
where f_r is the resonant frequency of the antenna, X_{nm} is the mth root of the derivative of the Bessel function of order n. In that m represents the radial mode and n represents the angular mode. The values of the X_{nm} are given in Table 1 and a_e is the effective radius of the circular patch and is calculated from

$$a_e = a\left\{1 - \frac{2h}{\pi a \varepsilon_r}\left(\ln\frac{\pi a}{2h} + 1.7726\right)\right\}^{1/2} \quad (2)$$

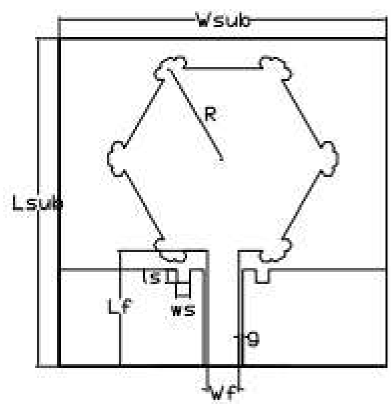
where h is the height of the dielectric substrate and a is the actual radius of the circular patch antenna.



(a) Hexagonal monopole antenna



(b) Hexagonal antenna with addition of first-order iteration hexagon fractal elements



(c) The proposed UWB hexagonal antenna with addition of second-order iteration hexagon fractal and DGS in ground plane.

Fig. 1: Structure of the proposed UWB hexagonal monopole antenna

The hexagonal monopole antenna is designed by using Eqs. (1) and (2) by relating the areas of the circular patch with the hexagonal patch structure, is given in Eq. (3)

$$\pi a_e^2 = \frac{3\sqrt{3}}{2} s^2 \quad (3)$$

Table 1: Values of X_{nm}

Modes	X_{nm}
TM_{11}	1.841
TM_{21}	3.054
TM_{31}	4.201
TM_{41}	5.317
TM_{51}	6.415

Table 2: Antenna design parameters

Antenna Parameters	Specifications
FR4 substrate Dielectric constant	4.4
Thickness of the substrate h	1.588 mm
Frequency range	1.7 GHz to 11 GHz
Radius of the main hexagon R	8 mm
Feed length L_f	8.85 mm
Feed width W_f	2.4 mm
First iterative fractal radius	1 mm
Second iterative fractal radius	0.5 mm
Ground plane length L_g	7.4 mm
Ground plane width W_g	11 mm
Length of ground plane cut L_s	1 mm
Width of ground plane cut W_s	1mm

where s is the side length of the hexagonal patch antenna. Hence the radius R of the hexagonal patch is approximately equal to the side length s.

3 Results and Discussion

In microwave imaging and radar imaging applications the sensing of reflected signals over a wideband of frequency range is the essential factor. In medical diagnosis systems resolution of the reconstructed image is a major requirement to identify the defects in the object under scanning. Hence the antenna used for imaging is required to operate for a wide bandwidth which is obtained by adding fractal elements at the edges to improve the bandwidth the antenna. The dimensions of the proposed hexagon fractal UWB monopole antenna are given in Table 2 From the proposed antenna design the parameters such as R, W_f, L_f are the radius of the patch, width and length of the feed line. The optimization of the feed width W_f results in a better impedance matching between the 50Ω SMA connector and the input impedance of the patch. The addition of first-order iteration hexagon fractal elements at the corners of the hexagon patch results the antenna to resonate towards the higher frequency and has a minimum $|S_{11}| < -15$ dB at 2.4 GHz.

To improve the return-loss characteristics of the hexagon radiator around 8 GHz to 11 GHz few more small hexagon elements are attached at the corners. Finally the proposed fractal hexagon antenna resonates at 1.7 GHz to 11 GHz where it covers S, C, X band frequency ranges and its return loss characteristics are shown in Fig. 2. The current distribution of the proposed hexagonal fractal antenna at 3 GHz, 5.8 GHz, 8 GHz and

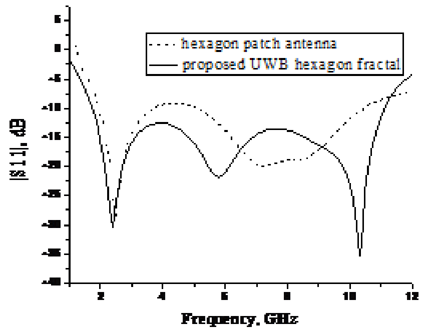
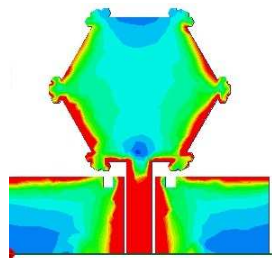
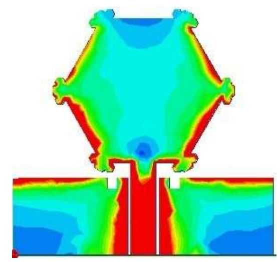


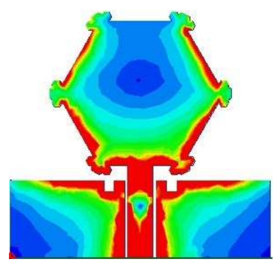
Fig. 2: Return-loss characteristics of the proposed CPW-fed hexagonal fractal antenna



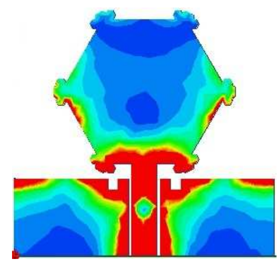
(a) 3 GHz



(b) 5.8 GHz



(c) 8 GHz



(d) 10 GHz

Fig. 3: Current distribution of proposed antenna

10 GHz are shown in Fig. 3. The current distribution of the proposed antenna is mainly concentrated on the edges of the small fractal elements. For the lower frequencies the current distribution is near the lower edge around the feed. It describes that the feed of the patch affects the impedance characteristics of the antenna. For the higher frequencies of 8 and 10 GHz the current distribution is seen under the edges of the first and second iterative fractal elements, where the frequency shift takes place towards the higher frequency. The antenna parameters of the proposed antenna are compared with the existing literature is given in Table 3.

3.1 Effect of the radius of hexagon patch

The variation in the distance between the center and the location of the hexagonal edge results the antenna to resonate between 2 GHz to 3.4 GHz and 10 GHz to 11.5

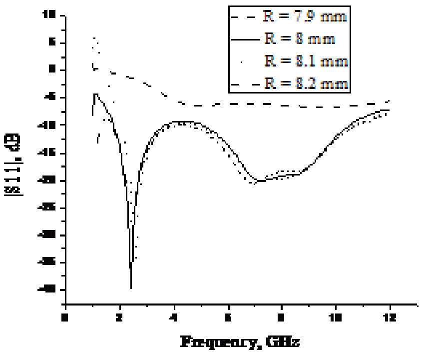


Fig. 4: Effect of varying radius of a hexagon antenna

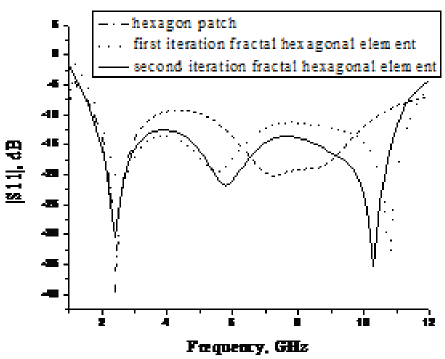


Fig. 5: Return-loss characteristics of developed UWB hexagon antenna with fractal elements

GHz is shown in Fig. 4. The effect of varying the radius of the hexagon patch results the antenna to resonate at the three different frequencies of 2.5 GHz, 6.9 GHz and 9 GHz respectively. By increasing the radius of the hexagon the antenna resonance shifted towards low frequency is observed from Fig. 4. The proposed antenna gives a better impedance matching at the radius $R = 8$ mm with a return loss of -39 dB at 2.5 GHz.

3.2 First order and second order iteration of hexagonal fractal elements

In recent research, the design of miniaturized antennas for wideband of operation is a significant concern in wireless communication and radar systems. Minimizing the height of the radiating element makes changes only at the higher frequencies. To introduce multiband operation and increasing the bandwidth of the antenna various structures of slots and also fractal elements are incorporated in the antenna geometry. In the proposed design six hexagonal fractal elements with the optimum radius of 1 mm are attached at the corners.

Addition of fractal elements results in maximum resonance at the higher frequency of 10.6 GHz. There is a

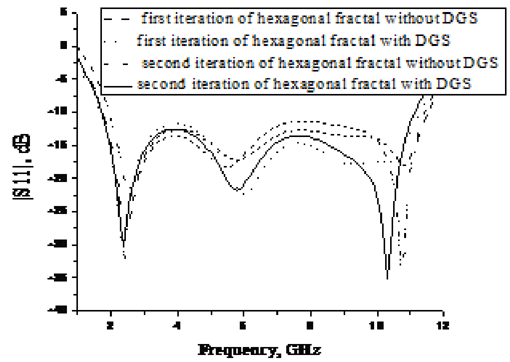


Fig. 6: Effect of varying DGS in first and second iterative fractal elements of the proposed antenna

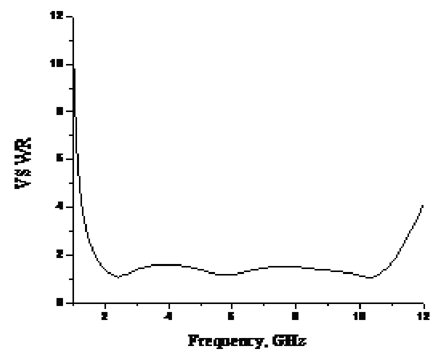


Fig. 7: The graph shows the VSWR plot for the proposed antenna

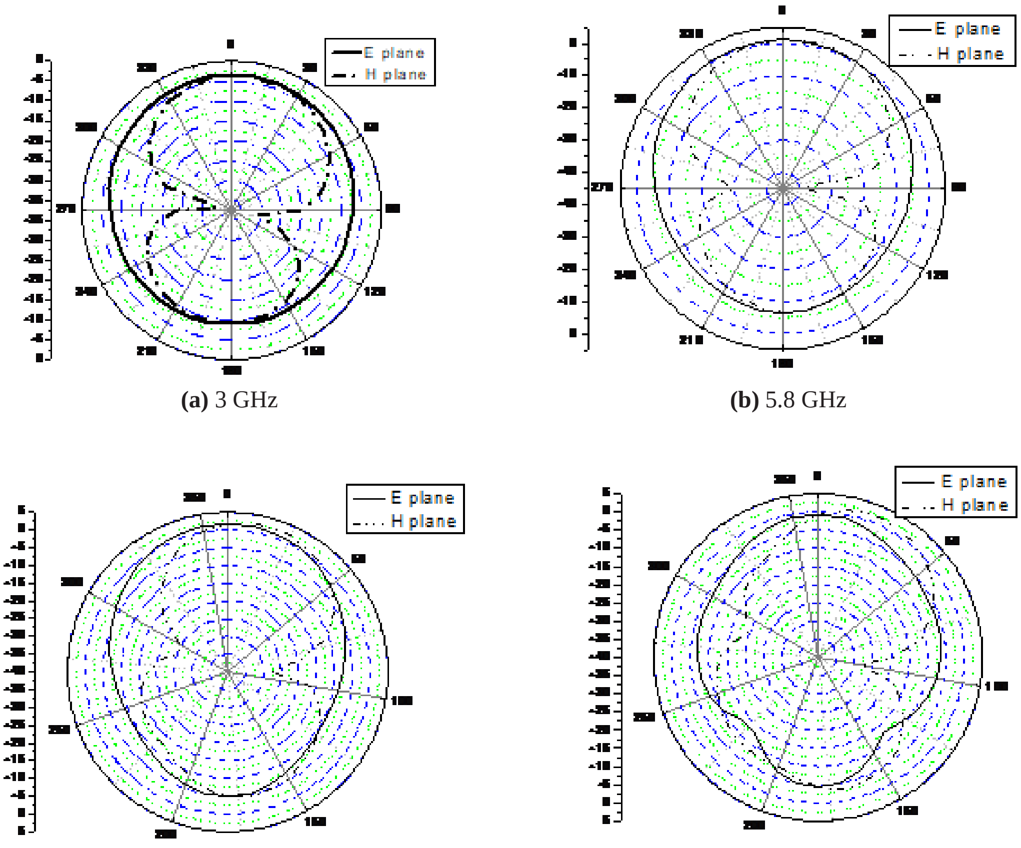
shift in the low-frequency resonance from 2.4 GHz to 2.6 GHz over the full bandwidth. Another twelve hexagonal fractal elements of radius 0.5 mm are attached to the first fractal elements to give multi-resonance. The proposed UWB antenna consists of second iteration of fractal elements at the corners of the first hexagon fractal elements which increases the length of the antenna and shifts the frequency of resonance towards low frequency, and this is shown in Fig. 5 results in a wider bandwidth.

3.3 Effect of DGS in the CPW ground plane

On the microwave scanning of the human body organs, the low frequency will penetrate in depth of a human body. The high-frequency signals are reflected from the skin, fat and bone layers of the human body surface. The gap between the feed and both sides of the ground plane defines the amount of power coupling through the patch radiator. The surface currents in the finite ground plane fractal antenna result from the proposed antenna to resonate towards the higher frequency. To suppress the surface currents over the lower frequency a small square shape cut is etched on ground plane at both sides of the

Table 3: Comparison of antenna parameters of the proposed UWB antenna with the earlier literature

Antenna parameters	From literature [9]	[4]	[6]	Proposed Hexagonal Antenna with Fractal Elements
Antenna Dimensions	$25 \times 25 \times 1$ mm^3	$40 \times 30 \times 1.6$ mm^3	$39 \times 36.5 \times 1.524$ mm^3	$25 \times 25 \times 1.588$ mm^3
Bandwidth	7.9 GHz	12.5 GHz	10.57 GHz	9.4 GHz
Radiation Efficiency	—	79 % to 95 %	—	93 % to 96%
Radiation Pattern	Omnidirectional	Nearly omni directional	E plane is bidirectional and *H* plane is omnidirectional	Nearly directional



(a) 3 GHz **(b)** 5.8 GHz

(c) 8 GHz **(d)** 10 GHz

Fig. 9: Radiation pattern of the proposed UWB monopole antenna

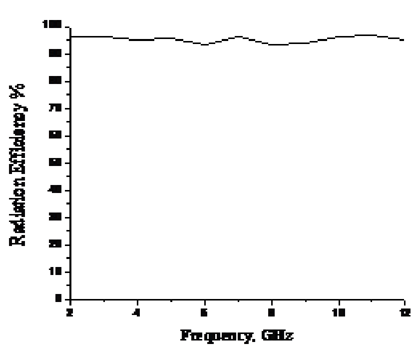


Fig. 8: Radiation efficiency of the proposed CPW-fed hexagon antenna with fractal elements

coplanar waveguide feed which creates a better resonance at 2.4, 5.8 and 10.3 GHz respectively. From the graph, it is observed that there is a shift in the resonance form 10.6 GHz to 10.3 GHz and also an additional resonance at 5.8 GHz respectively. The optimized dimensions of the ground slot $L_s \times W_s$ are 1 mm $\times$ 1 mm respectively.

The reflection coefficient plot of the proposed antenna with and without defective ground structure is shown in Fig. 6. The voltage standing wave ratio is another parameter of the antenna which describes the impedance bandwidth of the antenna. The proposed antenna has an optimum VSWR value of 1 to 2 over the whole bandwidth of operation shown in Fig. 7. It is observed that the graph shows the proposed UWB hexagon antenna with fractal elements having a good impedance matching

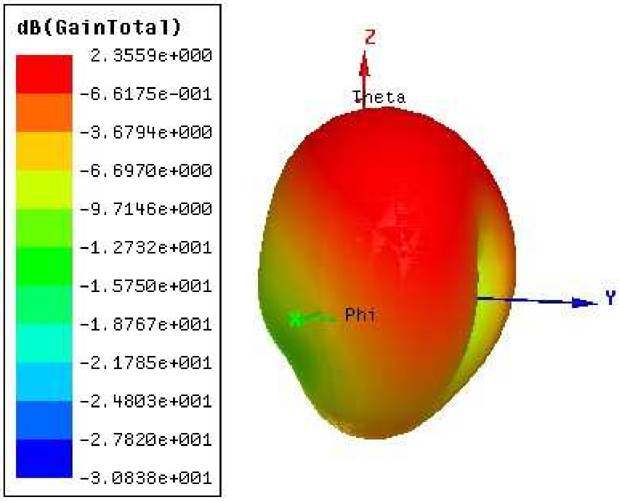


Fig. 10: 3D radiation pattern of the proposed UWB antenna

between the operating frequencies from 1.7 GHz to 11.1 GHz respectively. Finally, the proposed hexagonal fractal antenna operates from 1.7 GHz to 11 GHz resulting in a fractional bandwidth of 146% and is calculated using Eq. (4) [3].

$$\text{Fractional Bandwidth} = 2\frac{f_h - f_l}{f_h + f_l} \quad (4)$$

where the f_h is the highest frequency of resonance and f_l is the lowest frequency of resonant antenna.

3.4 Radiation Fields

The proposed structure results in a nearly directional radiation pattern, with approximately flat radiation efficiency of 93% to 96% for the UWB frequency range shown in the Fig. 8. The efficiency is the ratio of power radiated to the input power which tells about the maximum power coupling between the SMA feed to the radiator. The E and H field radiation pattern of the proposed UWB antenna for different frequencies of 3 GHz, 5.8 GHz, 8 GHz and 10 GHz are shown in Fig. 9. The 3D pattern of the proposed UWB antenna is shown in Fig. 10. It shows that the radiation field is directional in E field and has a gain of 2.35 dB. Since the proposed UWB antenna has nearly directional radiation pattern it is suitable for UWB applications such as ground penetration radar, non destructive testing and cancer detection in medical diagnosis.

4 Conclusion

A CPW-fed UWB hexagonal antenna with fractal elements is the design investigated in the proposed work. The miniaturized hexagonal fractal of size $25 \times 25 \times 1$ mm^3 is proposed to operate in UWB frequency range. The parametric study of fractal elements attached is examined from the current distributions at frequencies 3 GHz, 5.8 GHz, 8 GHz and 10 GHz respectively. The current distribution of the fractal radiator shows the response of the antenna from lower to a higher frequency. The proposed antenna has multi-resonance at 2.4 GHz, 5.8GHz and 10.3 GHz with a reflection coefficient of -30 dB, -21 dB and -35.24 dB. Improved gain of 2.35 dB and an average radiation efficiency of 95% is accomplished with a nearly directional radiation pattern. Hence the designed antenna is best suitable for microwave imaging, non-destructive testing, and radar applications.

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